Climate model biases in ocean stratification in the vicinity of Antarctica: origins and impacts

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INTRODUCTION

In the vicinity of Antarctica, large amounts of heat stored in the ocean subsurface can potentially access the atmosphere and the ice shelves, with important implications for climate warming and sea level rise. Model representation of stratification and water mass properties in this region is thus key to climate projections. However, climate models generally do poorly in polar regions due to the lack of observations and the complex coupling between atmosphere, ocean, sea ice and ice sheet. Studies have suggested that some improvement in model performance could be obtained through increasing oceanic resolution.

Here, **we examine the effect of refining the ocean resolution in climate models on the stratification of the Weddell Sea**. We also briefly discuss the use of mesoscale eddy parameterization versus increasing resolution in CMIP6 climate model generation.

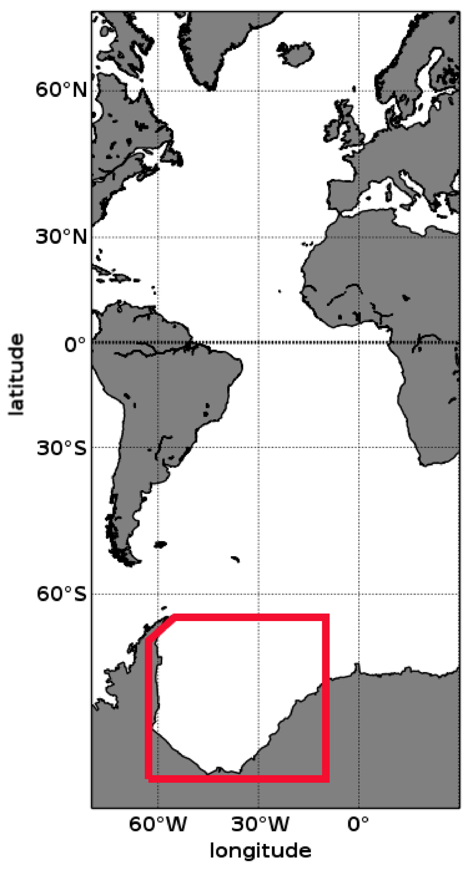


FIG. 1: The region of our study, the Weddell Sea, is highlighted by the red box.

MODELS

model	ocean	sea ice	atmosphere	land
CM2 [1]	MOM5	SIS	AM2	LM3
CM4	MOM6	SIS2	AM4	LM4

TABLE 1 (left): Components used in the GFDL CM2 and CM4 climate models. CM4 is the new climate model that will be used in CMIP6.

TABLE 2 (below): Main characteristics of the ocean component and of the simulations used in this study.

simulation	horizontal resolution	nb of vertical levels	eddy param.	radiative forcing	simulation length (years)
CM2_0.10	0.10°	50	submesoscale	1860	200
CM2_0.25	0.25°	50	submesoscale	1860	200
CM4_0.25	0.25°	75	submesoscale	2010	60
CM4_0.5	0.5°	75	meso and submesoscale	2010	60

RESULTS

(1) Effect of increasing resolution [2]

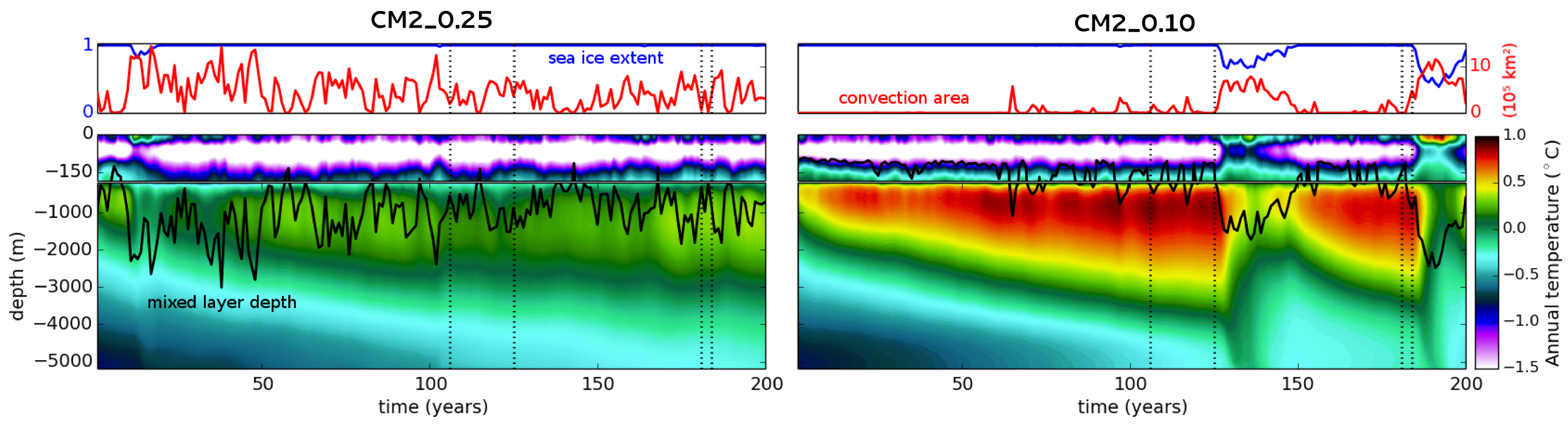


FIG. 2. Top panels: Timeseries of Winter (July-September) sea ice extent and convection area. Bottom panels: Hovmöller diagram of annual mean potential temperature with a zoom on the top 200 m, and timeseries of Winter mixed layer depth. All fields are averaged over the Weddell Sea open-ocean region (i.e. regions deeper than 1000 m). The convection area is calculated as the area occupied by Winter mixed layers deeper than 2000 m. The vertical dashed lines indicate the two time periods analyzed, respectively years 106 to 125 and years 181 to 184.

Open-ocean stratification and impact on deep convection (Fig.2)

CM2_0.25 resolves a weaker stratification than CM2_0.10. As a result, CM2_0.25 features quasi-continuous deep convection. In contrast, CM2_0.10 simulates two large polynyas similar to that observed in the 1970s [3].

Restratifying effect of transient mesoscale eddies (Fig.3)

The enhanced stratification in CM2_0.10 arises from its refined resolution which allows a better representation of the restratifying effect by mesoscale eddies.

Dense water overflows off the continental shelf (Fig.4)

Refined resolution in CM2_0.10 leads to reduced spurious numerical entrainment [4] and better resolution of topographic features (such as canyons, troughs and seamounts) that are both key to the representation of overflows, and as such to the open-ocean stratification.

Diapycnal mixing (not shown)

The finer resolution of CM2_0.10 also allows reduced rates of spurious diapycnal mixing leading to a better preservation of thermohaline properties of Antarctic Bottom Waters.

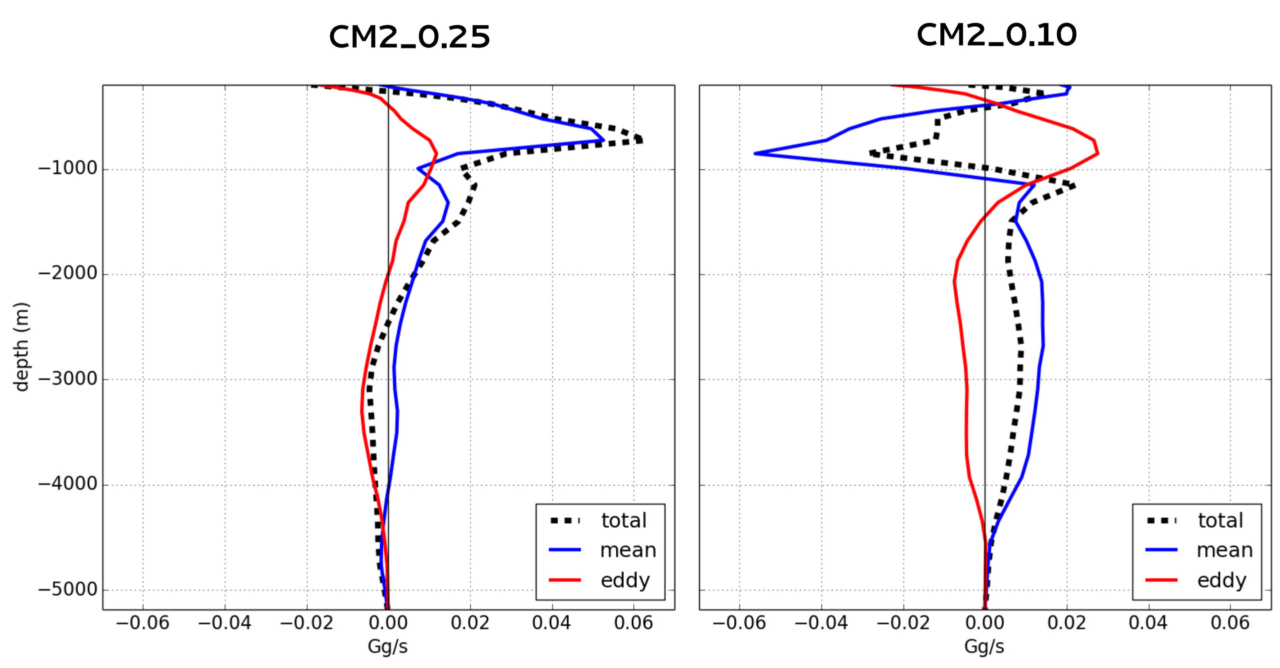
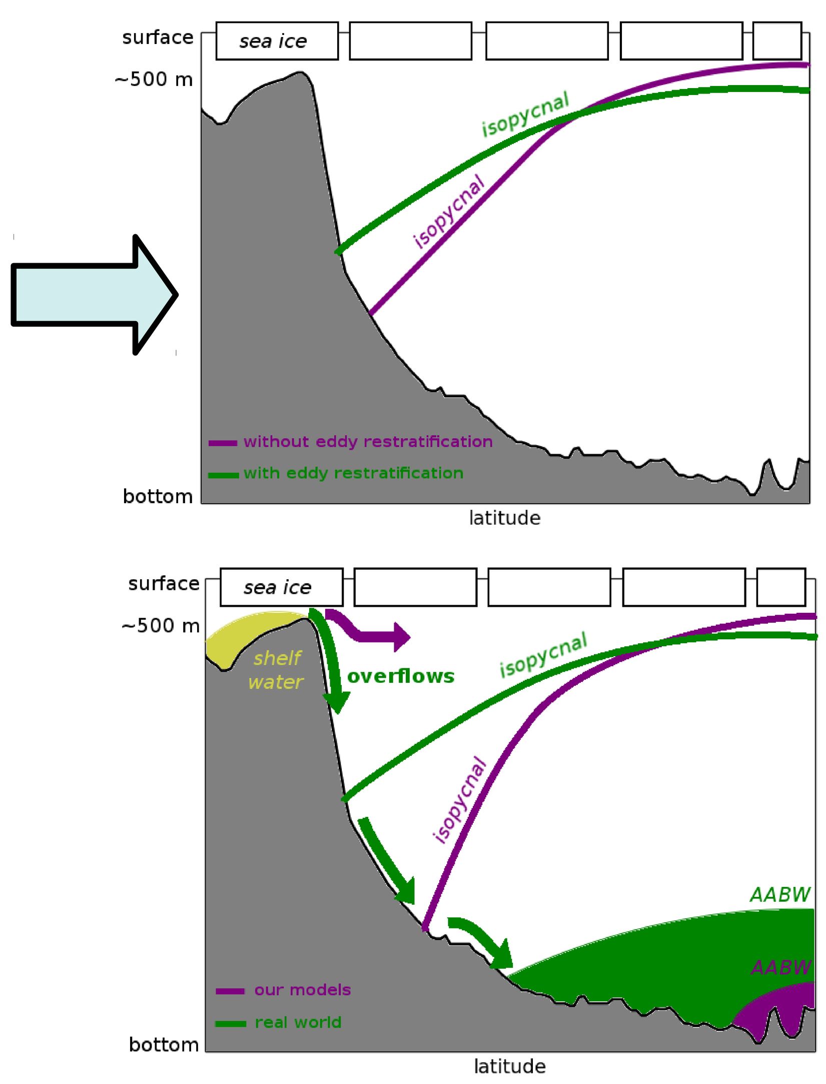


FIG. 3: Salt convergence (Gg/s 10^{-3} Sv) due to advection in the open-ocean region of the Weddell Sea (i.e. regions deeper than 1000 m) for years 181-184 in CM2_0.25 (left) and CM2_0.10 (right) below 200 m. The total advection (black dashed line) is decomposed into a time-mean component (blue plain line) and a transient eddy component (red plain line). Positive values indicate salt convergence.



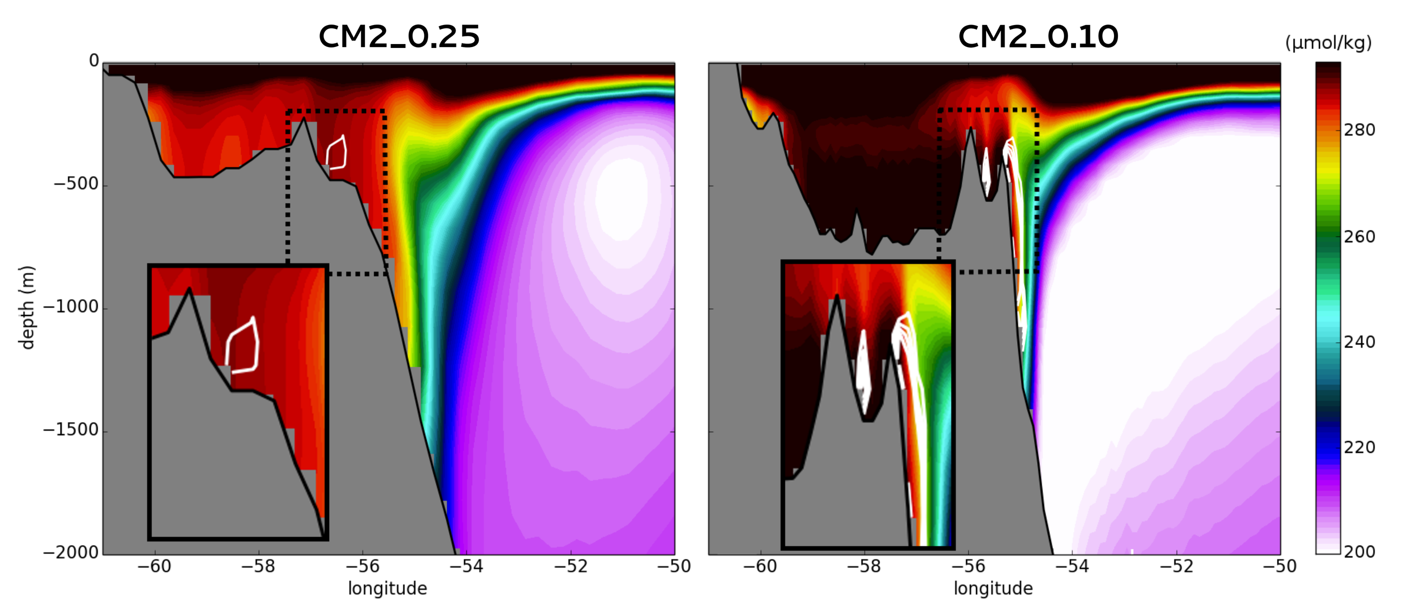


FIG. 4: Cross-shelf section of oxygen concentration (colors; µmol/kg) and downward vertical velocity (white contours; m/s) at 66.5°S averaged over years 106-125. Black boxes show close-up views of the topographic sill (dashed contoured region). Note that depth only extends to 2000 m.

(2) Eddy parameterization versus increased resolution

Stratification

- CM4_0.5 resolves a stronger stratification than CM4_0.25 (isopycnals remain more flat at the center of the gyre and above the continental slope) most likely due to the effect of the mesoscale eddy parameterization.
- While both models show a downward displacement of isopycnals with time, the displacement is generally larger in CM4_0.5 than in CM4_0.25, which is likely to be the signature of larger rates of spurious diapycnal mixing.

Ventilation

Neither models show ventilation of the abyssal ocean by waters originating from the continental shelf over the 60 year period..

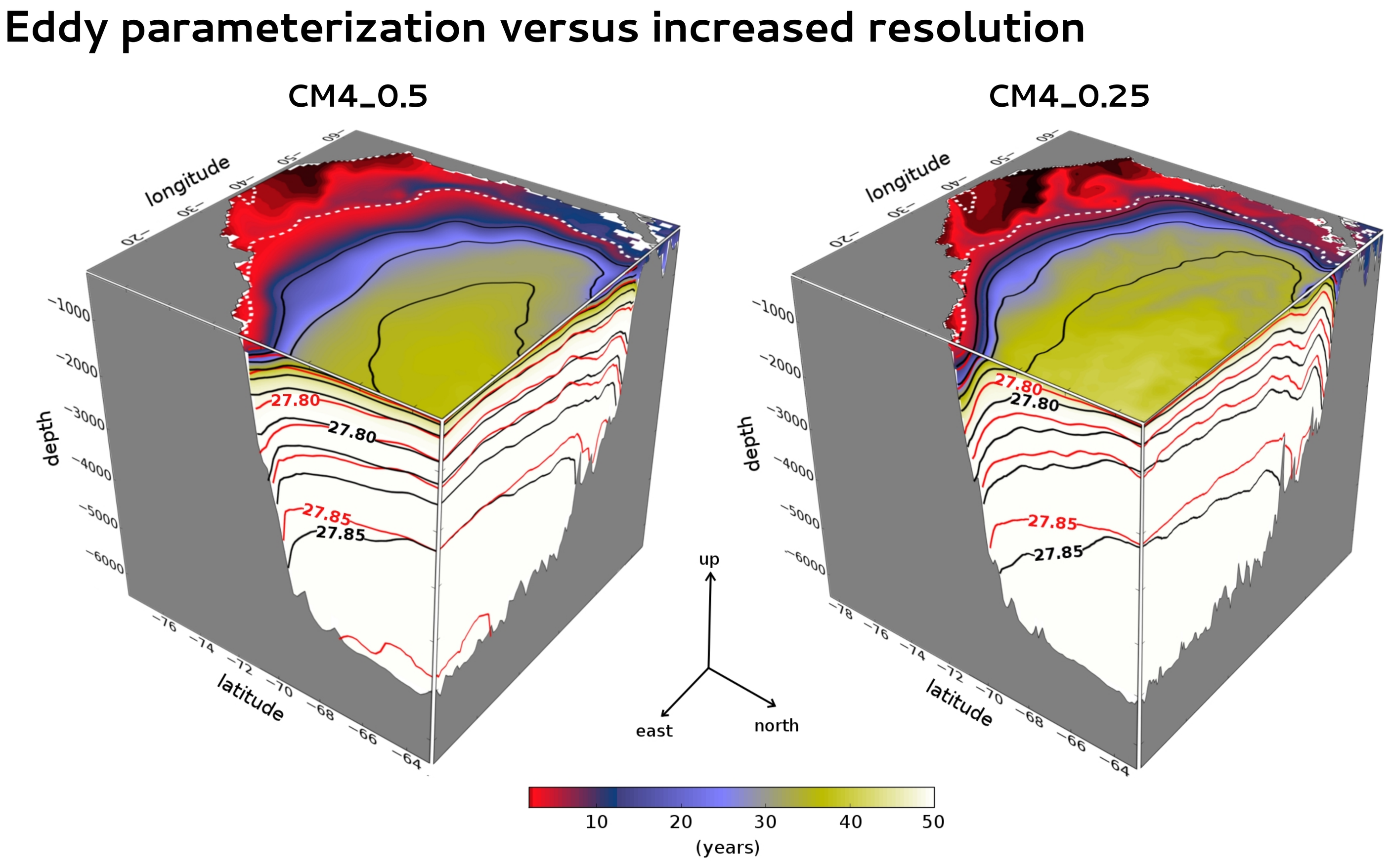


FIG. 5: Age of water (years; colors) and σ_0 isopycnals (kg m^{-3}; solid black lines) for CM4_0.5 (left) and CM4_0.25 (right) between 200 m depth and the ocean bottom of the Weddell Sea region averaged over years 41 to 60. The solid red lines correspond to σ_0 isopycnals averaged over years 1 to 20 of the simulations, and are only shown at the eastern and northern boundaries of the domain for clarity. Isopycnals range from 27.3 kg m^{-3} to 27.86 kg m^{-3}, are unevenly distributed and are masked on the continental shelf (i.e. Regions shallower than 1000 m). The thick dashed white line indicates the 1000 m isobath that is used to separate the open-ocean from the continental shelf.

CONCLUSIONS

The comparison between the CM2 0.25° and 0.10° models shows that the 0.10° simulates a stronger stratification than the 0.25° due a better representation of both mesoscale eddies and overflows [2]. *However, the cost of running a 0.10° climate model still remains prohibitive in the context of CMIP6.*

Most modeling centers can now afford running climate models with resolutions of 0.5° or 0.25° for CMIP6. Comparison between the CM4 0.5° model with a mesoscale eddy parameterization and the 0.25° without such a parameterization shows that the 0.5° produces a stronger stratification near the Antarctic continent.

However, both models show a lack of ventilation of the abyssal ocean due to a poor representation of overflows. The resolution required to resolve overflows in traditional vertical coordinate ocean models is beyond the current computational capacities [4], in which case a parameterization is needed for such processes. Alternatively, there is great promise in the use of hybrid vertical coordinates for overflow processes [5].

REFERENCES: [1] Delworth et al. (2012), Climate, 25 (8), 2755-2781. [2] Dufour et al. (in rev.), J. Climate. [3] Carsey (1980), Mon. Wea. Rev., 108 (12), 2032–2044. [4] Winton et al. (1998), J. Phys. Oceanogr., 28 (11), 2163–2174. [5] Legg et al. (2006), Ocean Modelling, 11 (12), 69–97.