Multidecadal variability of the MOC and its impact on climate

Rym MSADEK*, Claude Frankignoul

*GFDL/NOAA
Princeton University

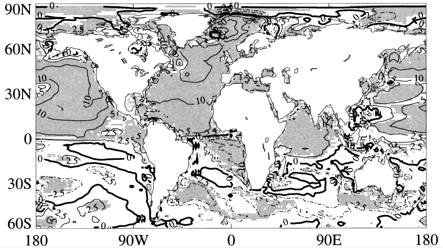
US AMOC Annual Meeting
Annapolis

May 3-5 2009

Is there an observed influence of MOC on climate ?

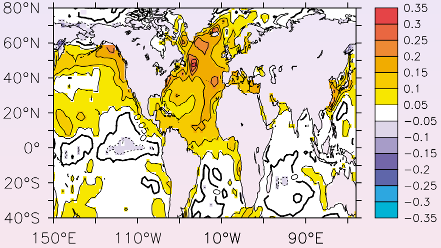
Simulated SST anomalies associated with a max of the MOC

(Vellinga and Wu 2004*)*



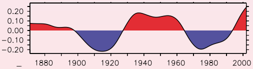
Observed SST anomalies associated with the AMO

(Sutton and Hodson 2005*)*



The AMO has been linked to various climate anomalies :

- Sahel droughts *(Rowell et al.* 1995*)*
- Northeast Brazilian rainfall *(Folland et al.* 2001*)*
- Frequency of Atl. Hurricanes *(Goldenberg et al.* 2001*)*
- Changes in the European/US climate *(Sutton and Hodson* 2005*)*



$\Rightarrow$ Are they MOC-induced impacts ?

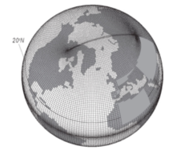
Outline

- Is there a direct influence of the MOC on the atmosphere ?
- What is the seasonality of the atmospheric response ?

The IPSL-CM4 coupled model

IPSL-CM4

- Atmosphere :**LMDZ**, horizontal resolution 3.75 °, 19 vertical levels
- Ocean :**OPA/NEMO**, resolution 2 °, 31 vertical levels
- Sea ice : **LIM**, dynamics and thermodynamics
- Land surface : **ORCHIDEE**
- Coupling : **OASIS**

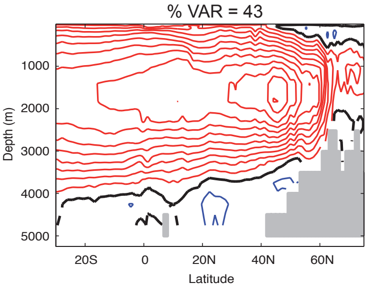


Marti et al. 2005

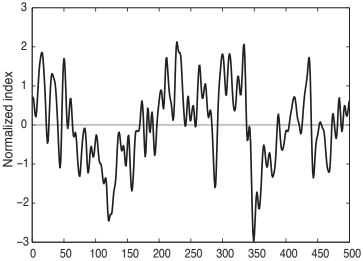
http ://mc2.ipsl.jussieu.fr

Model used for IPCC AR4
Control simulation 500 yrs
Fixed present-day CO2 level **no anthropogenic forcing**

Decadal variability of the MOC



EOF1 MOC

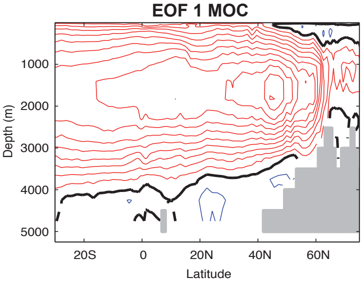


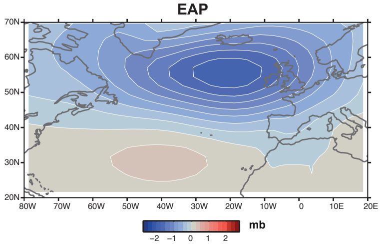
PC1 MOC

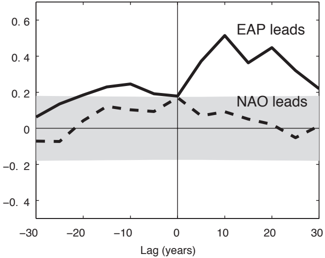
⇒ Decadal to multidecadal variability

⇒ Red spectrum but no significant peak

MOC response to atmospheric forcing







Cross-correlation
PC1 MOC/EAP
Low-frequency

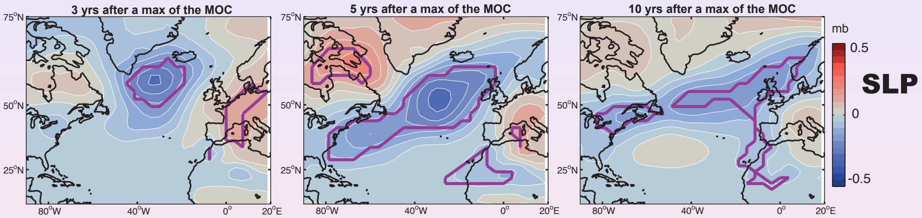
(Msadek and Frankignoul 2008*)*

Detecting an influence of the ocean on the atmosphere

Lagged cross-correlations/regressions between oceanic and atmospheric fields

- In phase : both forcings of the ocean and the atmosphere
- When the atmosphere leads : atmospheric forcing only
- **When the ocean leads : ocean forcing only**

Summer SLP anomalies when the MOC leads

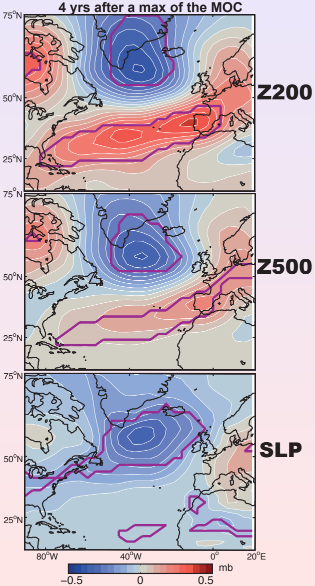


- Significant EAP-like signal in summer when the MOC leads
- Robust and persistant : t-test + MonteCarlo
- The annual response is dominated by the summer response

$\Rightarrow$ Weak positive feedback

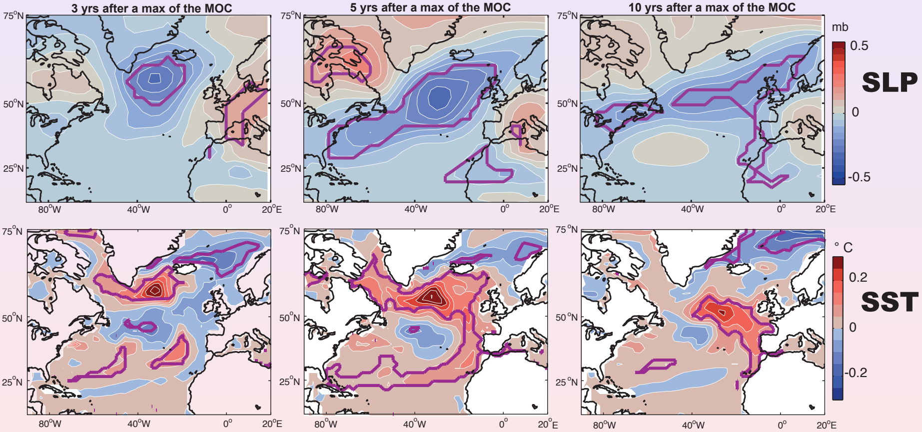
(Msadek and Frankignoul 2008*)*

Vertical structure of the summer response

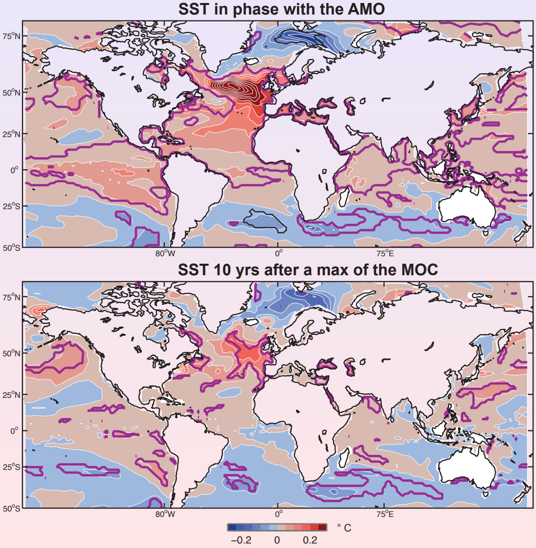


- Equivalent barotropic response in the mid and high latitudes
- Baroclinic in the tropics
- Very similar to the vertical structure of the EAP in the model

What are the SST anomalies few years after the MOC



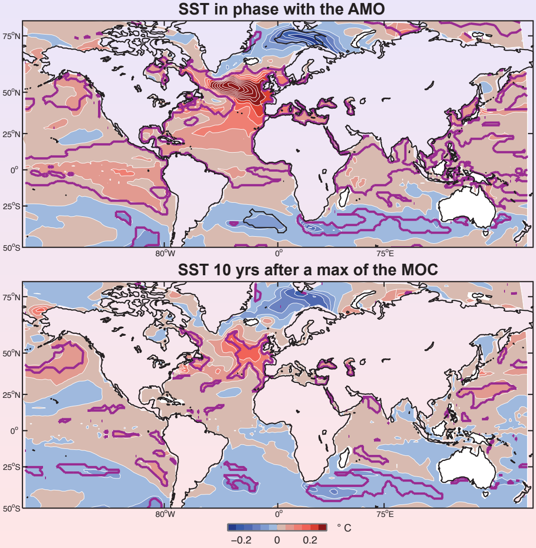
Link with the AMO

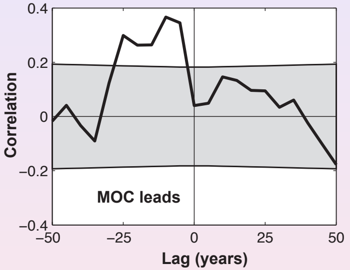


SST anomalies in phase with the model AMO index : low-passed filtered SST averaged over the North Atlantic (0°-60°N-75°W-7.5°E)

SST anomalies 10 yrs after a maximum of the MOC

Link with the AMO

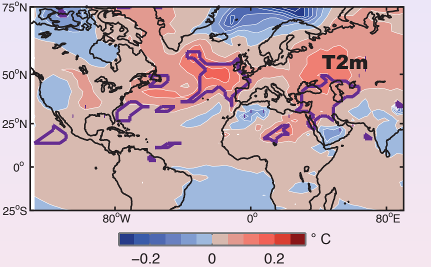


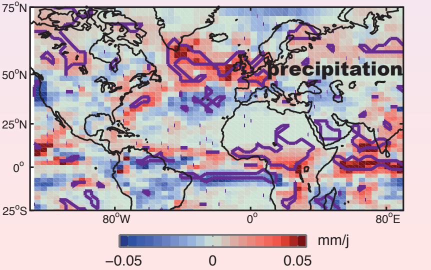


The MOC leads the AMO by 5 to 10 yrs
$\Rightarrow$ significant influence of the AMO on the atmosphere with a 5-yr lag

Climatic impacts forced by the MOC

Temperature and Precipitation anomalies 10 yrs after a max of the MOC



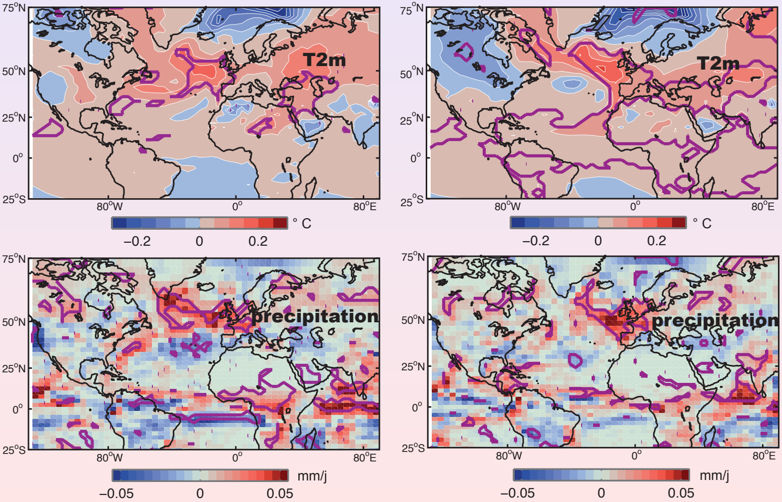


- **2-m temperature response**
  - over the ocean : quite similar to the SST
  - over land : warming of eastern US, Euradia, Sahel
    $\Rightarrow$ potential predictibility (hindcast) of about 10%, 5 to 10 yrs in advance
- **Precipitation response**
  - Increased rainfall in the subpolar gyre, the Indian ocean, central Africa
  - Northward shift of the ITCZ

Comparison with climatic impacts induced by the AMO

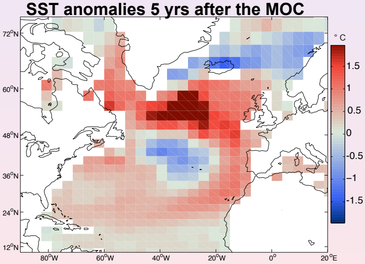
10yrs after the MOC

5yrs after the AMO



Sensitivity experiments with a simplified coupled model

Slab ocean mixed-layer model coupled to an AGCM (LMDZ) in the North Atlantic

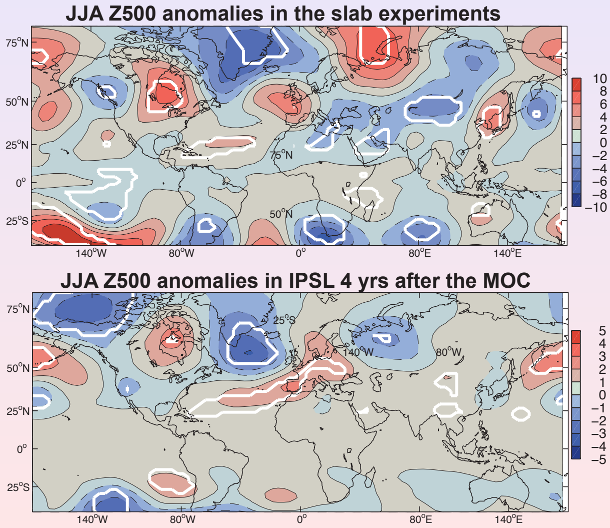


amplified to increase the signal-to-noise ratio

- 80 yr control simulation
- 80 yr with the SST anomaly added as a boundary condition

→ Anomalous minus control run gives an ensemble of 80 independant runs that are averaged to obtain the equilibrium response

Geopotential height response in summer

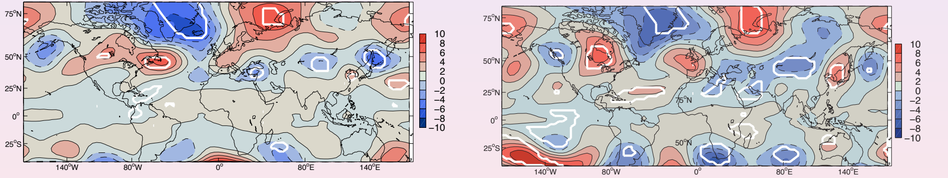


- EAP-like signal in the North Atlantic
- Global-scale anomalies
- Resembles the response identified in IPSL

Non-linearity of the summer response

Z500 anomalies in JJA

SST - SST +



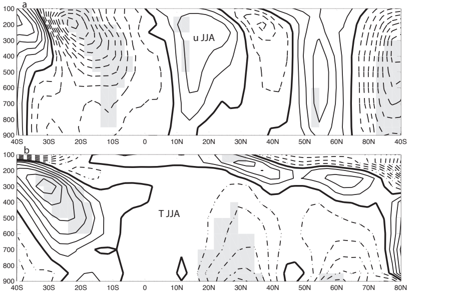
Very similar response whatever the sign of the SST forcing

$\Rightarrow$ Strong non-linearities

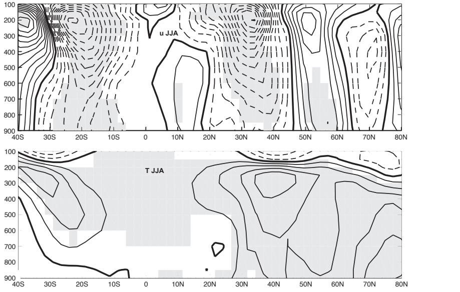
Non-linearity of the summer response

Zonal mean temperature and wind anomalies

SST -



SST +

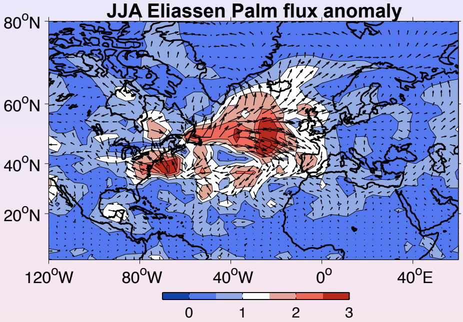


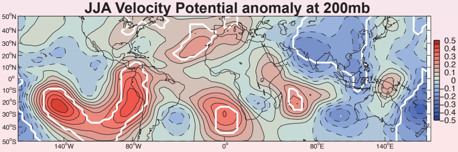
- change of sign in temperature
- but asymetrical response

⇒ Negative anomalies in the zonal wind between 30 °N et 45 °N for SST- et SST+

⇒ Eddy-mean flow interaction

Mechanisms of the summer atmospheric response





Eddy-mean flow interaction

- Increased Storm track Activity in the North Atlantic

-Anomalous divergence

$\Rightarrow$ Jet acceleration

Global scale response

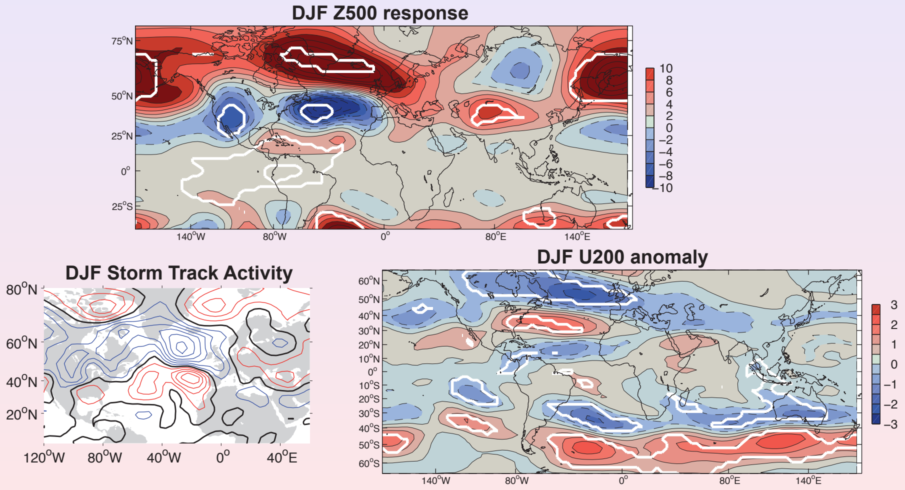
-Strengthened convection over the Asian summer monsoon region

$\Rightarrow$ North Atl./Asia teleconnection

- Rossby wave sources

$\Rightarrow$ Asia/North Atl. teleconnection ?

The winter signal



(*Msadek et al.* 2009 *in prep.*)

Summary

- The variability of the Atlantic MOC at decadal timescales is primarily driven by the EAP (poor location of the convection sites)
- Significant influence of the MOC on the atmosphere during summer through an extratropical AMO-like SST pattern.
- Weak positive feedback of the MOC on the atmosphere
- The climate impacts extend beyond the North Atlantic region and are broadly consistent with previous model studies and observations
- The summer atmospheric response is controlled by an eddy feedback mechanism by perturbing the North Atlantic storm tracks
- The MOC has also a significant impact on the atmosphere in winter : NAO-like response
- Highly non linear response $\Rightarrow$ difficult to detect in coupled simulations using linear methods (regressions etc..)