Atlantic Ocean circulation variations over the Holocene

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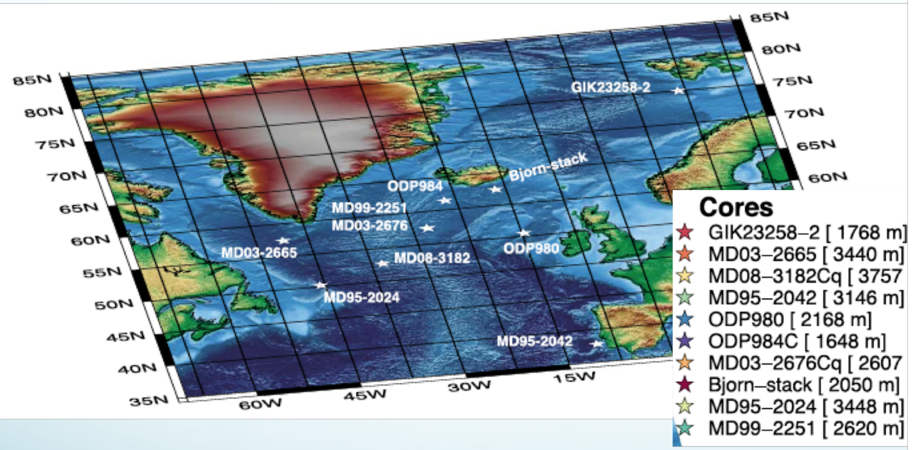
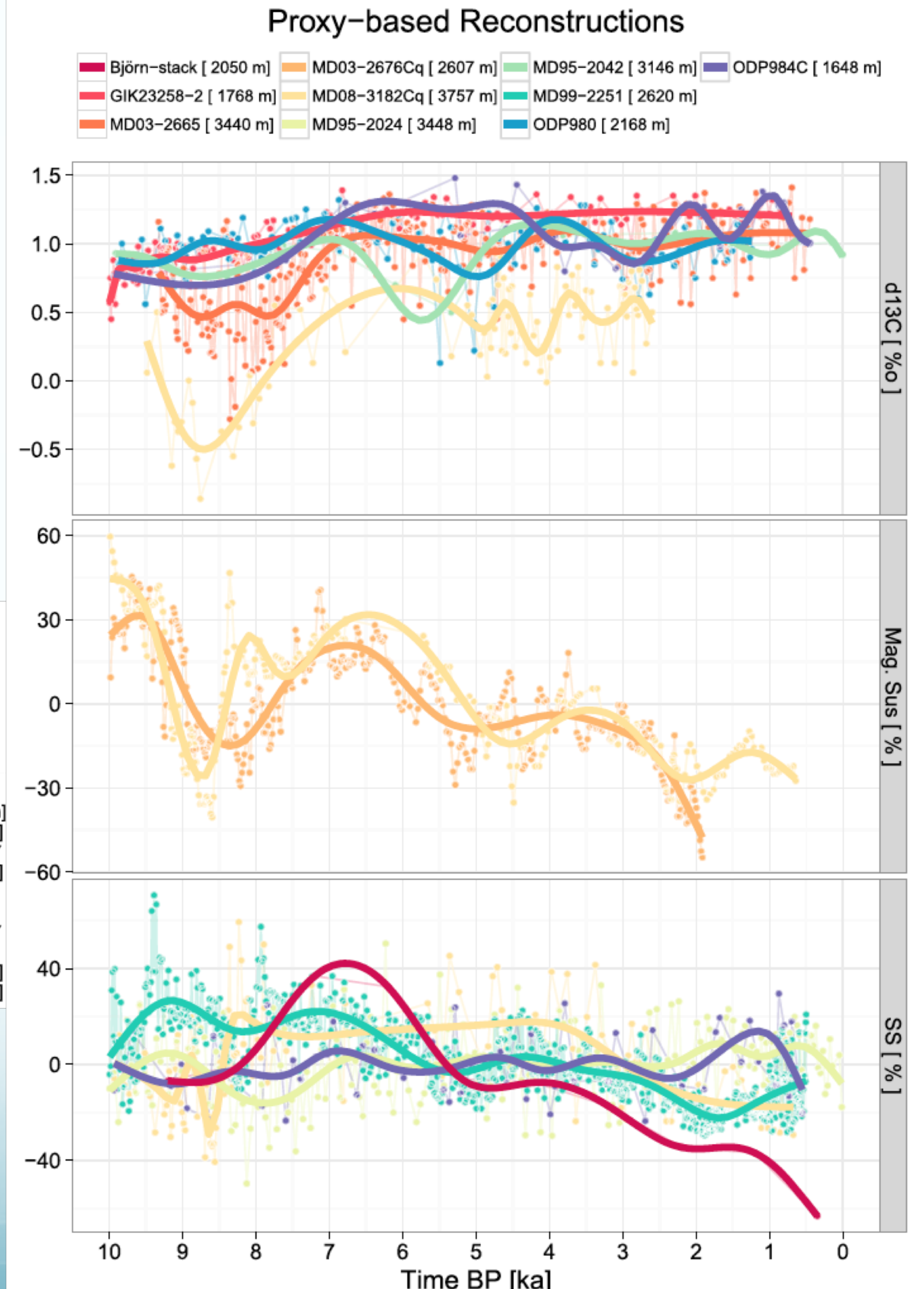
AMOC over the Holocene

- Different proxies not in agreement

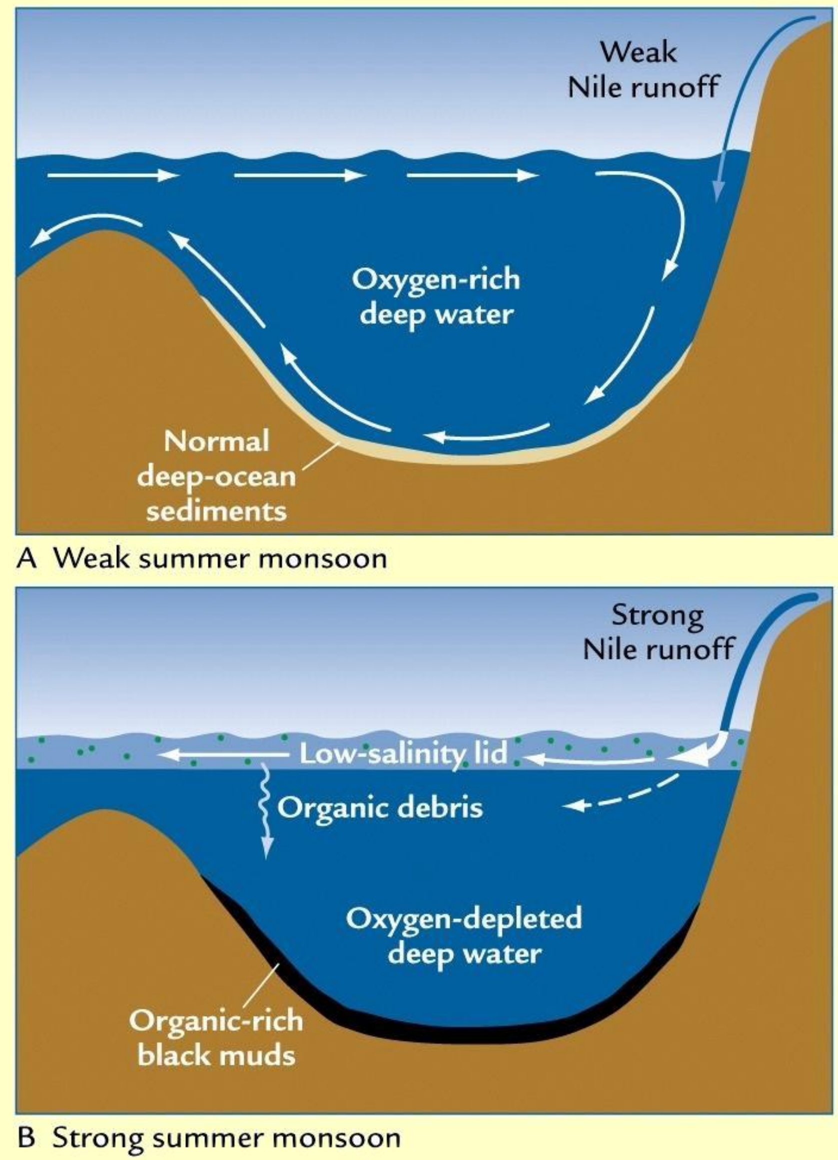


Blaschek et al., *paleoceanogr.,* 2015



Holocene Sapropel event

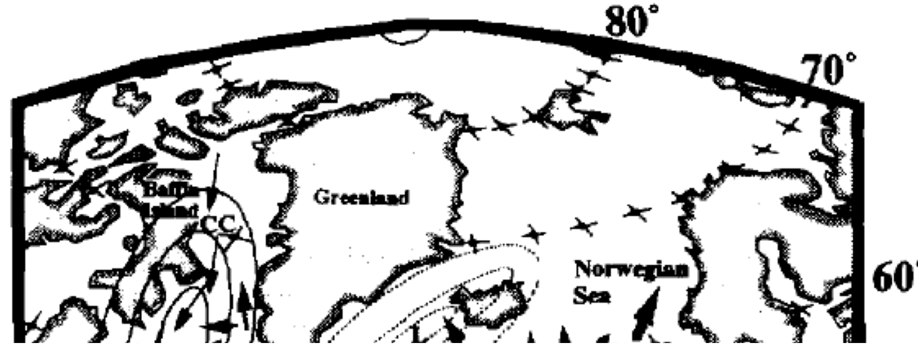
- Marine sediment cores from the Mediterranean indicate large **sapropelic deposit during early Holocene** (10-6 kyr BP) (Bethoux and Pierre 1999, Delange et al. 2008)
- Such Sapropelic deposit may be related with **fresh surface water in the Mediterranean**, potentially related with large increase of River Nile flow, in link with Green Sahara at the same period (remnant Fennoscandian melting as well)



MOW impact on the AMOC?

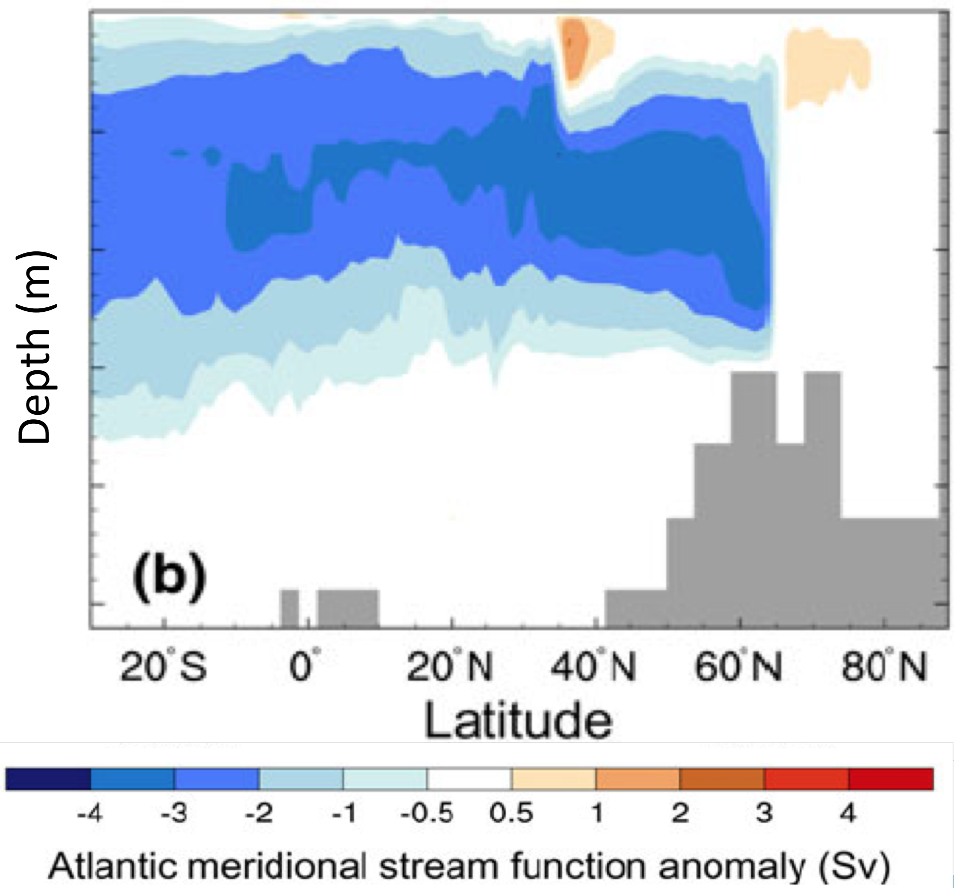
- Such changes in surface may strongly affect the Mediterranean outflow (MOW) and potentially the Atlantic Meridional Overturning Circulation (AMOC)
- Johnson (1997) using qualitative arguments: Aswan Dam ➔ reduced Nil flow ➔ increased MOW ➔ increased AMOC ➔ increased evaporation in Labrador ➔ new ice age!
- Rahmstorf (1998) using simple climate model: salty Med ➔ increased AMOC
- Ivanovitch et al. (2013) using HadCM3: decrease of AMOC when MOW ceases, except at the surface...

Johnson (1997) process



Ivanovitch et al. 2013 (HadCM3, Halving Med salinity)

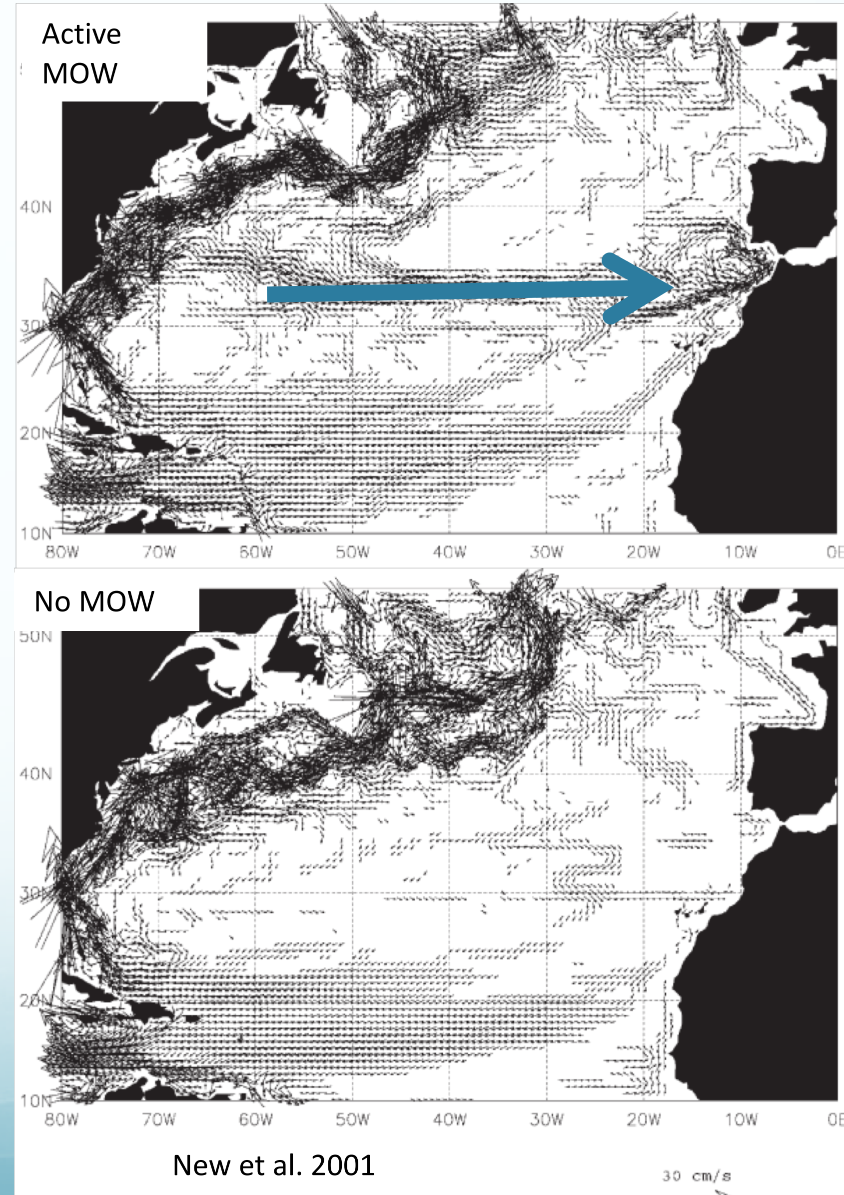
Depth



Effect of MOW on surface ocean circulation

Jia (2000), New et al. (2001) using of high-resolution (<0.5) ocean GCMs, one with active MOW, the other without MOW

- With active MOW, there is clear branch of surface water going towards the Mediterranean
- Without any MOW, this branch disappears
- **What could the impact of these 3D large-scale circulation changes on tropical salinity transport, and then AMOC and climate?**



New et al. 2001

Two opposing mechanisms for the AMOC

1) No MOW: direct impact on density distribution in the ocean

⇒ Lower zonal density gradient at depth (≈500-1500m)

⇒ Thermal wind relationship: **weakened AMOC at depth**

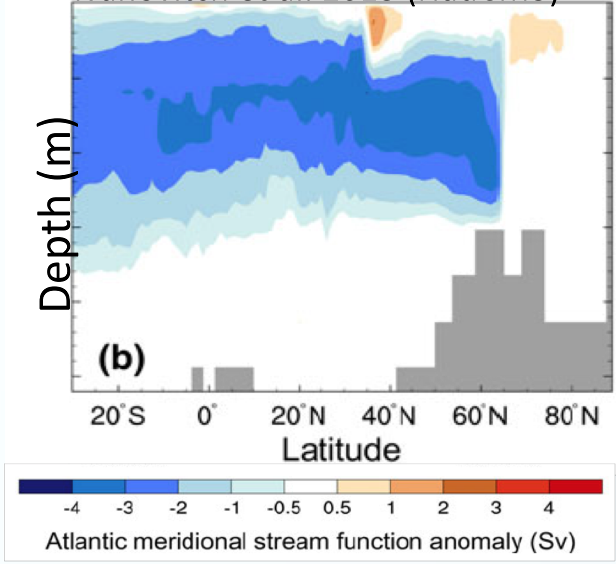
2) No MOW: impact on subtropical gyre geometry

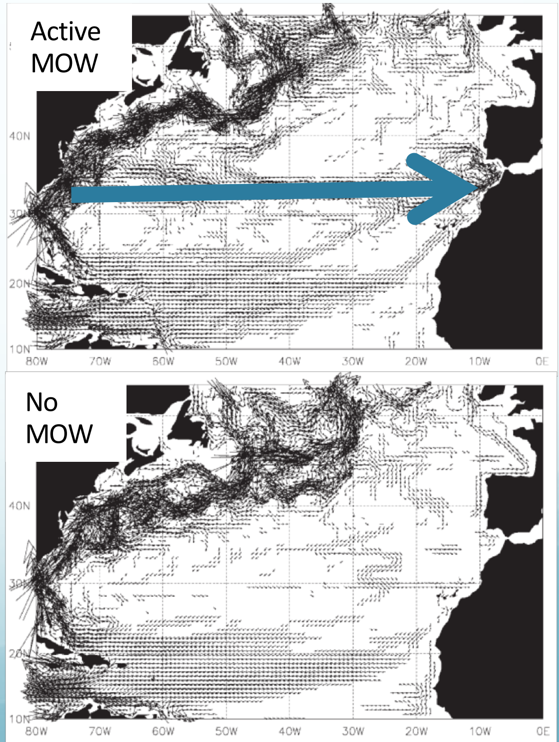
⇒ Increased subtropical surface water transport in the North Atlantic

⇒ Increased surface salinity and convection in the North Atlantic

⇒ **Increased AMOC and subpolar gyre**

Ivanovitch et al. 2013 (HadCM3)





New et al. 2001

Outlines

- How to reconstruct AMOC variations over the Holocene?
- Can MOW variations play a role?
- What are the implications of these AMOC variations?
- And what about recent evolution

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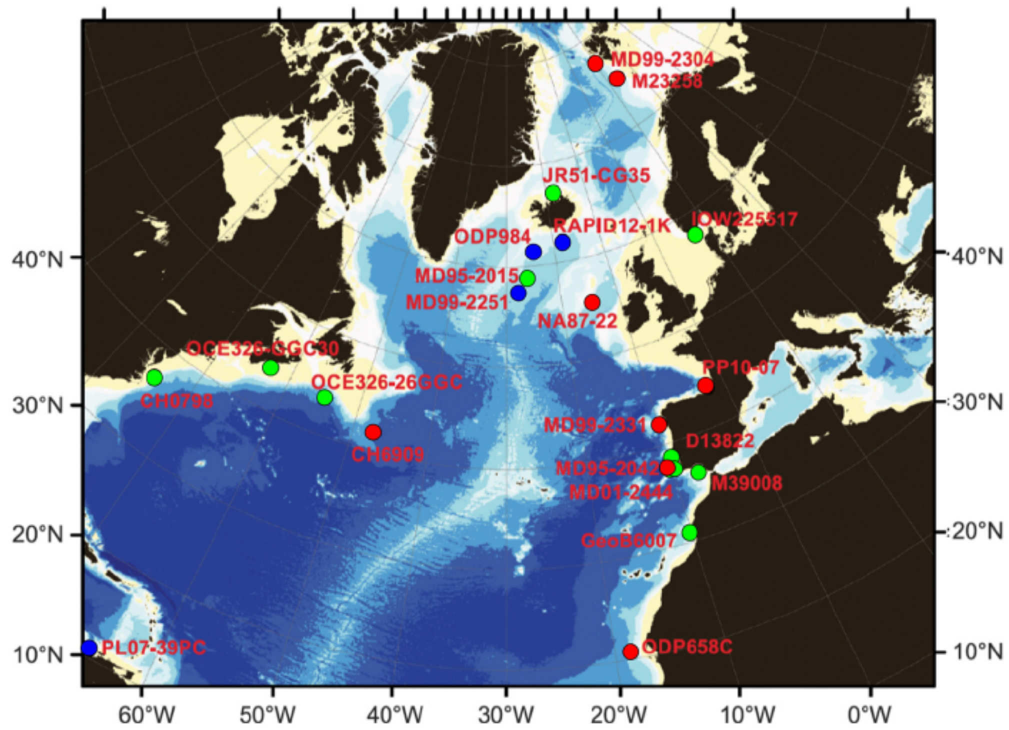
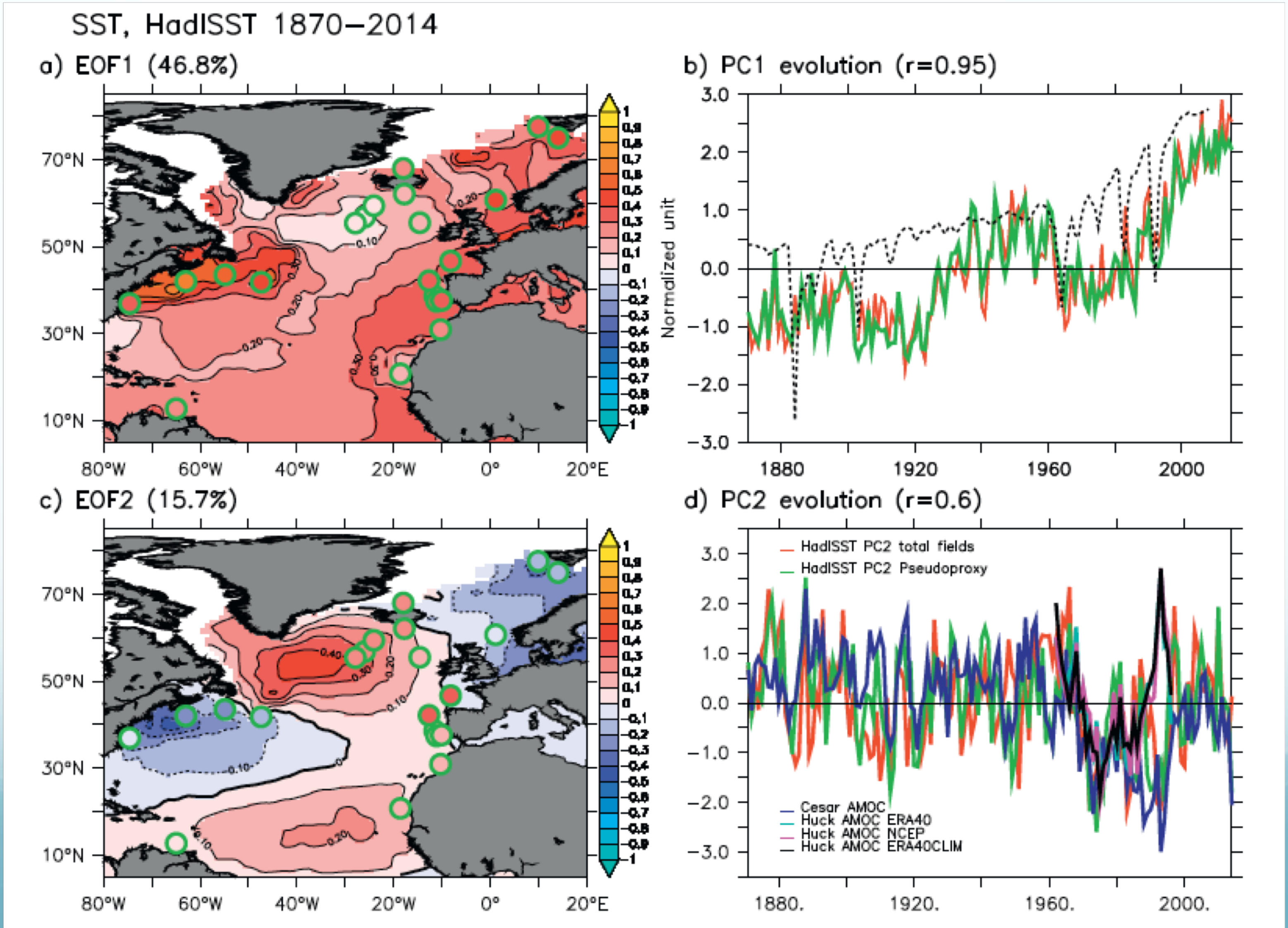
HAMOC SST database

Core Name	Mean resolution (yr)	SST data type
CH0798	61	Alkenones
CH6909	161	Foraminifera
D13822	70	Alkenones
GeoB6007	27	Alkenones
IOW225517	120	Alkenones
JR51-GC35	110	Alkenones
M23258	49	Foraminifera
M39008	156	Alkenones
MD01_2444	182	Alkenones
MD95–2015	83	Alkenones
MD99–2251	47	Mg/Ca
MD99–2304	114	Foraminifera
MD95–2042	113	Foraminifera
MD99–2331	42	Foraminifera
NA87–22	134	Foraminifera
OCE326- 26GGC	95	Alkenones
OCE326-GGC30	80	Alkenones
ODP658C	176	Foraminifera
ODP984	110	Mg/Ca
PP10–07	48	Foraminifera
PL07-39PC	110	Mg/Ca
RAPID12_1K	78	Mg/Ca

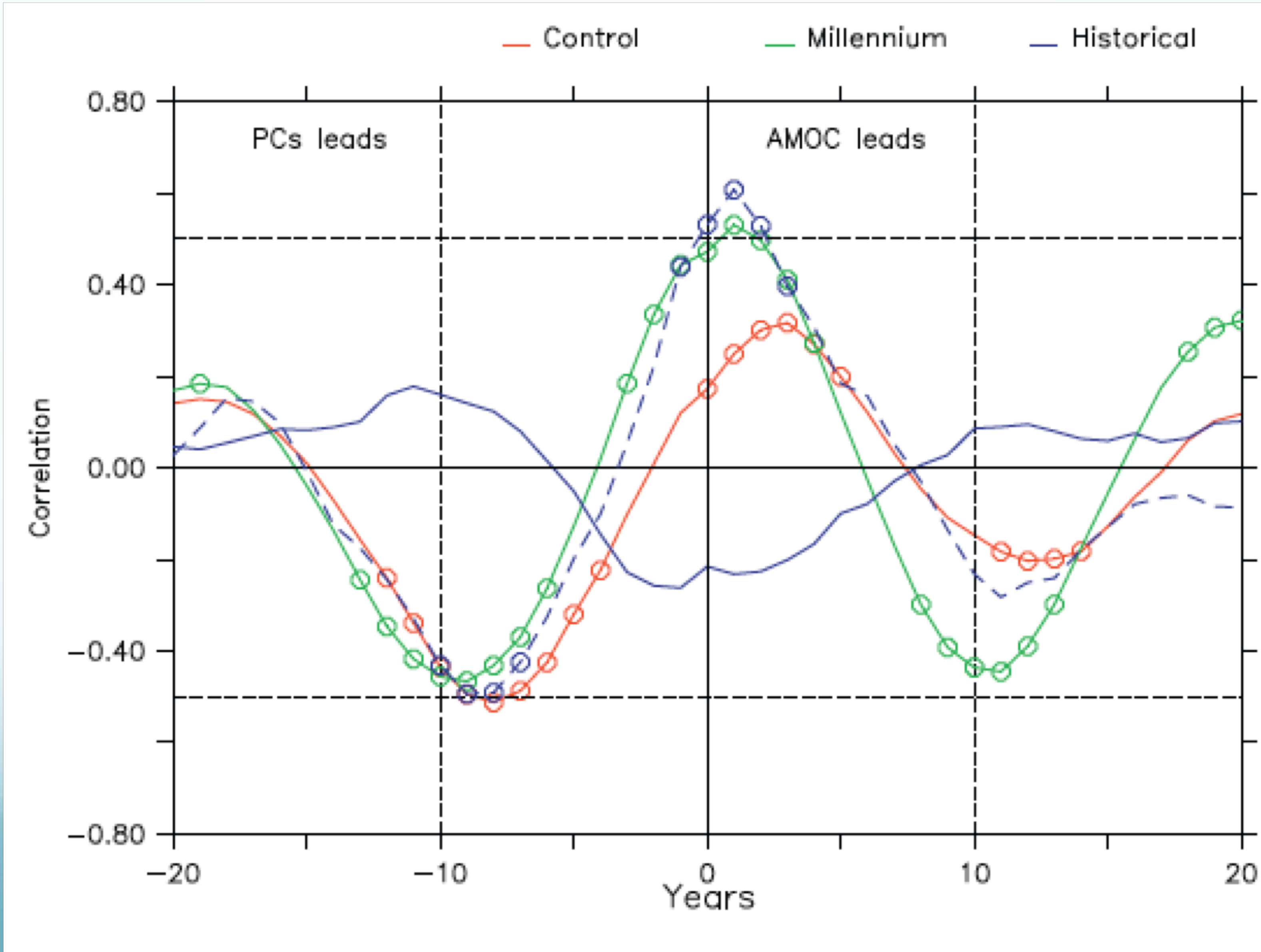


Ayache et al. GPC 2018

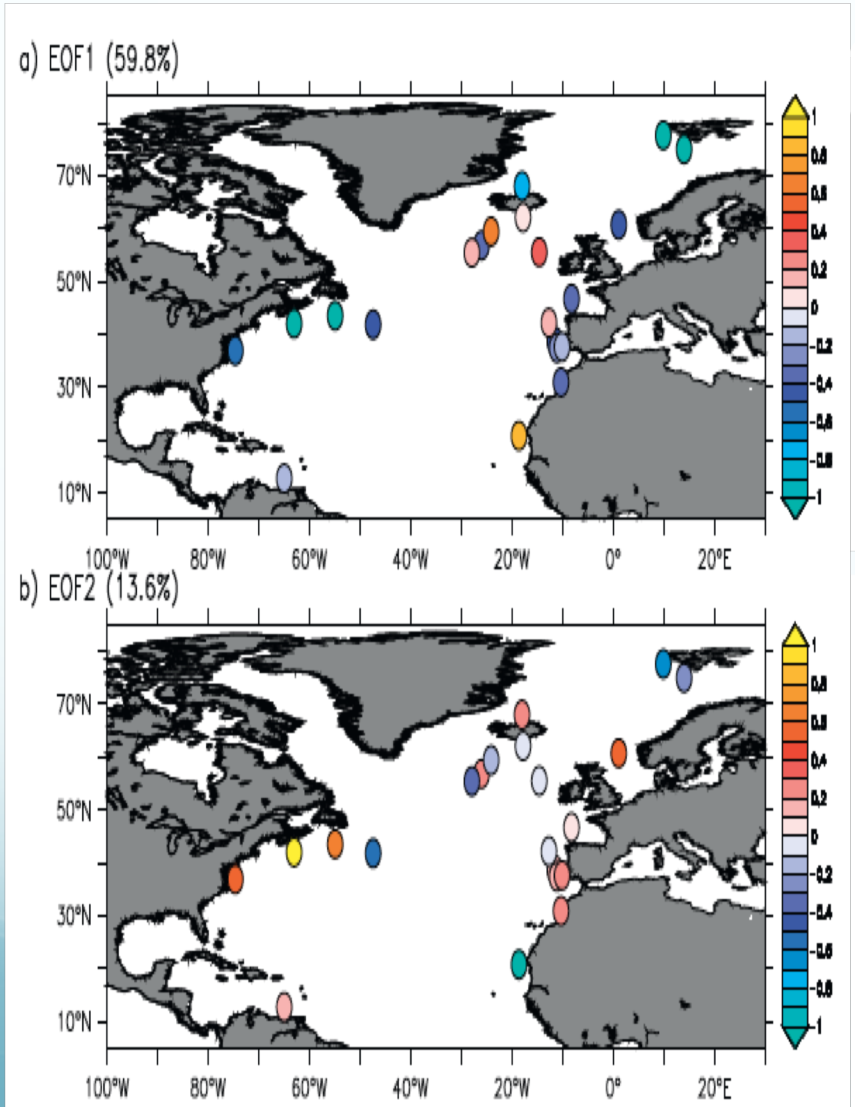
Link between SST and AMOC

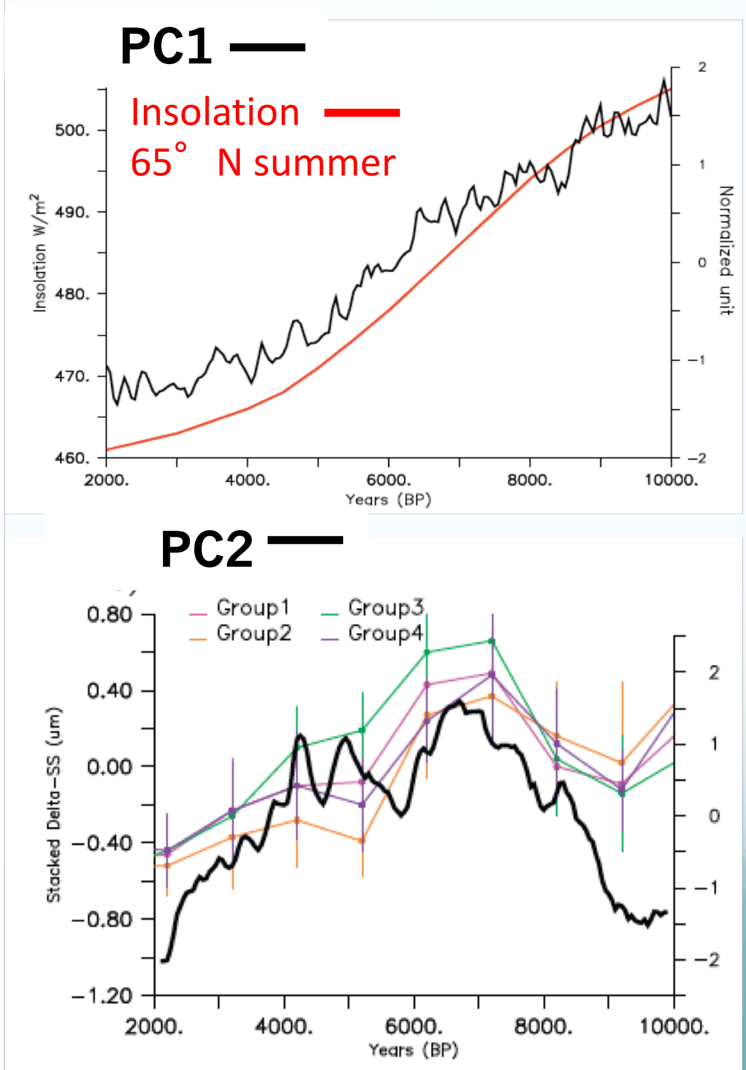


Link between SST and AMOC

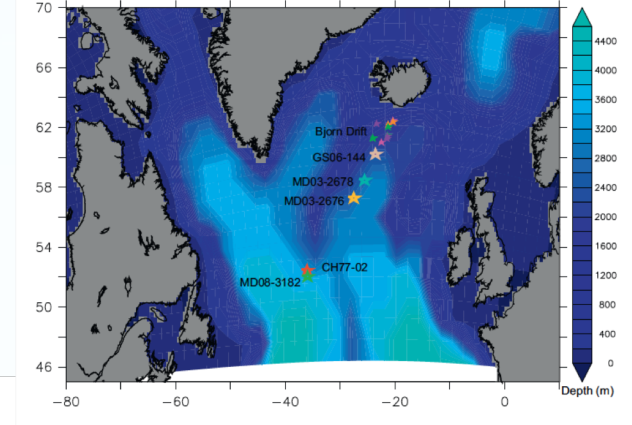


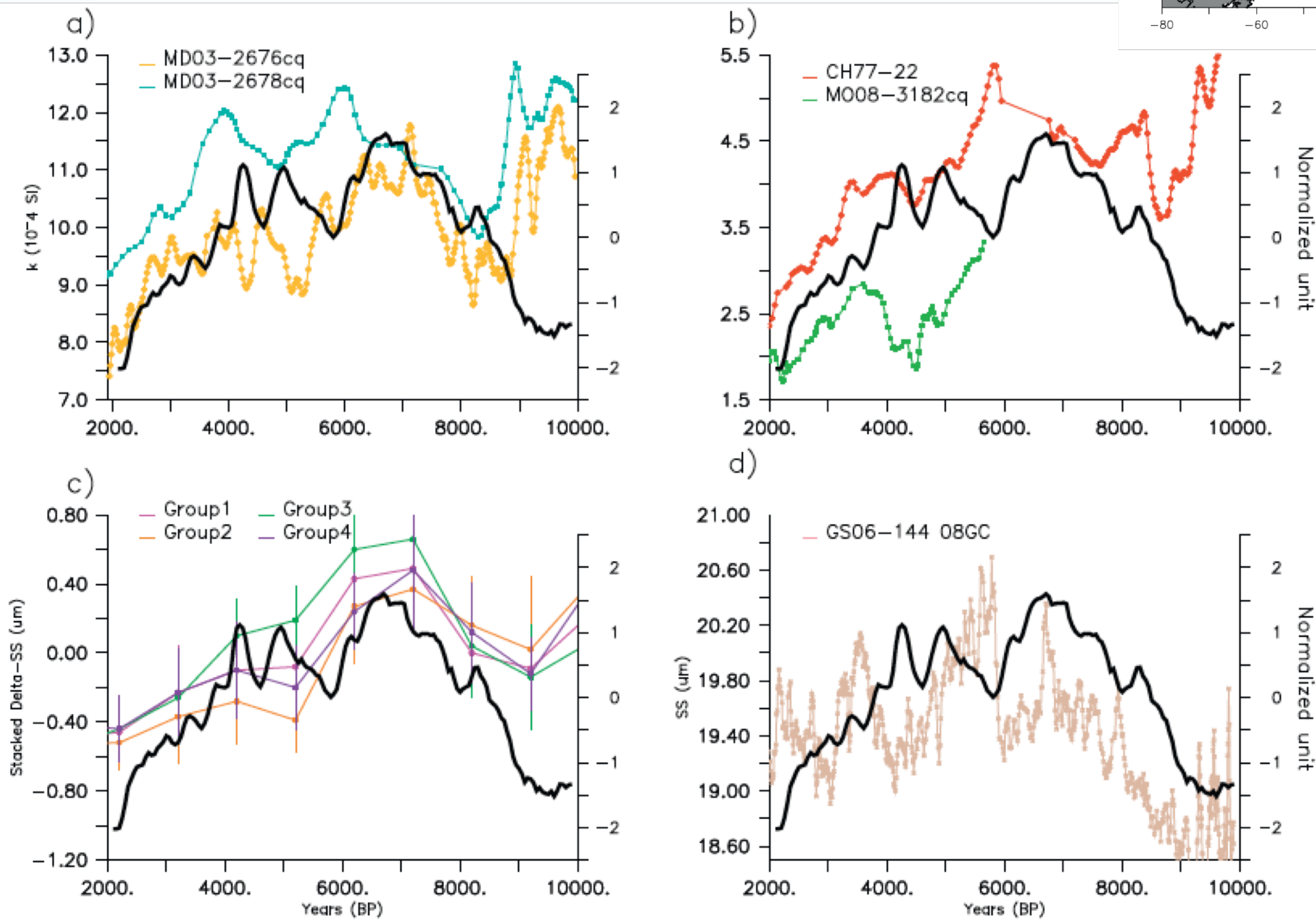
Principal component analysis in the HAMOC database





Our AMOC reconstruction





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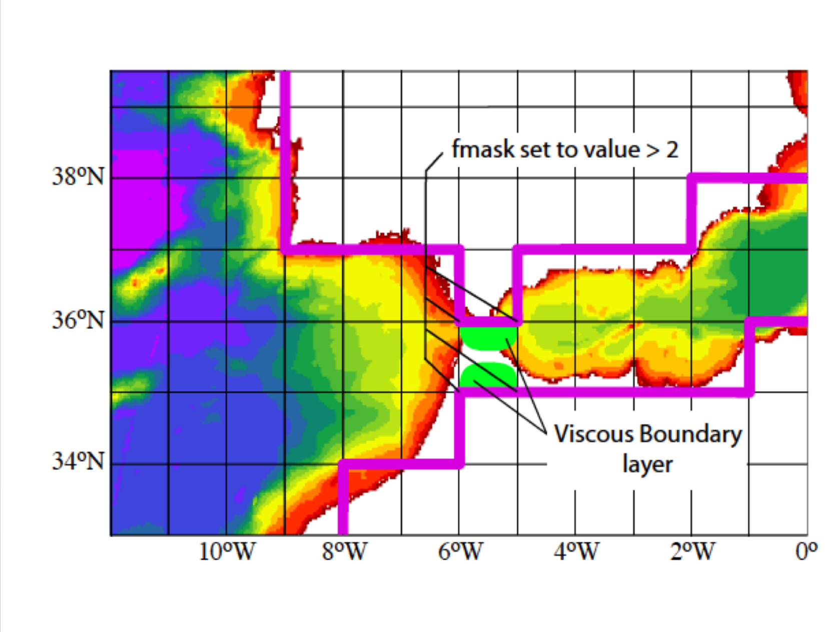
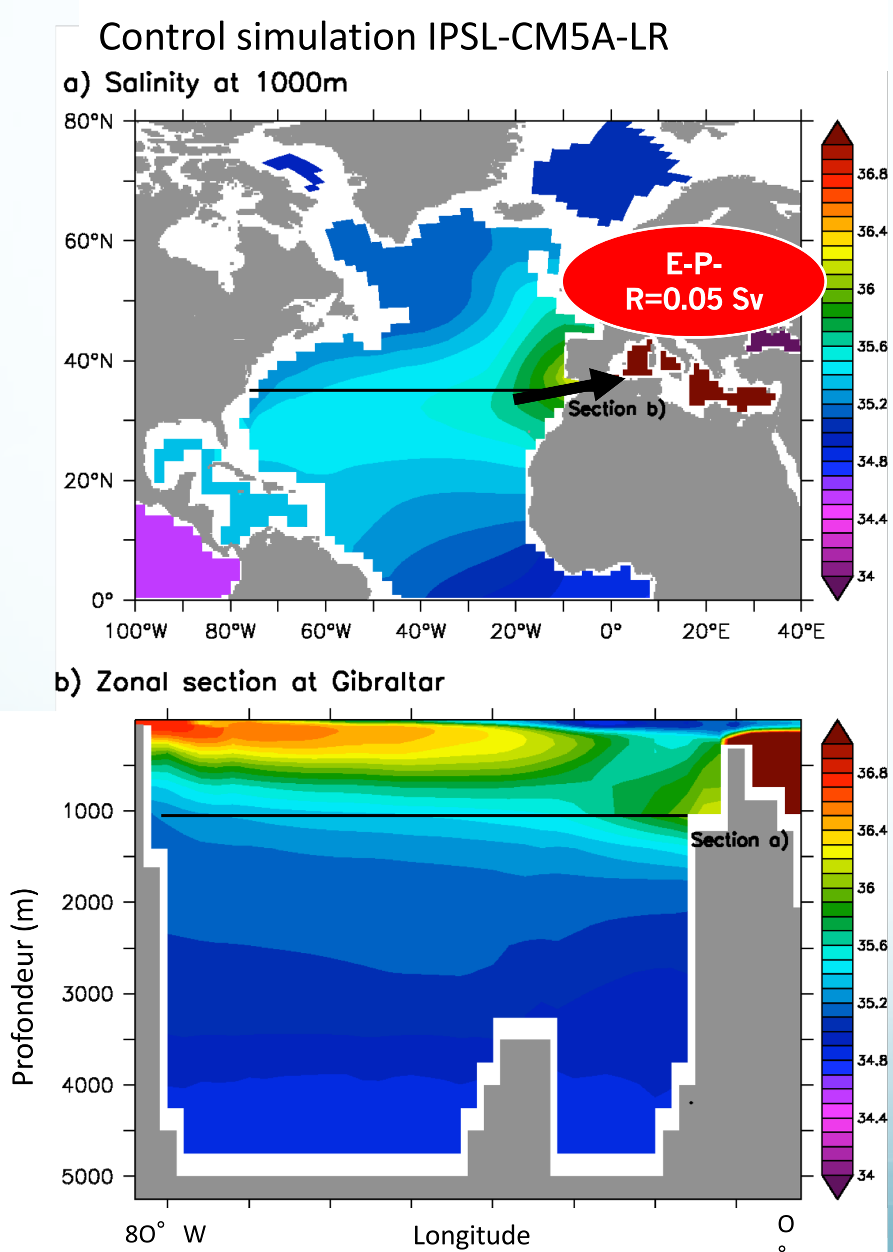
Experimental design

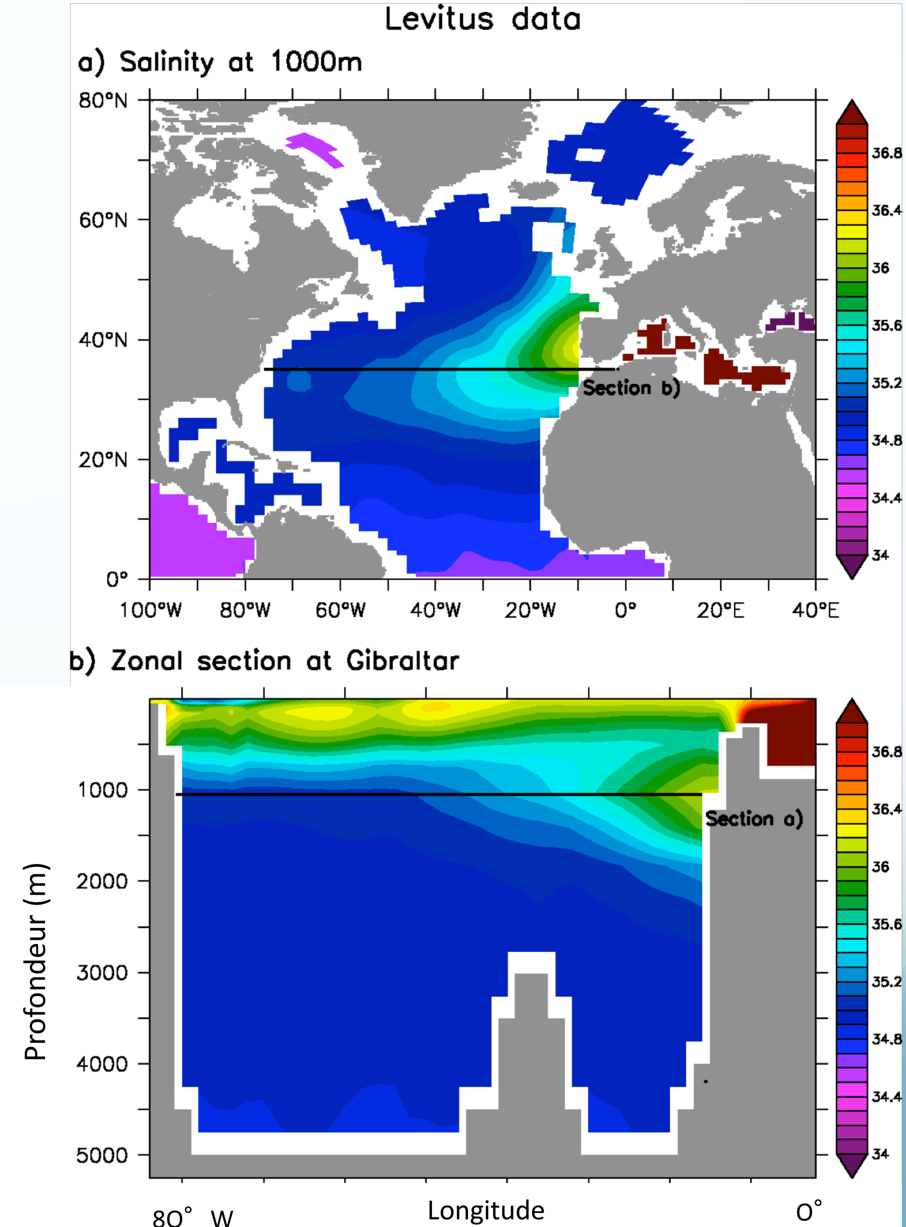
Objective: *What is the impact of a MOW disappearance on large-scale ocean and climate in a state-of-the art climate model?*

- IPSL-CM5A-LR:
  - Ocean-atmosphere GCM (≈2°)
  - Representation of Gibraltar by playing with viscosity for having realistic transport (modelled MOW=2.2 Sv, obs.≈1.8 Sv)
- Freshwater put homogenously over the Mediterranean for 1000 years with rates of:
  - 100 mSv (**HosMed1**)
  - 50 mSv (**HosMed05**)
  - 20 mSv (**HosMed02**)
- Last test with 200 mSv for 500 years (**HosMed2**)



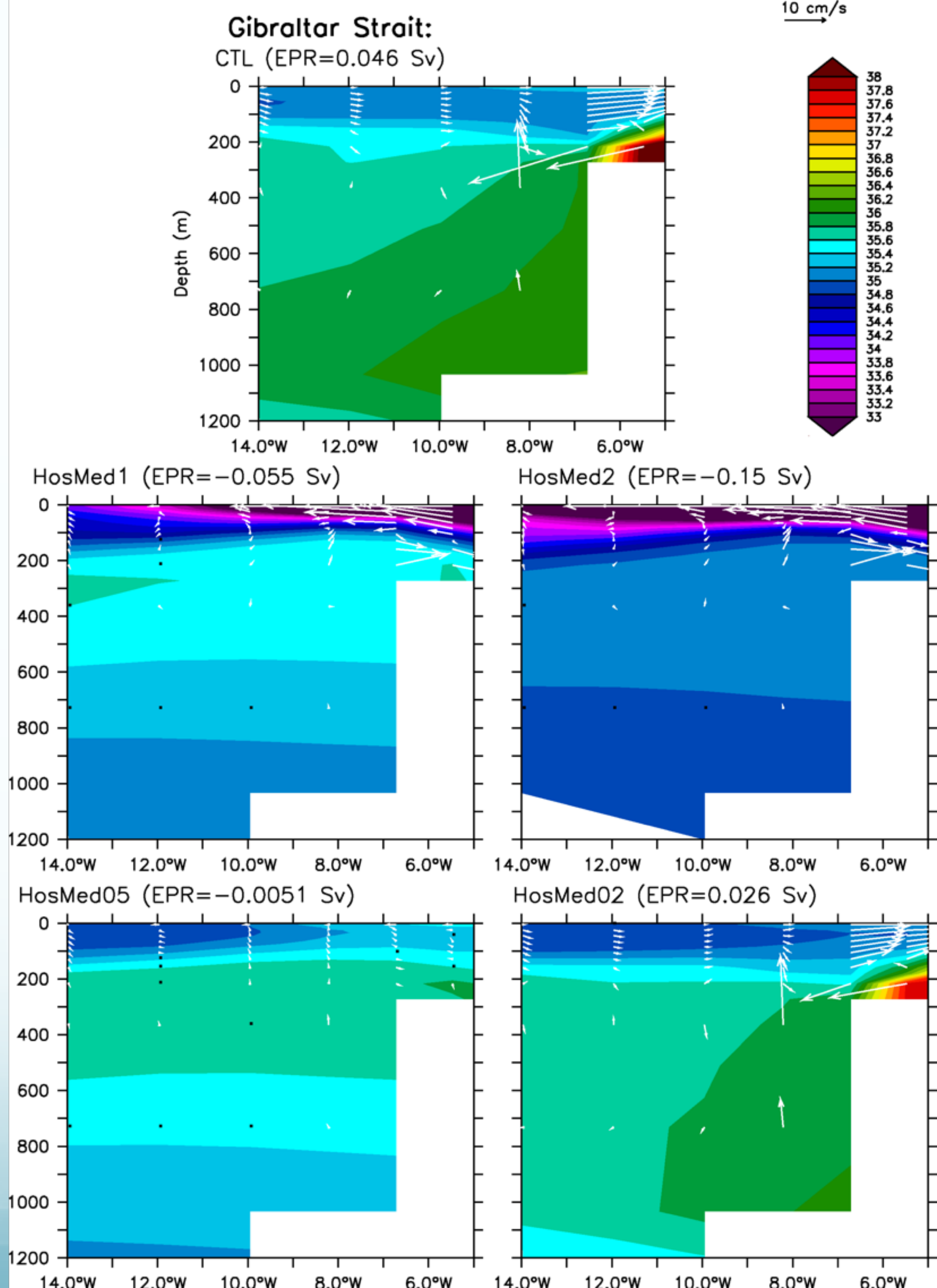
MOW within IPSL-CM5A-LR





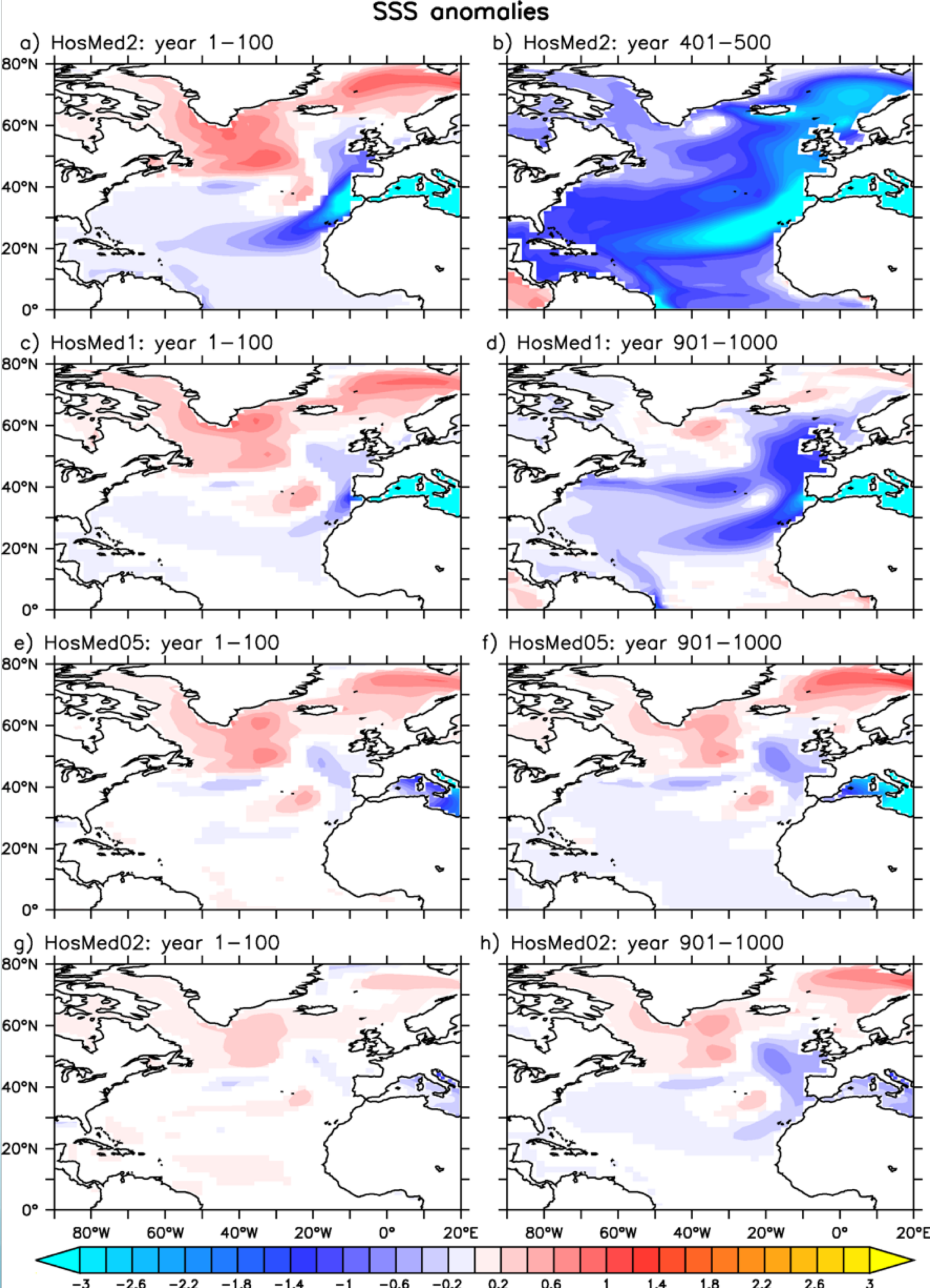
Freshwater impact on the MOW

- Different type of MOW response from collapse to around 20% reduction
- HosMed02 and Med05 more in line with different estimates of MOW variations (Bahr et al. 2015)



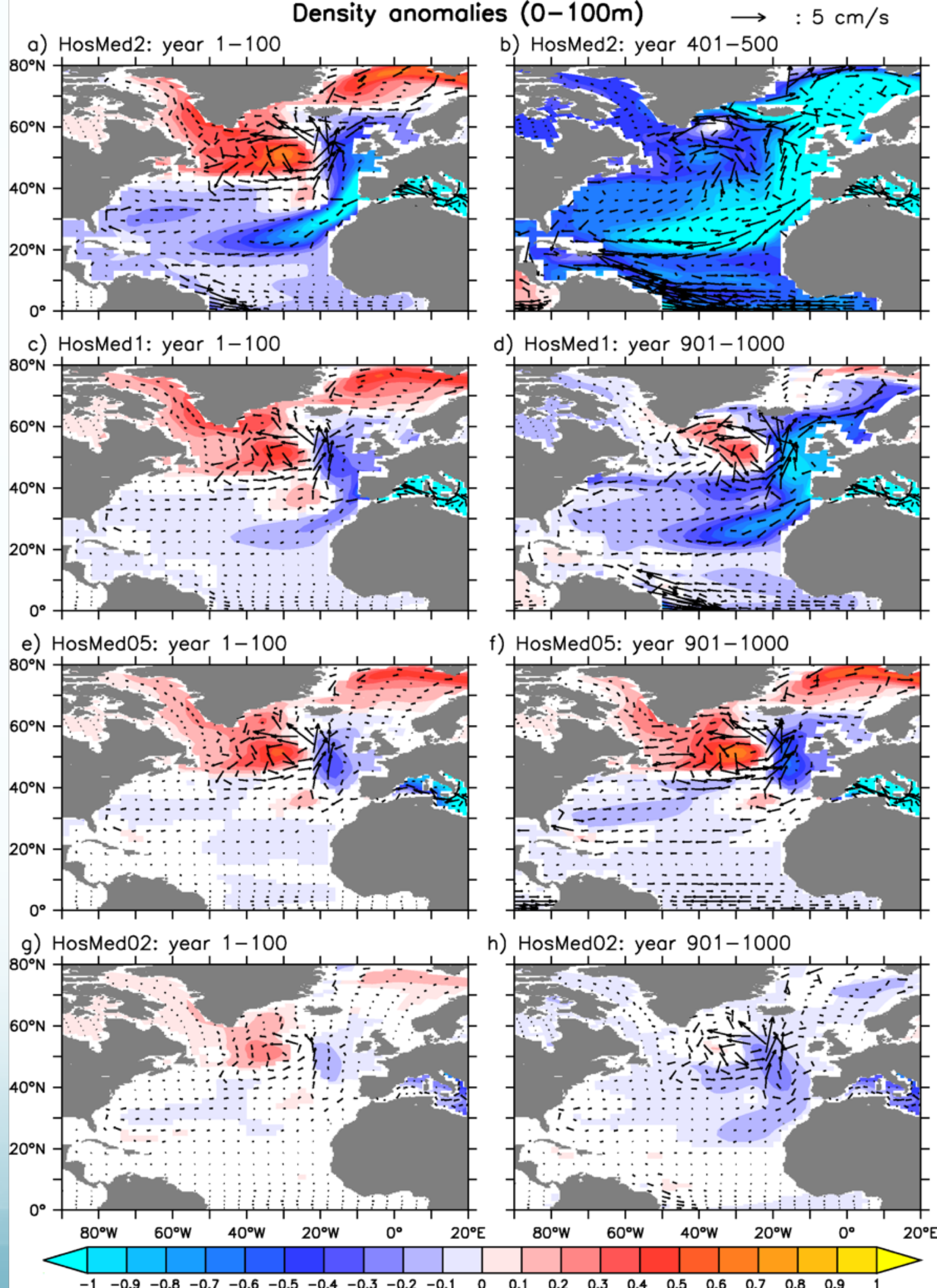
Changes in surface salinity

- Only a small proportion of the freshwater released leaves the Mediterranean at the surface (except in HosMed2)
- Increase of SSS in the North Atlantic!
- And of convection



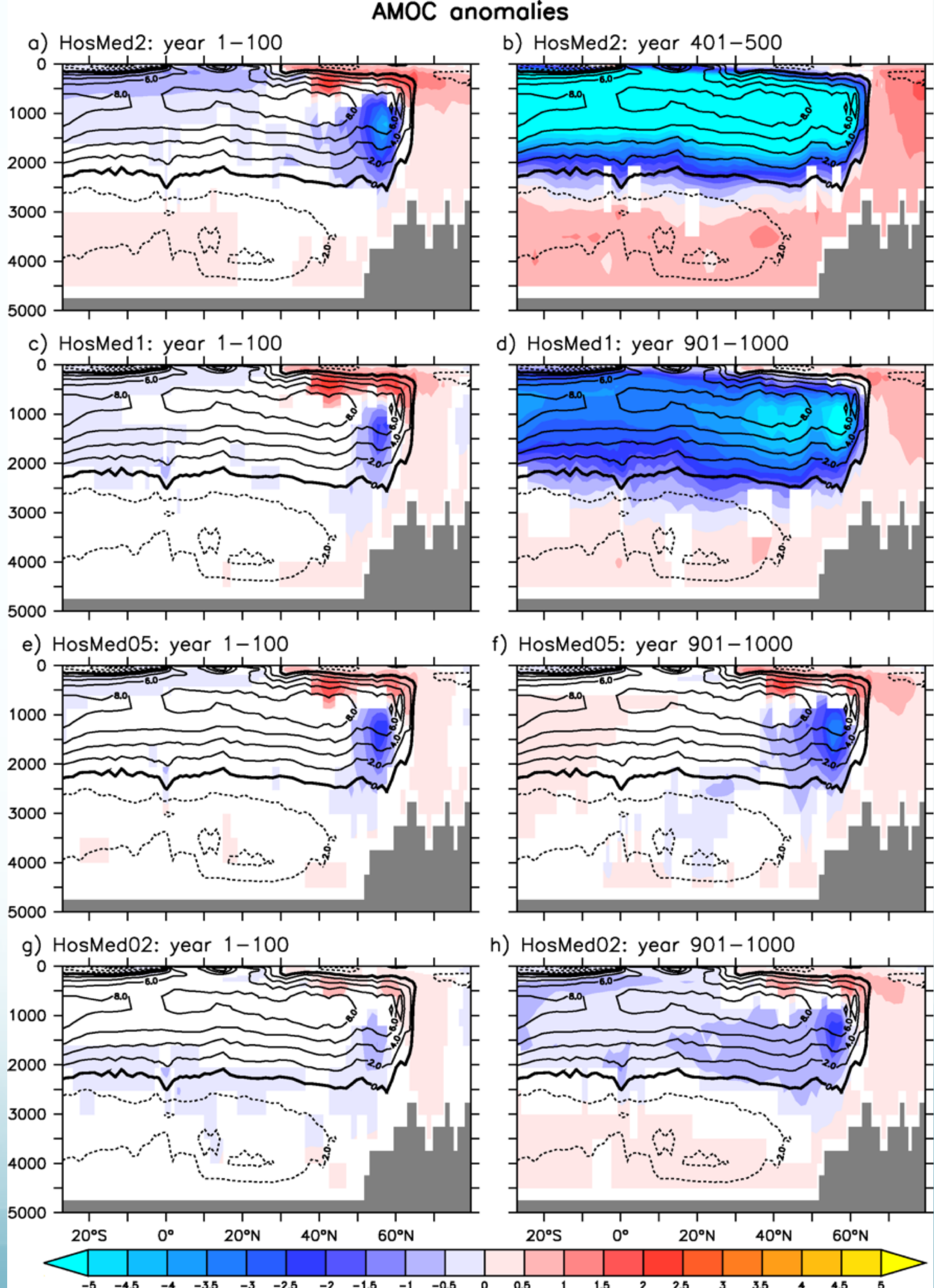
Upper ocean circulation changes

- Changes in density is inducing changes in transport through geostrophy
- Positive feedback loop: stronger northward transport induced strong density in the west subpolar gyre which increases the density gradient



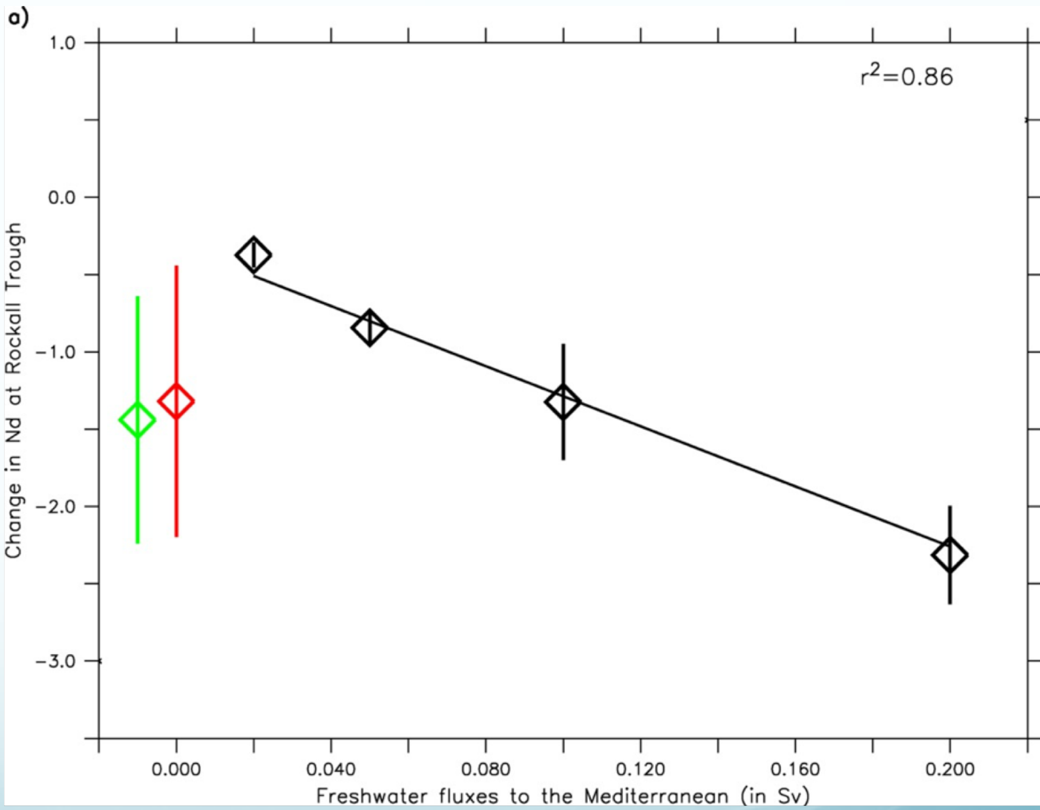
AMOC response

- Increase of AMOC at the surface, decrease at depth
- Different processes may be at play…



Comparison with Nd at Rockall

- HosMed02 and HosMed05 more in line with Sapropel S1 in terms of freshwater input
- But need at least HosMed05 to be in agreement with Corals
- Eastward shift of the subpolar gyre



Summary of the three processes at play for the AMOC response

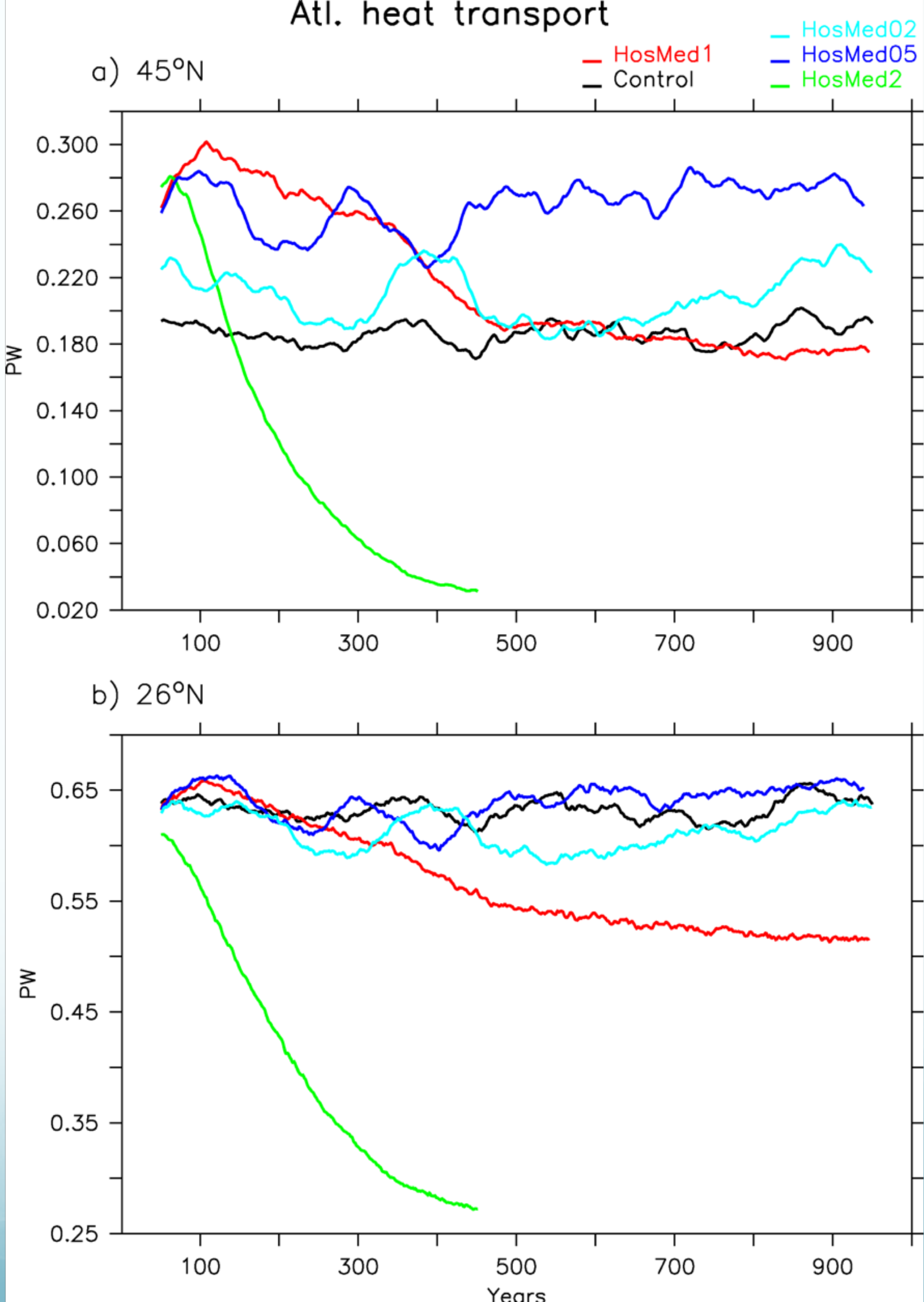
1. Geostrophic adjustment at depth in response to the collapse of MOW and the associated changes in zonal density gradients for depth between around 500m to 2000m.

2. Changes in surface currents, and notably the enhancement of the North Atlantic drift, leading to an increase of SSS in the subpolar gyre, enhancing deep water

3. Slow spread in the upper ocean of freshwater anomalies from the Mediterranean and its accumulation in the North Atlantic, leading to a decrease of SSS and deep convection

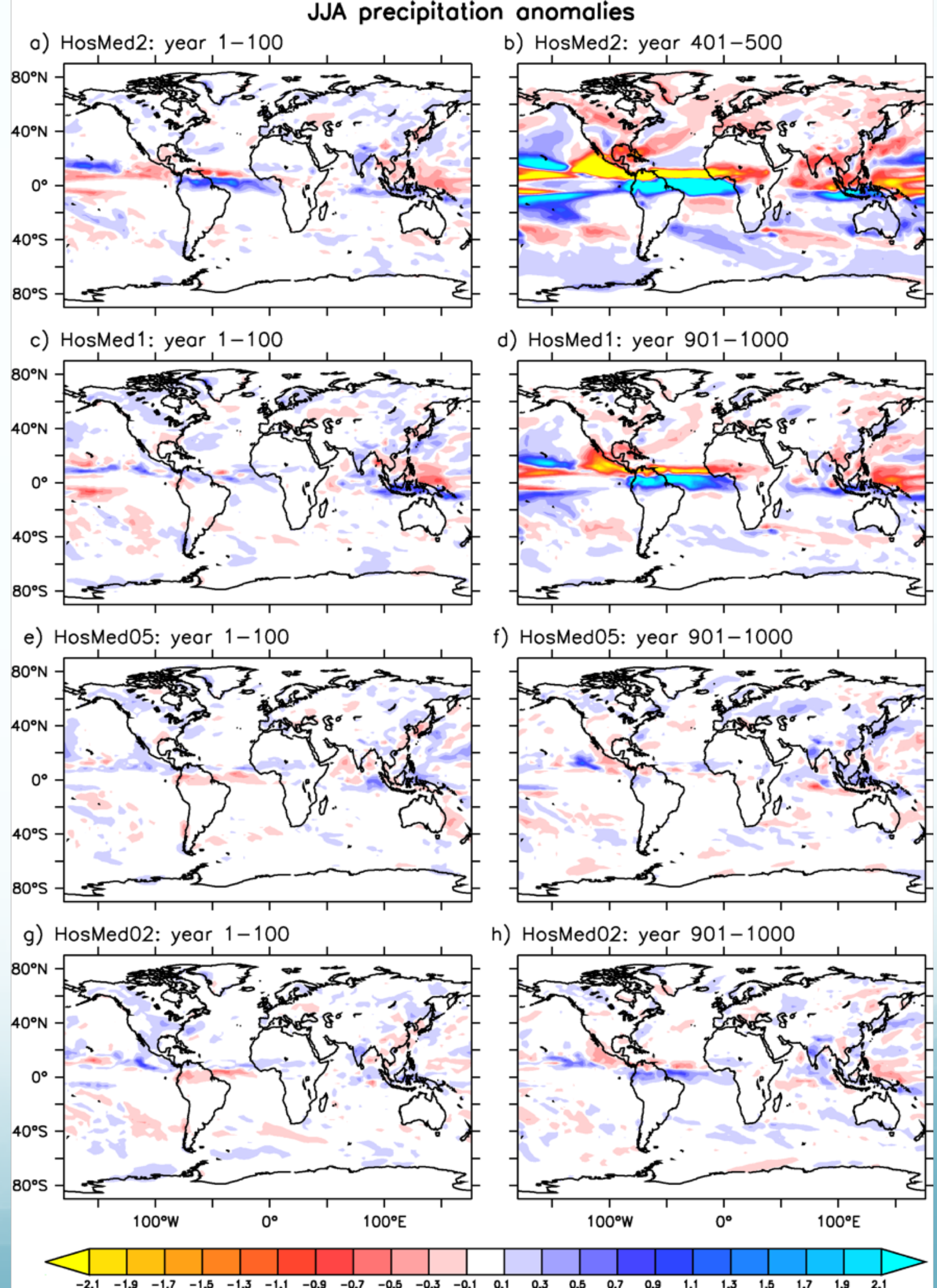
Changes in meridional ocean heat transport

- Upper ocean changes in the AMOC is dominating is dominating the heat transport
- Logical since upper ocean is where the temperature gradient is located.



Climatic impact

- Warming of the North Atlantic (except HosMed2), in line with increase in heat transport
- Northward shift of the ITCZ in all simulations but HosMed2
- Positive feedback: northward shift of the ITCZ
  - => increase in Nile
  - => decrease of MOW
  - => increase in northward heat transport
  - => northward shift of the ITCZ



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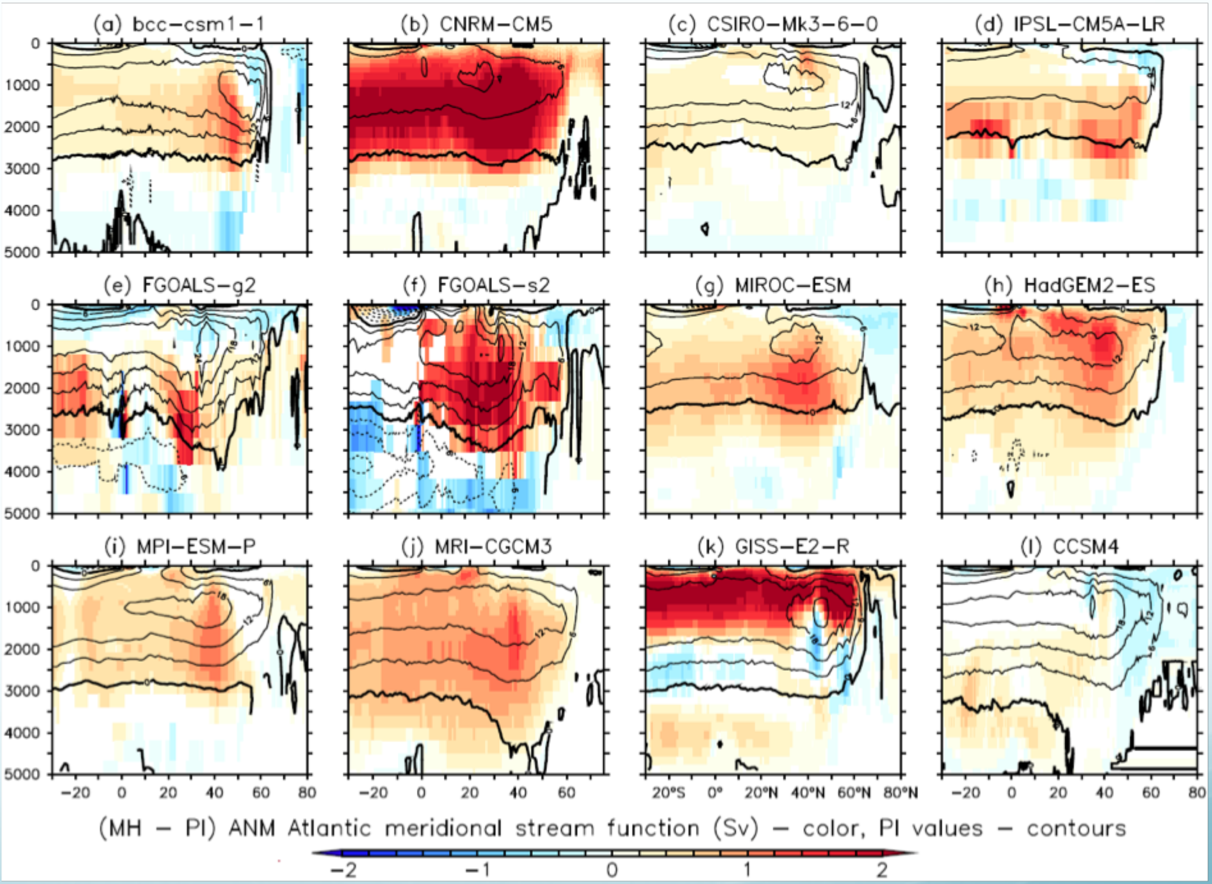
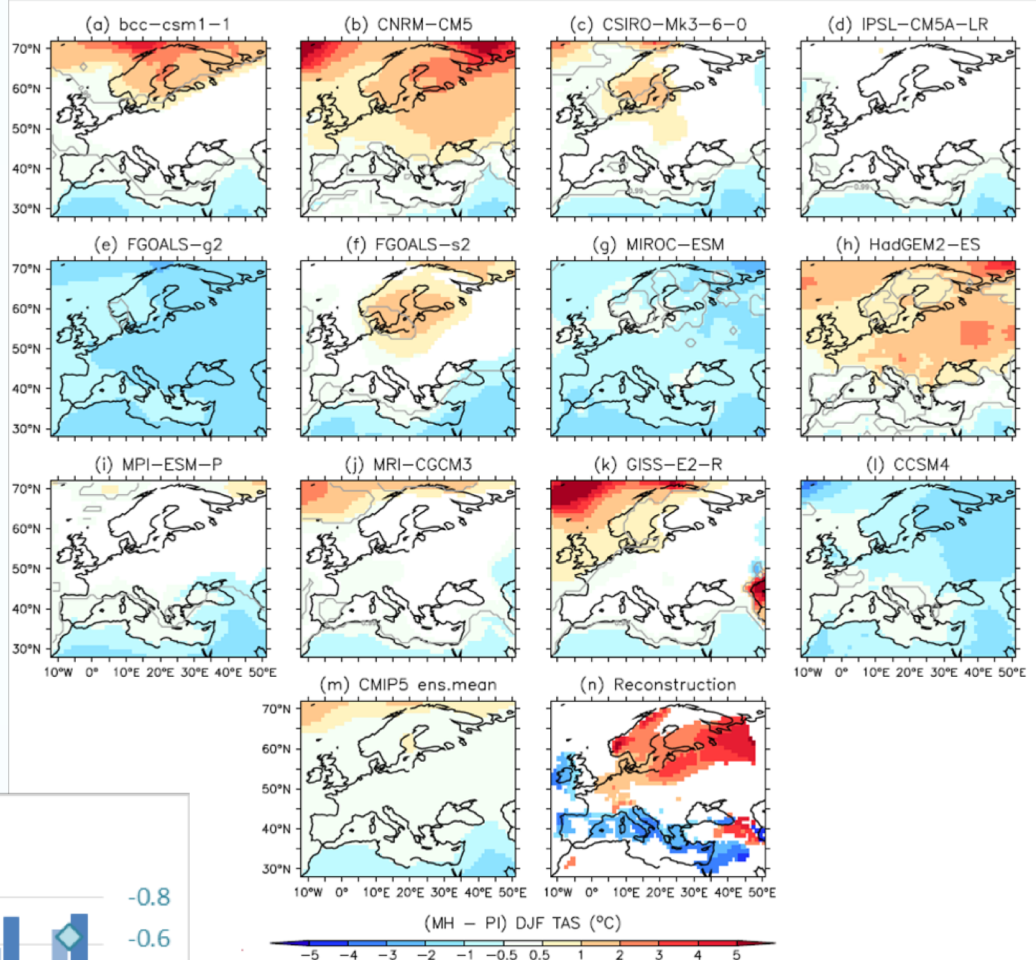
A stronger AMOC at 6 ka?

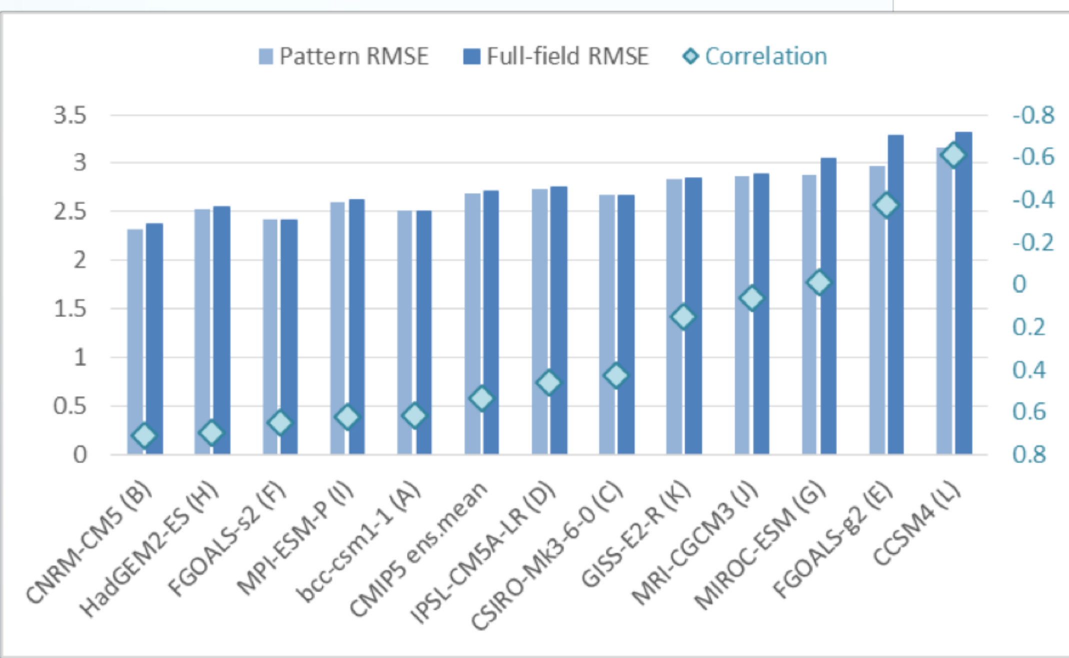
- **Gainusa-Bogdan** et al. (in prep.): analysis of PMIP3 simulation at 6ka
- Increase of the AMOC in most models (a priori more related to insolation effect, not MOW changes)



Can the AMOC increase explain climate signature at 6ka?

- Comparison with Mauri et al. winter temperature reconstruction for Europe





- « Best models » are the one with large AMOC enhancement

Conclusions and outlooks

- H1: the changes in the MOW explain large part of potential AMOC variations over the Holocene.
- H2: changes in the AMOC explain some remarkable climatic features over this period and notably changes over Europe (AMOC not NAO…)?
- Need for analysis of a transient Holocene simulation:
  - Increase in freshwater in the Mediterranean?
  - If not sufficient, sensitivity test with additionnal freshwater release in the North Atlantic
  - Impact on higher resolution ocean model (Azores current better resolved => one order of magnitude too low in IPSL-CM5A-LR!)

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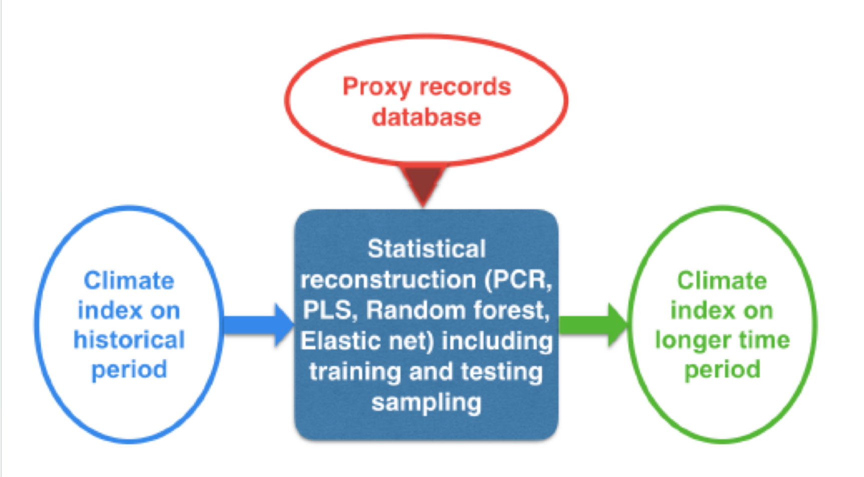
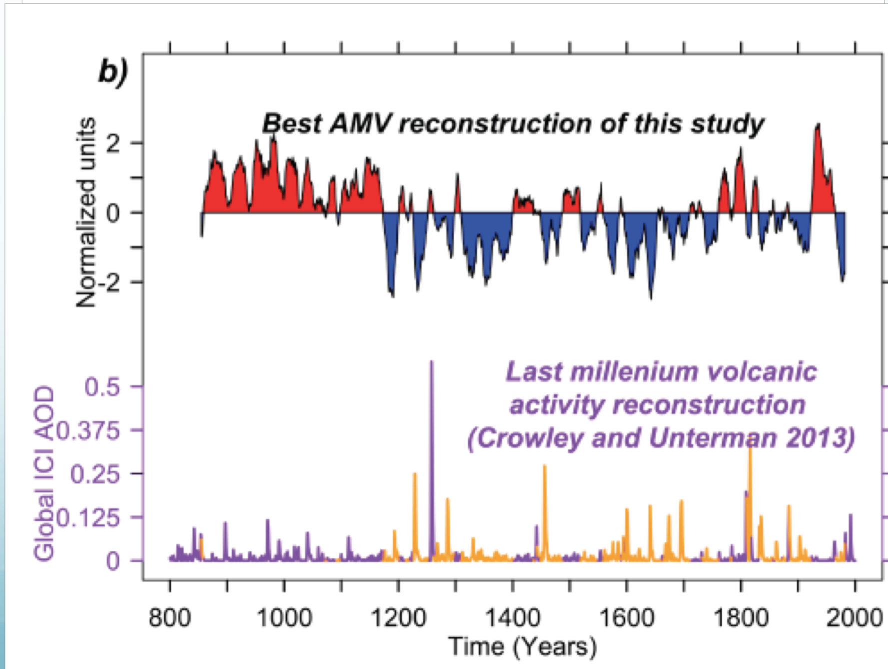
Reconstruction of climatic indices using machine learning techniques

- A statistical device to reconstruct any climatic modes from a given database (**Michel** et al. GMDD) available to the community
- Application for AMV using PAGES 2K database

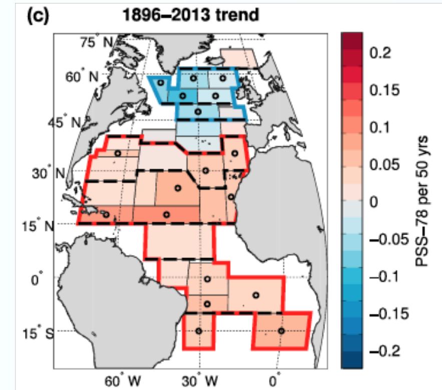


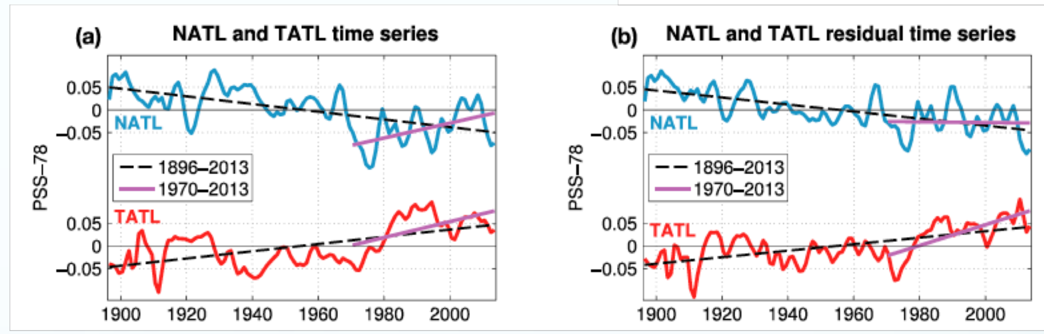


Variation of the AMOC over the historical era

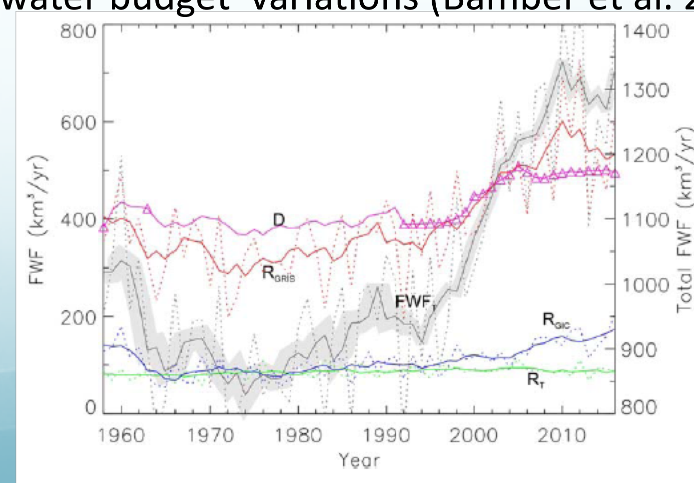
- AMOC decreasing over the historical era (Caesar et al. 2018)
- Decrease of SSS in the subpolar (Friedmann et al. 2017)
- Inclusion of Greenland melting in historical IPSLCM6 simulations (Blue-Action project, **Marion Devilliers**)

SSS variations over the subpolar regions (Friedmann et al. 2017)



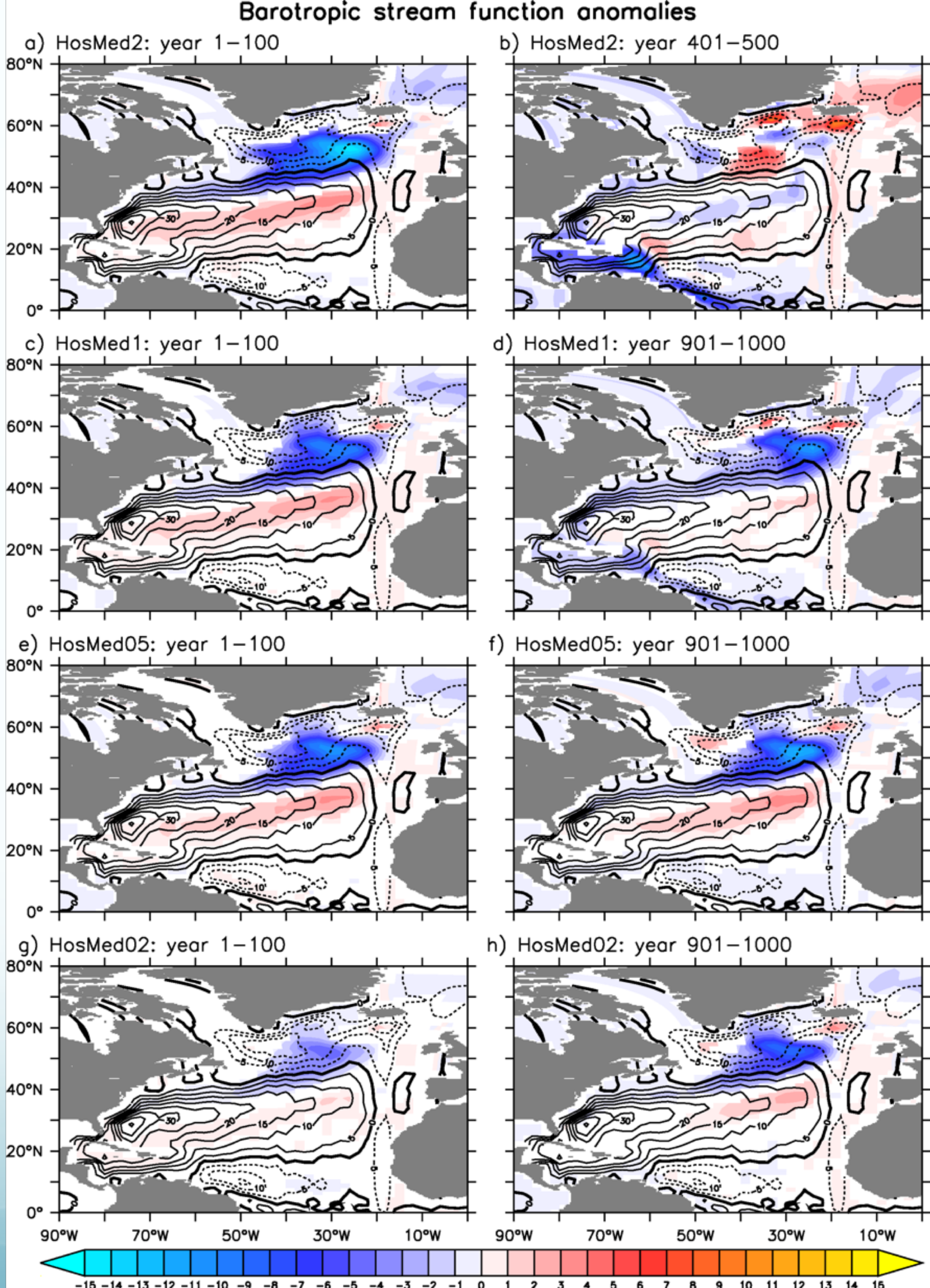


Freshwater budget variations (Bamber et al. 2018)



BLUE ACTION

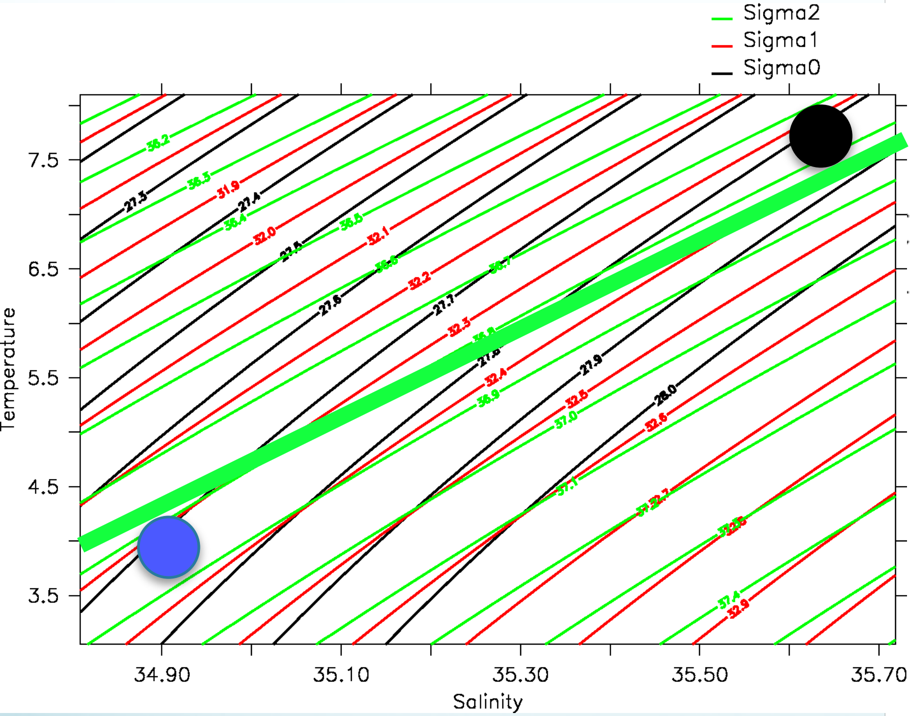
Thank you!



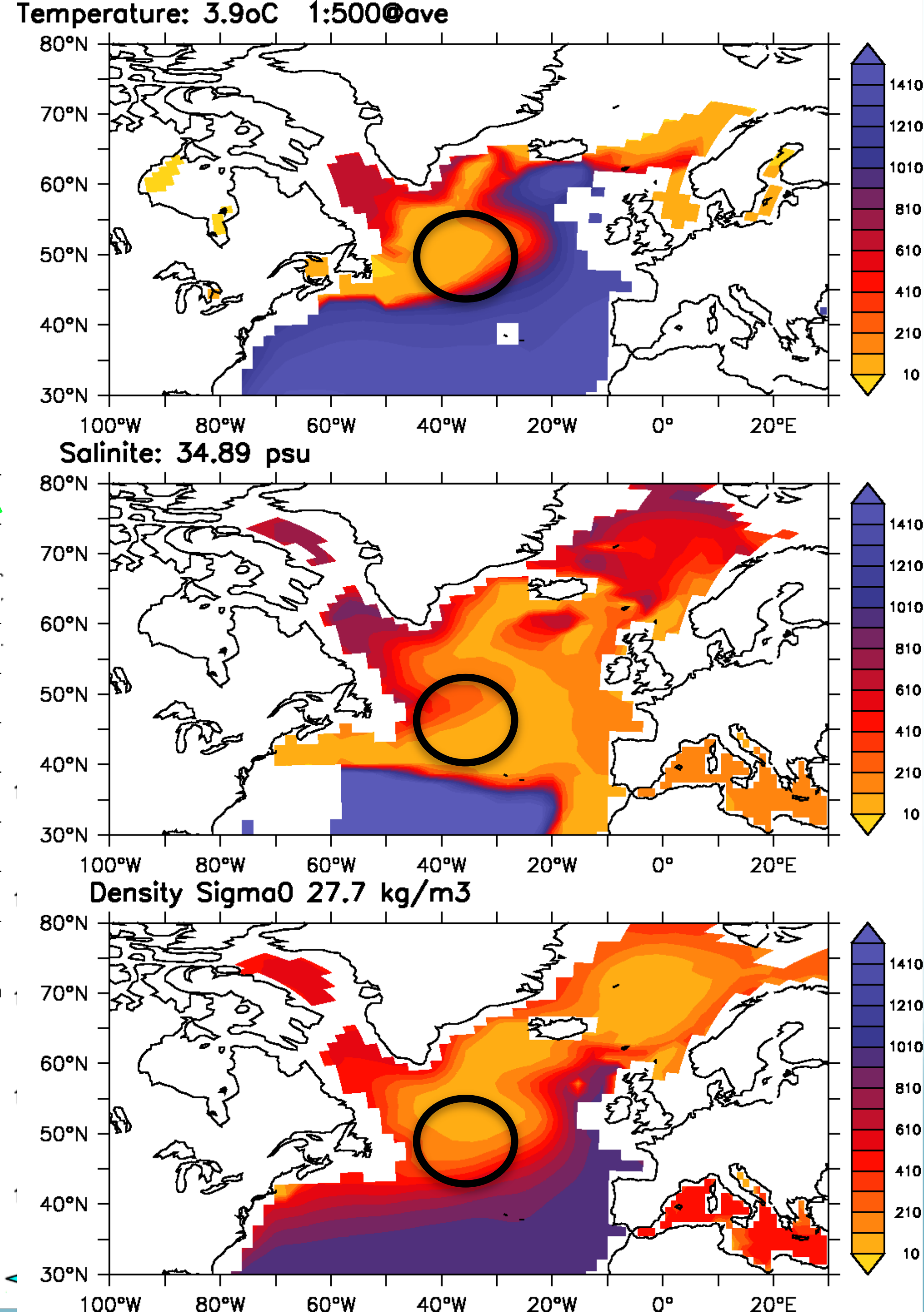
Barotropic stream function anomalies
a) HosMed2: year 1–100
b) HosMed2: year 401–500
c) HosMed1: year 1–100
d) HosMed1: year 901–1000
e) HosMed05: year 1–100
f) HosMed05: year 901–1000
g) HosMed02: year 1–100
h) HosMed02: year 901–1000
80°N
60°N
40°N
20°N
0°
90°W
70°W
50°W
30°W
10°W
-15 -14 -13 -12 -11 -10 -9 -8 -7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

Effect of the depth

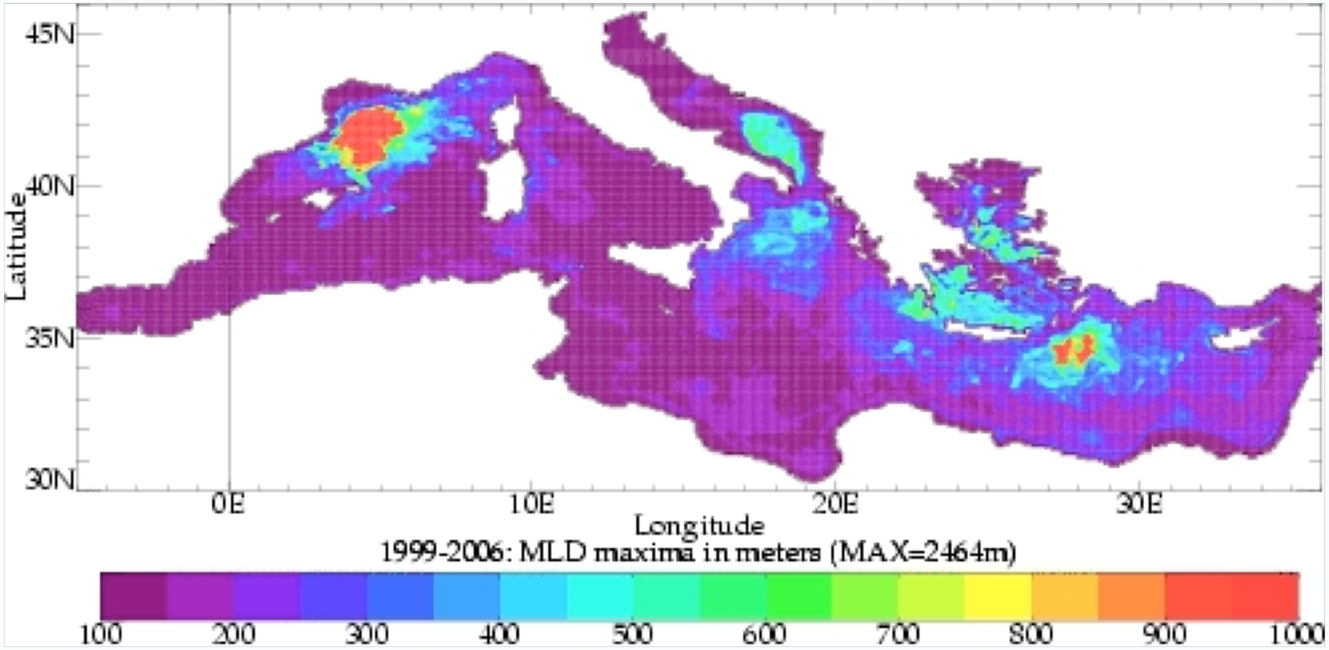
- Origin of the water mass replacing the MOW?
  [35.6, 7.5] => [34.9, 3.9]

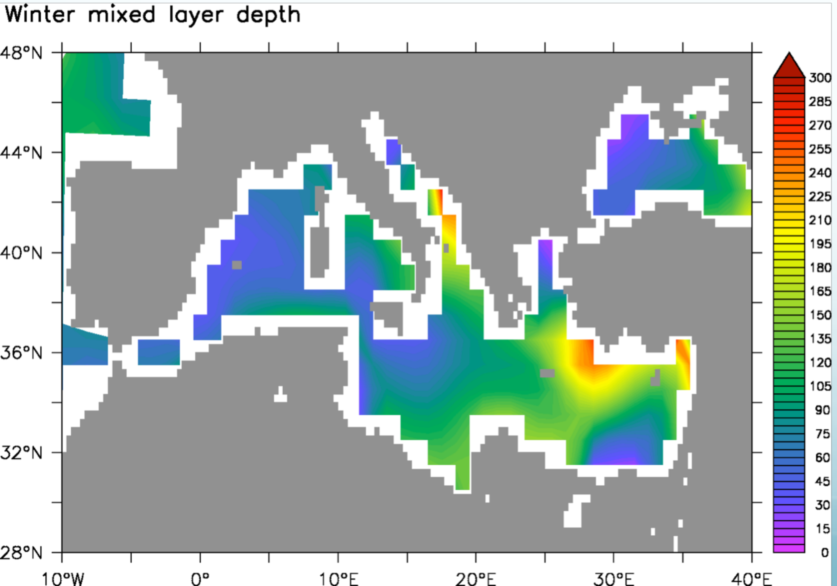


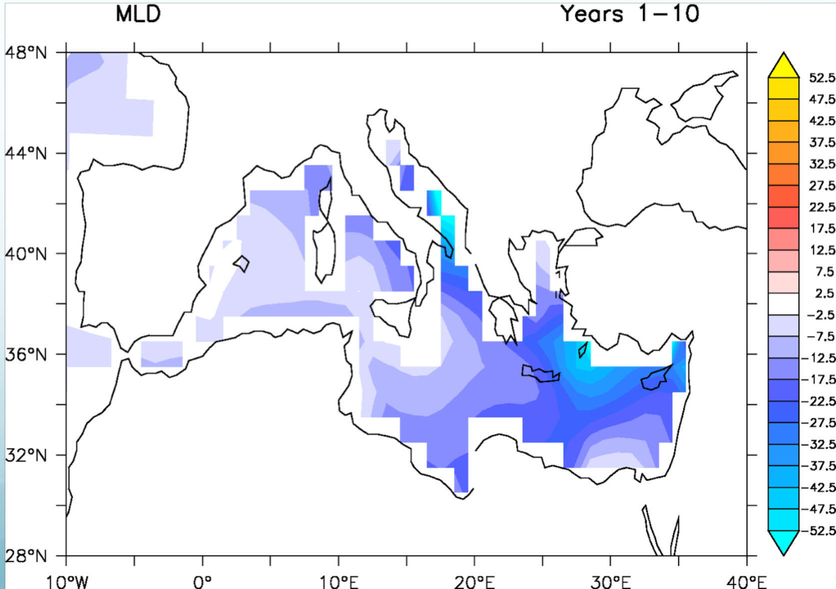
- Density changes with depth
- It has a strong impact here!



Mediterranean convection



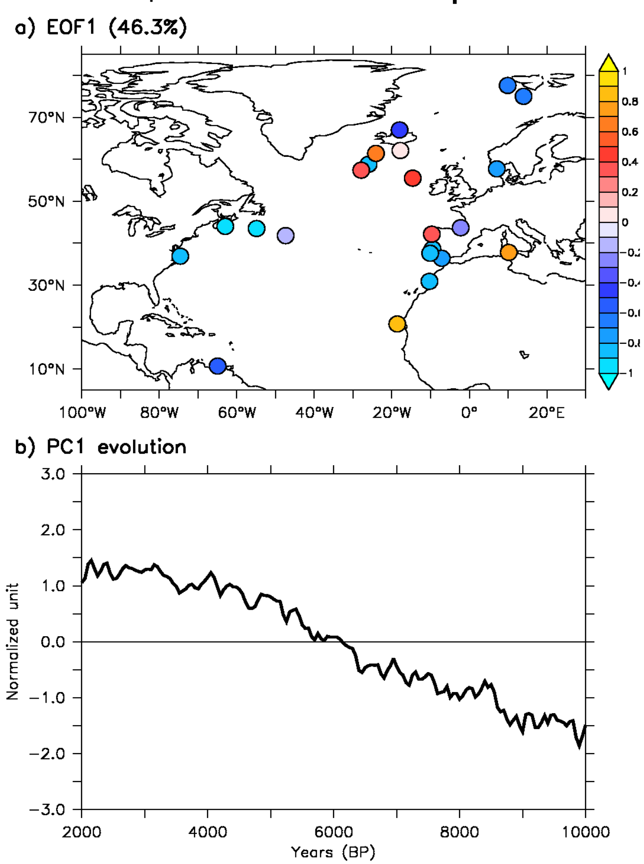




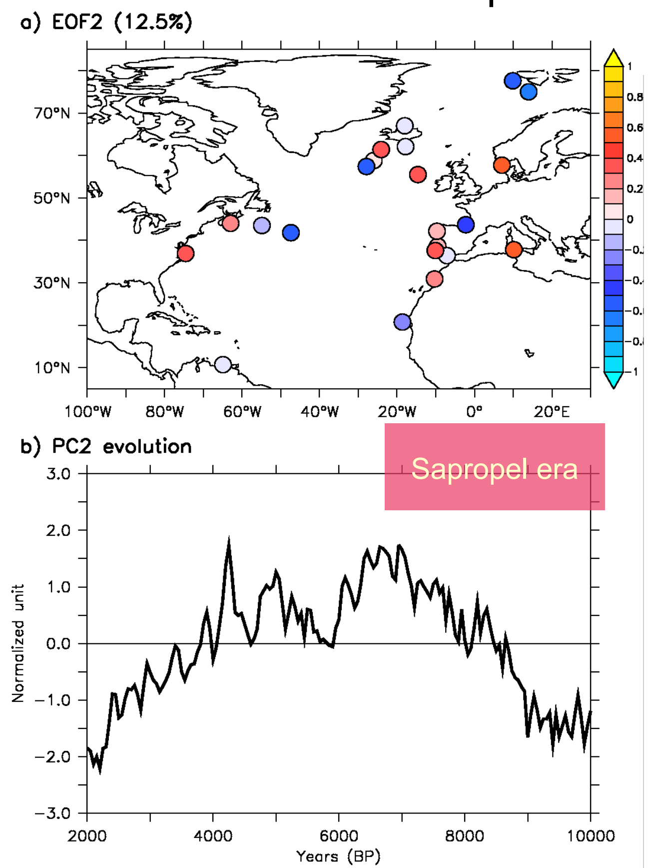
Implications

- Time and rate dependent response! i.e. the size matters a lot.
- Can it have played a role in AMOC variability over the Holocene? For rate larger or equal than 0.1 Sv, clearly not (e.g. reconstruction from Kissel et al. 2013 + on-going analysis from Yannick Mary database)

First mode from SST proxies



Second mode from SST proxies



Deep flow dynamics proxy records from Kissel et al. (2013)