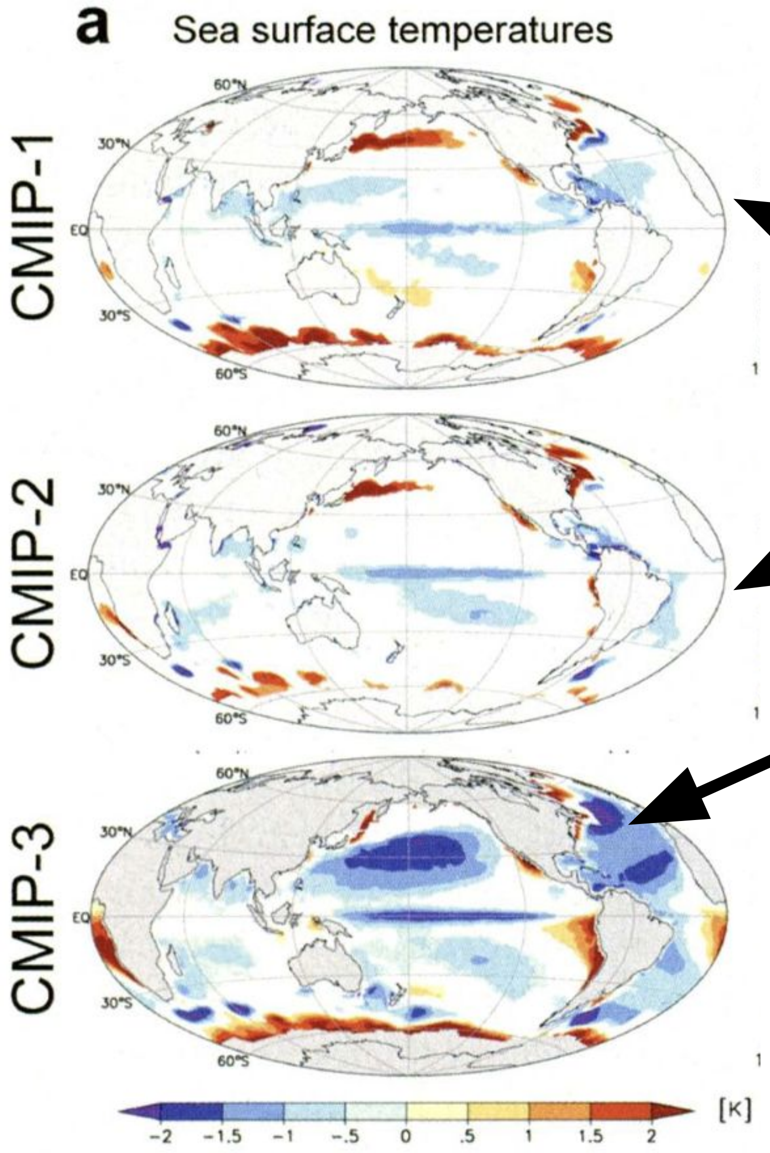
Process-Oriented Diagnostics of the Subpolar North Atlantic for Ocean and Coupled Model Development

Elizabeth Maroon, Steve Yeager, Taydra Low, Brendan Myers, Feng Zhu, Dylan Oldenburg, Teagan King

(Plus a few thoughts at the end from the NOAA Model Diagnostics Task Force)

We gratefully acknowledge support from NOAA MAPP Award NA22OAR4310111

The Problem: Climate models struggle with the sea surface temperature and salinity fields in the Northwest Corner



Multimodel mean biases in sea surface temperature biases *(CMIP1-3 from Reichler and Kim, 2008*

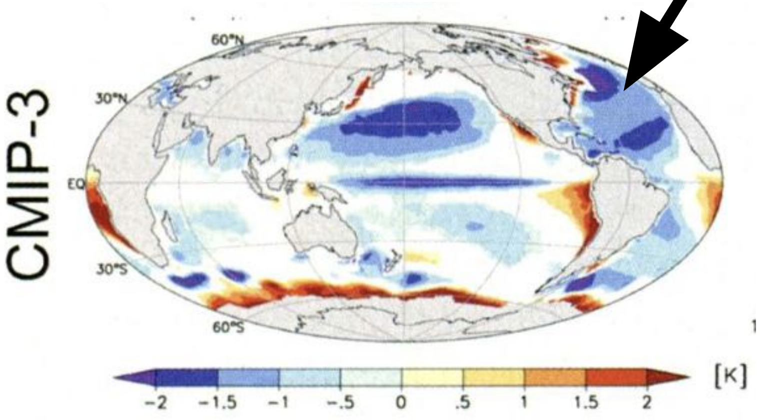
Most CMIP1/2 models were flux-corrected

"the blue spot of death" (Gnanadesikan et al. 2007)

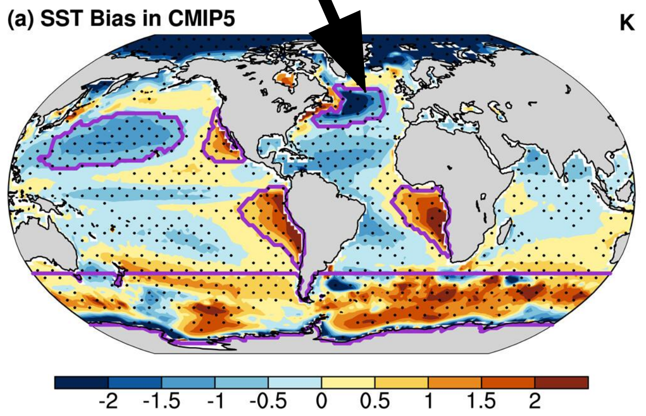
The Problem: Climate models struggle with the sea surface temperature and salinity fields in the Northwest Corner

Multimodel mean biases in sea surface temperature biases *(CMIP3 from Reichler and Kim, 2008 and CMIP5-6 from Zhang et al. 2023)*

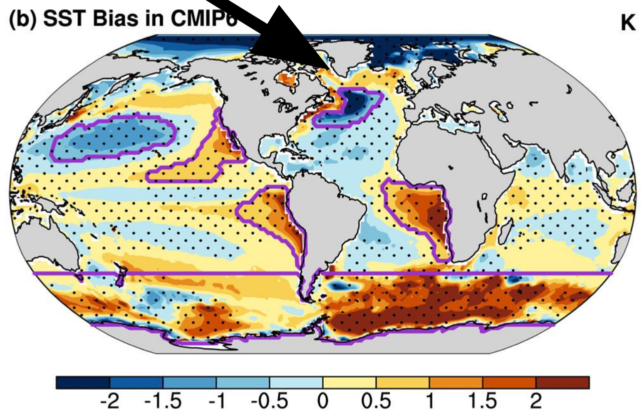
“the blue spot of death” (Gnanadesikan et al. 2007)



CMIP3



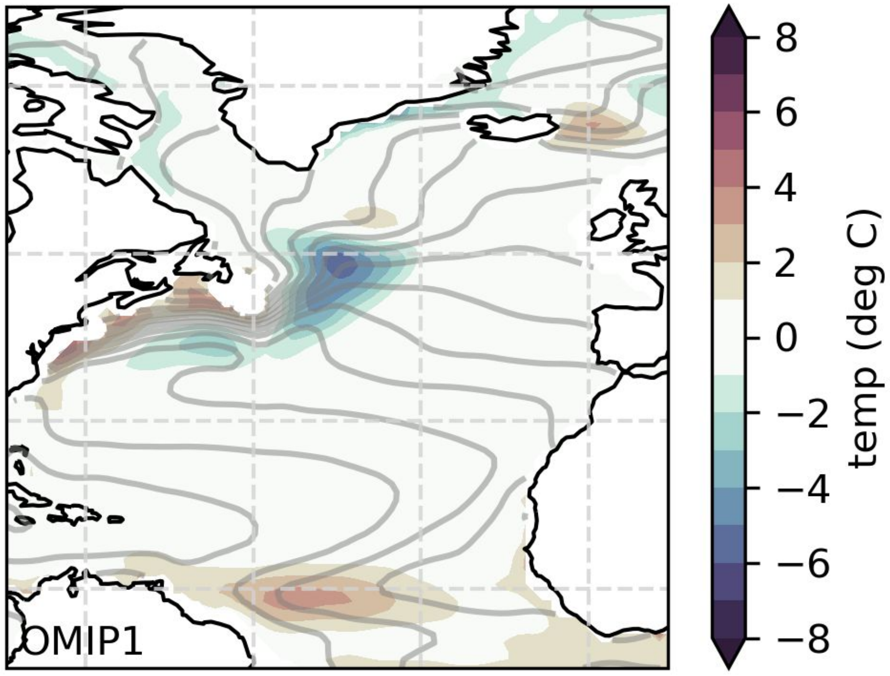
CMIP5



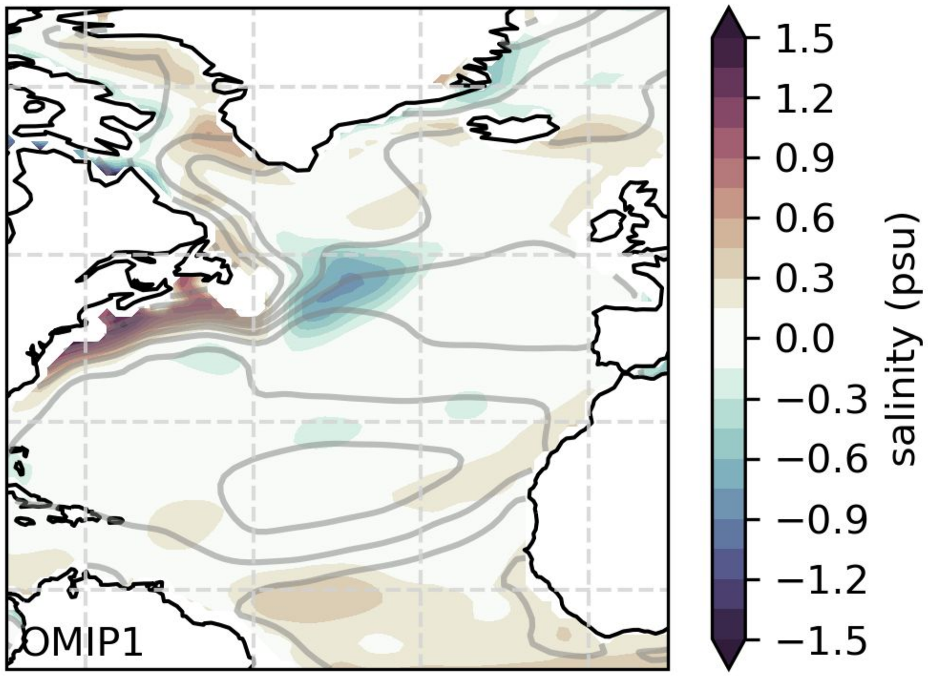
CMIP6

Why? Ocean models consistently place the North Atlantic Current too far east

OMIP1
Upper-Ocean Temperature bias



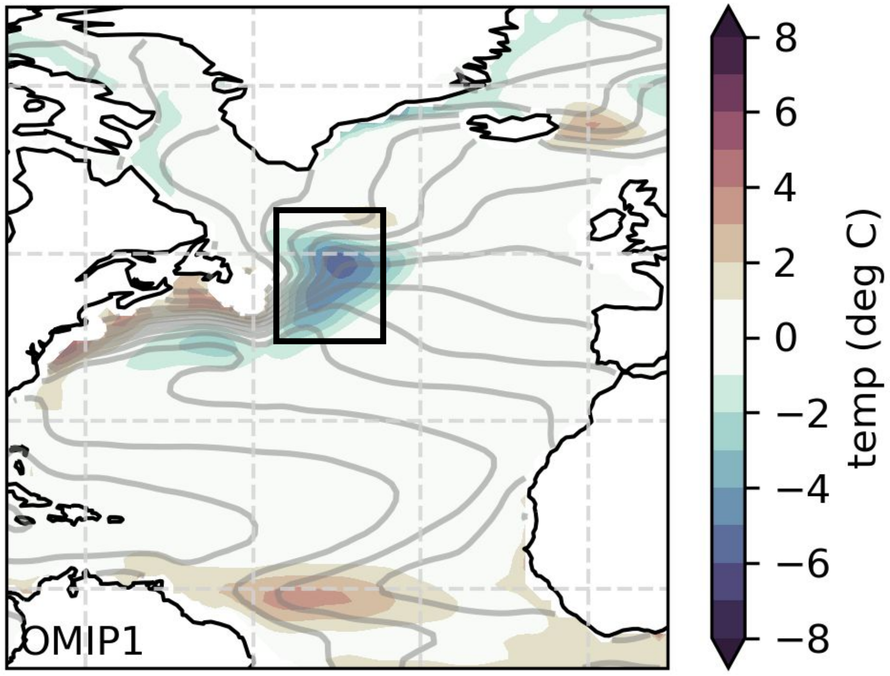
OMIP1
Upper-Ocean Salinity bias

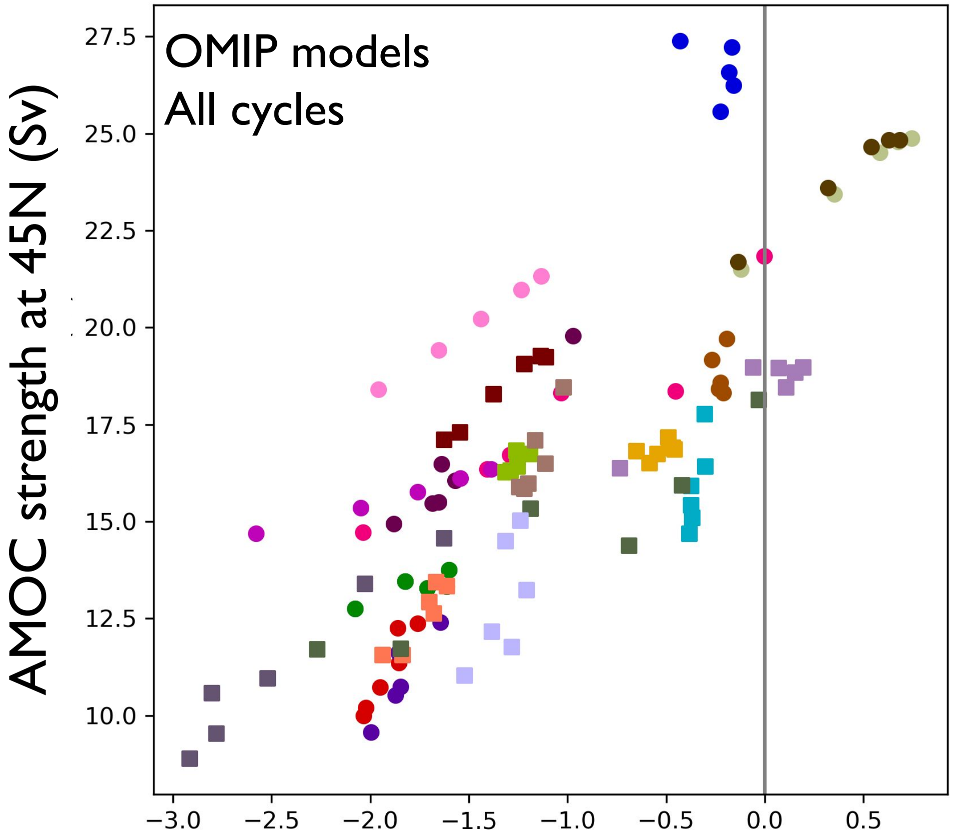


Biases (shading) relative to EN4, 1978-2007 means.
EN4 climatology in gray contours.

Inter-related issues for the ocean: Colder+fresher NW Corner bias weaker AMOC

Upper-Ocean Temperature bias

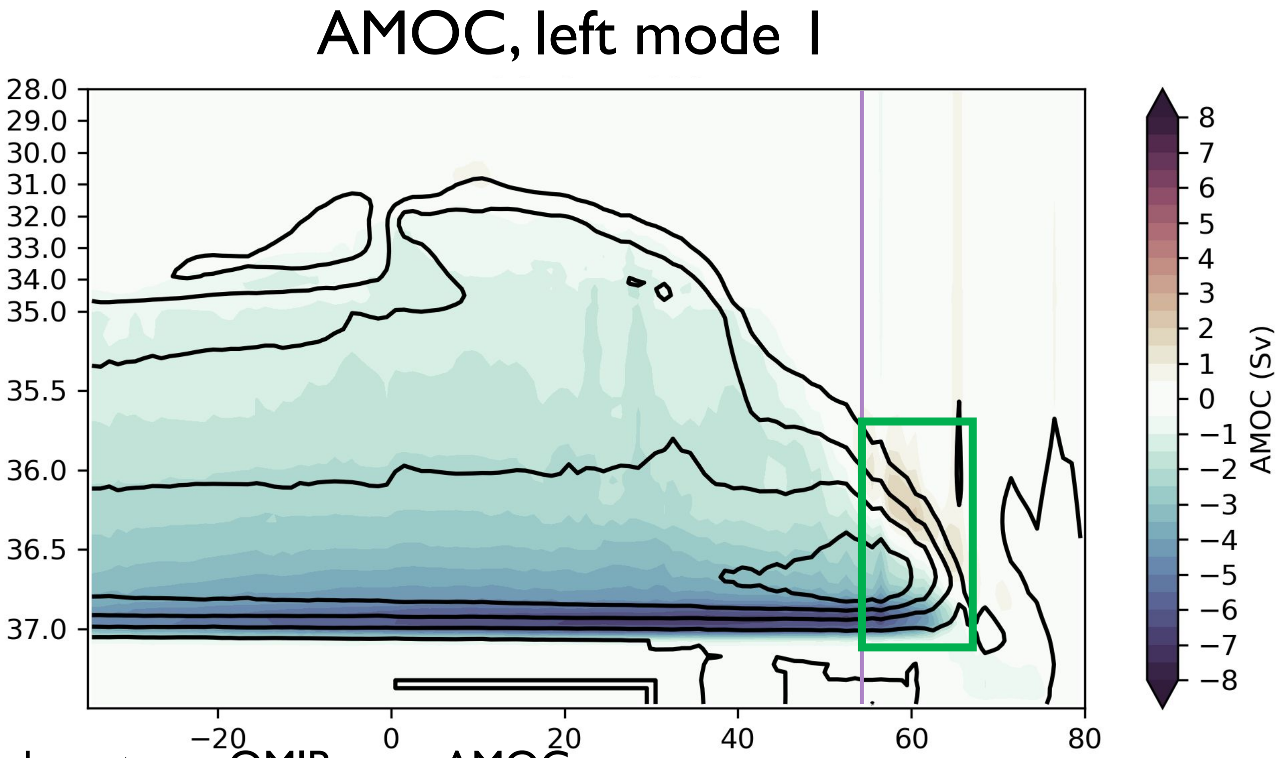


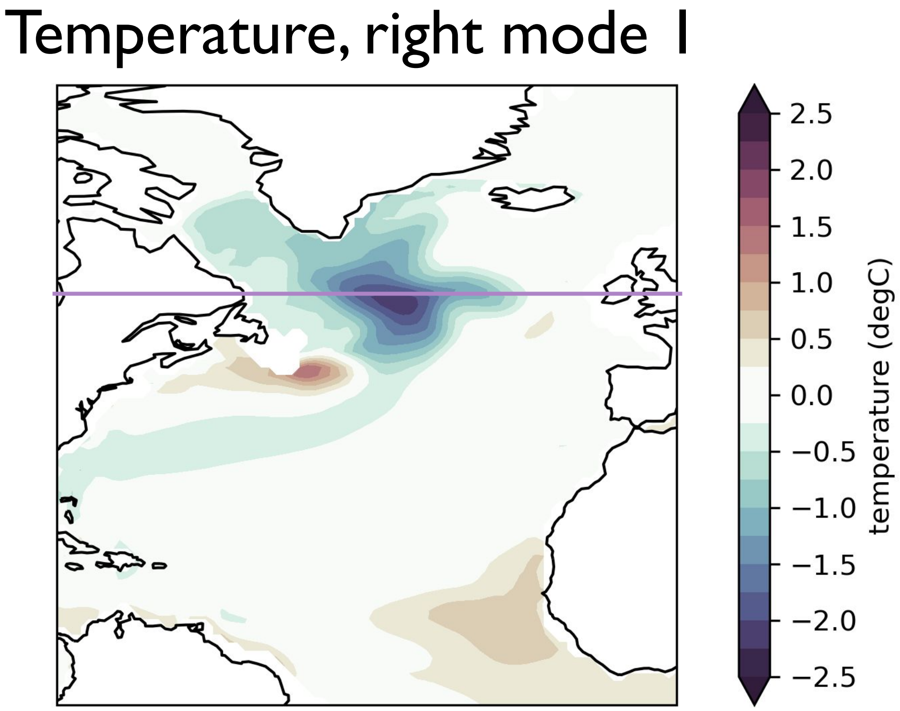


Biases (shading) relative to EN4, 1978-2007 means.
EN4 climatology in gray contours.

Models with more intense cold bias also have weaker AMOC and a North Atlantic Current-extension+a Deep Western Boundary Current shifted toward lighter density classes

Maximum Covariance Analysis of AMOC and upper-ocean temperature across OMIP space



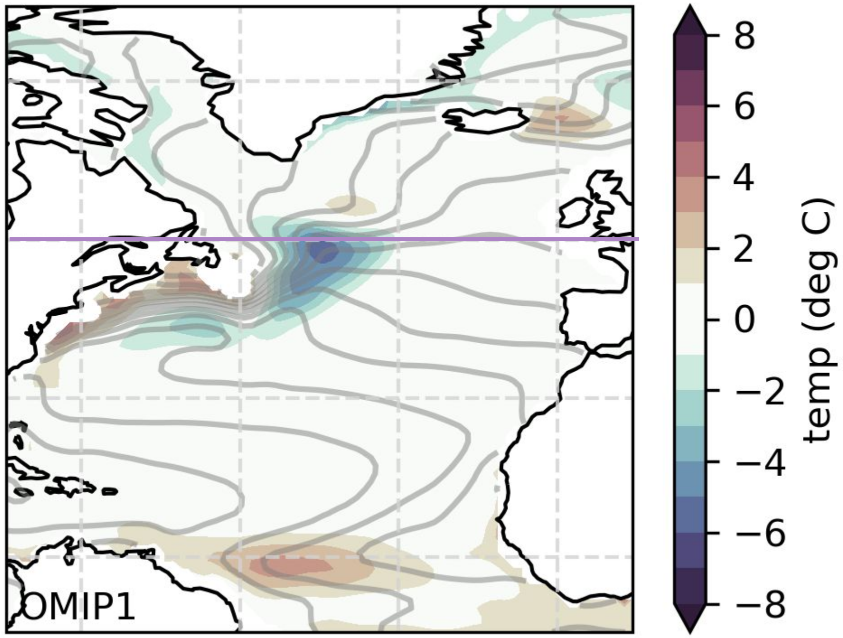


Black contours: OMIP-mean AMOC

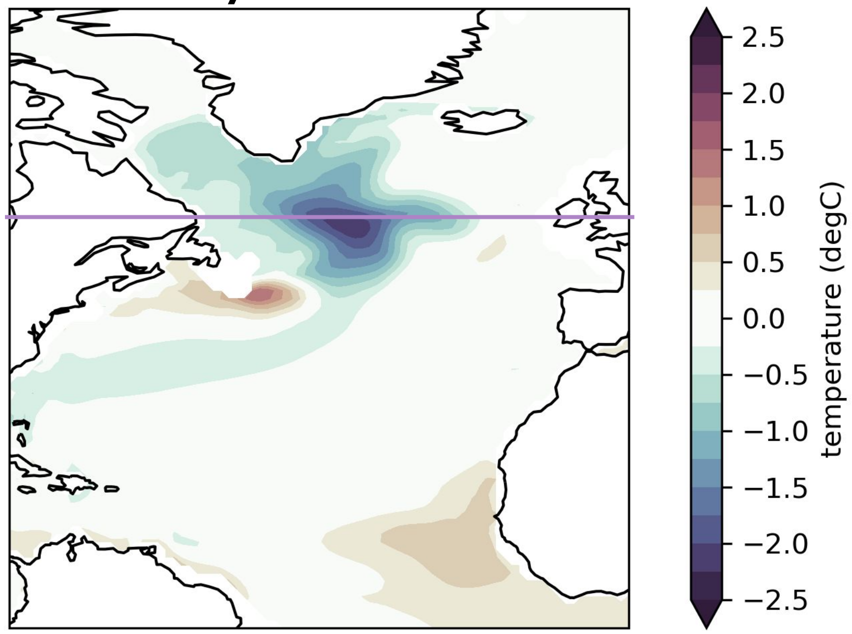
Root mean square covariance of AMOC and upper ocean temperature: 0.43
MCA Mode 1 explains 86% of the AMOC/temperature covariance

Northwest Corner cold bias exists on southern half of the Model-MCA pattern

OMIP-mean Temperature Bias



Temperature pattern associated with AMOC variability across models



Gray contours: EN4 200m upper-ocean mean temperature

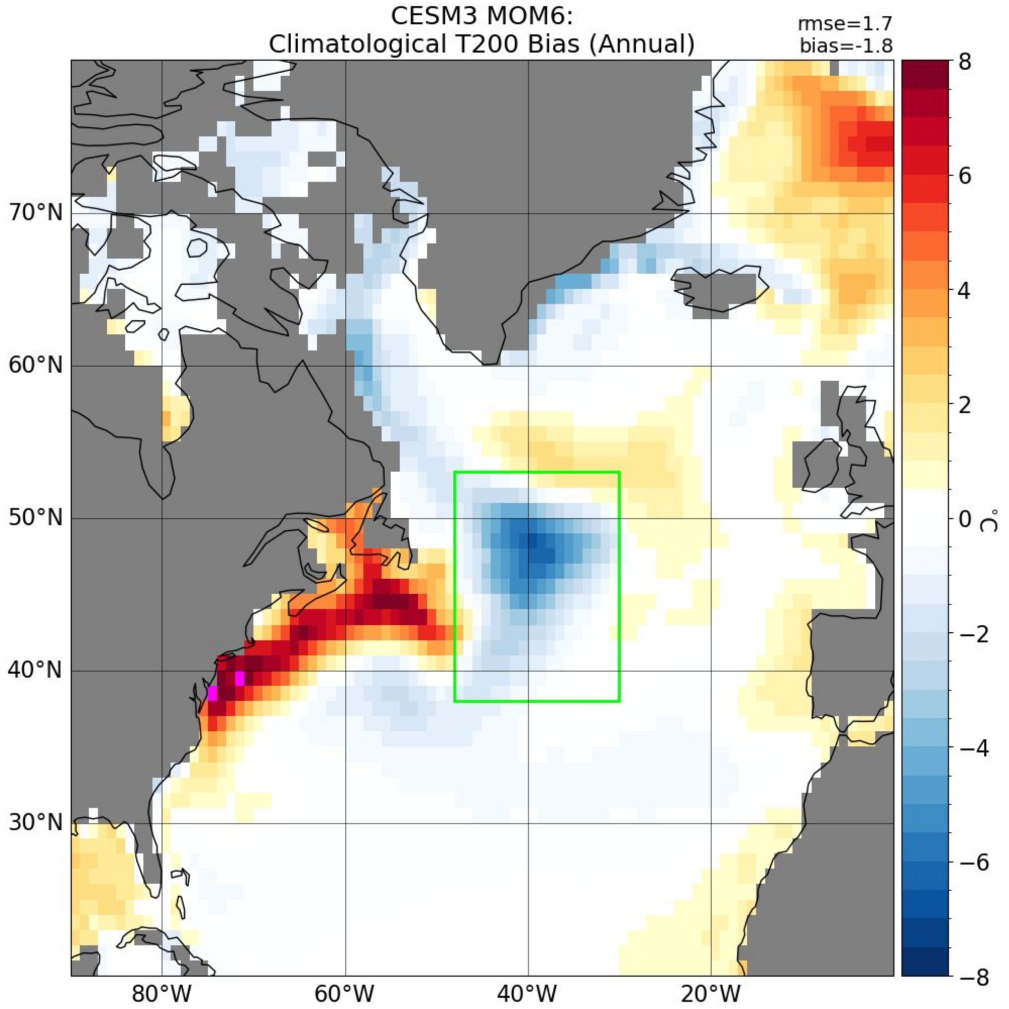
Reducing North Atlantic bias and its interrelated effects on the AMOC would be desirable for CMIP7 models

Our project: A diagnostic suite to aid developers with this difficult set of inter-related biases

Features of the package:

- Compares North Atlantic biases to OMIP simulations
- AMOC in density coordinates for comparison to WMT
- Observational Benchmarks for Water Mass Transformation (*Low et al., in prep*)
- Connect North Atlantic upper-ocean biases to WMT biases

Feature 1: Comparing an under-development run to the suite of OMIP simulations



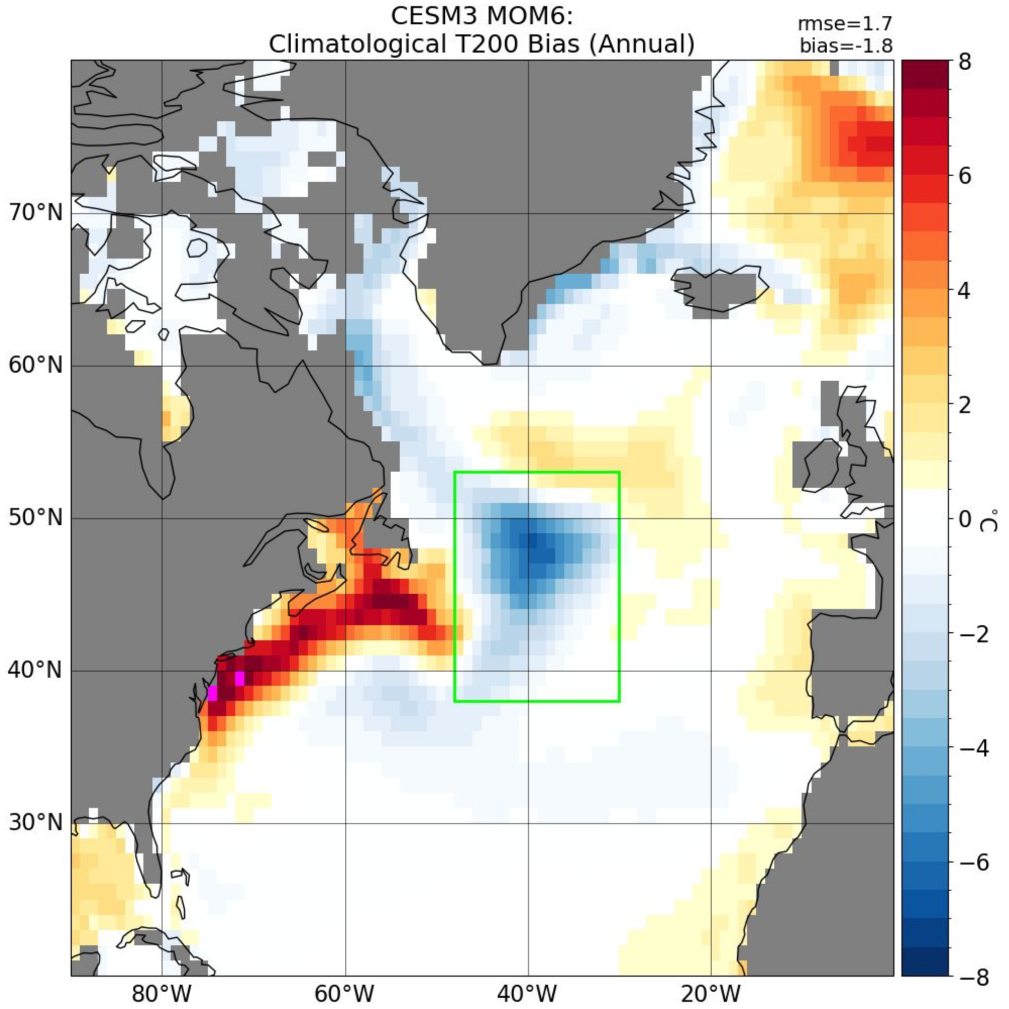
Upper-200m temperature bias

CESM3-MOM6-exp
minus
EN4

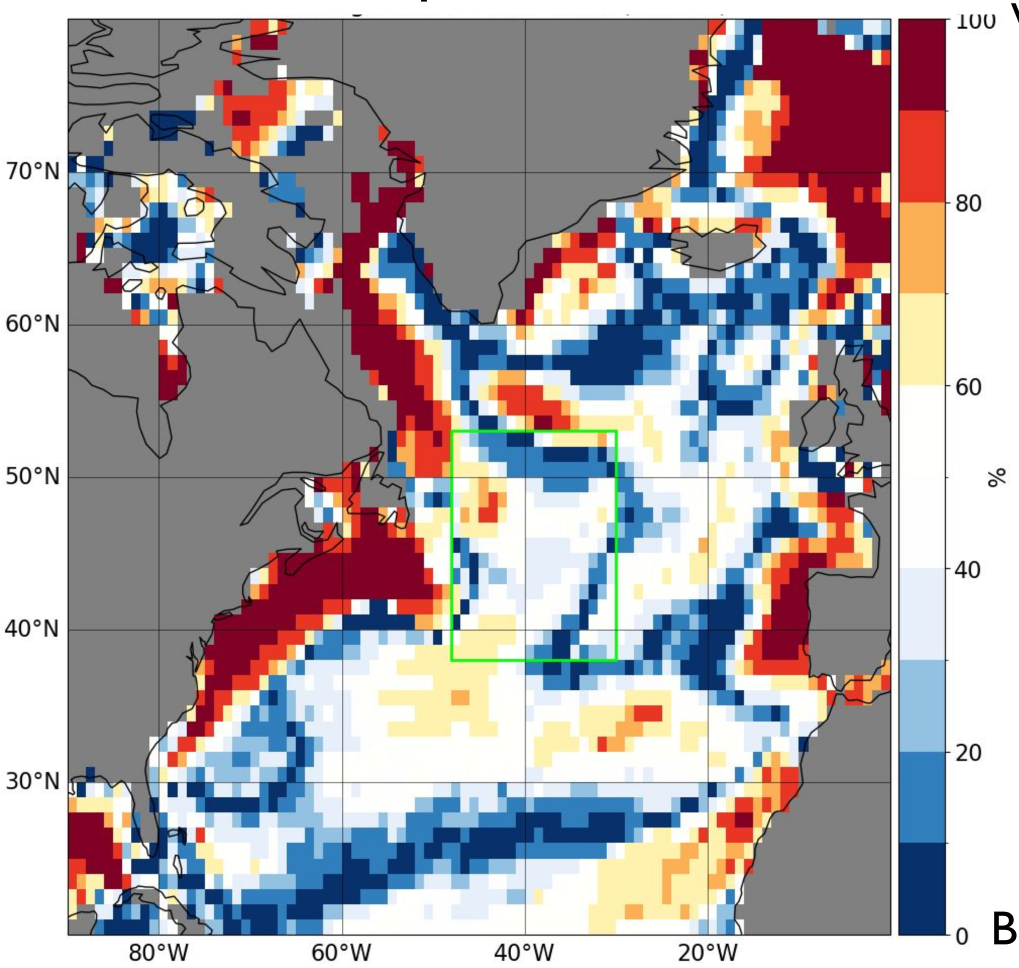
Figure by Brendan Myers and Steve

Thanks to Gustavo Marques for access to the under-development CESM3 run for diagnostic testing purp

CESM3 biases ranked by relative to OMIP ensemble



Bias rank compared to OMIP suite



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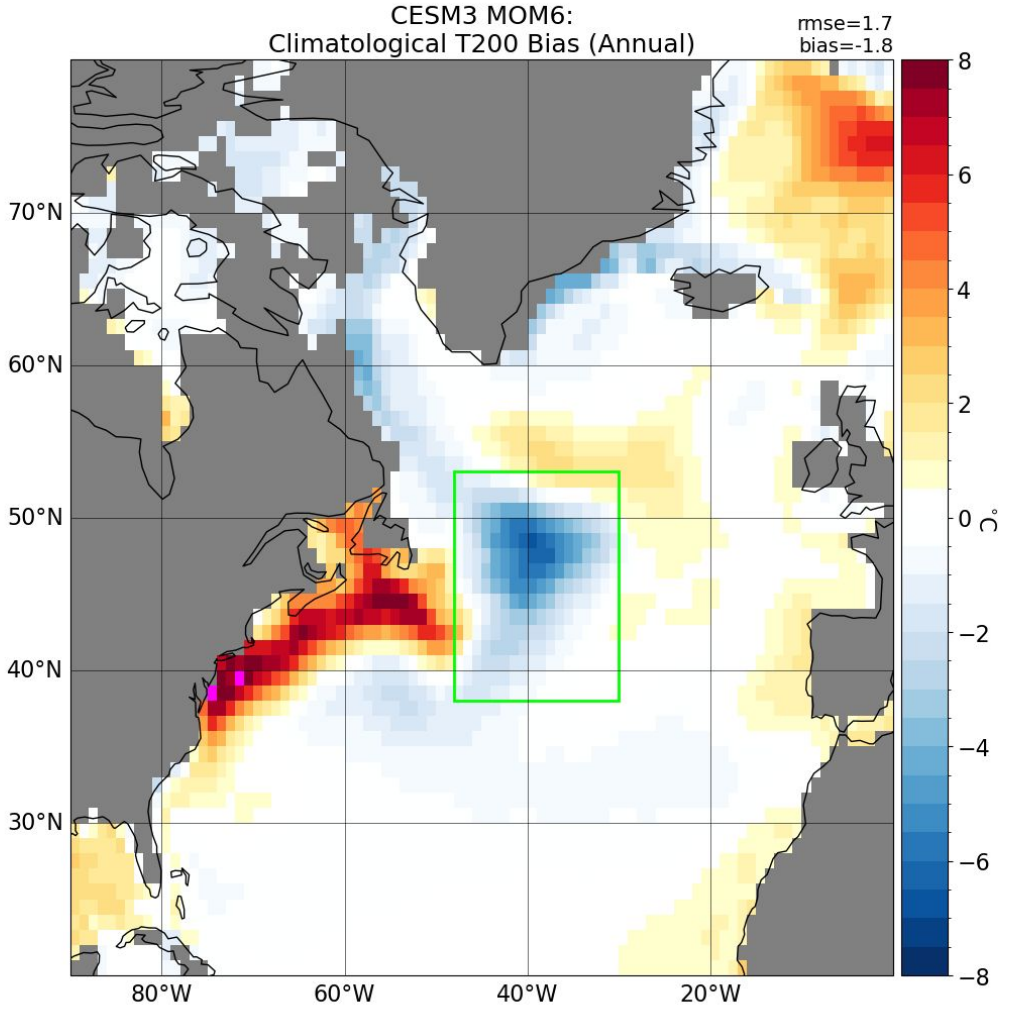
CESM3 upper-ocean temperature biases ranked by relative to OMIP ensemble



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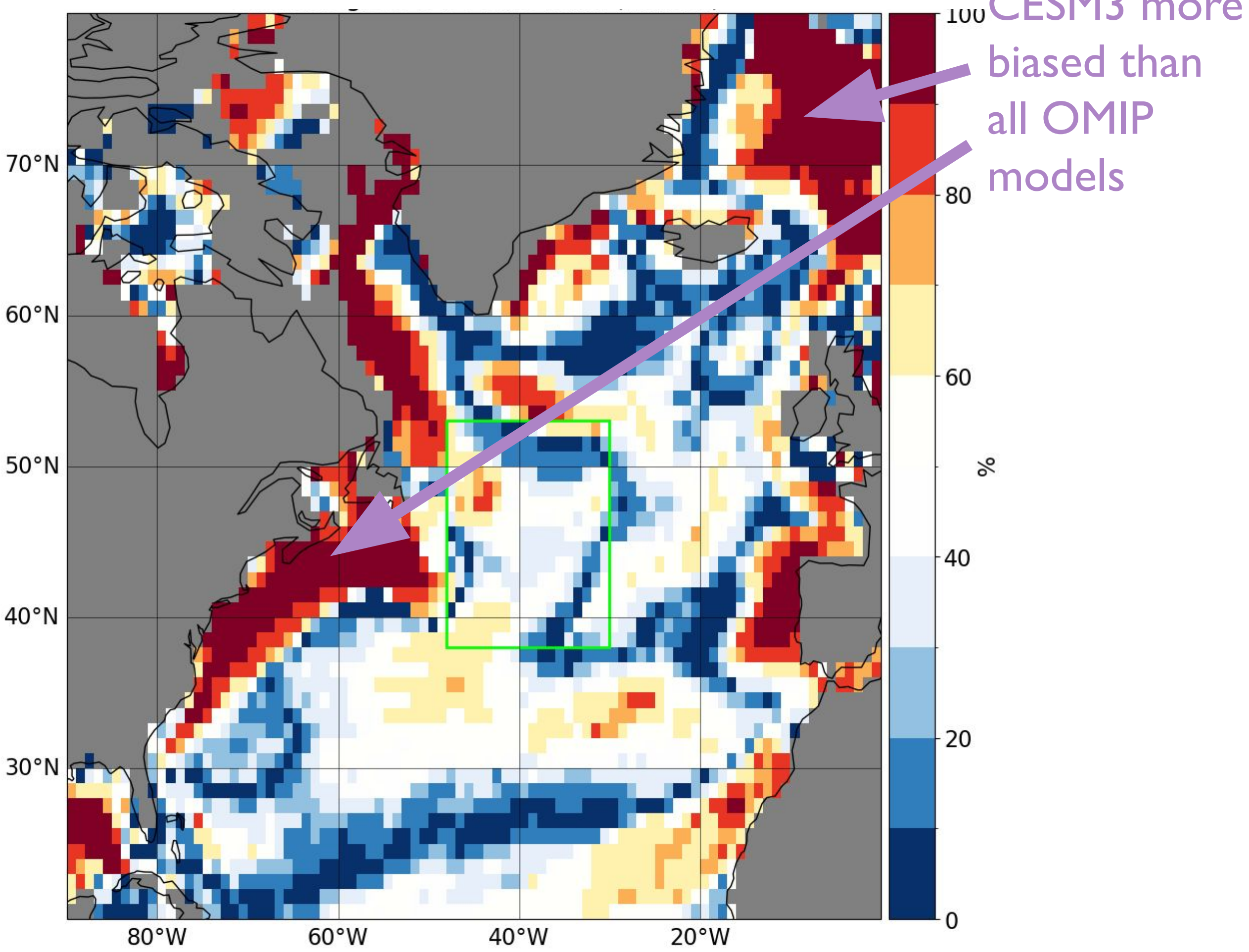

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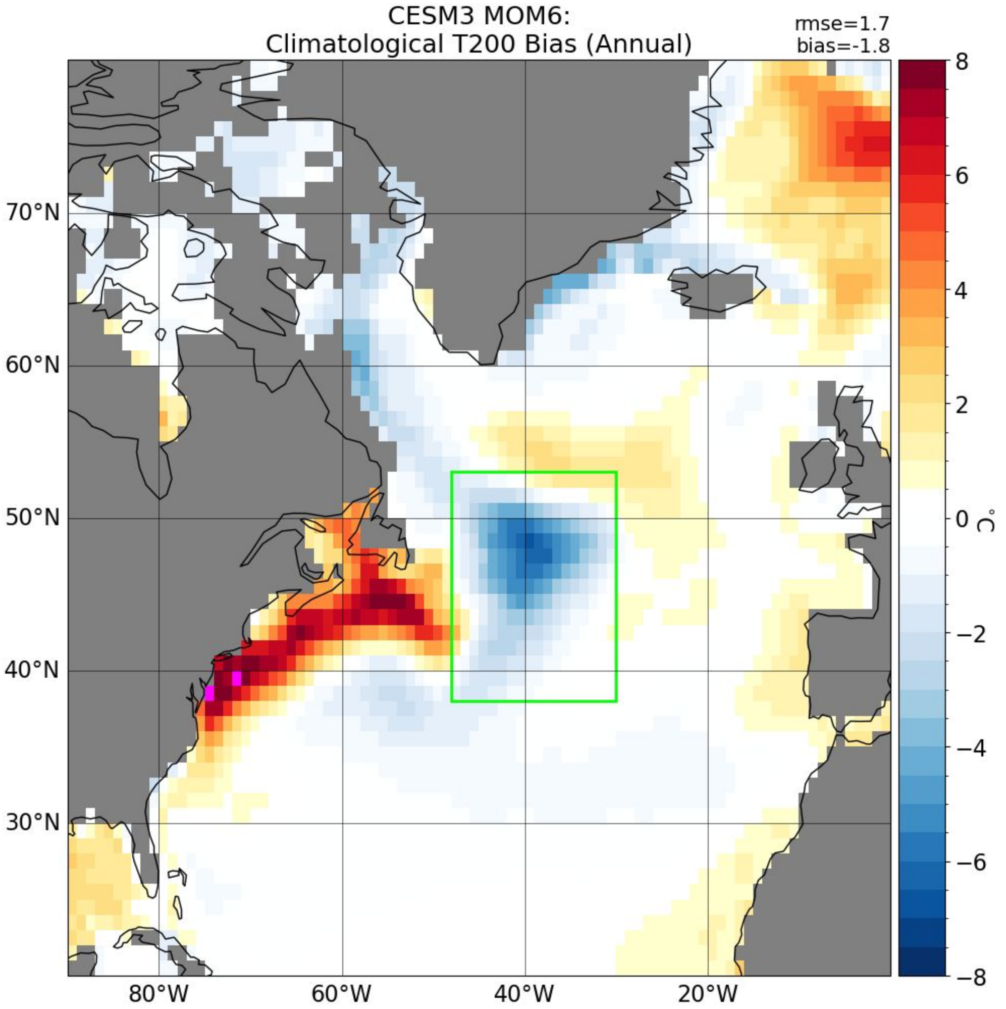

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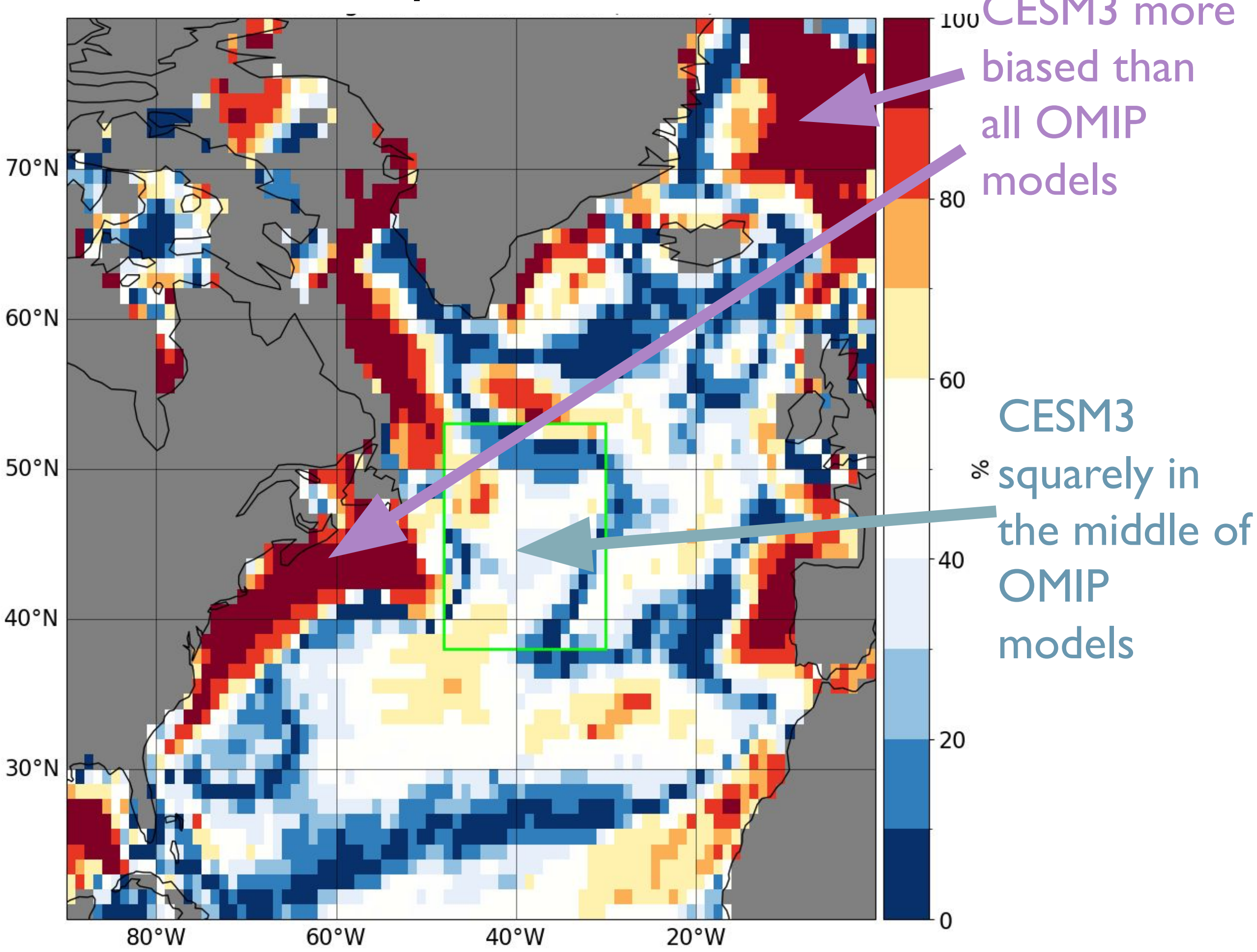

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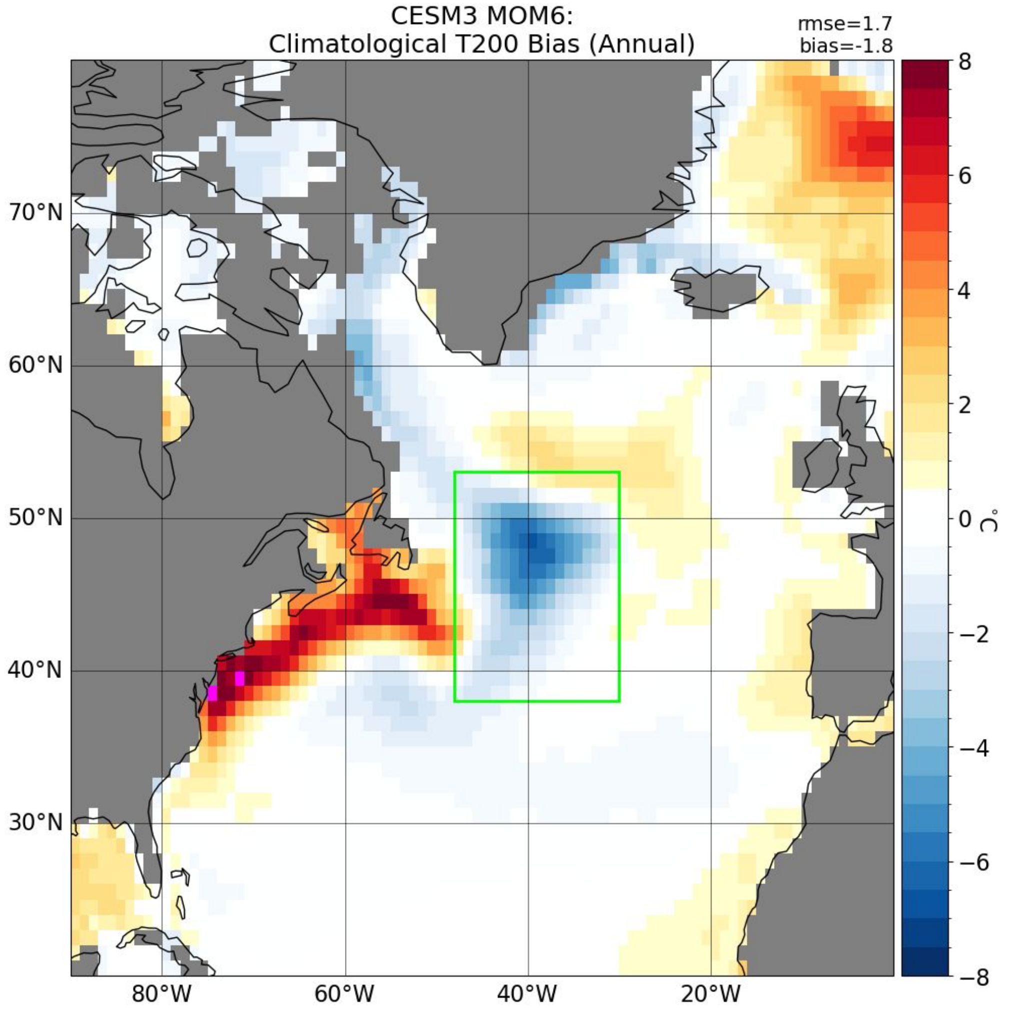

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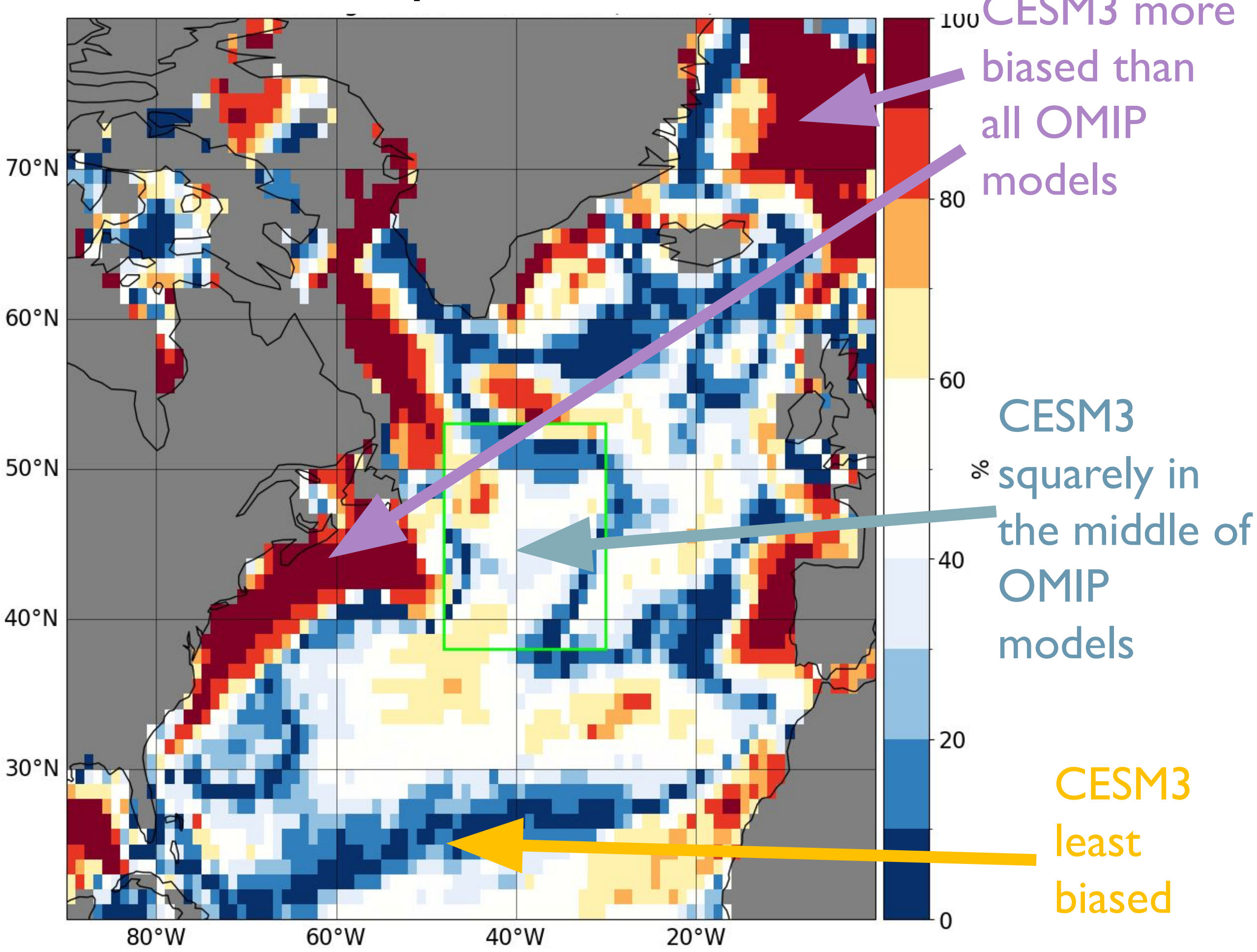

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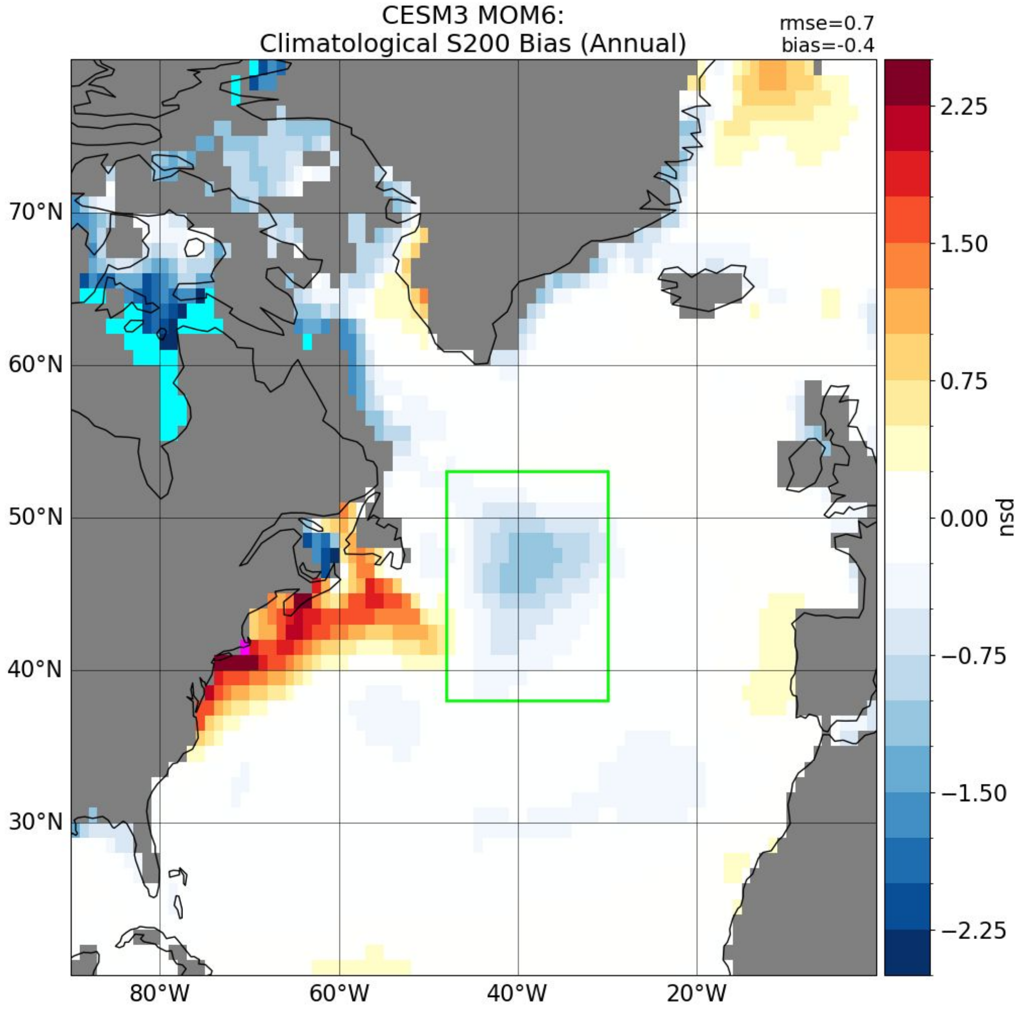
Bias+rank analysis also produced for salinity



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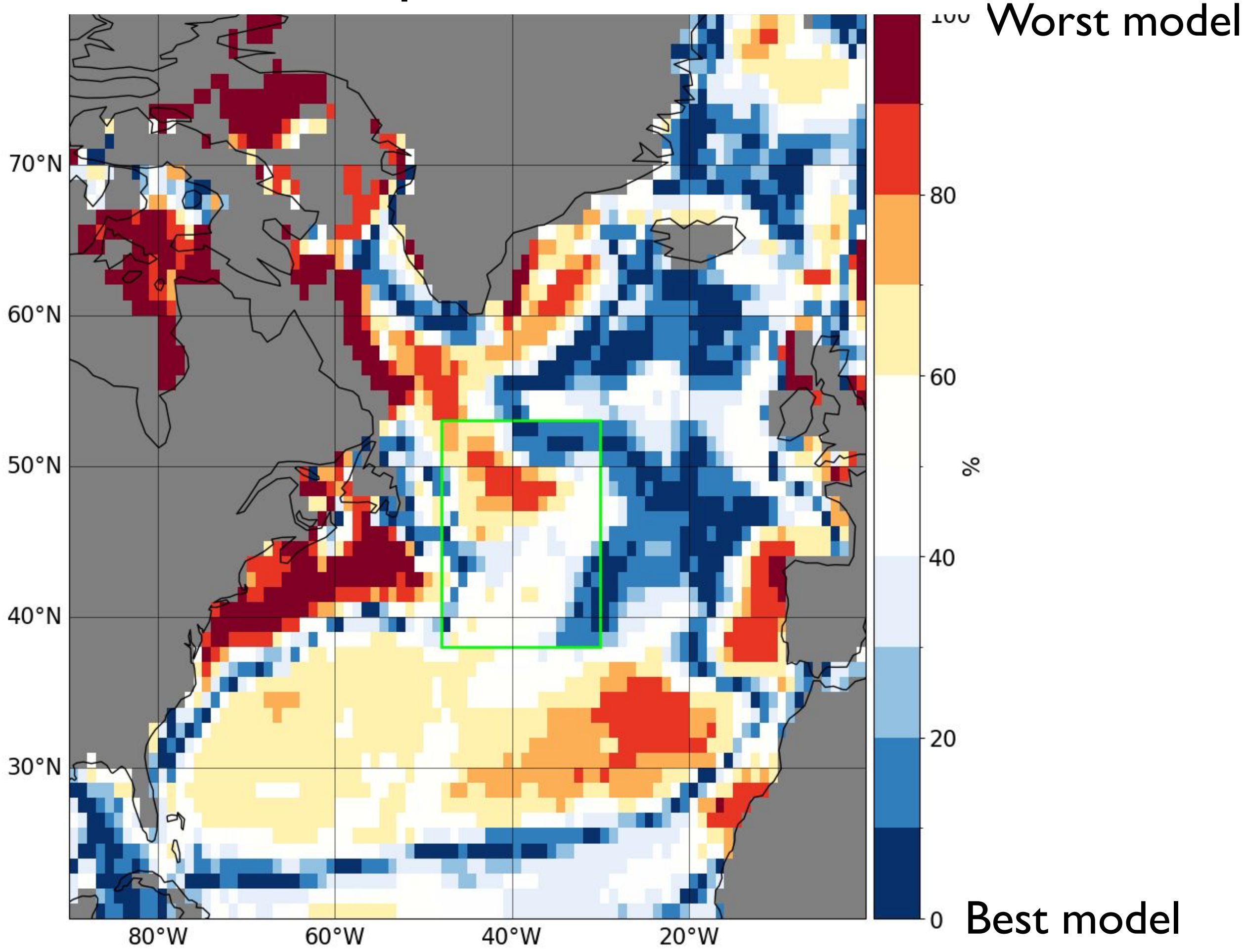

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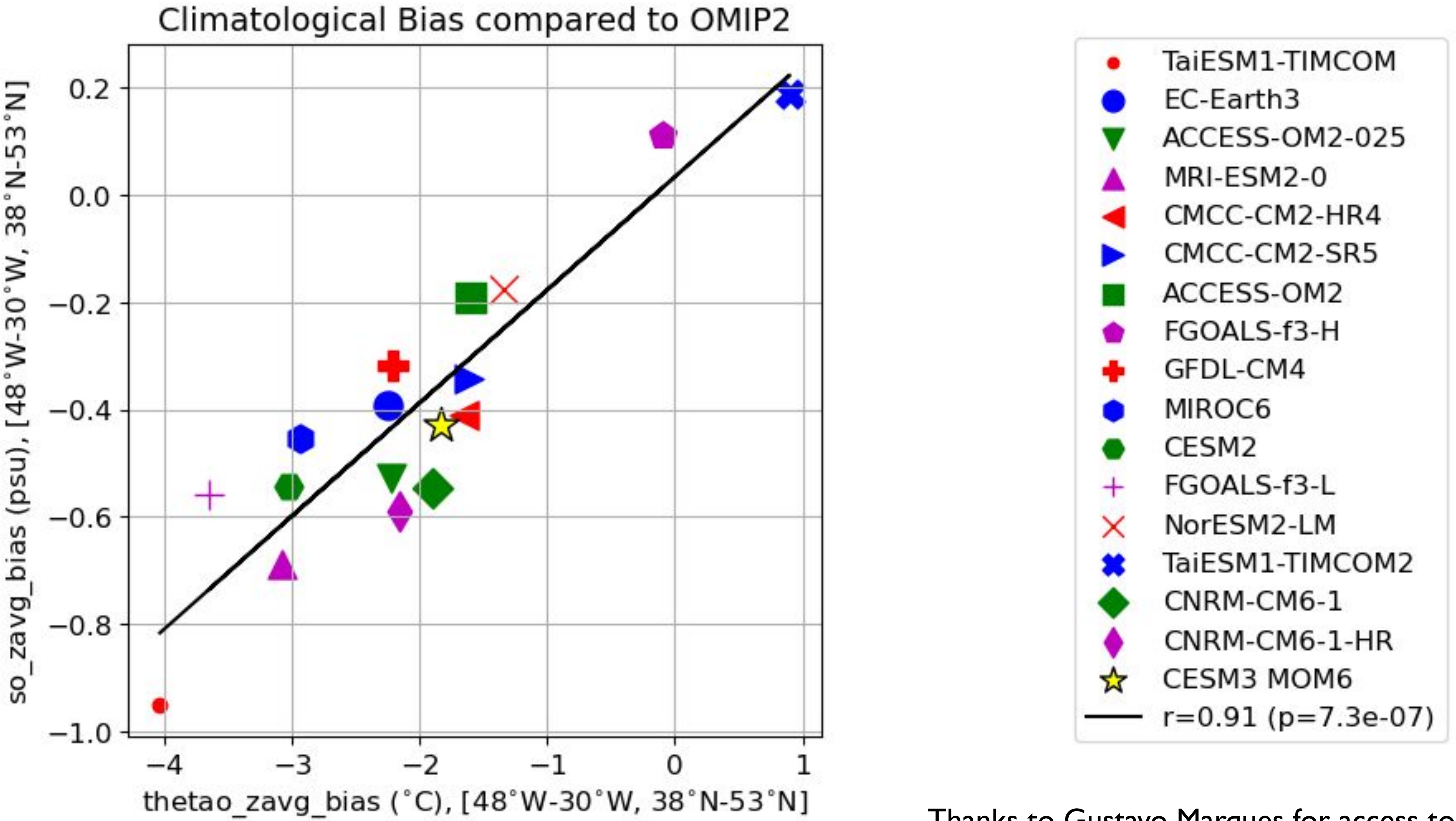

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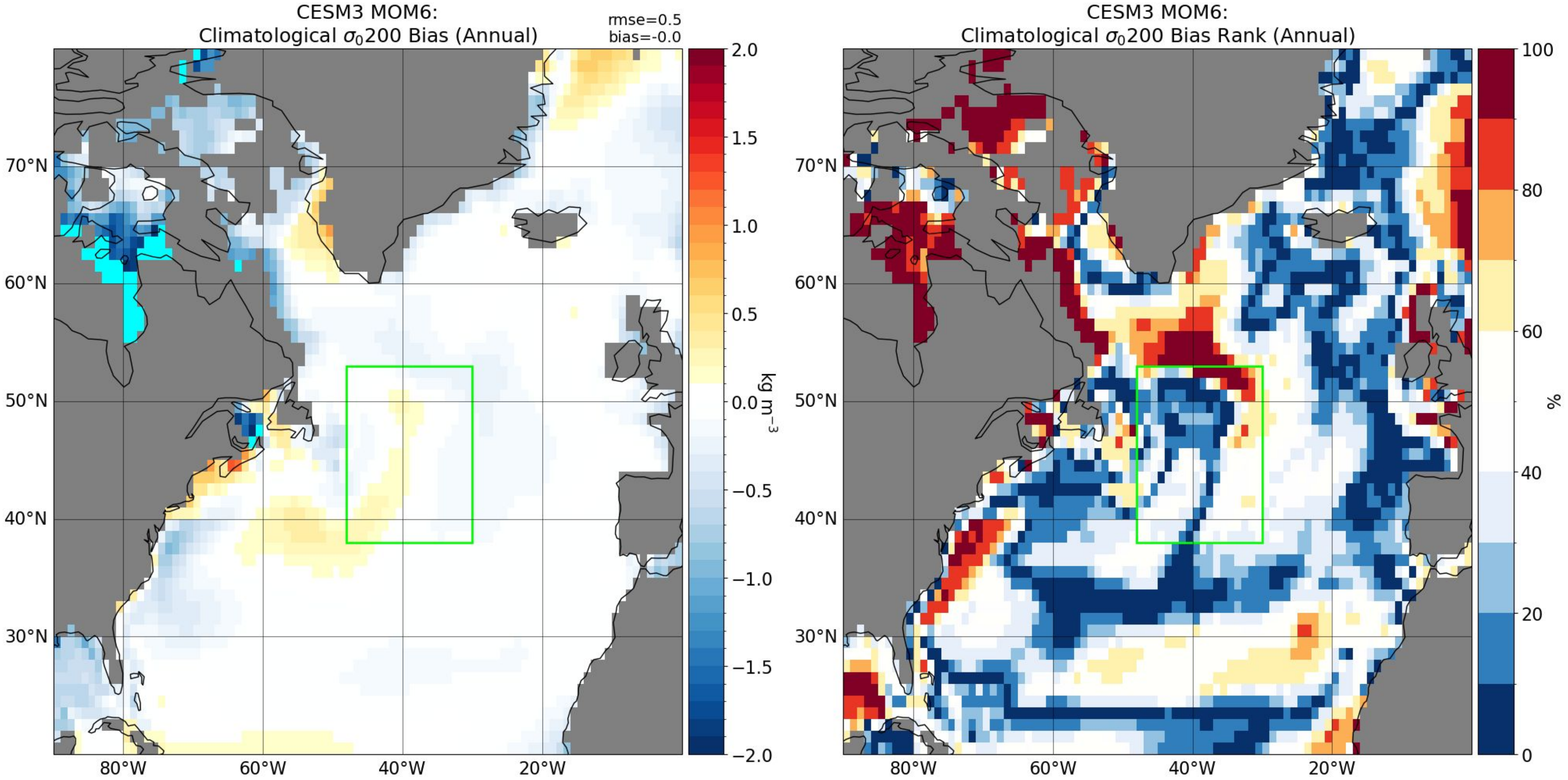
Largely compensating temperature and salinity biases in the Northwest Corner region



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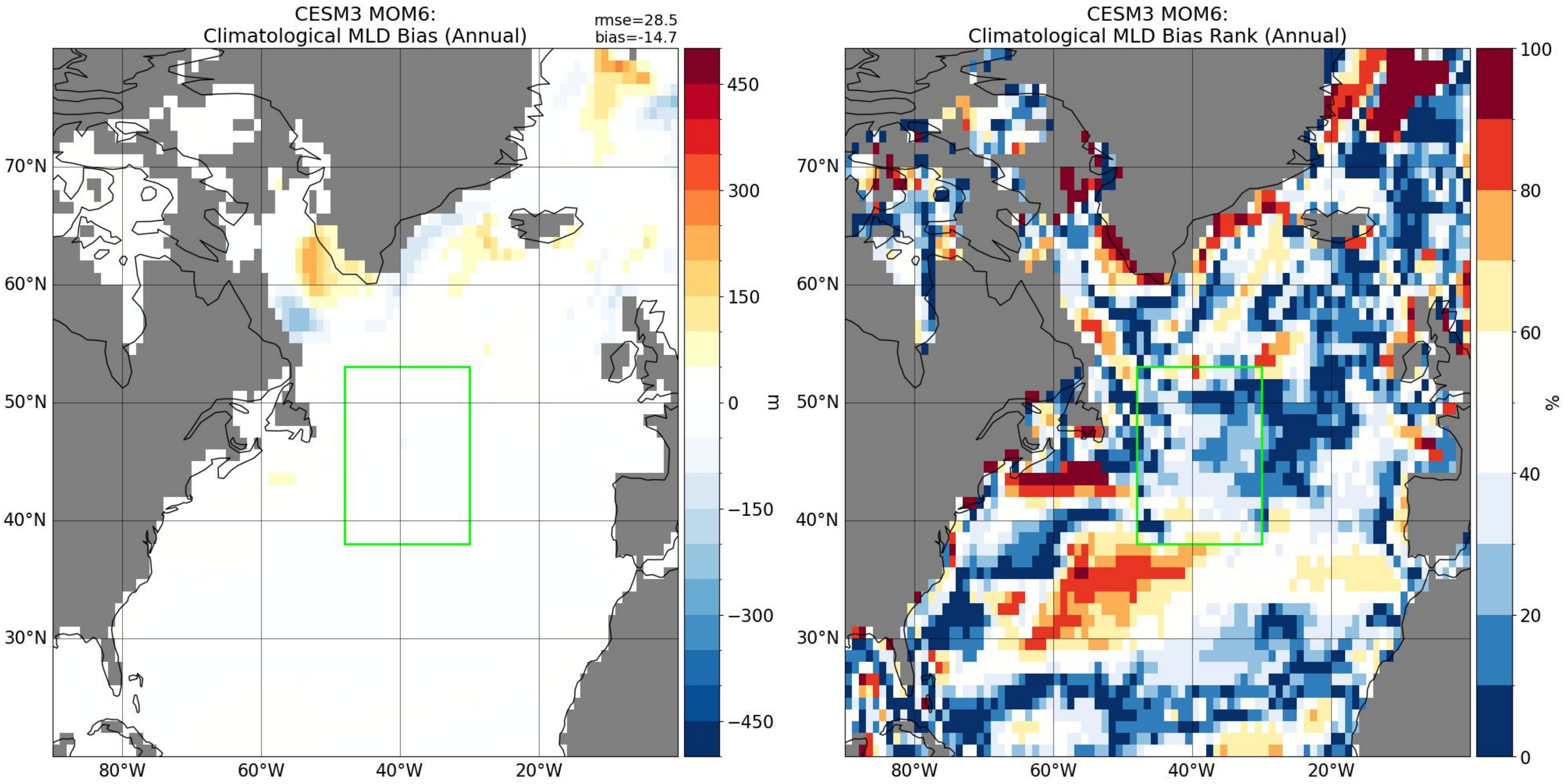
Similar rank figures for other relevant fields (like mixed layer depth)



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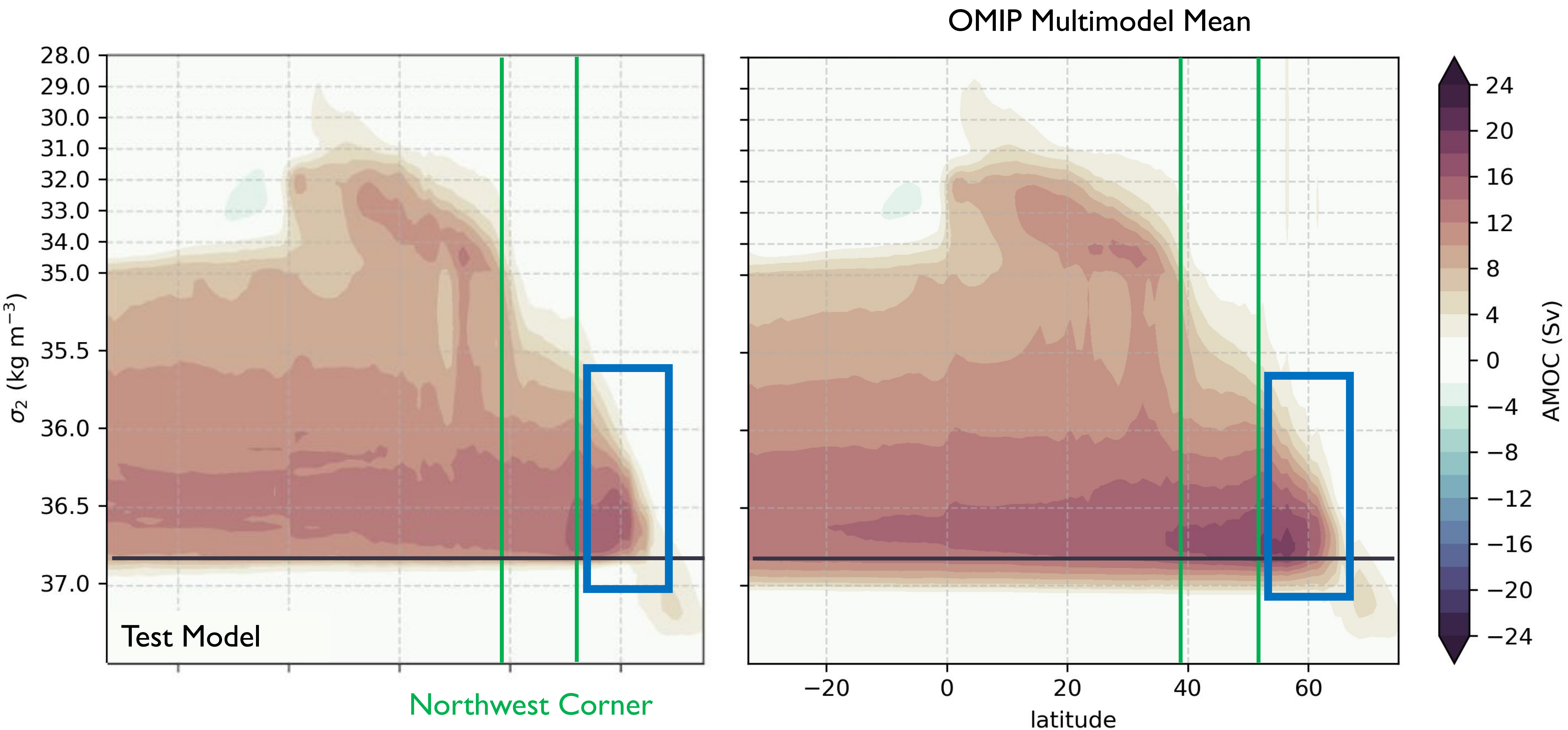
Feature 2: AMOC(σ_2) streamfunction for comparison to WMT

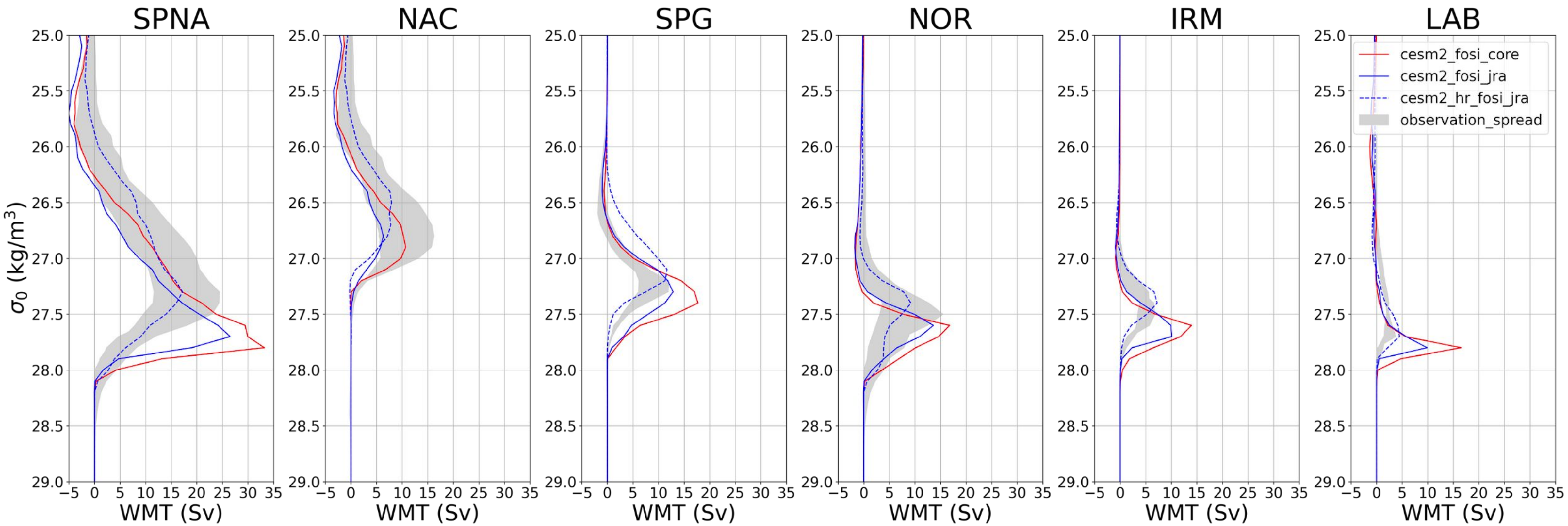


Shifts in NAC+DWBC to different water classes

Feature 2: AMOC(σ_2) streamfunction for comparison to WMT

Figure from Taydra Low

Feature 3: Analysis of WMT by region and density class compared to observation-based estimates

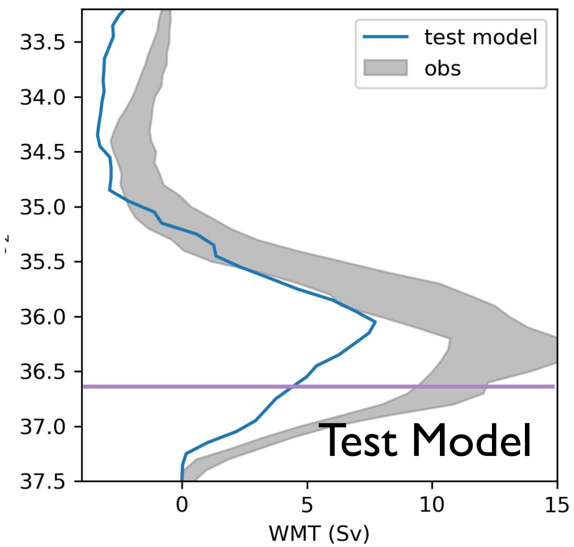


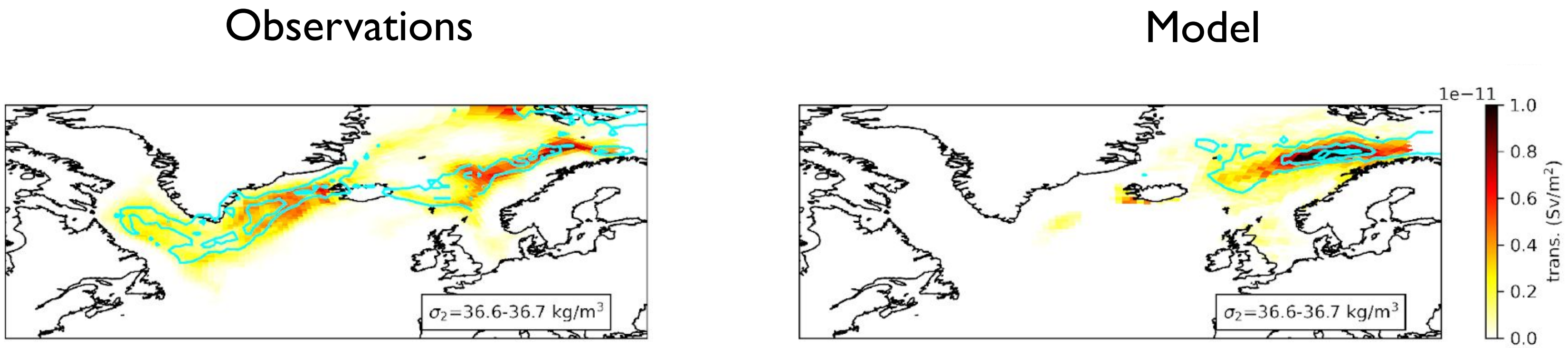
Gray shading: Observational WMT benchmarks

Red and blue lines: Model simulations

Figure from Taydra Low

Feature 4: Connecting upper-ocean biases to where WMT occurs



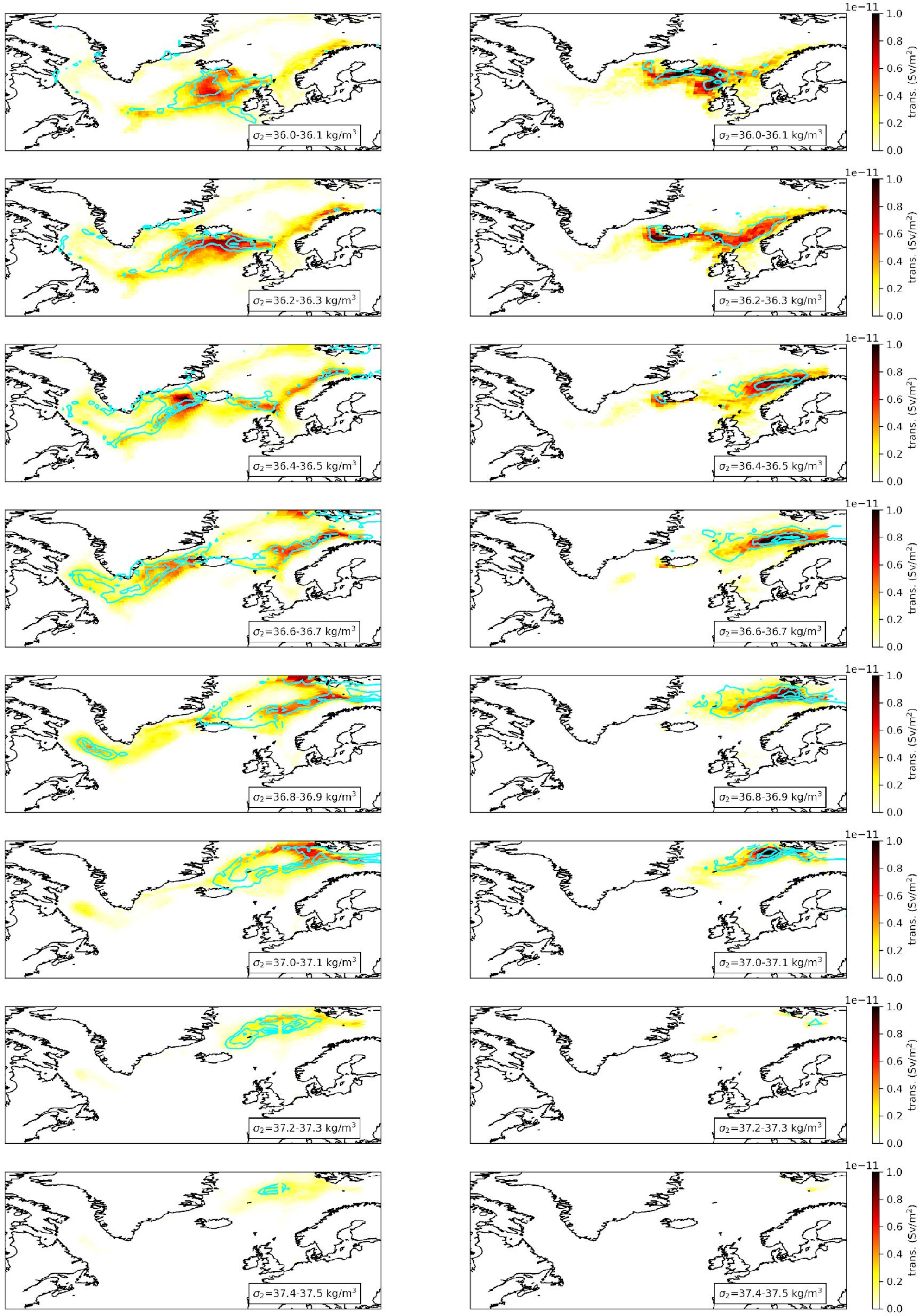


Shading: WMT observation benchmarks
Contours: Frequency of occurrence of water class (first contour: 0.1)

If WMT does not match observations, two possible inter-related issues:

1. Wrong air-sea fluxes
2. Isopycnal outcrops in the wrong location

This diagnostic help identify how much #2 is at fault.



σ_2=36.0-36.1 kg/m^3
σ_2=36.2-36.3 kg/m^3
σ_2=36.4-36.5 kg/m^3
σ_2=36.6-36.7 kg/m^3
σ_2=36.8-36.9 kg/m^3
σ_2=37.0-37.1 kg/m^3
σ_2=37.2-37.3 kg/m^3
σ_2=37.4-37.5 kg/m^3
1e−11
trans. (Sv/m^2)
0.0
0.2
0.4
0.6
0.8
1.0

Summary

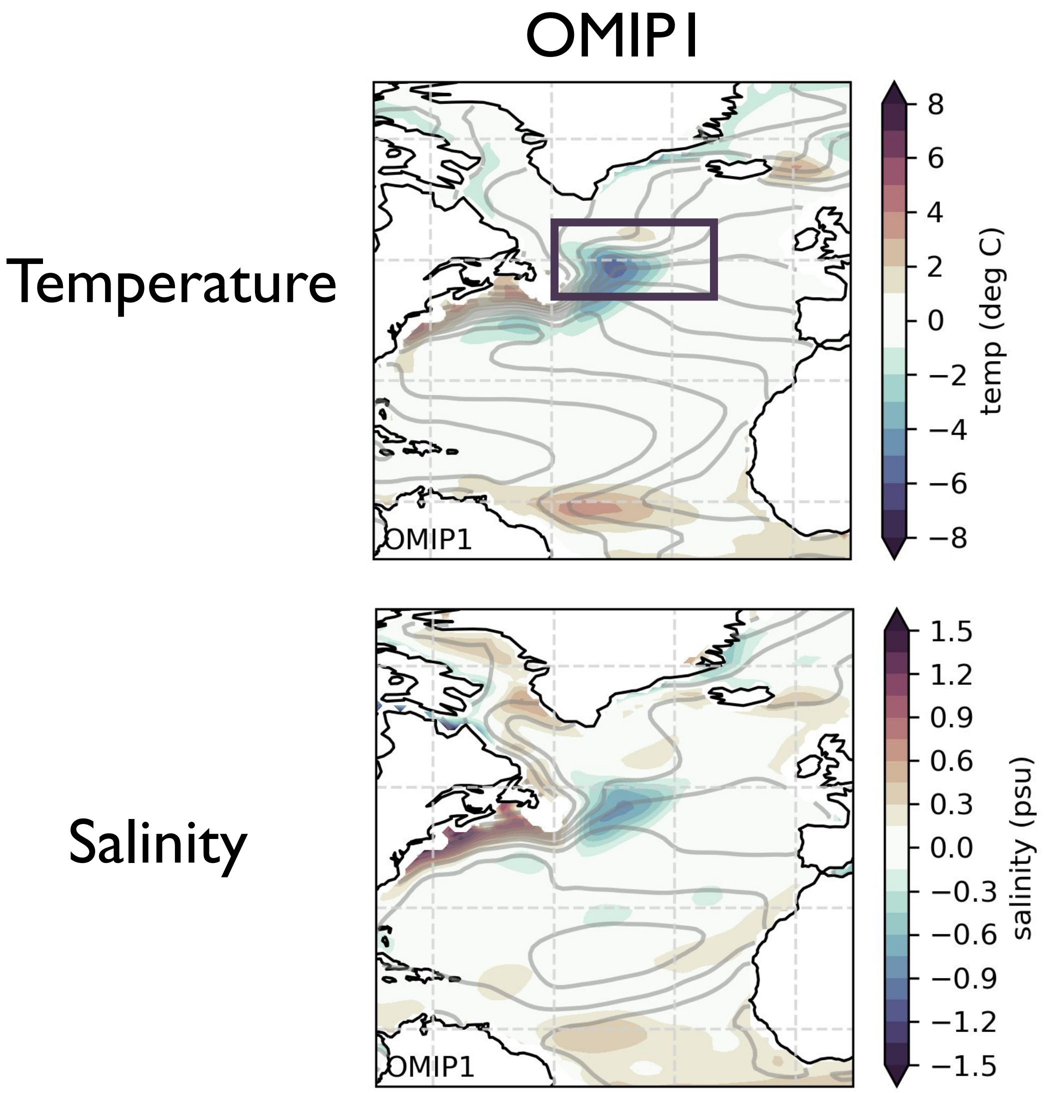
- We’re building a suite of North Atlantic model diagnostics to be completed and delivered as part of the NOAA MDTF
- Features:
  - Leveraging the OMIP suite to show how a model ranks
  - Model-agnostic AMOC(sigma) calculation
  - WMT decompositions and observational benchmarks
- Also, one current direction from the MDTF: notebooks

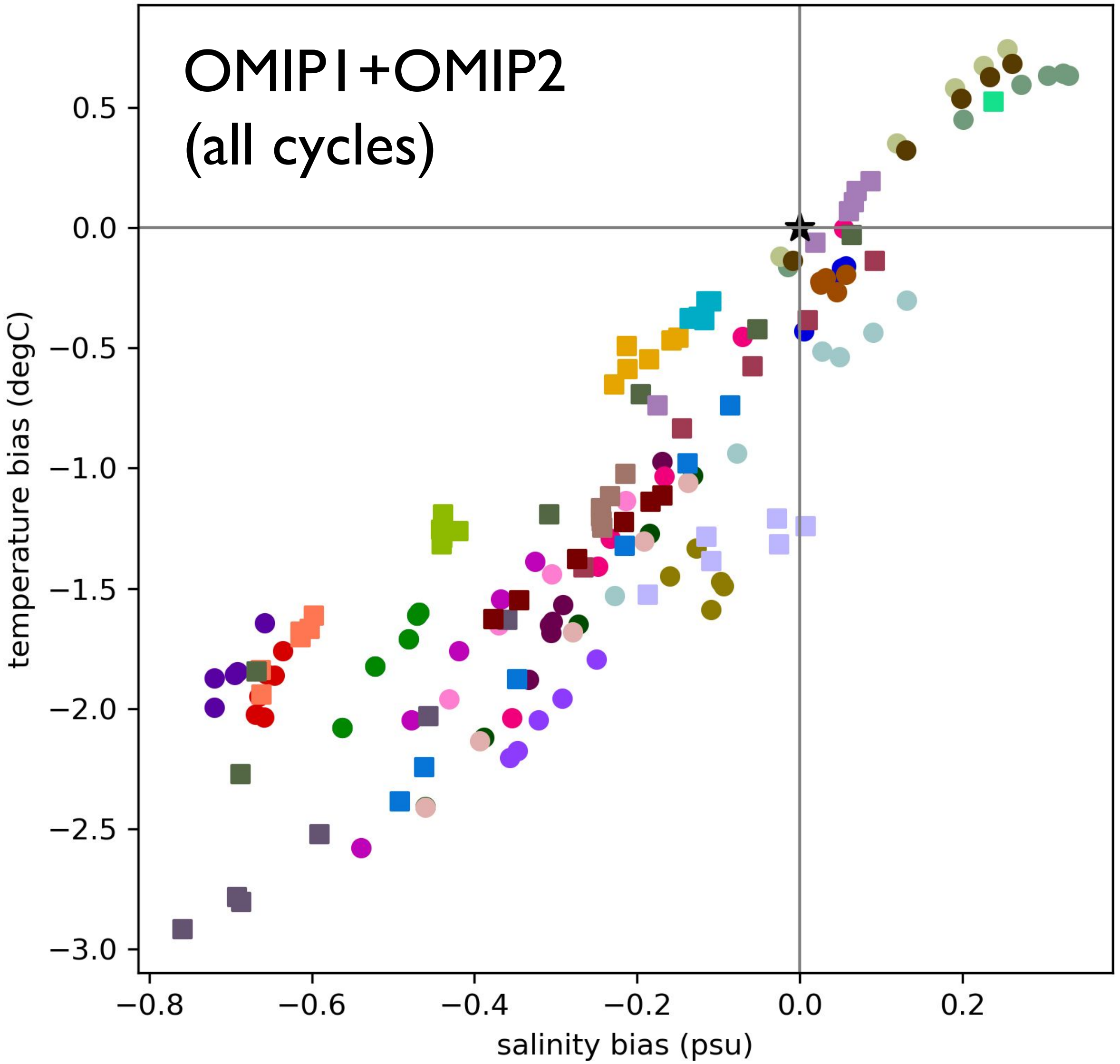
Notebooks

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)

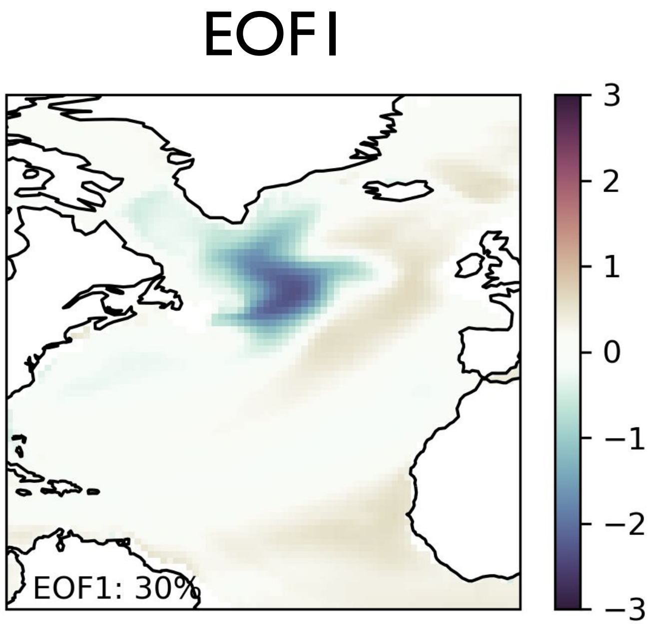
Temperature and salinity biases co-vary

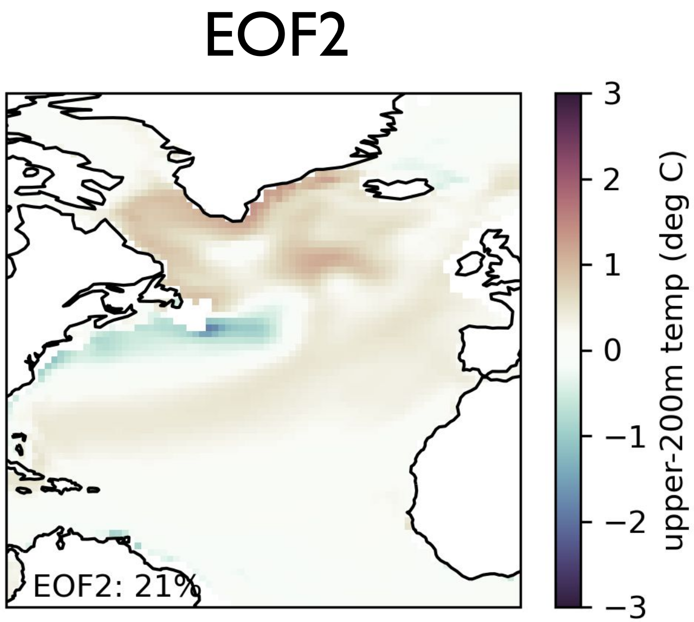




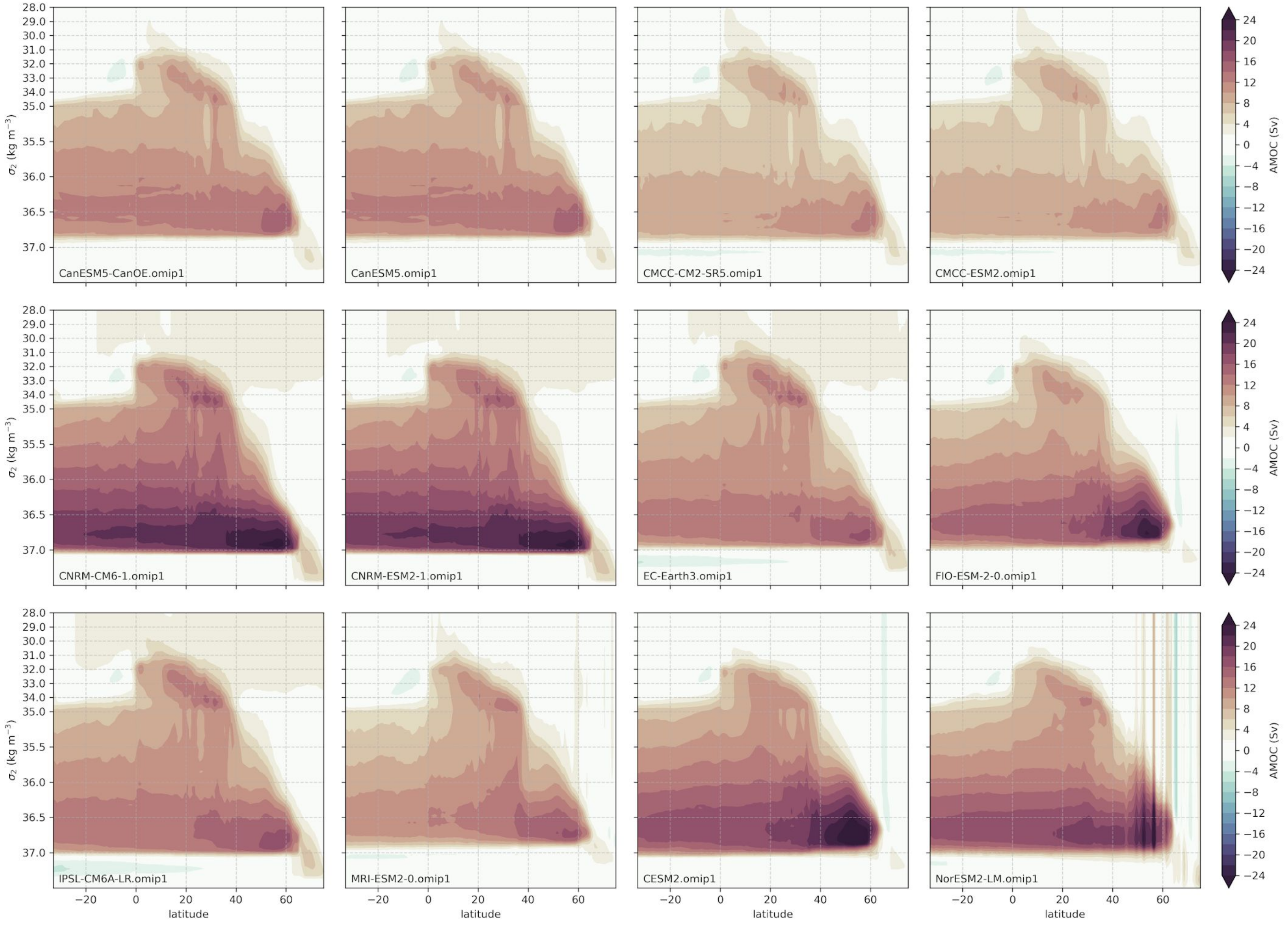
EOFs across models of temperature and salinity biases

Temperature

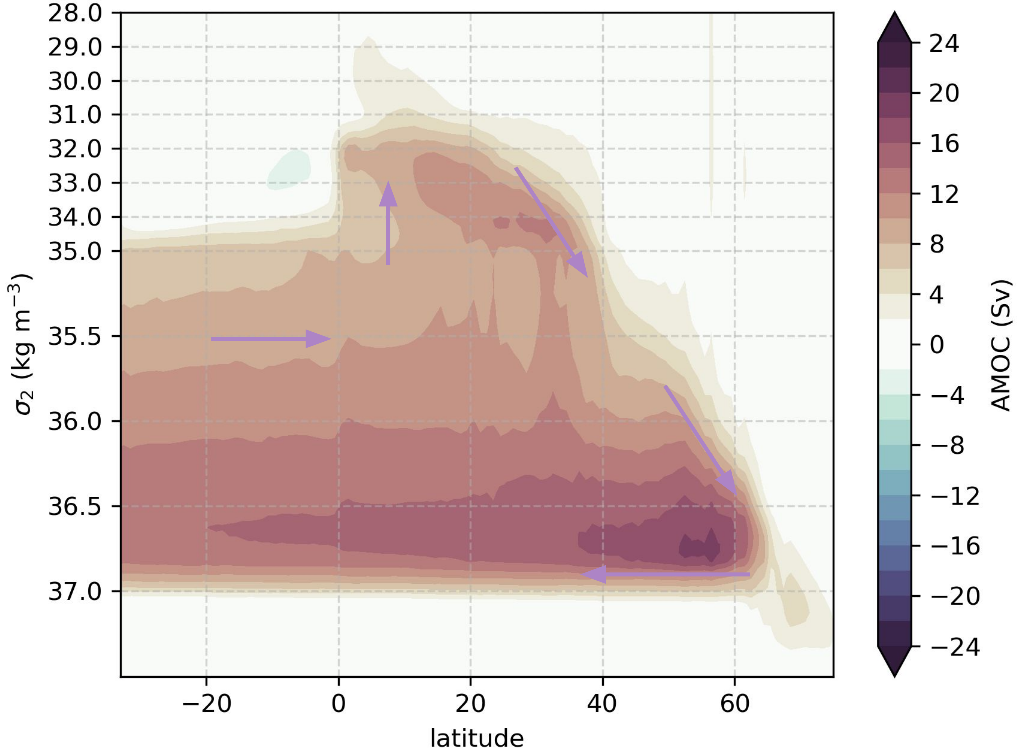




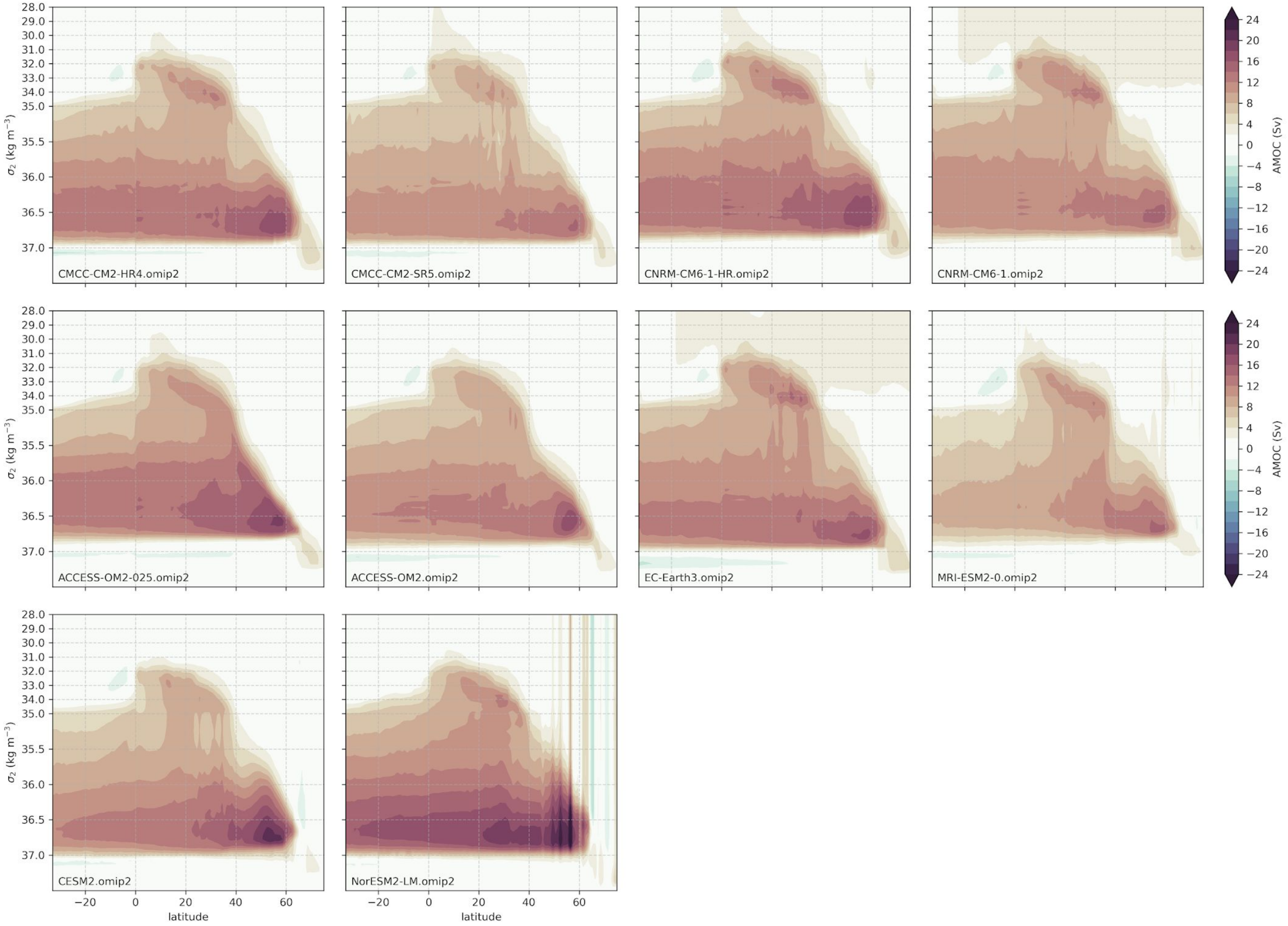
OMIP1 AMOC (Cycle 5)



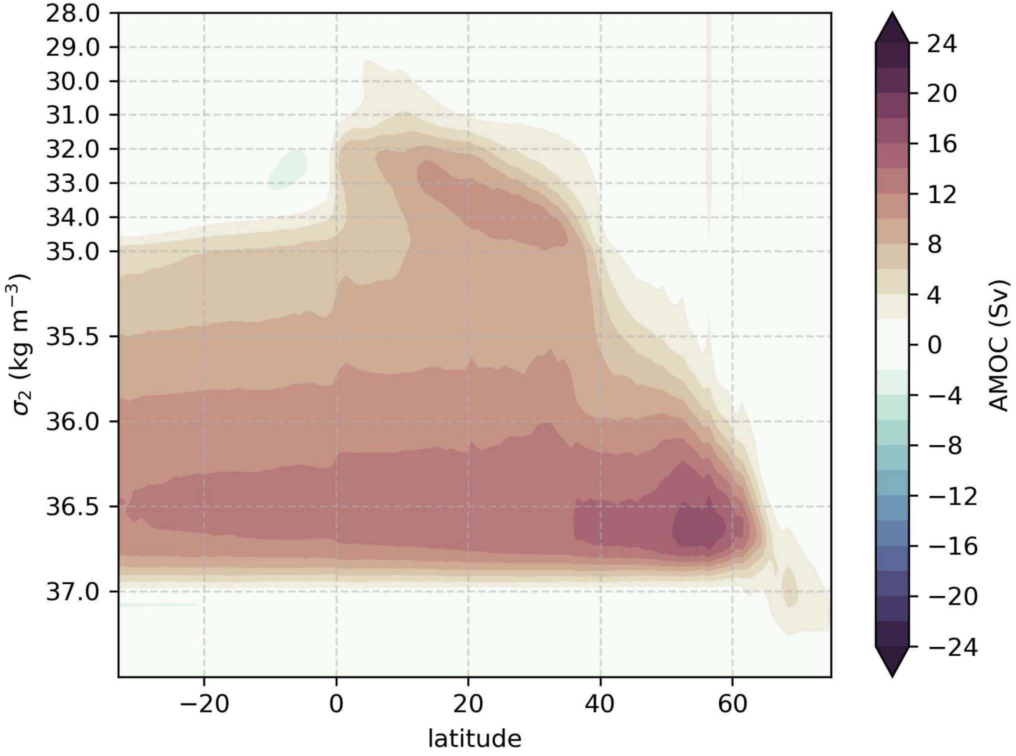
OMIP1 Multimodel Mean



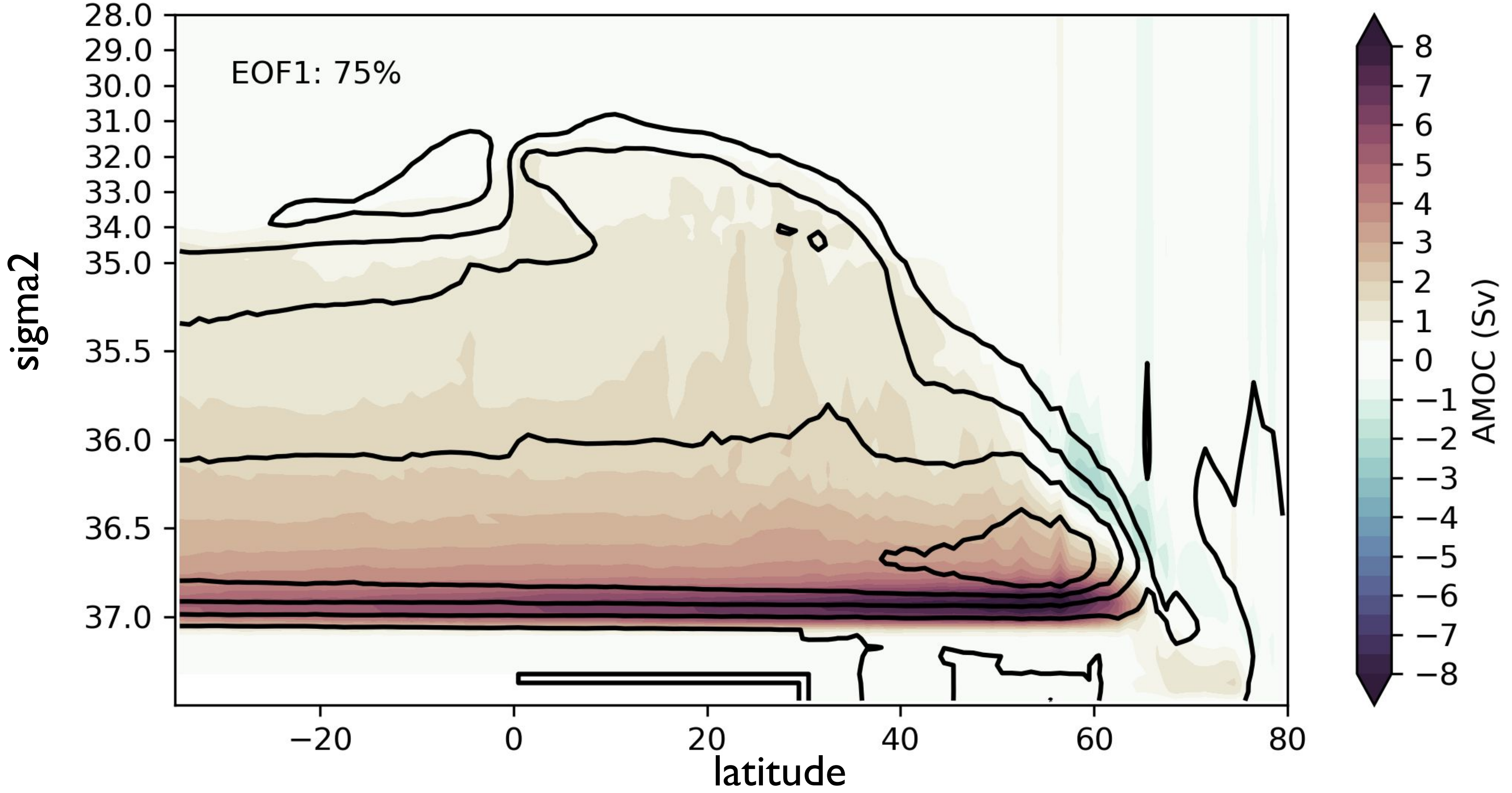
OMIP2 AMOC (Cycle 5)



OMIP2 Multimodel Mean

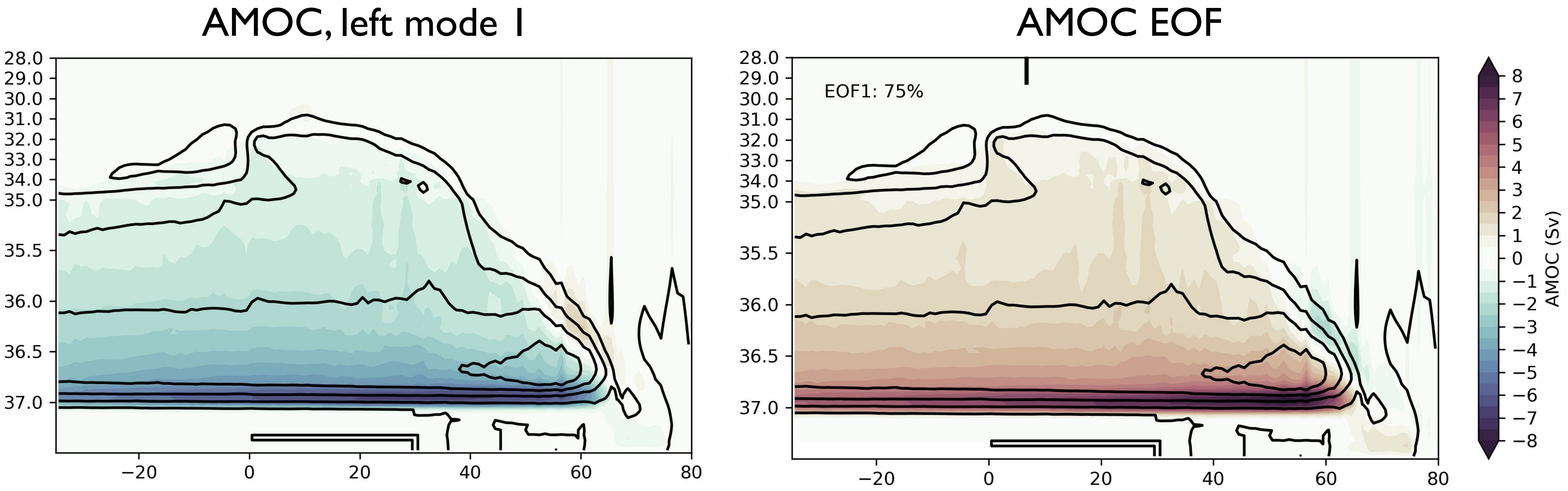


AMOC EOF1: Stronger AMOC associated with denser deep western boundary current and denser upper branch from 50-70°N



Contours: AMOC multimodel mean

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



Same pattern, just opposite

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)*