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Mechanisms for Late 20th and Early 21st Century Decadal AMOC Variability

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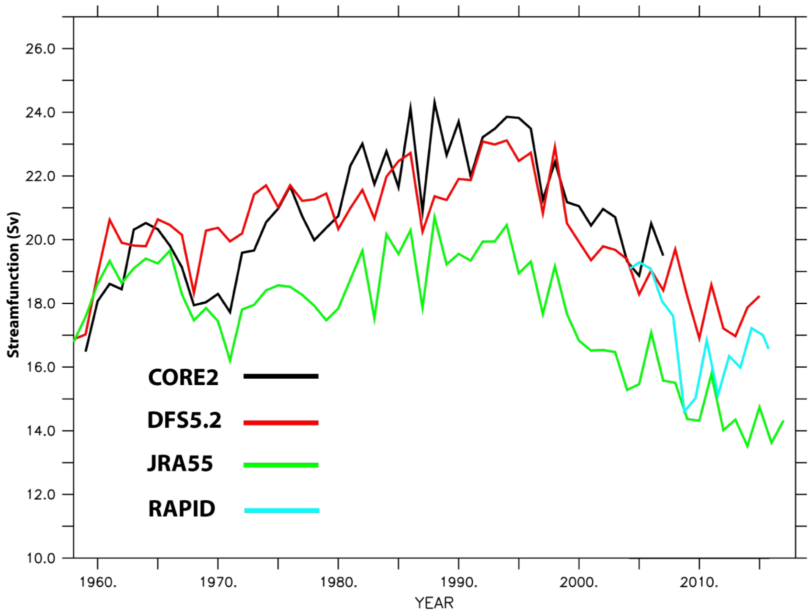
Background

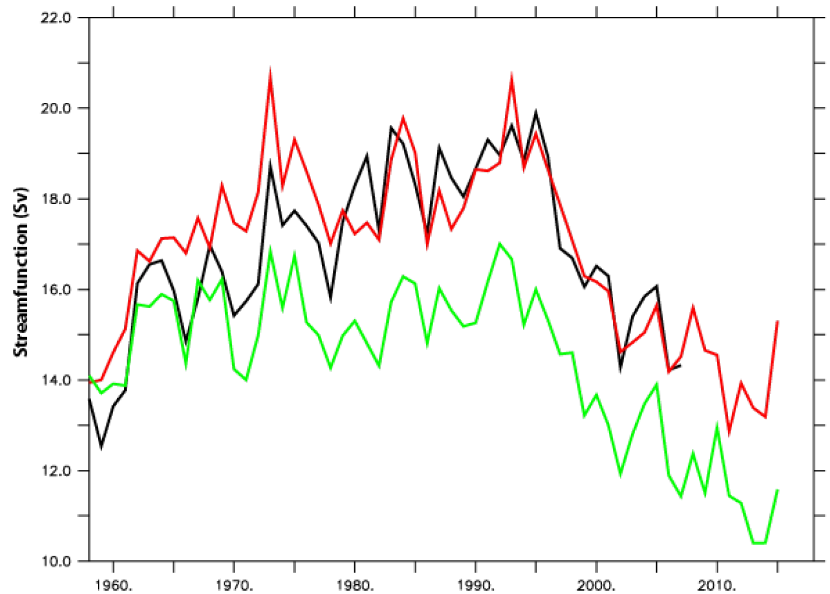
- Smeed et al (2018) use observations from the RAPID array to infer that the AMOC has declined by about 3 Sv since 2008.
- Proxy data (e.g. Delworth et al, 2016) suggest that the AMOC was previously increasing up to a maximum in around 2005.
- Can we identify a physical mechanism in forced hindcast models for the increase in the late 20th Century, and for the decrease since then?
- Can we derive a predictor of future AMOC changes with any skill?

We use ensemble of three ¼° GO6 (NEMO v3.6 / CICE v5.1.2) integrations with different forcing datasets (CORE2, DFS5.2 and JRA-55) to address these questions.

AMOC time evolution in simulations



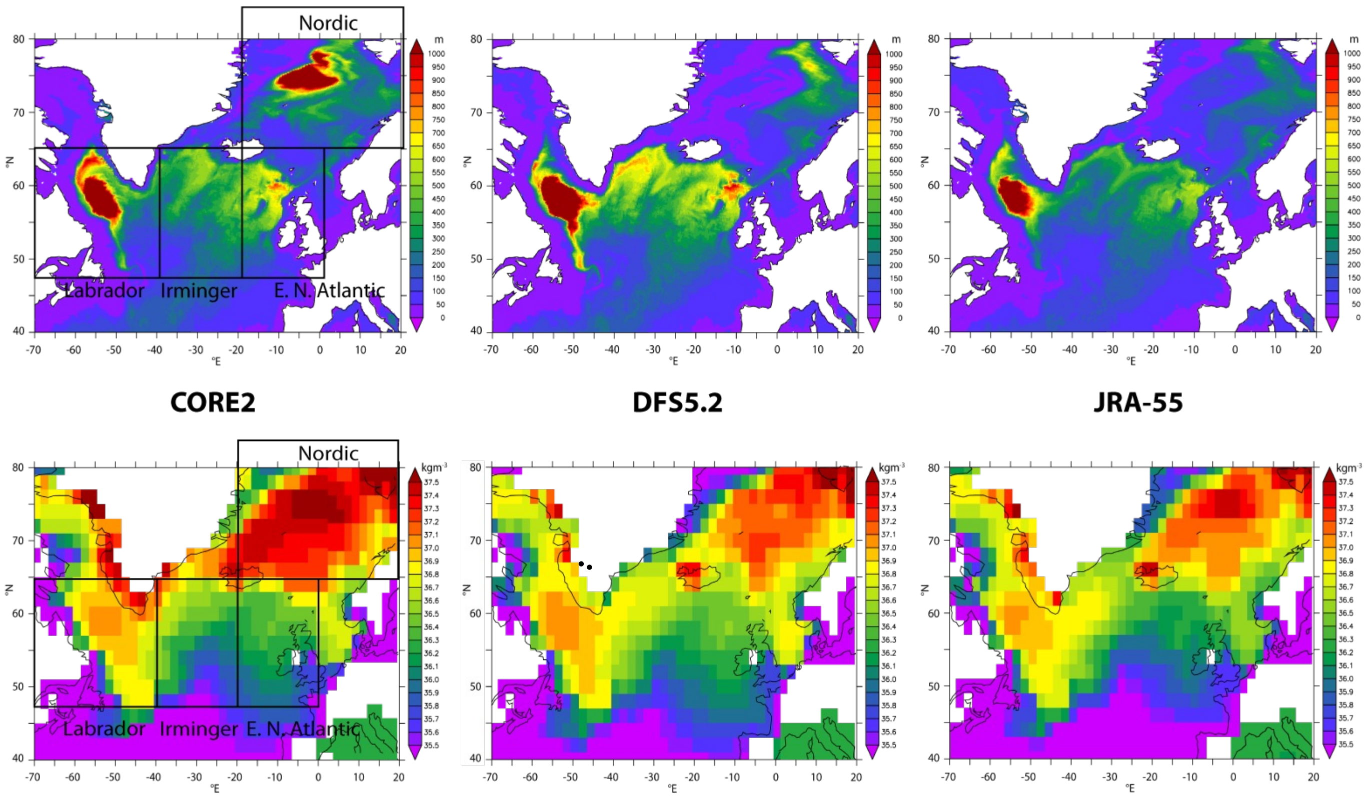
26°N



45°N

- Simulations show an increase of 2-3 Sv from 1975 to 1990, and a reduction of over 5 Sv since mid-1990s.
- The three forcing sets give similar trajectories on both interannual and decadal time scales, even though individual means are different.

MLD and maximum surface density



March MLD

Max surface density (σ_2)

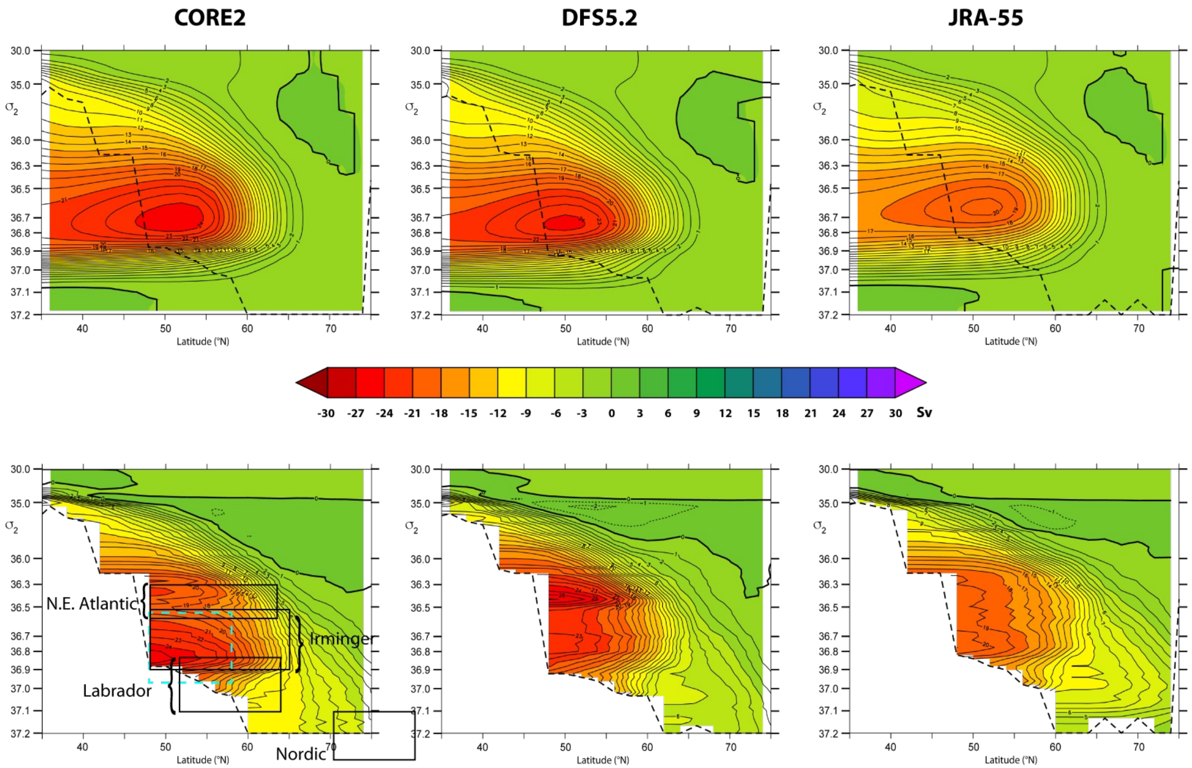
- Winter convection to over 500m occurs around northern edge of SPG.
- Maximum surface density increases progressively westwards from NE Atlantic, through Irminger Sea, and then to Labrador Sea.

The picture

1. Subpolar Mode Water (SPM) is formed in north-east Atlantic each winter.
2. SPM is advected westward in the subpolar gyre, and becomes denser from further buoyancy losses.
3. In the Labrador Sea further densification occurs, along with deep convection, resulting in the formation of NADW at depths down to 1,000m or more (as in McCartney and Talley, 1982).
4. NADW is exported southwards in the DWBC.

- So what forces the AMOC variability?
- We use the surface-forced streamfunction approach, which relates changes in the overturning in density space to changes in surface buoyancy fluxes.

Overturning and surface-forced streamfunctions

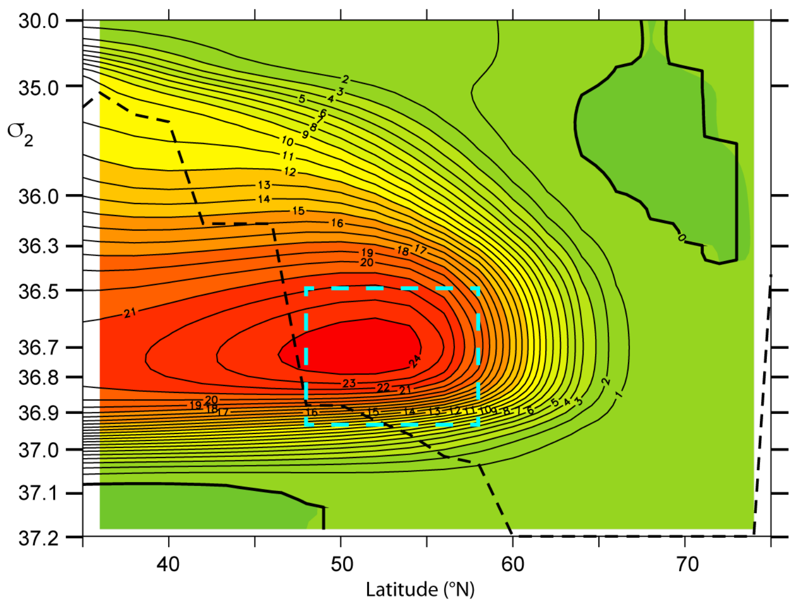


Overturning Ψ (1996-2005)

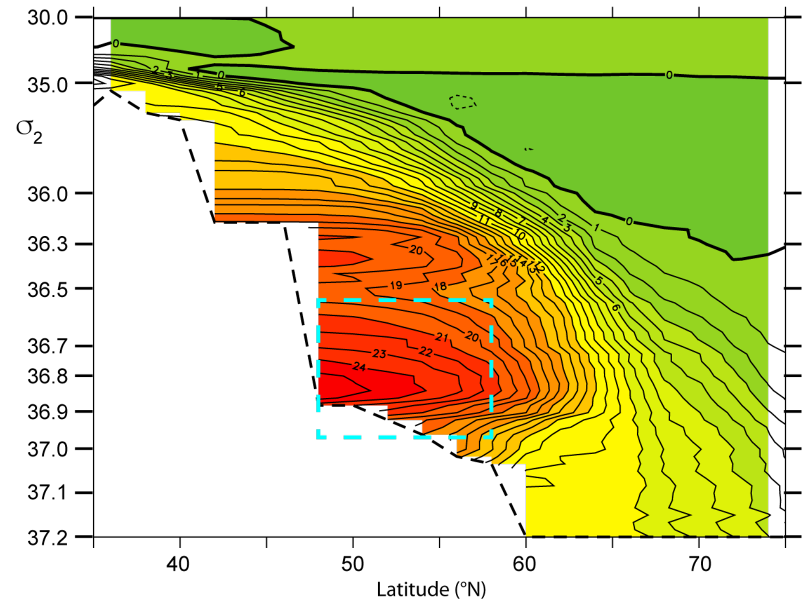
Surface forced Ψ

- Surface-forced Ψ_{surf} has similar overall form and strength to overturning Ψ, but shows watermass transformation from surface fluxes more directly.
- Ψ_{surf} shows separate transformation processes in Irminger and NE Atlantic.
- Strong buoyancy losses in Nordic Seas, but little export to Atlantic.

Defining a surface-forced index



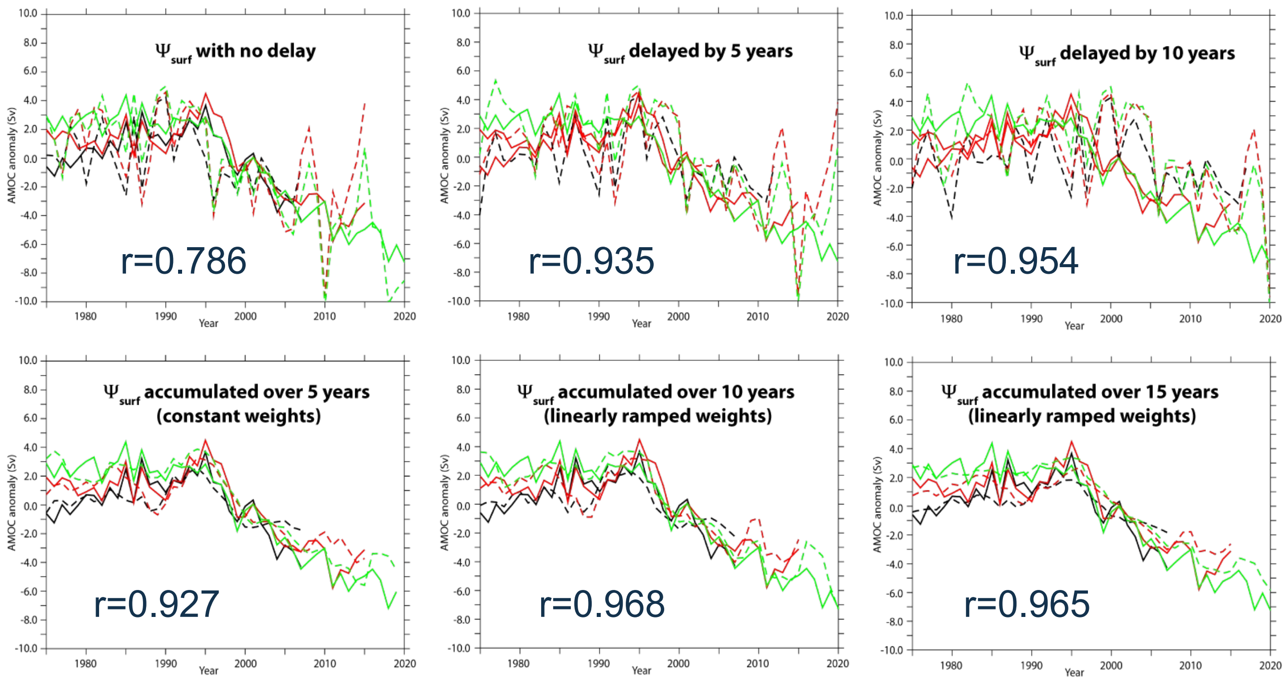
Overturning Ψ



Surface forced Ψ

- Ψ_{surf} shows separate transformation processes in Irminger and NE Atlantic.
- Strong buoyancy losses in Nordic Seas, but little export to Atlantic.
- Define an annual index for each streamfunction (T_{over} and T_{surf}) as a mean over the region of density and latitude space (cyan box) typically containing maximum values.

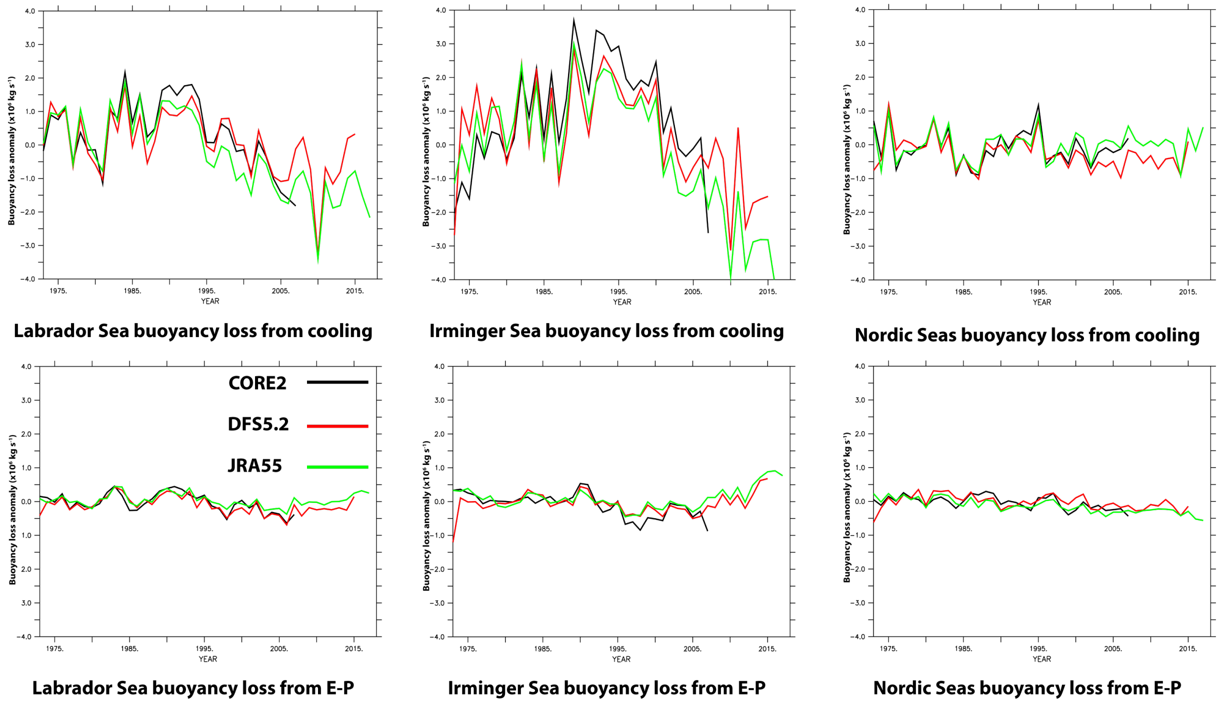
Lag timescale for surface fluxes and AMOC



Overturning (solid lines) and surface-forced (dashed lines) indices

- Highest correlation found with T_{surf} accumulated over ten years with linearly ramped weighting. We use this accumulated index T_{accum}.
- This confirms time scale, over which changes in surface fluxes in subpolar gyre influence overturning strength, as 5-10 years (ref. Josey et al, 2009).
- Potential for predictability of AMOC changes…

Where is overturning circulation forced?



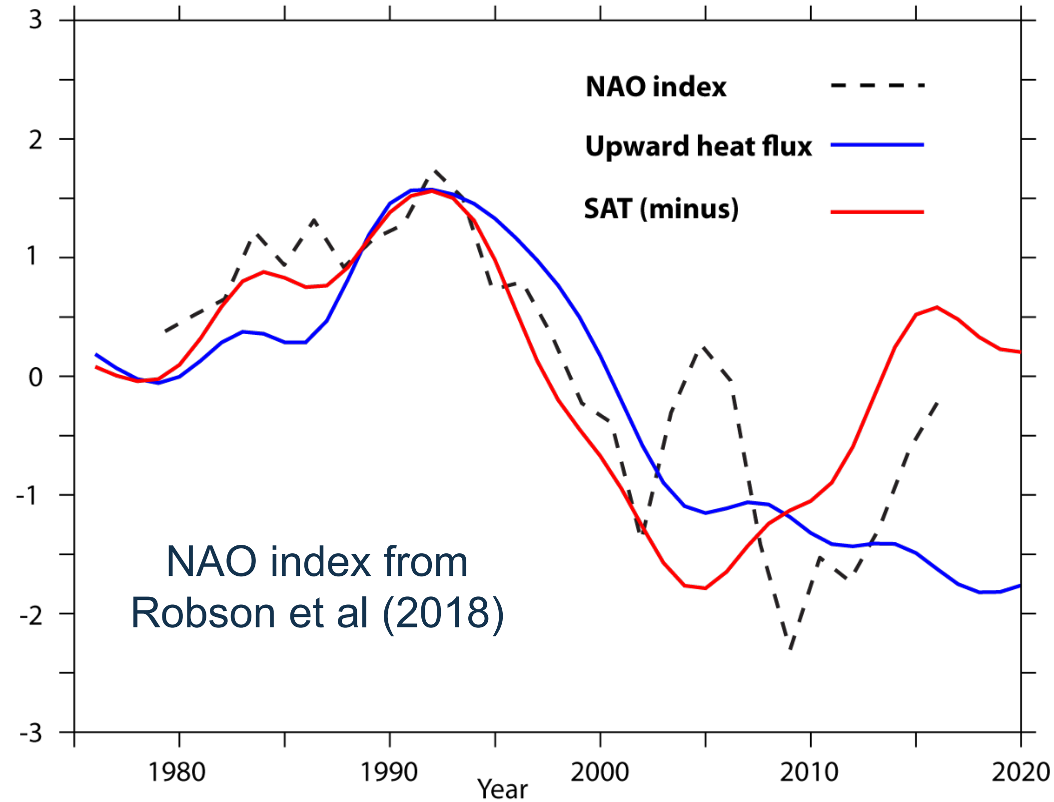
Regionally integrated buoyancy loss anomalies (in kg s^{-1}) in subpolar North Atlantic.

<u>Note: all on same vertical axis</u>

- Buoyancy loss through cooling from Irminger Sea shows similar time evolution to overturning at 45°N, while in Labrador Sea only post-1975 decline occurs, and at about half the rate seen in Irminger Sea.
- FW fluxes have negligible contribution to variability, as does heat loss in Nordic Seas.

What is driving the heat loss in the Irminger Sea?

- Strongest correlation is with surface air temperature, more specifically the air-sea temperature difference.
- Similar evolution seen in Labrador Sea.
- SAT changes follow NAO until about 2010.
- In last decade SST appears to control heat flux more than SAT – advective feedback to AMOC?



Summary

- ¼° NEMO/CICE is integrated from 1958 with three different forcing datasets.
- Decadal AMOC variability consistent with estimates from observations: increase from 1970s to 1990s, followed by marked decline.
- Surface-forced index T_{accum}, derived from surface forced streamfunction by accumulating over ten years, is well correlated with overturning strength.
- T_{accum} has predictive skill for overturning circulation.
- Regionally integrated surface heat loss in Irminger Basin has similar decadal variation to the overturning strength, and dominates other contributions.
- Heat loss strongly correlated with SST minus SAT: mainly controlled by air temperature, which follows NAO.
- Signs of AMOC recovery (e.g. Moat et al, 2018) not seen (yet) …

Storkey, D., et al., 2018. UK Global Ocean GO6 and GO7: a traceable hierarchy of model resolutions. *Geosci. Model Dev.*, **11**, 3187–3213. DOI: 10.5194/gmd-11-3187-2018.

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