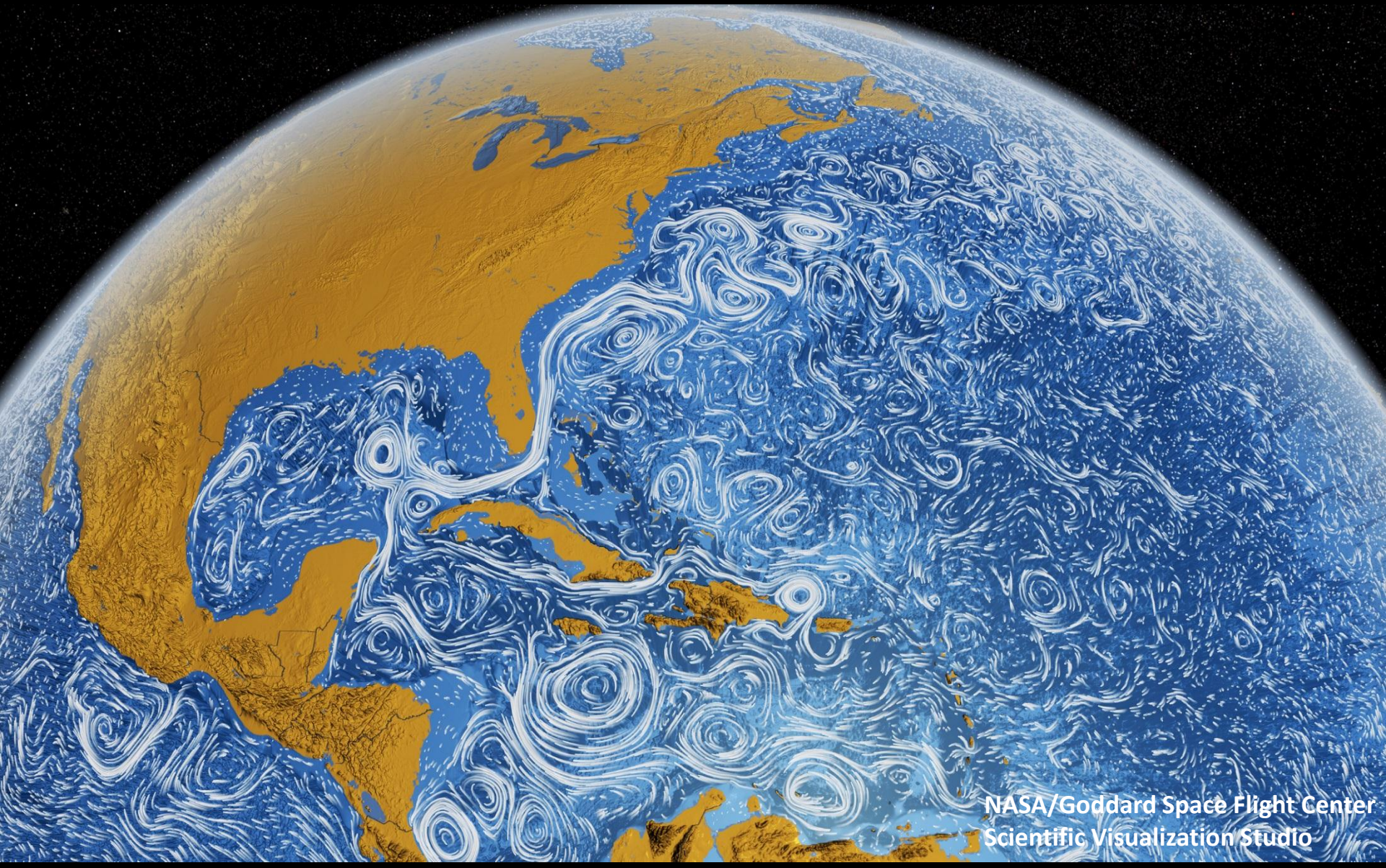
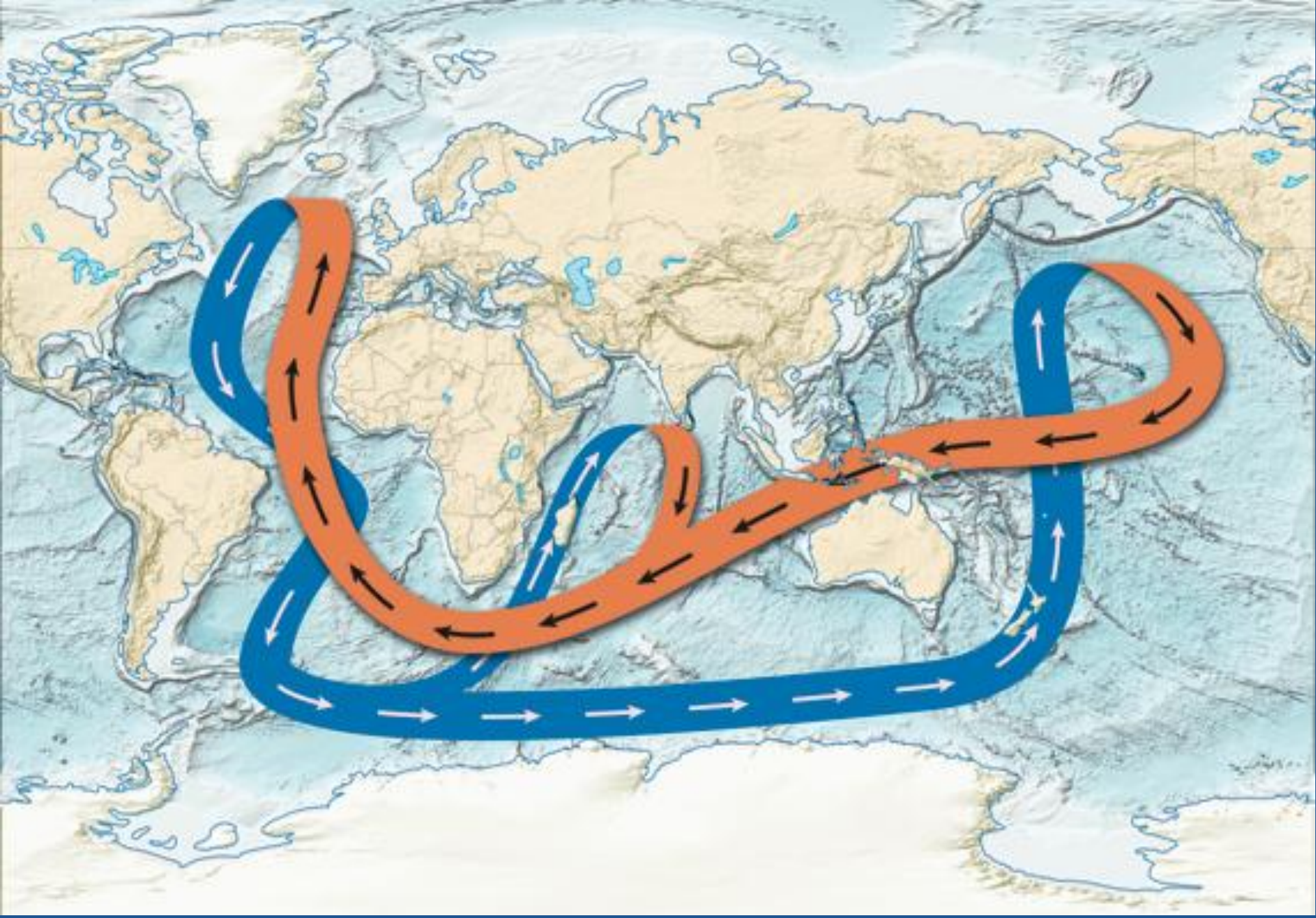
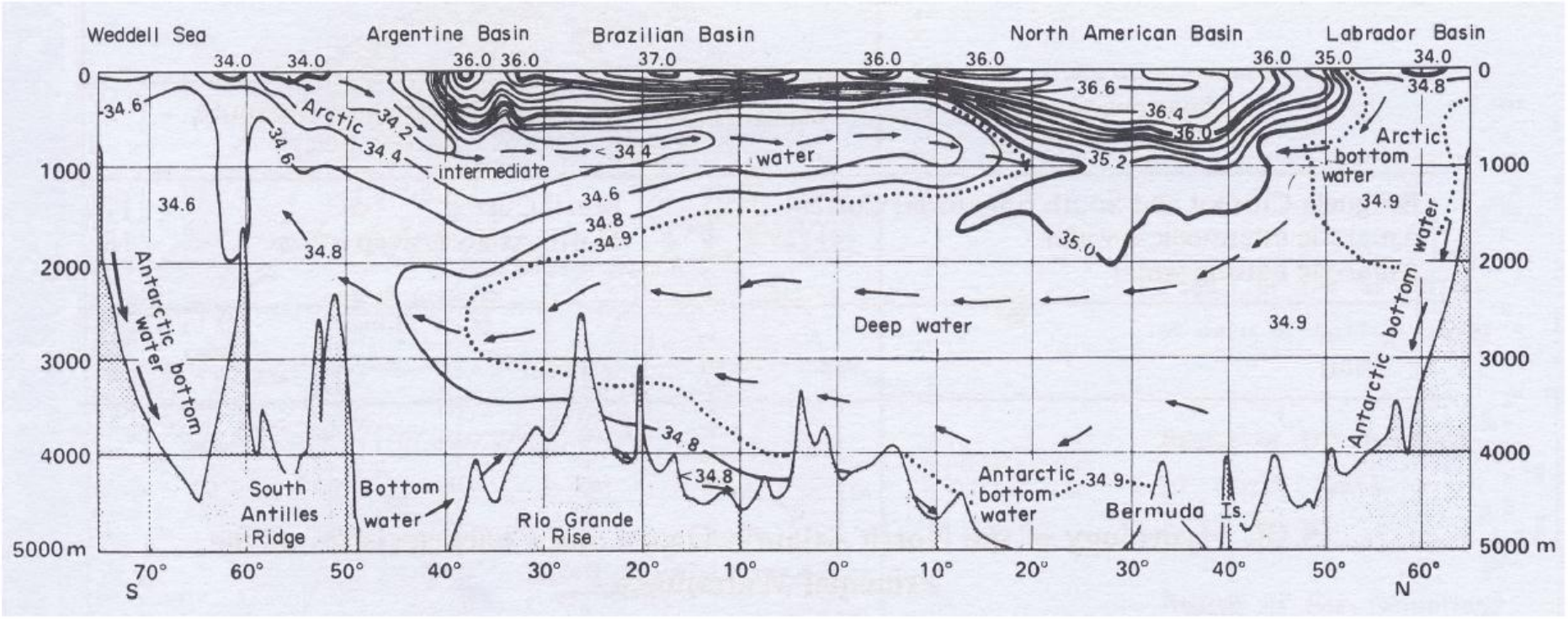
A Decade After *The Day After Tomorrow*: Our Current Understanding of the Ocean's Overturning Circulation





Adapted from Broecker 1987

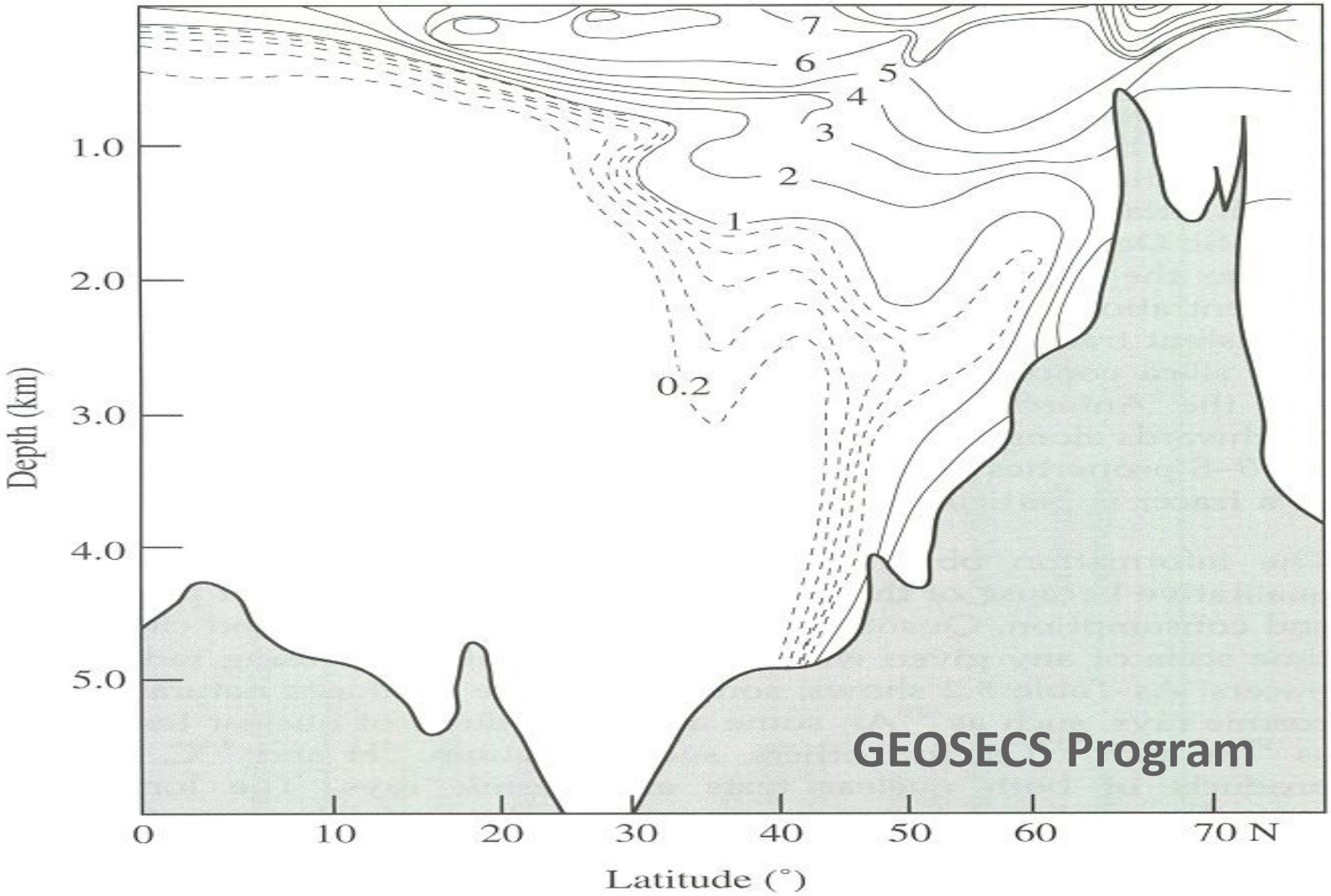
Early Traces of Water Masses in the Atlantic



Salinity along 30°W during the German Atlantic expedition: 1925-1927

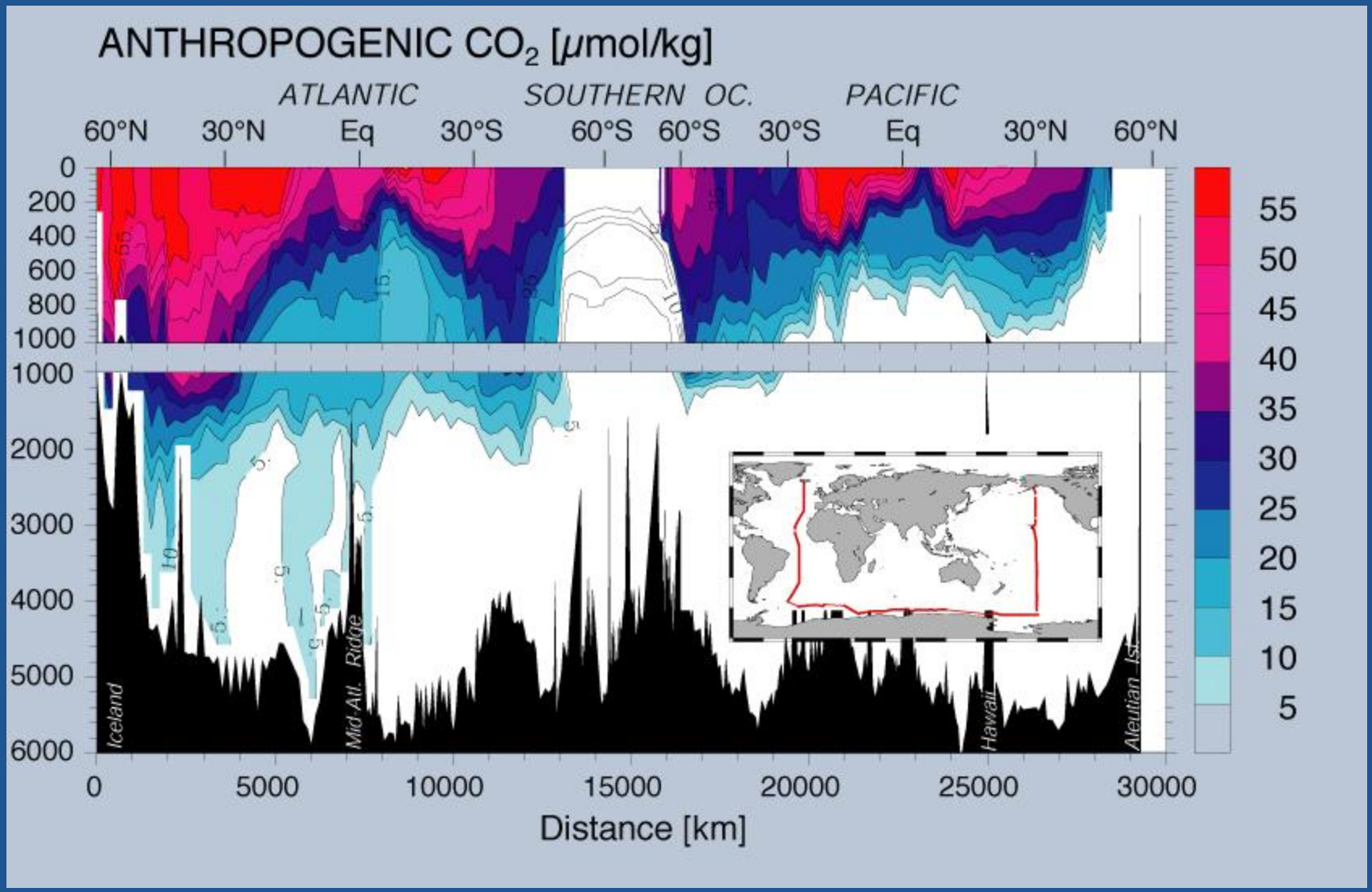
Merz 1925

Spreading of Tracers in the Deep Ocean



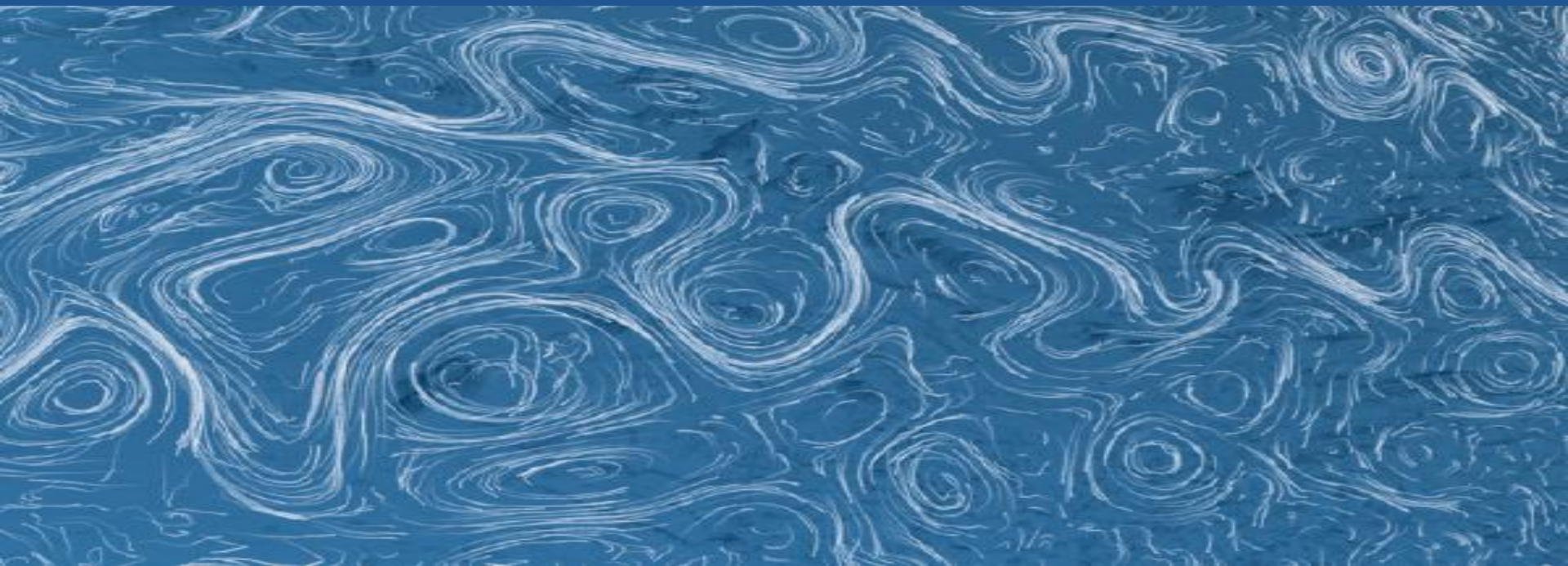
Tritium and Helium-3 concentrations in the North Atlantic: 1972-73

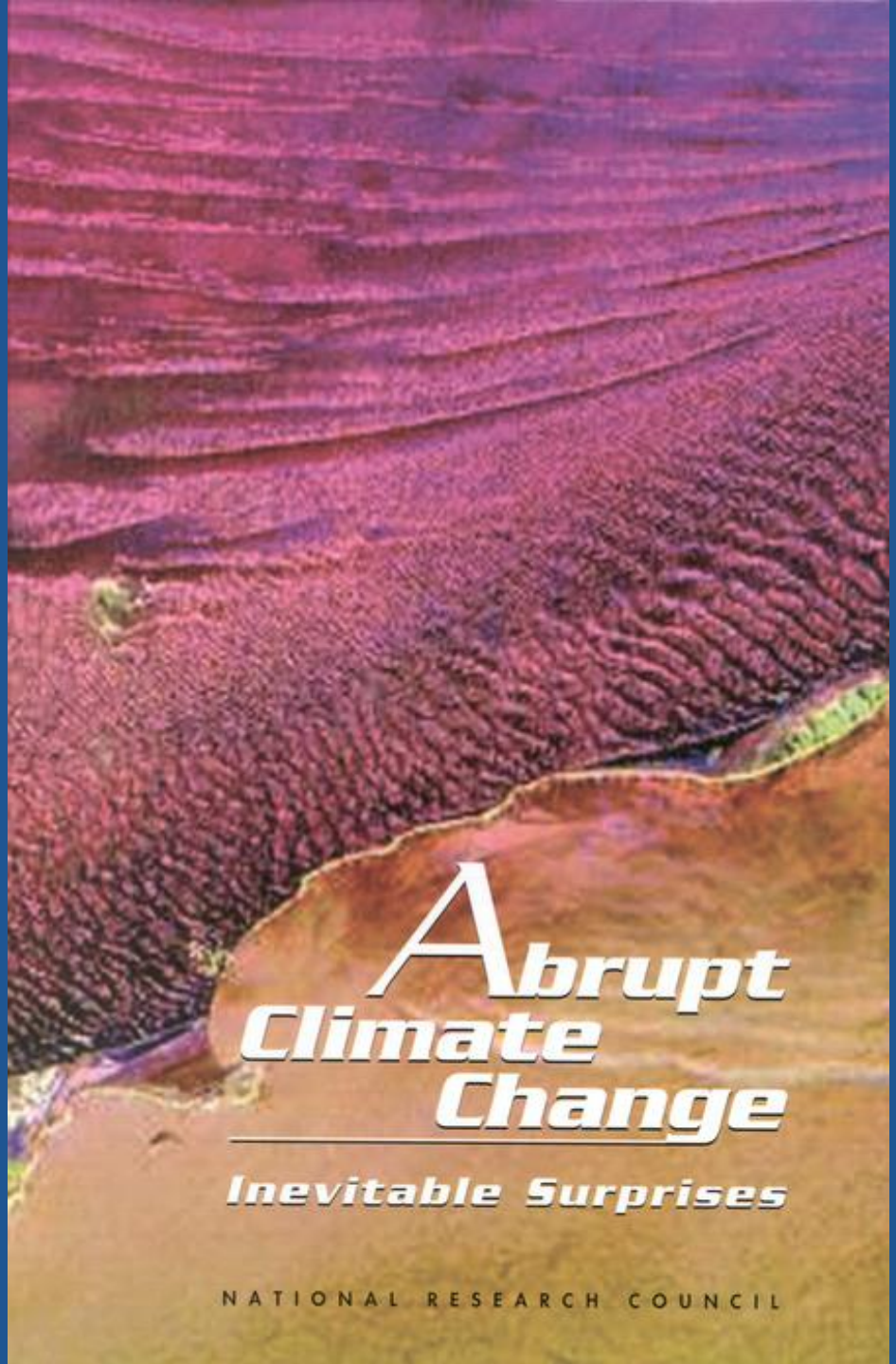
Spreading of Anthropogenic CO_2 in the Deep Ocean



Sabine et al. 2004

Understanding the fate of the ocean as a carbon reservoir hinges on our understanding of overturning variability.

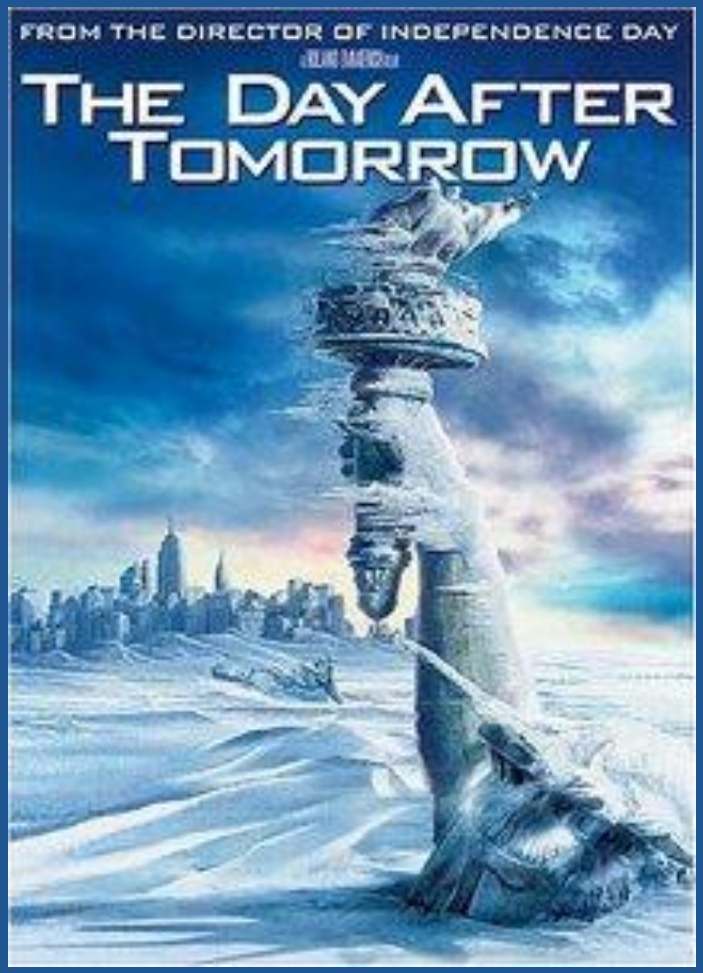




"The climate record for the past 100,000 years clearly indicates that the climate system has undergone periodic--and often extreme--shifts, sometimes in as little as a decade or less."

Published 2002

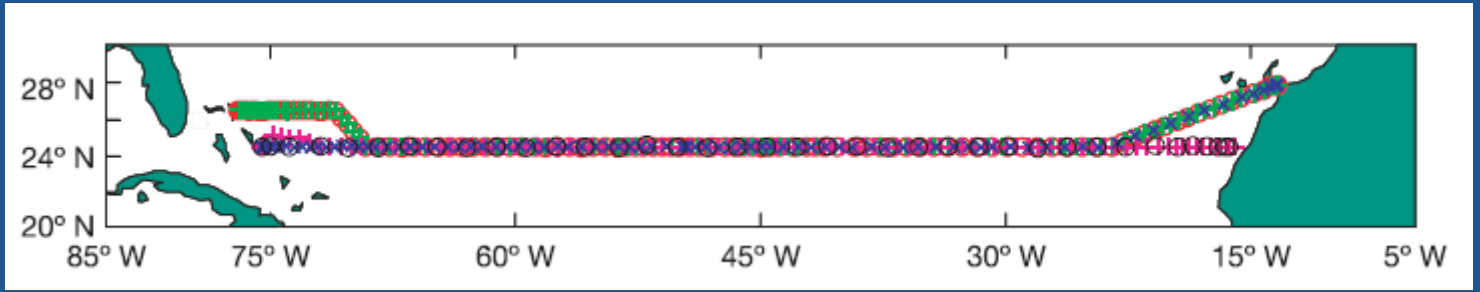
Out of Hollywood



2004

In the Scientific Press

Reported reduction in AMOC over 5 decades: 30%



Bryden et al., 2005. Slowing of the Atlantic meridional overturning circulation at 25°N, *Nature*, 655-657.

Overturning Assumptions

1. The overturning varies on time scales of years to decades.

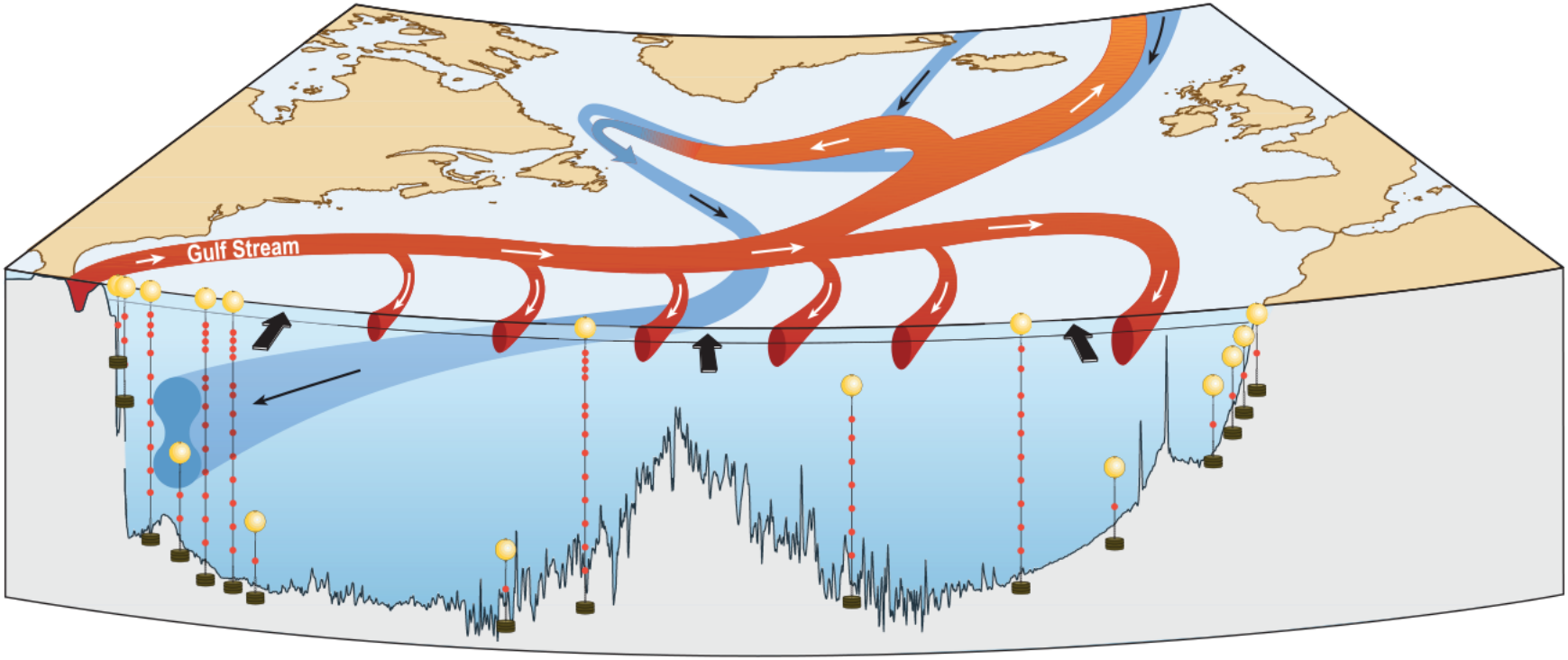
2. Waters in the lower limb of the overturning circulation are carried along deep western boundary currents.

3. Surface Gulf Stream waters constitute the upper limb of the overturning circulation.

4. Temporal variability in overturning transport is coherent from one latitude to the next.

5. Overturning variability primarily results from deep water mass formation variability.

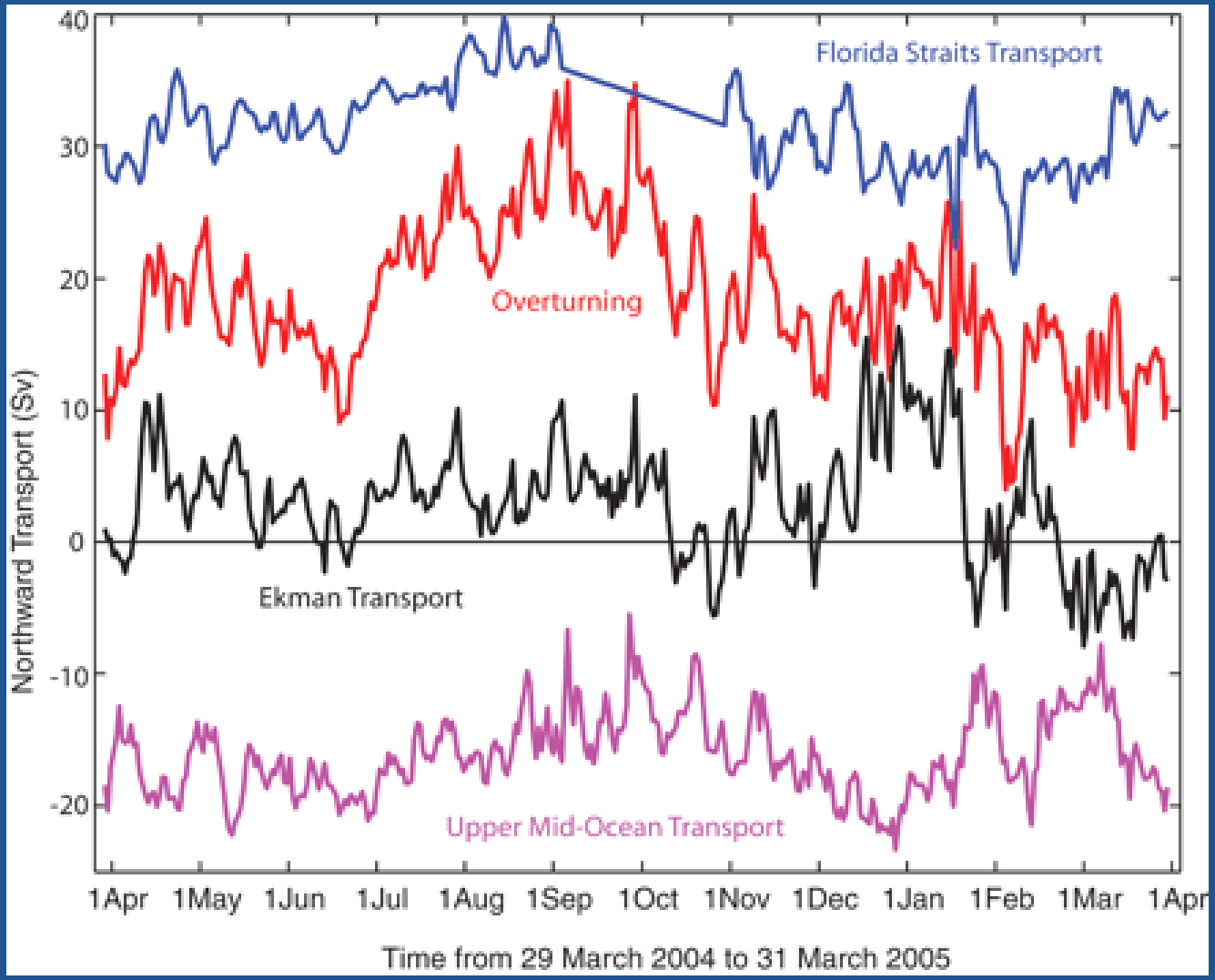
U.K. and U.S. AMOC Monitoring Array: RAPID



Since 2004 this program has continuously monitored the strength of the meridional overturning circulation and ocean heat transport at 26°N in the North Atlantic.

Srokosz and Bryden 2015

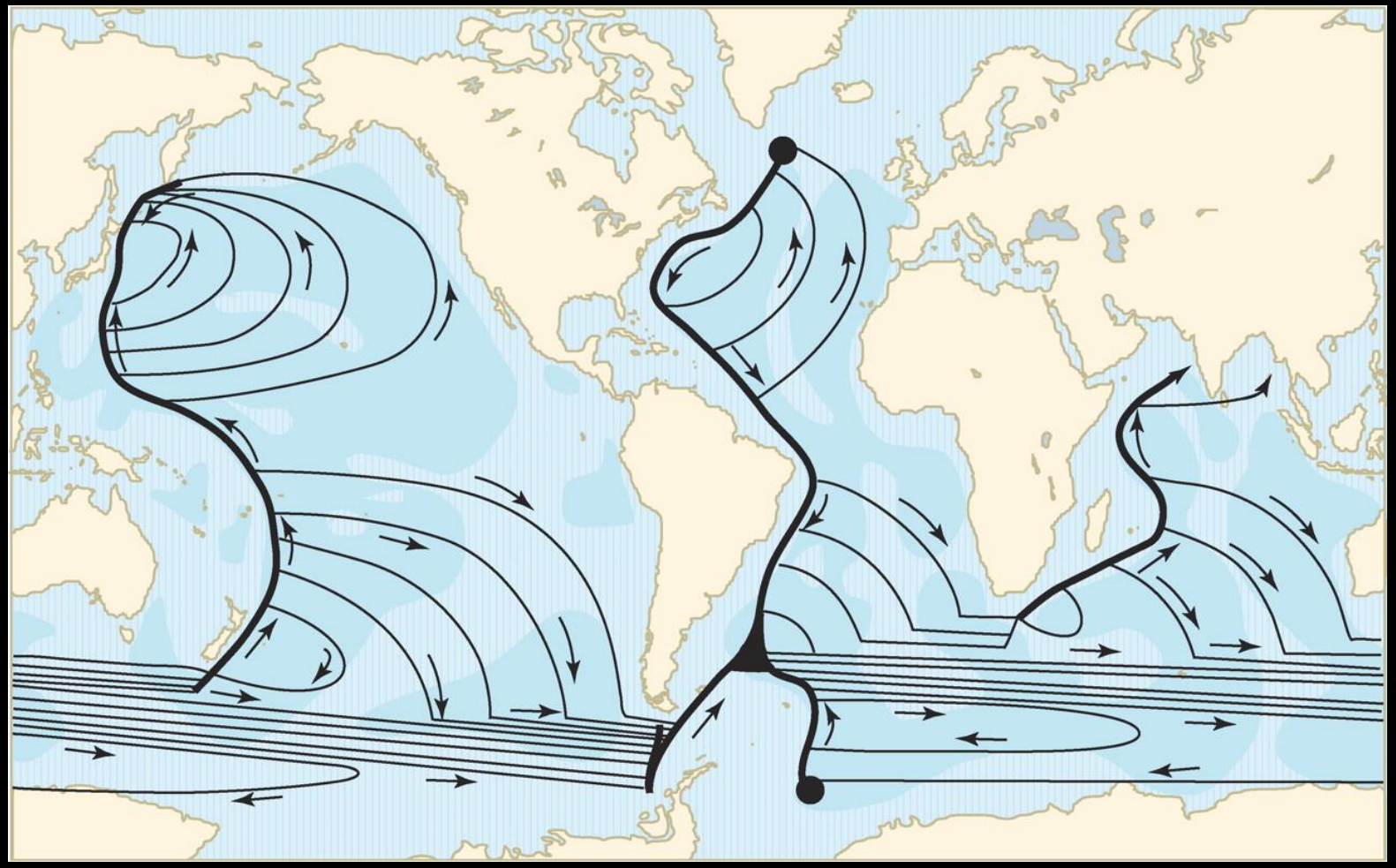
Temporal Variability of the Atlantic Meridional Overturning Circulation at 26°N



Cunningham et al. 2007

Maximum northward transport of upper-layer waters on each day

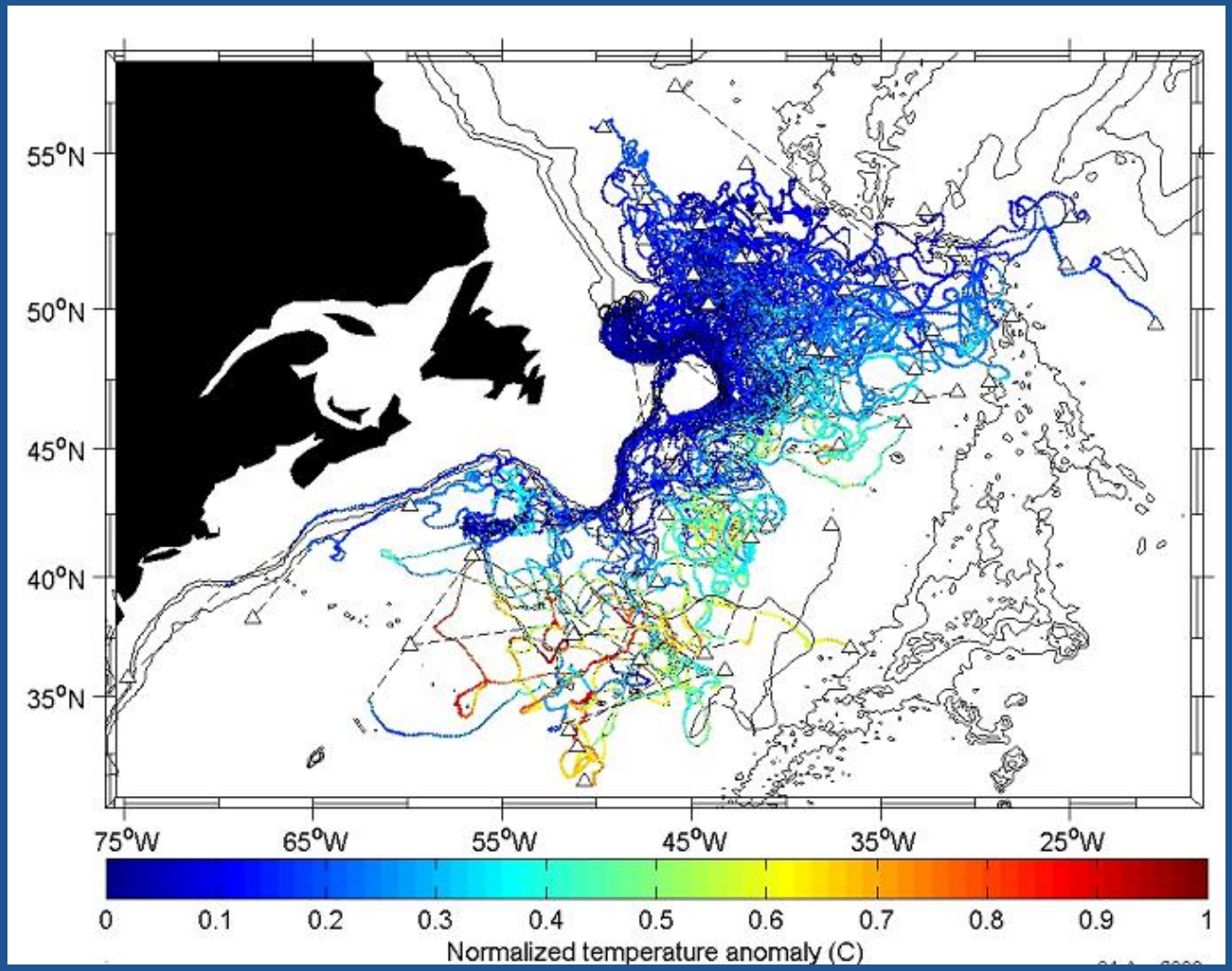
Deep Western Boundary Current as Conduit



Stommel 1958

Assumption 2: Lower limb pathways

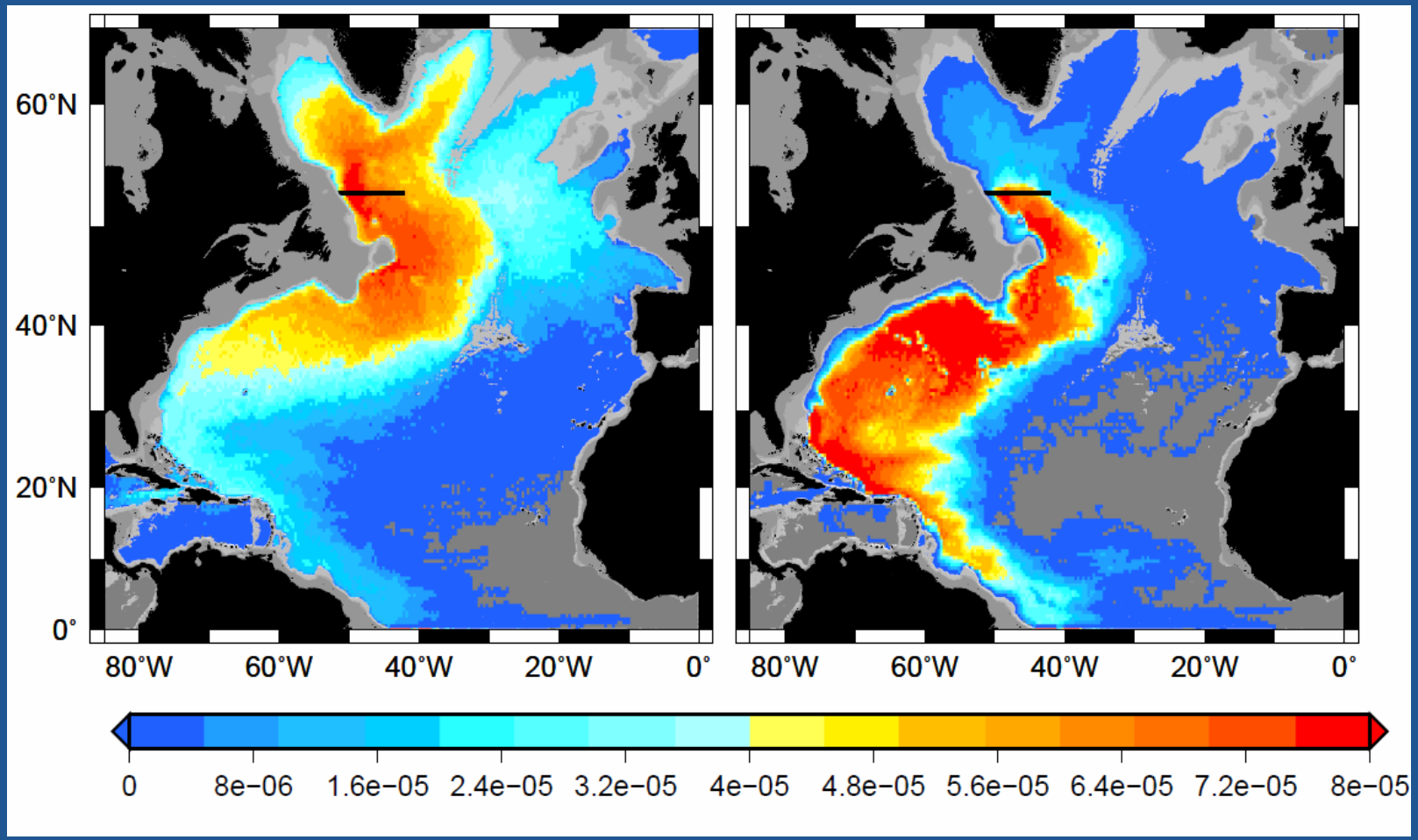
Lower Limb Subpolar to Subtropical Pathways



Trajectories of RAFOS floats deployed in the Lab Sea from 2003-2006 and tracked for 2 years.

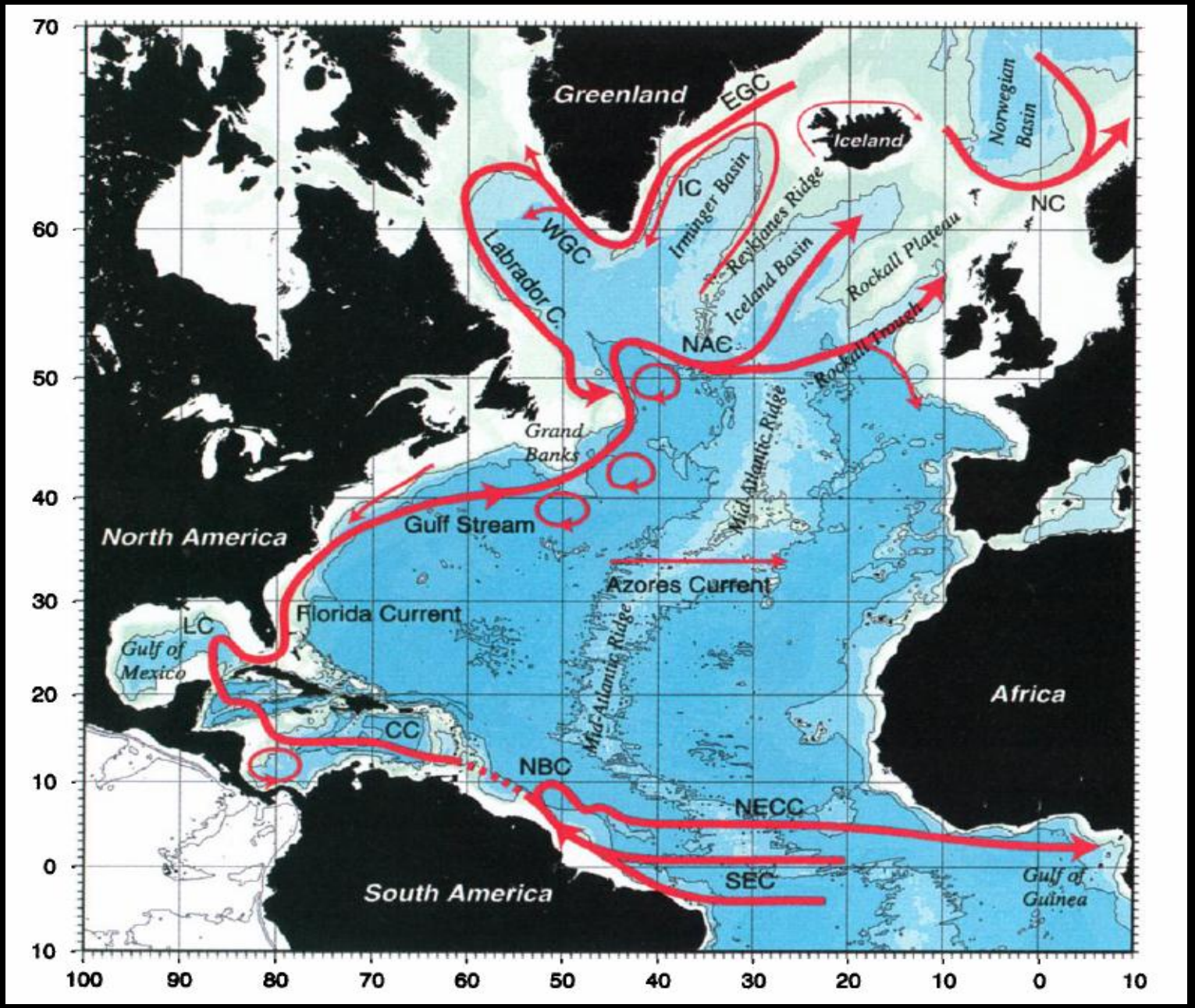
Bower et al. 2009

Equatorward spreading of deep waters



Probability map constructed from 50-yr simulated trajectories

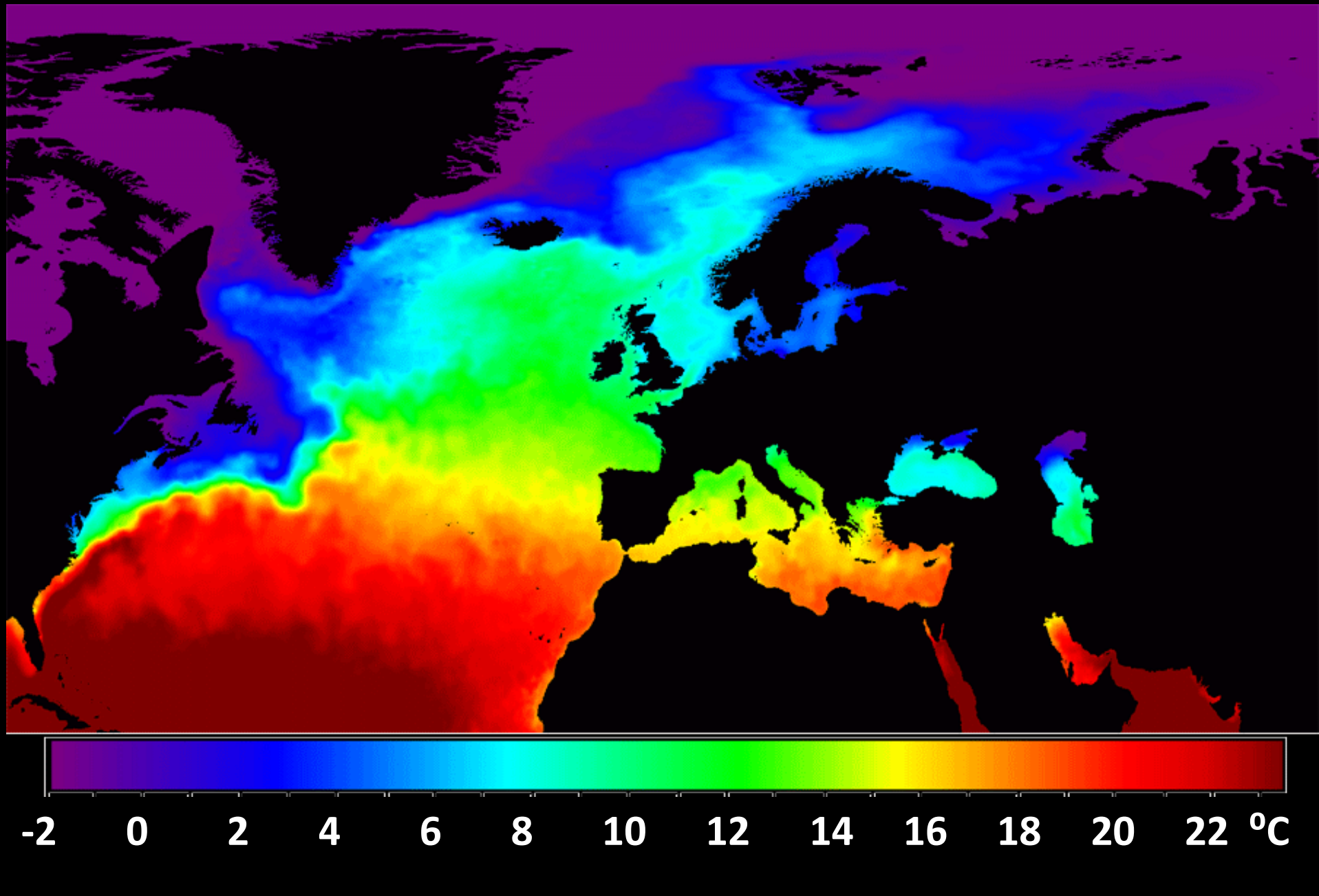
Lozier et al. 2013



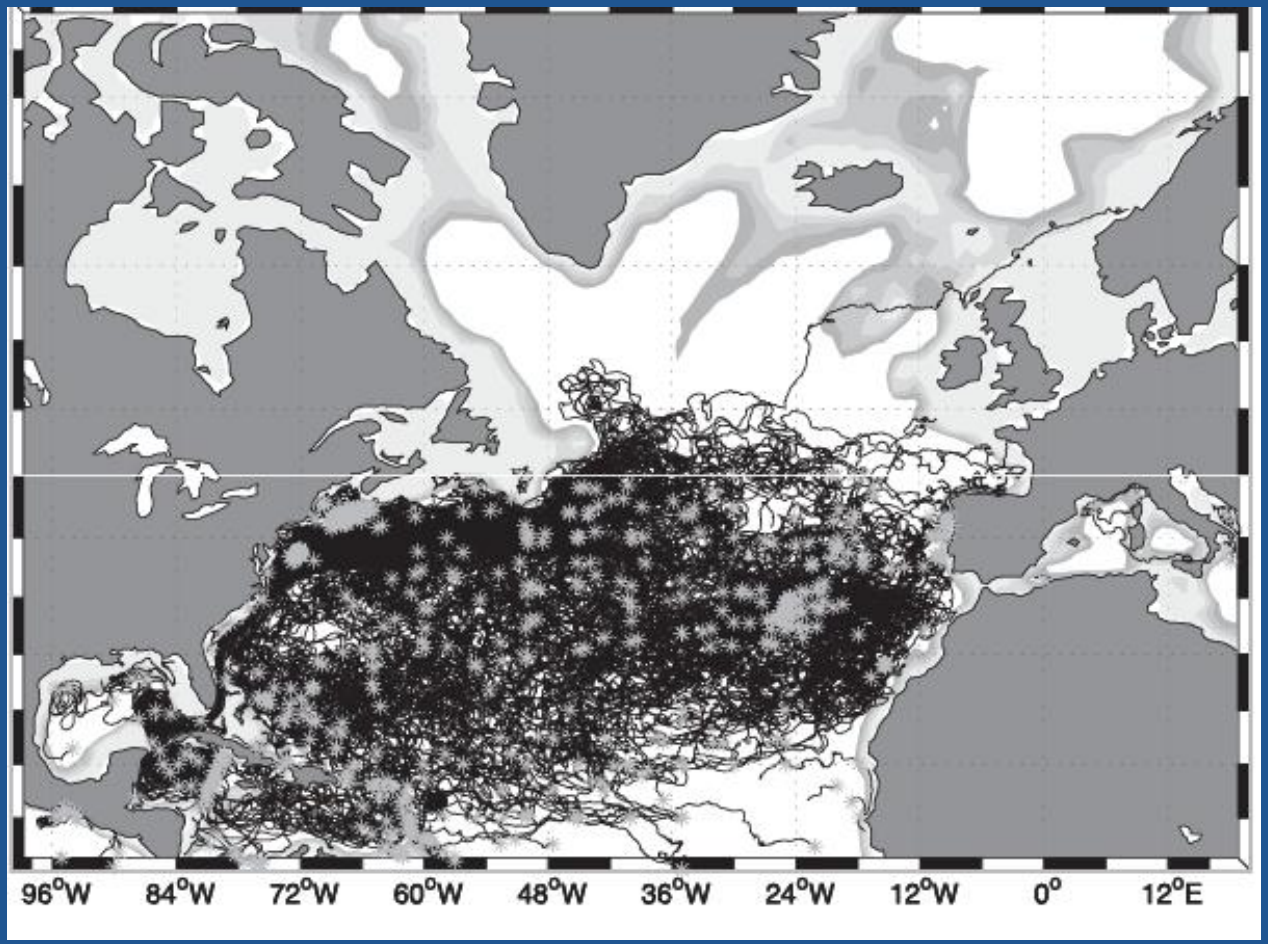
Assumption 3: Surface pathway

Fratantoni 2001

Sea Surface Temperature

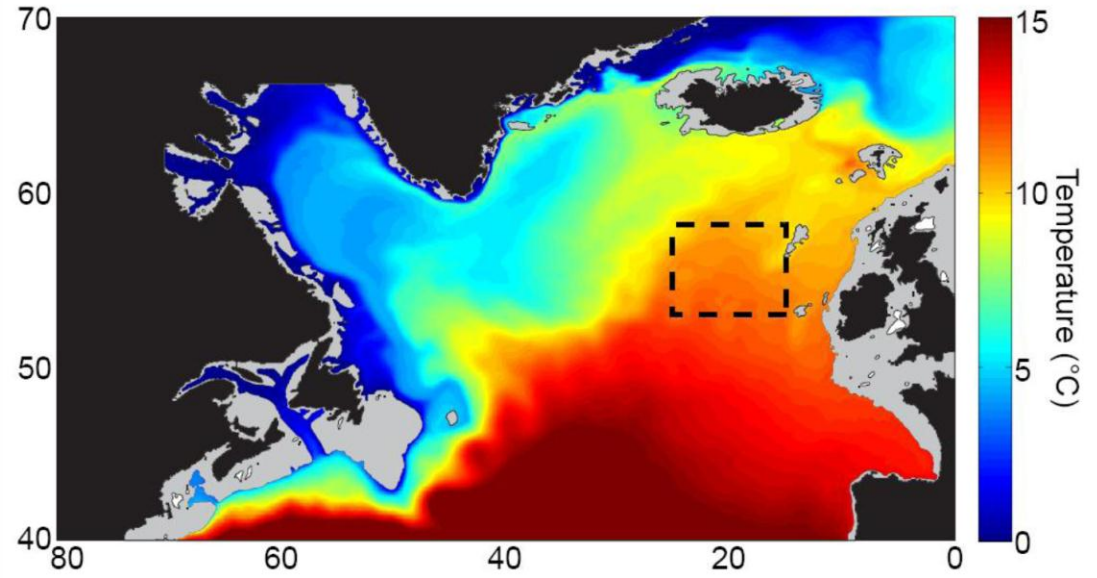


Surface Exchange Between the Subtropical and Subpolar Gyres: the Lagrangian View

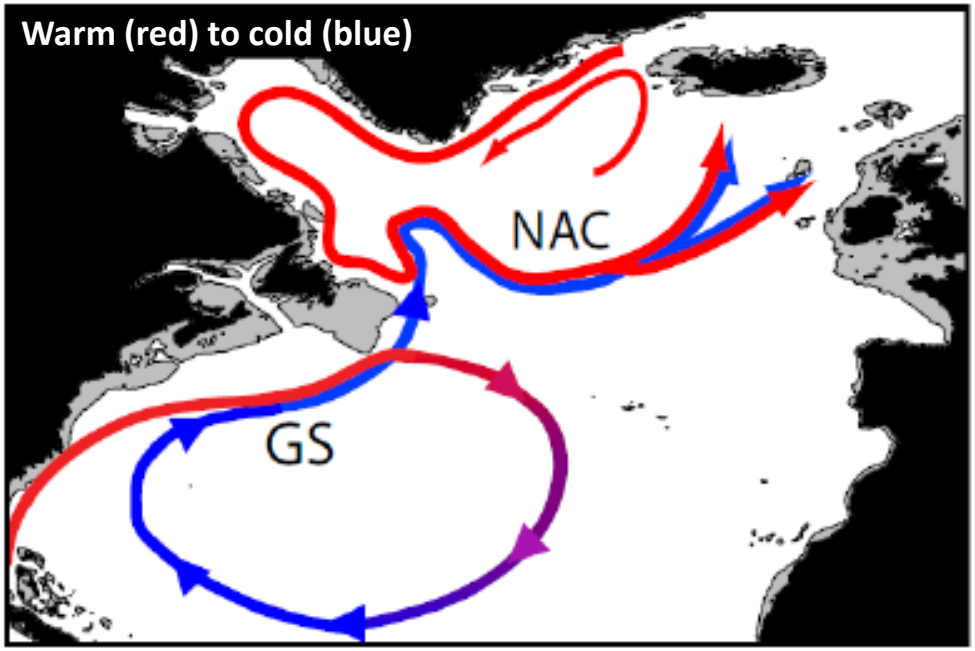


Trajectories of surface drifters deployed south of 45°N. Gray asterisks are deployment locations.

Brambilla and Talley 2006



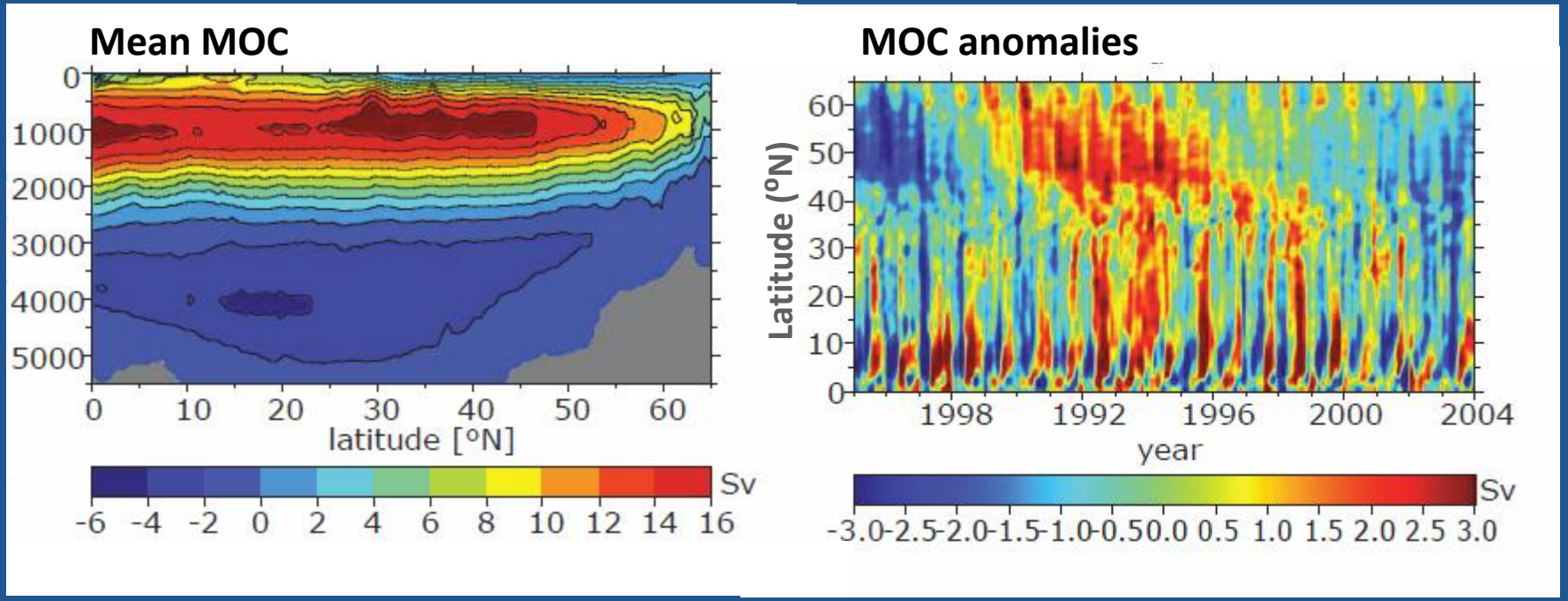
What is the source of these warm surface waters in the eastern subpolar gyre?



Revised AMOC surface throughput

Burkholder and Lozier 2014

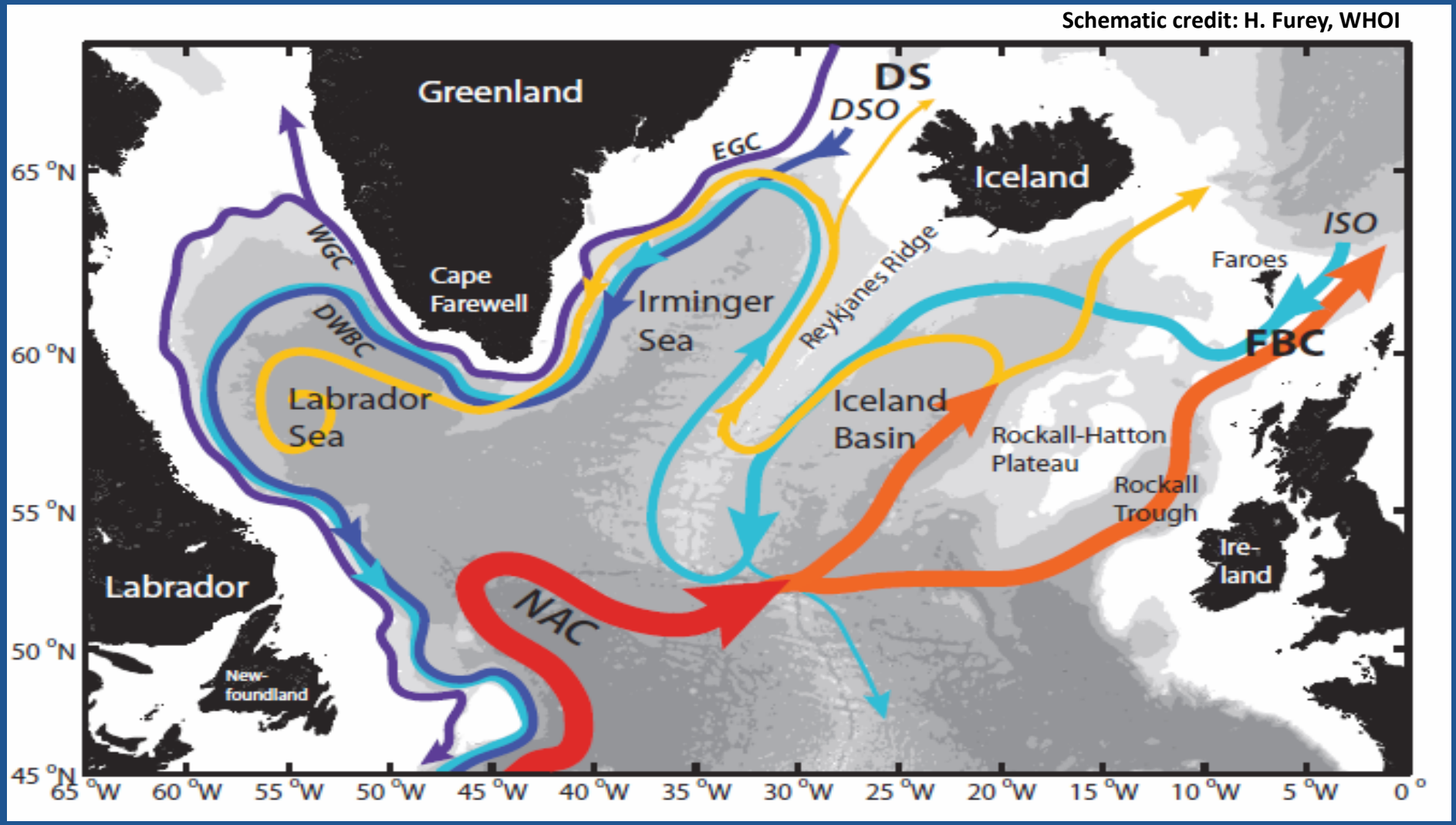
Meridional coherence of MOC anomalies



Bingham et al. 2007

Assumption 4: MOC spatial coherence

Lower Limb of the Overturning: Labrador Sea Water and Arctic Overflow Waters

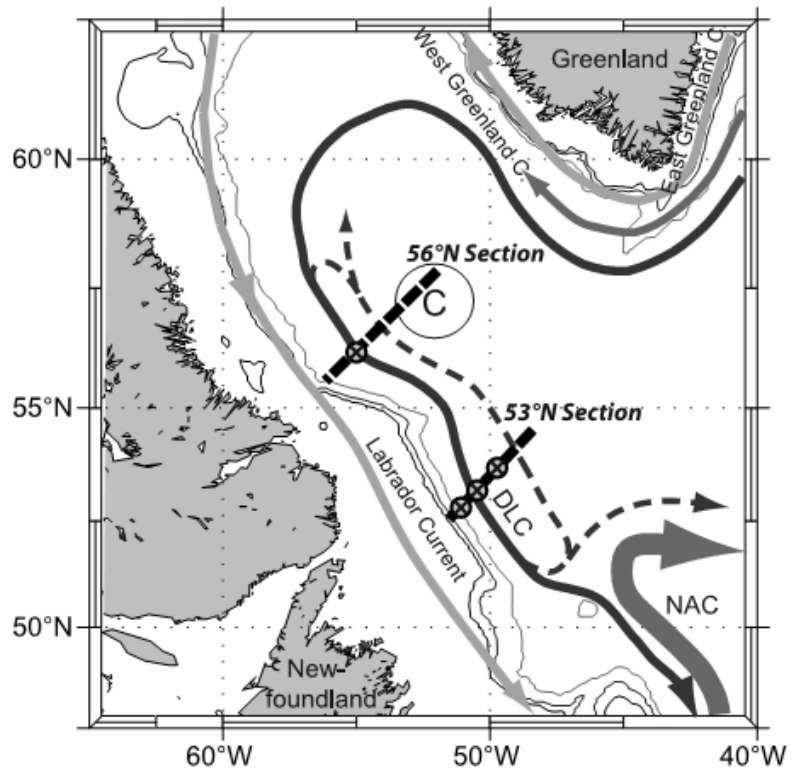


What is the *observational* basis for the linkage between convective activity in the Labrador and Nordic Seas and a temporally variable meridional overturning?

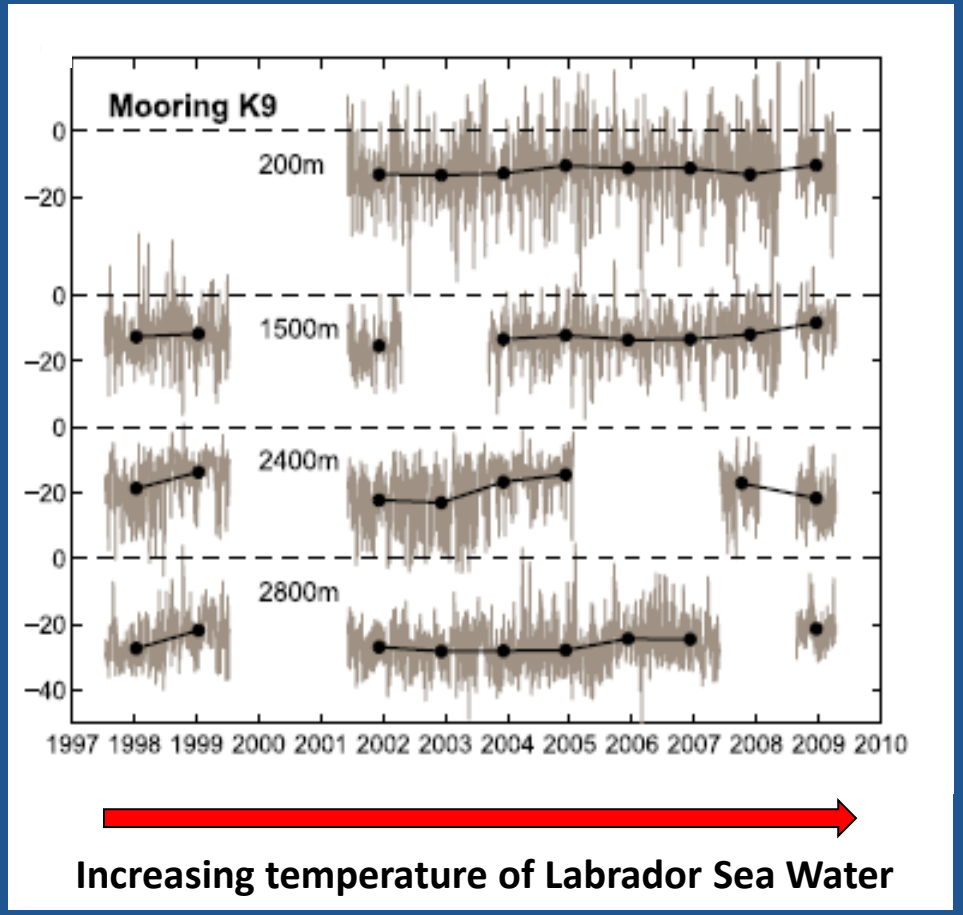
Assumption 5

Lab Sea Convective Activity Compared to DWBC Transport

Fischer et al. 2010



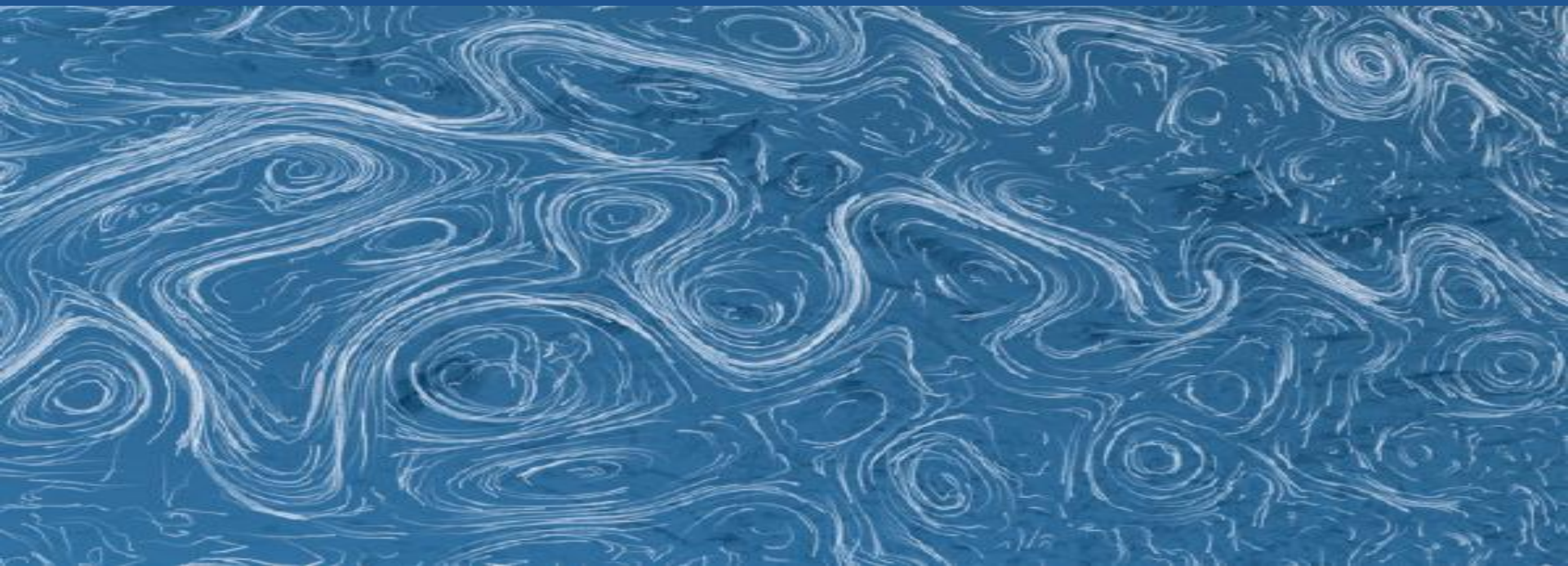
Dengler et al. 2006



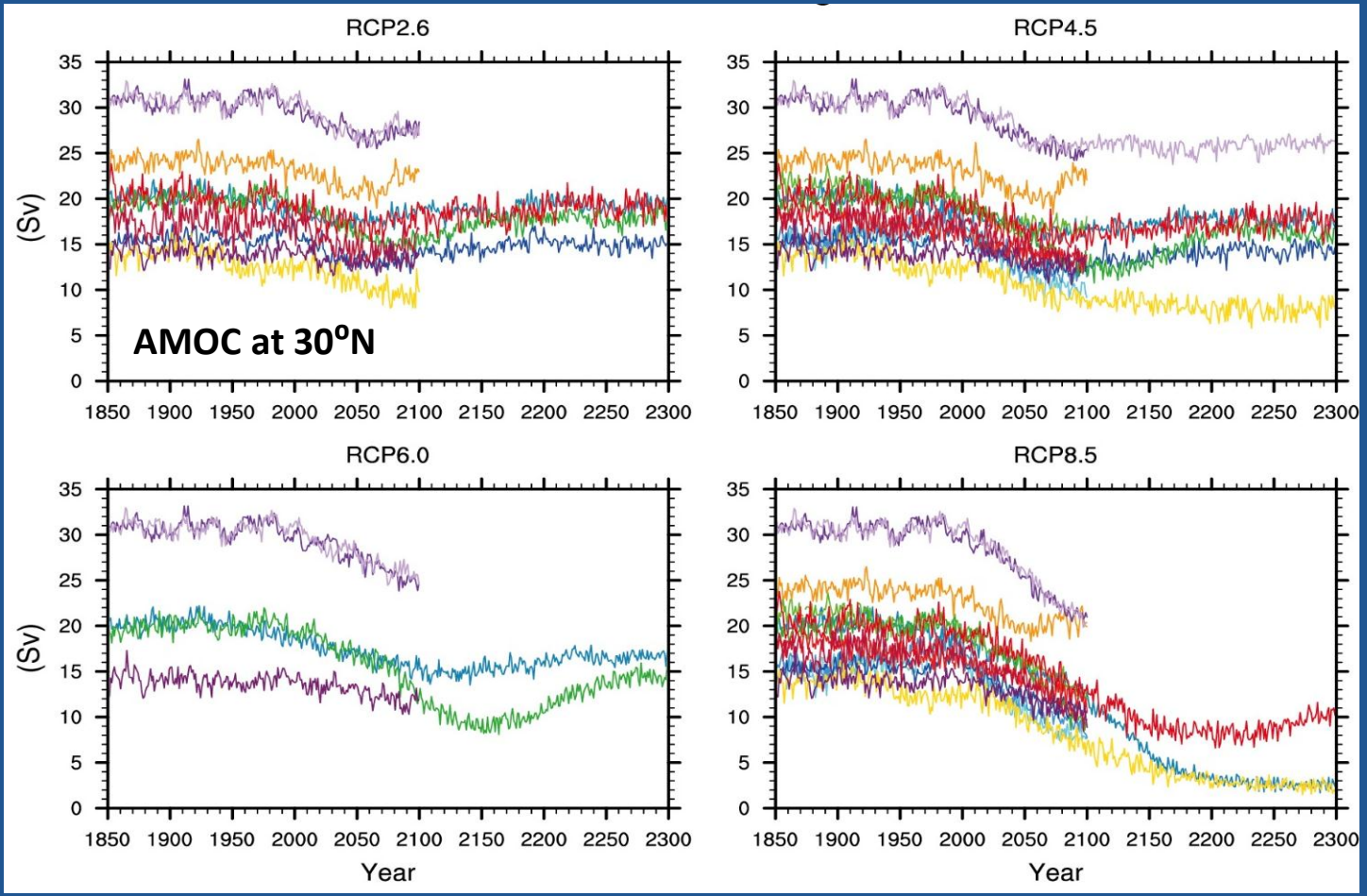
Increasing temperature of Labrador Sea Water

Reduction of convection in the Labrador Sea, indicated by warming temperatures, is not accompanied by a weakening DWBC.

What *do* we know?



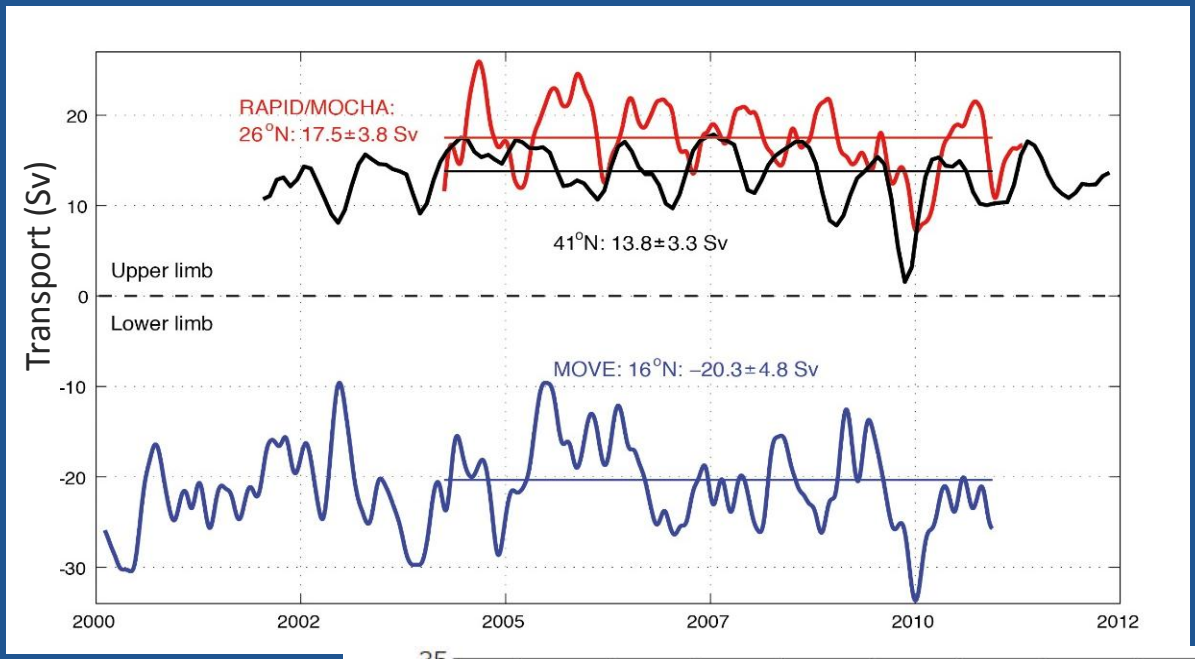
Looking down the road of the 21st century



IPCC 5th Assessment Report (2014)

- It is very likely that the AMOC will weaken over the 21st century, with best estimates for the reduction of 11% to 34%.
- It is very unlikely that the AMOC will undergo an abrupt transition or collapse in the 21st century.

But what have we seen lately?



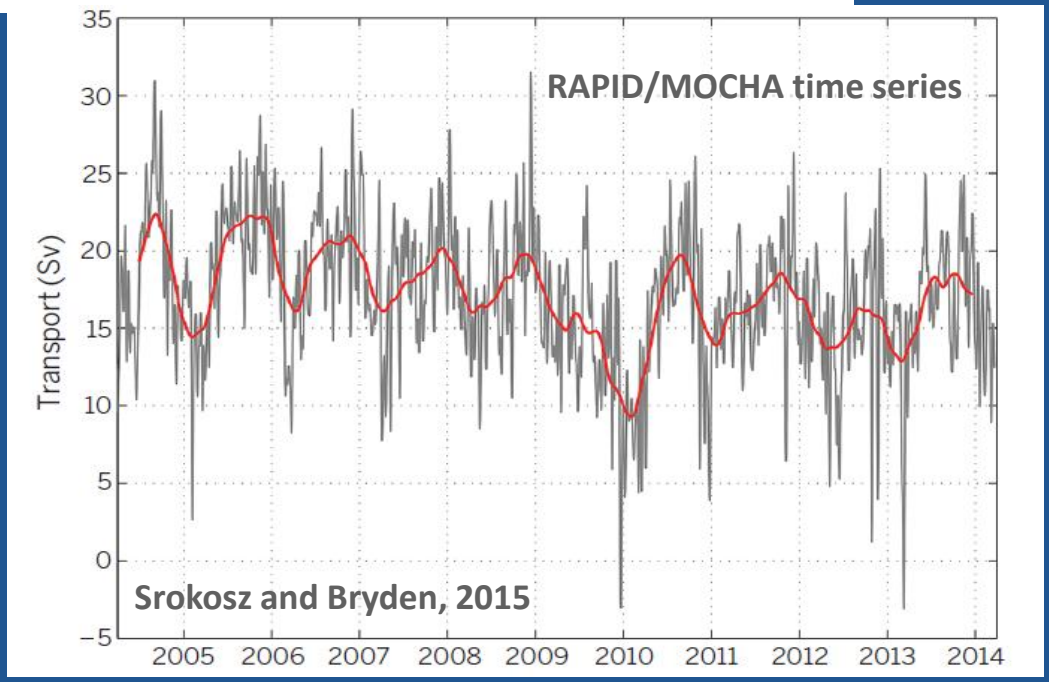
IPCC 5th Assessment Report:

There is no observational evidence of an AMOC trend, based on the decade-long record of the complete AMOC and longer records of individual AMOC components.

Srokosz & Bryden 2015:

The AMOC has been declining at a rate of ~ 0.5 Sv per year, 10 times as fast as predicted by climate models.

Unclear if related to global warming.



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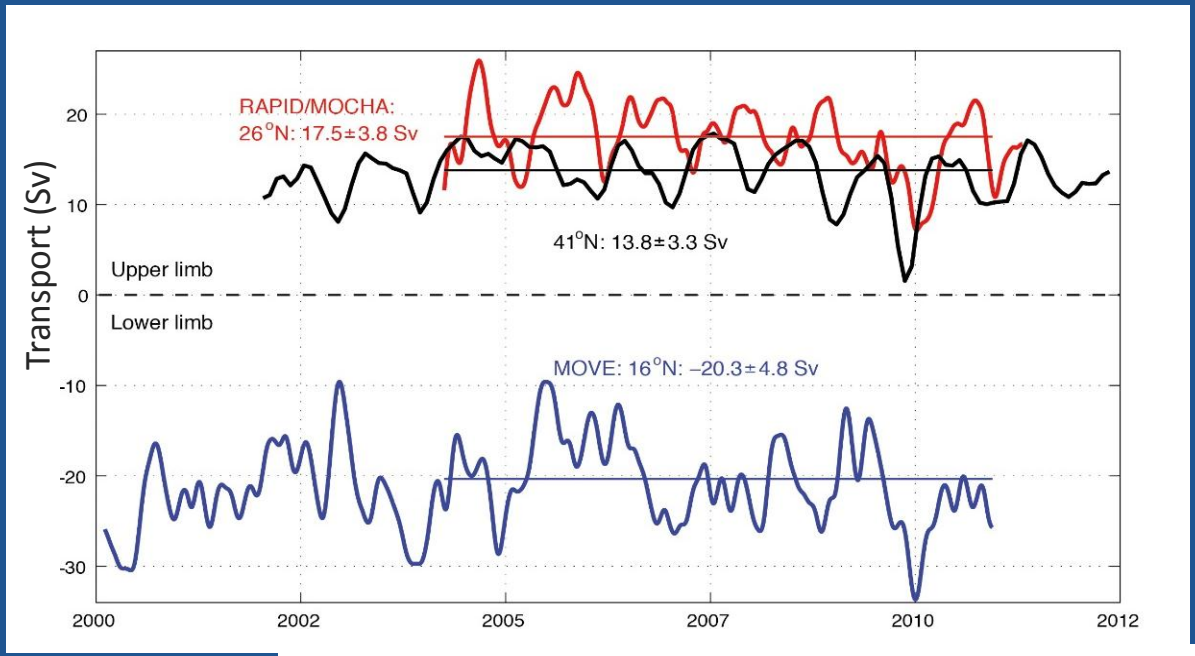

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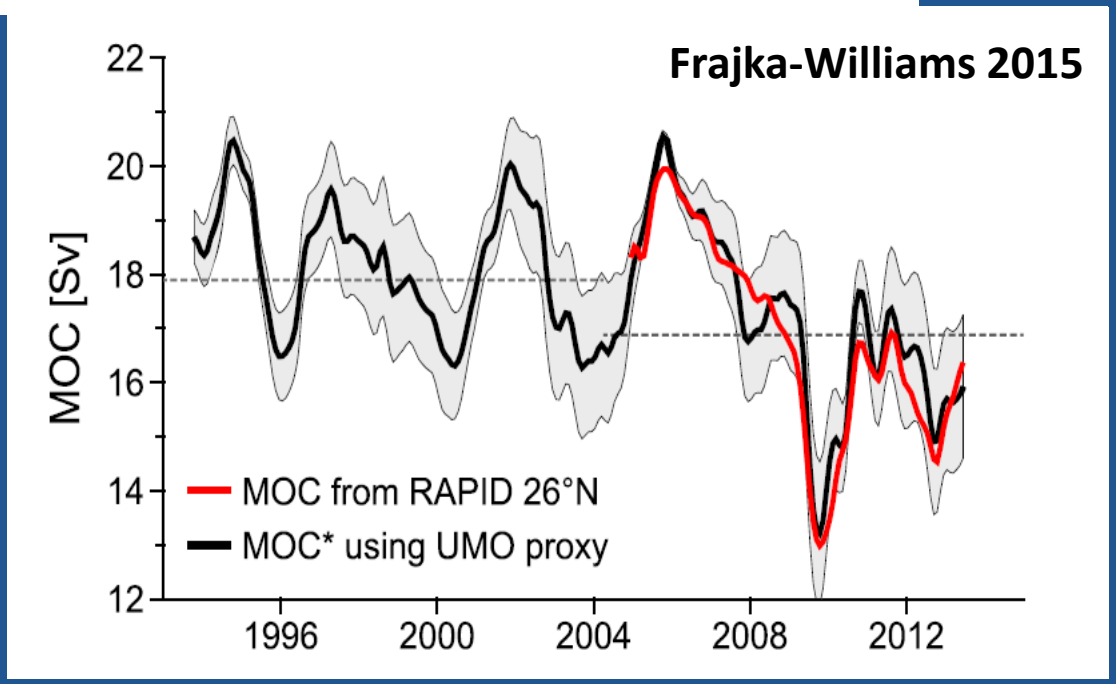
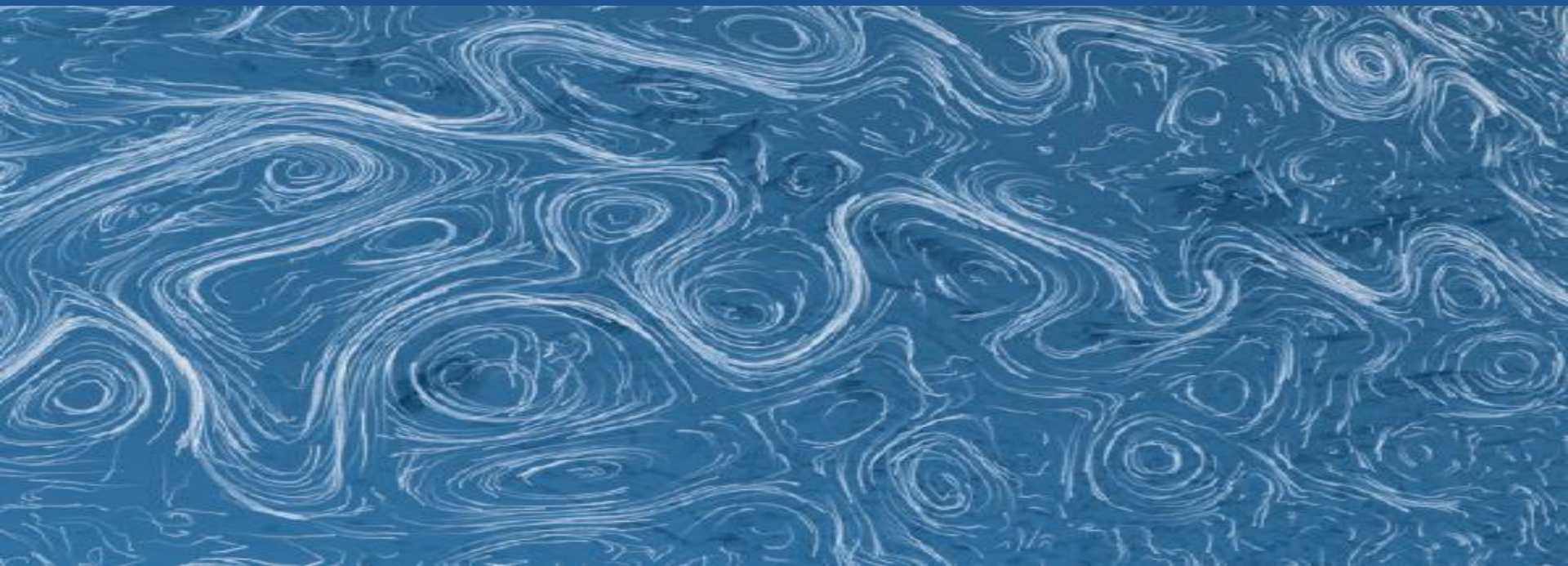


Average reduction of the MOC of –0.13 Sv/yr, yet not significant.

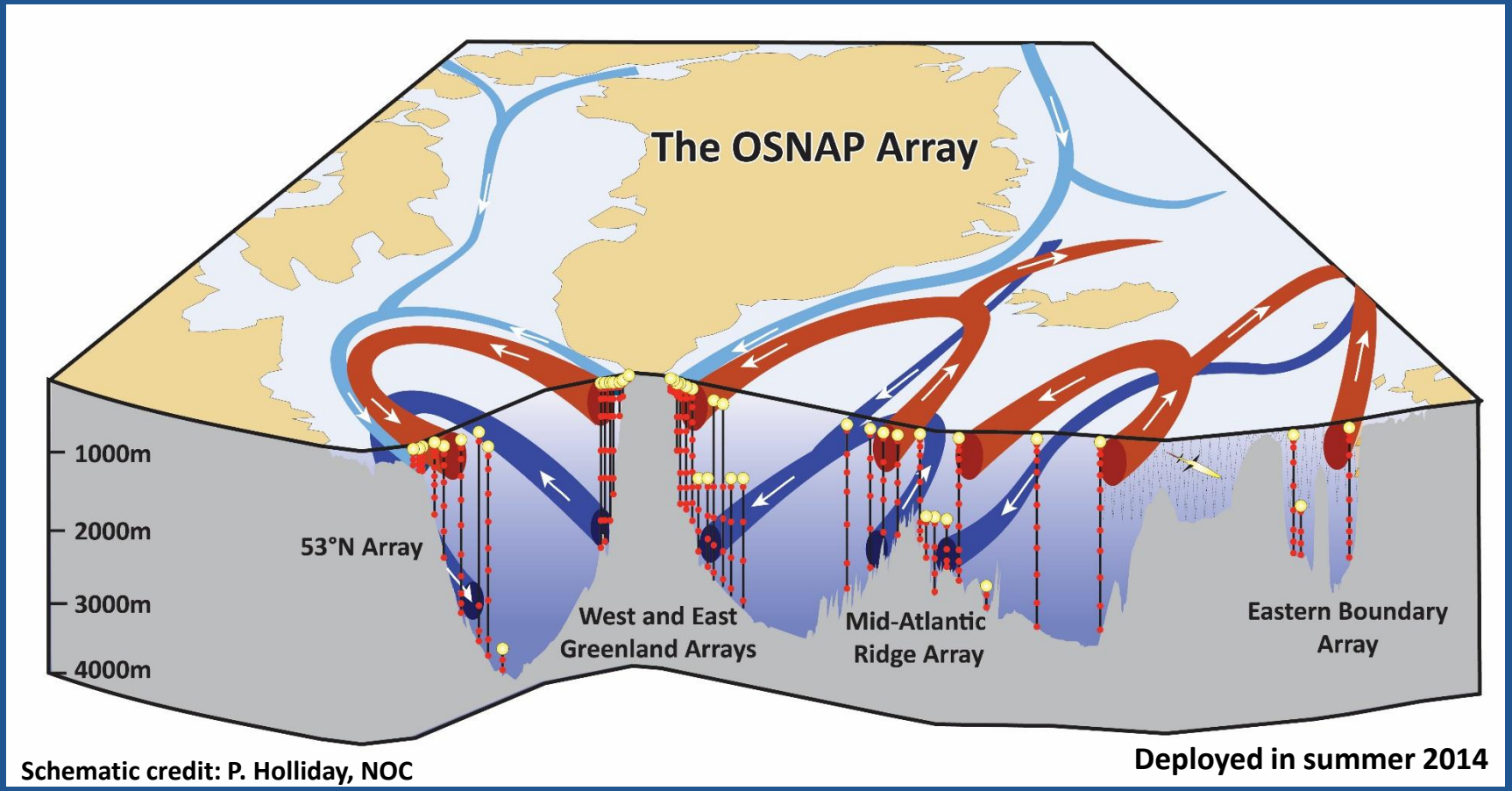
So where are we?

- An observational linkage between convective activity and overturning variability has been elusive.
- Yet warming and freshening at high latitudes continue apace, both in the direction of stabilizing the surface waters.
- Numerous studies illustrate impact of overturning changes.



OSNAP: Overturning in the Subpolar North Atlantic Program

An international program: US, UK, Germany, Netherlands, France, Canada and China



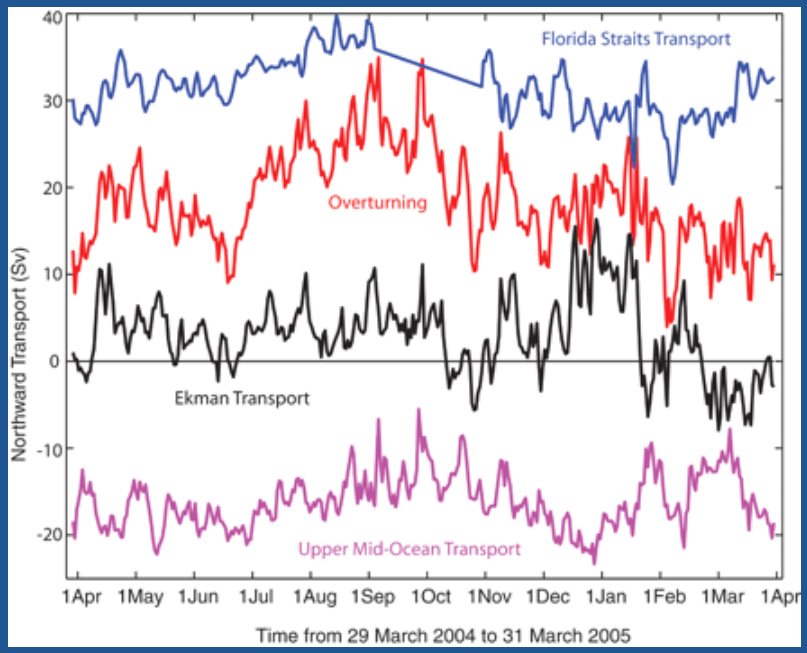
Overall design: A transoceanic line in the subpolar North Atlantic that captures the net transport of the overflow waters from the Nordic Seas, as well as Labrador Sea export. Designed to test linkage between water mass production variability and overturning variability.

Summary

Our conceptual understanding of the ocean's mean overturning circulation has been significantly advanced over the past two decades.

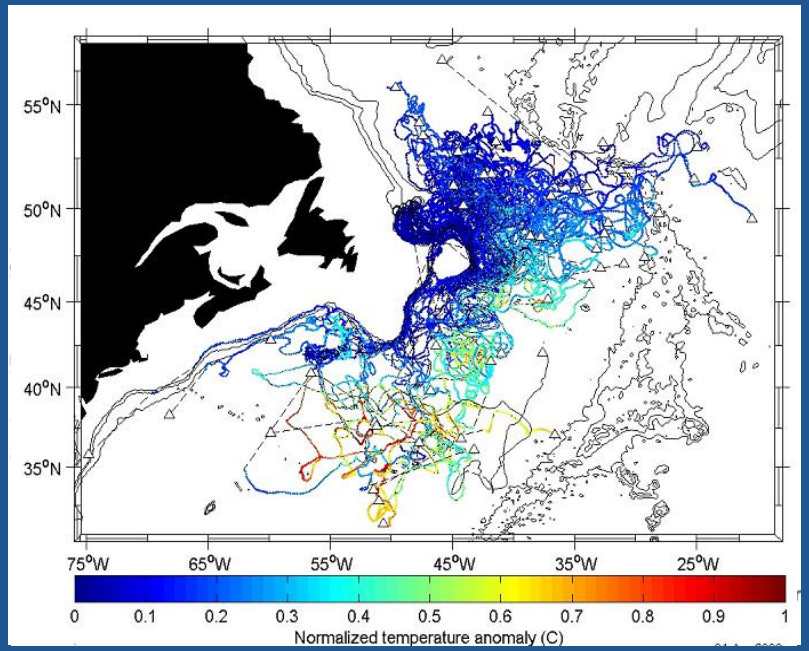
Summary

The overturning circulation has strong variability on seasonal and subseasonal time scales.



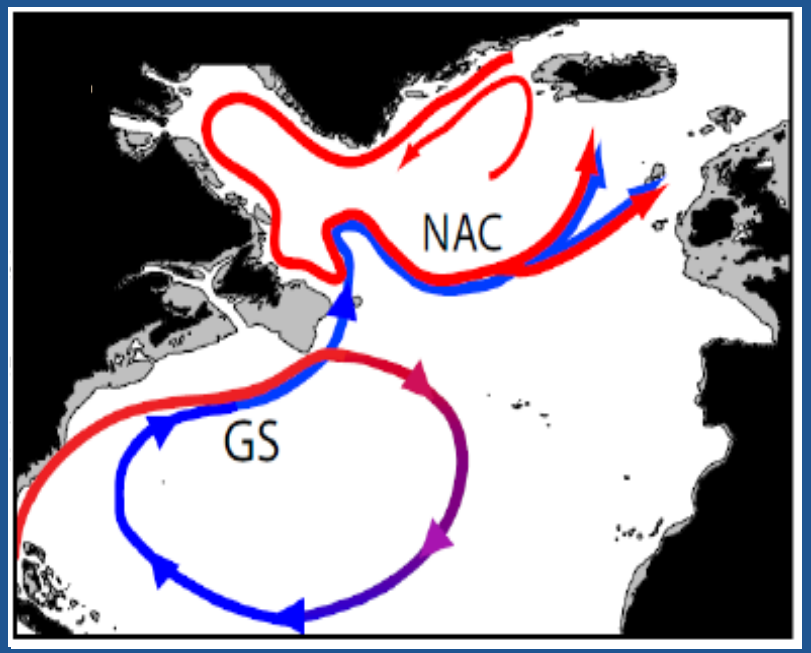
Summary

The Deep Western Boundary Current is not the sole conduit for the lower limb of the MOC.



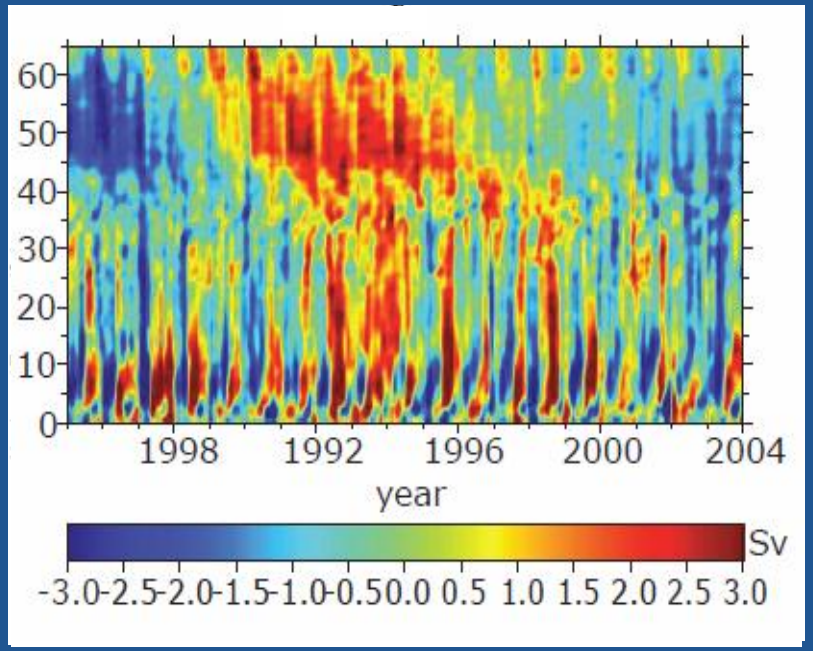
Summary

Surface Gulf Stream waters do not flow directly into the subpolar gyre as the upper MOC limb.



Summary

The MOC is not meridionally coherent; subtropical and subpolar anomalies can differ.



Summary

Our understanding of the overturning *variability*- why it changes and on what time scales – is an open question.