Evaluating and understanding AMOC variability over the Holocene

Didier Swingedouw[1], Yannick Mary[1], Frédérique Eynaud[1], Christophe Colin[2]

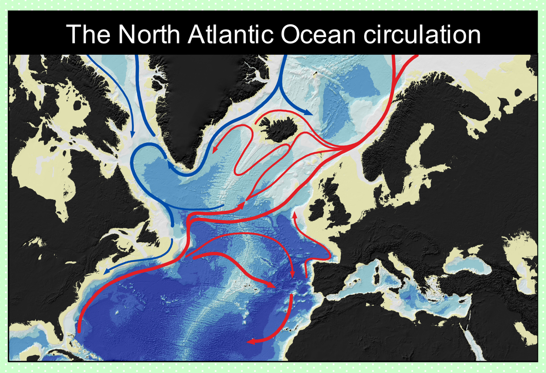
[1]EPOC-CNRS, University of Bordeaux, France [2]GEOPS-CNRS, University of Paris South, France

Mailto: didier.swingedouw@u-bordeaux1.fr Web site: http://www.epoc.u-bordeaux.fr/indiv/Didier/public_html/index.html

Background

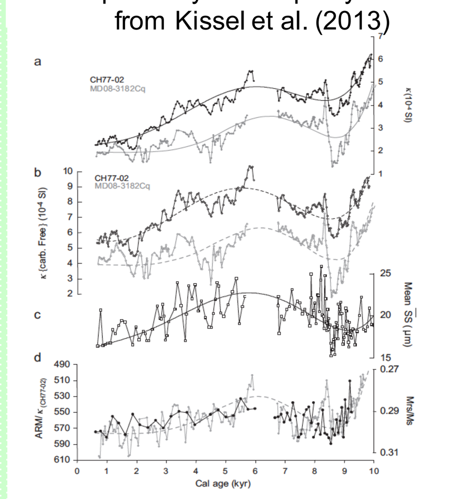
- The climate of the Holocene is closer to present-day conditions than to the ones during Ice age
- It is believed that substantial variations occur in the Atlantic Meridional Overturning Circulation (AMOC) during this time period (*e.g.* Kissel et al. 2013)
- Around 6000 kyrs BP and before, there are indications of the Sahara being partially covered by vegetation (so-called "Green Sahara")
- Marine sediment cores from the Mediterranean indicate large sapropelic deposit during early Holocene (10-6 kyr BP, *e.g.* Rohling et al. 2015)
- 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.

The North Atlantic Ocean circulation

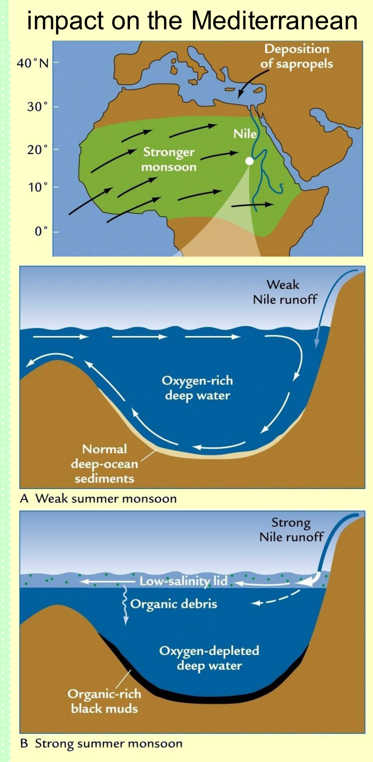


Sapropel layer in a marine core

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



The Green Sahara and its impact on the Mediterranean



Aim of this work

1. **Can we further confirm the AMOC variations using multi-proxy records of SST**
2. **Is there any link between Sapropel events in the Mediterranean and AMOC variations over the Holocene?**

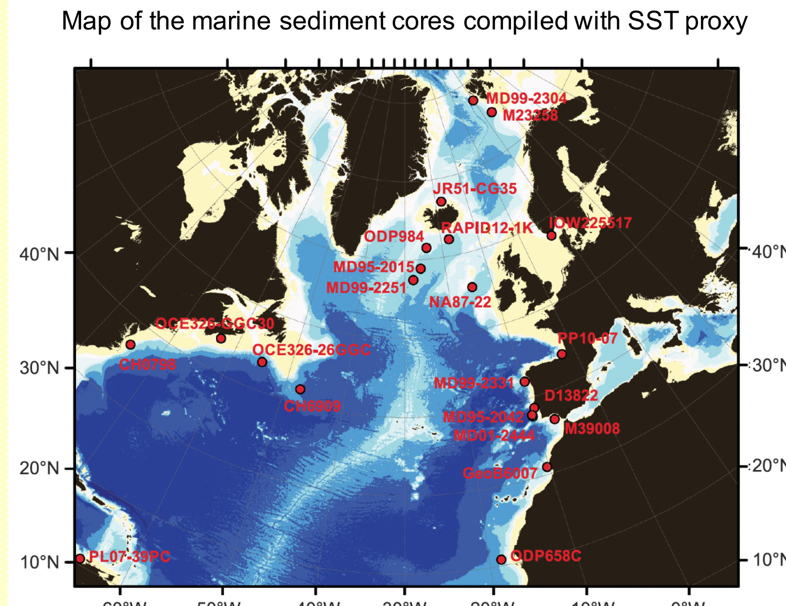
1) Holocene data in the North Atlantic

- We compiled available cores in the North Atlantic sector providing Sea Surface Temperature (SST) data with time resolution of less than 200 years on average and covering the period 2000-10,000 yrs. BP
- We found 22 cores that follow our criteria, based on different data type, but representing annual mean according to their producers

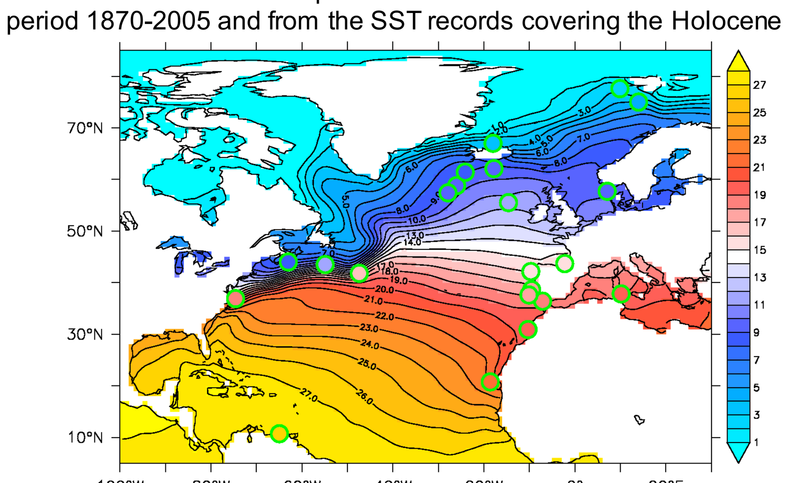
Table of the data compiled

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

Map of the marine sediment cores compiled with SST proxy



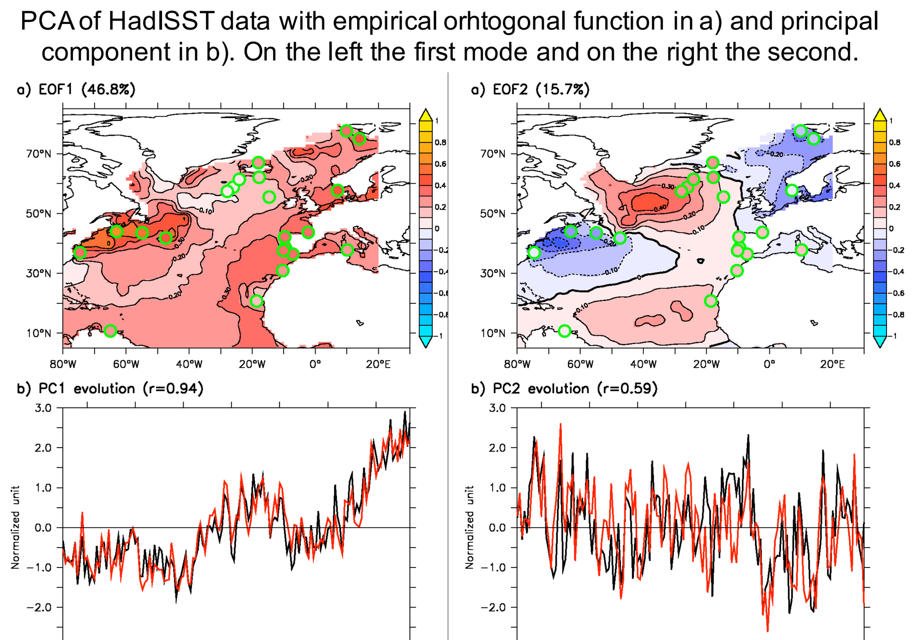
Annual sea surface temperature from HadISST data over the period 1870-2005 and from the SST records covering the Holocene



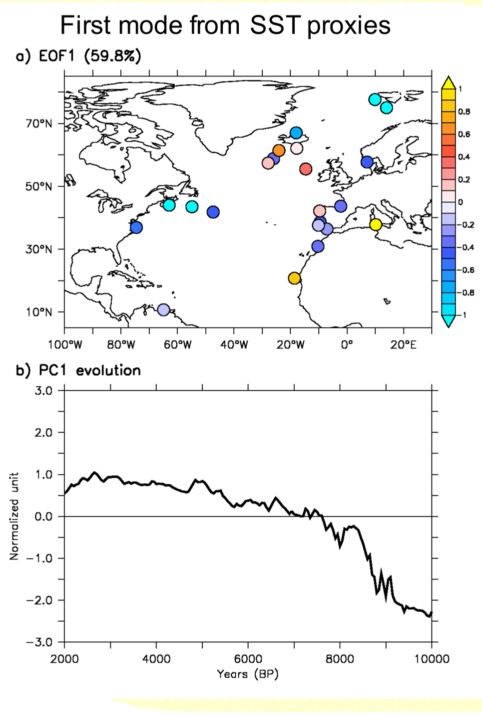
2) Pseudo proxy analyses

- We perform a Principal Component Analysis (PCA) on the whole available data points to filter out similar signals from our database
- To estimate the spatial representativeness of our database, we use a pseudo-proxy approach applied on hadISST data covering the period 1870-2010 (Rayner et al. 2003)
- We find that performing the PCA on the whole Intrumental gridded dataset or on the subsample points from our database gives very similar results for the pattern and time series of the first two modes
- The first mode resembles external forcing
- The second mode is reminiscent of the AMOC variability and of its signature on SST (*e.g.* Zhang et al. 2008)

PCA of HadISST data with empirical orhtogonal function in a) and principal component in b). On the left the first mode and on the right the second.

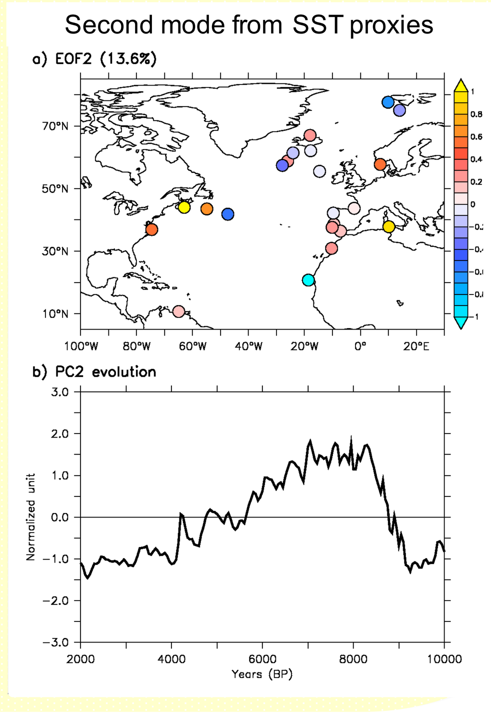


First mode from SST proxies



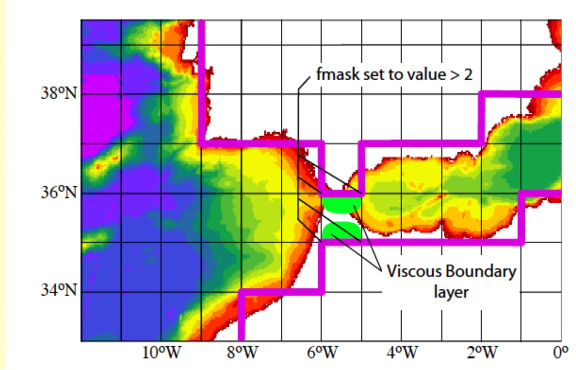
- We hypothesis that the same may well be true for our paleo-ocean SST database
- The first mode is indeed reminiscent of the insolation changes, with a general cooling of the Northern Hemisphere from 9 kyrs BP.
- The second mode resembles AMOC reconstruction from Kissel et al. (2013)
- From this result, we find an **AMOC enhancement in the Early Holocene and a weakening from around 7 kyrs BP**
- While the AMOC enhancement can be related with the decrease of ice sheet melting, what can explain the AMOC weakening later on?

Second mode from SST proxies



3) Model simulations

- We use the IPSL-CM5A-LR (Dufresne et al. 2013), a coupled AOGCM participating in last CMIP5 database.
- The ocean (NEMO) has a horizontal resolution of 1-2° and 31 vertical levels; the atmosphere (LMDz) has a horizontal resolution of around 2° (96x95) and 39 vertical levels
- The model also includes sea ice (LIM2) and land surface (ORCHIDEE) models as well as biogechemical ocean module (PISCES)
- The representation of Gibraltar Strait is made by enhancing the number of grid points there and playing with viscosity

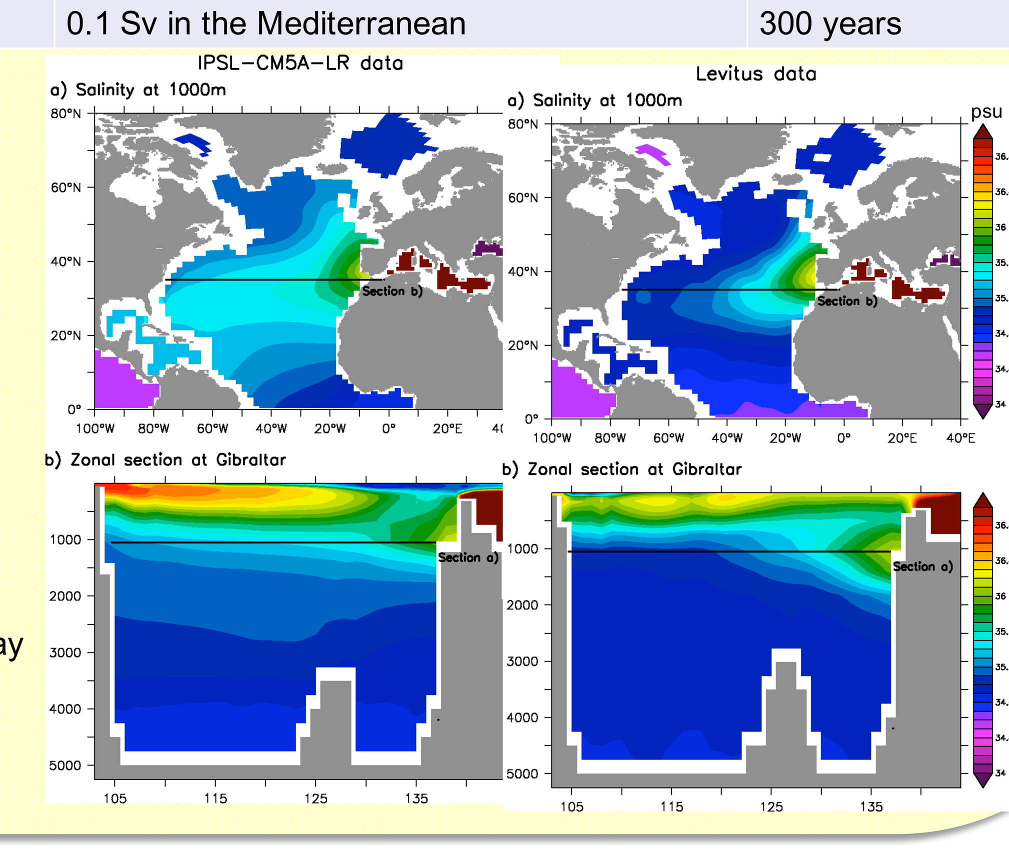


Parametrisation of the Gibraltar Strati flow in ocean model NEMO

Table summarizing the two simulations analysed

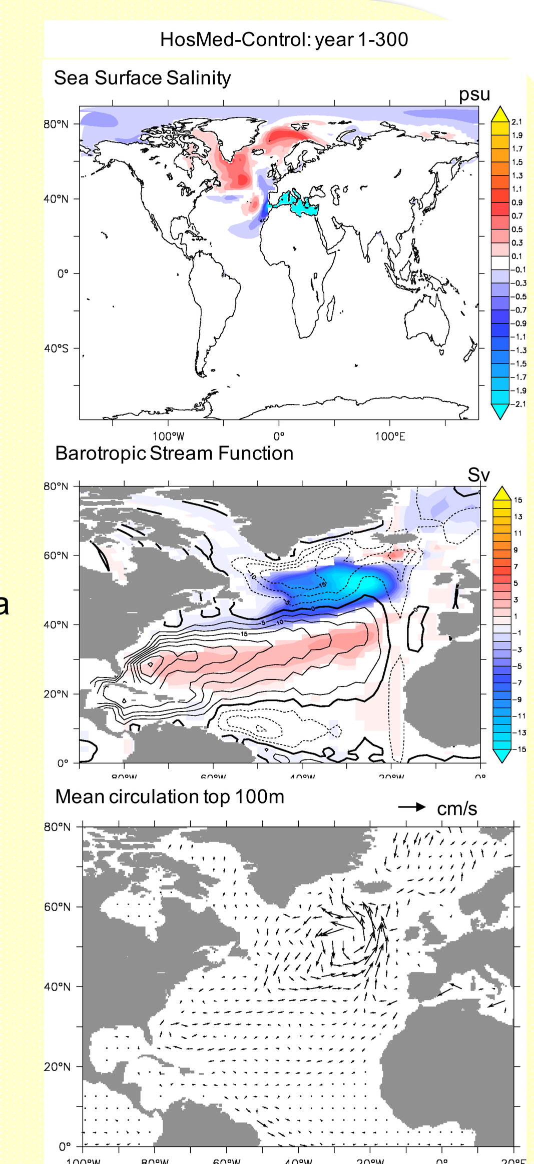
Name	Forcing	Hosing	Length
Control	Pre-industrial conditions	none	1000 years
HosMed	Pre-industrial conditions	0.1 Sv in the Mediterranean	300 years

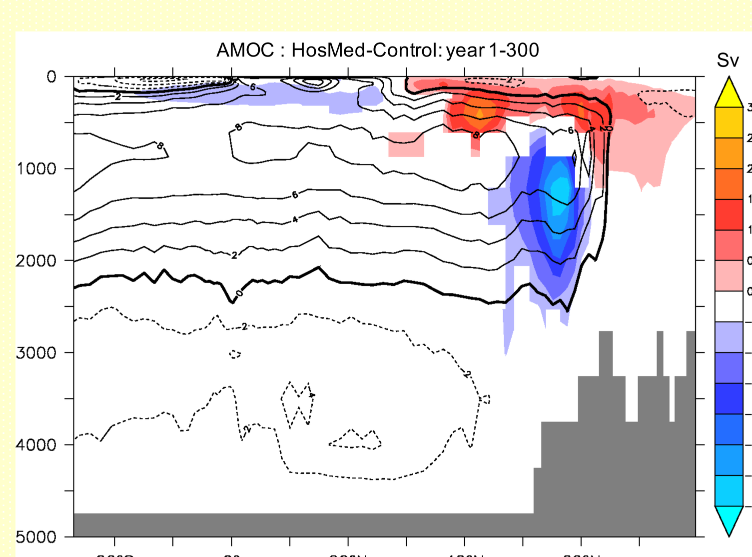
- When compared with Levitus data, the representation of the Mediterranean Outflow (MOW) has correct temperature and salinity properties and depth in the control simulation
- When leaving Lagrangian tracers (using ARIANE software) at the Gibraltar Strait, we find a simulated MOW of 2.2 Sv comparable to the 1.8 Sv obtained when doing the same within the ¼° resolution GLORYS ocean reanalysis
- The hosing of 0.1 Sv over the Mediterranean is large, but represents a Nile outflow of only around half present-day Amazon flow (present-day: Nil=3 mSv ; Amazon=200 mSv)



4) MOW impact on the AMOC

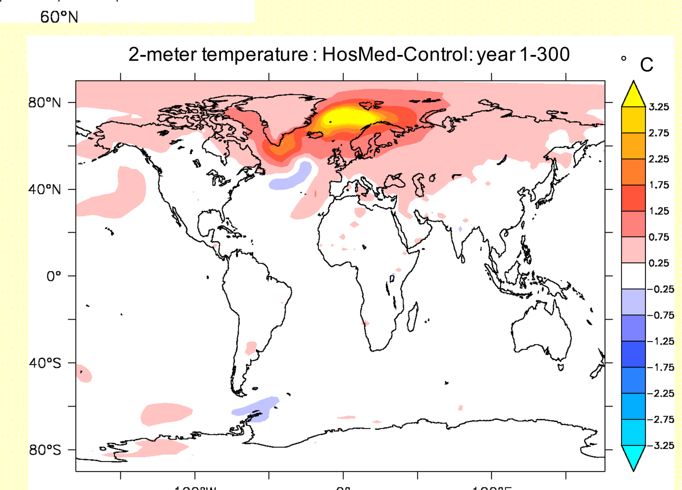
- Salinity in the Mediterranean Sea decreases a lot and no more deep water is formed, leading to a collapse of MOW production
- Part of the SSS anomaly is leaving the Mediterranean along the Canary current
- Surprisingly the SSS is increasing in the North Atlantic
- The barotropic circulation changes show an enhanced subpolar gyre (SPG)
- The surface circulation changes indicate that more water from the North Atlantic drift enters the SPG and increases the MLD





- The AMOC weakening at depth is in agreement with a collapsed MOW leading to lower zonal gradient of density in the Atlantic
- **In the upper ocean, the AMOC is enhanced**
- The heat transport is more influenced by the upper ocean variation

- As a consequence of MOW reduction and AMOC-related heat transport increase, **the North Atlantic is strongly warming**

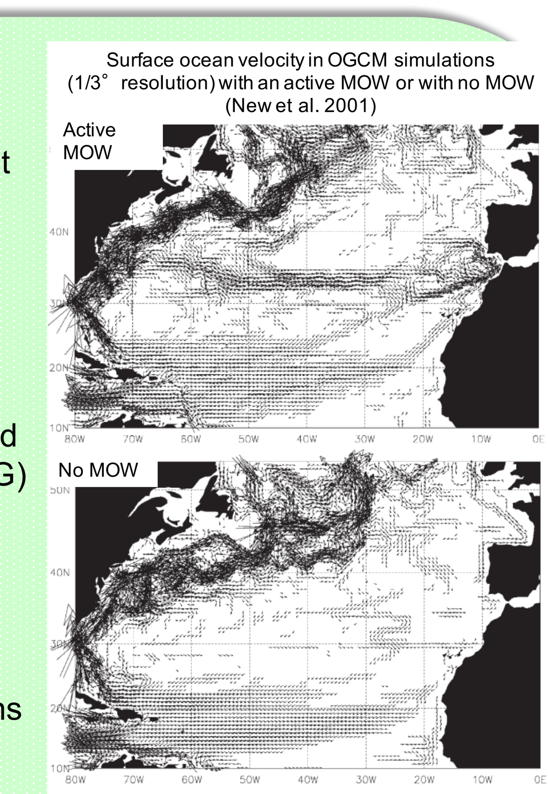


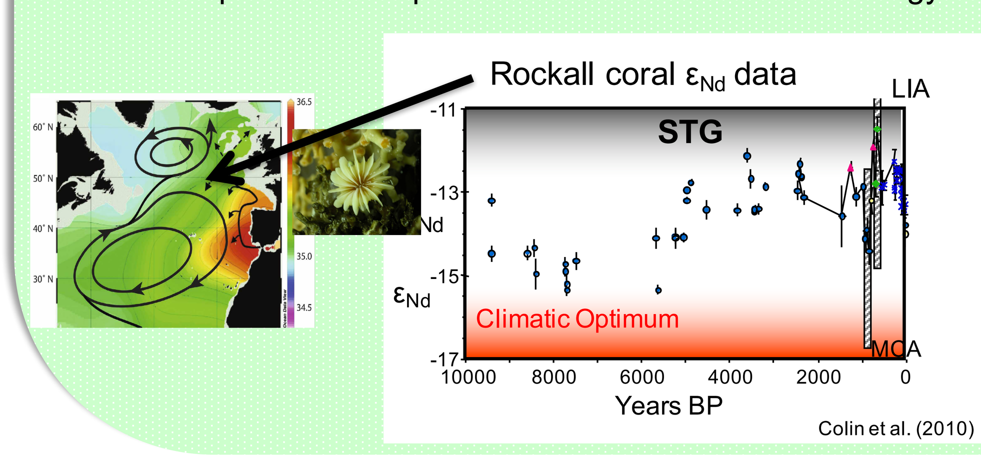
- In the Nordic Seas, the classical sea ice feedback (albedo and insulation effect) is clearly enhancing the warming

Discussions and conclusions

- A new compilation of paleo-ocean SST data and their statistical analysis suggest a maximum of AMOC around 6-7 kyrs BP
- The increase of River Nile discharge during the Green Sahara period can have contributed to enhancement of the AMOC until the Mid-Holocene
- The end of Green Sahara could have then led to a MOW resumption, thus reducing the AMOC from the mid-Holocene
- The mechanisms by which the MOW affects the AMOC are related with gyre response to MOW: when the MOW collapse, the Azore surface current is reduced and the water is following the Atlantic drift in place, so that more subtropical (STG) water is reaching the SPG, forming more deep water there
- Such a scenario of Azore current modification is coherent with higher resolution ocean model from New et al. (2001)
- The IPSL model results is not entirely consistent with Ivanovitch et al. (2013) results, indicating a potential sensitivity of this result to the model used.
- The next step of the HAMOC project will be to release ε_{Nd} tracer in the simulations and compare with deep coral data to better evaluate the gyre adjustments

Surface ocean velocity in OGCM simulations (1/3° resolution) with an active MOW or with no MOW (New et al. 2001)





References:

- Colin C et al. (2010) Neodymium isotopic composition of deep-sea corals from the NE Atlantic: implications for past hydrological changes during the Holocene. Quaternary Science Reviews 29(19-20):2509-2517
- Dufresne, J.-L. et al. Climate change projections using the IPSL-CM5 Earth System Model: from CMIP3 to CMIP5. Clim. Dyn. 40, 2123–2165 (2013).
- Ivanovic RF et al.. (2013) The parameterisation of Mediterranean–Atlantic water exchange in the Hadley Centre model HadCM3, and its effect on modelled North Atlantic climate. *Ocean Modelling*, 62, 11-16.
- Kissel C et al. (2013) Variations in the strength of the North Atlantic bottom water during Holocene, Earth Planet. Sc. Lett., 369–370, 248–259.
- New AL et al. (2001) On the role of the Azores Current in the ventilation of the North Atlantic Ocean. *Progress in Oceanography*, 48, (2-3), 163-194
- Rohling EJ et al. (2015) Mediterranean climate and oceanography, and the periodic development of anoxic events (sapropels). Earth-Sci. Rev. 143, 62–97.
- Rayner NA et al. (2003) Global analyses of sea surface temperature, sea ice, and night marine air temperature since the late nineteenth century. J Geophys Res 108(D14):4407.
- Zhang, R. (2008) Coherent surface-subsurface fingerprint of the Atlantic meridional overturning circulation. *Geophysical Research Letters*, 35, L20705,