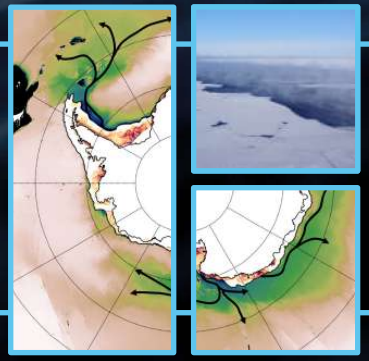

State of the art and gaps of models:
Antarctic bottom water formation and connetivity

Torge Martin

with contributions from

Mathias Zeller, Lavinia Patara, Joakim Kjellsson, Malin Ödalen

GEOMAR Helmholtz Centre for Ocean Research Kiel, Germany

EU Polar Science Week, Copenhagen, DK, 4 September 2024

DISCLAIMER

The following presentation focuses on **global ocean* and climate models** and their ability to represent AABW, its formation processes and export.

However, process oriented, regional ocean* models with realistic or idealized bathymetry are in many ways more advanced.

Remote sensing products, though limited to the surface, povide critical parameters and are used for validation, parameterization improvements and assimilation.

**incl. sea ice, eventually also ice shelf cavities and icebergs*

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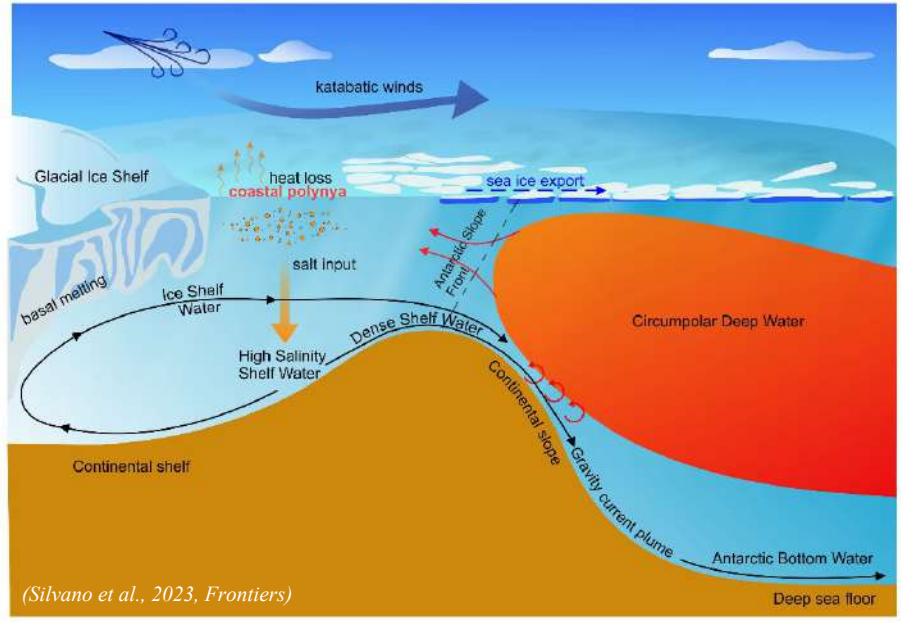
Key processes for modelling AABW

wind

land-fast sea ice

ice shelf cavities

bathymetry / coastline



sea ice cover

mixed layer properties

circumpolar deep water properties

mixing scheme

downslope flow

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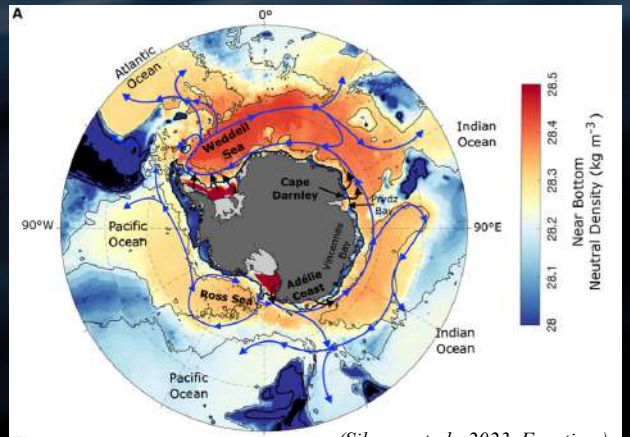
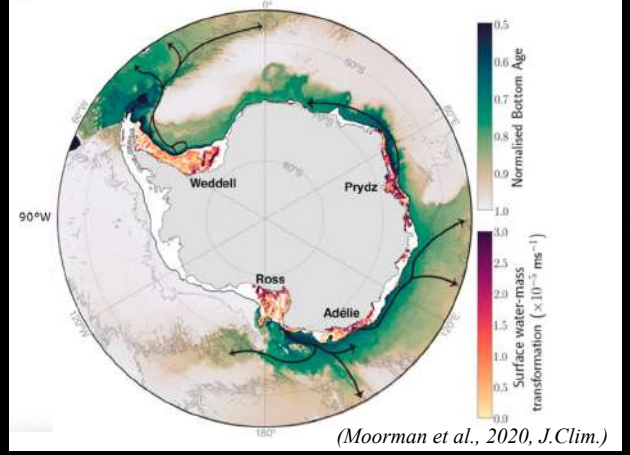
AABW formation in ocean/climate models: *Location*



(Silvano et al., 2023, Frontiers)



(Moorman et al., 2020, J.Clim.)

location, location!

- Four main sites of AABW formation, all on the continental shelf
- Simulations at 1/10˚ grid resolution capable of reproducing these

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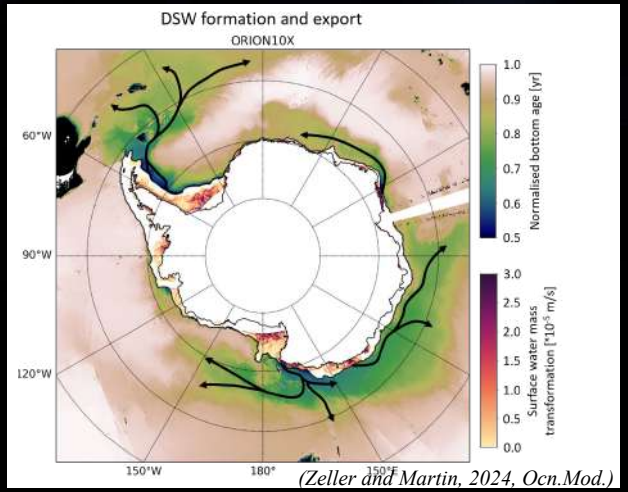
AABW formation in ocean/climate models: Location



(Zeller and Martin, 2024, Ocn.Mod.)

- Simulations at 1/10˚ grid resolution capable of reproducing formation sites
- This also works in a fully coupled climate model with ocean nesting at eddying resolution

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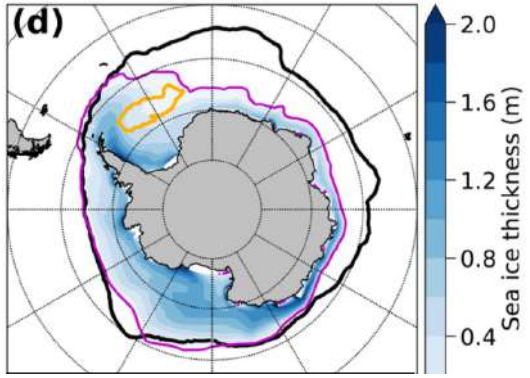
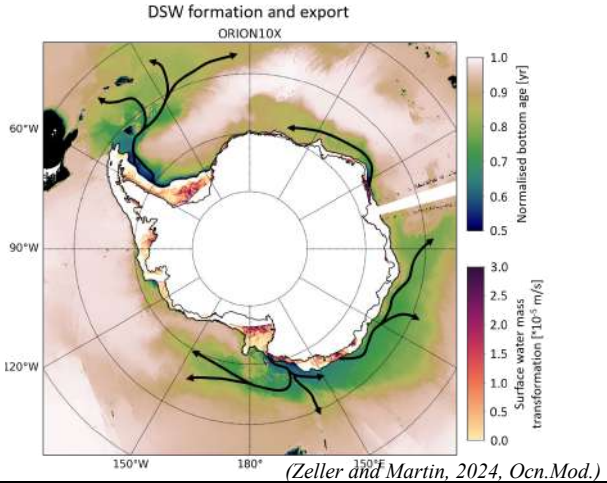
AABW formation in ocean/climate models: Location



(Matthes et al., 2020, GMD)



(Zeller and Martin, 2024, Ocn.Mod.)

- Most (non-eddying) climate models form AABW through open ocean deep convection
- Simulations at 1/10˚ grid resolution capable of reproducing formation sites
- This also works in a fully coupled climate model with ocean nesting at eddying resolution

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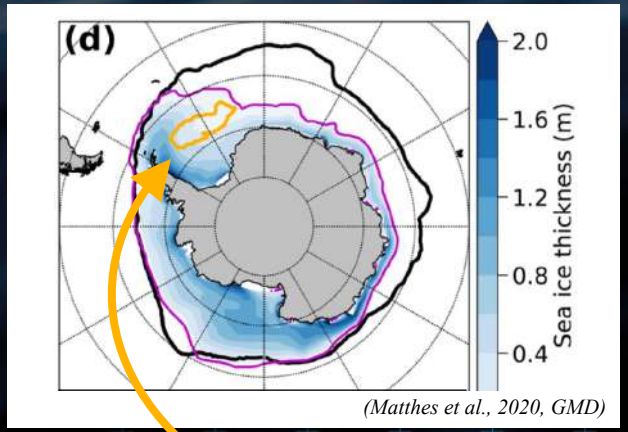
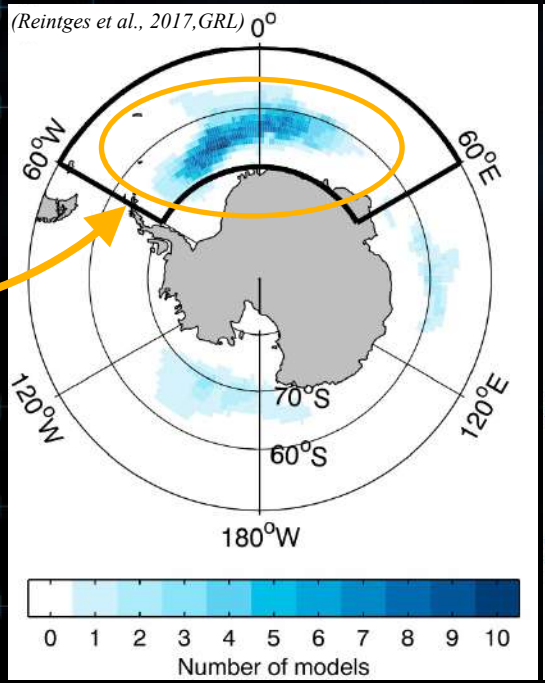
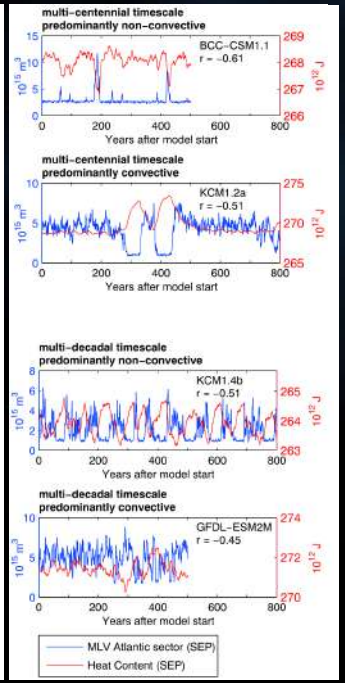
AABW formation in ocean/climate models: Location



(Matthes et al., 2020, GMD)

- Most (non-eddying) climate models form AABW through open ocean deep convection





- Often in the Weddell Gyre, sometimes Ross Gyre or Kerguelen Plateau

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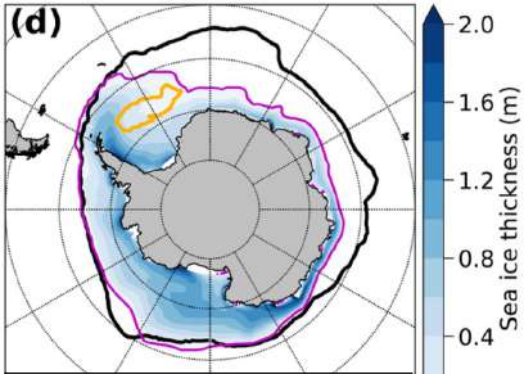
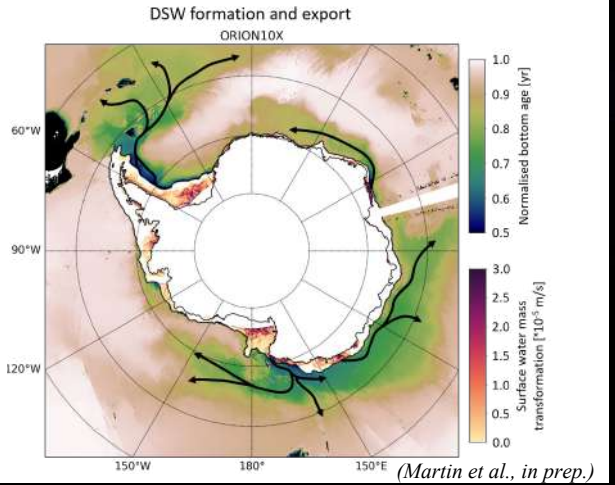
AABW export

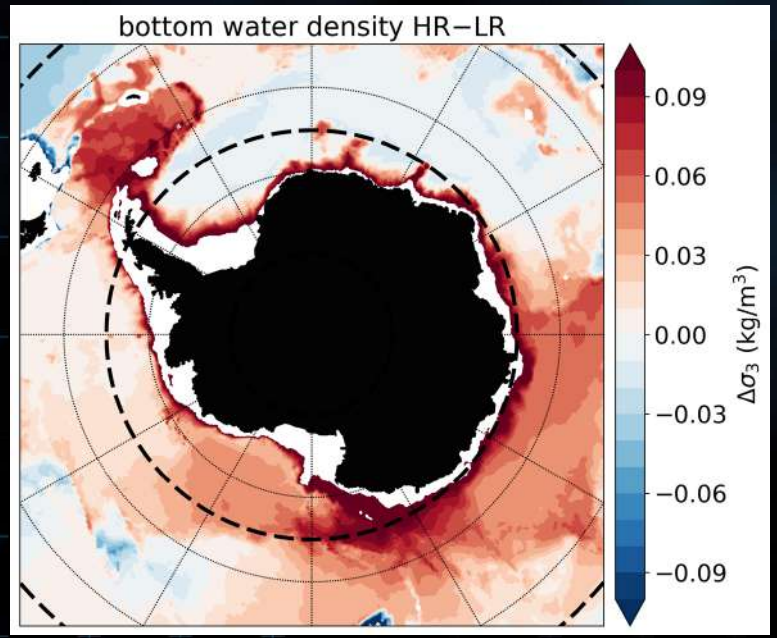


(Matthes et al., 2020, GMD)



(Martin et al., in prep.)

- Significant differences in bottom density of up to 0.1 kg/m^3



(Martin et al., in prep.)

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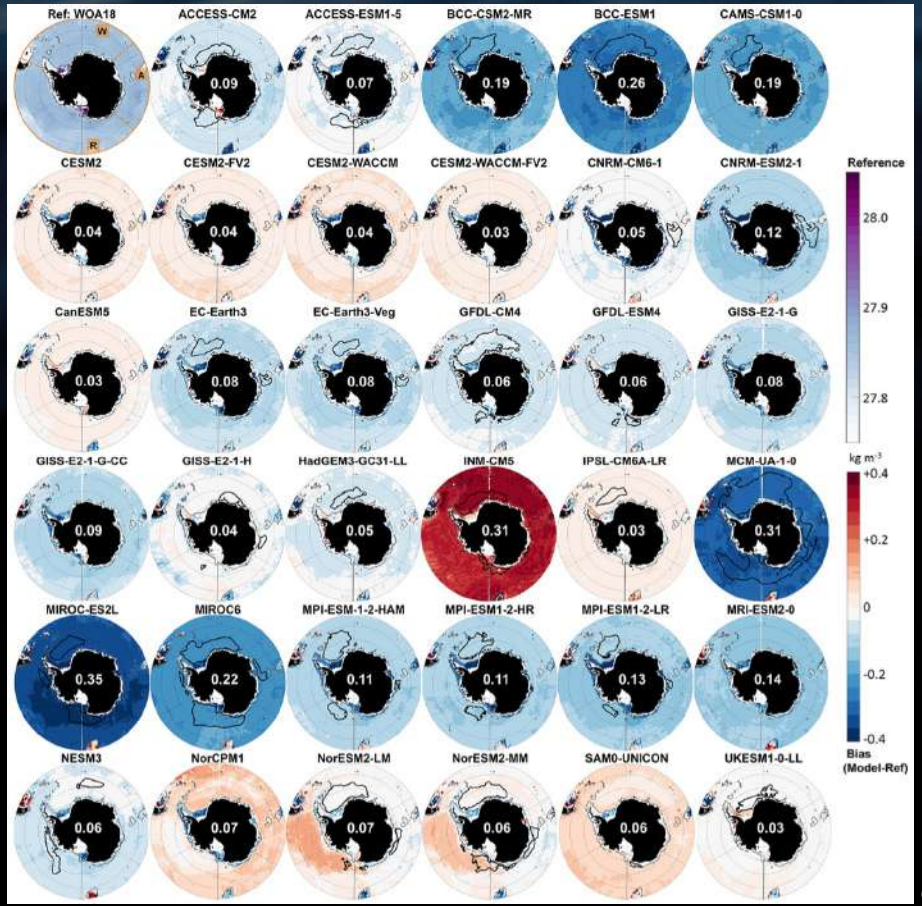
CMIP6 bottom density bias



- Range of significant biases in bottom density compared to World Ocean Atlas, around ±0.1 kg/m^3, up to ±0.4 kg/m^3

(Heuzé, 2021, OS)

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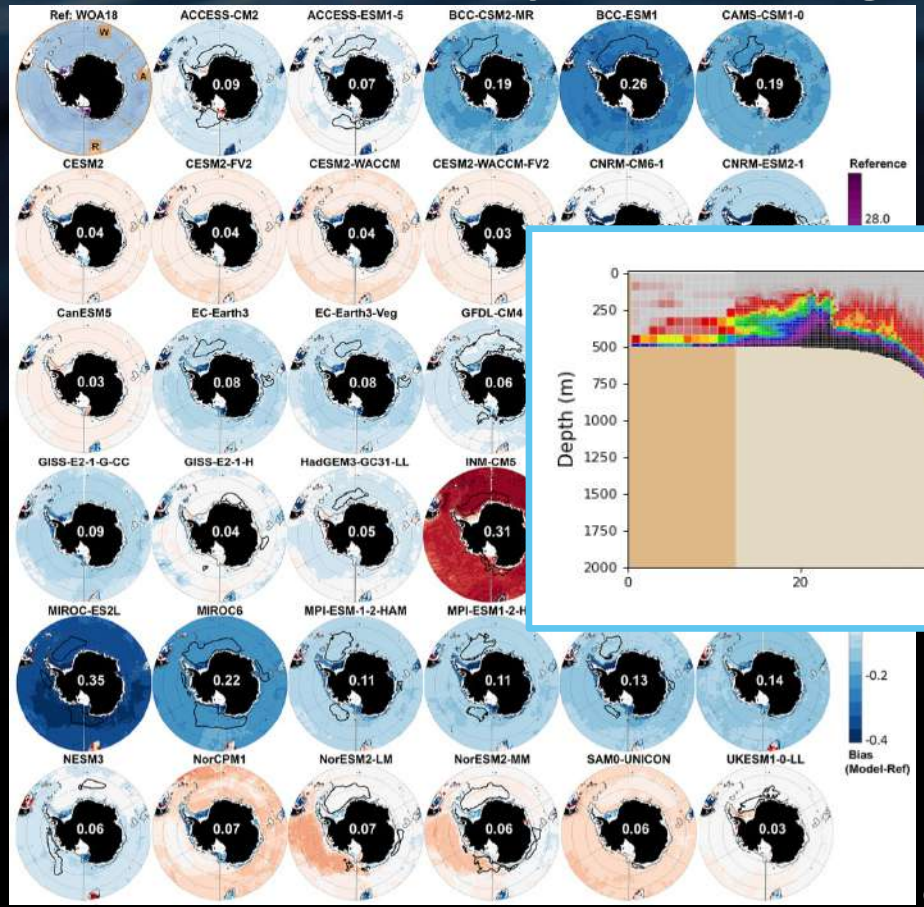
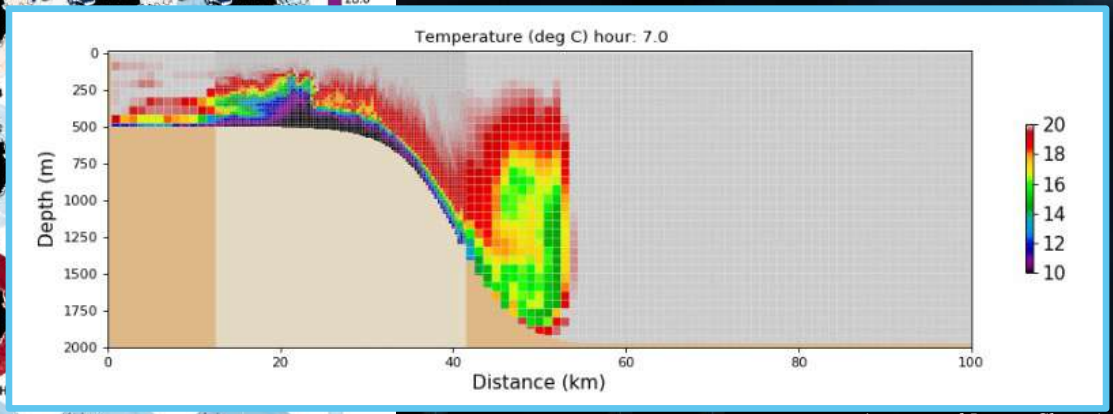
CMIP6 bottom density bias and long-known overflow issues



- Range of significant biases in bottom density compared to World Ocean Atlas



(courtesy of Jerome Chanut)

- Improvements by different vertical coordinate porous bottom layer approach

(Heuzé, 2021, OS)

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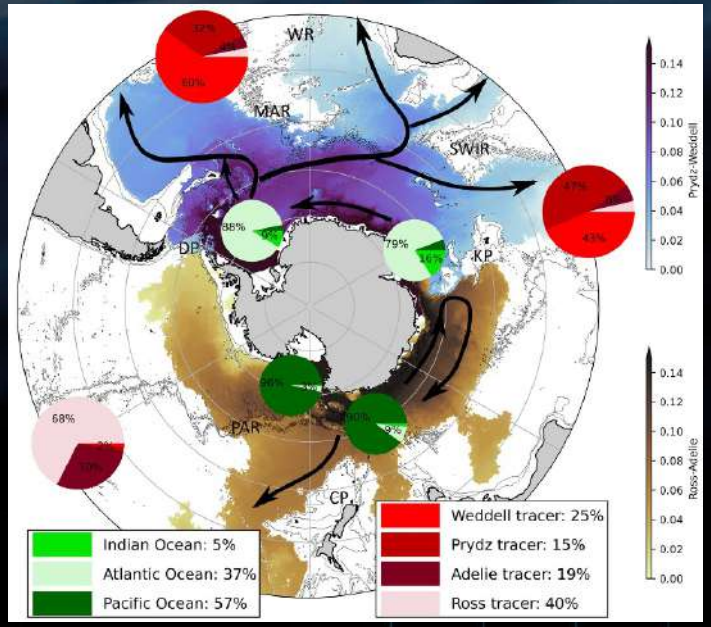
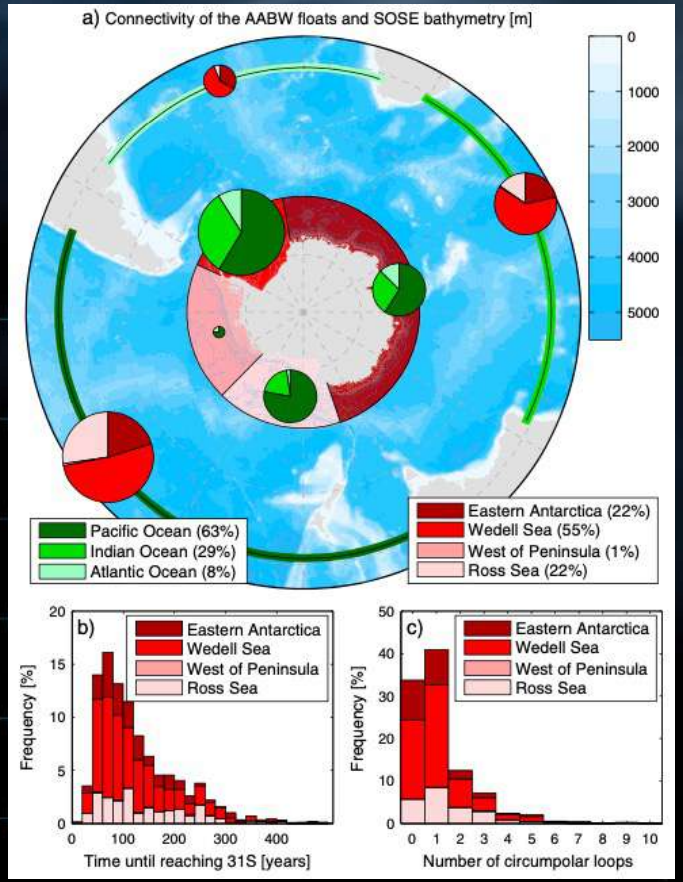
Tracking AABW export with tracers and Lagrangian particles



(Solodoch et al., 2022, GRL)

(van Sebille et al., 2013, GRL)



- Passive tracers to track watermass distribution
- Lagrangian modeling based on Eulerian model output at formerly 5-daily, now daily resolution

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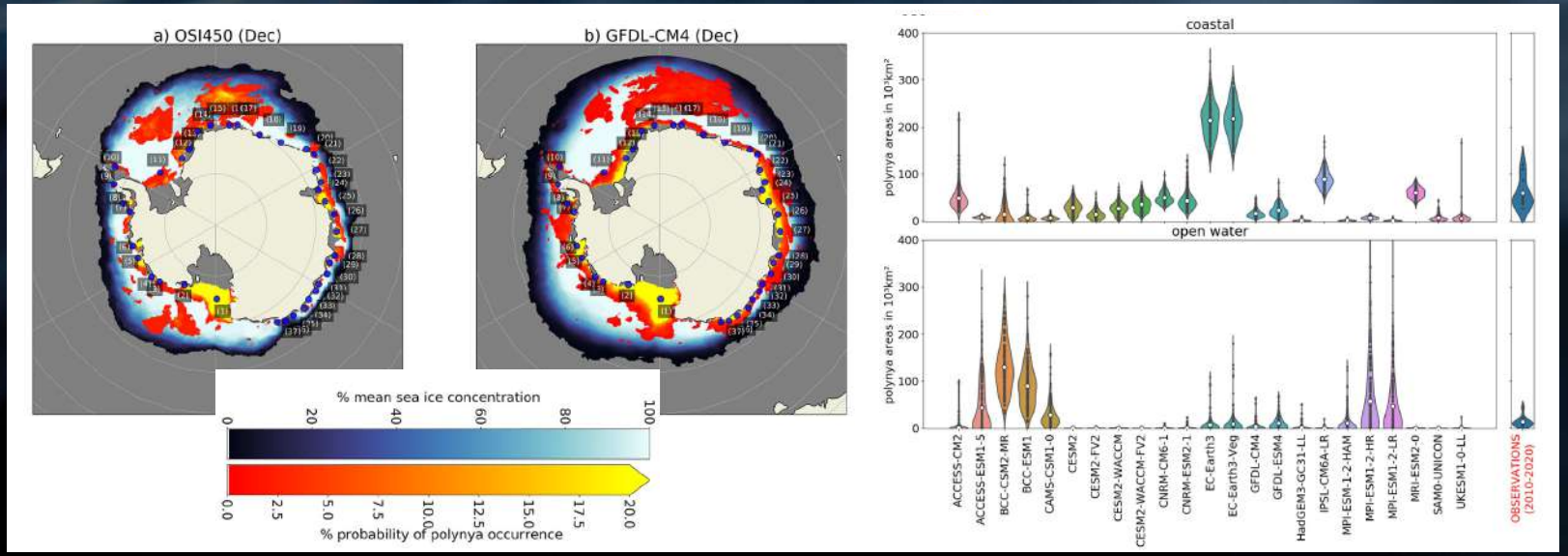
Polynyas



(Mohrmann et al., 2021, TC)

- only half of the CMIP6 models have open ocean polynyas
- polynya area is often underestimated
- coastal polynya area is overestimated
- grid resolution reduces bias

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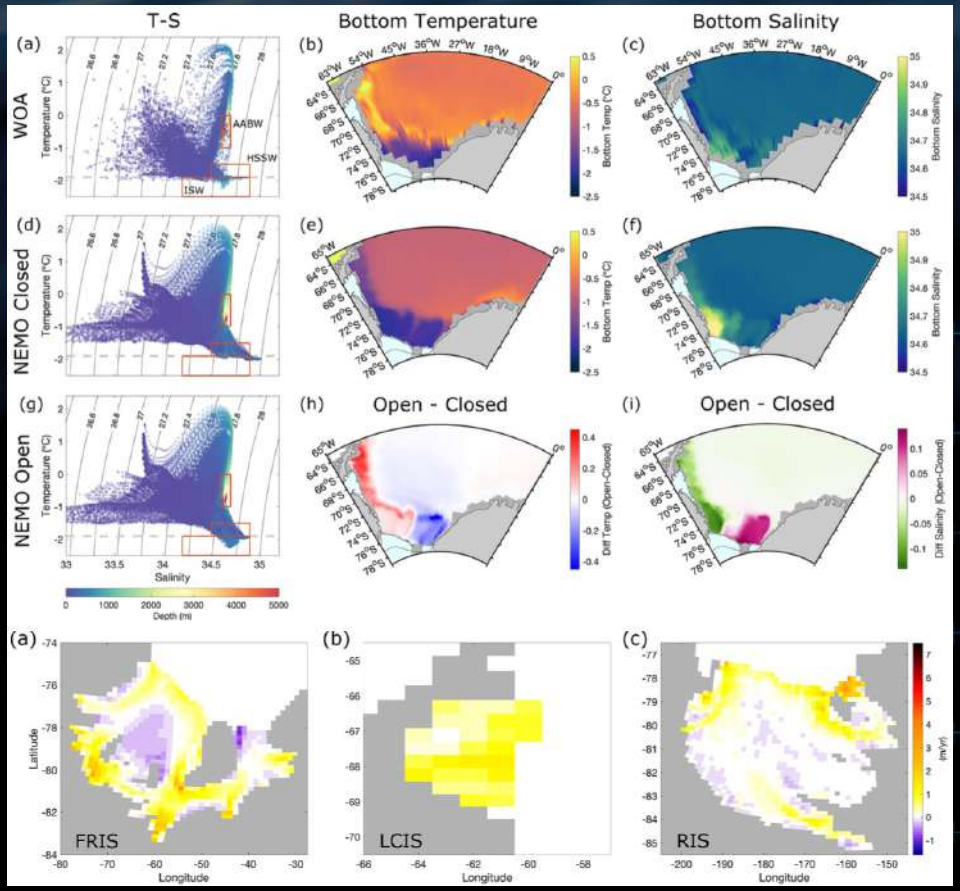
Ice shelf cavities



(Hutchinson et al., 2023, GMD)

- Ice-shelf ocean interaction crucial for watermass transformation on continental shelf
- Ice Shelf Water can already be realistically formed at 1˚ horizontal grid resolution
- Melt rates depend on inflow properties and bathymetry

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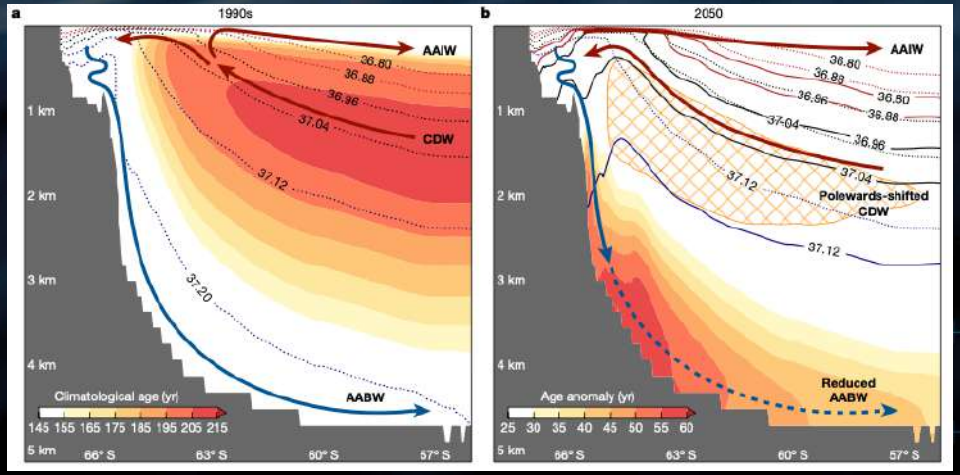
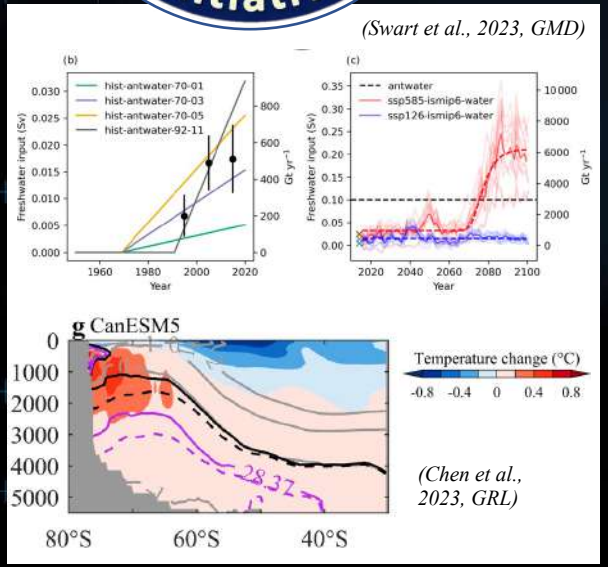
Meltwater impacts



(Li et al., 2023, Nature)

- Enhanced melting of the Antarctic ice sheet will lead to reduced AABW formation and ventilation of the deep Southern Ocean
- Surface cooling, mid-depth warming and shrinking AABW water volume are robust responses across climate models

(Swart et al., 2023, GMD)



(Chen et al., 2023, GRL)

1. AABW ingredients
2. Location, location, location
3. Bottom density and overflow
4. AABW export
5. Polynyas
6. Ice shelf cavities
7. Meltwater
8. Eddies
9. Carbon uptake
10. Summary

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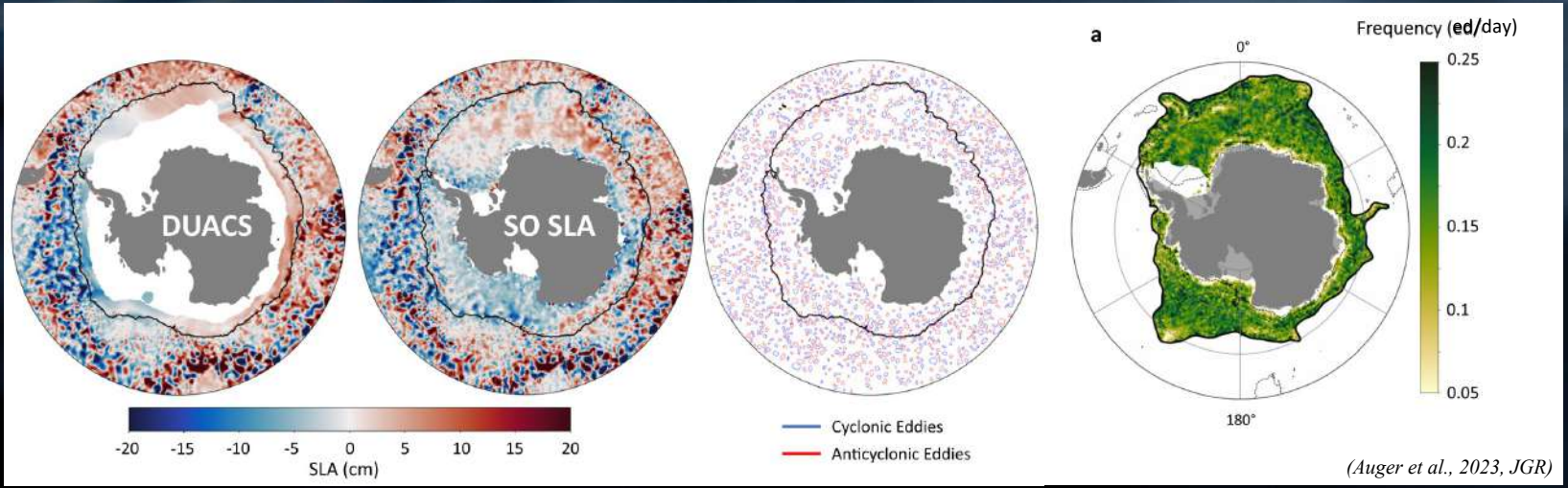
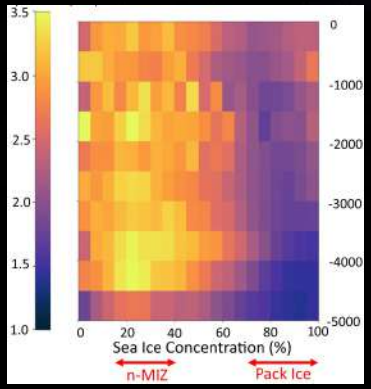
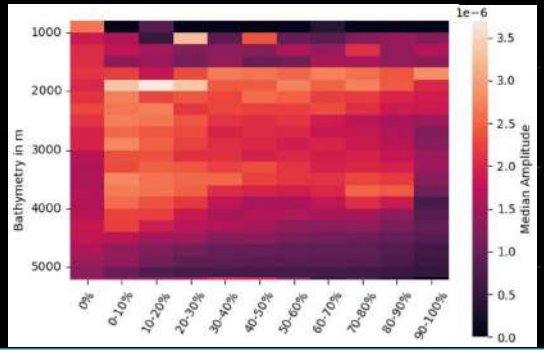
Ocean mesoscale dynamics – sea surface height variability

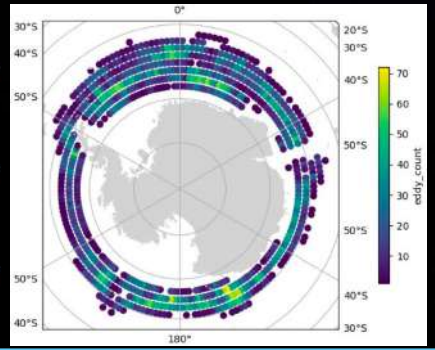


(Auger et al., 2023, JGR)



eddy detection in 1/10˚ nested ocean model ORION10





(Zoe Brunssen, BSc thesis, 2023)

1. AABW ingredients
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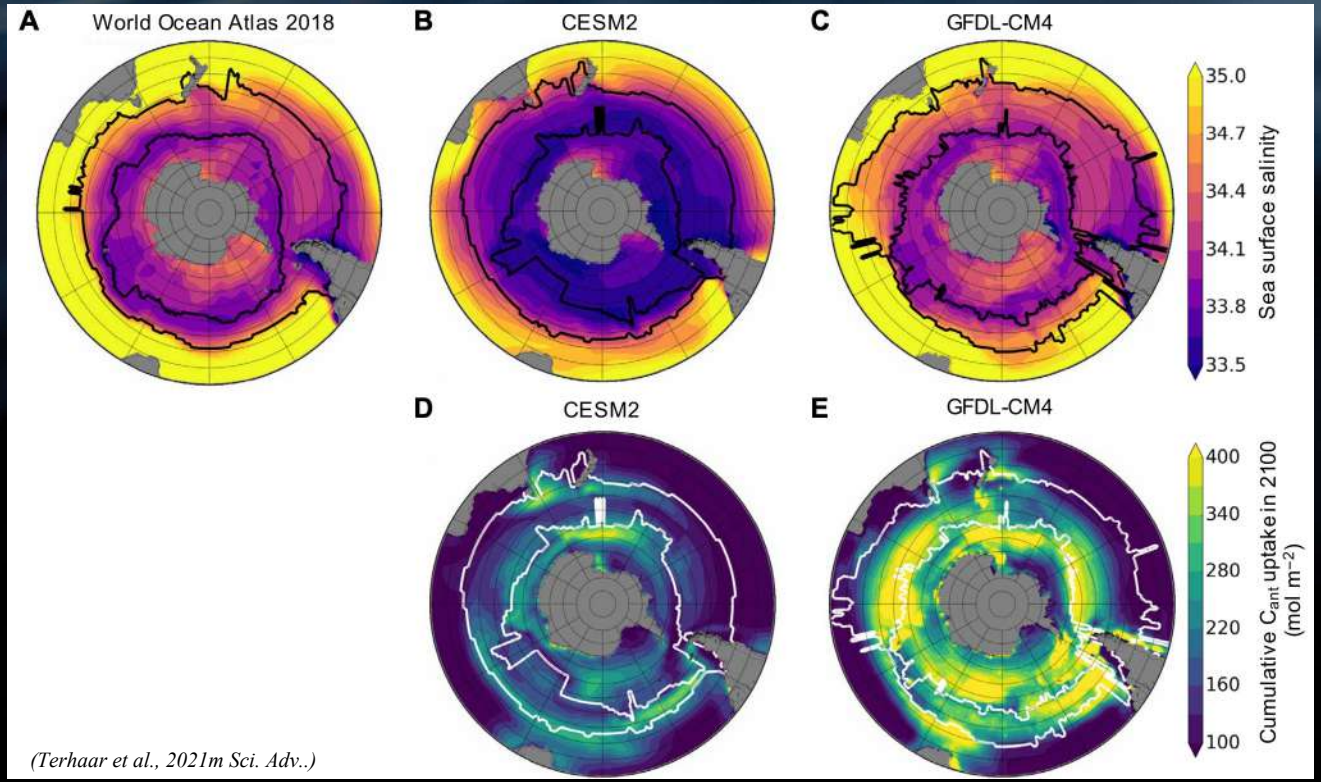
Sea surface salinity – link to carbon uptake



(Terhaar et al., 2021m Sci. Adv..)

- Mean salinity between subtrop. and polar front
- Fresher means less anthrop. Carbon uptake

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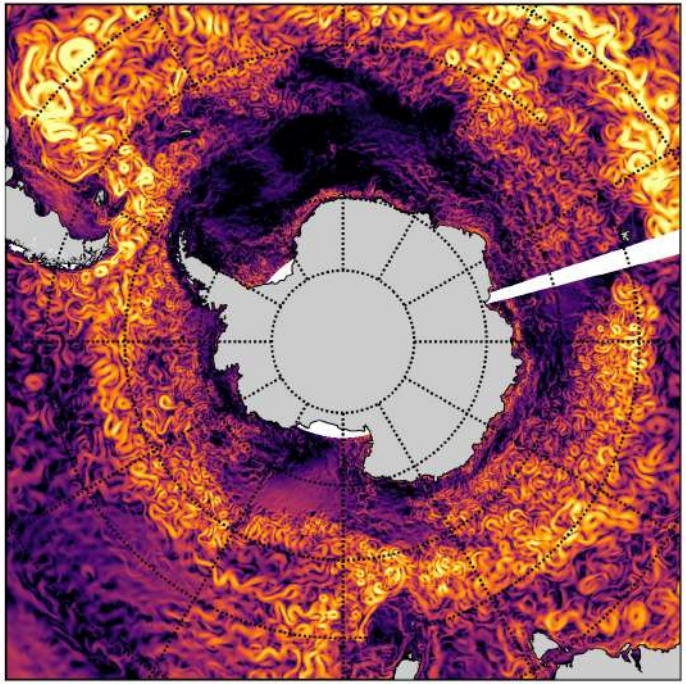
Take home message

- Southern Ocean and climate models have been advanced a lot, with many of the features and processes essential for AABW formation generally available
- Urgently needed is better understanding and observational constrain of the (surface) (coastal) ocean properties in the high latitude, seasonally sea ice covered Southern Ocean
- Satellite products will continue to be an asset to model validation

Southern Ocean at 1/10˚ in a climate model



(Zeller and Martin,2024, Ocn.Mod.)

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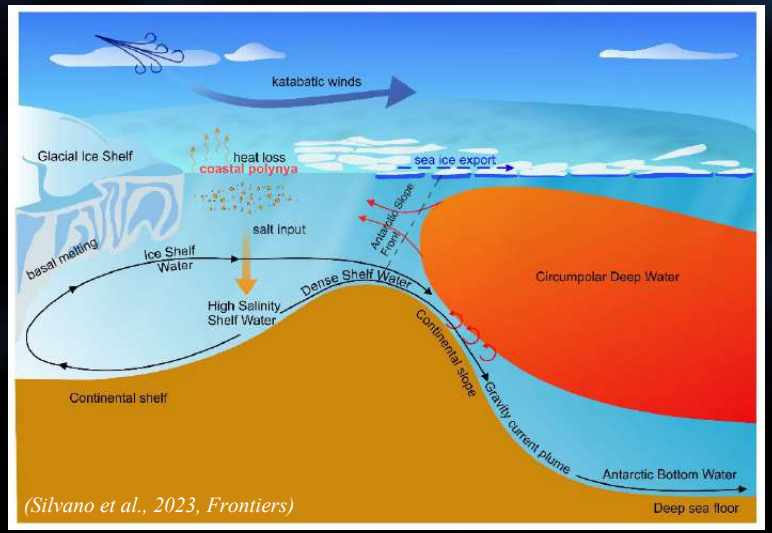
Where surface observations connect to the deep ocean

wind/surface roughness: mixing

polynyas: direct link to AABW formation

land-fast sea ice: shaping polynyas, collects platelet ice from supercooled water, productive habitat



sea surface hight: mesoscale ocean dynamics, eddies under sea ice

sea ice cover: indicator of climate change

icebergs: export of freshwater

sea surface temperature & salinity: ocean fronts, mixed layer, carbon uptake

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