

# 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)

$\varepsilon$ : OHU efficiency

$\Delta T$ : Global surface warming

$\lambda$ : Climate feedback parameter

$t$ : Time

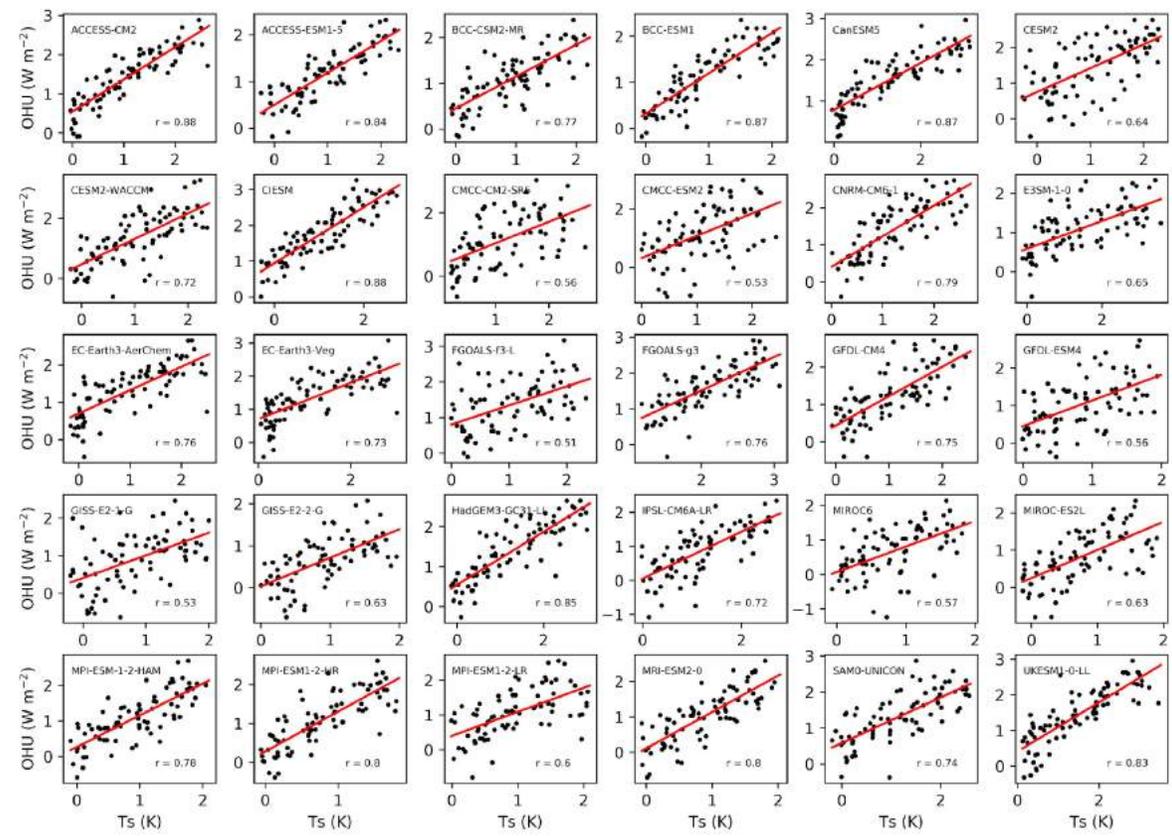
A **higher** OHU efficiency means **lower** surface warming given the **same** amount of OHU

**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

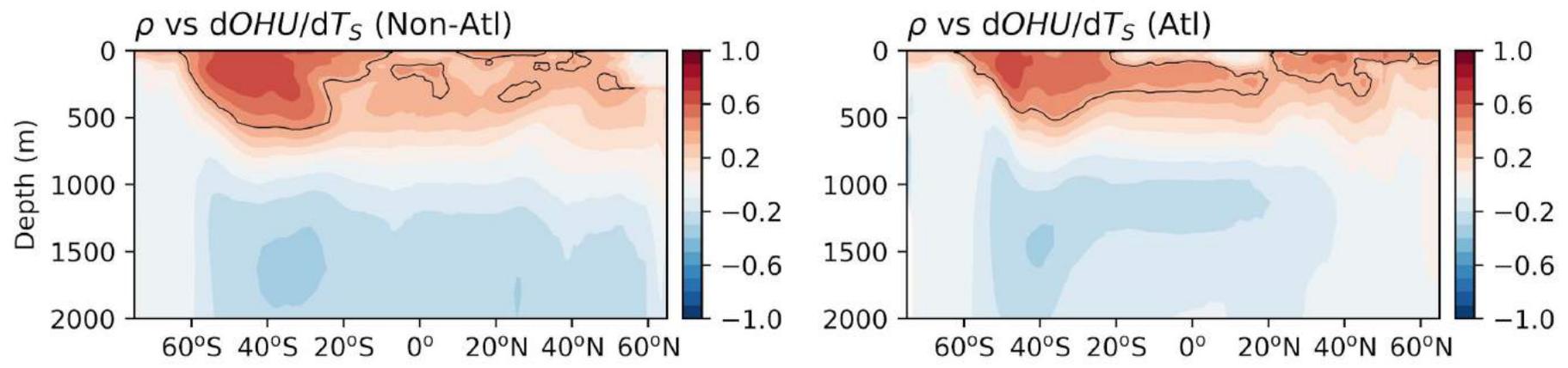
- Models:** a set of 30 CMIP6 coupled global climate models
- Simulations:** 1pct CO2 simulations in which CO2 concentration increases 1% per year
- Definition of OHU efficiency:** the slope of the linear regression between OHU change and surface warming for the first 80 model years
- TOP and BOT efficiency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

Linear regression: OHU VS surface warming

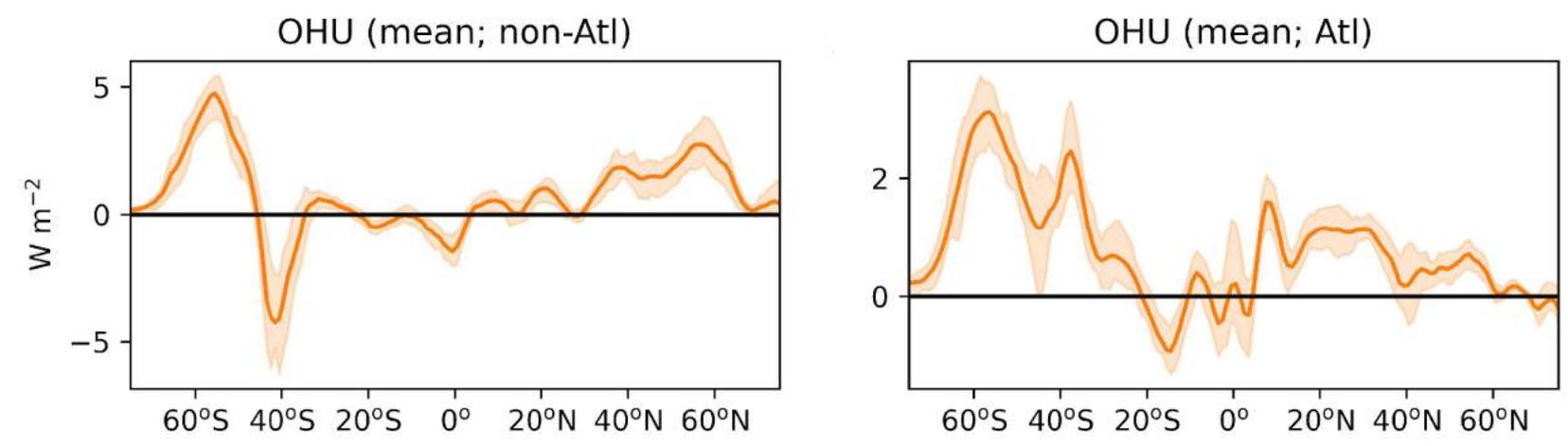


# Weaker ocean stratification, especially in Southern Ocean, statistically correlates with higher OHU efficiency

Correlation: zonal-mean ocean density VS OHU efficiency



Zonal mean OHU for both non-Atlantic and Atlantic Oceans

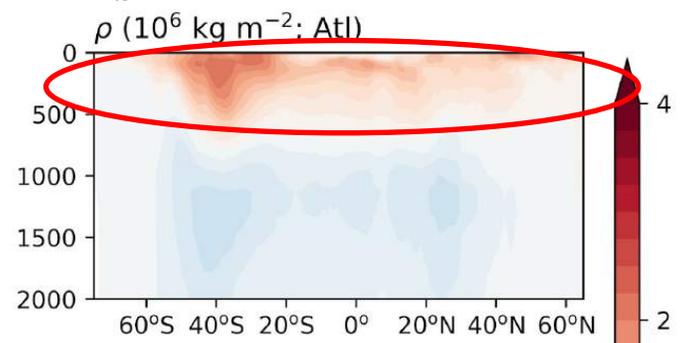
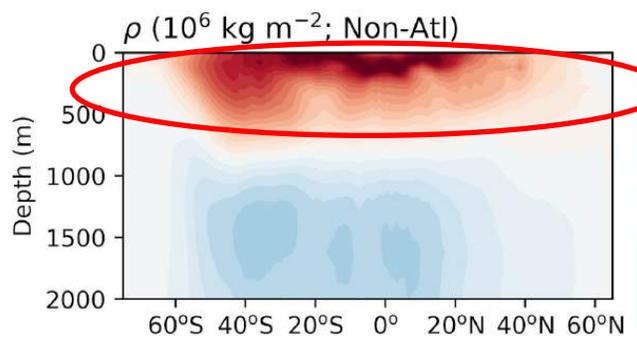


Positive: into the ocean

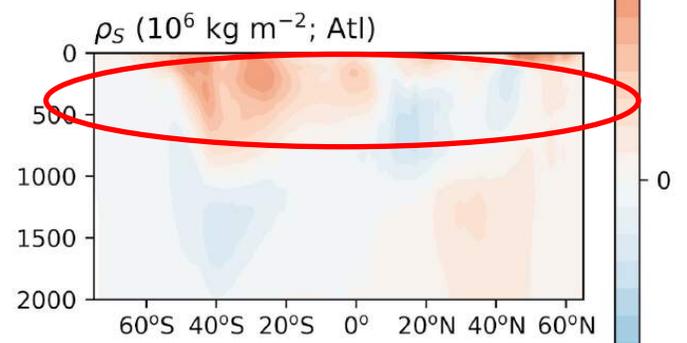
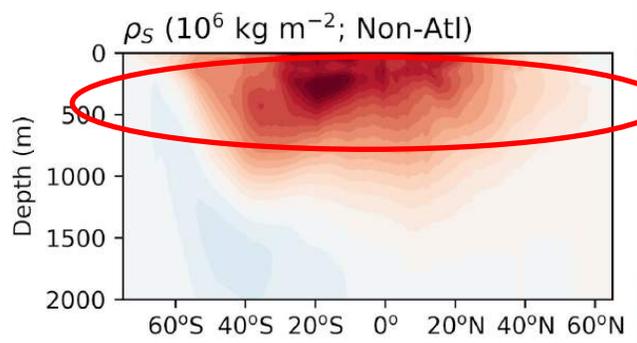
# The weaker ocean stratification in higher OHU efficiency models is dominated by **salinity** instead of temperature!

## TOP efficiency models minus BOT efficiency models

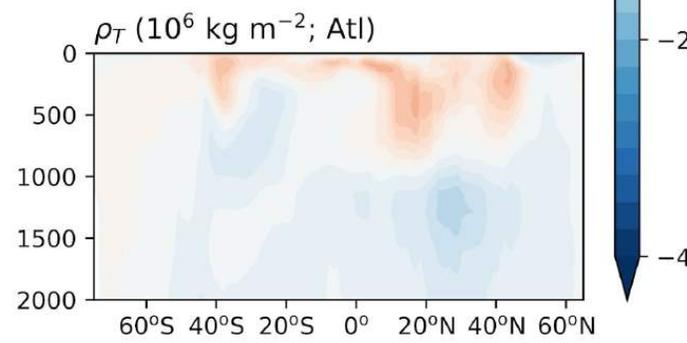
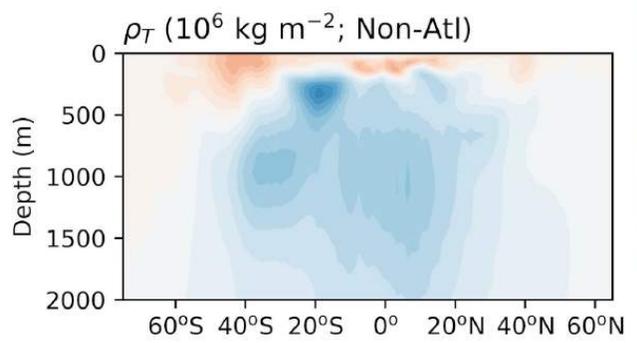
base-state ocean density  
from pre-industrial control  
runs



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**?

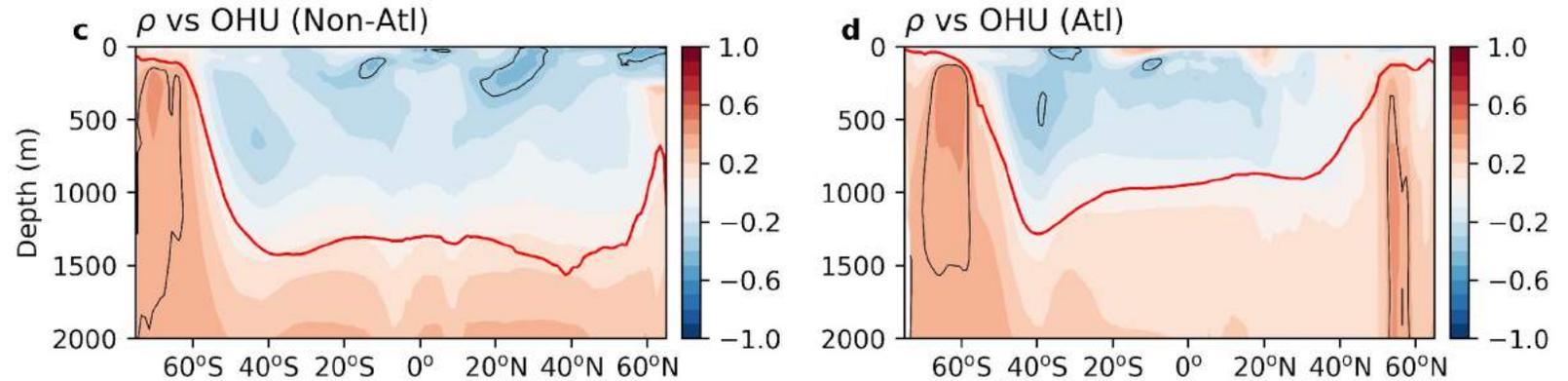
$$\varepsilon(t) = \frac{N(t)}{\Delta T(t)}$$

$\varepsilon$ : OHU efficiency

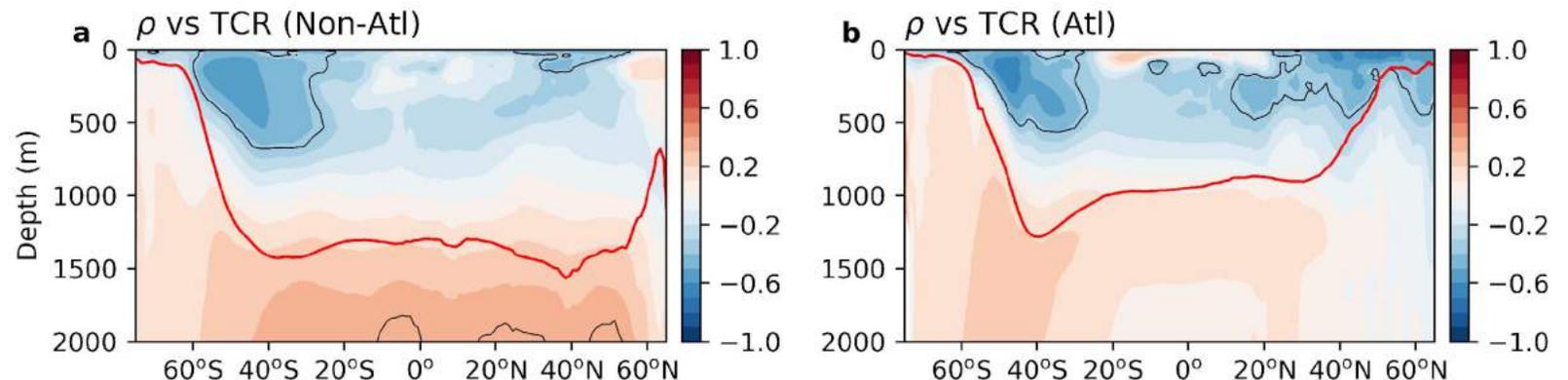
$N$ : OHU

$\Delta T$ : Surface warming

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



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

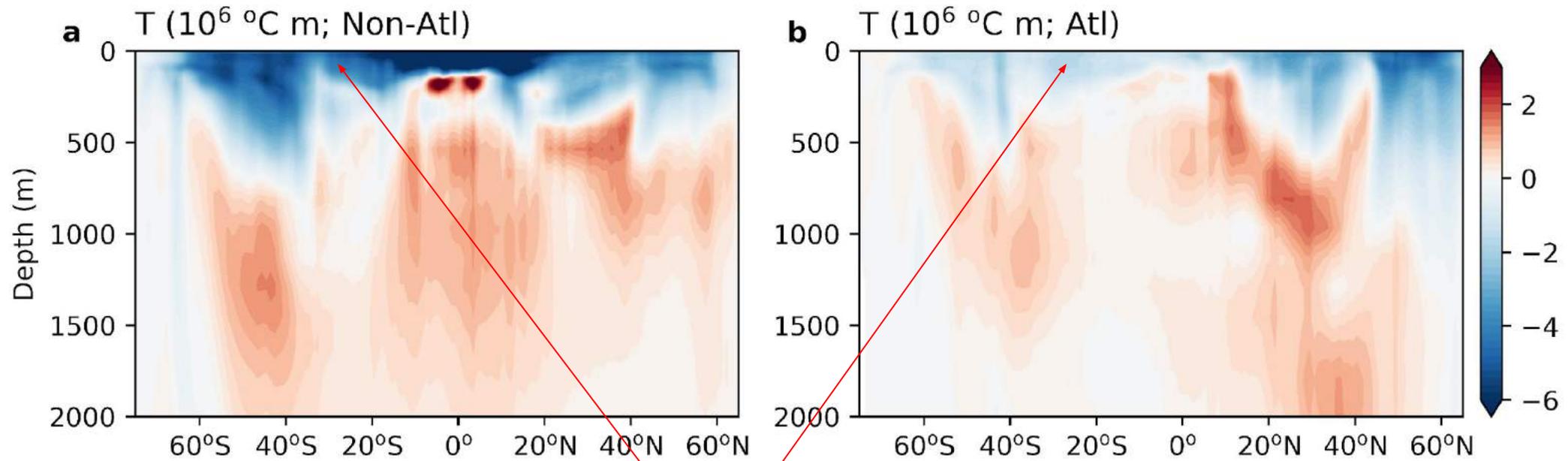


Ocean density impact on surface warming dominates!

**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**

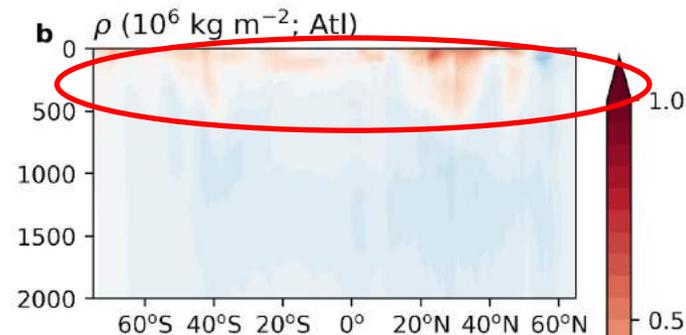
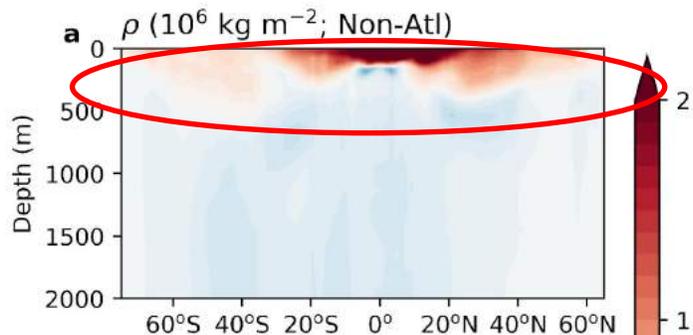


Reduced surface warming!

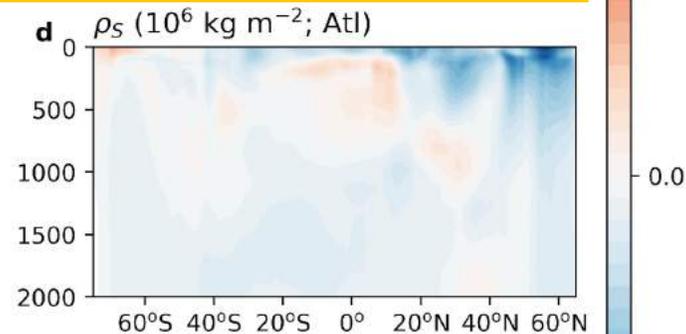
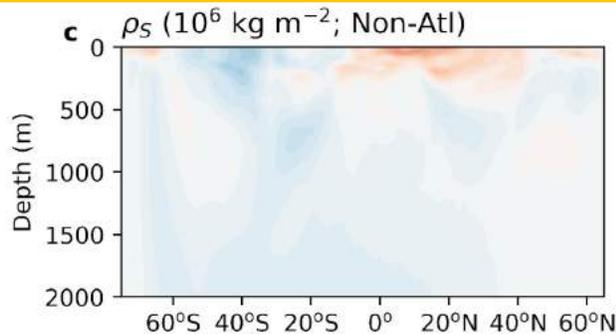
# Ocean temperature response further enhances ocean density impact on OHU efficiency through a positive feedback

TOP efficiency models minus BOT efficiency models

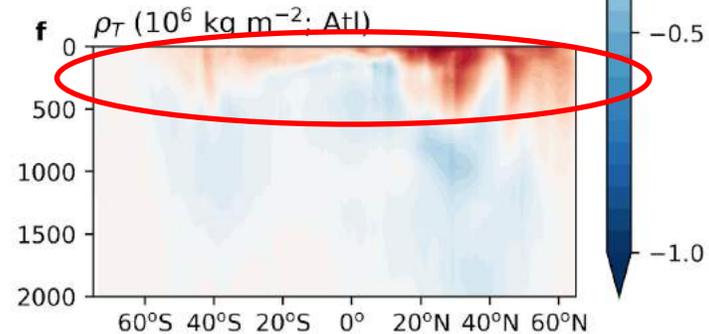
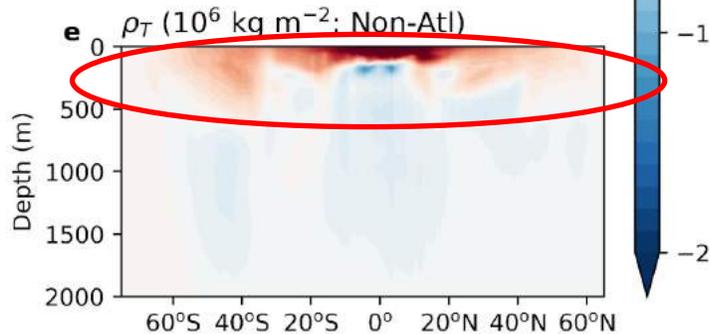
ocean density response to CO2 forcing



Salinity contribution to ocean density response

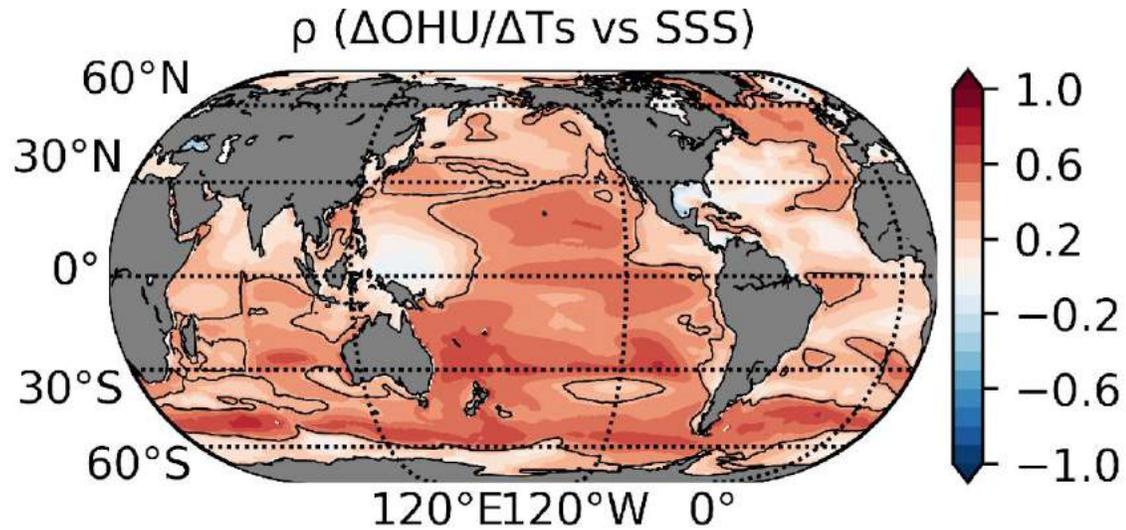


Temperature contribution to ocean density response

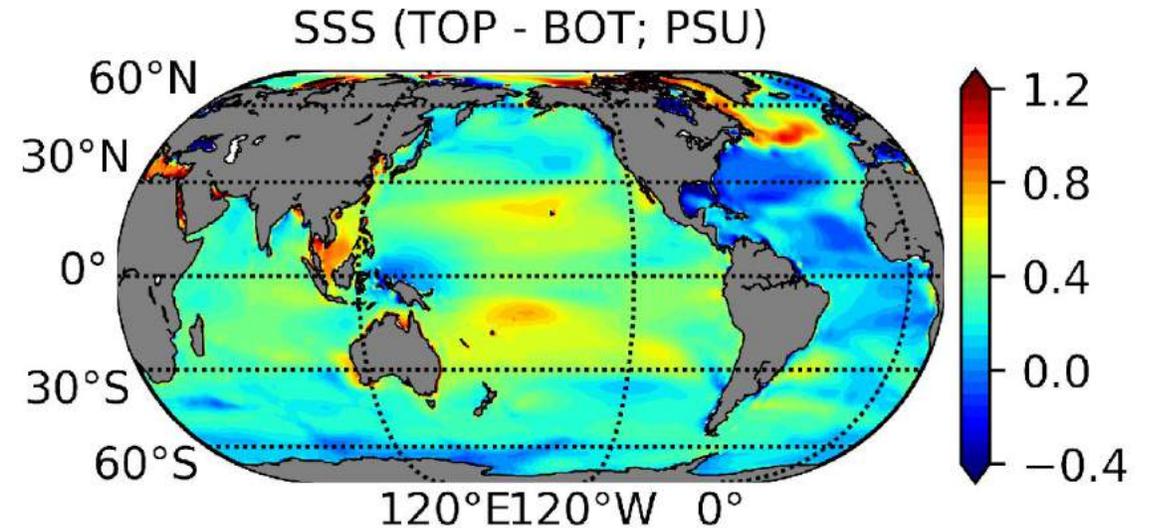


# What about OHU efficiency VS sea surface salinity (SSS)?

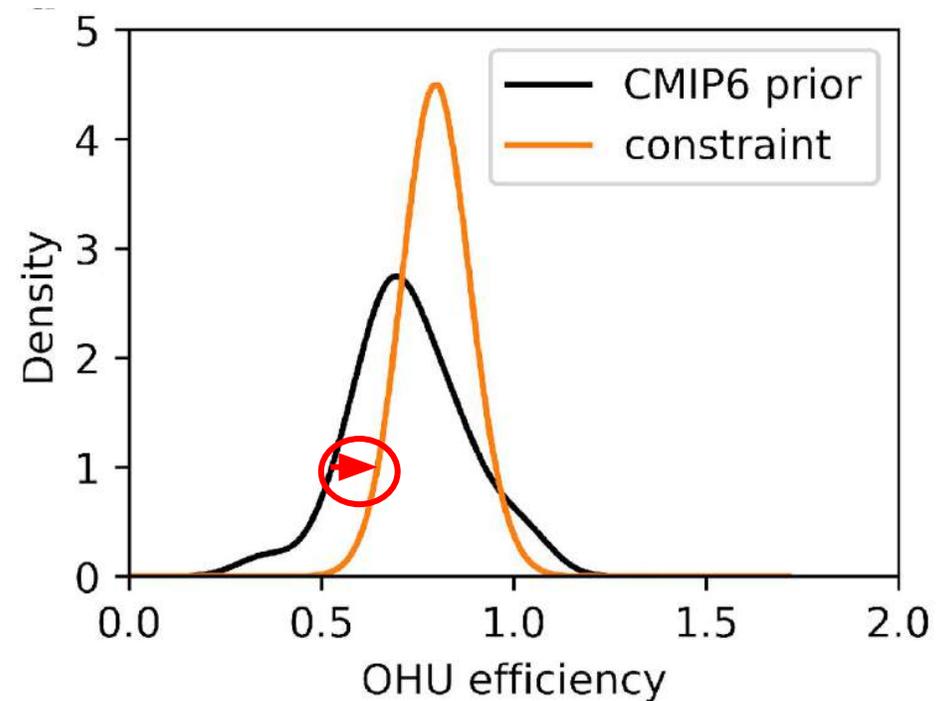
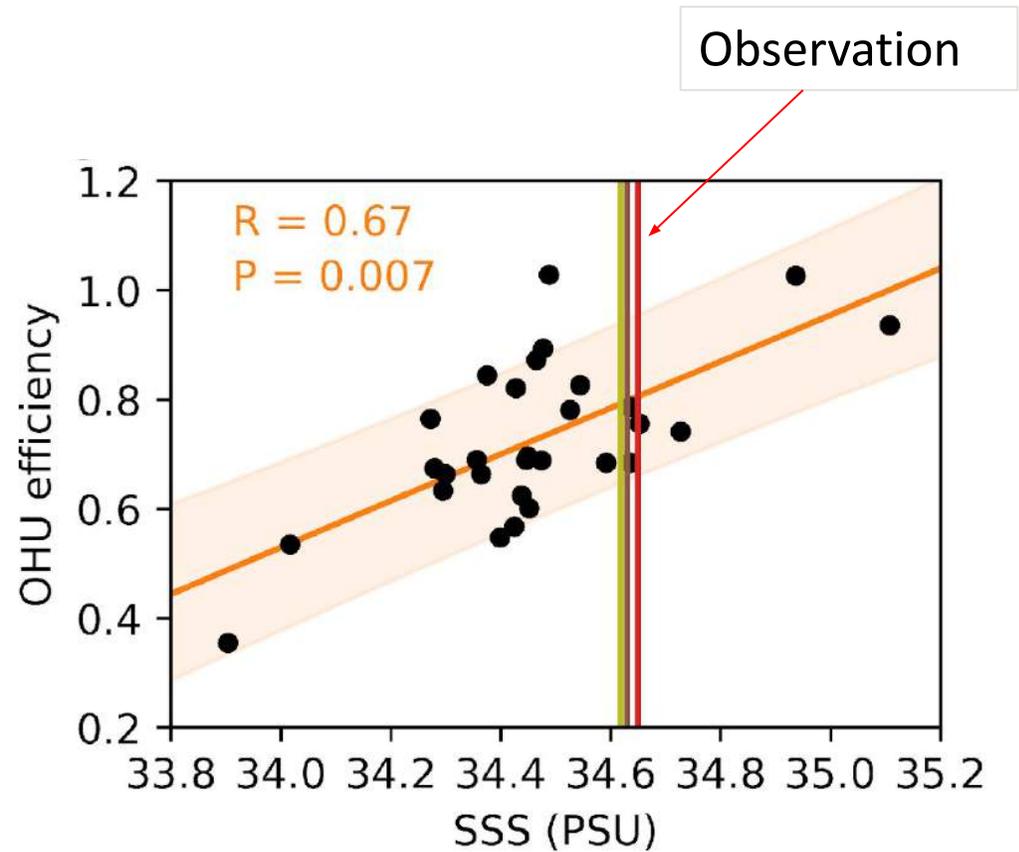
Correlation: OHU efficiency VS SSS



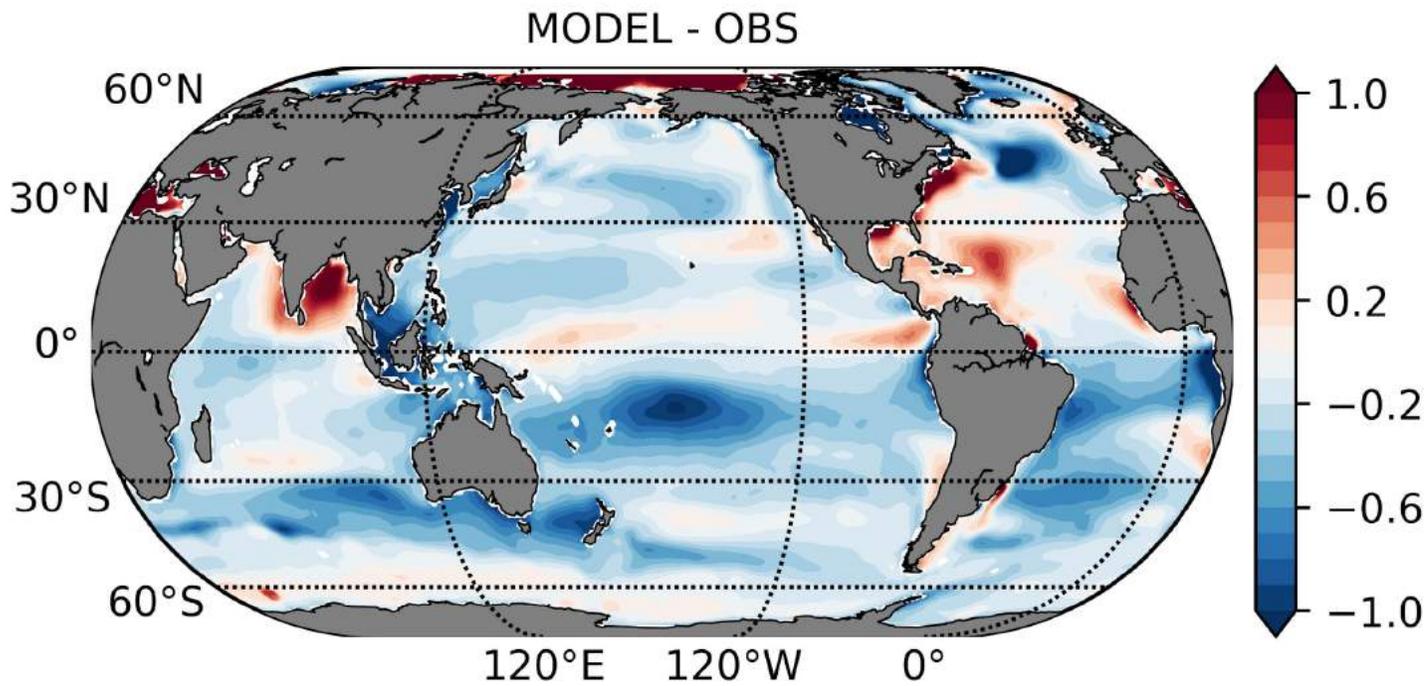
SSS difference: TOP OHU efficiency models minus BOT models



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

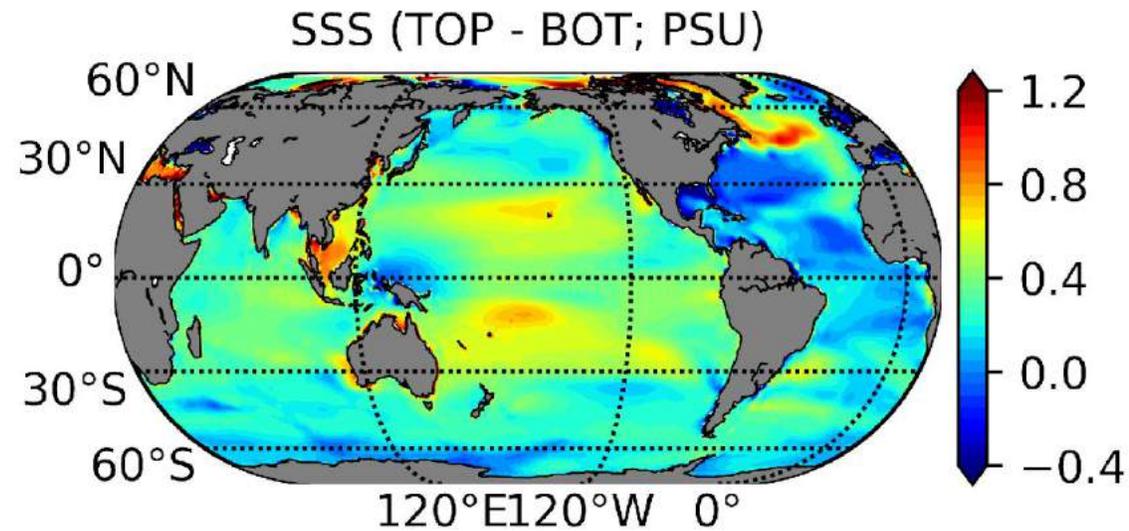


# CMIP6 models on average underestimate sea surface salinity

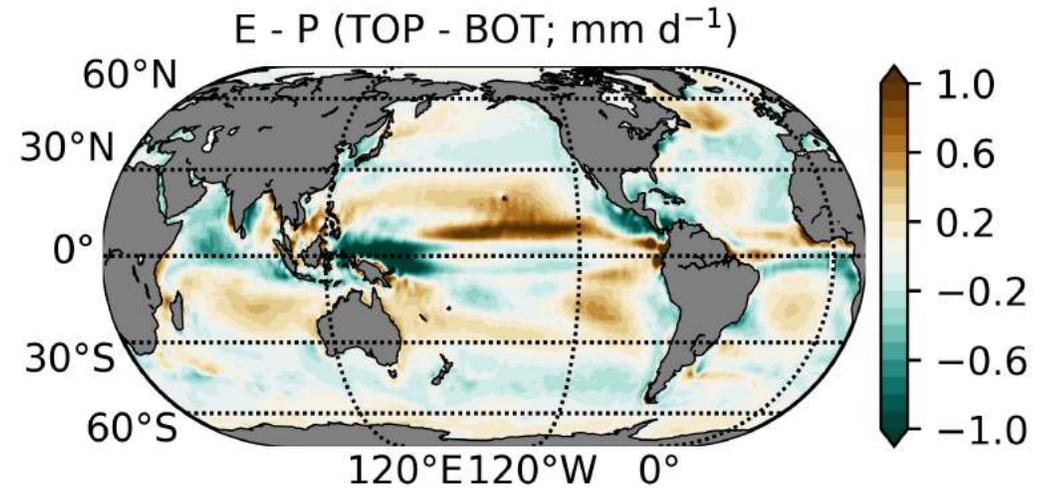


# Models' spread in simulating hydrological cycle is probably an important source of their spread in surface salinity

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.