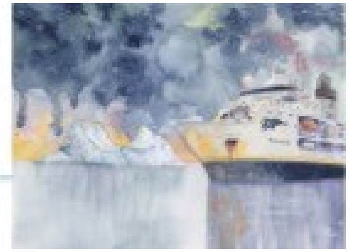


Oceanic control of multidecadal variability in the North Atlantic:
a large-scale baroclinic Rossby waves mechanism

Thierry Huck[1], Olivier Arzel[1], Alain Colin de Verdière[1], Quentin Jamet[2], Florian Sévellec[3]

[1] **LOPS** (UMR 6523 CNRS IFREMER IRD UBO), Brest
[2] FSU, Tallahassee, USA
[3] Ocean and Earth Science, University of Southampton, UK

Observing and Understanding the AMOC, 3-5 May 2017, Brest

Atlantic Multidecadal Oscillation / Variability?

► North Atlantic SST shows variability at multidecadal time scales

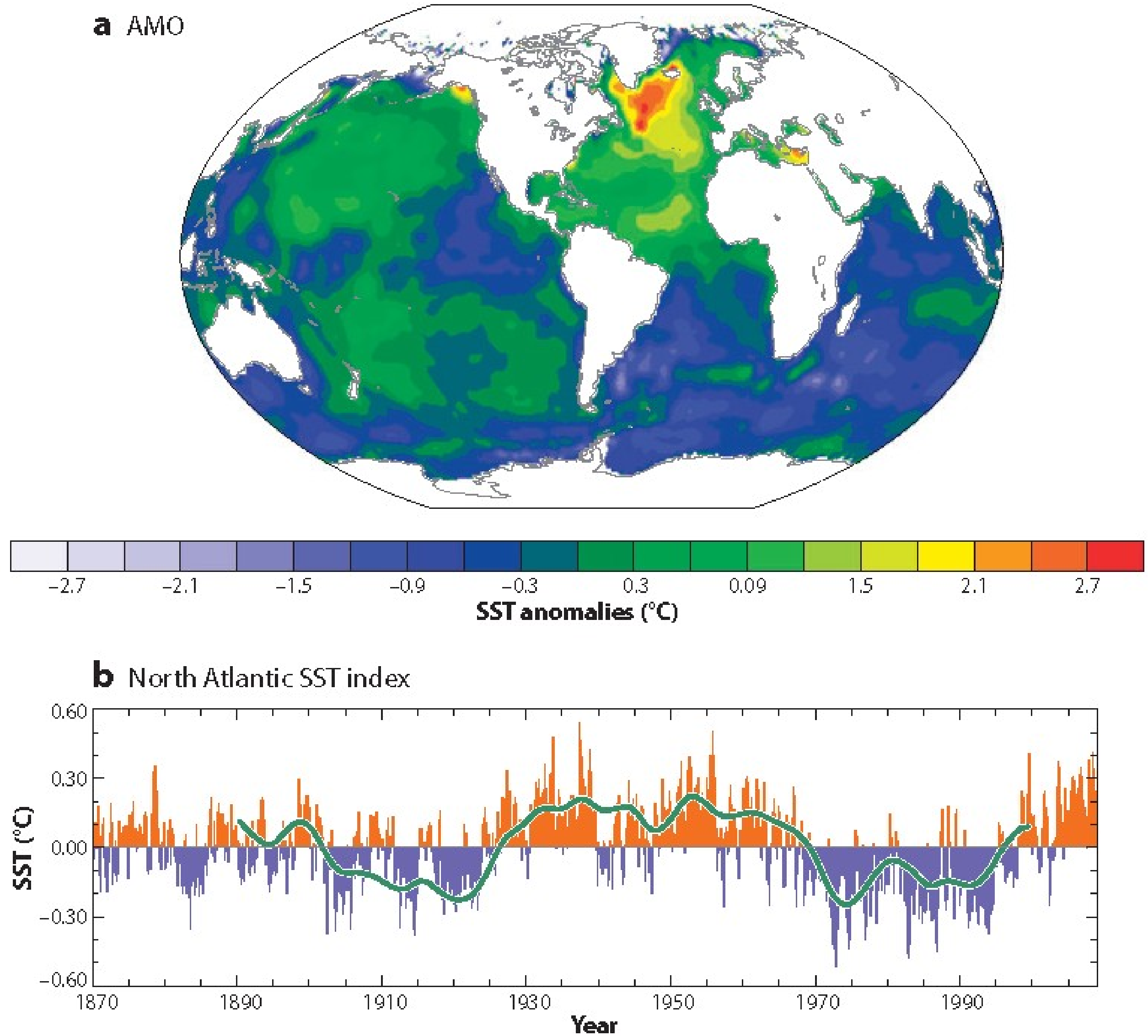
AMO=Atlantic Multidecadal Oscillation

$$AMO = \langle SST \rangle_{North\ Atlantic}$$

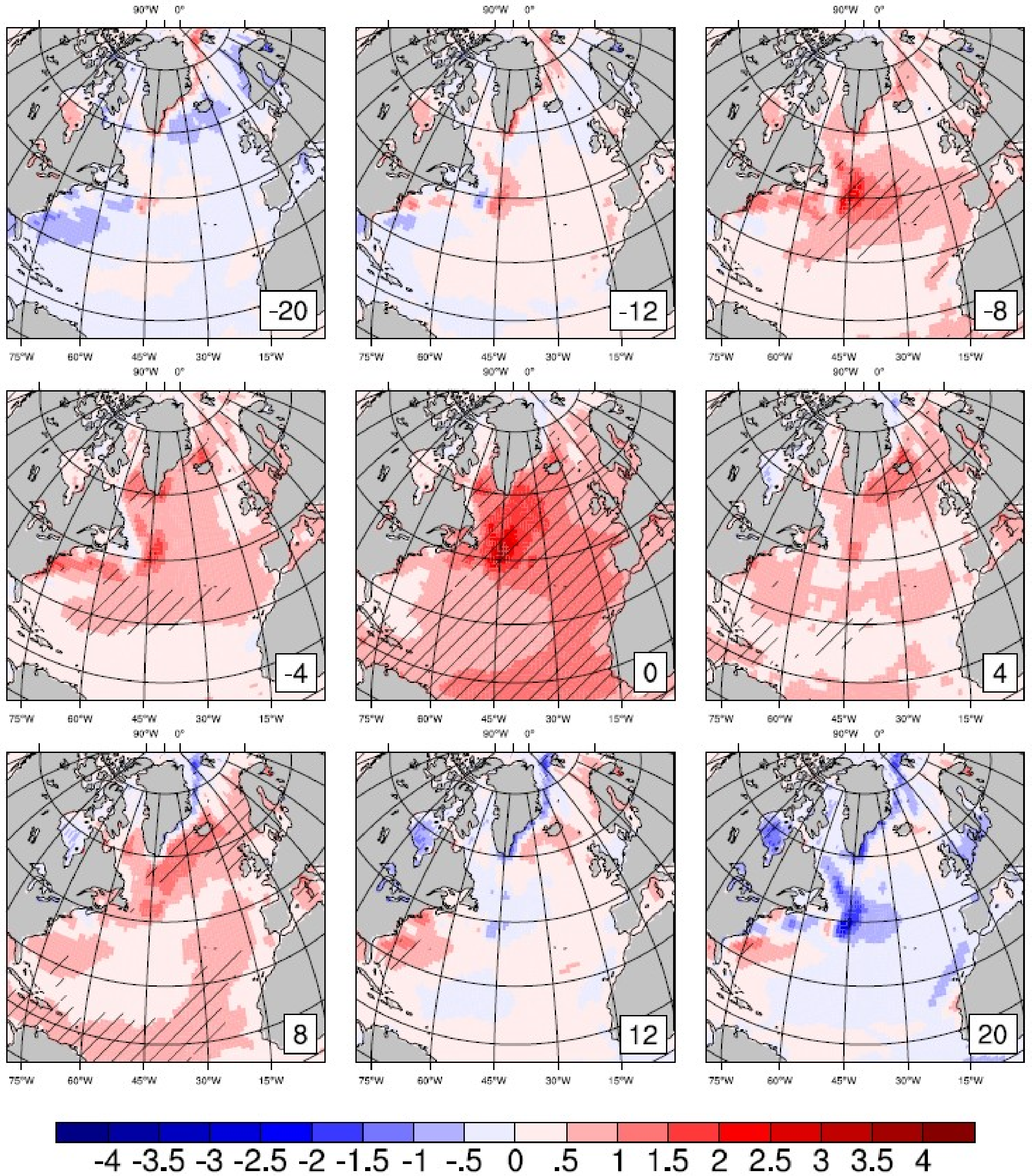
► correlated to the Atlantic **MOC** through Ocean Heat Transport [Knight et al. 2005]

MOC=Meridional Overturning Circulation

$$MOC = \int_{x_w}^{x_e} \int_{-h}^{z} v \, dz \, dx$$



(top) Regressed SST on the AMO index, (bottom) AMO index time series, derived from HadISST dataset [Deser et al. 2010, Ting et al. 2009]



Lag regression of SST on AMV index derived from the HadISST dataset (Drews & Greatbatch 2017)

Origin of Atlantic multidecadal variability? an ongoing active debate...

No consensus on the role of the atmosphere or the ocean:

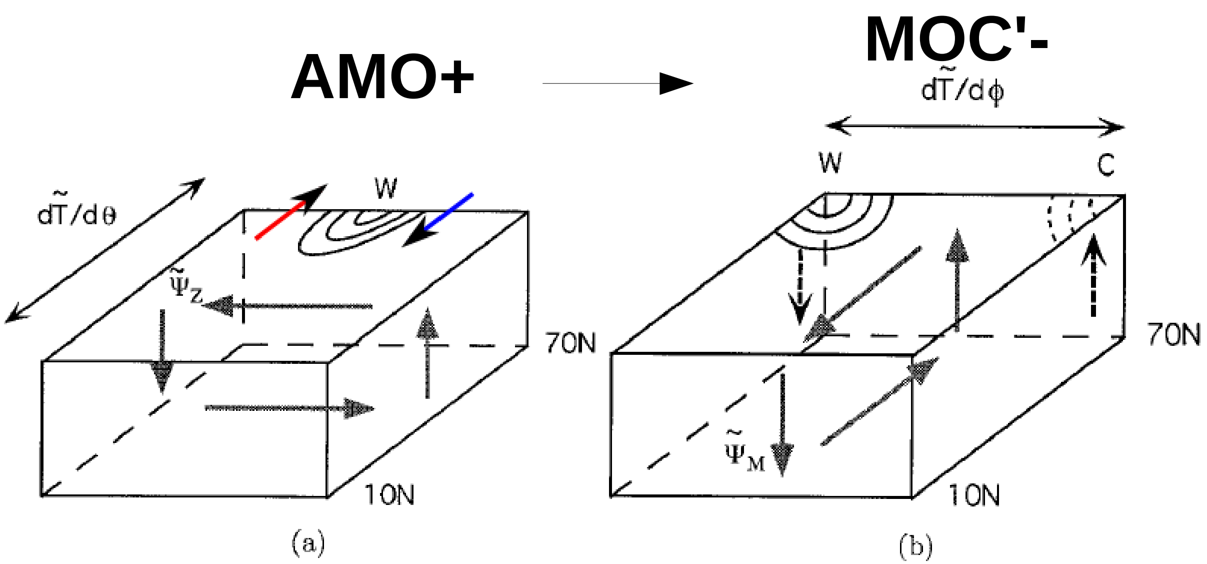
- coupled mode [Timmermann et al 1998]

- oceanic response to NAO atmospheric forcing [Eden & Willebrand 2001]

- slab ocean response to NAO forcing? [Clement et al. 2015]

► **oceanic intrinsic mode** related to the propagation of large-scale **baroclinic Rossby waves** [Colin de Verdière & Huck 1999, teRaa & Dijkstra 2002, Buckley et al. 2012]

➔ **How robust is this mechanism to ocean-atmosphere interactions?**



*Schematic diagram of **baroclinic Rossby waves** mechanism [teRaa & Dijkstra 2002, Sévellec & Huck 2015]*

prototype: flat bottom ocean basin under constant heat flux at low resolution

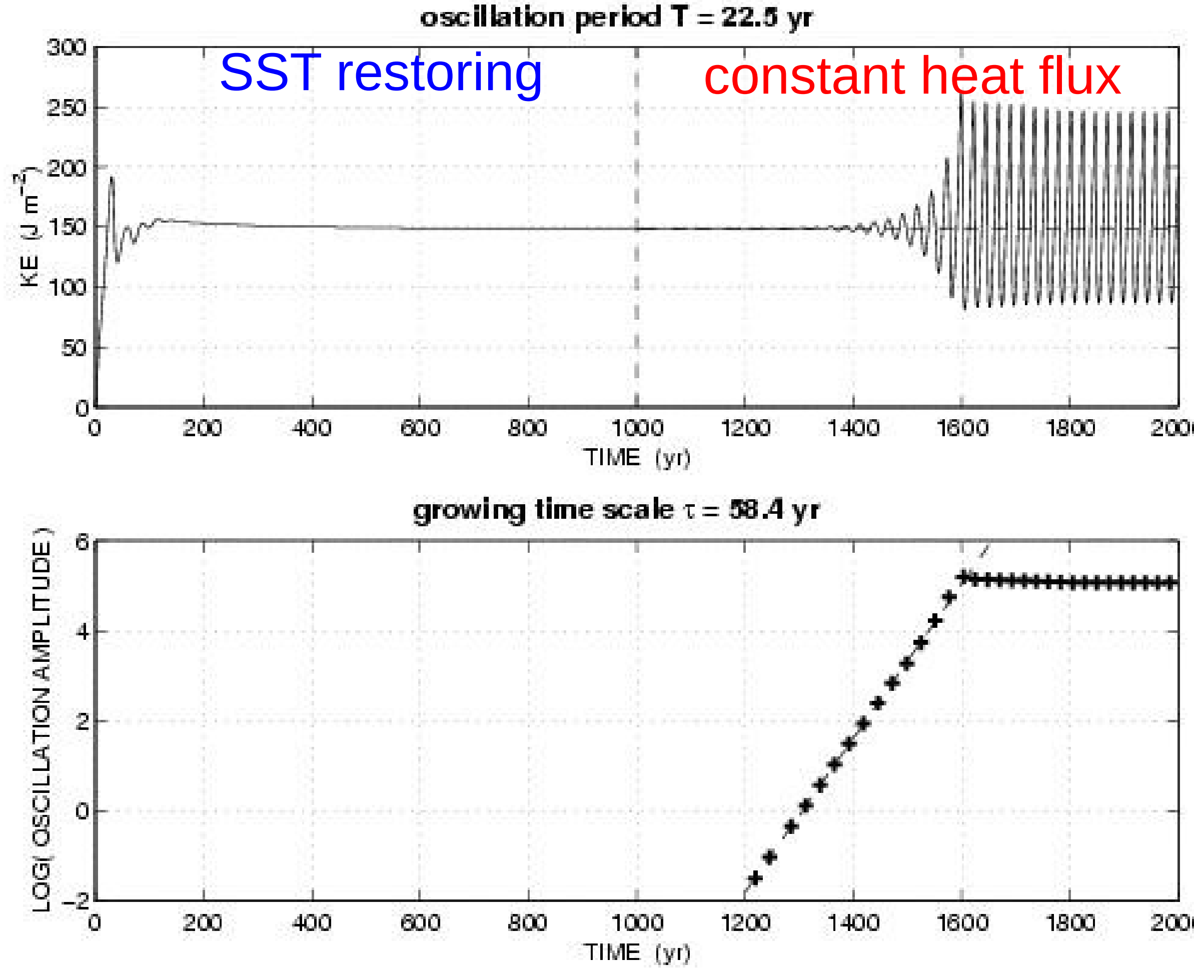
Idealized box-geometry ocean model, mid-latitude β-plane:

►critical influence of surface forcing for oceanic decadal variability (no salinity): constant heat flux vs surface restoring

SST restoring > steady state

constant heat flux > oscillations

►weak growth rate O(yr^{-1}) makes large-scale instability very sensitive to surface boundary condition



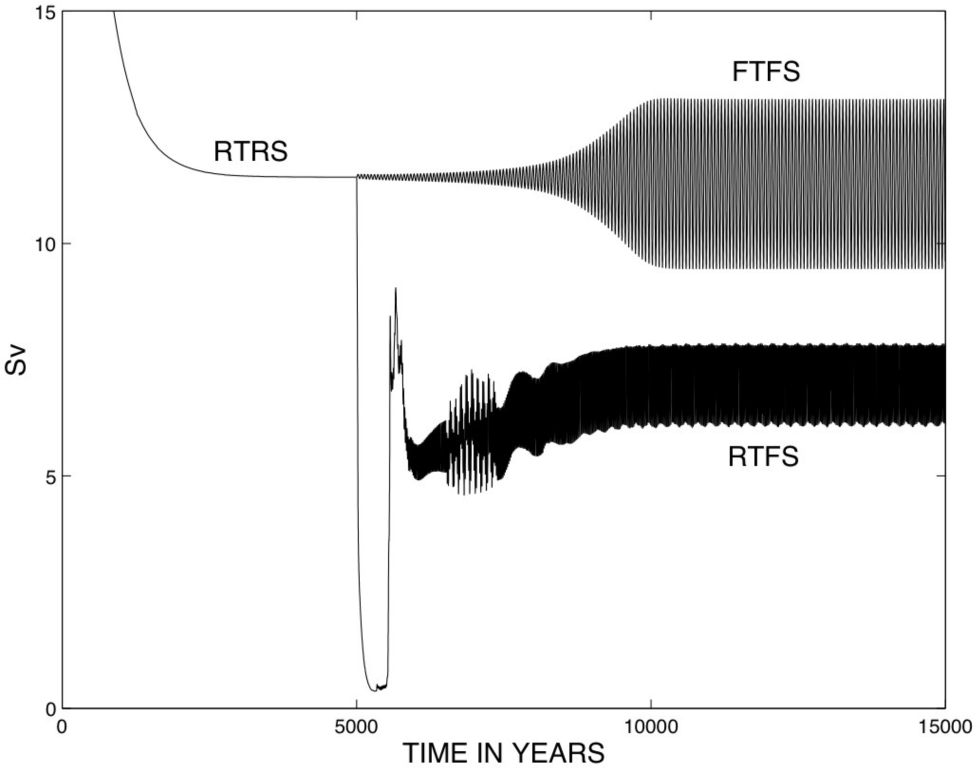
Influence of surface forcing on idealized ocean model decadal variability: SST restoring > steady state, constant heat flux > oscillations [Huck & Vallis 2001]

prototype: flat bottom ocean basin under constant buoyancy flux at low resolution

►combinations of constant flux or surface restoring for temperature and salinity lead to various types of decadal variability:

FTFS > thermal Rossby mode

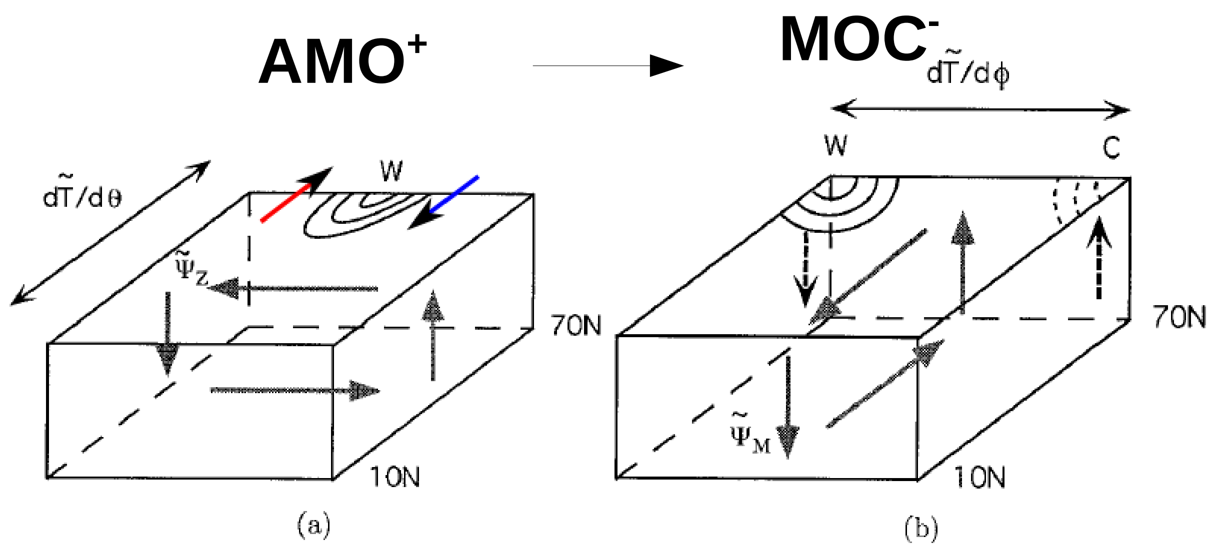
RTFS = mixed b.c. oscillations



Influence of surface forcing on idealized ocean model decadal variability: RT=SST restoring, FT=constant heat flux, RS=SSS restoring, FS=constant freshwater flux [Arzel & al. 2006]

prototype: flat bottom ocean basin under constant heat flux at low resolution

► driving mechanism identified as large-scale baroclinic instability, possibly due to displacement of maximum growth rate by eddy diffusivity/viscosity

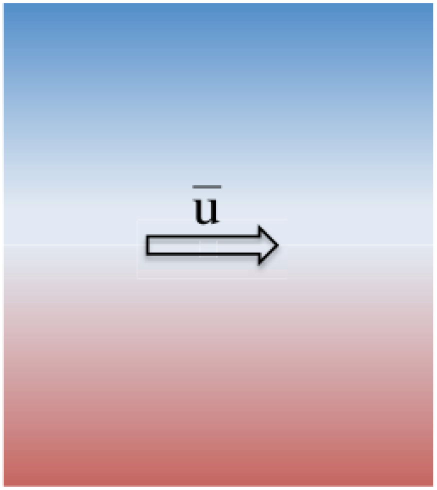


*Schematic diagram of **baroclinic Rossby waves** mechanism [teRaa&Djkstra 2002]*

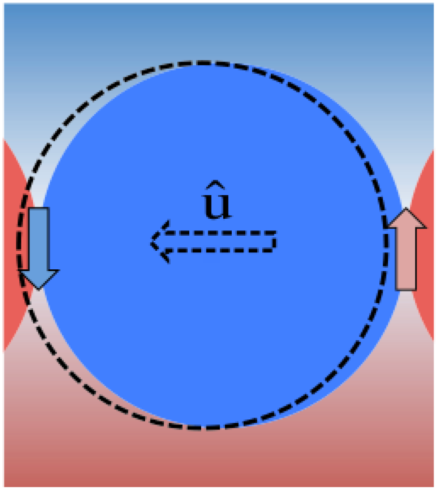
Revised schematic diagram of baroclinic Rossby waves mechanism

[Sévellec&Fedorov 2013, Sévellec&Huck 2015]

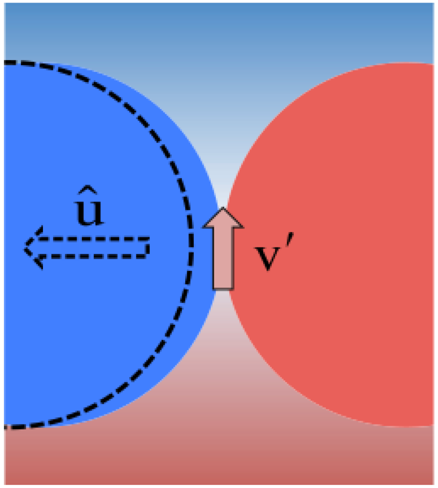
Background: mean stratification and meridional temperature gradient (light colors), mean eastward geostrophic sheared flow $\bar{u}$



Oscillation phase A:
cold temperature anomaly (AMO<0)
but no change in MOC



Oscillation phase B:
dipole temperature anomaly (AMO~0)
and strong MOC anomaly >0
due to northward geostrophic flow v'



▶ *westward propagation through* $\bar{u}$, $v'\nabla\bar{T}$ *and* β
sets oscillation period.
damped in 1.5 layer, growth in 2.5 layer model

Multidecadal variability of the overturning circulation in presence of eddy turbulence - flat bottom ocean basin

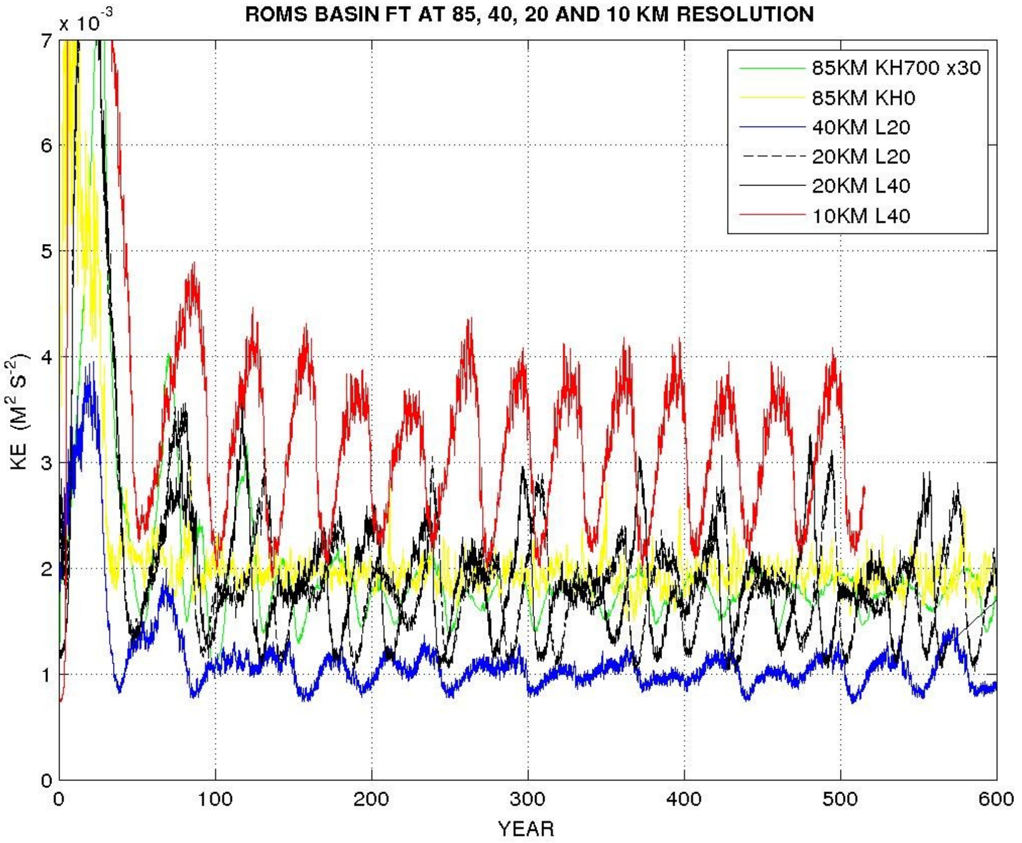
Troublesome sensitivity of previous oscillations to sub-grid-scale processes parameterization => series of numerical simulations with resolution increasing from 160km to 10km, several centuries long, performed with ROMS

► multidecadal variability is a generic ubiquitous feature

► mean circulation and spatial structure of the variability largely modified, but no clear influence of the resolution on main oscillation period

► interdecadal variability more robust to low vertical diffusivity and overturning when mesoscale eddies are resolved

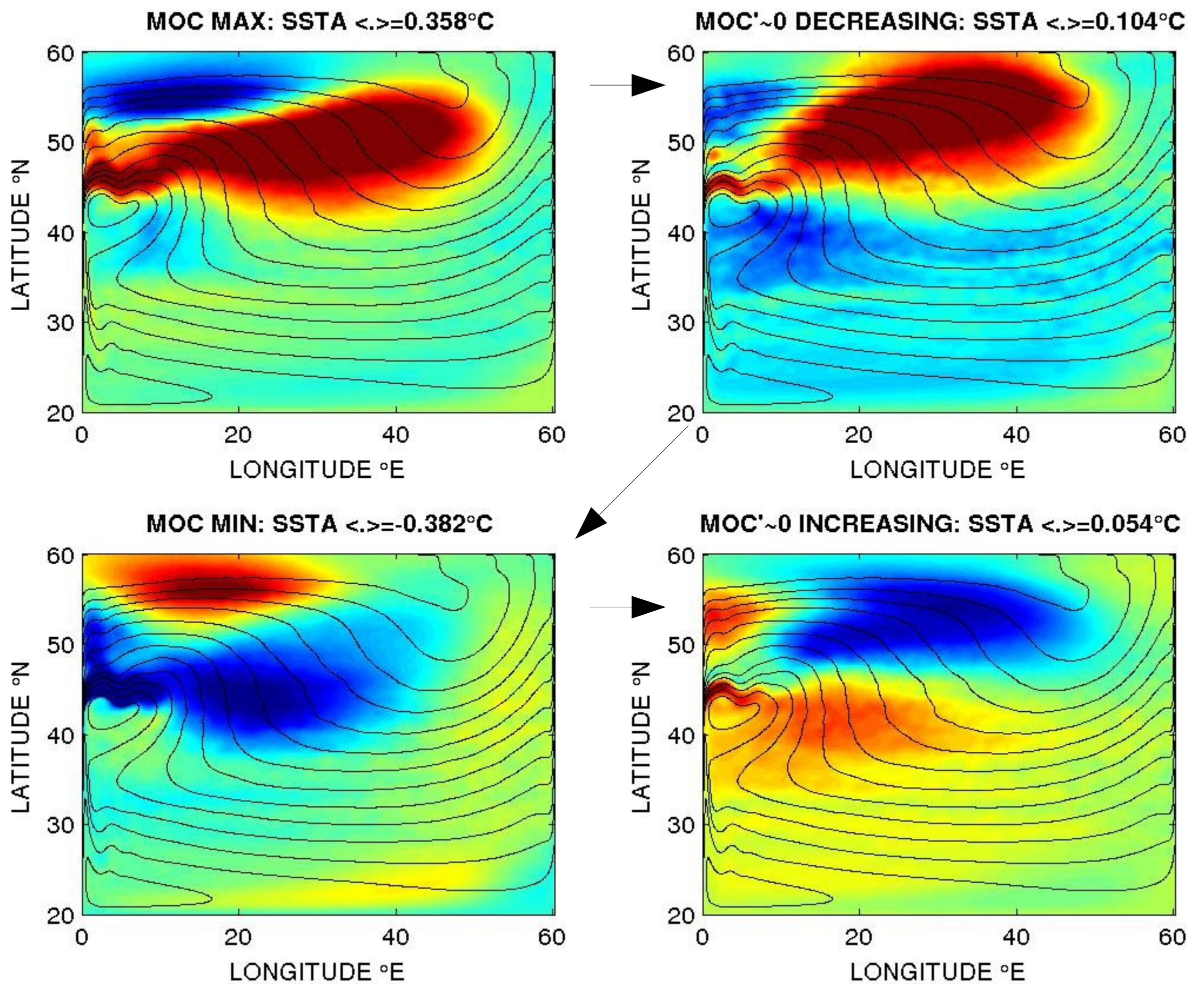
► mechanism previously proposed for these oscillations, involving westward-propagating baroclinically unstable Rossby waves in subpolar region and its feedback on mean circulation, appears unaffected by mesoscale turbulence and is simply displaced following the polar front



Multidecadal variability in presence of eddy turbulence

MOC'+

AMO+

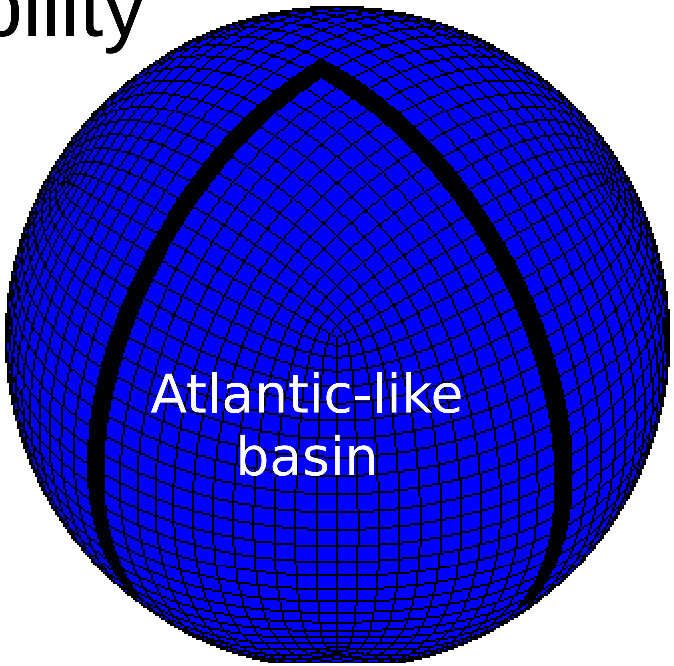


MOC'-

AMO-

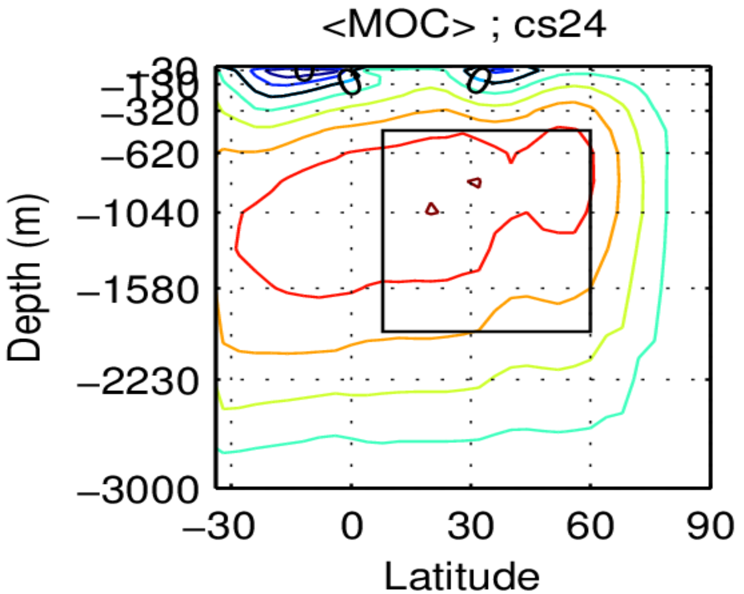
SSTA (upper 100m) associated with 4 consecutive phases of the 30-yr period oscillations for the 10-km experiment with Kv=3 10^{-5} m^2/s: (top left) when MOC is maximum, (top right) when MOC anomaly is small and decreasing, (bottom left) when MOC is minimum, and (bottom right) when MOC anomaly is small and increasing. Background mean SST appears as black contours and gives some insight on upper circulation [Huck et al. 2015 JPO]

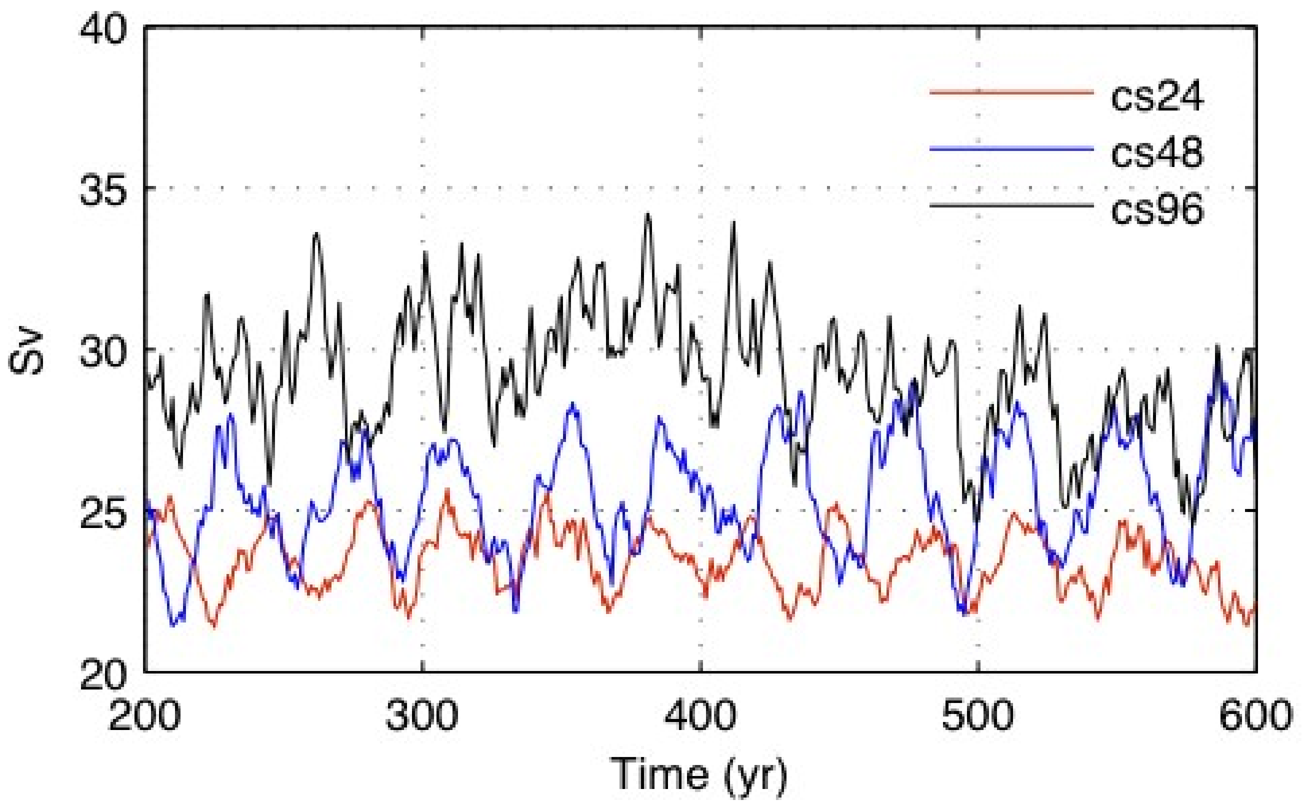
Oceanic control of multidecadal variability in idealized coupled GCM



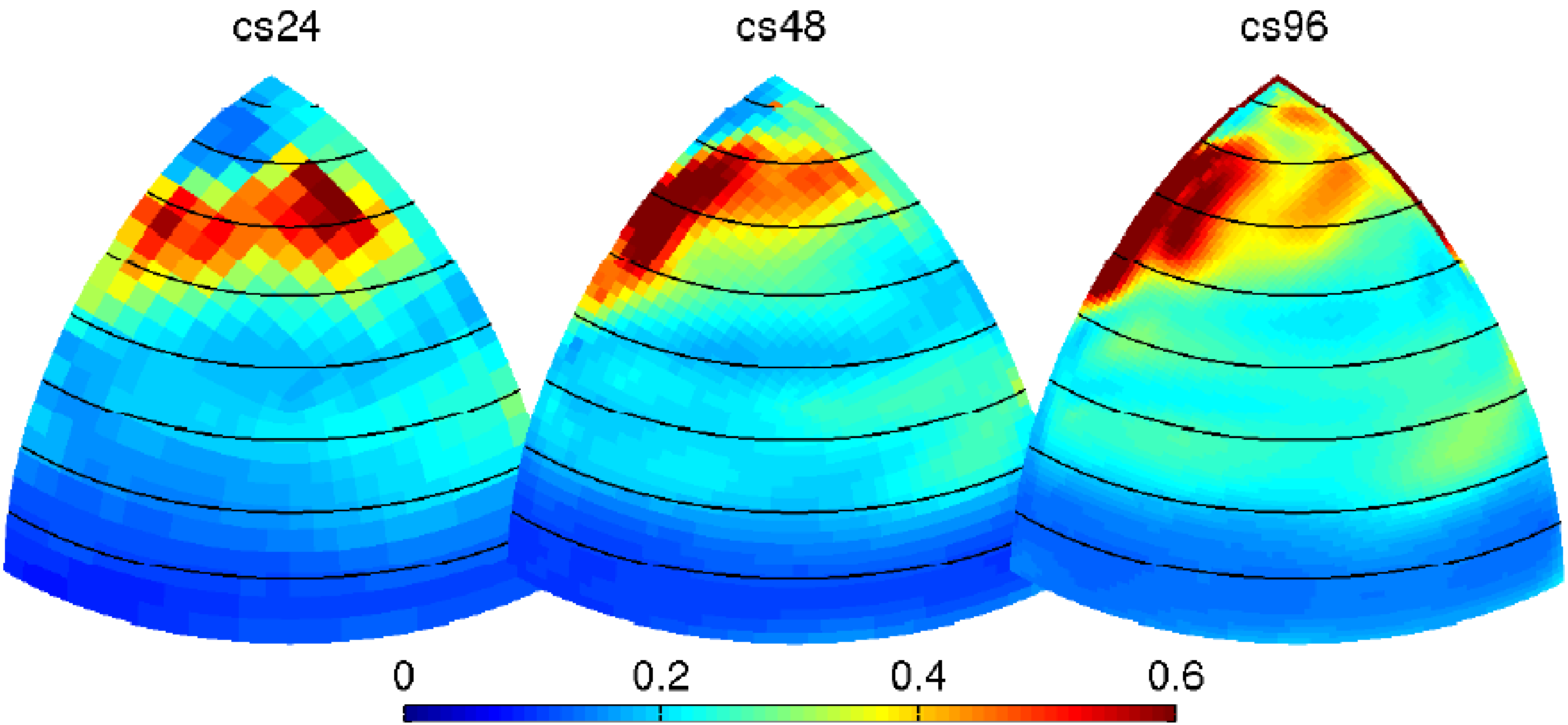
MIT coupled ocean-atmosphere-ice GCM (Speedy PE atmospheric model) in the Double-Drake configuration: flat-bottom aquaplanet geometry with 2 basins, Pacific- and Atlantic-like, run at 4° (Buckley et al. 2012), 2° and 1° horizontal resolution

► spontaneous multidecadal AMOC variability on 30-40 yr time scale in all simulations





Oceanic control of multidecadal variability in idealized coupled GCM

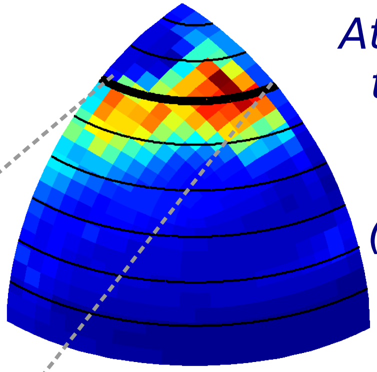


Standard deviation of annual-mean SST (K) for the 4° (cs24), 2° (cs48) and 1° (cs96) resolutions [Jamet et al. 2015]

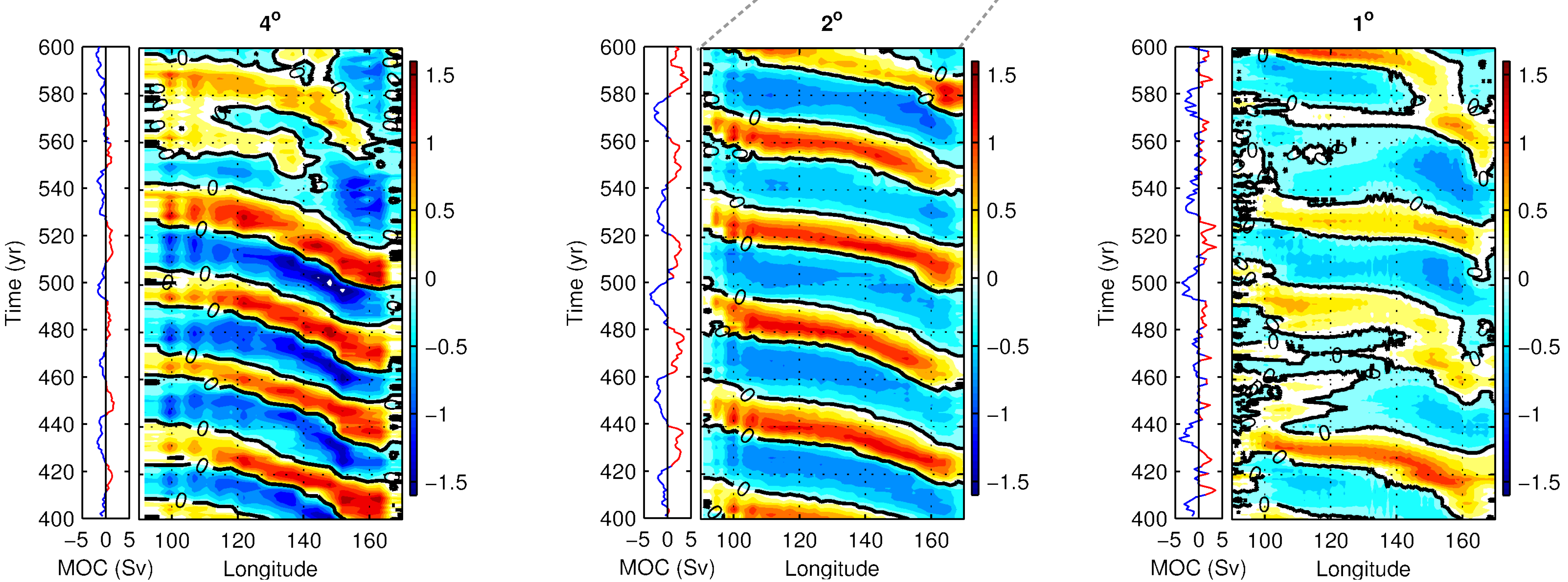
Large scale oceanic Rossby waves

- Westward propagation of large scale temperature anomalies, interacting with the MOC along the western boundary

➔ ***Large scale Rossby waves mechanism seems robust at all resolutions***



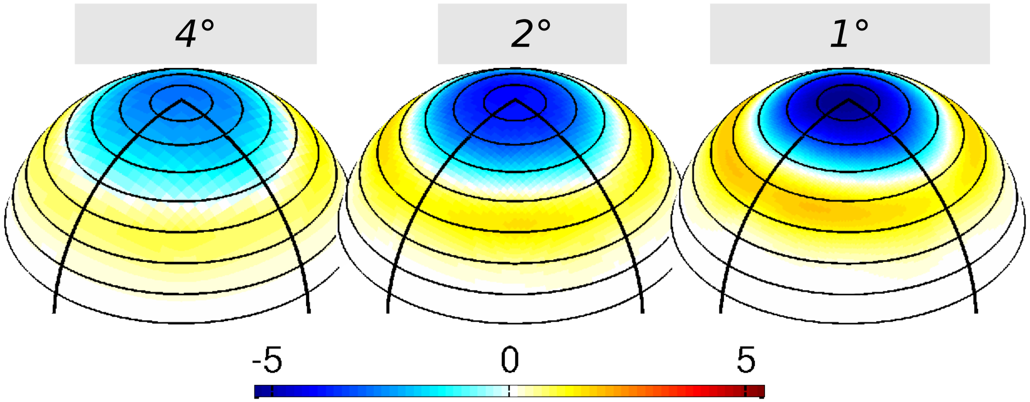
Atlantic subsurface temperature std (σ), maximum around 60°N (thick black line)



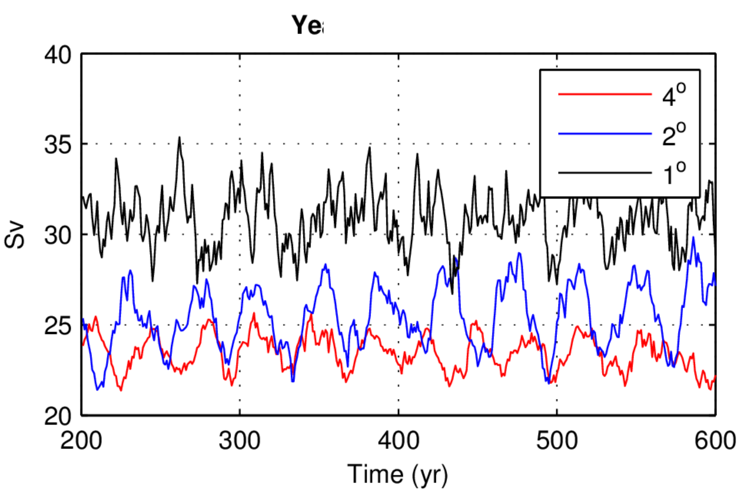
Subsurface temperature anomalies near 60°N, propagating from east to west; associated MOC anomalies on the left

Atmospheric variability

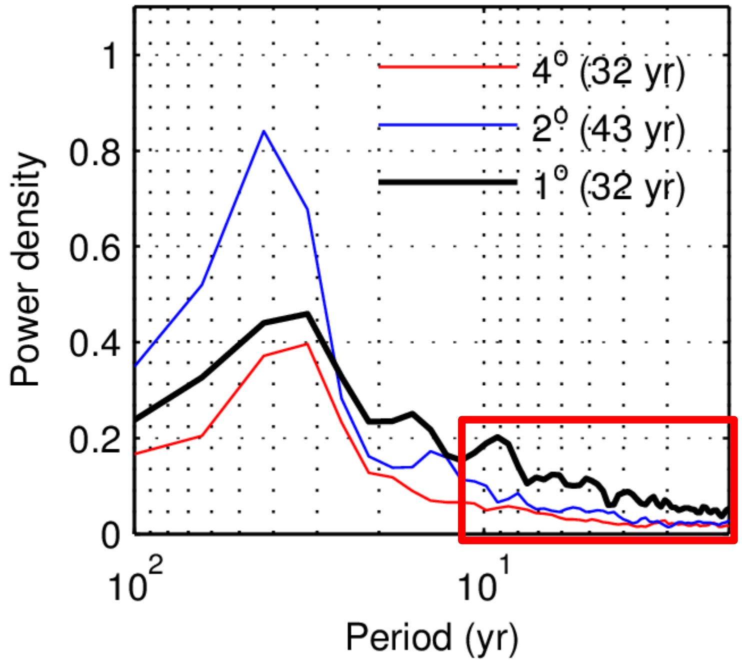
- Increased horizontal resolution
  - ➔ Increased atmospheric variability …



EOF1 of yearly North hemisphere SLPA (hPa)



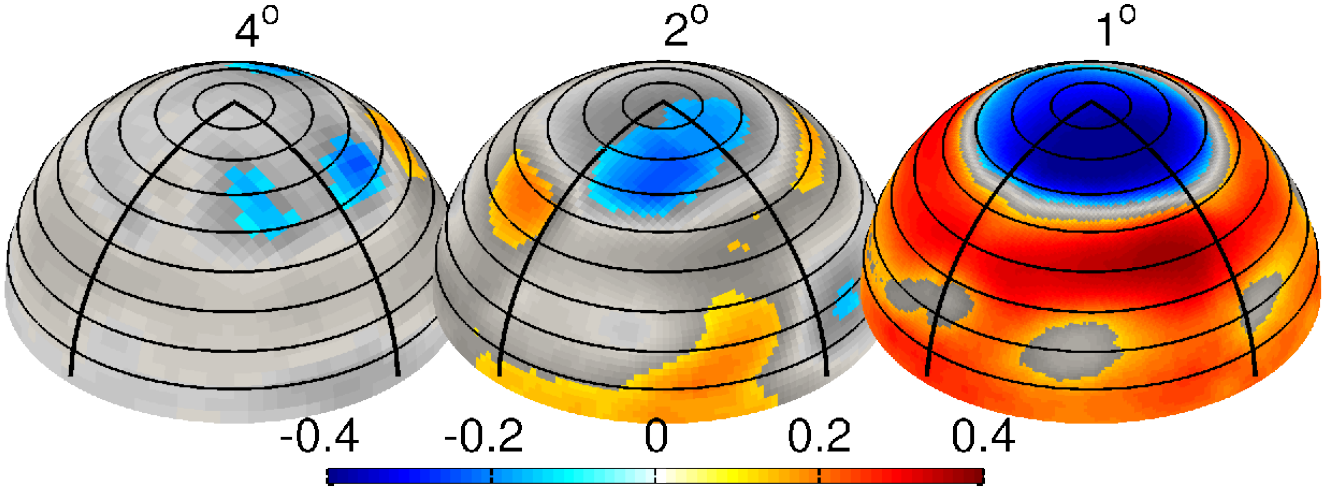
Yearly MOC index at 4°, 2° and 1° (top) and respective power spectrum (right)



➔ … associated with emergence of higher frequency signal at 1°

Ocean-Atmosphere interactions

- Correlation between Sea Level Pressure Anomalies (SLPA) and the MOC index most significant when the SLPA leads the MOC by 2 years



Significant correlation (coloured) between SLPA and the MOC 2 yrs later (SLPA leads)

- No significant correlation at 4°:

▶ oceanic intrinsic mode [Buckley et al. 2012]

- Significant correlation at 1° :

▶ Similar to climate models [Gastineau and Frankigoul, CD 2012]

➔ **Does the NAO drive the oceanic variability at 1°?**

Ocean-Atmosphere interactions

- Observed SST variability driven by [Bjerknes, 1964; Gulev et al., Nature 2013]:
  - Atmosphere at interannual time scales
  - Ocean at multidecadal time scales

$\langle SST'.Q' \rangle > 0$ → atmosphere drives

$\langle SST'.Q' \rangle < 0$ → ocean drives

$Q \propto \left(T_a - SST \right)$

Q positive downward

Ocean-Atmosphere interactions

- Observed SST variability driven by [Bjerknes, 1964; Gulev et al., Nature 2013]:
  - Atmosphere at interannual time scales
  - Ocean at multidecadal time scales

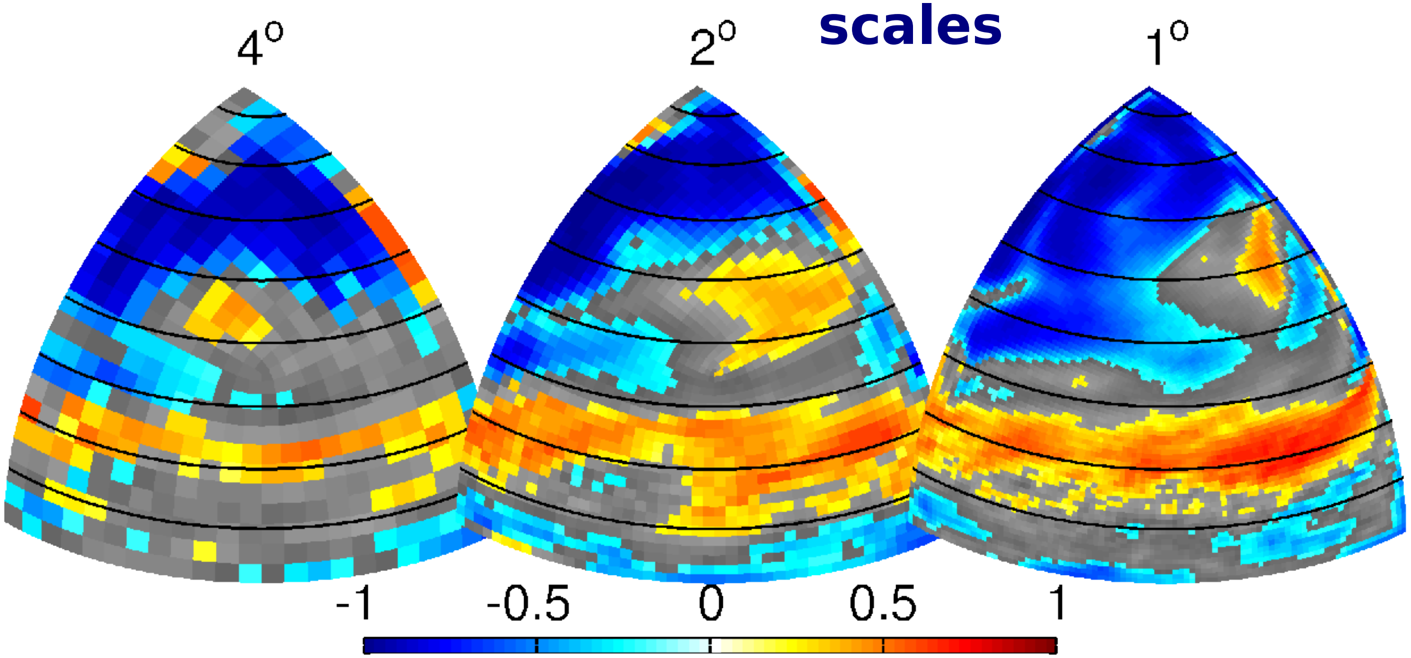
$\langle SST'.Q'\rangle > 0$ → atmosphere drives

$\langle SST'.Q'\rangle < 0$ → ocean drives

$Q \propto (T_a - SST)$

Q positive downward

→ **In our simulations, SST variability in the north "Atlantic" is driven by the ocean on multidecadal time scales**

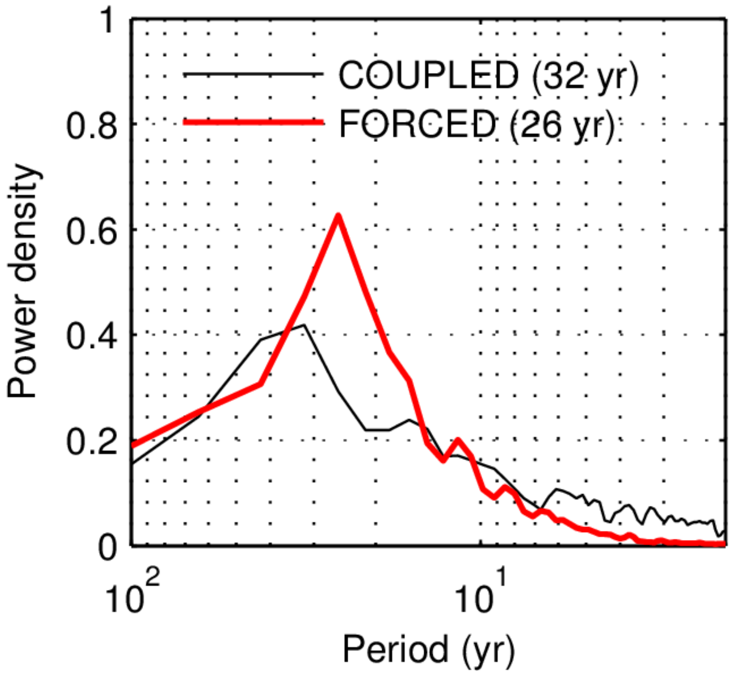


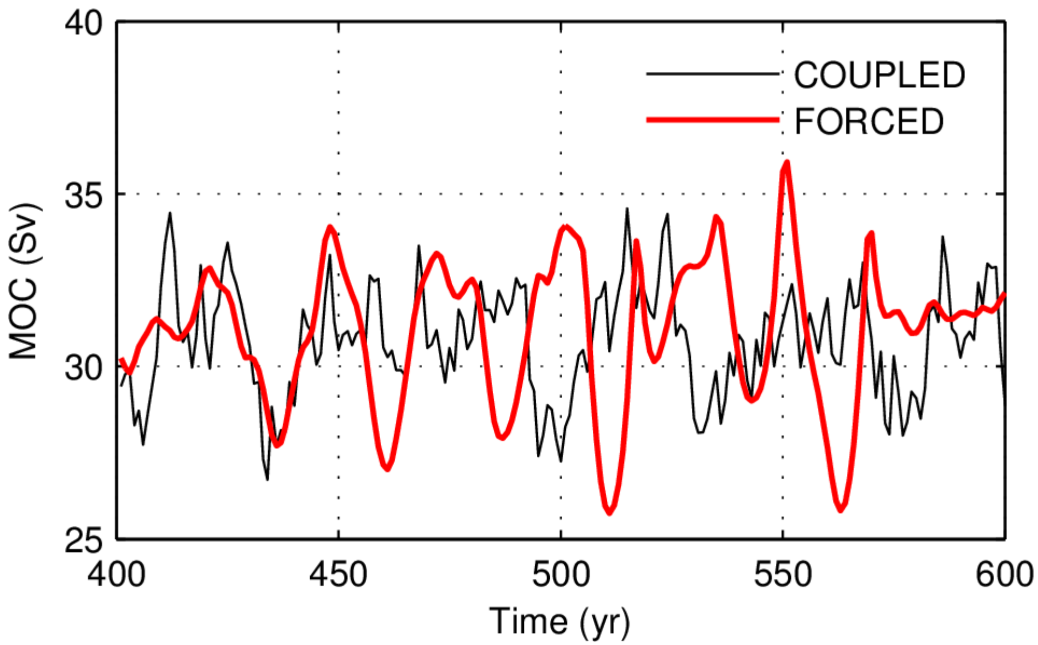
Correlation $\langle SST'.Q'\rangle$, based on the 10-yr smoothed SST and heat fluxes (Q) anomalies

Ocean-only forced experiment

- Ocean-only experiment at **1°**
- Forced with **200yr averaged** atmospheric fluxes from the coupled model (wind, heat, FW)

➔ The MOC variability is **more regular**

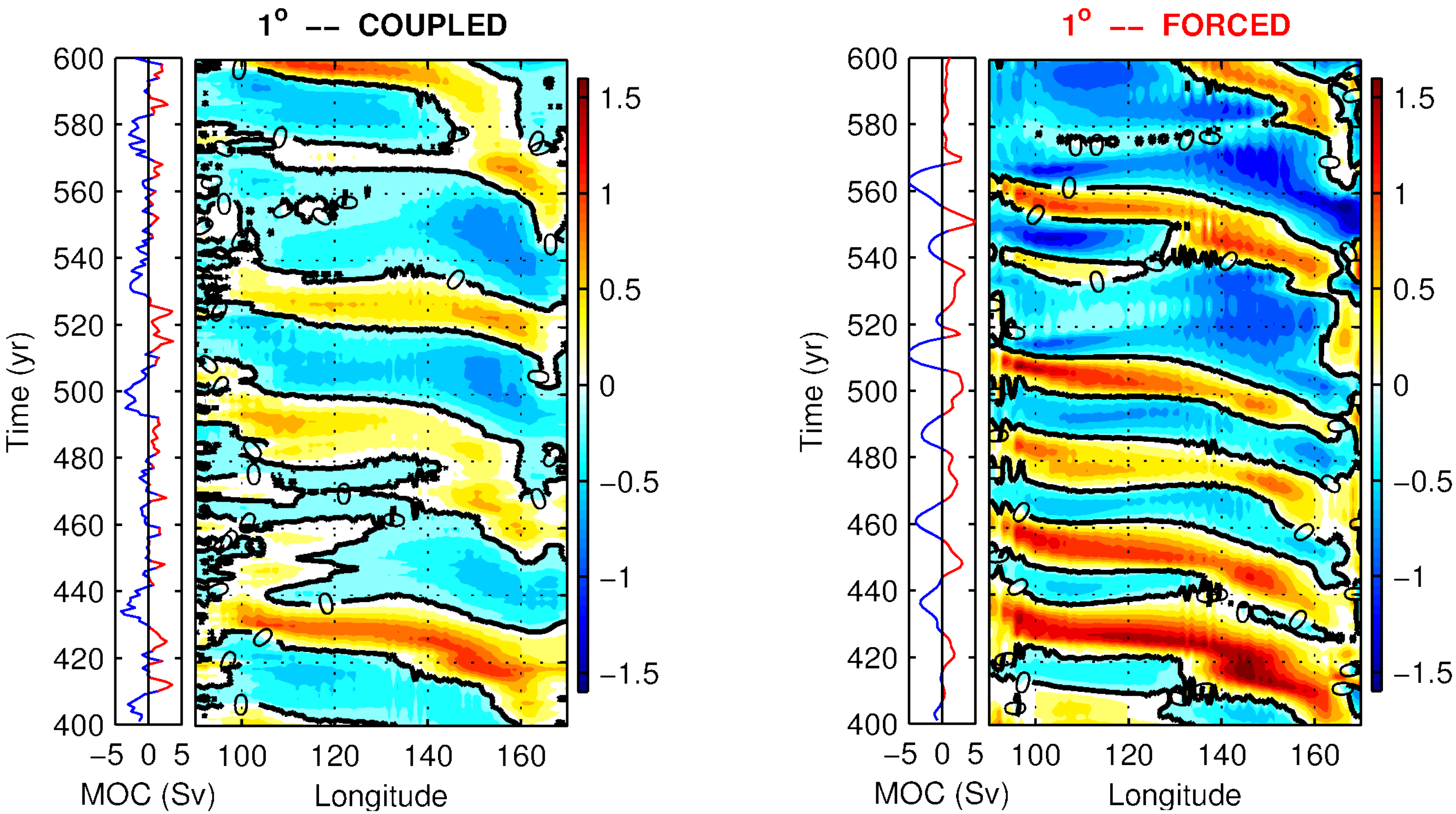




*Yearly MOC index for the **coupled** and **forced** runs (left) and respective power spectrum (top)*

Ocean-only forced experiment

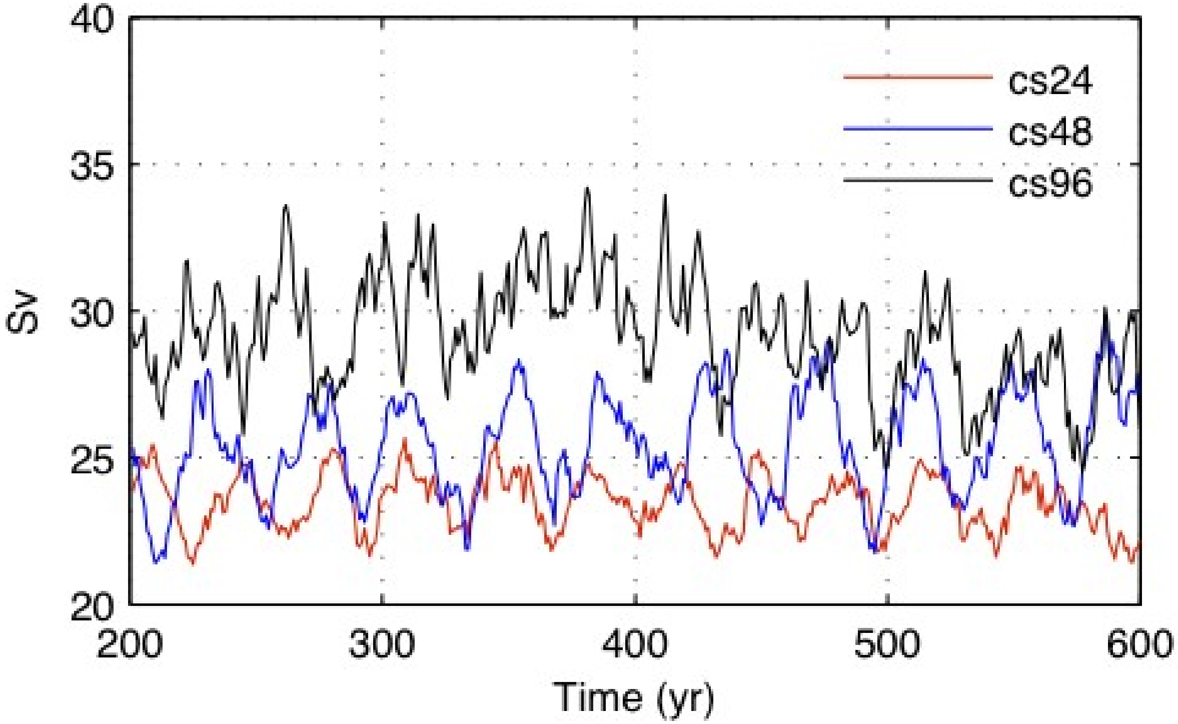
➔ **MOC variability** and propagation of large scale **baroclinic Rossby waves** are more regular



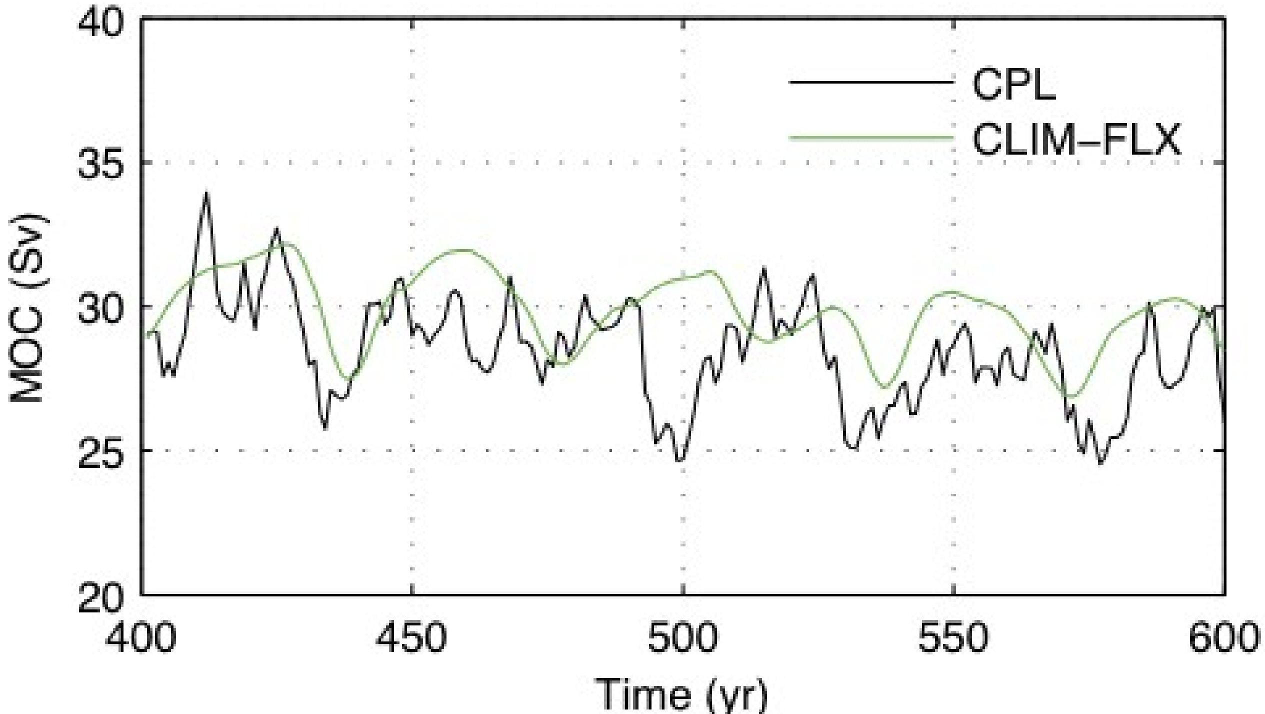
Subsurface temperature anomalies near 60°N, propagating from east to west; associated MOC anomalies on the left

Oceanic control of multidecadal variability in CGCM

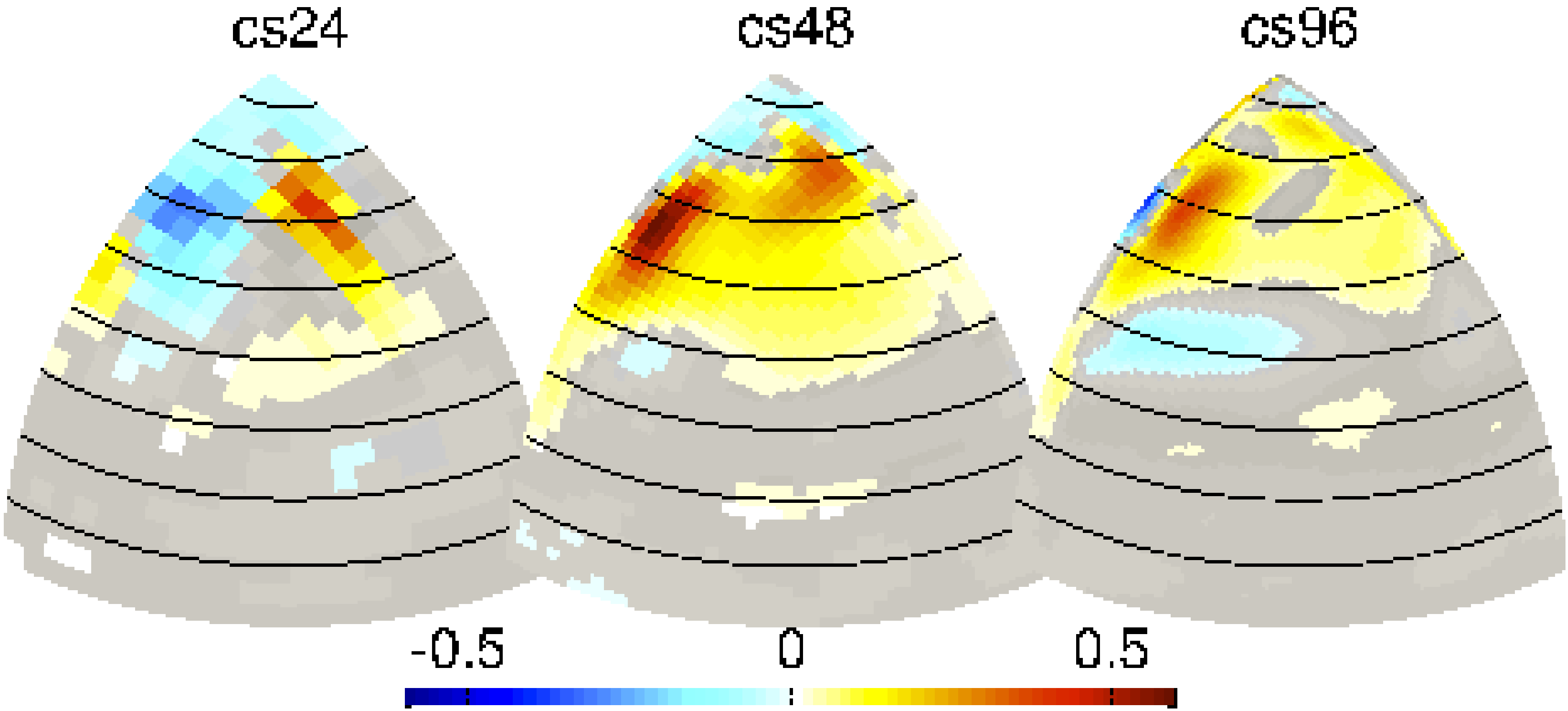
►disruptive effect of NAO-like intrinsic atmospheric variability at higher resolution, responsible for interannual MOC variability



►ocean-only 1° simulation forced by climatological fluxes show more regular multidecadal oscillations



►multidecadal variability results from intrinsic mode of ocean circulation



Yearly SSTA (K) associated with one standard deviation of the yearly MOC index at lag 0 (grey-shading when not statistically significant at 5%)

Oceanic control of multidecadal variability in MIT idealized coupled GCM

► disruptive effect of NAO-like intrinsic atmospheric variability at higher resolution

► ocean-only 1° simulation forced by climatological fluxes show more regular multidecadal oscillations

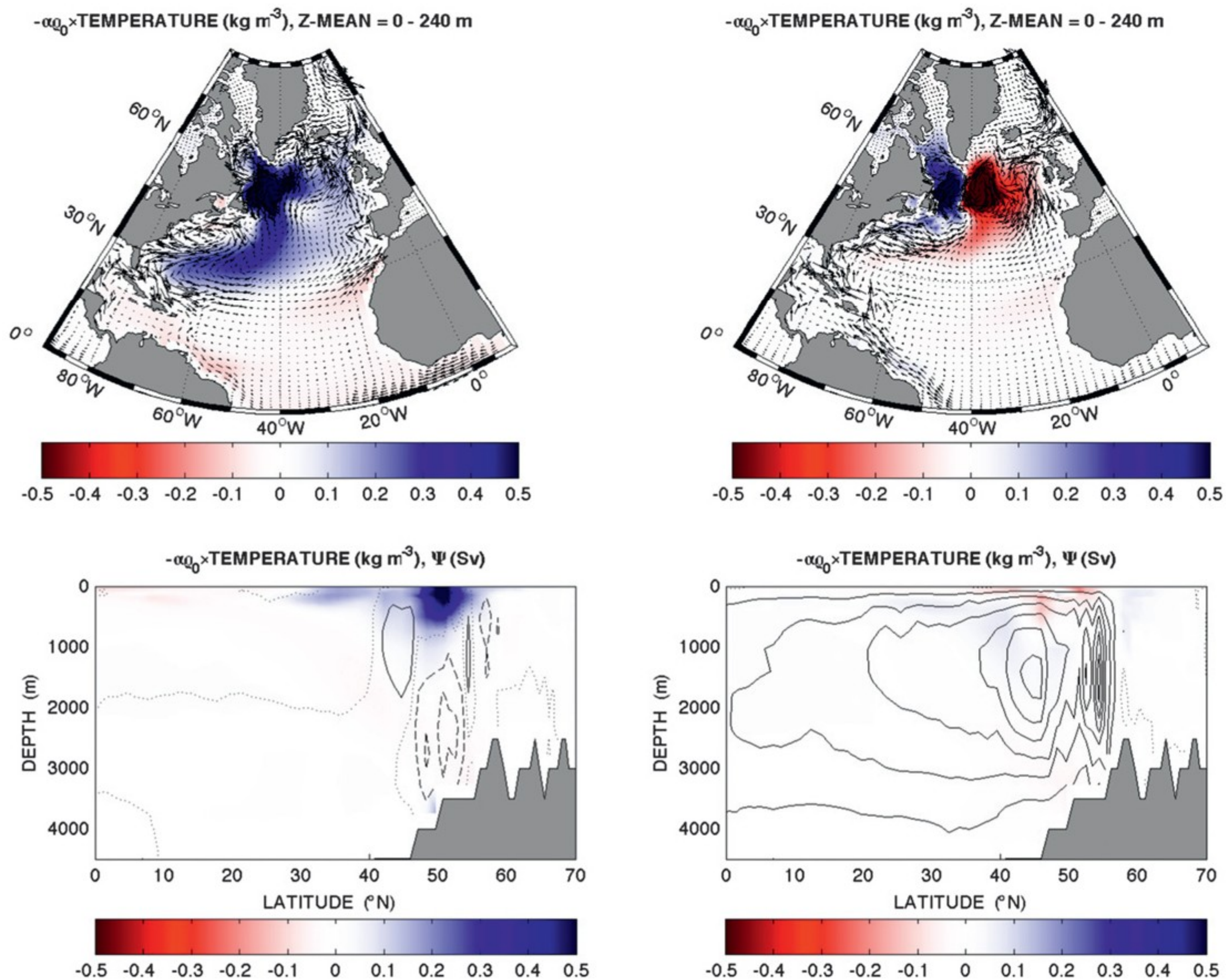
► significant correlation are found between model NAO and AMOC, BUT the variability is driven by the ocean!

NEMO ORCA2° realistic OGCM

► leading interdecadal eigenmode of the Atlantic meridional overturning circulation in global ORCA2° OGCM (NEMO) has 24-yr period, 40-yr decay time scale, and show westward propagating SSTA similar to idealized models oscillations [Sévellec & Huck 2015]

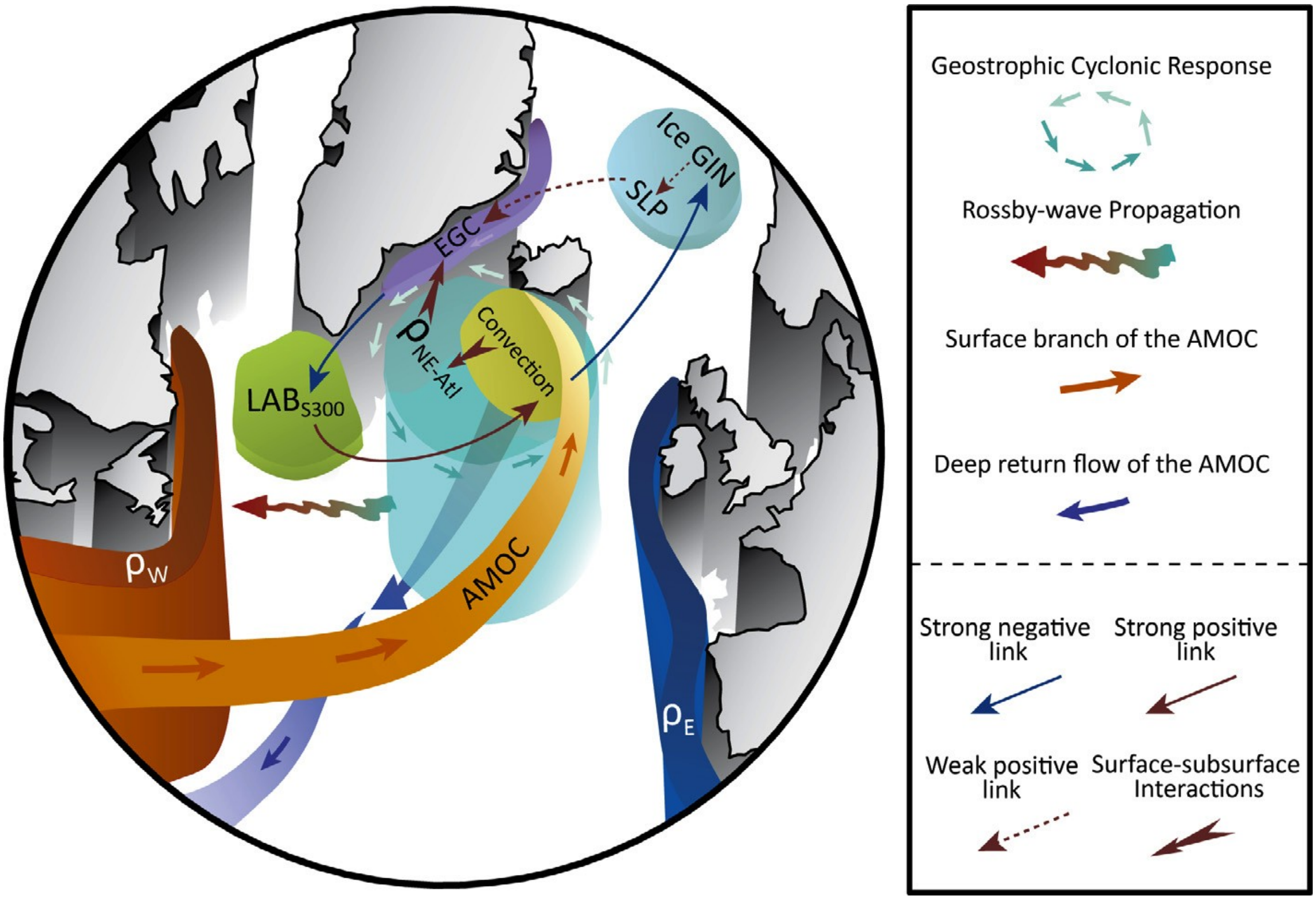
Phase A: AMO<0

Phase B: MOC'>0

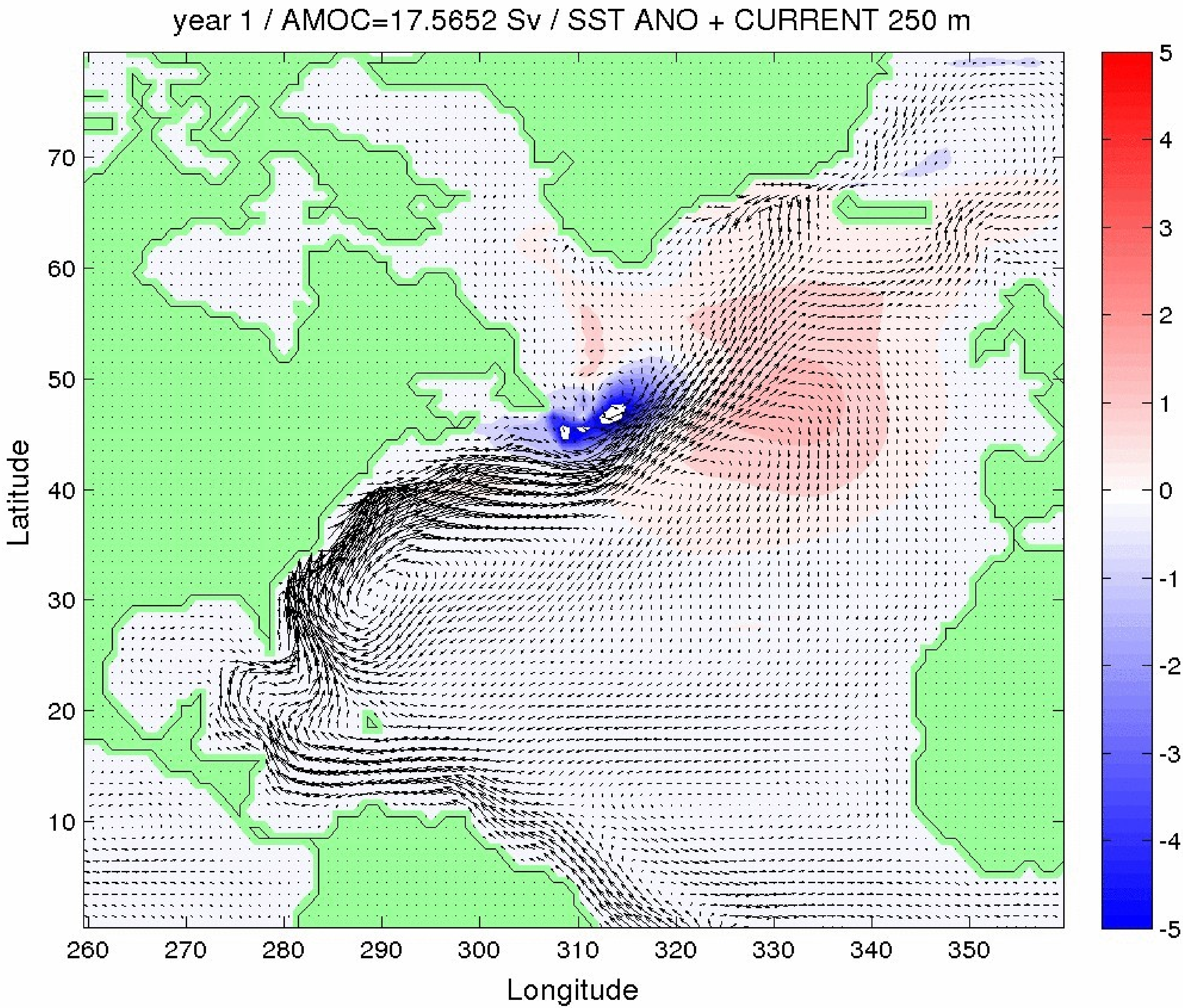


Spatial structure of least-damped eigenmode of tangent linear model with 24-yr period, 2 phases 6-yr apart : (top) upper 240m temperature and surface currents, (bottom) zonally-averaged temperature and meridional streamfunction [Sévellec&Fedorov 2013]

IPSL fully coupled model realistic GCM



Schematic of variables and interactions involved in North Atlantic 20-year cycle in IPSL-CM5A [Ortega et al. 2015]



year 1 / AMOC=17.5652 Sv / SST ANO + CURRENT 250 m
Latitude
Longitude
70
60
50
40
30
20
10
260
270
280
290
300
310
320
330
340
350
5
4
3
2
1
0
-1
-2
-3
-4
-5

Conclusions

►**correlation does not imply causality**: MIT coupled GCM simulations show significant correlation between NAO and AMOC, although multidecadal variability results from an intrinsic ocean mode (ie self-sustained under climatological air-sea fluxes)

►Several examples of intrinsic oceanic variability associated with westward propagating large-scale baroclinic Rossby waves in idealized and realistic model configurations

►large-scale baroclinic instability of the mean oceanic circulation may be a source of interannual to multidecadal variability [Hochet et al. 2015]

►ocean modes of variability may be the only source of decadal predictability...

Thank you for your attention!

- Hochet, A., T. Huck, A. Colin de Verdière, 2015: *Large scale baroclinic instability of the mean oceanic circulation: a local approach*. JPO, 45, 2738-2754.
- Huck, T., O. Arzel, F. Sévellec, 2015: Multidecadal variability of the overturning circulation in presence of eddy turbulence. JPO, 45, 157-173.
- Jamet, Q., T. Huck, A. Colin de Verdière, O. Arzel, J.-M. Campin, 2016: *Oceanic control of multidecadal variability in an idealized coupled GCM.* Clim. Dyn., 46, 3079-3095.
- Sévellec, F., T. Huck, 2015: *Theoretical investigation of the Atlantic multidecadal oscillation*. JPO, 45, 2189-2208.
- Jamet, Q., T. Huck, O. Arzel, A. Colin de Verdière, A. Hochet, C. Vic, 2017: *Diabatic processes controlling the growth of long baroclinic oceanic waves*. JPO, submitted.

Contact: Thierry.Huck@univ-brest.fr **http://www.ifremer.fr/lpo/thuck/**