Ocean Freshwater transport in the LGM Freshening Experiments

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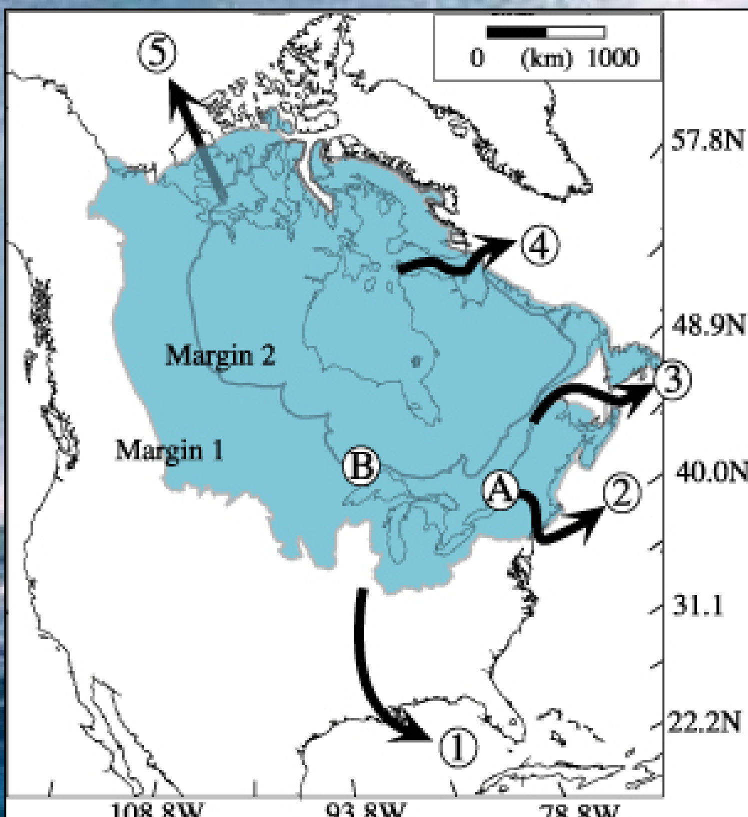
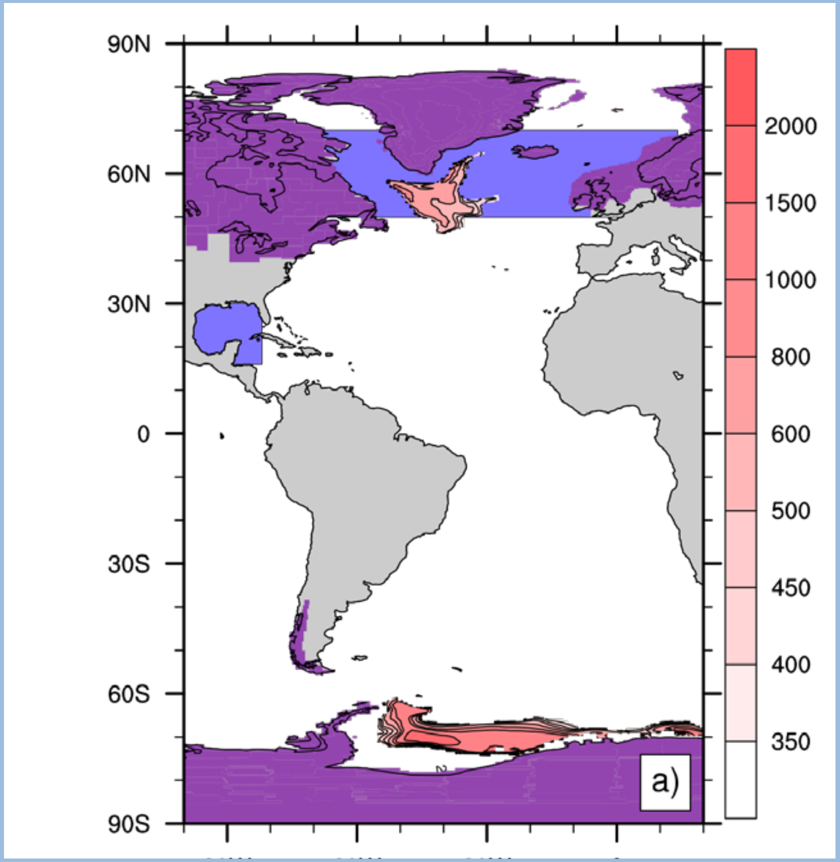


Clark et al., Science, 2001

The proxy record indicates a variety of freshwater input into the North Atlantic (and elsewhere) and a variety of regional responses attributed to these inputs.

- What are the mechanisms that explain the response?
- How sensitive is the response to amplitude of freshwater perturbation and location?

T42x1 CCSM3 LGM Freshening aka ‘Hosing’ Experiments



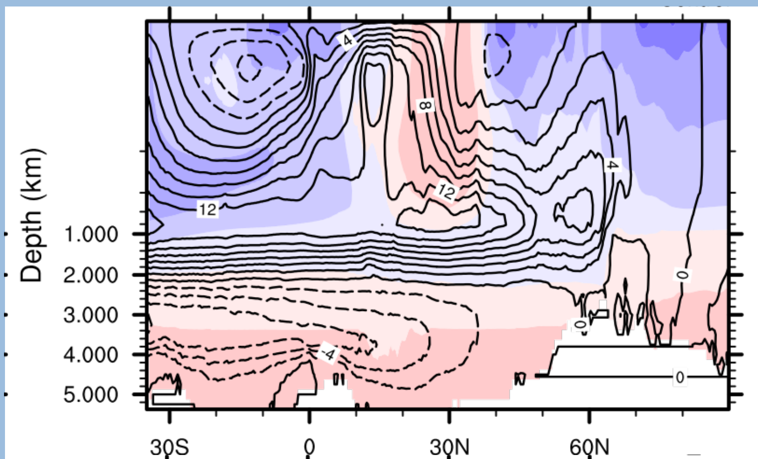
Region	Amt (Sv)
North Atlantic	1
"	0.5
"	0.25
“	0.1
Gulf of Mexico	0.5
"	0.28

Forcing applied as a Negative Salinity Flux For 100 years, then shut off.

Zonal Average Atlantic Salinity and MOC

last 20 years of Forcing Period

LGM Control

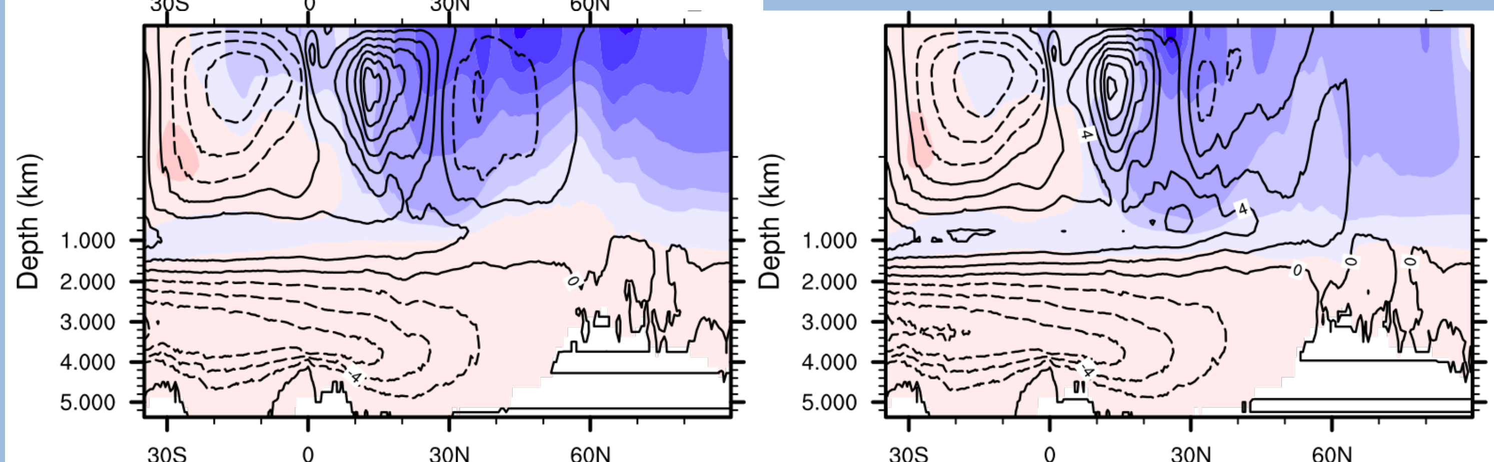


Large Vertical Salinity gradient in LGM Control.

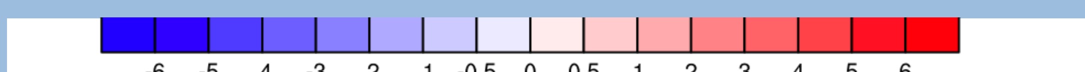
Weakening of AMOC assoc. with GNAIW is greater in NATL case.

Subpolar Salinity anomaly penetrates deeper in GOM case.

Shallow MO cells more pronounced when AMOC weakens



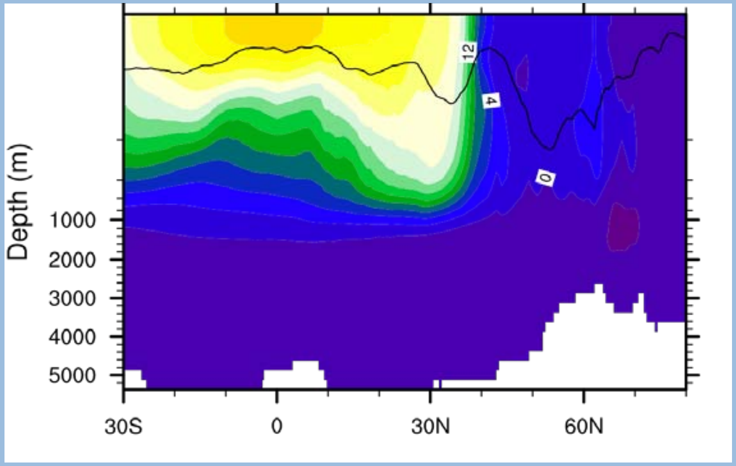
NATL 0.5 Sv **GOM 0.5 Sv**



Zonal Average Atlantic Temperature and HMXL

last 20 years of Forcing Period

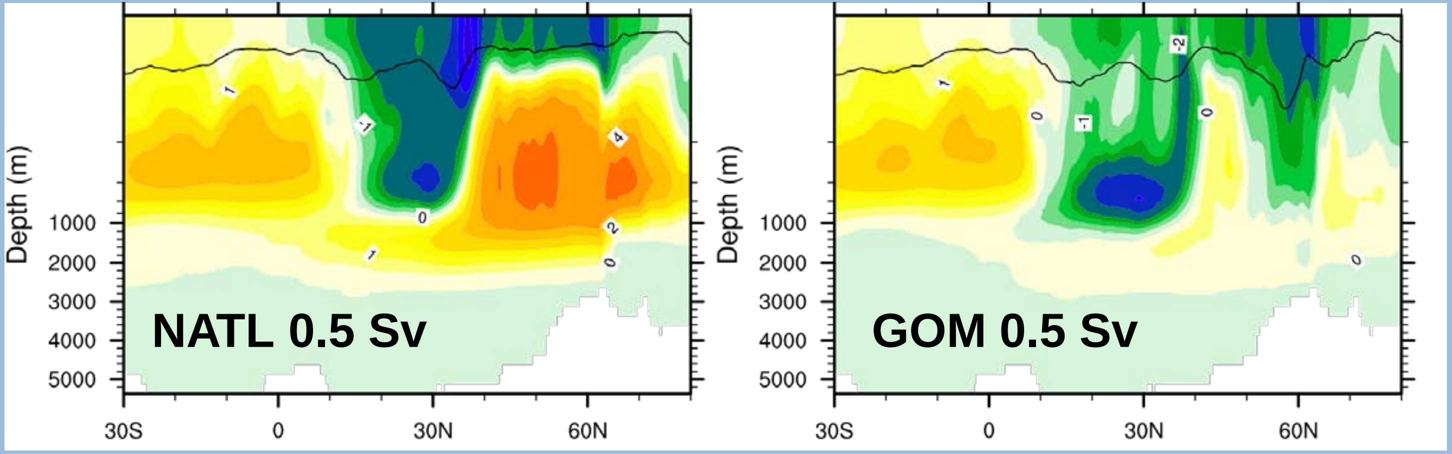
LGM Control

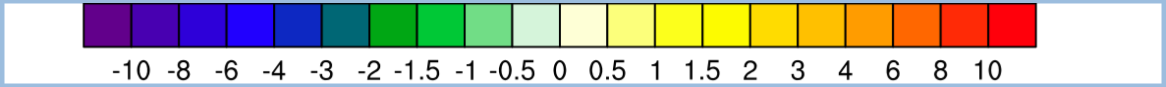


Much more subpolar subsurface warming in NATL case.

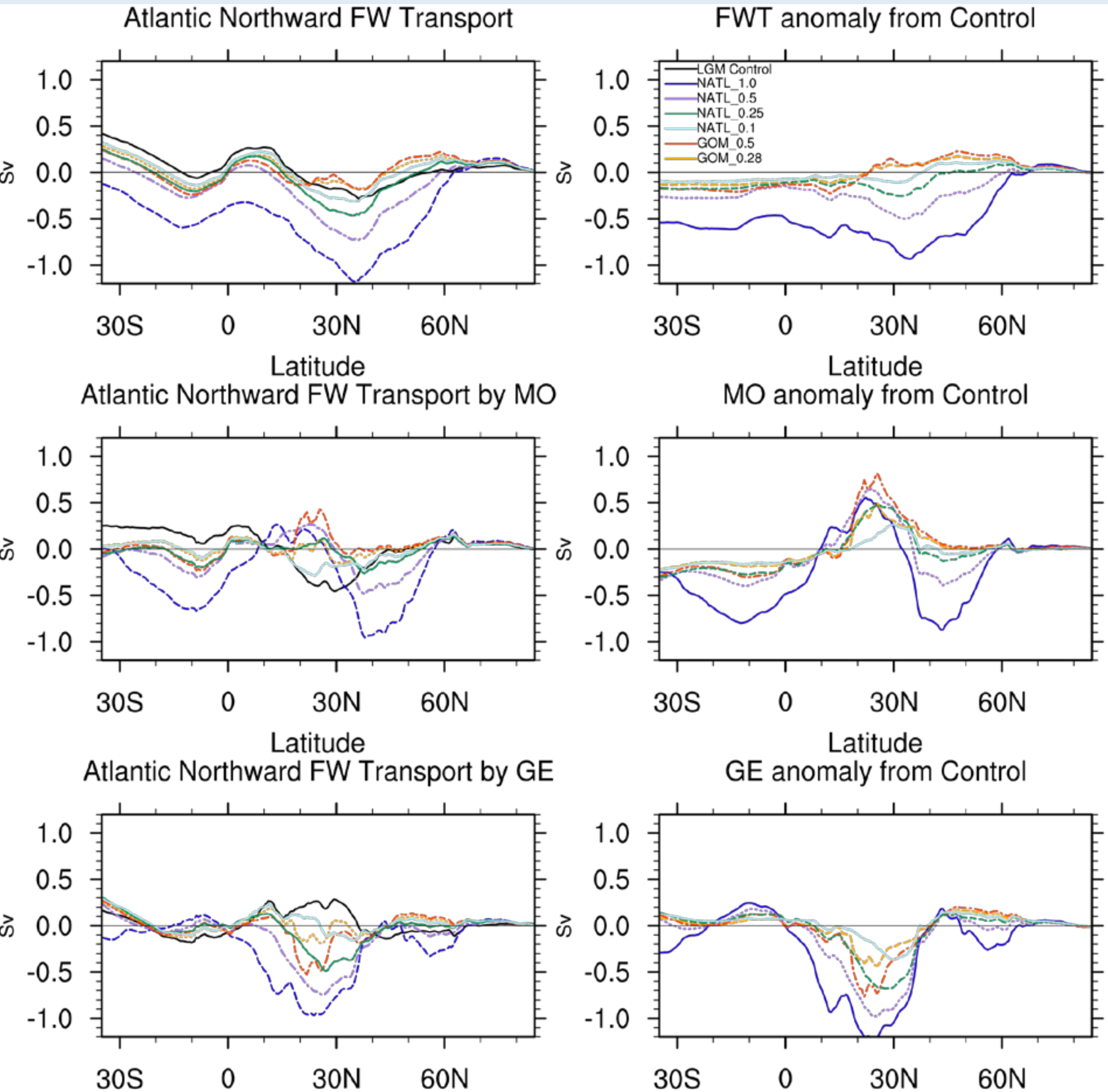
Deep cooling from 50-65N in GOM case.

Mixed layer depth is deeper in GOM case.





Northward ‘Freshwater’ Transport (FWT)



$FWT = \Sigma (S_{ref} - S)V/S_{ref}$

$FWT(MOC) = \Sigma(1 - [S_k]/S_{ref})[V_k]$

NATL:

•MOC exports FW out of subpolar region to compensate for FWF.

•GE exports FW out of subtropics.

•Weakened AMOC exports FW out of basin at 34S.

•FWT acts to maintain higher salinities in NA. (Stabilizing)

GOM:

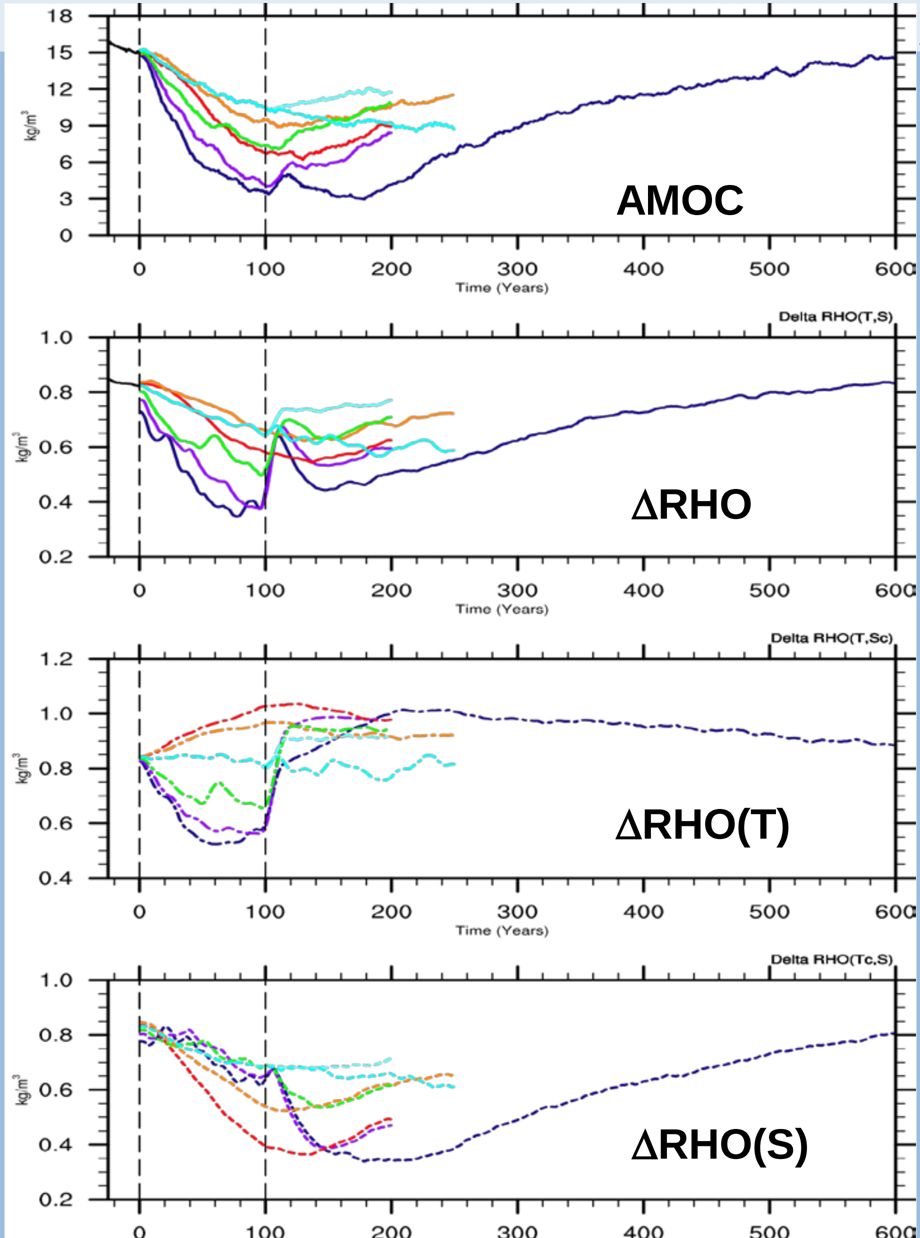
•Both MOC and GE transport FW northward into subpolar region.

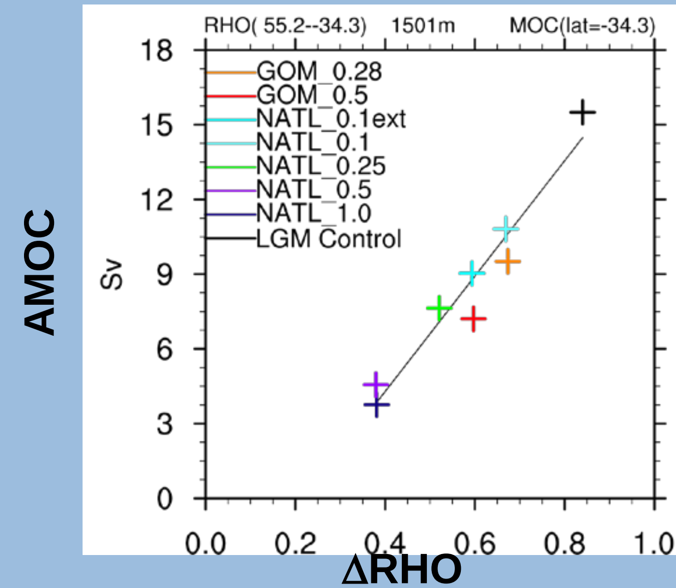
Time means are computed over the last 20 years of the forcing period.

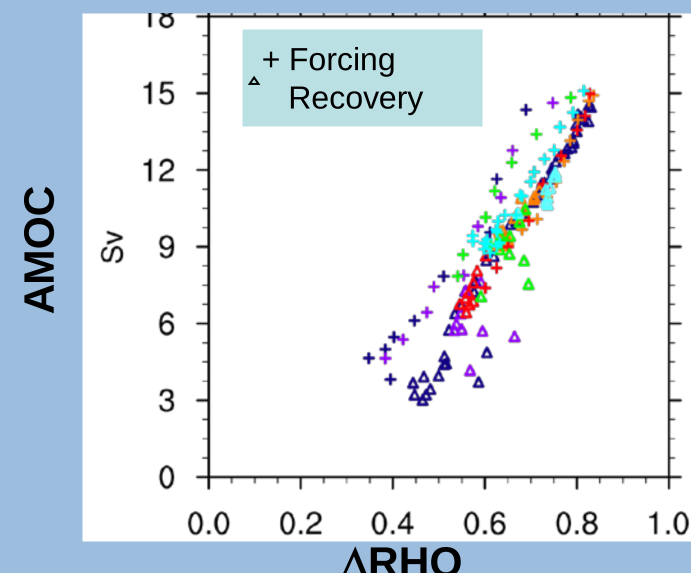
Response of AMOC

AMOC~ΔRHO·D²

ΔRHO= [RHO(55N)]-[RHO(34S)]







Conclusions

- NATL cases show an export southward of FW out of subpolar region by upper ocean Ekman cells. FW is also exported south by the horizontal circulation in mid-latitudes. This moderates freshening at high latitudes acting to stabilize AMOC response. These advective responses are not included in box models or zonally-averaged ocean models.

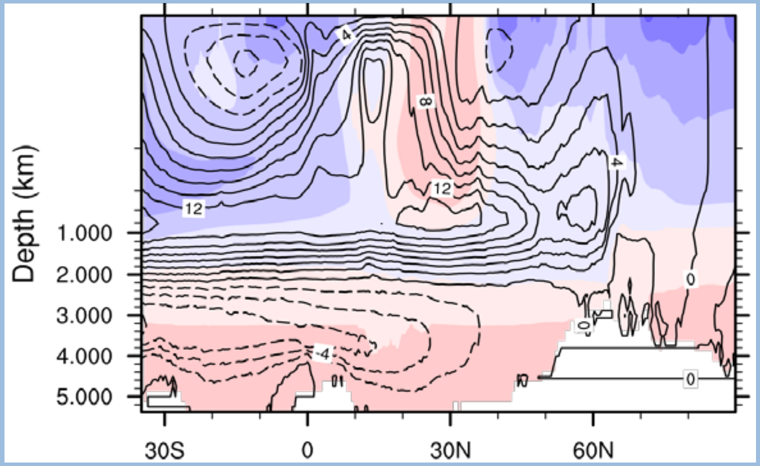
- Transient AMOC reponse is shown to be linearly related to transient upper ocean meridional density gradient during both forcing and recovery periods.

- Sensitivity of AMOC response to location of FWF can be explained by the different T and S responses induced.

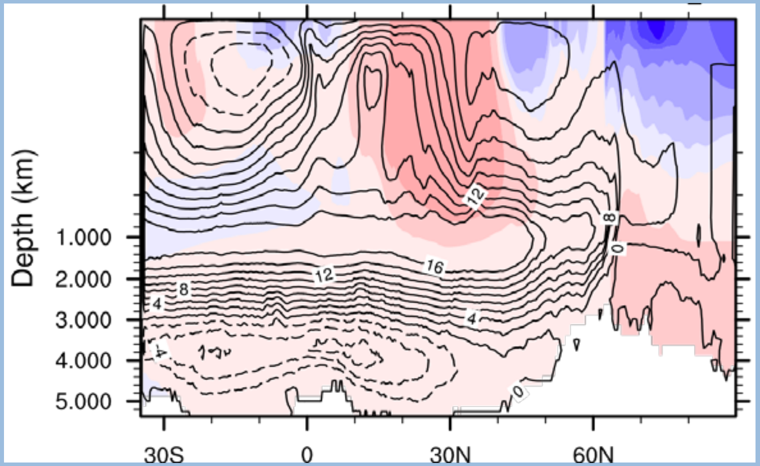
- FWF into GOM is less effective at weakening AMOC due to a high latitude cooling response that offsets the lowering of density by freshening. In the NATL cases, subsurface warming enhances the lowering of upper ocean subpolar density by a freshening leading to greater reduction of AMOC.

Northward 'Freshwater' Transport

LGM Control



Mid Holocene Control

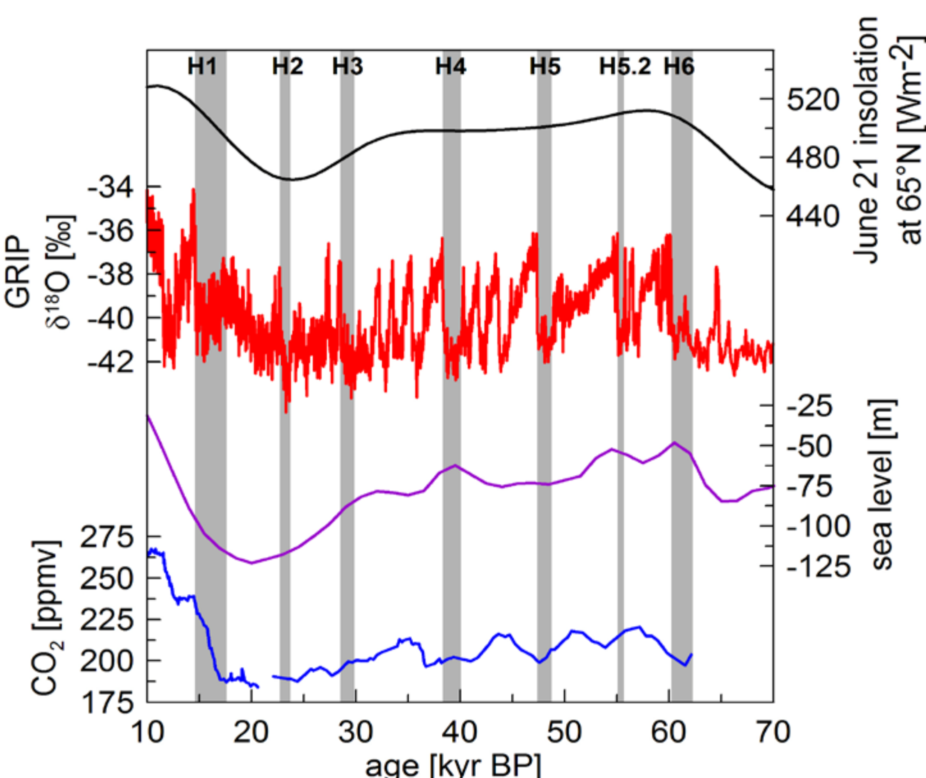


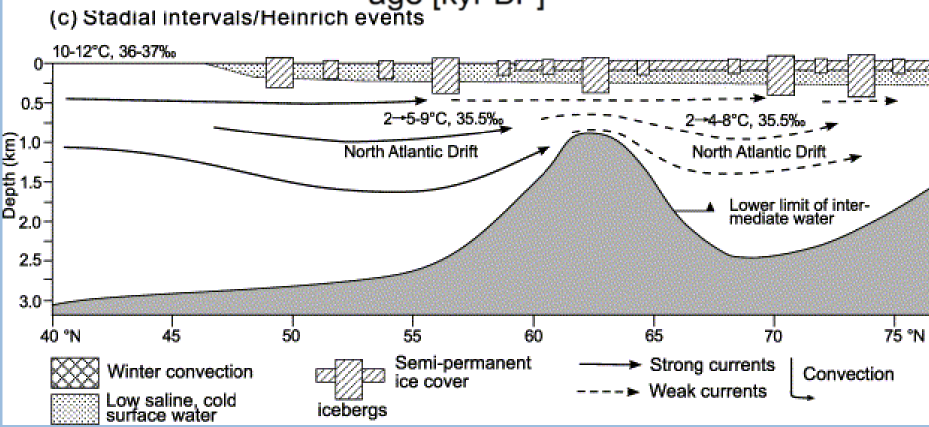
	Total FWT @34S	FWT@ 34S by MOC
LGM Control	0.4 Sv	0.25 Sv (.35 by NADW)
Holocene Control	0.35 Sv	0.07 Sv (.01 by NADW)

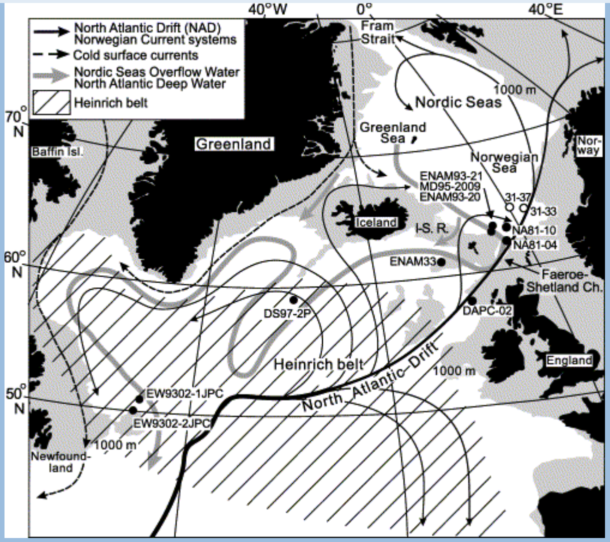
LGM -Larger Vertical Salinity gradient →AMOC transports FW into the Atlantic basin, mostly by GNAIW cell.

Mid-Holocene -Weak vertical gradient →AMOC carries very weak northward FW transport.

Comparison to Proxy Data







HE's

~3-5m/200-500yrs

(.2Sv - 0.05Sv)

MWP1A

~20m/200-500yrs

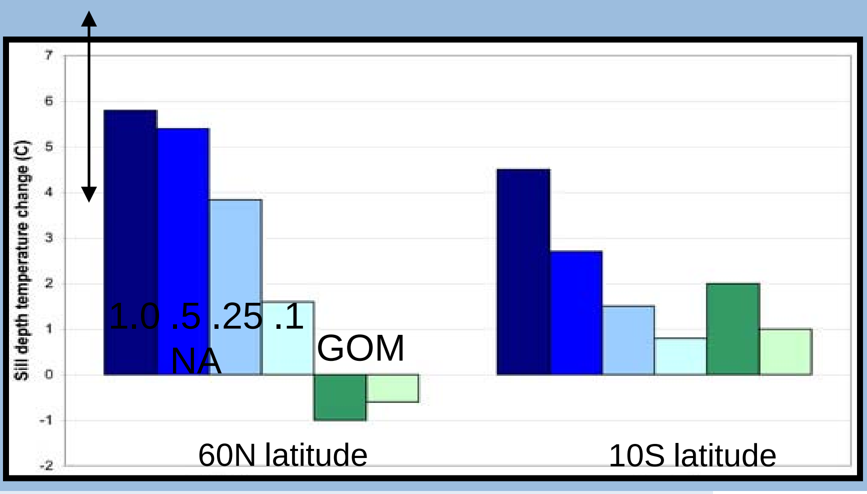
(1.-0.4 Sv)

YD (Cold Event)

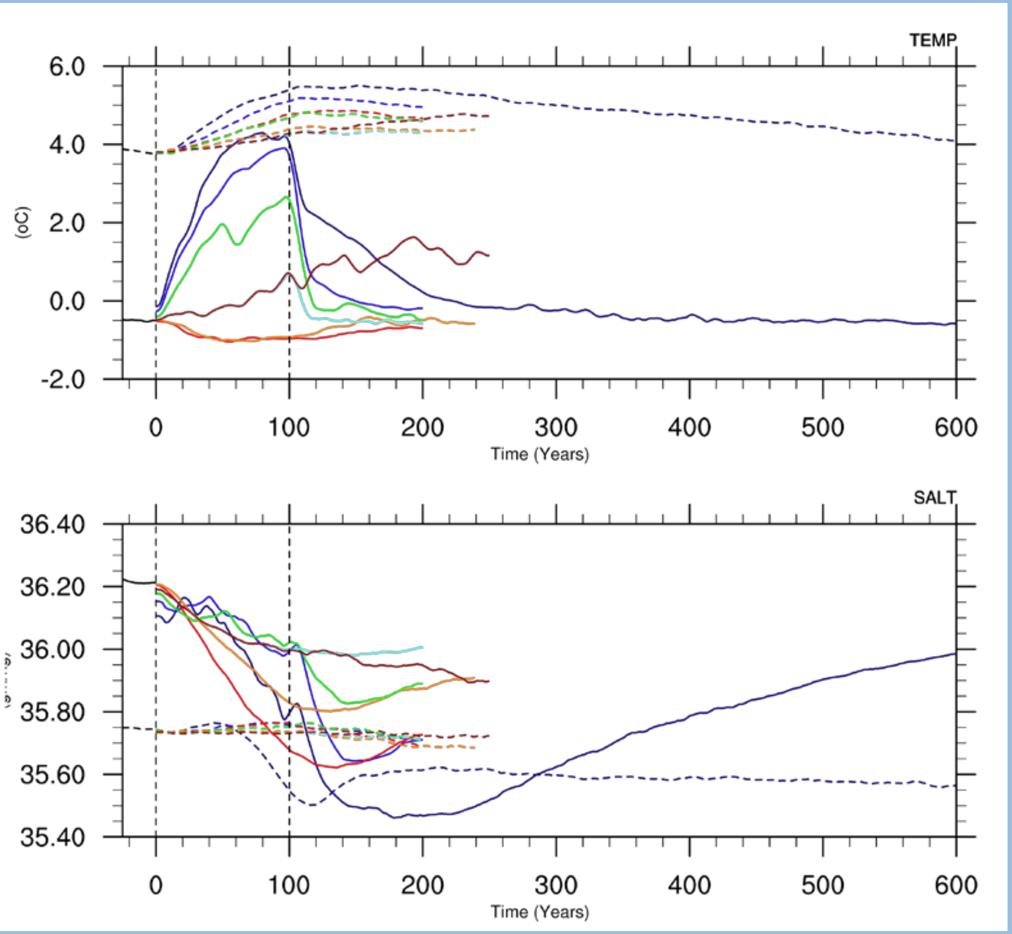
~13m/1100yrs

(0.13Sv)

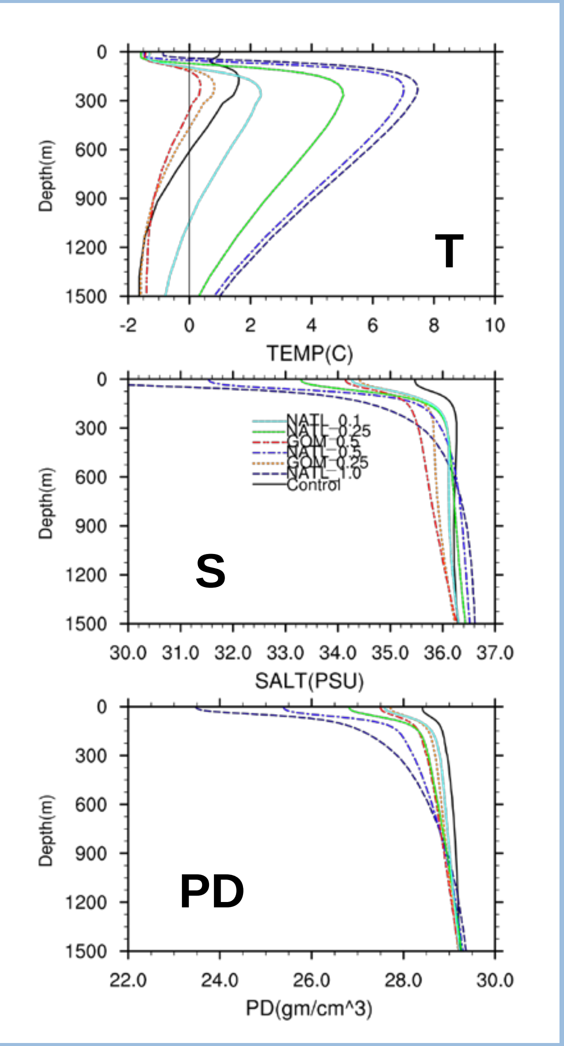
Rasmussen and Thomsen (*PPP*, 2004) suggest 4-8^{o}C rise in intermediate Water, down to 1750m depth during HEs.



Temperature and Salinity

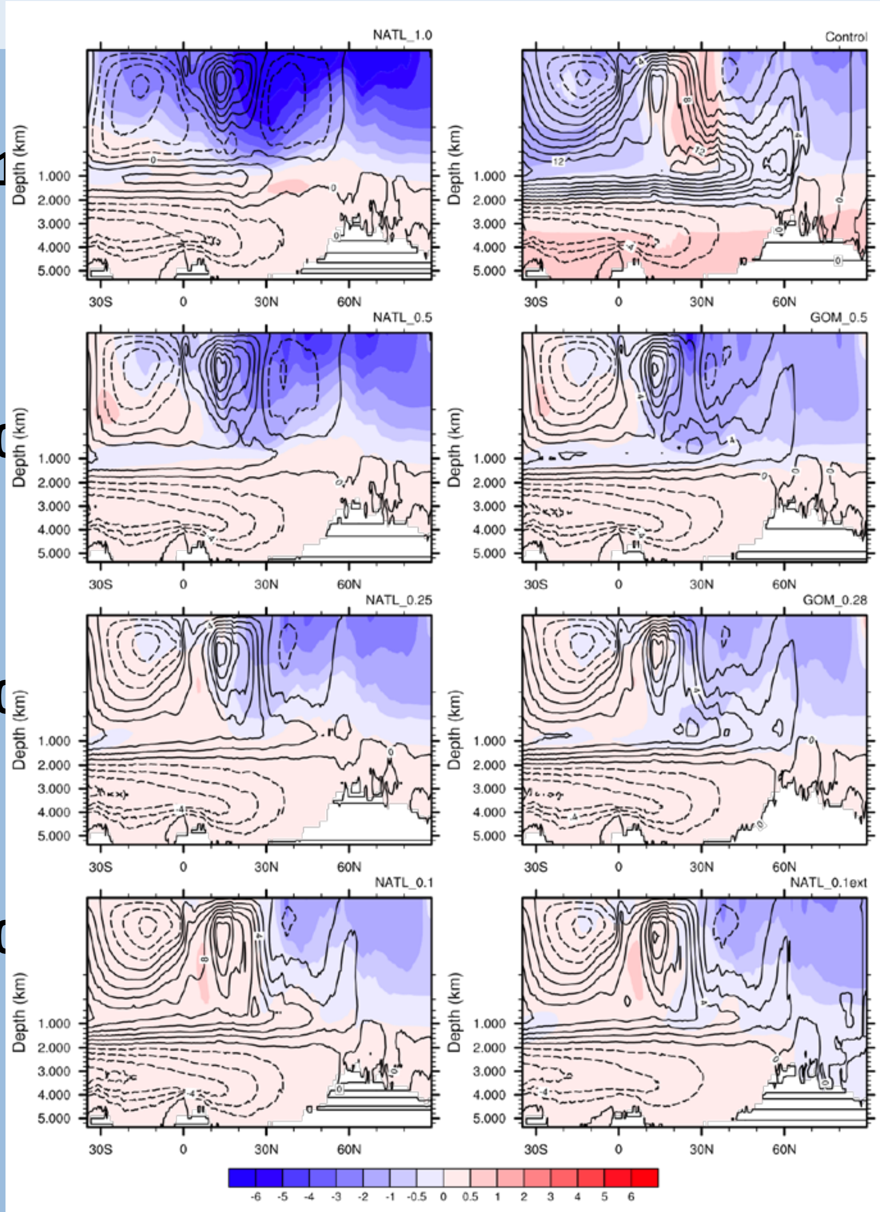


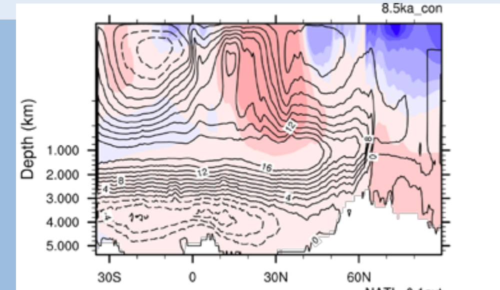
Vertical Profiles at 55N



Zonal Average Atlantic Salinity and MOC

last 20 years of Forcing Period





GOM

Zonal Average Atlantic Temperature and HMXL

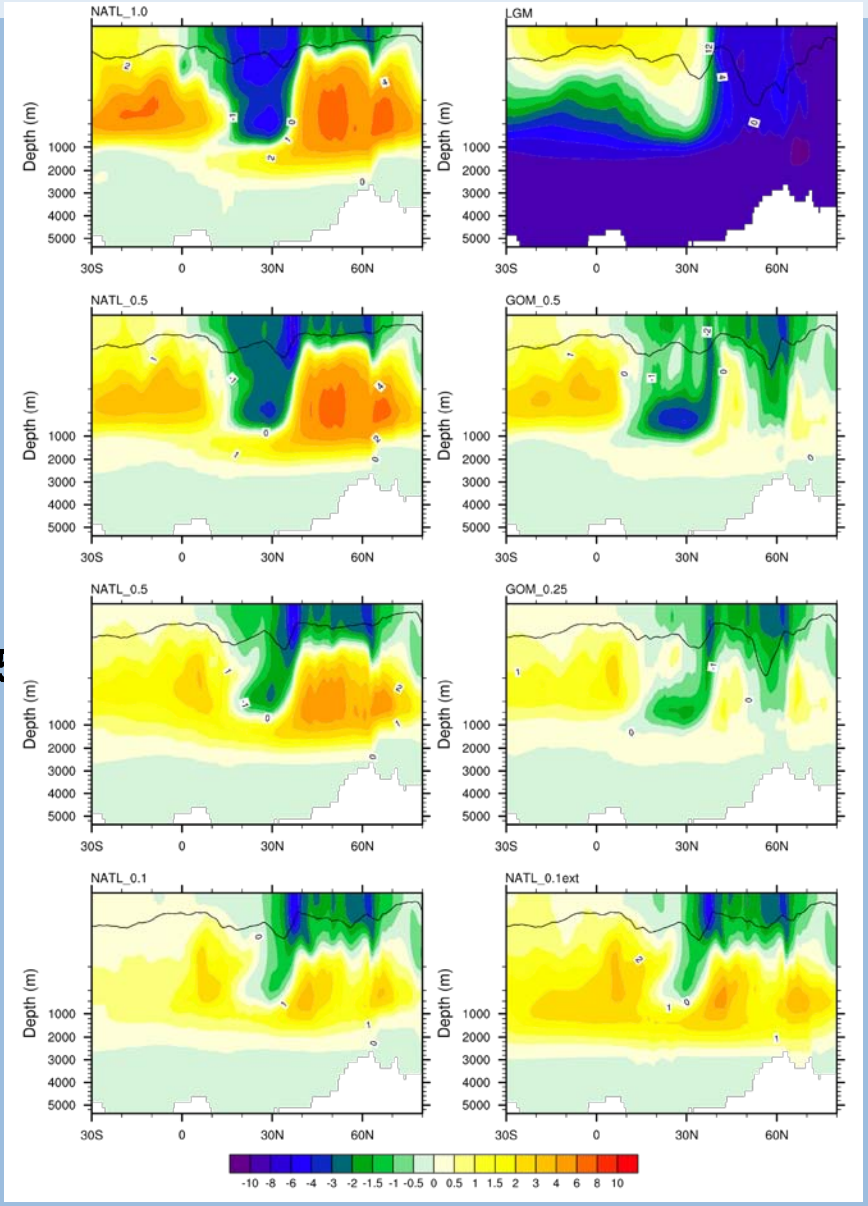
last 20 years of Forcing Period

1.0

0.5

0.25

0.1



GOM

0.1 Svx500 years

Conclusions

- When FWF causes the cessation of subpolar deep vertical mixing, a halocline forms, causing the wind-driven upper ocean circulation in CCSM3 to export FW from high latitudes. FW is also exported by the horizontal circulation in mid-latitudes. This negative feedback is missing in conceptual box models and zonally-averaged models.

- This suggests the importance of having realistic surface winds and an upper ocean vertical circulation in high latitudes to promote a realistic response to high latitude FWF.

- FWF into GOM is less effective at weakening MOC due to a high latitude cooling response that offsets the lowering of density by freshening. In the NATL cases, warming enhances the lowering of upper ocean subpolar density by a freshening leading to greater reduction of MOC.