North Atlantic Ocean in CESM low and high-resolution simulations compared to observational benchmarks

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CESM Workshop 2023

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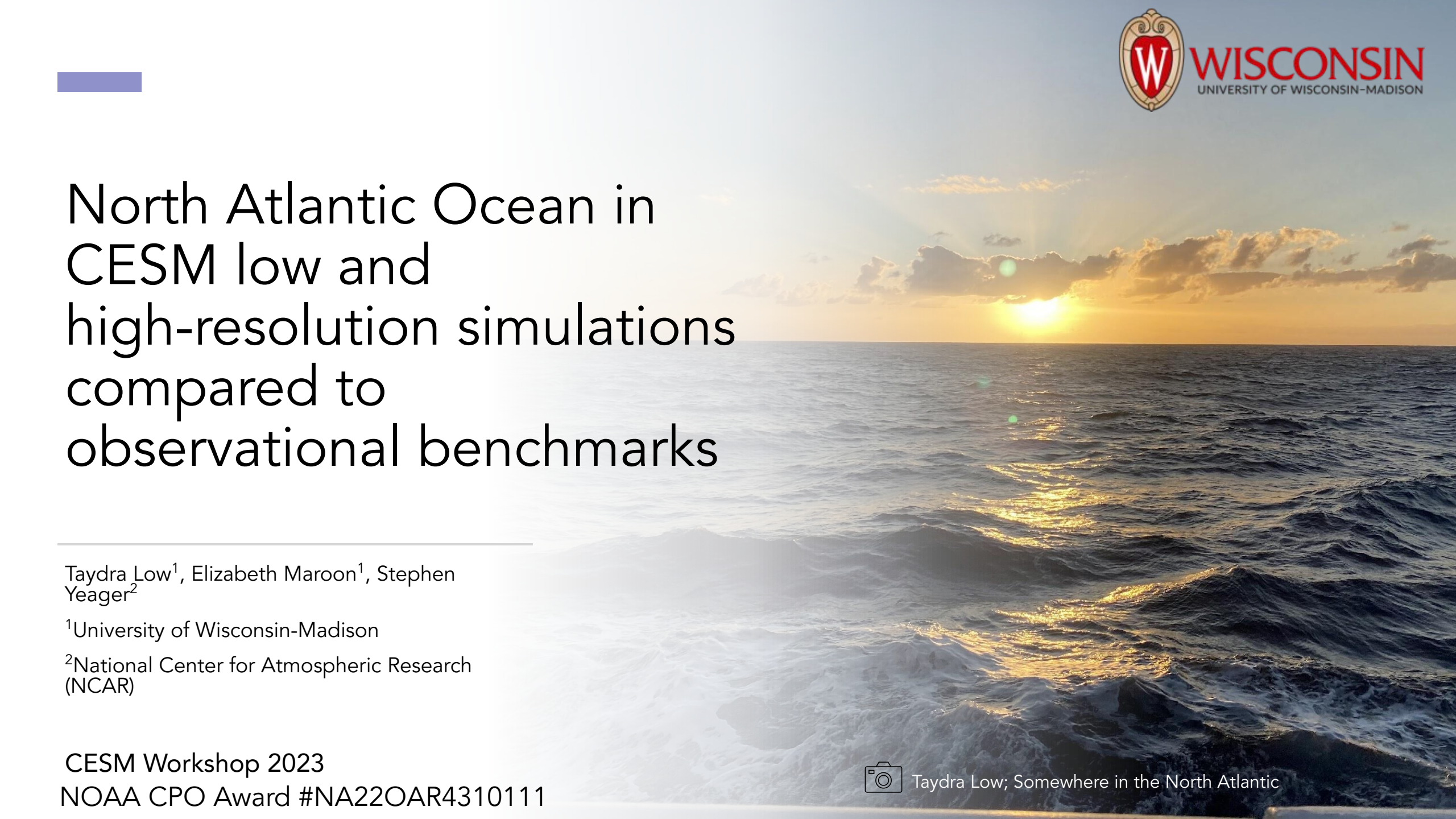
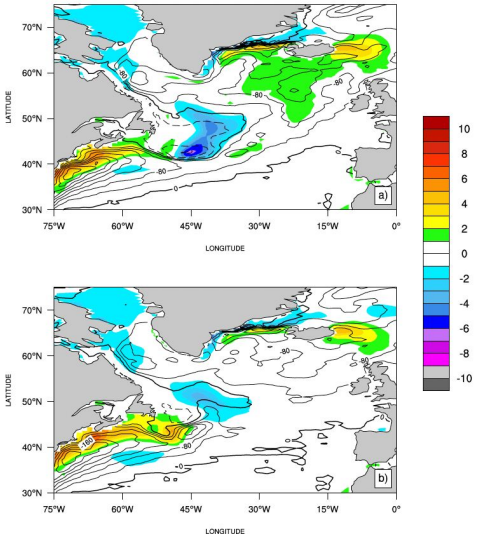
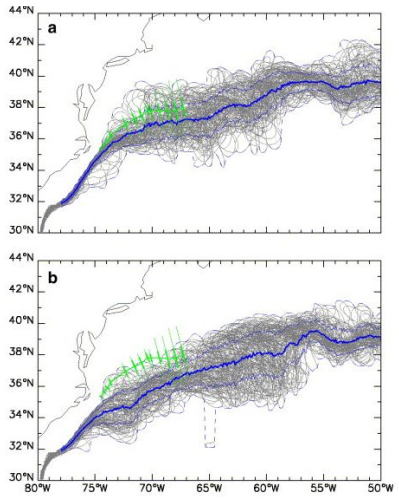


Taydra Low; Somewhere in the North Atlantic

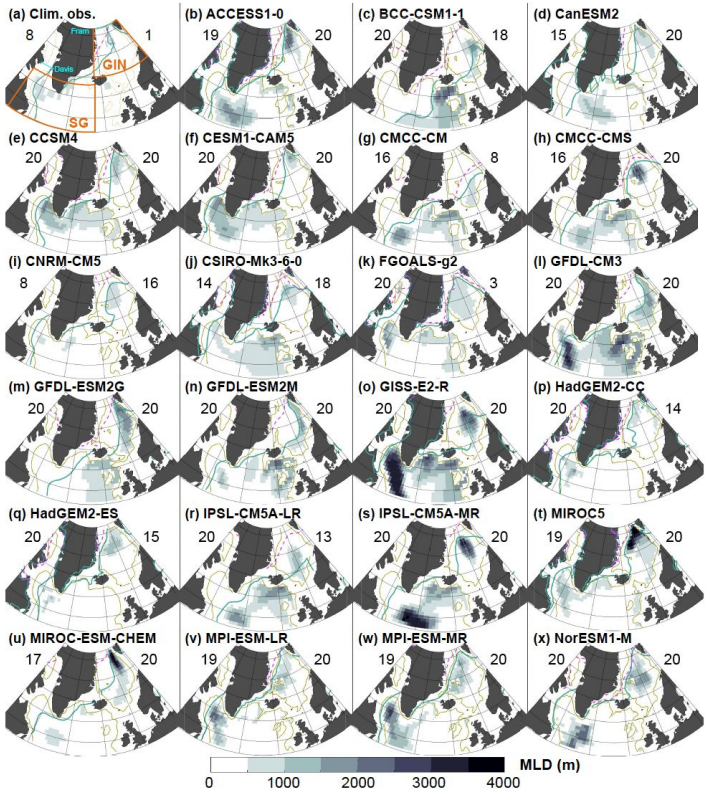
Global climate models have longstanding interrelated biases in the North Atlantic



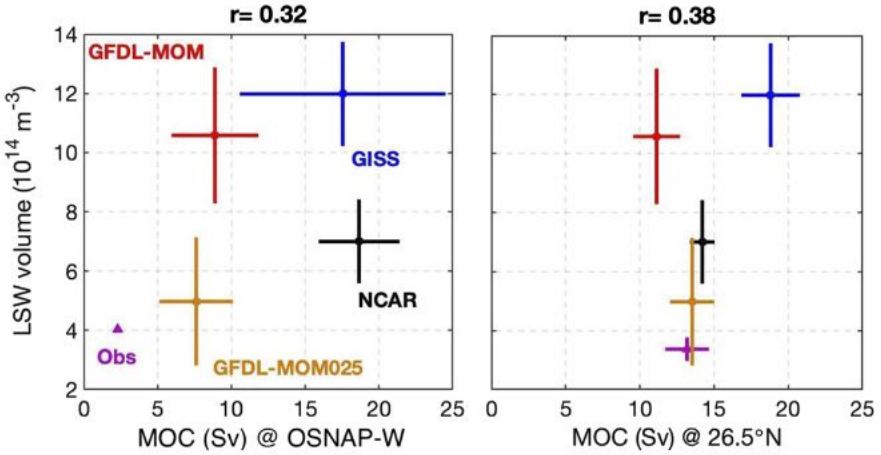
Weese and Bryan 2006



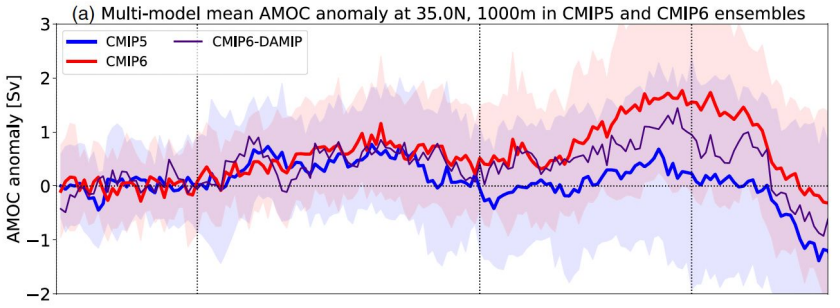
Bryan et al 2007



Heuzé 2017



Li et al. 2019

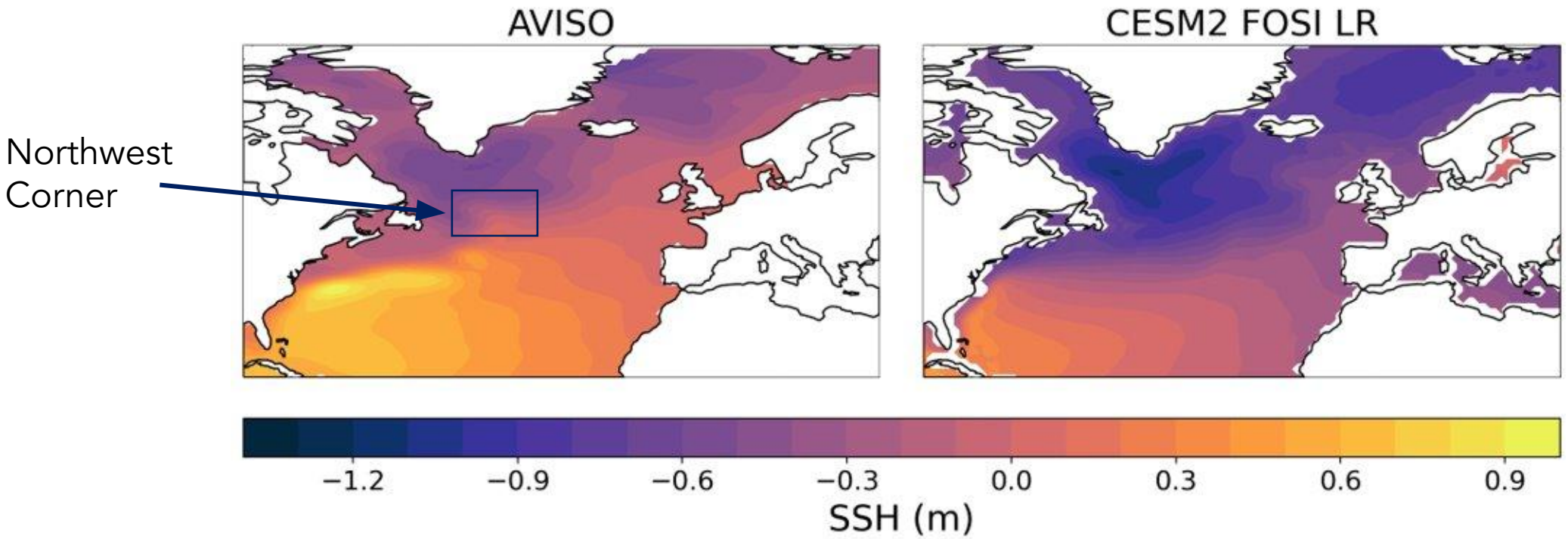


Menary et al. 2020

The misplacement of the North Atlantic current is related to errors in SST

Altimetry based SSH

Model based SSH



AVISO (Archiving, Validation and Interpretation of Satellite Oceanographic data)

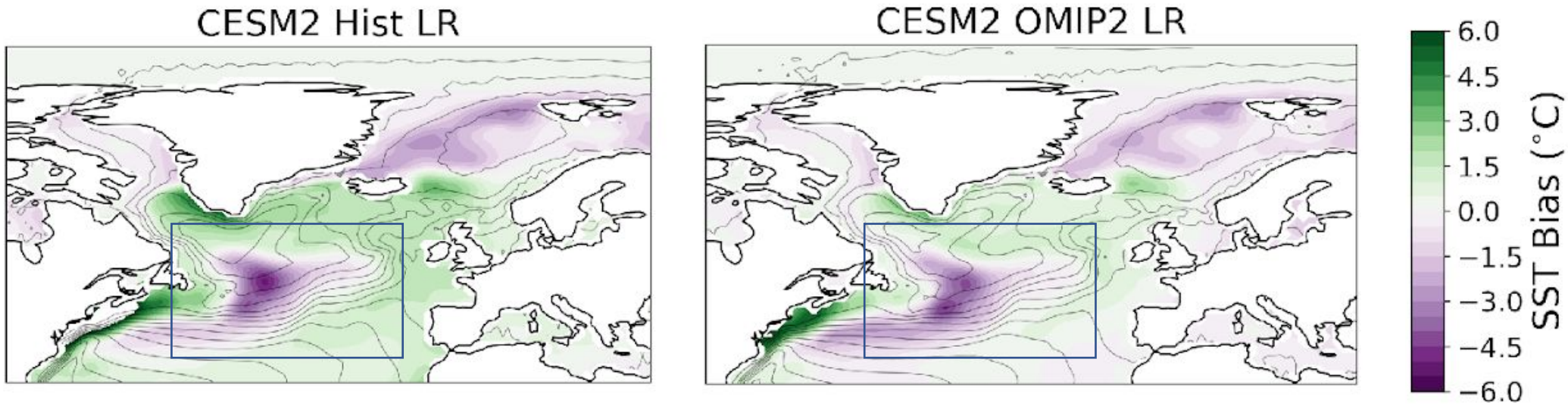
G-compset

FOSI (Forced Ocean Sea Ice)

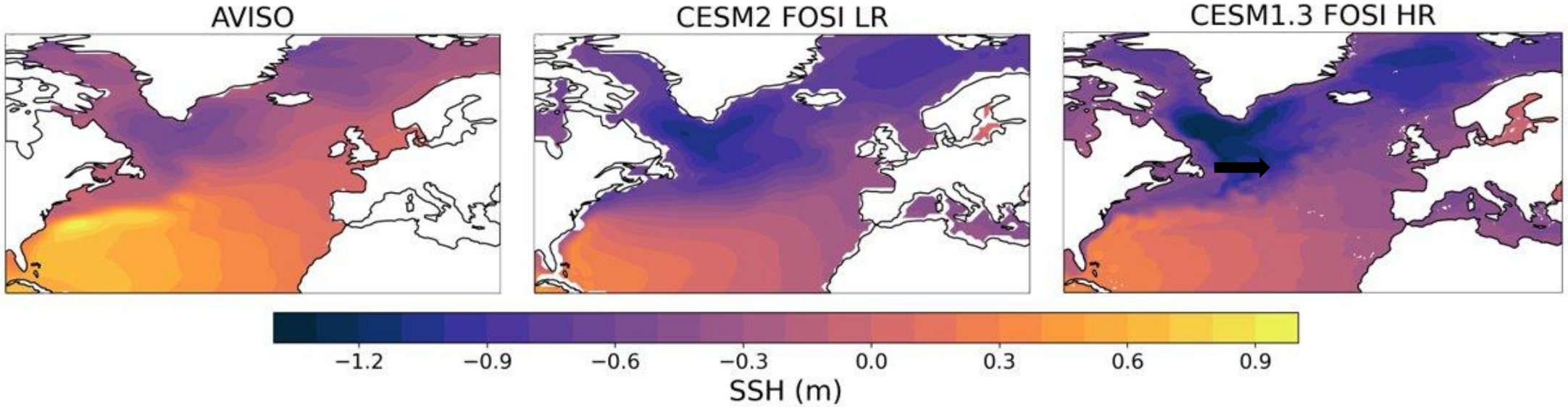
The misplacement of the North Atlantic current is related to errors in SST

Fully Coupled

Ocean and Sea-ice Only (FOSI)

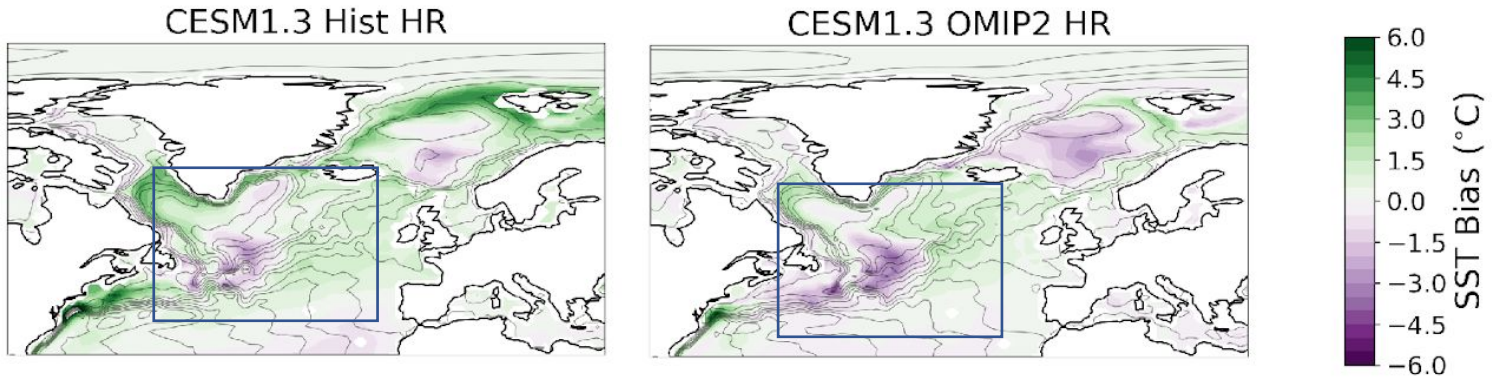


Unlike LR CESM, HR CESM has a North Atlantic Current with sharp bends, but they are too far east.



Fully Coupled

FOSI



Goal

Use surface buoyancy forced water mass transformation (WMT) as method to connect sea surface biases to circulation in both the LR and HR CESM

WMT (σ) = The amount of seawater changing from one density to another.

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

Density flux

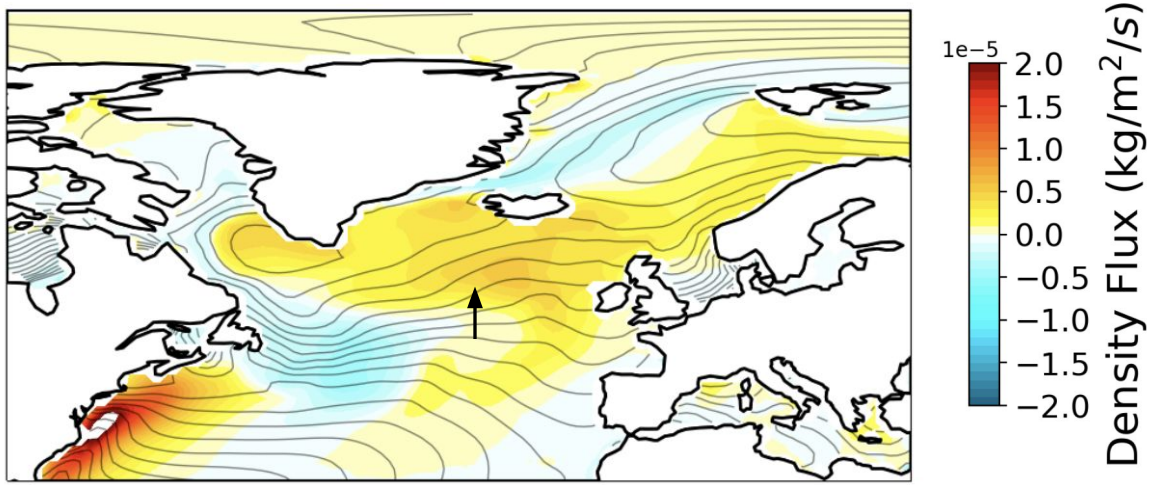
Surface heat flux

Surface freshwater flux

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

Density class area

Cross isopycnal circulation



$\sigma = 35\ kg/m^3$

WMT (σ) = The amount of seawater changing from one density to another.

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

Density flux

Surface heat flux

Surface freshwater flux

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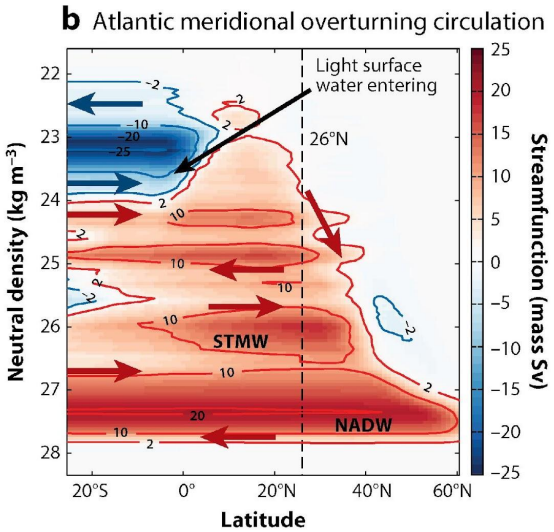
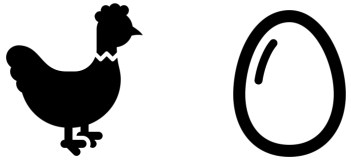


Groeskamp et al. 2018

$$\Psi(\sigma) \sim WMT(\sigma)$$

Overturning circulation balanced by surface buoyancy forcing

NAC bias → surface bias (sst,sss) → density class area and SHF bias → WMT/circulation bias



xWMT

Questions

1. How does LR vs HR WMT compare to observation-based WMT?
2. How are surface biases connected to WMT biases?

Data

Model Output

	LR (1x1)	HR (iHESP) (0.1x0.1)
Fully Coupled	CESM2 Historical	CESM1.3 Historical
Forced Ocean Sea Ice (FOSI)	CESM2 OMIP1/OMIP2	CESM1.3 OMIP2

OMIP (Ocean Model Intercomparison Project)

1993-2006 Means

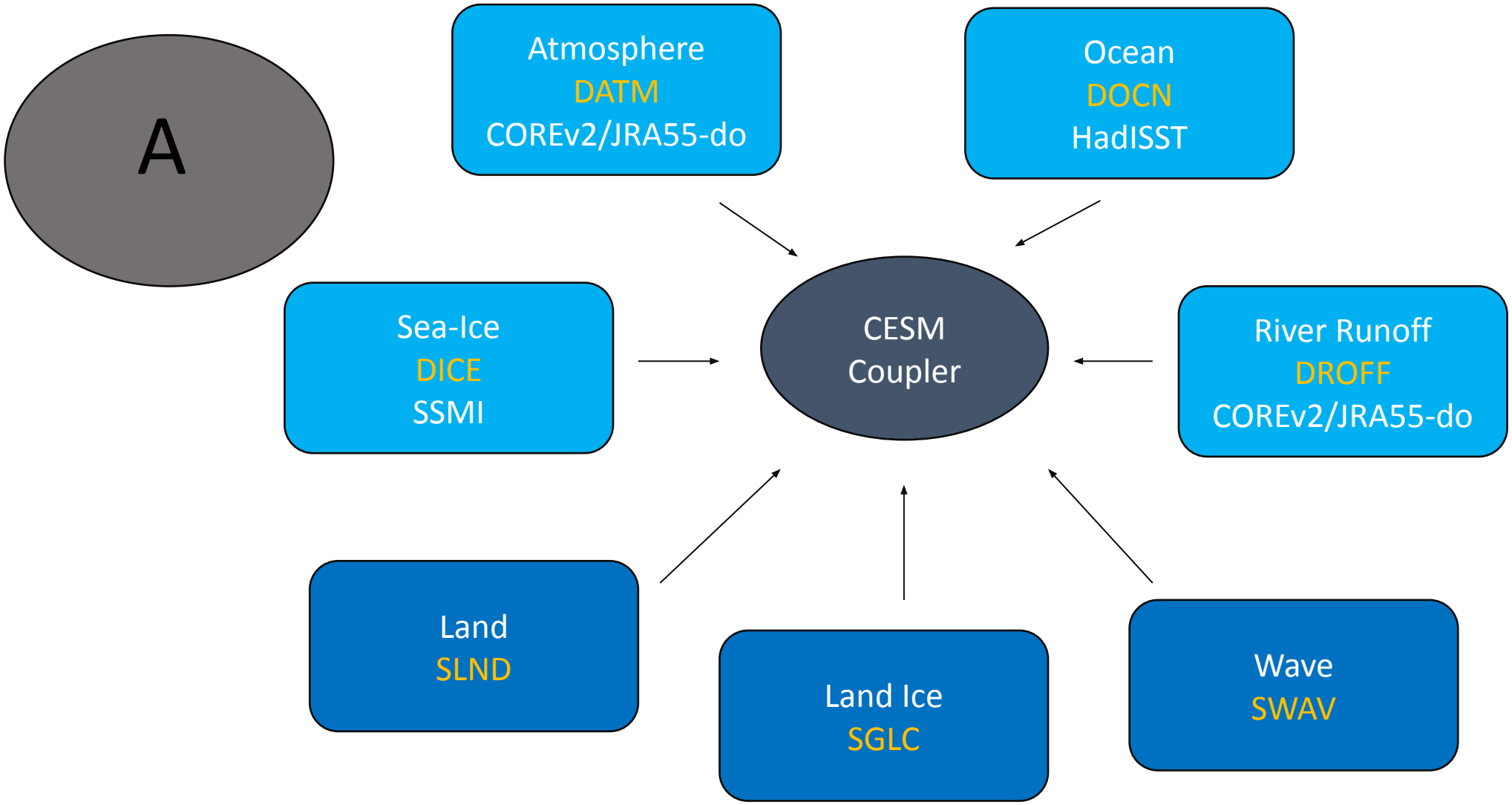
Bias = model simulation – observations

Observations

- SST (HadISST)
- SSS (EN4)
- Sigma (EN4+HadISST)
- "Observational" WMT
  - COREv2 fluxes + HadISST + EN4
  - JRA55-do fluxes + HadISST + EN4

Good et al. 2013, Chang et al. 2020, Danabasoglu 2019

“Observational” WMT: CESM A-compset simulation following the method of Large and Yeager (2009)



Question 1

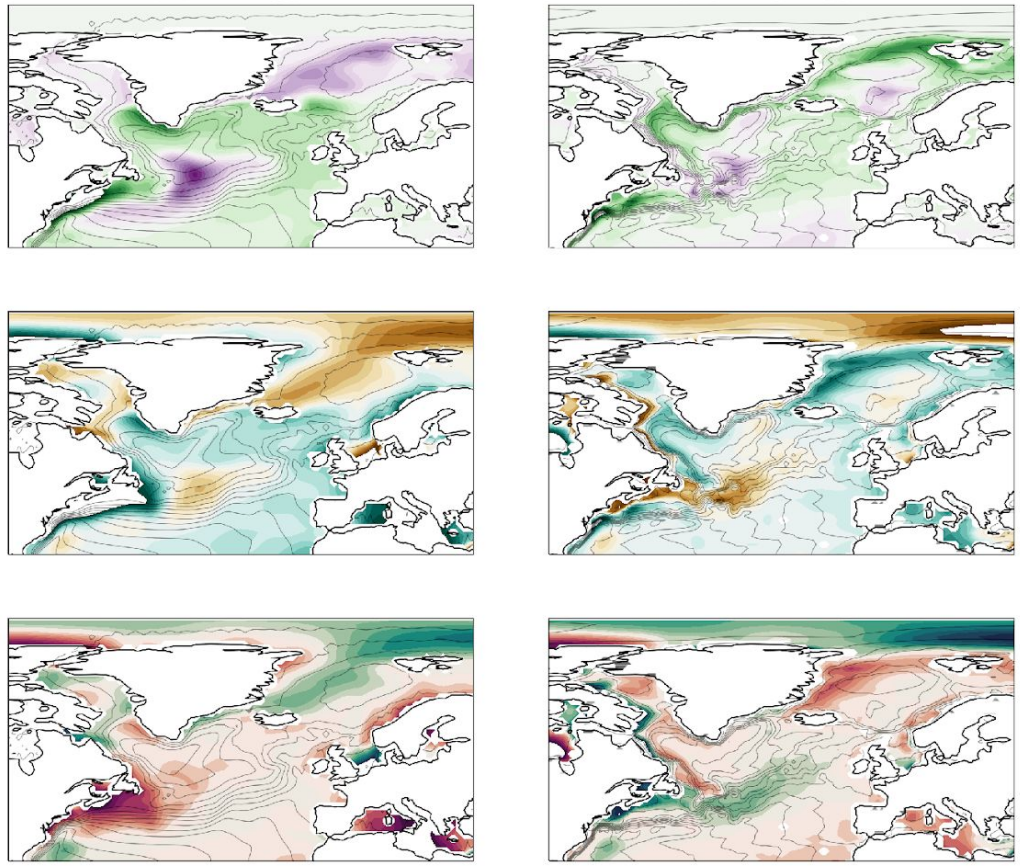
How do sea surface biases compare between LR and HR CESM?

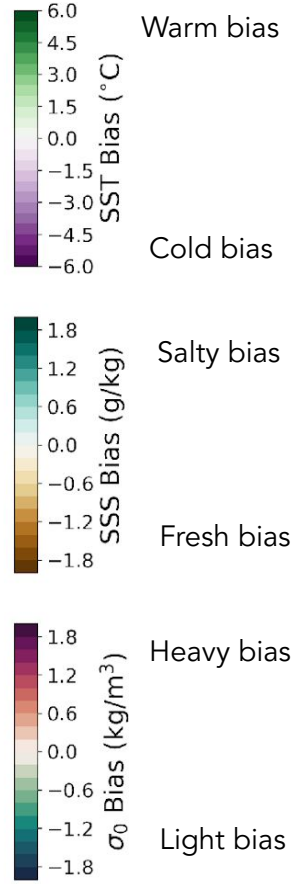
Density biases aren’t necessarily improved in HR CESM

Fully Coupled

CESM2 Hist LR

CESM1.3 Hist HR



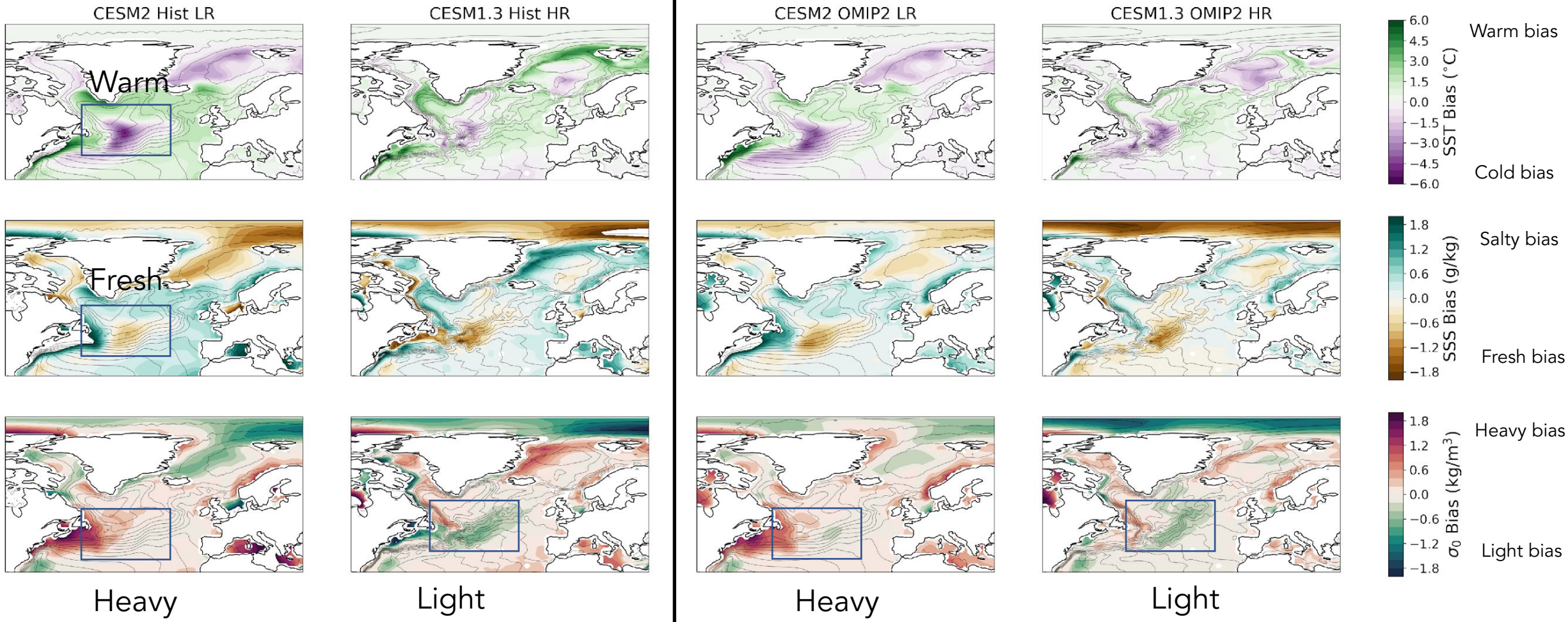


Bias = model simulation – observations

Density biases aren’t necessarily improved in HR CESM

Fully Coupled

Ocean and Sea-ice only (FOSI)

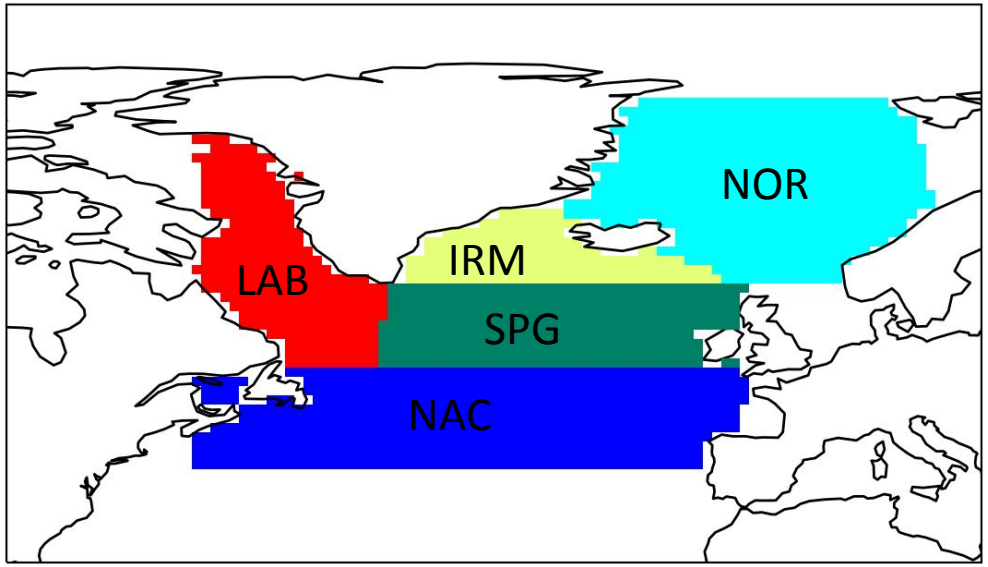


Bias = model simulation – observations

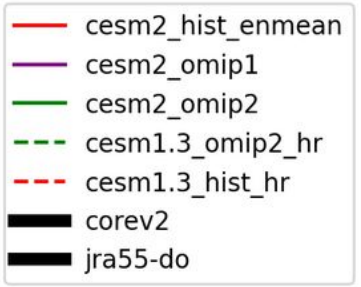
Question 1

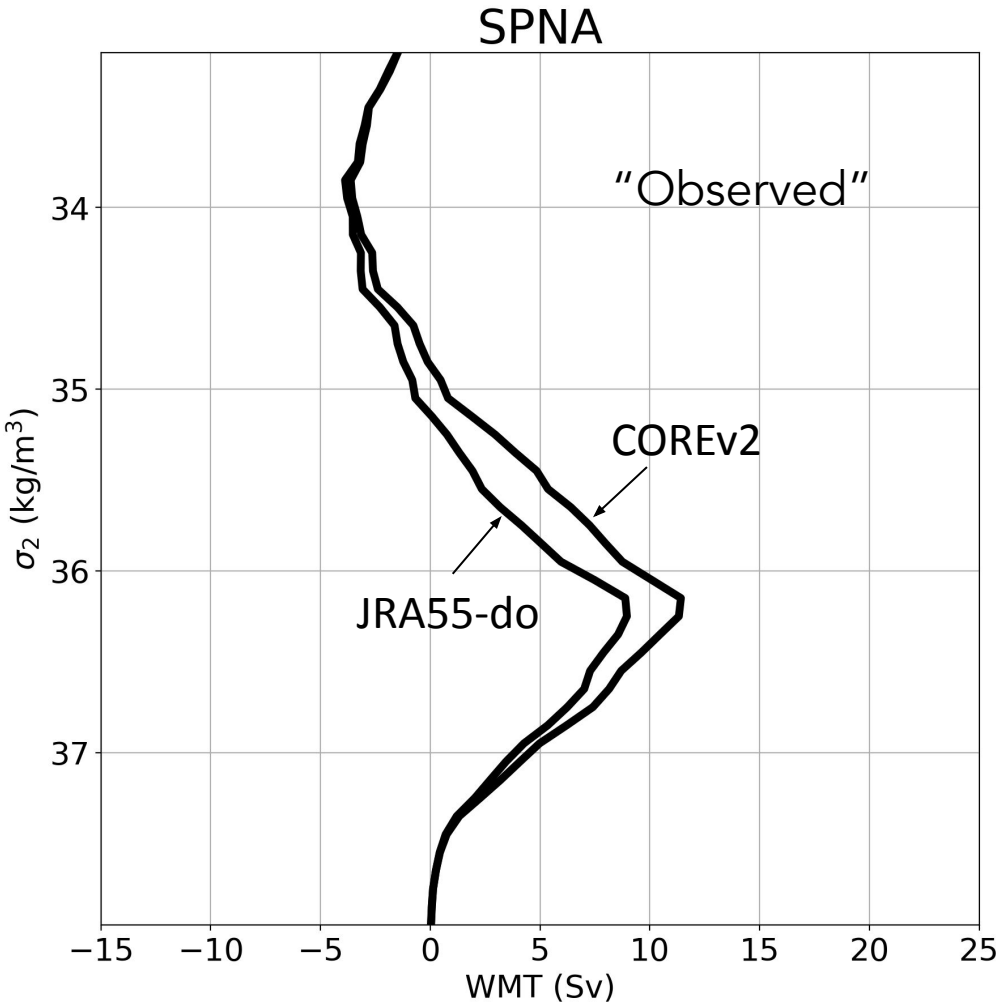
How does LR vs HR WMT compare to “observational” WMT?

The two observation-based WMT estimates are similar, but JRA55-do has less WMT than COREv2 due to surface heat flux.

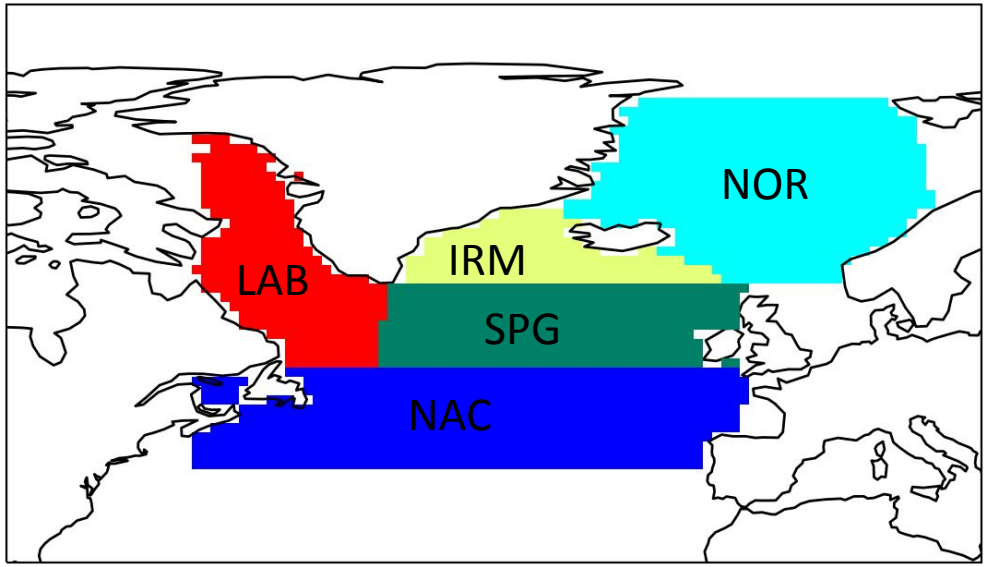


SPNA = LAB+SPG+IRM+NOR+NAC





Too much WMT in the densest classes in the LR CESM



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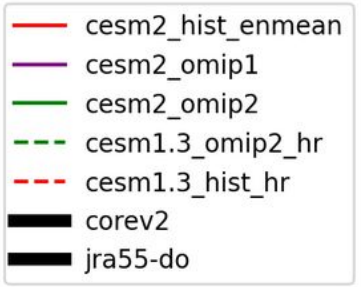
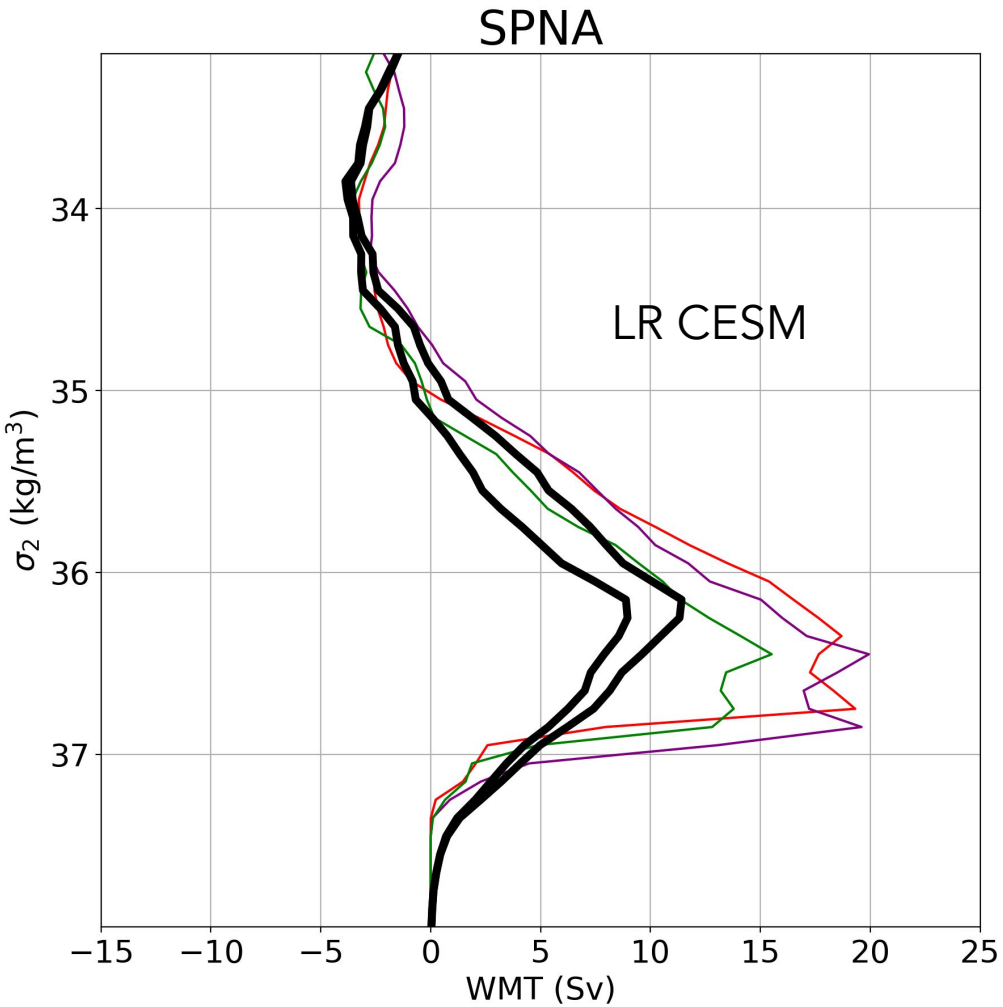
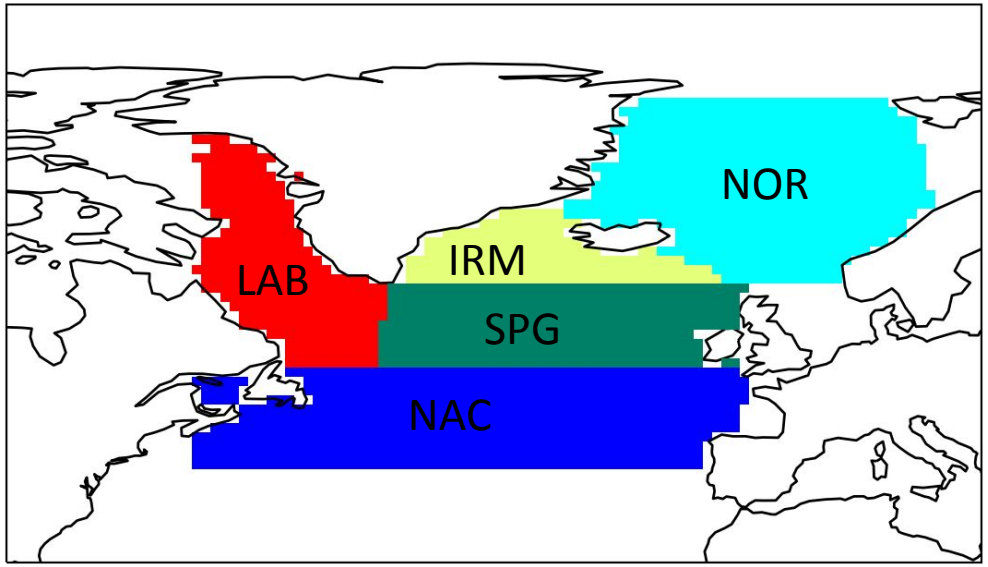




HR CESM has too much WMT in subtropical water mass classes



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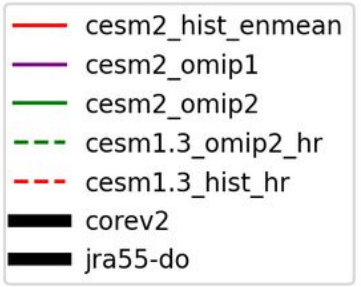
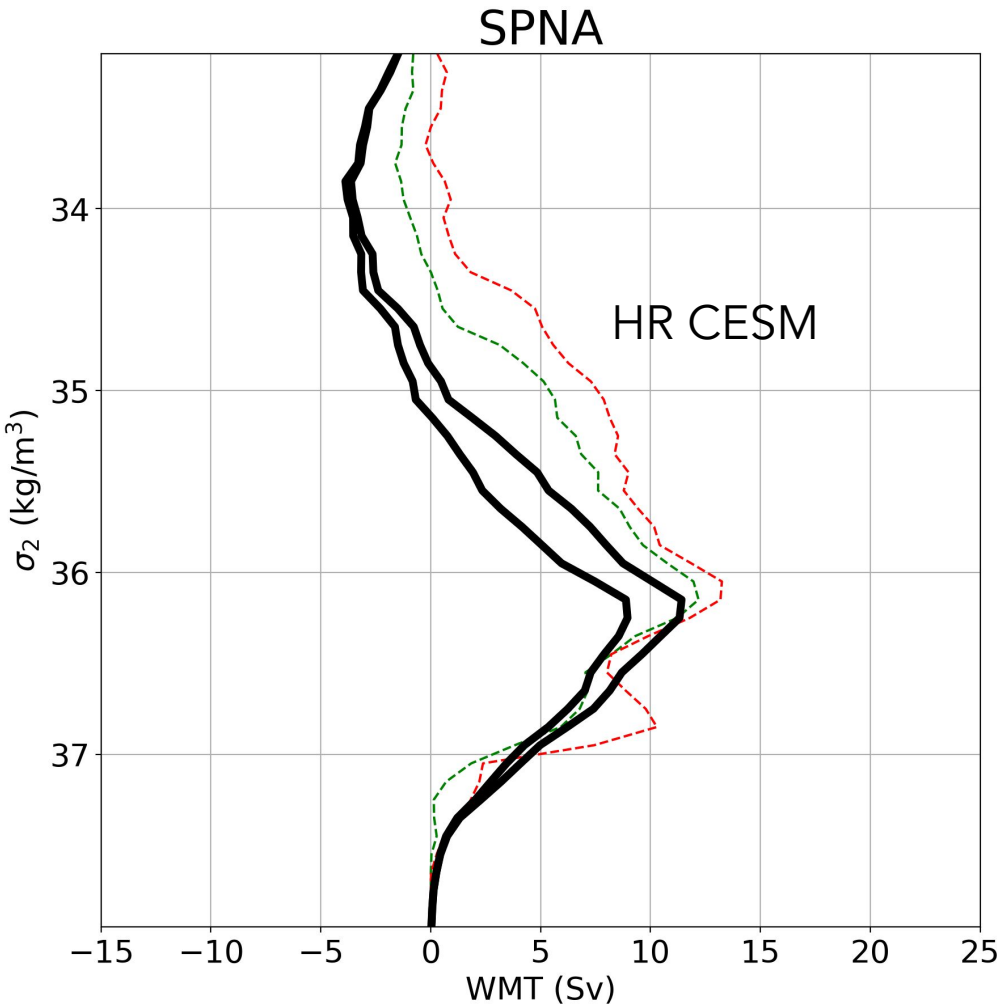
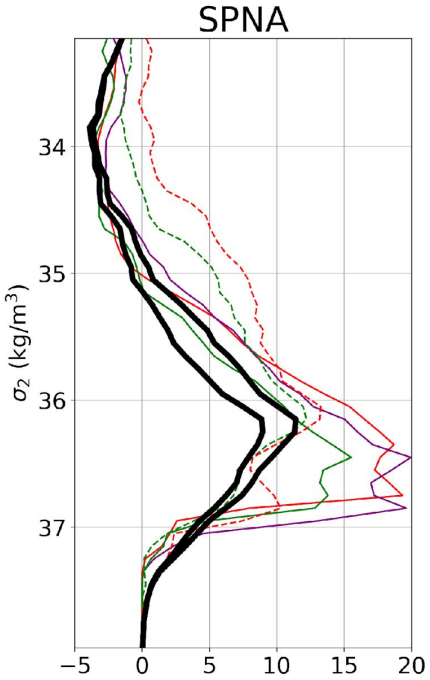
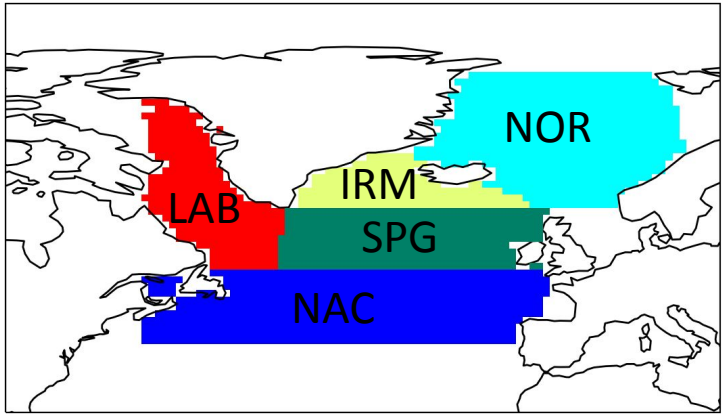
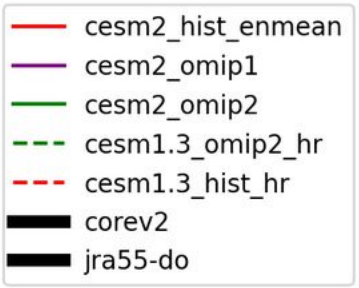




Regional breakdown shows where model WMT errors originate.







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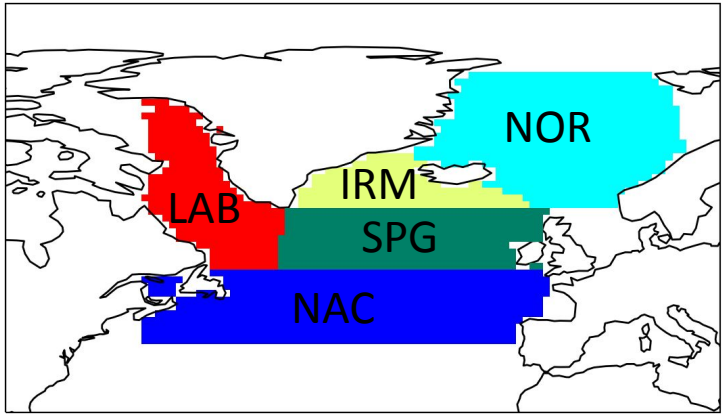

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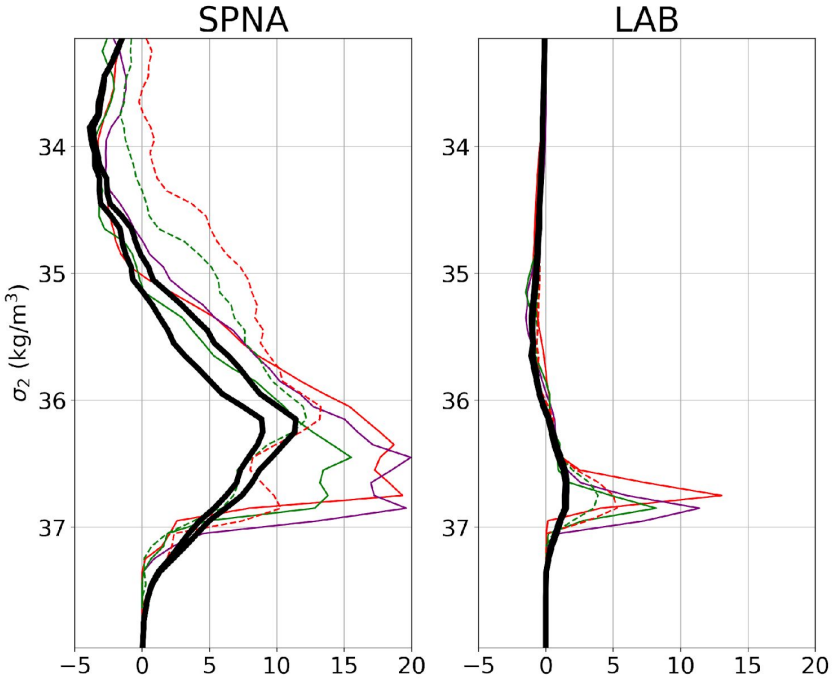

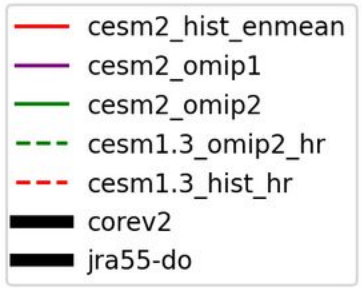

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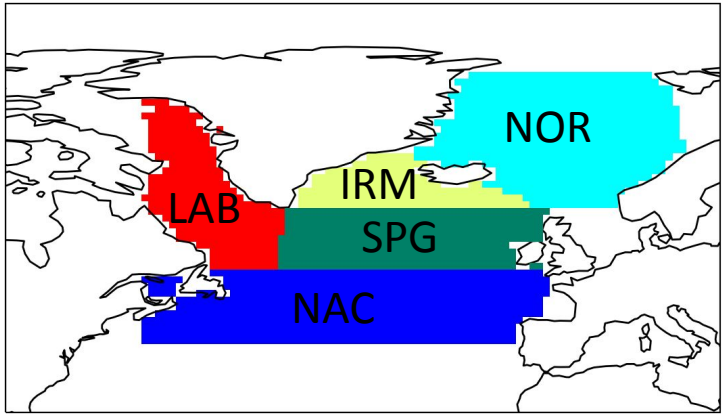

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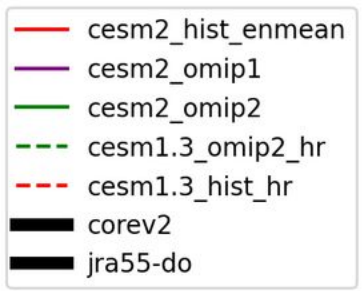

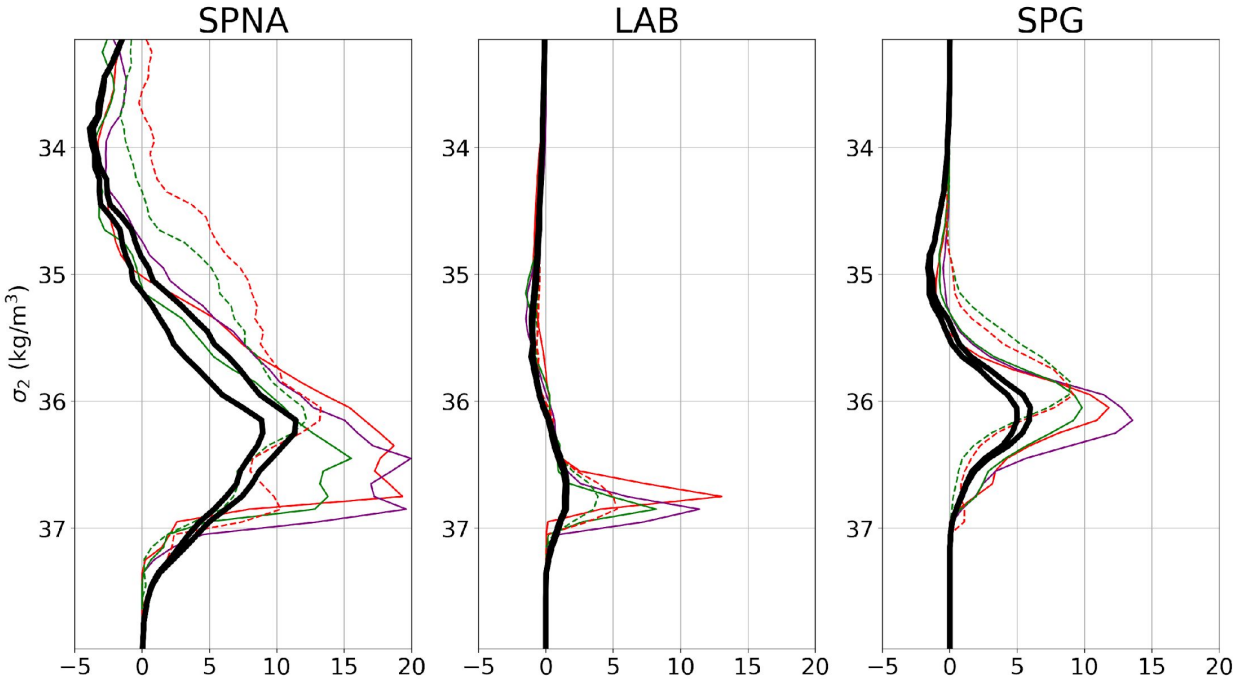

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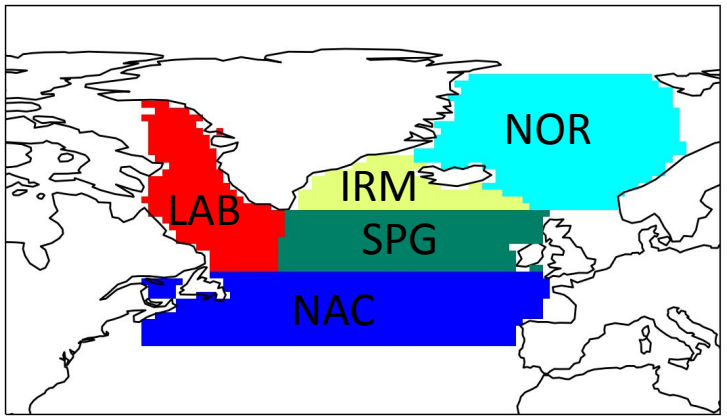

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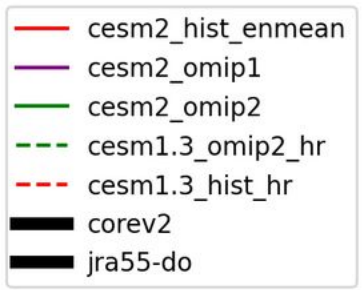

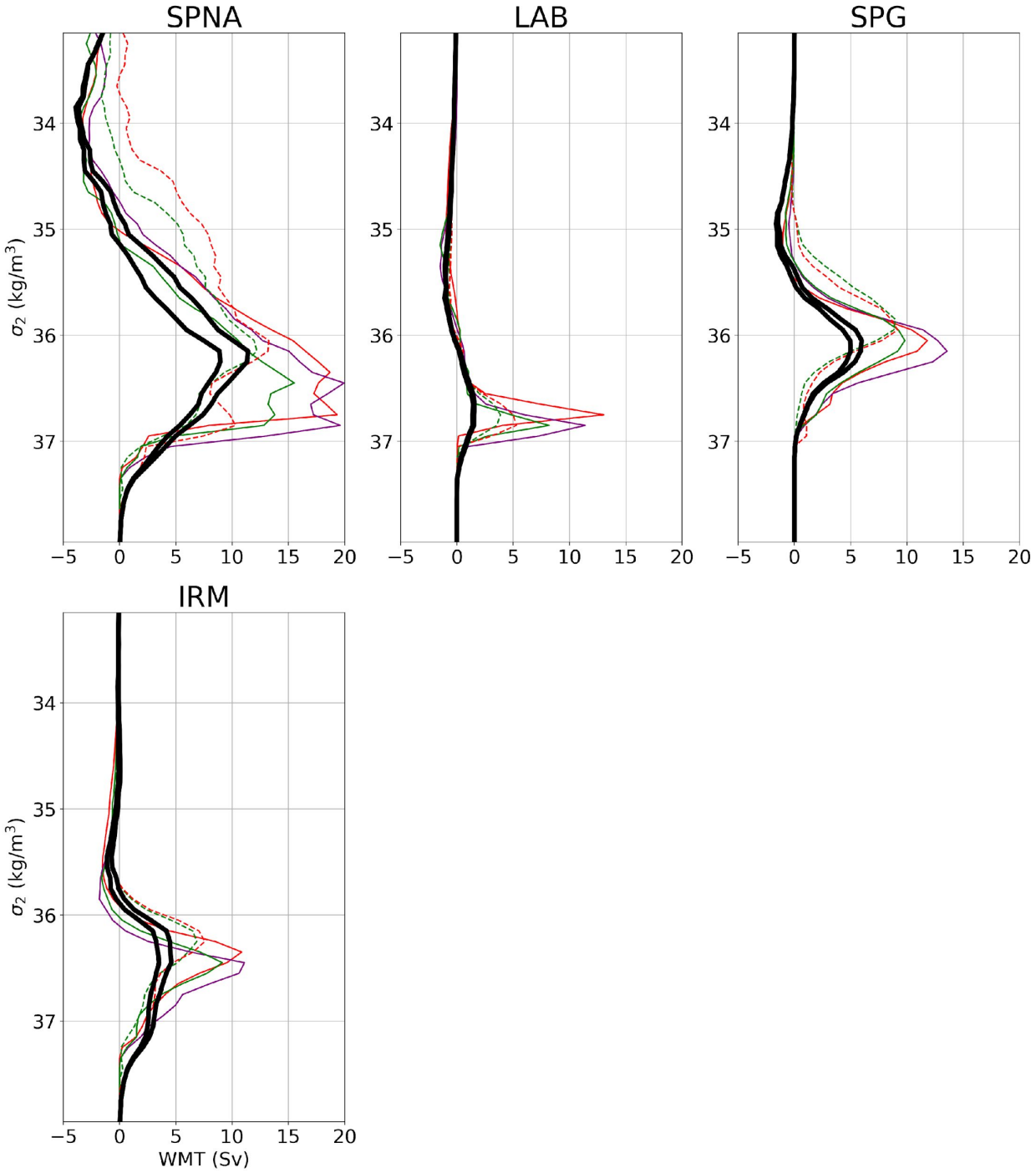

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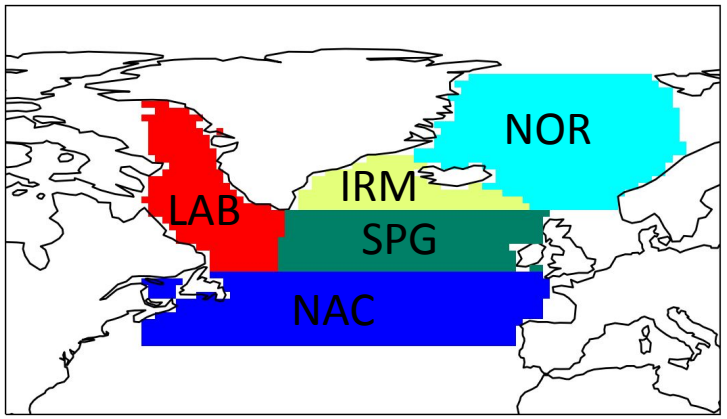

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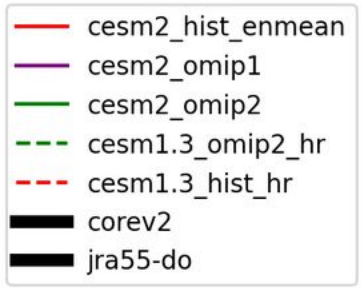

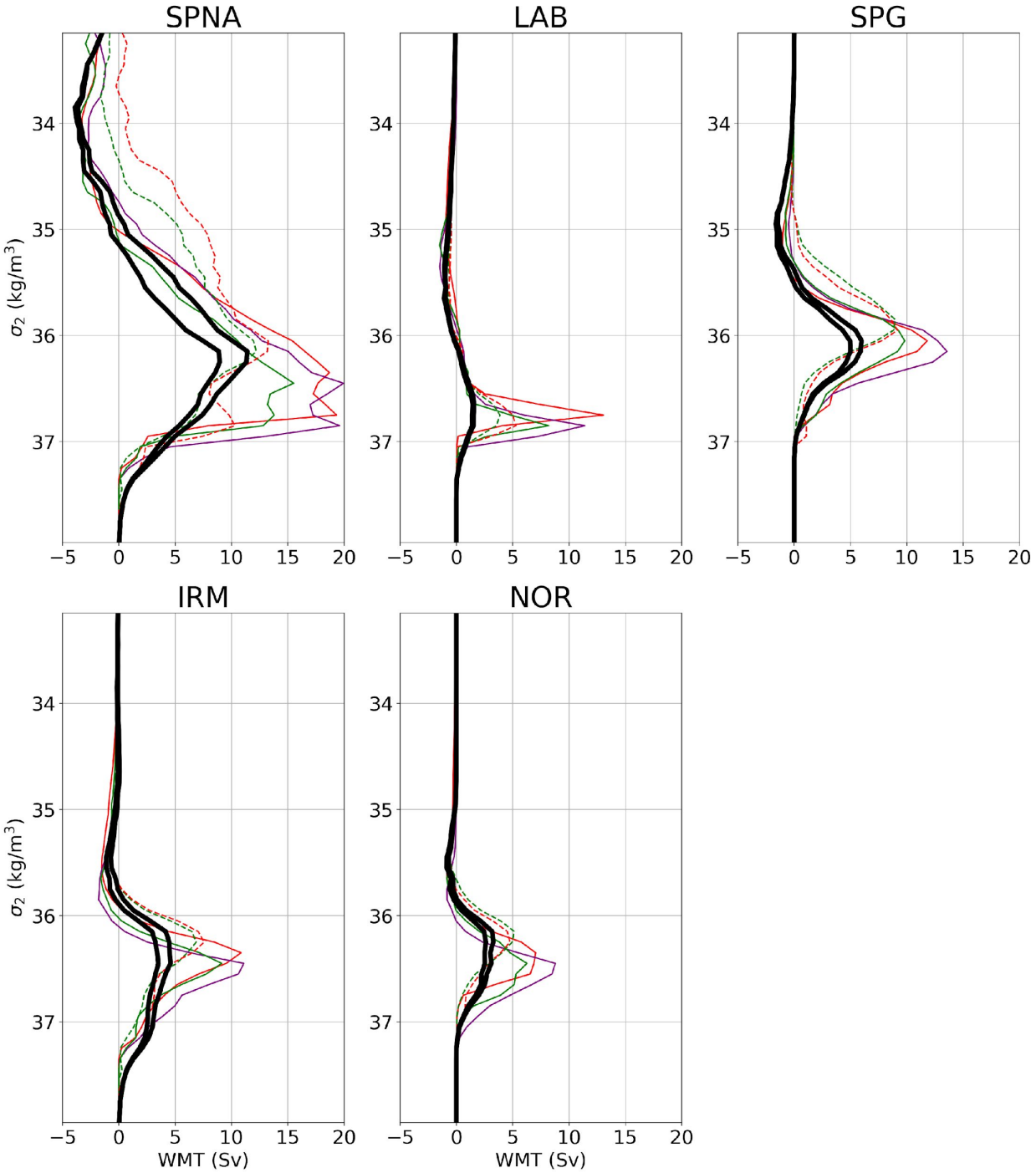

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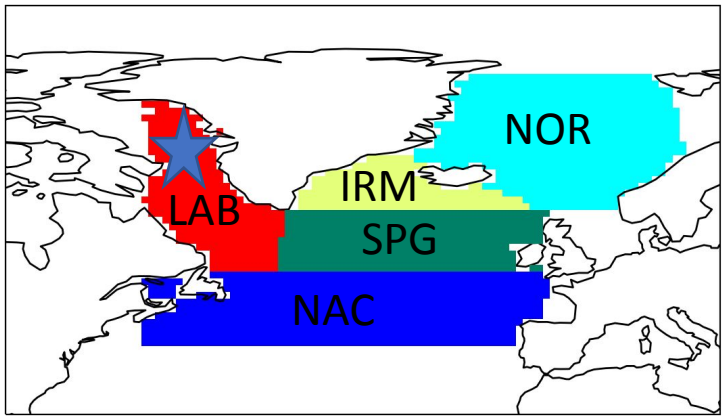

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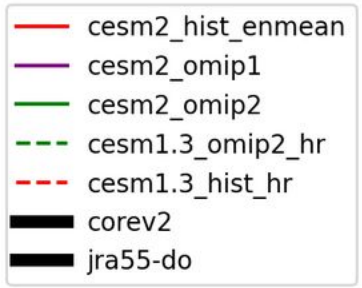

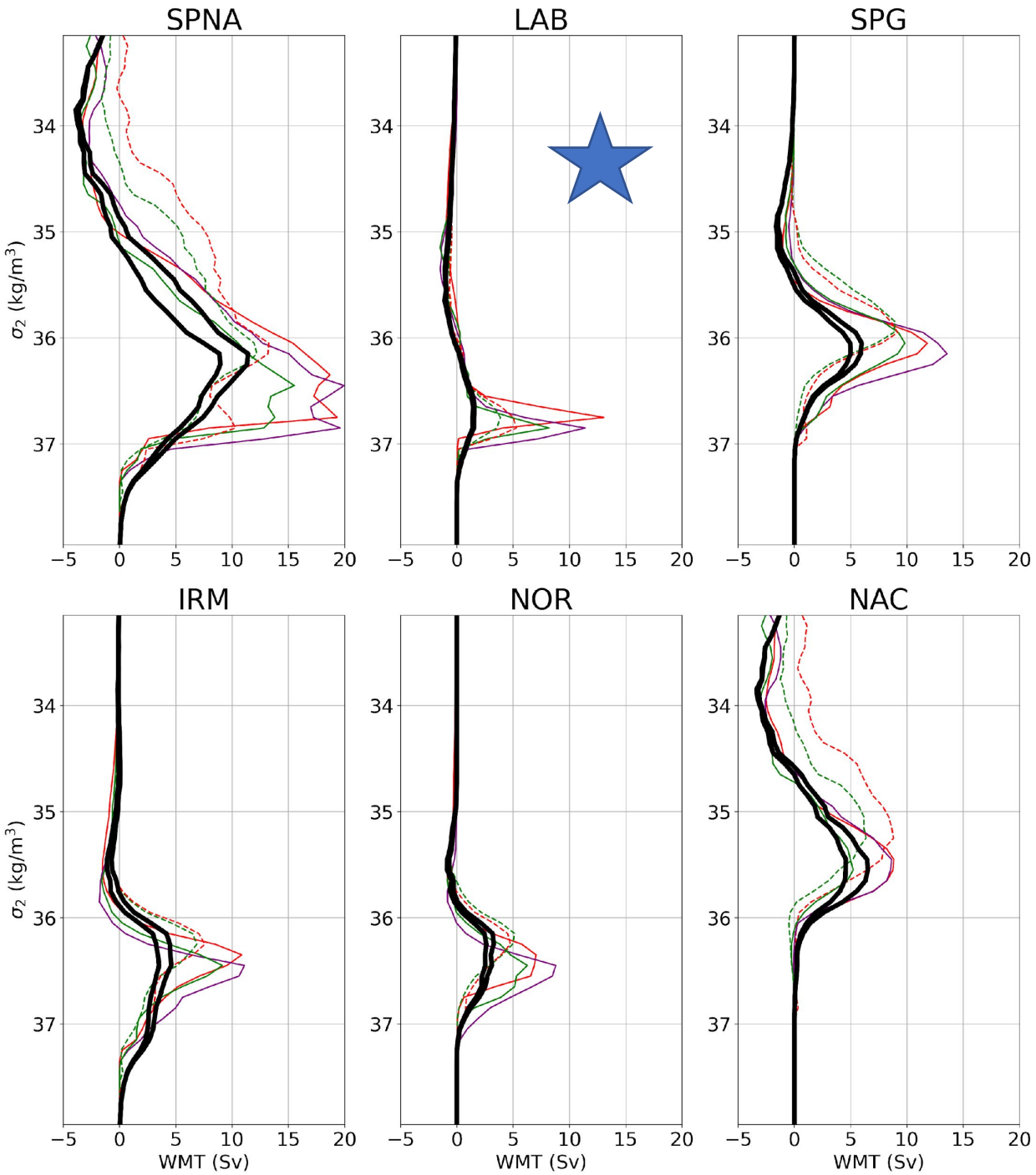

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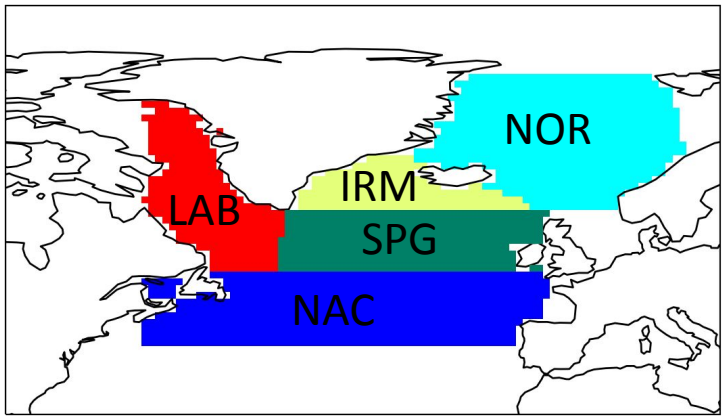

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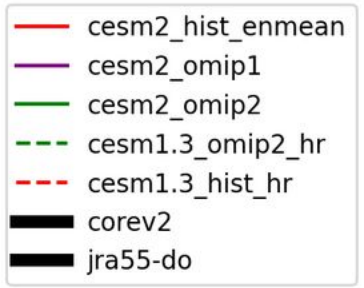
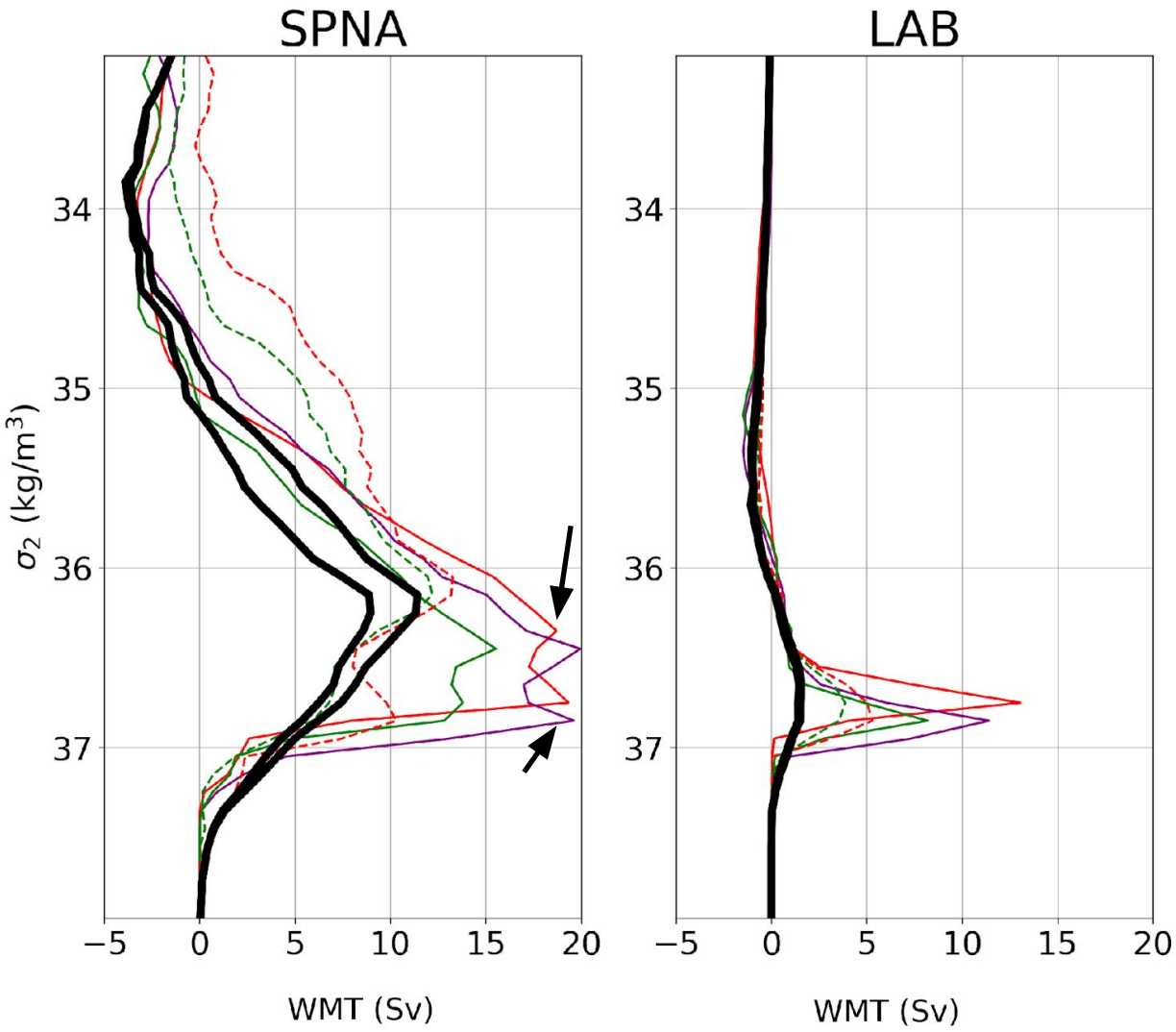
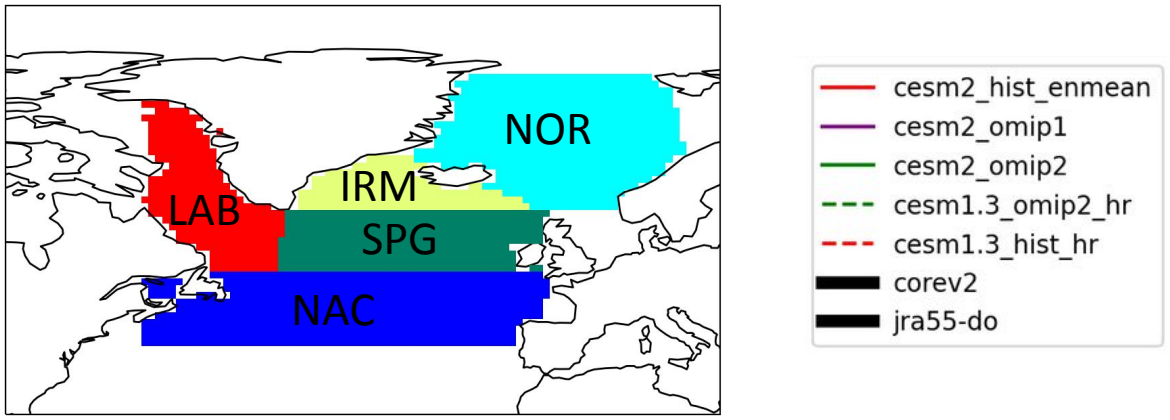




Regional breakdown of WMT shows places where ObsWMT and ModWMT differ the most



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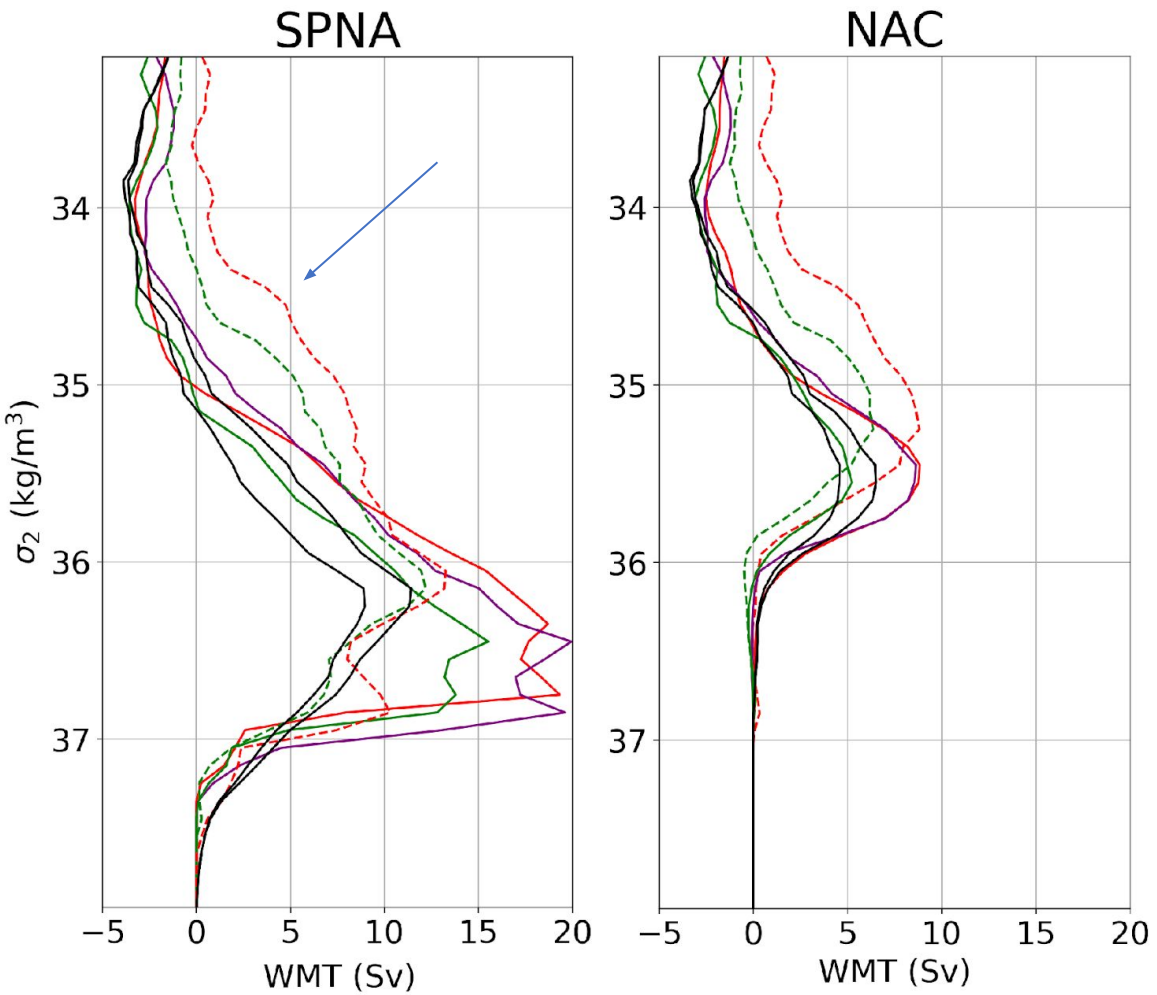


Question 2

How are surface biases connected to biases in WMT?

Breaking down WMT biases into errors due to SHF and surface density

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

Density flux

Surface heat flux

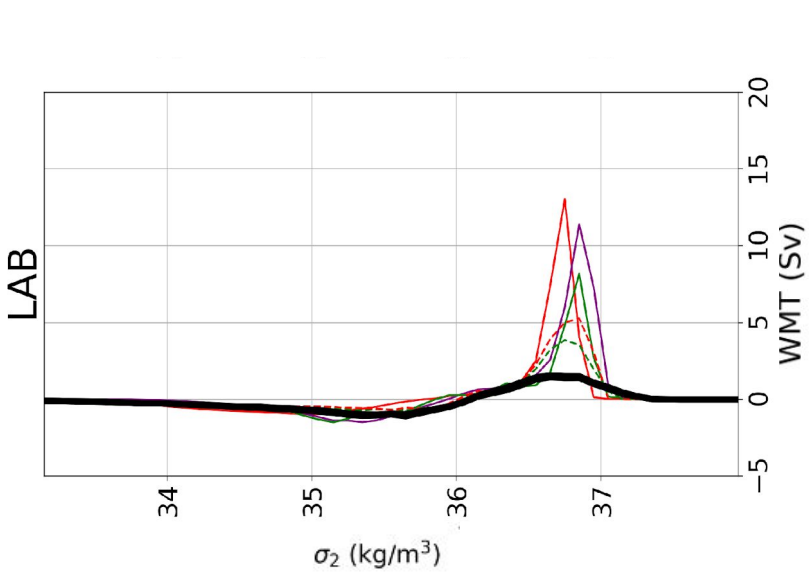
Surface freshwater flux

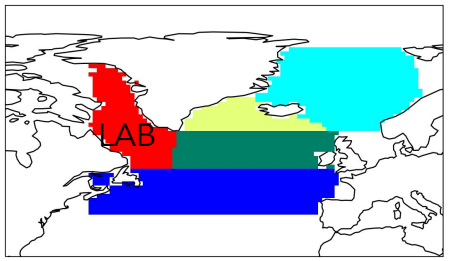
$$WMT(\sigma) = \frac{1}{\Delta\sigma} \iint f \, dA_\sigma$$

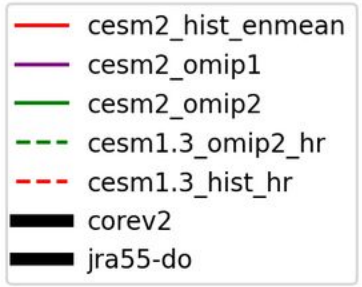
Density class area

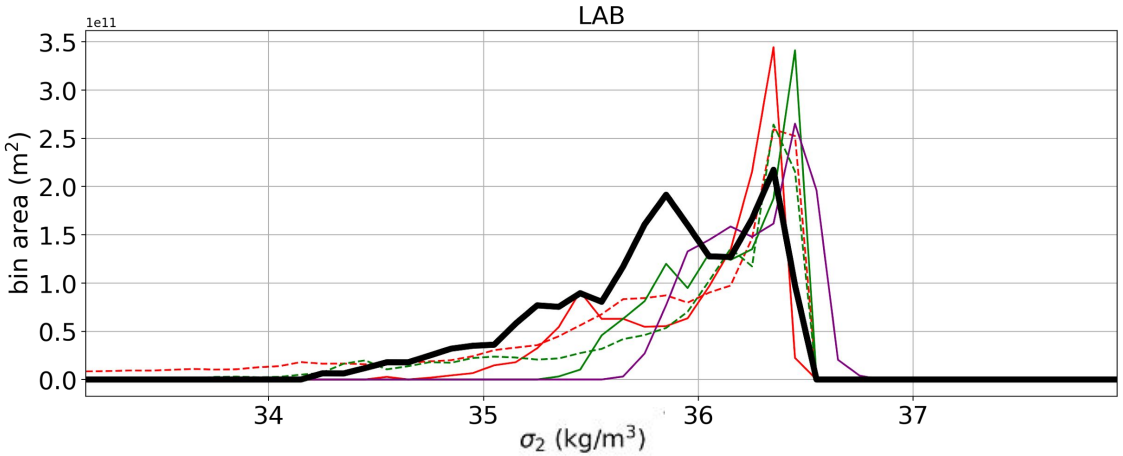
Surface freshwater flux << Surface Heat Flux

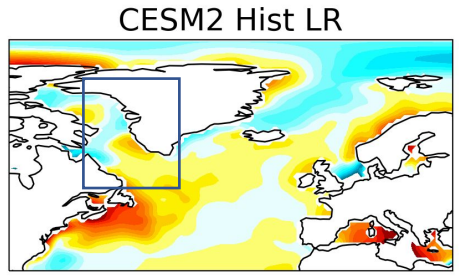
Lab Sea errors: surface density too high and surface cooling too strong in CESM

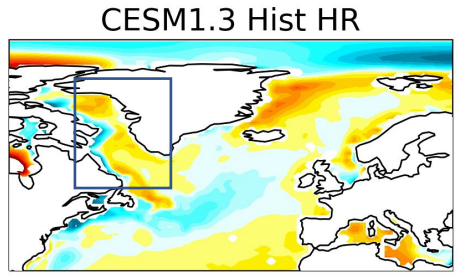


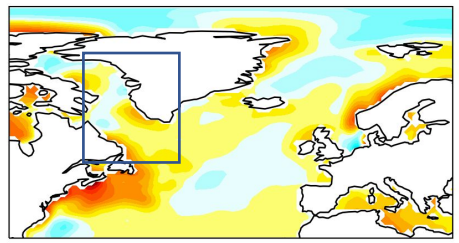


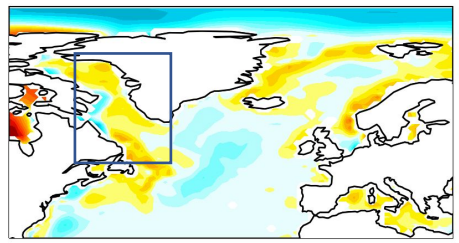


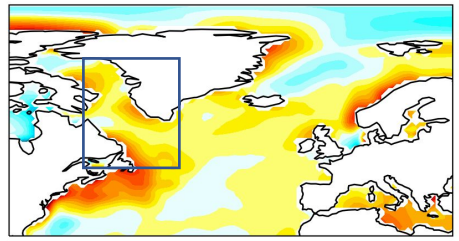


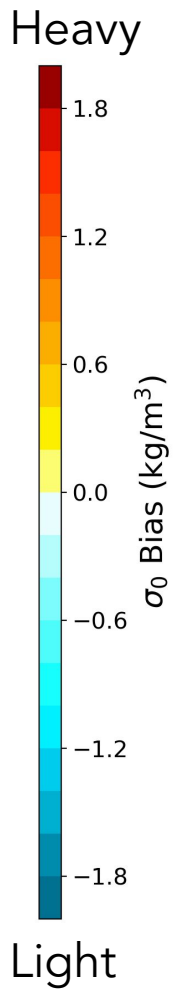




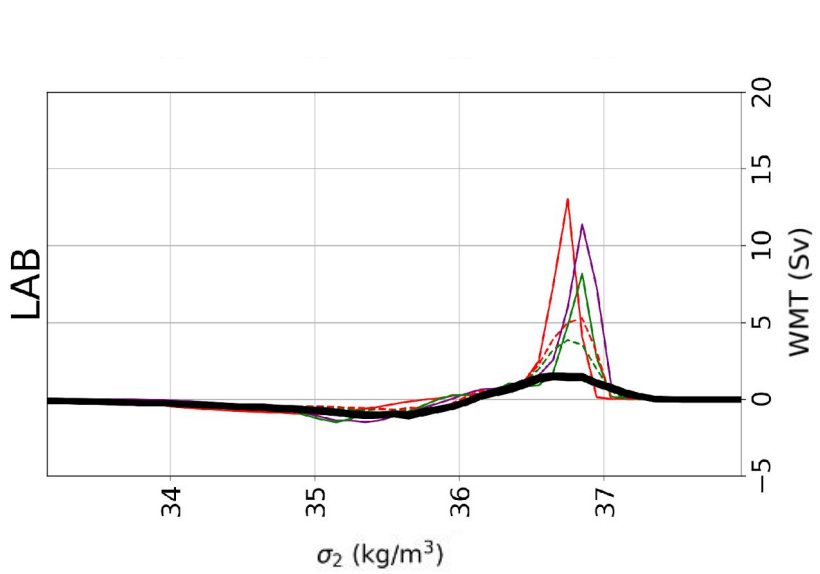


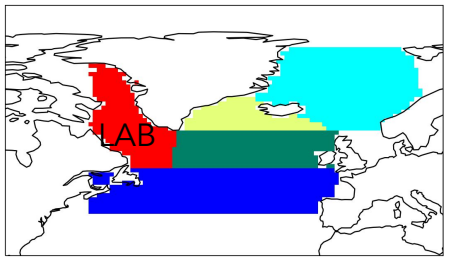


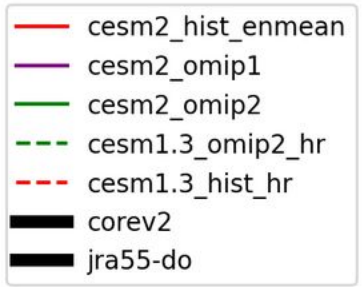


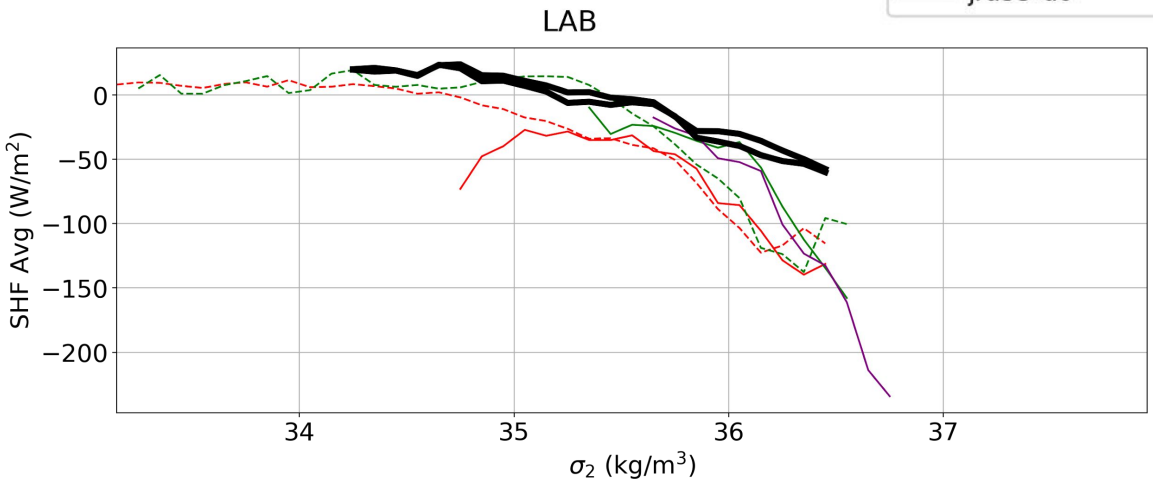


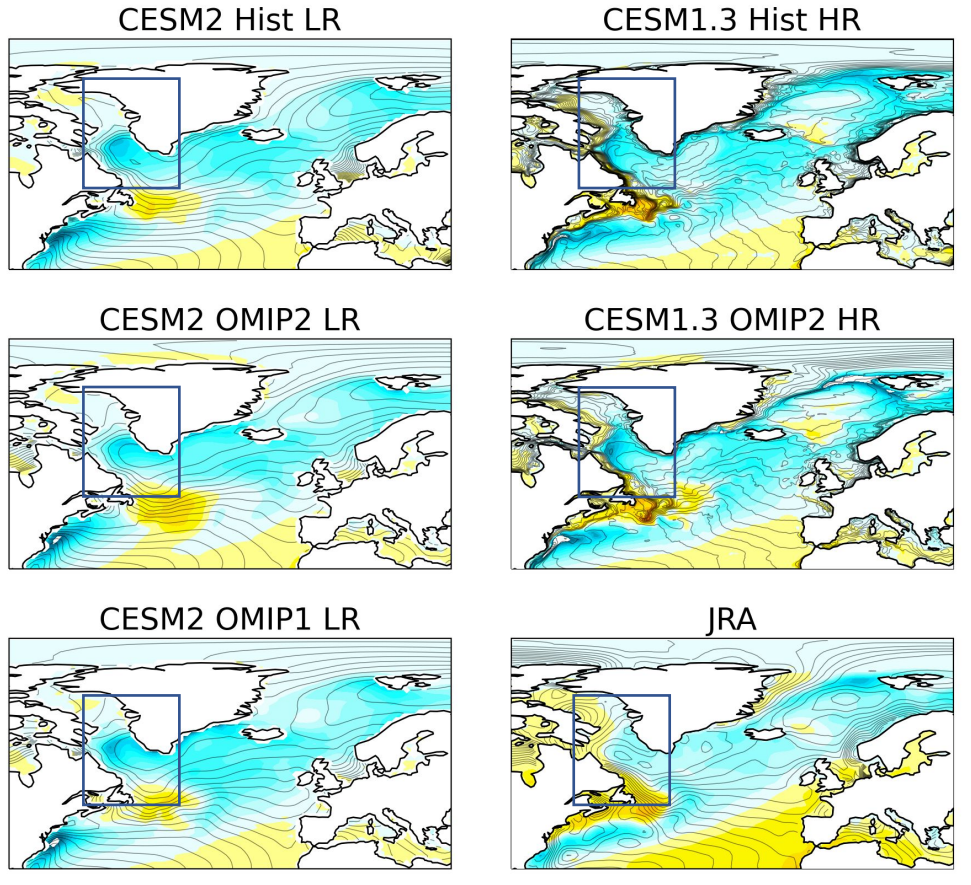
Lab Sea errors: surface density too high and surface cooling too strong in CESM



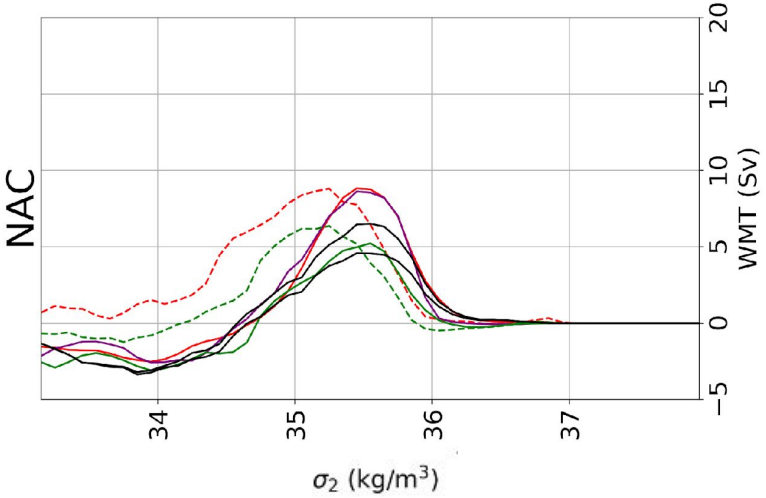


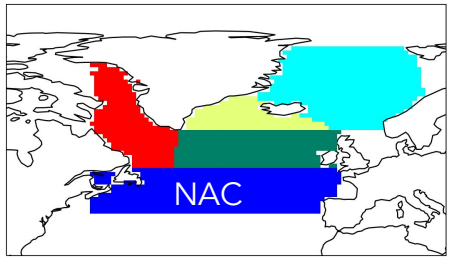


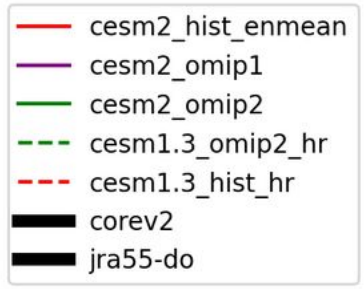


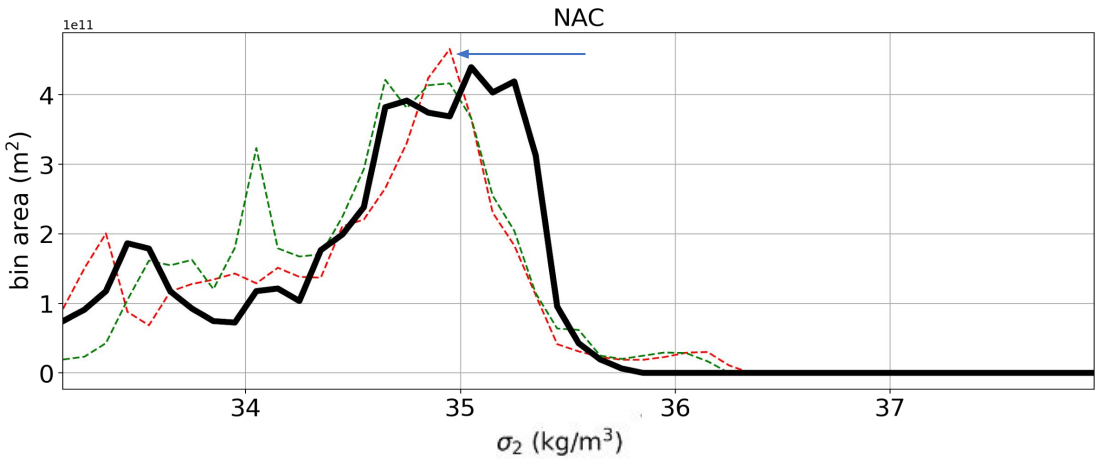


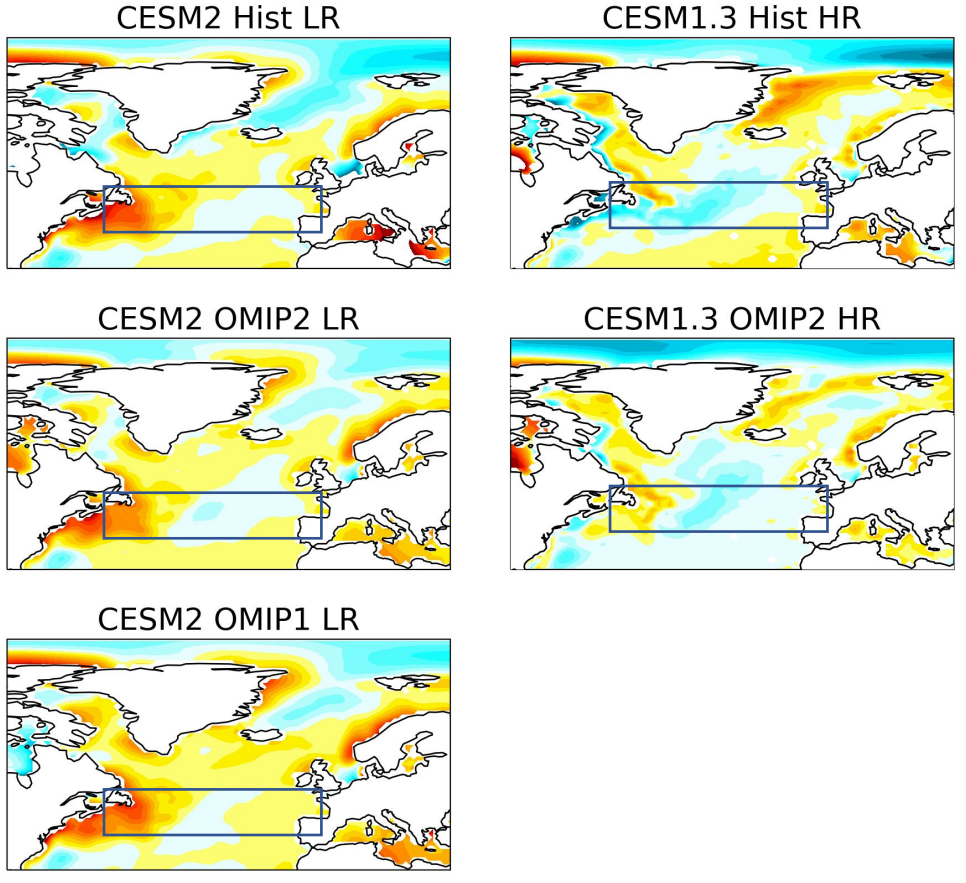
Decomposing WMT shows that isopycnal bin area/location and SHF are main the reason for differences between ObsWMT and ModWMT



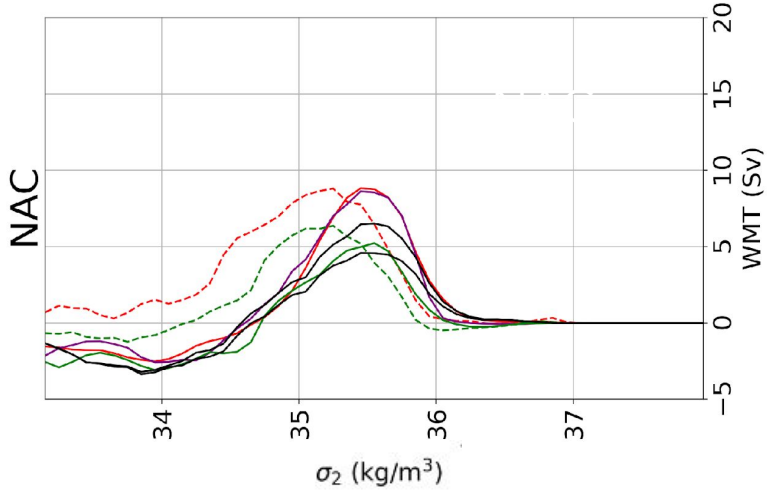


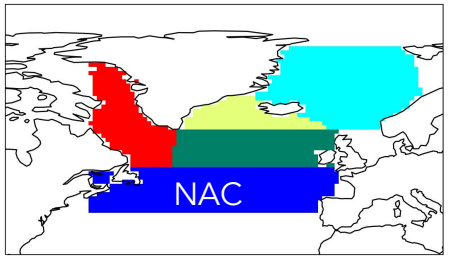


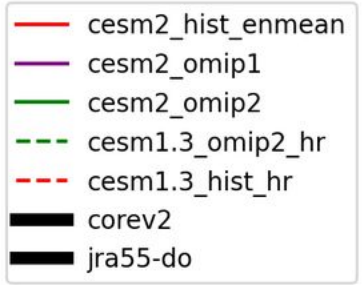


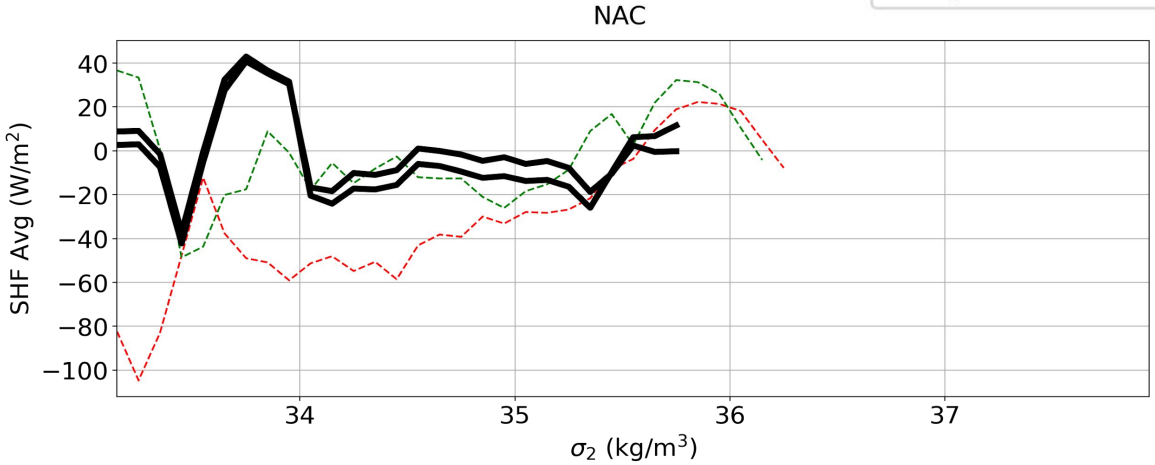


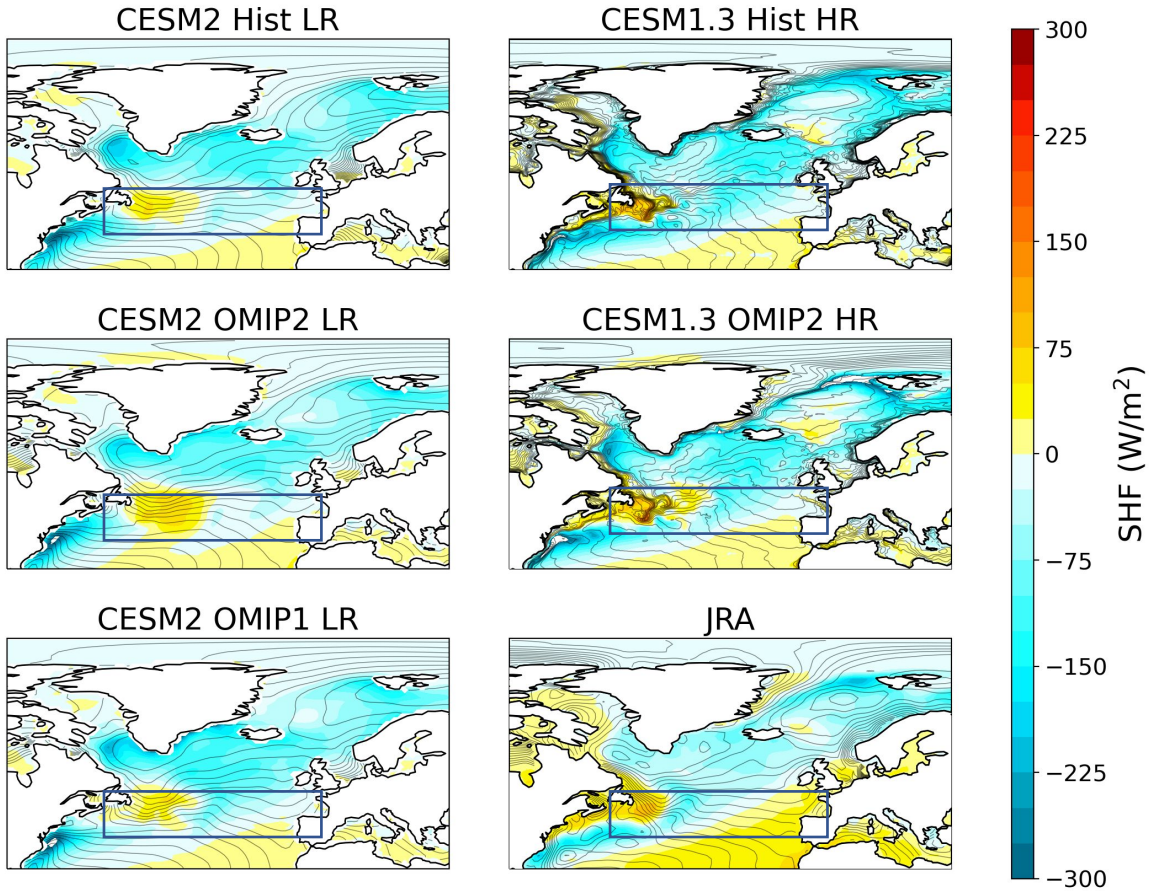
Decomposing WMT shows that isopycnal bin area/location and SHF are main the reason for differences between ObsWMT and ModWMT











Summary

- We have used CESM A-compset simulations to create observation-based WMT benchmarks
- Compared to LR, HR has better WMT in Lab Sea, but has too much WMT in northern edge of subtropics.
- Errors in both surface density, but mostly SHF lead to WMT errors

MDTF POD

- More observation-based WMT testing to come, but eventually these will be available to the community through our process oriented diagnostic in the NOAA Model Diagnostics Task Force software package.