An interdecadal oscillatory mode of the AMOC related to westward-propagating temperature anomalies in ocean and climate models (CMIP5)

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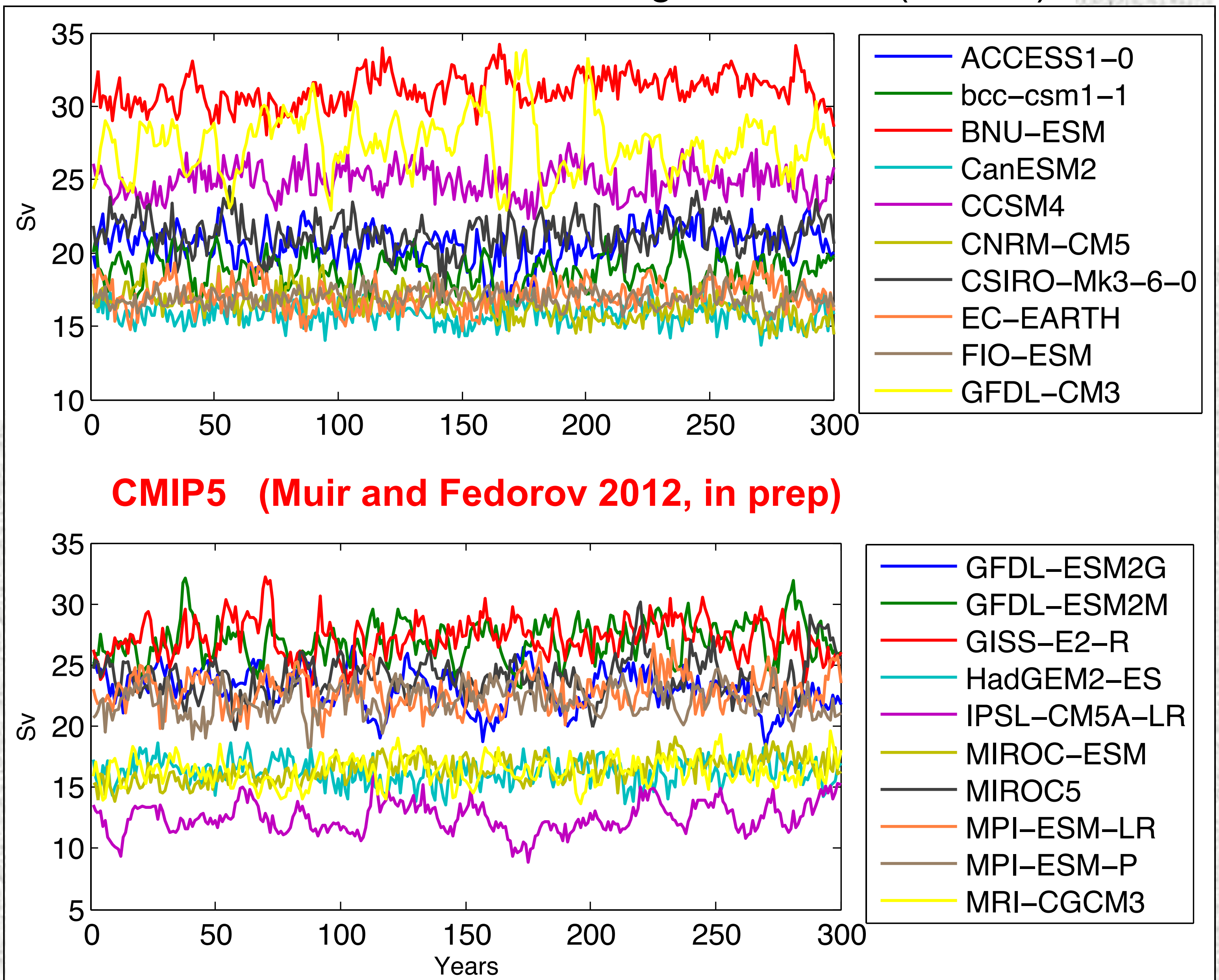
Atlantic Meridional Overturning Circulation (AMOC)

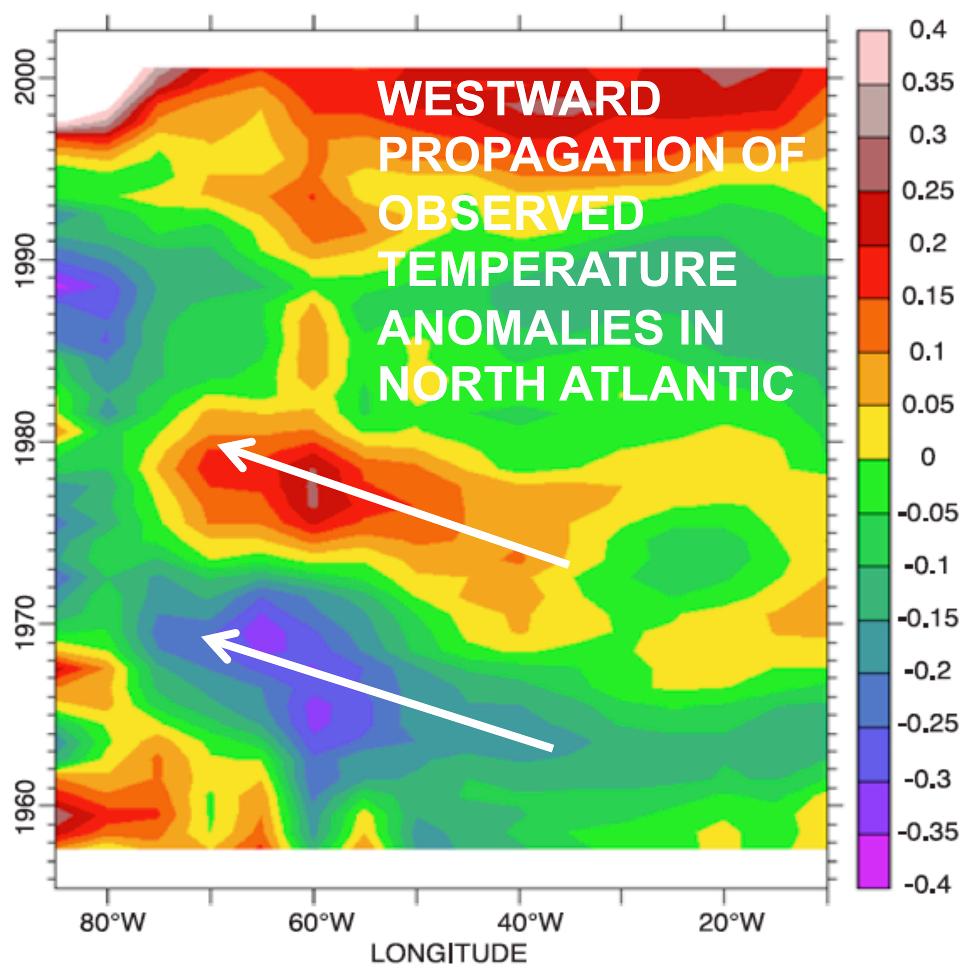


AMOC decadal and multi-decadal variability

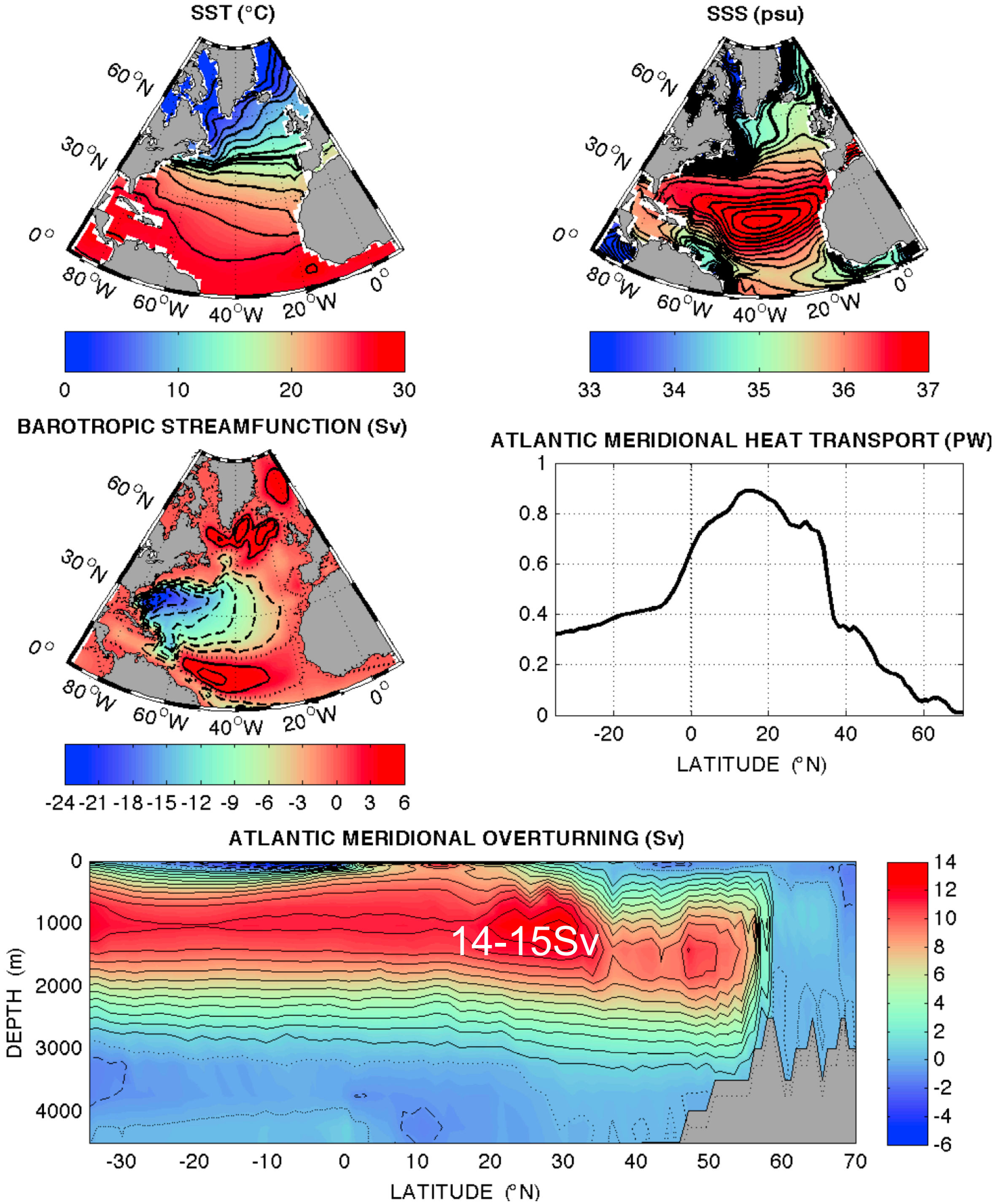
Working hypothesis: *AMOC variability in GCMs is related to an oceanic internal mode sustained by noise or weak ocean-atmosphere coupling*

- ***Emphasis:*** *Westward propagation of temperature (density) anomalies in the northern Atlantic interacting with the AMOC*

Huck et al. 1999, Colin de Verdière and Huck 1999, Marshall et al 2000, te Raa and Dijkstra 2002, Dijkstra et al. 2006, Frankcombe et al. 2009, Sévellec et al. 2009, ***Sévellec and Fedorov 2012, Muir and Fedorov 2012, in prep****.*



Hovmoller diagram *of observed temperature anomalies averaged between 300-400m and 10–60°N in the North Atlantic (XBT data), Frankcombe et al 2008*



Ocean GCM:

OPA 8.2
2°-global configuration
31 levels (ORCA2)

We use tangent linear and adjoint versions of the model

*Could we extract the leading AMOC **eigenmode** in this ocean GCM?*

Sevellec and Fedorov 2012

Method:

1. Ocean GCM :

$$\frac{d\mathbf{X}}{dt} = F(\mathbf{X},t)$$

Non-autonomous

$\mathbf{X}$ - the state vector

2. Linearize

$$\frac{d\mathbf{x}'}{dt} = \left.\frac{\partial F}{\partial \mathbf{X}}\right|_{\mathbf{X}_o} \mathbf{x}'$$

$$\mathbf{X} = \mathbf{X}_o + \mathbf{x}'$$

$\mathbf{X}_o$ - seasonally varying mean state of the ocean

$\mathbf{x}'$ - anomalies

3. Integrate between t_1 and t_2

$$\mathbf{x}(t_2) = \mathbf{M}(t_1,t_2)\mathbf{x}(t_1)$$

$\mathbf{M}$ - the linear propagator of the system

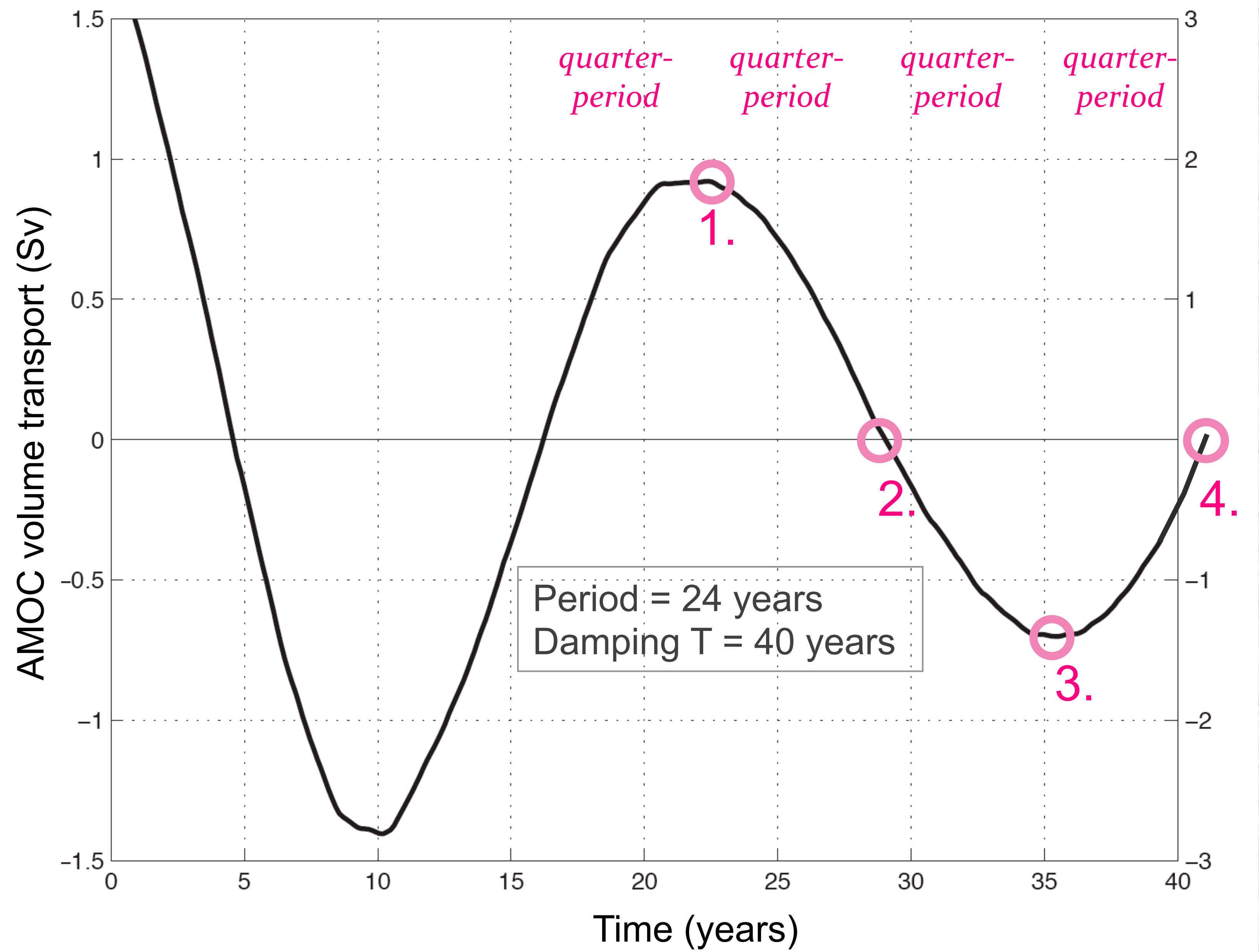
4. Eliminate the seasonal cycle from $\mathbf{M}$

$\tilde{\mathbf{M}} = \mathbf{M}(t, t + n \cdot year)$ $\;->$ *a Poincare section,*

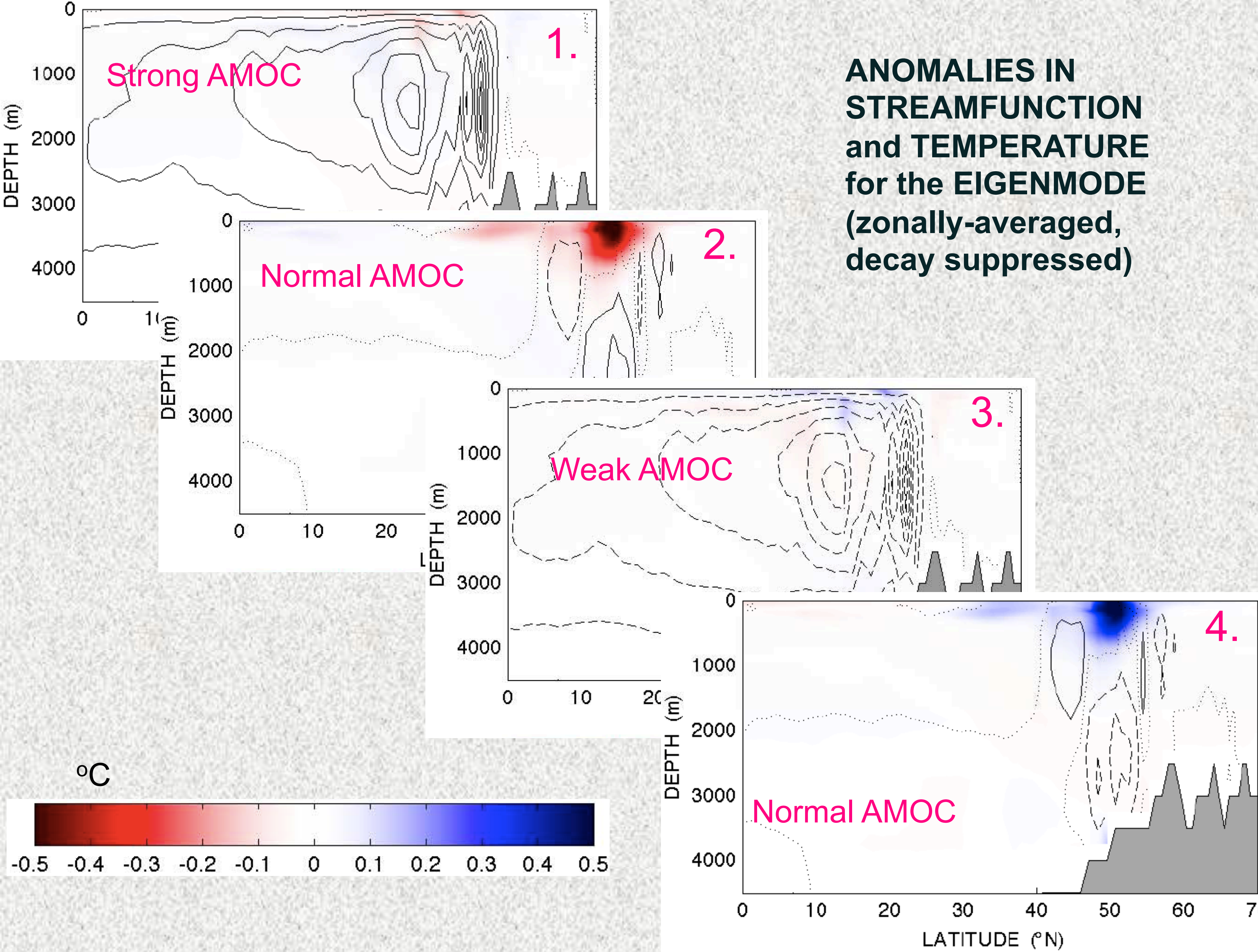
e.g. consider $\mathbf{M}$ *on every Jan 1*

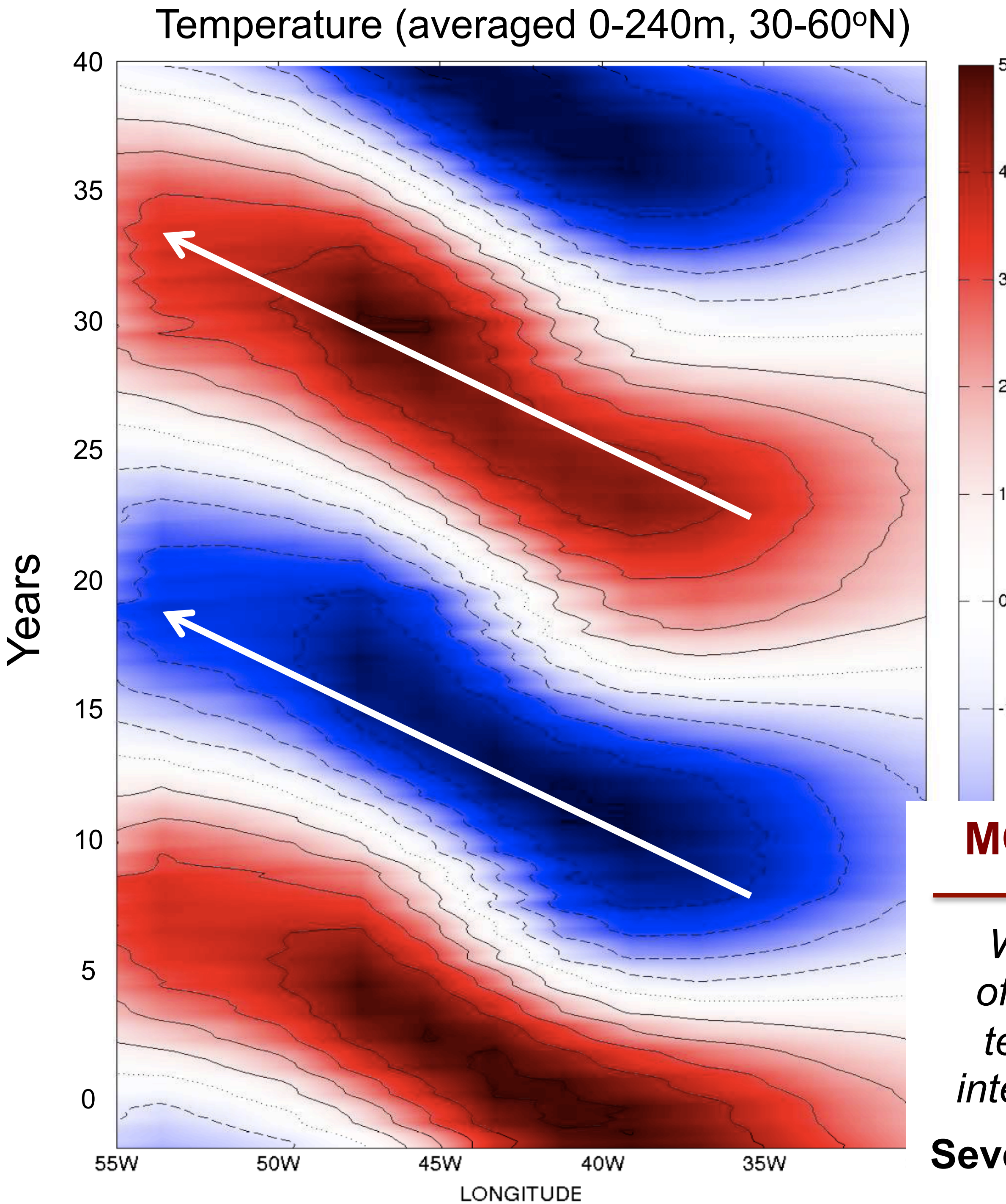
5. Obtain the least damped ***eigen-mode*** *of* $\tilde{\mathbf{M}}$

The least-damped mode: AMOC variations



ANOMALIES IN STREAMFUNCTION and TEMPERATURE for the EIGENMODE (zonally-averaged, decay suppressed)





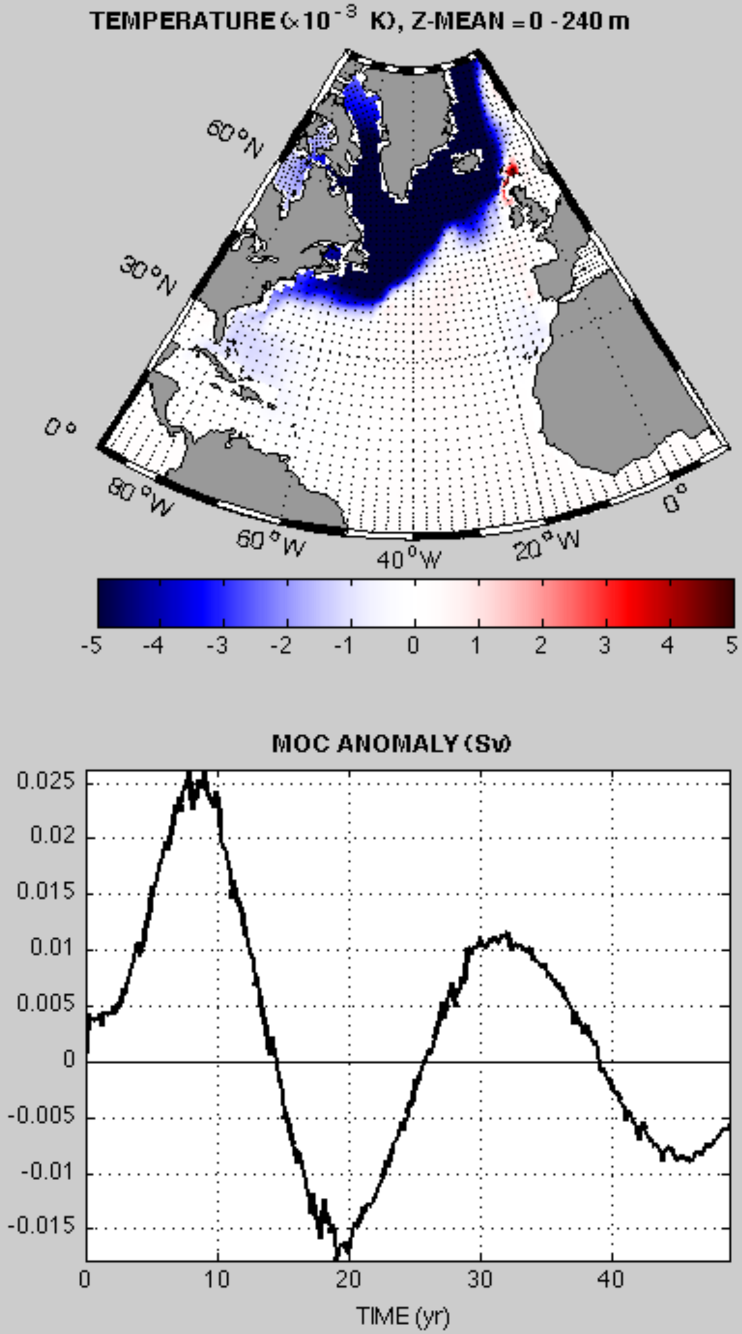
Hovmoller diagram for depth-integrated temperature anomalies propagating across the North Atlantic;

Decay suppressed

MODE MECHANISM:

Westward propagation of large-scale horizontal temperature anomalies interacting with the AMOC

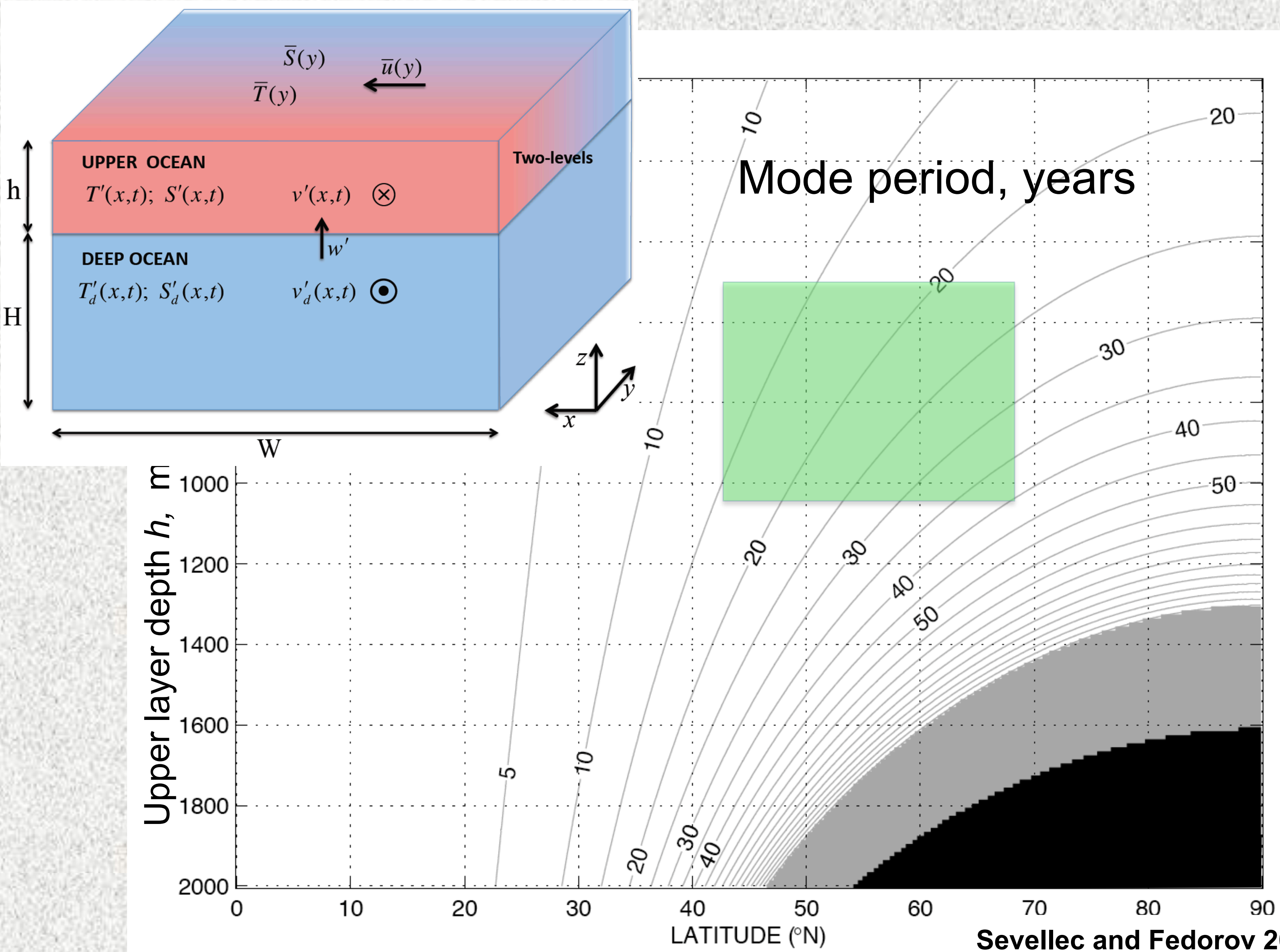
Sevellec and Fedorov 2012



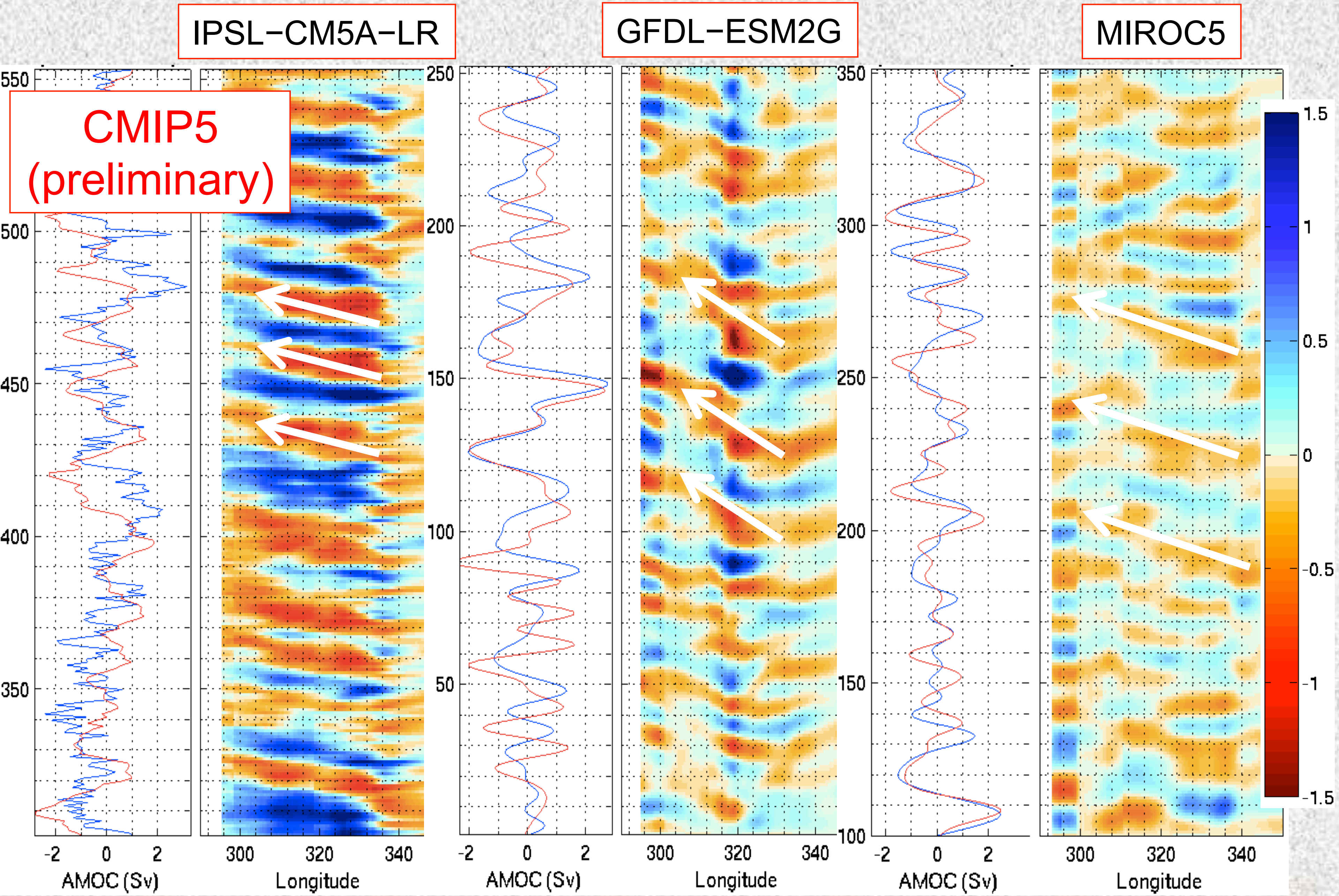
Excitation of the eigenmode by **optimal initial perturbations** (temperature anomalies around Greenland)

Sevellec and Fedorov 2012b

OSCILLATION PERIOD: idealized 2-layer model

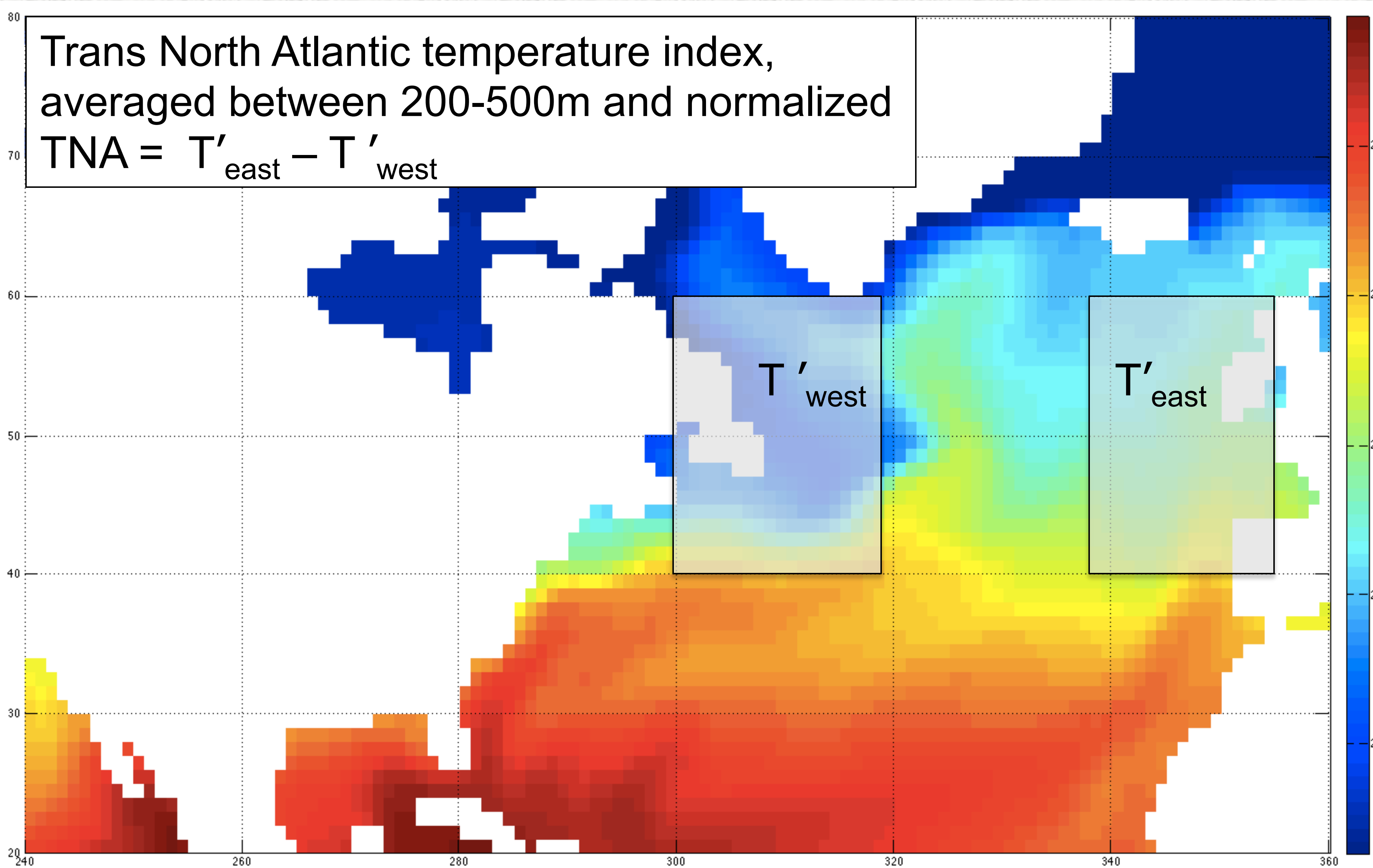


Sevellec and Fedorov 2012



Blue line = AMOC (Sv), Red line = TNA temperature index (normalized)
Hovmoller maps = temperature anomalies correlated with the AMOC

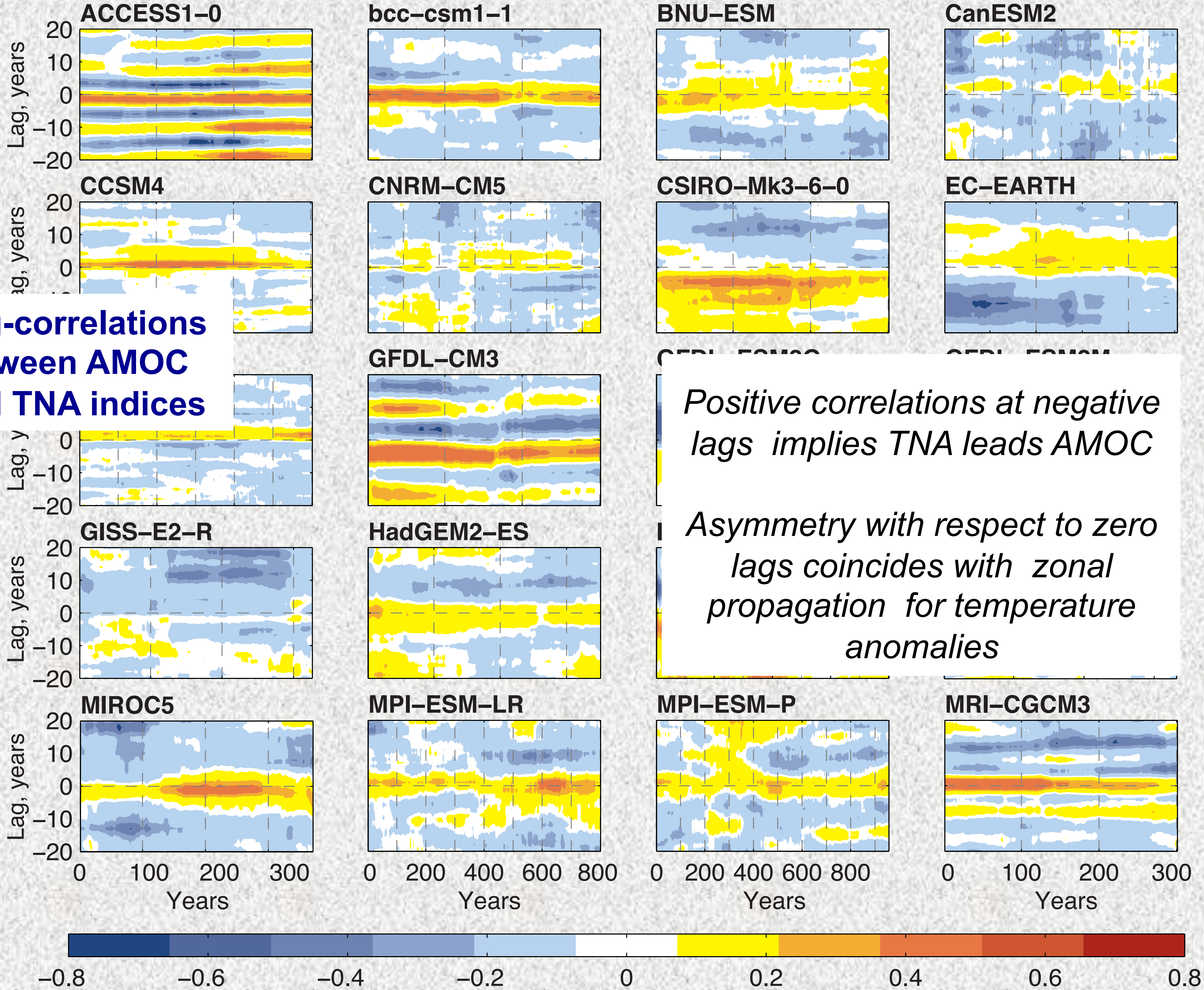
TNA temperature index



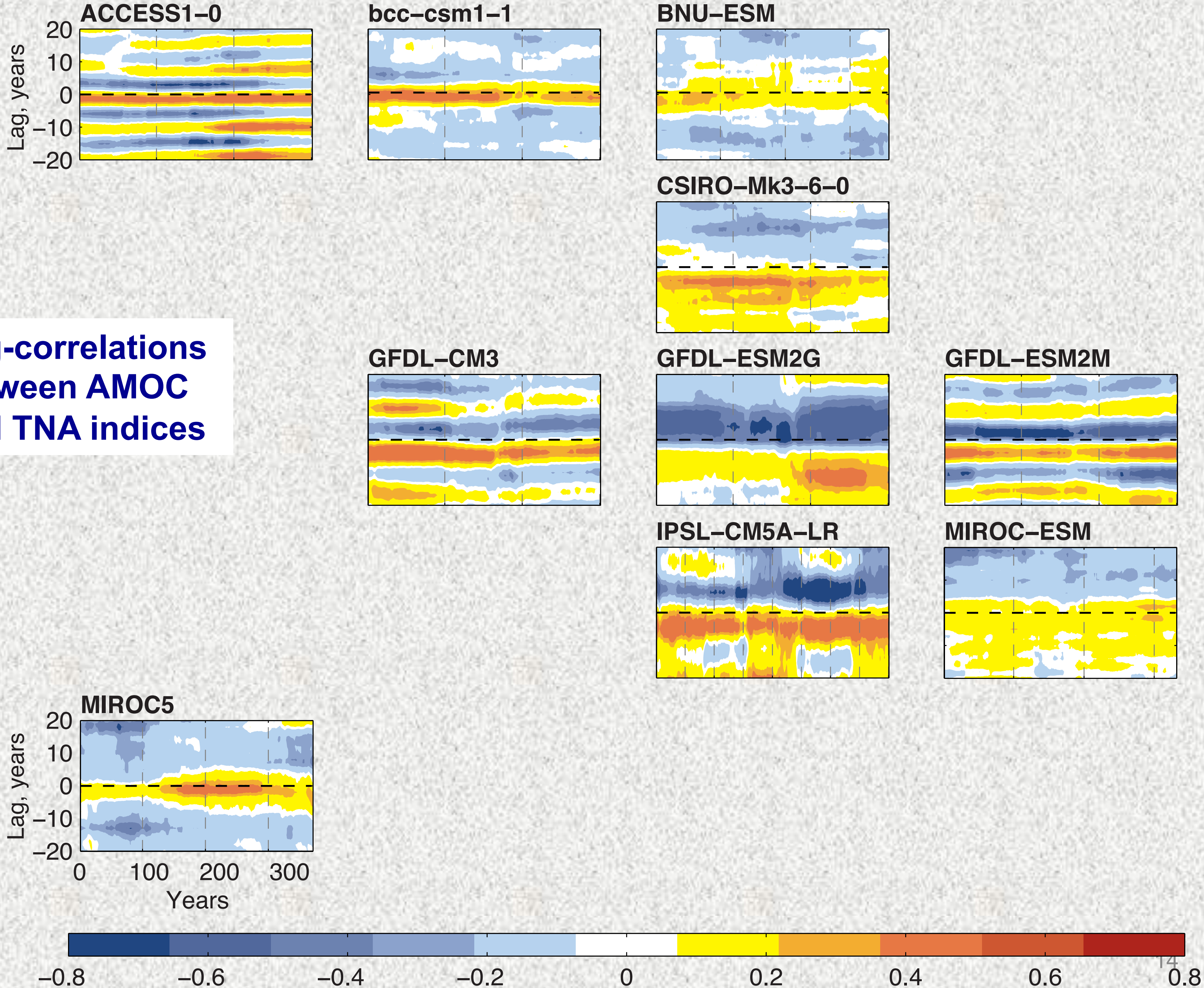
Lag-correlations between AMOC and TNA indices

Positive correlations at negative lags implies TNA leads AMOC

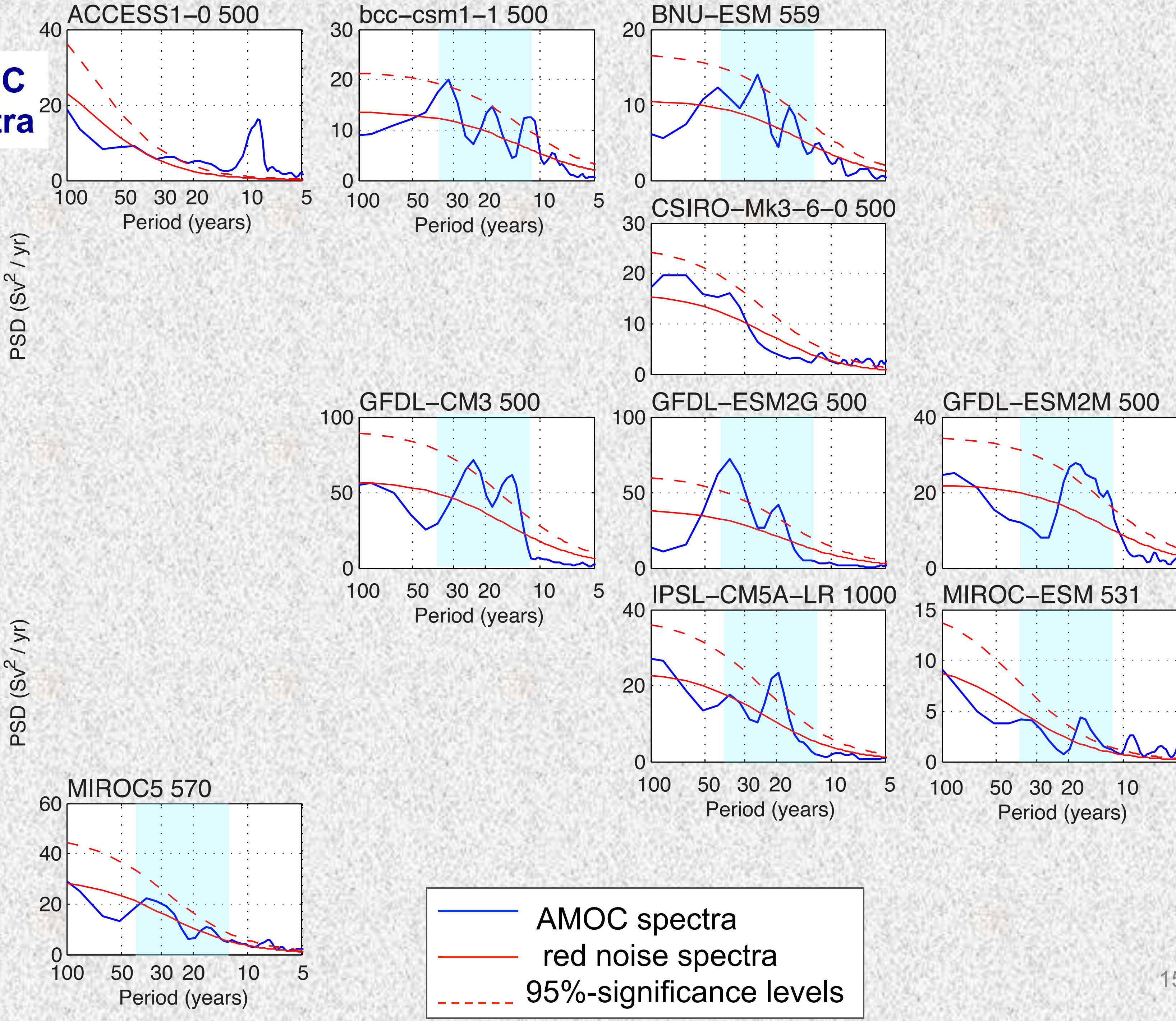
Asymmetry with respect to zero lags coincides with zonal propagation for temperature anomalies



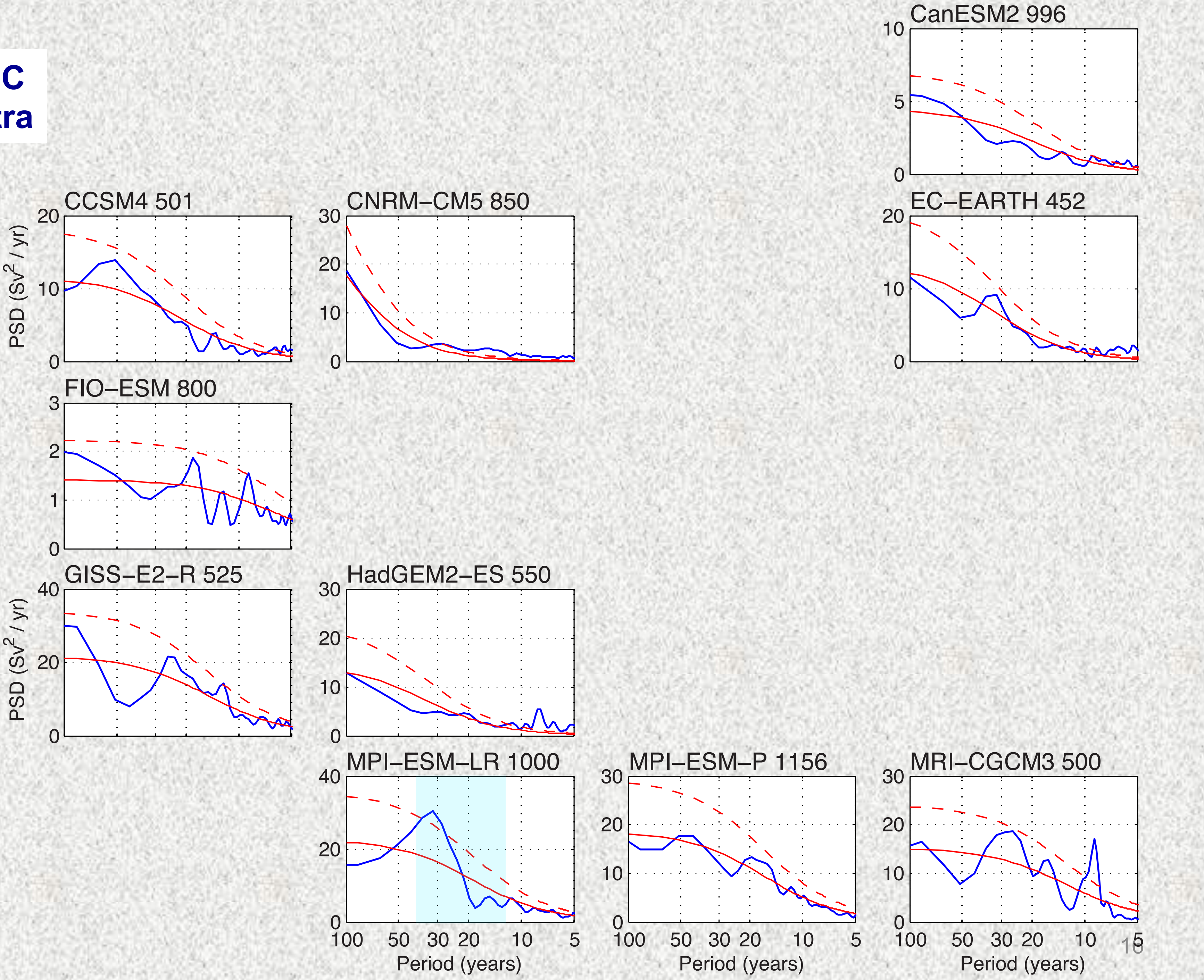
Lag-correlations between AMOC and TNA indices



AMOC spectra



AMOC spectra



Summary

- *We have identified the leading, interdecadal oscillatory eigenmode of the AMOC in a realistic ocean model (T~ 20 years), also present in simple 2-layer models*
- *Its mechanism is related to westward propagation of temperature anomalies in the upper northern Atlantic ocean (~500m) interacting with the AMOC*
- *This eigenmode is possibly present in CMIP5 models (IPSL-CM5, GFDL-ESM2G, MIROC5 ...), as evidenced by spectral peaks between 15-40 years and westward-propagating temperature anomalies correlated with the AMOC*
- *Lag-correlations between AMOC and TNA indices reach 0.8*
- *Most models without the westward propagation do not develop statistically significant interdecadal spectral peaks*
- *Also, a poster "AMOC variability and its effect on SST in CMIP5"*

Lag-correlations between AMOC and TNA indices