A centennial-scale Arctic - North Atlantic recharge oscillator in a coupled climate model

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Outline

Introduction

AMOC characterization in CNRM-CM6-1

AMOC - thermal wind relation

Drivers of AMOC variability in CNRM-CM6

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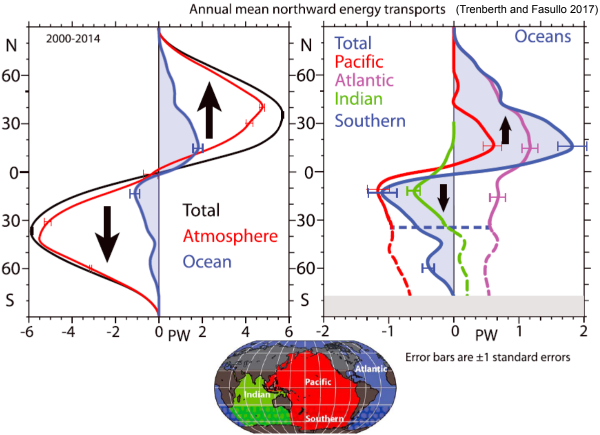
A mostly overturning MHT in the Atlantic Ocean



- Atlantic ocean stands out with MHT exclusively northward : AMOC-related

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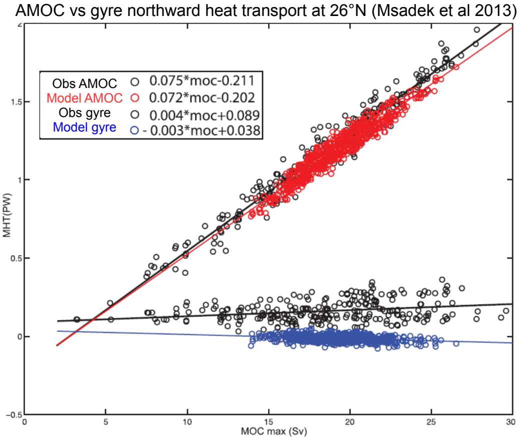
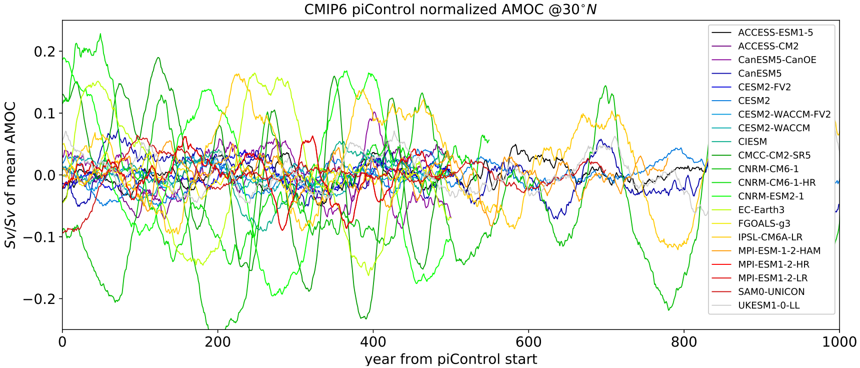


- At 26.5° N, over 90% of the MHT is AMOC-driven

The AMOC low-frequency variability in climate models

- Many AMOC low-frequency spectral peaks documented in climate models over the past 20 years. However, "dominant timescales vary markedly between models" and "there is currently no consensus on the mechanisms responsible for low-frequency AMOC variability" (Buckley and Marshall 2016).
- A widely documented $\sim 20 - year$ variability related to ocean-only advection/wave processes and deep convection within the North Atlantic SPG (Menary et al 2015)
- Multidecadal to centennial variability generally salinity-driven and involving interactions with Arctic (Jungklaus et al 2005) and (Sub)Tropical Atlantic (Vellinga and Wu 2004)

The AMOC low-frequency variability in CMIP6 models



- Large diversity of magnitude (two orders of magnitude in normalized variance) and time scales (interannual to centennial)
- Two "families" of models :
  - Strong multidecadal to centennial variance : exclusively NEMO model at nominal 1° - 75-level resolution (CNRM, CMCC, EC-Earth, IPSL)
  - Weaker variance, with a diversity of time scales and ocean models (including some NEMO 1° configurations)

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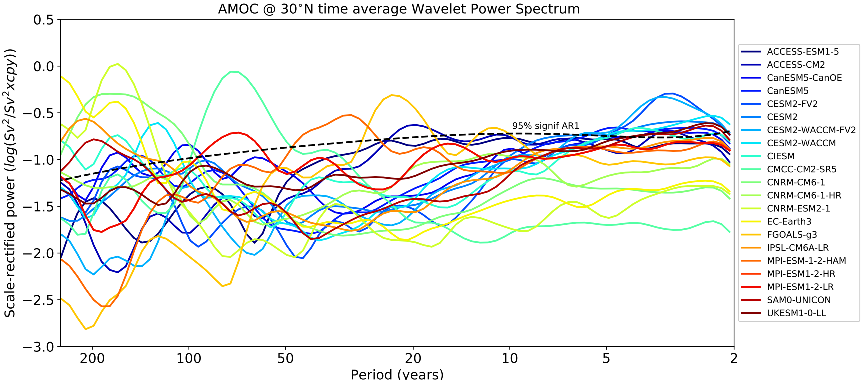

- Most models display significant low-frequency spectral peaks at $T > 20$ years

Aim of the study :

- To investigate the AMOC low-frequency variability of the CNRM-CM6-1 climate model, pertaining to the strong AMOC variance subgroup
- To propose a revised AMOC dynamical decomposition for use in models and observations alike

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CNRM-CM6-1

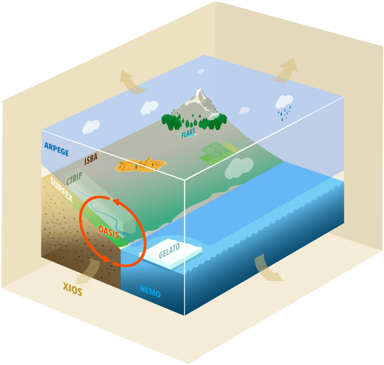
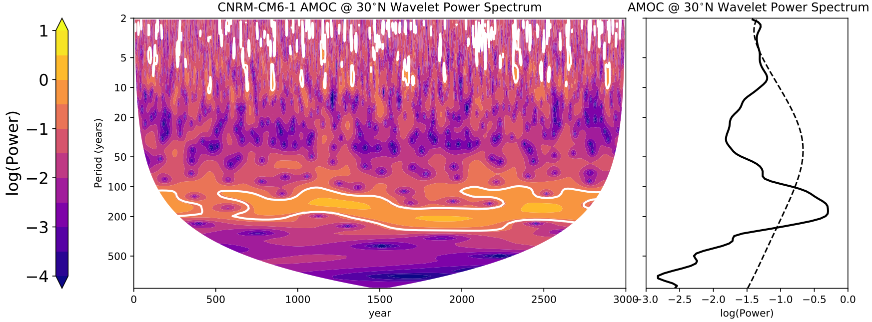


Figure 1 – Components of CNRM-CM6 [Voldoire et al 2019, Séférian et al 2020]

Ocean component :

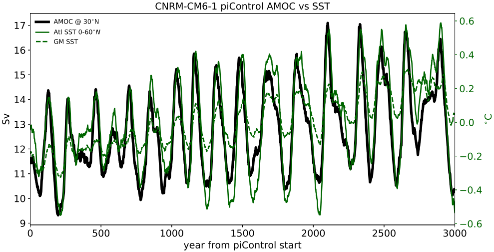
- NEMO v3.6, ORCA1 (1° nominal resolution), 75 levels
- Physics : turbulent kinetic energy [Blanke and Delecluse 1993], enhanced vertical diffusivity [Madec et al 2008], isoneutral mixing [Redi 1982], eddy-induced and mixed layer eddy velocities [Gent and McWilliams 1990, Fox-Kemper et al 2008], tidal mixing [de Lavergne et al 2016a, 2019], bottom boundary layer [Madec et al 2008]

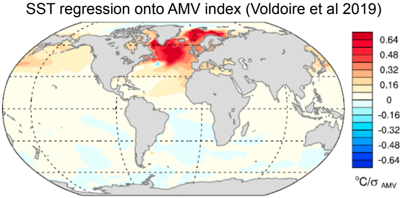
The AMOC low-frequency variability in CNRM-CM6-1



- A sustained centennial cycle of 100–200yr time scale (Waldman et al JPO 2020)

The AMOC low-frequency variability in CNRM-CM6-1

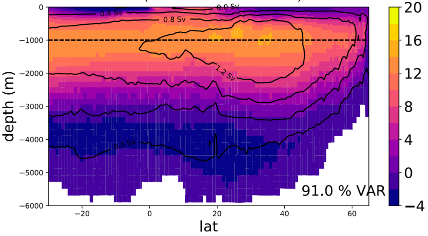




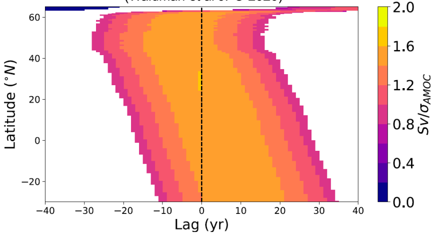
- AMOC explains 88% of the North Atlantic and 61% of the global mean SST low-frequency variability
- Intense SST signature in Subpolar North Atlantic and Nordic Seas

The AMOC low-frequency variability in CNRM-CM6-1

Mean AMOC (shades) and multidecadal EOF1 (contours)
(Waldman et al JPO 2020)



AMOC regression onto AMOC @ 30°N
(Waldman et al JPO 2020)



- Multidecadal AMOC EOF1 is meridionally-coherent and explains 91% of variance
- Southward propagation of AMOC anomalies (at 1.9cm/s) from subpolar North Atlantic

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Approach

How does the AMOC couple with water mass properties ? Answers from the AMOC dynamical decomposition (Waldman et al JPO 2020) :

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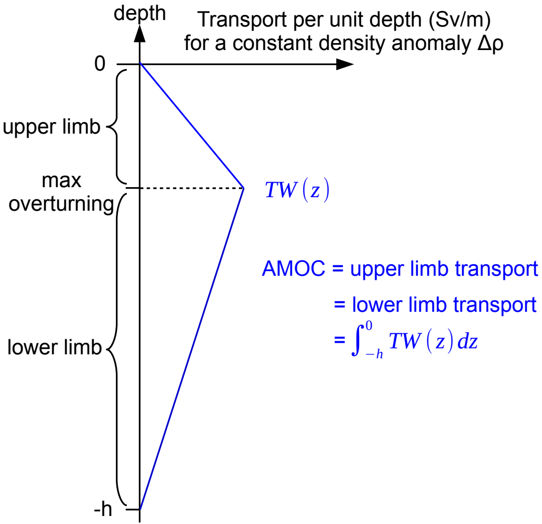
Novelty of the approach :

- Expression of $AMOC_{g-sh}$ as a simple vertical integral of densities at zonal boundaries :

$$AMOC_{g-sh} = \int_{-h}^{0} TW(z)dz$$

  with TW(z) a linear function of densities.
- Explicit expression of $AMOC_{EM}$ as a function of bottom velocities.

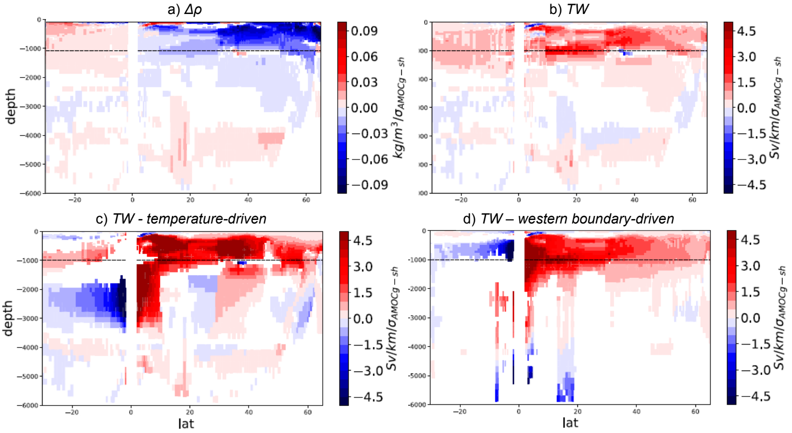
Prediction



- Max AMOC transport generated by zonal density gradient near the interface between upper and lower AMOC limb (Waldman et al JPO 2020)

Application to CNRM-CM6-1

Thermal wind and zonal density regression onto AMOC PC1 (Waldman et al JPO 2020)



In CNRM-CM6-1, AMOC low-frequency variability is driven by :

- The zonally-integrated thermal wind relation
- Mid-depth (200m–1500m) density anomalies which are temperature and western boundary-driven

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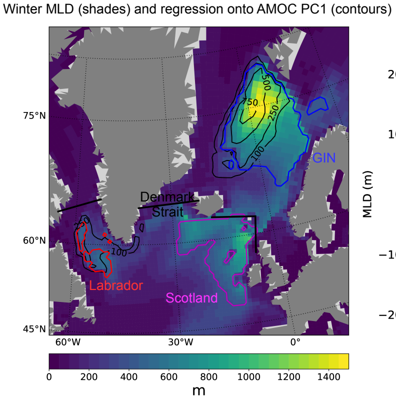
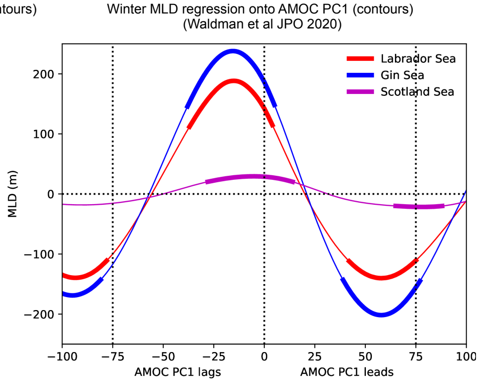
Deep convection



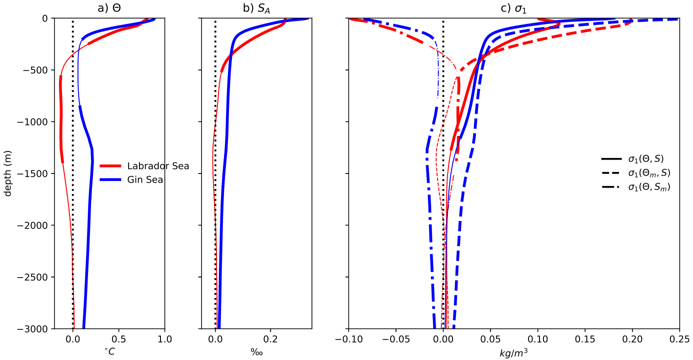


Strong lead regression between Labrador-GIN Seas winter MLD and AMOC PC1 :

- Labrador Sea convection is a direct driver of AMOC variability
- GIN Sea is a potential driver if its dense waters propagate to the western boundary

Deep convection

Regression of hydrographic profile onto AMOC PC1

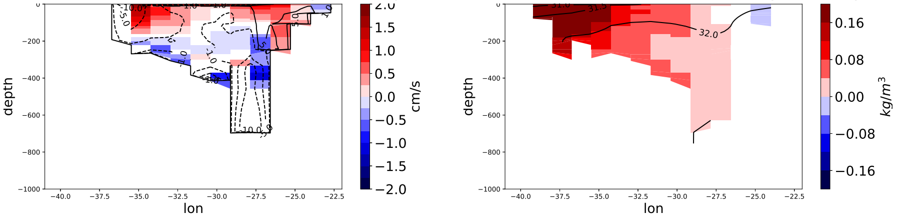


- Overall, salinity-driven density anomaly over top 1200m depth, intensified in the upper 500m depth.
- Exception : temperature-driven at mid-depths of the Labrador Sea. It is the dynamical AMOC driver and it relates to the mean thermal inversion profile.

Denmark Strait overflow

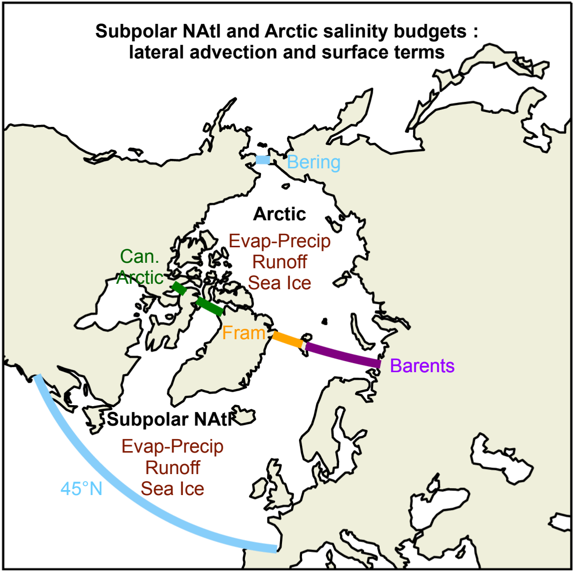
Velocities : mean (contours) and reg. onto AMOC PC1 (shades)

Density : mean (contours) and reg. onto AMOC PC1 (shades)

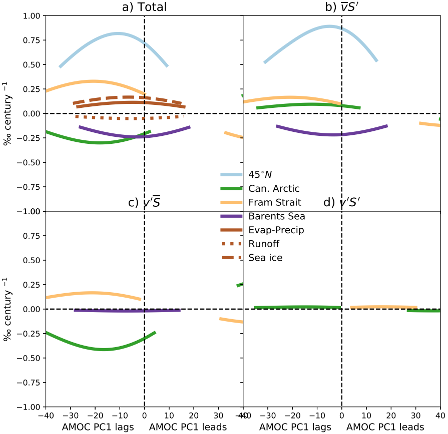


- Weak regression of velocities and density onto the AMOC PC1 at the Denmark Strait overflow.
- Hence no causal link between GIN Sea convection and AMOC variability.

Salinity budget

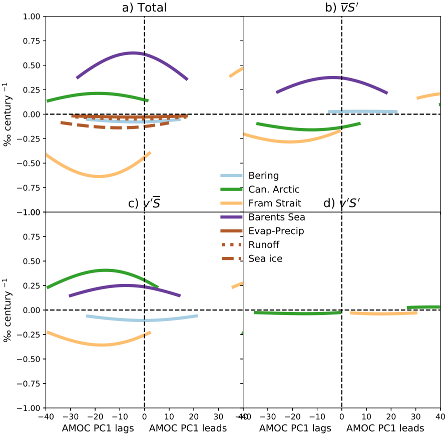


Subpolar gyre salinity budget



- Fram Strait advection leads AMOC PC1 by $\sim$ 20 years : both positive salinity anomaly and negative southward velocity anomaly
- Intense positive feedback of advection at 45°N, salinity-driven and $\sim$ in phase with AMOC.
- Weak positive feedback of surface fluxes.

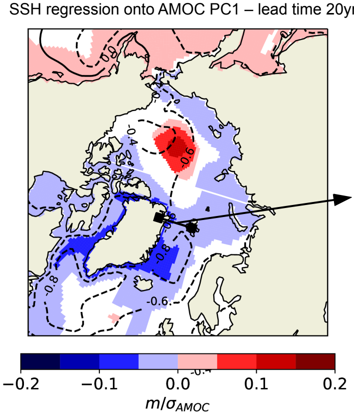
Arctic salinity budget

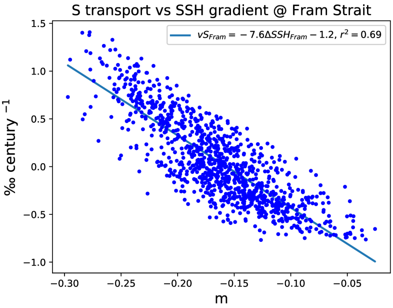


Symmetrical picture in the Arctic :

- Fram Strait advection is the main salinity sink at ~ 20-year lead time, mitigated by Canadian Arctic
- Weak positive feedback of surface fluxes and Bering transport
- Strong negative feedback of Barents Sea transports.

Arctic - Nordic Seas circulation variability





- At Fram Strait, S transport driven by local SSH gradient.
- Intensification of anticyclonic circulation in the Arctic and cyclonic circulation in the SPG : similar to Jungklaus et al 2005.

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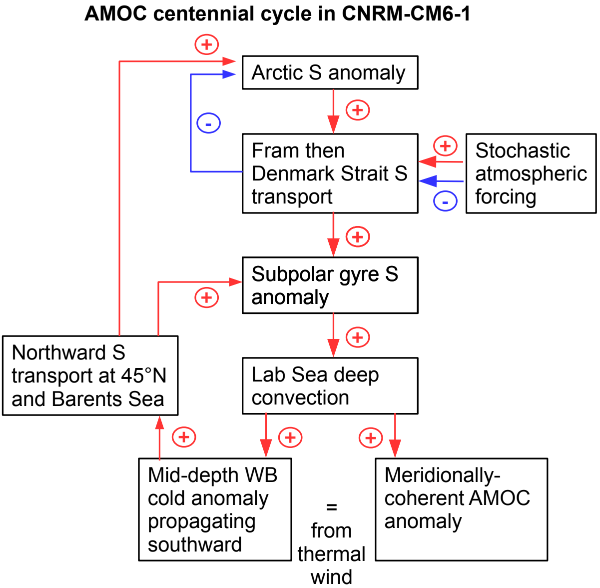
Synthetic schematic



Key points

- The CMIP6 ensemble includes two types of AMOC behaviours : strong multidecadal to centennial AMOC variability (exclusively models with a NEMO 1° ocean component) versus weak AMOC low-frequency variability (a large diversity of ocean configurations).
- A new dynamical AMOC decomposition is proposed which sheds light on the role of densities at zonal boundaries.
- In CNRM-CM6-1, a centennial variability driven by an Arctic - North Atlantic recharge oscillator.