Arctic sea ice decline weakens the Atlantic meridional overturning circulation

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Sea ice in the Earth System
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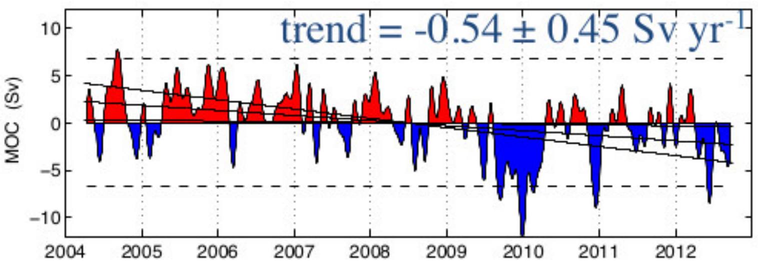
Is the AMOC slowing down?

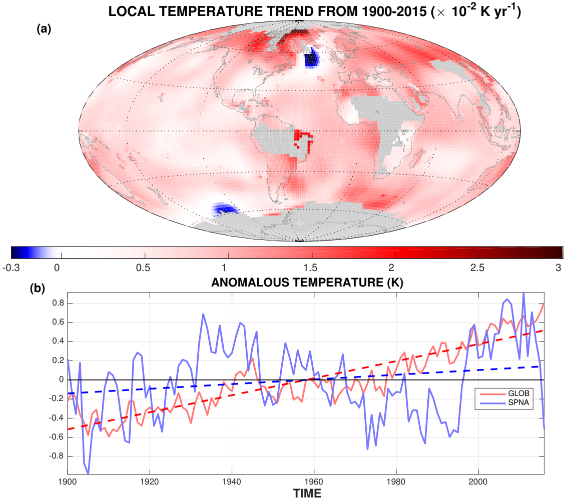
◇ Rapid measurement of AMOC at 26°N:



Smeed et al. (2014)

⇒ **The AMOC seems to slow-down on a decadal timescale.**

Is the AMOC slowing down on longer timescale?



NASA GISS temperature data.

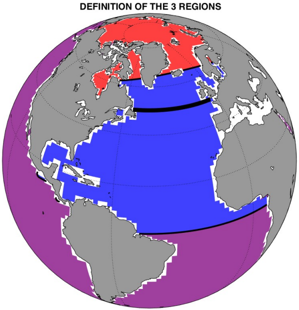
⇒ This "Warming Hole" has been conjectured to be the signature of **a long-term AMOC slow-down.**

(Drijfhout et al., 2012; Rahmstorf et al., 2015)

◊ Objective: **Can we attribute this AMOC slow-down?**

◊ Method:

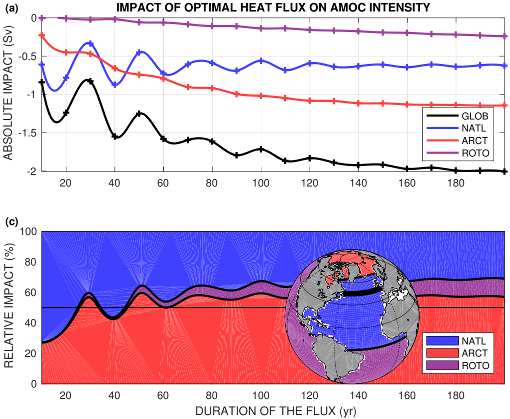
1. We compute AMOC sensitivity to constant surface buoyancy fluxes,
   - Optimization procedure based on Lagrangian multipliers,
   - This requires the "adjoint" model (NEMO-OPA at 2° resolution),
   - AMOC - baroclinic volume transport at 1,500 m depth and 50°N.
2. Optimal fluxes for a range of imposed duration from 10 yr to 200 yr.
3. We separate the fluxes in 3 regions:



- **ARCT**: Arctic Ocean,
- **NATL**: North Atlantic,
- **ROTO**: Rest Of The Oc.

⇒ **A dynamical attribution of heat flux influences on the AMOC.**

AMOC sensitivity to constant heat flux

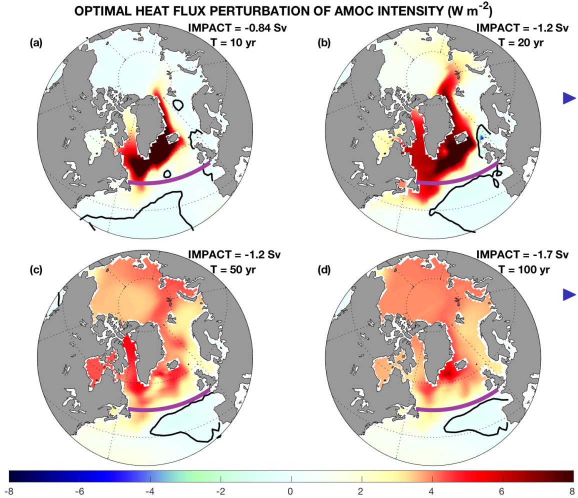


- **North Atlantic** dominates changes from years to a few decades,
- **Arctic** dominates changes from several decades to centuries.

(Fluxes are normalized to 1 W m^{-2}.)

⇒ **On centennial timescales, despite NATL being 3 times as large as ARCT, ARCT is twice as effective for weakening the AMOC!**

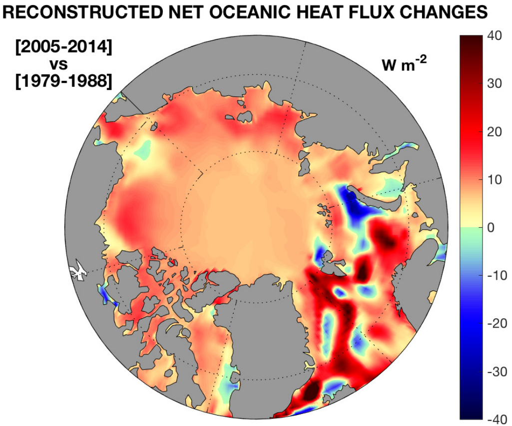
AMOC sensitivity to constant heat flux



(Fluxes are normalized to 1 W m^{-2} for comparison.)

- On annual to decadal timescales, the sensitivity is located in the **subpolar N. Atl.**,
- On multidecadal timescales, the sensitivity further expand northward, spreading in the **Arctic region**.

Change in oceanic heat flux in the Arctic since 1979



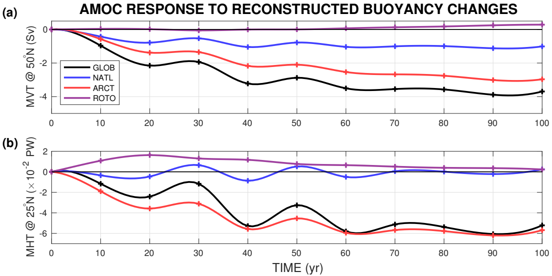
◇ ERA-Interim structure,

◇ Uniformly rescaled to $+0.55$ W m^{-2} (IPCC, 2013).

⇒ **Arctic is warmed at a rate of ∼8 W m^{-2} over the last 35 yr.**

AMOC response to change in surface oceanic heat flux

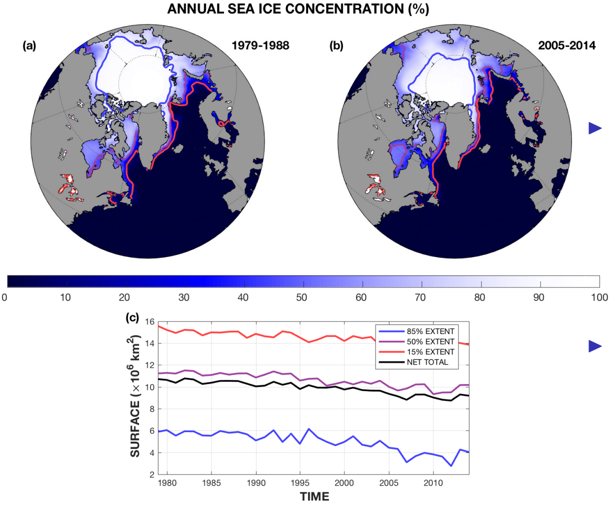
- **A 100-yr steady change**, equivalent to the current one, **would slow down the AMOC by 4 Sv**,



- The Arctic contribution to this slow-down is nearly **3 times as efficient** as the N. Atl. one.

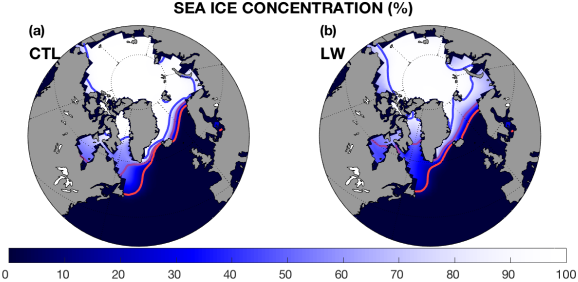
- Unlike for other oceanic regions, **Arctic** heat flux change reduces northward Atl. heat transport ⇒ *Warming Hole?*

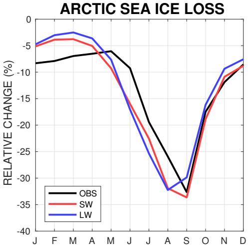
Change in Arctic sea ice cover since 1979



- There is a reduction of the **sea ice cover** in the Arctic since 1979,
- This increases the **heat flux** reaching the ocean surface.

Simulating Arctic sea ice changes

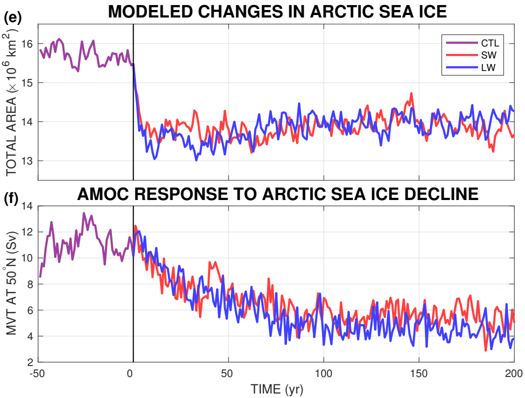


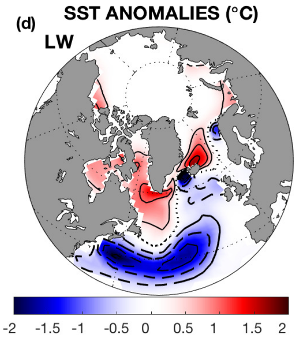


A coupled experiment (CESM):

- Modifying the properties of sea ice and snow:
  - Reduce the emissivity (LW),
  - Reduce the albedo (SW).
- Reproducing quantitatively the observed Arctic sea ice decline.

Impact of Arctic sea ice change in the North Atlantic





- AMOC slow-down by ∼50% in 100 yr,
- Cooling of up to 2°C in the subpolar N. Atl.

Conclusion (Published as: Sévellec et al., *Nature Climate Change*, 2017)

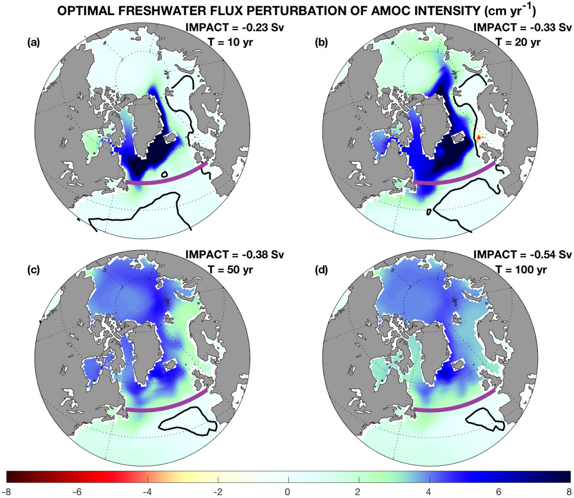
Attribution of the AMOC slow-down to buoyancy fluxes.

- Potential impacts:
  - **Subpolar North Atlantic** has higher potential impact on timescales from years to a few decades,
  - **Arctic** has higher potential impact on timescales from several decades to centuries (6 times as efficient).
  - Results for freshwater are qualitatitively equivalent but quantitatively one order of magnitude weaker than for heat.

Reduction in Arctic sea ice increases ocean heat uptake.

- Projected impacts:
  - **AMOC** would **slow-down by 4-6 Sv in a century** under current observed changes,
  - 30% can be attributed to the **N. Atl.** and 60% – to the **Arctic**.
  - Consequently, N. Atl. **STT** would **cool-down by up to 2°C**.

AMOC sensitivity to constant freshwater flux



(Fluxes are normalized to 1 cm yr^{-1} for comparison.)