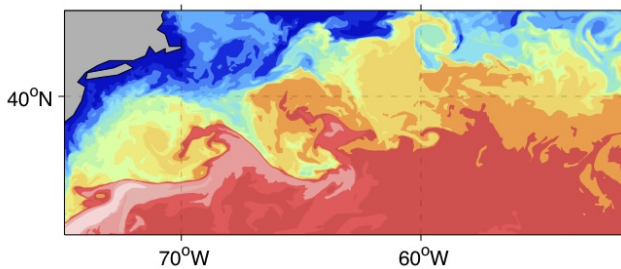
THE GULF STREAM AND NORTH ATLANTIC CIRCULATION IN CHANGING CLIMATE



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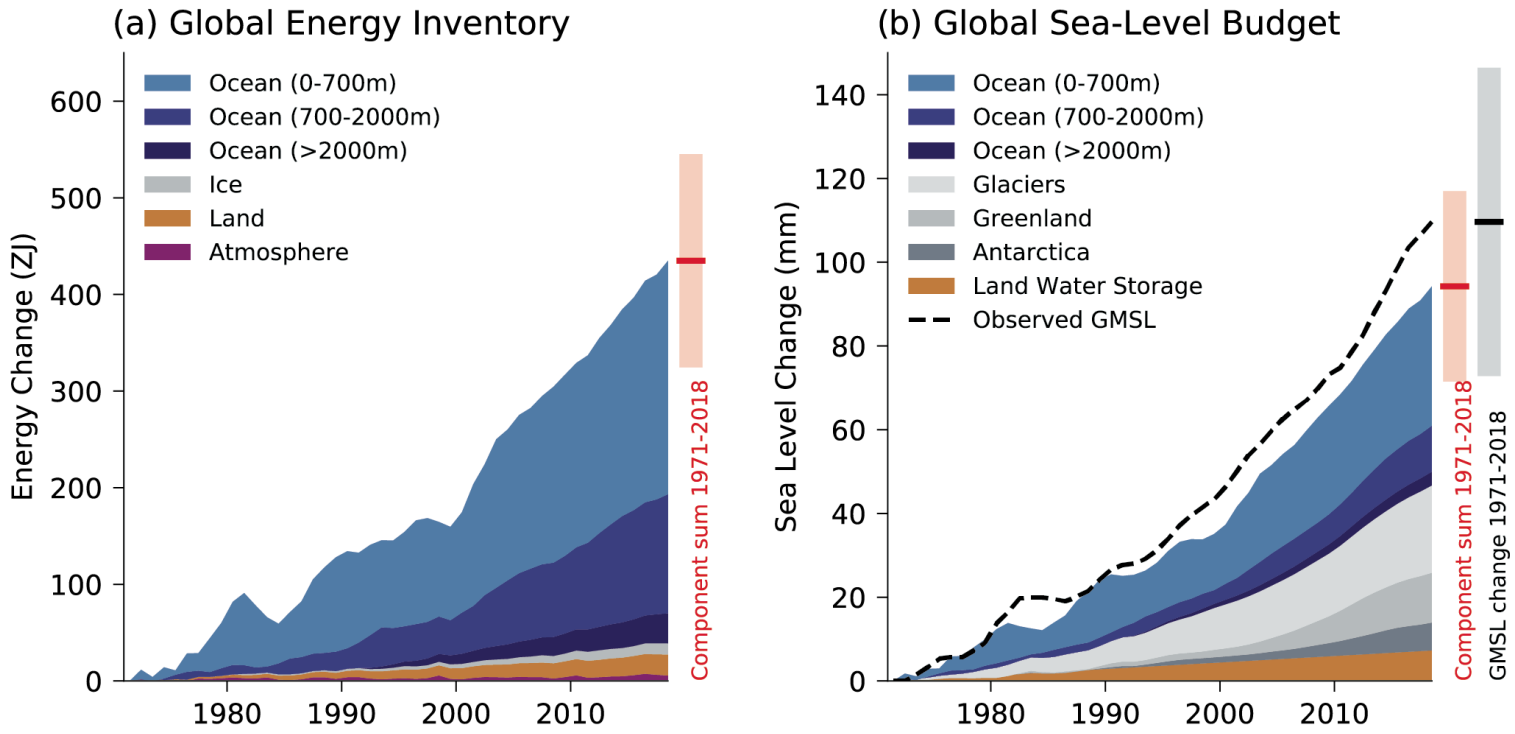
Basilisk Meeting – Oxford – July 2025

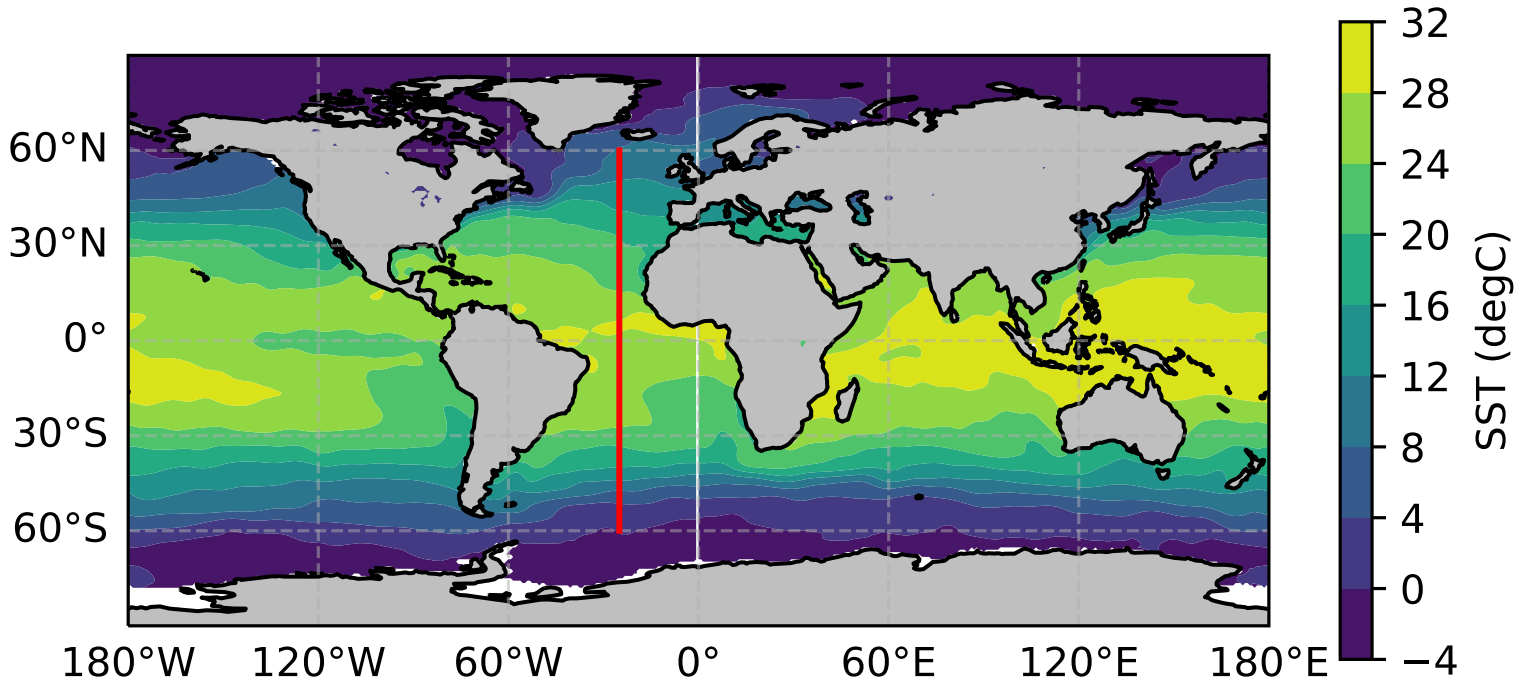
WHY DO WE CARE ABOUT THE OCEAN?



- Most of the excess heat is absorbed by the ocean
- Sea level rise will have a tremendous impact on humanity

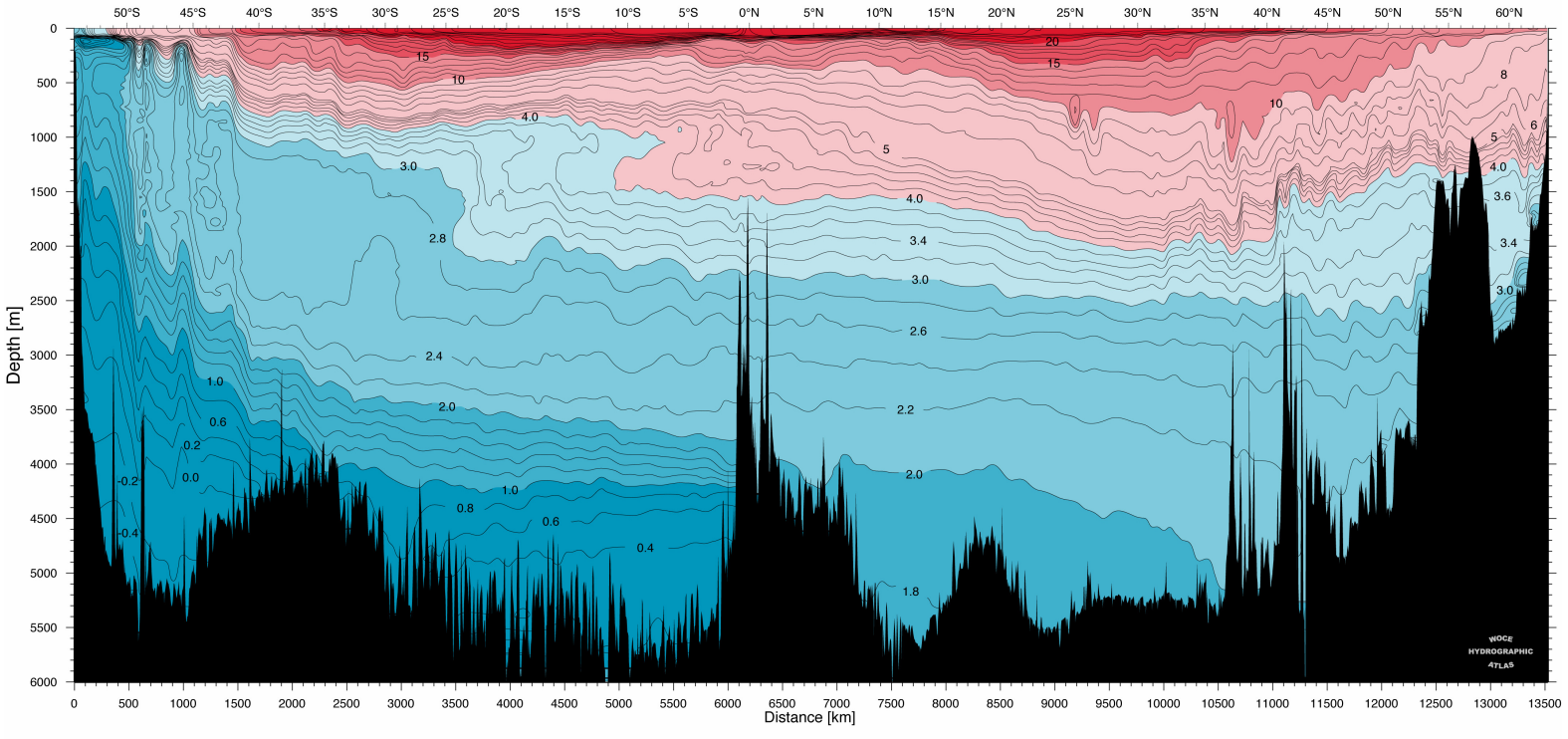
IPCC report AR6 (2023)

TEMPERATURE DISTRIBUTION IN THE OCEAN (SURFACE)



- Warm at the equator, cold at the pole (heated by the sun)
- Redistribution of heat by ocean currents

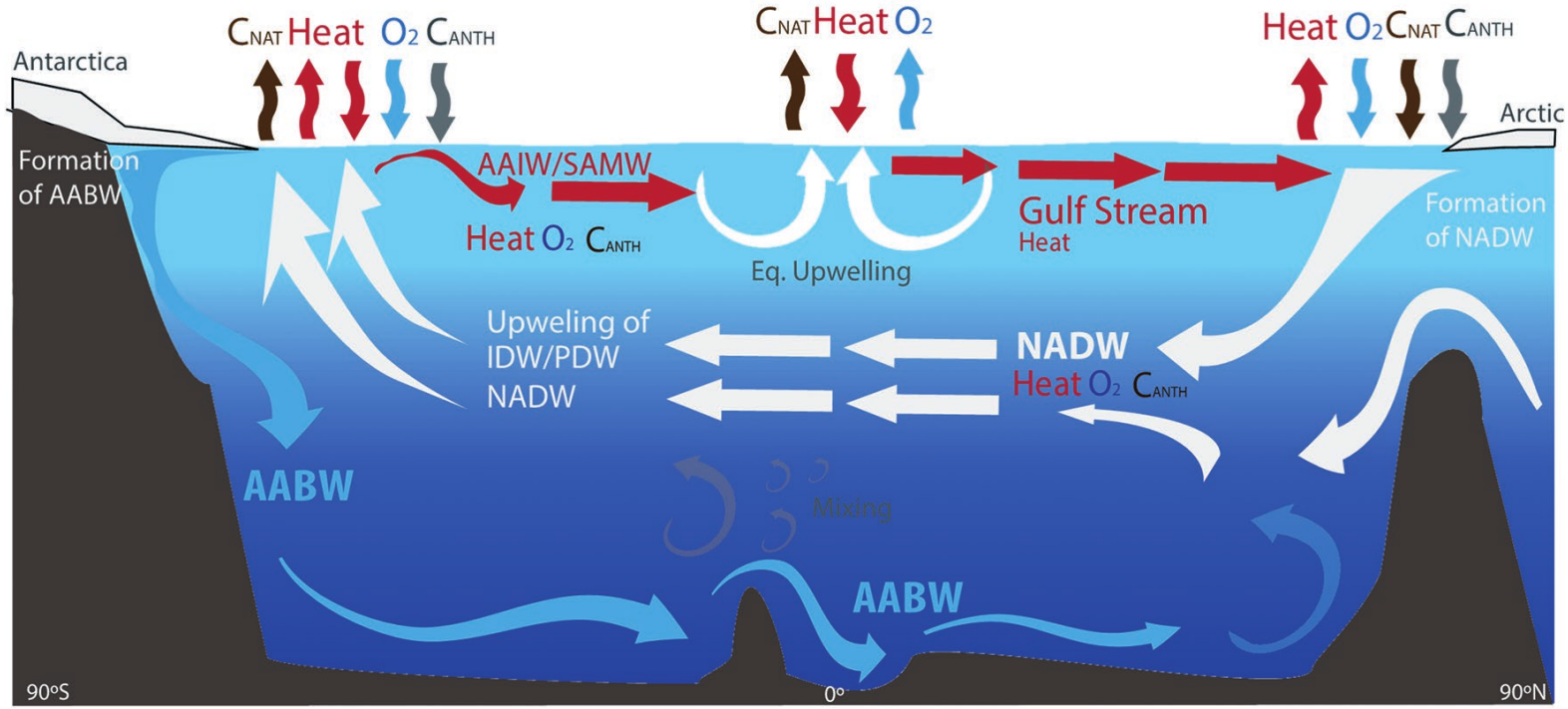
Temperature distribution in the ocean (vertical)



- Thin warm layer at the surface
- Unstratified (well mixed) deep ocean

WOCE temperature section

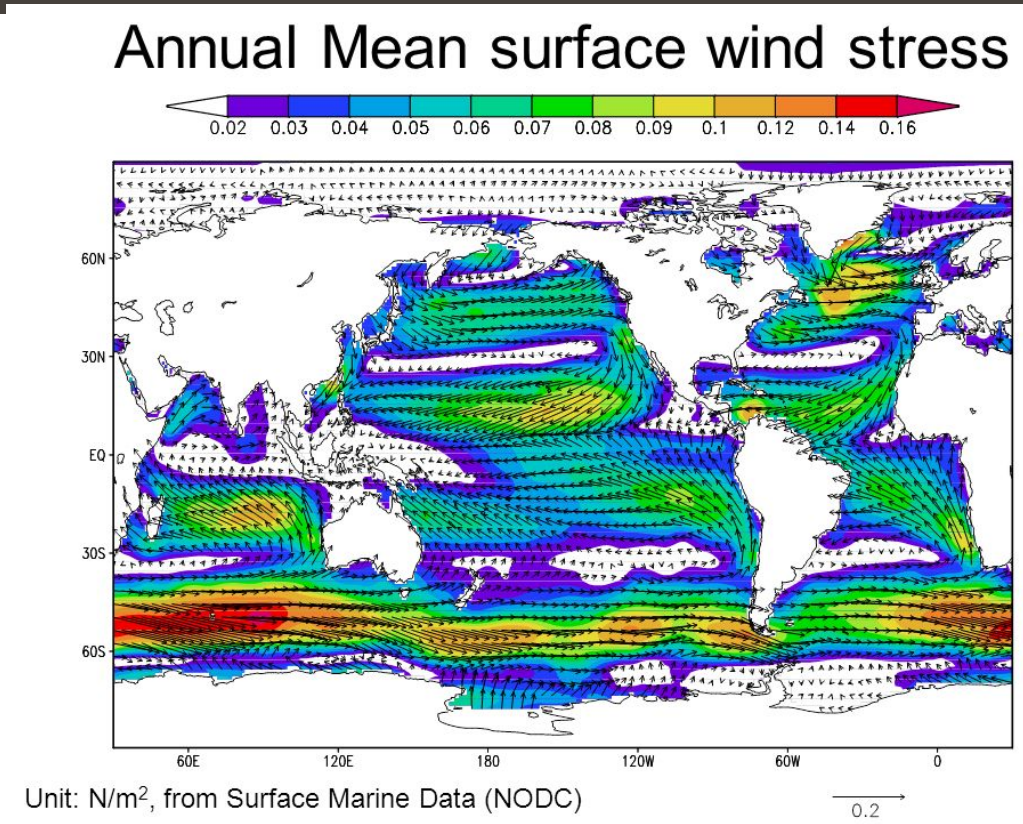
Side view of the ocean currents

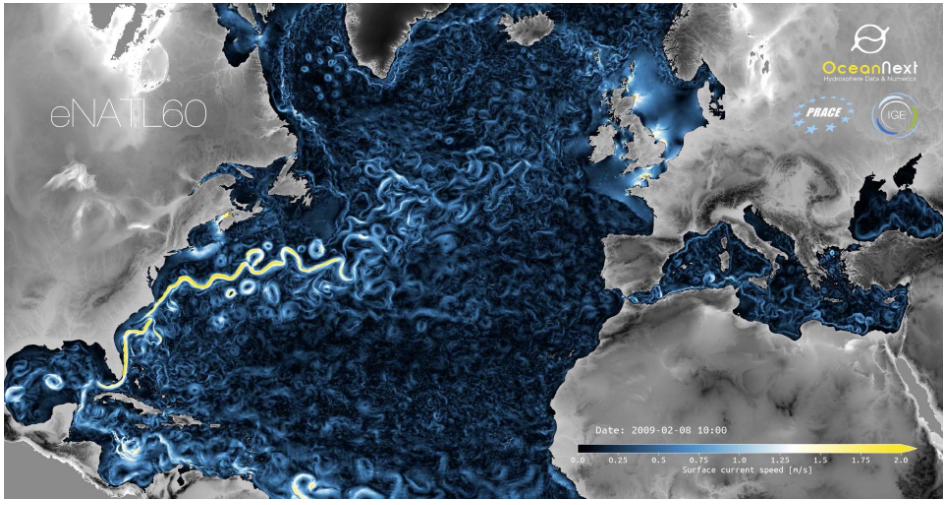


Key role played by the interfaces (Boundary conditions)

- Air – sea interaction
- Sea – topography interaction
- Water – ice interaction

Horizontal circulation

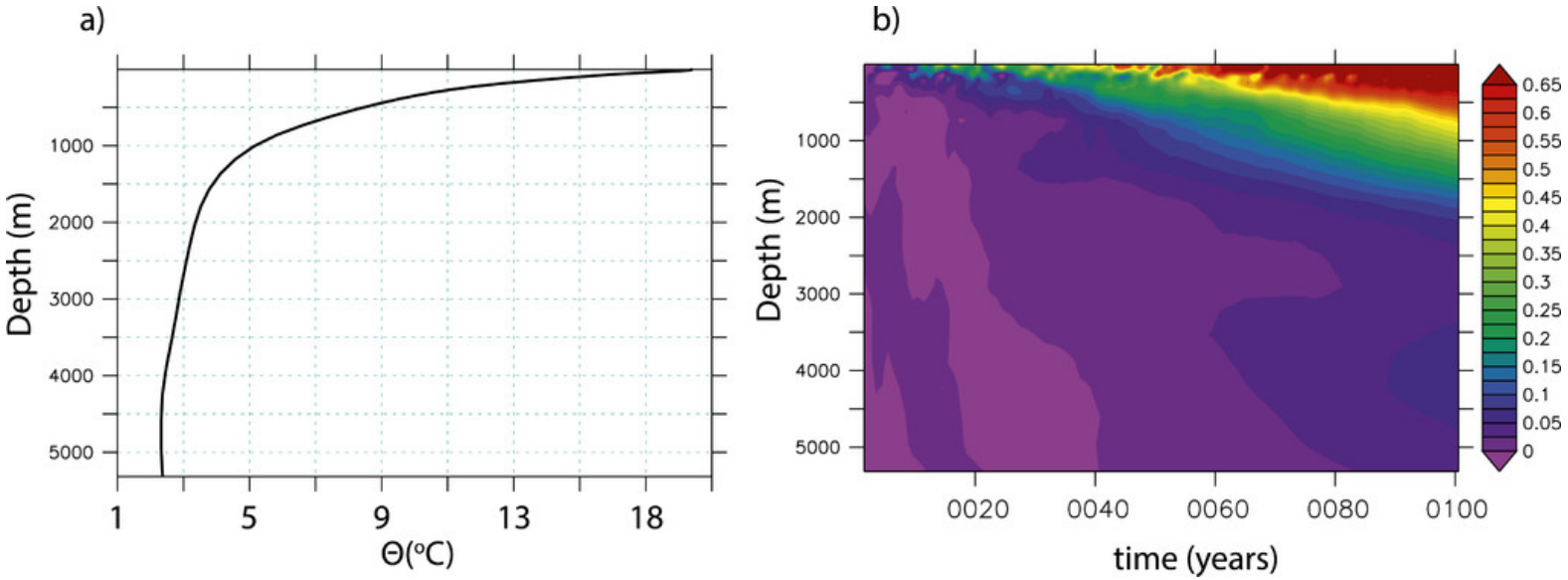




- Surface atmospheric winds drive the ocean “gyre” circulation
- North Atlantic currents organized in gyres separated by an energetic gulf stream

HOW WILL THESE CURRENTS EVOLVE IN THE CONTEXT OF GLOBAL WARMING?

Evolution of the temperature



- The surface warms faster than the deep ocean
- We expect a more surface intensified stratification
- We are going to exaggerate this trend to capture the changes (not realistic).

Figure from Palter et al. (2014)

EVOLUTION OF THE TEMPERATURE

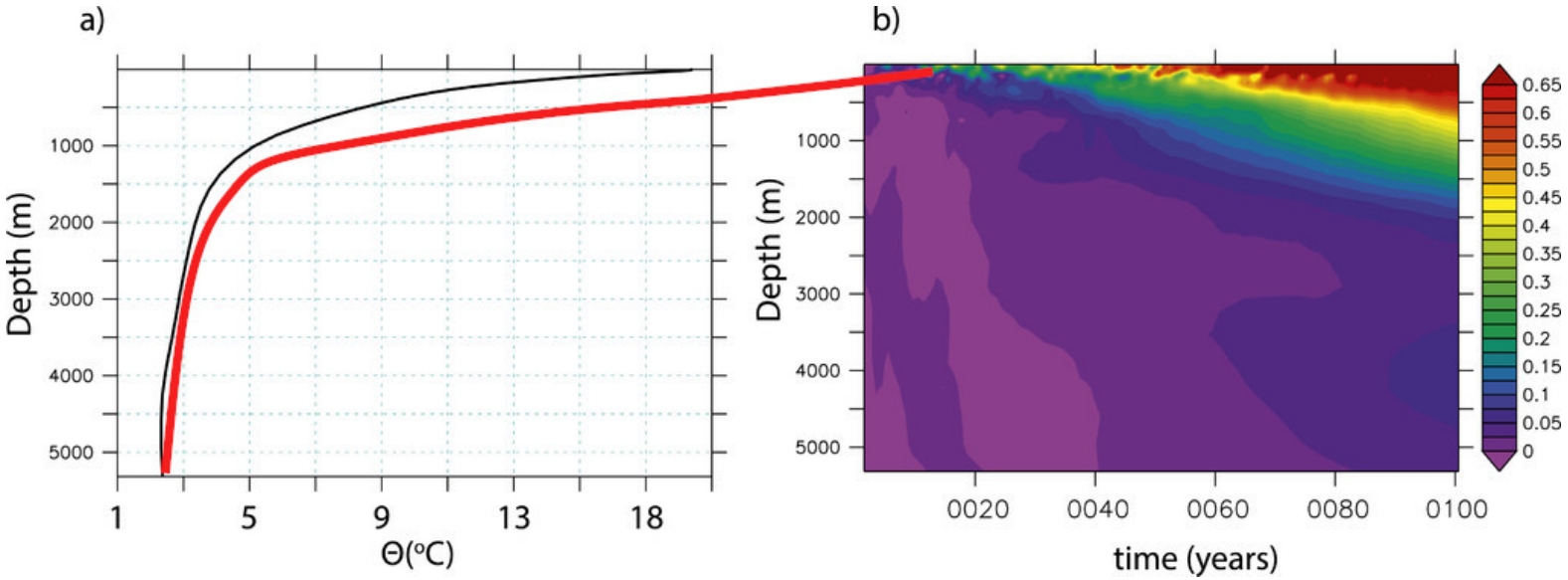


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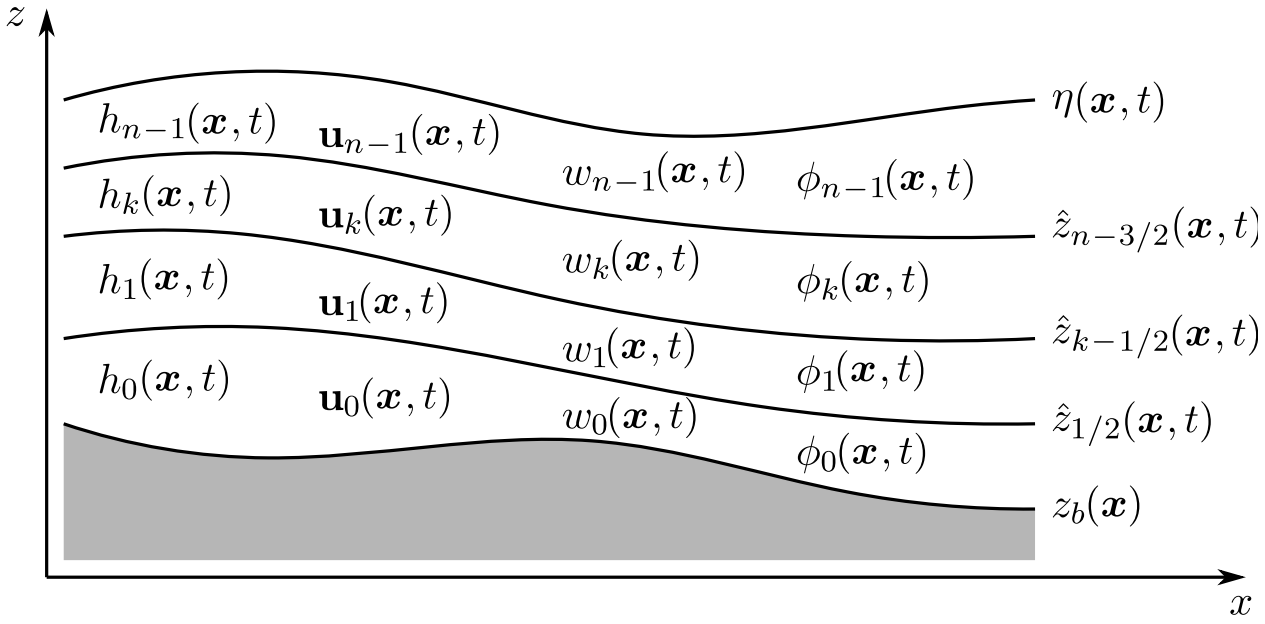
Figure from Palter et al. (2014)

North Atlantic model with Basilisk

- We use the Multi layer shallow water solver:

$$\partial_t h_k + \nabla \cdot (h\mathbf{u})_k = 0,$$
$$\partial_t (h\mathbf{u})_k + \nabla \cdot (h\mathbf{uu})_k = -gh_k\nabla(\eta) - \nabla(hq)_k + [q\nabla z]_k$$

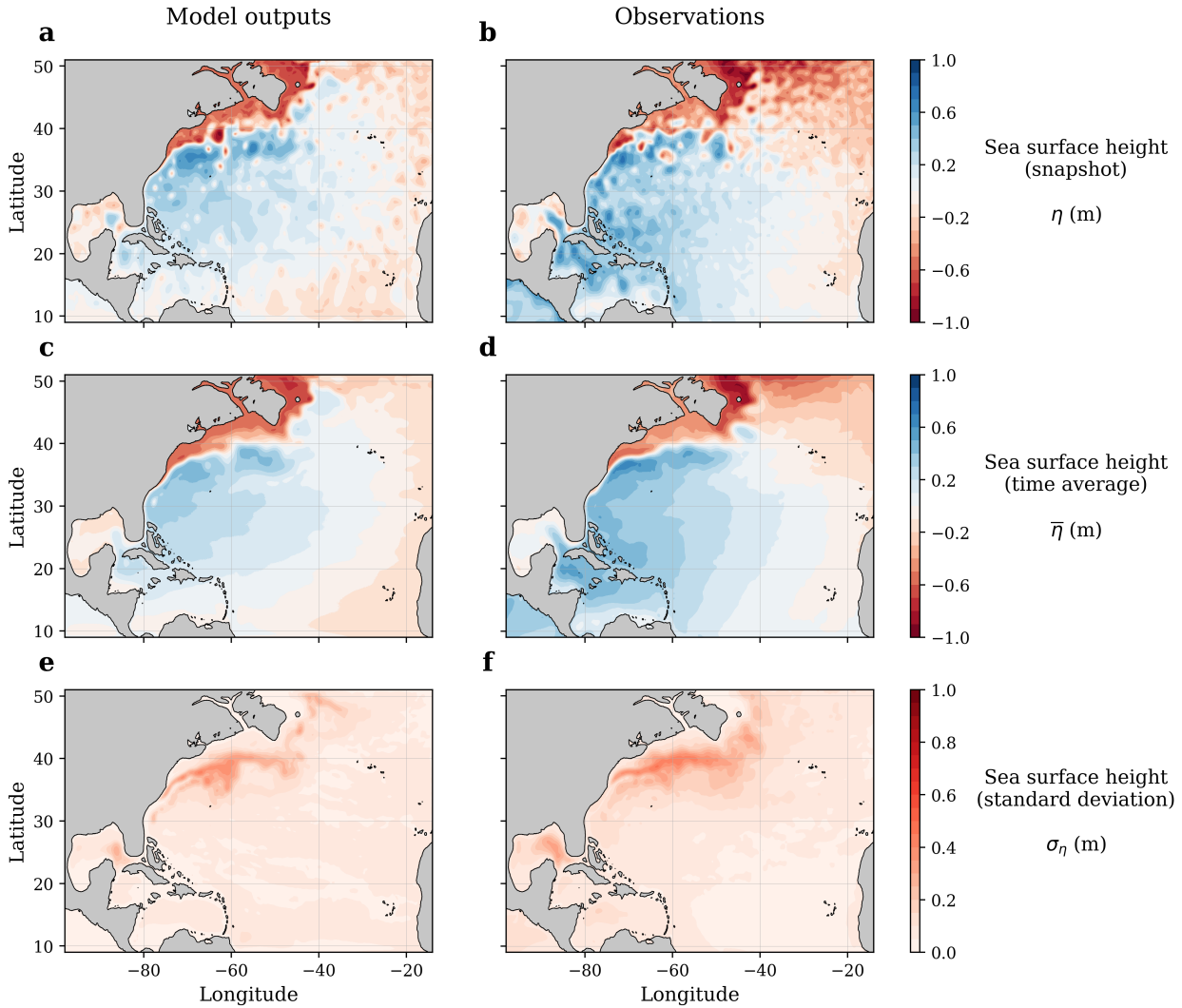


- Main variables are $\boldsymbol{u}, h$.
- We specify the vertical density profile (density of each layer)

`http://basilisk.fr/src/examples/ocean.h`

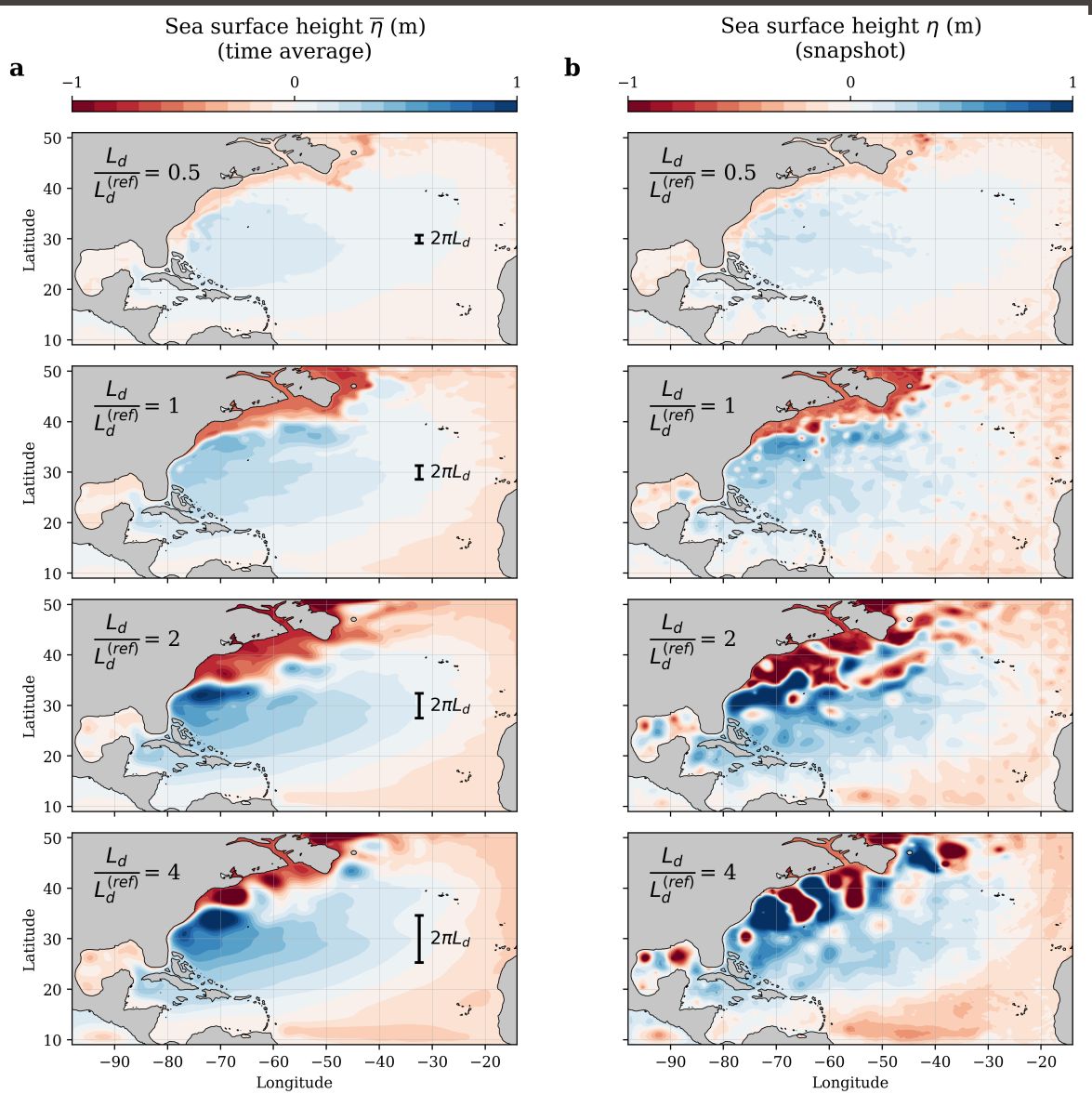
Validation with observations

- Validation of the model with satellite altimetry data (AVISO)
- Mean and variance Sea Surface Height compare well with observations.



`http://basilisk.fr/src/examples/gulf-stream.c`

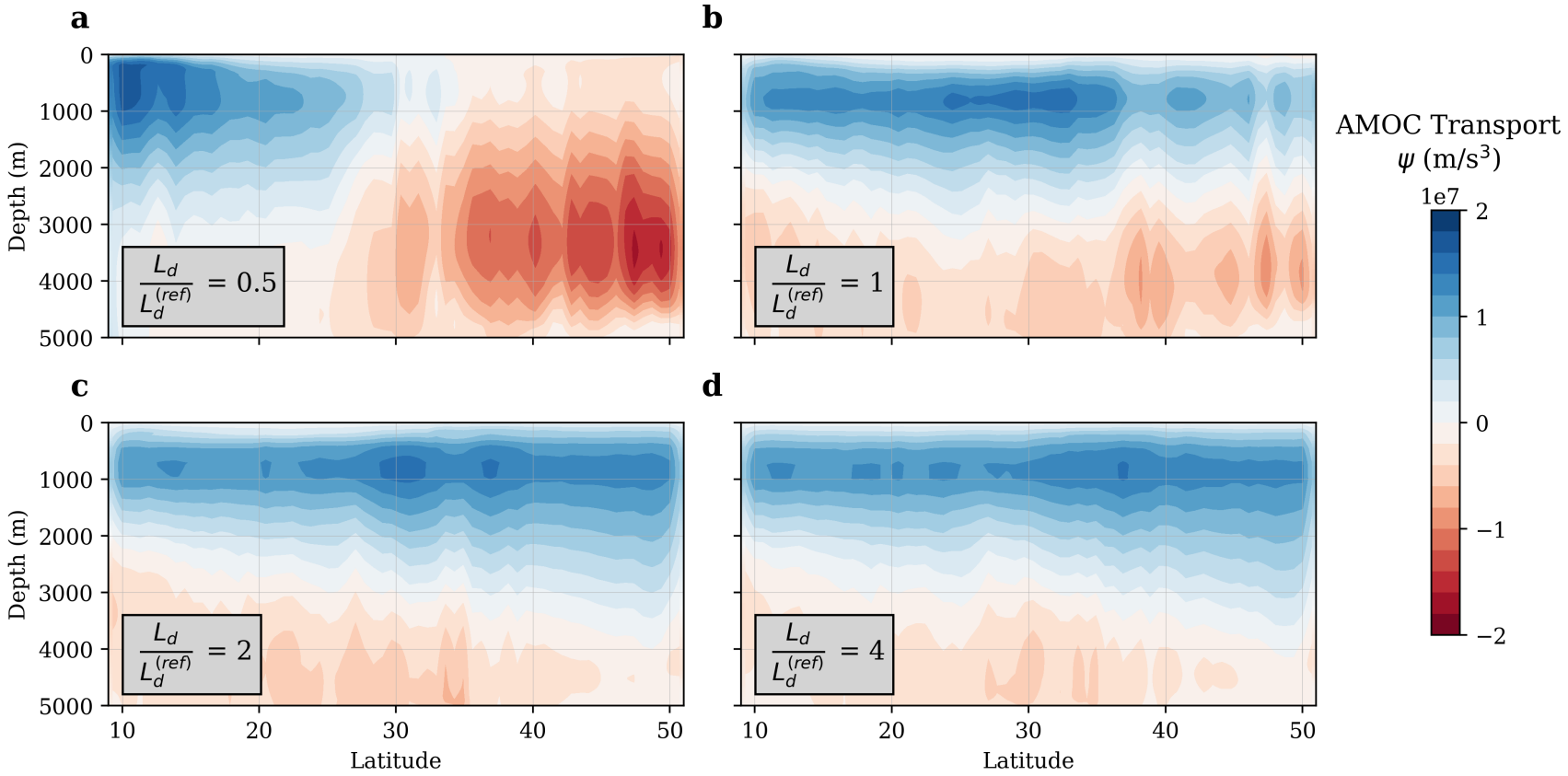
New regimes – Horizontal circulation



- Less stratified
- Reference run
- More stratified

consistent with Miller et al. (2025) (theory of oceanic jets)

New regimes – Vertical circulation



- Vertical circulation is also changing with stratification.
- Link Gulf-Stream — AMOC is not trivial
- Work in progress

Conclusion

- Stratification governs the stability of the Gulf Stream.
- We showed dramatic regime changes driven by unrealistic stratification.
- In the context of global warming, the gulf stream will not change much.
- The AMOC will weaken but due to other processes not discussed here.
- Consequences for eddy parameterizations (WIP with C. Merchant and F. Cooper).