

The spread of ocean heat uptake efficiency in CMIP6 models traced to ocean salinity

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Ocean heat uptake (OHU) efficiency within the context of global warming

$$F(t) = N(t) - \lambda(t)\Delta T(t)$$



$$F(t) = \varepsilon(t)\Delta T(t) - \lambda(t)\Delta T(t)$$



$$\Delta T(t) = \frac{F(t)}{\varepsilon(t) - \lambda(t)}$$

F : radiative forcing due to CO2

N : Ocean heat uptake (OHU)

ε : OHU efficiency

ΔT : Global surface warming

λ : Climate feedback parameter

t : Time

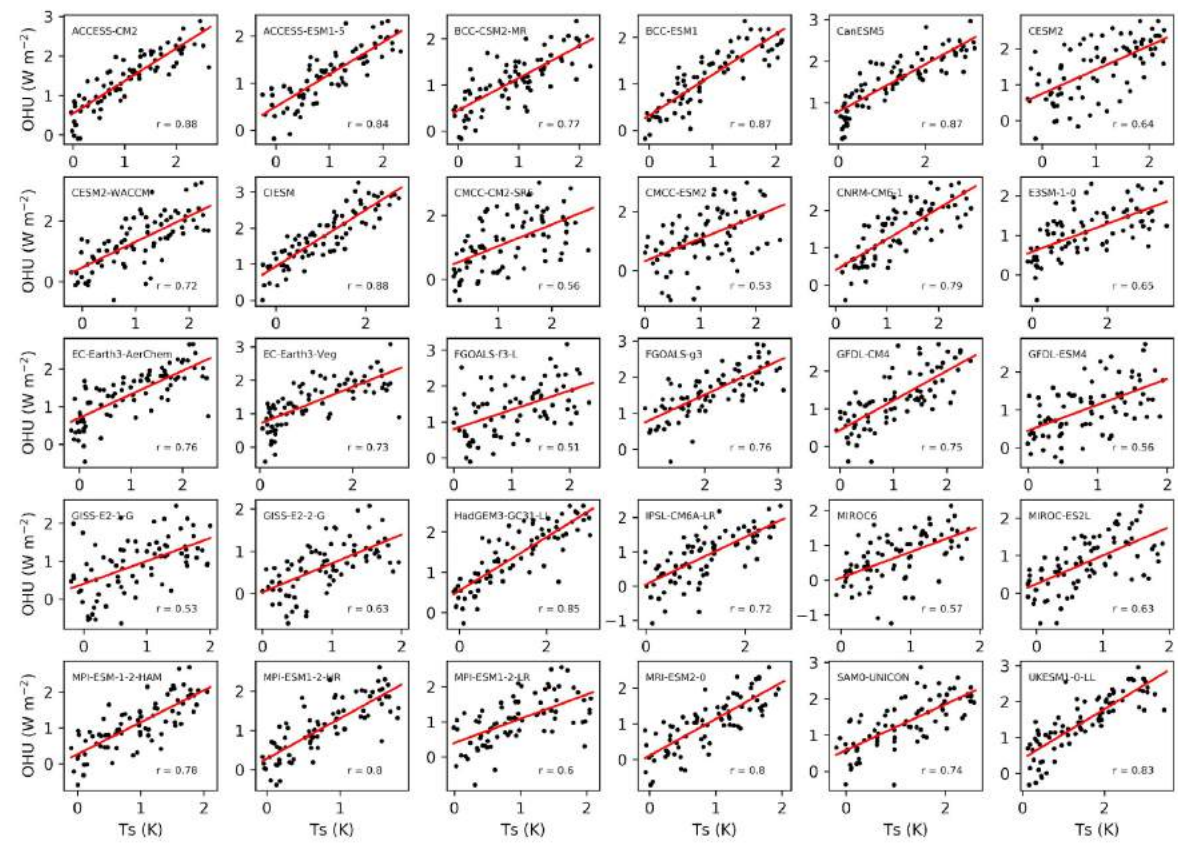
A **higher** OHU efficiency means **lower** surface warming given the **same** amount of OHU

Question: 1) How well does climate models simulate OHU efficiency, and 2) what are the sources of their uncertainty?

A brief introduction of models and methods

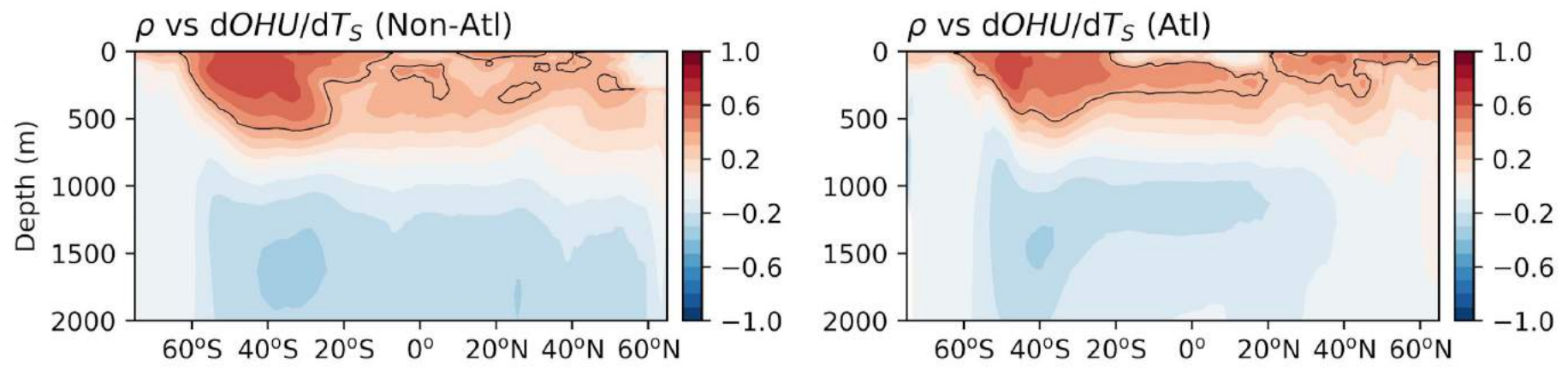
- Models:** a set of 30 CMIP6 coupled global climate models
- Simulations:** 1pct CO2 simulations in which CO2 concentration increases 1% per year
- Definition of OHU efficiency:** the slope of the linear regression between OHU change and surface warming for the first 80 model years
- TOP and BOT efficiency models:** Rank models based on OHU efficiency and select TOP and BOT efficiency models; **bootstrap** method...

Linear regression: OHU VS surface warming

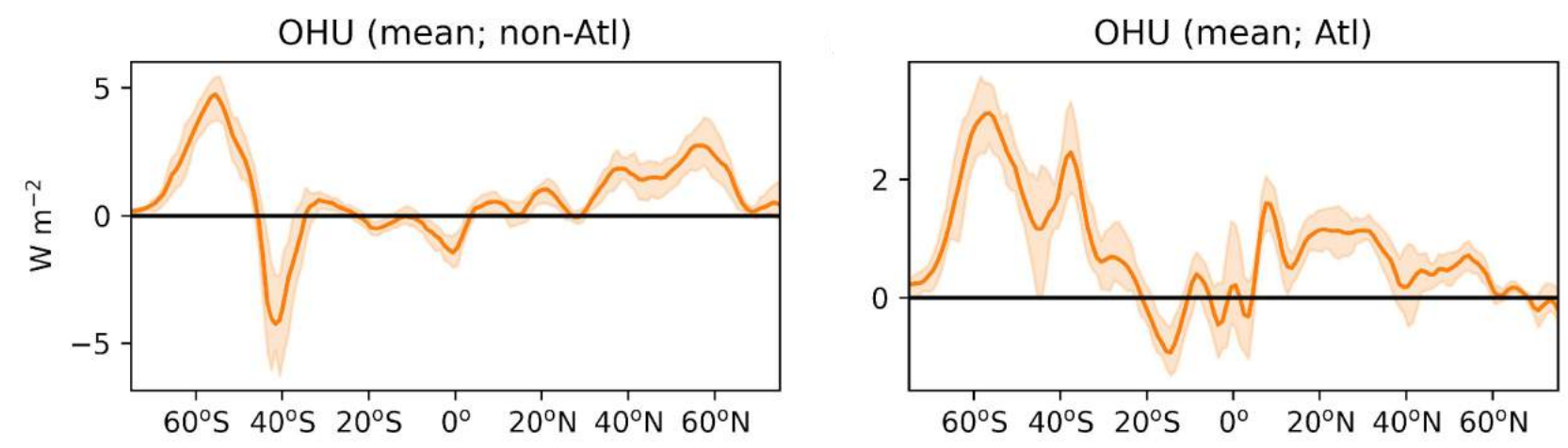


Weaker ocean stratification, especially in Southern Ocean, statistically correlates with higher OHU efficiency

Correlation: zonal-mean ocean density VS OHU efficiency



Zonal mean OHU for both non-Atlantic and Atlantic Oceans

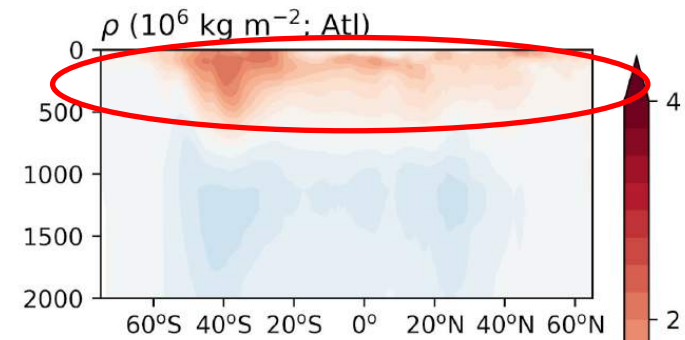
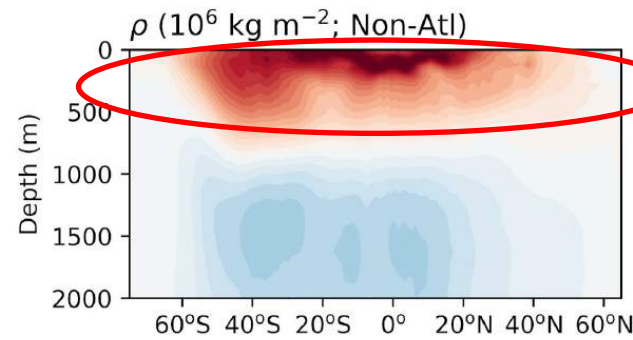


Positive: into the ocean

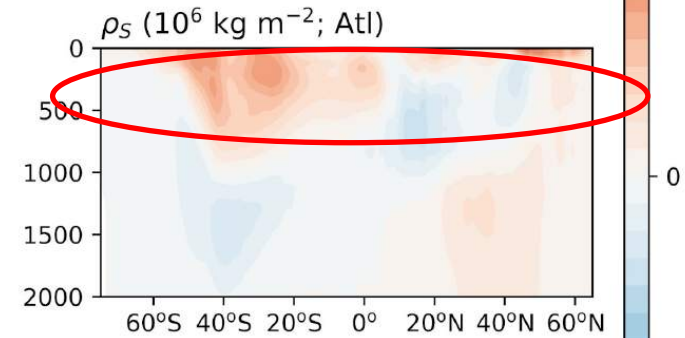
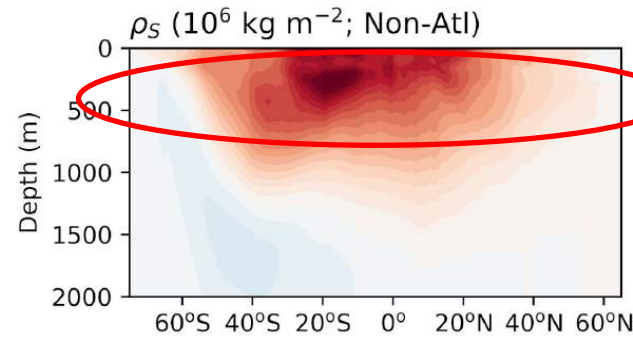
The weaker ocean stratification in higher OHU efficiency models is dominated by **salinity** instead of temperature!

TOP efficiency models minus BOT efficiency models

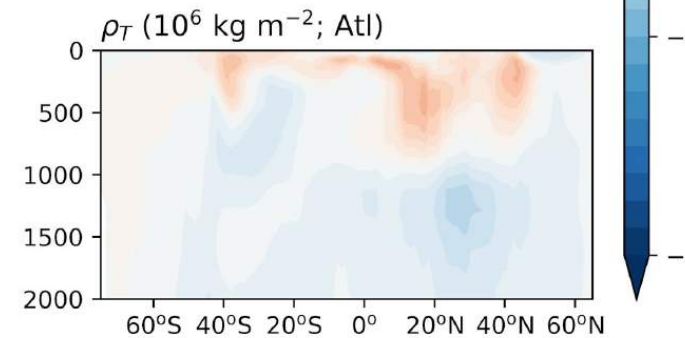
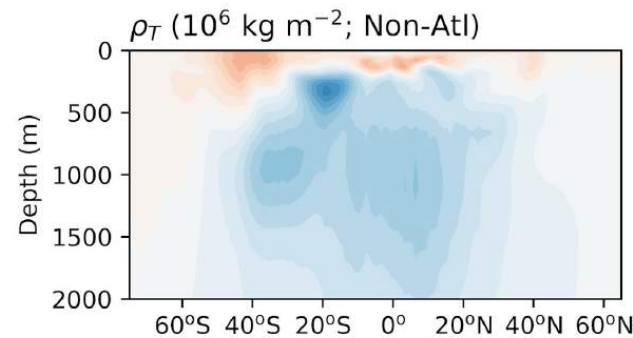
base-state ocean density
from pre-industrial control
runs



Salinity contribution to
ocean density



Temperature contribution
to ocean density



What is more important for ocean density impact on models' spread in OHU efficiency: **OHU** or **surface warming**?

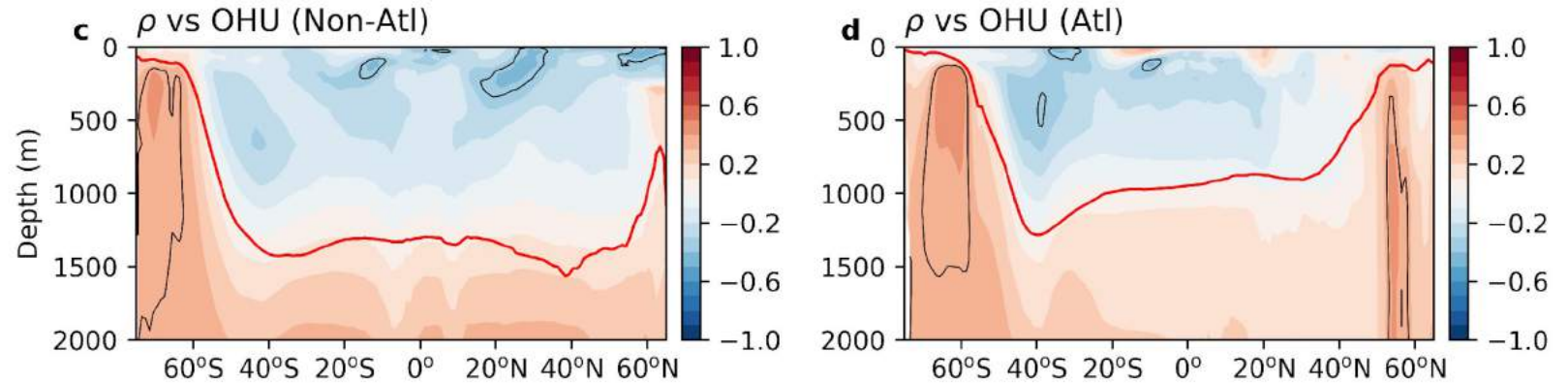
$$\varepsilon(t) = \frac{N(t)}{\Delta T(t)}$$

ε : OHU efficiency

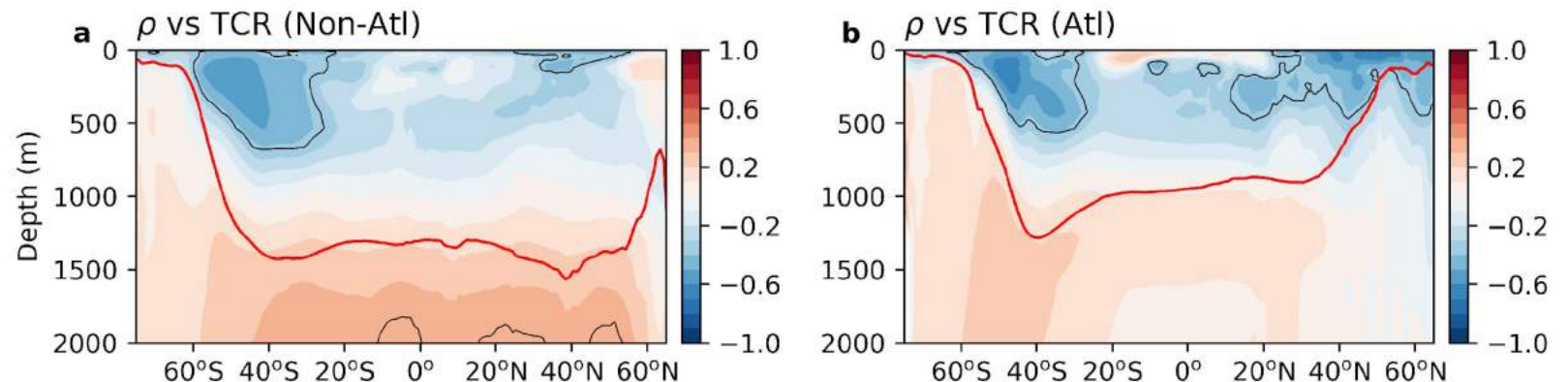
N : OHU

ΔT : Surface warming

Correlation: zonal-mean ocean density VS global-mean **OHU**



Correlation: zonal-mean ocean density VS global-mean **surface warming**

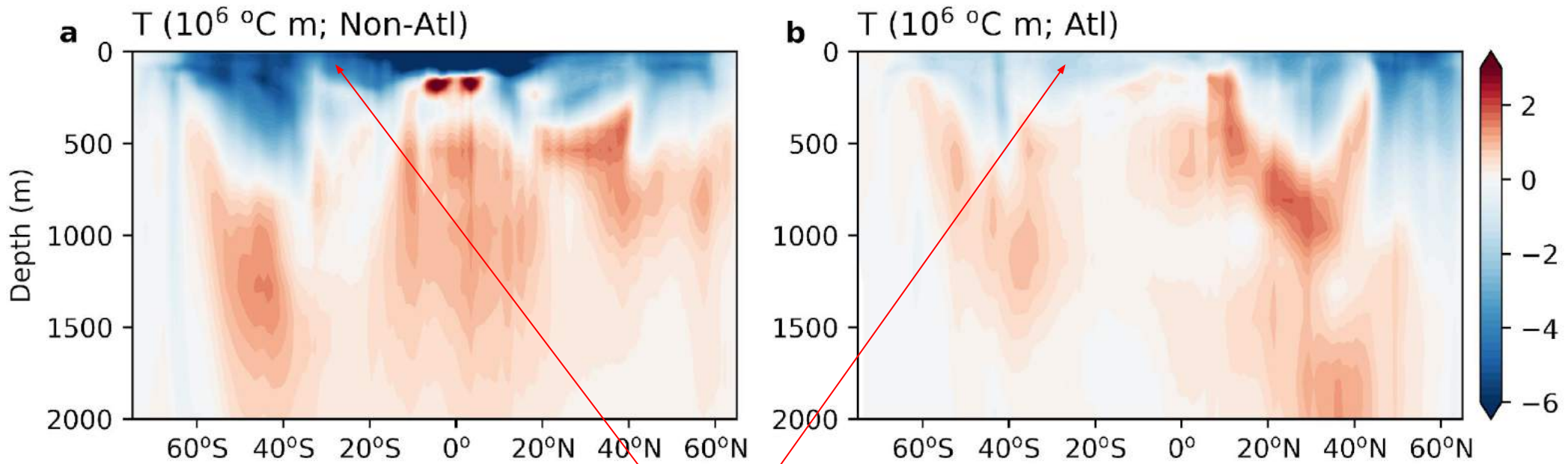


Ocean density impact on surface warming dominates!

How?

Weaker ocean stratification in **higher** efficiency models drives a **deeper** ocean warming: less (more) warming in upper (deep) oceans

TOP efficiency models minus BOT efficiency models: **ocean temperature response**

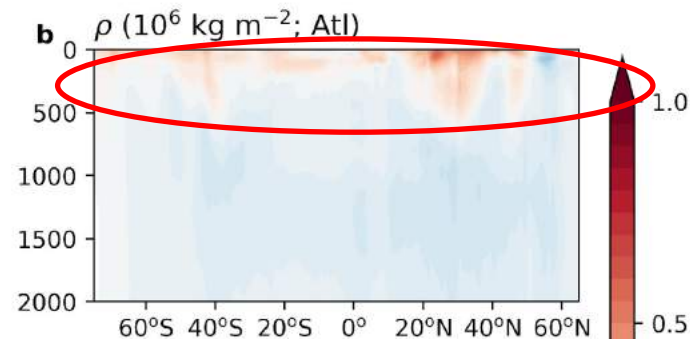
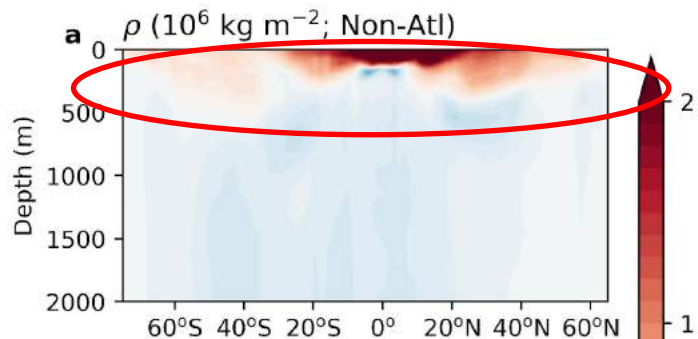


Reduced surface warming!

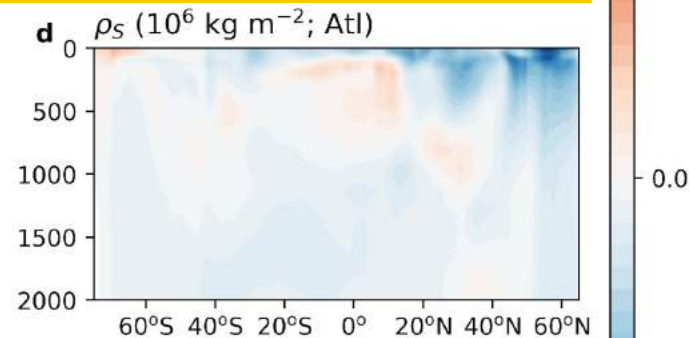
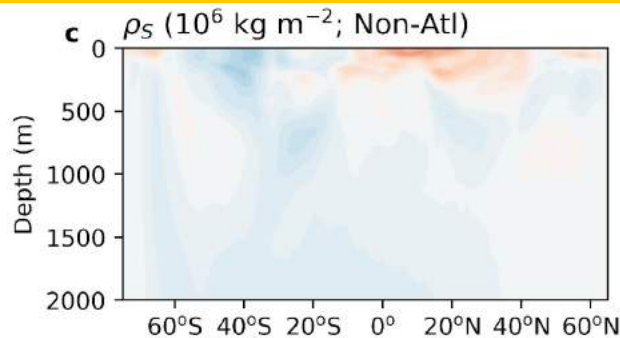
Ocean temperature response further enhances ocean density impact on OHU efficiency through a positive feedback

TOP efficiency models minus BOT efficiency models

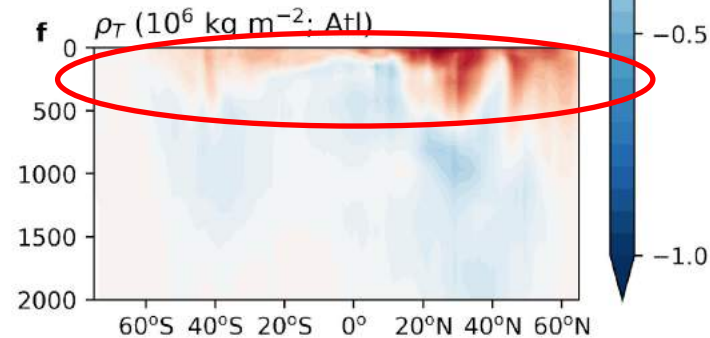
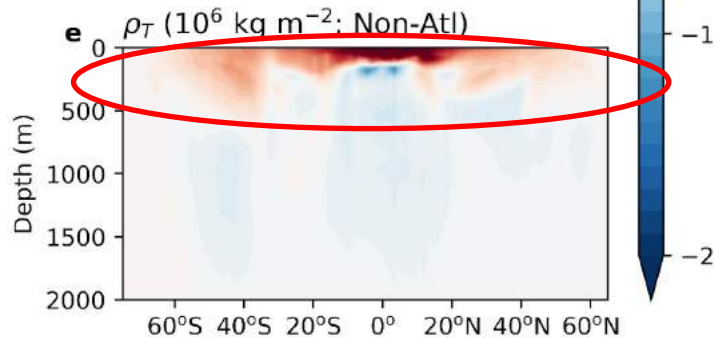
ocean density response to CO2 forcing



Salinity contribution to ocean density response

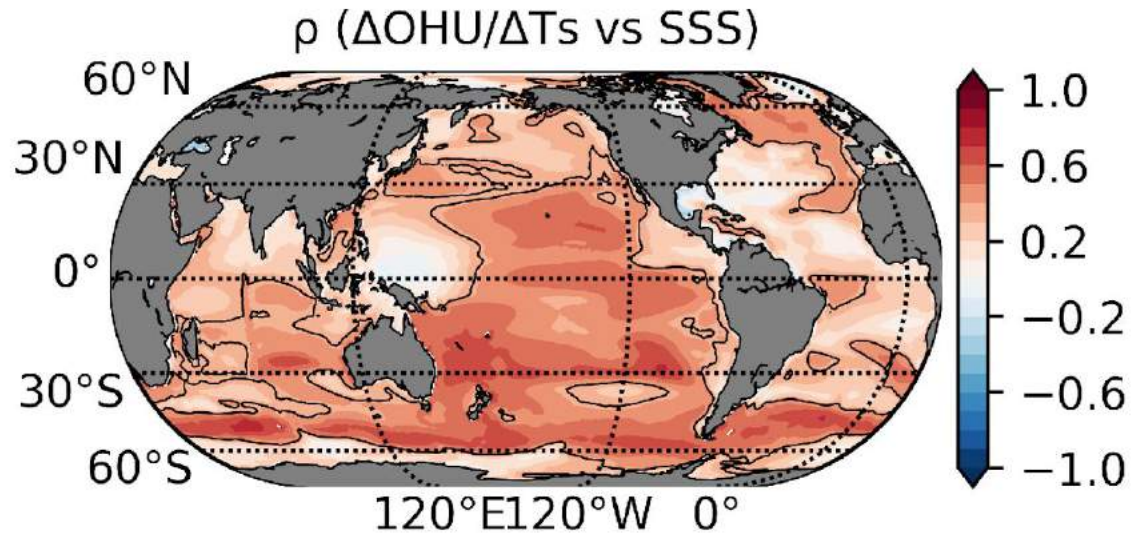


Temperature contribution to ocean density response

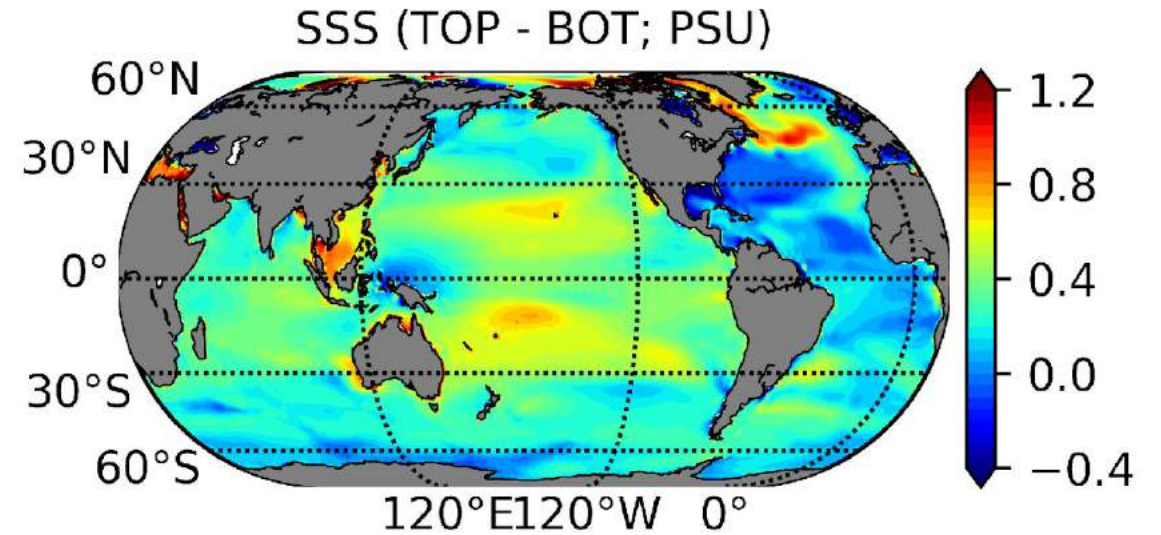


What about OHU efficiency VS sea surface salinity (SSS)?

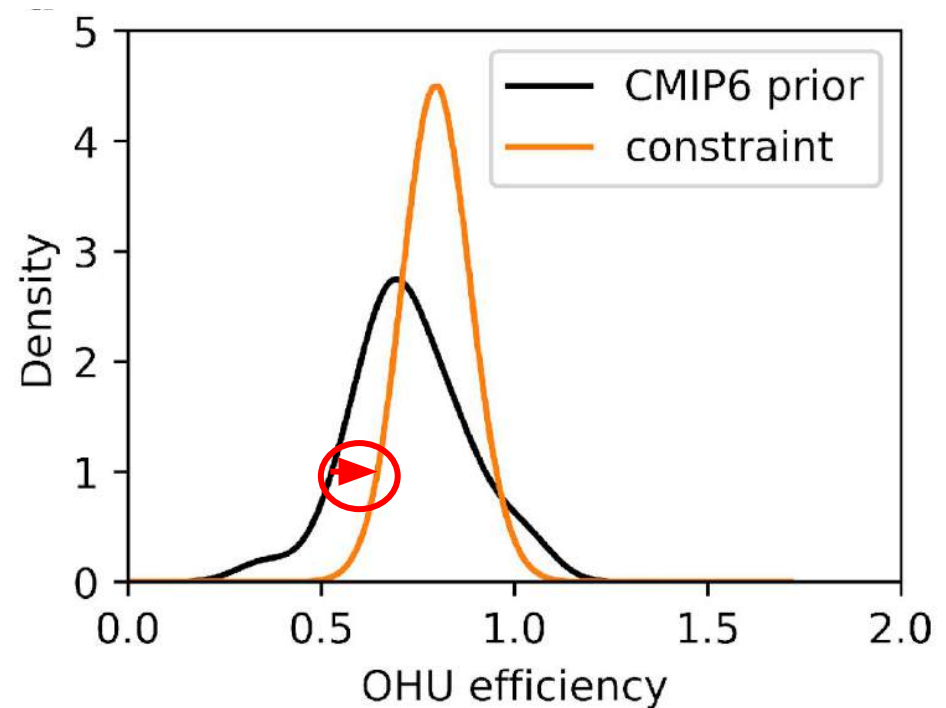
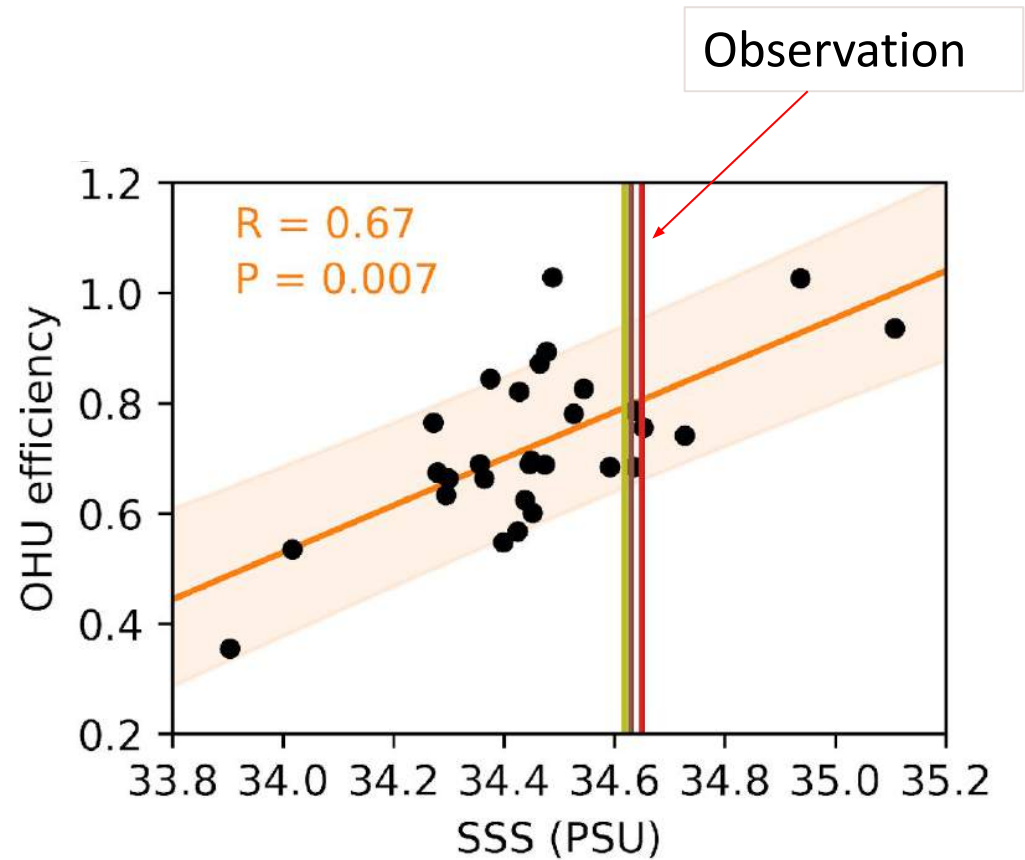
Correlation: OHU efficiency VS SSS



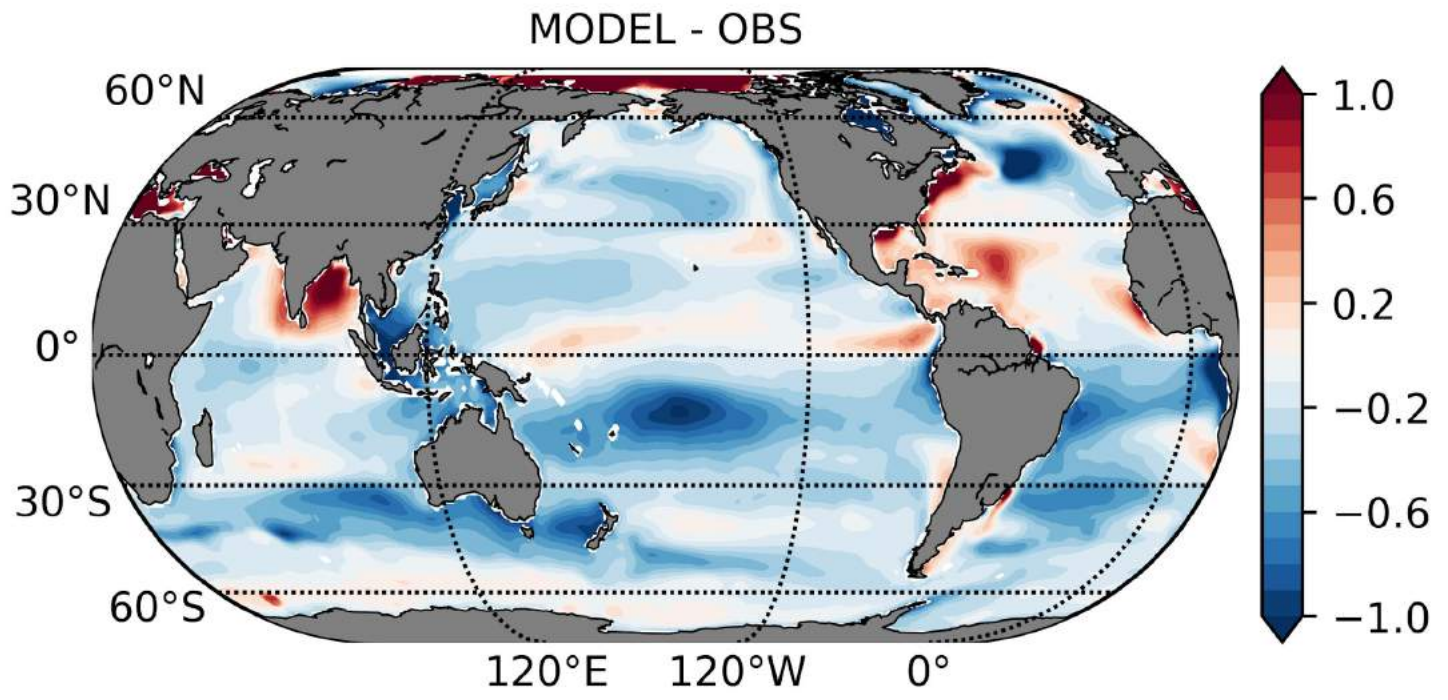
SSS difference: TOP OHU efficiency models minus BOT models



Emergent constraint narrows the uncertainty in OHU efficiency and argues against **low** OHU efficiency models

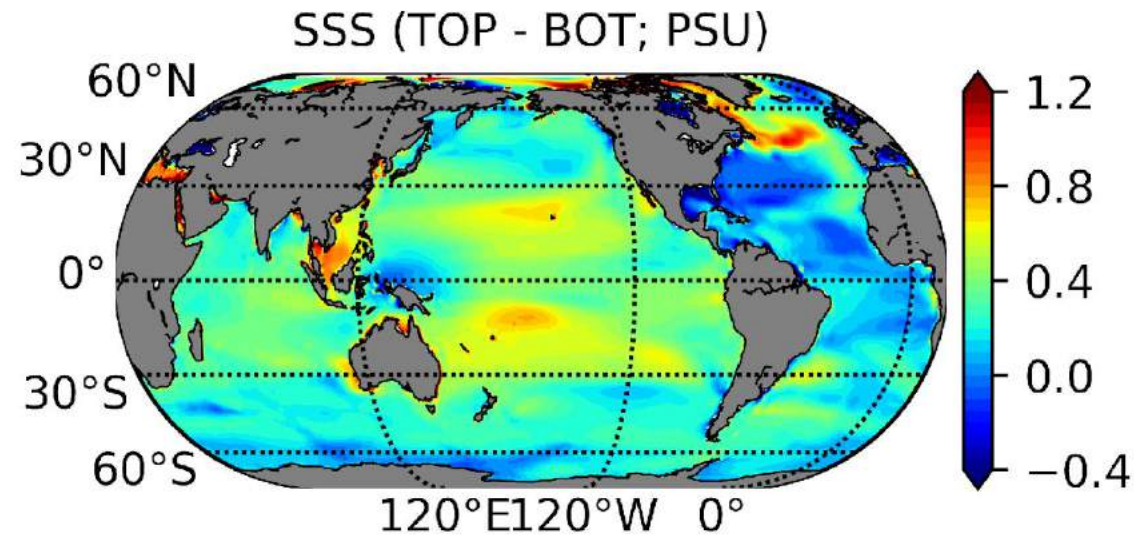


CMIP6 models on average underestimate sea surface salinity

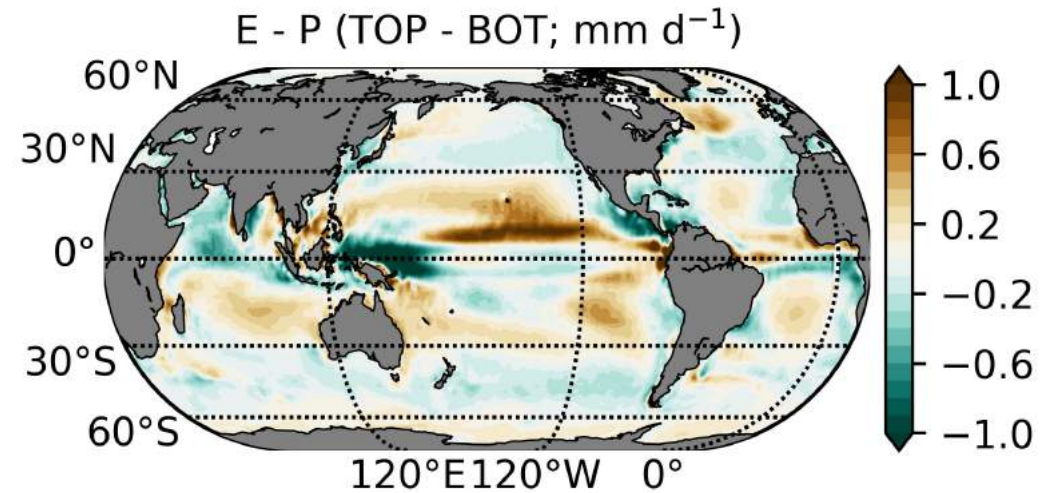


Models' spread in simulating hydrological cycle is probably an important source of their spread in surface salinity

SSS difference: TOP OHU efficiency models minus BOT models



E-P difference: TOP OHU efficiency models minus BOT models



E: Evaporation
P: Precipitation

Summary

- The spread in ocean heat uptake (OHU) efficiency among CMIP6 models is statistically correlated with base-state ocean stratification.
- The model spread in ocean stratification is dominated by **ocean salinity** instead of ocean temperature.
- **Weaker** stratification models produce a **deeper** ocean warming and therefore **lower** surface warming, which dominates ocean stratification impact on OHU efficiency.
- Emergent constraint using sea surface salinity observations narrows the model spread in OHU efficiency and argues against relatively low efficiency models due to models' fresh biases.