Persistent coastal temperature biases in km-scale climate models due to unresolved oceanic tidal mixing

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Coastal Oceans and Shelf Seas Task Team International Meeting
Brest, 17-20 June 2025

EERIE
European Eddy-Rich ESMs

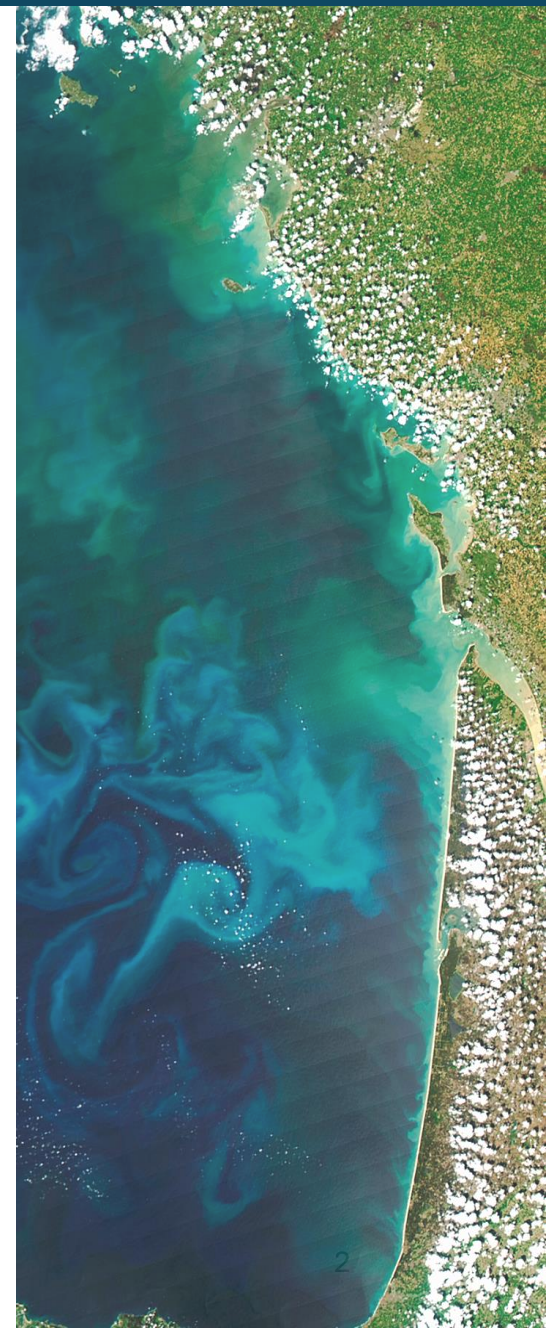
European Commission

- Coastal regions are crucial for climate system and ecosystem services
- But they are very often badly represented in global ocean and climate models (Holt et al. 2017).
- Climate models are valuable to predict the mid- and long-term evolution of the coastal oceans.
- Newly developed km-scale climate models offer capabilities for better representing regional and local scale climate and downscaling climate information at the scale needed for adaptation policies.

→ Necessity to evaluate the capabilities of these models in coastal regions.

1) What are the dominant processes underlying sea surface temperature biases on the shelf in km-scale climate models?

2) What are the implications for the local ocean-atmosphere coupled system?



Outline

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2. Data and Methods
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   b. Observations

3. Results
   a. Sea surface temperature biases on the shelves in climate models
   b. Correlation with barotropic tidal mixing fronts
   c. Impact on the atmospheric temperature biases

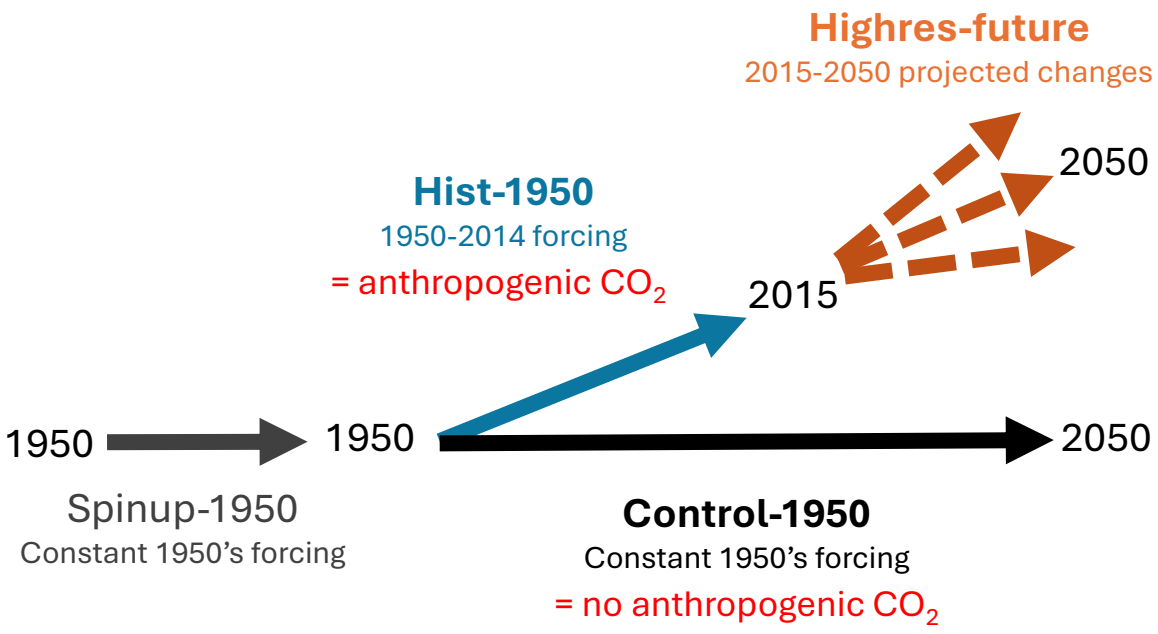
4. Discussion and Conclusion: Towards a parameterization of barotropic tidal mixing in climate models?

2. Data and Methods

a. Climate models and simulations

HighResMIP **simulation protocol**

- Coupled ocean-atmosphere-sea ice-land
- Ocean nominal resolution < 20km



a. Climate models and simulations

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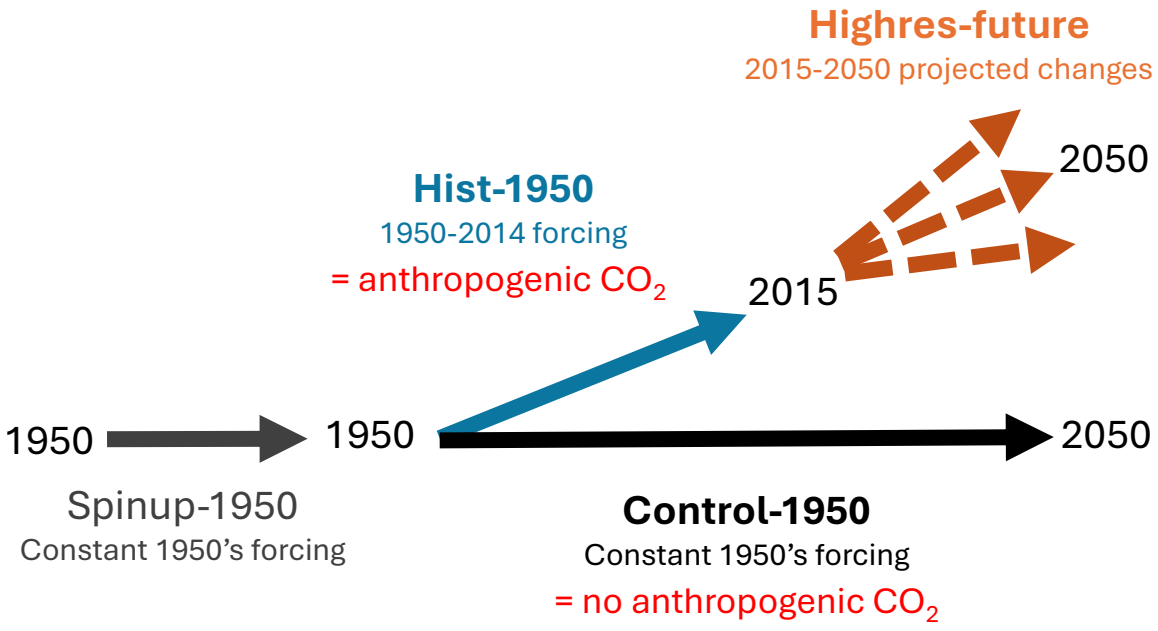
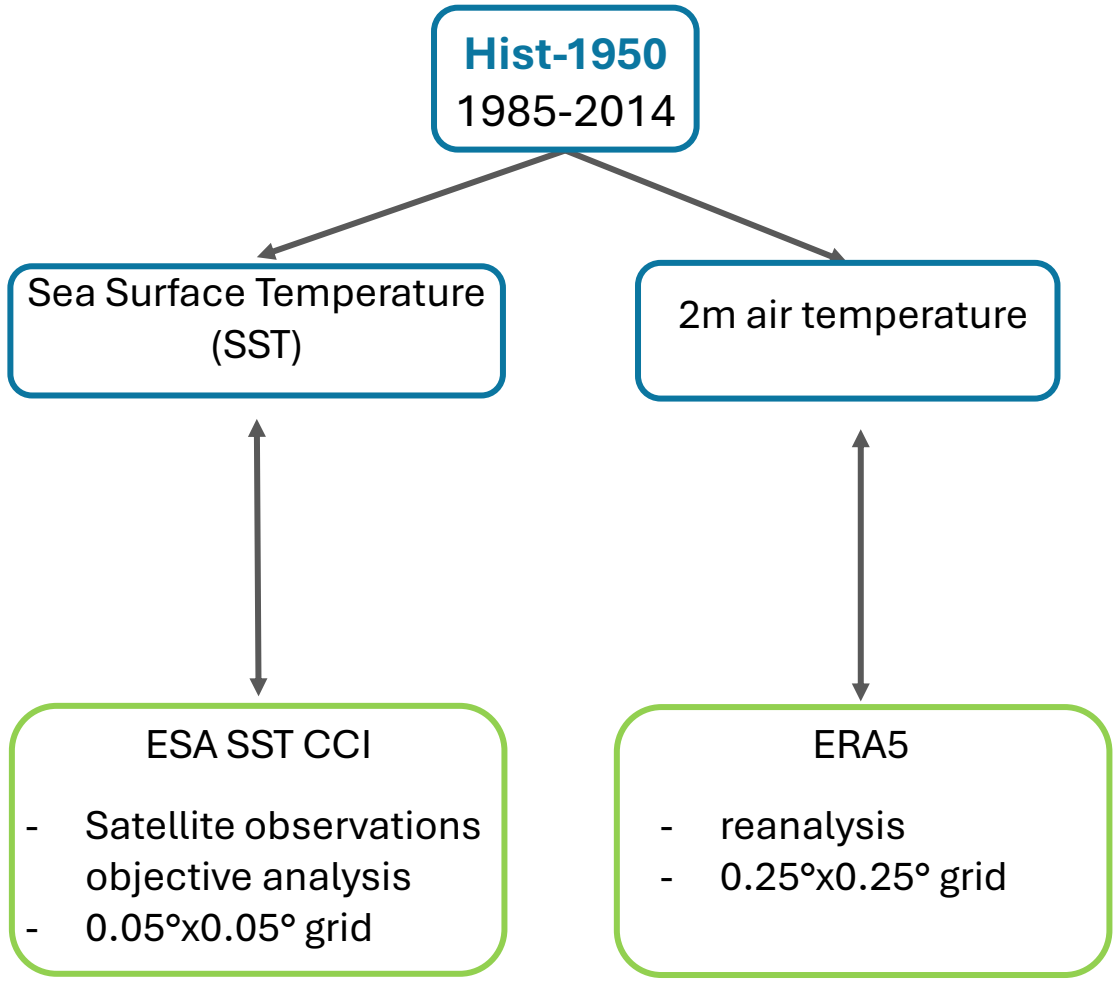


b. Comparison with observational datasets



a. Climate models and simulations

Institution	Model	Ocean Model	Ocean Resolution	Atmosphere Model	Atmosphere Resolution	Reference
Met Office (UK)	HadGEM-GC31-HH	NEMO-GO6.0	8 km	UM-GA7.1	50 km	M. J. Roberts et al. (2019)
NCAR (USA)	CESM1-CAM5-SE-HR	POP2	8 km	CAM5.2	25 km	Chang et al. (2020)
EC-Earth (EU)	EC-Earth3P-HR	NEMO	20 km	IFS	30 km	Haarsma et al. (2020) Moreno-Chamarro et al. (2025)
BCC (China)	BCC-CSM2-HR	MOM4	20 km	BCC-AGCM3	40 km	Wu et al. (2020)
AWI (Germany)	AWI-EERIE-IFS-FESOM	FESOM	6 km	IFS	15 km	Ghosh et al. (2025)
CNRM (France)	CNRM-CM6-1-HR	NEMO	20 km	ARPEGE3.6	50 km	Voldoire et al. (2019)
CMCC (Italy)	CMCC-CM2-VHR4	NEMO3.6	20 km	CAM4	20 km	Scoccimarro et al. (2022)
ECMWF (Europe)	ECMWF-IFS-HR	NEMO3.4	20 km	IFS	30 km	C. D. Roberts et al. (2018)

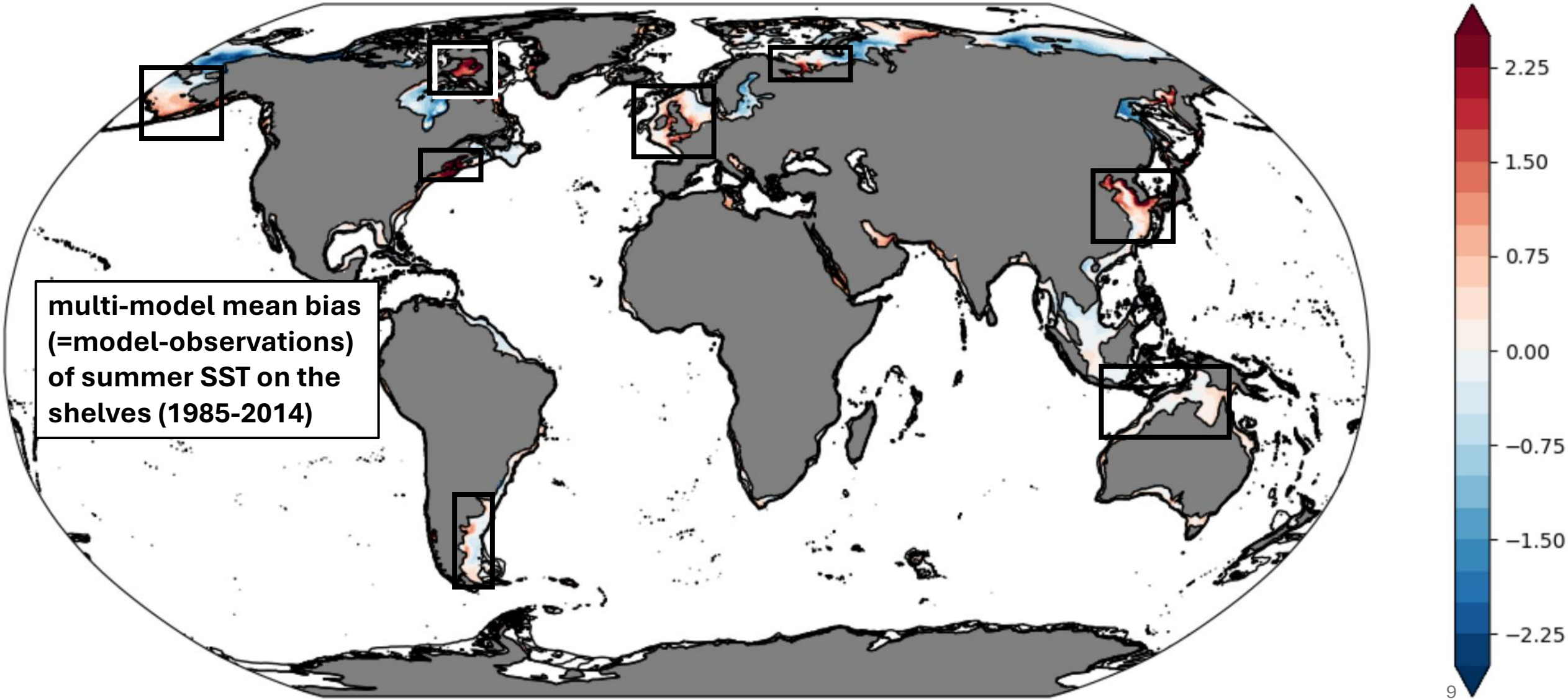
→ 8 simulations from different models and institutions

= independent models

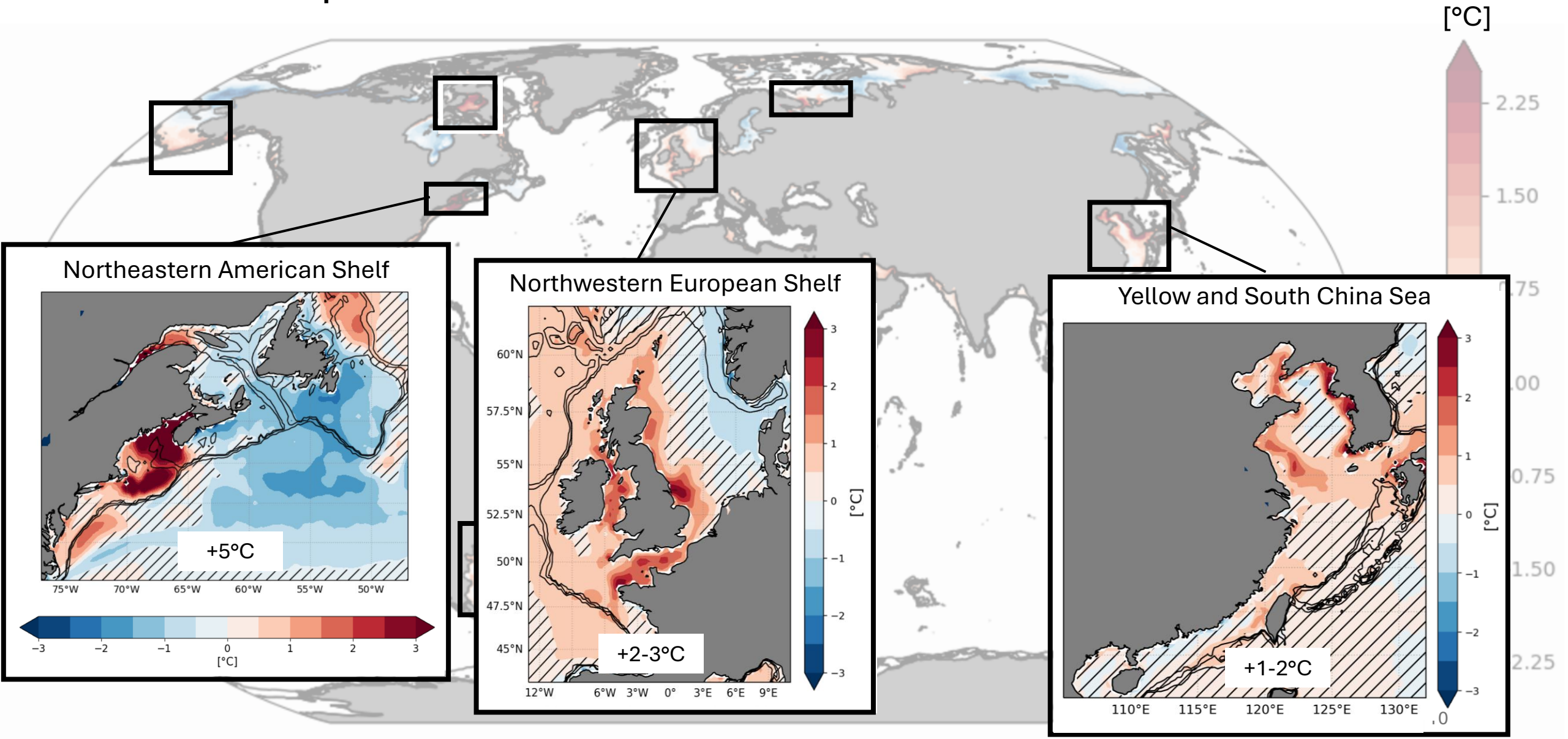
3. Results

a. **Sea surface temperature biases on the shelves in climate models**
b. Correlation with barotropic tidal mixing fronts
c. Impact on the atmospheric temperature biases

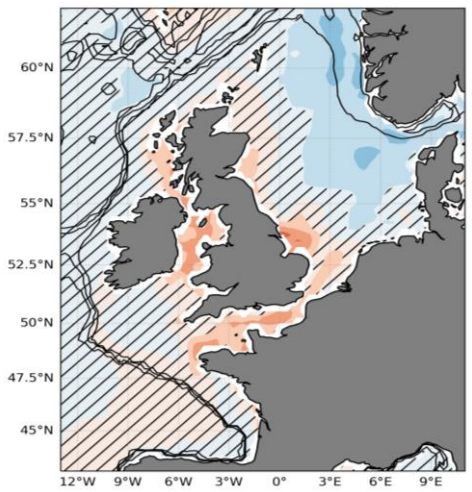
a. Sea surface temperature biases on the shelves in climate models



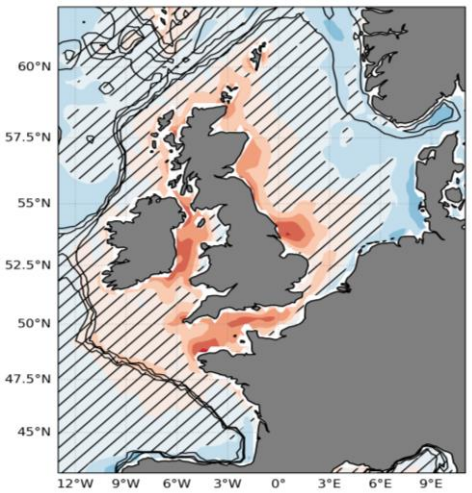
a. Sea surface temperature biases on the shelves in climate models



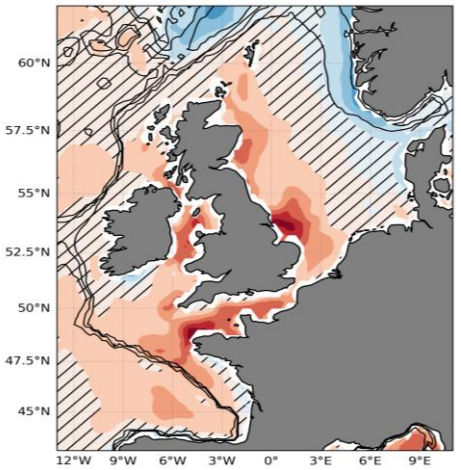
HadGEM-GC31-HH
(Met Office)



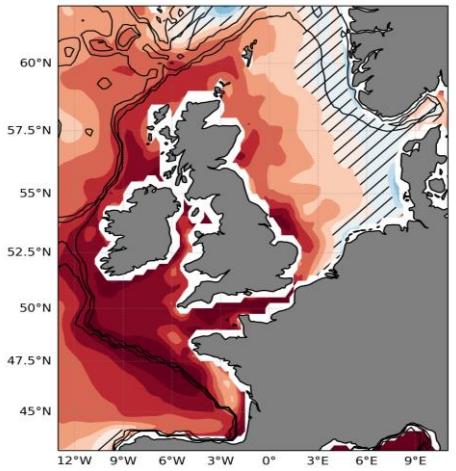
CESM
(NCAR)



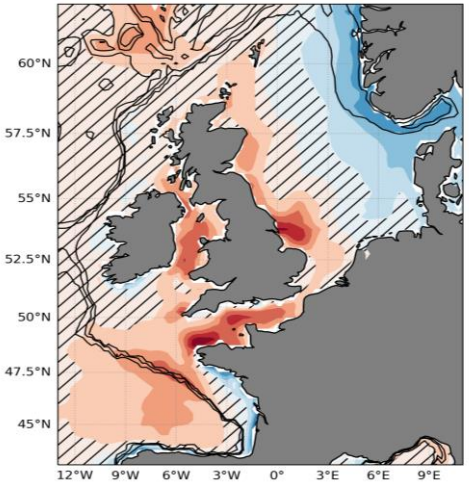
EC-Earth
(EU)



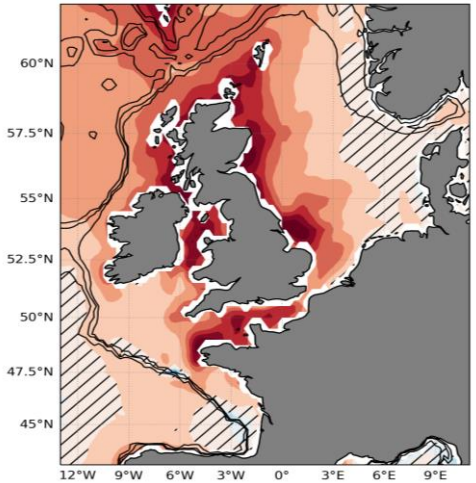
BCC-CSM2-HR
(BCC)



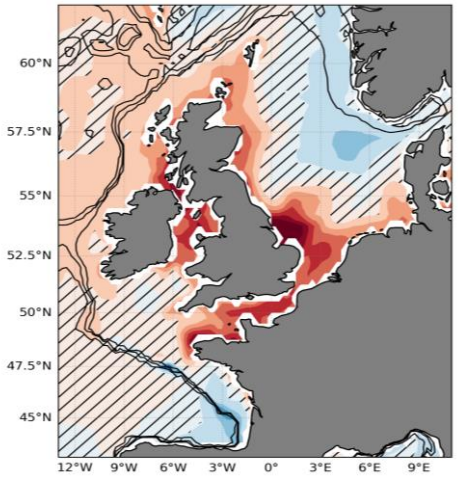
AWI-EERIE-IFS-FESOM
(AWI)



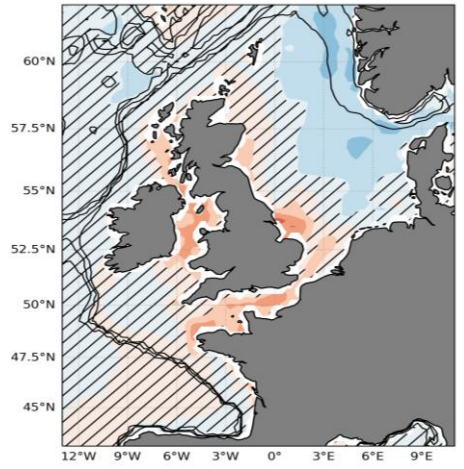
CNRM-CM6-1-HR
(Meteo France)

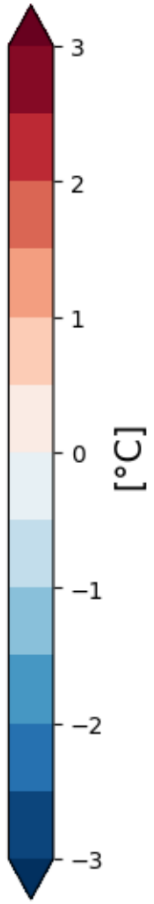


CMCC-CM2-VHR4
(CMCC, Italy)

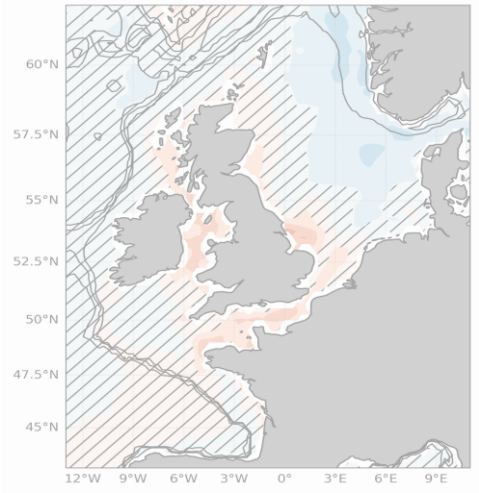


ECMWF-IFS-HR
(EU)





HadGEM-GC31-HH
(Met Office)



CESM
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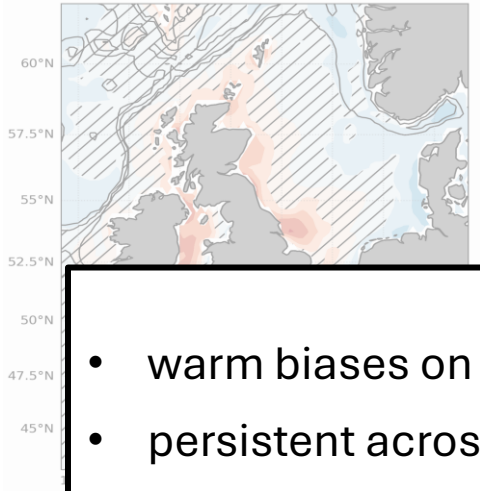
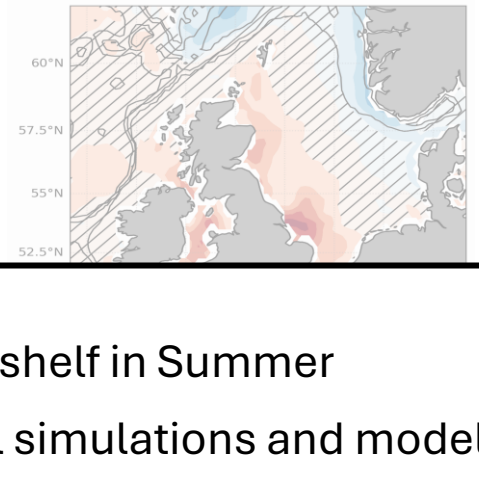
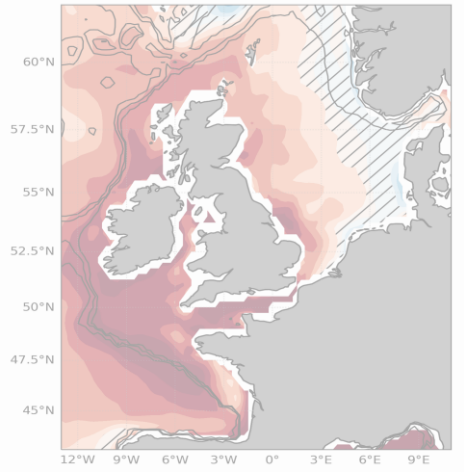


EC-Earth
(EU)



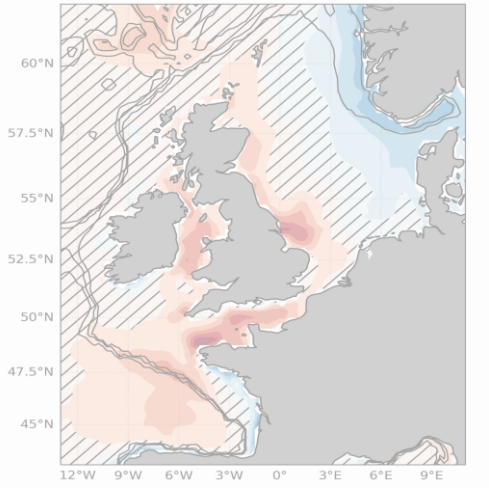
BCC-CSM2-HR
(BCC)

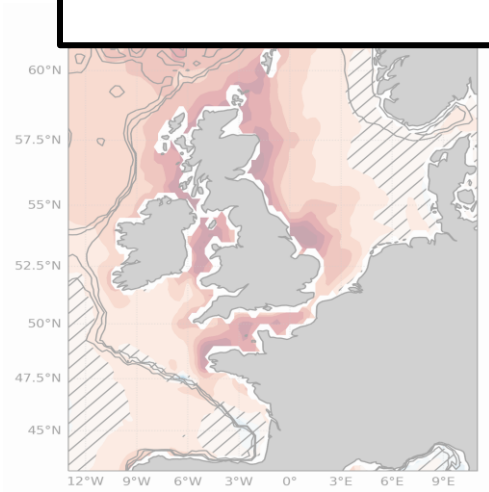


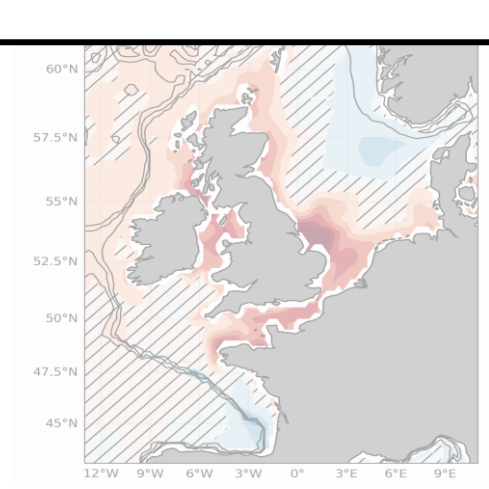
- warm biases on the shelf in Summer
- persistent across all simulations and models

→ **missing physical process.**

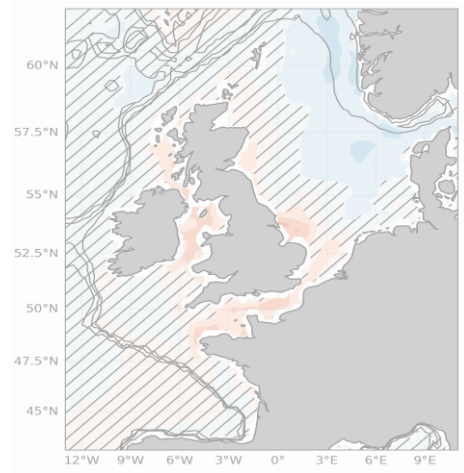
AWI-EERIE-IFS-FESOM
(AWI)

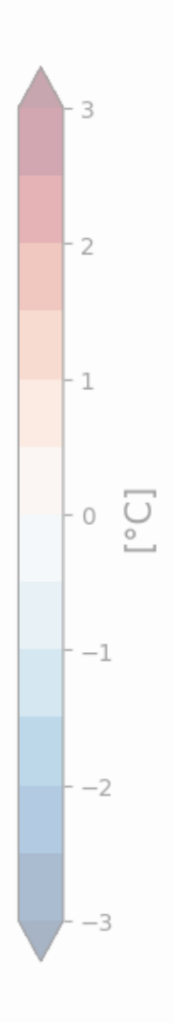






ECMWF-IFS-HR
(EU)





3. Results

a. Sea surface temperature biases on the shelves in climate models
b. Correlation with barotropic tidal mixing fronts
c. Impact on the atmospheric temperature biases

b. Correlation with tidal mixing fronts

What are the regions dominated by barotropic tidal mixing ?

Balance between seasonal stratification and tidal mixing: Pingree and Griffiths (1978) ratio

Thermosteric expansion
Heat flux
depth
Heat capacity

$$R = \frac{g\alpha Q h (2C_p)^{-1}}{\rho C_d u^3}$$

Tidal currents
Drag coefficient

Assuming C_p, C_d, *Q, alpha, rho* constant
R ~ Simpson-Hunter (1974) parameter

R >> 1 Stratification dominates over mixing

R << 1 Mixing dominates over stratification

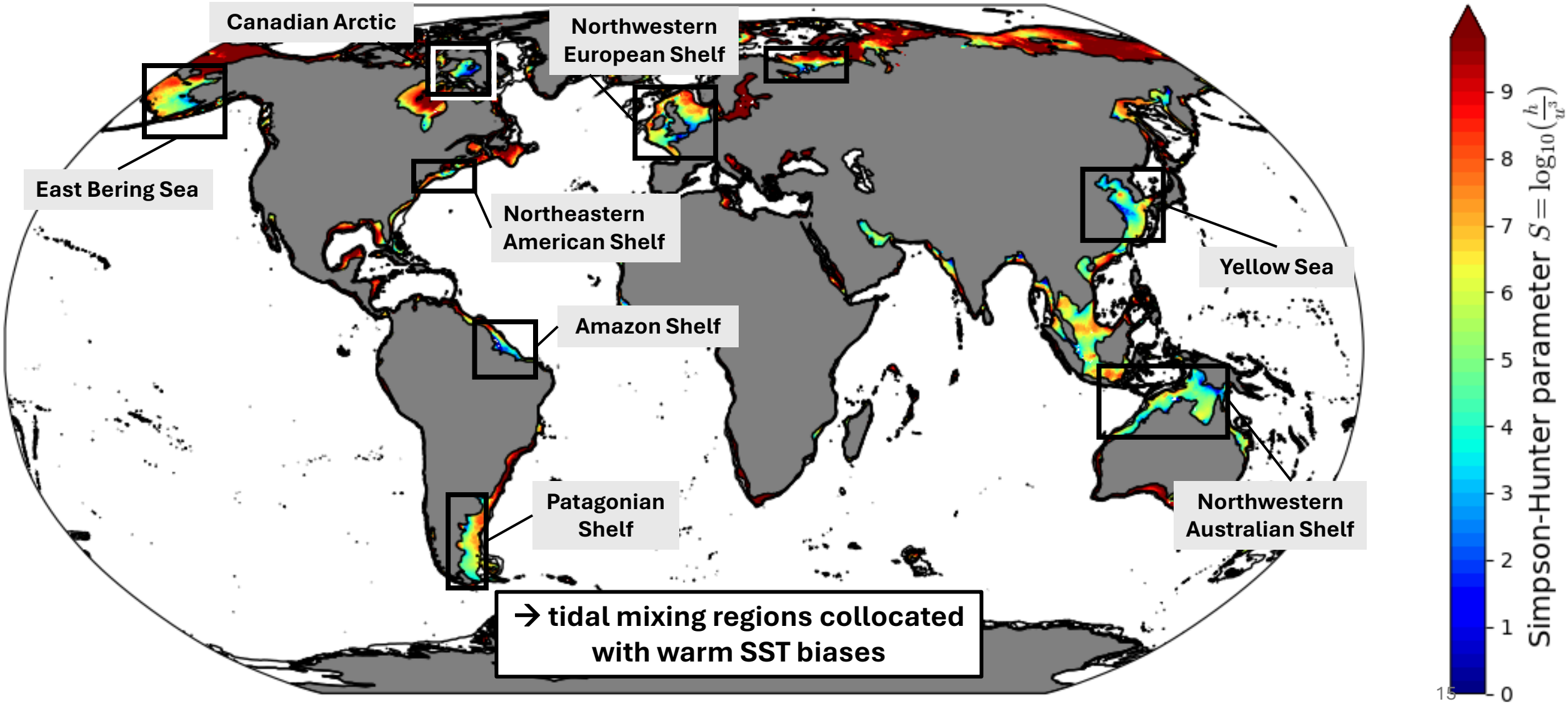
R ~ 1 Mixing fronts

$$S_h = \frac{h}{u^3}$$

Bathymetry: GEBCO

Tidal currents: atlas FES2014

b. Correlation with tidal mixing fronts



b. Correlation with tidal mixing fronts

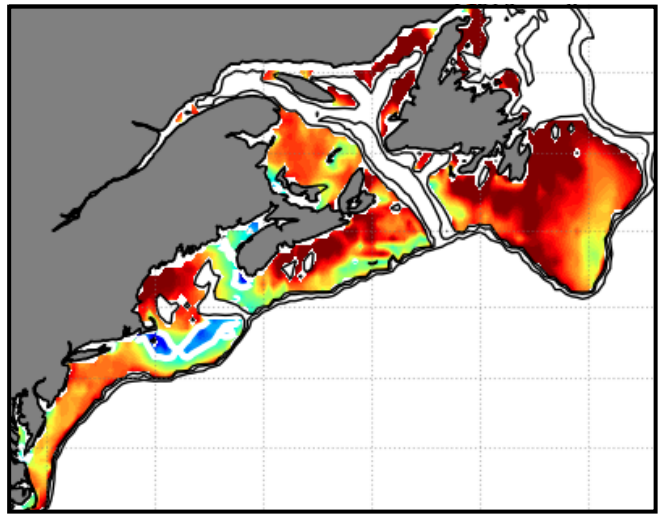
Northeastern American Shelf

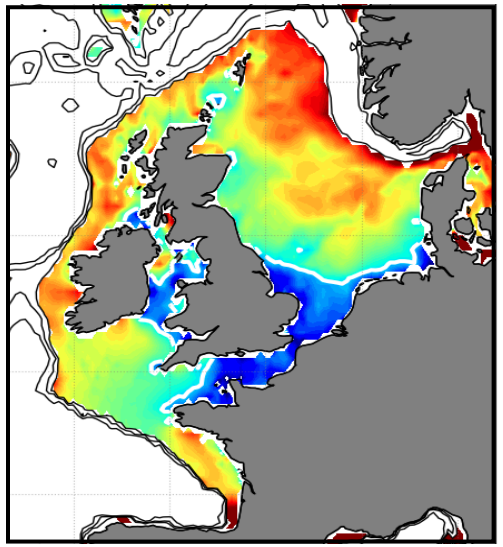
Northwestern European Shelf

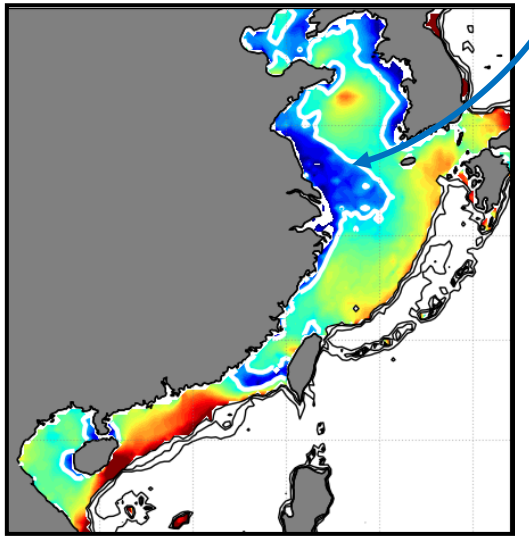
Yellow Sea

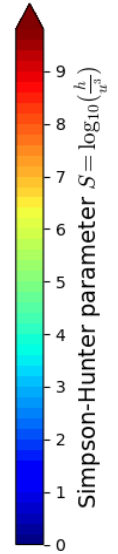
Tidal mixing-dominated regions

S_h

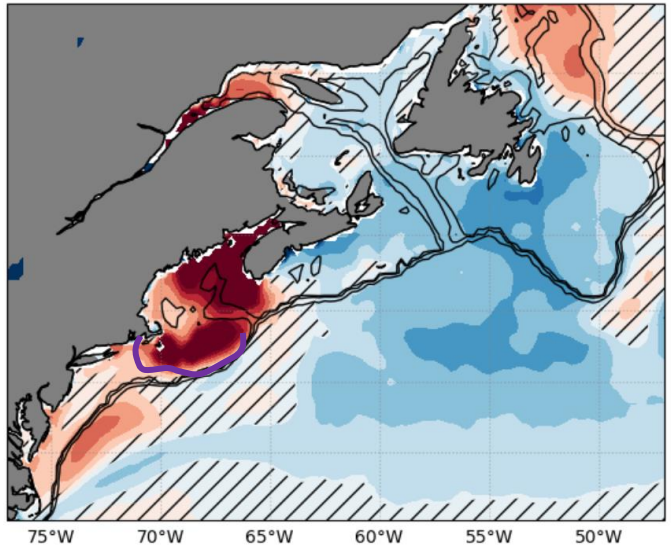


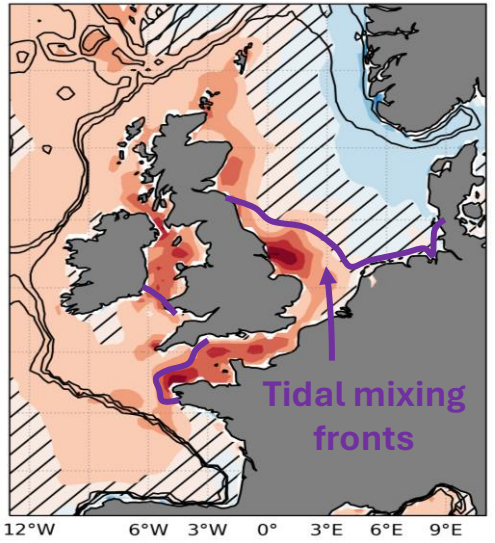


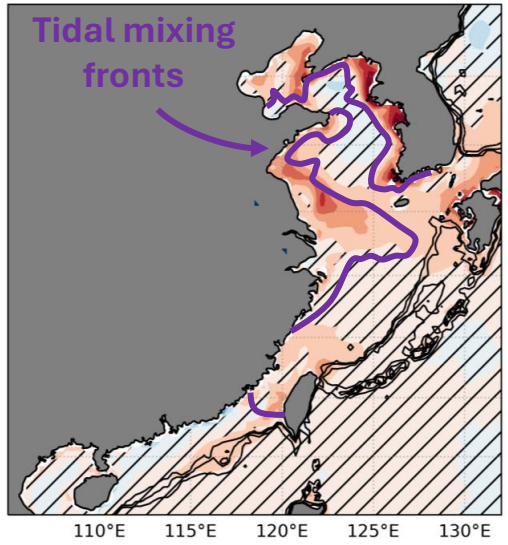


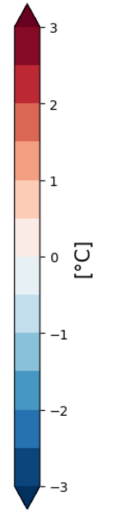


Suumer SST bias (multi-model mean)









3. Results

a. Sea surface temperature biases on the shelves in climate models
b. Correlation with barotropic tidal mixing fronts
c. Impact on the atmospheric temperature biases

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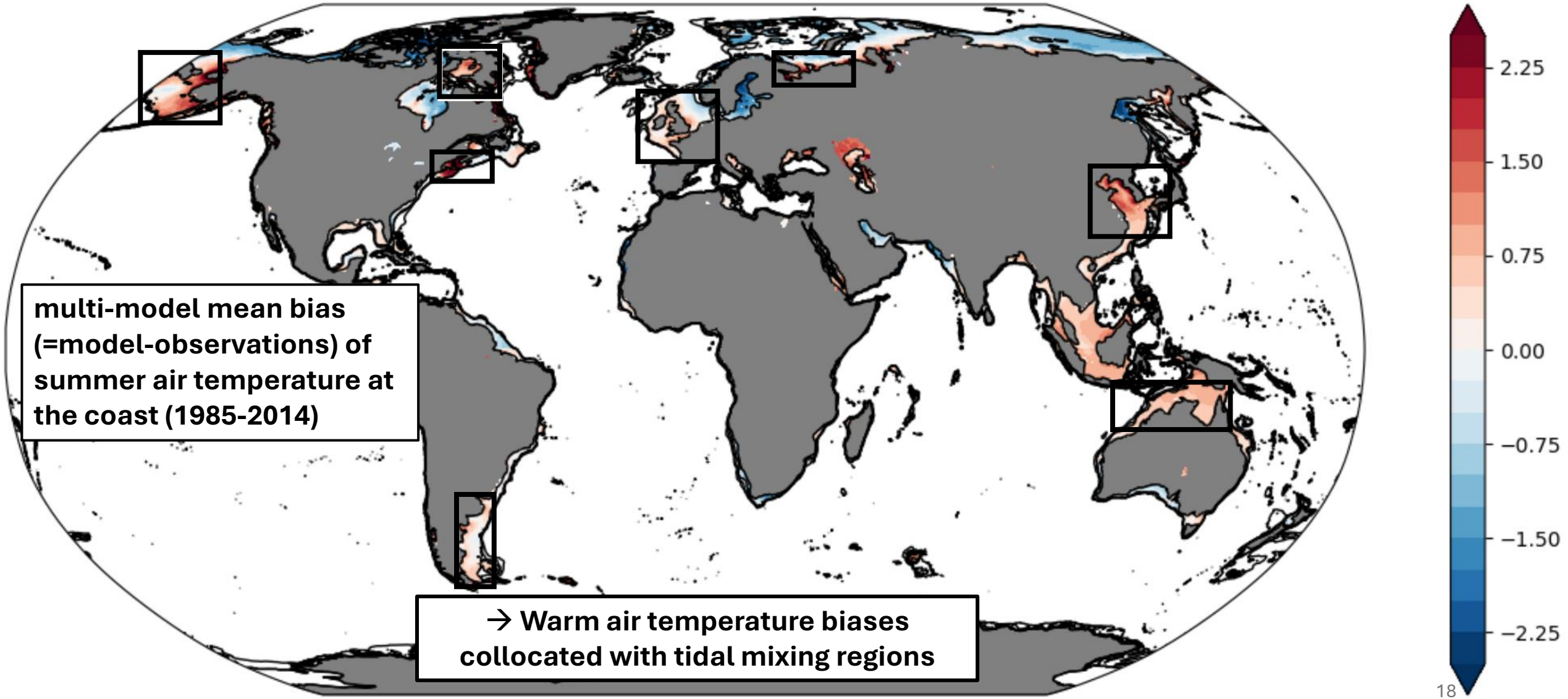
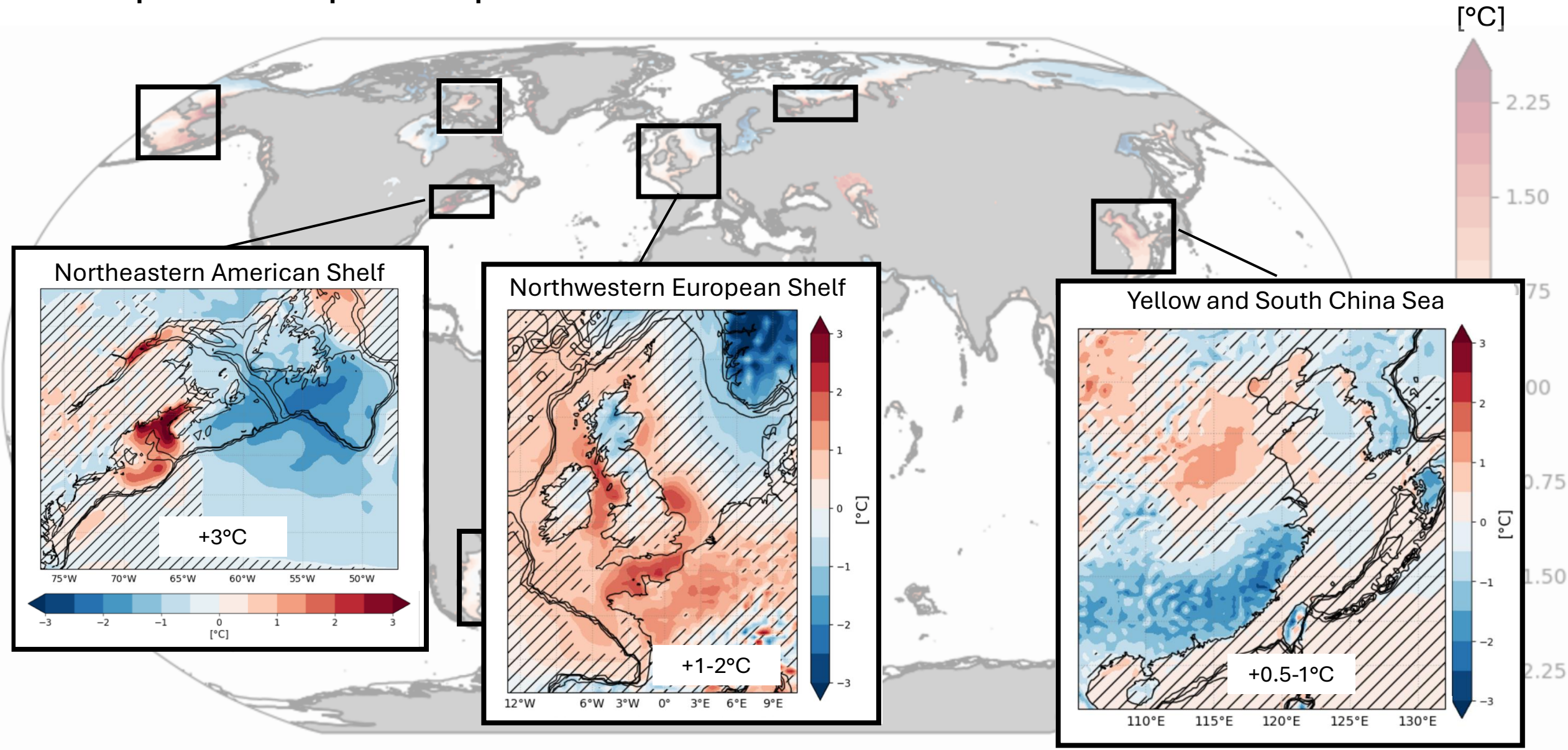


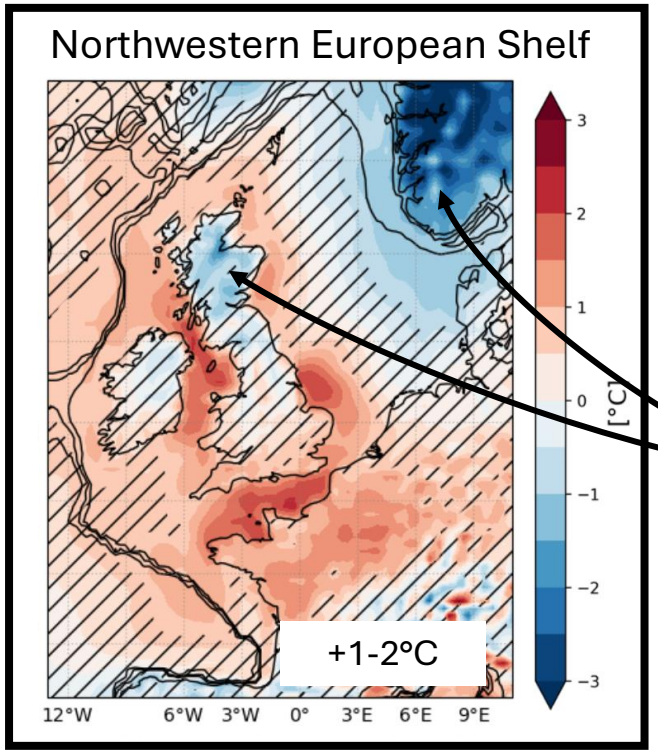
multi-model mean bias (=model-observations) of summer air temperature at the coast (1985-2014)

→ Warm air temperature biases collocated with tidal mixing regions

c. Impact on atmospheric temperature biases



c. Impact on atmospheric temperature biases



→ Missing barotropic tidal mixing not only induce oceanic temperature biases but also atmospheric temperature biases.

! Air temperature biases over land may be underestimated because of averaged cold biases over mountainous regions.

4. Discussion and Conclusion

Summary

- There exists a correlation between mean surface temperature biases (both oceanic and atmospheric) and regions marked by tidal mixing fronts ($S_h << 1$).

- These biases are systematic in all HighResMIP models (not shown: also in previous CMIP-like models)

→ necessity of parameterizing barotropic tidal mixing in climate models for an accurate representation of temperatures in coastal regions.

Next steps / ongoing work :

- Investigate the impact of this missing tidal mixing on the representation of
  - temperature variance
  - temperature extremes
  - other meteorological variables: wind, precipitations.

- Develop a parameterization based on bottom TKE injection to account for the missing mixing

Thank You !

audrey.delpech@cnrs.fr

Delpech et al. (2024). Impact of ocean mesoscale in ocean model biases: an assessment of eddy-rich coupled climate simulations. https://doi.org/10.5281/zenodo.14802628

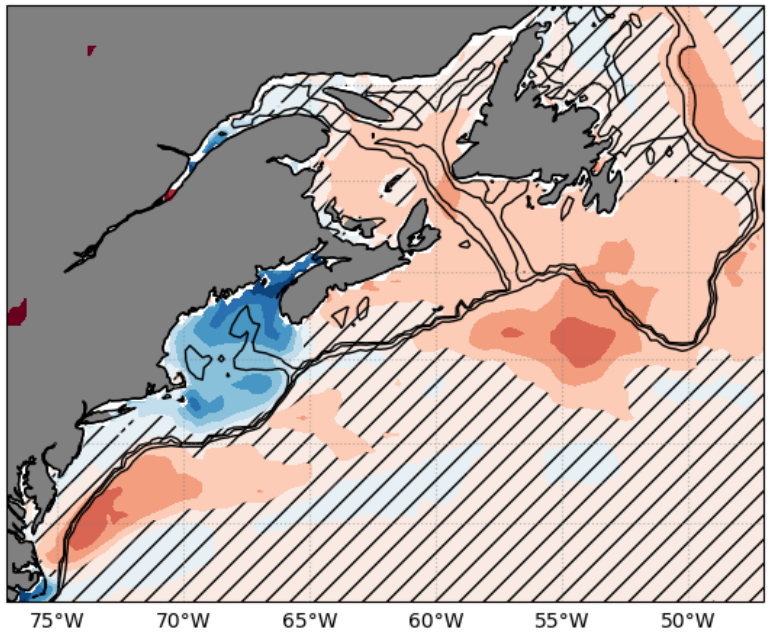
Delpech et al. (2025). Persistent coastal temperature biases in km-scale climate models due to unresolved oceanic tidal mixing. Submitted to *Geophysical Research Letter*. Preprint

Backup slides

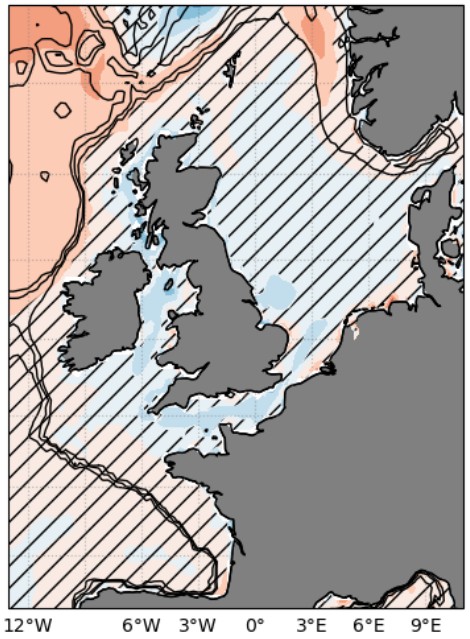
a. Sea surface temperature biases on the shelves in climate models

multi-model mean bias (=model-observations) of winter SST on the shelves (1985-2014)

Northeastern American Shelf



Northwestern European Shelf



Yellow Sea