On the implications of a warm bias in modelling an eddying Southern Ocean

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1 Background

- High wind speeds and the zonally unbounded extent of the Southern Ocean (SO) evoke high mean and eddy kinetic energy
- SO eddies are anticipated to play a key role for the global heat and carbon budgets and the redistribution of Antarctic melt water
- Computational limits still prevent the use of global eddying ocean models for studies concerning long-term climate projections, asking for nested model setups
- Common SO biases in CMIP-type models, such as in temperature, complicate the initialisation of regional high-resolution nests
- Here, we test three different initial states in a nested climate model with regard to their effect on SO dynamics

2a A global climate model with a nested SO

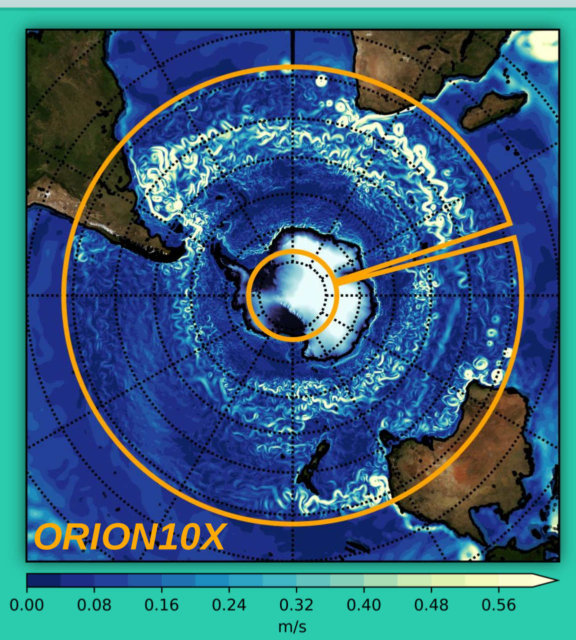


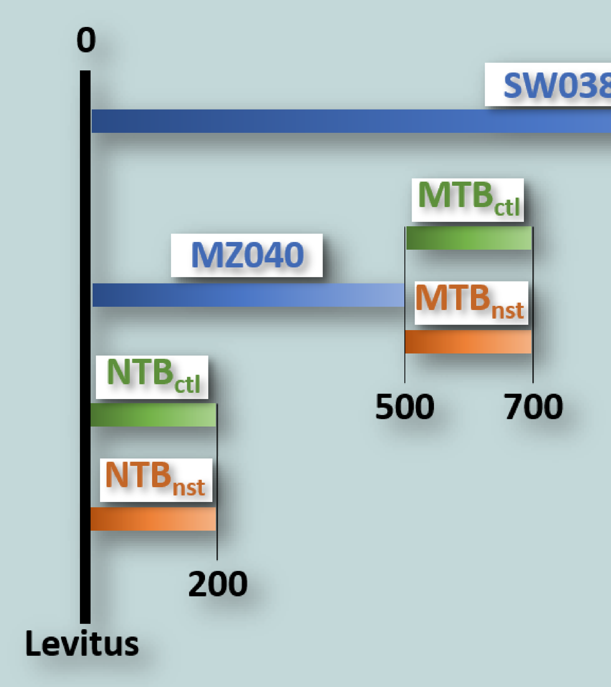
Figure 1: Snapshot of 5-daily mean surface velocity. The SO nest is outlined in orange.

The Flexible Ocean and Climate Infrastructure (**FOCI**) model:
- NEMO3.6-L46 ocean + LIM2 sea ice
- ECHAM6.3-T63 atmosphere + JSBACH land
- OASIS3-MCT coupler

Ocean component (NEMO):
- 0.5° horizontal resolution, 46 z-levels

ORION10X nest (**Figure 1**):
- high-resolution ocean nest (0.1°) embedded south of 28°S applying AGRIF
- 2-way exchange with global ocean
- fully coupled

2b Experimental setup



Scheme of experimental setup:
- *blue: coarse-resolution spin-up runs*
- *green: coarse-resolution control simulations*
- *brown: high-resolution nested simulations*
- *STB = strong temperature bias*
- *MTB = moderate temperature bias*
- *NTB = no temperature bias*
- *black numbers indicate model years*

3 Warm bias in the Southern Ocean

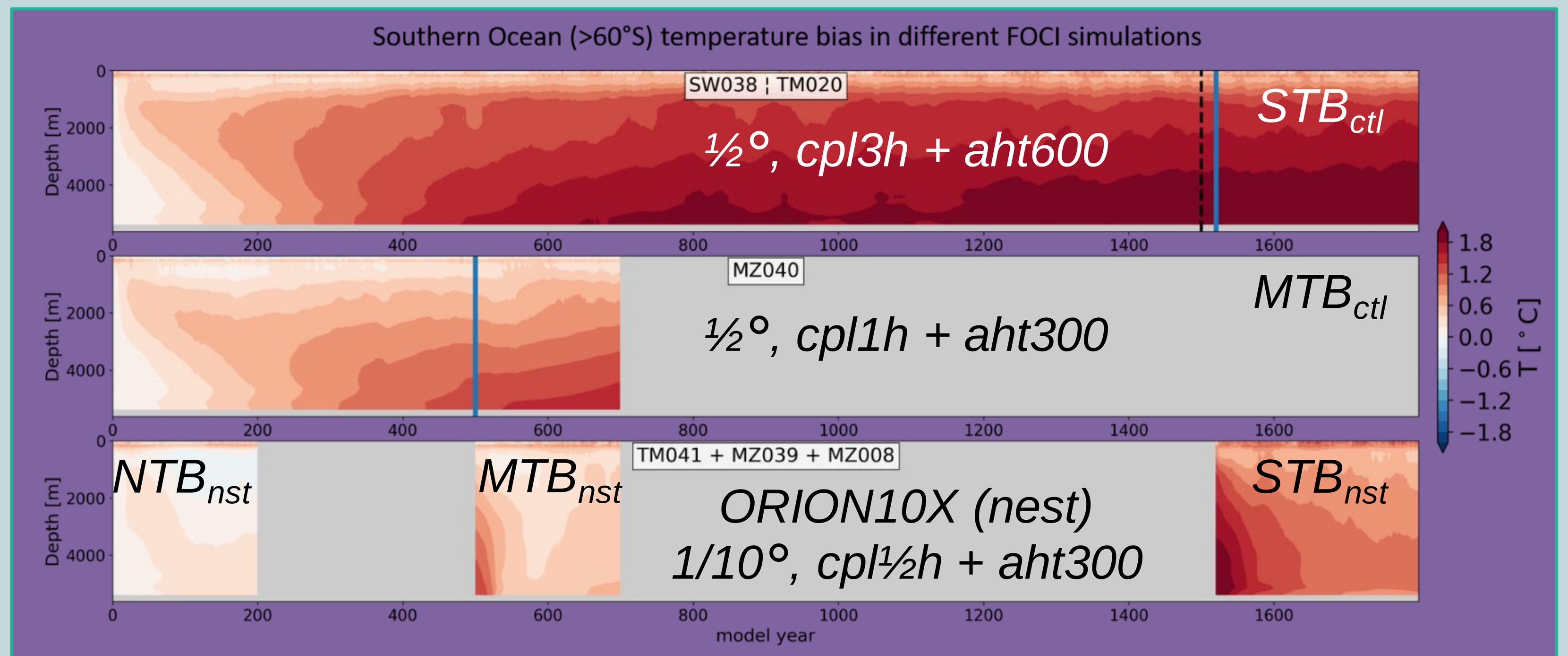


Figure 2: Temperature bias relative to World Ocean Atlas 2013 over depth and time for the standard non-nested control simulation (top panel), the non-nested control simulation with modified mixing parameters and coupling time step (middle panel), and the three nested simulations initialised from different spin-up conditions (bottom panel). The data is averaged over the Southern Ocean south of 60°S.

- build-up of warm bias over time in coarse-resolution FOCI spin-up runs (**Figure 2, top**)
- warm bias reduced by increasing ocean-atm. coupling frequency from 3 hours to 1 hour and reducing iso-neutral diffusion from 600 m^2/s to 300 m^2/s (**Figure 2, middle**)
- increasing horizontal resolution from 0.5° to 0.1°, thus including mesoscale dynamics, results in vast decline of warm bias within 2-3 decades (**Figure 2, bottom**)
- initialising nest from observed conditions does not entail a heat build-up (**Figure 2, bottom**)

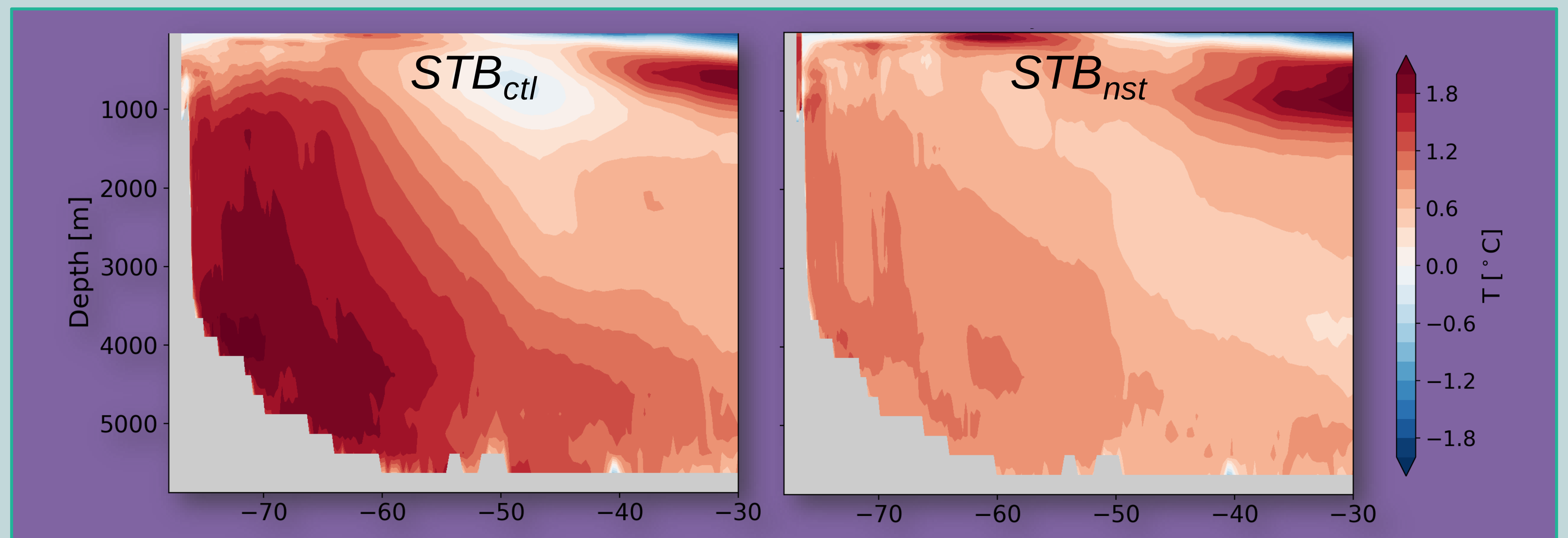


Figure 3: Zonal average temperature bias relative to Levitus for STB_{ctl} (left panel) and STB_{nst} (right panel). The data is averaged over the last 50 years of each simulation.

- SO warm bias in FOCI (**Figure 3, left**) causes unstable conditions when branching off the nested ORION10X simulation
- … causing massive open ocean deep convection (**Figure 4**), which releases the excess heat to the atmosphere
- eddying simulation yields improved temperature distribution, esp. in the deep ocean (**Figure 3, right**)

4 Implications on dynamics

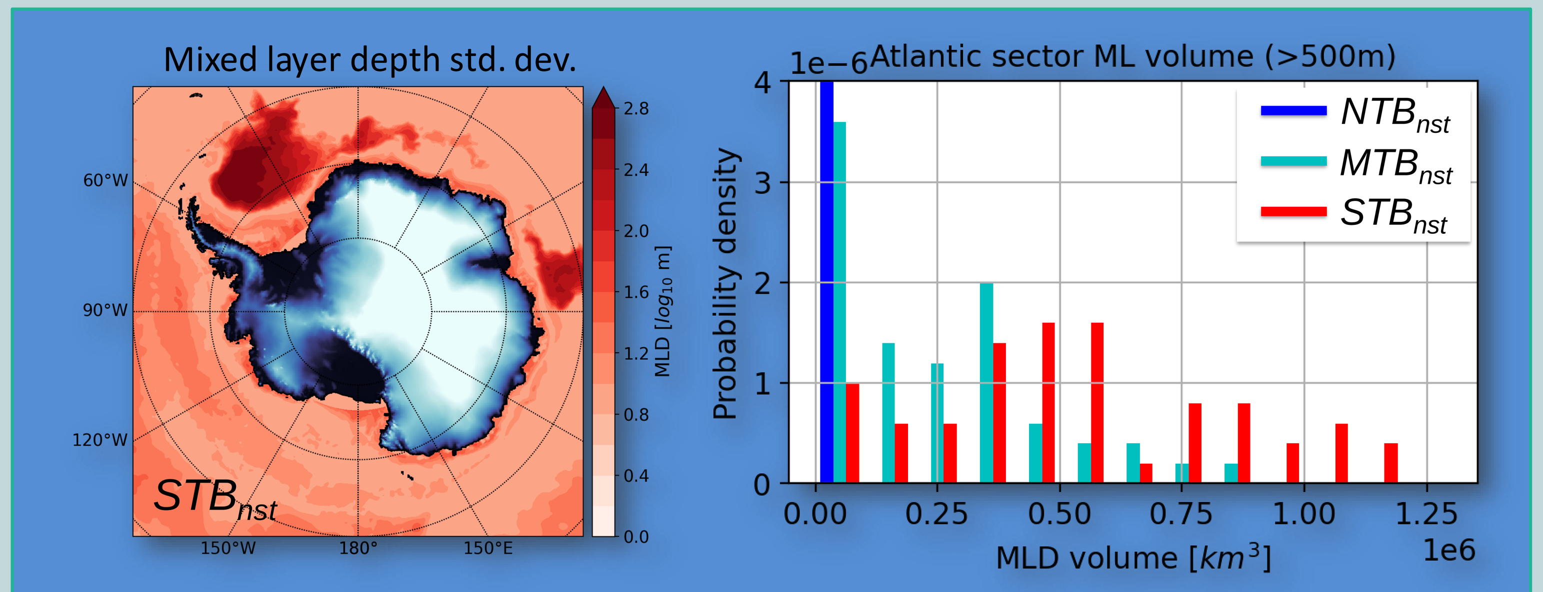


Figure 4: Left: Annual standard deviation of mixed layer depth for STB_{nst} simulation. Note that the colour bar is on log scale. Right: Histogram of annual Atlantic sector mixed layer volume (>500m) for the three high-resolution nested simulations.

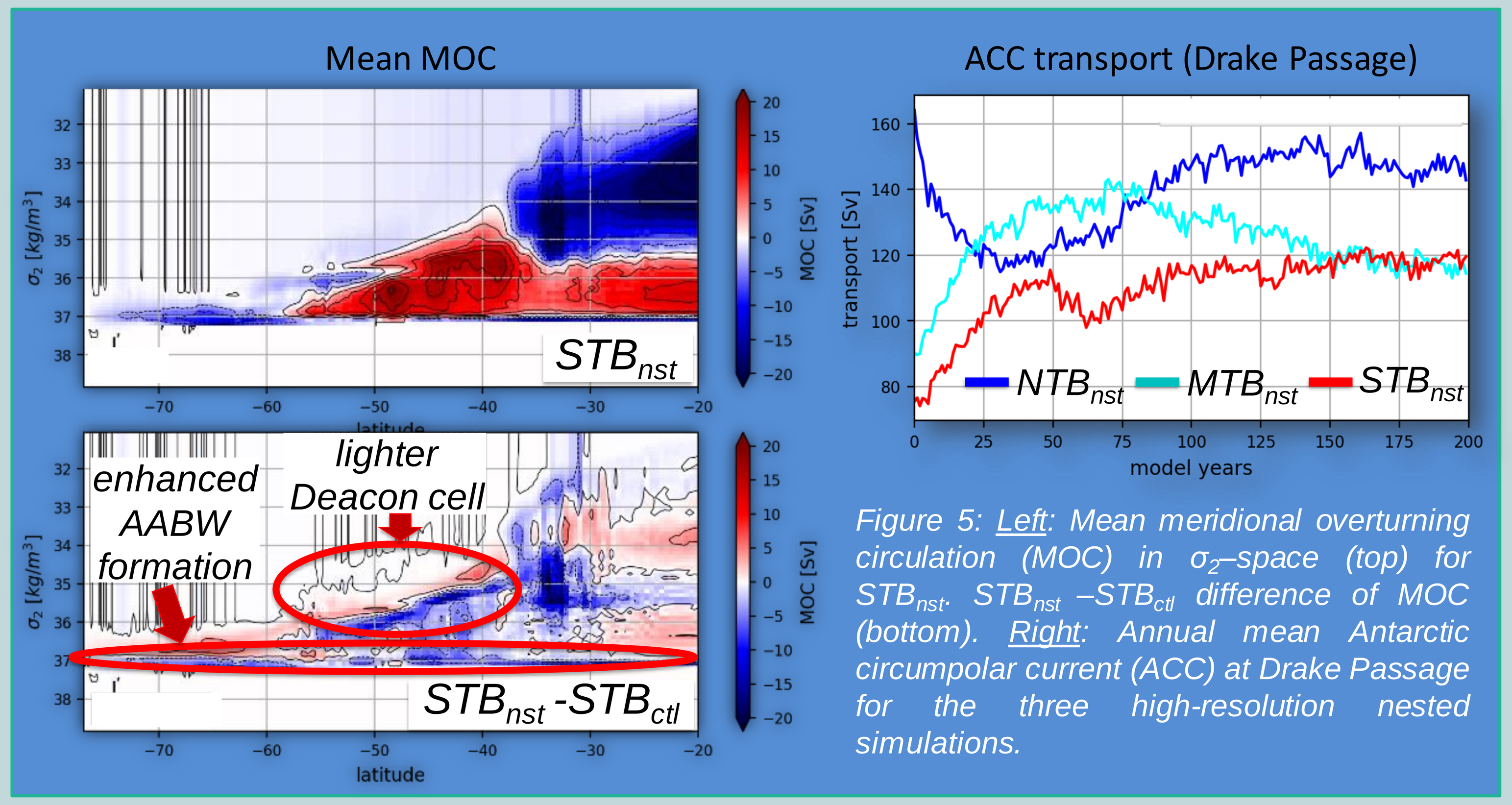


Figure 5: Left: Mean meridional overturning circulation (MOC) in σ_2-space (top) for STB_{nst}, STB_{nst} −STB_{ctl} difference of MOC (bottom). Right: Annual mean Antarctic circumpolar current (ACC) at Drake Passage for the three high-resolution nested simulations.

5 Conclusions

- **nesting reduces warm bias in the Southern Ocean**
- initialising a high-resolution nest from a biased SO leads to baroclinic instabilities due to different dynamics (resolved vs. parameterized processes)
- these instabilities initiate massive deep convection, in turn inducing spurious anomalies in the global circulation
- **best practice is to initialise a SO nest from observed conditions**

- Deep convection in the nest mainly occurs in Weddell Gyre & Amery basin (**Fig. 4, left**)
- Enhanced spurious deep convection with increasing warm bias (**Figure 4, right**)
- Deep convection leads to modifications of the horizontal (ACC, **Figure 5, right**) and overturning (MOC, **Fig. 5, left**) circulations
  - → high production rate of Antarctic bottom water (AABW, STB_{nst}:13 Sv ± 5 Sv)
  - → upper branch of Deacon cell becomes lighter in nested simulations

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