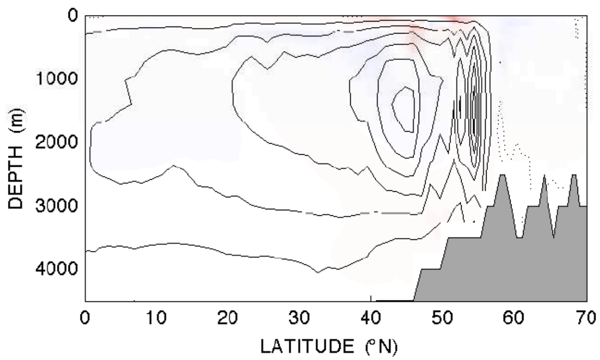
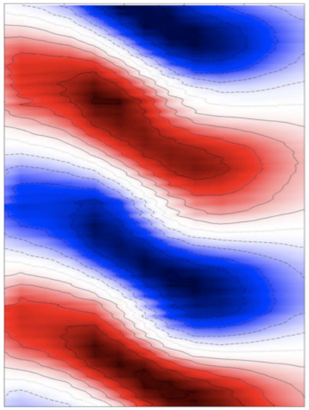
The interdecadal AMOC mode related to westward propagation of temperature anomalies, in theory and in CMIP5 models





Alexey Fedorov

Thanks to: Les Muir and Florian Sevellec

Yale University

July 2013

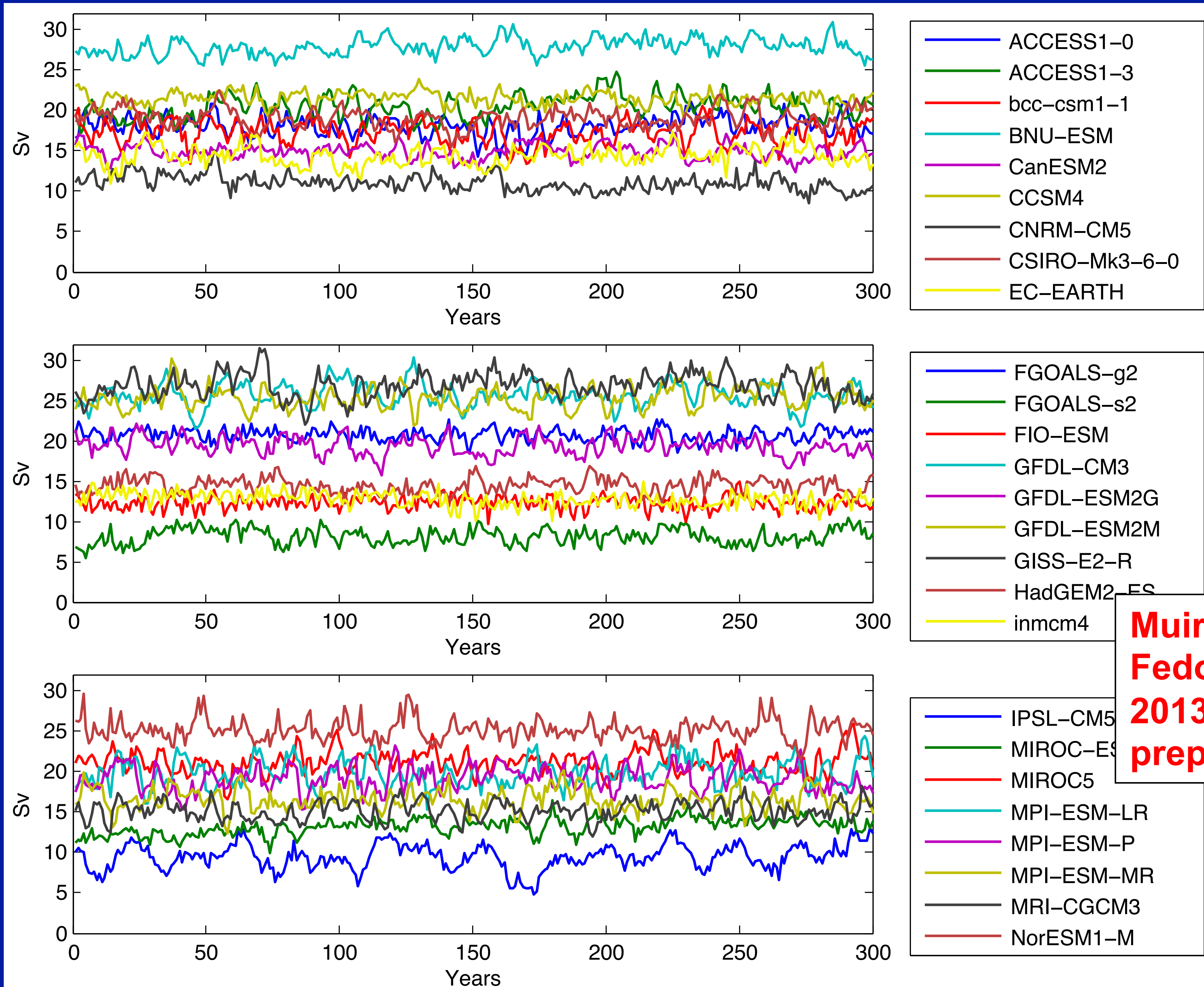
Sevellec, F., and Fedorov, A.V. 2013a: The leading, interdecadal eigenmode of the Atlantic meridional overturning circulation in a realistic ocean model. *J. Climate* 26, 2160-2183.

Sevellec, F., and Fedorov, A.V. 2013b: Optimal temperature and salinity perturbations for the AMOC in a realistic ocean GCM. *Progress in Oceanography, Accepted*

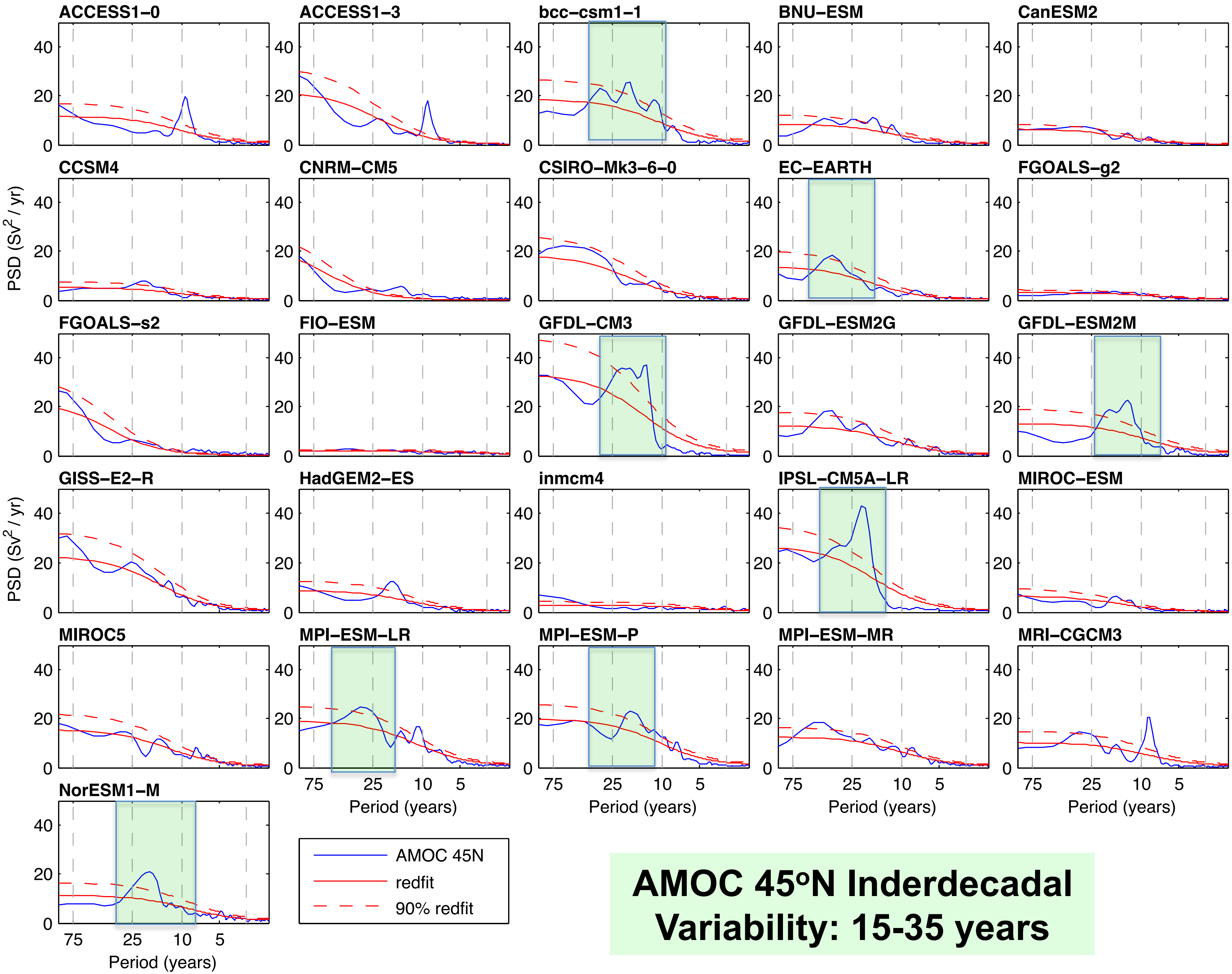
Sevellec, F., and Fedorov, A.V. 2013c: Model bias and the limits of oceanic decadal predictability: importance of deep ocean. *J. Climate 26,3688-3707.*

Muir, L., and Fedorov, A.V. 2013a: The AMOC mode related to westward propagation of density anomalies: results from CMIP5, *In prep.*

AMOC 45ºN decadal to multi-decadal variability in CMIP5

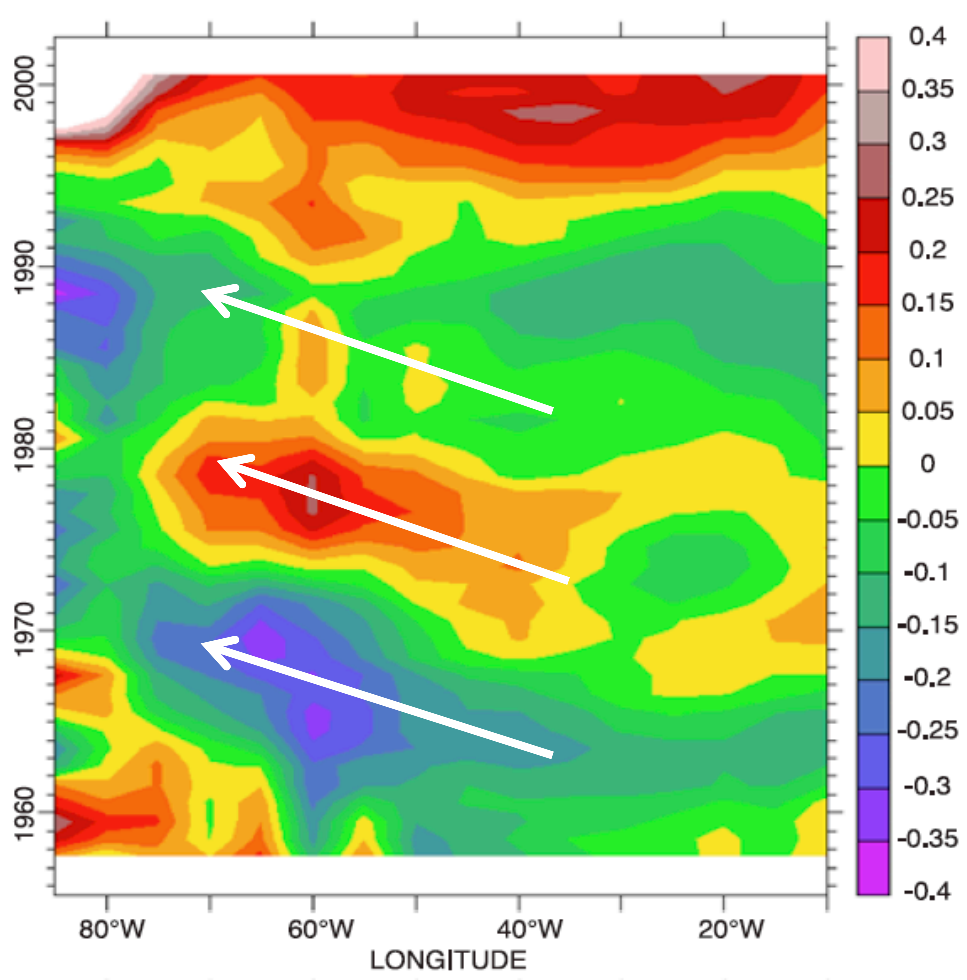


Muir and Fedorov 2013a, in prep



AMOC 45°N Inderdecadal Variability: 15-35 years

What controls the dynamics of this interdecadal variability of the AMOC?



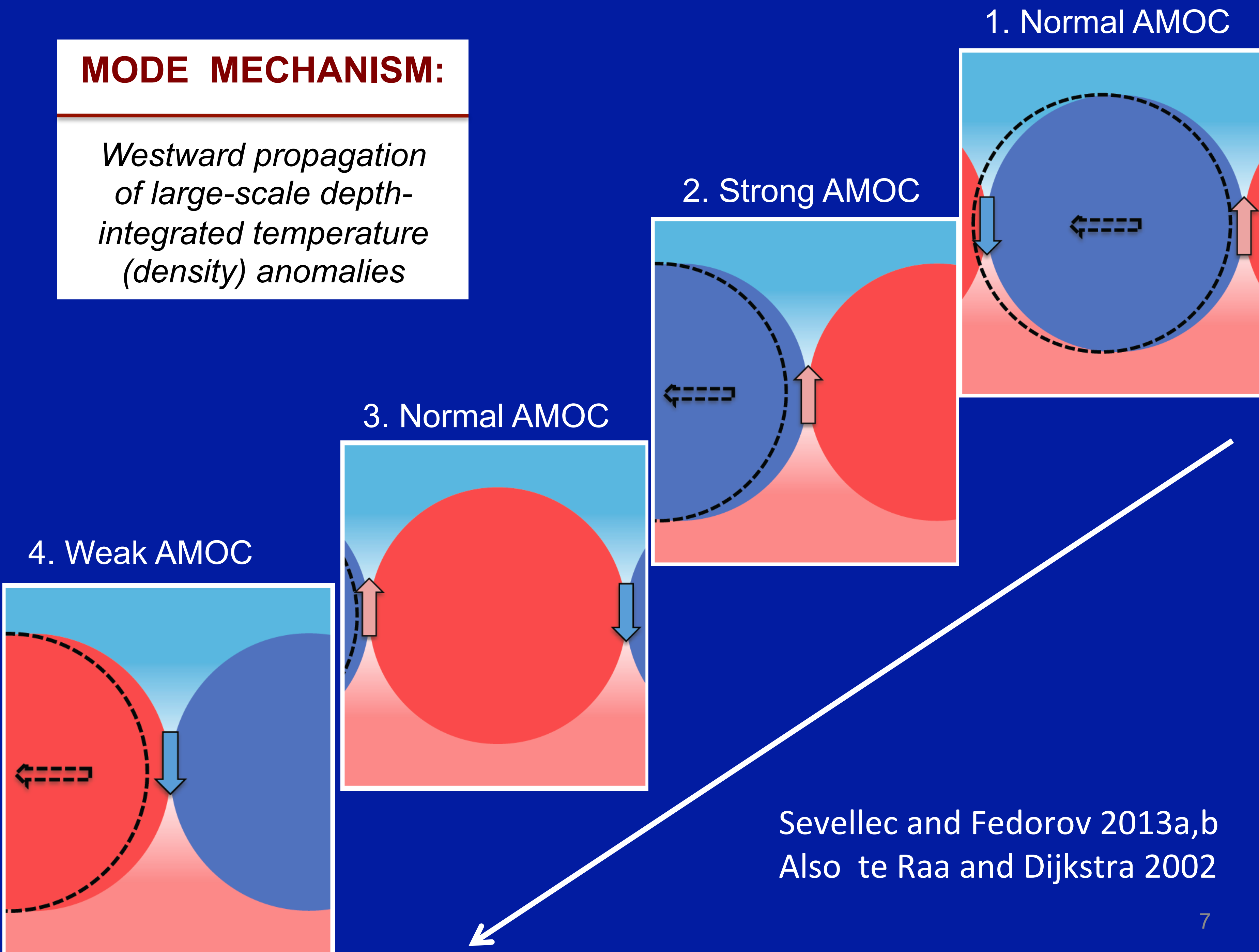
Hovmoller diagram of observed temperature anomalies *averaged between 300-400m and 10–60^{o}N in the North Atlantic (XBT data), Frankcombe et al 2008*

One of the proposed mechanisms: westward propagation of temperature (density) anomalies in the North Atlantic interacting with the AMOC

Huck et al. 1999
de Verdière and Huck 1999
Marshall et al 2000
te Raa and Dijkstra 2002
Dijkstra et al. 2006
Frankcombe et al. 2008, 2009
Sévellec et al. 2009
Buckley et al. 2012
Sévellec and Fedorov 2013a,b
Muir and Fedorov 2013a in prep

MODE MECHANISM:

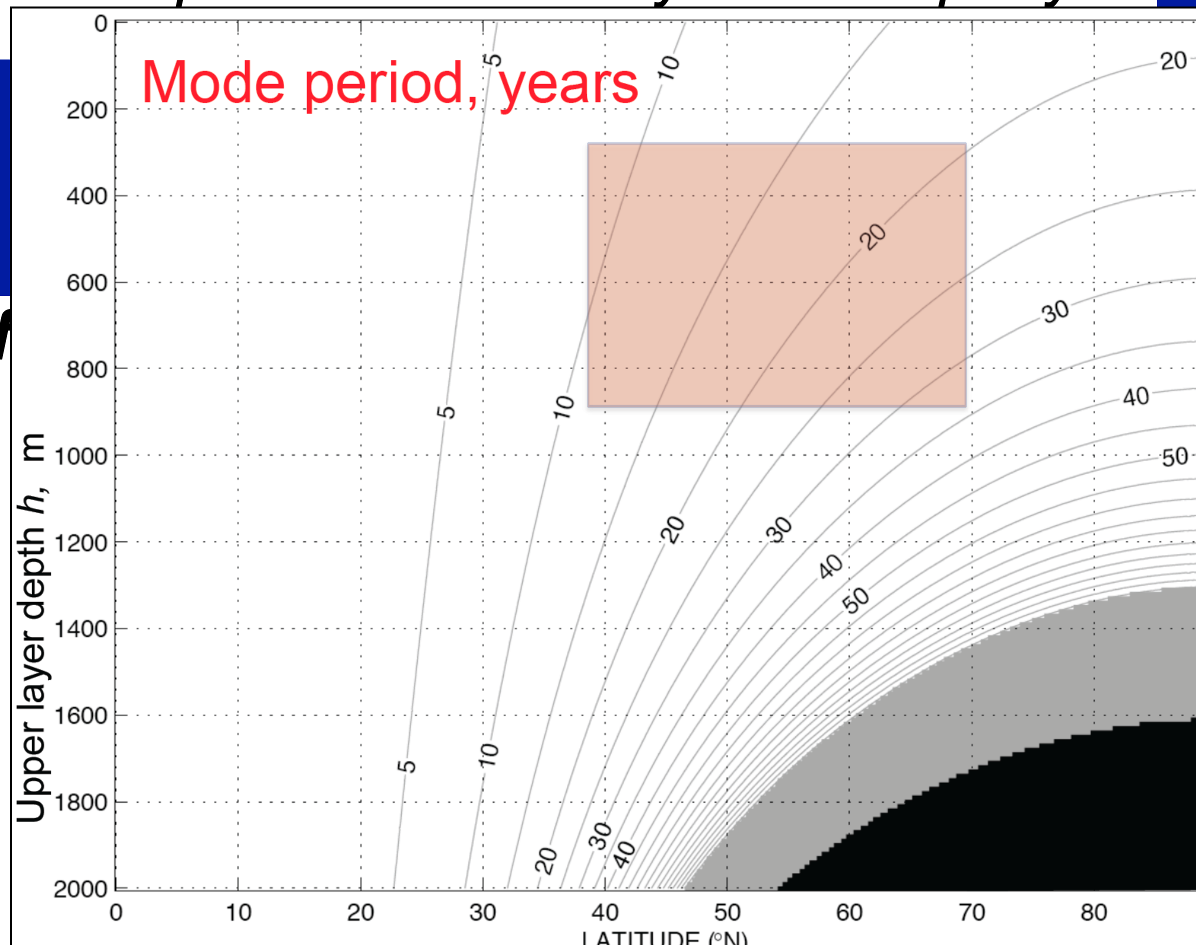
Westward propagation of large-scale depth-integrated temperature (density) anomalies



Sevellec and Fedorov 2013a,b
Also te Raa and Dijkstra 2002

Simple model (Sevellec and Fedorov 2013a,c)

$$\frac{\partial T'}{\partial t} = -c\,\partial_x T' + k\partial_{xx} T';$$ *T' - temperature anomaly in the top layer*



Propagation speed of temperature anomalies

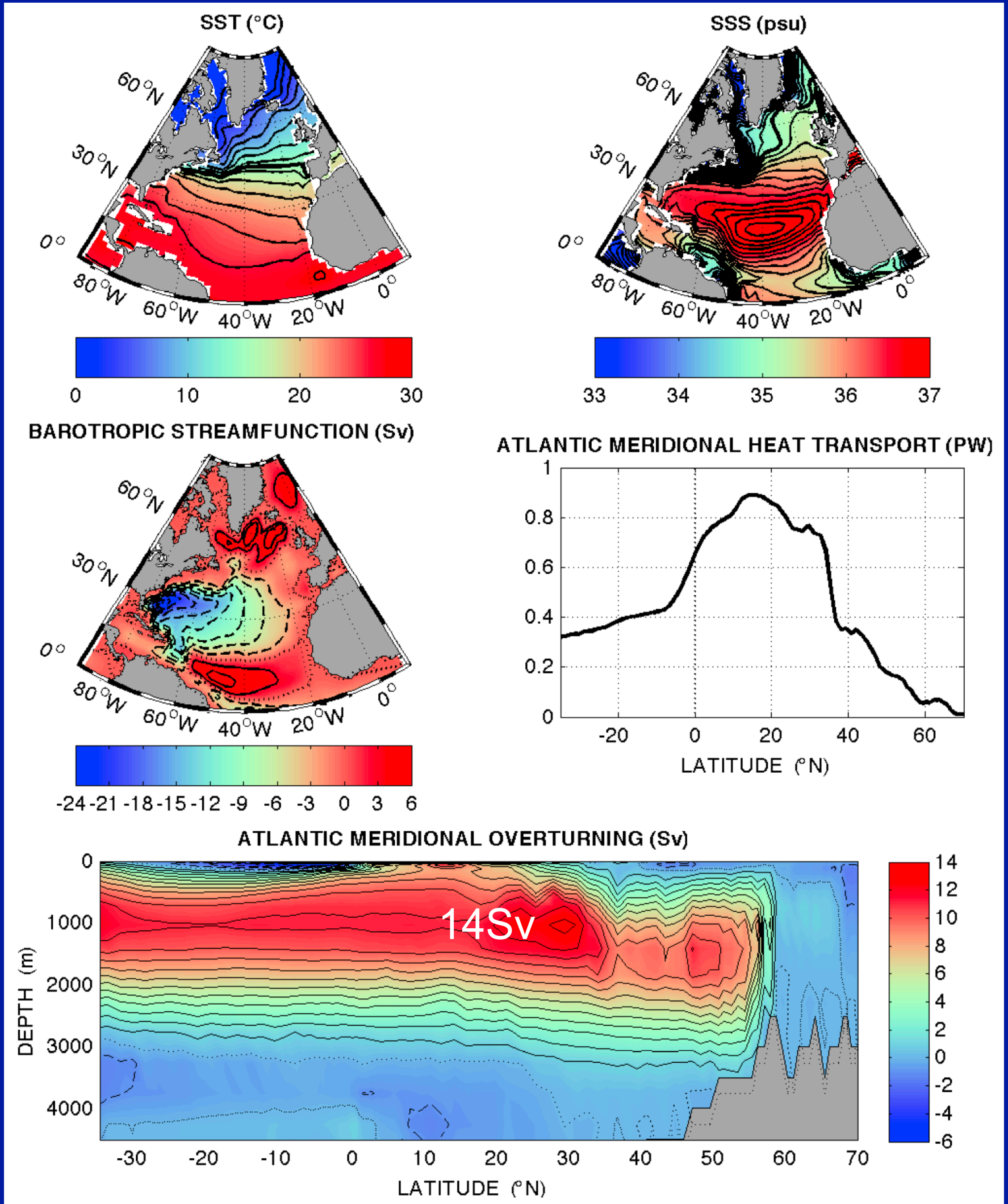
$$c = \bar{U} + U' + c_{rossby}$$

$\bar{U}$ *- eastward advection*

$U' \propto \partial_y \bar{T}$ *- westward geostrophic self-advection on temp grad*

c_{rossby} *- baroclinic Rossby wave speed (the β-effect)*

Realistic ocean GCM



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

We extract the leading AMOC ***eigenmode*** *in this ocean GCM*

Sevellec and Fedorov 2013a

Generalized linear stability analysis of ocean GCM

1. Ocean GCM

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

X - the state vector of the ocean

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

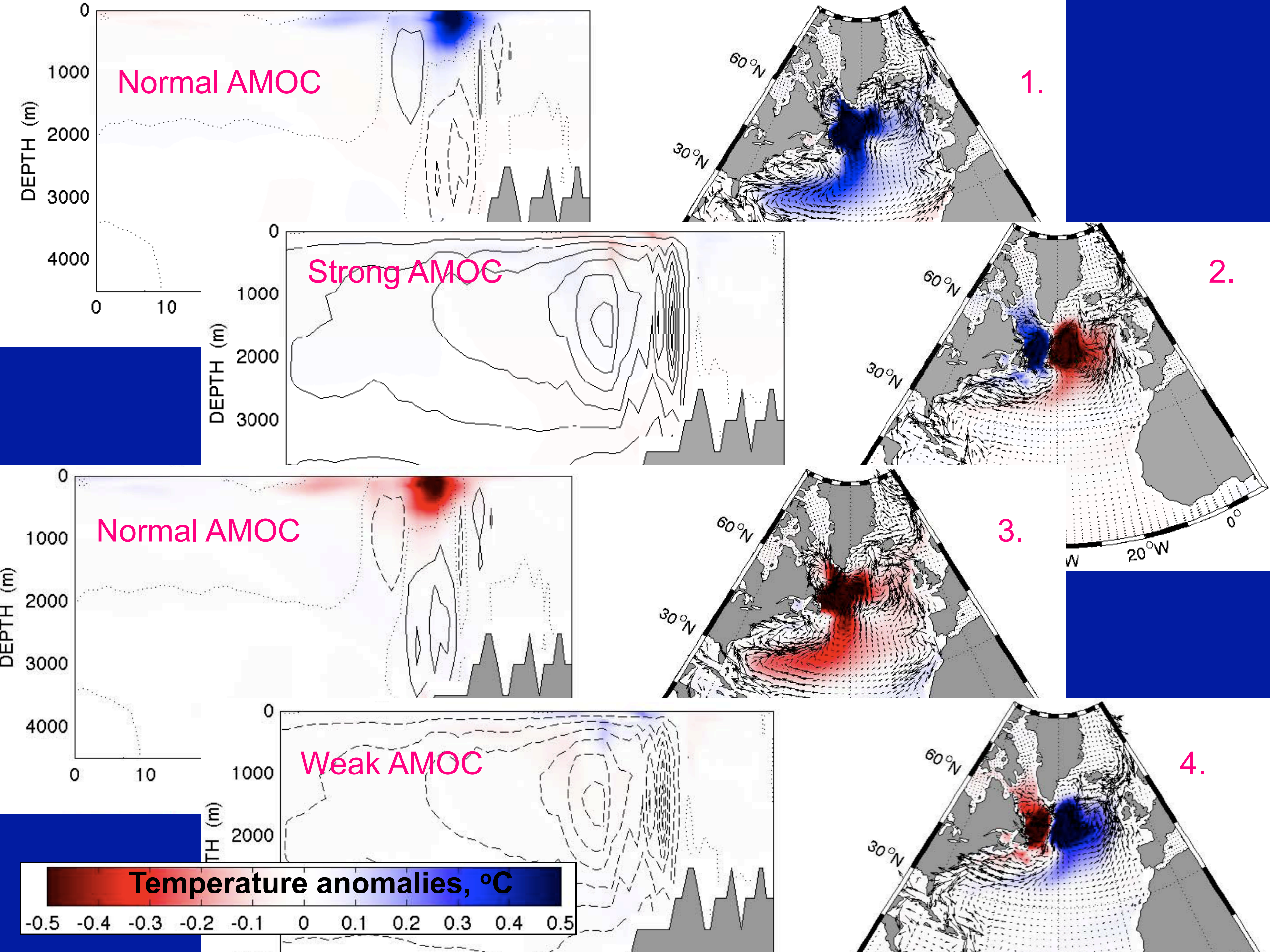
$\mathbf{x}'$ - anomalies

3. Integrate between t_1 and t_2

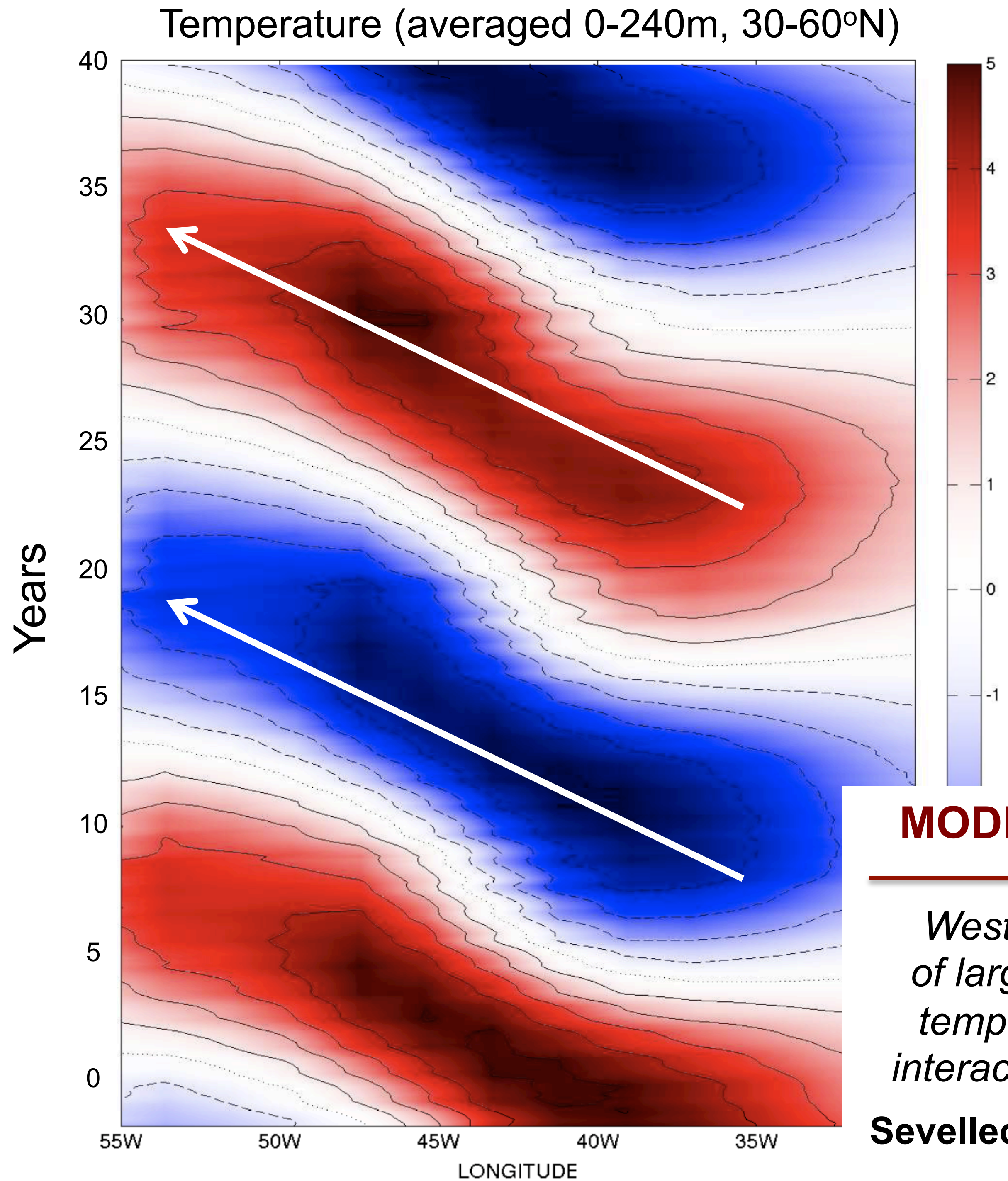
$$\mathbf{x}(t_2) = \mathbf{M}(t_1,t_2)\mathbf{x}(t_1)$$

M - the linear propagator of the system

4. Obtain the least damped ***eigen-mode*** *of* **M***, etc.*



Normal AMOC
Strong AMOC
Normal AMOC
Weak AMOC
1.
2.
3.
4.
DEPTH (m)
60 °N
30 °N
20 °W
0°
Temperature anomalies, °C
-0.5 -0.4 -0.3 -0.2 -0.1 0 0.1 0.2 0.3 0.4 0.5



Hovmoller diagram for depth-integrated temperature anomalies;

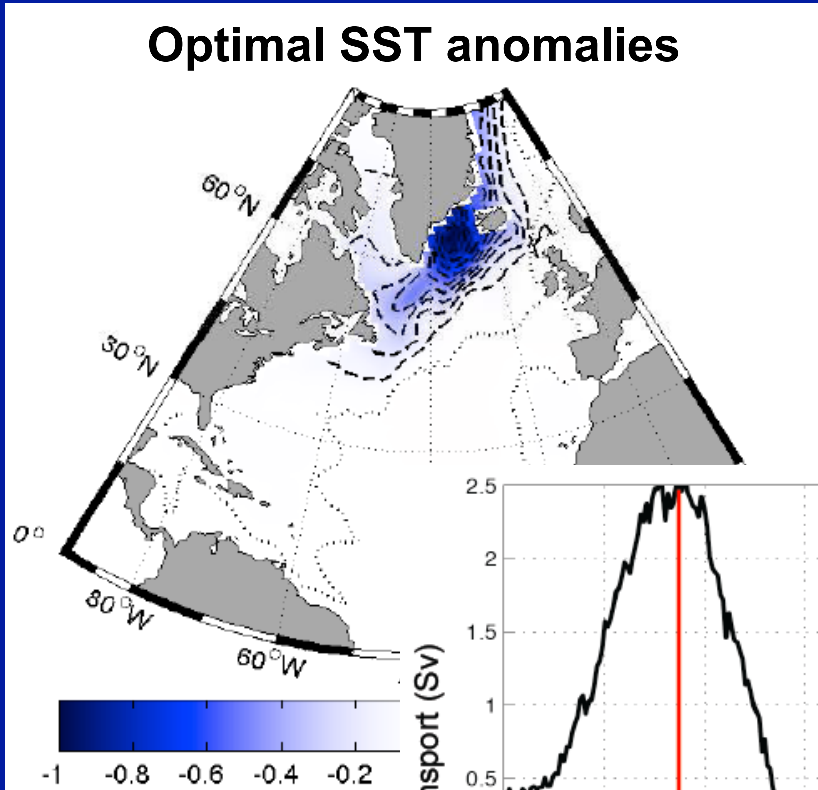
Decay suppressed

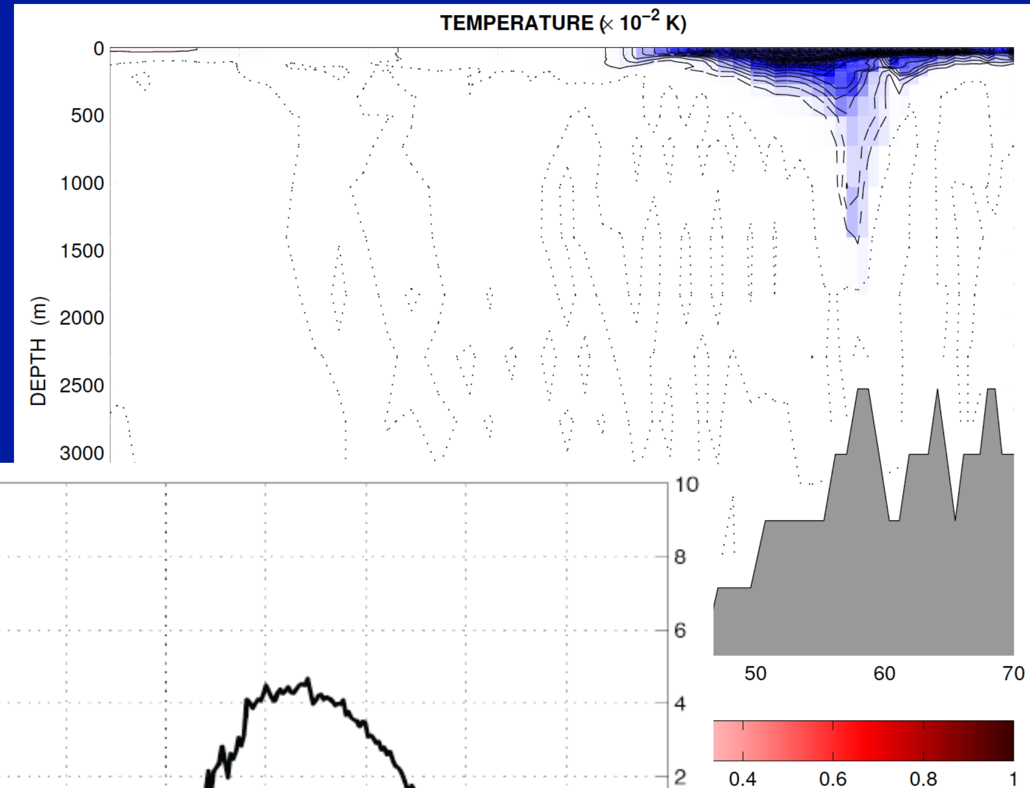
MODE MECHANISM:

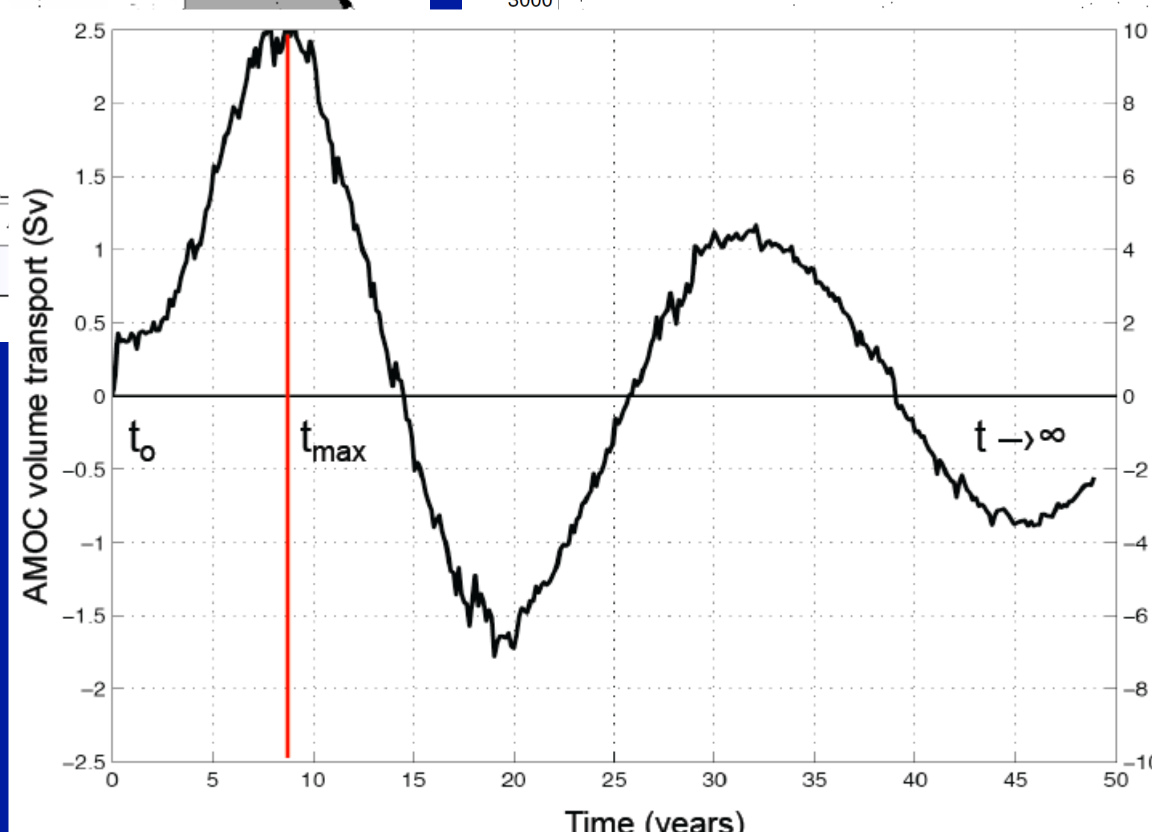
Westward propagation of large-scale horizontal temperature anomalies interacting with the AMOC

Sevellec and Fedorov 2013a

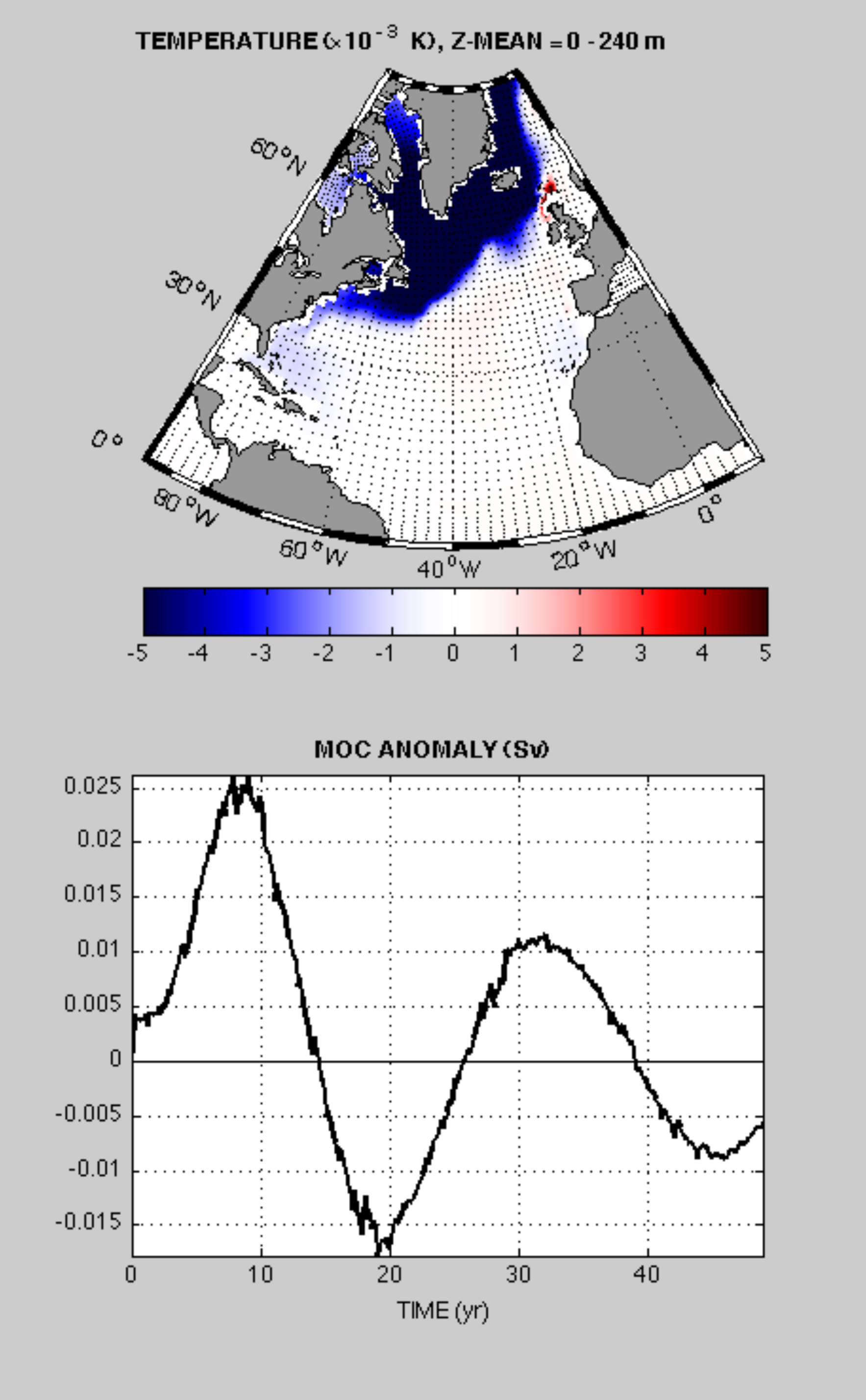
OPTIMAL EXCITATION BY INITIAL SURFACE TEMP OR SALINITY PERTURBATIONS







Sevellec and Fedorov 2013b

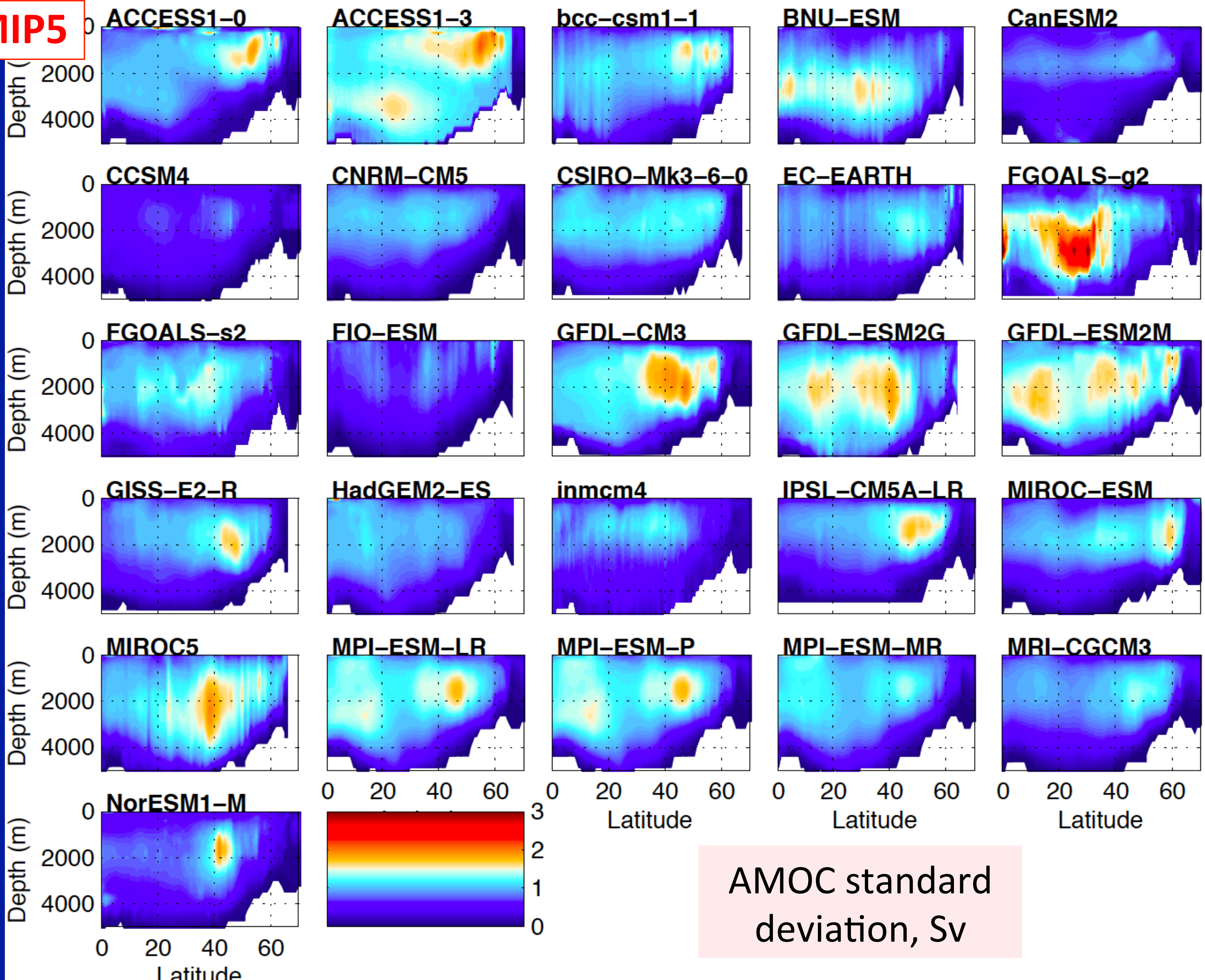


Excitation of the eigenmode by **optimal initial perturbations** (temperature or salinity anomalies around Greenland)

The mode is damped.

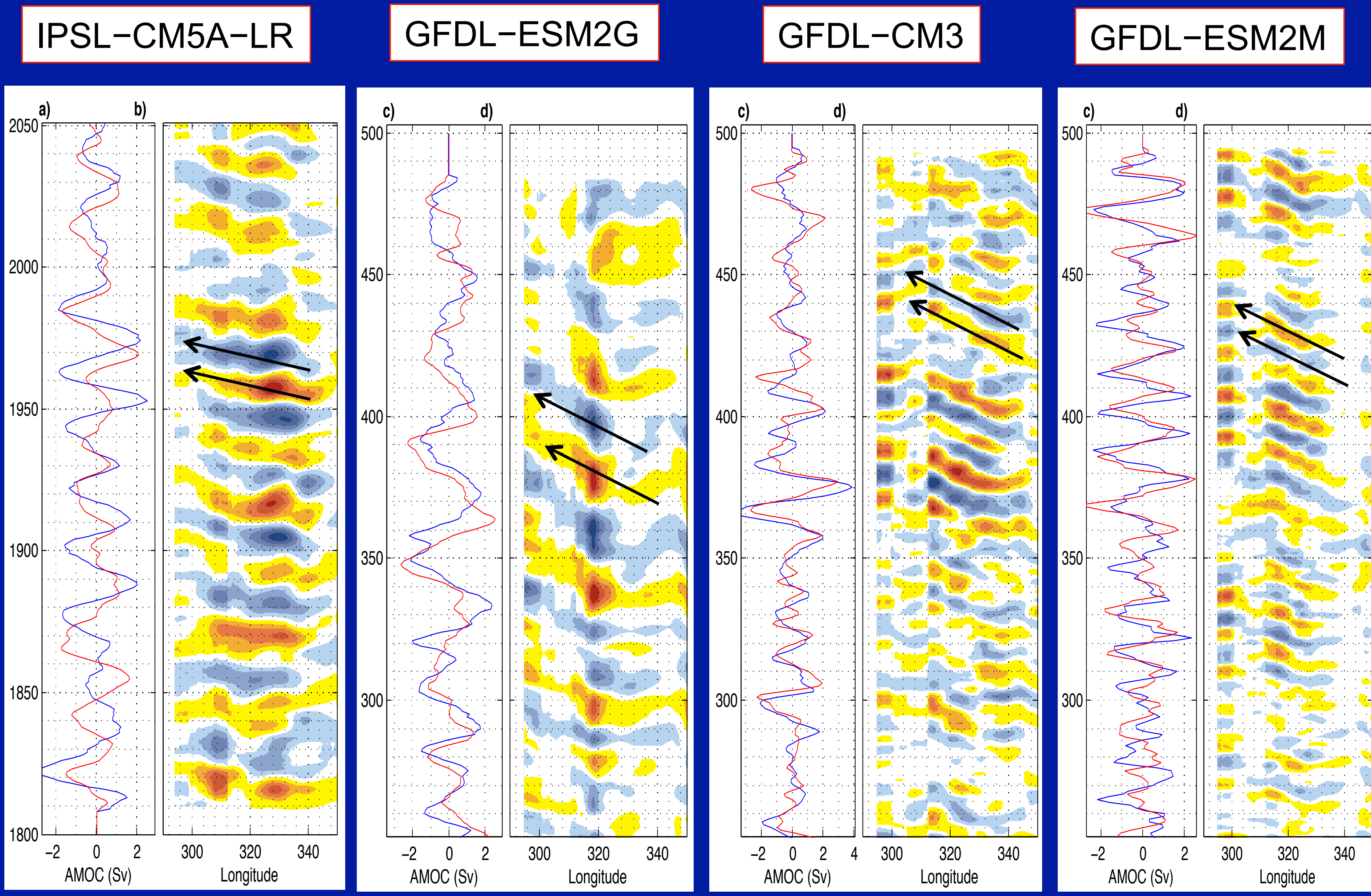
Sevellec and Fedorov 2013b

CMIP5



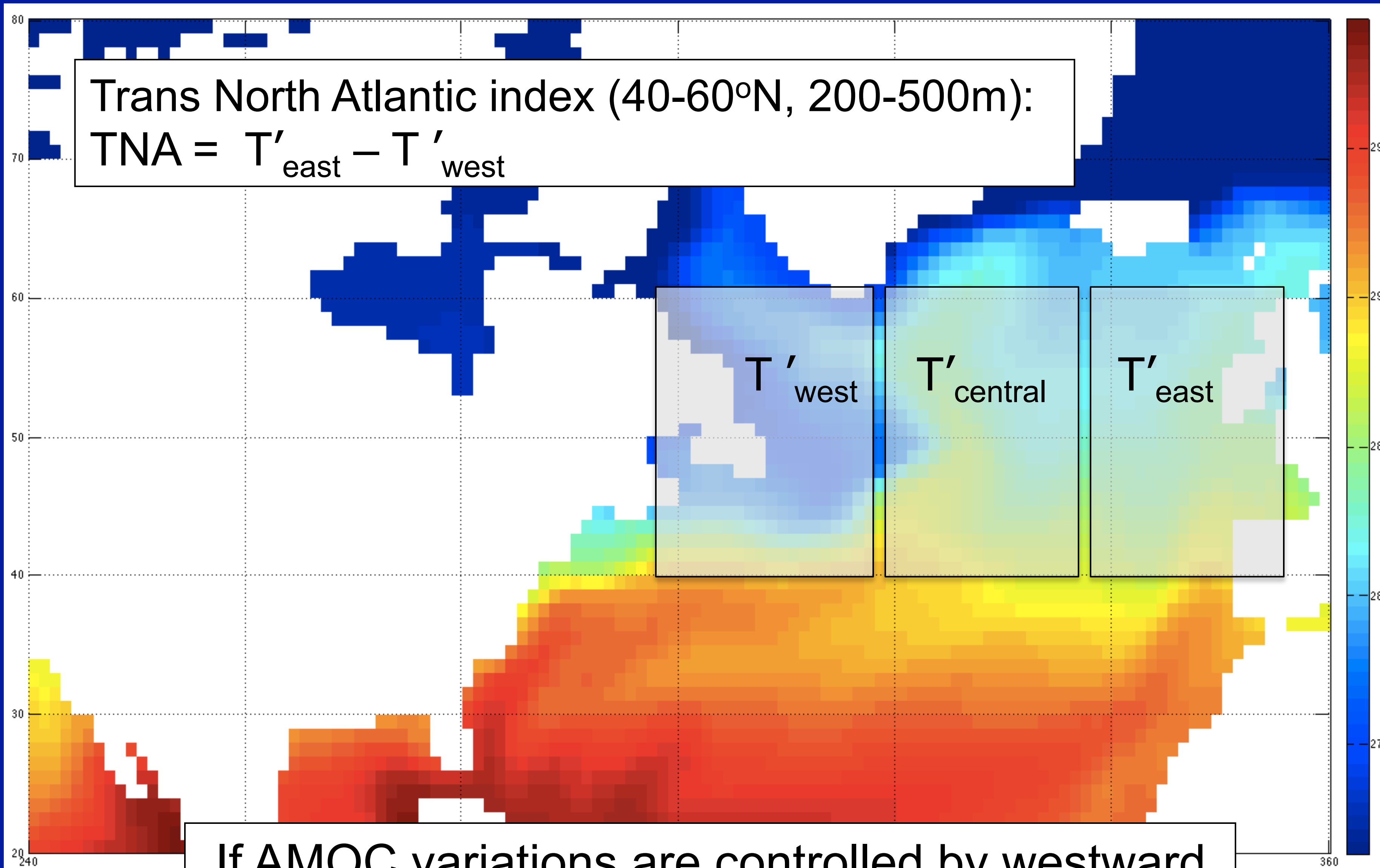
AMOC standard deviation, Sv

Westward propagation of temperature anomalies (200-500m,40-60°N)

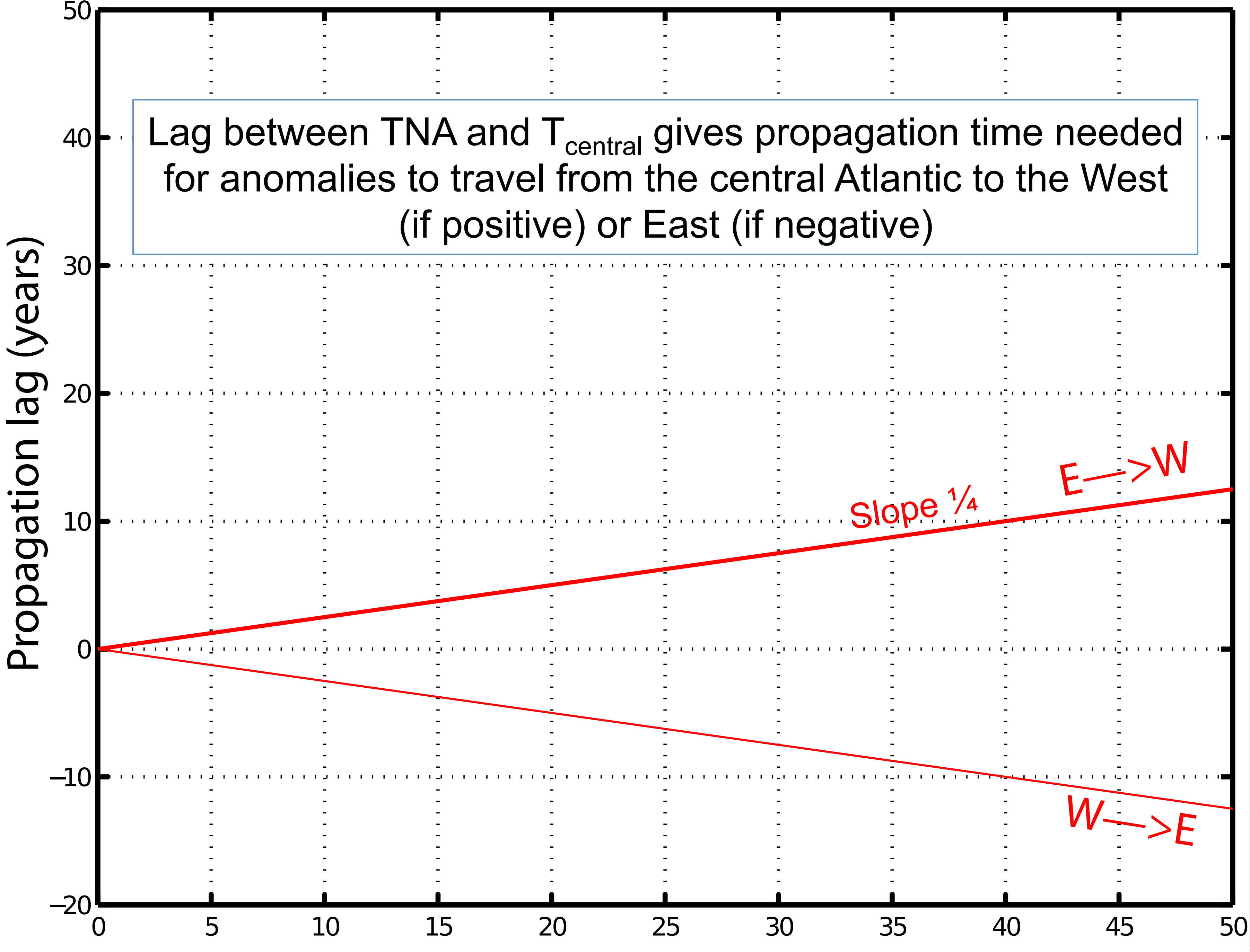


Trans North Atlantic index (40-60°N, 200-500m):

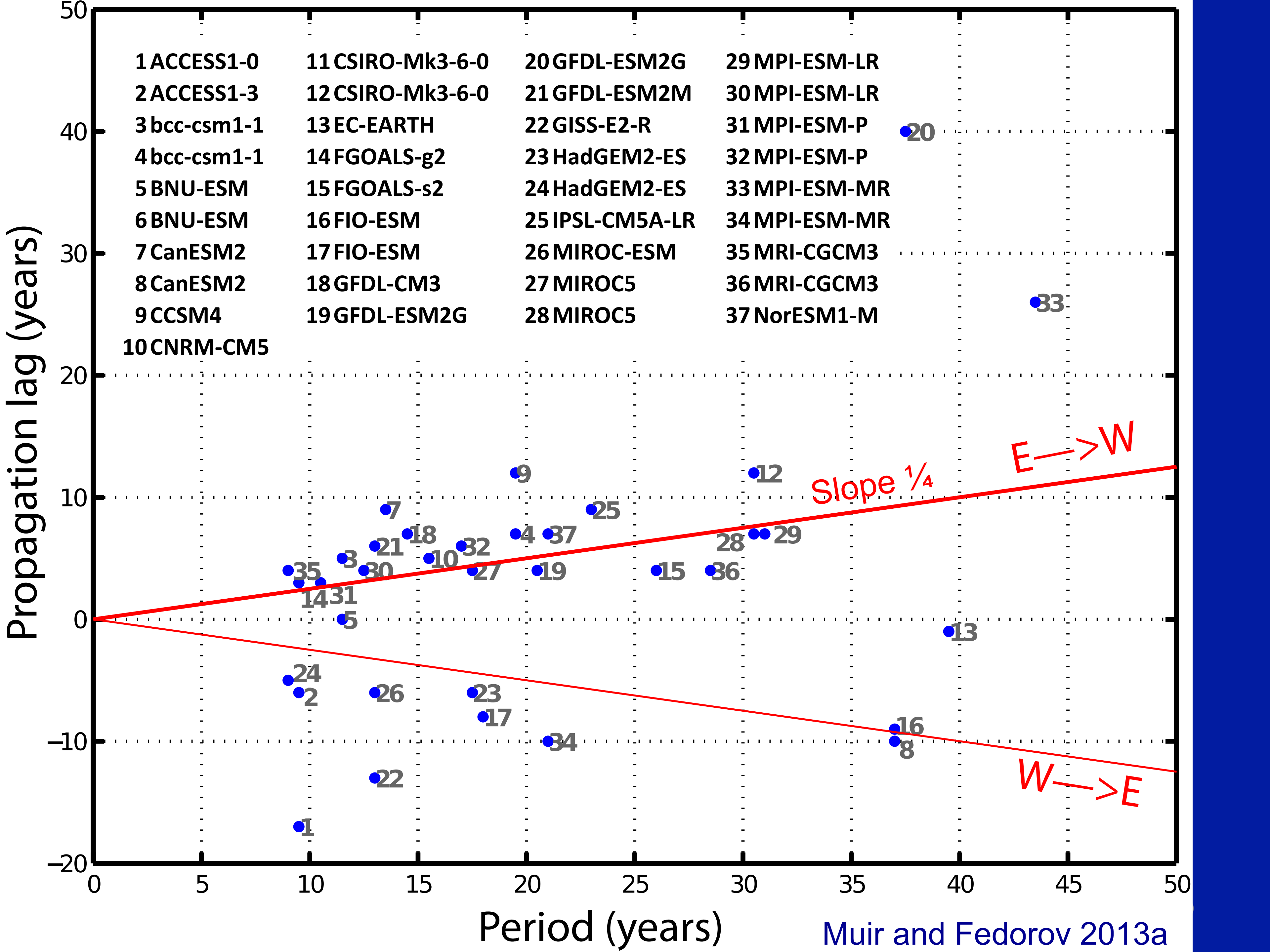
$TNA = T'_{east} - T'_{west}$



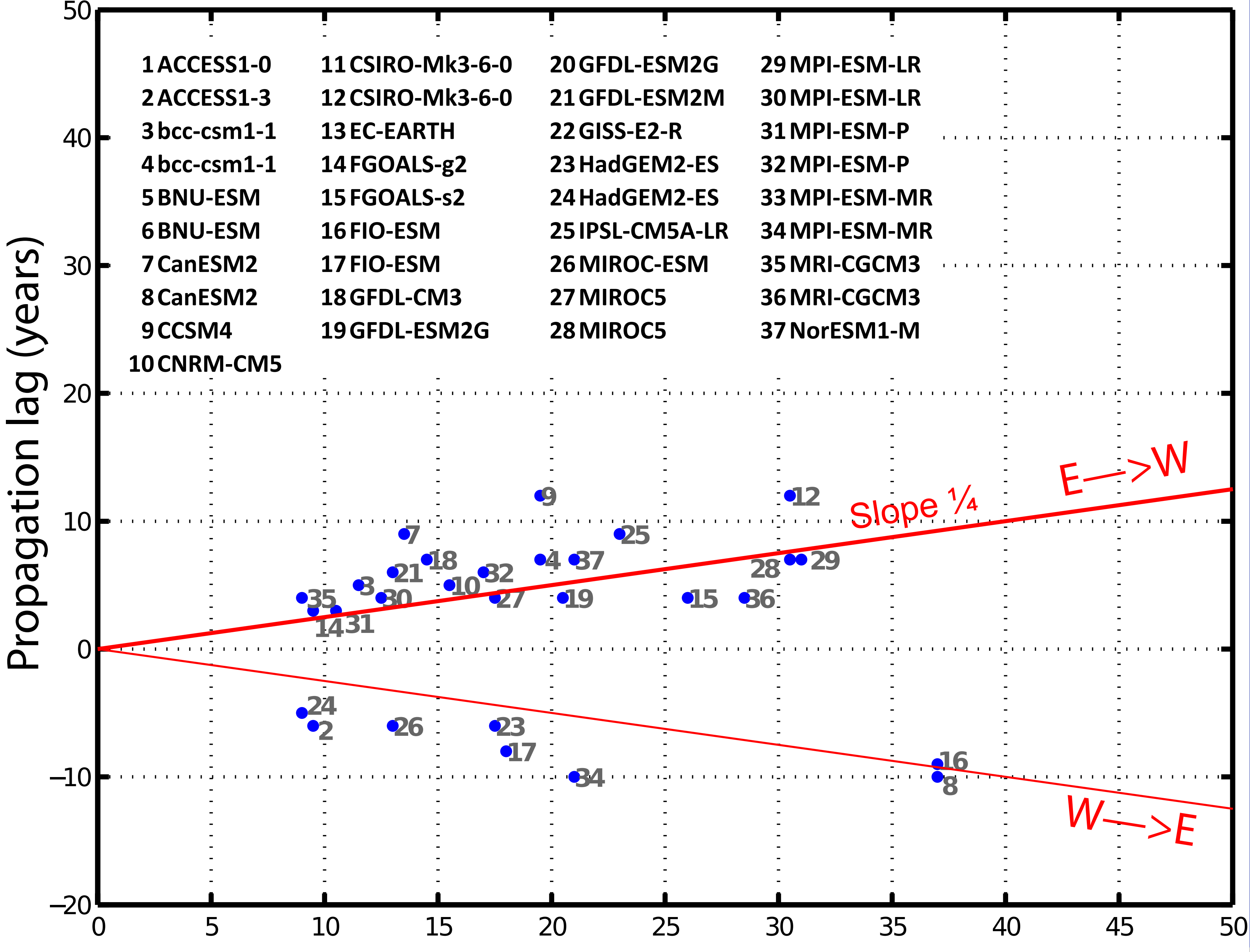
If AMOC variations are controlled by westward propagation of density anomalies, then TNA should lead $T'_{central}$ by ~¼ of the mode period



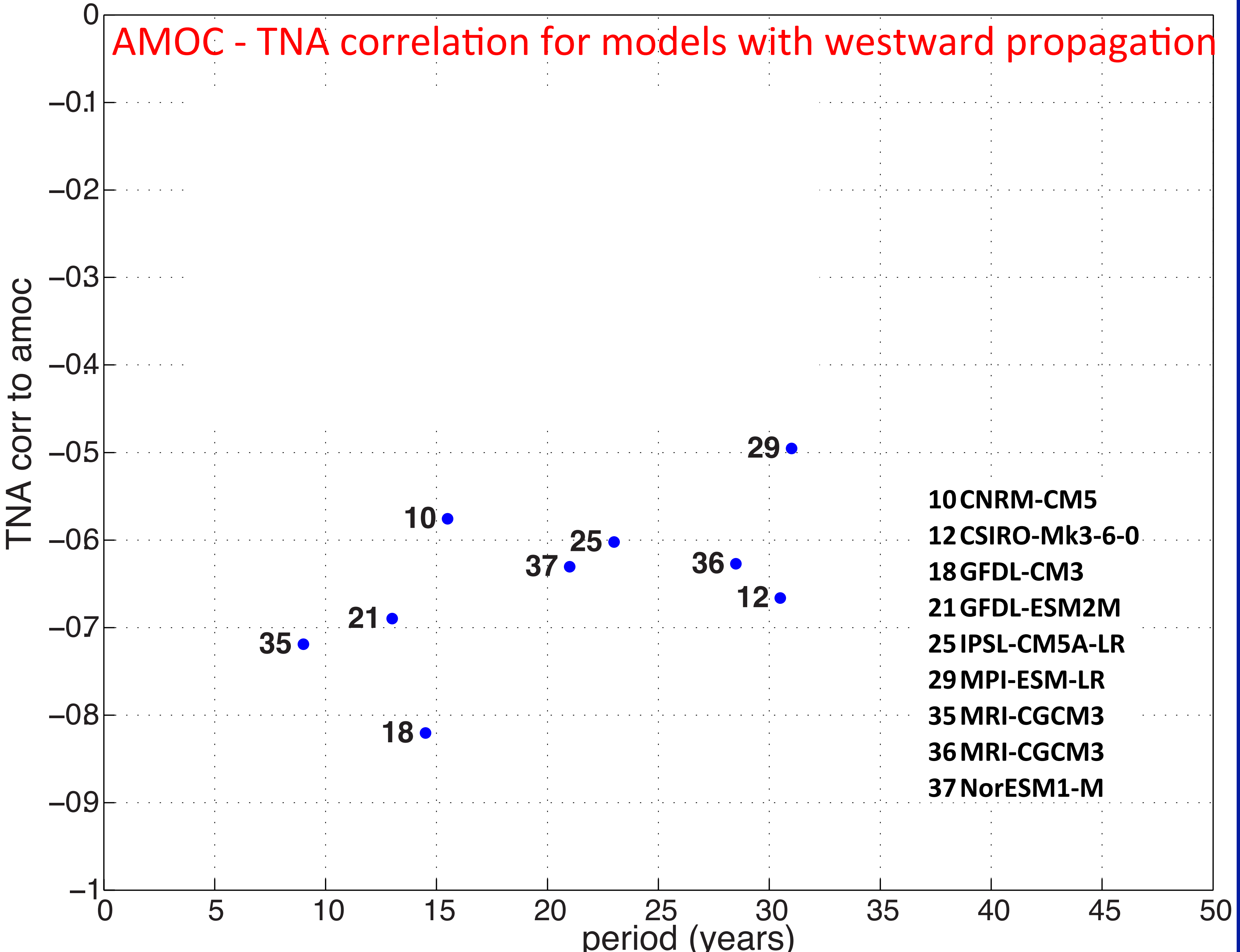
Muir and Fedorov 2013a



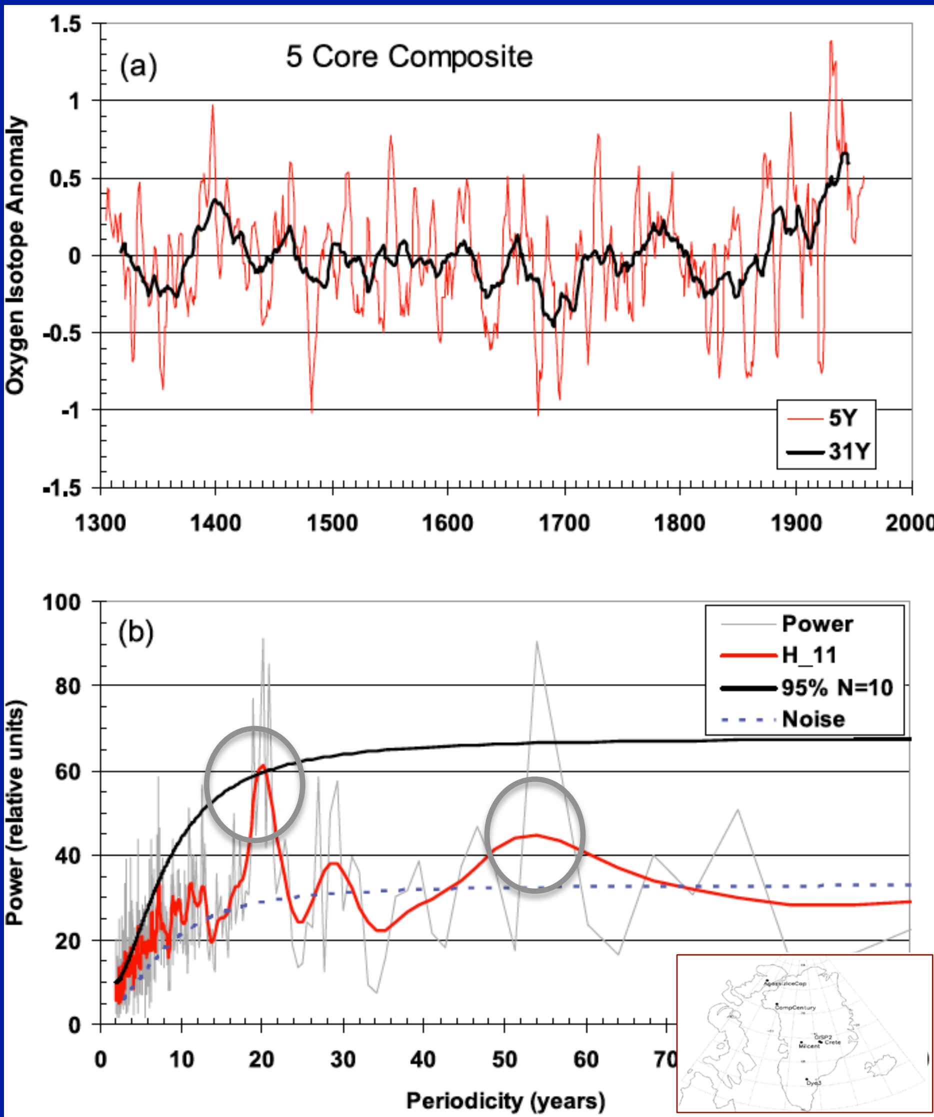
1 ACCESS1-0
2 ACCESS1-3
3 bcc-csm1-1
4 bcc-csm1-1
5 BNU-ESM
6 BNU-ESM
7 CanESM2
8 CanESM2
9 CCSM4
10 CNRM-CM5
11 CSIRO-Mk3-6-0
12 CSIRO-Mk3-6-0
13 EC-EARTH
14 FGOALS-g2
15 FGOALS-s2
16 FIO-ESM
17 FIO-ESM
18 GFDL-CM3
19 GFDL-ESM2G
20 GFDL-ESM2G
21 GFDL-ESM2M
22 GISS-E2-R
23 HadGEM2-ES
24 HadGEM2-ES
25 IPSL-CM5A-LR
26 MIROC-ESM
27 MIROC5
28 MIROC5
29 MPI-ESM-LR
30 MPI-ESM-LR
31 MPI-ESM-P
32 MPI-ESM-P
33 MPI-ESM-MR
34 MPI-ESM-MR
35 MRI-CGCM3
36 MRI-CGCM3
37 NorESM1-M
Propagation lag (years)
Period (years)
Slope ¼
E—>W
W—>E
Muir and Fedorov 2013a



Muir and Fedorov 2013a

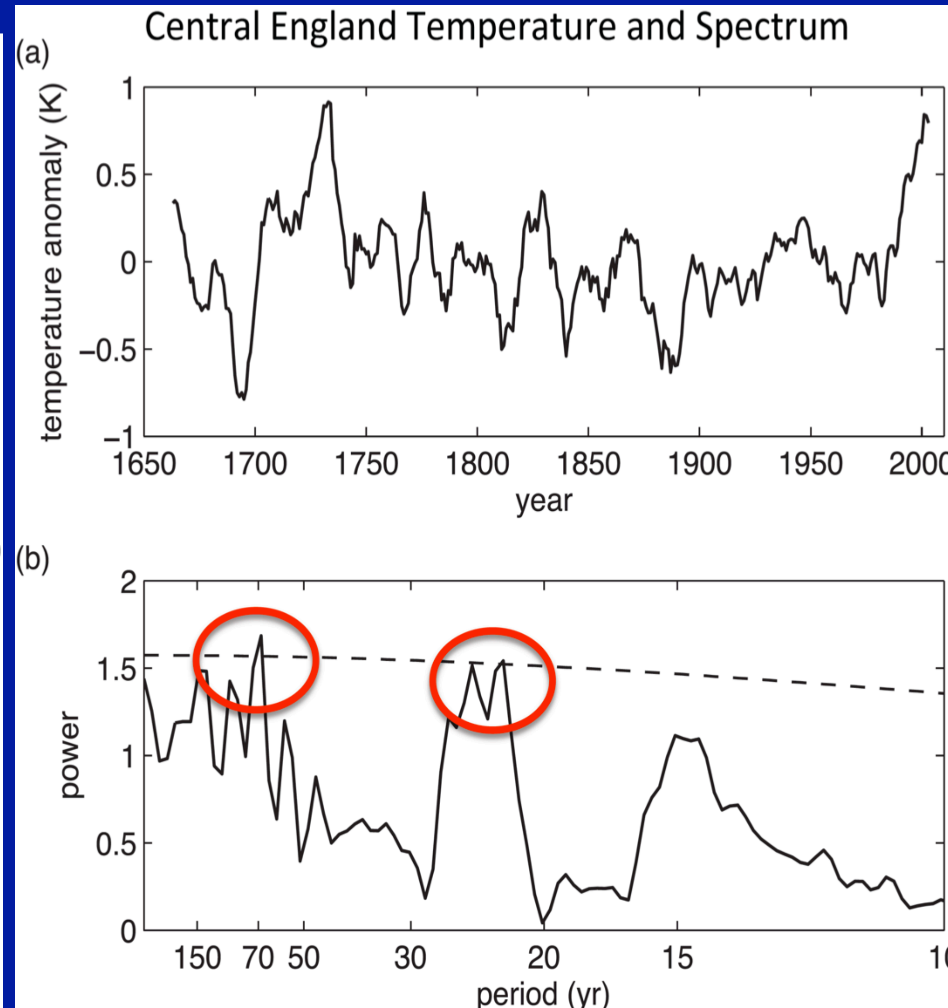

AMOC - TNA correlation for models with westward propagation
TNA corr to amoc
period (years)
0
−0.1
−0.2
−0.3
−0.4
−0.5
−0.6
−0.7
−0.8
−0.9
−1
0 5 10 15 20 25 30 35 40 45 50
29
10
25
37
36
12
21
35
18
10 CNRM-CM5
12 CSIRO-Mk3-6-0
18 GFDL-CM3
21 GFDL-ESM2M
25 IPSL-CM5A-LR
29 MPI-ESM-LR
35 MRI-CGCM3
36 MRI-CGCM3
37 NorESM1-M

Greenland ice core records



Chylek et al., 2012

Proxy temperature records



Frankcombe and Dijkstra, 2010

Summary

- Interdecadal AMOC variability in the models is largely controlled by an oceanic mode related to westward-propagating temperature (density) anomalies interacting with the AMOC in the upper ocean (~500m)

- This mode is present in simple 2-level models and can be identified by a linear stability analysis of realistic ocean models (T~ 20 years). The mode is non-normal – transient decadal growth is possible due to initial buoyancy perturbations

- This mode appears to be present in two thirds of all CMIP5 models (IPSL-CM5, GFDL-ESM2M, MIROC5, etc.)

- Nearly all **strong** interdecadal spectral peaks are associated with the westward propagation of density anomalies