Subpolar and subtropical Atlantic overturning: sources of interannual variability and meridional coherence

Yavor Kostov*, Marie-José Messias*, Herlé Mercier**,
Helen Johnson+, David Marshall+,
Patrick Heimbach++, Gael Forget***,
Penny Holliday#, Susan Lozier##, Feili Li##, +++,
Helen Pillar++, Timothy Smith###

*U. of Exeter; **IFREMER – Brest; +U. of Oxford; ++ U. of Texas – Austin; ***MIT; #National Oceanography Centre, UK; ##Georgia Tech; +++Xiamen University; ### GFDL, Princeton

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ARTICLES

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Distinct sources of interannual subtropical and subpolar Atlantic overturning variability

Yavor Kostov[1], Helen L. Johnson[2], David P. Marshall[3], Patrick Heimbach[4,5,6], Gael Forget[7], N. Penny Holliday[8], M. Susan Lozier[9], Feili Li[9], Helen R. Pillar[4] and Timothy Smith[4]

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Climate Dynamics

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Fast mechanisms linking the Labrador Sea with subtropical Atlantic overturning

Yavor Kostov[1] · Marie-José Messias[1] · Herlé Mercier[2] · Helen L. Johnson[3] · David P. Marshall[4]

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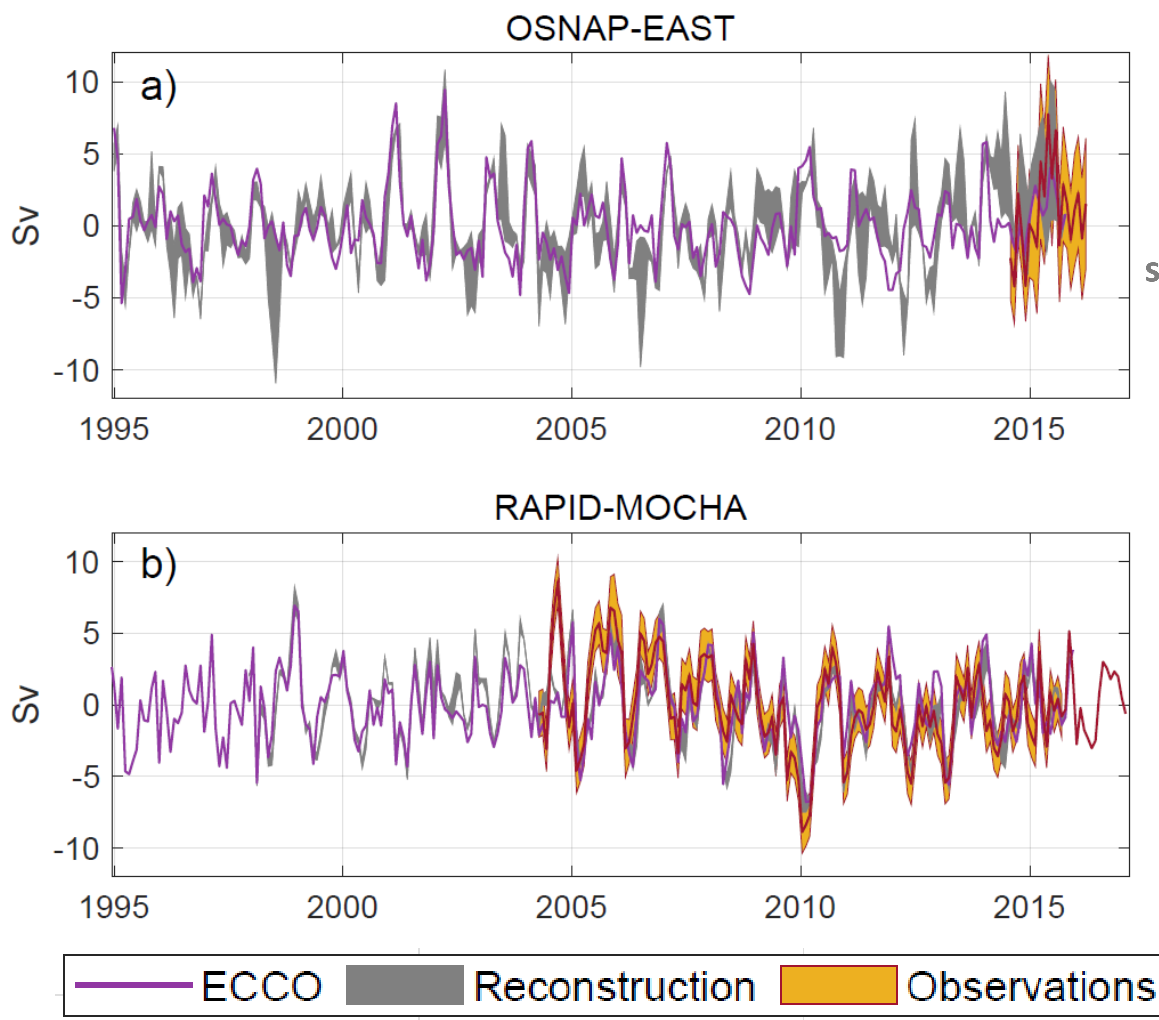
Both studies use the ECCOv4 configuration and the adjoint of the MITgcm.

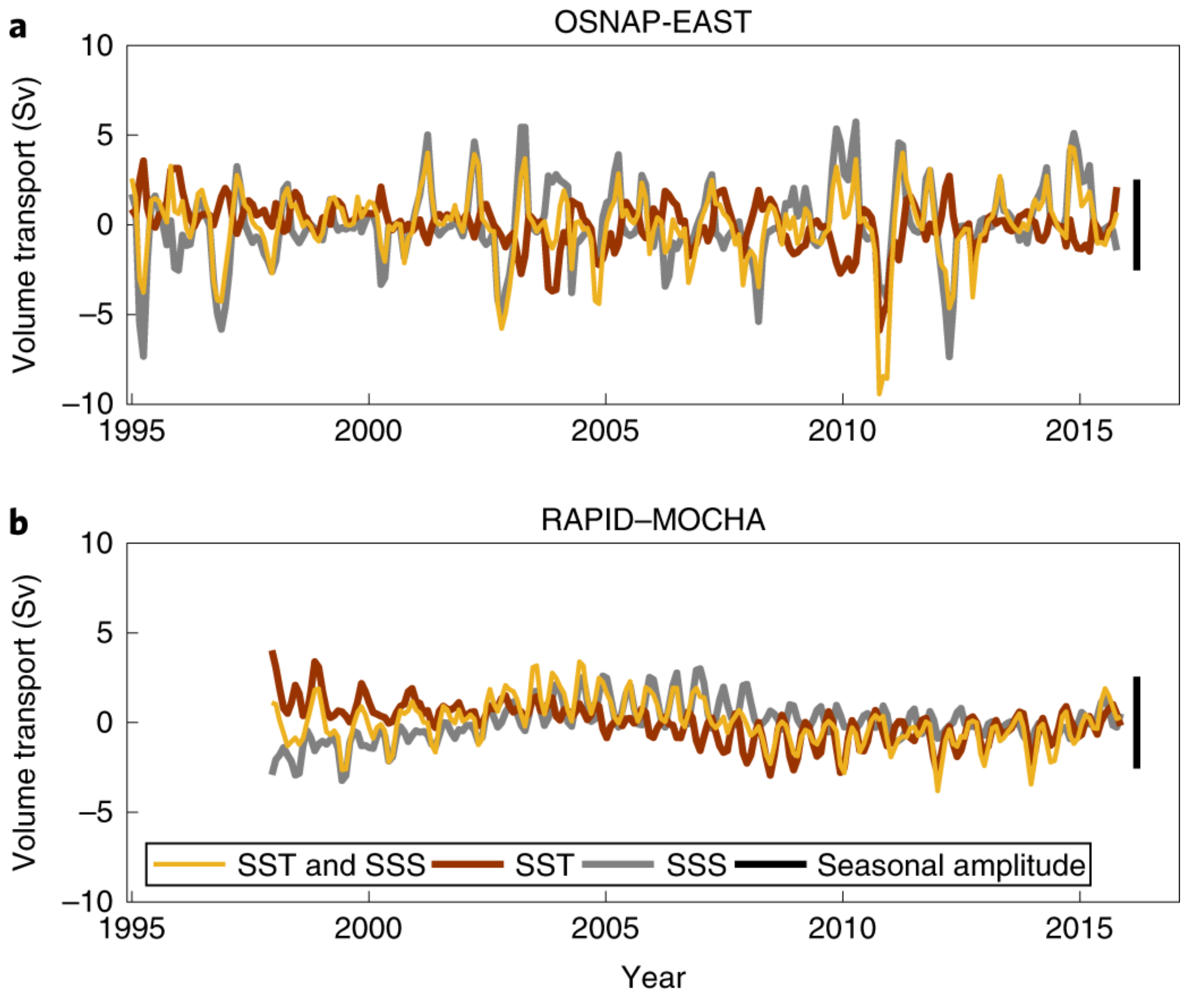
Reconstruction of RAPID AMOC and OSNAP-EAST variability using the adjoint sensitivity patterns and surface boundary conditions: SST, SSS, wind stress



OSNAP EAST overturning defined in density space rather than the model's depth space

Kostov et al. (2021)

Reconstruction of variability using only SST and SSS

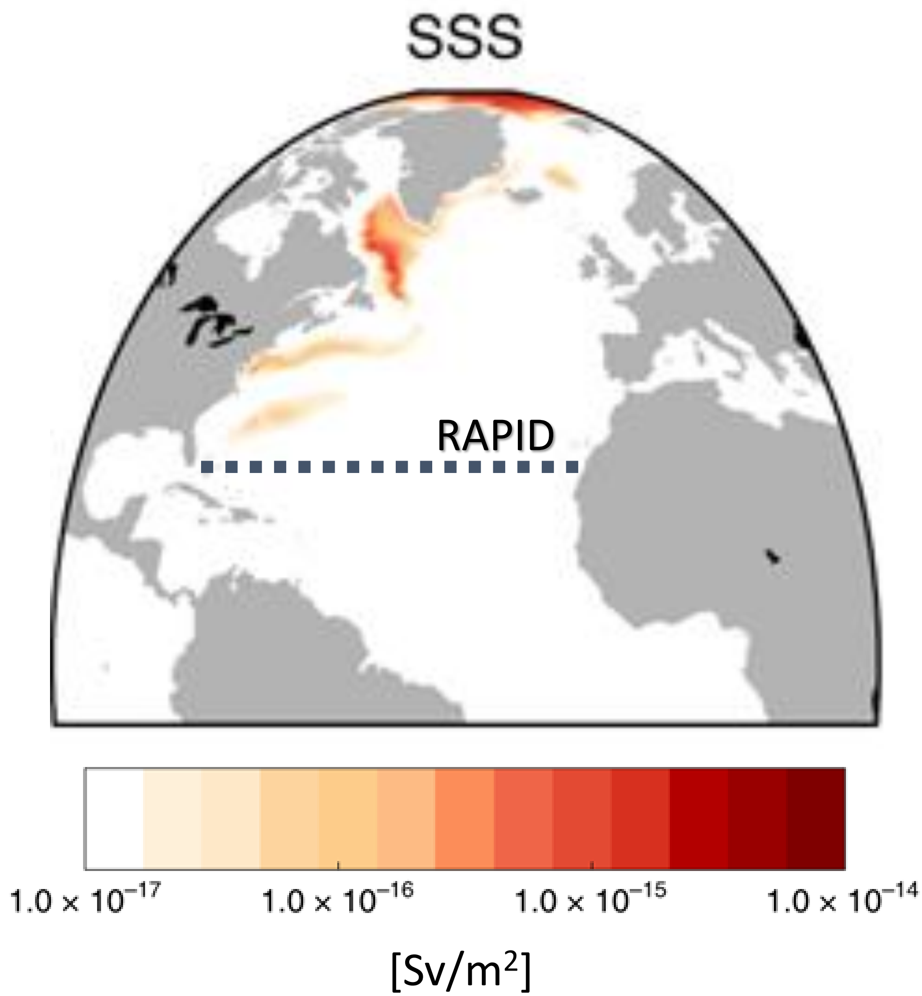


Partial density compensation

Smeed et al. (2014) 2004-2012 step decline in the RAPID AMOC

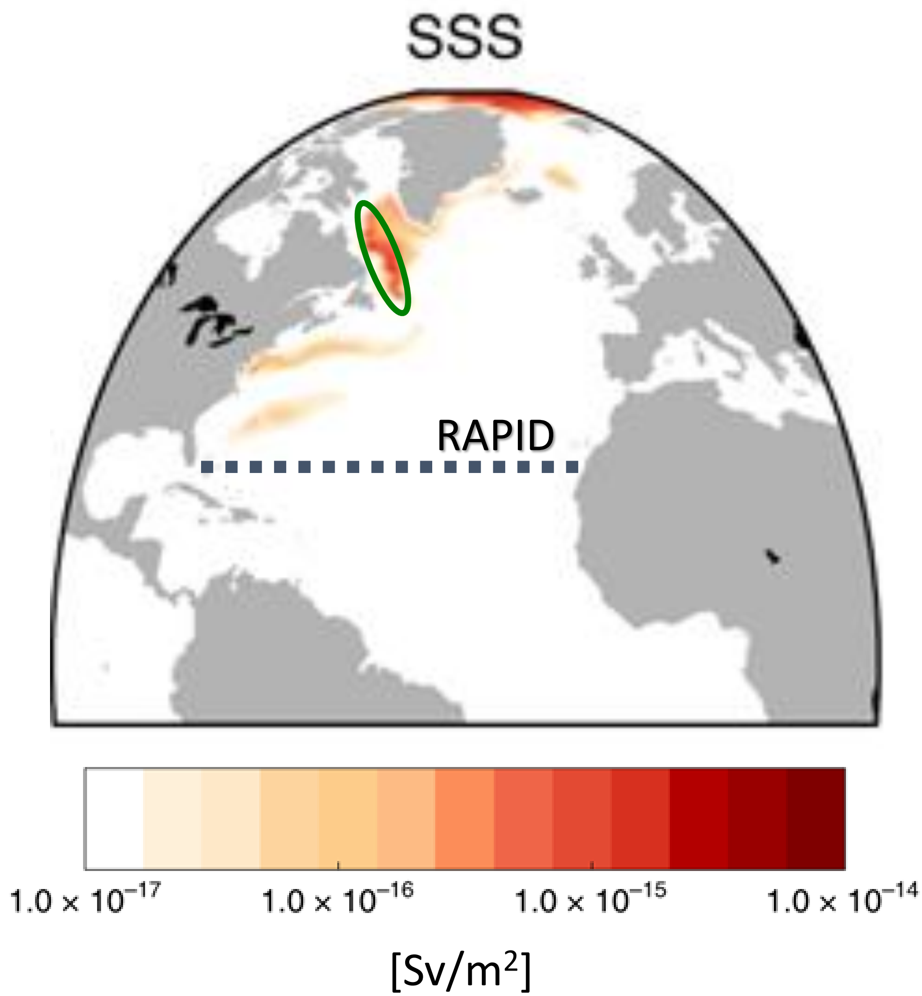
Kostov et al. (2021)

Contribution of SSS to RAPID AMOC variability



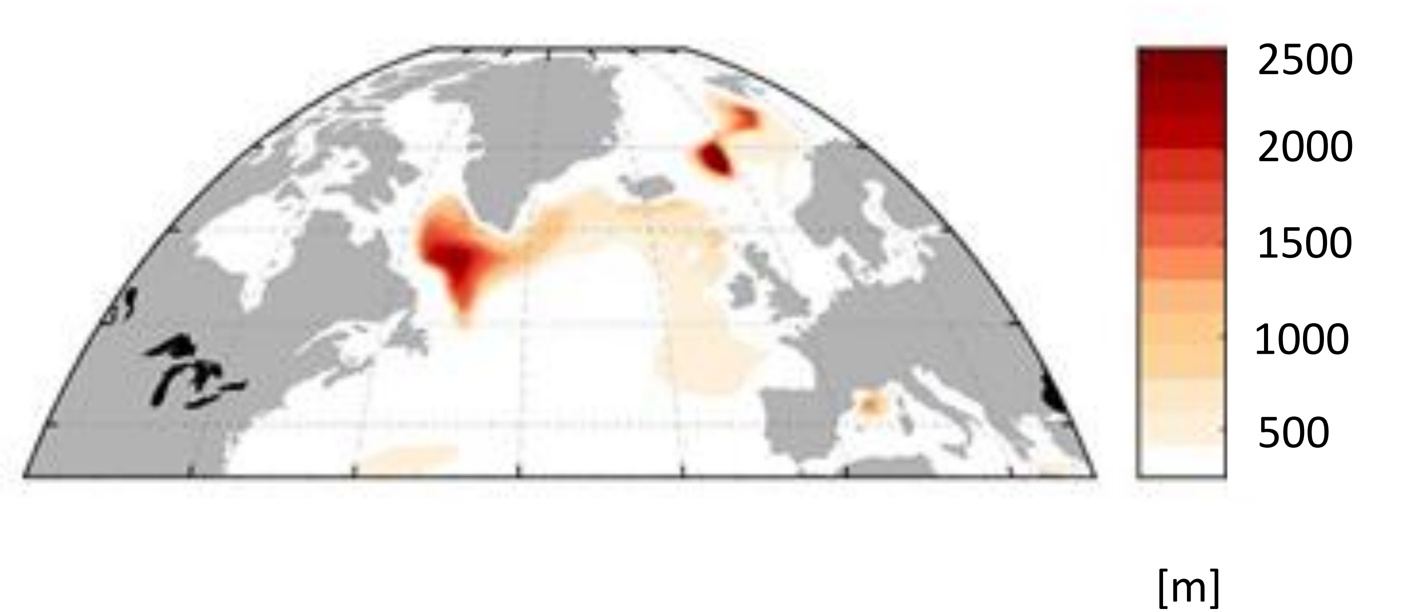
Kostov et al. (Nature Geoscience, 2021)

Contribution of SSS to RAPID AMOC variability



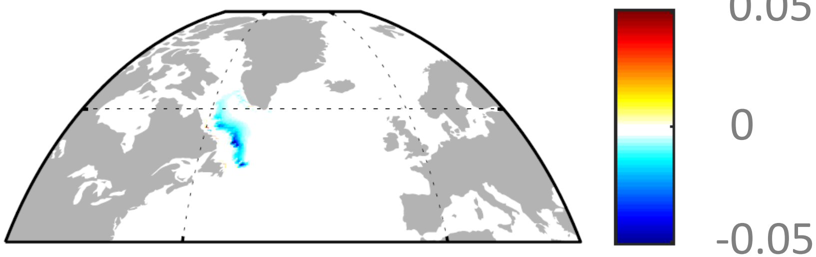
Kostov et al. (Nature Geoscience, 2021)

March mixed layer depth in ECCO



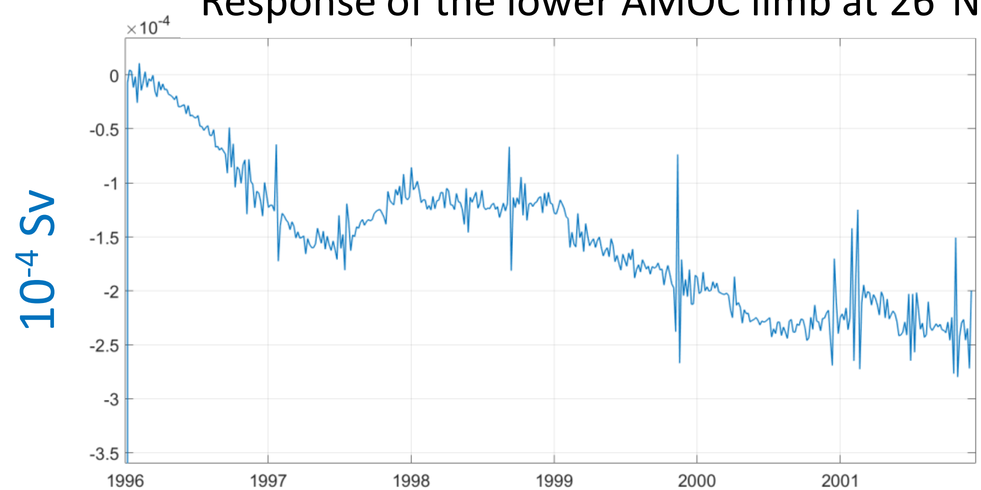
Kostov et al. (published in Nature Geoscience, 2021)

SSS perturbation [psu]



We impose a deliberately small negative SSS initial condition perturbation with this pattern in the **Western Labrador Sea.**

Response of the lower AMOC limb at 26°N

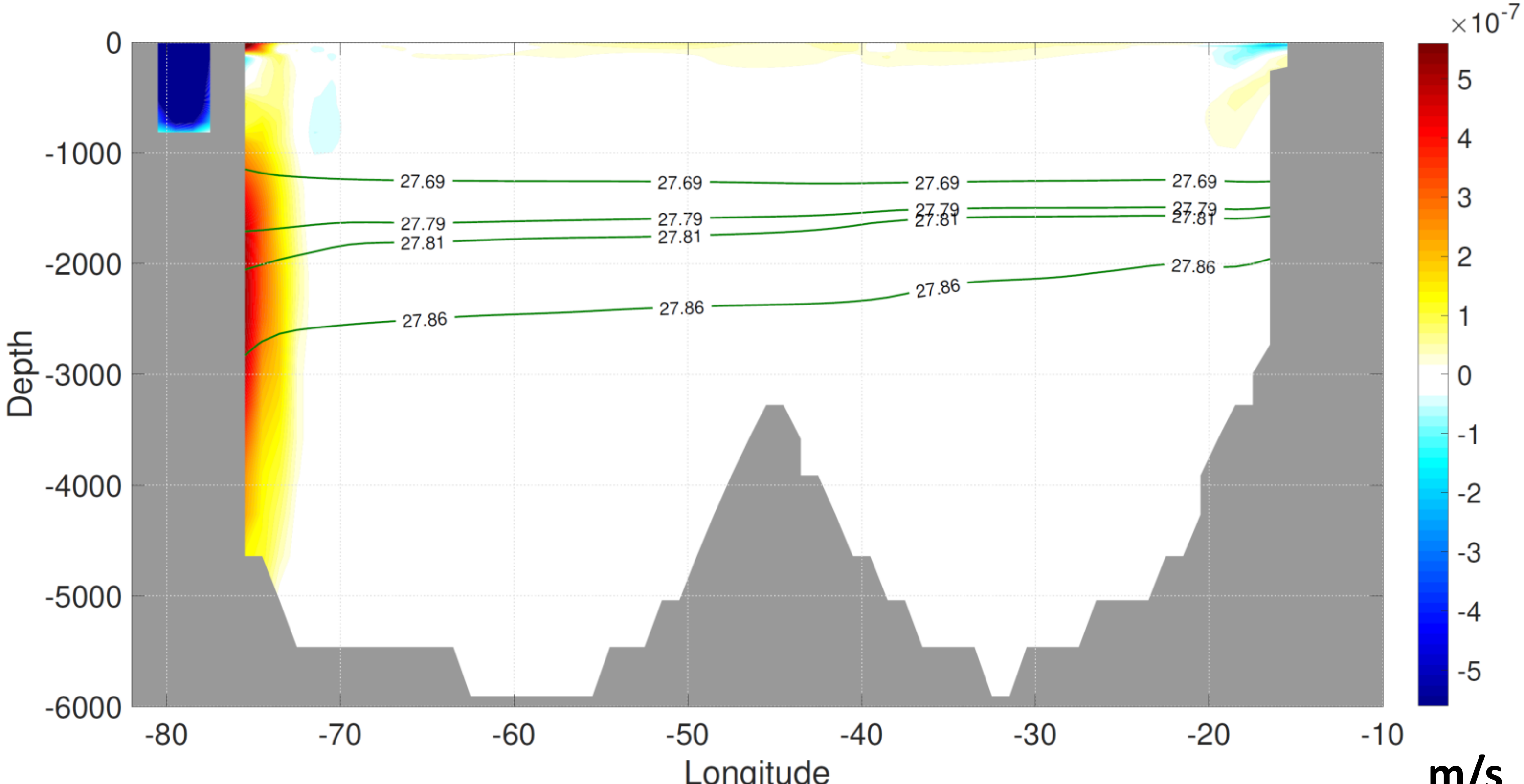


RAPID-AMOC response to a small SSS anomaly with the above pattern applied as an initial condition perturbation in Jan. 1996

Kostov et al. (2022), Climate Dynamics

Slowdown in the LSW & LNADW layers at 26°N

Anomaly 4.5 years after the Labrador Sea SSS perturbation

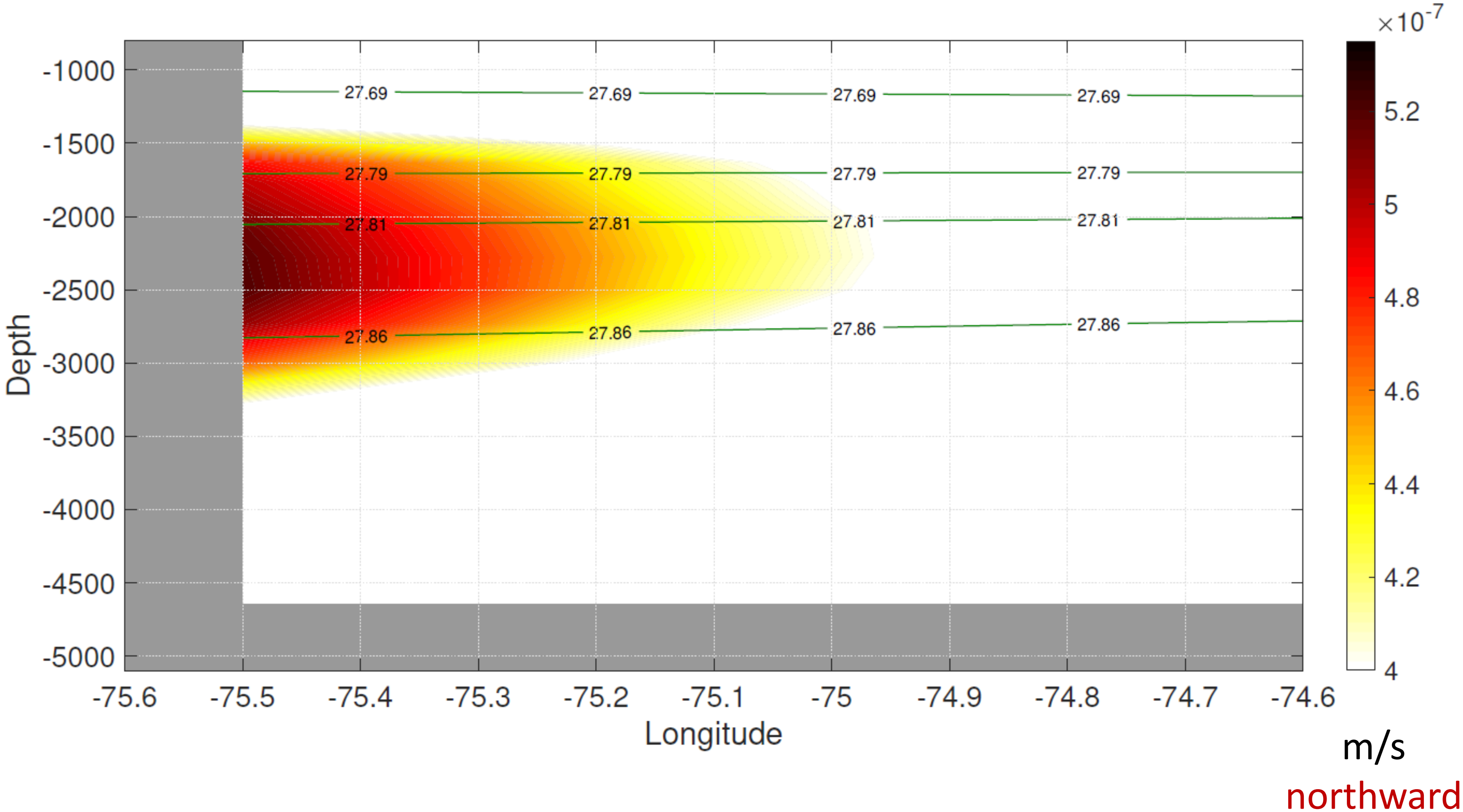


m/s

northward

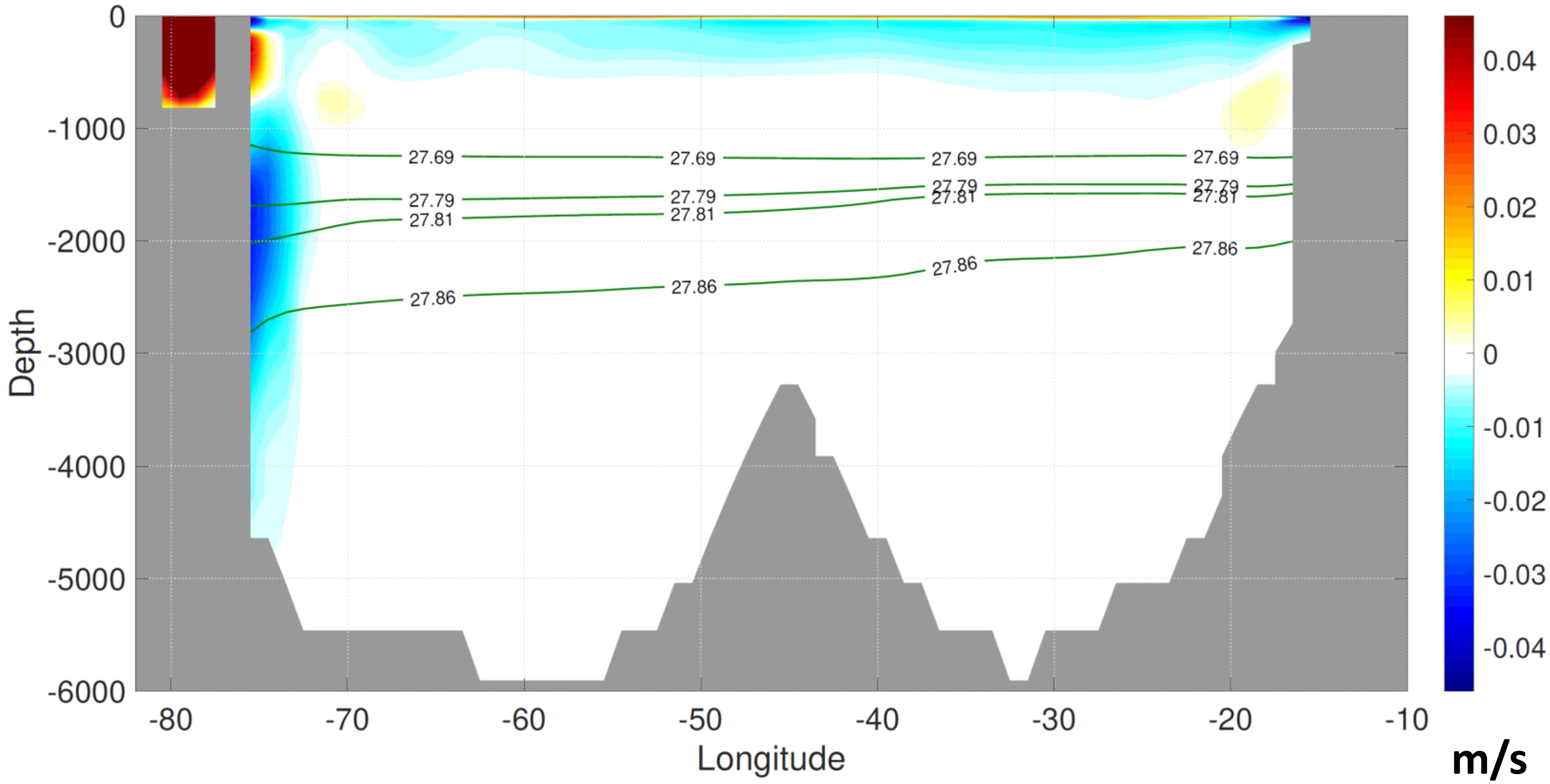
Slowdown in the LSW & LNADW layers at 26°N

Velocity anomaly 4.5 years after the Labrador Sea SSS perturbation



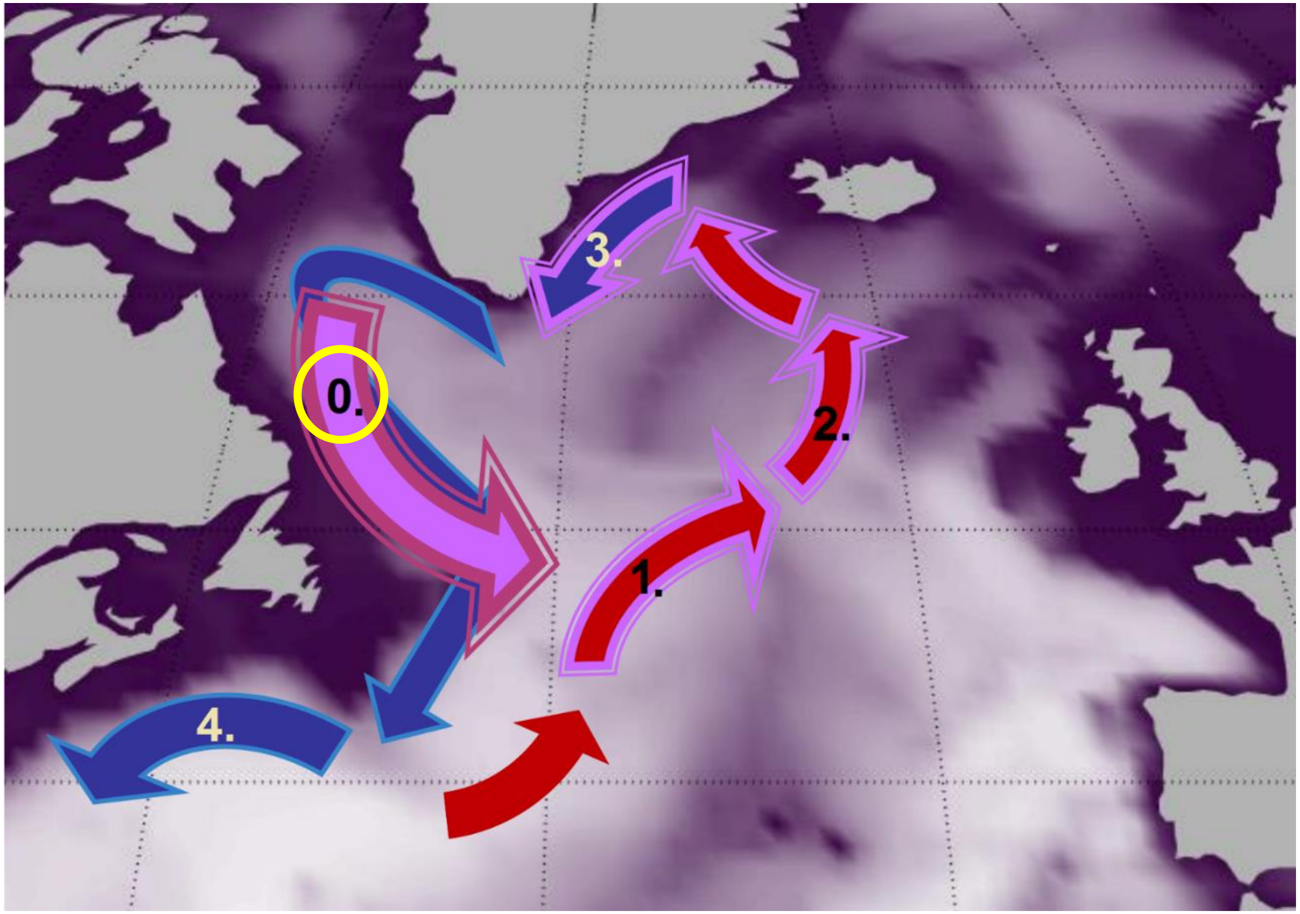
However, the climatological DWBC at 26°N in ECCO is strongest in the lighter LSW layer.

<u>Time-mean climatological</u> circulation at 26°N: deep boundary current strongest in the LSW layer

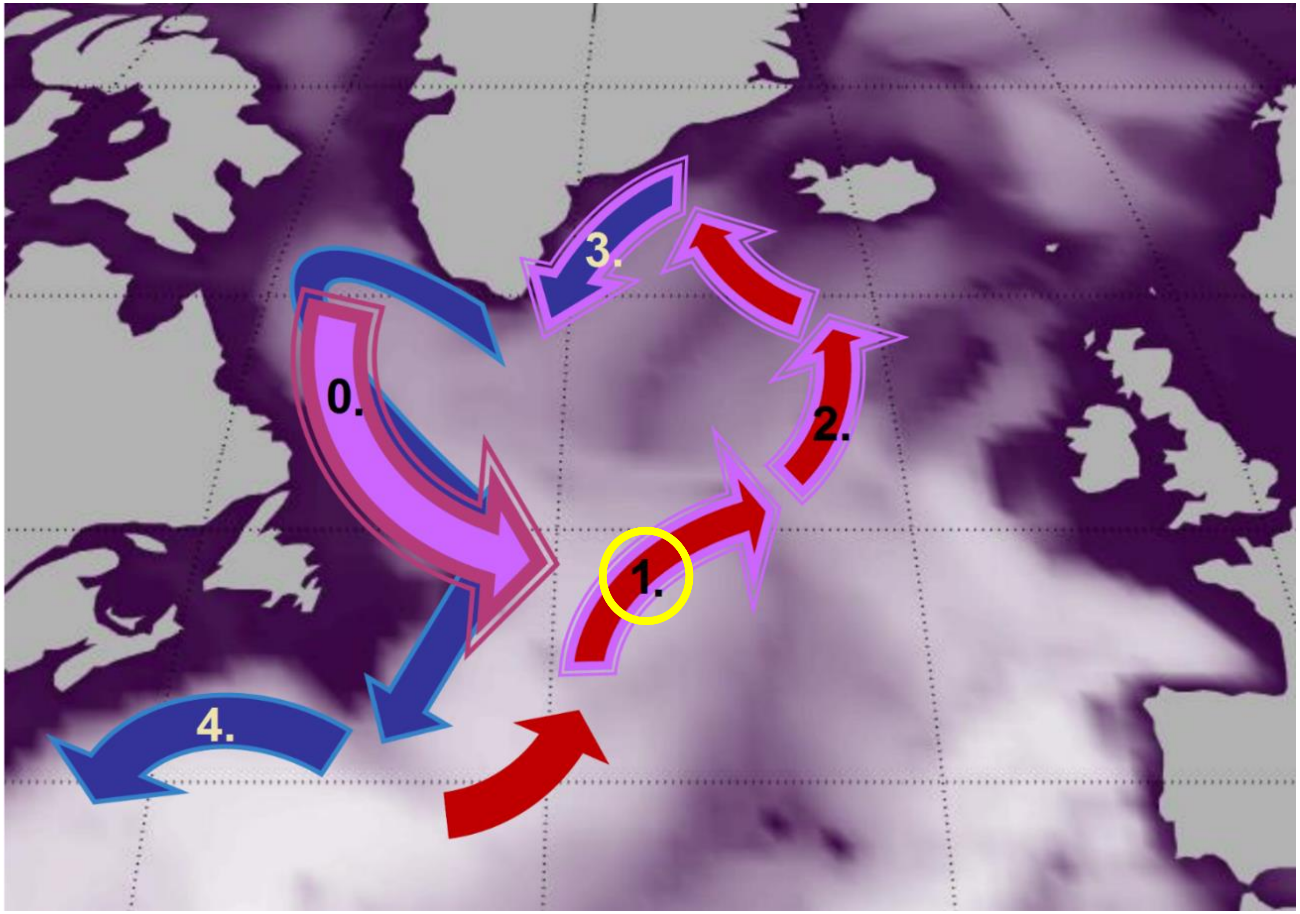


m/s

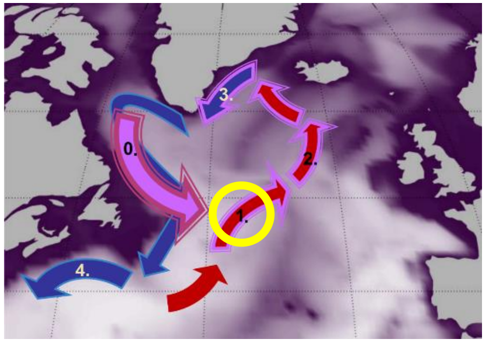
northward



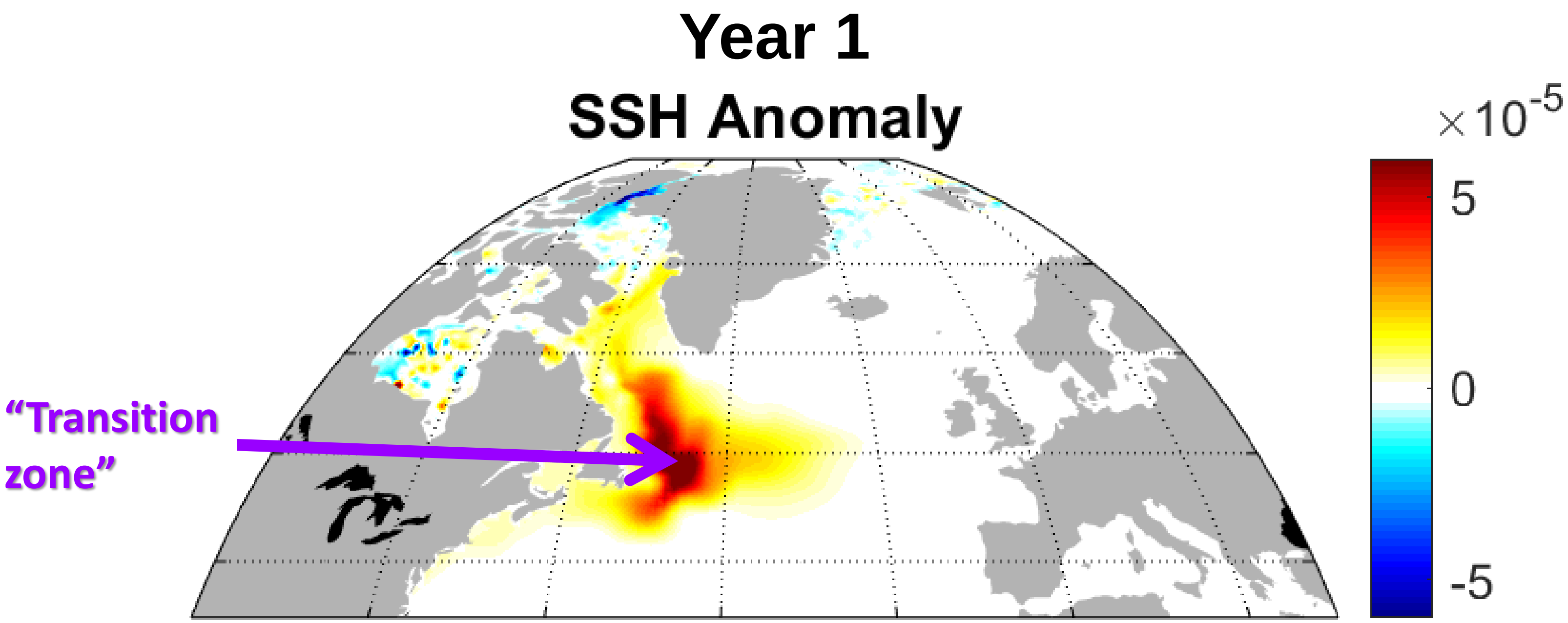
Causal Chain

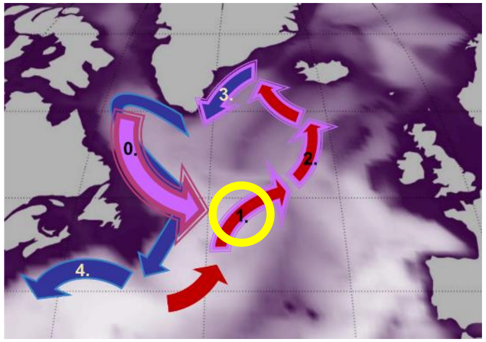


Causal Chain



1. Response of the NAC across 45°N





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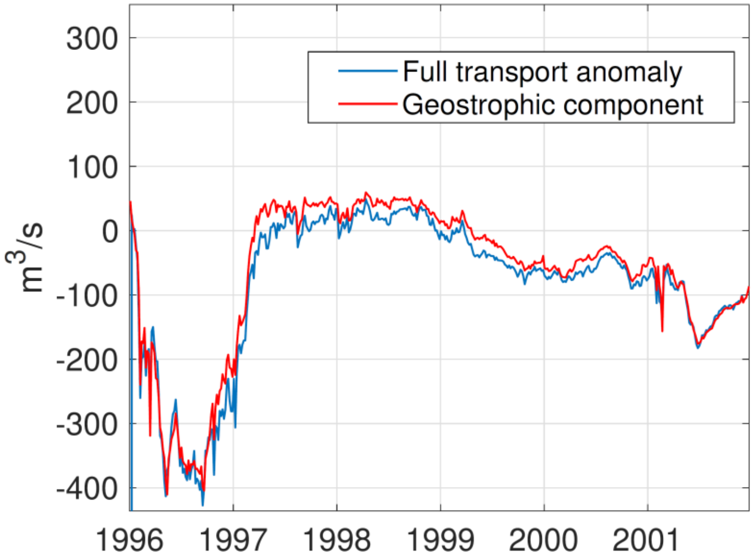
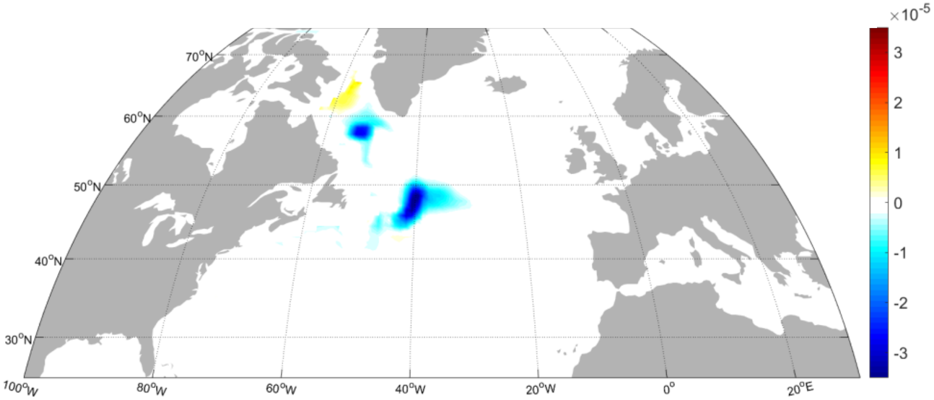
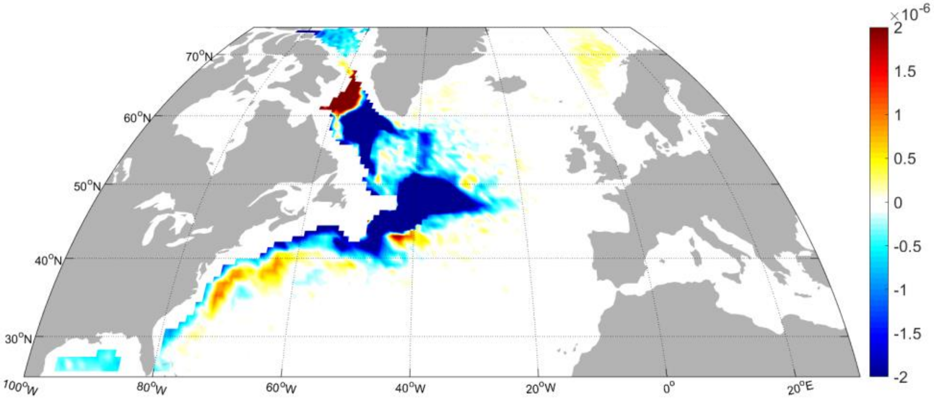


ρ in-situ anomaly [kg m⁻³] at 550 m in Months 6 to 12



Same but with a saturated color scale

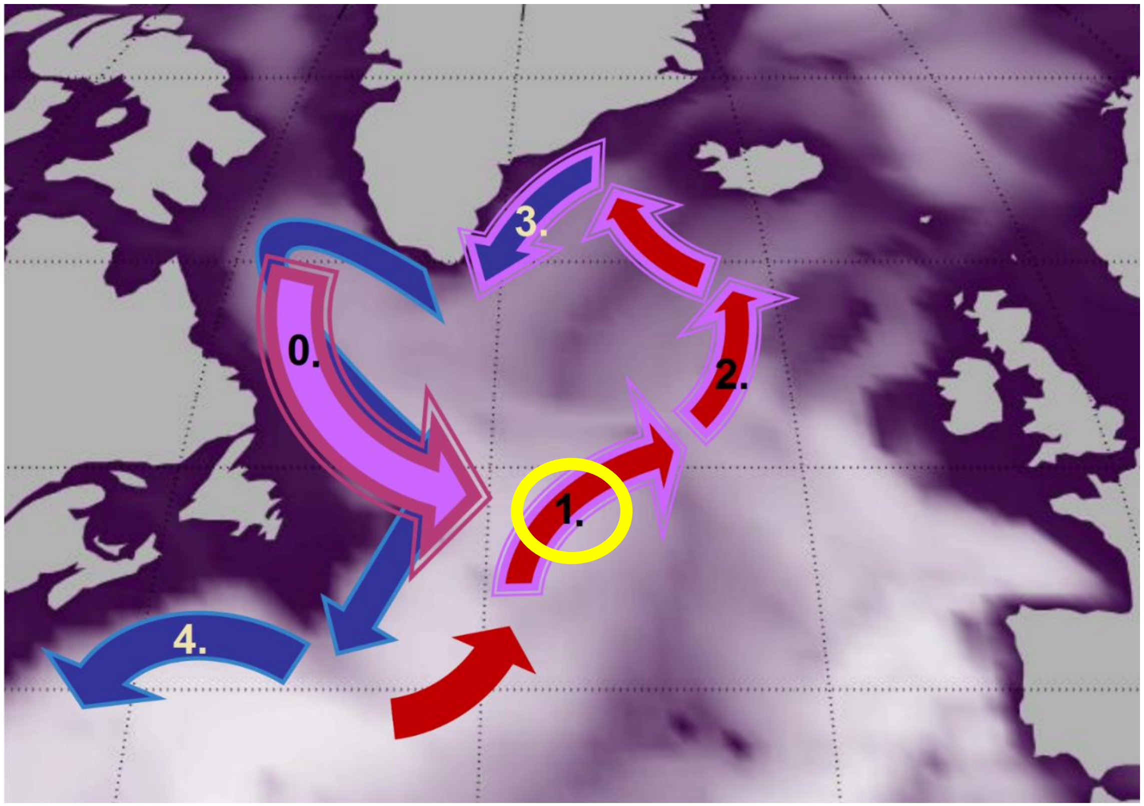


Negative density anomaly communicated along the western boundary → fast AMOC slowdown.

0. Labrador Sea SSS anomaly

<1 year

1. Adjustment of the NAC



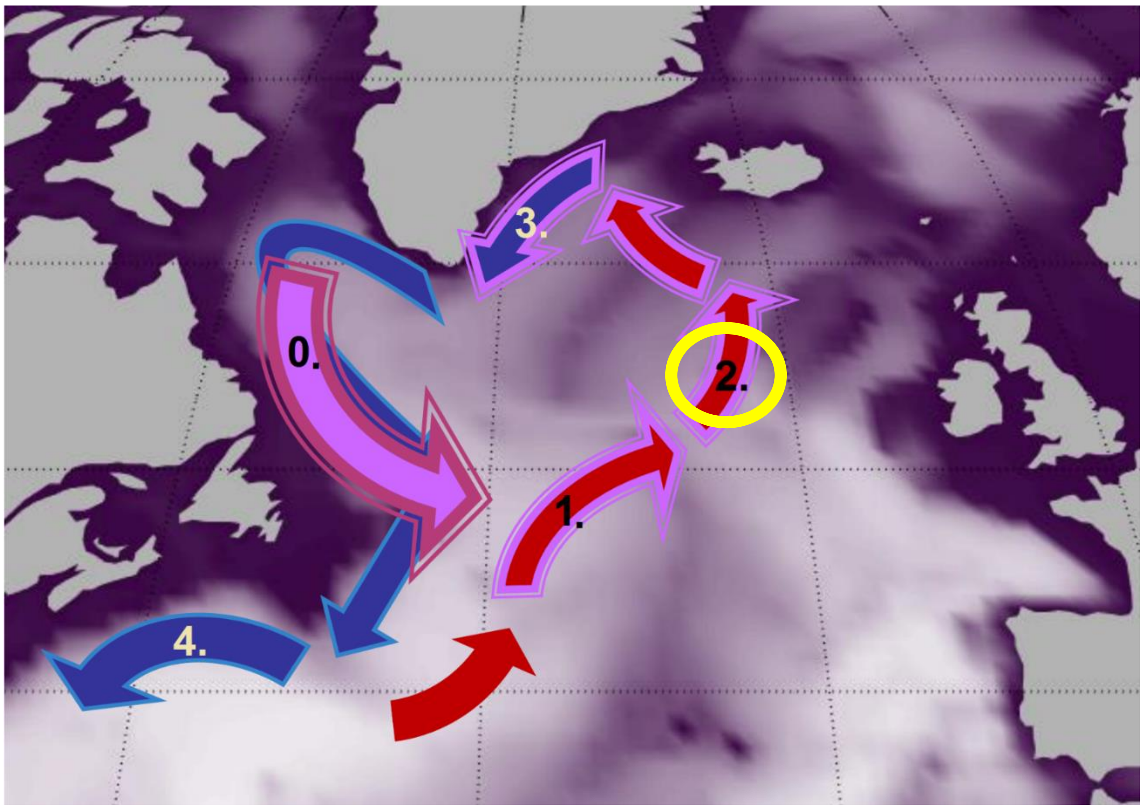
0. Labrador Sea SSS anomaly

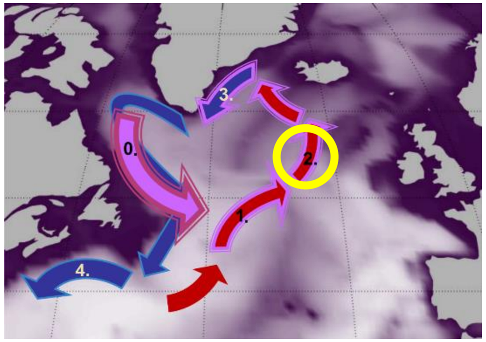
→ <1 year

1. Adjustment of the NAC

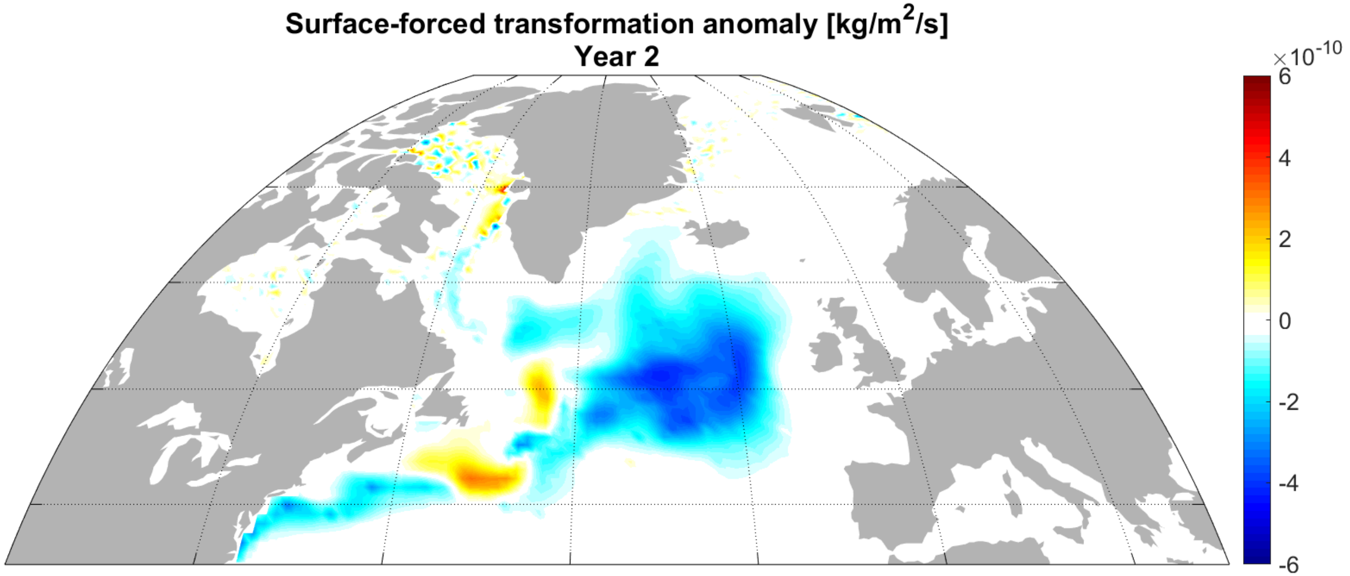
→ ~1 year

2. Anomaly in the Iceland Basin water mass transformation





Positive feedback mechanism:
2. Surface water mass transformation



Less water mass densification at the surface of the eastern subpolar gyre.

0. Labrador Sea SSS anomaly

<1 year

1. Adjustment of the NAC

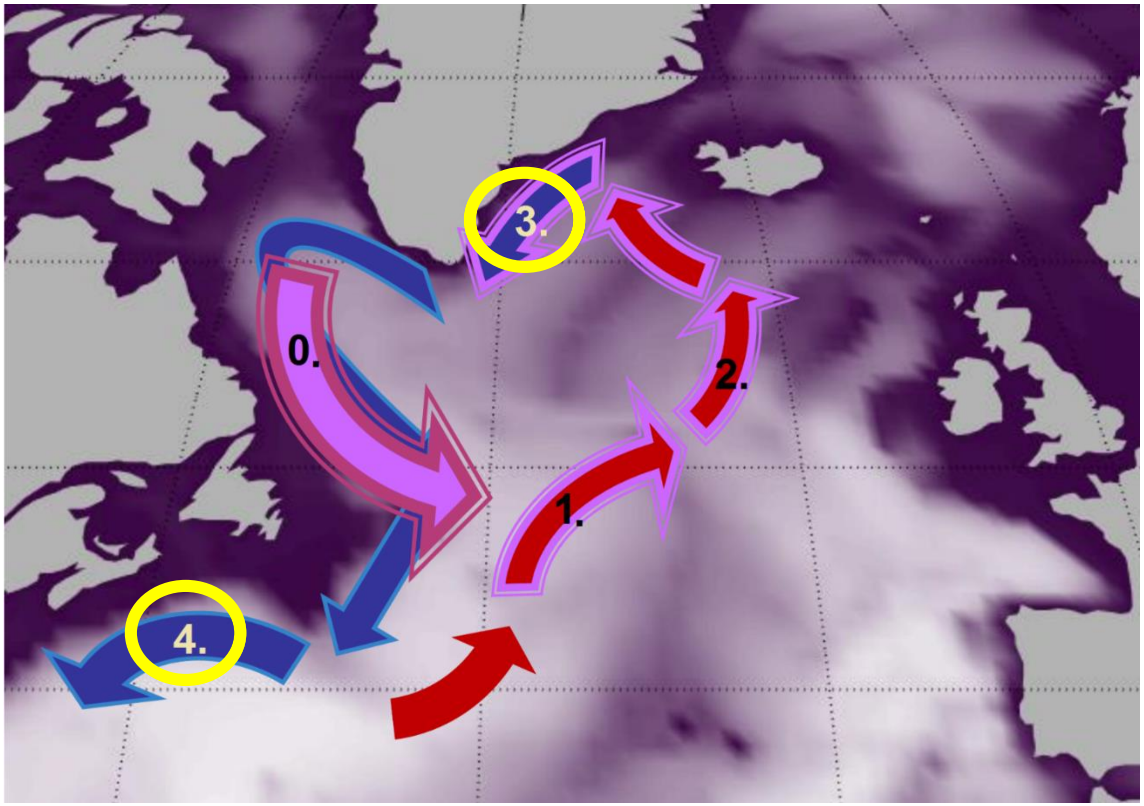
~1 year

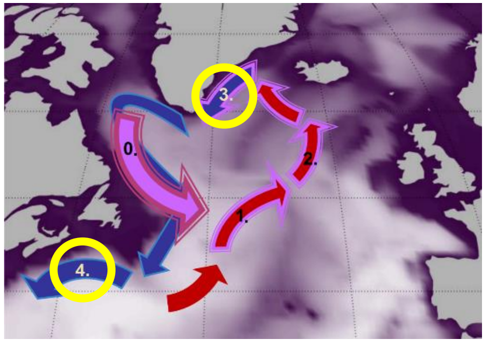
2. Anomaly in the Iceland Basin water mass transformation

~1 year

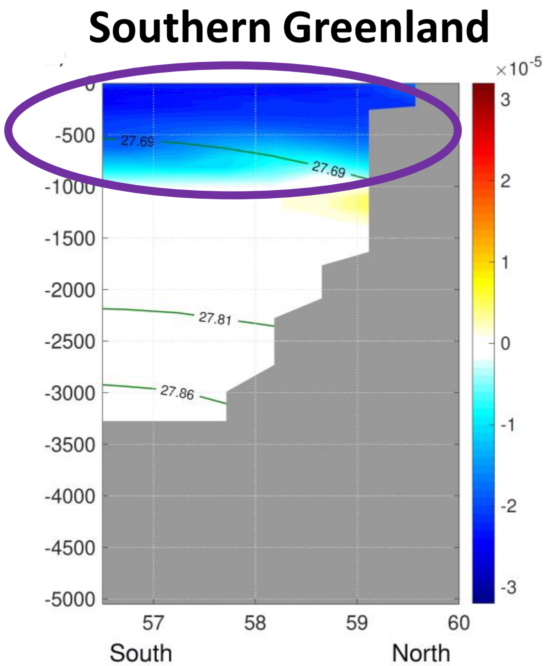
3. Anomaly in the subpolar gyre transport and a coastally-trapped wave

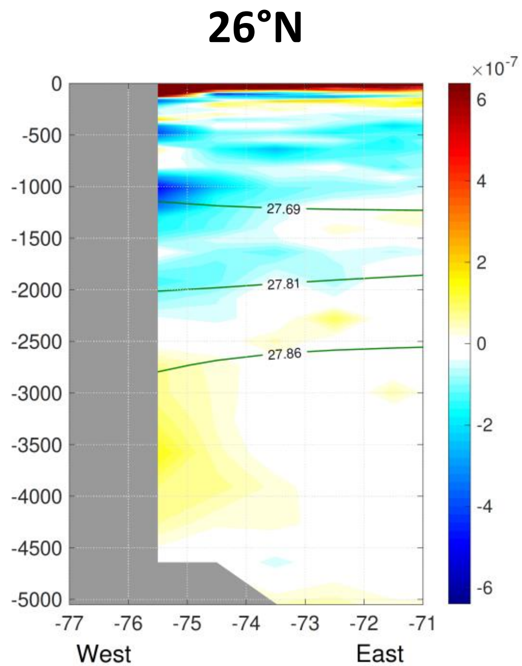
4. Adjustment of the western boundary density anomaly



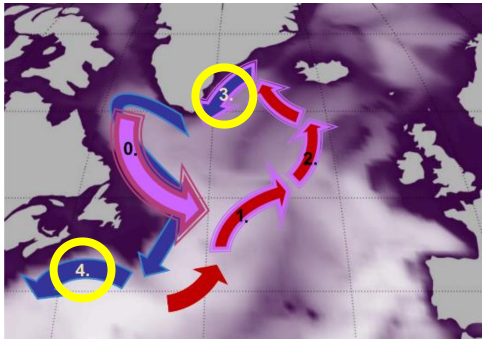


3., 4. Density Anomaly along the Boundary [kg/m³]

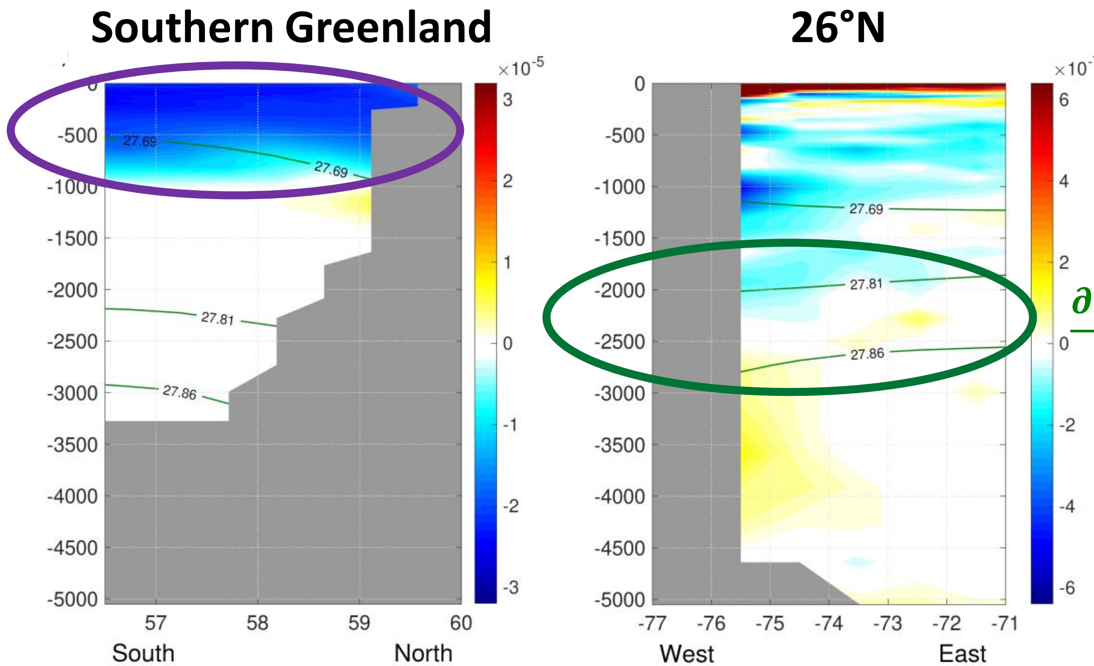




In the subpolar gyre, the negative density anomaly at the boundary <u>above a depth of 1 km</u> dominates the pressure anomaly in the LNADW layer below.



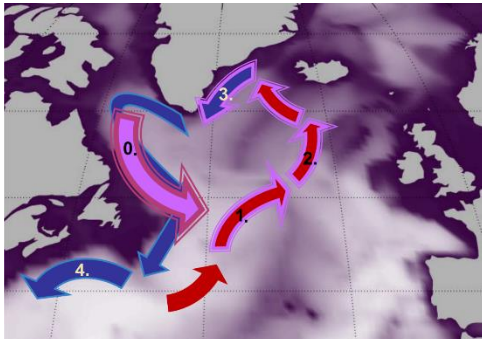
3., 4. Density Anomaly along the Boundary [kg/m³]



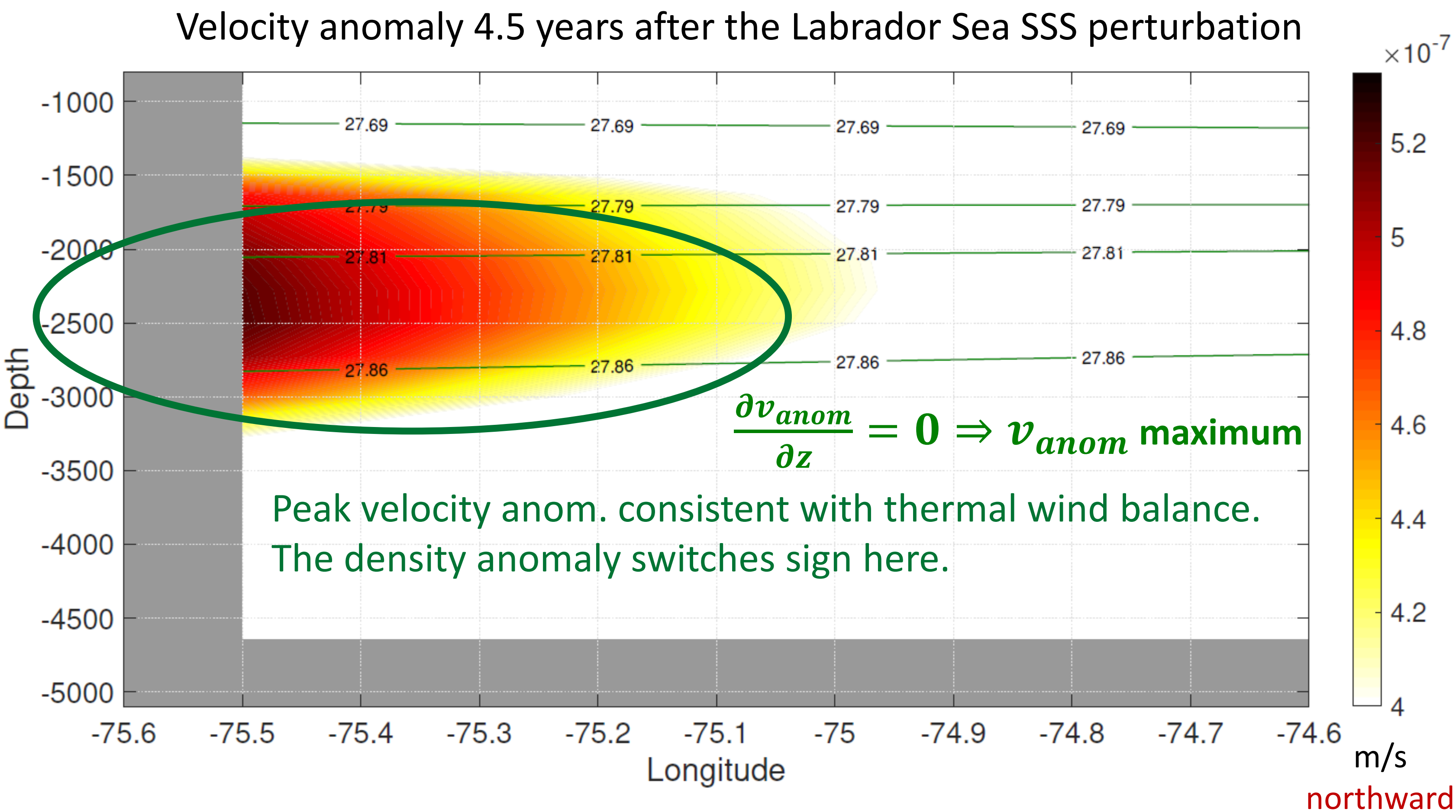
$$\frac{\partial v_{anom}}{\partial z} \propto \frac{\partial \rho_{anom}}{\partial x} = 0$$

In the subpolar gyre, the negative density anomaly at the boundary **above a depth of 1 km** dominates the pressure anomaly in the LNADW layer below.

In the subtropics, the density anomaly switches sign in the LNADW layer. The meridional velocity anomaly is maximum in the LNADW where the anomaly in the shear switches sign.



Slowdown in the LNADW layer at 26°N



$$\frac{\partial v_{anom}}{\partial z} = 0 \Rightarrow v_{anom}$$ **maximum**

Peak velocity anom. consistent with thermal wind balance.
The density anomaly switches sign here.

0. Labrador Sea SSS anomaly

<1 year

1. Adjustment of the NAC

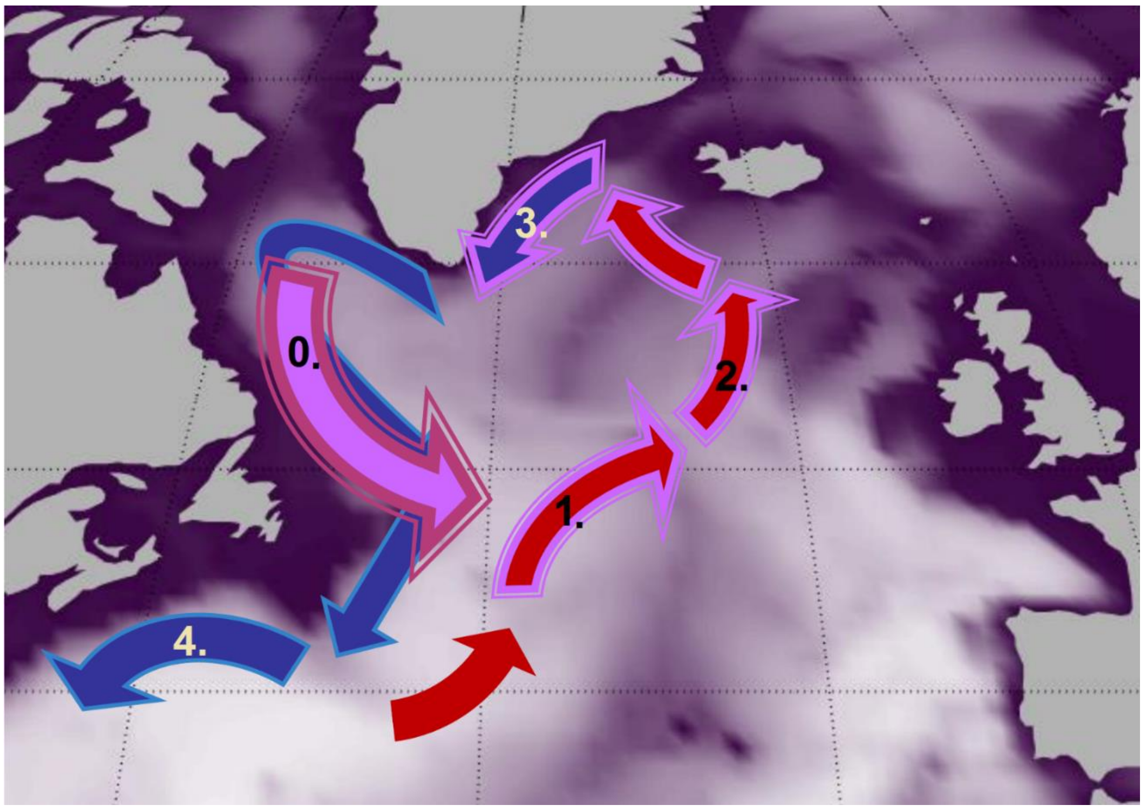
~1 year

2. Anomaly in the Iceland Basin water mass transformation

~1 year

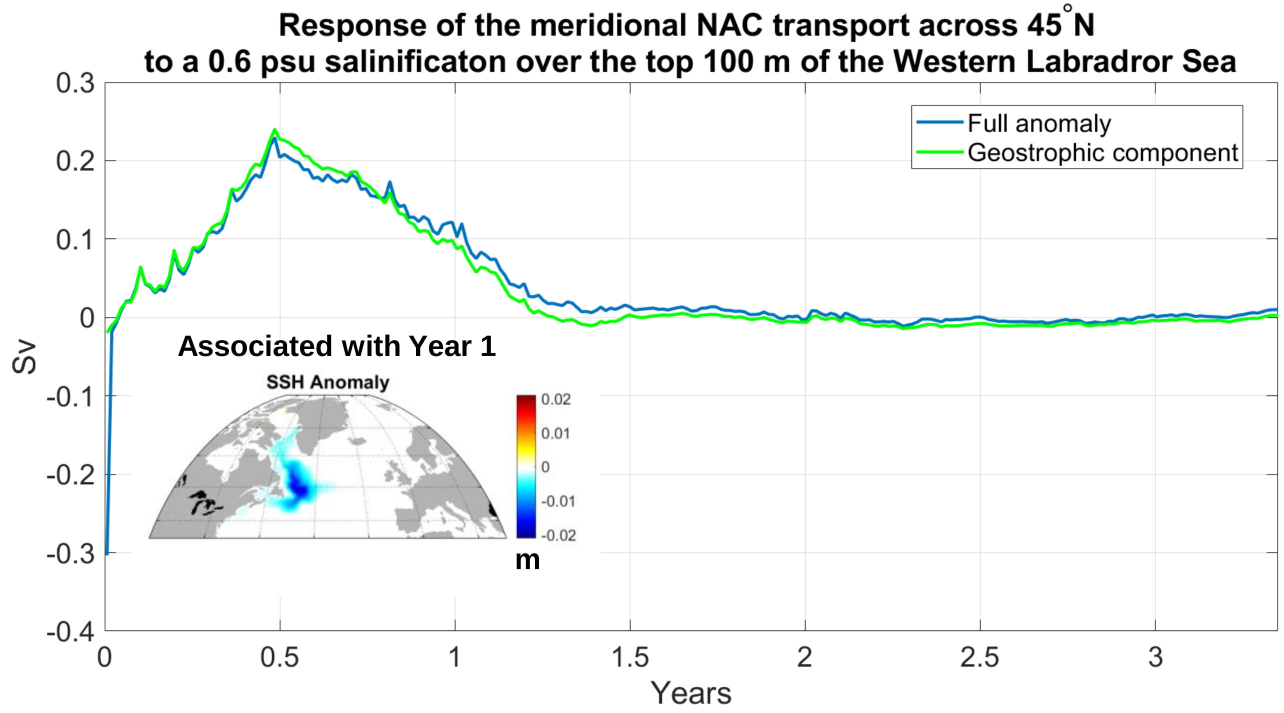
3. Anomaly in the subpolar gyre transport and a coastally-trapped wave

4. Adjustment of the western boundary density anomaly

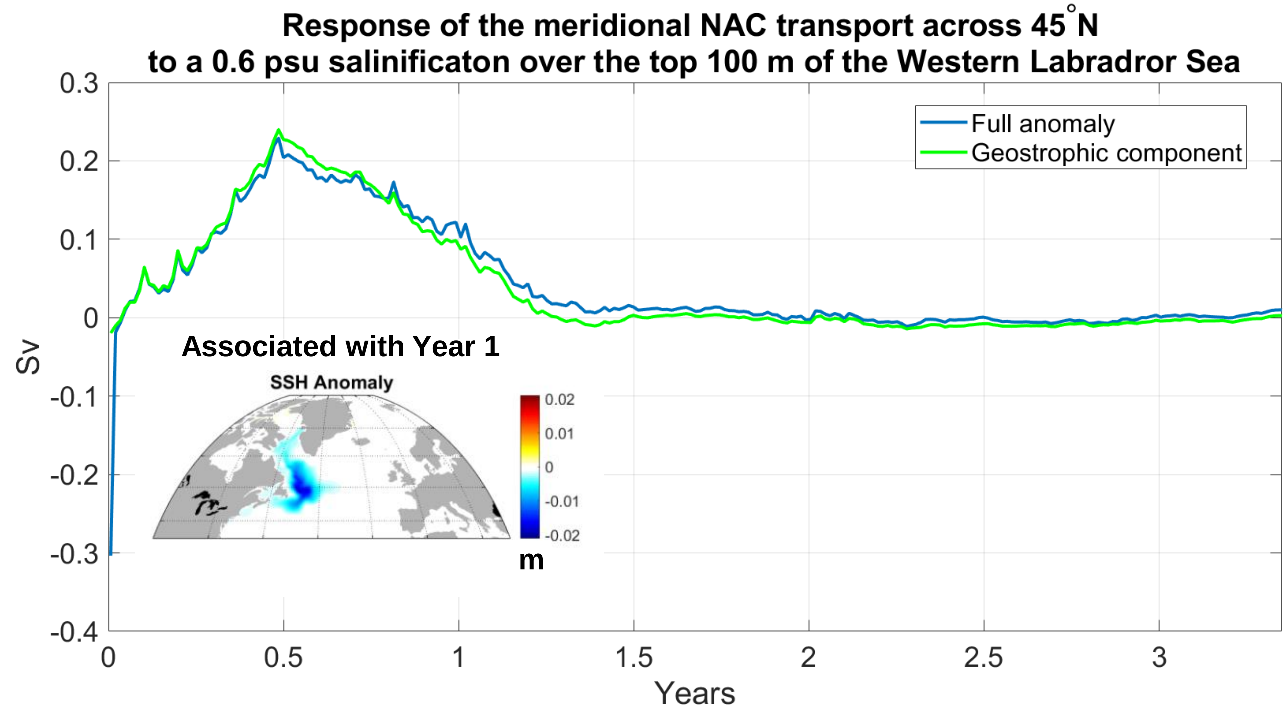


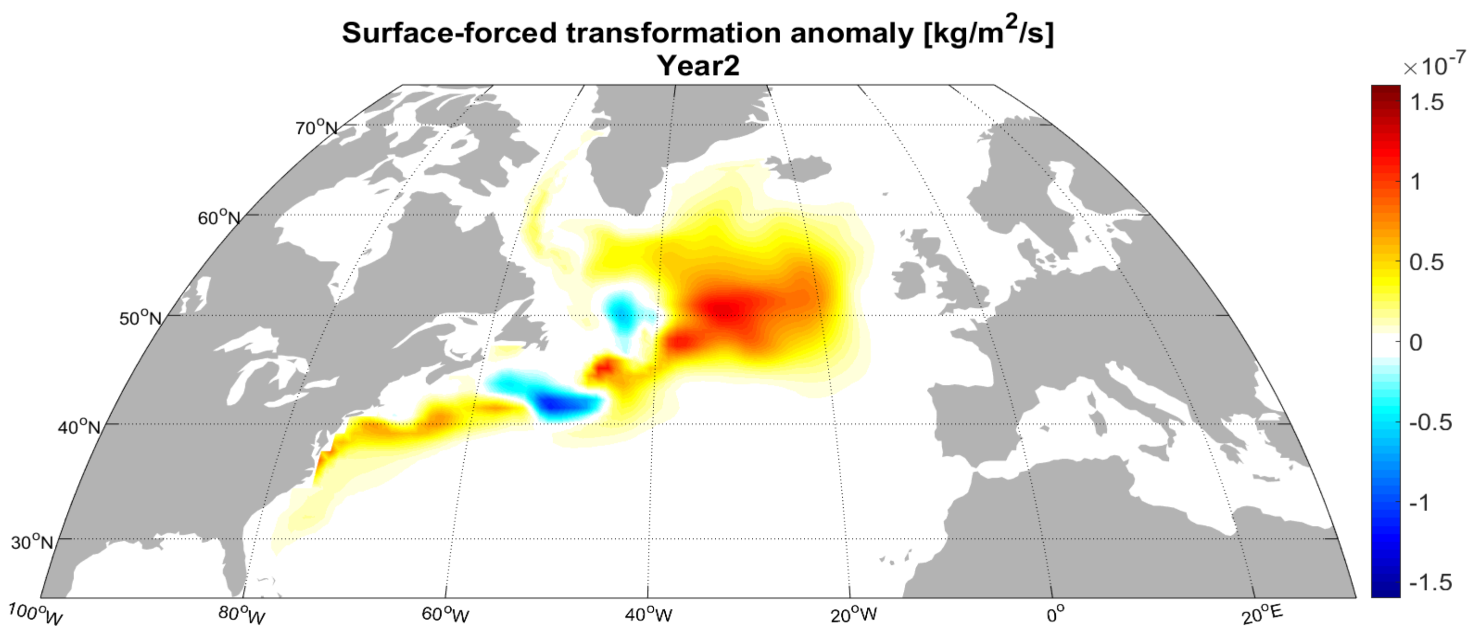
→ Anomaly in LNADW transport at 26°N

0.6 psu Salinification Experiment



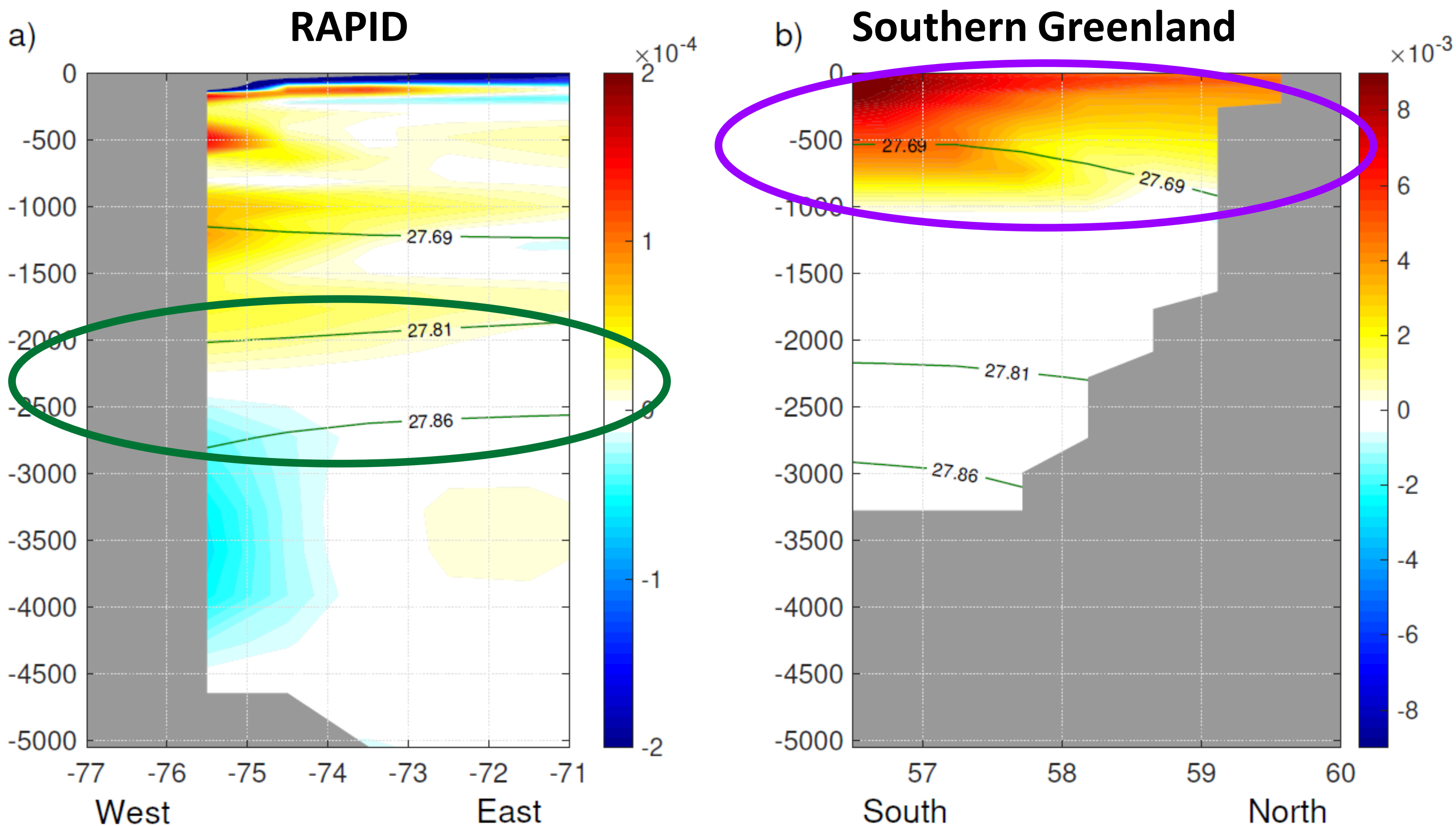
0.6 psu Salinification Experiment



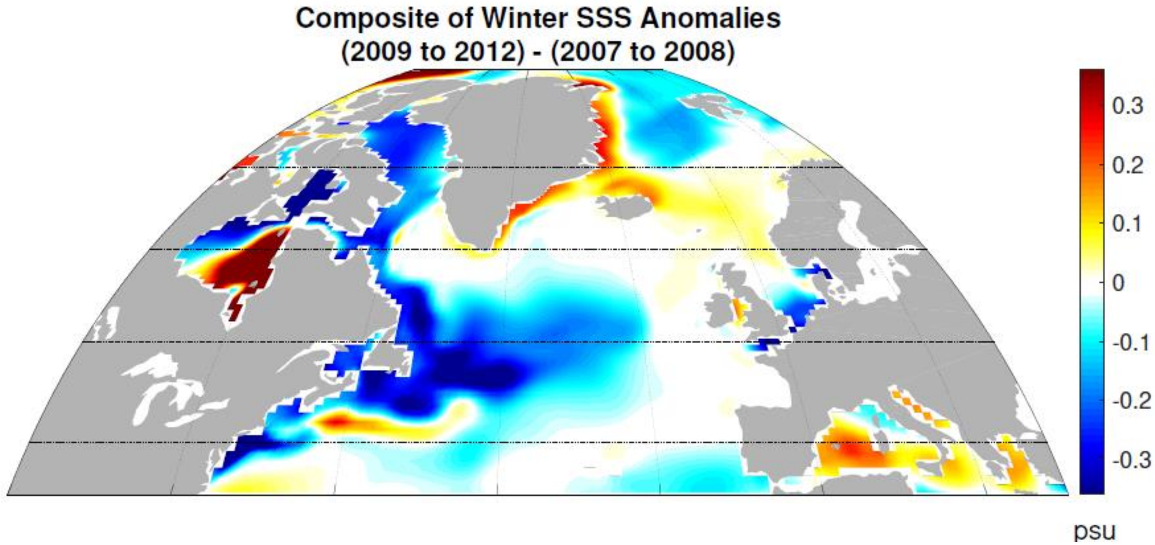


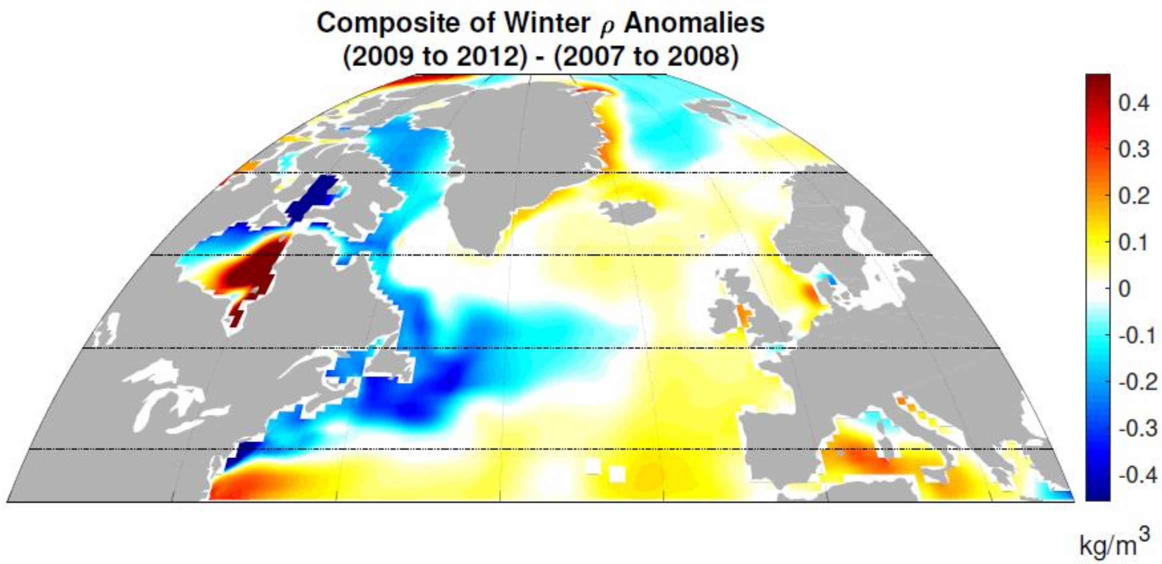
0.6 psu Salinification Experiment

Density Anomaly along the Boundary [kg/m^3] in Year 4



When is this connectivity mechanism at play in the real ocean?





Related to the 2008-2012 decline in the RAPID-AMOC

Conclusions

- The subtropical AMOC in ECCOv4 is sensitive to SST and SSS variability along the western boundary of the Labrador Sea.
- The NAC response to Labrador Sea surface density anomalies triggers a positive feedback mechanism.
- The eastern subpolar gyre adjusts on a timescale of 3-4 years after a Labrador Sea surface perturbation.
- The subpolar density anomaly is most pronounced in **the lighter layers above LSW** and the signal is communicated to the subtropics in these light layers.
- However, the response in the subtropical DWBC velocity is most intensified in **the LNADW layer below LSW**.
- **LSW does not play a dominant role in this fast mechanism.**

Thank you!

Yavor Kostov
Y.Kostov@Exeter.ac.uk

May 2021

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current work

Surface factors controlling the volume of accumulated Labrador Sea Water

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