Monitoring the North Atlantic Subpolar Overturning Circulation from surface observations

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The Subpolar AMOC: Overview and Question

Results
Monitoring the 1994-2015 Subpolar AMOC : a mechanistic approach
The role of the AMOC in 1994-2015 heat content trends

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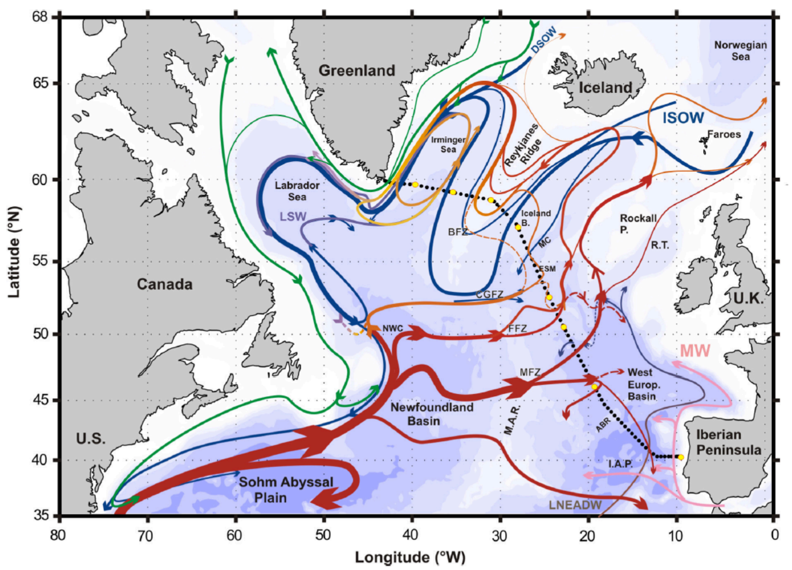
Take-home messages #1 and #2

The Subpolar AMOC$_\sigma$: Overview and Question

Warm waters advected northeastward by the North Atlantic Current

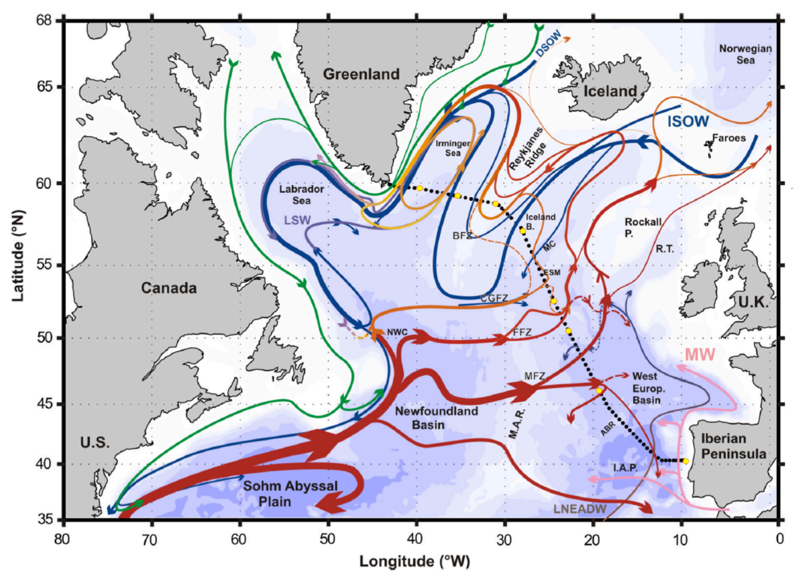


Schematic of the Subpolar Gyre circulation (red: warm upper currents, blue: cold deep currents). Daniault et al (2016)

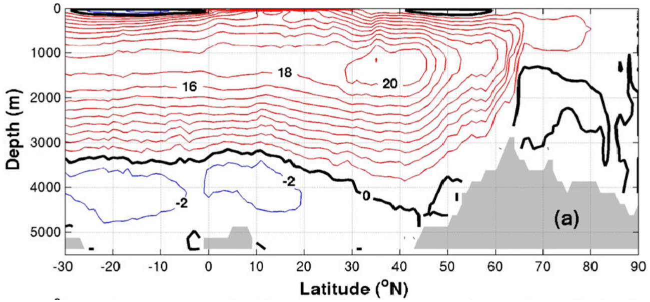
Cold waters returning southward via boundary and dispersive interior pathways

Warm-to-cold transformation (and some sinking) at high latitudes

The Subpolar AMOC$_\sigma$: Overview and Question

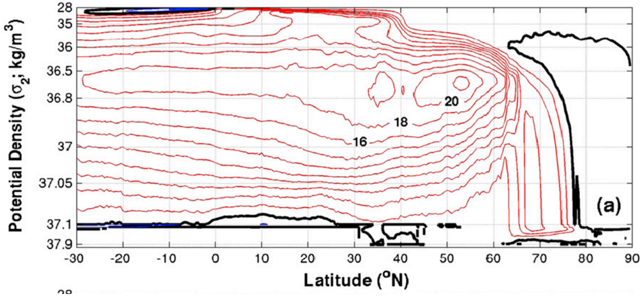


DEPTH-space AMOC$_z$

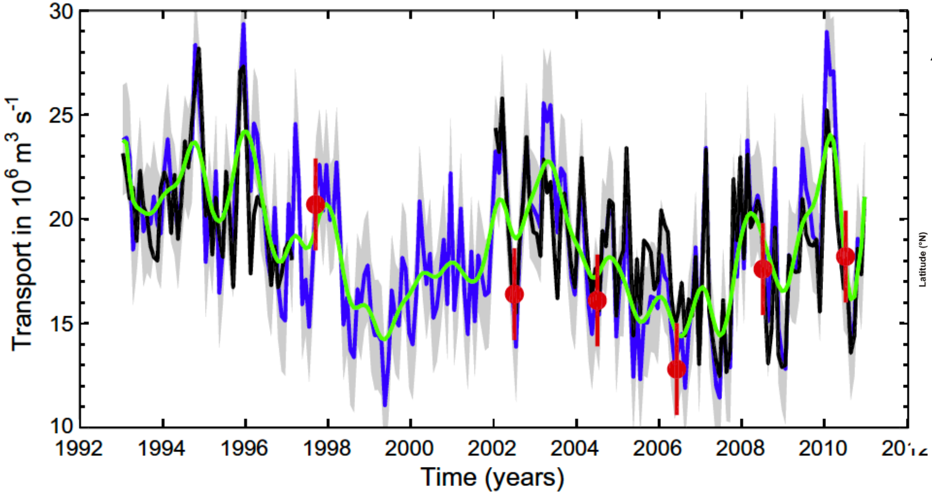


Kwon and Frankignoul (2014)

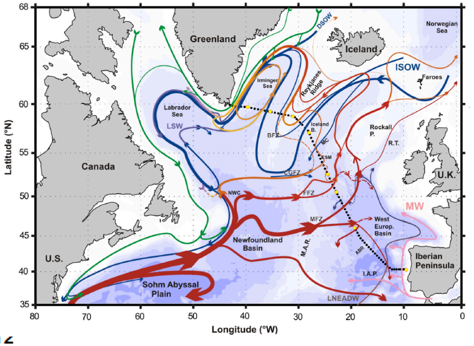
DENSITY-space AMOC$_\sigma$



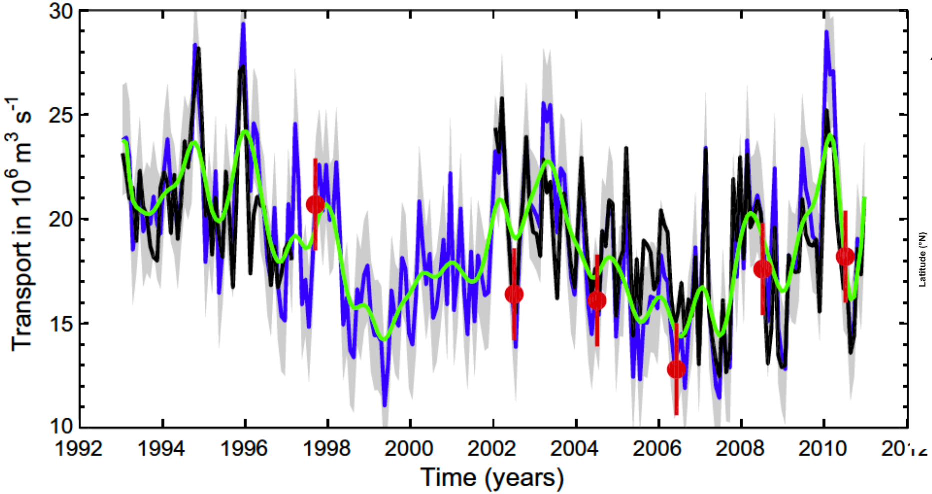
The Subpolar AMOC$_\sigma$: Overview and Question



*AMOC$_\sigma$ intensity across **A25-OVIDE line** as computed from Argo and altimetry data. Mercier et al (2015)*



The Subpolar $AMOC_\sigma$: Overview and Question



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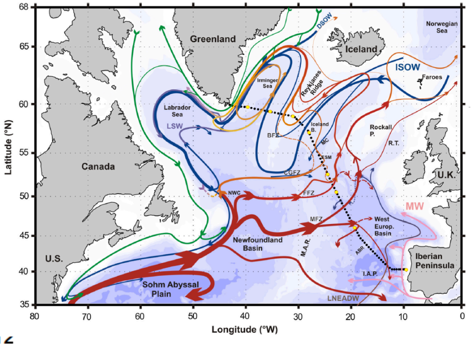
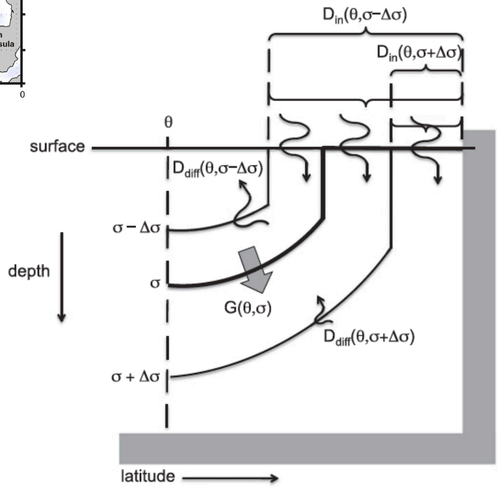


Schematic of diapycnal water mass transformation. Grist et al (2014), based on Wallin's (1982) theory.



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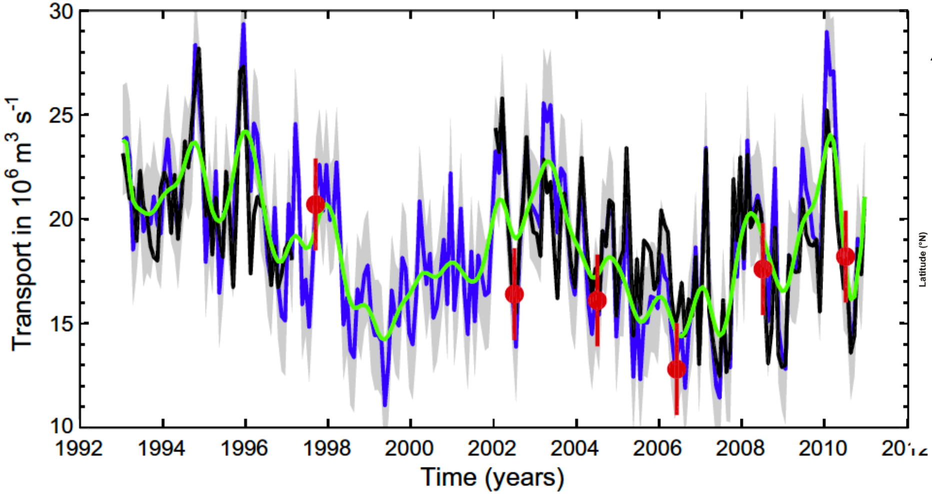

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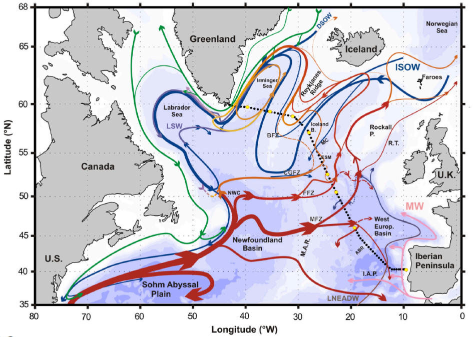

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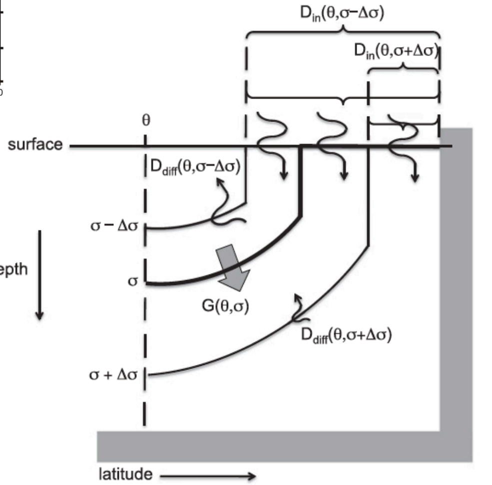


Can we predict AMOC$_\sigma$ variability from *surface-forced* water mass transformation rates ?

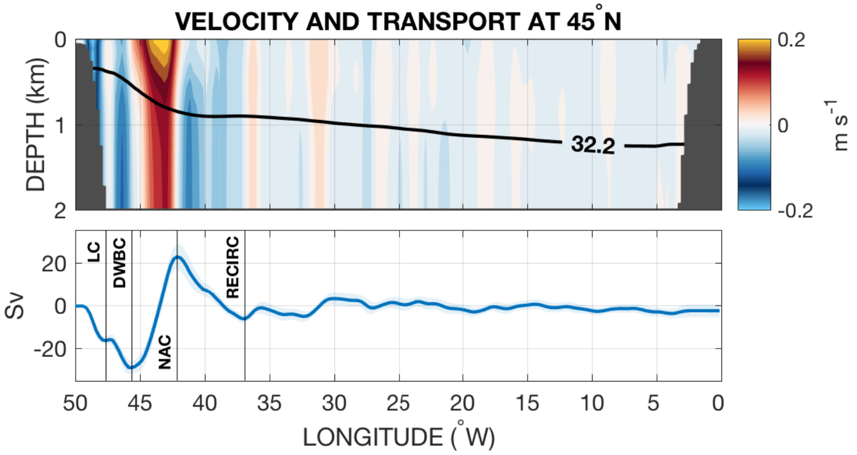
Monitoring the 1994-2015 Subpolar AMOC$_\sigma$

We estimate the meridional velocities at 45°N:

$$v = g/f \, \partial D/\partial x + v_s$$

D : Dynamic height obtained from *in situ a*nalyses (CORA / EN4 / ARMOR3D / ISHII)

V_s **: Meridional surface geostrophic velocity** obtained from AVISO



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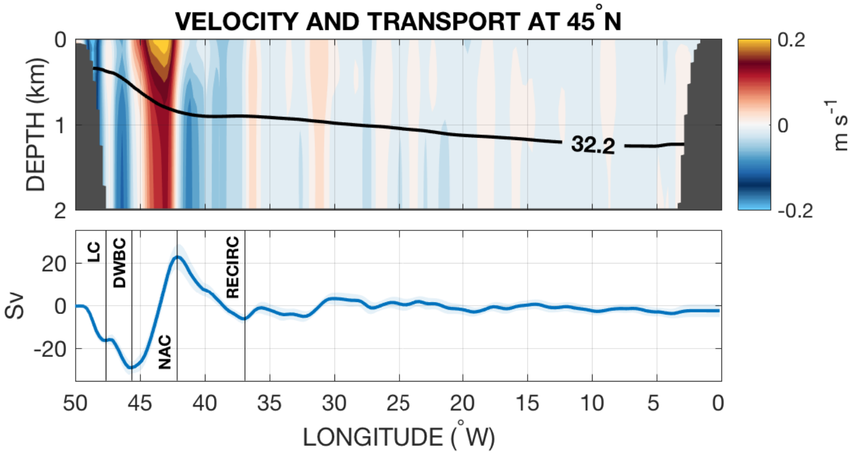
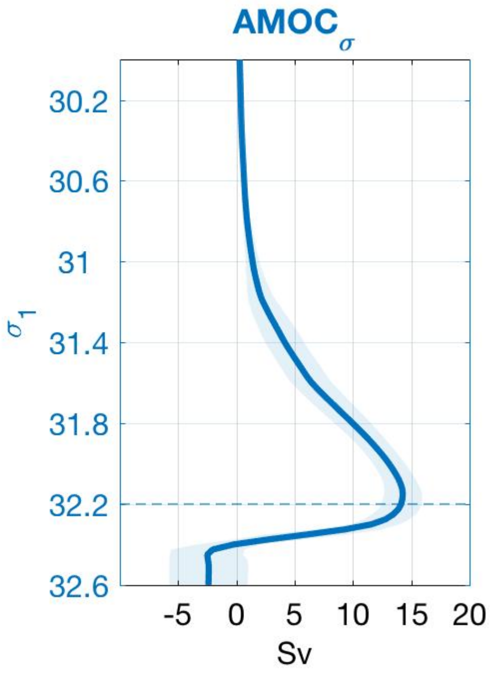


Zonal integral and accumulation below isopycnal surfaces gives the (partial) AMOC$_\sigma$ stream function



Monitoring the 1994-2015 Subpolar AMOC$_\sigma$

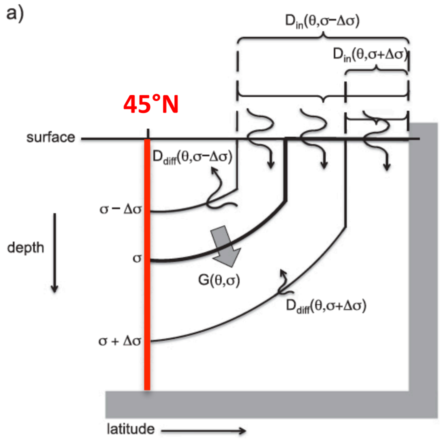
We estimate the *surface-forced* diapycnal volume flux across σ north of 45°N:

$$SFOC_{\sigma} = \frac{1}{\delta\sigma} \iint_{\sigma-\delta\sigma/2}^{\sigma+\delta\sigma/2} \left[-\frac{\alpha Q}{C_p} + \frac{\beta S}{1-S}(E-P) \right] dA$$

σ : surface density (CORA / EN4 / ARMOR3D / ISHII)

Q : Surface heat flux (NCEP2 / ERAI / CERES)

E-P : Surface freshwater flux (NCEP2 / ERAI) – seasonal



Schematic from Grist et al (2014)

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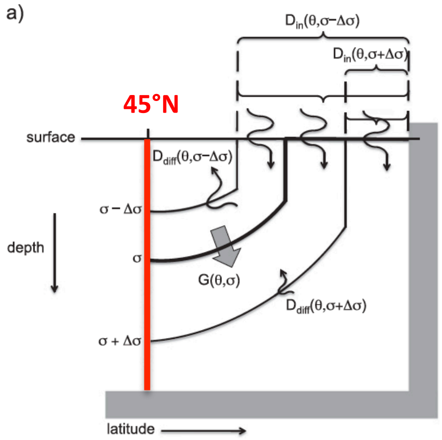

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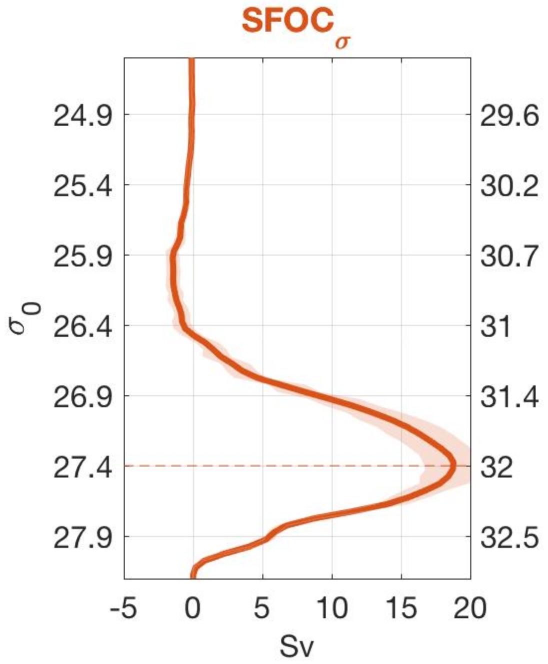
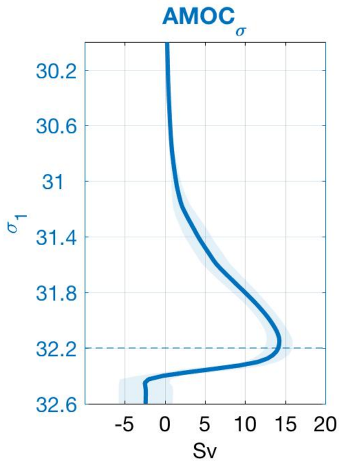
Applying this formula to a range of isopycnal surfaces σ gives the SFOC$_\sigma$ stream function

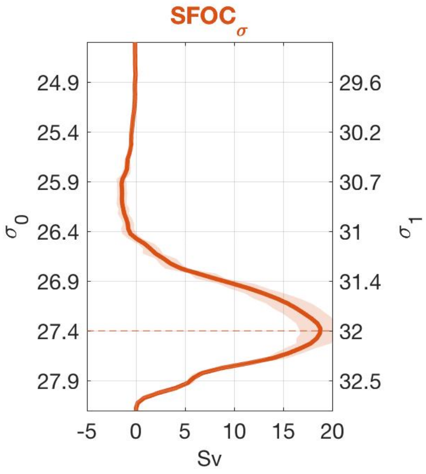


Monitoring the 1994-2015 Subpolar $AMOC_{\sigma}$

For both streamfunction ($AMOC_{\sigma}$ and $SFOC_{\sigma}$), we select the maximum every month, and run annual averaging and 7-year low pass filtering.



Meridional Overturning Circulation at 45°N



Surface-forced transformation north of 45°N

Monitoring the 1994-2015 Subpolar AMOC$_\sigma$

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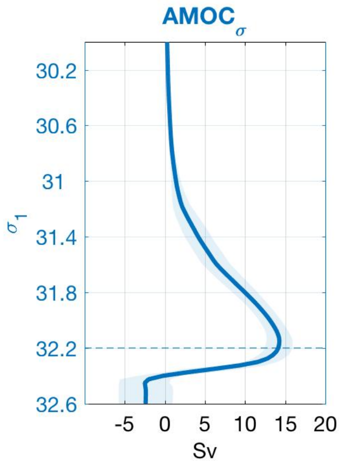

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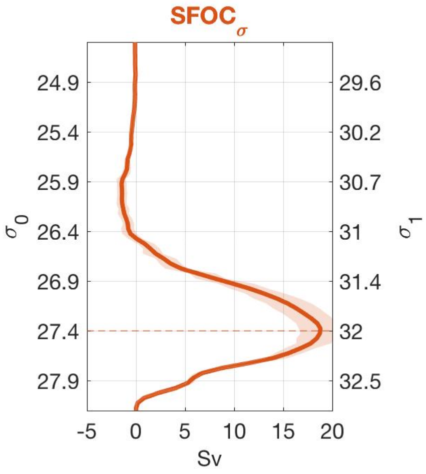

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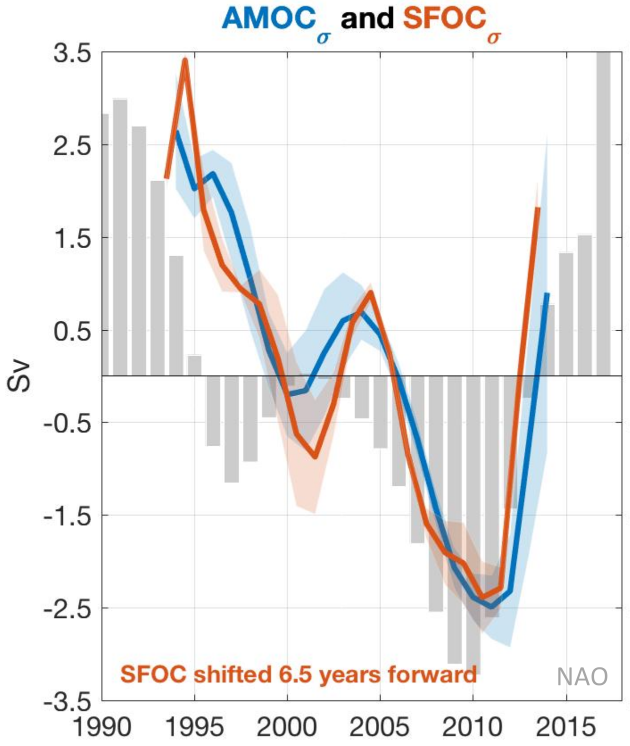


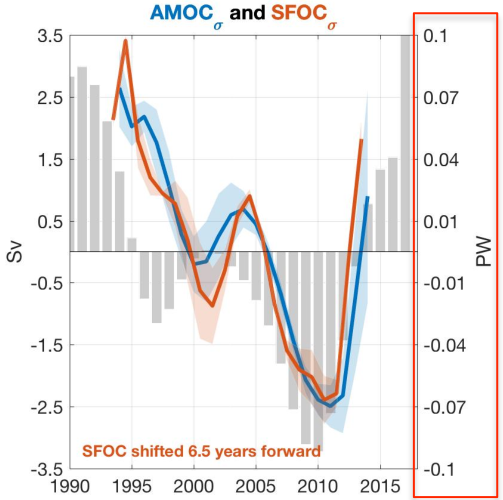
R = 0.87 at lag = 6.5 years and at the 99% confidence level

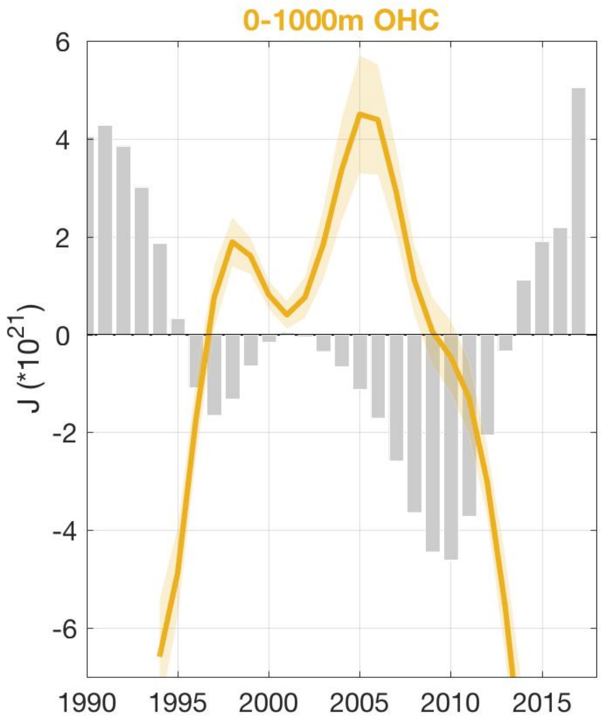
The role of $AMOC_\sigma$ in 1994-2015 heat content trends

We estimate the $AMOC_\sigma$-driven meridional heat transport at 45°N:

$$HT_\sigma = \rho_0 C_p * \max(AMOC_\sigma) * \Delta\theta$$

$\Delta\theta$: mean temperature difference between the upper and lower limbs of $AMOC_\sigma$





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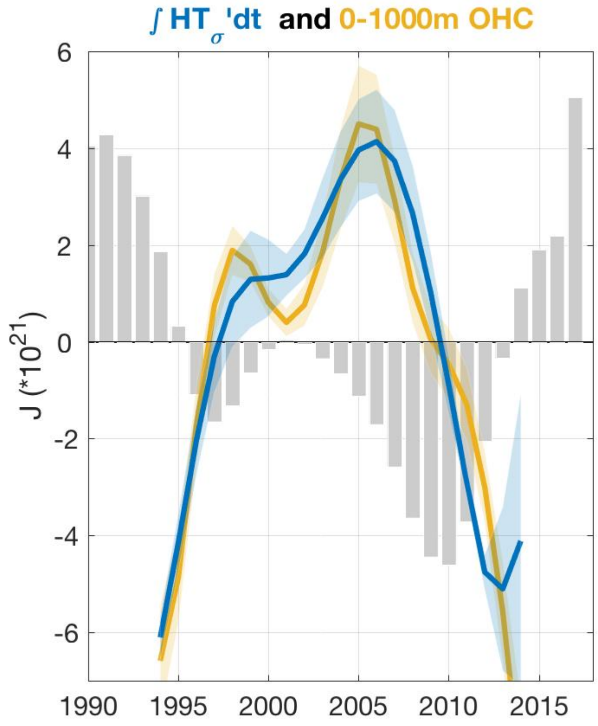
We compare the HT_σ -driven OHC anomalies with actual detrended OHC anomalies of the 0-1000m SPG (10°W-70°W; 45°N-65°N):

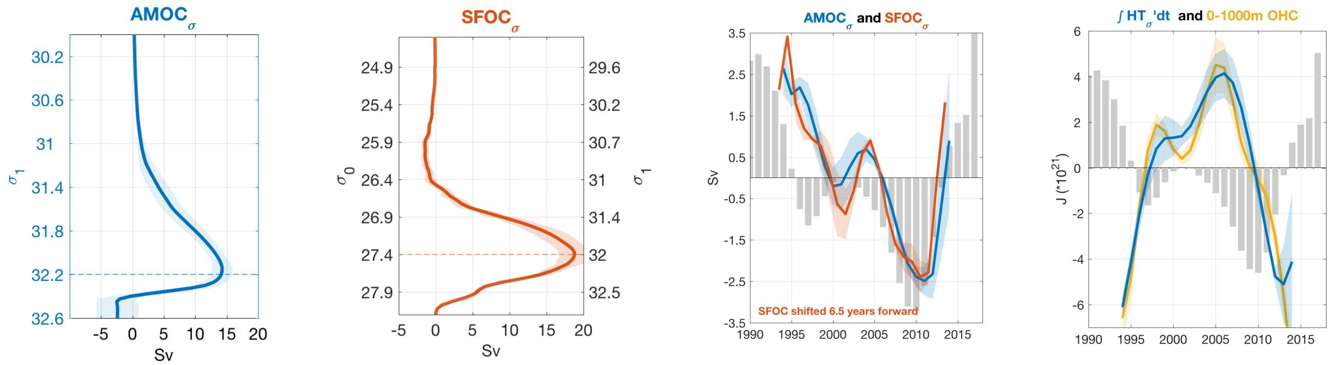
$$\int HT_\sigma' \, dt$$

vs

$$\rho_0 C_p * \iiint \theta' \, dxdydz$$



Conclusions



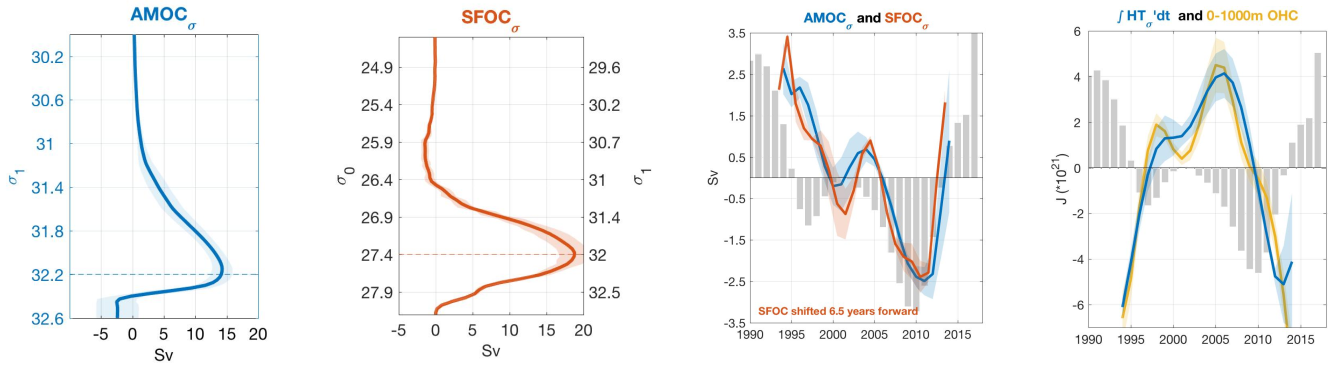
Take-Home message #1

A causal relationship exists between a reduction in *surface-forced* water mass transformation rates, the 1994-2015 decline of the $AMOC_{\sigma}$ at 45°N, and the reversal in SPG heat content in 2005

Take-Home message #2

The 6-7-year delay between surface-forced water mass transformation in the SPG and downstream circulation changes yields predictability skills for $AMOC_{\sigma}$ / MHT and OHC using surface observations alone

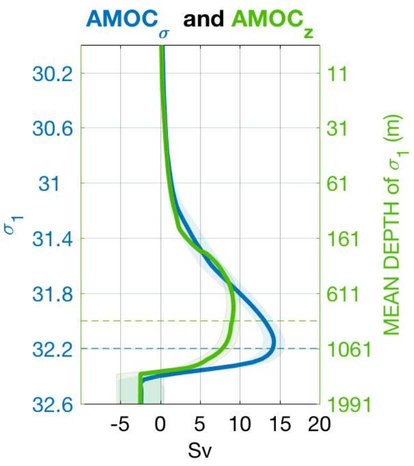
Conclusions

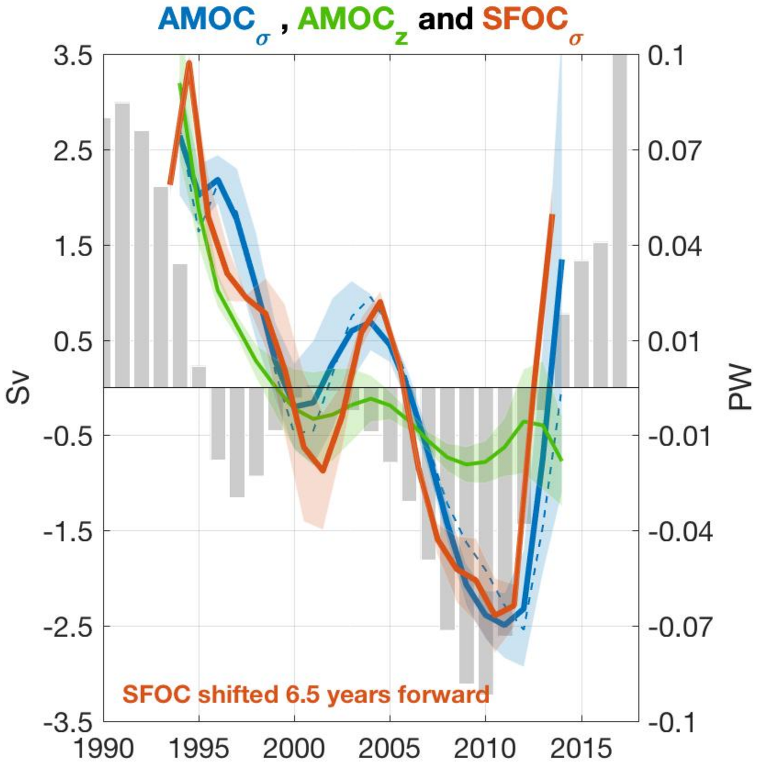


Thank you, any questions ?

Not shown today:

- Depth-spaced vs. density-spaced AMOC variability
- Impact of Labrador Sea Water formation rates on AMOC variability
- Nordic Seas vs. SPG contribution to AMOC variability
- Efficiency of OSNAP line to capture AMOC variability


AMOC σ and AMOC z
30.2
30.6
31
31.4
31.8
32.2
32.6
σ 1
11
31
61
161
611
1061
1991
MEAN DEPTH of σ 1 (m)
-5 0 5 10 15 20
Sv

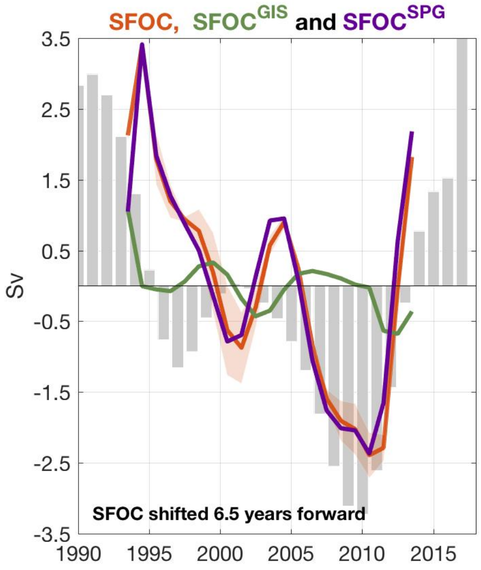

AMOC σ , AMOC z and SFOC σ
3.5
2.5
1.5
0.5
-0.5
-1.5
-2.5
-3.5
Sv
0.1
0.07
0.04
0.01
-0.01
-0.04
-0.07
-0.1
PW
1990 1995 2000 2005 2010 2015
SFOC shifted 6.5 years forward

The 1994-2015 time-mean Heat budget in the SPG

$$HT\downarrow\sigma = 0.42 \pm 0.04\ PW\ \boldsymbol{across\ 45°N}$$

$$Q\downarrow NET = -0.24 \pm 0.04 PW\ \boldsymbol{across\ the\ SPG\ surface}$$

$$HT\downarrow\sigma = 0.18\ PW\ \boldsymbol{toward\ the\ Nordic\ Seas}$$


SFOC, SFOC^GIS and SFOC^SPG
3.5
2.5
1.5
0.5
-0.5
-1.5
-2.5
-3.5
Sv
1990
1995
2000
2005
2010
2015
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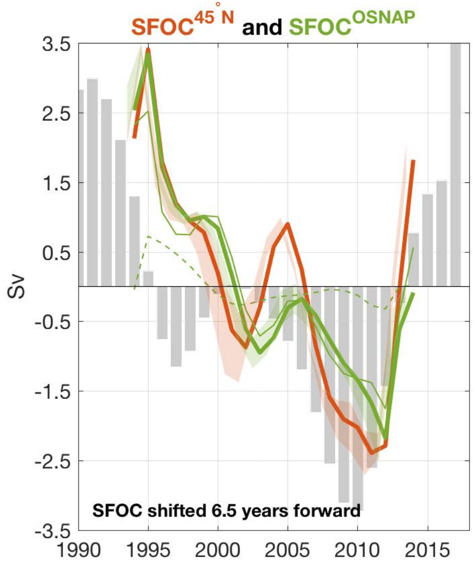
SFOC^45°N and SFOC^OSNAP
3.5
2.5
1.5
0.5
-0.5
-1.5
-2.5
-3.5
Sv
1990
1995
2000
2005
2010
2015
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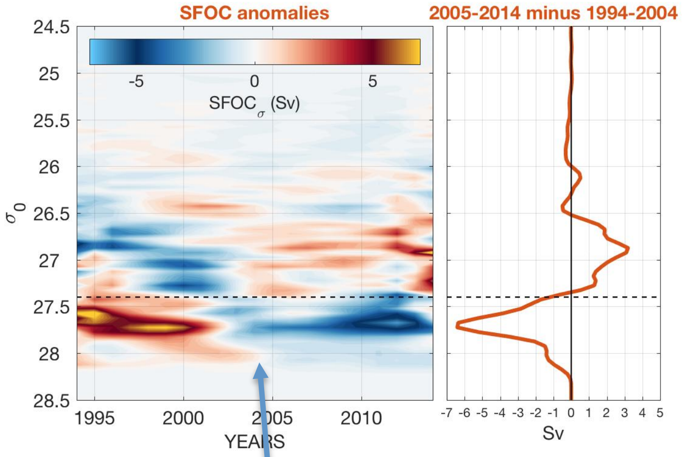
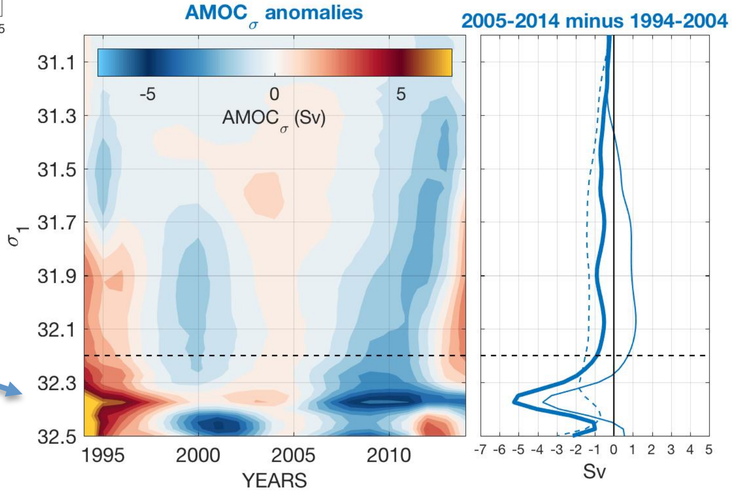
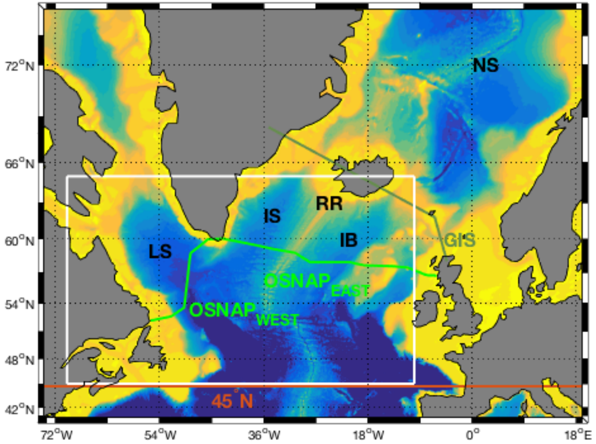


Increased transport of upper LSW and decreased transport of lower LSW

A volume redistribution restricted within the lower limb of the AMOC





The pattern of light-to-dense transformation across **σ**0 = 27.4