

Coupling between the Arctic and the Atlantic Meridional Overturning Circulation: A Review

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Background

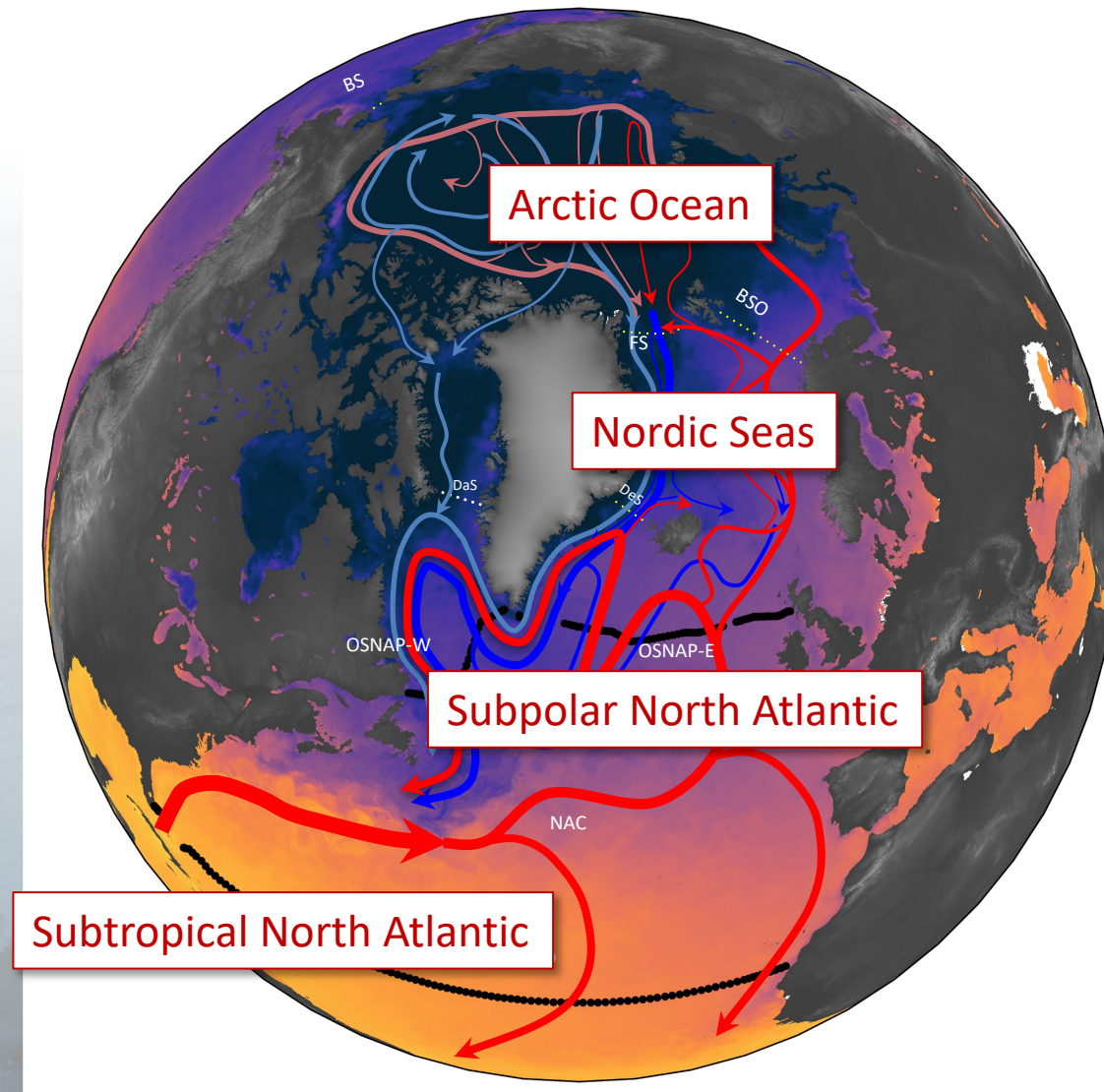


- Special issue of *Oceanography* on ***The New Arctic Ocean***
 - Several papers have already been published
 - <https://tos.org/oceanography/issue/volume-35-issue-2>
- This paper
 - Review recent advances in our understanding of interactions between the Arctic and the AMOC
- General audience
 - So not comprehensive

LINKING THE AMOC AND THE ARCTIC

Linking the AMOC and the Arctic

What are the main exchange pathways between the Arctic and North Atlantic?

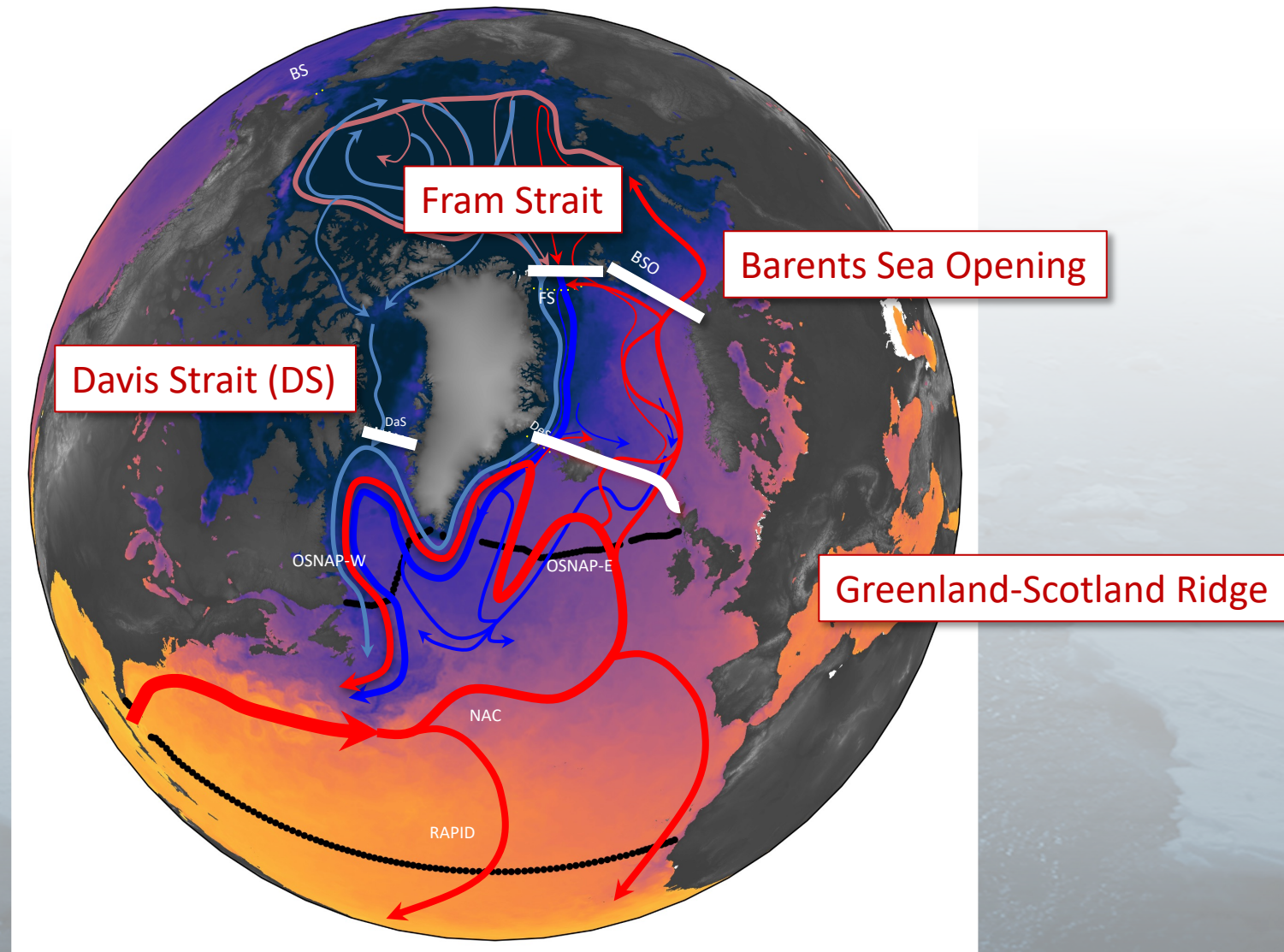


Definition: Arctic =

- Nordic Seas + Arctic Ocean
- Arctic Mediterranean

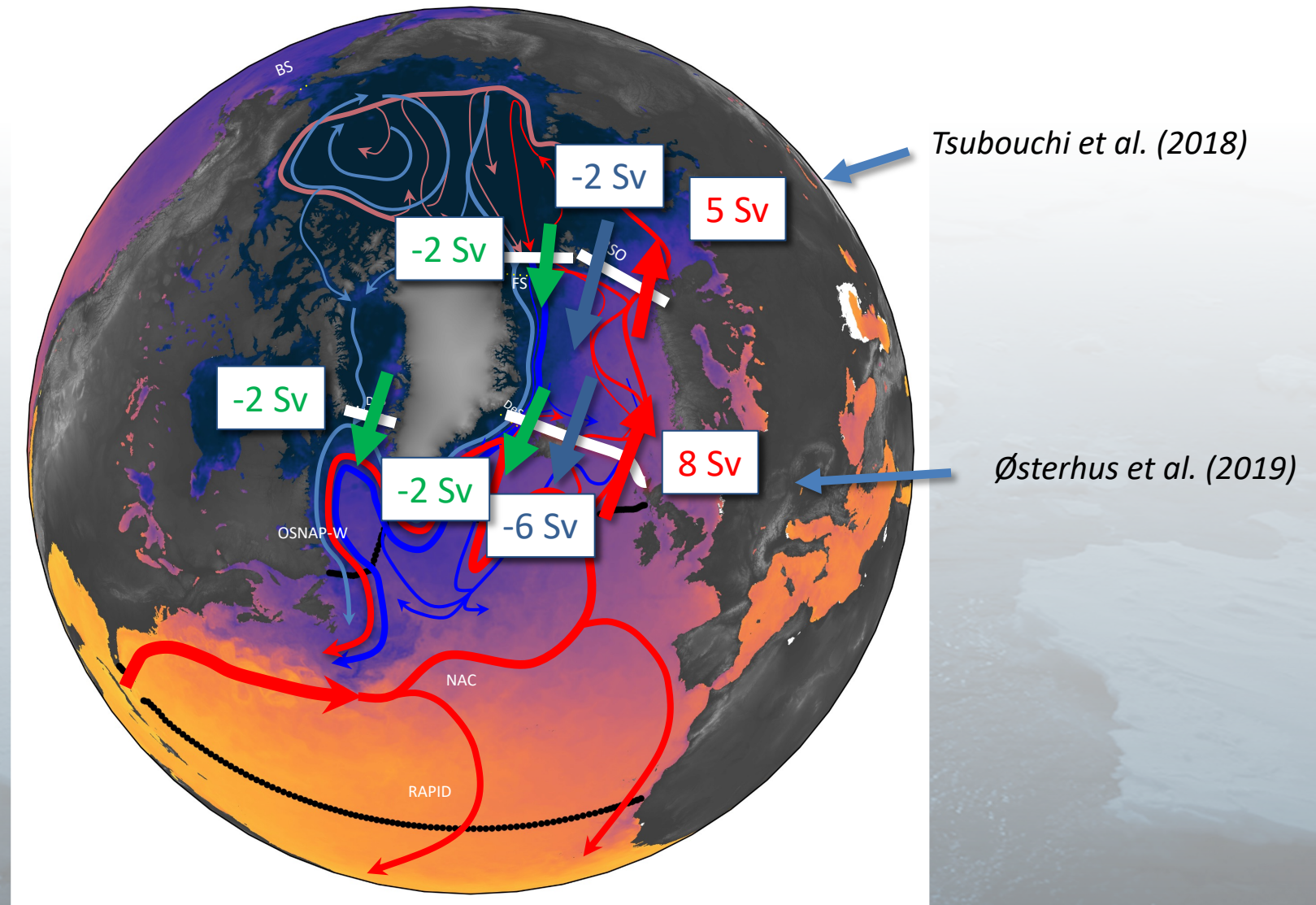
Linking the AMOC and the Arctic

What are the main exchange pathways between the Arctic and North Atlantic?



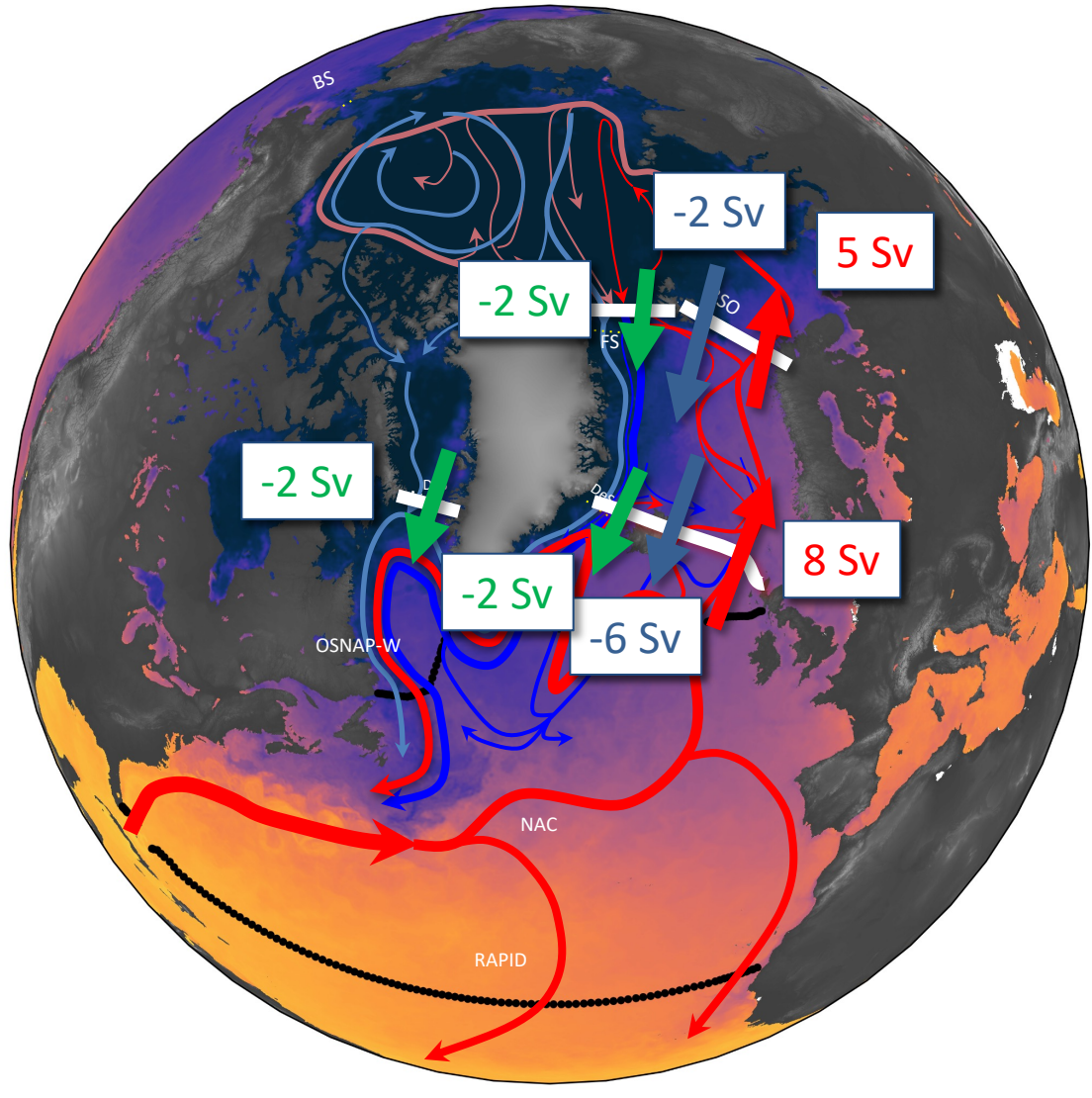
Linking the AMOC and the Arctic

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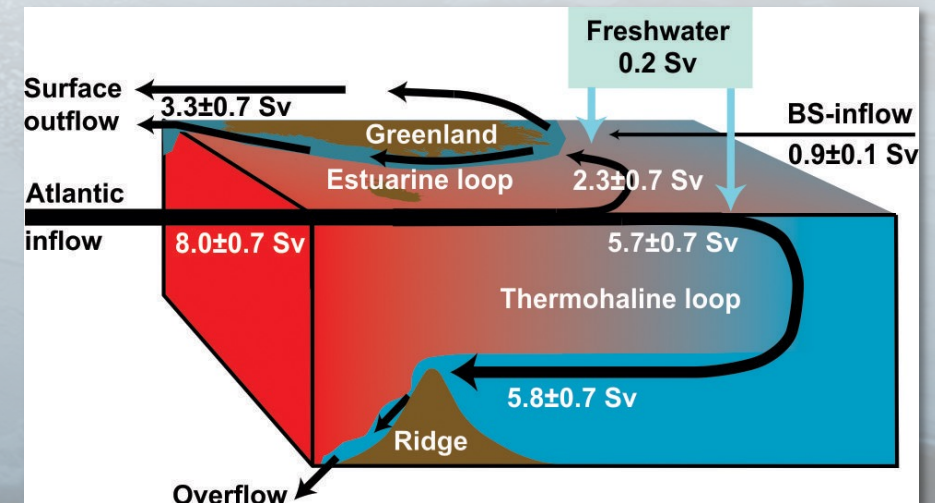
Linking the AMOC and the Arctic

What does this tell us about overturning cells?



- Double-estuarine model of the Arctic
 - Thermohaline cell: Atlantic Water to Overflow Water
 - Estuarine cell: Atlantic Water to Polar Water
- Thermohaline cell: 6 Sv
 - 2 Sv in Arctic Ocean
 - 4 Sv in Nordic Seas
- Estuarine cell: 3 Sv
 - In Arctic Ocean

Østerhus et al. (2019)

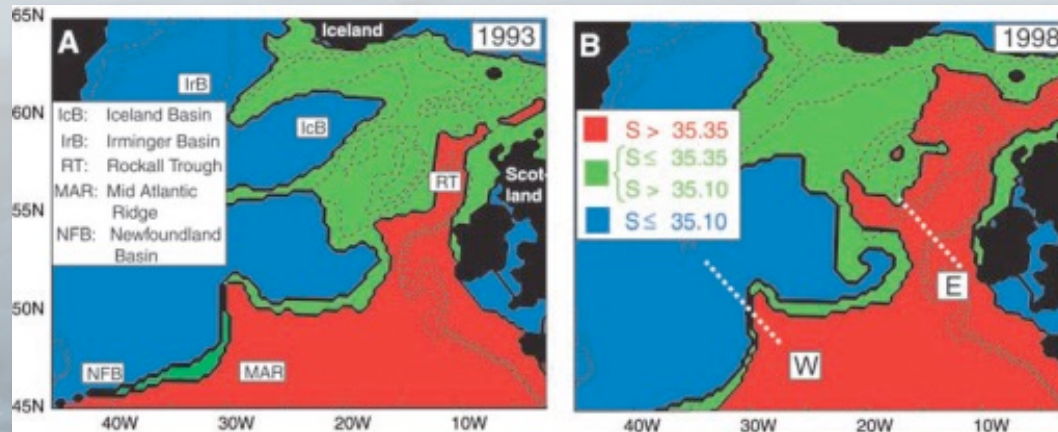


Linking the AMOC and the Arctic

How much inflow into Nordic Seas is of subtropical origins?

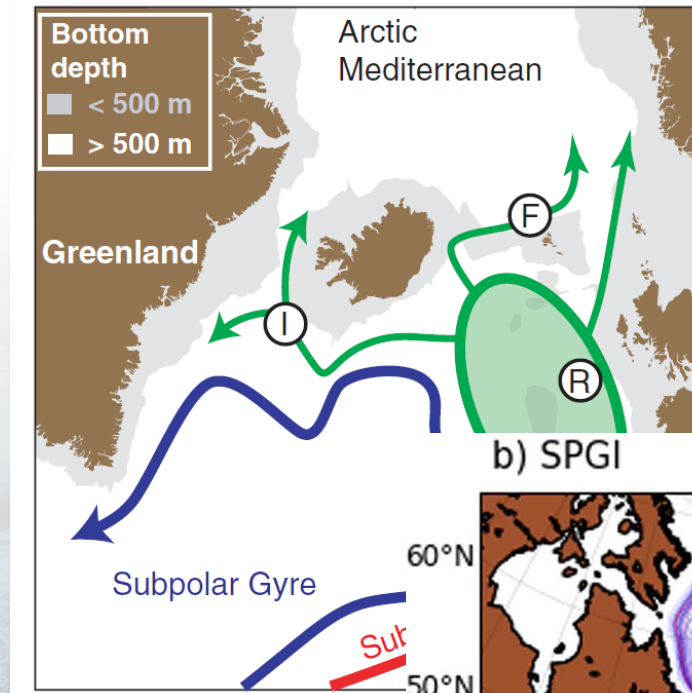


- Subpolar gyre modulates salinity of Eastern North Atlantic (ENA)
 - Strong gyre: fresh ENA
 - Weak gyre: salty ENA
- Between 50% and 70% is of subtropical origin

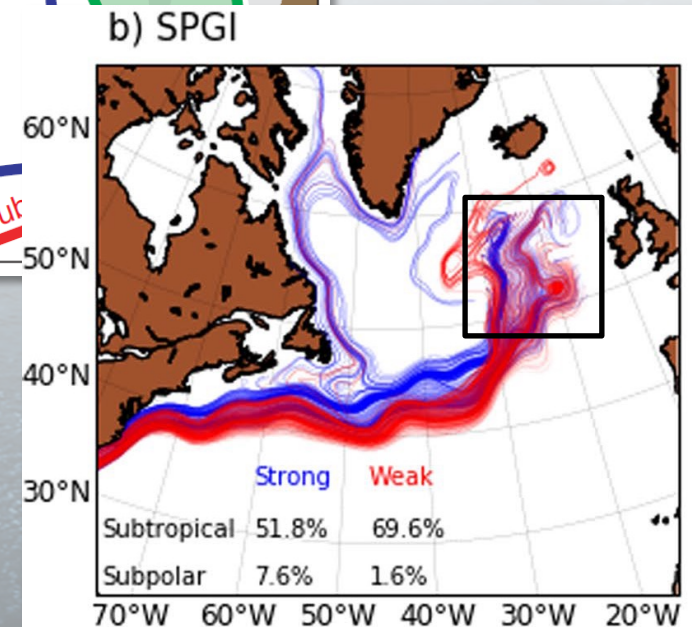


Strong gyre

Weak gyre



Hátún et al. (2005)



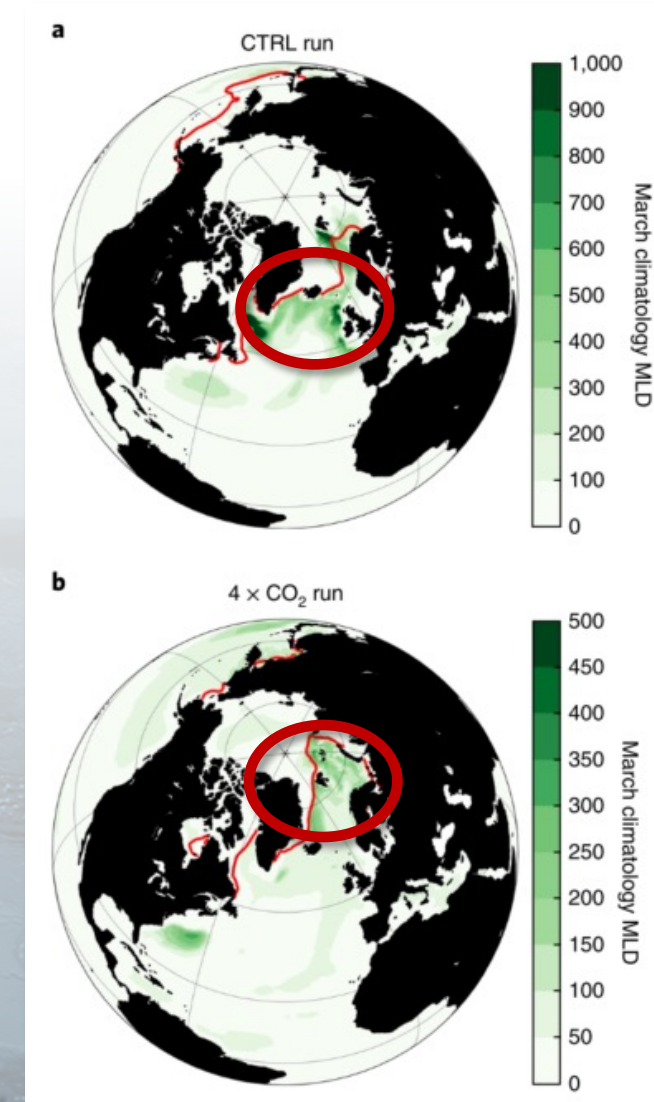
Koul et al. (2020)

Linking the AMOC and the Arctic

How will connection change in warming climate?



- AMOC projected to reach further into the Arctic
 - Northward shift of deep convection
 - E.g., Bitz et al. (2006), Lique & Thomas (2018)
- This implies a *stronger link* between the Arctic and the AMOC in the future
 - Despite weakening of the AMOC



Lique & Thomas (2018)

AMOC IMPACTS ON ARCTIC

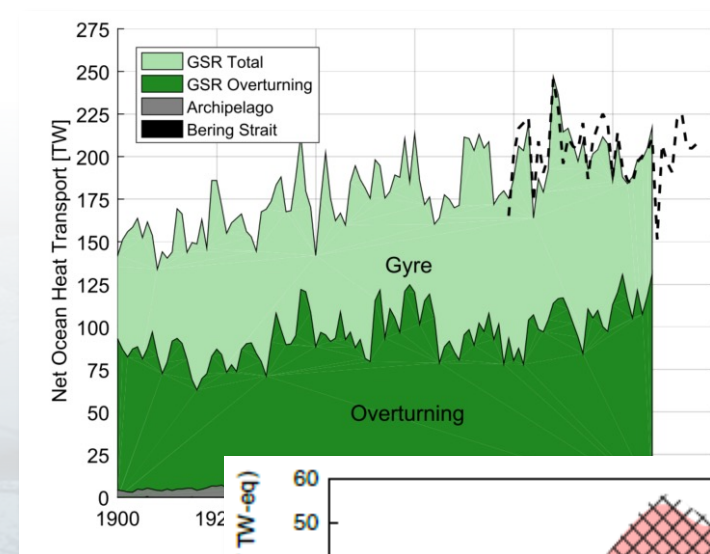
Impact of AMOC on Arctic

How important is the overturning circulation for the Arctic heat budget?

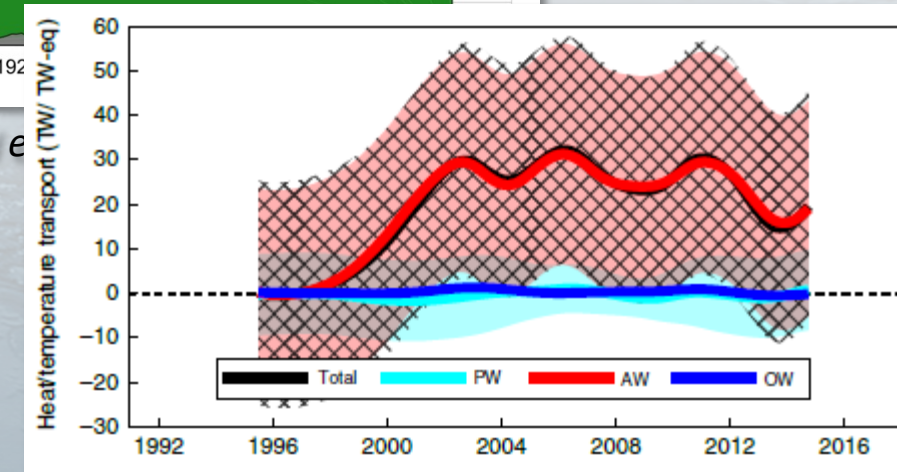


- Overturning critical element of Arctic heat budget
 - More than 50% of heat import across GSR is due to overturning
- Heat transport is increasing
 - Despite weakening AMOC at 26N since early 2000s
 - Discontinuity between AMOC and OHT into the Arctic

OHT across Greenland-Scotland Ridge



Smedsrud et al.



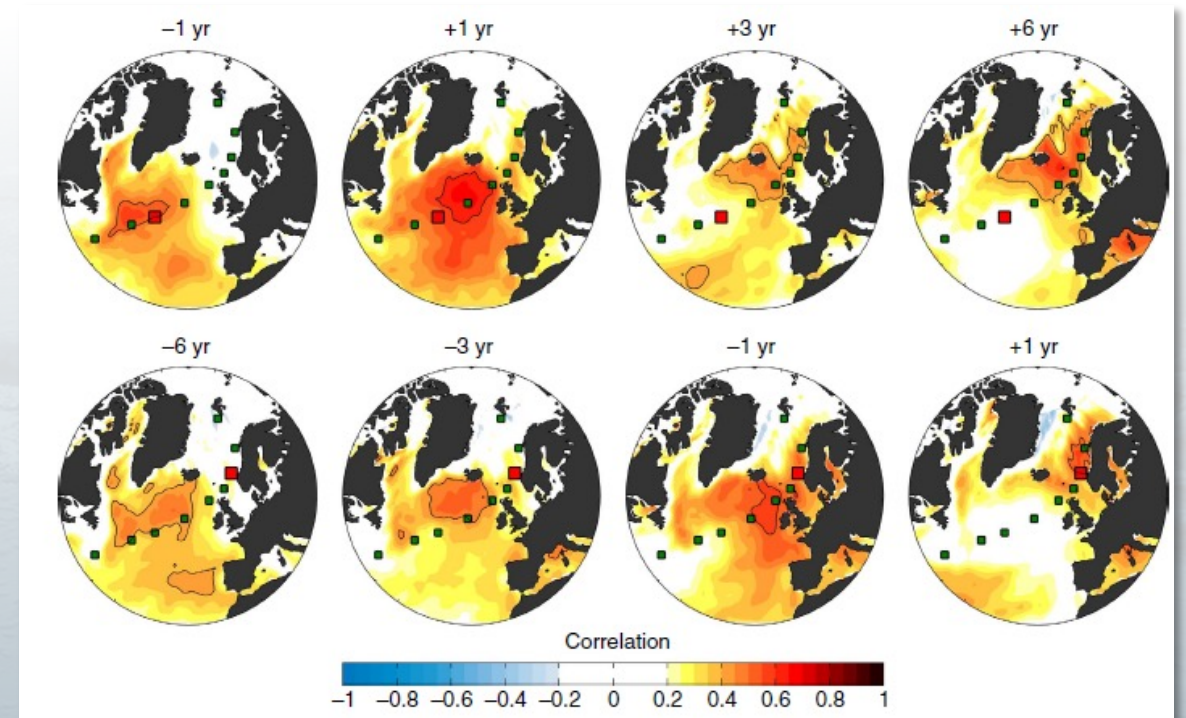
Tsubouchi et al. (2021)

Impact of AMOC on Arctic

To what extent does AMOC variability affect heat transport into the Arctic?



- Heat content anomalies can be followed from subpolar North Atlantic into Nordic Seas
 - Predictability of Arctic sea ice
 - E.g., Yeager et al. (2015), Årthun et al. (2017)



Årthun et al. (2017)

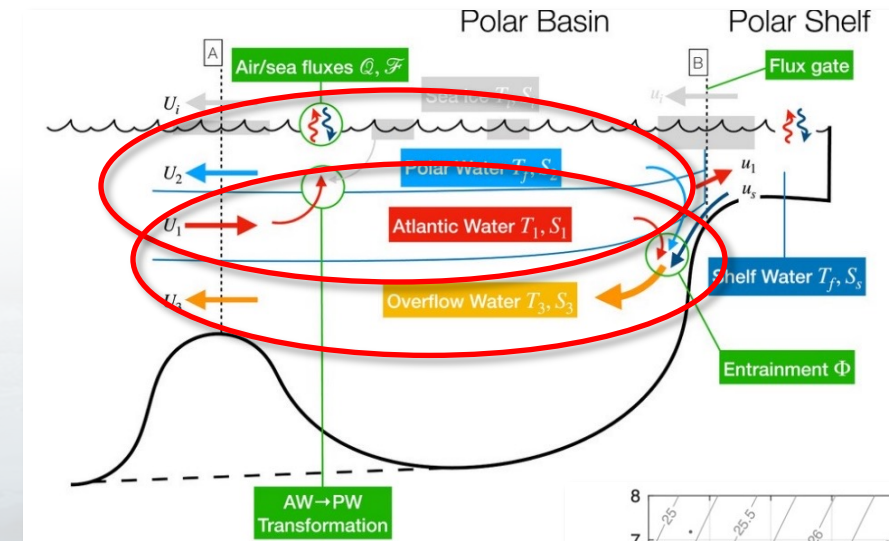
ARCTIC IMPACTS ON THE AMOC

Arctic Impacts on the AMOC

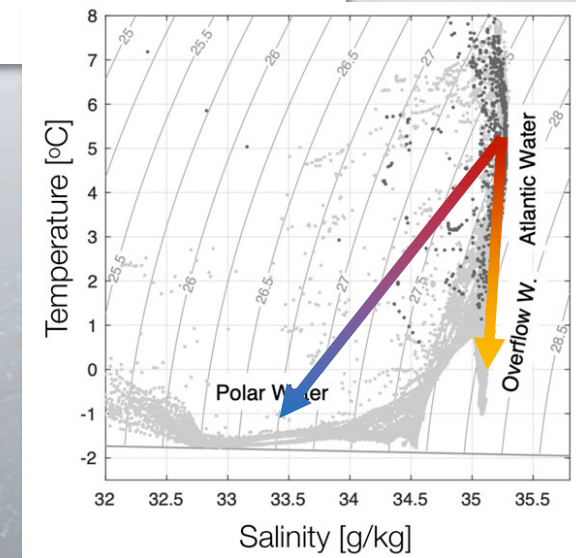
Water Mass Transformations



- Double-estuarine model
 - **Atlantic Water** gets cooled and freshened: **Polar Water**
 - **Atlantic Water** gets mixed with Shelf Water: **Overflow Water**
- Thermal cell is robust
- Estuarine cell is vulnerable to **heat crisis**
 - Warming Atlantic Water
 - Increase meteoric freshwater flux
- 'Atlantification' may be a **precursor**



Haine (2021)

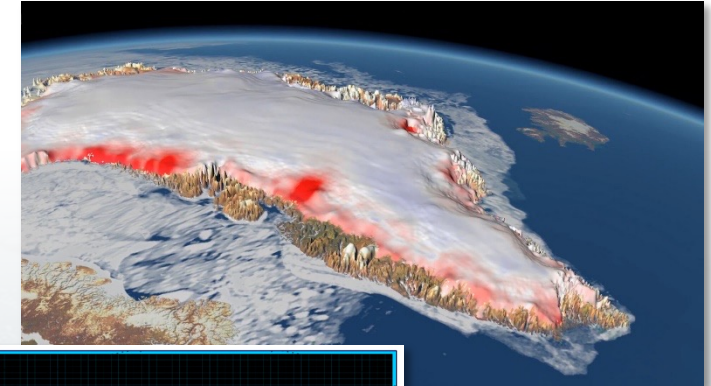


Arctic Impacts on the AMOC

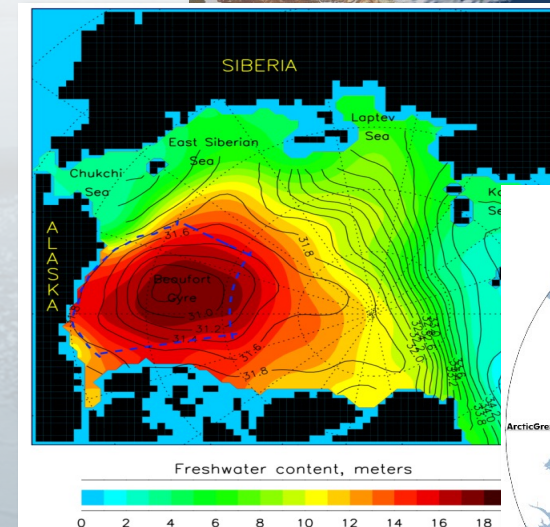
Freshwater inputs



- AMOC is thought to be sensitive to freshwater input
 - Freshwater capping inhibits deep convection
 - E.g., Gelderloos et al. (2012)
- Many sources and reservoirs in the Arctic freshwater system:
 - Greenland Ice Sheet
 - Arctic rivers
 - Pacific inflow
 - Precipitation
 - Beaufort Gyre
 - Sea ice
- Many changes due to anthropogenic forcing
 - Jahn & Laiho (2020); Haine (2020)



ESA



Proshutinsky et al. (2012)



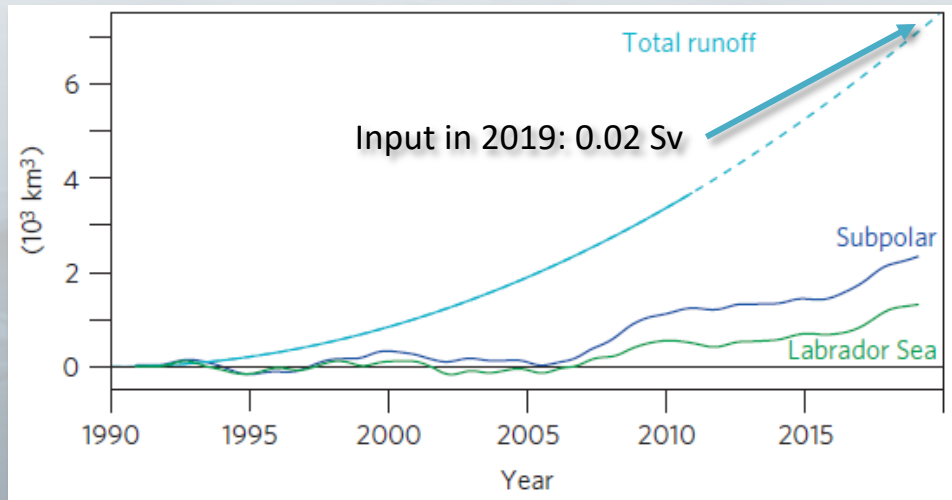
Arctic GRO

Impact of Arctic on AMOC

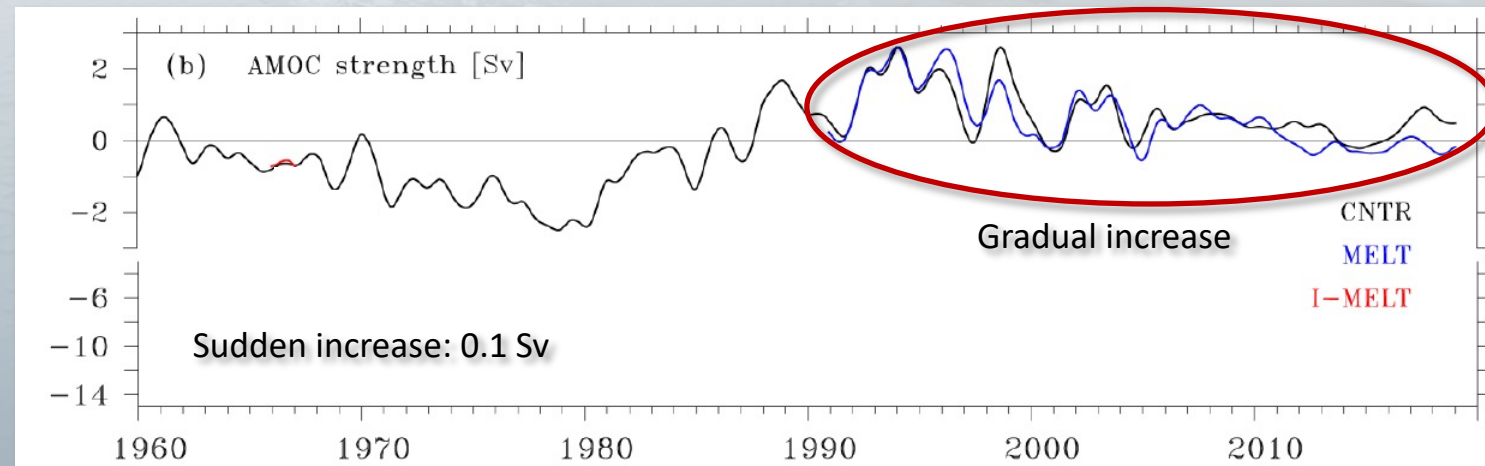
Impact of Greenland Ice Sheet melt?



- Böning et al. (2016): Greenland freshwater input in eddy-resolving ocean model
 - ‘Realistic’ gradual increase of 0.5 mSv/yr
 - *“freshwater anomaly has not yet had a significant impact on the Atlantic meridional overturning circulation”*



Böning et al. (2016)

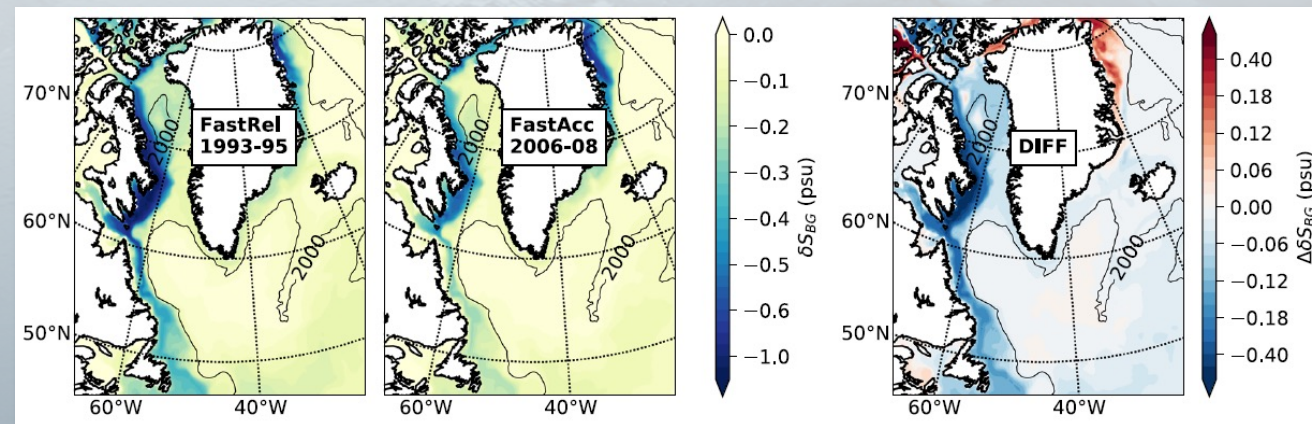
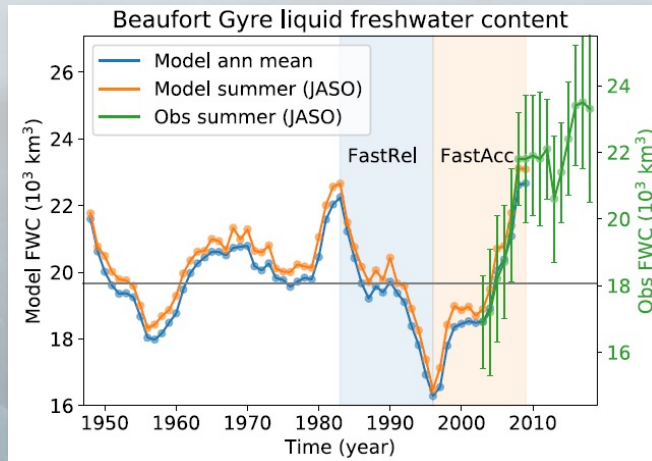


Impact of Arctic on AMOC

Impact of Beaufort Gyre variability?



- Zhang et al. (2021): Beaufort Gyre freshwater release in eddy-permitting ocean model
 - ‘Color’ BG waters during historical periods of:
 - Rapid freshwater release (1983–1995)
 - Rapid freshwater accumulation (1996–2008)
 - The Labrador Sea is freshened by 0.2-0.4 psu



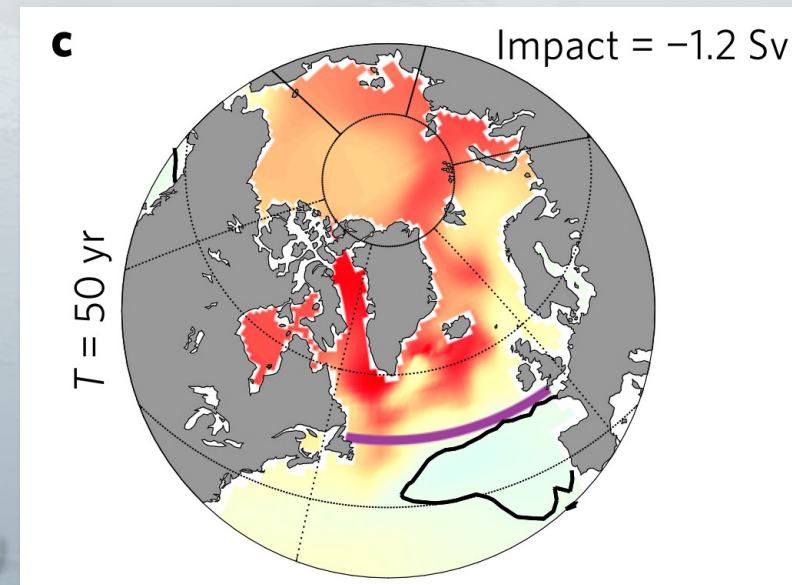
Zhang et al. (2021)

Impact of Arctic on AMOC

Impact of sea ice loss?



- Sévellec et al. (2017): Adjoint sensitivity study determines optimal heat and freshwater flux perturbations
 - On multi-decadal time scales, AMOC is most sensitive to buoyancy flux anomalies in the Arctic
 - Sea ice loss weakens AMOC, as Arctic Ocean absorbs more heat
 - Mediated by freshwater anomalies from changes in sea ice cycling (Liu et al. 2019)



Sévellec et al. (2017)

Summary



- AMOC only partially responsible for OHT transport into Arctic
 - Important role for regional winds, gyre dynamics
- Many ways in which Arctic can impact AMOC
 - Water mass transformations
 - Many sources and reservoirs of freshwater
- The link between Arctic and AMOC is projected to strengthen
 - Despite weakening AMOC
 - Concerning given the large changes in Arctic freshwater budget

EXTRAS

Challenges



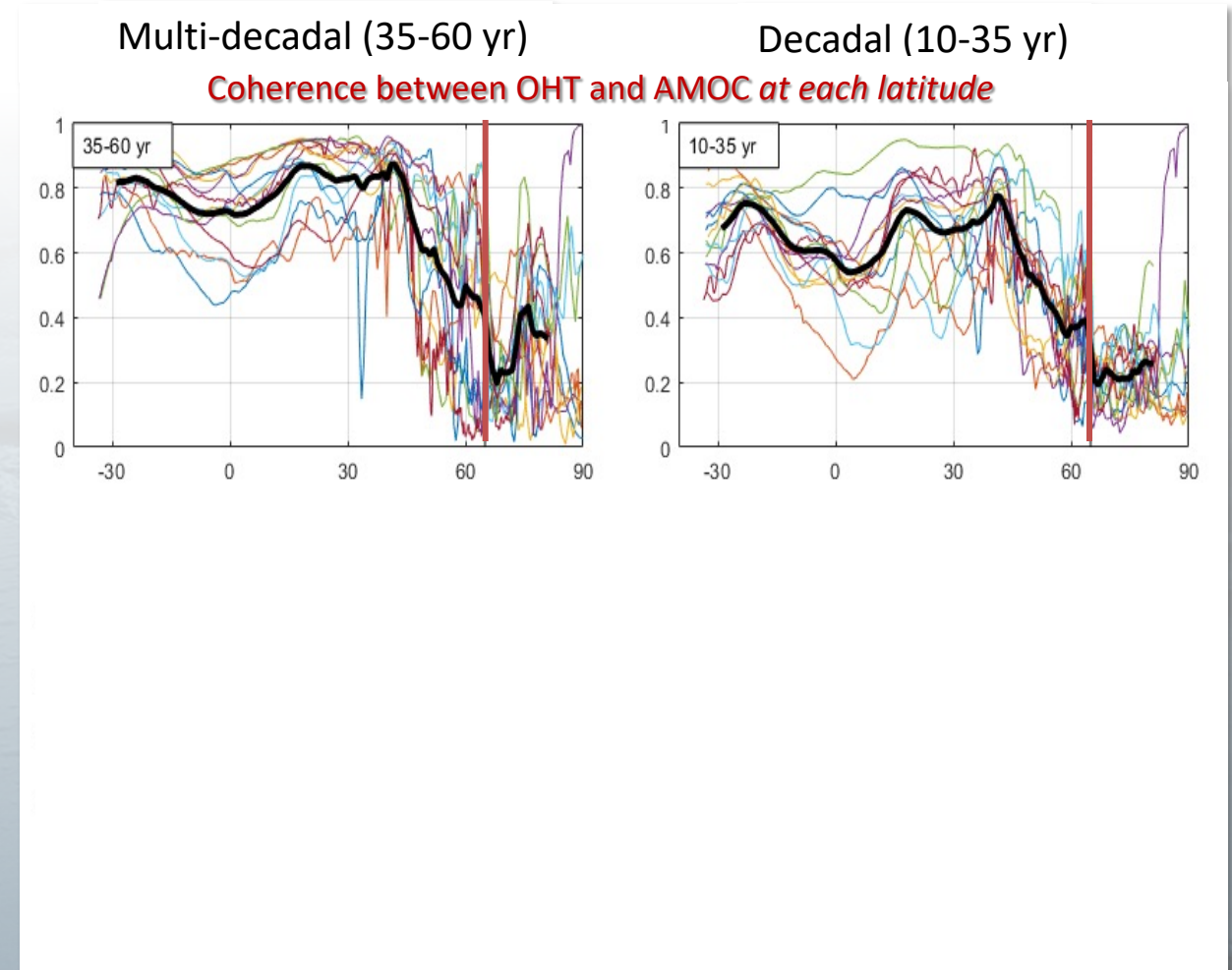
- Climate models continue to have significant biases in the Arctic and AMOC
 - Multi-model means often okay, but considerable model spread
- Most models do not resolve the fine-scale processes that are important for AMOC, the Arctic, and their interactions
 - Narrow boundary currents
 - Mesoscale eddies
 - Cross-shelf exchanges
 - Deep convection
 - Complex bathymetry
- Limited monitoring of critical gateway transports
 - No closed budgets
- Arctic, AMOC, and climate communities are not as well integrated as they should
 - Integration of modeling and observational communities has improved with US AMOC Science Team, FAMOS

Impact of AMOC on Arctic

To what extent does AMOC variability affect heat transport into the Arctic?



- Analysis of CMIP6 models:
 - OHT strongly related to AMOC south of 60°N
 - OHT at 65°N weakly related to AMOC at lower latitudes

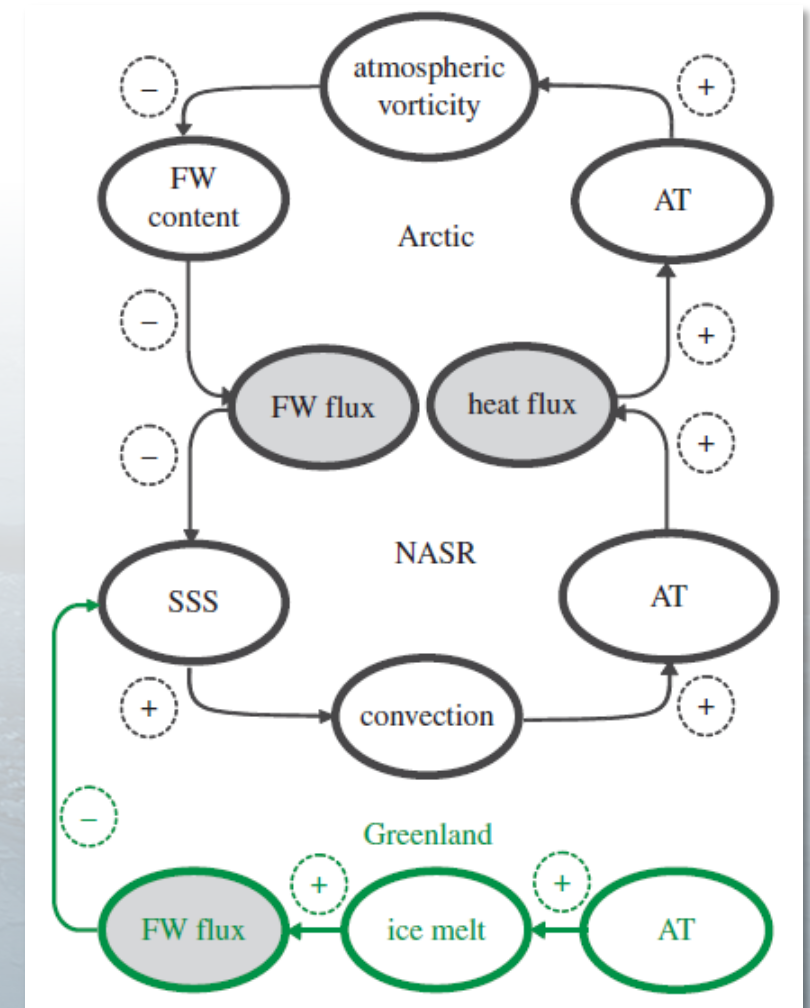


Two-way Interactions Between Arctic and AMOC

Coupled interactions



- Proshutinsky et al. (2015)
 - Explain decadal variability of alternating circulation patterns in the Arctic
 - Interaction between Arctic and subpolar North Atlantic
 - The Arctic regulates the North Atlantic via freshwater flux
 - The North Atlantic influences the Arctic via atmospheric heat flux
 - Greenland freshwater input might have interrupted feedback loop
- Also
 - Escudier et al. (2013)
 - Jungclaus et al. (2005)



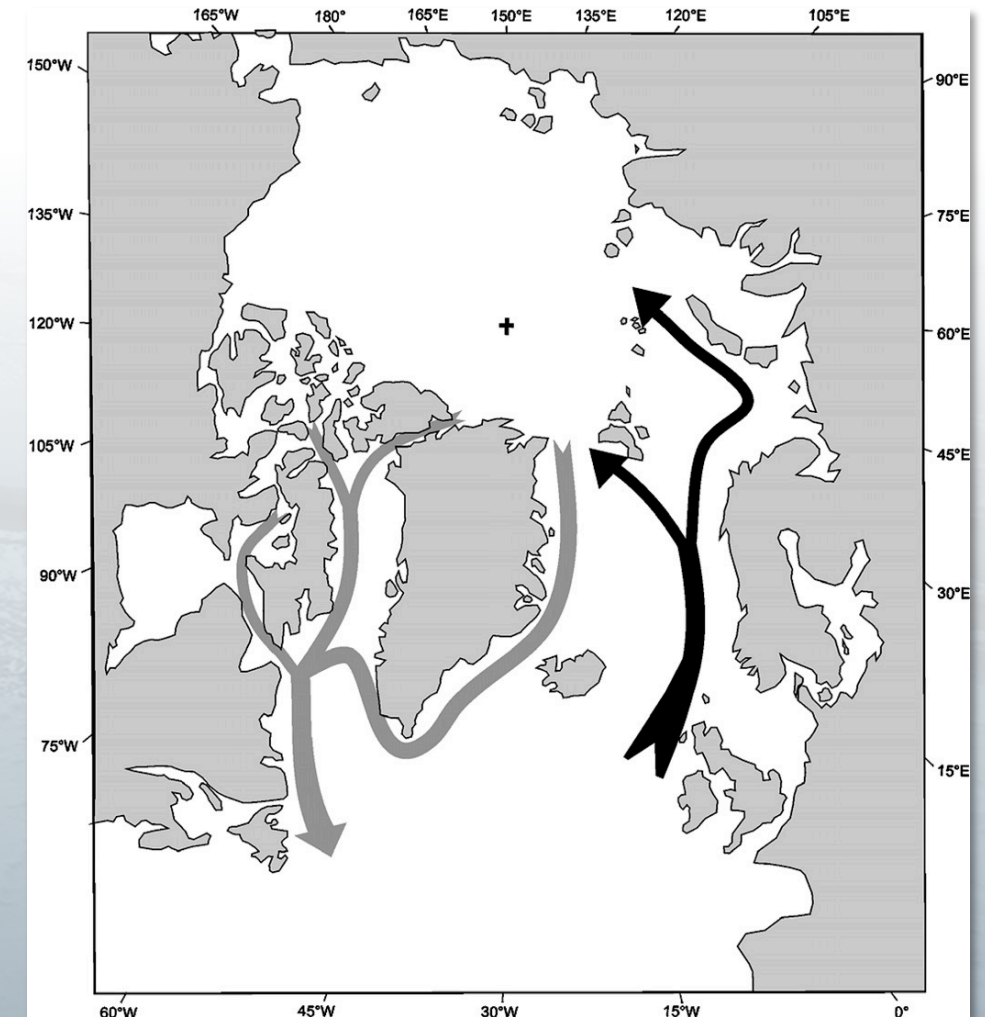
Proshutinsky et al. (2015)

Two-way Interactions Between Arctic and AMOC

Is northward inflow and southward outflow related?

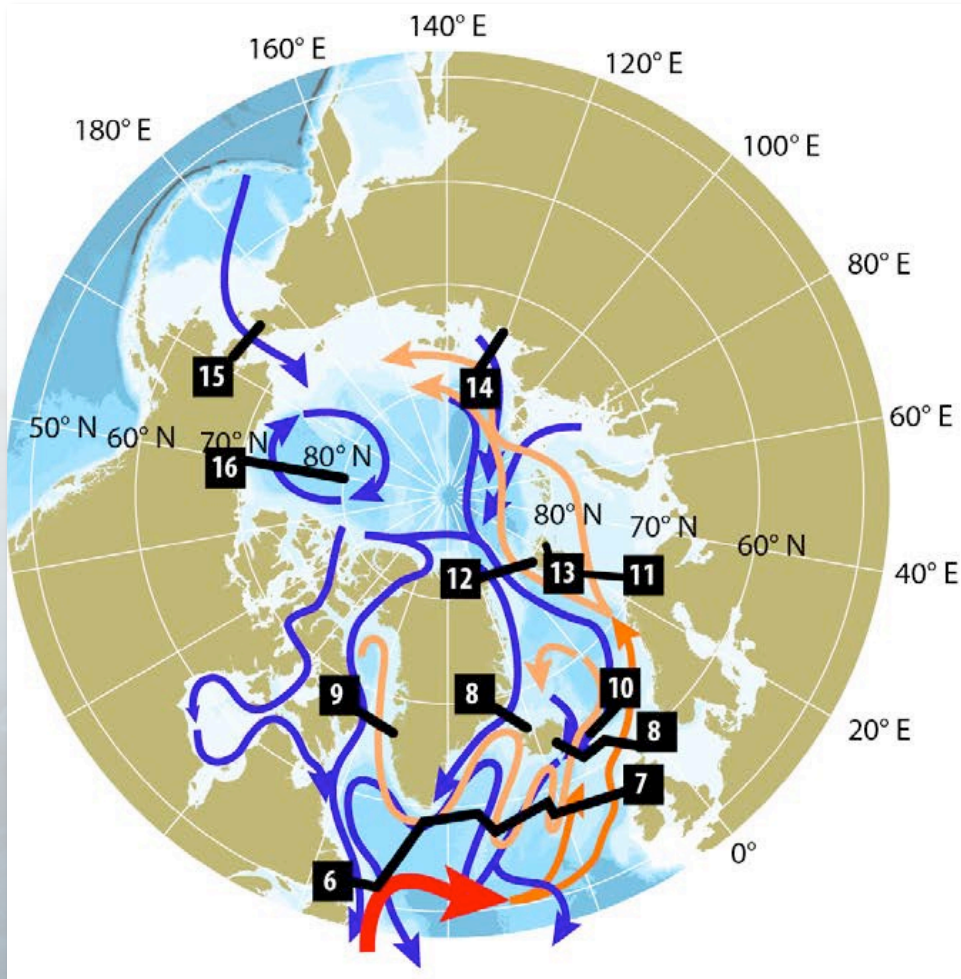


- Sundby & Drinkwater (2007):
 - GSAs may not reflect ‘salinity’ anomalies but ‘transport’ anomalies
 - Transport anomalies on the eastern and western side are anticorrelated
 - Fresh anomalies in the west (GSA’s) correspond to salty anomalies in the east (enhanced inflow of Atlantic Water)
 - May be driven by NAO



Sundby & Drinkwater (2007)

Monitoring Arrays



Berx et al. (2022)

- (6) The Overturning in the Subpolar North Atlantic Program (OSNAP) West array.
- (7) OSNAP East array.
- (8) the Greenland-Scotland Ridge (GSR) arrays.
- (9) Davis Strait array.
- (10) Svinoy mooring array.
- (11) Barents Sea Opening array.
- (12) Fram Strait array.
- (13) Long-term variability and trends in the Atlantic Water inflow region (ATWAIN) array.
- (14) Nansen and Amundsen Basin Observing System (NABOS).
- (15) Bering Strait array.
- (16) Beaufort Gyre Observing System (BGOS).

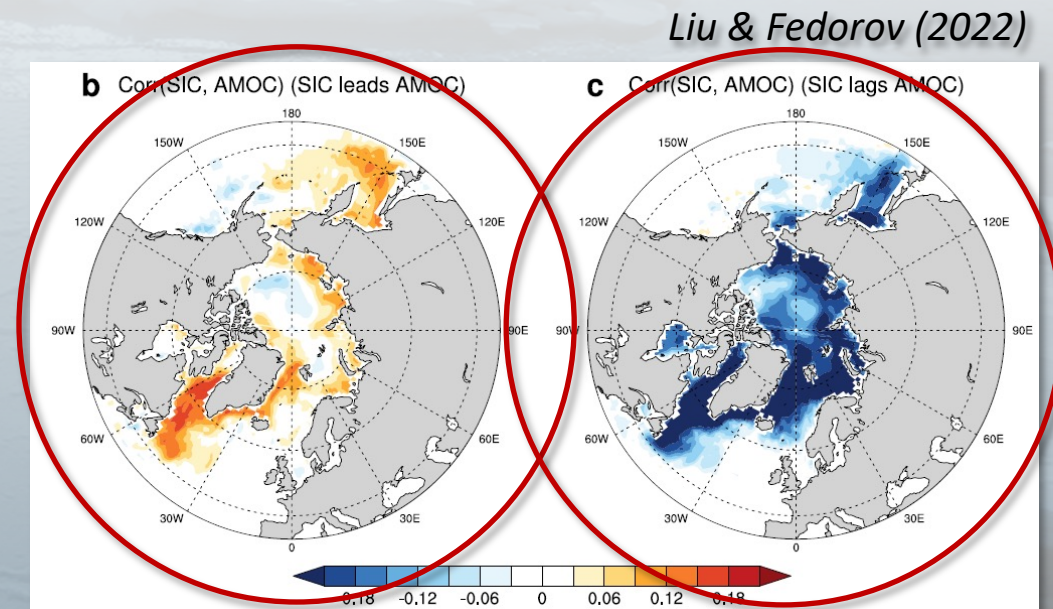
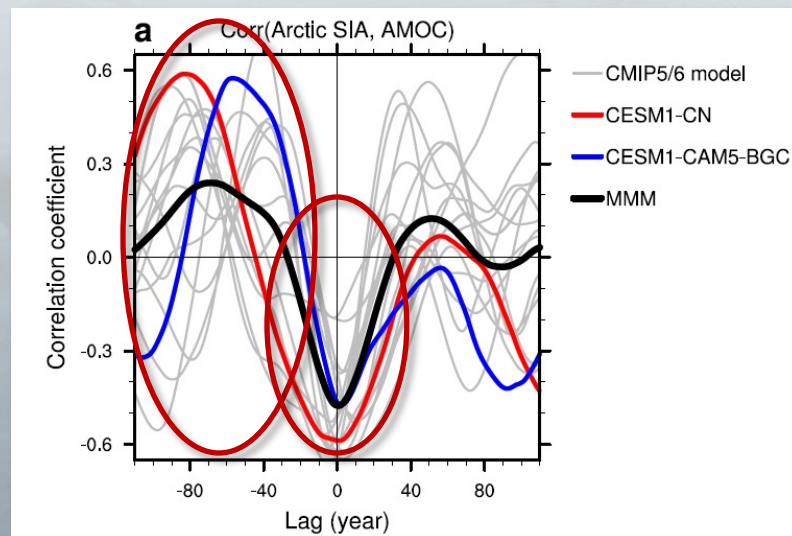
TWO-WAY INTERACTIONS BETWEEN ARCTIC AND AMOC

Two-way Interactions Between Arctic and AMOC

Is there evidence for two-way interactions between sea ice and AMOC?



- Liu & Fedorov (2022): explore two-way interactions in CMIP models
 - AMOC anti-correlated with sea ice area
 - AMOC leads by 1 year
 - Sea ice area correlated with AMOC
 - Sea ice leads by 80 years

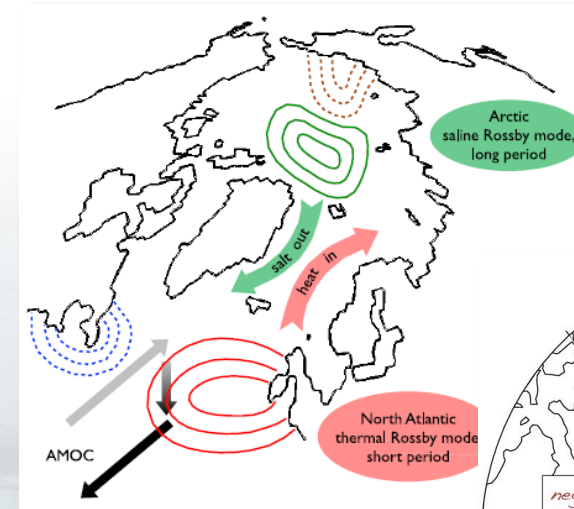


Two-way Interactions Between Arctic and AMOC

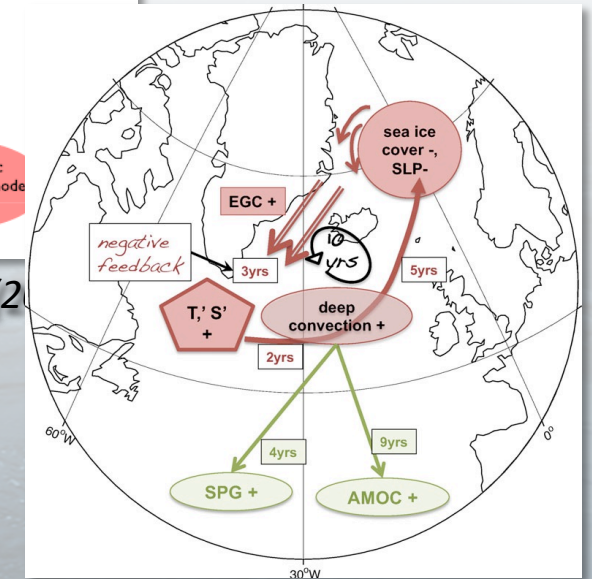
Is there evidence for two-way interactions between sea ice and AMOC?



- Other mechanisms have been proposed
 - Jungclaus et al. (2005)
 - Frankcombe & Dijkstra (2011)
 - Escudier et al. (2013)



Frankcombe & Dijkstra (2011)



Escudier et al. (2013)