Mechanisms of seasonal to decadal AMOC variability

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Mechanisms of inter-annual to decadal AMOC variability

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What can we learn from (non-assimilative) ocean model simulations?

1. Which aspects are realistic, which are not?

   model-data and model-model comparisons

2. Role of wind vs. buoyancy forcing?

   use of flux perturbation experiments

3. Regional manifestations of decadal changes?

   can we identify simple (observable) indices?

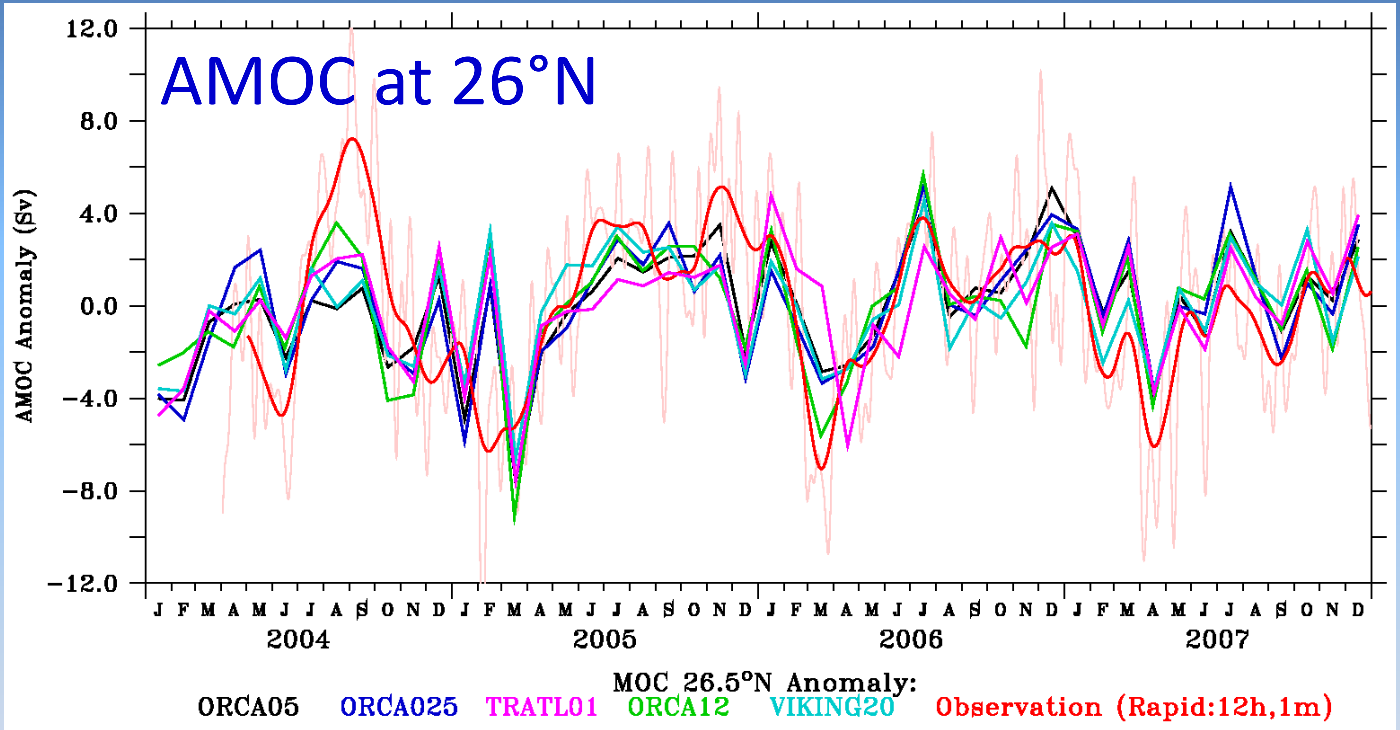
Basis

Global ocean-sea ice experiments

- based on NEMO (Kiel group) and others (*i.e.,* CORE comparison)
- various grids: ½° - ¼° - 1/12° - 1/20°
- atmospheric forcing products: CORE; JRA-55
- perturbation exps.: isolating momentum and buoyancy fluxes

Hindcast simulations: AMOC response to CORE forcing

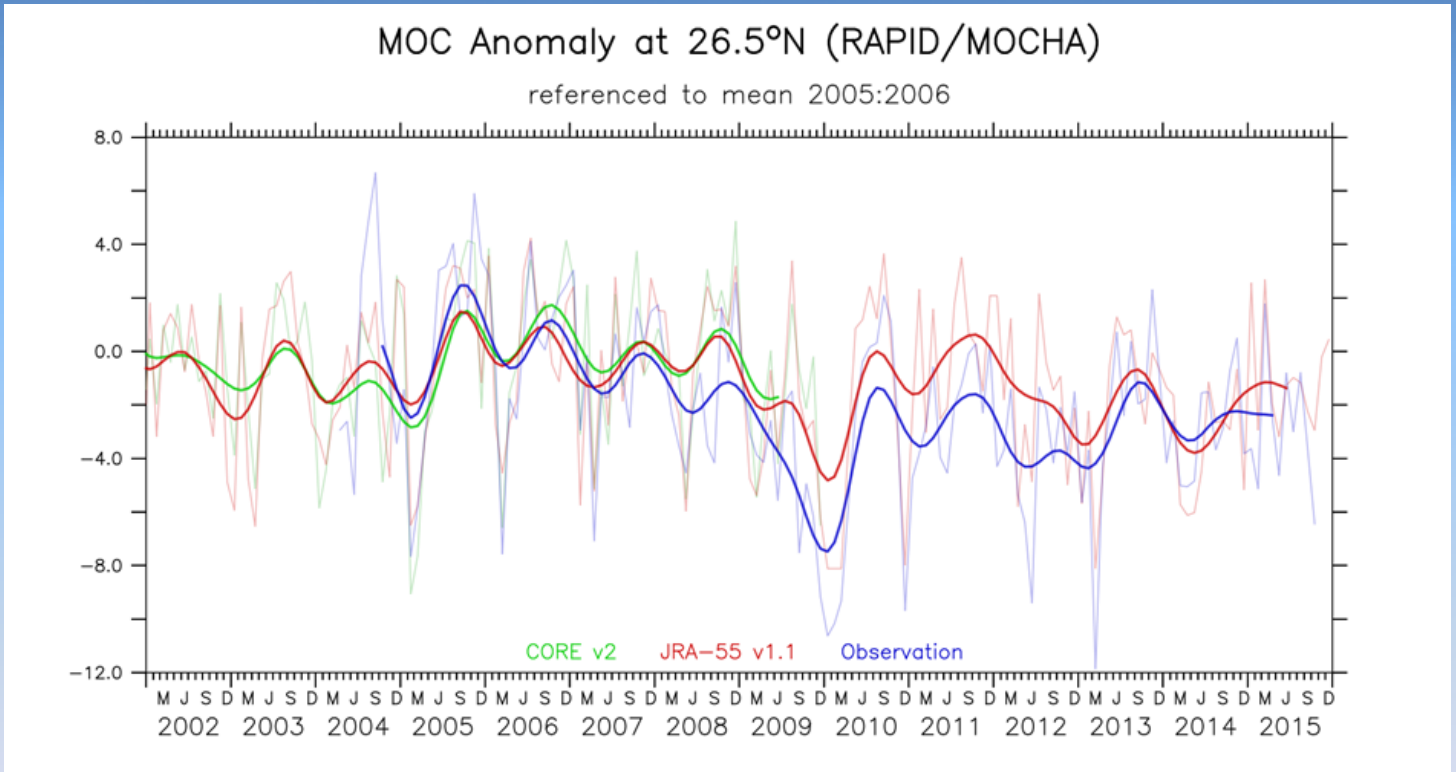
Here: 5 model simulations differing in resolution (1/2° - 1/12°)



- ➢ seasonal to inter-annual variability: robust!
- ➢ not much increase in variance with resolution

AMOC variability in comparison to RAPID/MOCHA

ORCA025 with CORE (until 2009) and JRA (until 2015)



- models capture (much of) the observed inter-annual variability

What about (multi-)decadal time scales?

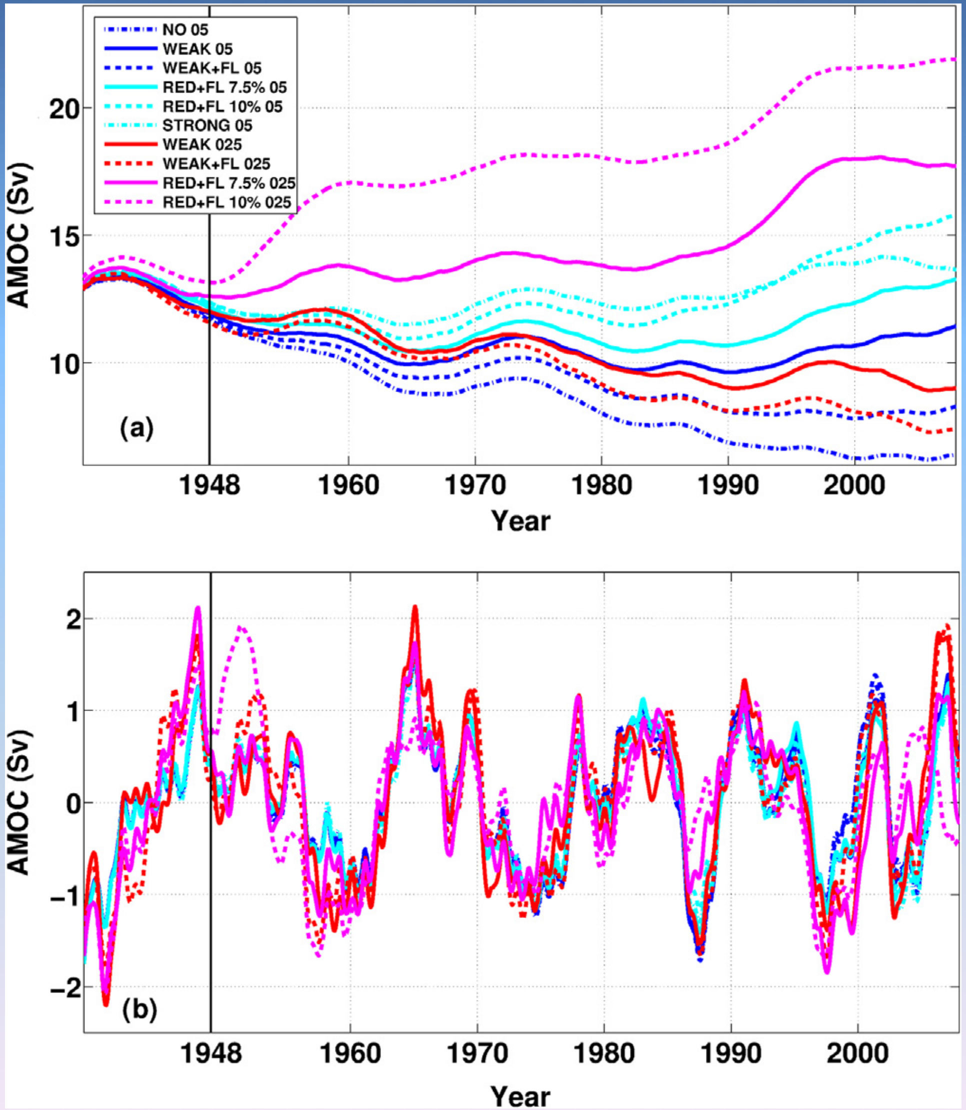
→ Look at sequence of experiments (1/2°, 1/4°):

- forced by the „CORE“-reanalysis (1948-2007)

- differing in subarctic freshwater forcing:
  i.e., precipitation & surface salinity relaxation

10 hindcast simulations (CORE forcing, 1948-2007)

with small variations in fw forcing



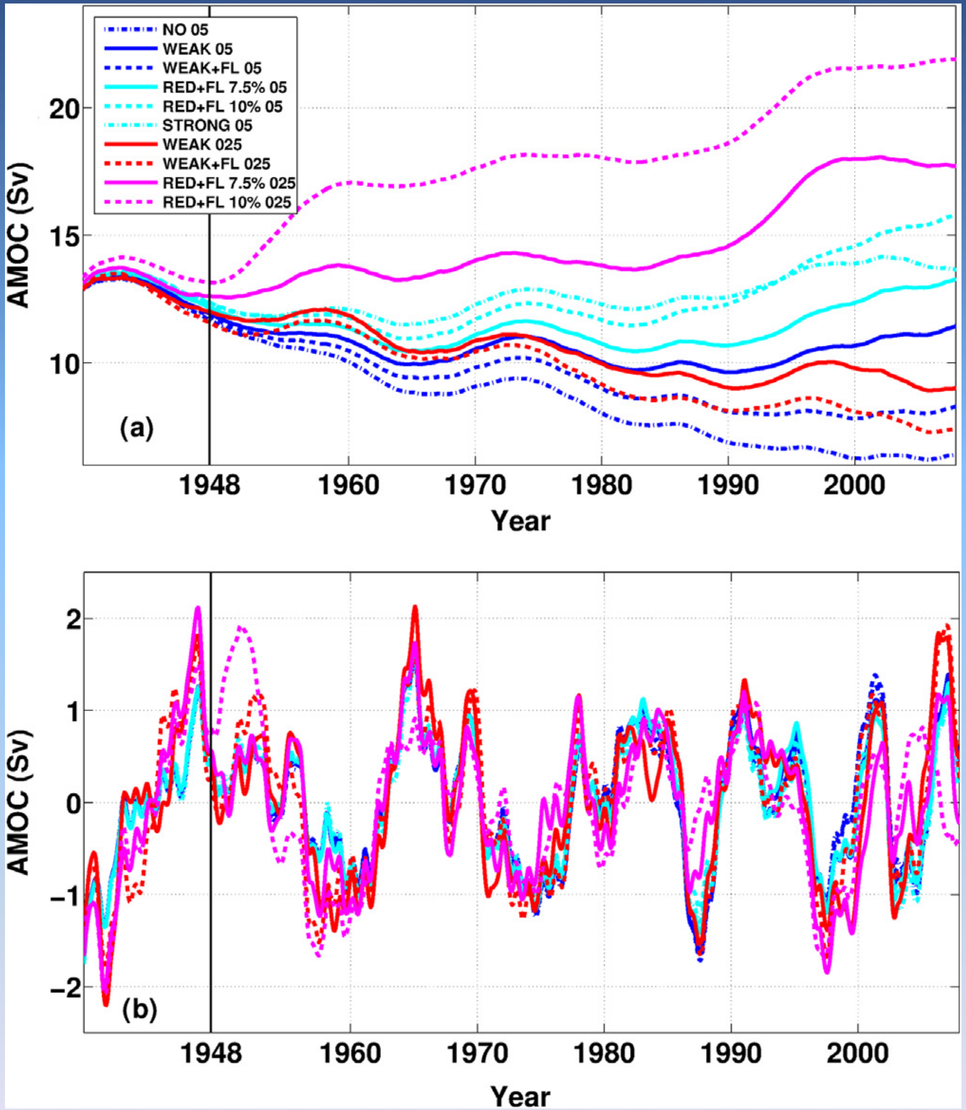
Low-pass filtered

(>7 yrs)

Band-pass

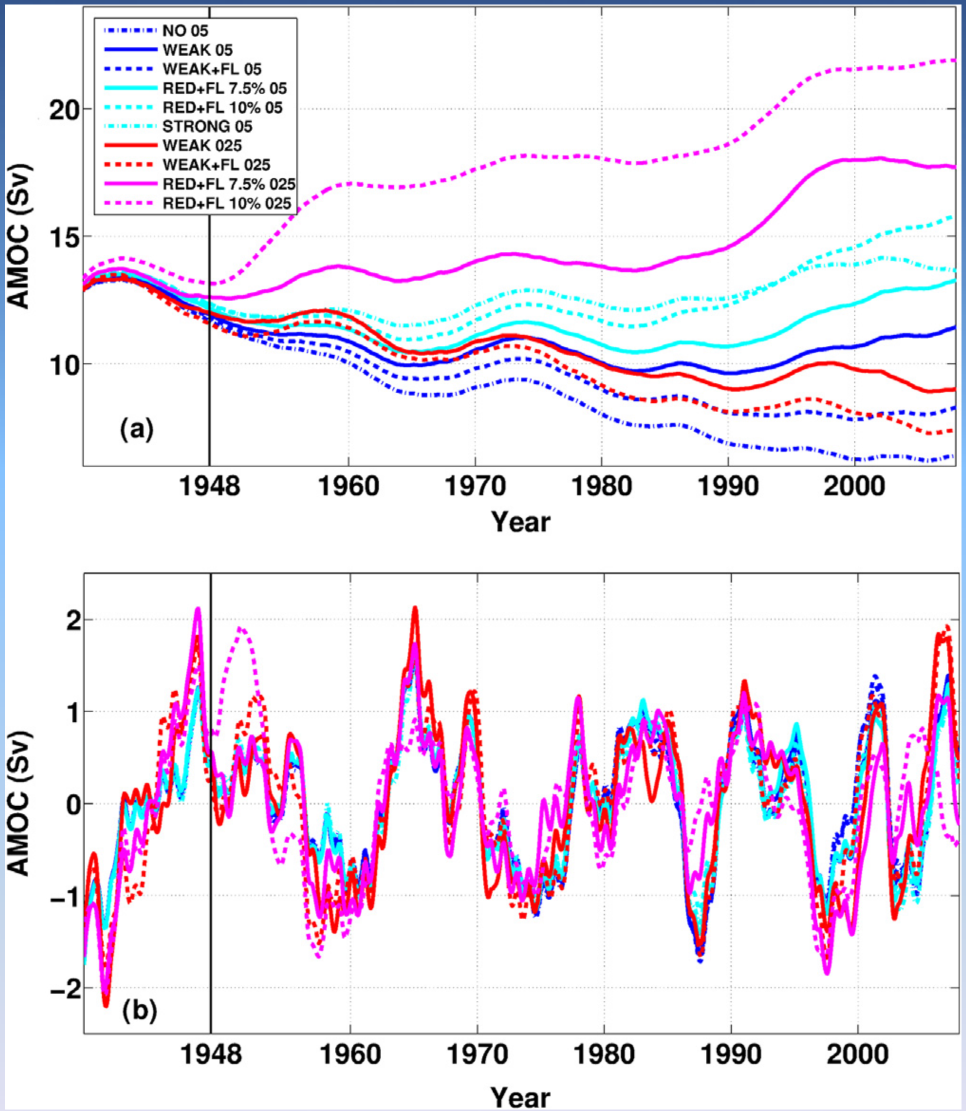
(1-7 yrs)

Behrens et al.
(Ocean Modell. 2013)



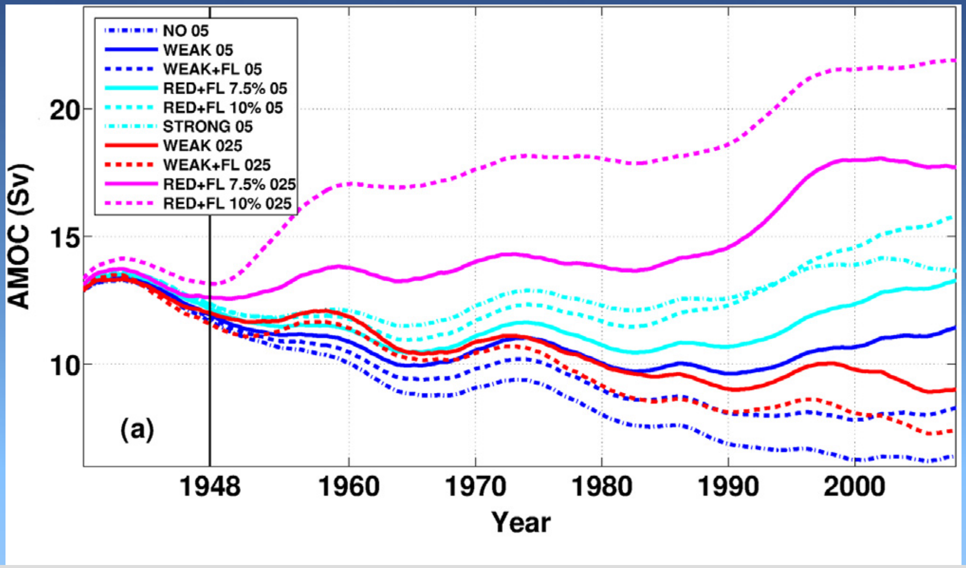
Interannual-decadal:

robust model behavior



Long-term changes:

large sensitivity to artificial parameters (spurious trends!)



Long-term changes:

large sensitivity to artificial parameters (spurious trends!)

→ *Models useless in studies of multi-decadal changes*

Reason:

bulk formulation of heat fluxes, in conjunction with prescribed atmospheric conditions

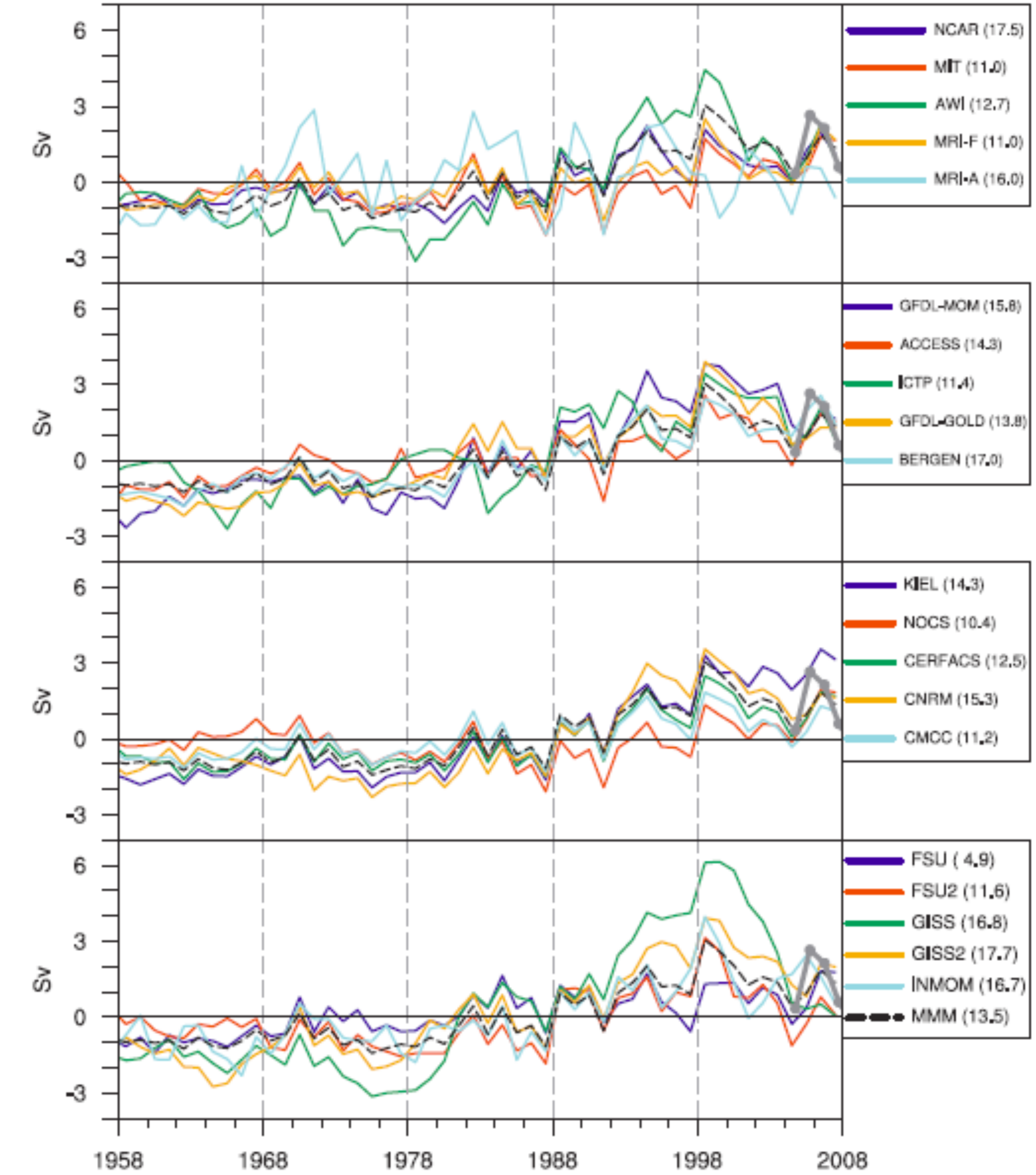
→ damping of SST towards prescribed conditions

→ eliminates important (negative) feedback

→ rendering AMOC excessively sensitive

CORE-II intercomparison of 20 global ocean models

Danabasoglu et al. (Ocean Modelling, 2016)



Origin of interannual – decadal variations

- momentum (M) vs. buoyancy fluxes (B)?

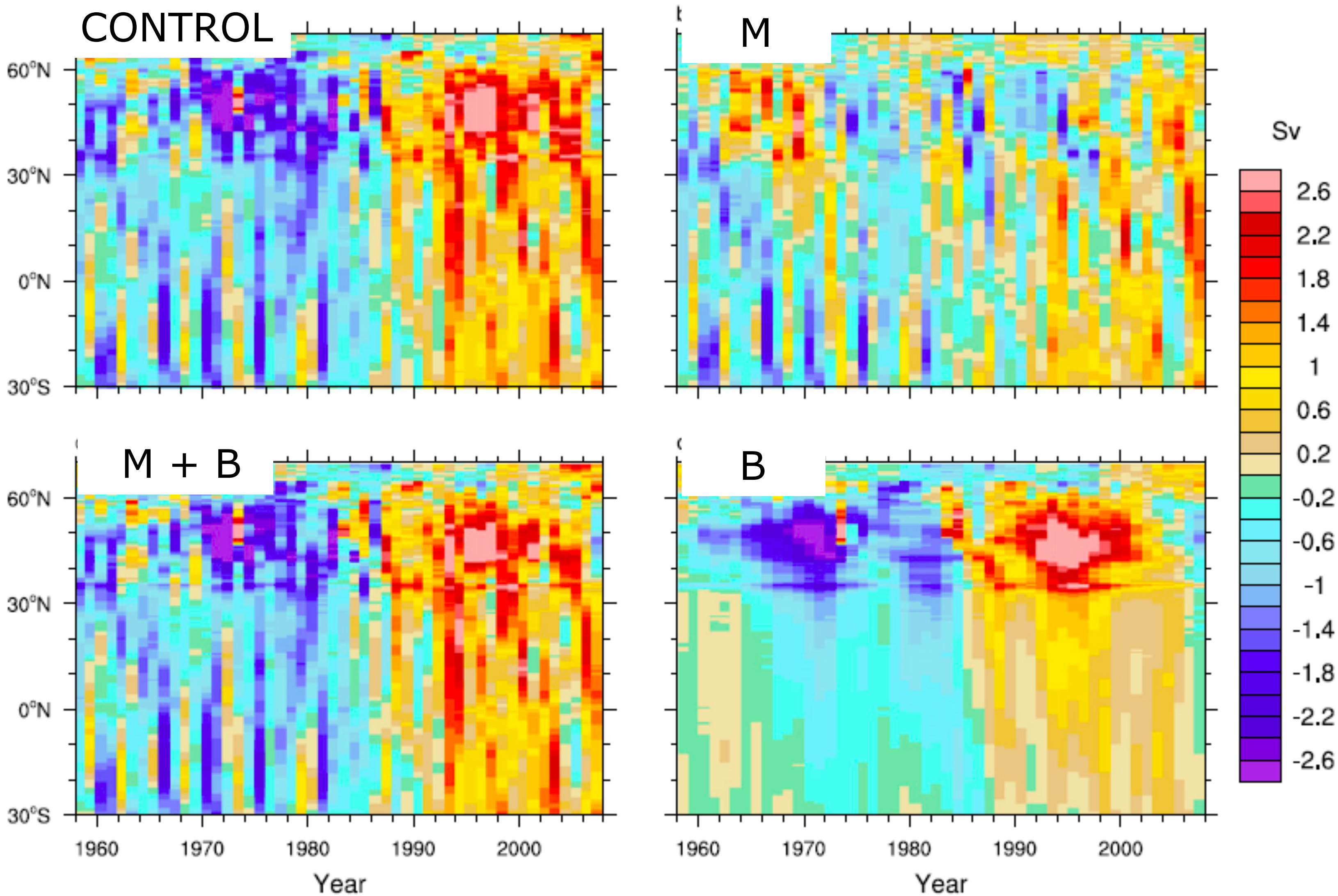
Consistent findings of several studies (*e.g., Biastoch et al., 2008; Yeager and Danabasoglu, 2014*):

(1) The late 20th-century AMOC variability can be understood as a linear superposition of M and B

(2) The inter-annual variability is governed by M

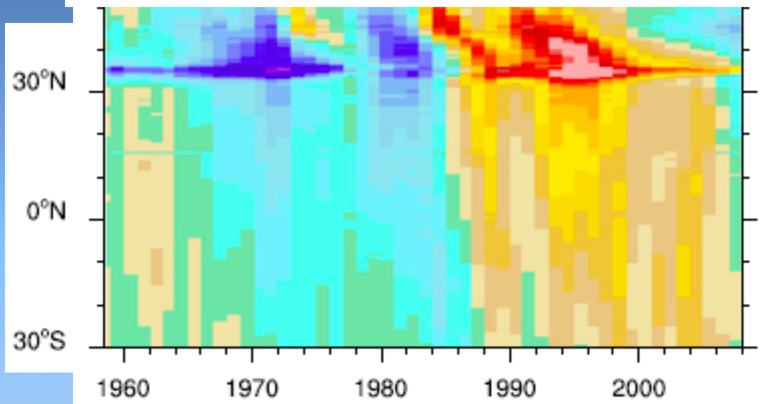
(3) Decadal changes (in the North Atlantic): by B

Yeager and Danabasoglu (J. Climate 2014)

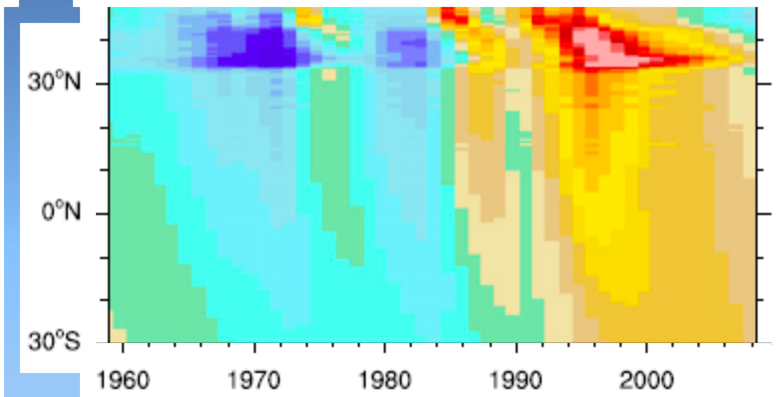


AMOC computed in density (σ_2) space

B Buoyancy-forced AMOC variations …



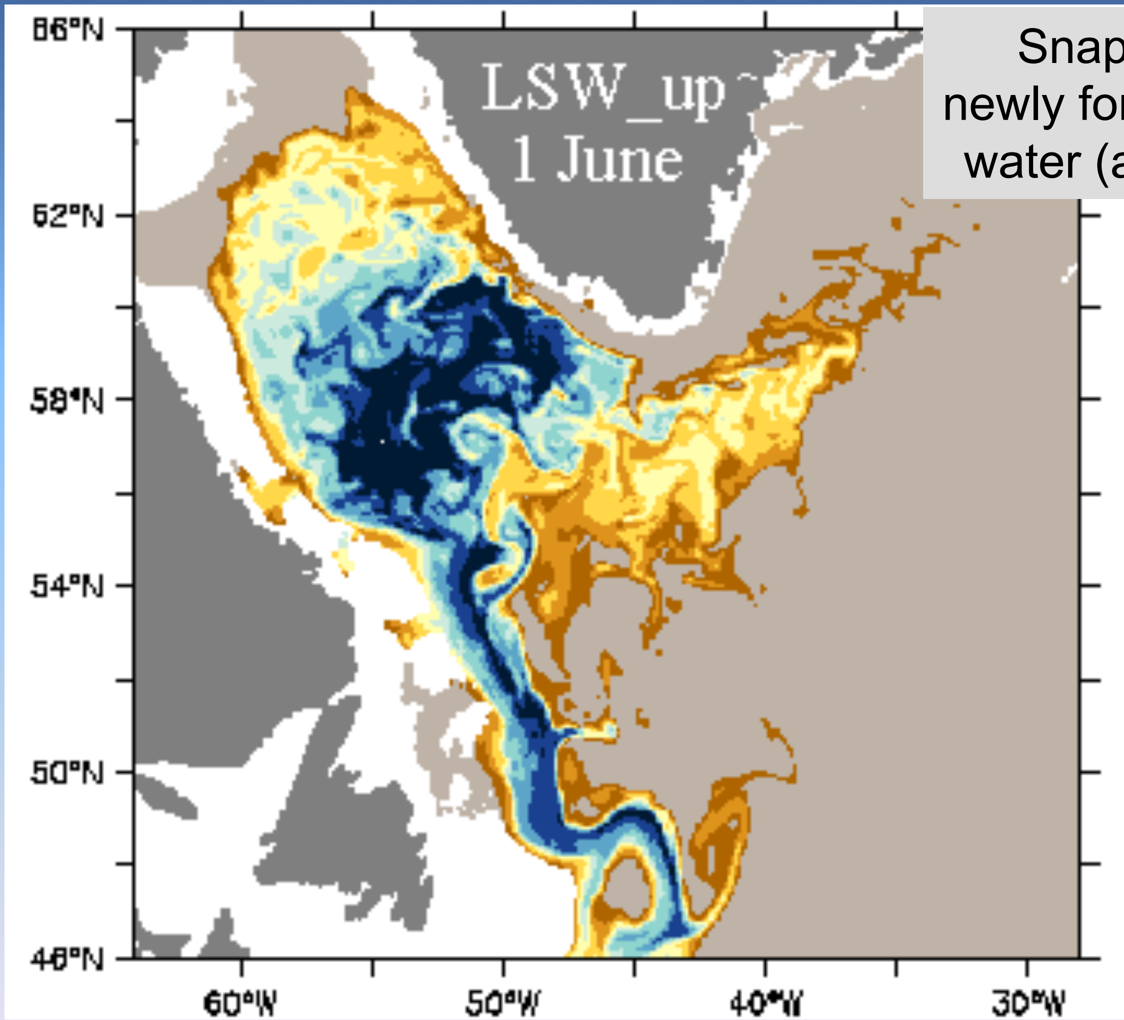
B … Lab Sea only



conclude that most of the decadal variability in AMOC over the last half of the twentieth century can be traced to variations in the turbulent heat and freshwater forcing over the Labrador Sea alone.

Yeager & Danabasoglu (2014)

Dynamical effect of changes in LS buoyancy fluxes?



Snapshot of newly formed deep water (at 1500m)

Figure: Lars Czeschel (Ph.D. thesis, 2004)
Discussion of export: **Brandt et al. (JPO, 2007)**

→ Changes in LSW formation can lead to deep density anomalies on the western boundary

Propagation of deep density anomalies on the western boundary

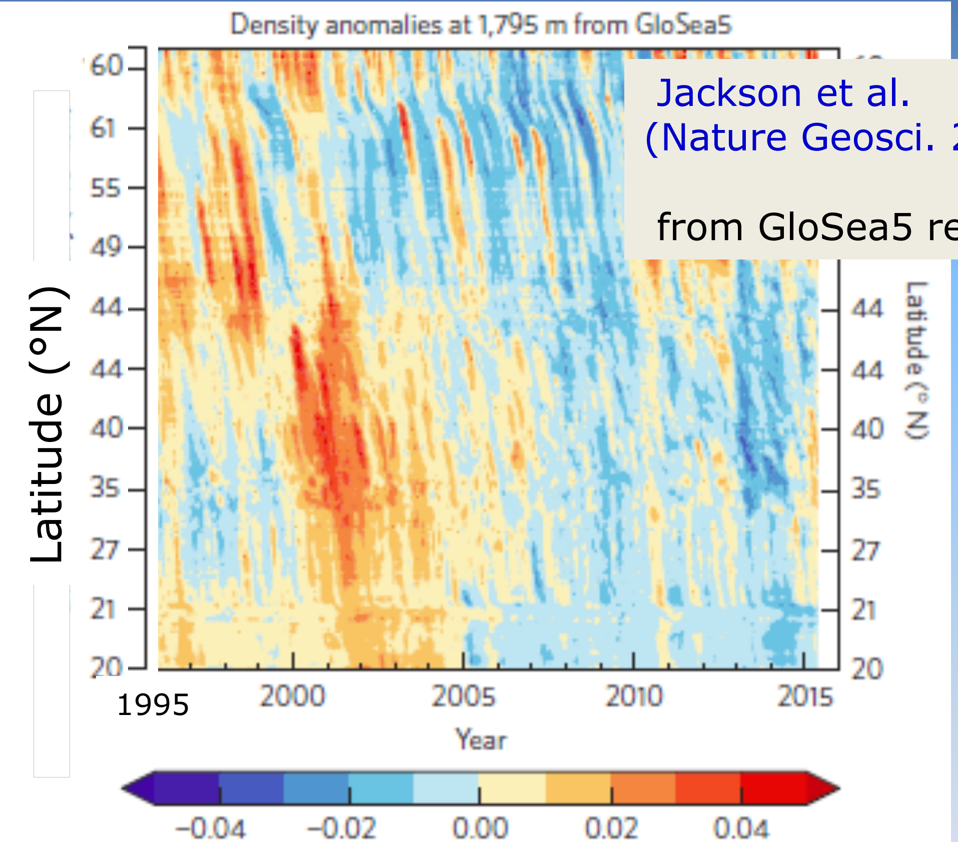


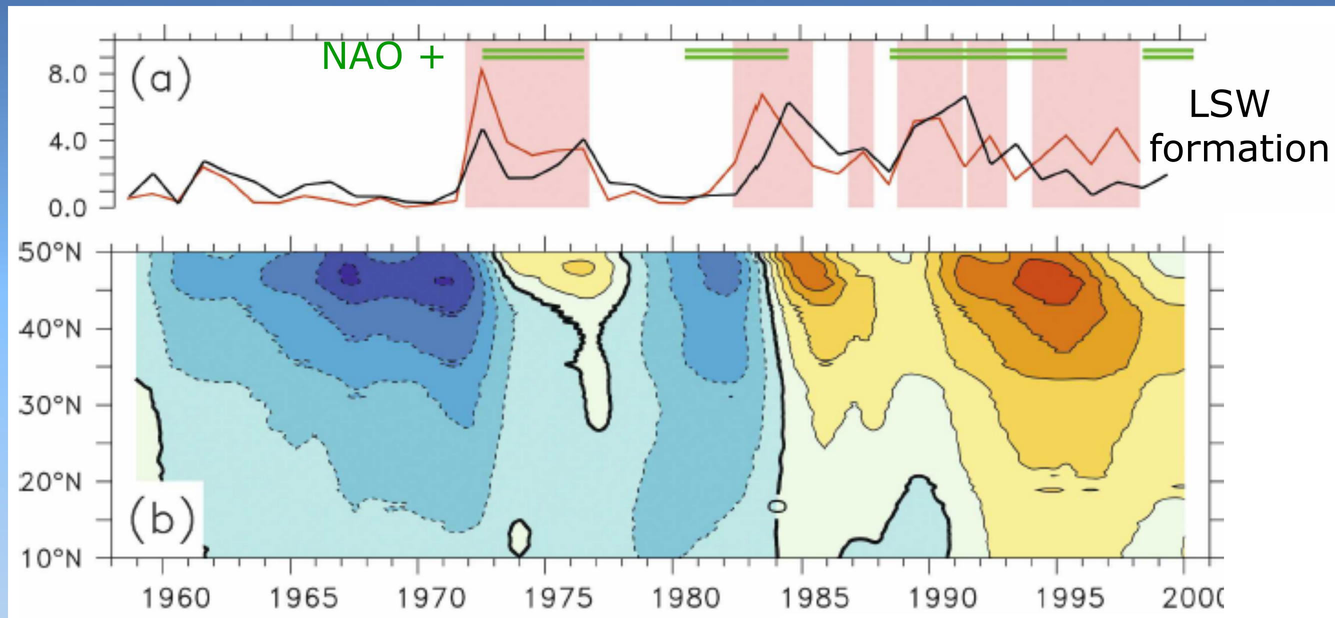
Figure 3 | Propagation of density anomalies in the GloSea5 reanalysis. Density anomalies ($kg\,m^{-3}$) on the western boundary at 1,795 m. The

Jackson et al.
(Nature Geosci. 2016)

from GloSea5 reanalysis

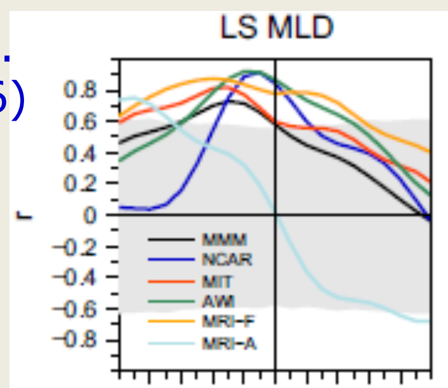
Decadal AMOC changes follow buoyancy-forced signals in the subpolar North Atlantic

Biastoch et al. (J. Clim. 2008)



Danabasoglu et al. (Ocean Mod. 2016)

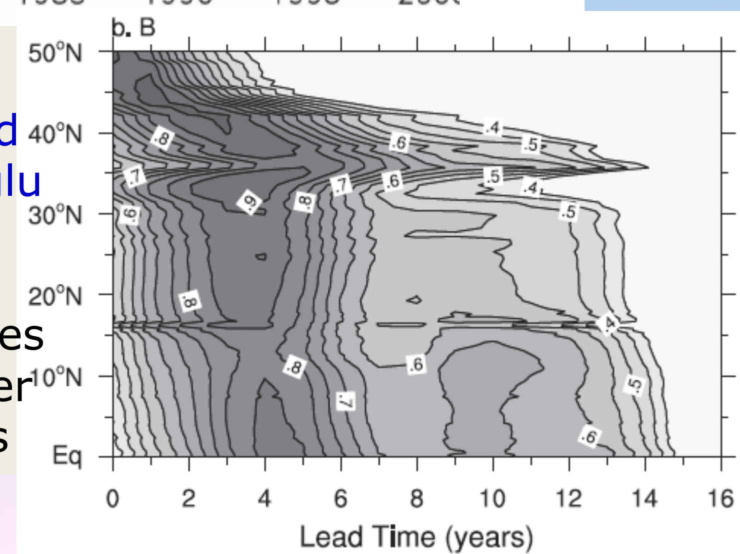
correlation MLD - AMOC



Lag (years)

Yeager and Danabasoglu (2014)

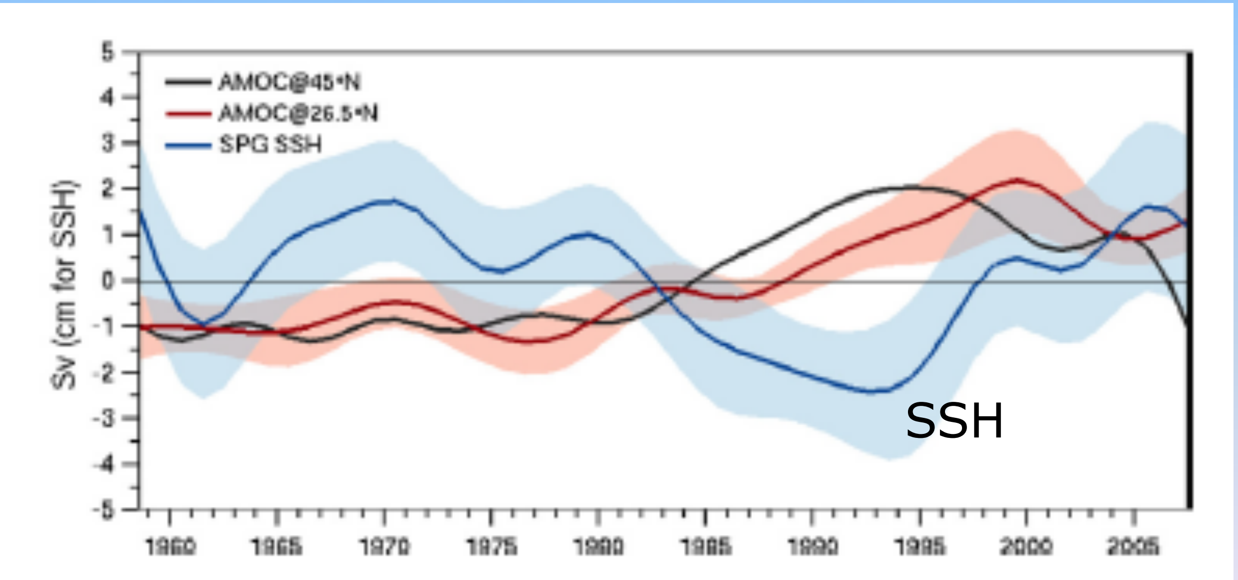
lag increases with lower latitudes



But the buoyancy forcing also affects the subpolar gyre transport!

… which is captured by a simple „SSH index"

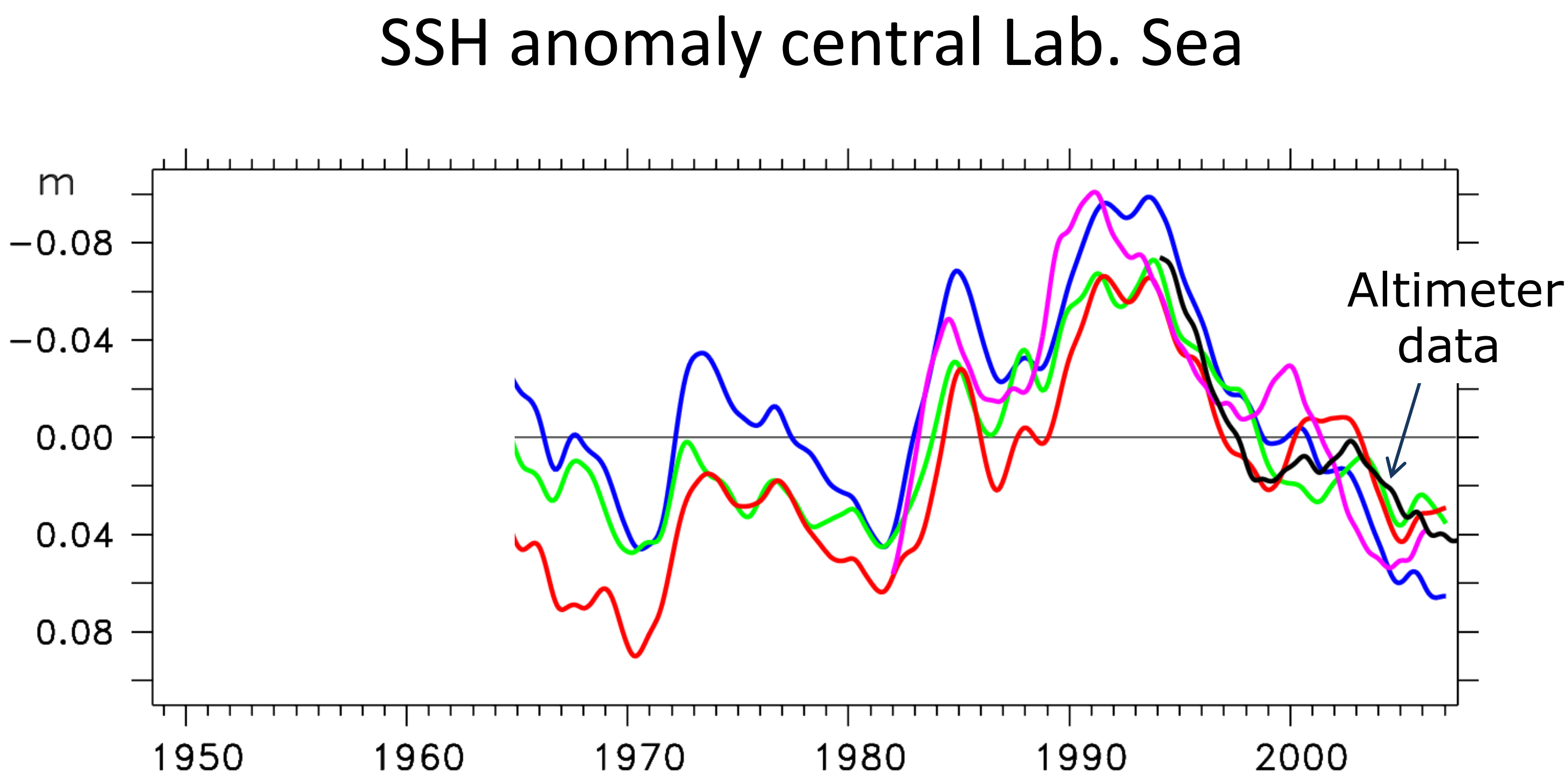
Lead – lag relation in the multi-model CORE simulations:



r ~ -0.6 for 2-3 year lags

(Danabasoglu et al. 2016)

Note: models capture the altimeter signal



ORCA05 - ORCA025 - ORCA12 - VIKING20

here: definition of SSH index following Böning et al. (2006)

- suggests that it may be possible to monitor slow, buoyancy-driven AMOC variations by observing Labrador Sea SSH changes

- with a potential for advance prediction of slow AMOC change at lower latitudes

Yeager and Danabasoglu. 2014

Note:
- Y & D define SSH index over a rather *large* area (53°-65°N, 45°-60°W), for which they find a negligible contribution of momentum flux forcing
- differs from earlier findings for a *central* LS box (Böning et al., 2006)

→ *needs further testing and probably refinement*

Summary

Ocean model hindcasts & flux perturbation exps. suggest that in the *North* Atlantic:

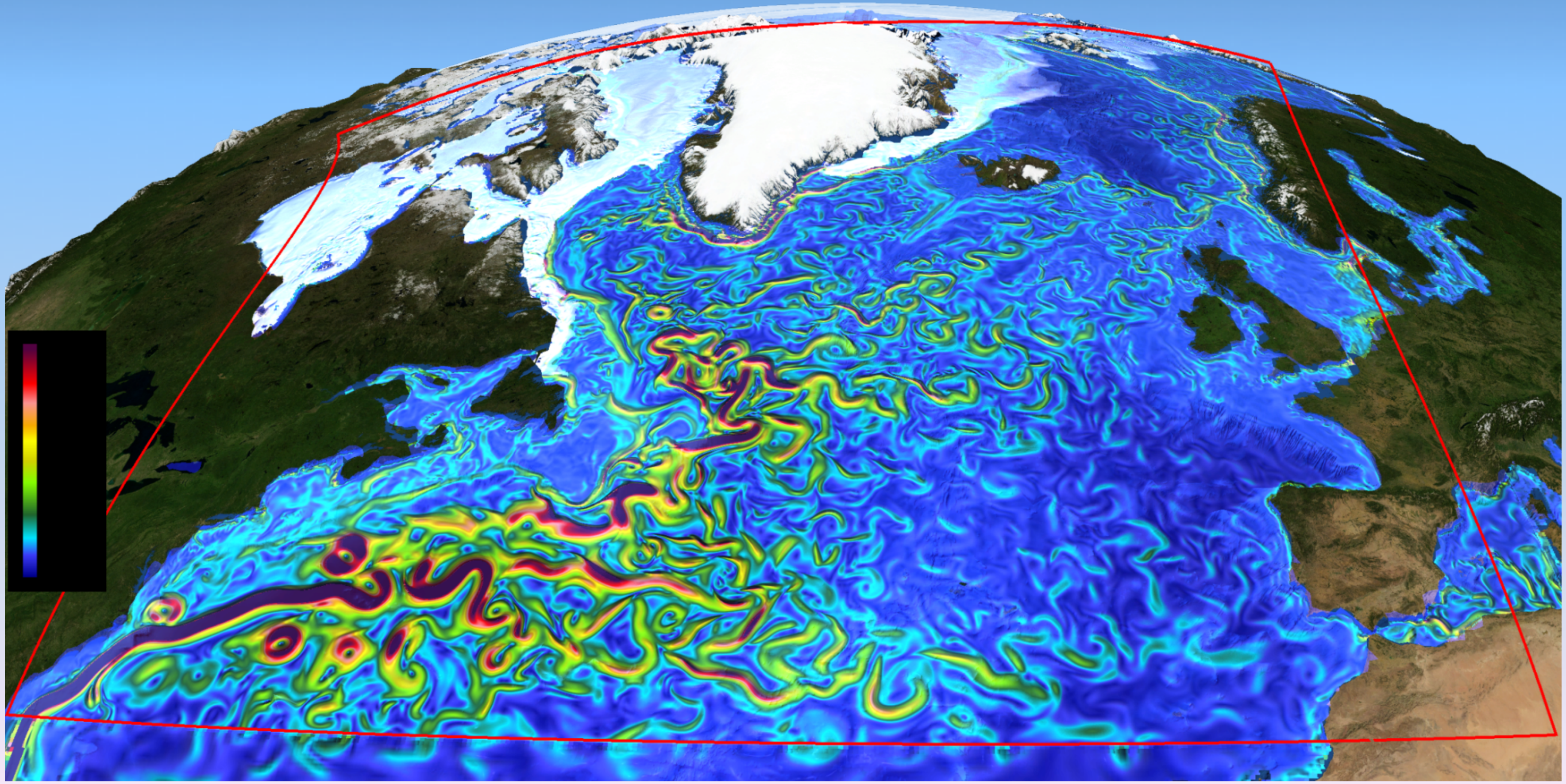
- AMOC variability up to O(5 years) is governed by wind stress (with limited meridional coherency)
- Decadal changes are driven by variations in buoyancy fluxes
- ... mainly over the Labrador Sea
- … with a lead-lag correlation with the subpolar gyre SSH

For the South Atlantic there are additional sources of decadal changes: Southern Ocean wind stress,…

Response of the subpolar North Atlantic to increasing Greenland Ice Sheet melting?

Simulations with a 1/20°-ocean model („VIKING20“):

Global ¼°-model with a 1/20°-“nest“ in the North Atlantic



Response of the subpolar North Atlantic to increasing Greenland Ice Sheet melting?

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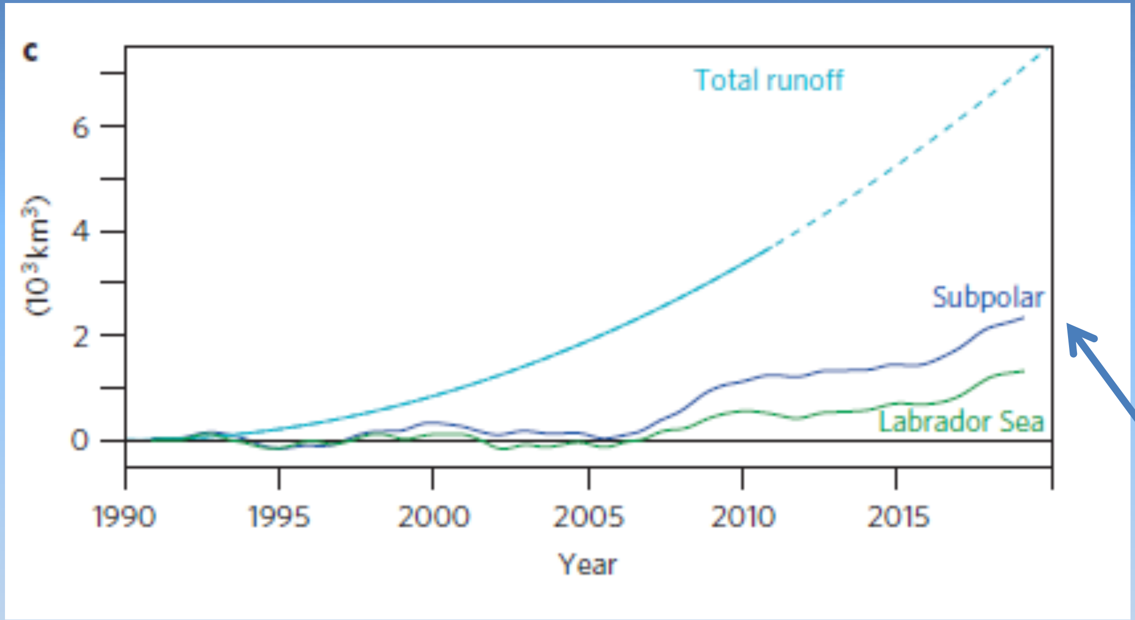
Global ¼°-model with a 1/20°-“nest“ in the North Atlantic

Emerging impact of Greenland meltwater on deepwater formation in the North Atlantic Ocean

Claus W. Böning[1*], Erik Behrens[1,2], Arne Biastoch[1], Klaus Getzlaff[1] and Jonathan L. Bamber[3]

(July 2016)

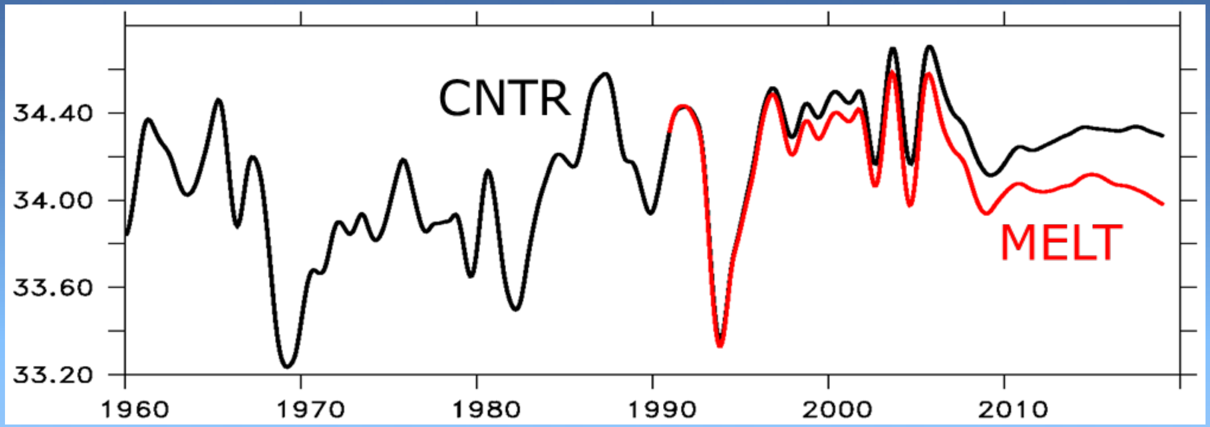
The tracer distribution is reflected in the evolution of the freshwater content



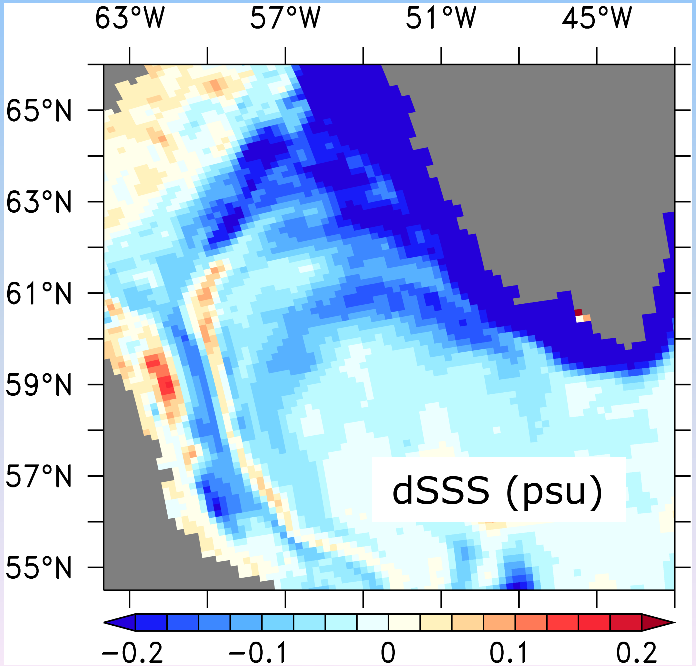
Accumulation in the subpolar North Atlantic: ~ 1/3 of the run-off

(2000 km^3 by 2016)

Q2: Impact? (a) Salinity signal in the Labrador Sea

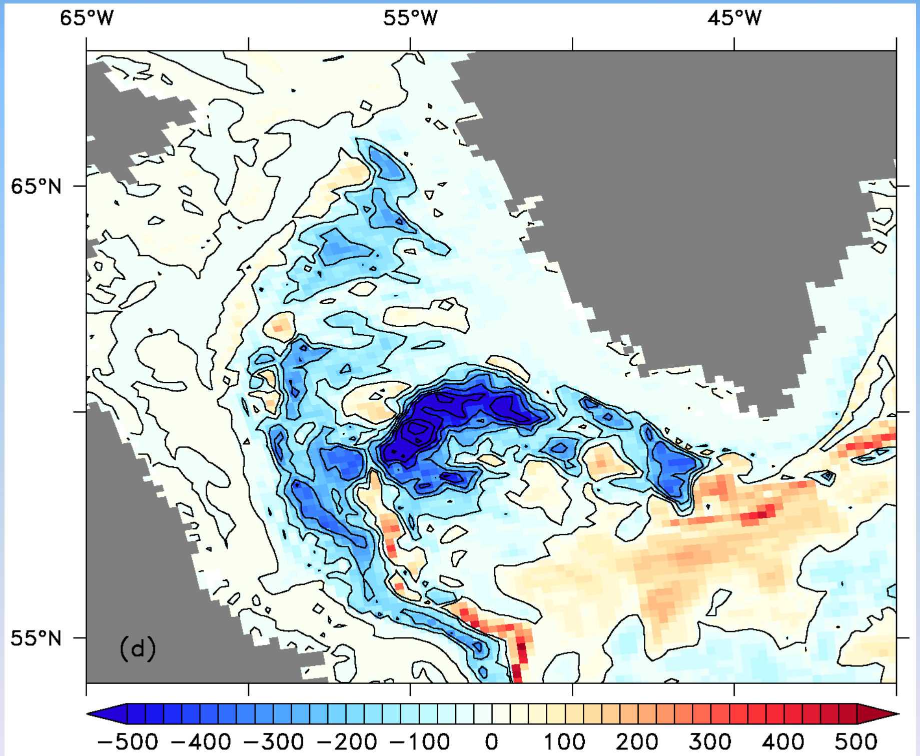


SSS (1960-2020)
in the WGC



MELT – CNTR
(last year)

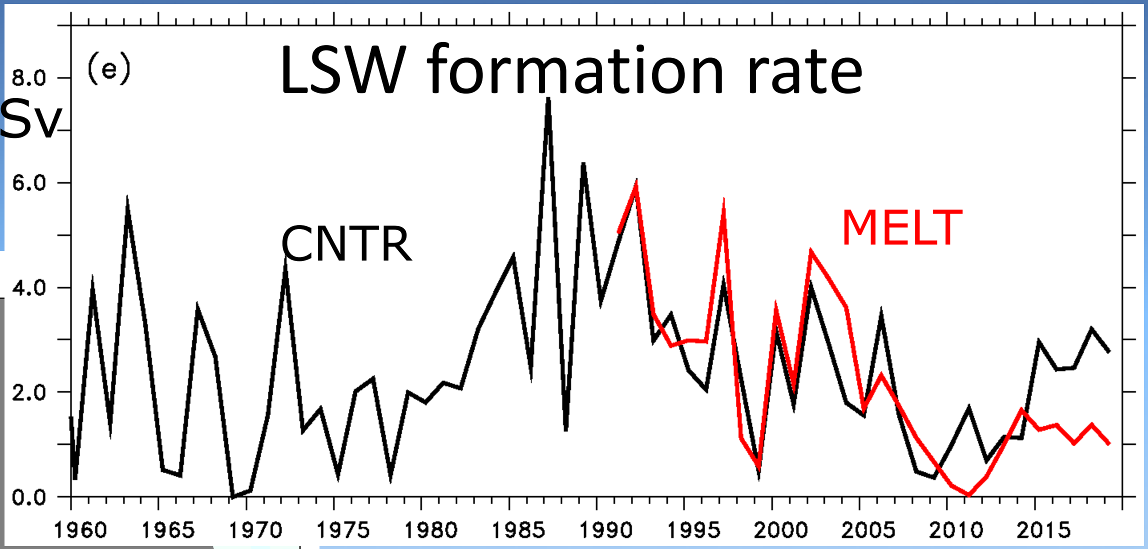
(b) Impact on the winter convection

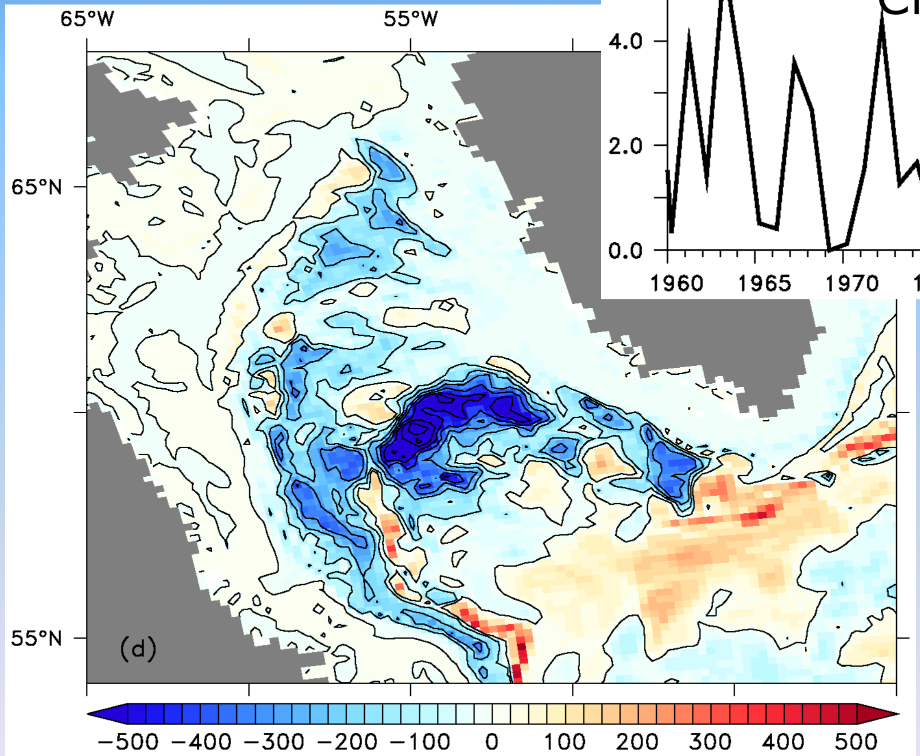


m

Change by 2020
in the depth
of convection

(b) Impact on the winter convection





m

Change by 2020
in the depth
of convection

Conclusion

The increasing FW fluxes from Greenland

have begun to initiate a freshening trend of the Labrador Sea surface waters which is gradually becoming large enough to progressively dampen the deep winter convection in the coming years.