RAPID AMOC sensitivity to surface buoyancy fluxes: the role of air-sea feedback mechanisms

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University of Oxford

OSNAP Project

Part of our OSNAP work

RAPID AMOC sensitivity to surface buoyancy fluxes: the role of air-sea feedback mechanisms

<u>Building other international OSNAP Collaborations</u>

Reconstruction of the most recent OSNAP variability

jointly with Susan Lozier, Feili Li, Penny Holiday, Gael Forget

Impact of OSNAP variability on RAPID AMOC and vice-versa

jointly coordinated with **Helen Pillar**, Patrick Heimbach's group, Susan Lozier, Feili Li, Fiamma Straneo, Isabela Le Bras

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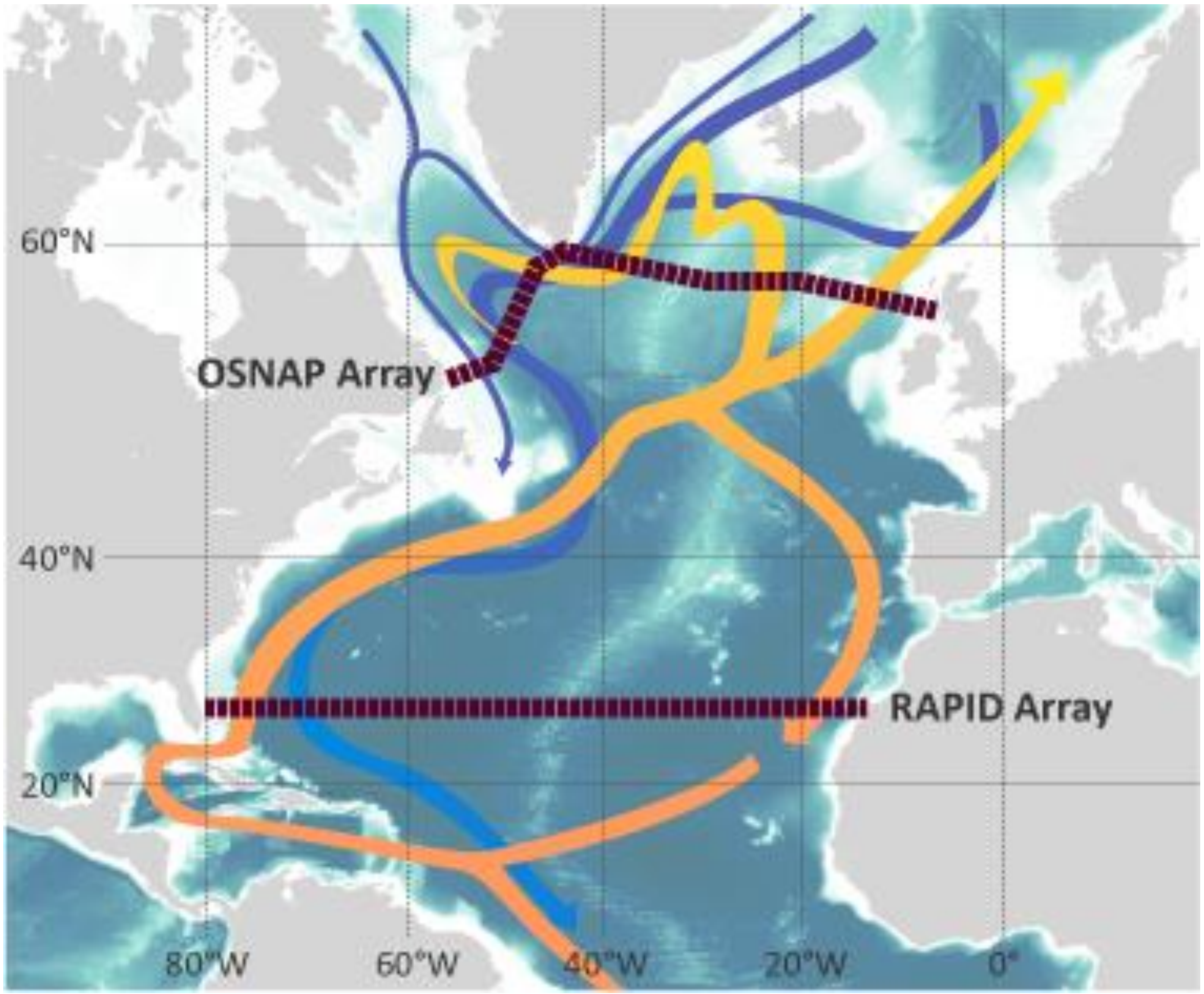
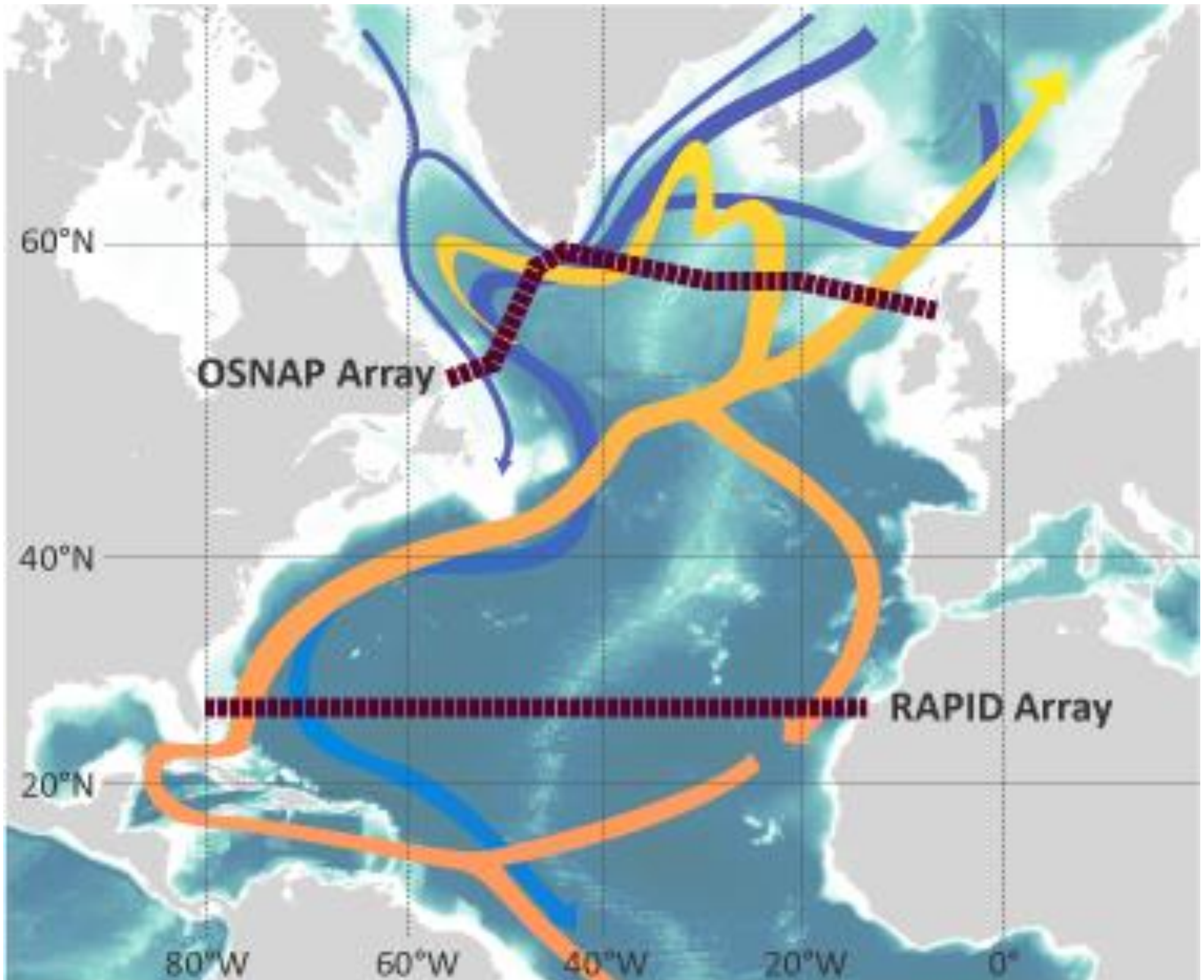
Sensitivity of RAPID AMOC to surface buoyancy fluxes over the Subpolar Gyre (OSNAP region)



http://www.rapid.ac.uk/

North-South / South-North Connectivity in the Atlantic
Isolating the role of air-sea feedback



http://www.rapid.ac.uk/

ECCO version 4 configuration of the MITgcm

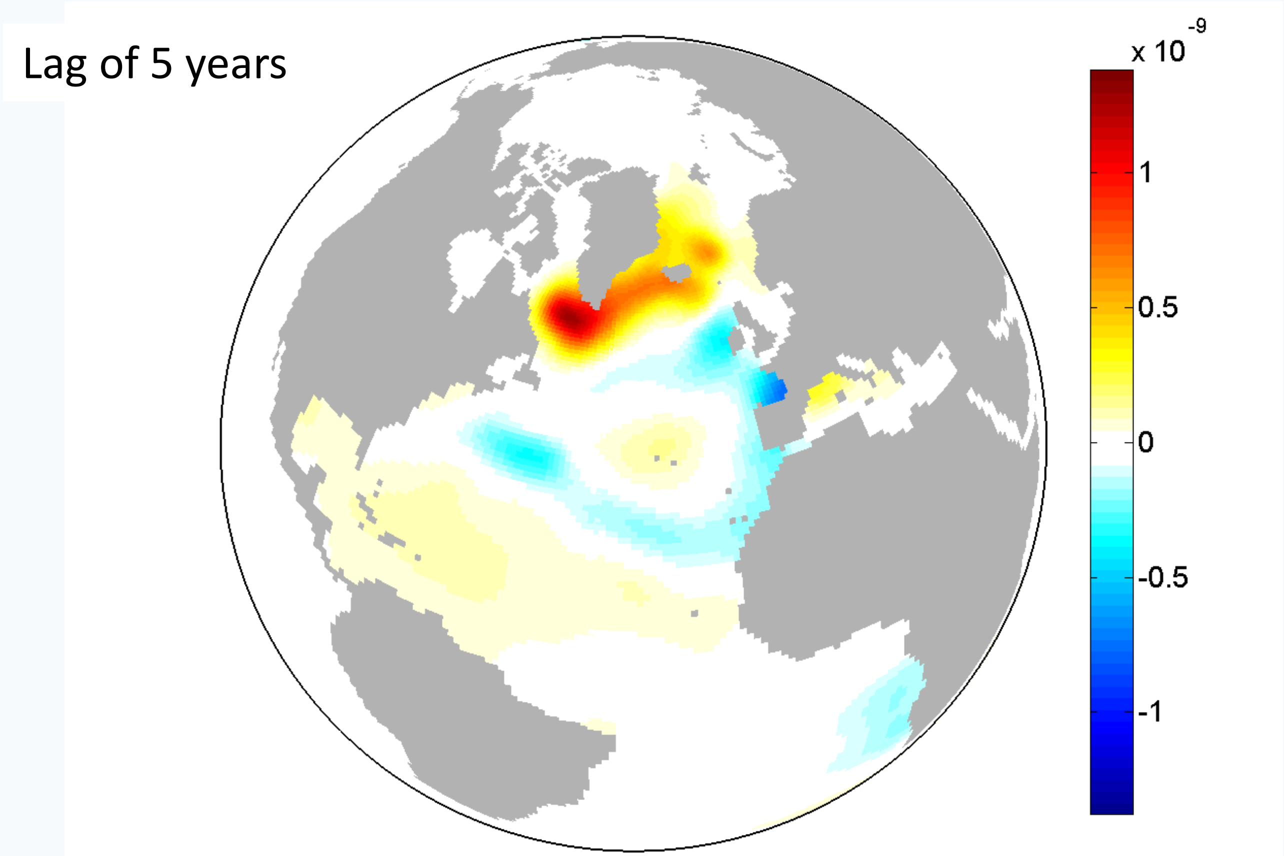
- ECCO: combines the MITgcm with observations to obtain a time-evolving global ocean state estimate;
- Roughly 1x1° resolution on a lat-lon-cap grid;
- Eddy and vertical mixing schemes with optimized parameters;
- Optimized surface fluxes (no restoring);
- Optimized ocean state.

MITgcm
ADJOINT CALCULATIONS

Linear sensitivity analysis using algorithmic differentiation

- No perturbation is applied.
- Not a symbolic analytical differentiation.
- It can handle loops and conditional statements.
- Algorithmic (automatic) differentiation of the code in adjoint mode

Sensitivity of RAPID AMOC to surface heat fluxes

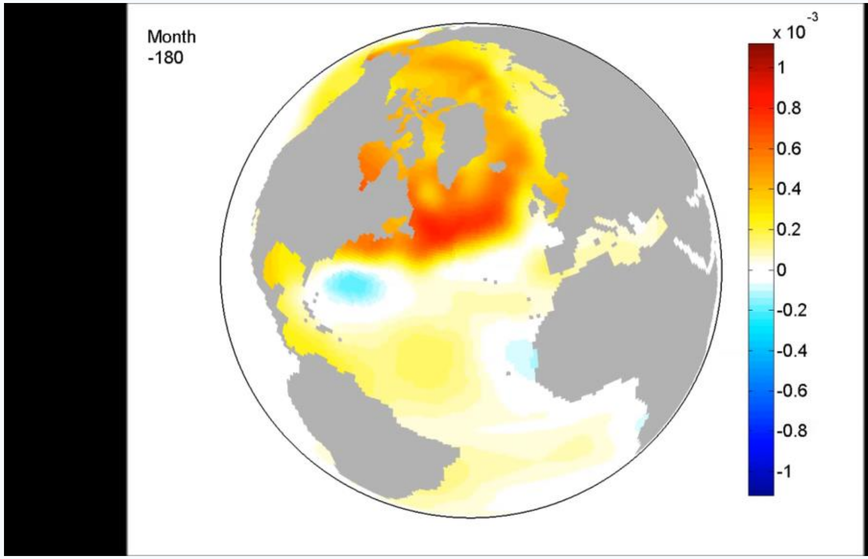


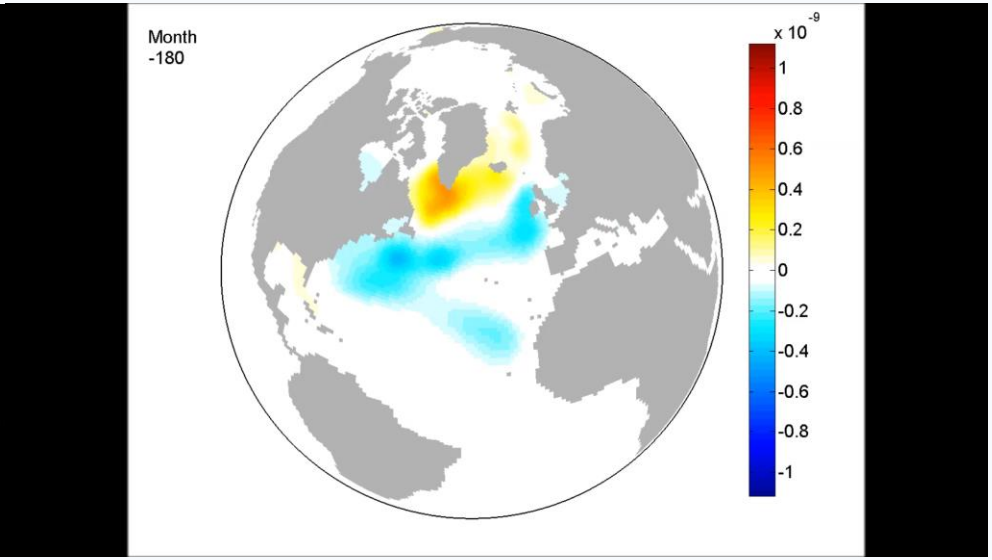
<u>Example:</u> Lagged sensitivity of RAPID AMOC to surface heat fluxes out of the ocean *[Sv/(W/m^2 sustained over 1 hour)]*

Red (blue): Delayed AMOC strengthening (weakening) in response to surface heat loss.

Sensitivity to evaporation minus precipitation

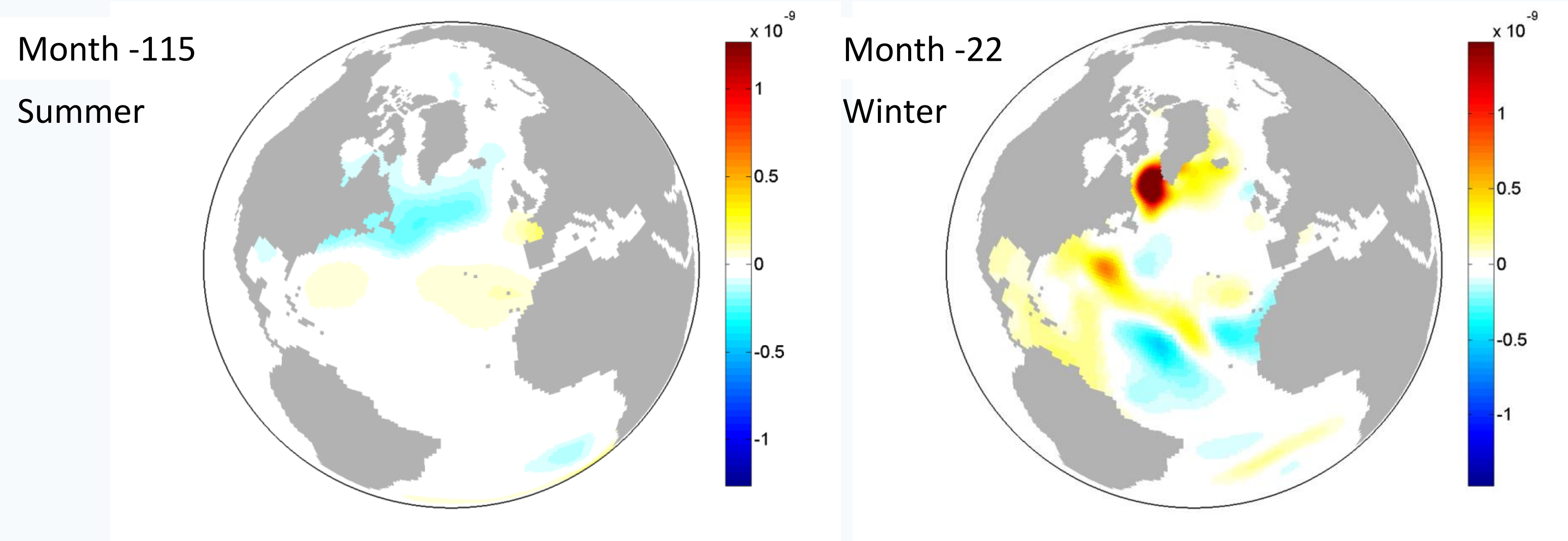
Sensitivity to surface heat fluxes



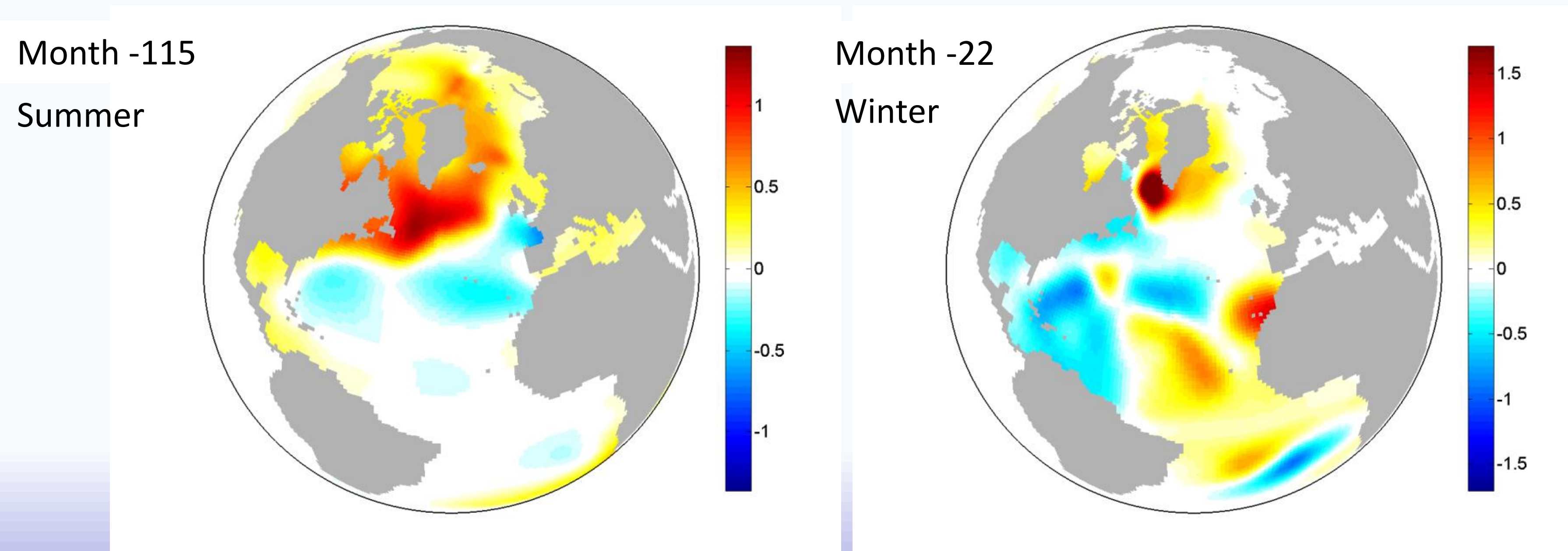


- The magnitude does not change fast with lag – long memory.
- Long memory in the Subpolar Gyre, but also the Arctic.
- Stronger global response to freshwater at zero lag.
- **Stronger seasonality in the sensitivity to heat fluxes than freshwater.**

Lagged Sensitivity of $AMOC_{26N}$ to Heat Fluxes [Sv/(W/m^2 sustained over 1 hour)]

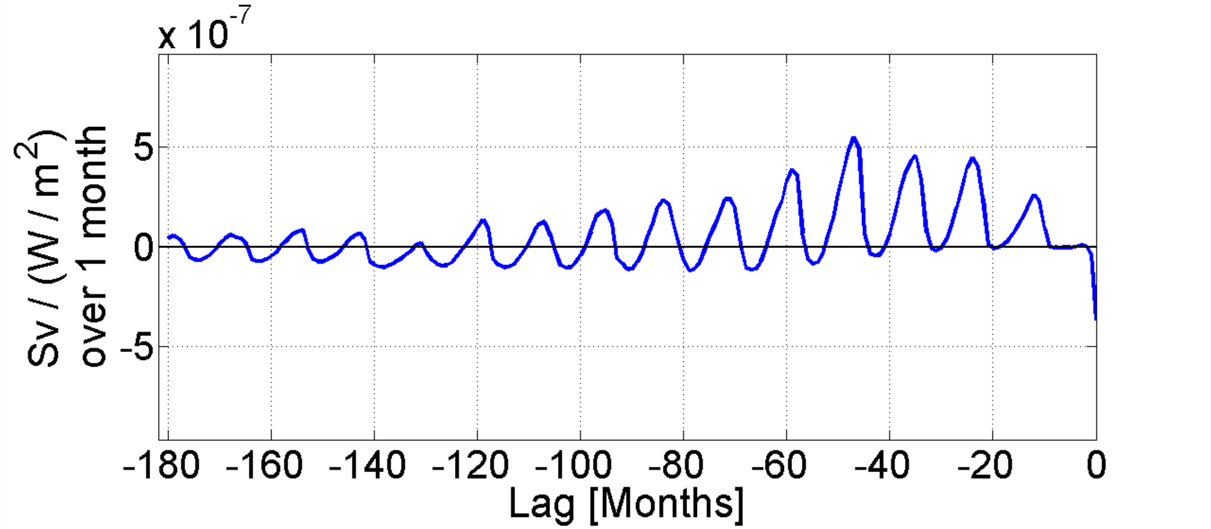


Lagged Sensitivity of $AMOC_{26N}$ to Freshwater Fluxes [Sv/(kg/m^3 sustained over 1 hour)]

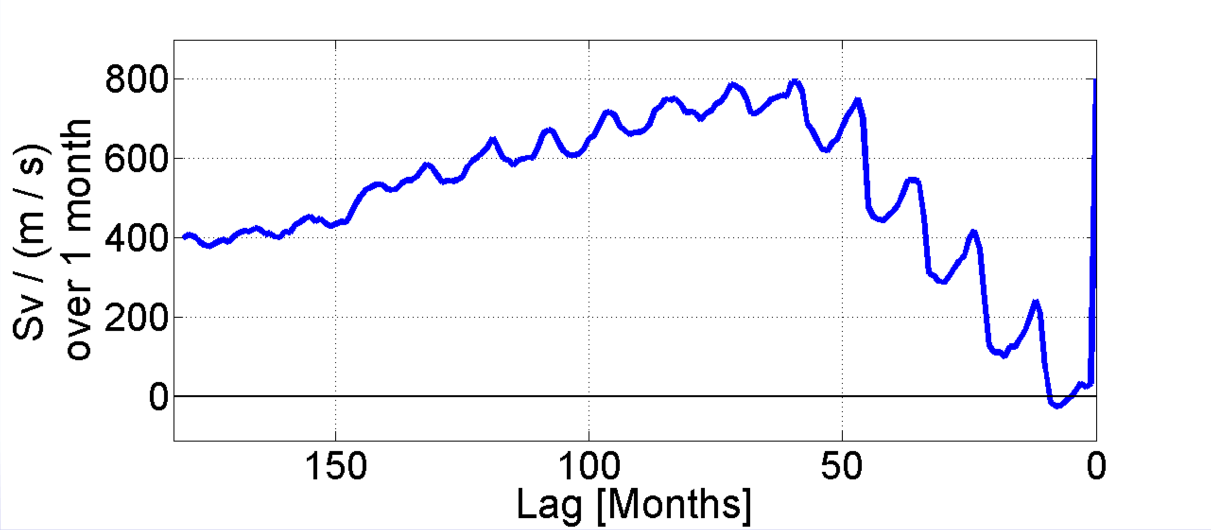


Sensitivity of RAPID AMOC to surface heat and freshwater fluxes out of the Subpolar Gyre

Heat



Freshwater



Sensitivity of RAPID AMOC to surface heat and freshwater fluxes out of the Subpolar Gyre

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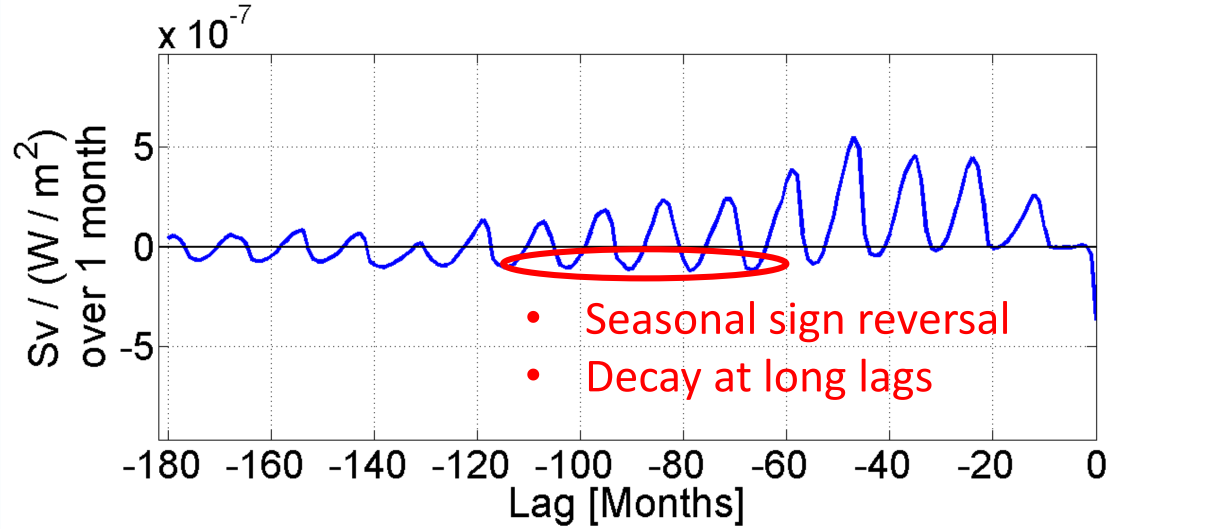
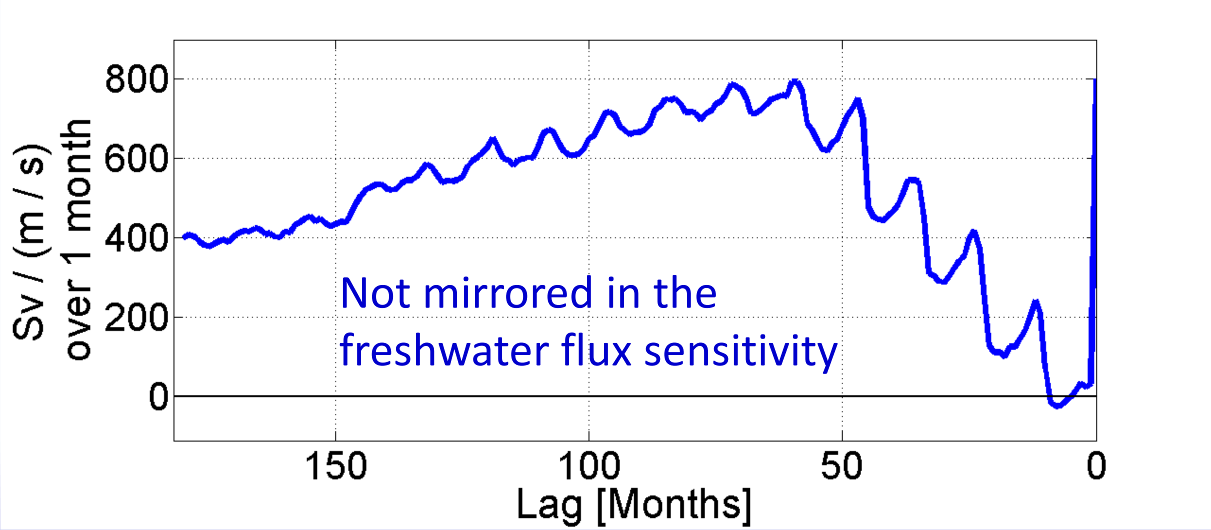
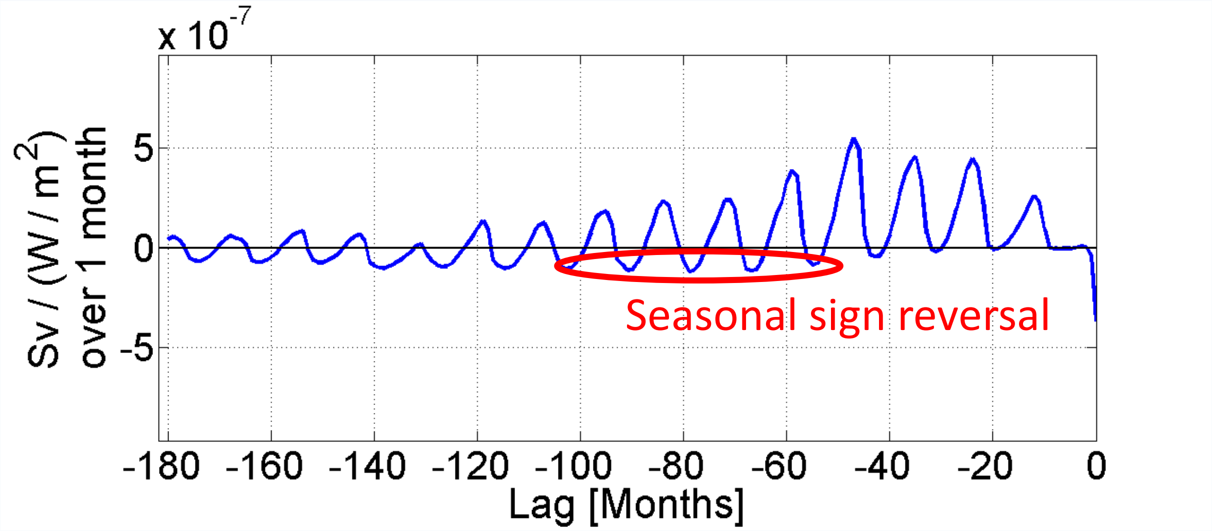


Freshwater



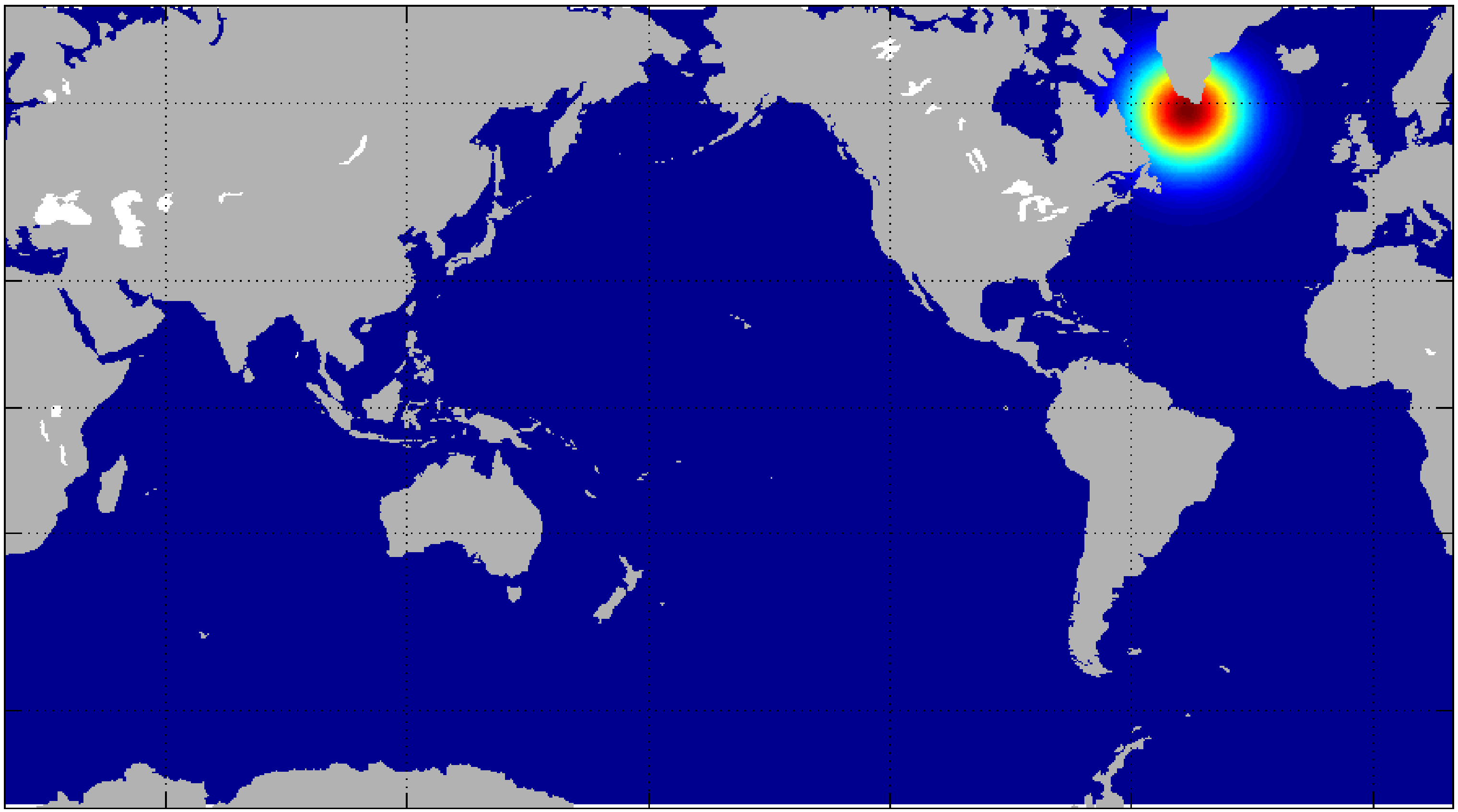
Sensitivity of RAPID AMOC to surface heat and freshwater fluxes out of the Subpolar Gyre



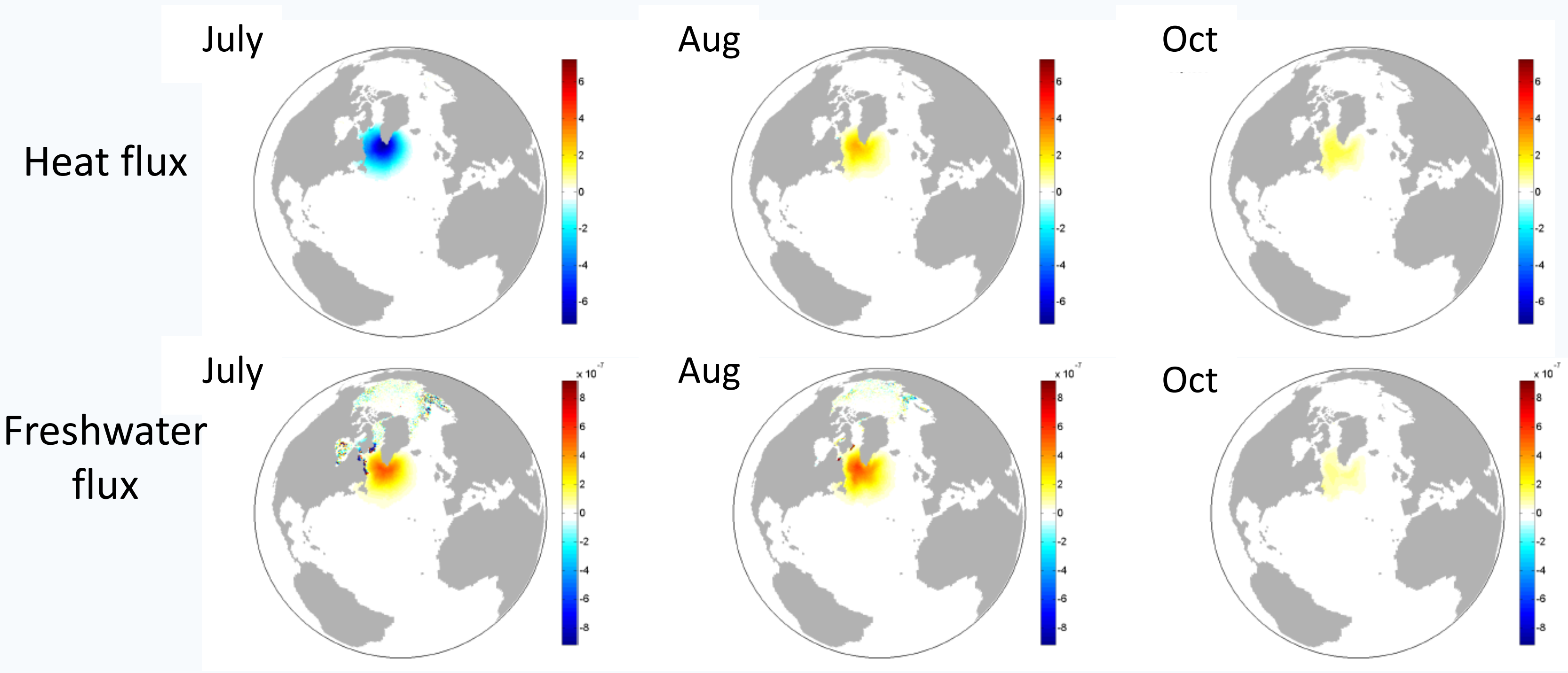
Winter cooling → AMOC strengthening;
Summer heating → AMOC strengthening!

FORWARD PERTURBATION EXPERIMENTS

Forward heat flux perturbation experiments



Summer heat flux perturbation experiments



Red = into the ocean

<u>Mechanism behind summer sensitivity:</u>

Summer cooling → larger SST decrease in the shallow mixed layer →

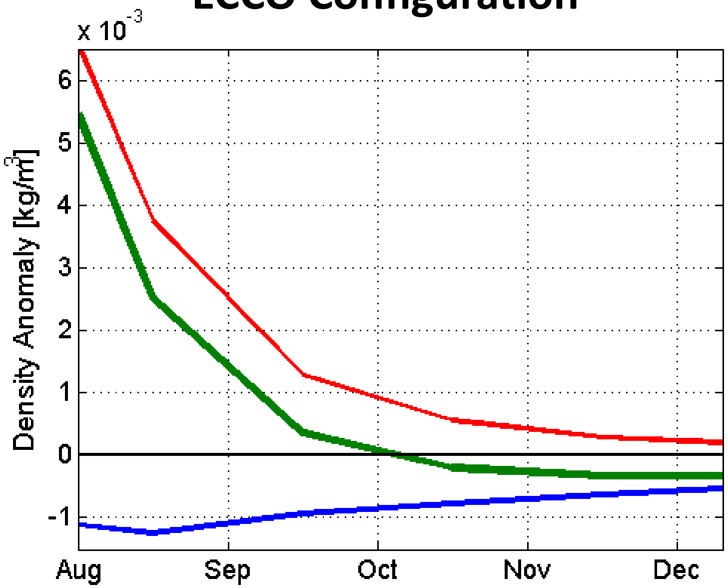
→ Decrease in evaporation → Negative salinity anomaly that persists until the winter.

Meanwhile the atmosphere damps the cooling anomaly in the shallow mixed layer.

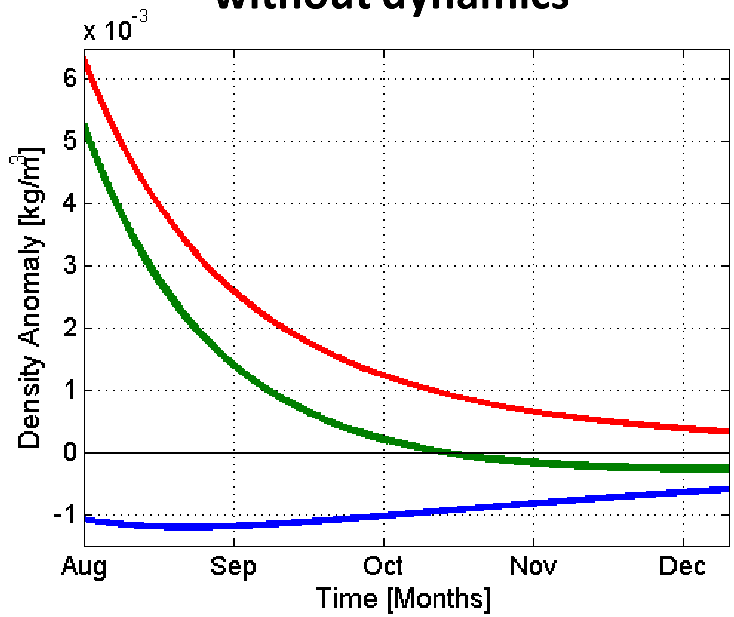
OFFLINE MIXED LAYER MODEL

Density in the upper 30m of the Western Subpolar Gyre after imposed summer cooling

MITgcm Perturbation Experiment
ECCO Configuration



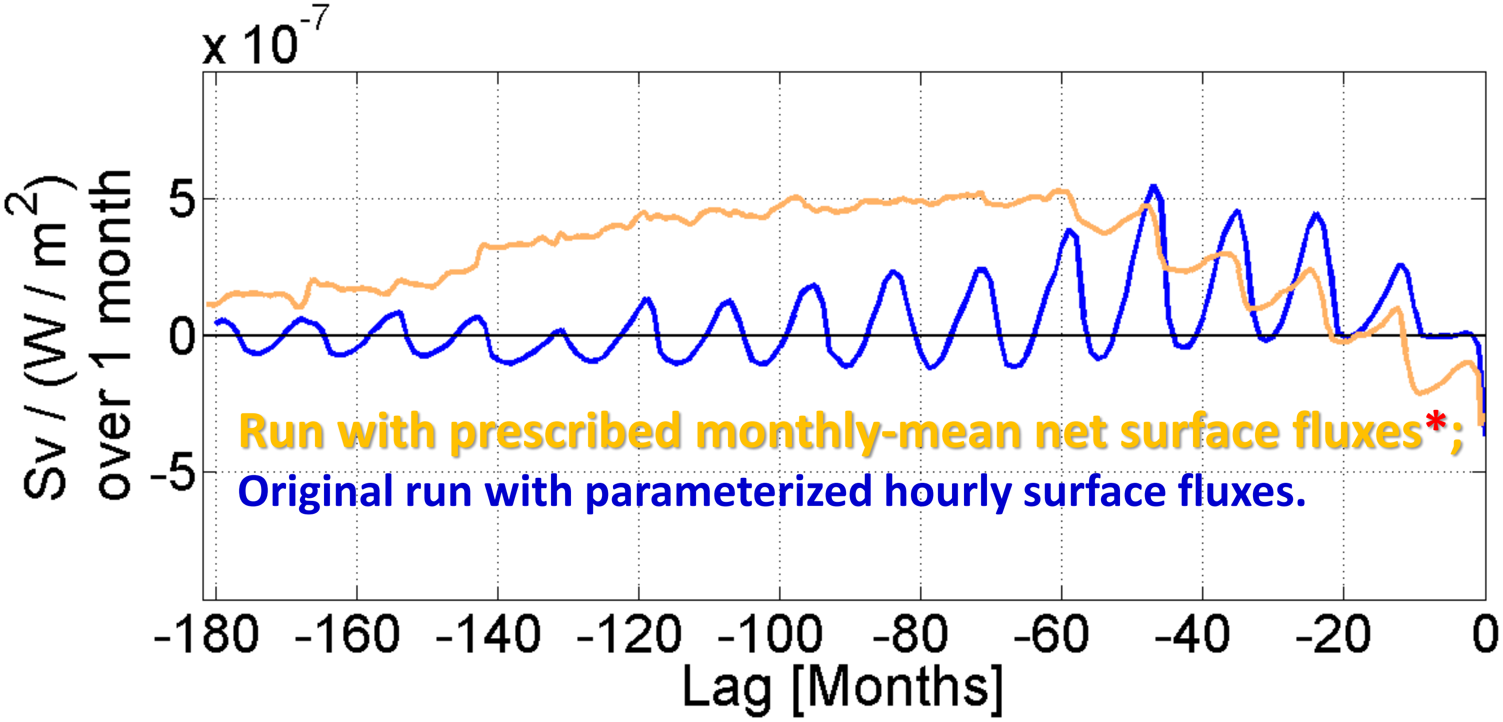
Offline regional mixed layer model
without dynamics



Temperature contribution to the density anomaly;
Salinity contribution to the density anomaly;
Total density anomaly.

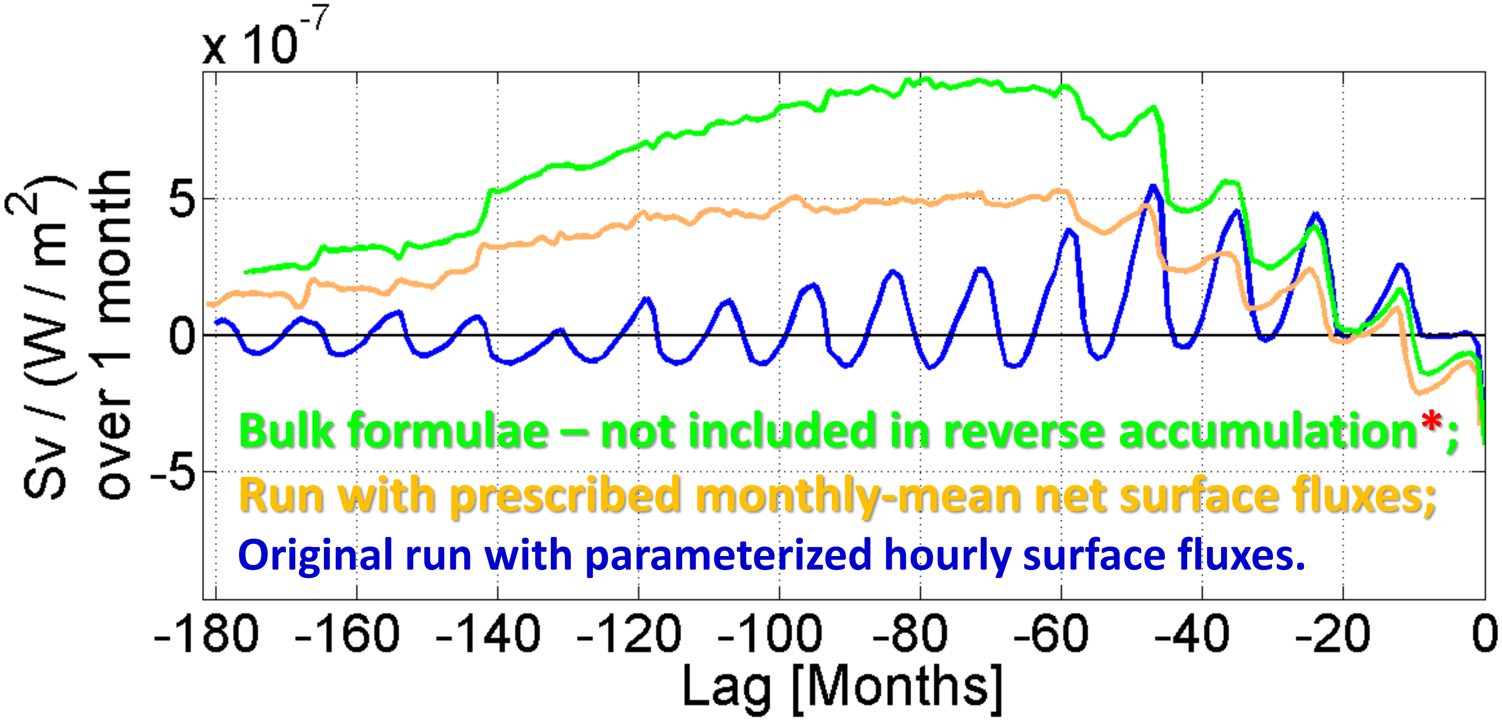
MODIFIED ADJOINT CALCULATIONS

Sensitivity of RAPID AMOC to surface heat fluxes out of the Subpolar Gyre



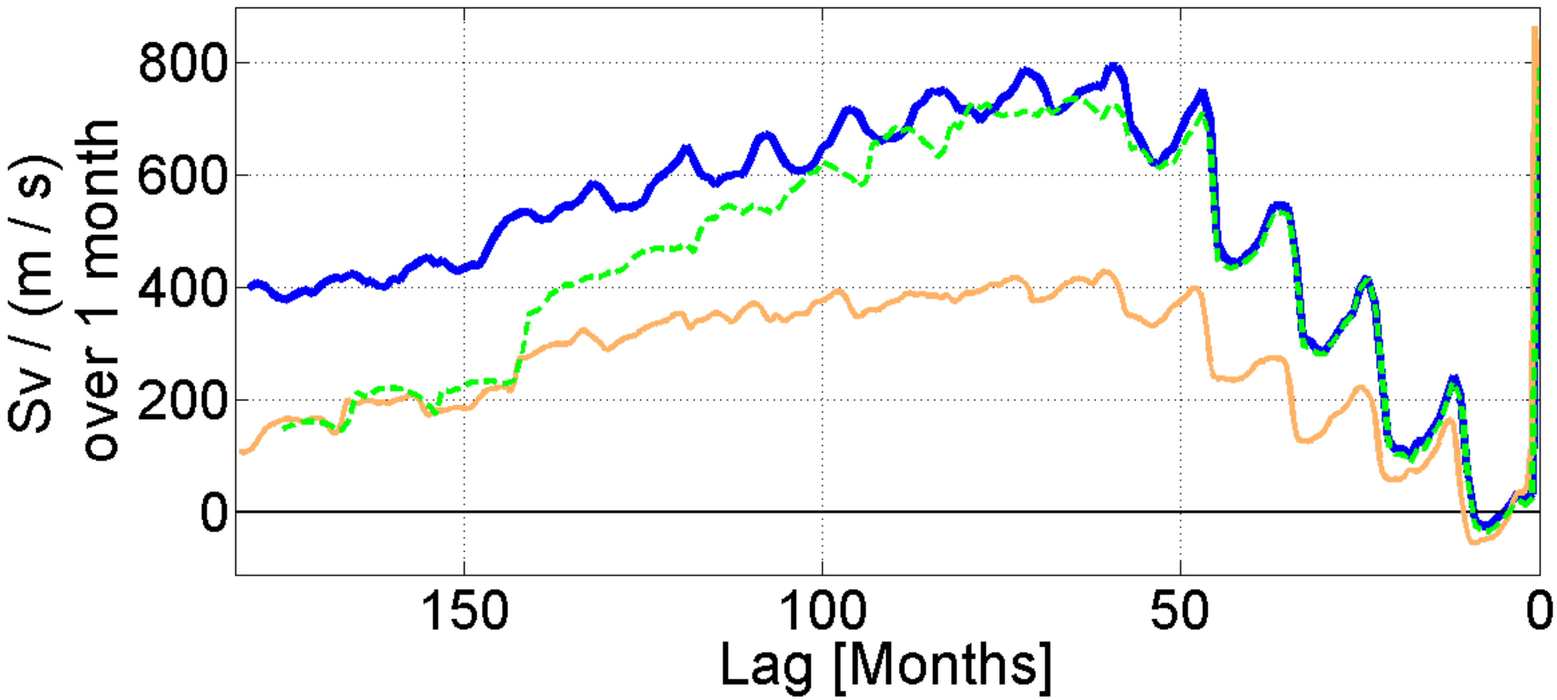
*Surface fluxes are not allowed to respond to SST but are fully provided as external forcing. However, the high latitude North Atlantic drifts relative to the ECCO simulation!

Sensitivity of RAPID AMOC to surface heat fluxes out of the Subpolar Gyre



*The forward ECCO historical simulation remains unchanged,
but I do not include the contribution of bulk formulae in the reverse accumulation.

Sensitivity of RAPID AMOC to surface freshwater fluxes out of the Subpolar Gyre



Bulk formulae – not included in reverse accumulation*;

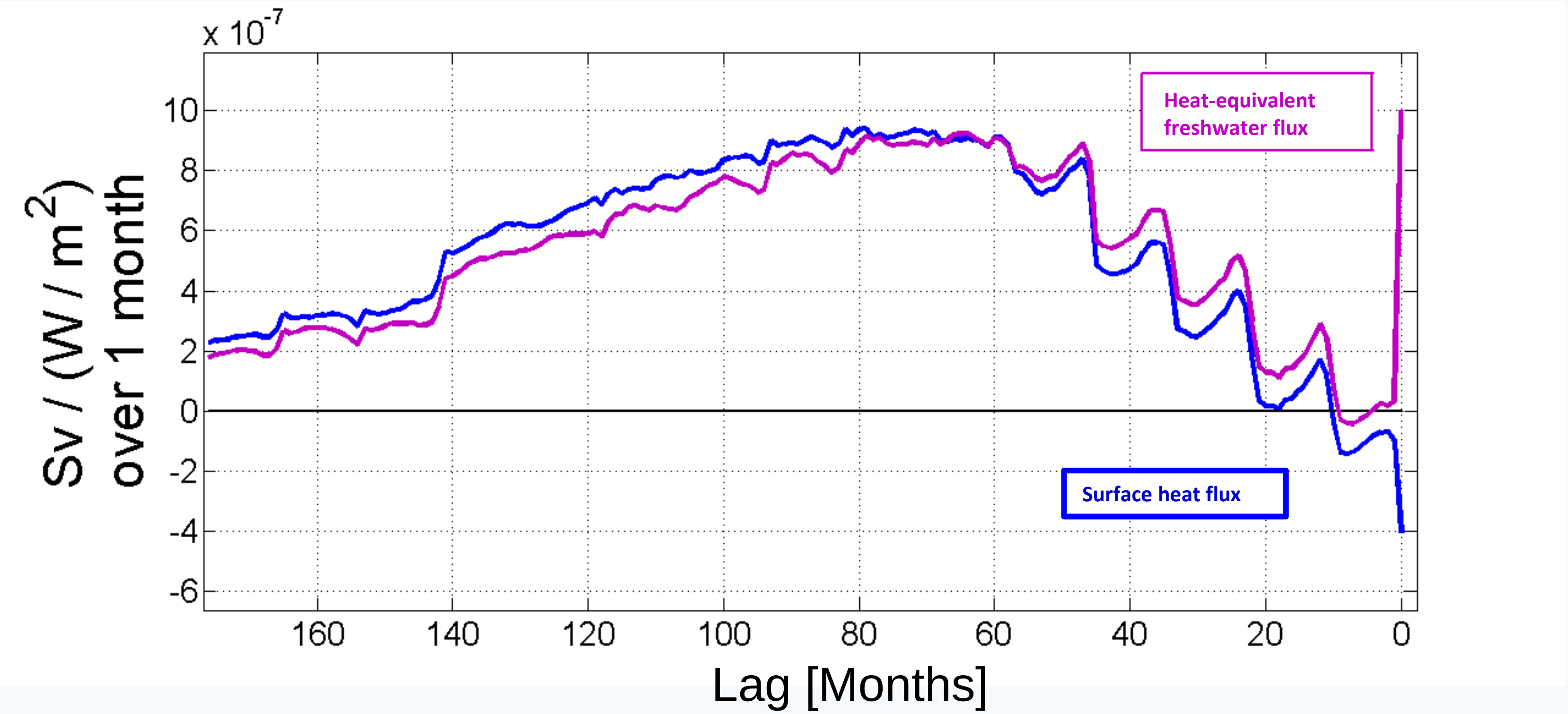
Run with prescribed monthly-mean net surface fluxes;

Original run with parameterized hourly surface fluxes.

***The forward ECCO historical simulation remains unchanged,**
but I do not include the contribution of bulk formulae in the reverse accumulation.

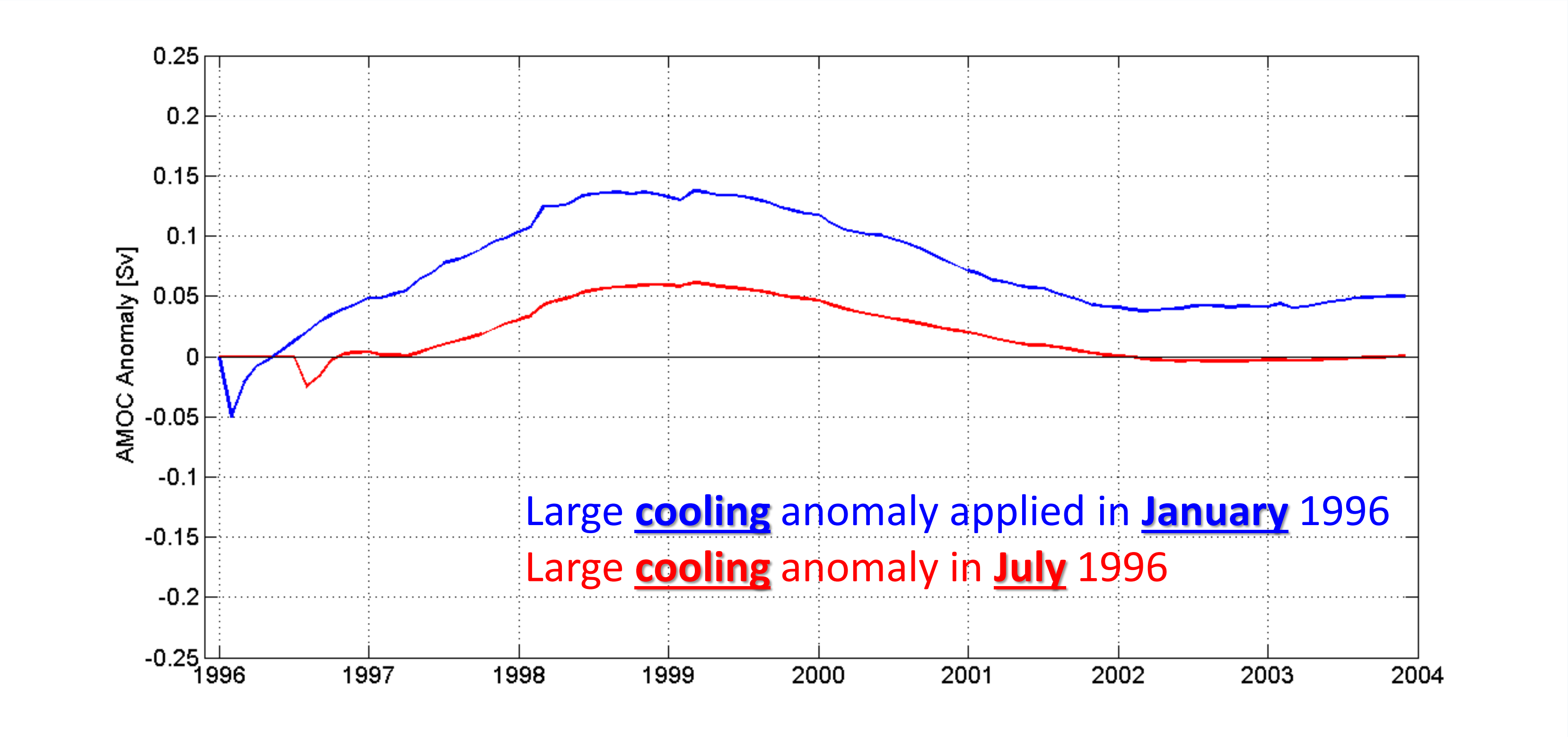
Sensitivity of RAPID AMOC to heat-equivalent surface freshwater fluxes

Bulk formulae – not included in the reverse accumulation, but the forward trajectory remains unchanged



Surface freshwater fluxes are rescaled in units of heat fluxes. Notice the same rate of decay at long lags.

Nonlinearity in the $AMOC_{26N}$ response to surface heat fluxes



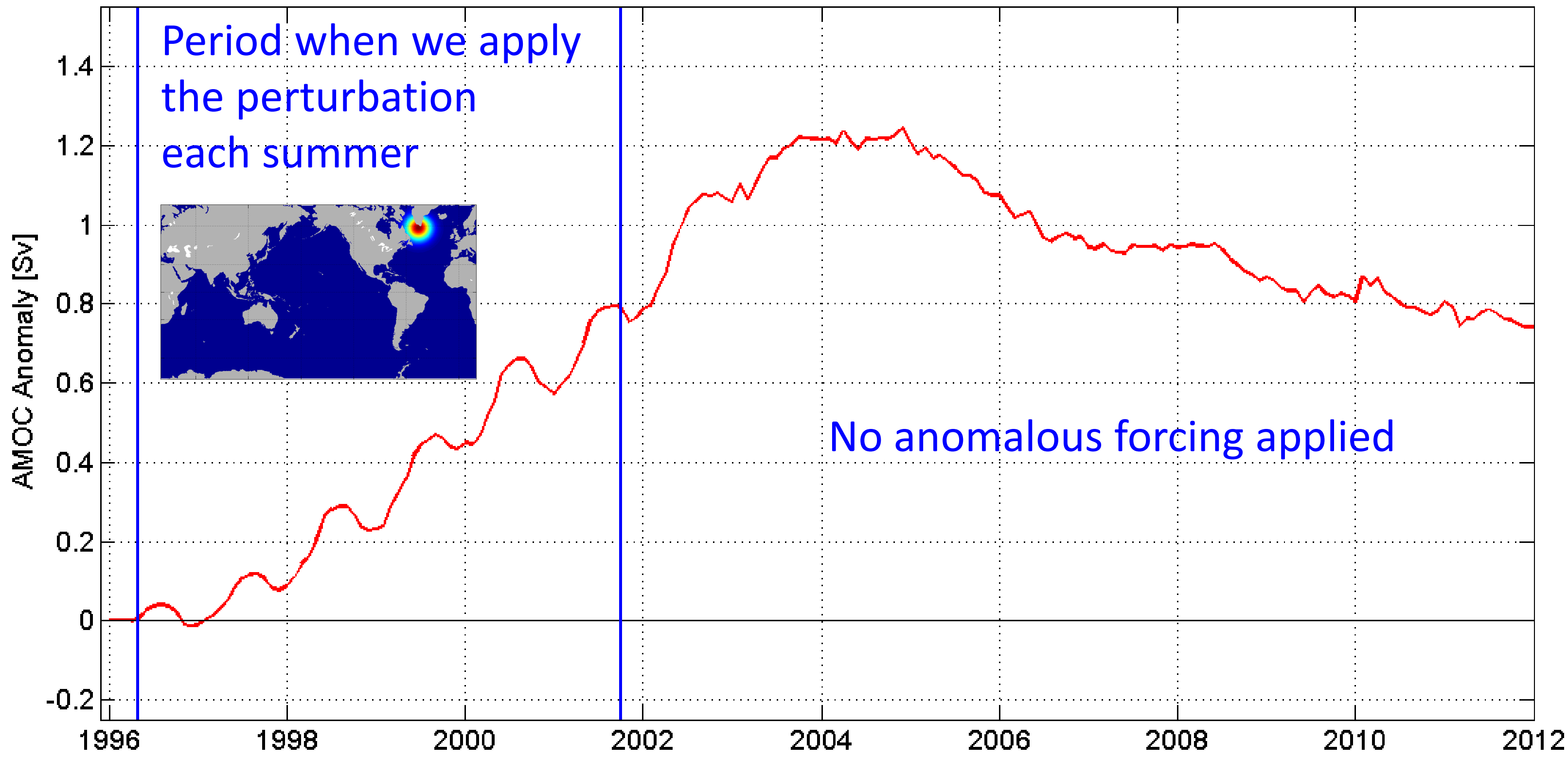
- The response to *winter* cooling is intuitive: a stronger AMOC.
- In the *summer*: the response to surface cooling is more nonlinear than the response to surface warming.

A short-lived but large cooling perturbation in the *summer* strengthens the AMOC!

A sustained small warming perturbation in the *summer* also strengthens the AMOC!

- Key processes that compete: change in MLD Vs. change in surface salinity.

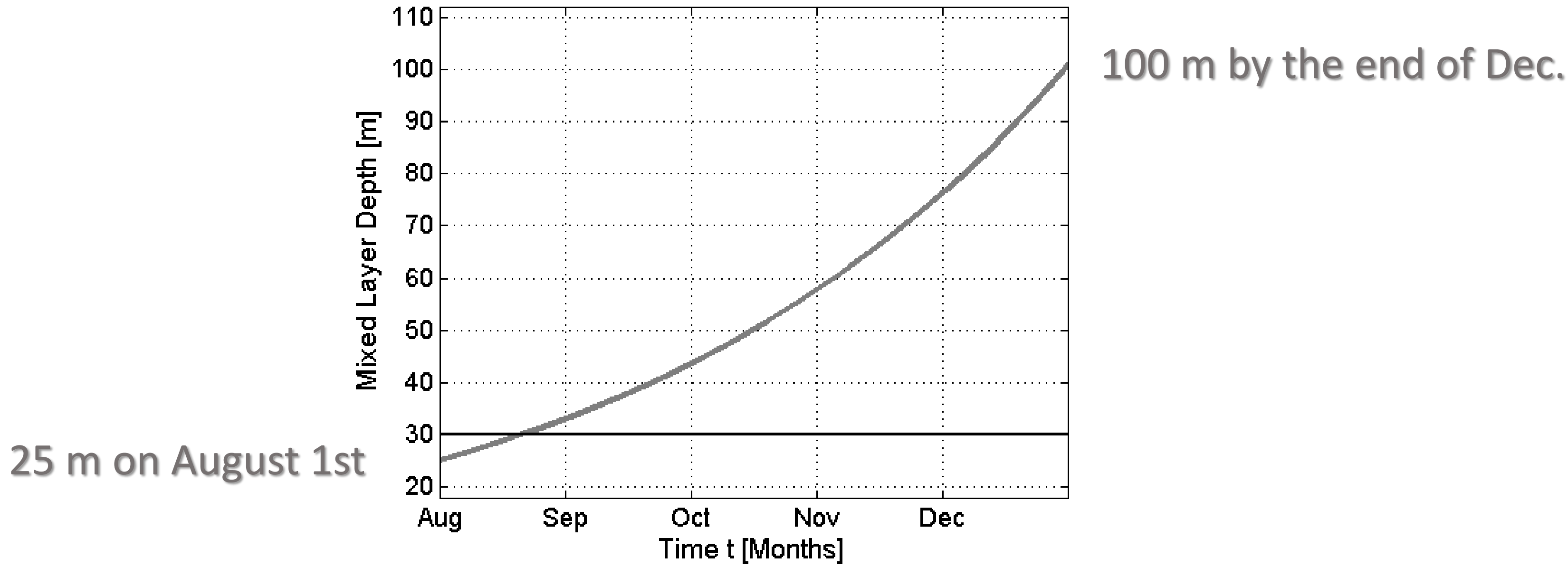
Response of AMOC$_{26N}$ to repeated positive heat flux perturbations (warming) in the summer

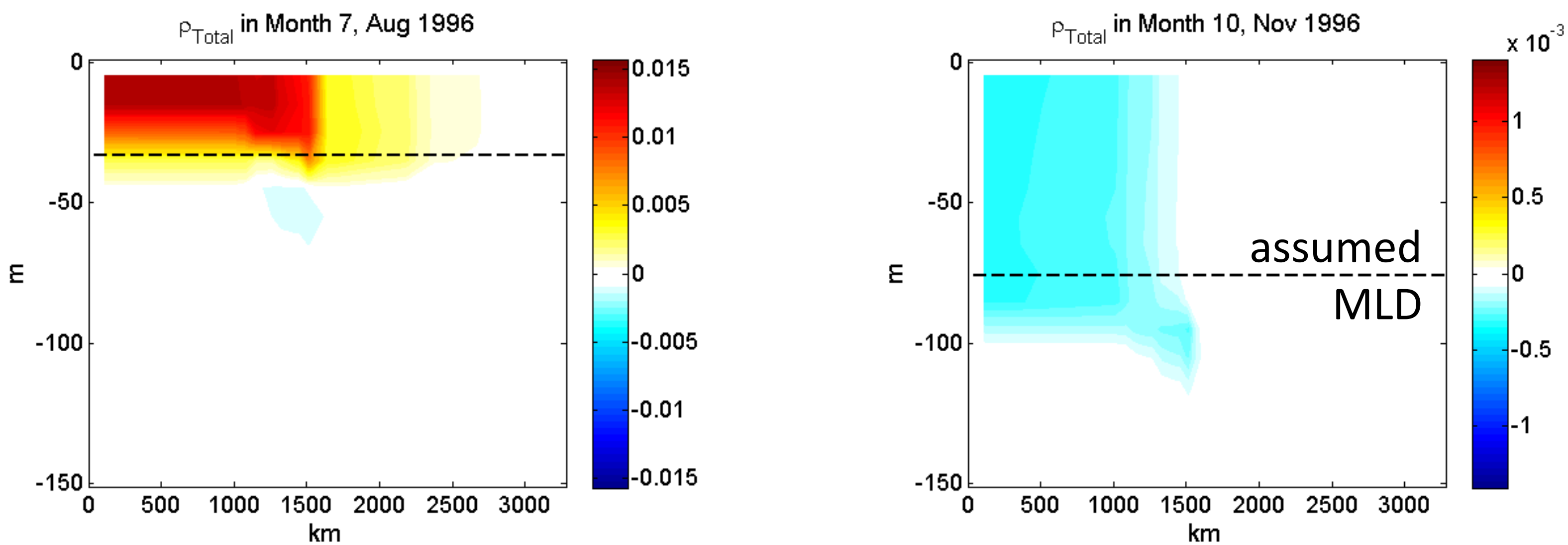


Conclusions

- Local air-sea feedback mechanisms play an important role in the North Atlantic Subpolar Gyre.
- Air-sea feedback explains the seasonal sign reversal in the RAPID AMOC sensitivity to surface heat flux out of the Subpolar Gyre.
- The AMOC sensitivities to surface heat and freshwater fluxes are related via air-sea feedback mechanisms. The representation of surface boundary conditions in models is thus very important. Using parameterized or prescribed fluxes; relaxing surface temperature and salinity impacts the AMOC sensitivity.
- Forward experiments highlight the nonlinearity of the response to surface heat fluxes.
- However, sustained linear changes can also add up over time to give a net drift in the AMOC.

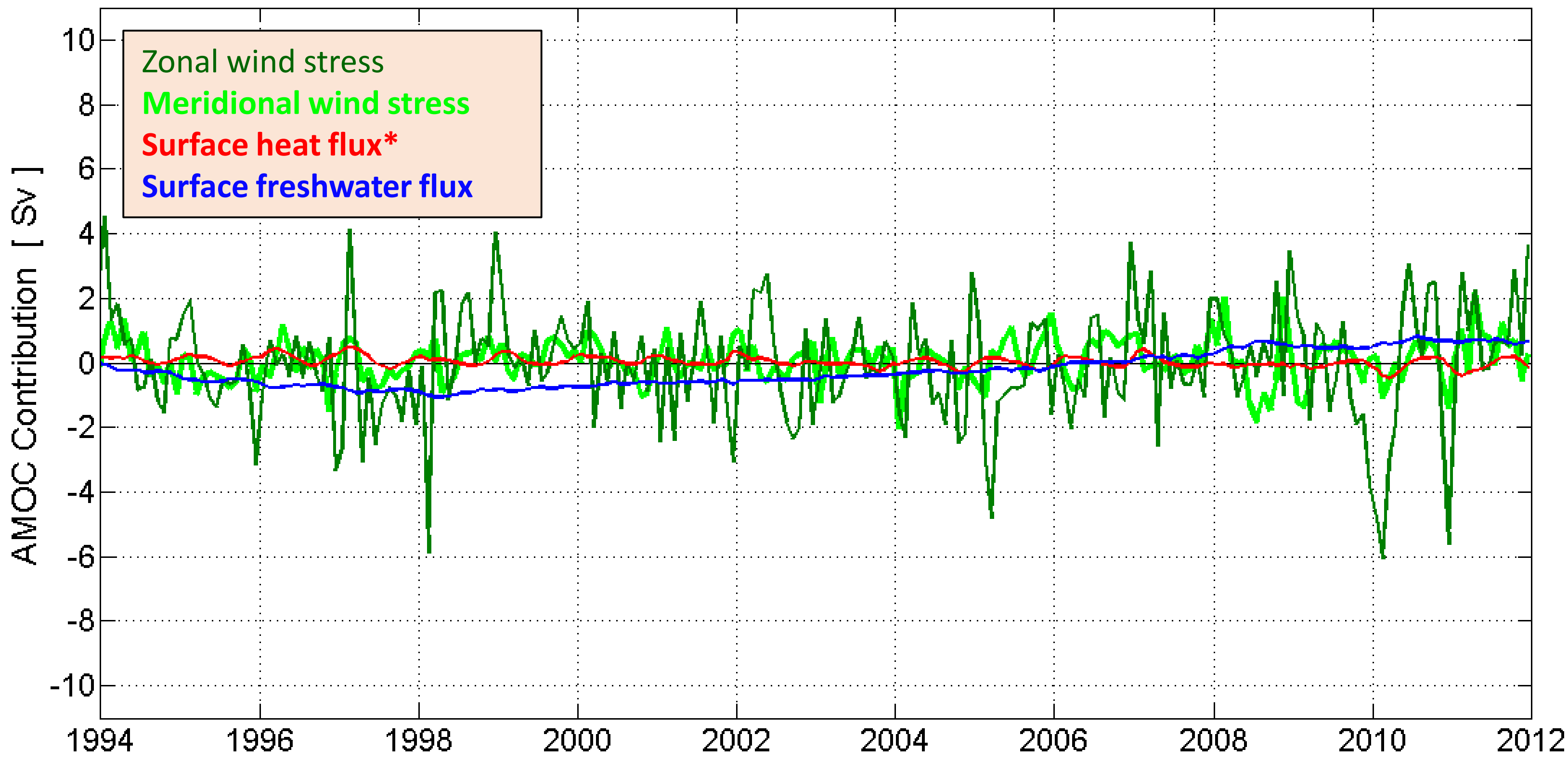
Assumed idealized evolution of the seasonal mixed layer depth



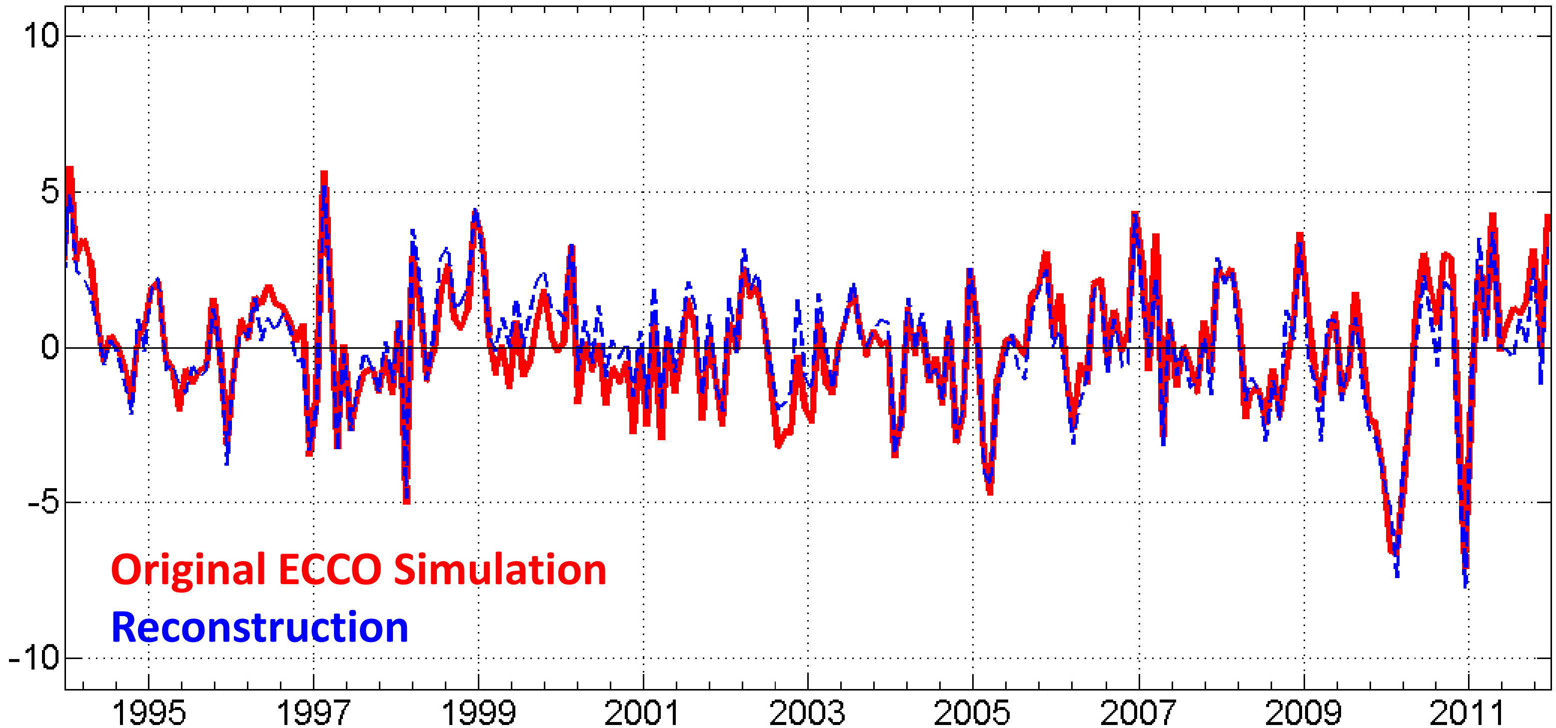


Section at 57°N from the summer cooling perturbation experiment with the MITgcm.
Notice the sign reversal of the density anomaly.

Breakdown of linear contributions to AMOC variability in ECCO



ECCO Reconstruction
using only wind-stress



Linear Response of the AMOC at 26°N to past forcing