On the wintertime atmospheric response to the AMOC variability

Claude Frankignoul and Guillaume Gastineau

LOCEAN, Université Pierre et Marie Curie, Paris

The research leading to these results has received funding from NOAA Climate Program Office (NA10OAR4310202 and NA13OAR4310139), NSF EaSM2 (OCE 124289), the European Union 7th Framework Programme (FP7 2007-2013), under grant agreement n.308299 NACLIM, IPSL, and the Agence Nationale de la Recherche.

Does the AMOC influence the atmospheric circulation in climate models?

Can observations determine if a climate model response is realistic?

Does the AMOC influence the atmospheric circulation in climate models?

How to estimate the response?

AMOC variability is in part driven by the atmosphere

To separate cause and effect, use relation between atmospheric and **previous** AMOC anomalies at time lag > atmospheric persistence and < oceanic persistence

(trend and ENSO influence should be removed)

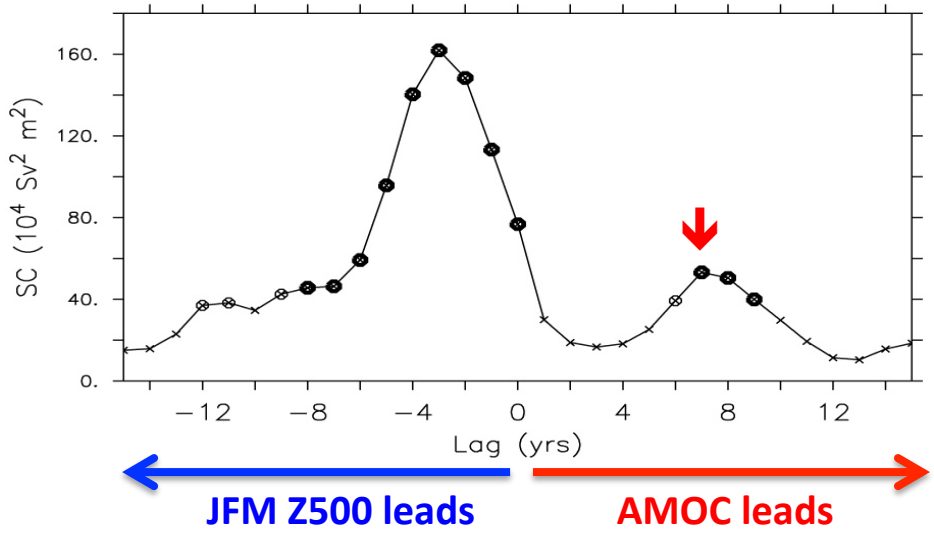
Our method

Lag maximum covariance analysis between the yearly AMOC and seasonal 500 hPa geopotential height (Z500) or SLP anomalies

Focus on the cold season

Lag MCA between yearly AMOC and winter Z500 in the North Atlantic in CCSM4

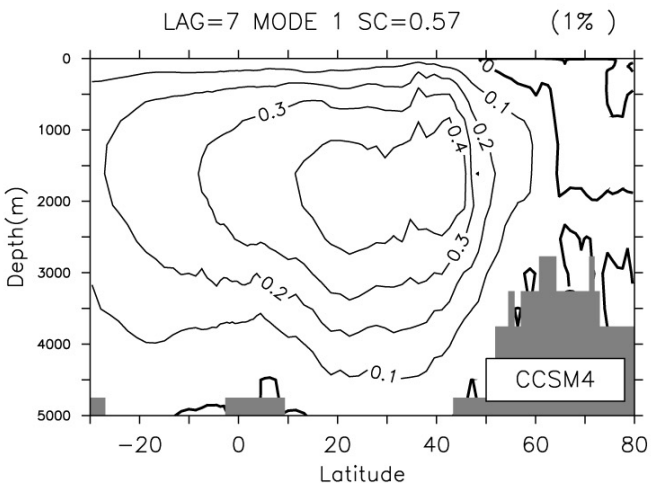
- ¼-½-¼ smoothing applied to 3 consecutive years, tropical SST impact removed

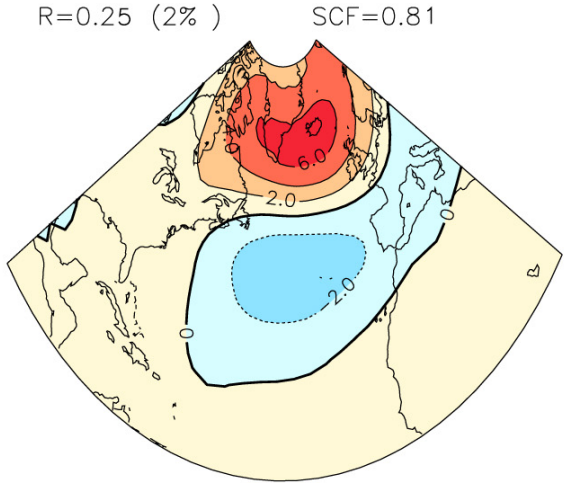


Leading MCA mode between ***AMOC*** and ***JFM Z500***

Filled circle: significant at 5%
Open circle: significant at 10%

AMOC influences JFM Z500 when AMOC leads by 6-9 yr





Small equivalent barotropic negative NAO-like response

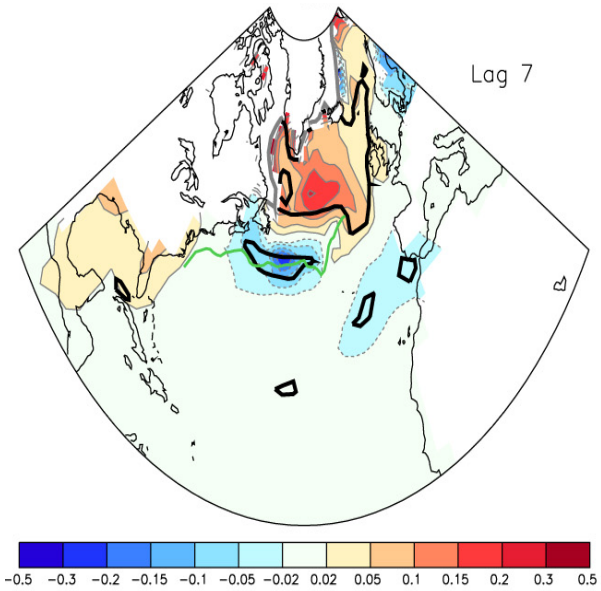
Resembles AMOC EOF1

Frankignoul, Gastineau, and Kwon 2015

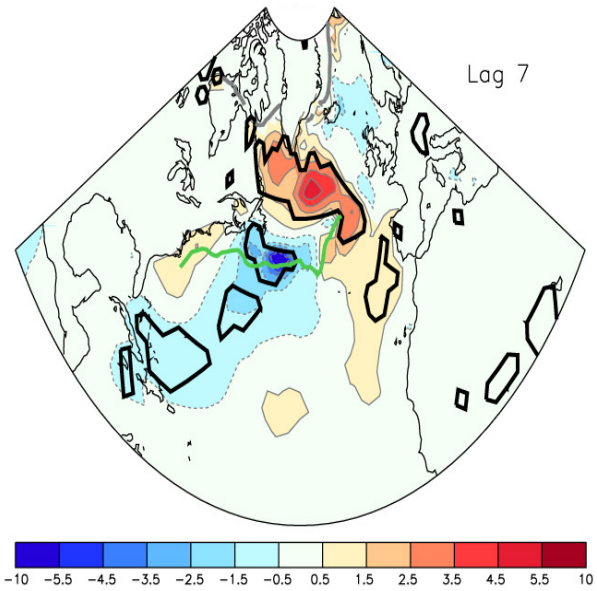
How does the AMOC influence the atmosphere?

Lag regressions on the lag 7 MCA AMOC time series (anomalies associated with JFM Z500 response)

SST (in K)



Surface heat flux (Wm^{-2})

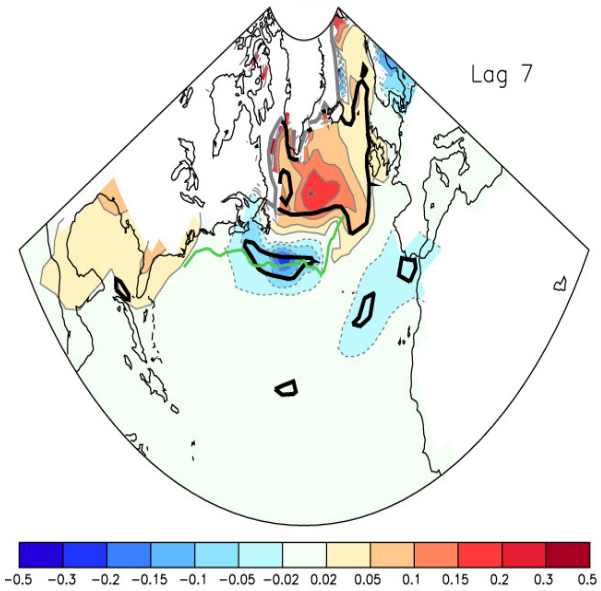


Green curves: mean GS-NAC position

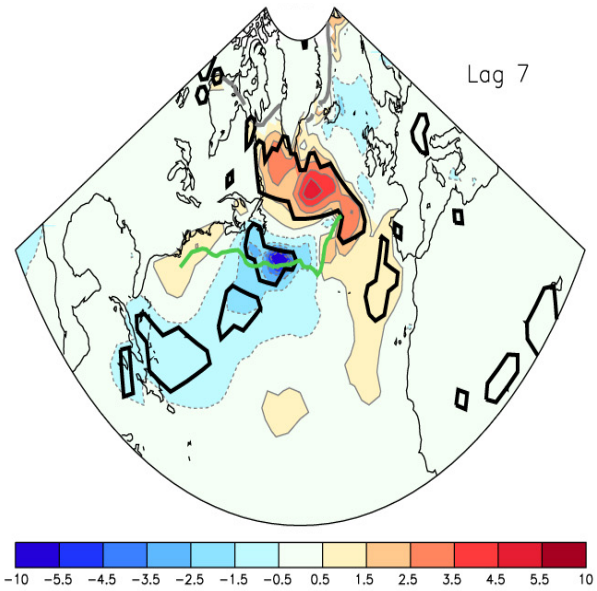
How does the AMOC influence the atmosphere?

Lag regressions on the lag 7 MCA AMOC time series (anomalies associated with JFM Z500 response)

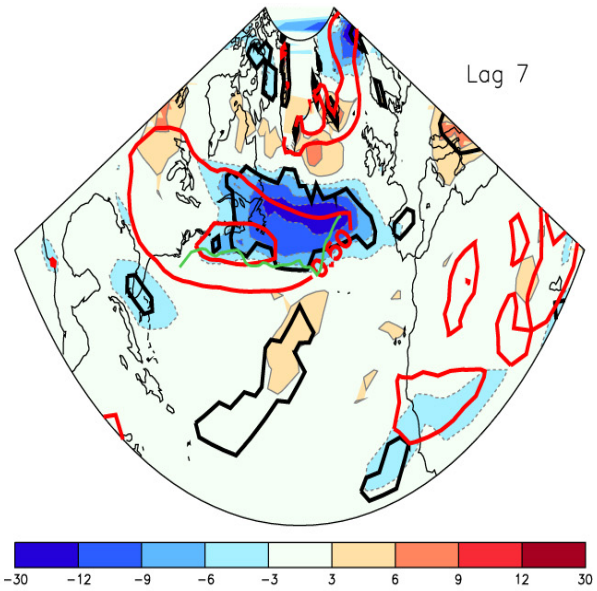
SST (in K)



Surface heat flux (Wm^{-2})



Eady growth rate at 850 hPa (10^{-2} day^{-1})



Green curves: mean GS-NAC position

Red contours: climatology

Meridional SST dipole (reduced dSSTdy) → **Damped by surface heat flux** → **Southward shift of storm track and NAO-**

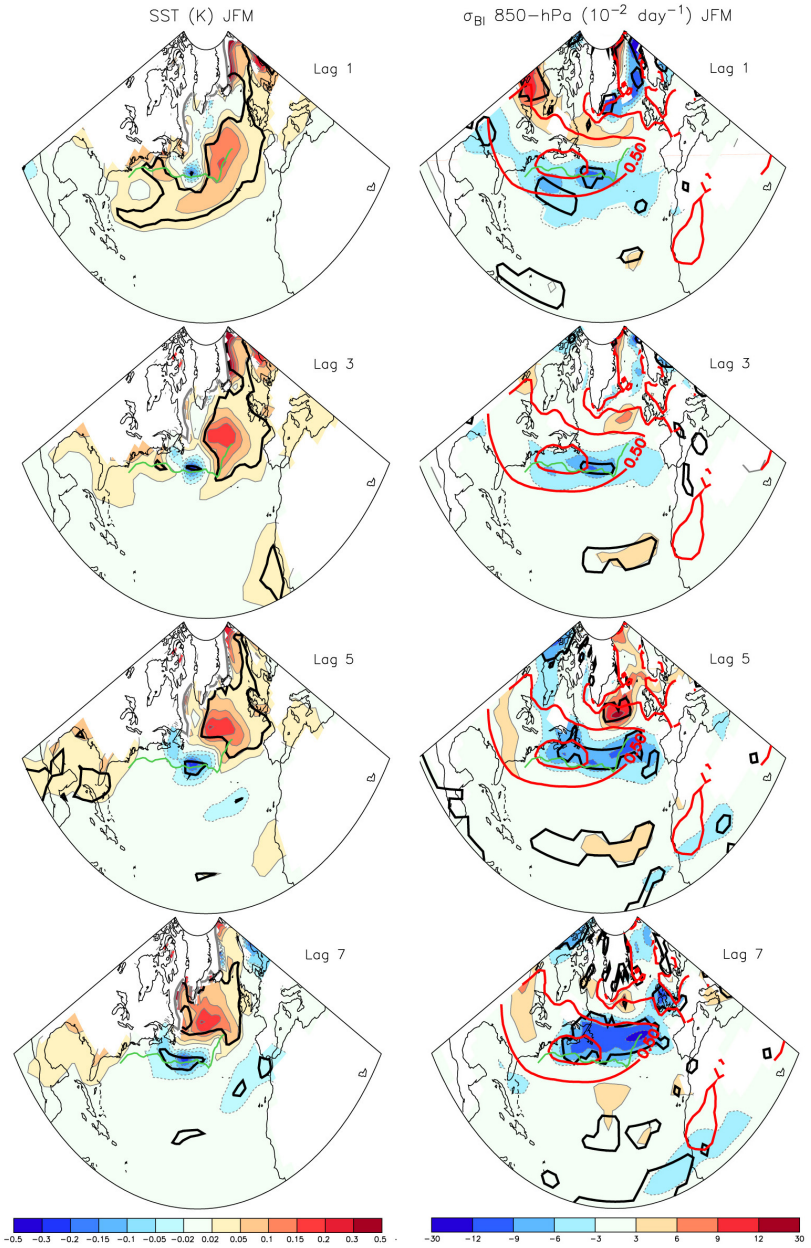
Why the atmospheric response only becomes significant near lag 7

Initial zonal SST dipole

Increasing warming along NAC and in subpolar gyre

Increasing southward shift of GS

AMOC leads meridional SST dipole by 6 to 9 yr



Lag regression of SST and baroclinicity on AMOC MCA time series

Black contour 5% significant

GS/NAC in green

Climatology in red

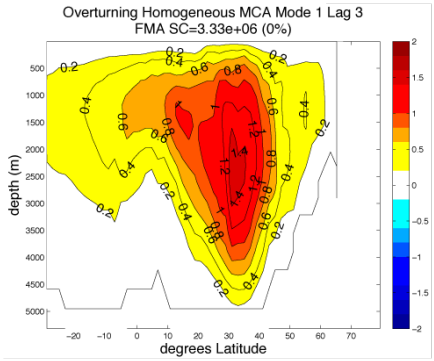
Mean and anomalous advection control the evolution of the AMOC SST footprint

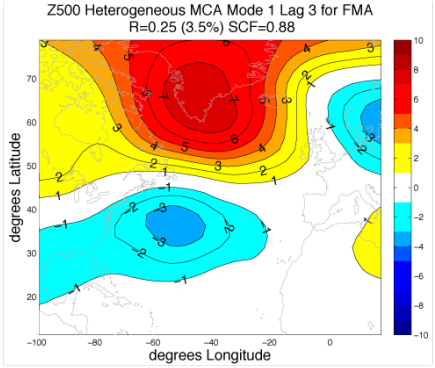
Frankignoul, Gastineau, and Kwon 2015

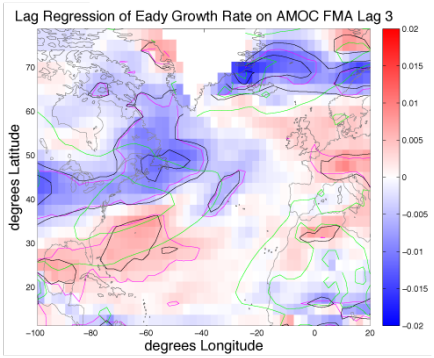
AMOC influence in the cold season in other climate models

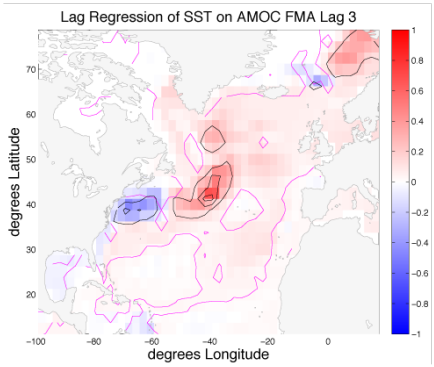
First MCA mode in **FLOR**, AMOC leads Z500 in FMA by 3 years

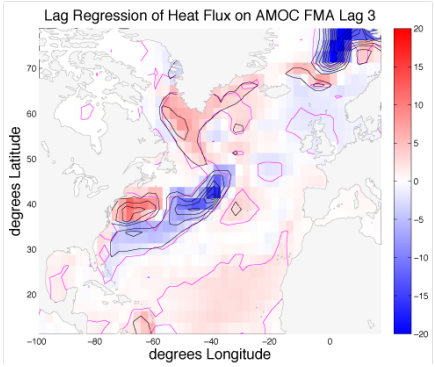
(atmosphere 50 km, ocean 100 km)

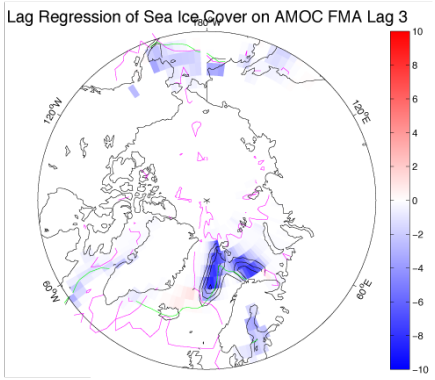












AMOC intensification leads a negative NAO in late winter (shifted south) in FLOR

Strongest SST fingerprint is Dipole along GS/NAC

Negative heat flux feedback (HF positive downward)

SIC retreat in Barents-Kara Seas Important role?

Year 1001-1500, ¼ ½ ¼ smoothing, cause and effect separated at lag ≥ 3 yr

Similar results in MAM

Work in progress

AMOC influence in the cold season in other climate models

A **negative NAO also** lags AMOC intensification in 6 low-resolution climate models (**IPSL-CM4**, **IPSL-CM5-LR**, **HadCM3**, **BCM**, **KCM**, **MPI-OM**)

A **positive NAO** is driven by the AMOC in **CCSM3** and **IPSL-CM5-MR**

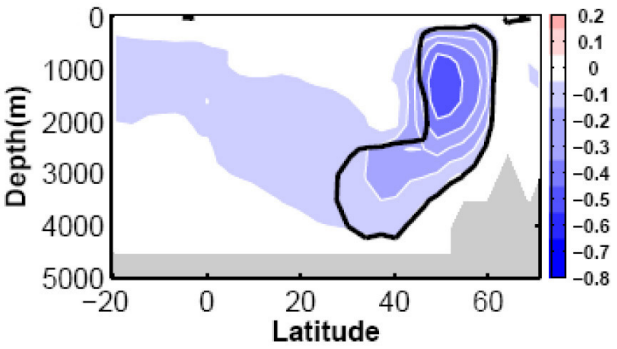
IPSL-CM5-MR Strong NAO+ response to northern part of the AMOC (2nd EOF)

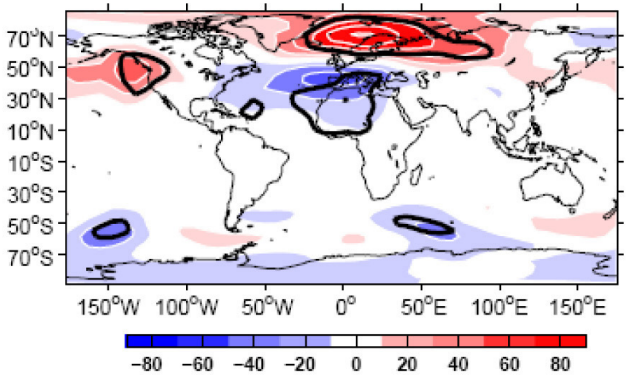
2.5° x 1.25°, 39 levels, 2° ocean

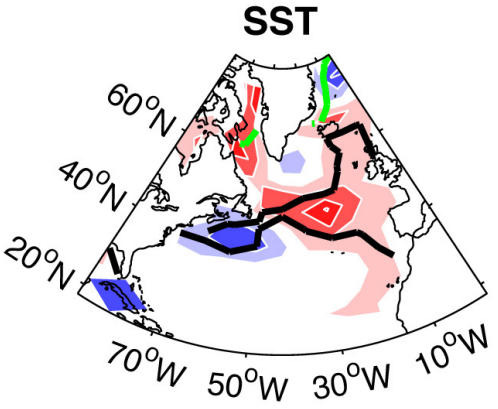
20-yr peak

Positive feedback on AMOC

SST footprint differs from the AMO







AMOC weakening

drives NAO-

E-W SST dipole

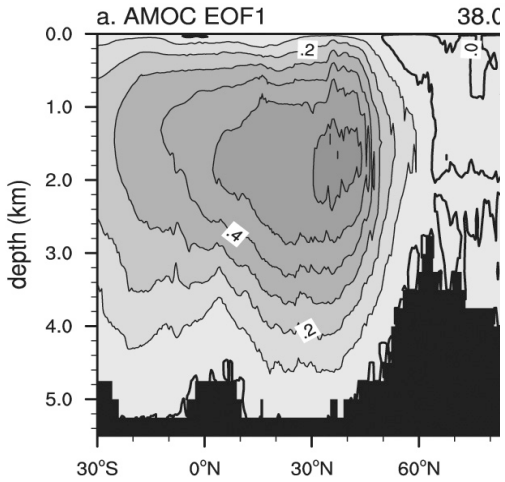
Wen, Frankignoul, and Gastineau, 2016

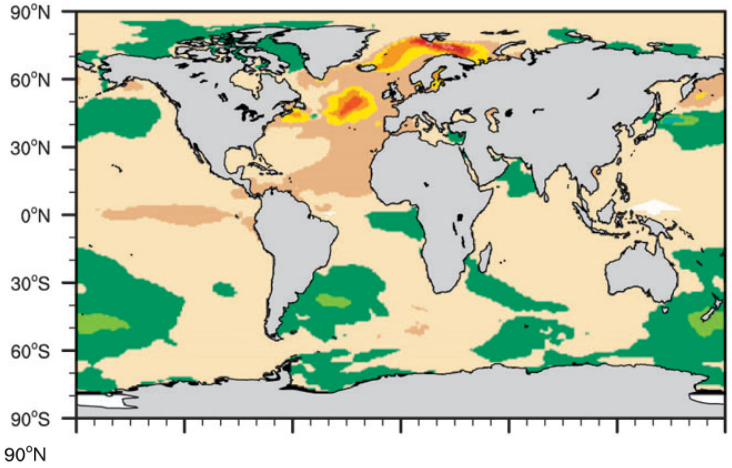
Can we compare the cold season response to the AMOC to observations?

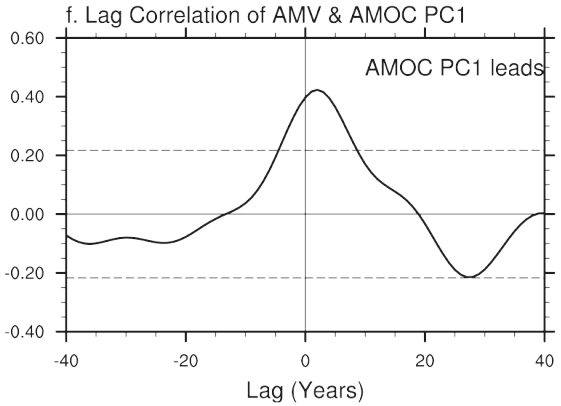
Climate model studies suggest that the AMOC largely contribute to the **Atlantic Multidecadal Oscillation** (AMO, low-pass mean SST in North Atlantic)

CCSM4

Danabasoglu et al. (2012)







AMOC EOF1 (38.0%) AMO (15-yr low-passed) Correlation

AGCM studies suggest that the AMO drives a negative NAO

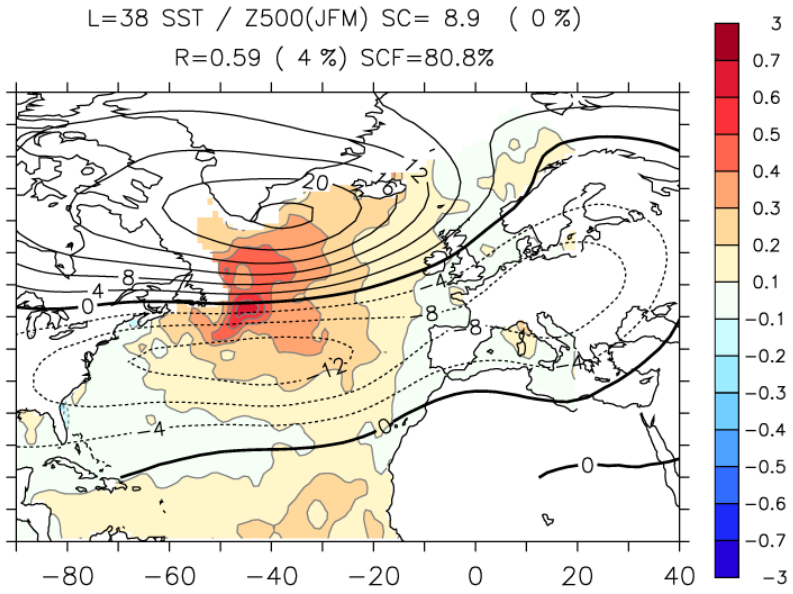
(Peings and Magnusdottir 2014; Omrani et al. 2014)

Observations also suggest a NAO- response

(Gastineau and Frankignoul 2015)

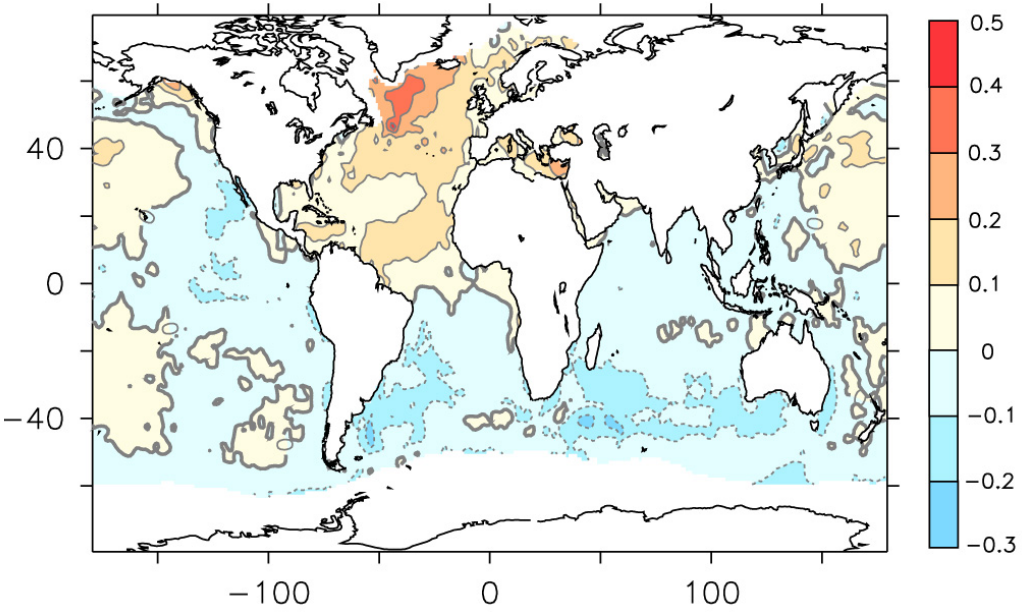
Response to North Atlantic SST anomalies at low frequency

NOAA-CIRES 20th Century Reanalysis, 1930-2010
(Weak binomial smoothing)

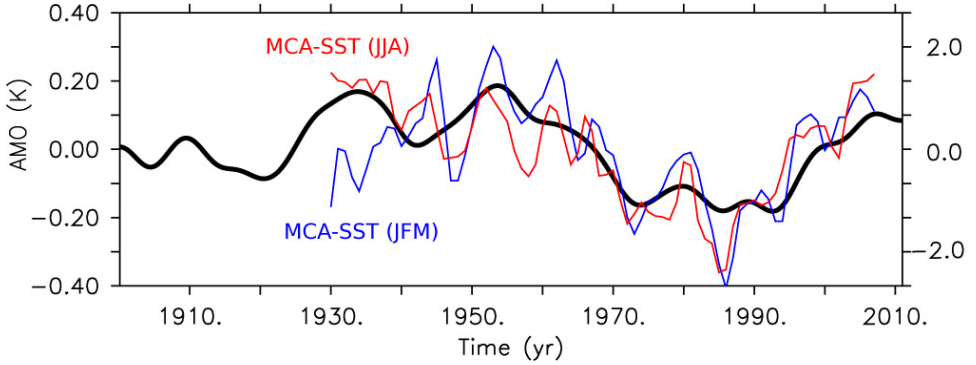


SST leads winter Z500 by 38 months
(cause and effect separated)

AMO pattern (positive phase) 10-yr low-pass filter



Times series



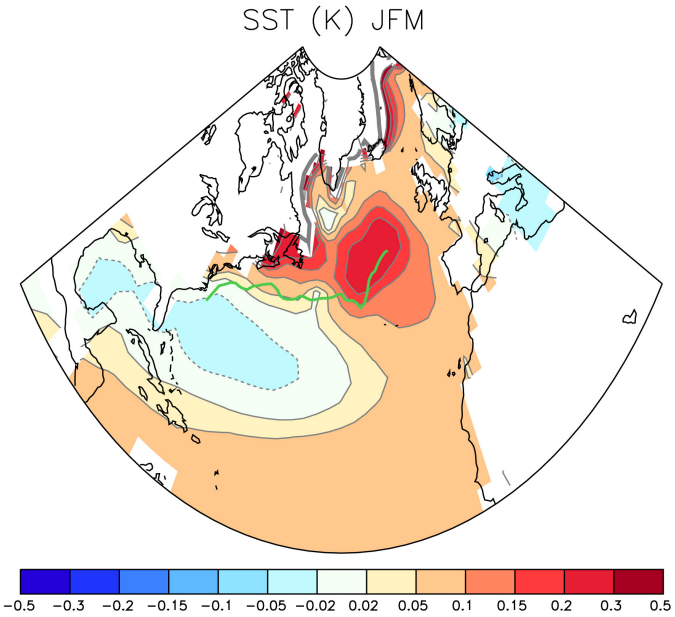
The AMO drives a negative NAO in winter

An AMO-like pattern also influences the lower troposphere in summer (as in Sutton and Hodson 2005)

Gastineau and Frankignoul 2015

Can we compare the cold season response to the AMOC to observations?

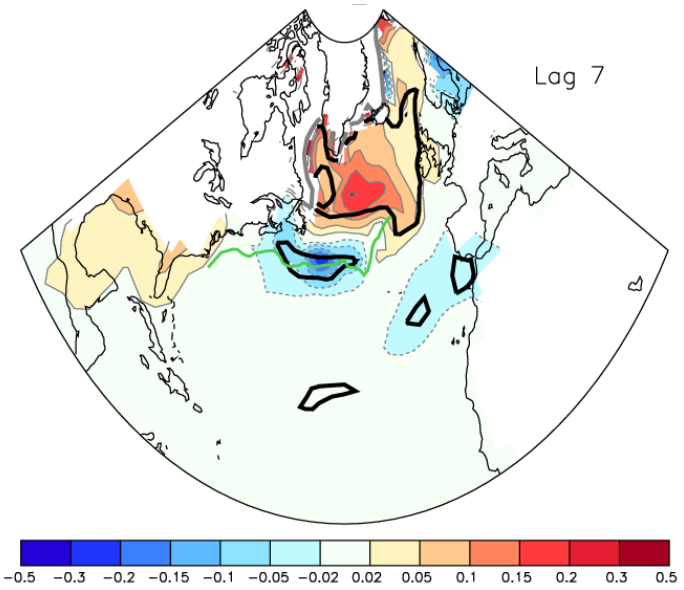
CCSM4



Winter AMO pattern
(regression on 10-yr low-passed SST)

AMO different from the AMOC SST footprint

No cooling along the Gulf Stream, weaker, southward shifted meridional SST gradient, warming in tropical North Atlantic



We could not find an cold season response to the AMO

Frankignoul, Gastineau, and Kwon 2015

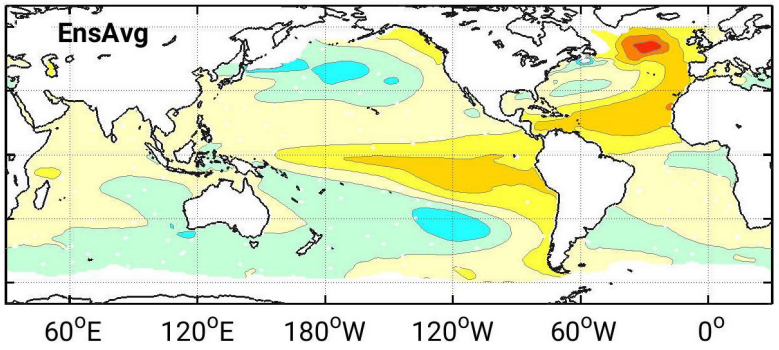
Can we compare the cold season response to the AMOC to observations?

Clément et al. (2015) found the the AMO is driven by local stochastic atmospheric (NAO) forcing, which also drives the AMOC variability

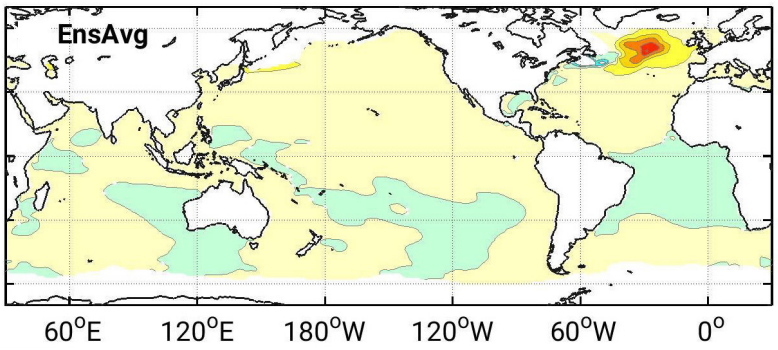
Comparing AMO and AMOC SST fingerprint in two Large Ensembles

CESM1-Large Ensemble (40 members, historical simulations 1940-2010)

AMO (10-yr low pass)

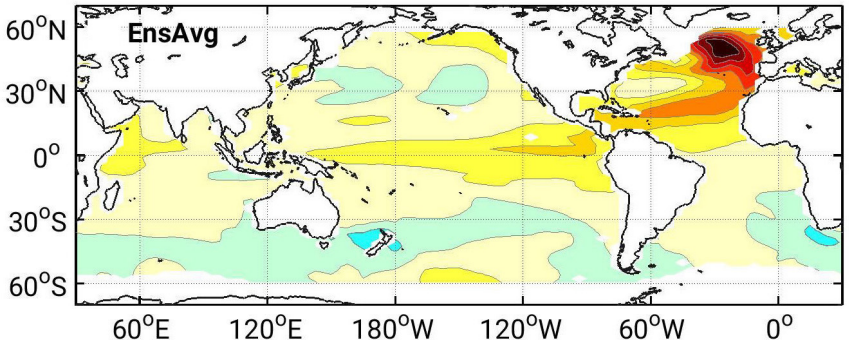


AMOC SST fingerprint (lagging AMOC by 2 yr)

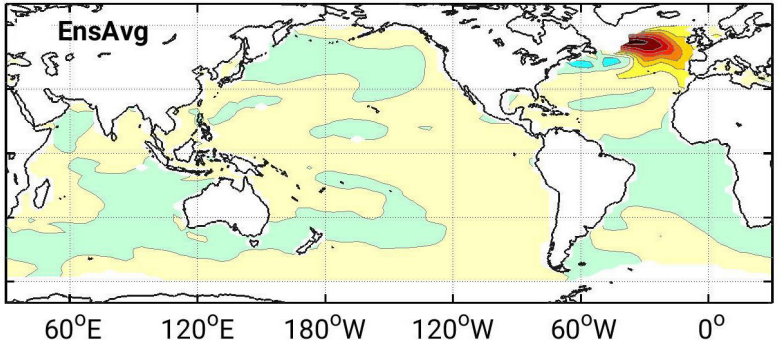


IPSL-CM5-LR Large Ensemble (30 members, historical simulations 1940-2010)

AMO (10-yr low pass)



AMOC SST fingerprint (lagging AMOC by 9 yr)



The AMO seems largely driven by the AMOC in the subpolar gyre, but by local atmospheric forcing and ENSO teleconnections in subtropical/tropical North Atlantic

(Frankignoul, Gastineau and Kwon, submitted)

Conclusions

- In many climate models, an AMOC intensification drives a negative NAO in winter
- Observations and AGCM studies suggest that the AMO drives a negative NAO
- **Can this be used for model validation?**

Conclusions

- In many climate models, an AMOC intensification drives a negative NAO in winter
- Observations and AGCM studies suggest that the AMO drives a negative NAO
- **Can this be used for model validation?**
- What is the link between AMOC and AMO?
- Does the AMO impact mostly arise from subpolar SST forcing
  or from tropical forcing *(Ruprich-Robert et al 2017)*?
- What are the mechanisms of the AMO and AMOC influences in winter?

  By shifting atmospheric baroclinicity (Peings and Magnusdottir 2014)?
  Via troposphere/stratosphere coupling (Omrani et al. 2014)?
  Role of sea ice cover variations

- Dedicated AGCM and climate model experiments must be undertaken