On the stationarity of the Atlantic Multidecadal Variability

in an ensemble of multi-century simulations

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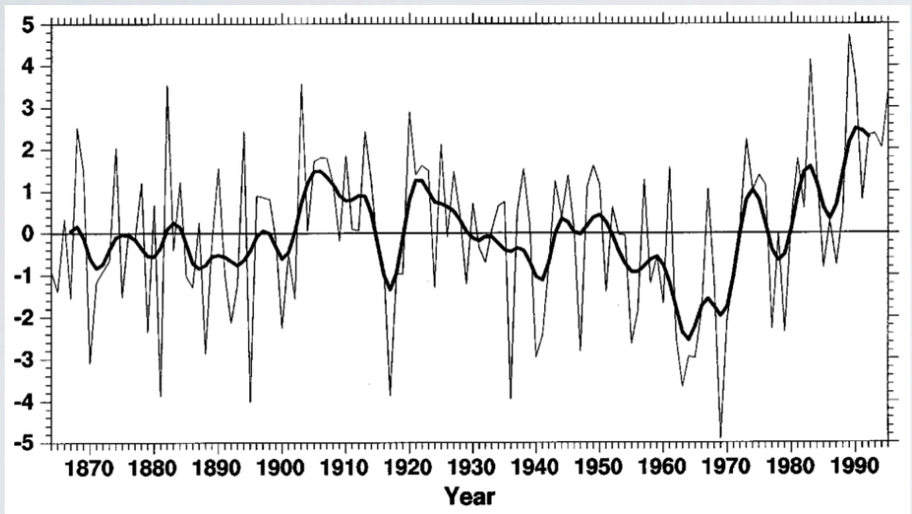
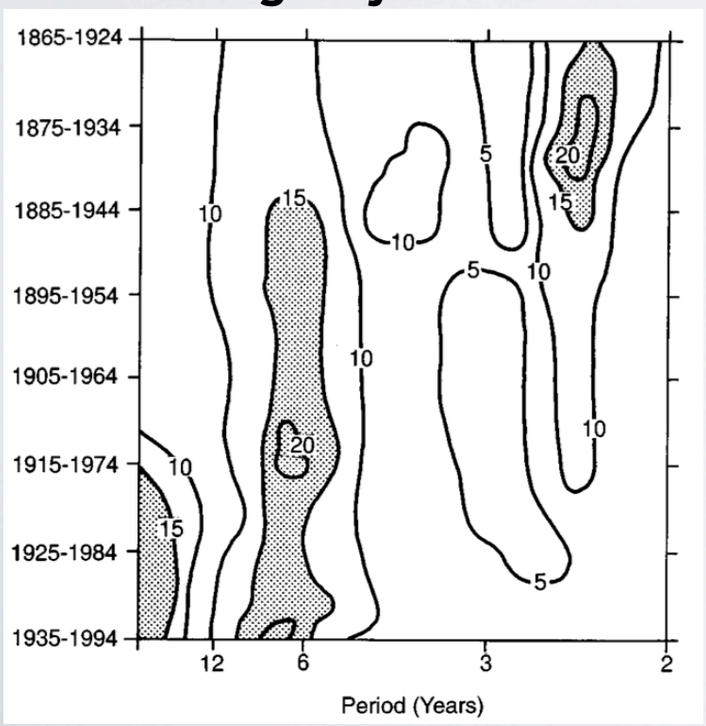
Non-stationarity in observations and models

NAO, *Hurrell and Van Loon* [1997]

NAO index from 1864-1995



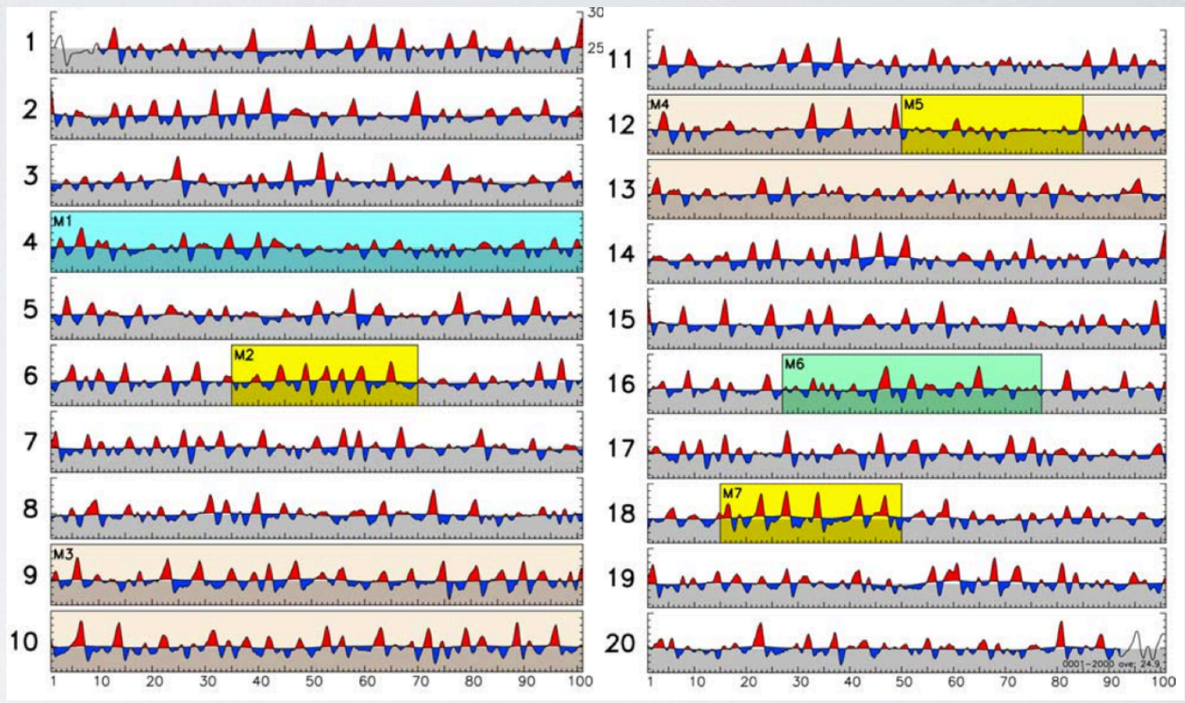
Power spectrum of NAO index for running 60-year intervals



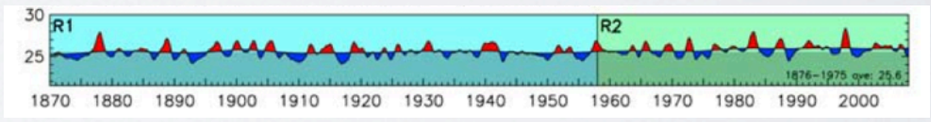
Largest NAO variance shifts from biennial periods to lower time scales

ENSO, *Wittenberg* [2009]

NIÑO3 SST (°C) for CM2.1 preindustrial control run



Observational reconstruction ERSST.v3

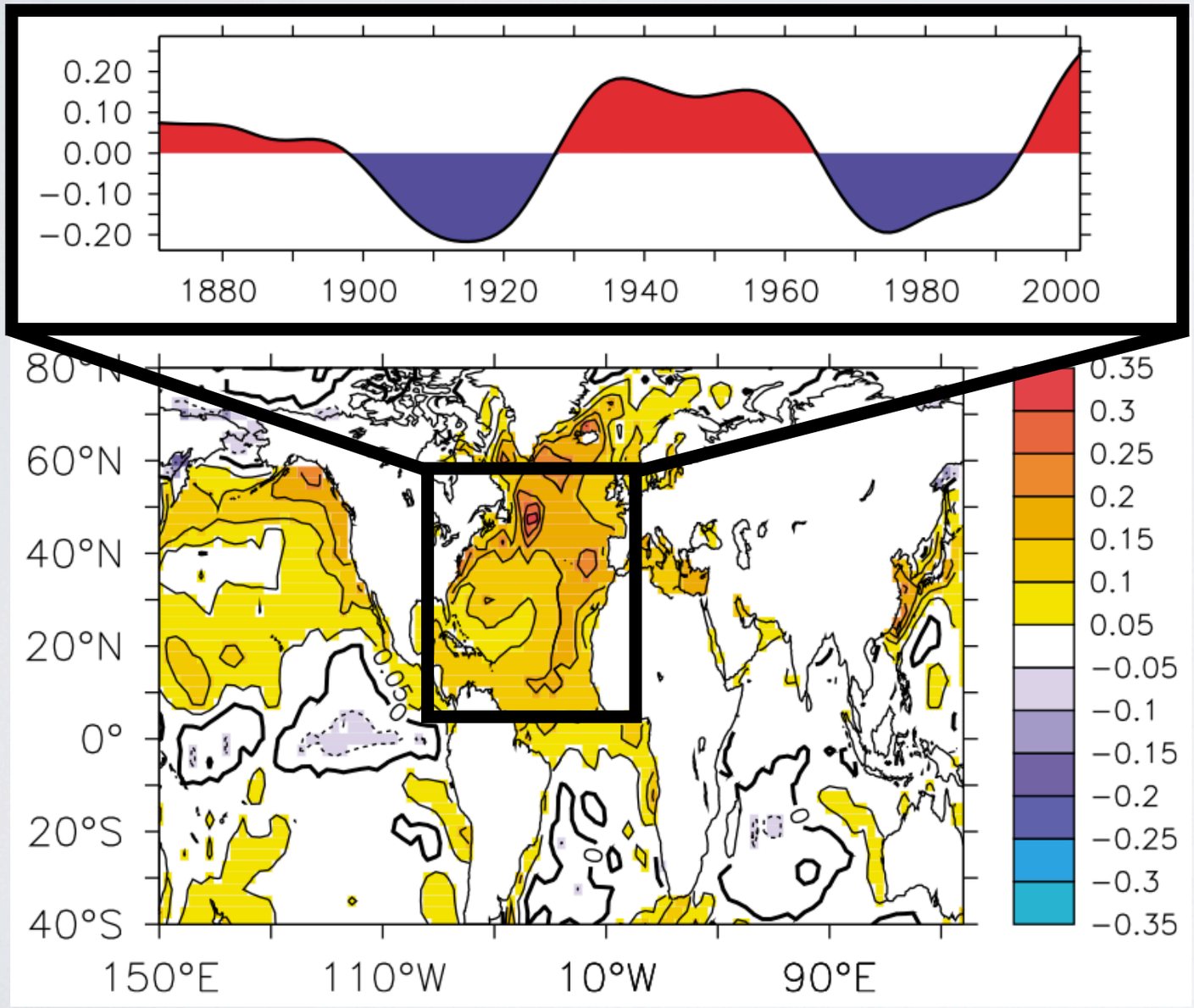


In a 2000-year simulation he identified different regimes of different durations, in ENSO modulations

ATLANTIC MULTIDECADAL VARIABILITY (AMV):

a coherent pattern of oscillatory changes in North Atlantic sea-surface temperature.

- It influences several components of the climate system in the Atlantic region, and the surrounding areas.
- It alternately obscures and exaggerates the global increase in temperatures due to human-induced global warming.



observed AMV (1871 to 2003) *[Sutton and Hodson, 2005]*

Time series

index of the AMV: low-pass filtered average of SST over the North Atlantic region.

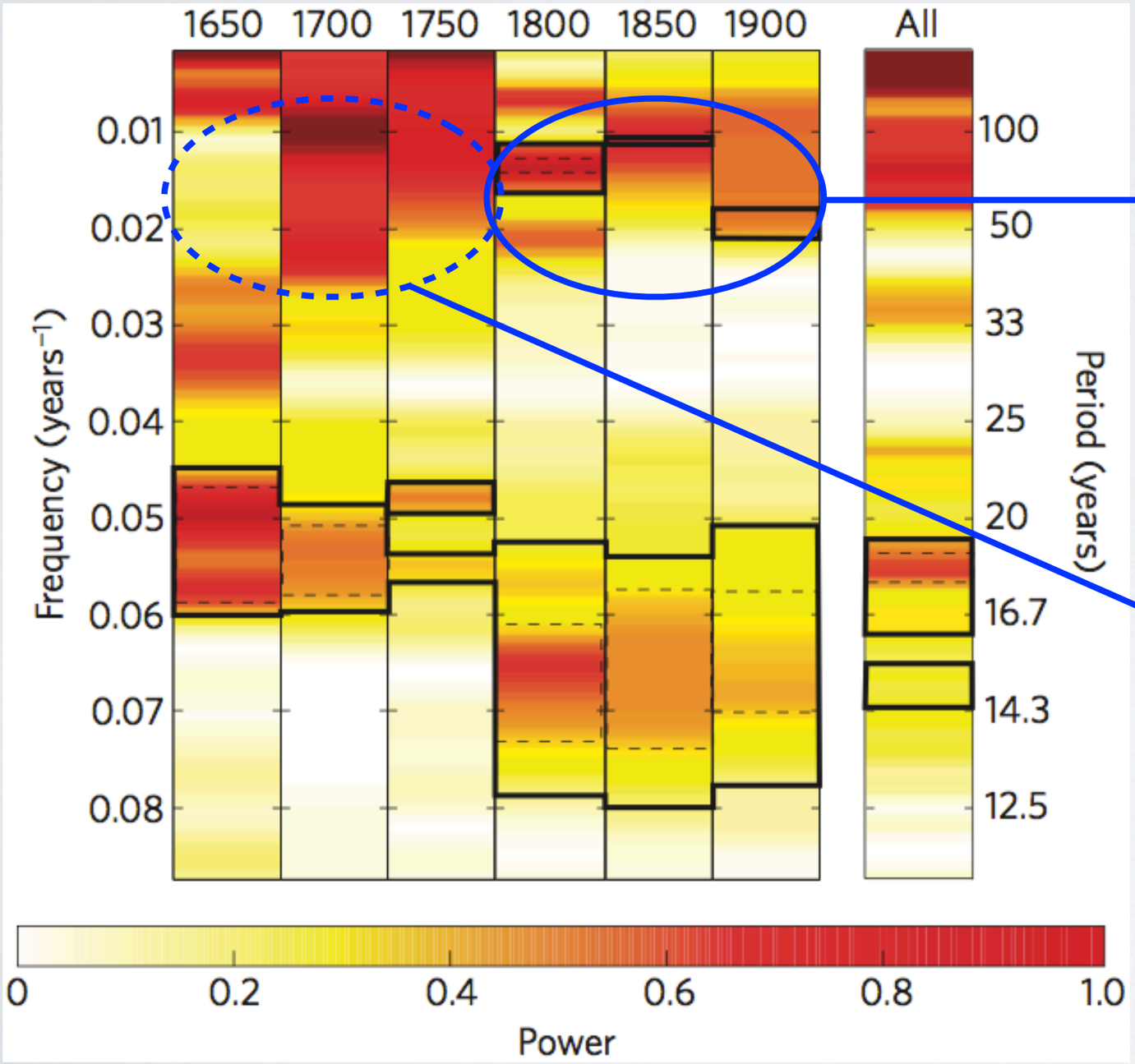
Spatial pattern

of SST variations associated with the AMV index: shown are the regression coefficients (°C per SD) obtained by regressing the SST data on the AMV index.

Non-stationarity in the past AMV

coral-based proxy record of Atlantic SST, *Saenger et al.* [2009]

Power spectrum for 200-year bins and for the entire record



Some periods show multidecadal power similar to the currently observed AMV...

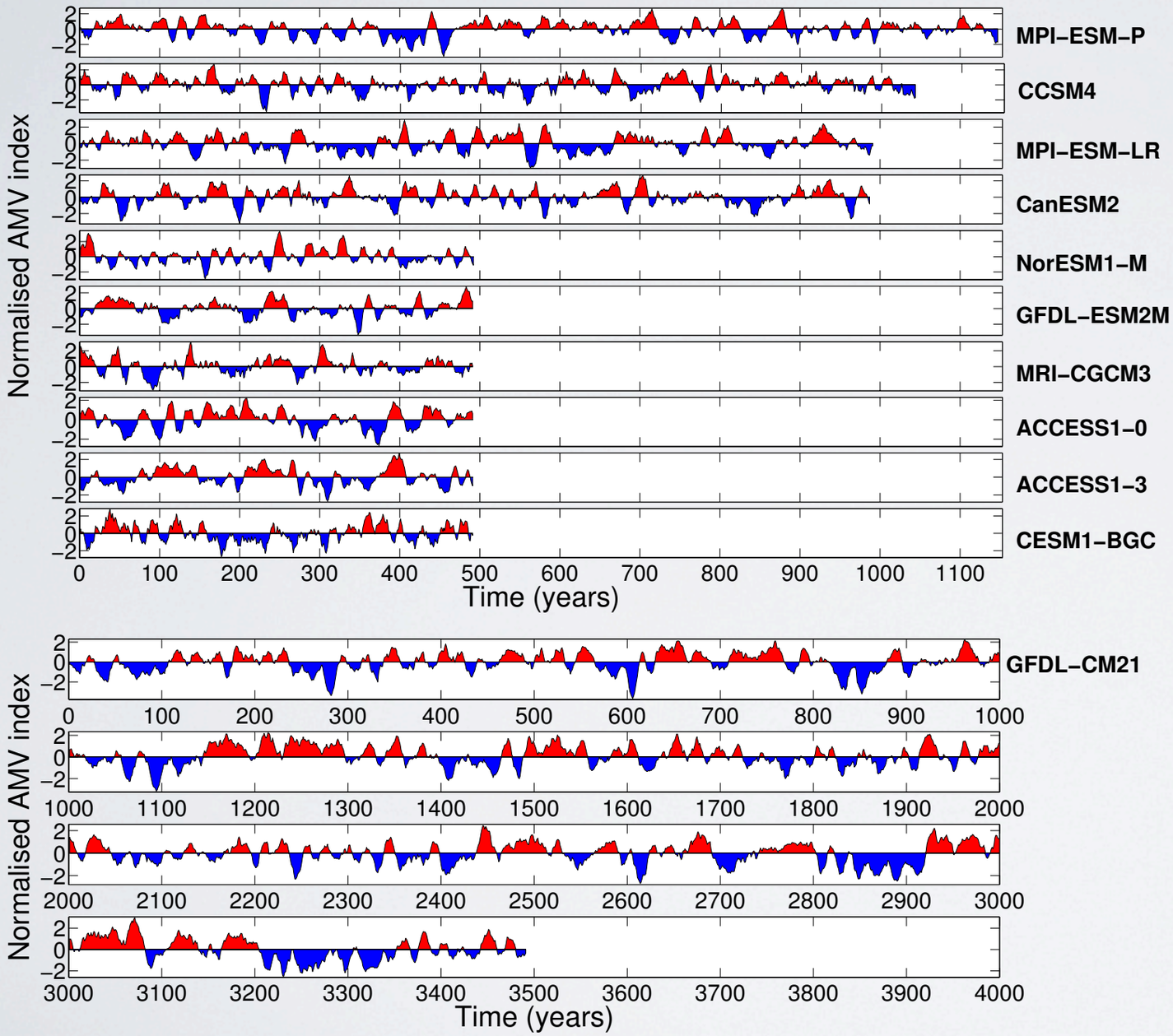
...whereas no significant multidecadal power is evident in other past epochs

PHENOMENOLOGY

Simulated AMV index

Time series of AMV index:

detrended 10-year running mean of SST averaged over the North Atlantic (0-60N and 75-7.5W)



DATA:

Ten longest multi-century preindustrial simulations:

LOW-FREQUENCY and INTERNAL variability

from CMIP5

model name	length (years)
MPI-ESM-P	1156
CCSM4	1051
MPI-ESM-LR	1000
CanESM2	996
NorESM1-M	501
GFDL-ESM2M	500
MRI-CGCM3	500
ACCESS1-0	500
ACCESS1-3	500
CESM1-BGC	500
GFDL-CM2.1	3500

Simulated AMV index

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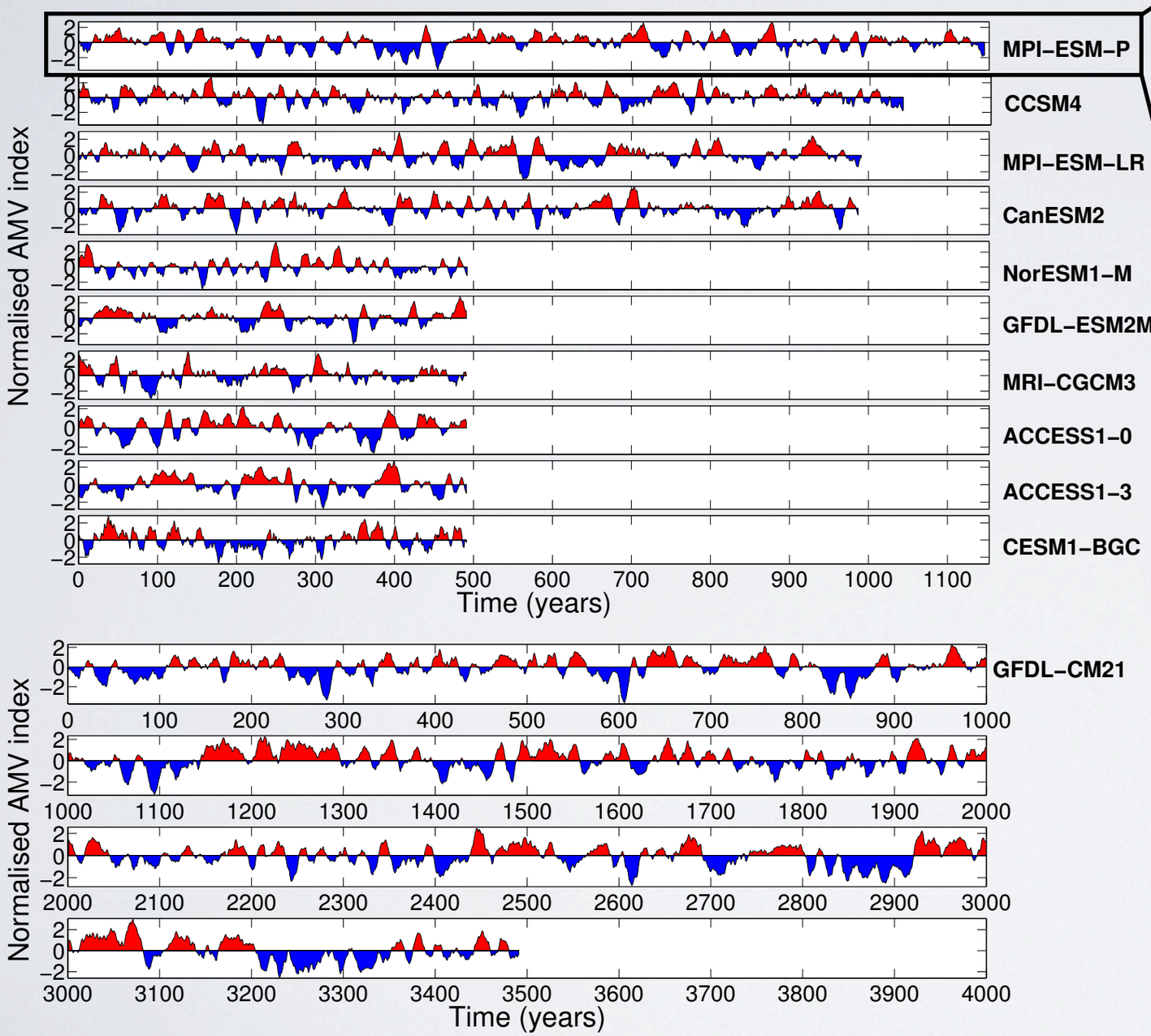
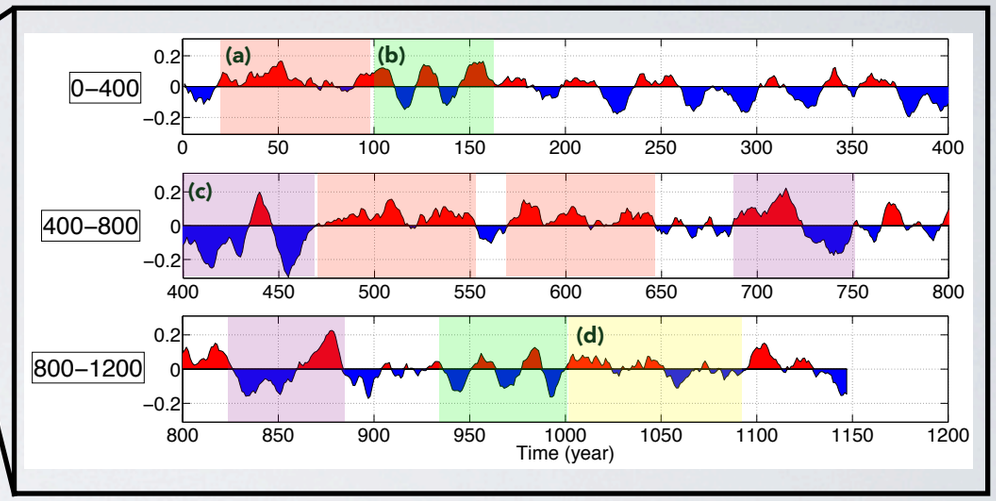




AMV shows epochs with different characteristics:

(a) ***RED****: mostly warm-skewed events*

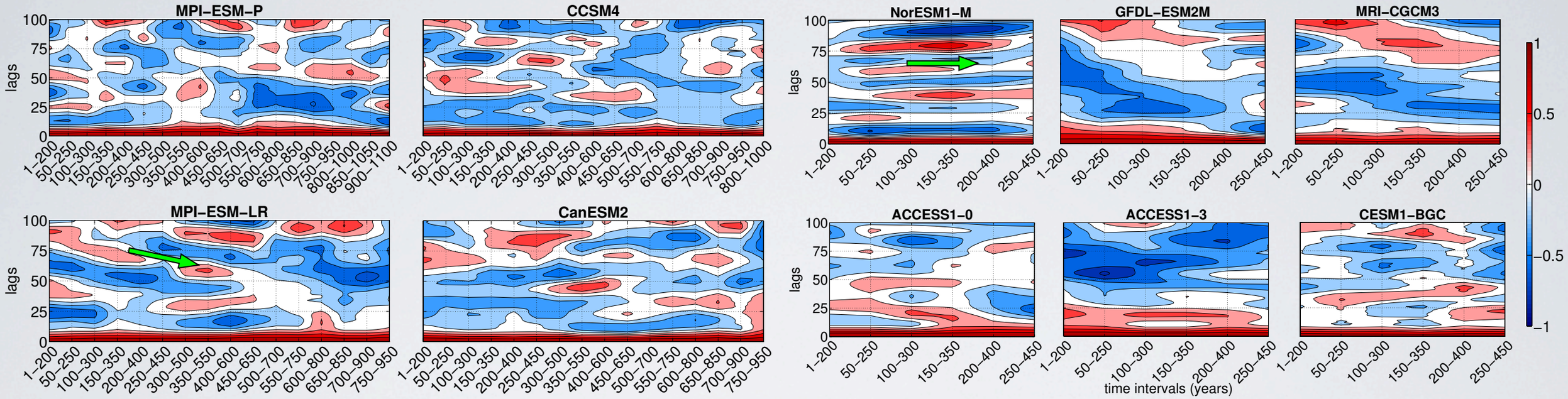
(b) ***GREEN****: moderate, nearly sinusoidal events*

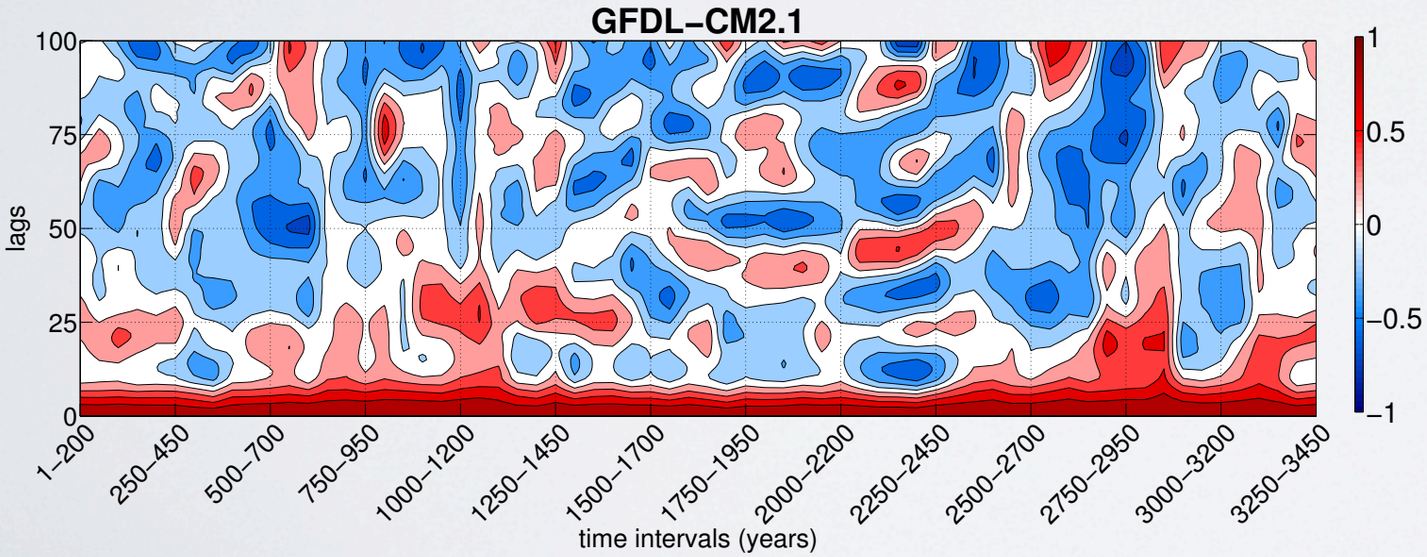
(c) ***PURPLE****: intense and longer-period events*

(d) ***YELLOW****: small amplitude events*

Evidence of AMV non-stationarity

AMV autocorrelation for moving and overlapping 200-year-long time windows



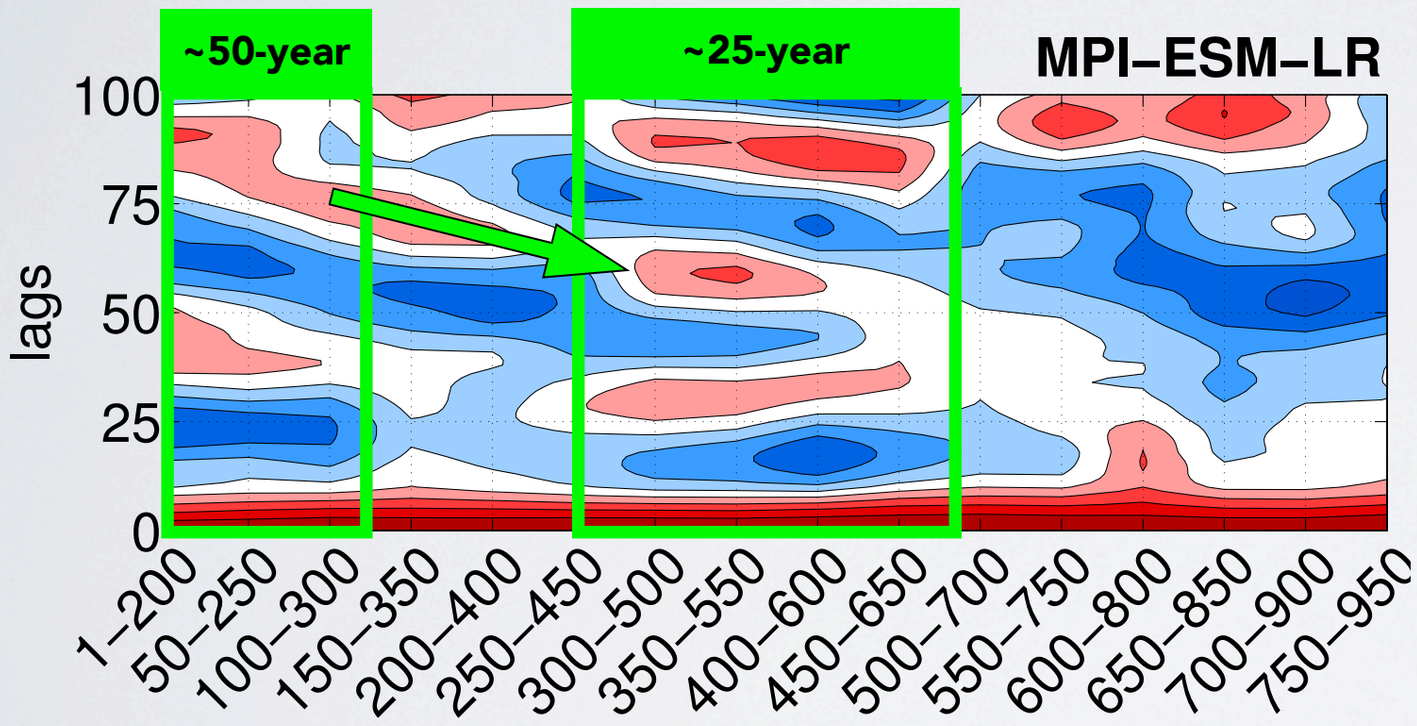


The dominant autocorrelation time scale changes with the period

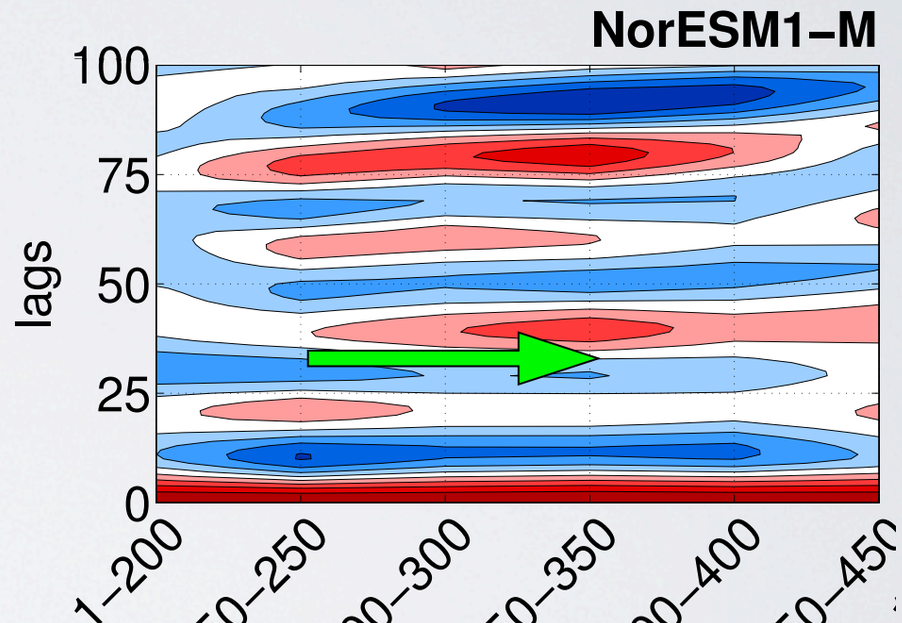
Evidence of AMV non-stationarity

AMV autocorrelation for moving and overlapping 200-year-long time windows

Non-stationary case



Stationary case



STATISTICAL TEST

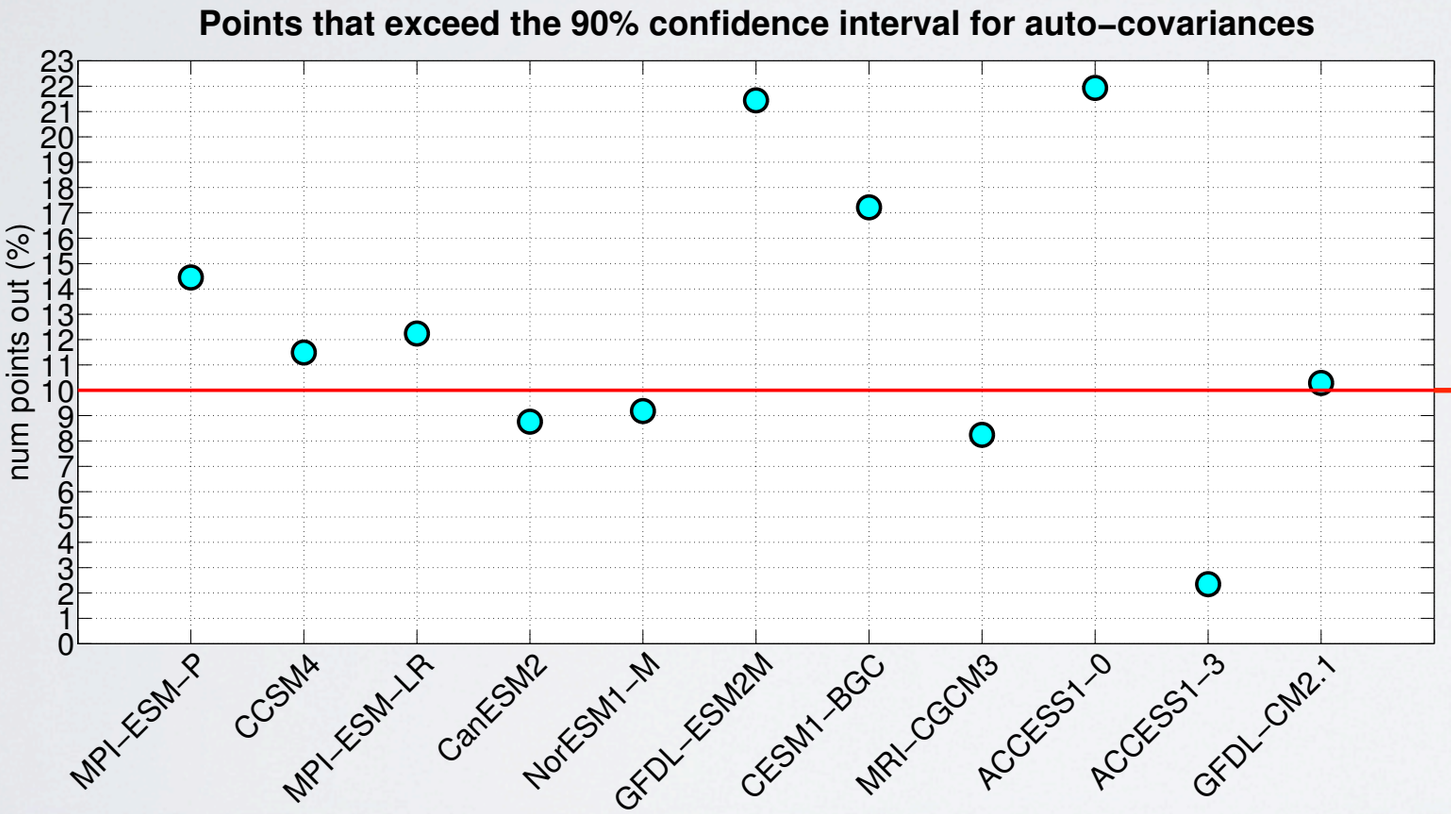
Statistical test for AMV stationarity

Does AMV modulation arise by chance?

The entire time series is not stationary if there are intervals that do not keep the same statistical properties (e.g. autocovariance) of the entire time series.

METHOD:

1) Generation of 1000 analytical time series with the same spectrum than the true one (bootstrap method).
2) Division of the 1000 analytical time series in 200-yr-long intervals shifted by 50 years.
3) Computation of the corresponding autocovariance functions.
4) Use of their distribution to compute the confidence intervals at 90% level.



7 OUT OF 11 MODELS PASS THE TEST:
THEIR AMV TIME SERIES IS NOT STATIONARY

Most of the models display epochs characterised by autocovariance which significantly deviates from the autocovariance of the whole time series

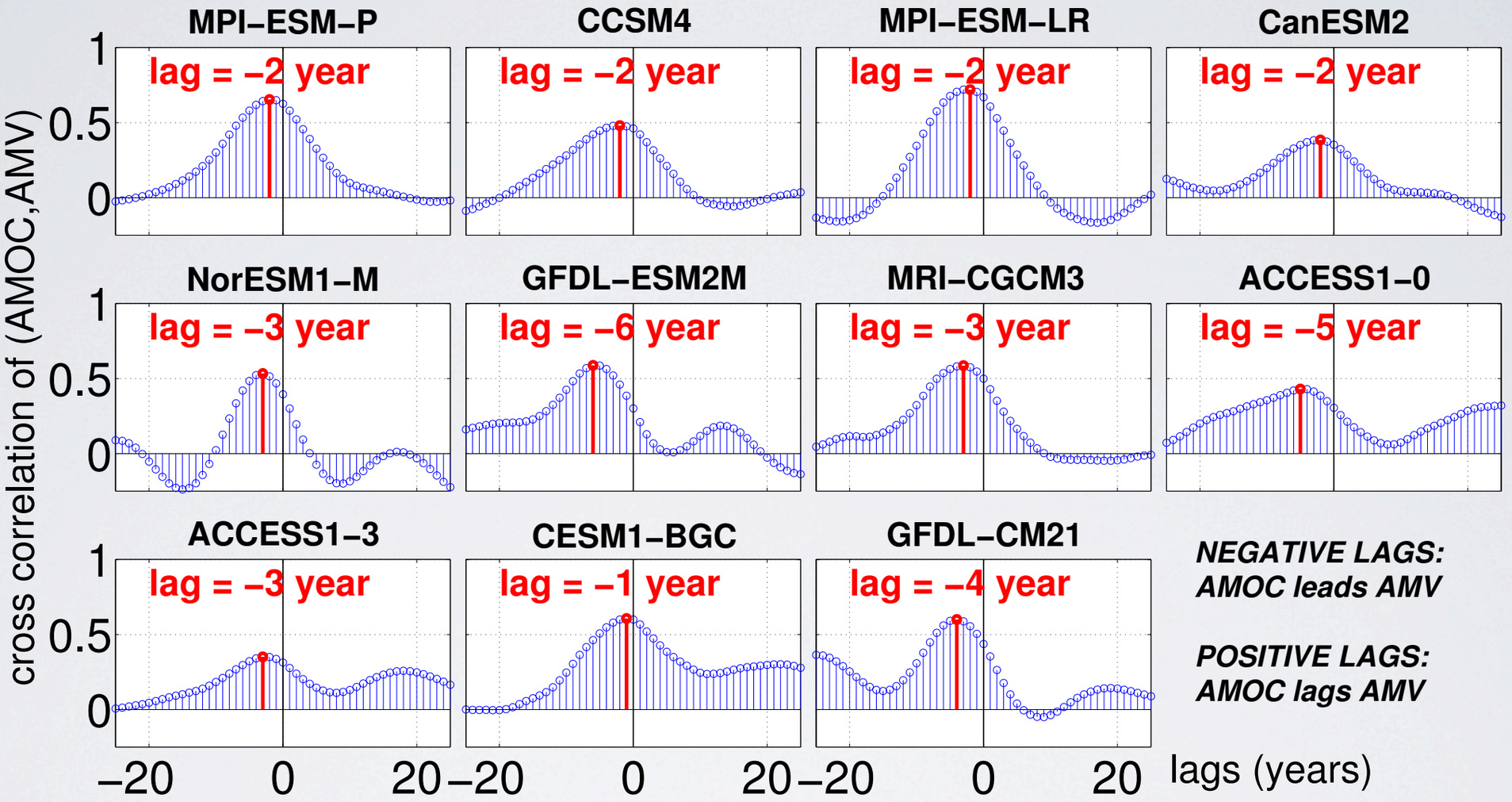
MECHANISMS

What drives the detected AMV non-stationarity?

- changes in AMV/AMOC relationship
  (internal ocean-only processes)
- changes in teleconnection patterns
  (coupled atmosphere-ocean interactions processes)

AMV/AMOC relationship

static view: for the entire time series



NEGATIVE LAGS:
AMOC leads AMV

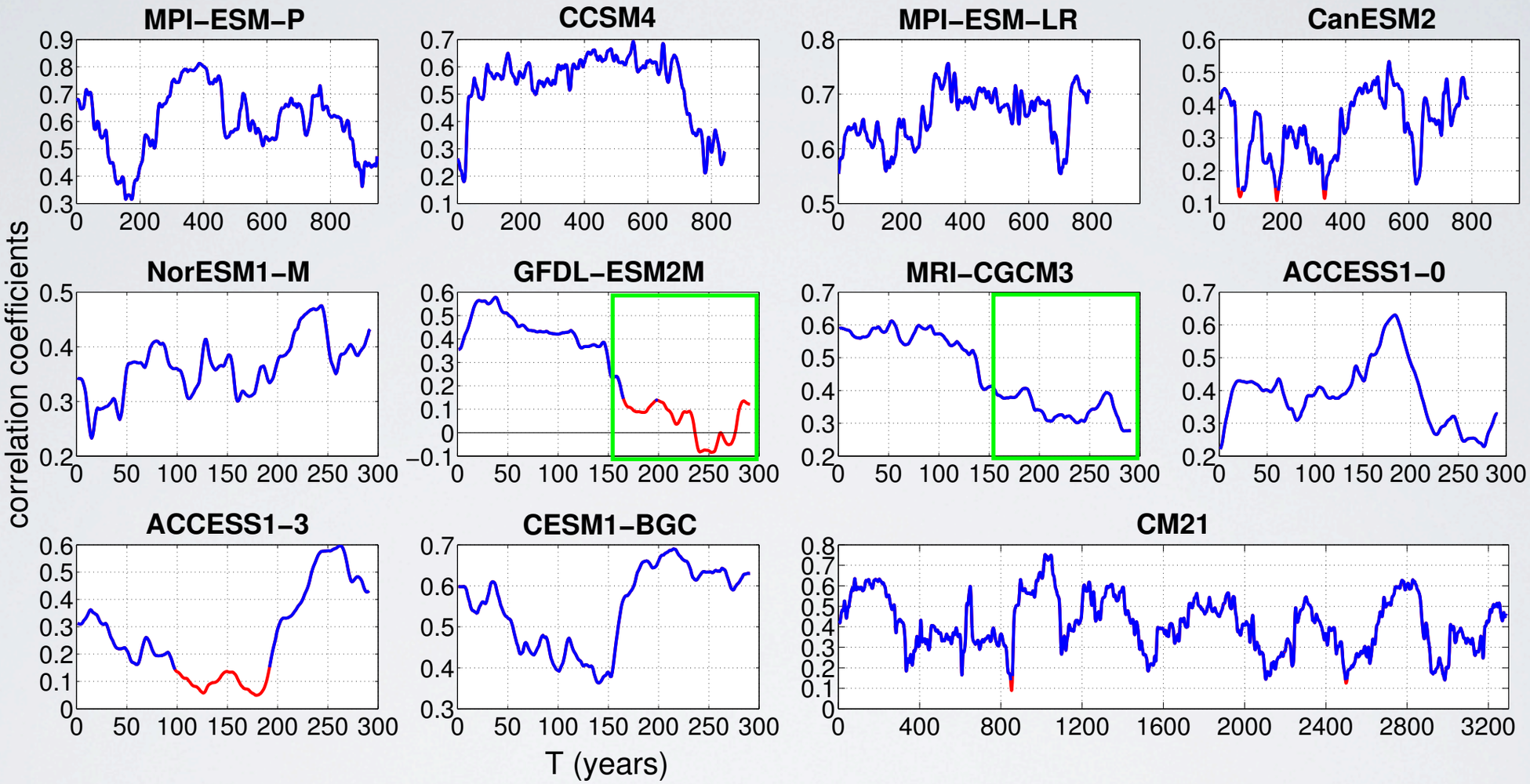
POSITIVE LAGS:
AMOC lags AMV

Maximum lagged correlation is in red

All models present the maximum of lagged correlation when AMOC leads AMV by few years: an increase in the overturning drives warming of the Atlantic

AMV/AMOC relationship

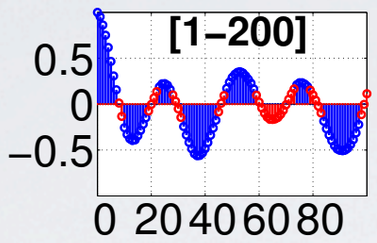
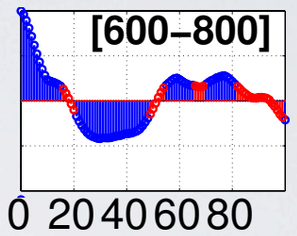
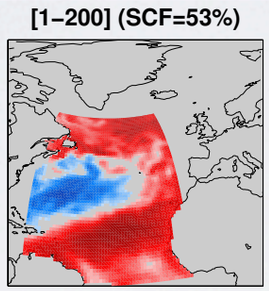
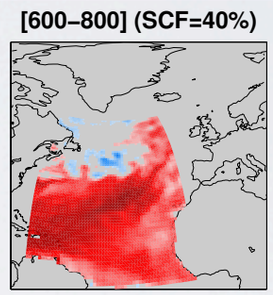
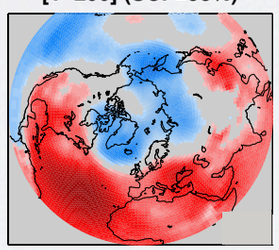
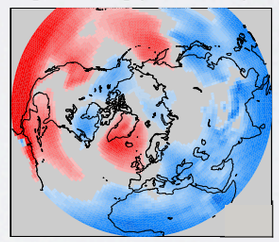
time evolving: for 200-year time windows



BUT → **AMV/AMOC correlation undergoes significant fluctuations with time**

Maximum Covariance Analysis (MCA)

applied to NA SST and global SLP

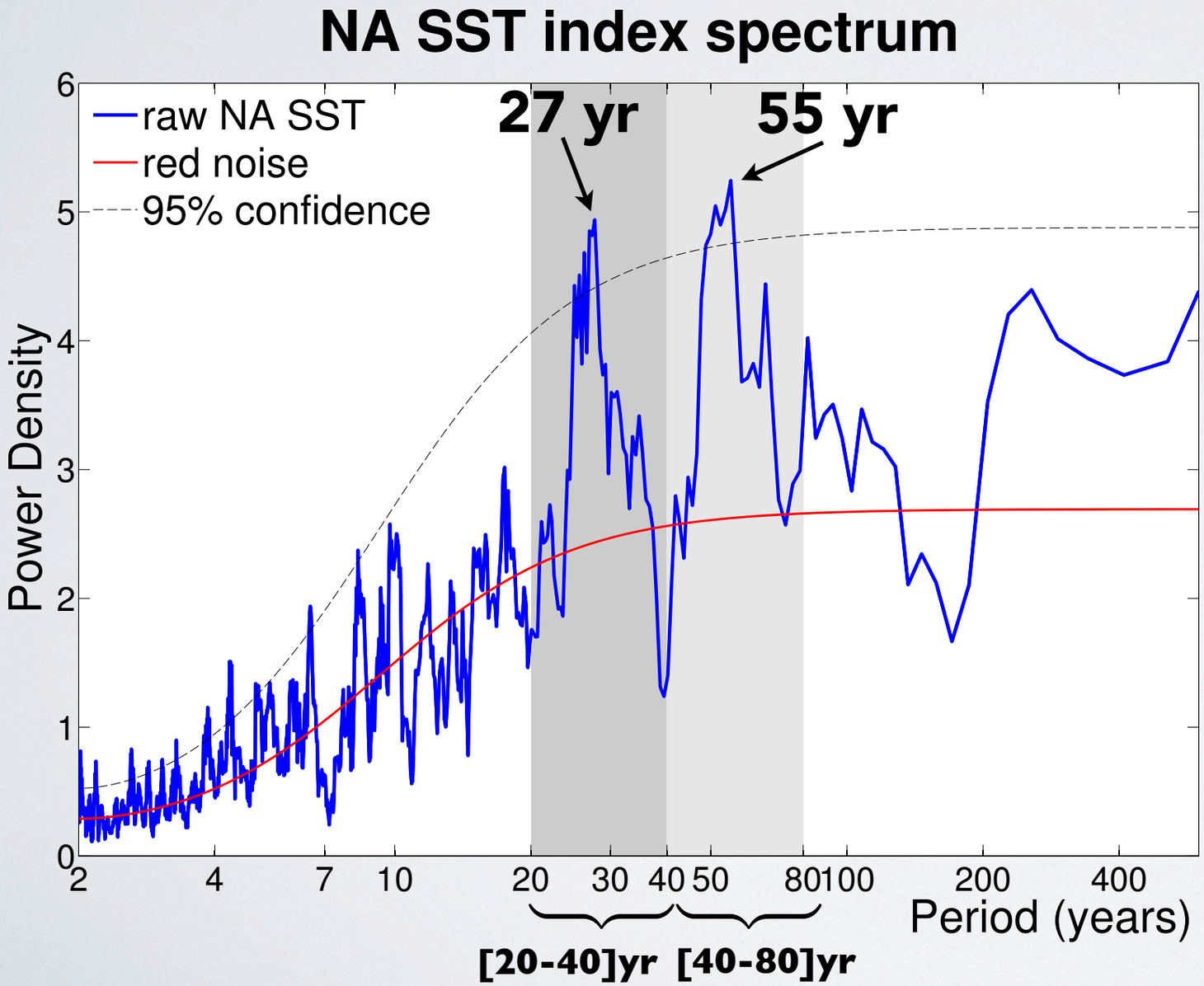
	MODE 1	MODE 2
AMV autocorrelation	 Higher frequency (~ 20 years)	 Lower frequency (~ 60 years)
MCA homogeneous map	 TRIPOLE	 MONOPOLE (AMV-like)
MCA heterogeneous map	 Strong signal in North Atlantic	 Weak signal in North Atlantic

A shorter time scale mode (~20 years) seems to alternate with a longer time scale mode (~60 years), with a gradual shift from one to another across different epochs, involving also their coexistence

Case of study: MPI-ESM-P model (1156 years)

RESULT: We can reject H_0, the entire time series is not stationary.

NEW QUESTION: Is this non-stationarity explained by the short time scale [20-40] years, by the long time scale [40- 80] years or by the combination of the two [20-80] years?



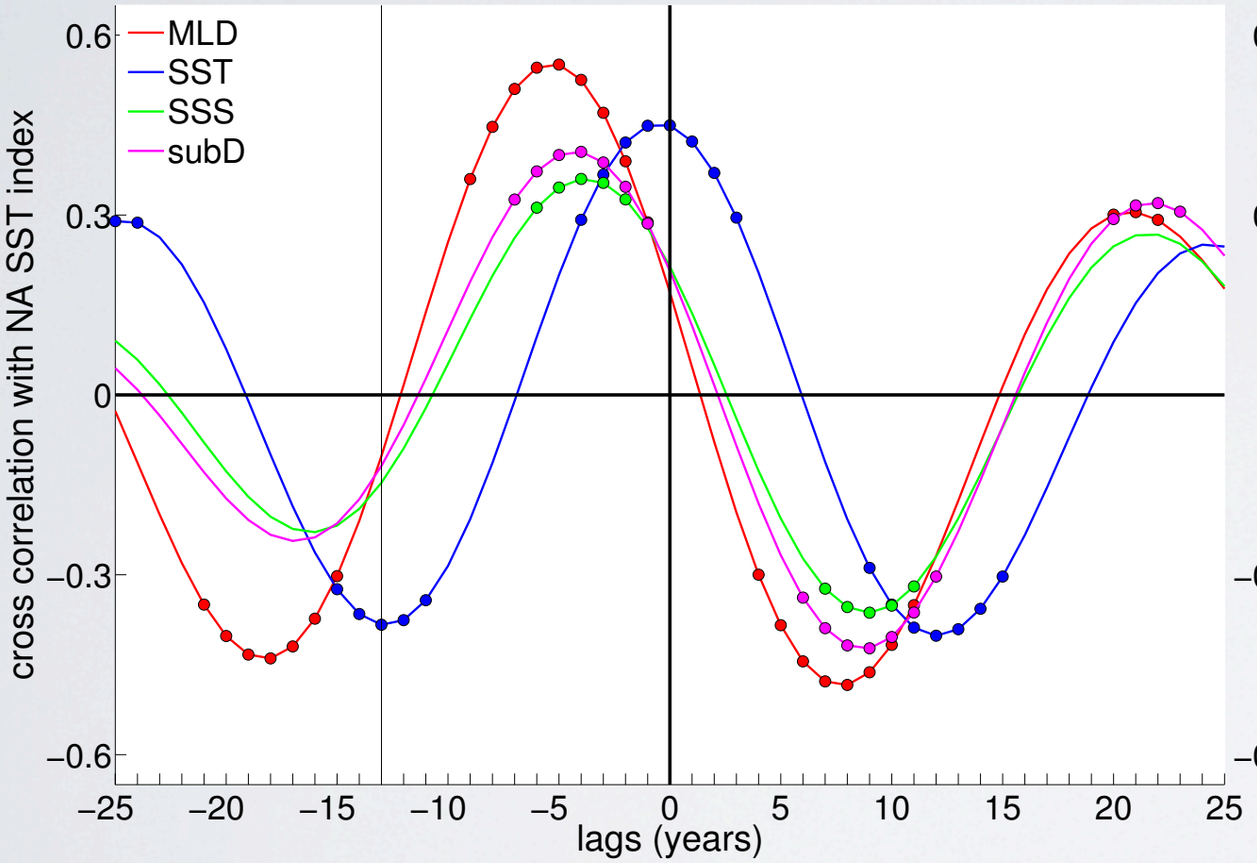
case	auto-covariance values that exceed the confidence band
BOTH [20-80] yr	12,89%
SHORT [20-40] yr	8,83%
LONG [40-80] yr	15,42%

The long time scale contributes most to the non-stationarity of the entire time series

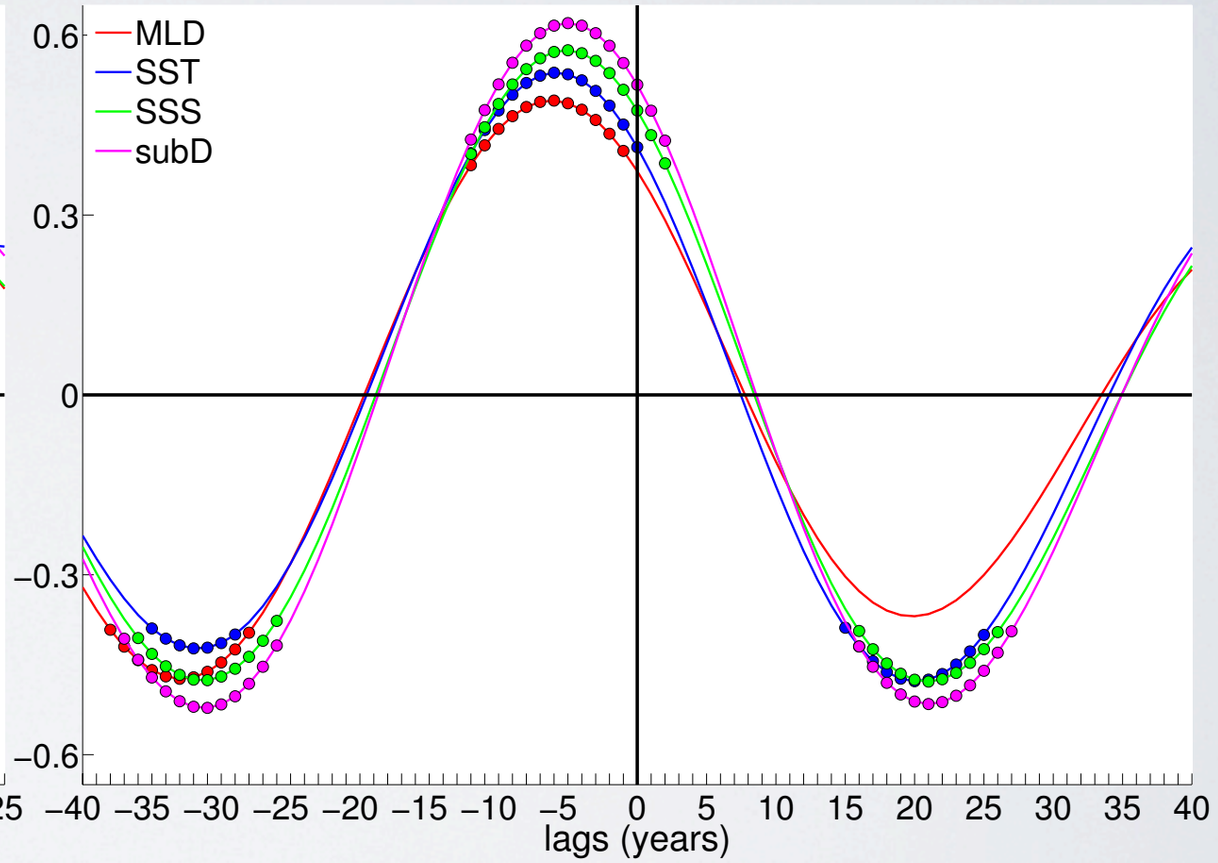
Physical characterization of the two preferential multidecadal modes

- LEAD-LAG CORRELATIONS: Mixed Layer Depth (MLD), Sea Surface Temperature and Salinity (SST/SSS), subsurface Density, averaged over Labrador Sea, **indices correlated with and North Atlantic SST index**.

Labrador Sea anomalies and NA SST, [20-40]years



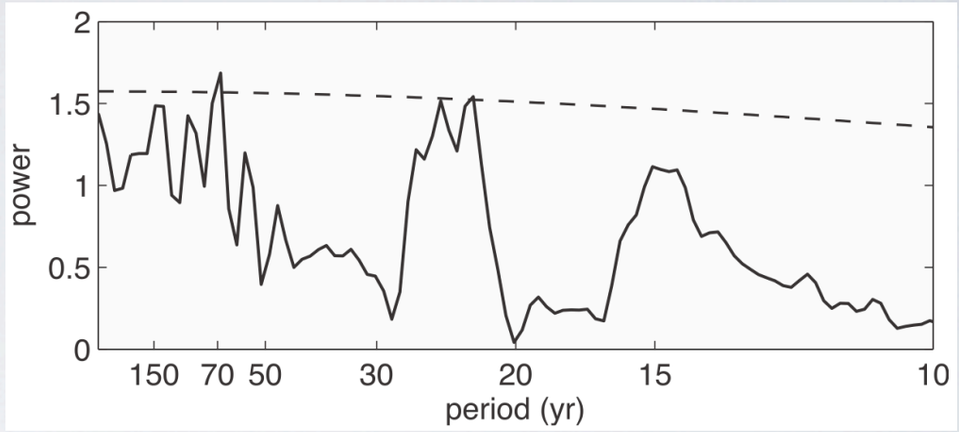
Labrador Sea anomalies and NA SST, [40-80]years



In MPI-ESM-P model the two preferred time scales correspond to different modes: temperature feedback prevails at short time scale, salinity feedback prevails at long time scale

RESULTS

- In most of the analysed preindustrial simulations the AMV exhibits a non-stationary behavior.
- Intermittence of the AMV/AMOC relationship.
- In most of the models a shorter time scale mode (~20 years), associated to a NA SST tripole pattern and NAO-like forcing, seems to alternate with a longer time scale mode (~60 years) that features an AMV-like monopole for the SST spatial pattern and a weaker coupling with the atmosphere.



Spectrum of the Central England Temperature (CET) record. [Frankcombe et al., 2010]

- In MPI-ESM-P model the two preferred time scales correspond to different modes: temperature feedback prevails at short time scale, salinity feedback prevails at long time scale.

CONCLUSIONS

- The non-stationary behavior identified in most models suggests that the character of the observed AMV may undergo significant changes in the future.
- The importance of reducing model inconsistency becomes even more stressed in the light of the non-stationary nature of climate variability.

THANK YOU

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