

How much Arctic fresh water participates in the subpolar overturning circulation?

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Virtual EGU 2021 materials



Why did you do this?

- ▶ Climate models suggest that increasing fresh water will disrupt the overturning circulation, yet we lack a baseline of fresh water pathways in the present day.

How did you do it?

- ▶ We constructed an internally consistent budget based on *observations* that is independent of a reference salinity and acknowledges the circulation.

What is the answer?

- ▶ Half of the Polar Waters flowing through Fram Strait participate in the eastern subpolar overturning circulation, plus $\gtrsim$ half of the Nordic/subpolar Seas surface fresh water.

How can I learn more?

- ▶ Check out the next slides, contact me at vEGU2021, or at ilebras@whoi.edu
- ▶ Read the paper: <https://doi.org/10.1175/JP0-D-20-0240.1>

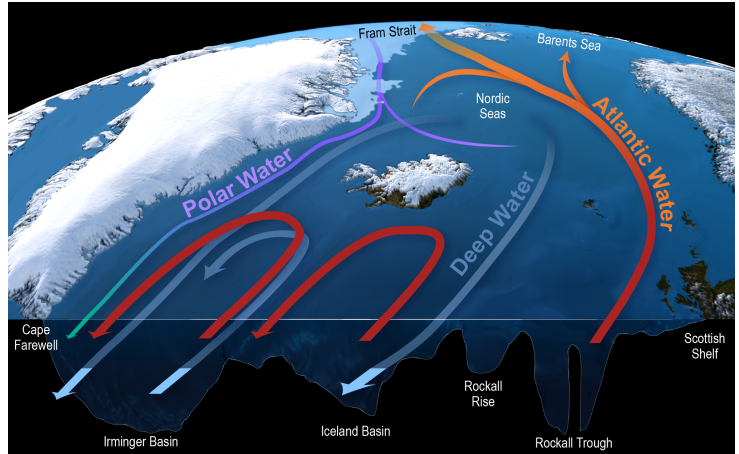
Circulation in the budget region:

We know that some fresh water participates in the overturning circulation as

- ▶ Deep Waters are fresher than Atlantic source waters

But not all of them, as

- ▶ Fresh Polar Waters are observed along full coast of Greenland



Observation based volume, salt, and heat budget

- Southern boundary: OSNAP East (Overturning in the Subpolar North Atlantic Program), 2014-2018

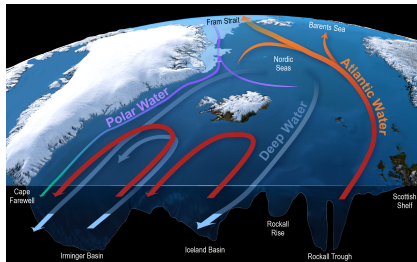
Lozier et al. 2019

- Northern boundary: Fram Strait and Barents Sea Opening, 2004-2010

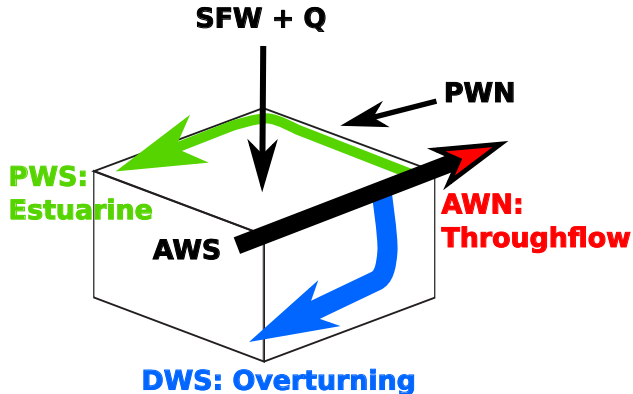
Ingvaldsen et al. 2004, Budeus et al. 2008,
Beszczynska-Möller et al. 2012, de Steur et al. 2014,
Tsubouchi et al. 2012,2018,2019

- Heat fluxes and surface fresh water fluxes from JRA55-do reanalysis/NorESM, 2000-2018

Tsujino et al. 2018, Bentsen et al. 2019



Split budget into water masses reflecting transformations



AW: Atlantic Water

PW: Polar Water

DW: Deep Water

SFW: Surface Fresh Water

Q: Heat flux

N: North

S: South

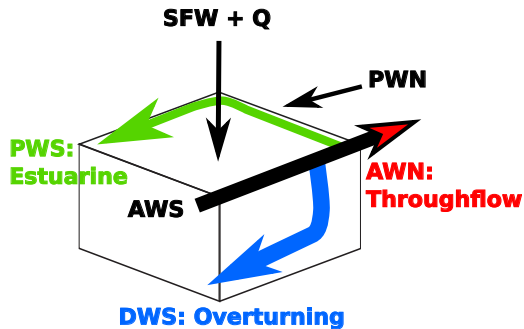
Budget framework: weighted linear inverse model

Steady-state conservation of

$$\text{volume} : \sum_i U_i = 0$$

$$\text{salt} : \sum_i S_i U_i = 0$$

$$\text{heat} : \sum_i T_i U_i = \frac{Q}{\rho_o c_p}$$



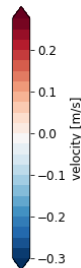
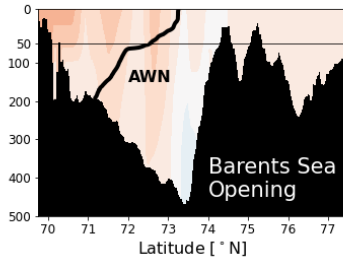
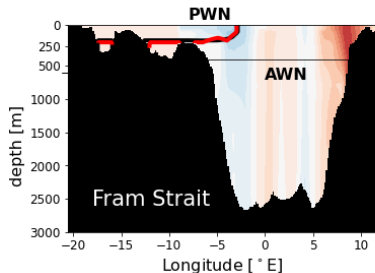
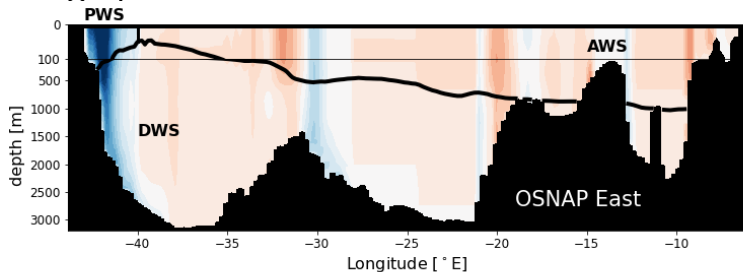
Water mass and SFW transports (U_i) and Q are unknowns

→ 3 equations, 7 unknowns (all elements in schematic)

SFW is a water mass with $S = 0$, $T = 0$ (no reference salinities)

→ Get S_i , T_i , and initial conditions from observations

Geographic distribution of water masses:

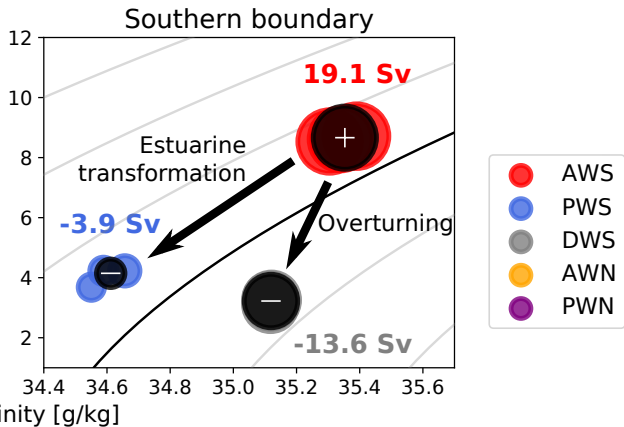
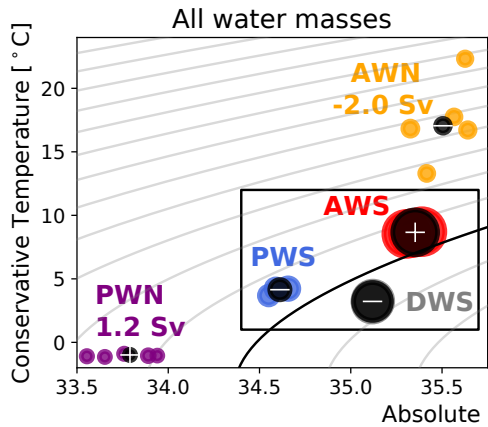


Black line: OSNAP
overturning isopycnal

Red line: 0°C isotherm

Integrate properties
over entire domain

Lozier et al. 2019,
Tsubouchi et al. 2019



$$T_i = \iint_i T \mathbf{u} \cdot \mathbf{n} dA / \iint_i \mathbf{u} \cdot \mathbf{n} dA;$$

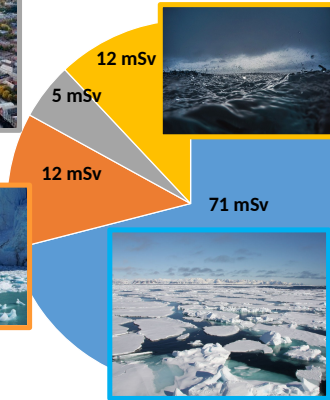
$$S_i = \iint_i S \mathbf{u} \cdot \mathbf{n} dA / \iint_i \mathbf{u} \cdot \mathbf{n} dA;$$

Surface fresh water (SFW) and heat fluxes (Q)

► SFW = 100 mSv

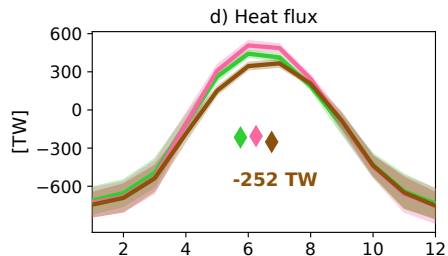
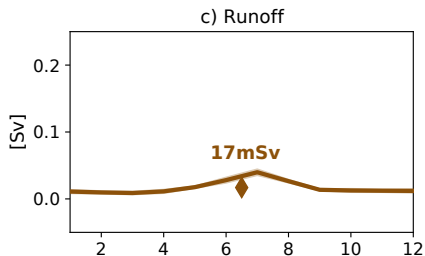
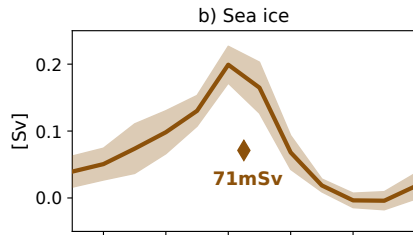
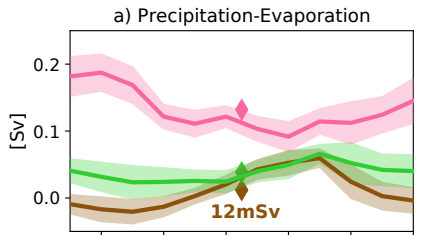
► Q = - 252 TW

JRA55-do/NorESM;
Tsujino et al. 2018,
Bentsen et al. 2019



Means over 2000 - 2018
NorESM and JRA55-do based

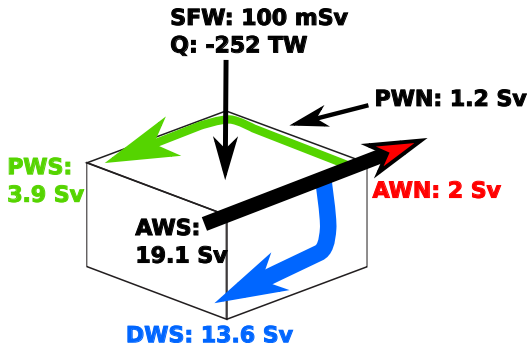
- Sea ice melt
- Runoff: Greenland
- Runoff: Rivers
- Precipitation -Evaporation



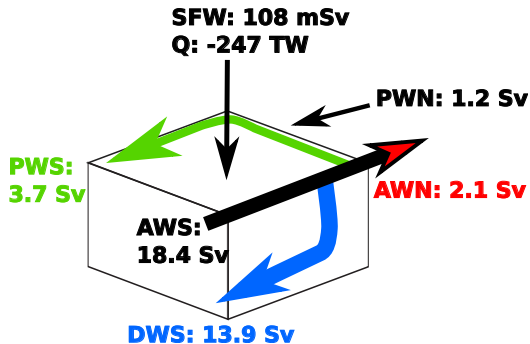
Month



Initial conditions:



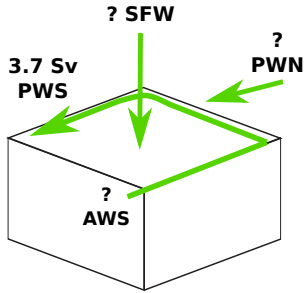
Inverse model solution:



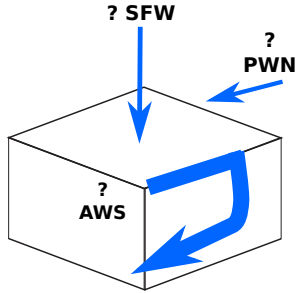
Initially: too much volume, heat, salt flowing in

Model adjustments: AWS ↓, SFW ↑

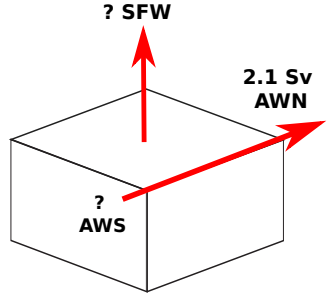
How are PWN and SFW split between each circulation component?



Estuarine (PWS)



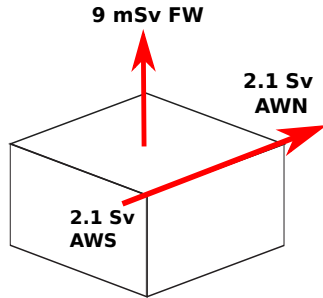
Overturning (DWS)



AW Throughflow (AWN)

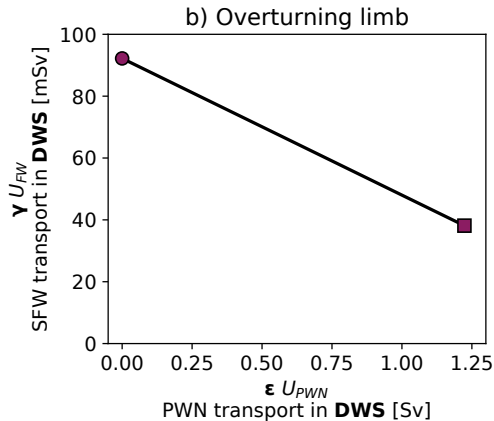
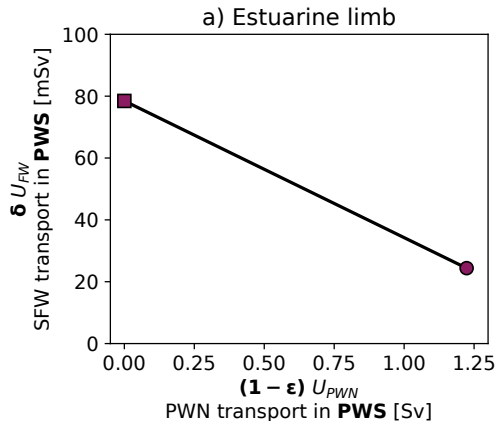
Can eliminate the Atlantic Water throughflow limb (it is not the focus)

- ▶ Assume no participation of Polar Water North in the AW throughflow
- ▶ Leaves 117 mSv of Surface Fresh Water fluxes for the overturning and estuarine circulations

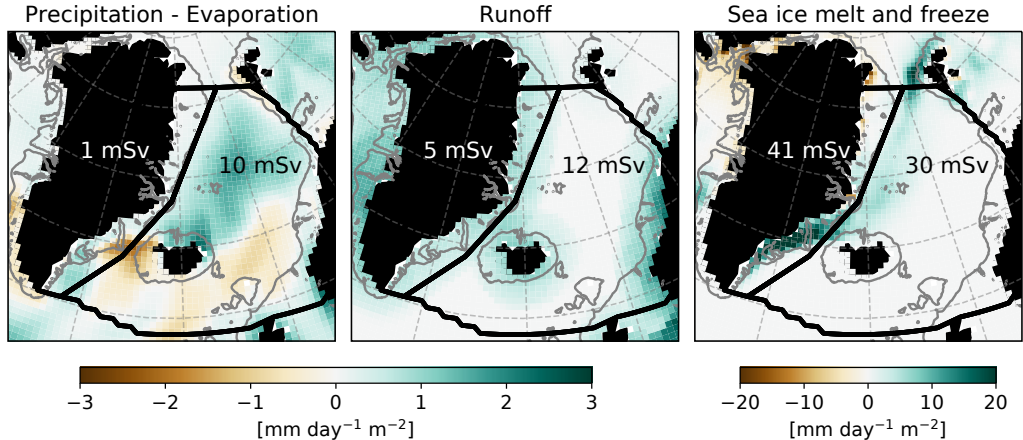


AW Throughflow (AWN)

Two sources of freshening: **P**olar **W**ater **N**orth and **S**urface **F**resh **W**ater
 Two resulting water masses: **P**olar **W**ater **S**outh and **D**eep **W**ater **S**outh
 All possible solutions:

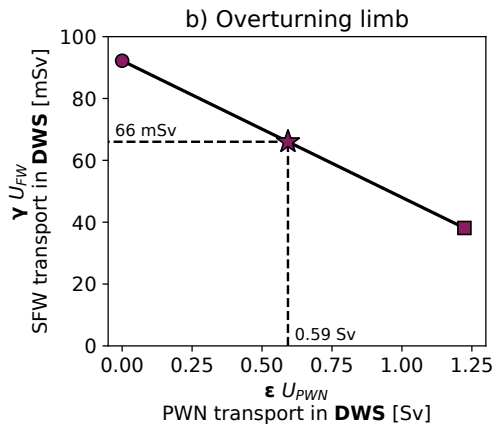
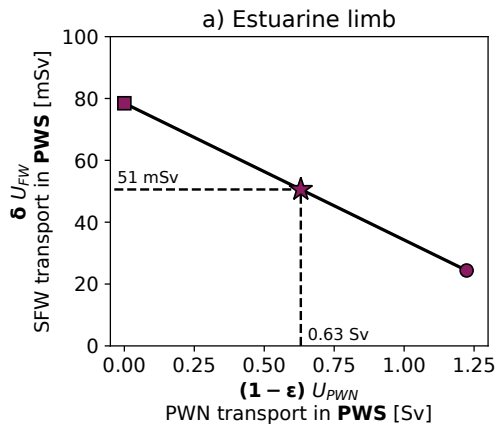


Constrain SFW participation using geographic distribution



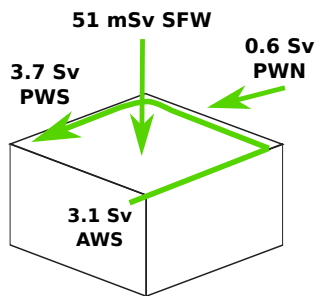
47%: west, Estuarine circulation; 53% east, Overturning circulation and AW throughflow

Best guess solution

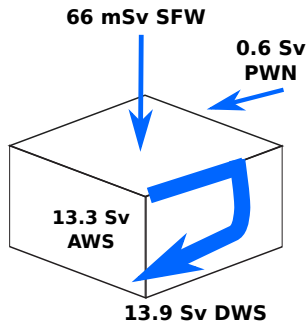


Final answer to:

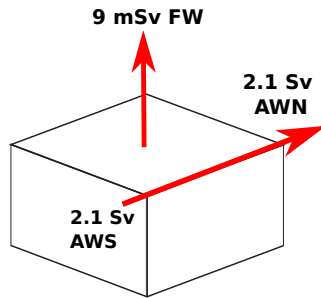
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Estuarine Limb (PWS)



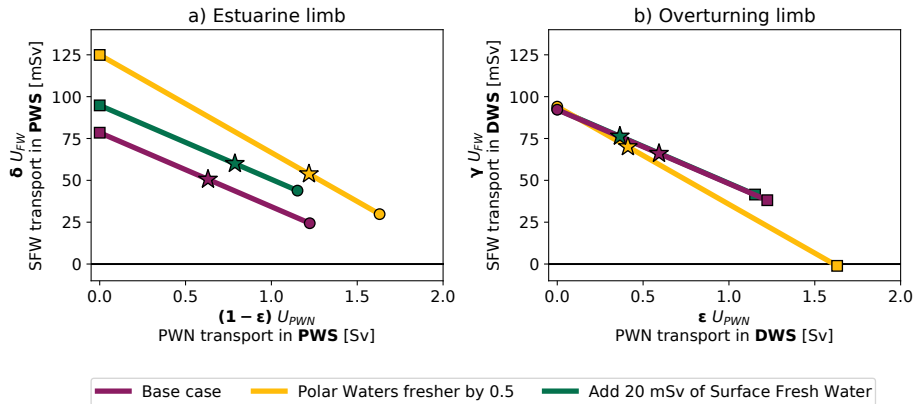
Overturning Limb (DWS)



AW Throughflow (AWN)

Consistent with transport offshore of the shelfbreak, as well as with the literature (de Steur et al. 2014, Tsubouchi et al. 2019, Foukal et al. 2020, Håvik et al. 2017)

Examining major uncertainties



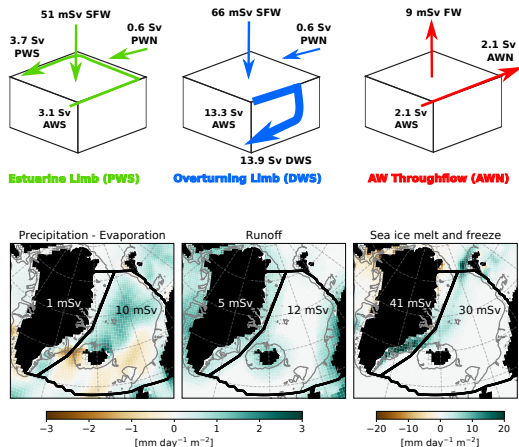
Stars: best guess solutions

About 0.5 Sv of Polar Water participates in overturning circulation in each case

Overall numbers are sensitive to assumptions, particularly for the estuarine circulation

How much Arctic fresh water participates in the subpolar overturning circulation?

- ▶ Half of the Polar Waters flowing through Fram Strait, plus substantial surface fresh water fluxes
- ▶ Arctic fresh water release more likely to impact overturning circulation than Greenland melt
- ▶ Framework could be applied to compare models with observations



Le Bras et al. 2021, Journal of Physical Oceanography