CESM has more subpolar North Atlantic water mass transformation than other models

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WARNING!!!

If you see wonky plots....I did my best with what I had since casper and scratch were both down

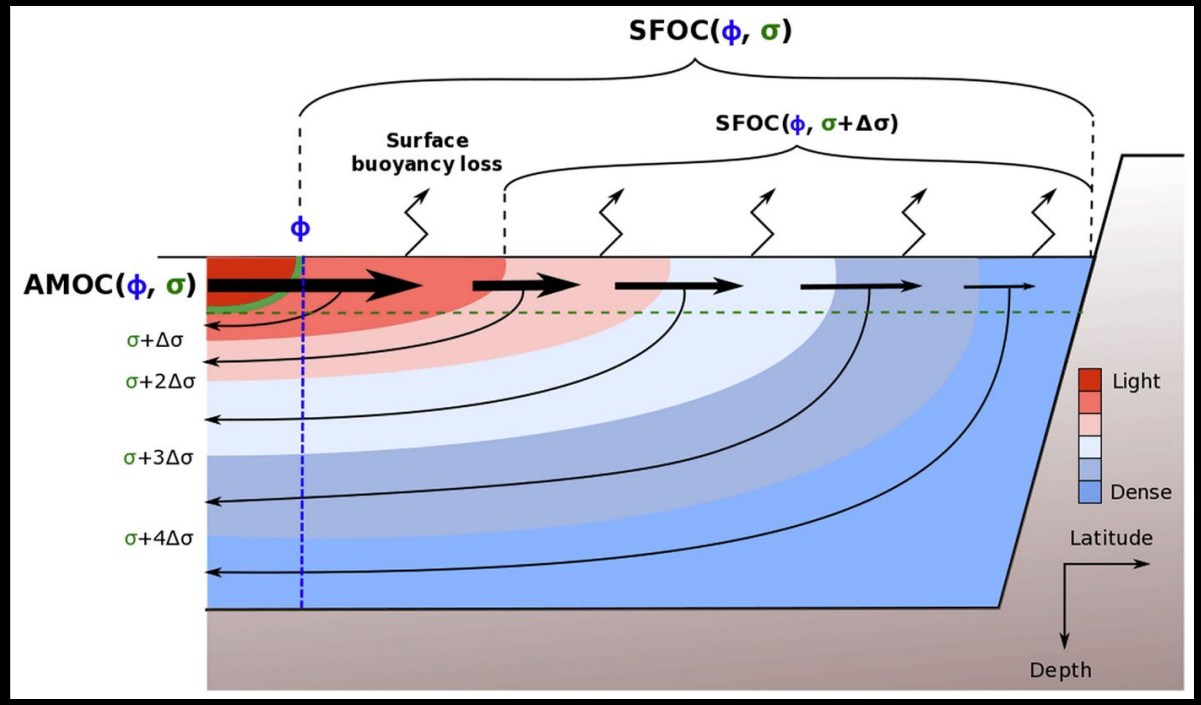
AMOC is largely balanced by water mass transformation (WMT) through **buoyancy** forcing

WMT = the amount of sea water transforming from one density class to another

Buoyancy forcing processes that change the ocean density/buoyancy

Walin Framework

$$\Psi(\sigma) = WMT(\sigma)$$



Desbruyéres et al. 2019

Walin 1982

We can estimate AMOC through surface fields!

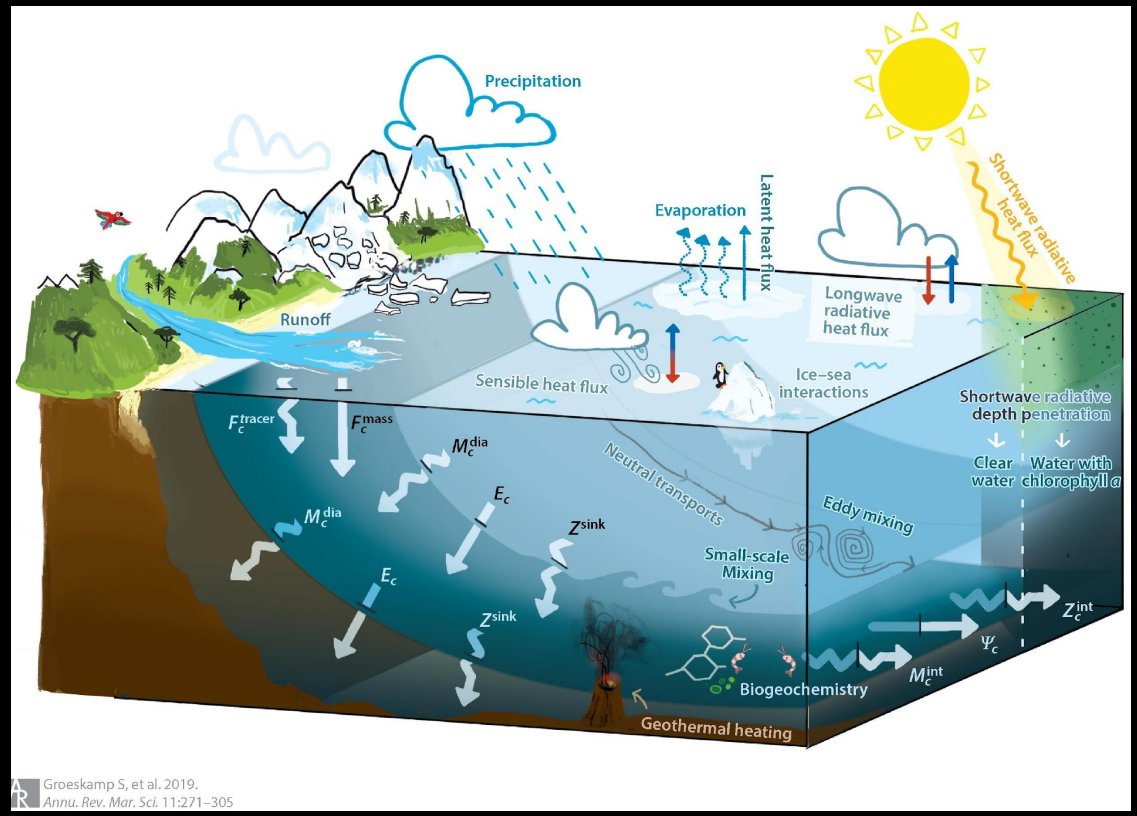
$$\Psi(\sigma) = WMT(\sigma)$$

$$WMT(\sigma) = WMT_{sfc}(\sigma) + WMT_{mix}(\sigma)$$

Heat and freshwater fluxes

Internal mixing

$$\Psi(\sigma) \approx WMT_{sfc}(\sigma)$$



Deconstructing surface forced WMT

$$f(x,y,t) = -\frac{\alpha}{c_p} f_{heat} + \beta f_{salt}$$

Density flux

Surface heat flux

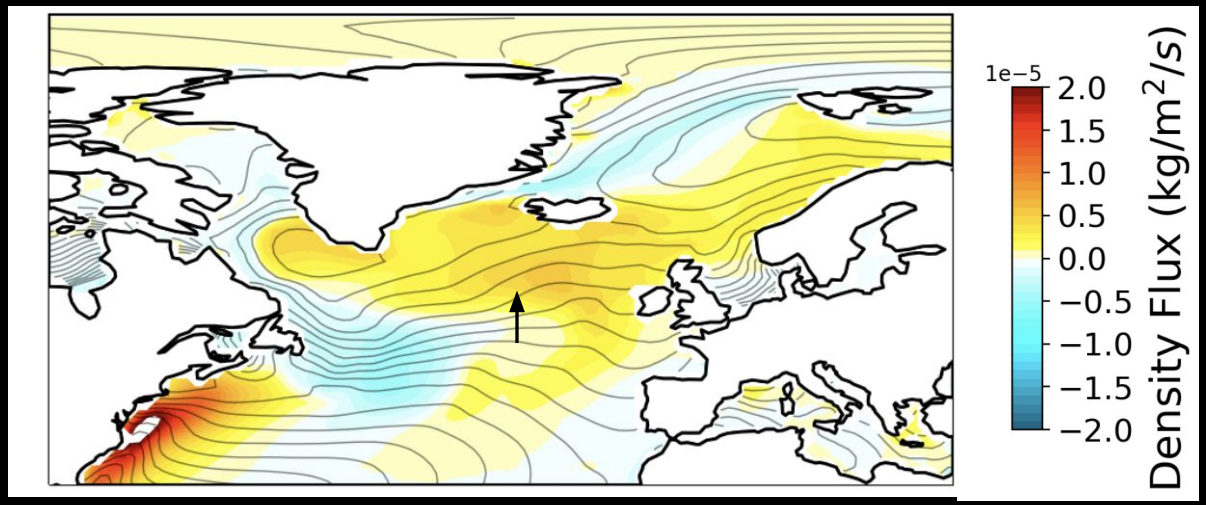
Surface freshwater flux

$$WMT_{sfc}(\sigma) = \frac{1}{\Delta\sigma} \iint f \, dA_\sigma$$

Density class area

xWMT

TEOS-10 EOS



Goal:

Investigate the differences in SPNA overturning circulation between CESM2 and other FOSI models that participated in the OMIP simulations

Objective:
Analyze WMT and AMOC(σ) in OMIP models

OMIP1 □ COREv2

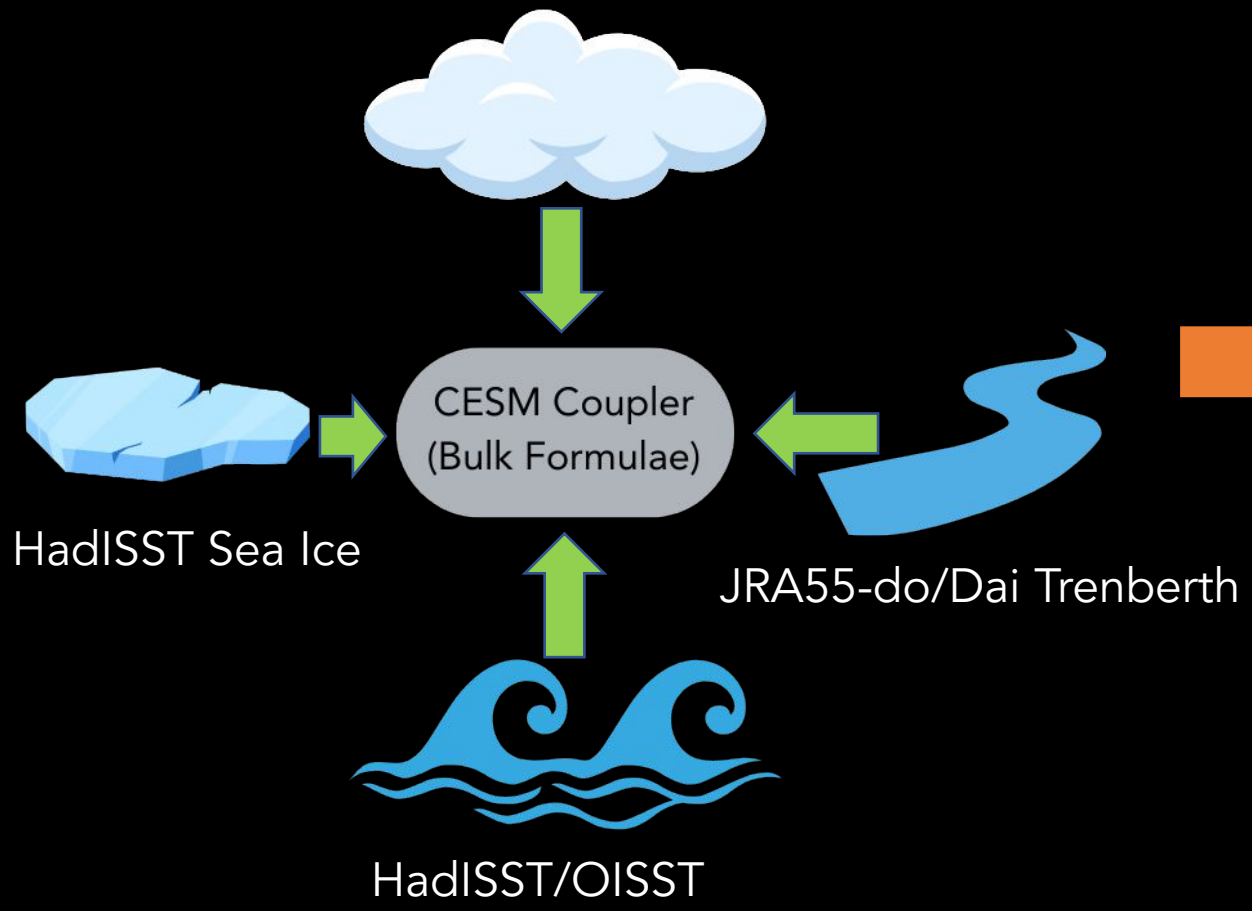
OMIP2 □ JRA55-do

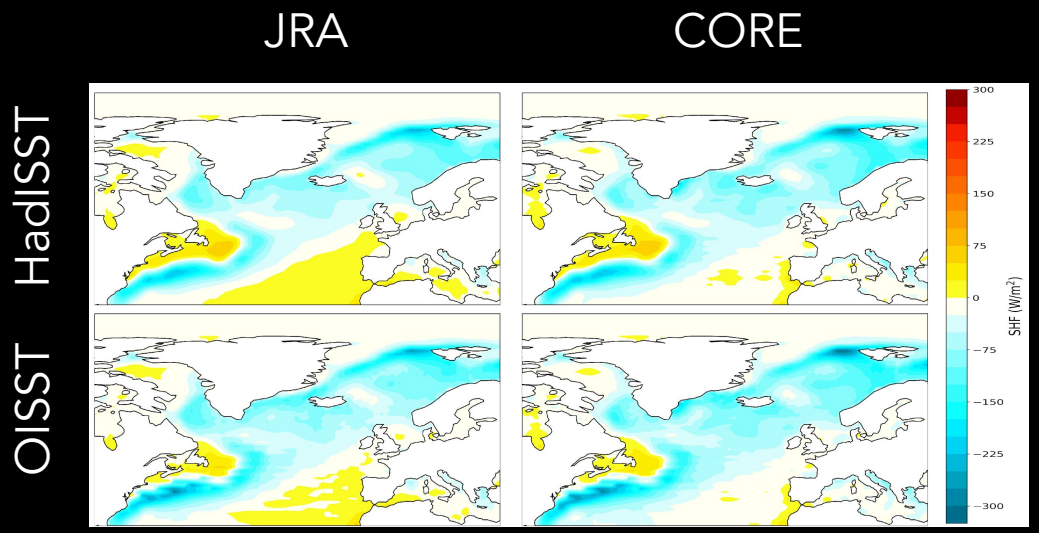
SPNA = subpolar North Atlantic OMIP = ocean model intercomparison project FOSI = forced ocean and sea-ice

We constructed observation-based estimates of WMT

A-compset

JRA55-do/COREv2





$$f(x, y, t) = -\frac{\alpha}{c_p} f_{heat} + \beta f_{salt}$$

Calculating Observation-based WMT

$$WMT(\sigma) = \frac{1}{\Delta\sigma} \iint f \, dA_\sigma$$

Surface fluxes

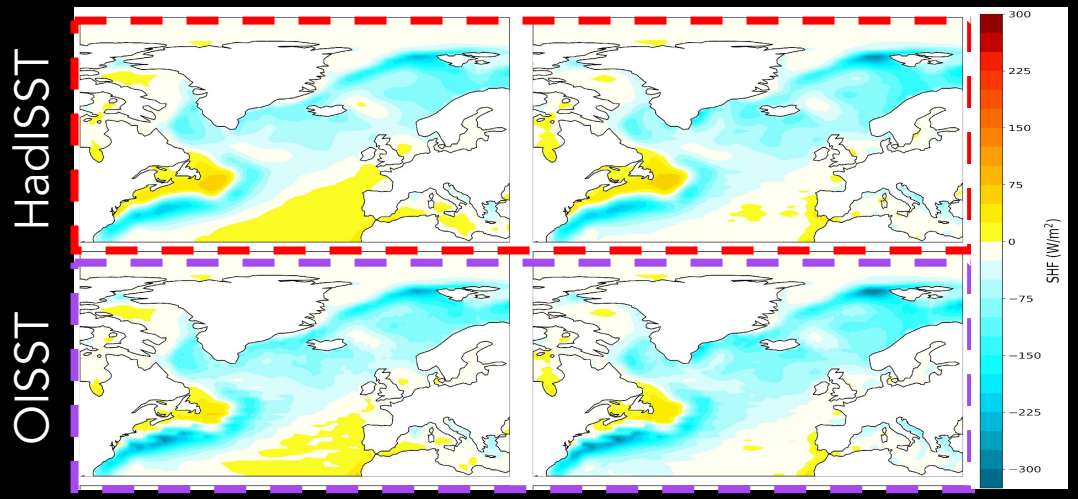
Density fields

JRA

CORE

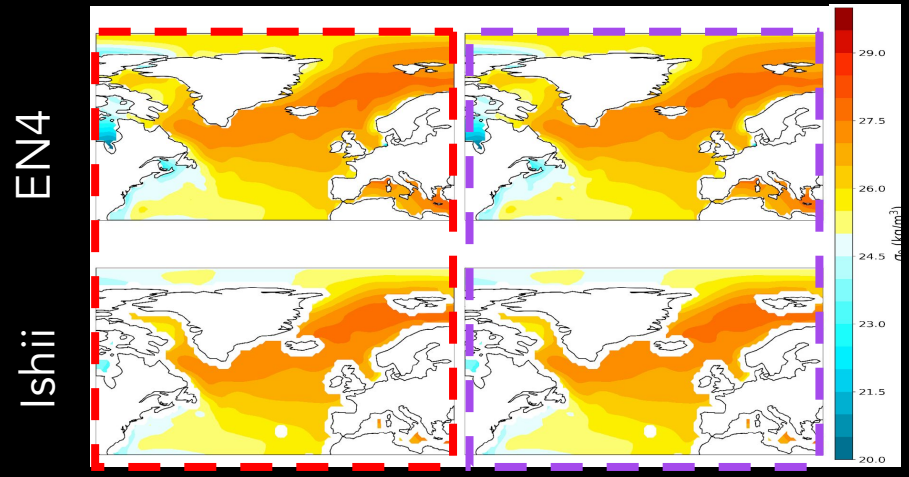
HadISST

OISST



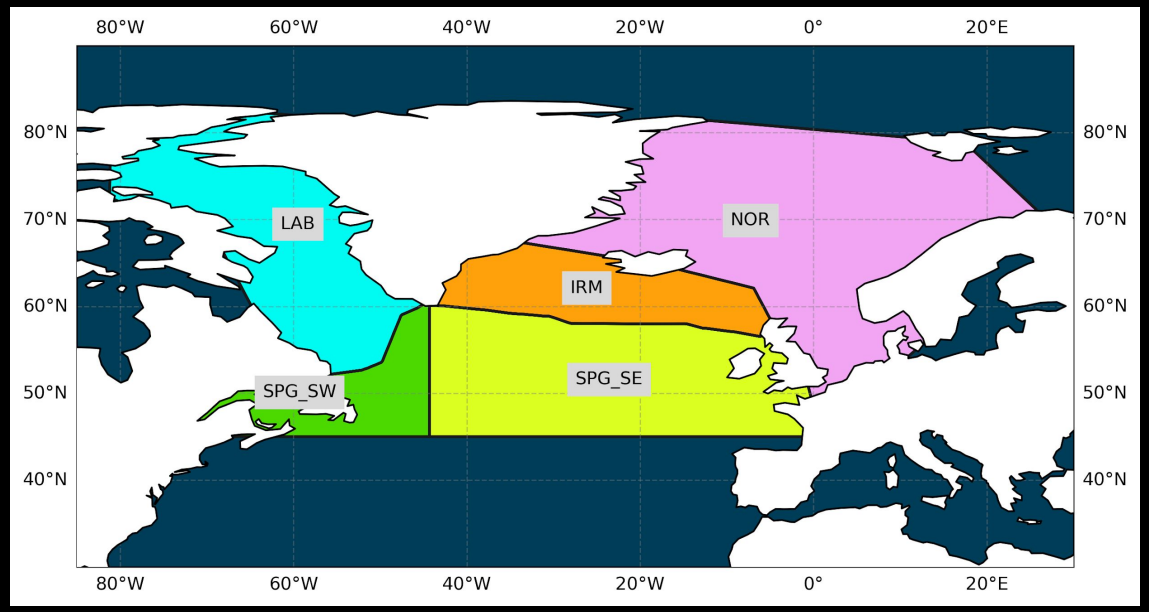
HadISST

OISST

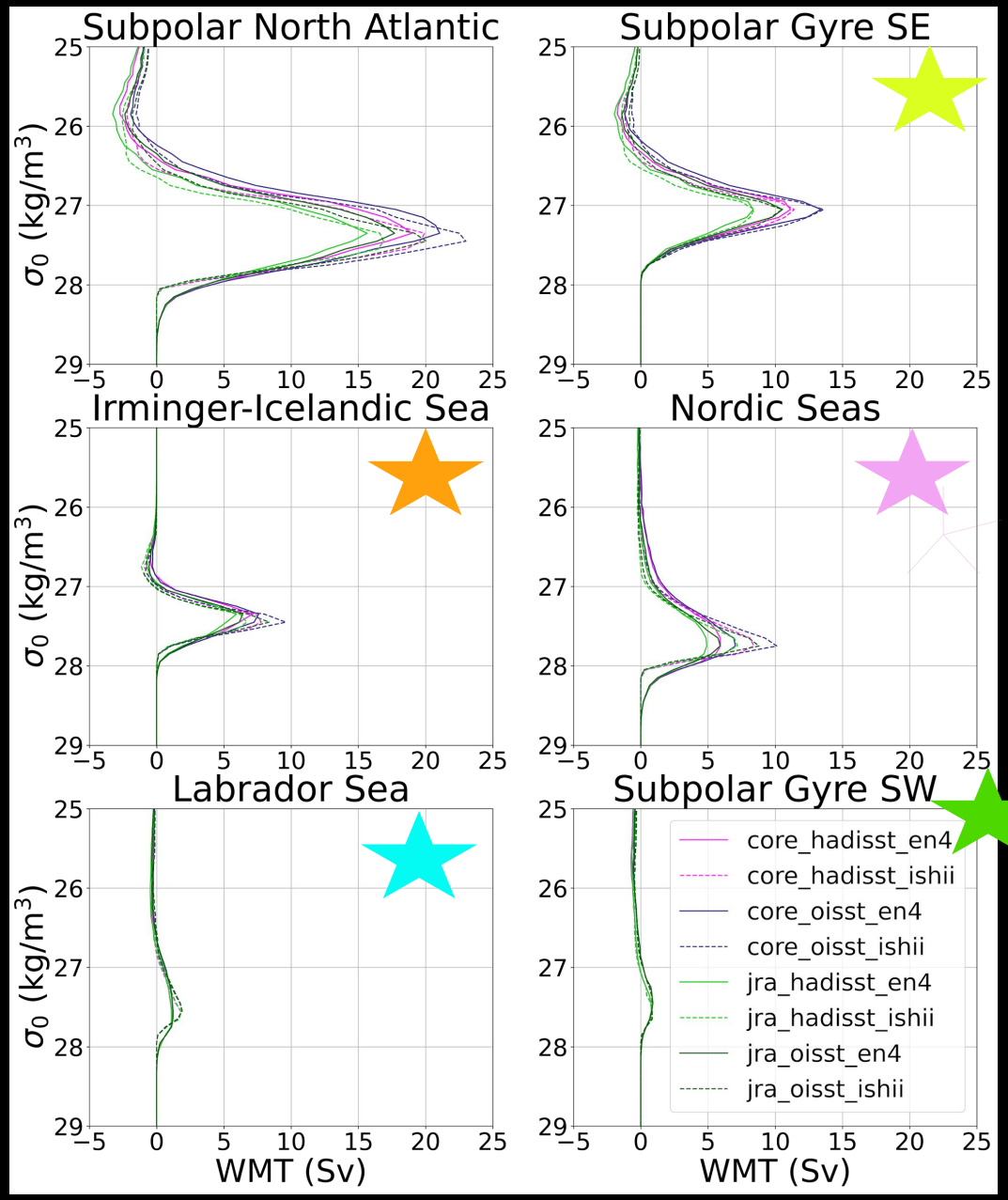


8 different observation-based WMT benchmarks

Different atmospheric forcings and surface fields (SST, SSS, fluxes) produce a spread in observational WMT



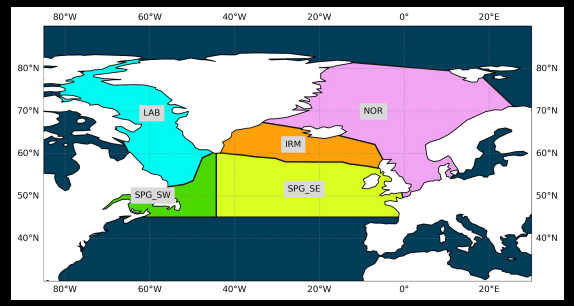
SPNA = LAB+IRM+NOR+SPG_SE+SPG_SW



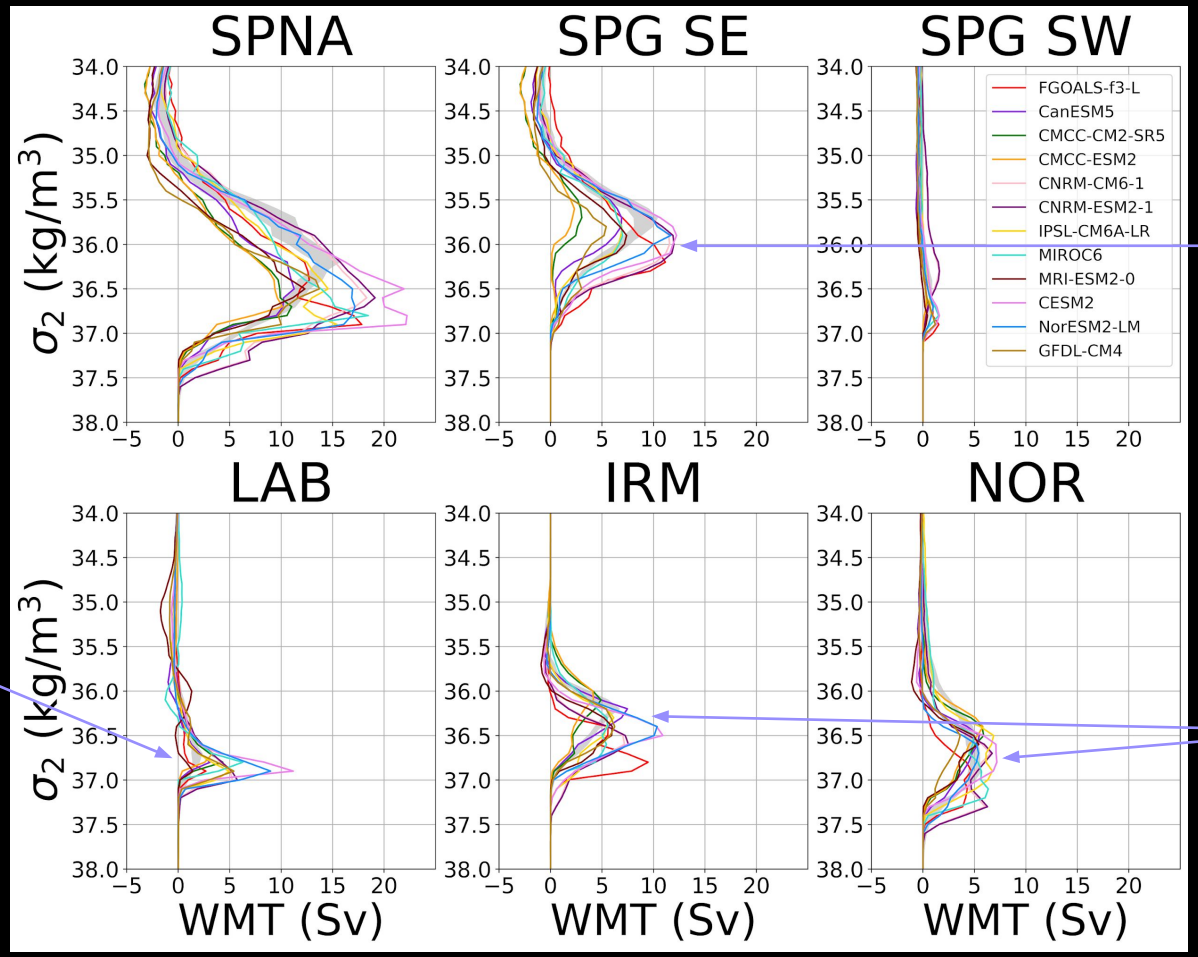
Low et al. in prep

1982-2009 Climatology

SPNA WMT is too strong and shifted towards heavier density classes in OMIP1 models



OMIP1

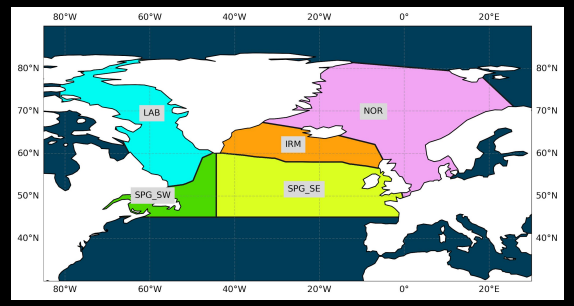


Large spread in max WMT and shifted towards heavier density classes

Max WMT Too strong

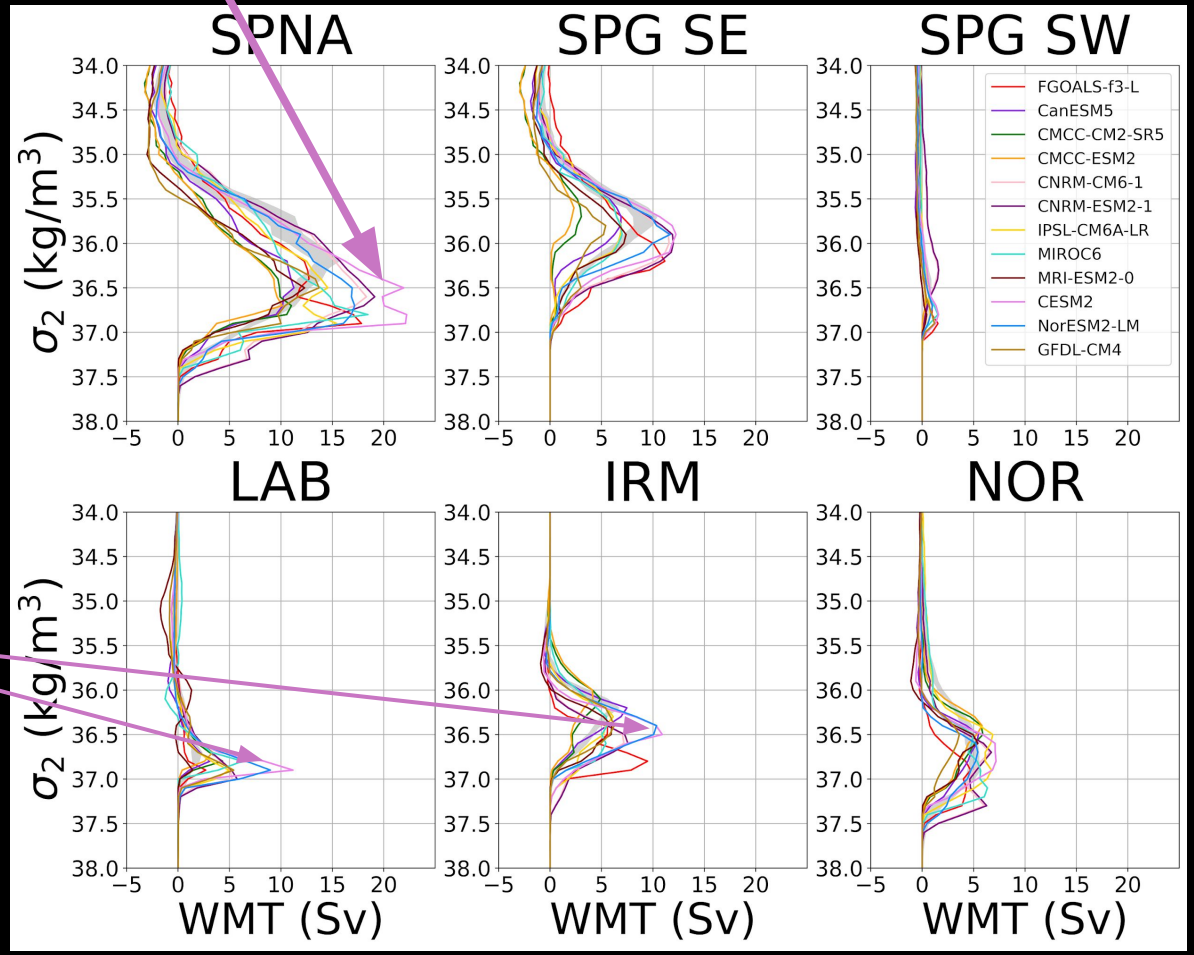
Large spread in density class of the max and too strong WMT

CESM2 has some of the strongest WMT biases in the SPNA



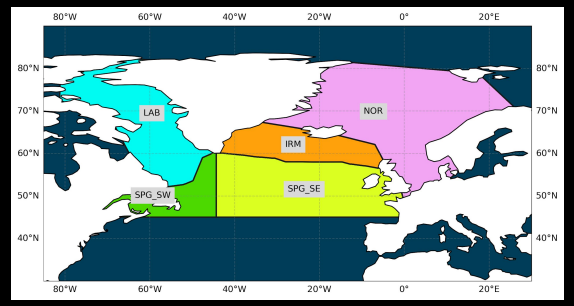
CESM2!!!

OMIP1

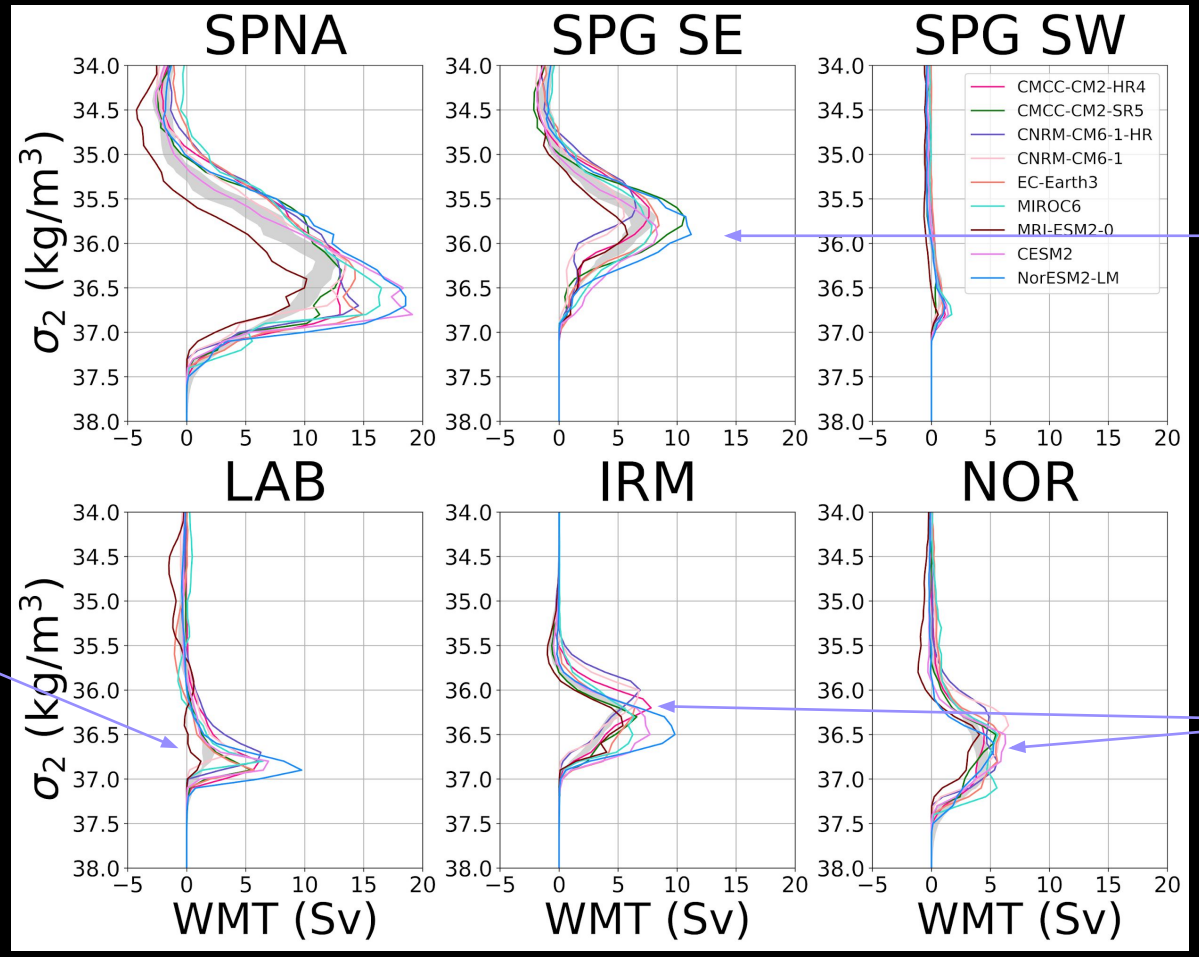


CESM2 WMT too strong in LAB and IRM

We find the same behavior in the OMIP2 models



OMIP2



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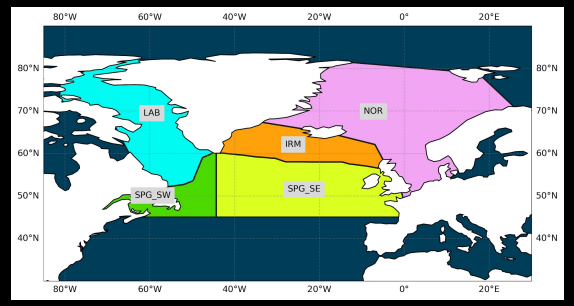
CESM2!!!



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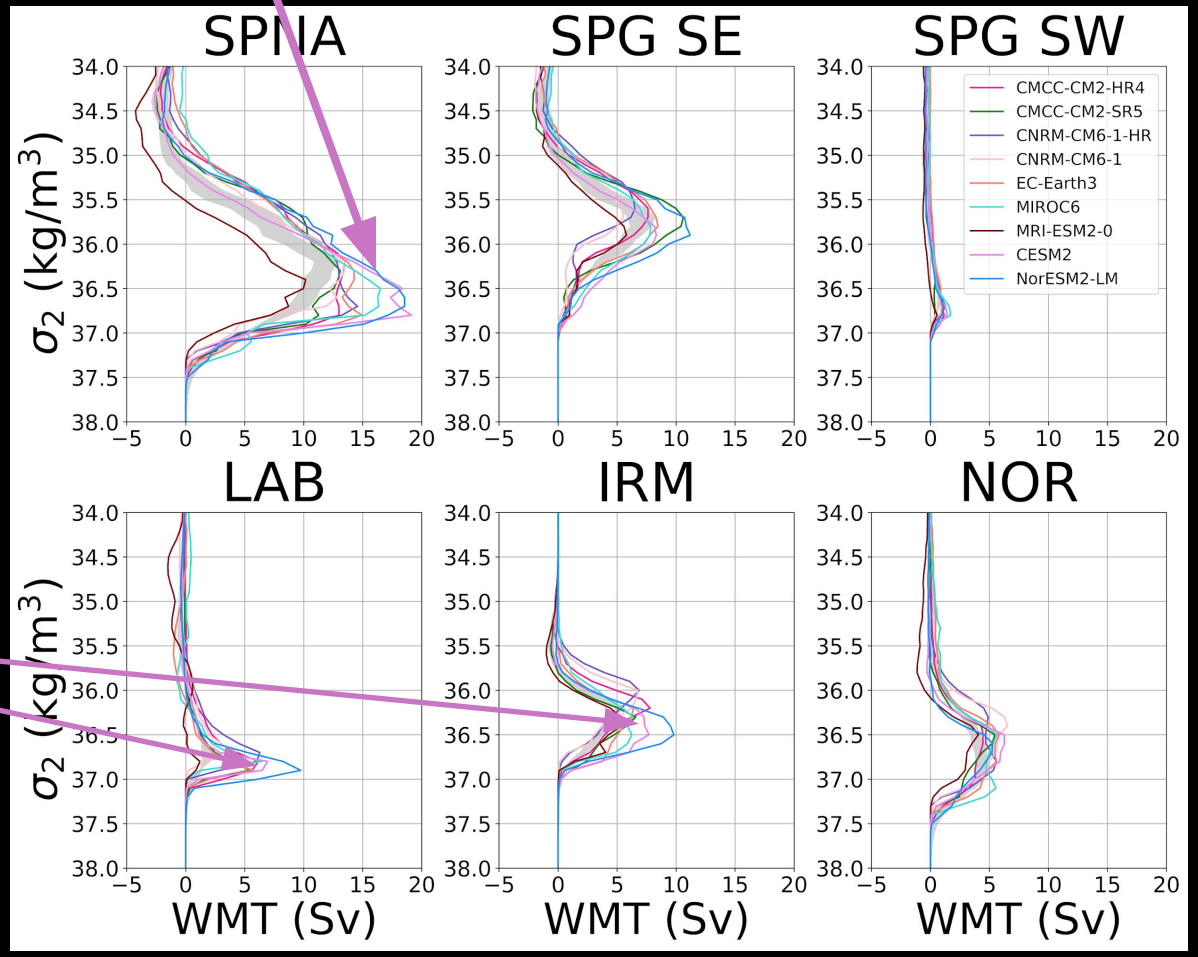
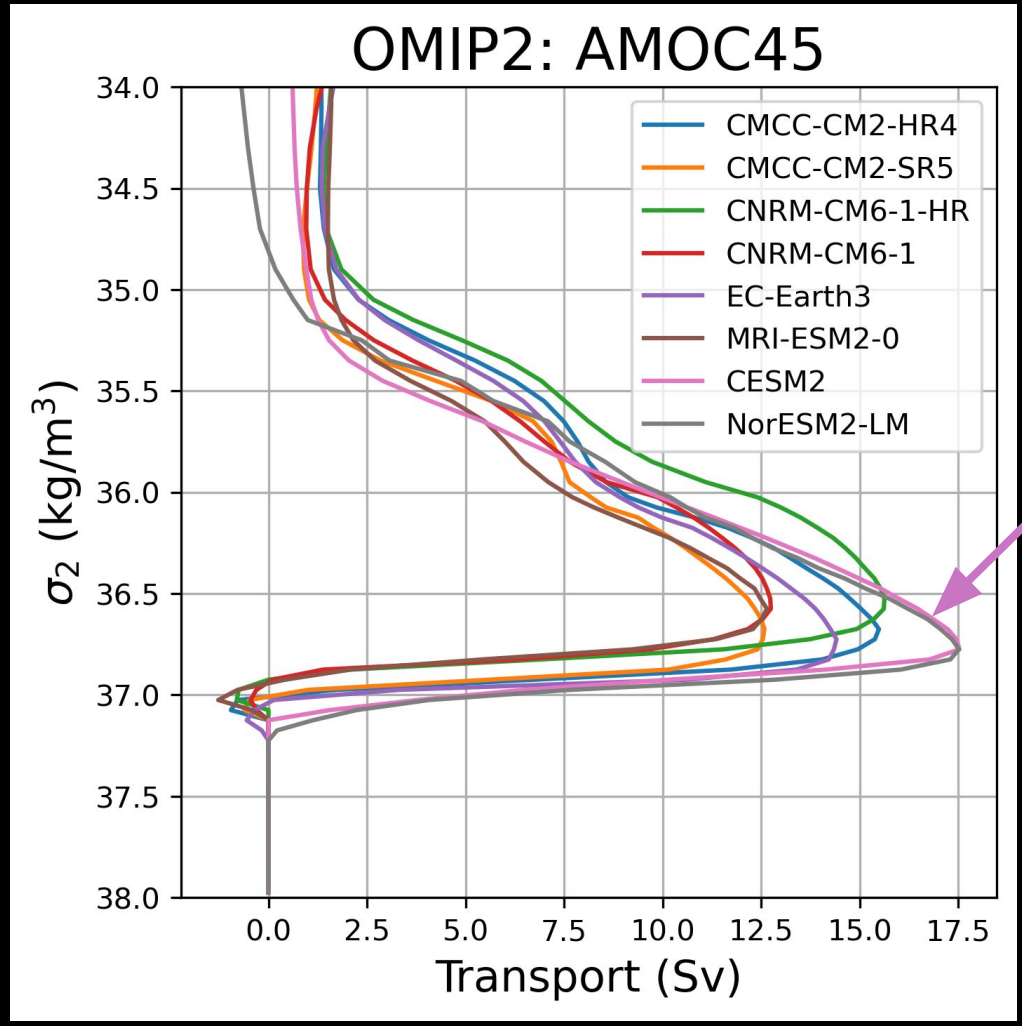


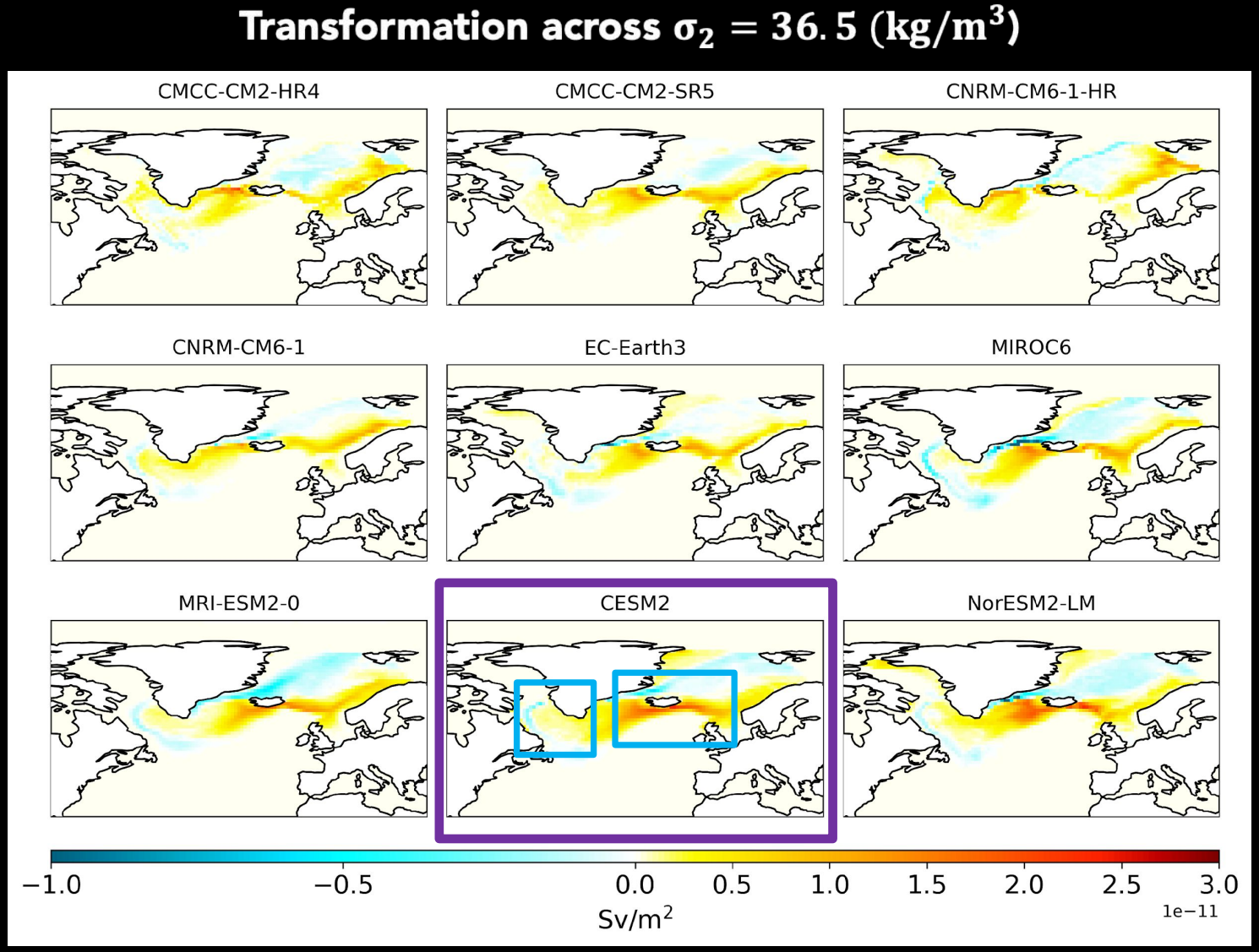
AMOC 45N is also stronger in CESM2 compared to other OMIP2 models



CESM2!!!

Data processed by Elizabeth Maroon and Stephen Yeager

Pinpointing locations of strong transformation



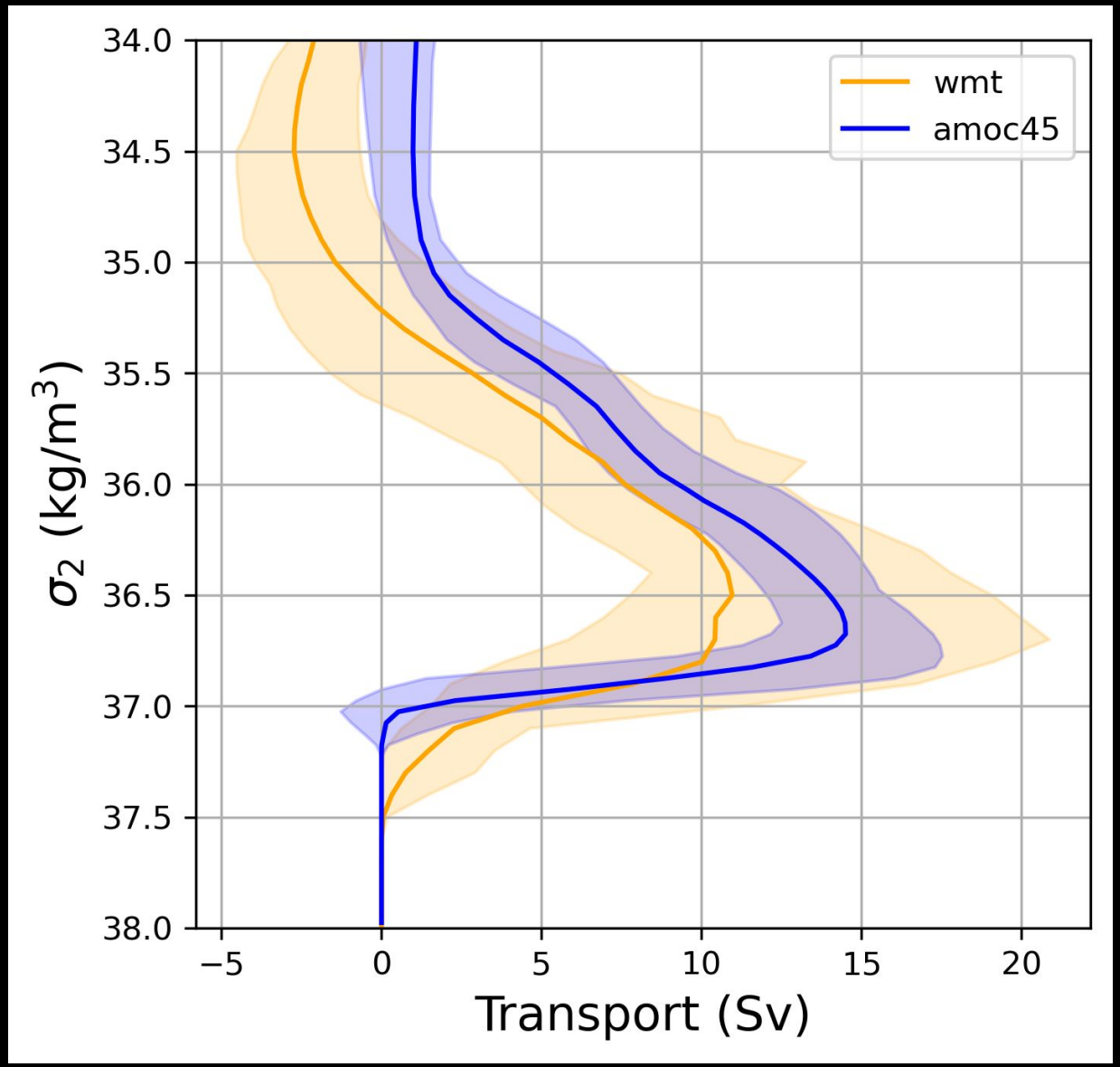
Key Takeaways

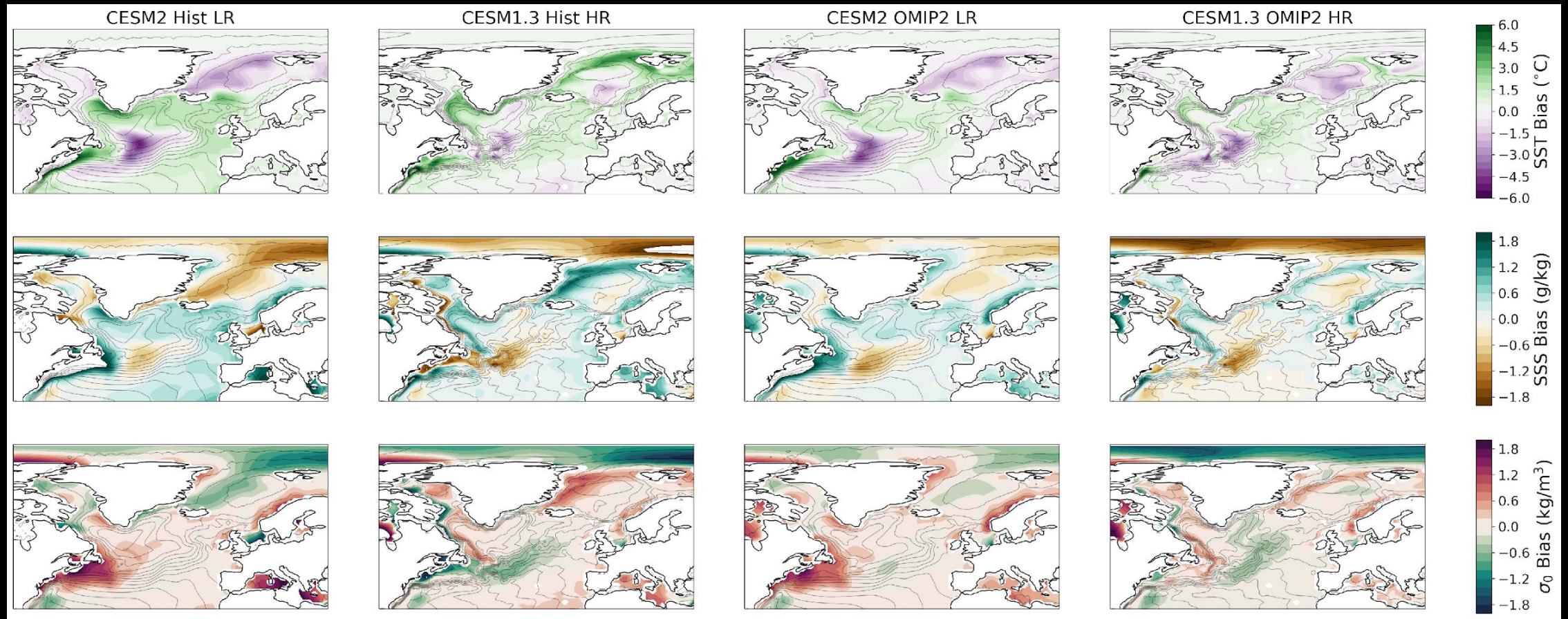
- Most OMIP simulations have WMT that falls outside the observational range
- Maximum transformation generally occurs at heavier density classes than observations imply
- The strong biased WMT is attributed to the Labrador and Irminger-Icelandic Seas
- Additional OMIP spread comes from the southeast subpolar gyre
- CESM2 has some of the strongest WMT and AMOC among OMIP models (because of LAB and IRM)

Questions?

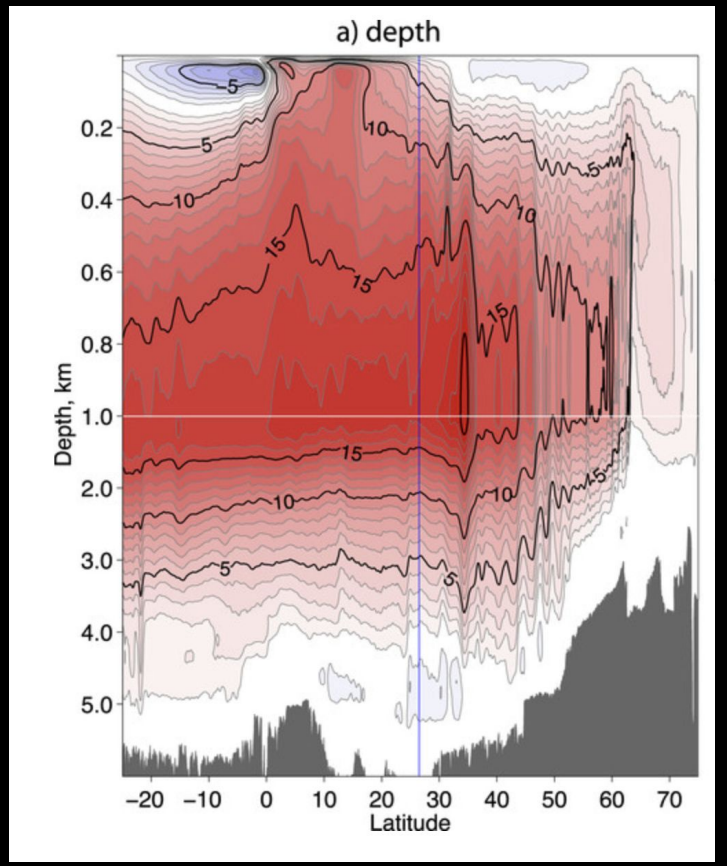
Email: tlow2@wisc.edu

Extra

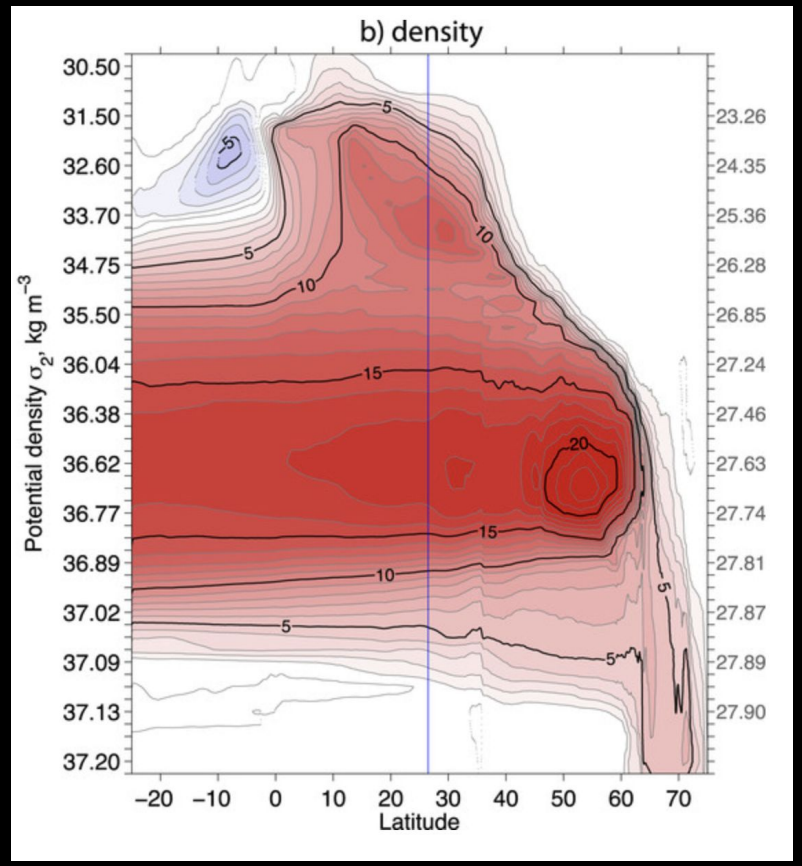

wmt
amoc45
34.0
34.5
35.0
35.5
36.0
36.5
37.0
37.5
38.0
σ_2 (kg/m^3)
−5
0
5
10
15
20
Transport (Sv)


CESM2 Hist LR
CESM1.3 Hist HR
CESM2 OMIP2 LR
CESM1.3 OMIP2 HR
6.0
4.5
3.0
1.5
0.0
−1.5
−3.0
−4.5
−6.0
SST Bias (°C)
1.8
1.2
0.6
0.0
−0.6
−1.2
−1.8
SSS Bias (g/kg)
1.8
1.2
0.6
0.0
−0.6
−1.2
−1.8
σ0 Bias (kg/m3)

AMOC(z)



AMOC(sigma)



$$\Psi(\sigma) \approx WMT$$

Xu et al. 2016

Putting it all together...but the mathy version 🥲

AMOC streamfunction primarily balanced by WMT

AMOC: $\Psi(\phi,\sigma)$ + Volume: $\frac{\partial V(\phi,\sigma)}{\partial t}$ = WMT: $G(\phi,\sigma)$ → $\Psi(\phi,\sigma) \approx G(\phi,\sigma)$

Total WMT is the sum of transformations due to surface and internal mixing processes

WMT: $G(\phi,\sigma)$ = Surface: $F(\phi,\sigma)$ + Mixing: $\frac{\partial D_{diff}(\phi,\sigma)}{\partial \sigma}$ + $C(\phi,\sigma)$

$G(\phi,\sigma) \approx F(\phi,\sigma)$

$\Psi(\phi,\sigma) \approx F(\phi,\sigma)$

Surface-forced WMT is a function of surface heat and fresh-water fluxes, SST, and SSS

Density Flux: $F(\phi,\sigma) = \frac{1}{\Delta\sigma} \iint \left[-\frac{\alpha}{C_p} Q + \beta S(E-P) \right] \prod(\sigma'(x,y))\, dxdy$

(Heat fluxes; Freshwater fluxes; Density outcrops)

AMOC can be estimated solely from surface processes

$$\prod(\sigma'(x,y)) = \begin{cases} 1, & for\ |\sigma'(x,y) - \sigma| \le \frac{\Delta\sigma}{2} \\ 0, & elsewhere \end{cases}$$