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AMOC thresholds in CMIP6 models: North Atlantic Hosing MIP

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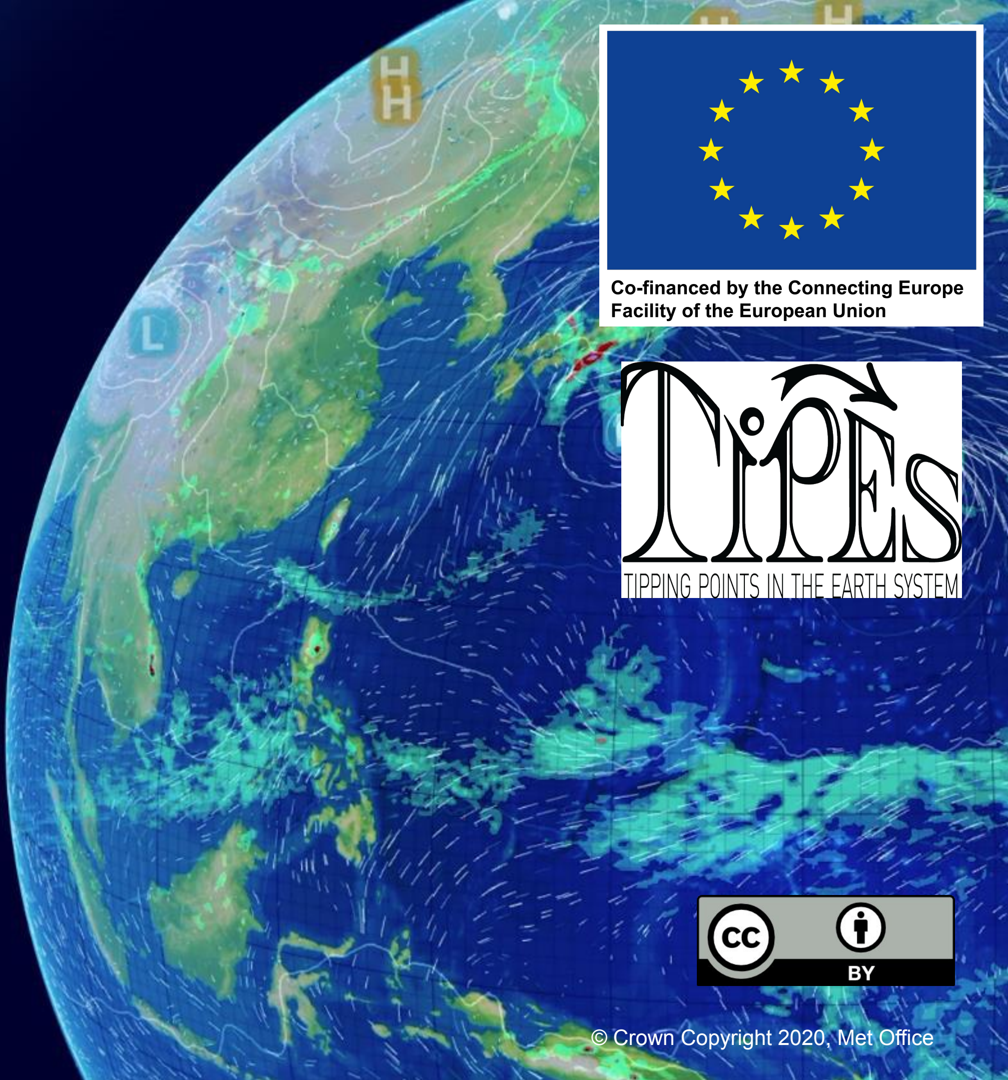

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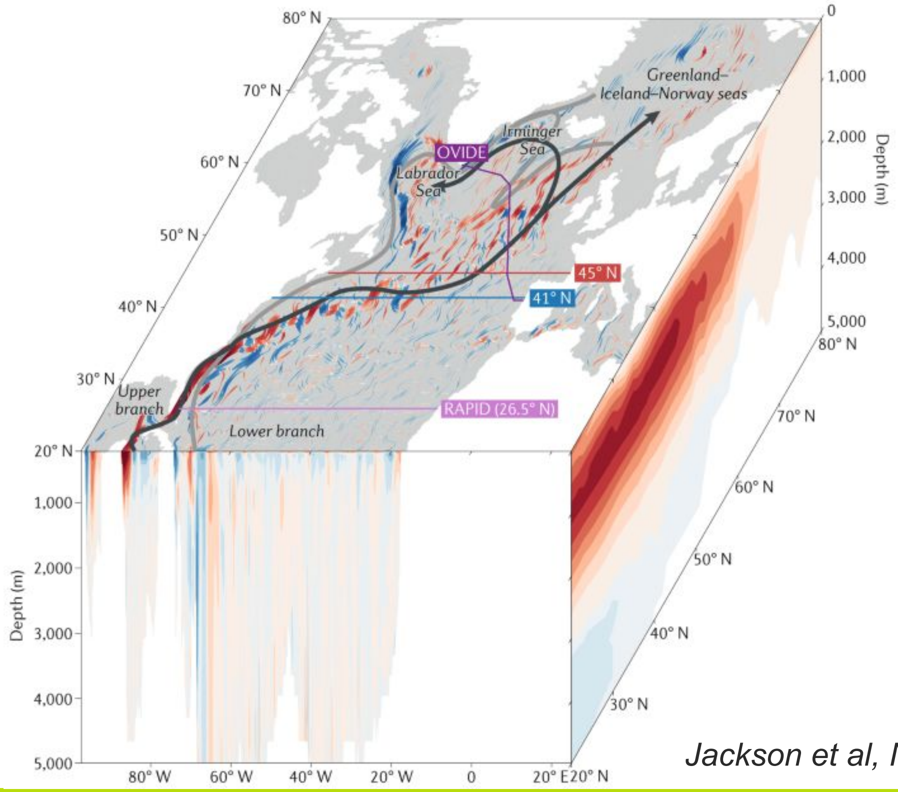
TiPES
TIPPING POINTS IN THE EARTH SYSTEM

AMOC Tipping Points



- The Atlantic Meridional Overturning Circulation (AMOC) transports the upper ocean northwards, where it cools, becomes denser and sinks. This transports heat northwards and impacts the climate.
- Future climate changes (warming, increase in freshwater input) would **weaken the dense water formation** and weaken the AMOC.
- IPCC: Very likely to weaken in the future, but medium confidence of no collapse before 2100.

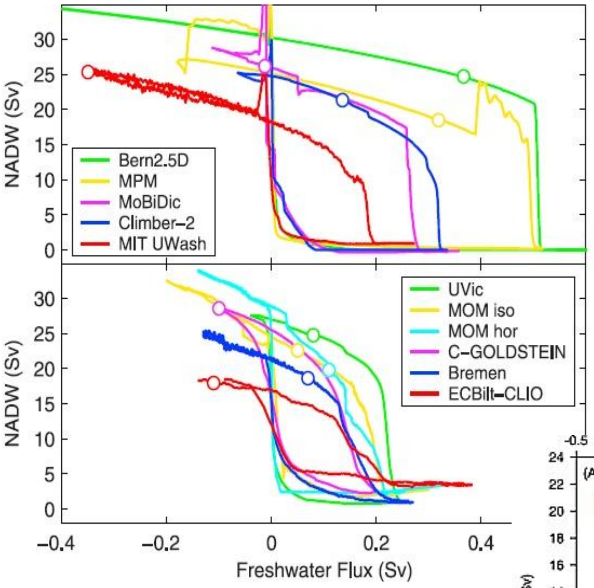
Jackson et al, Nature Rev Earth Env 2022

Investigating AMOC stability

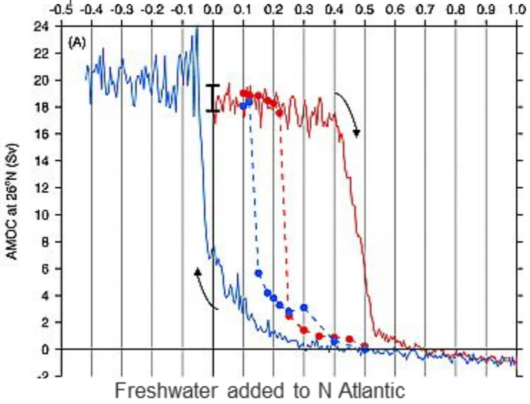
Theory and some models have shown that the AMOC can have **two stable states** – an “on” and an “off” state, with freshwater enabling the transition.

Paleo data suggests large amounts of freshwater input in the past may have caused the AMOC to collapse.

Future input of freshwater from Greenland Ice sheet melt not likely enough. BUT are climate models too stable? – want to understand what affects stability.



Rahmstorf et al. GRL 2005



Hawkins et al. GRL 2011

NAHosMIP: North Atlantic Hosing MIP

Aims: Examine AMOC thresholds in CMIP6 models in the presence of freshwater forcing.

- Understand whether CMIP6 models exhibit a threshold in the AMOC.
- Understand how different feedbacks contribute to different AMOC behaviour in different models, and what the implications of this are for the real world.

Models: 8 CMIP6 models of varying resolution and ocean component.

Experiments: Apply 0.3 Sv of freshwater (hosing) uniformly north of 50N for 20, 50, 100 years

Using large, idealised hosing helps to understand the model sensitivities and how they differ.

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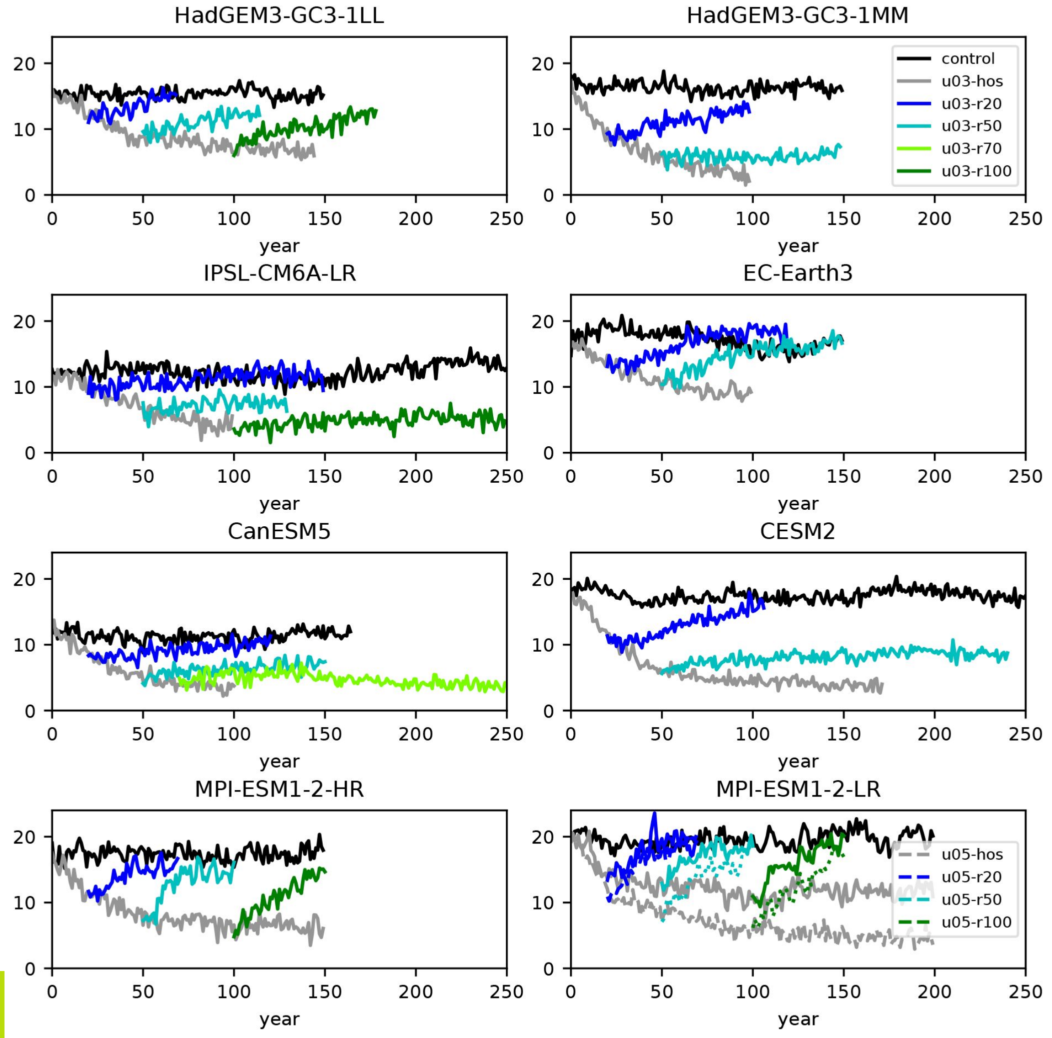
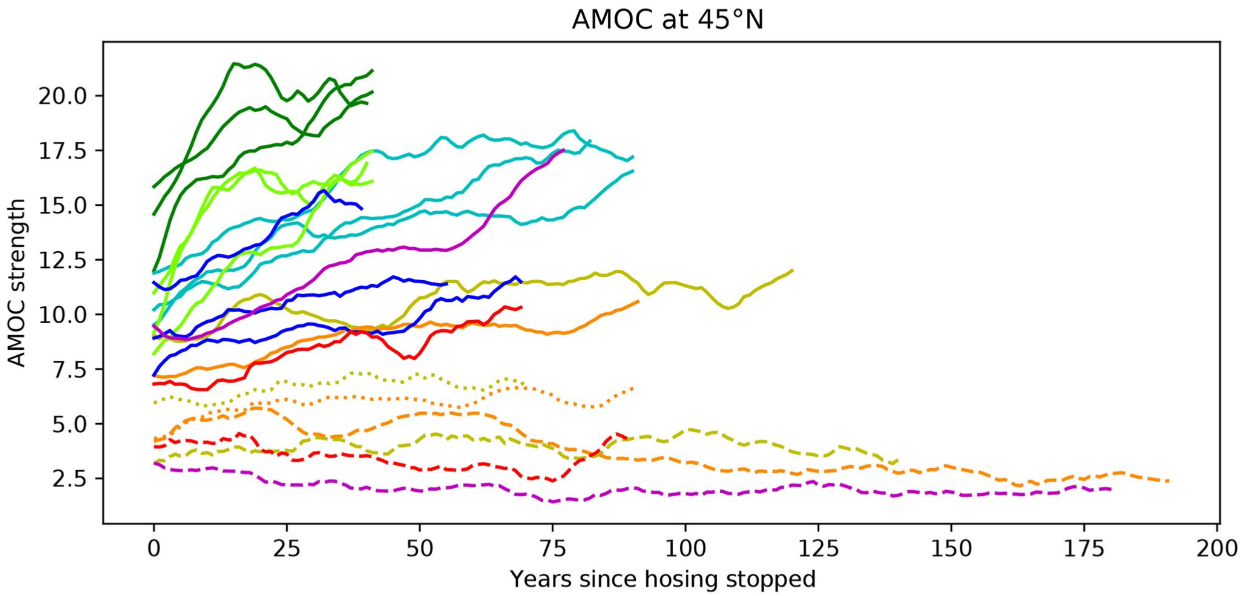
AMOC weakens during hosing (grey lines)

Half of the models reach a state where the AMOC does not recover when hosing stops.



In those experiments where the AMOC is weakened the most, the AMOC does not recover once hosing stops.



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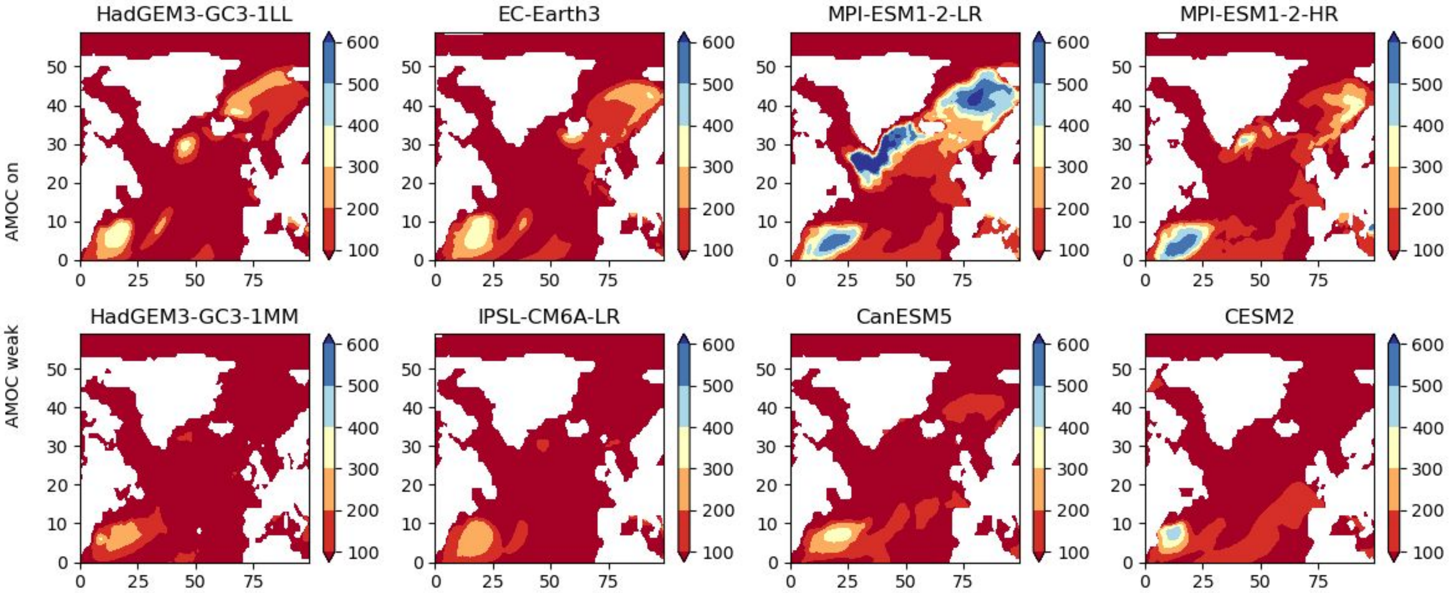


Those models where the AMOC does not recover (bottom) have very little deep convection (March MLD) after hosing. Particularly in GIN seas

What is different in different models?

AMOC recovery after hosing is NOT related to:

- Horizontal resolution

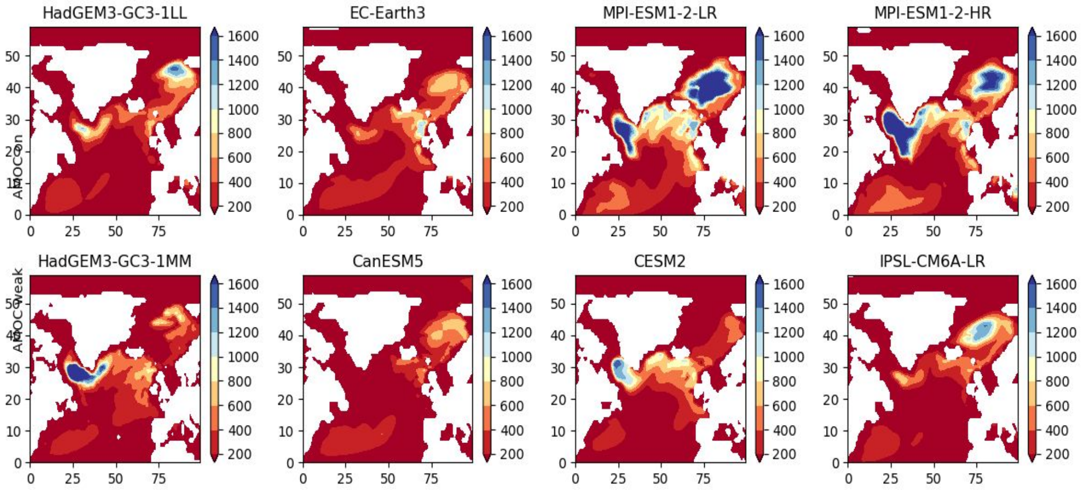
    AMOC stays in weak state in HadGEM3-GC3-1MM (1/4 degree) but also in lower resolution models (CanESM5, IPSL-CM6A-LR both 1 degree)

- Ocean model (ie NEMO)

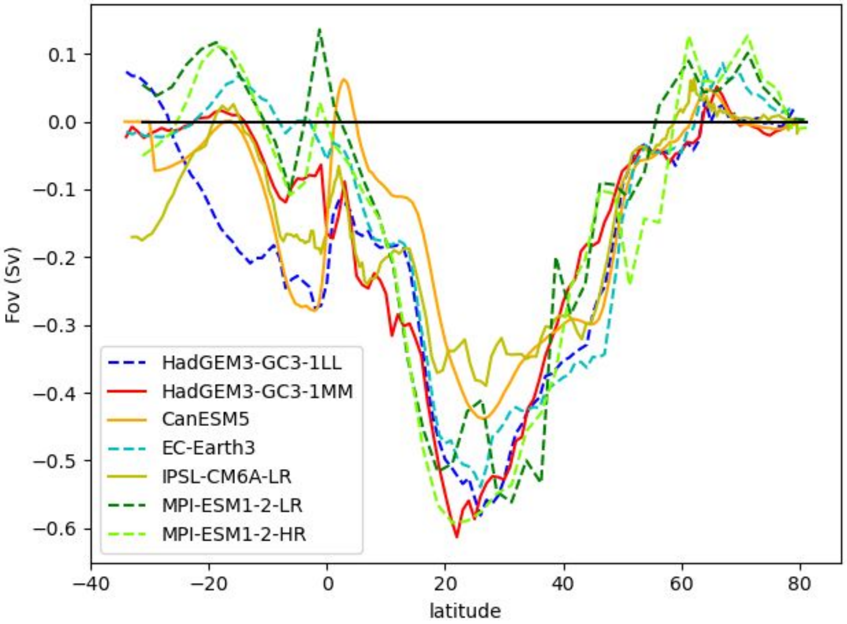
    - There are models with both weak and recovering AMOC in NEMO and non-NEMO models

- Mean state biases in SST, SSS, sea ice

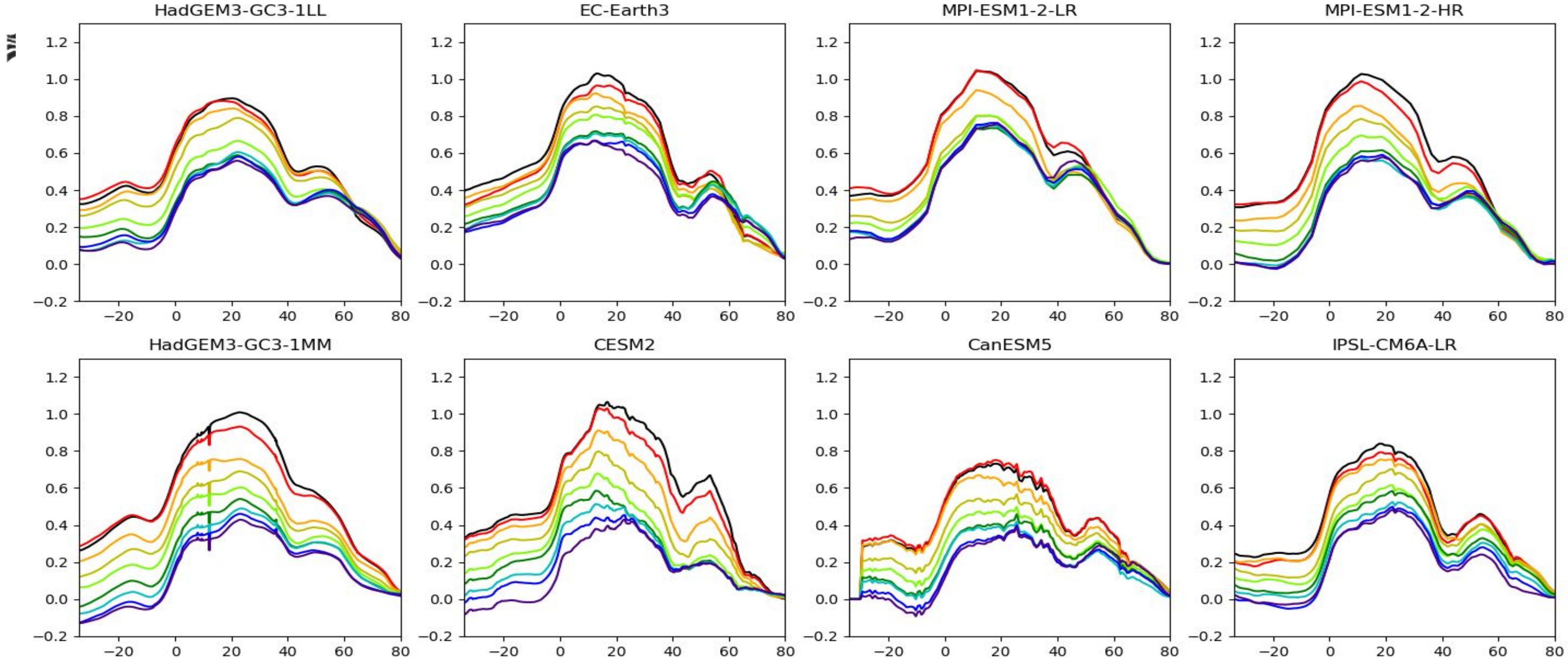
- Mean state biases in strength or location of deep convection



- Mean state biases in Fov (FW transport by AMOC). This has been proposed as an indicator of stability

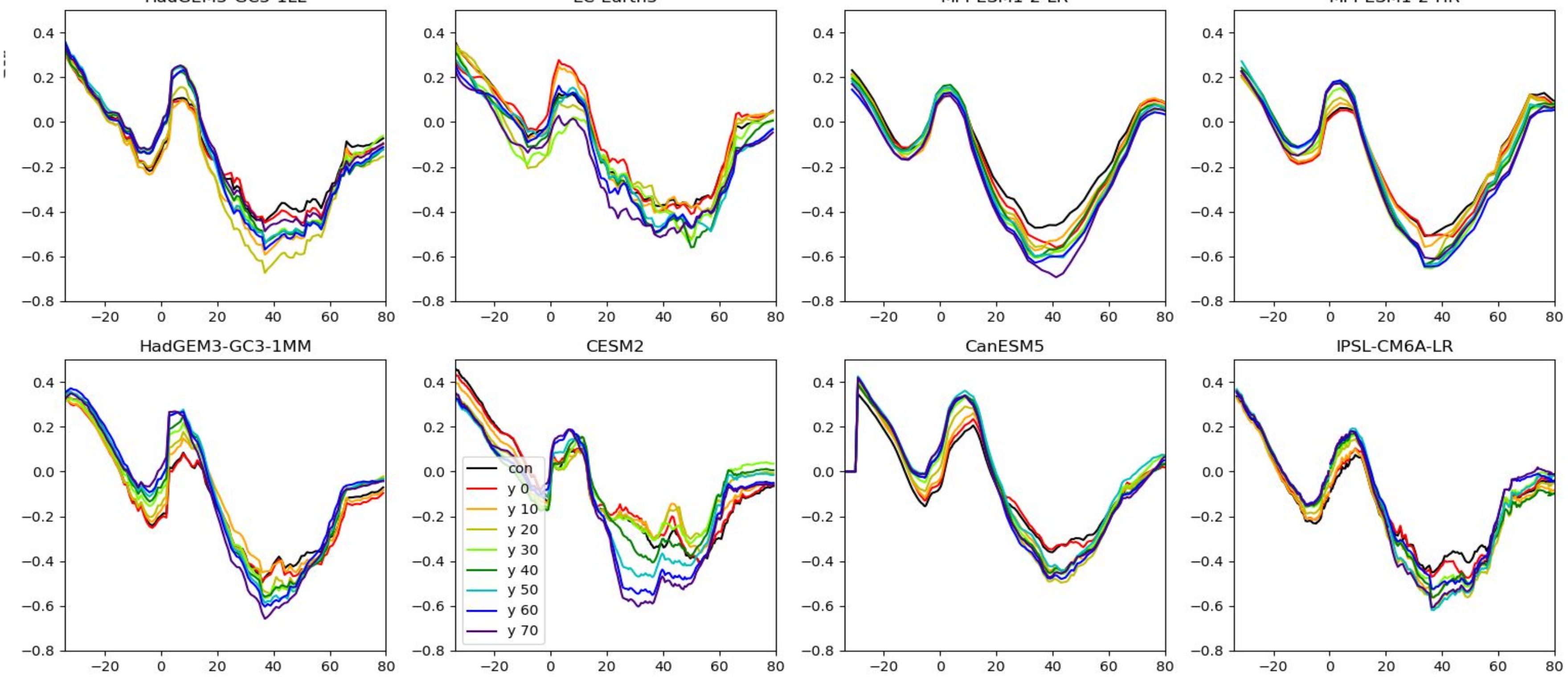


Protocol and initial results: Understanding AMOC stability: the North Atlantic Hosing Model Intercomparison Project https://doi.org/10.5194/gmd-16-1975-2023



Heat transport by latitude Control: black. First decade: red. Last decade: purple

Models where AMOC doesn't recover (bottom) have weaker heat transport after hosing (consistent with weaker AMOC)



FW transport by latitude Control: black. First decade: red. Last decade: blue

In all, 0.1-0.2Sv more FW exported from subpolar N Atlantic around 40N, but not enough to compensate the hosing

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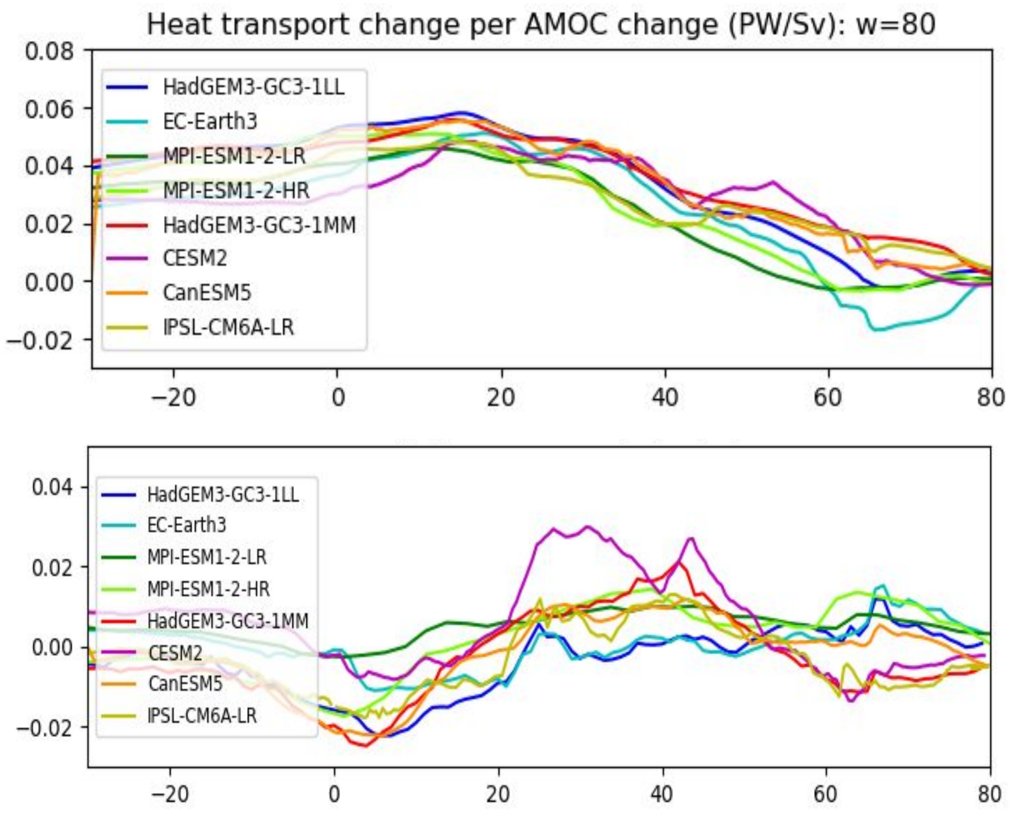
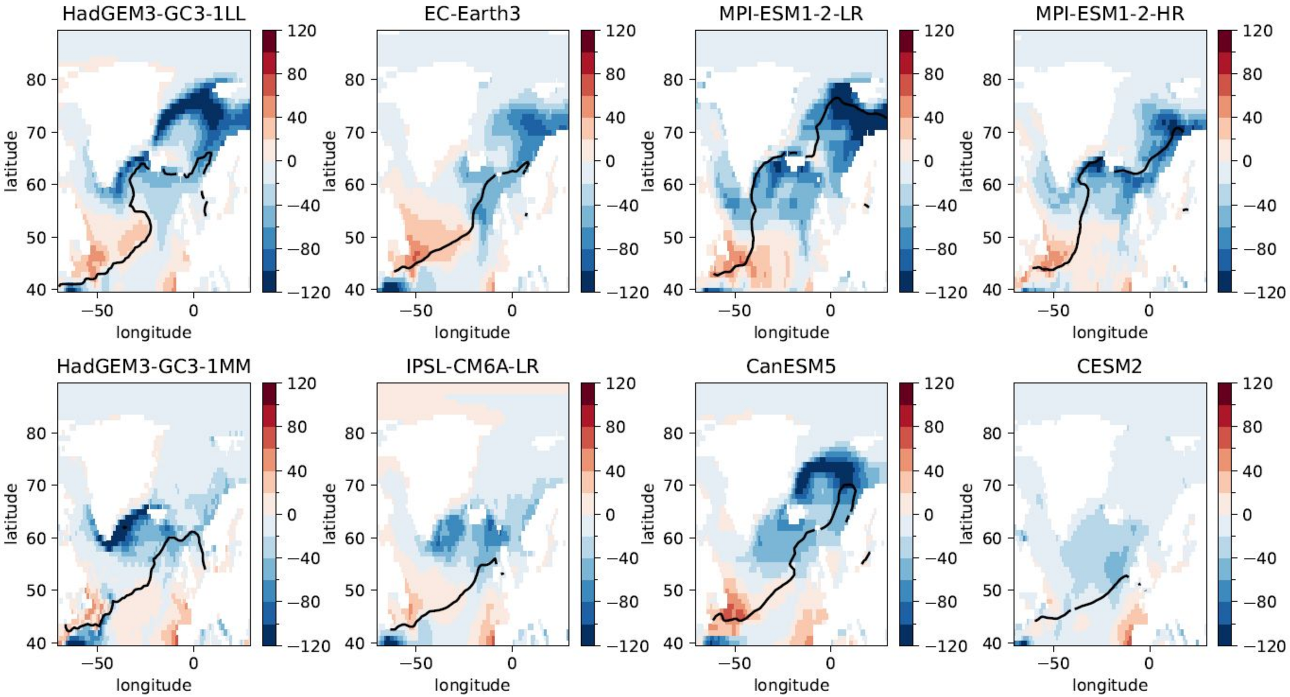


Regress OHT or OFWT against AMOC at 26.5N over first 80 years

In the models where the AMOC does recover (blue/green colours) there is an increase in heat and salt import into the GIN seas despite AMOC weakening. This would help to keep dense water mass formation and deep convection going.

In other models there is less import of heat and salt into the GIN seas.



In most models which don't recover (bottom panels) large extent of sea ice (shown in March, black lines) inhibits air-sea heat fluxes (contours) and hence formation of dense water.

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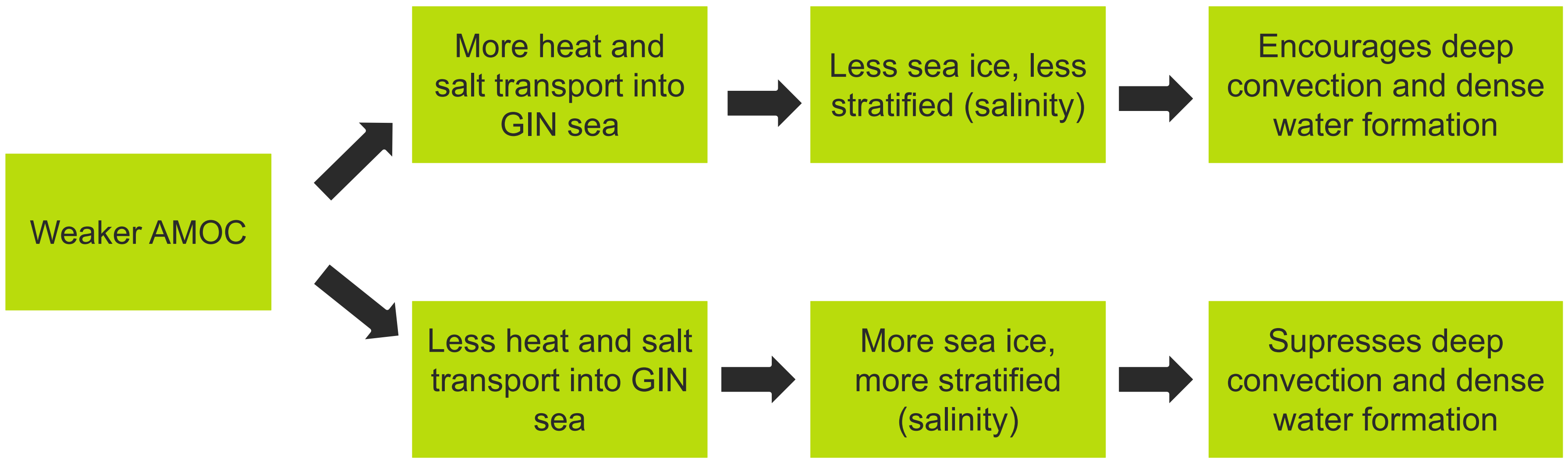


Conclusions

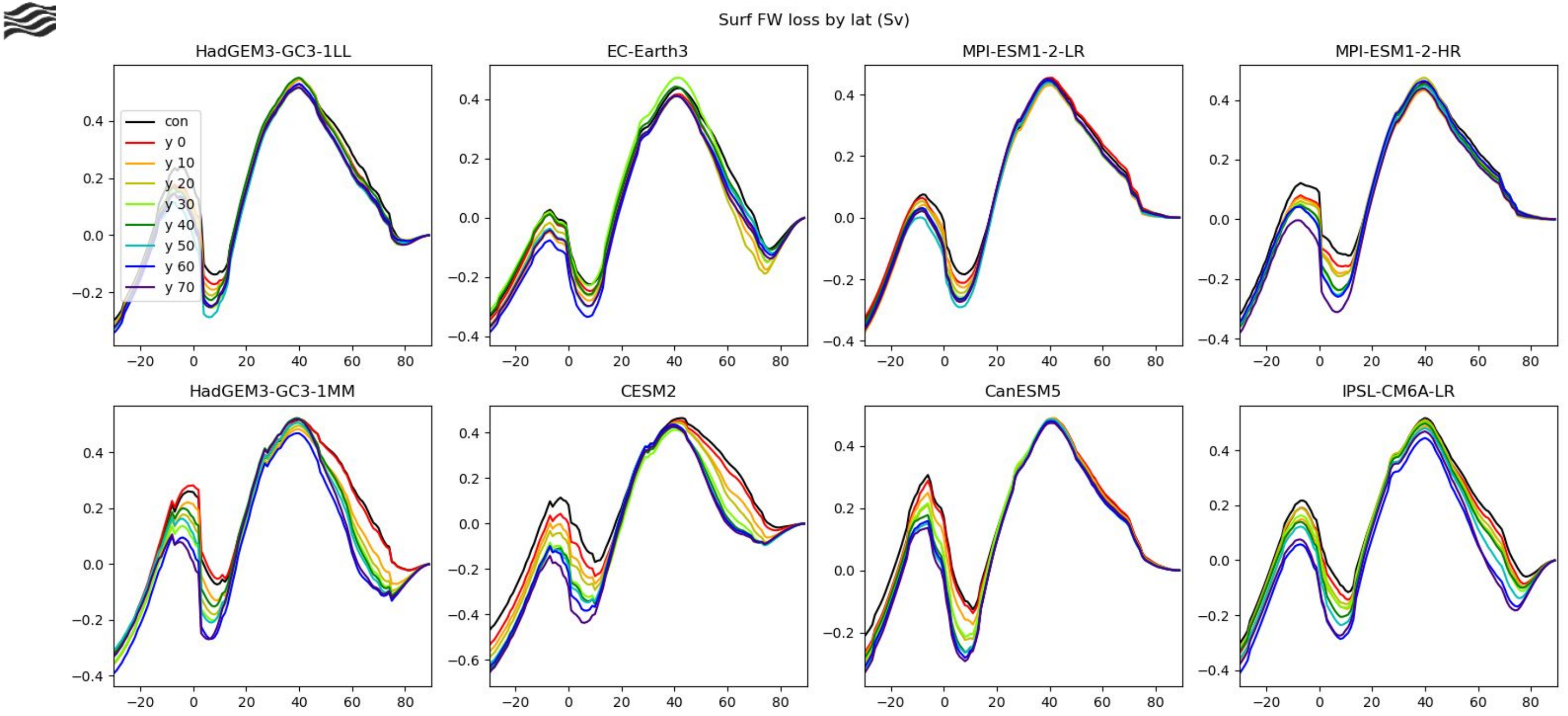
In half of the CMIP6 models participating there was a threshold beyond which the AMOC didn't recover after hosing.

AMOC recovery after hosing is related to:

- The strength of the AMOC after hosing
- The amount of deep convection after hosing

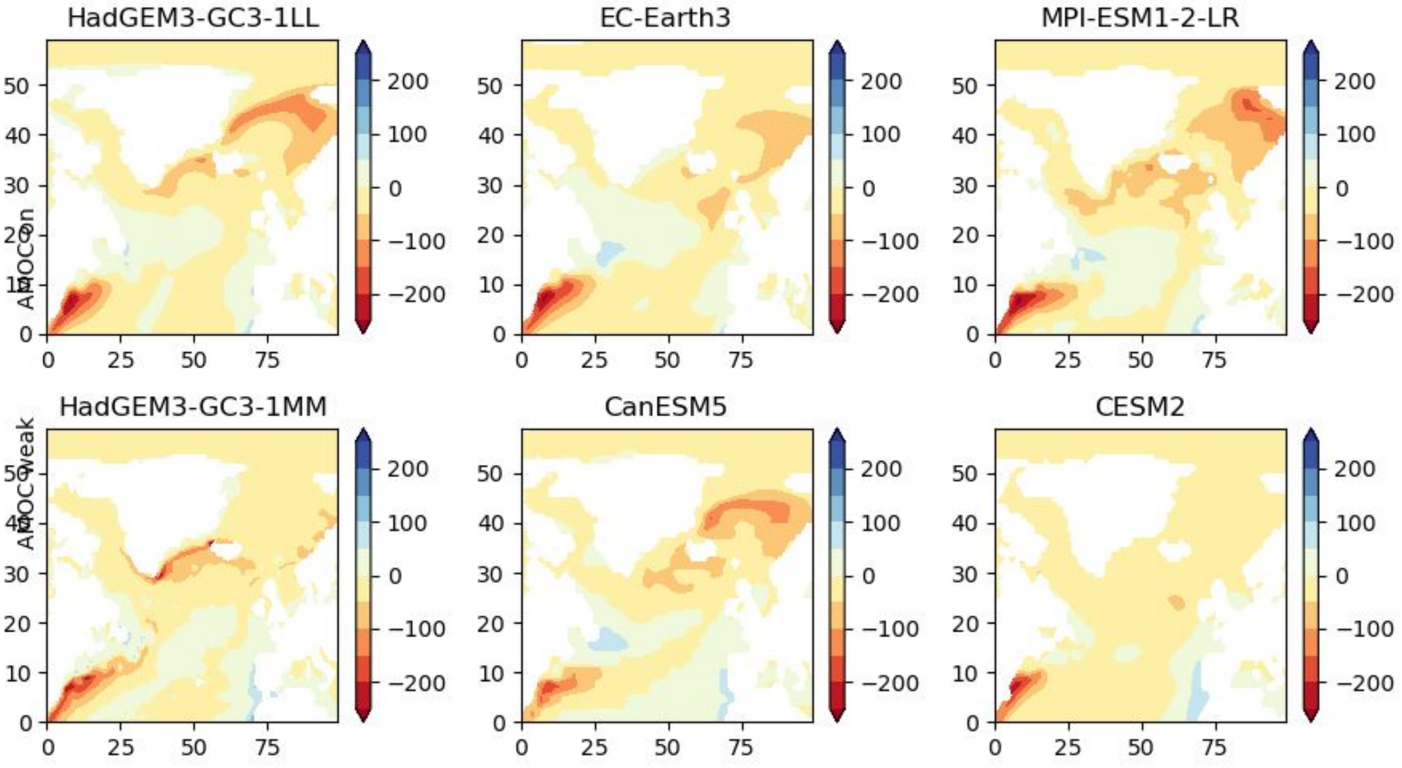
In models where the AMOC and MLD recover, there is an increase in heat and salt transport into the GIN seas which helps to sustain convection and dense water mass formation and encourage recovery of the AMOC.

- *Protocol and initial results: Understanding AMOC stability: the North Atlantic Hosing Model Intercomparison Project https://doi.org/10.5194/gmd-16-1975-2023*
- *Feedbacks paper in preparation*



Surface FW flux integrated by latitude Control: black. First decade: red. Last decade: blue

Shift in ITCZ, but little change around 40N. Some show opposing changes at high lats from sea ice, however ice contribution is missing from CanESM5.



Surface heat flux after 100 yrs hosing – CanESM5 still has significant heat loss in GIN seas.

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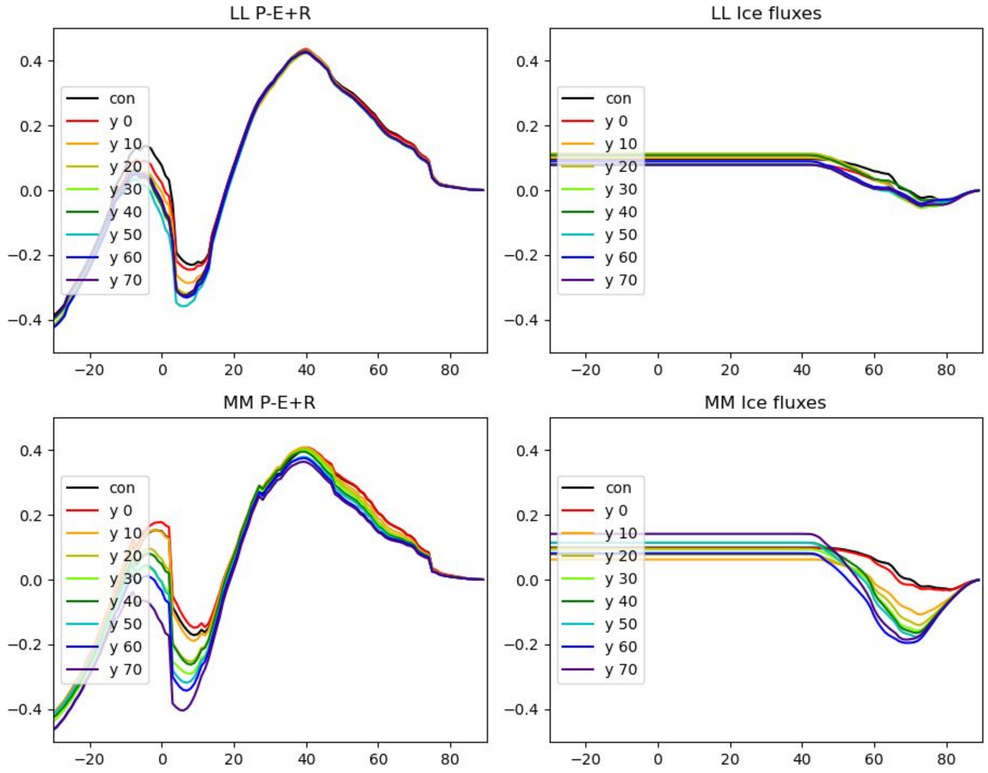

In the two MO models we separate the freshwater flux into that from precip and evap and that from ice processes.

The large changes at high latitudes in MM are from ice processes. Possibly ice formation in the north (removing FW) and transport southwards (adding FW)

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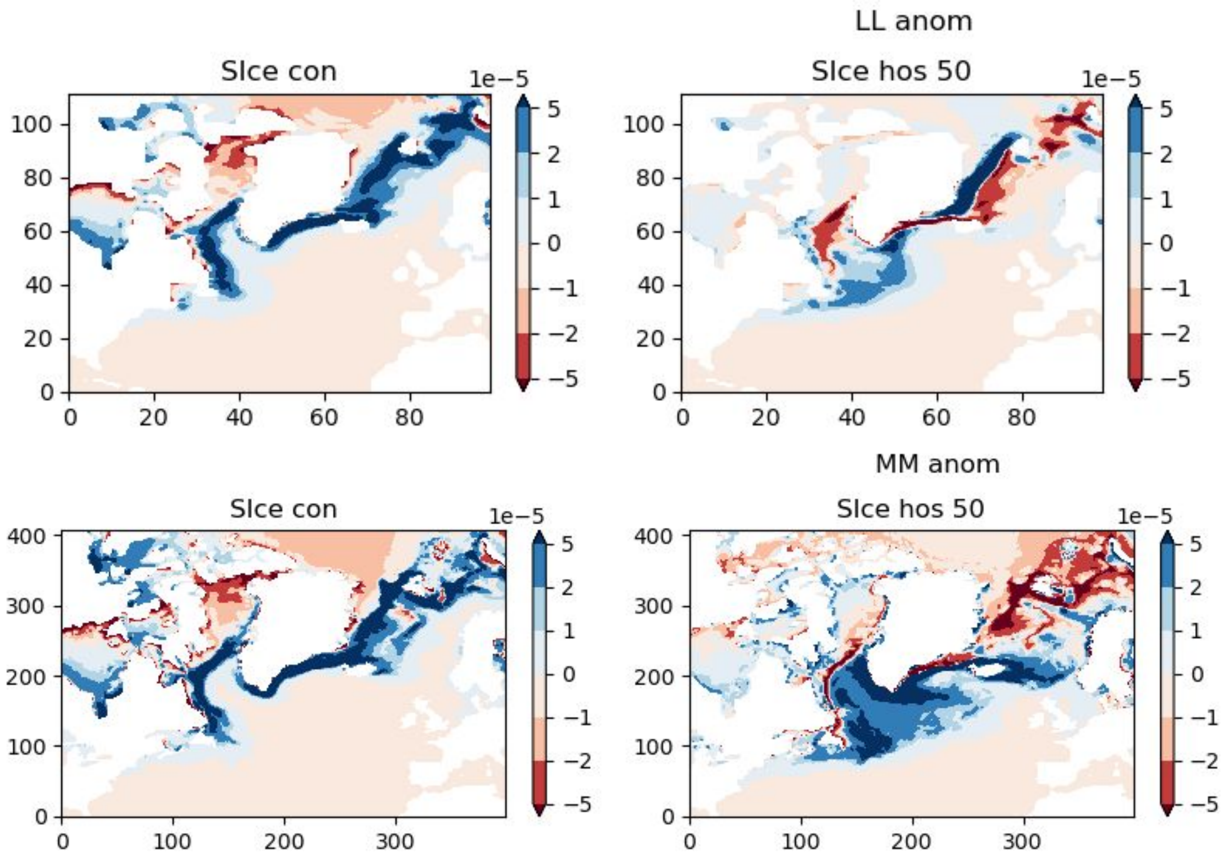

Annual mean ice fluxes

Ice much more widespread in MM and melting/freezing more meridional

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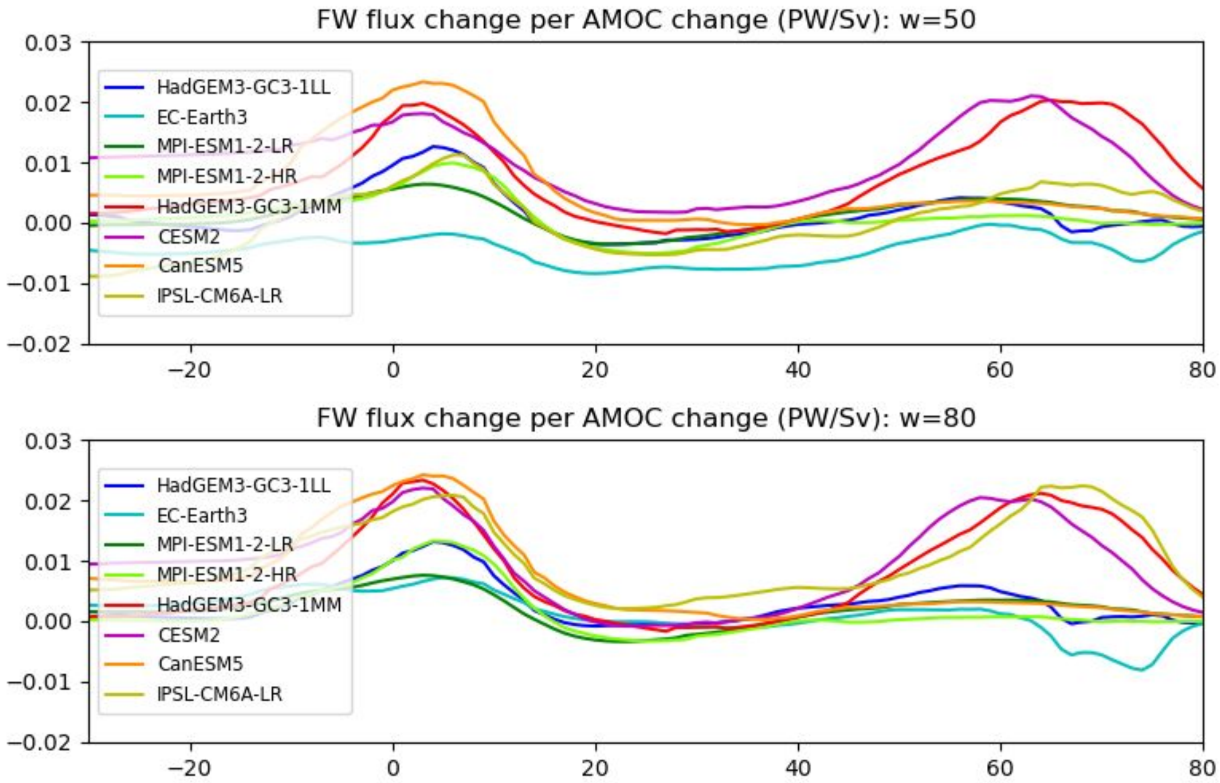
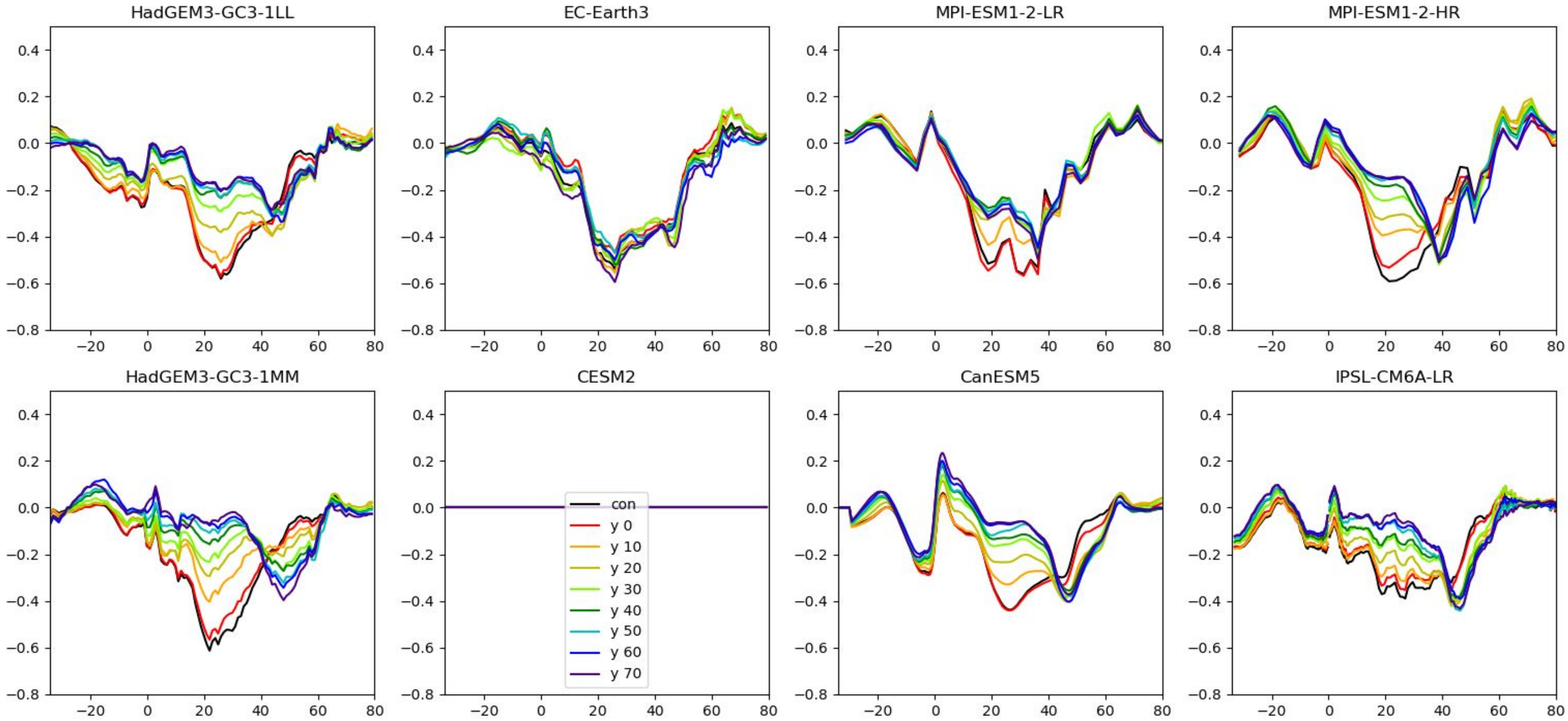


In the three models where the AMOC doesn't recover and which include the sea ice terms, the weakening AMOC is associated with possibly ice changes, but only after 80 years in IPSL



FW ovt transport by latitude Control: black. First decade: red. Last decade: blue

Larger changes in overturning component but compensated by gyre (note CESM2 data missing)