# Upper-ocean biases and the Atlantic meridional overturning circulation in OMIP simulations

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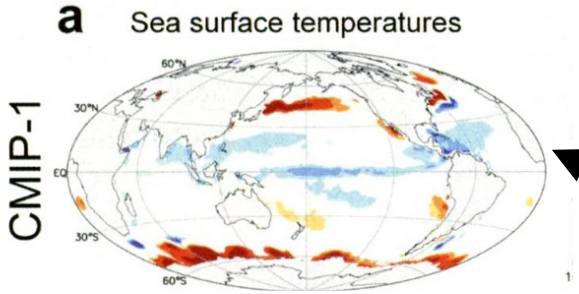
Model Diagnostics Task Force

We gratefully acknowledge support from NOAA MAPP Award NA22OAR4310111

# Climate models struggle with the sea surface temperature and salinity fields in the North Atlantic




Multimodel mean biases in sea surface temperature biases *(CMIP1-3 from Reichler and Kim, 2008 and CMIP5-6 from Zhang et al. 2023)*

Most CMIP1 models were flux-corrected

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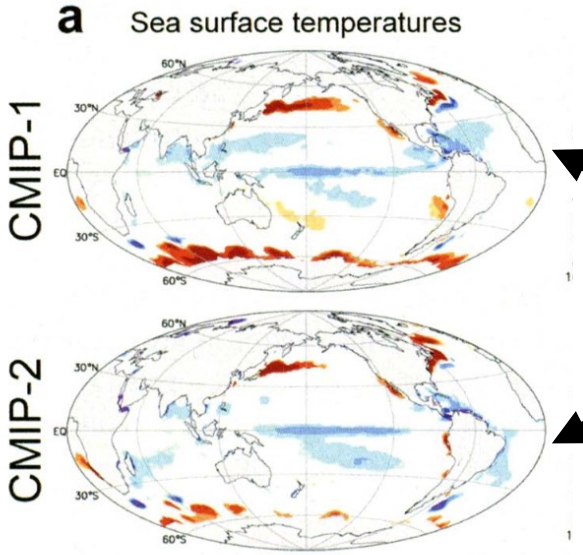


Multimodel mean biases in sea surface temperature biases *(CMIP1-3 from Reichler and Kim, 2008 and CMIP5-6 from Zhang et al. 2023)*

Most CMIP1/2 models were flux-corrected

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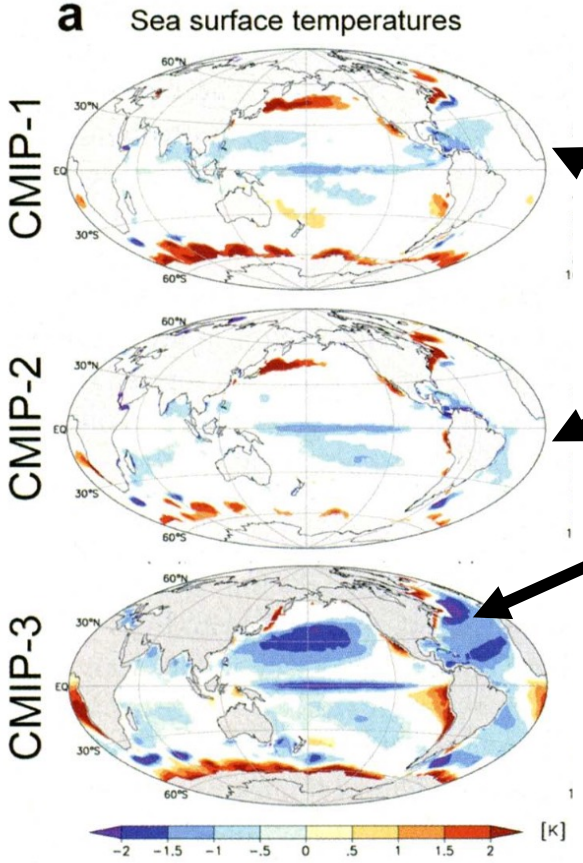


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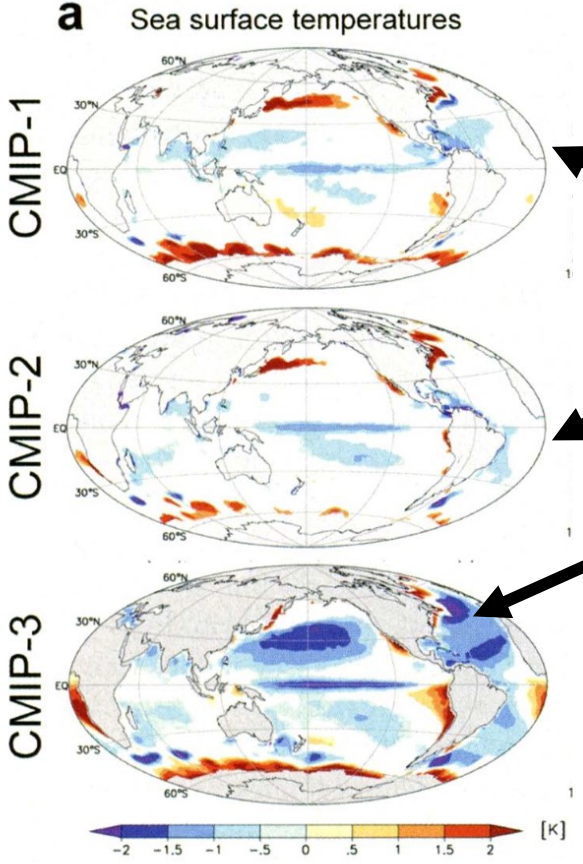


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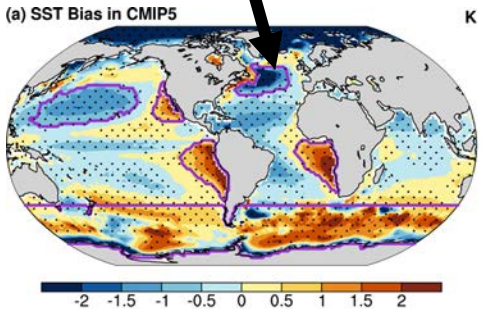
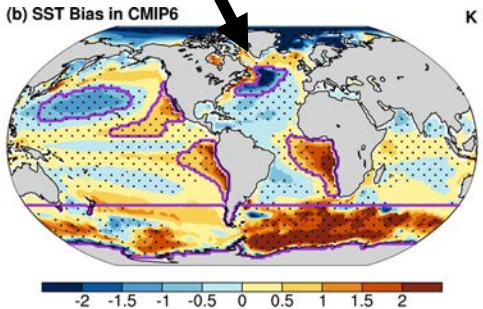
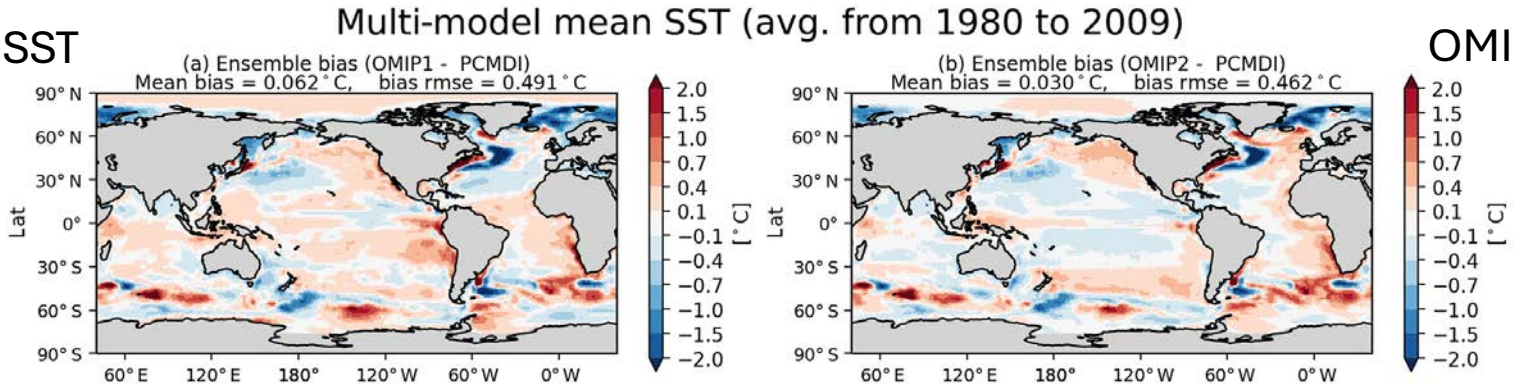


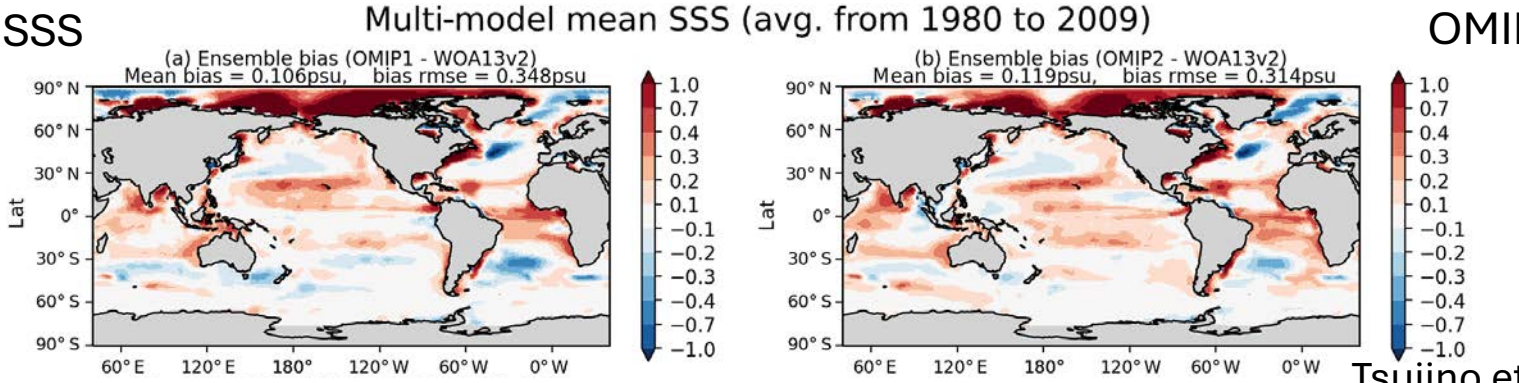
# These upper-ocean biases originate in the ocean models and are due to poor Gulf Stream/North Atlantic Current representation.

OMIP1 SST




OMIP2 SST

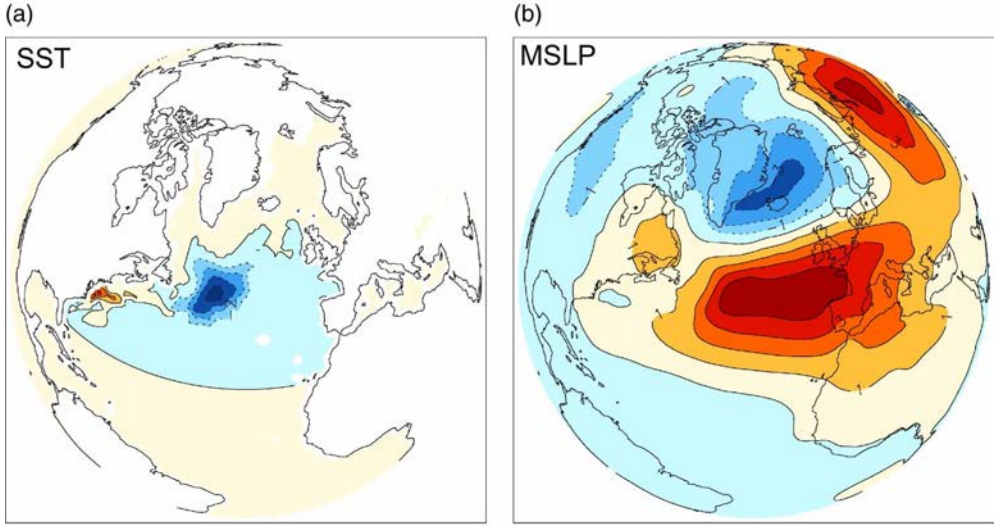
OMIP1 SSS




OMIP2 SSS

Tsujino et al. 2020

# North Atlantic SST biases have consequences for local and downstream climate.




*Keeley et al. (2012)*

Difference in SLP in AMIP simulations with and without climate model SST biases.

What can we learn about the relationship between upper-ocean biases and the overturning circulation from the suite of OMIP simulations?

# Project Goals

1. Develop Process Oriented Diagnostics (PODs) for the subtropical to subpolar North Atlantic Ocean
   → Model-agnostic surface-forced water mass transformation (check out Taydra Low's poster!)
   → Model-agnostic AMOC in density coordinates routine for comparison to water mass transformation
2. Process Ocean Model Intercomparison Project (OMIP) simulations such that they can be used for cross-model comparison of upper-ocean and thermohaline fields
3. Identify relationships between upper-ocean model biases, water mass transformation, and the Atlantic meridional overturning circulation (AMOC)

# OMIP Interannual Forcing (IAF) simulations are driven by past atmospheric conditions

### OMIP-1

Driving dataset: Coordinated Ocean-ice Reference Experiment (CORE, Large and Yeager 2009)

Time Period: 1948-2009

Cycles: 5

### OMIP-2

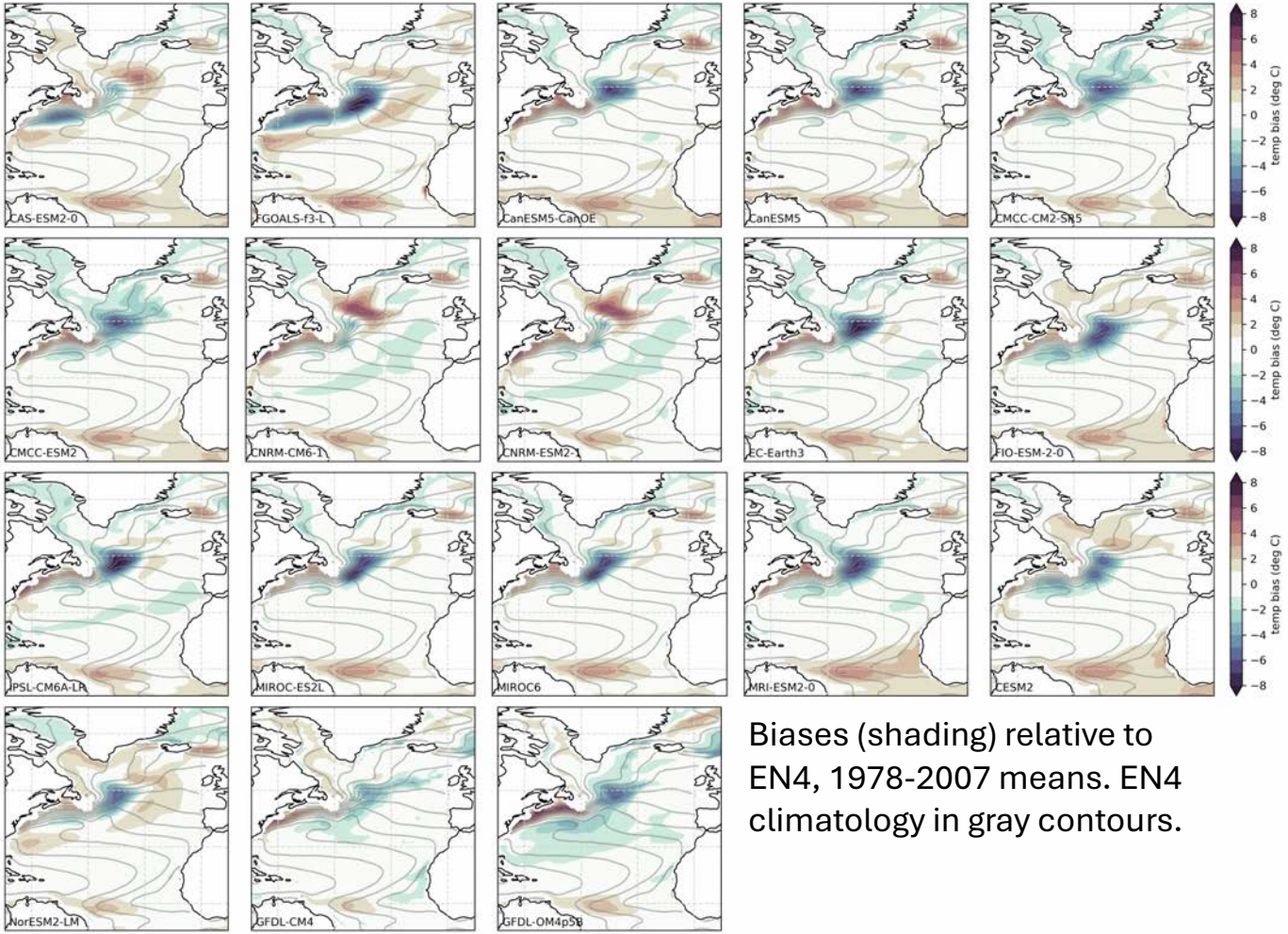
Driving dataset: Japanese 55-year atmospheric reanalysis-driving ocean (JRA55-do, Tsujino et al. 2018)

Time Period: 1958-2018

Cycles: 5-6

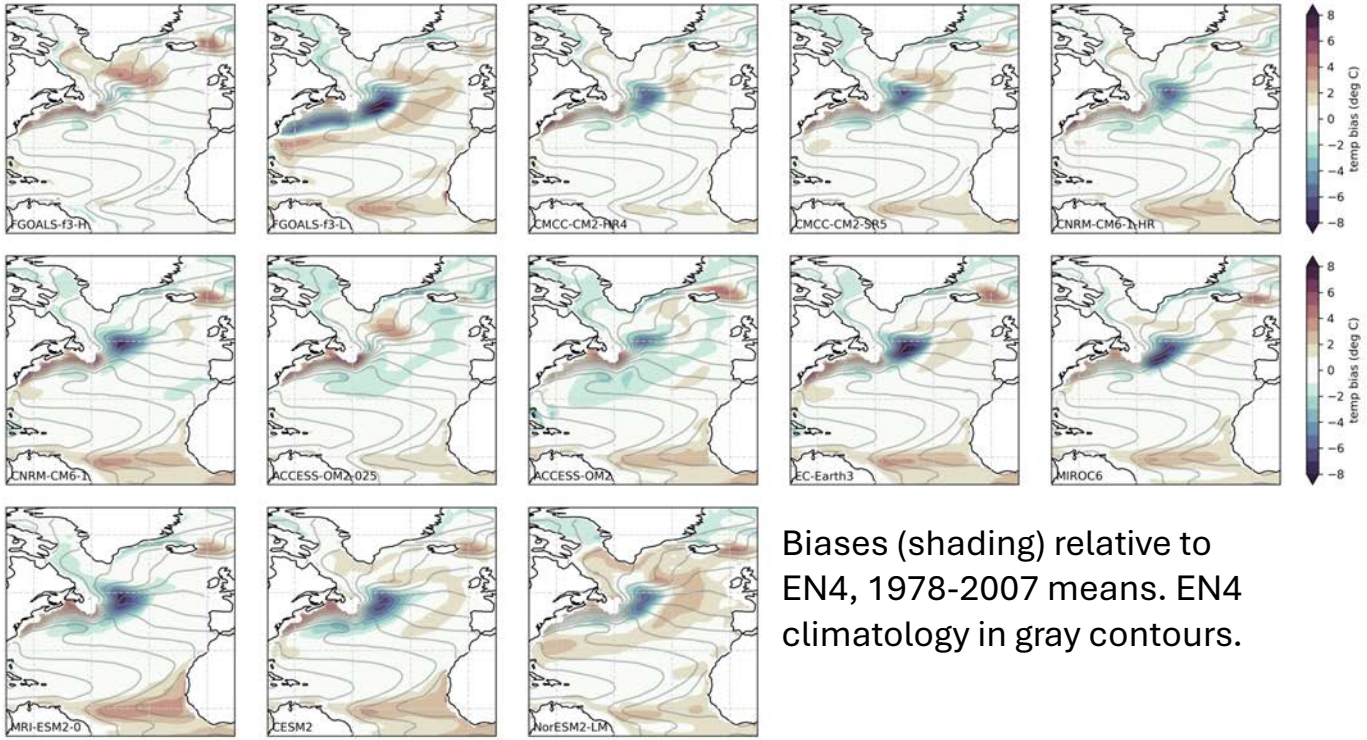
Summary of the CMIP6-OMIP protocol and results: *Griffies et al. (2016)* and *Tsujino et al. (2020)*

# OMIP1 upper-200 m temperature biases (cycle 5)




Biases (shading) relative to EN4, 1978-2007 means. EN4 climatology in gray contours.

# OMIP2 upper-200 m temperature biases (cycle 5)

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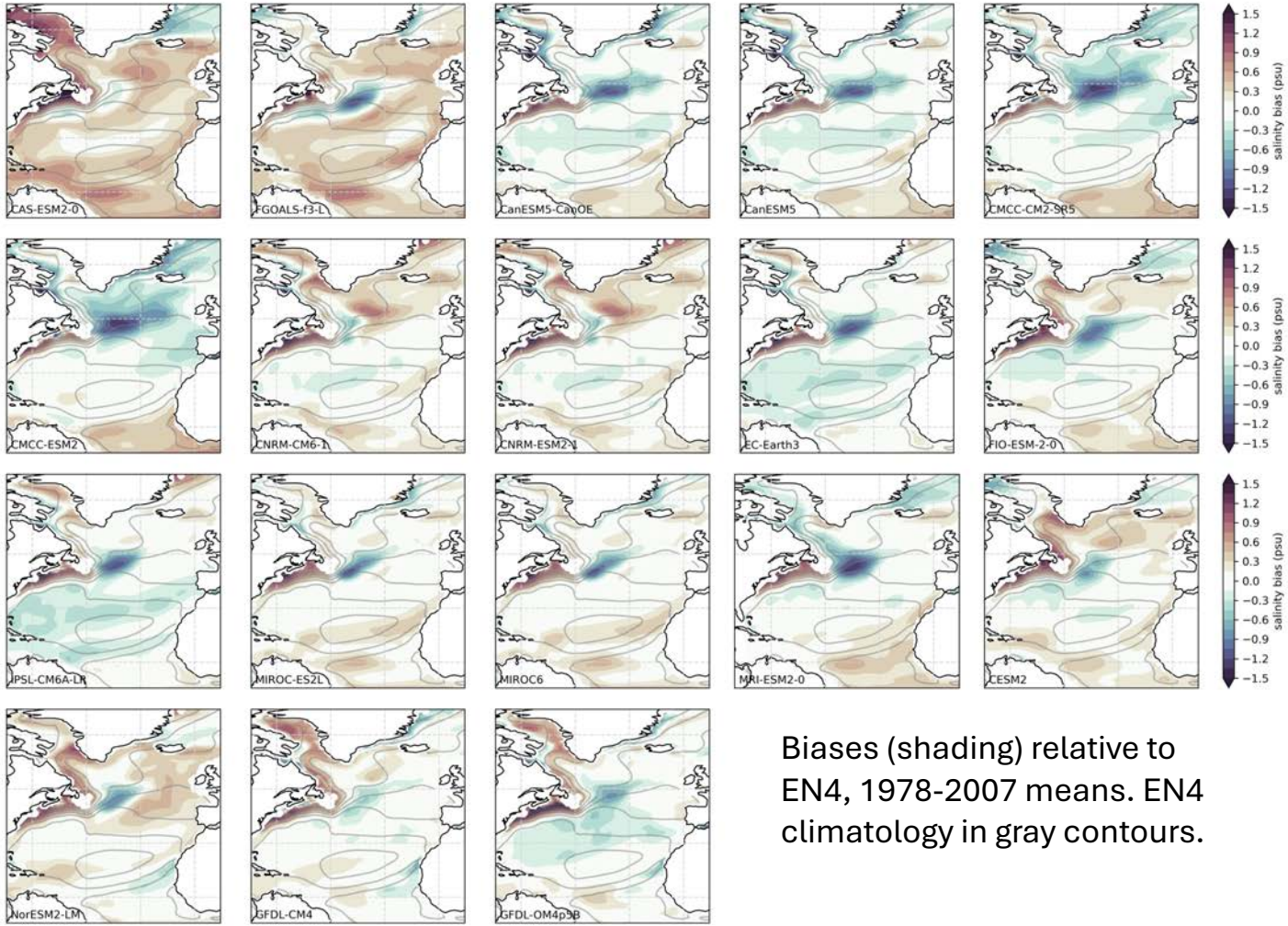
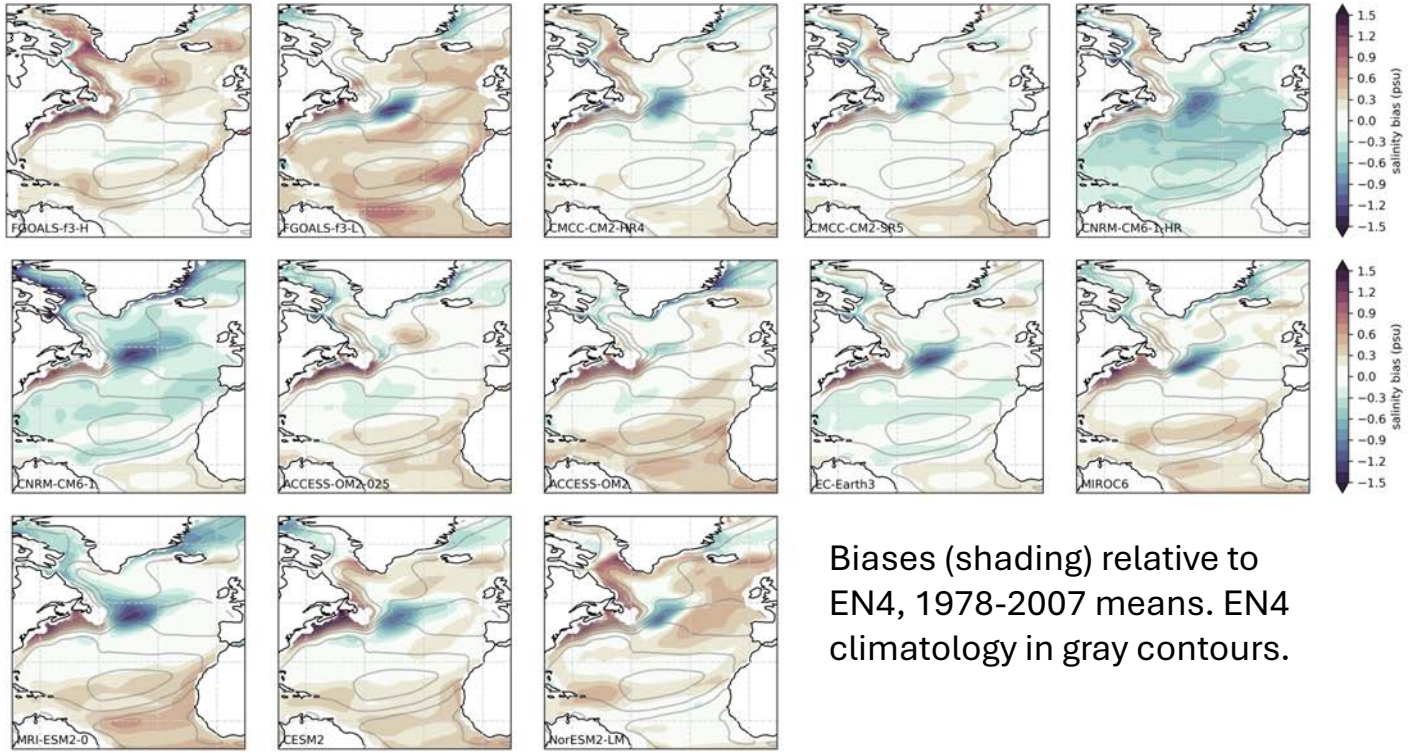
# OMIP1 upper-200 m salinity biases (cycle 5)




Biases (shading) relative to EN4, 1978-2007 means. EN4 climatology in gray contours.

# OMIP2 upper-200 m salinity biases (cycle 5)

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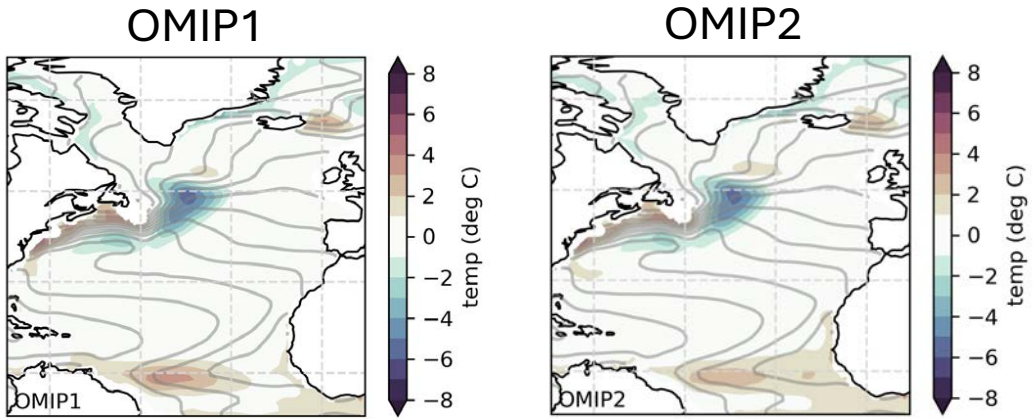
# OMIP1 and OMIP2 multimodel-mean, upper-200 m upper temperature and salinity biases (cycle 5)

Temperature

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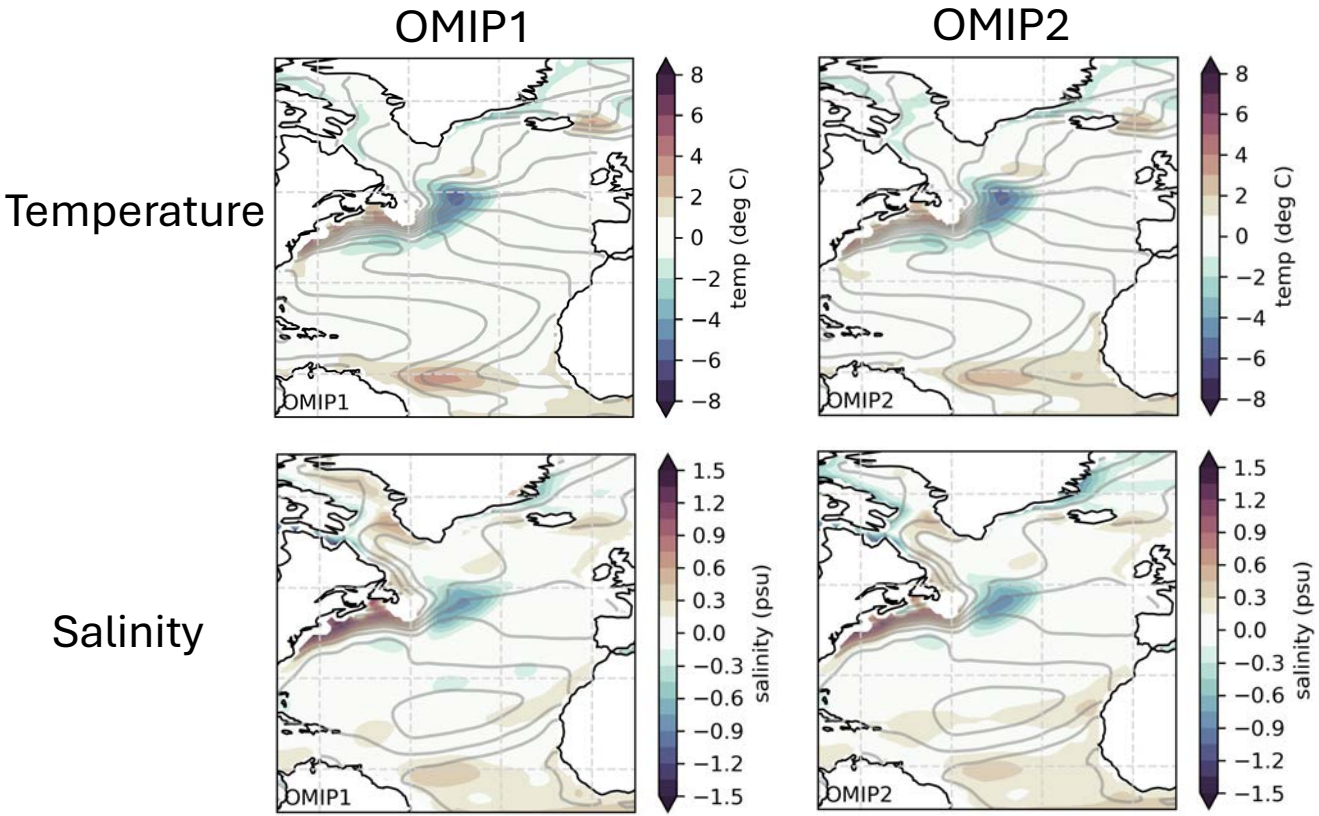


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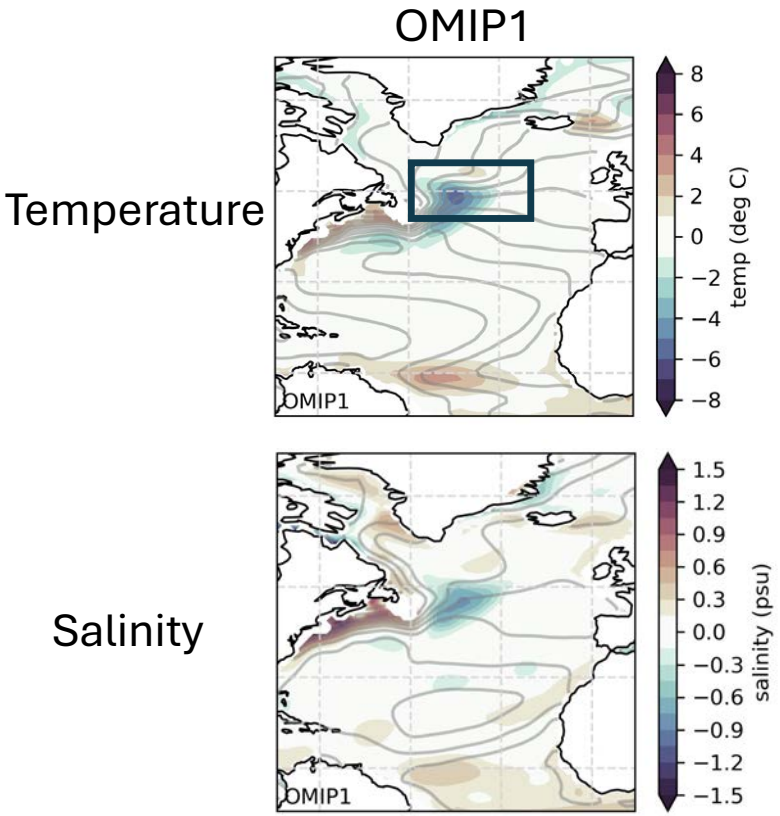
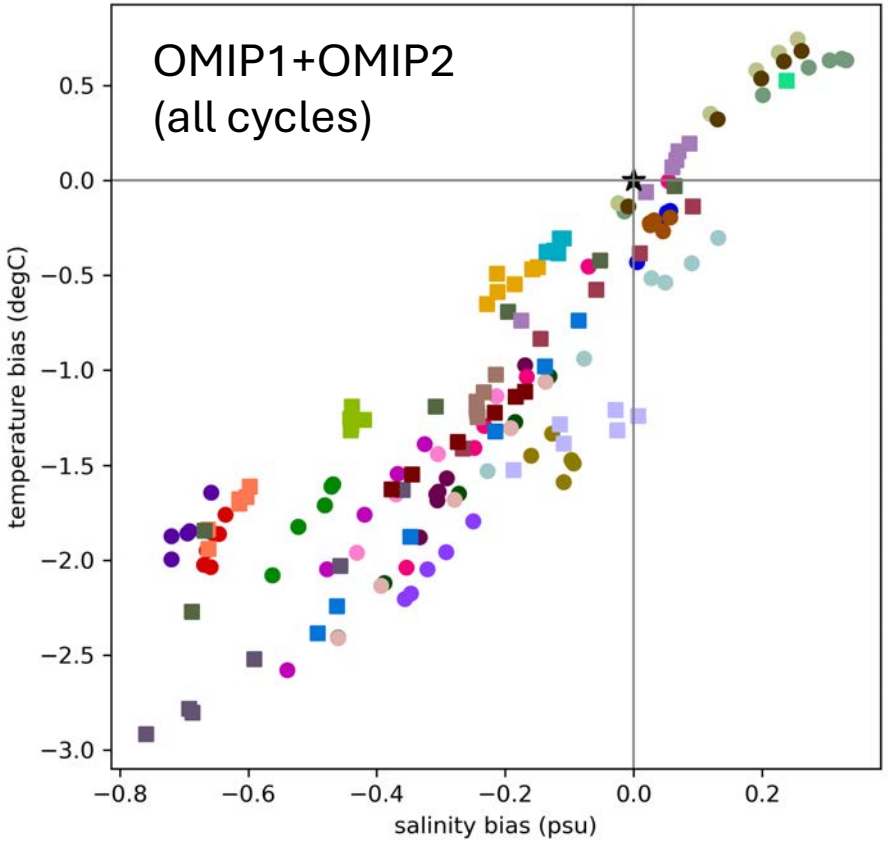
# Temperature and salinity biases co-vary

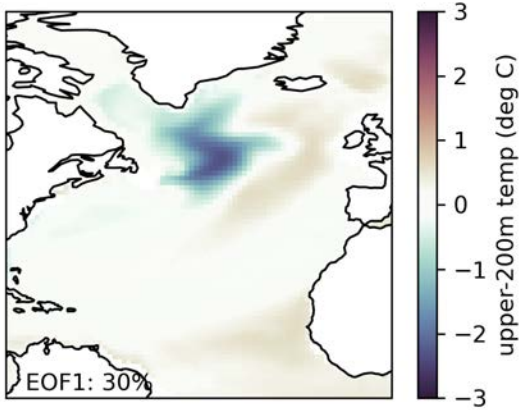


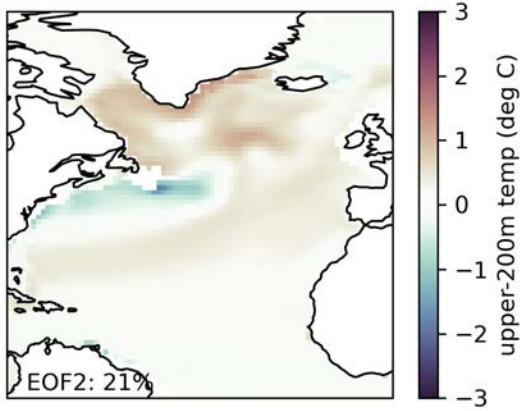
# EOFs across models of temperature and salinity biases

Temperature

EOF1




EOF2



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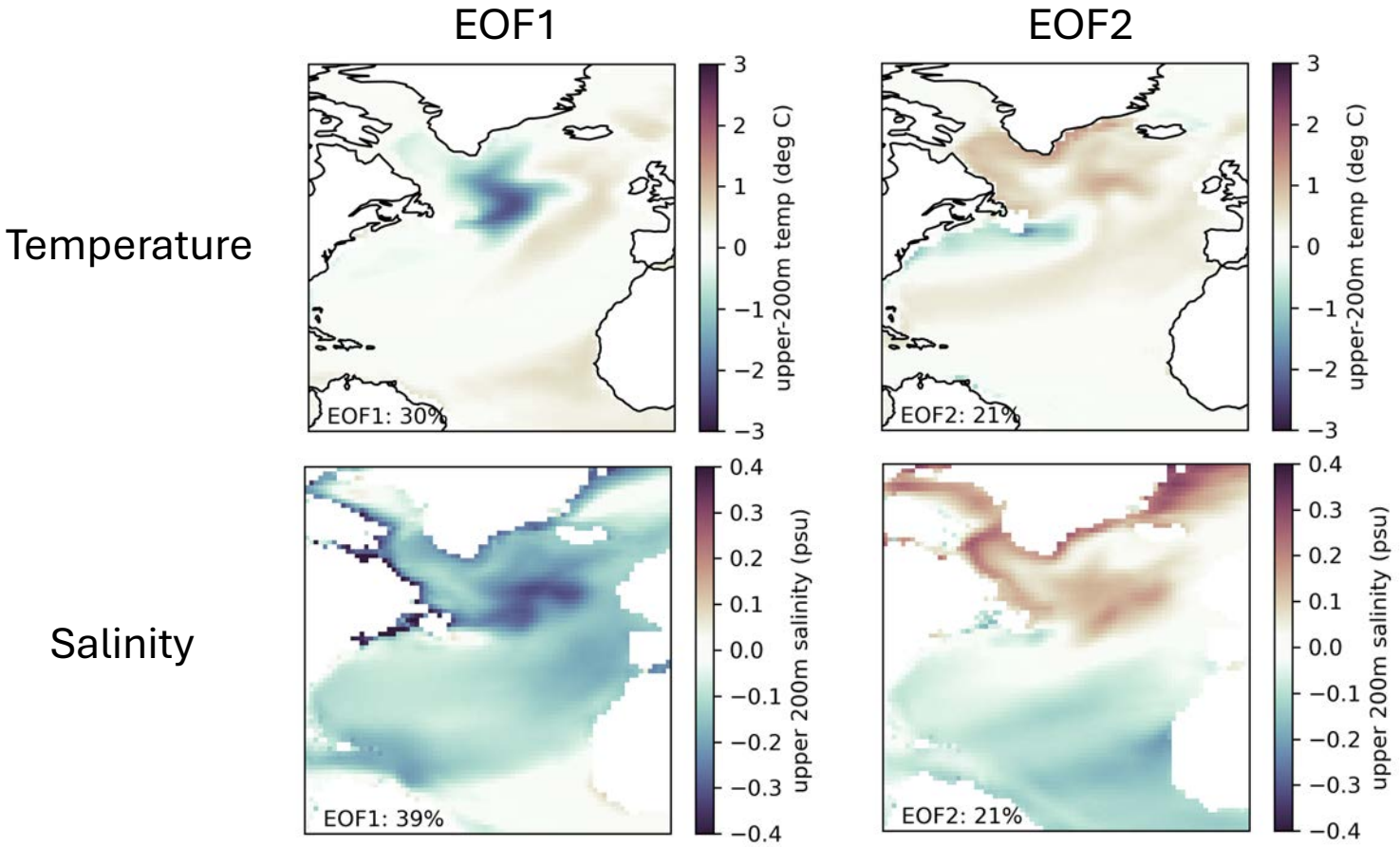
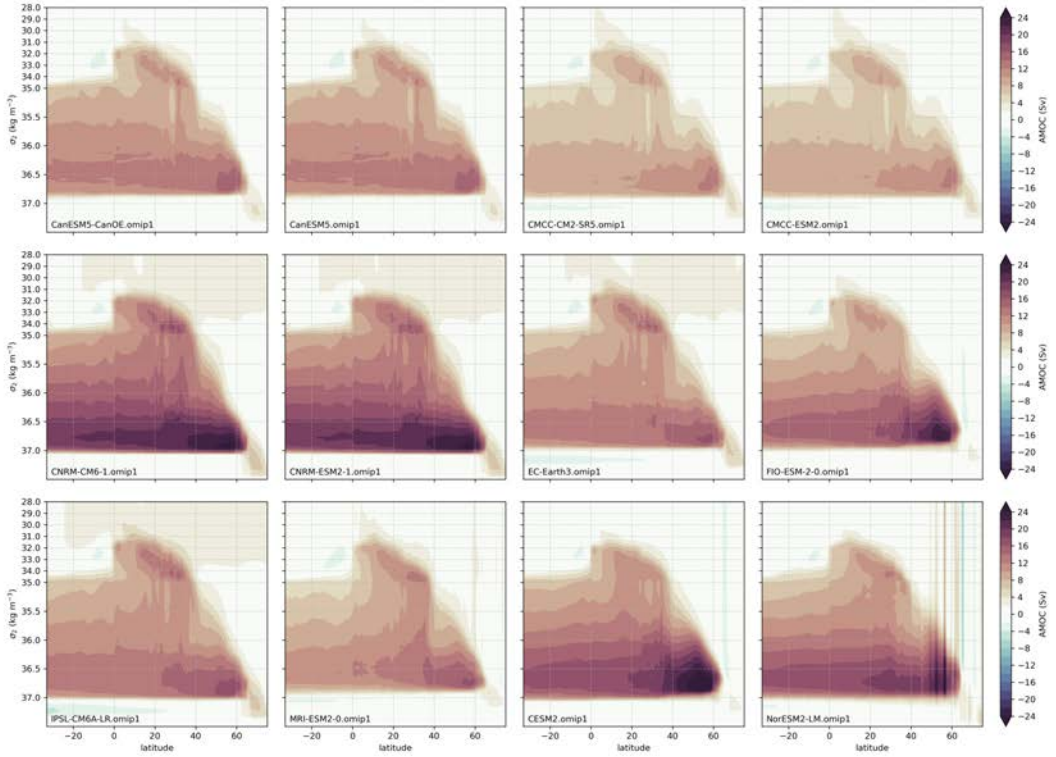
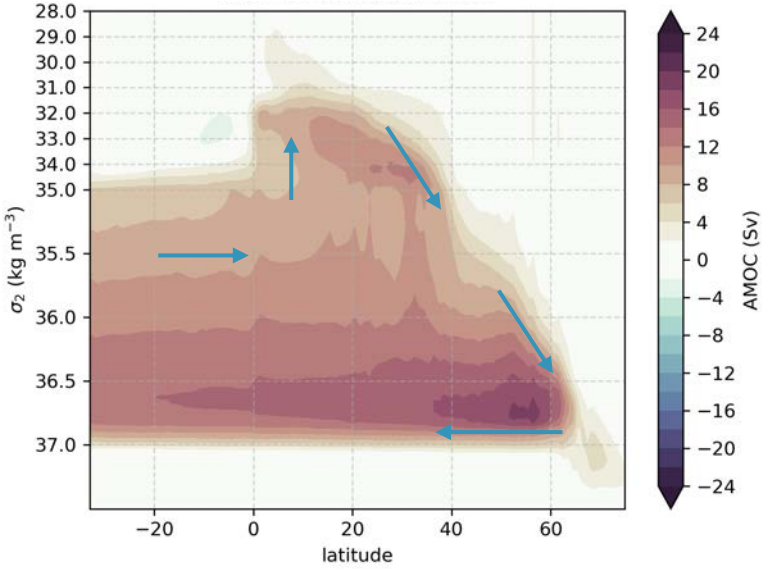


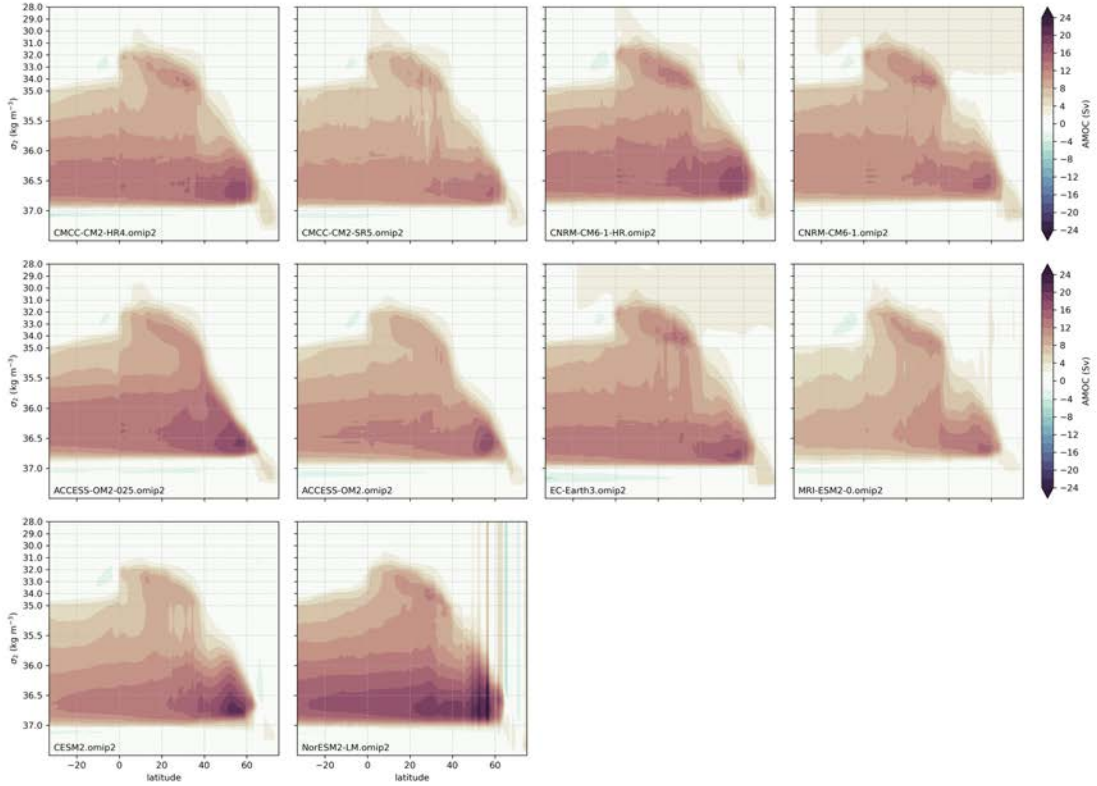
# OMIP1 AMOC (Cycle 5)



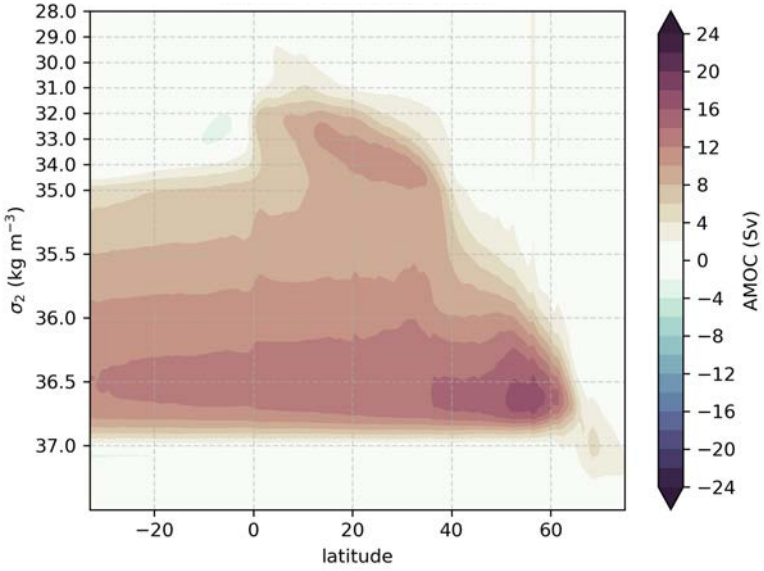

OMIP1 Multimodel Mean



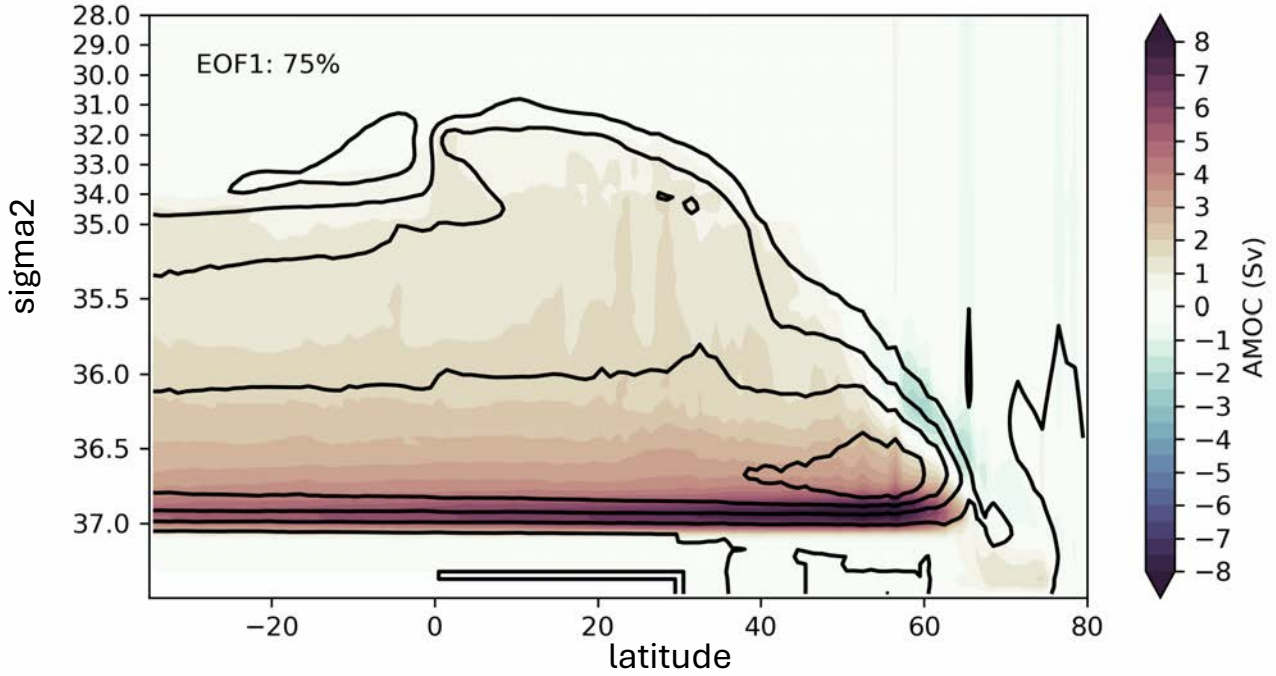
# OMIP2 AMOC (Cycle 5)




OMIP2 Multimodel Mean

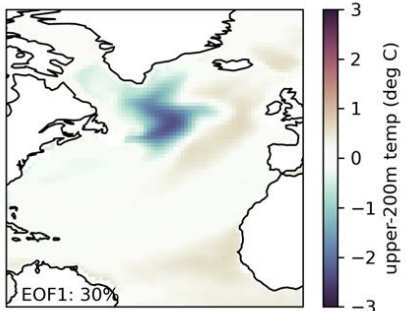


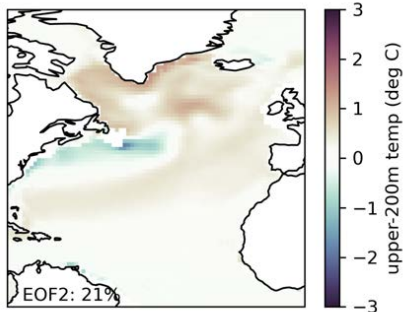
# AMOC EOF1: Stronger AMOC associated with denser deep western boundary current and denser upper branch from 50-70°N

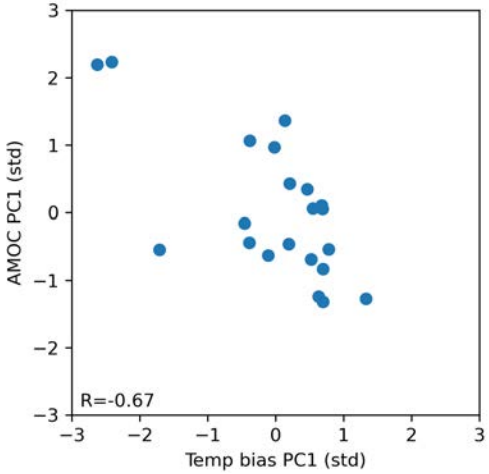



Contours: AMOC multimodel mean

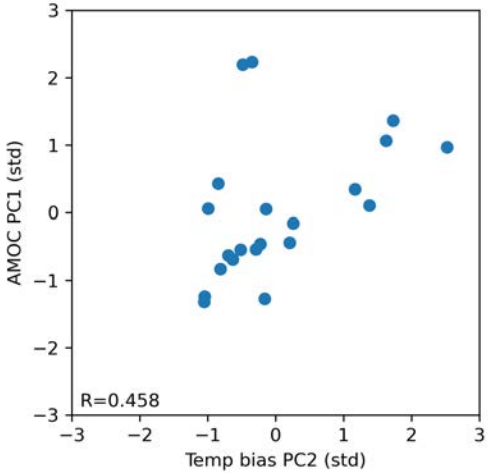
# AMOC(45°N) vs Temperature EOFs



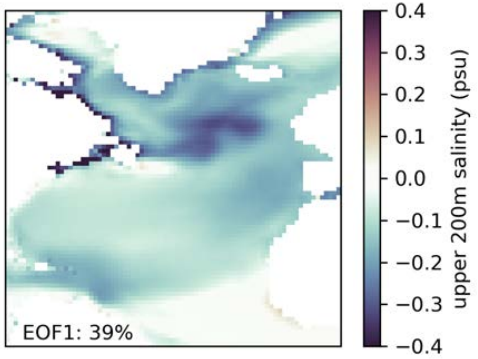



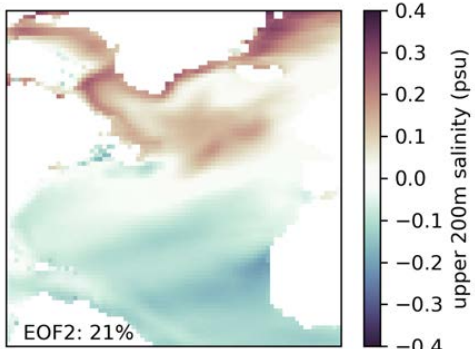

Models with stronger cold spot associated with weaker/lighter AMOC

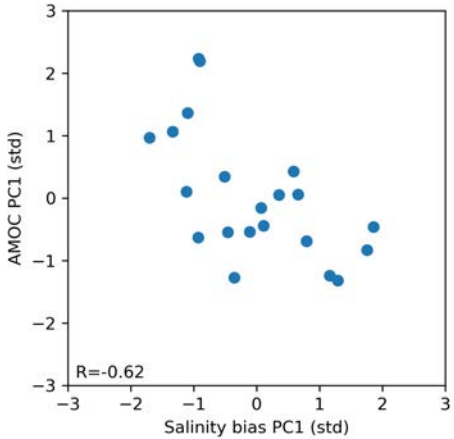



Models with stronger EOF2 pattern associated with stronger/denser AMOC

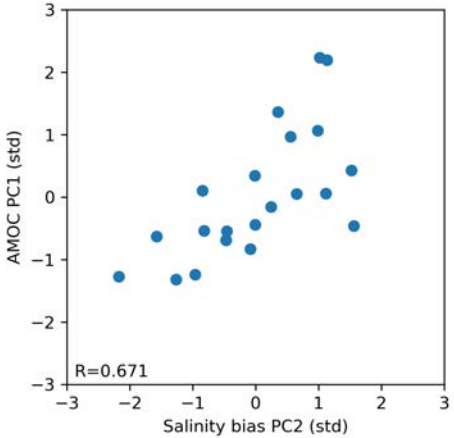
# AMOC(45°N) vs Salinity EOFs



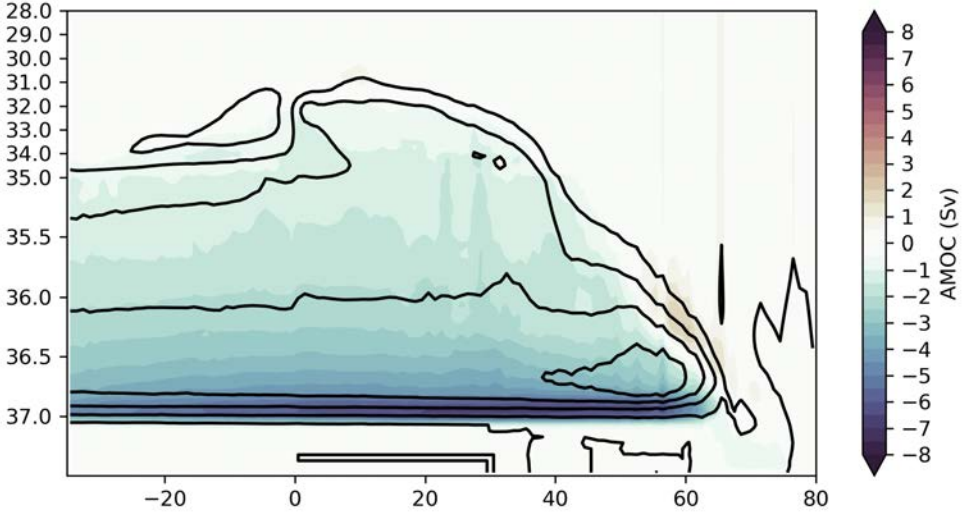

Models with fresh North Atlantic associated with weaker/lighter AMOC



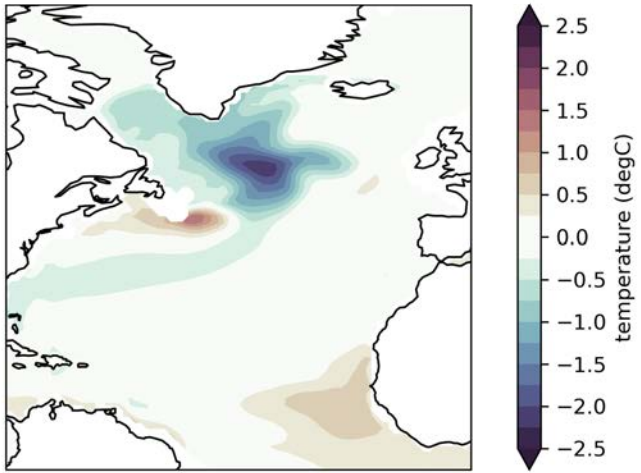

Models with stronger salty subpolar + fresh subtropics associated with stronger/denser AMOC

# Applying Maximum Covariance Analysis of AMOC and upper-ocean temperature in model space

AMOC, left mode 1




Temperature, right mode 1




Root mean square covariance of AMOC and upper ocean temperature: 0.43

MCA Mode 1 explains 86% of the AMOC/temperature covariance

Black contours: mean AMOC

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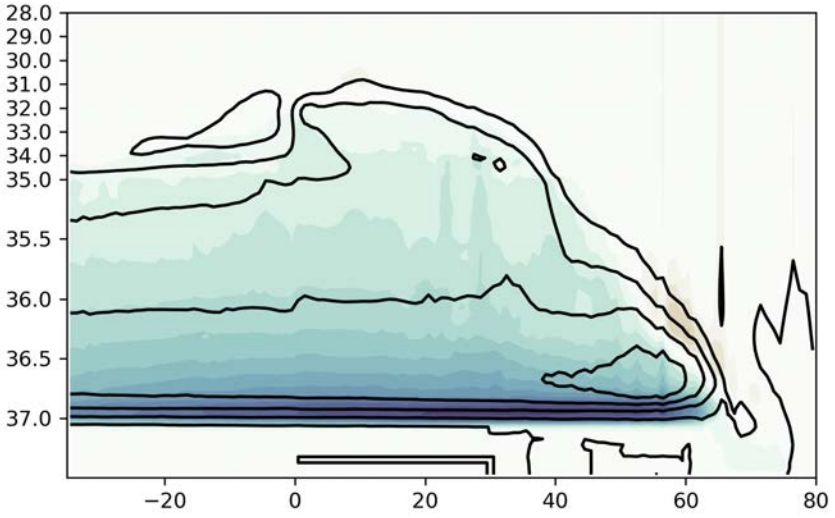
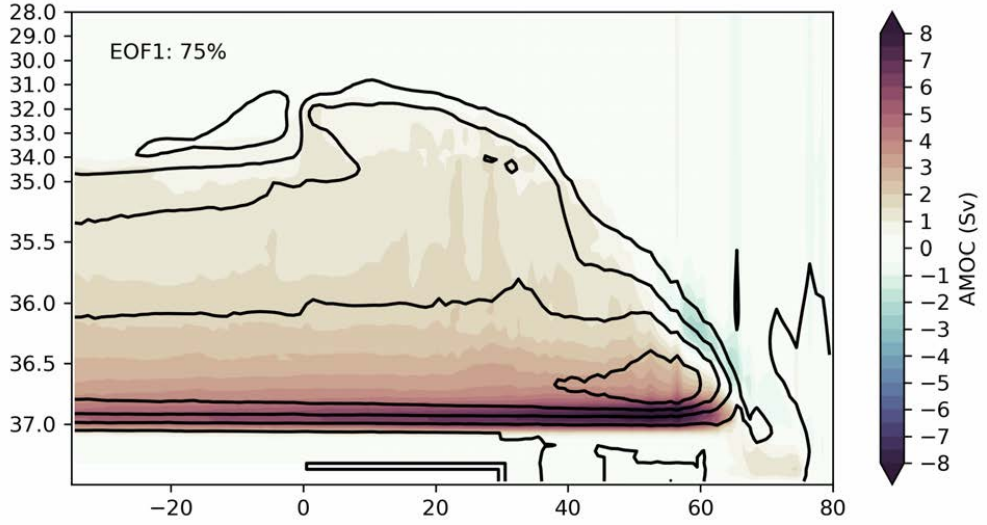


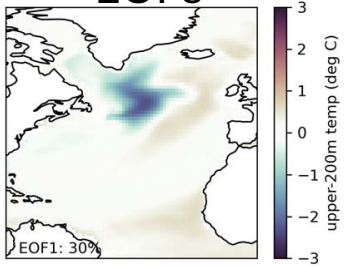

AMOC EOF 1

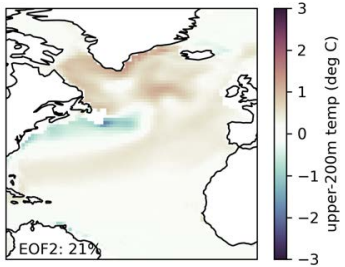



Same pattern, just opposite

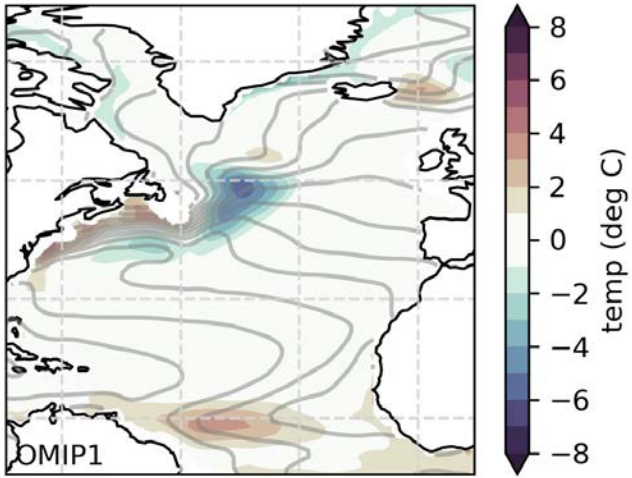
# Applying Maximum Covariance Analysis of AMOC and upper-ocean temperature in model space

EOFs

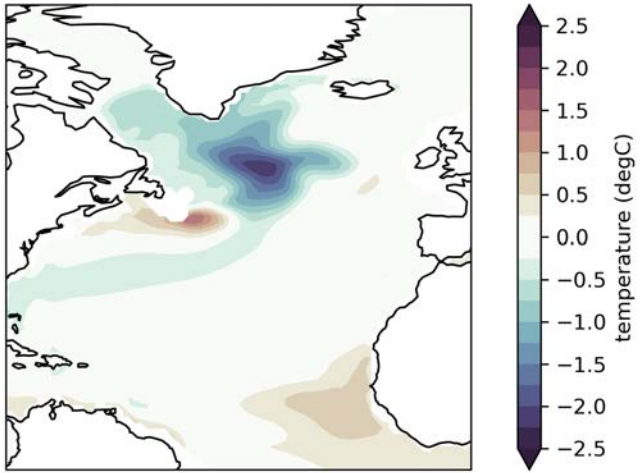



OMIP mean bias pattern




Temperature, right mode 1




Temperature's maximum covariance pattern combines the two EOFs. Both the MCA pattern and the EOFs have loading in the same areas as the SST biases:

Models with greater cold blob variability in the area of greatest temperature biases have weaker AMOCs.

# Summary

- We are processing OMIP simulations for easier multimodel comparison and have a working draft of a model-agnostic AMOC(sigma) routine for CMOR-ized output (and surface-forced WMT – check out Taydra Low's poster!).
- Subpolar North Atlantic temperature and salinity biases co-vary in OMIP simulations
- Models with weaker AMOC have a deep western boundary current and North Atlantic Current at lighter water mass classes.
- A larger magnitude cold+fresh spot in the subpolar North Atlantic is associated with a weaker+lighter AMOC in OMIP simulations.