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Theme 1: Southern Ocean and Antarctic heat, freshwater, carbon and other elements and their response to climate change

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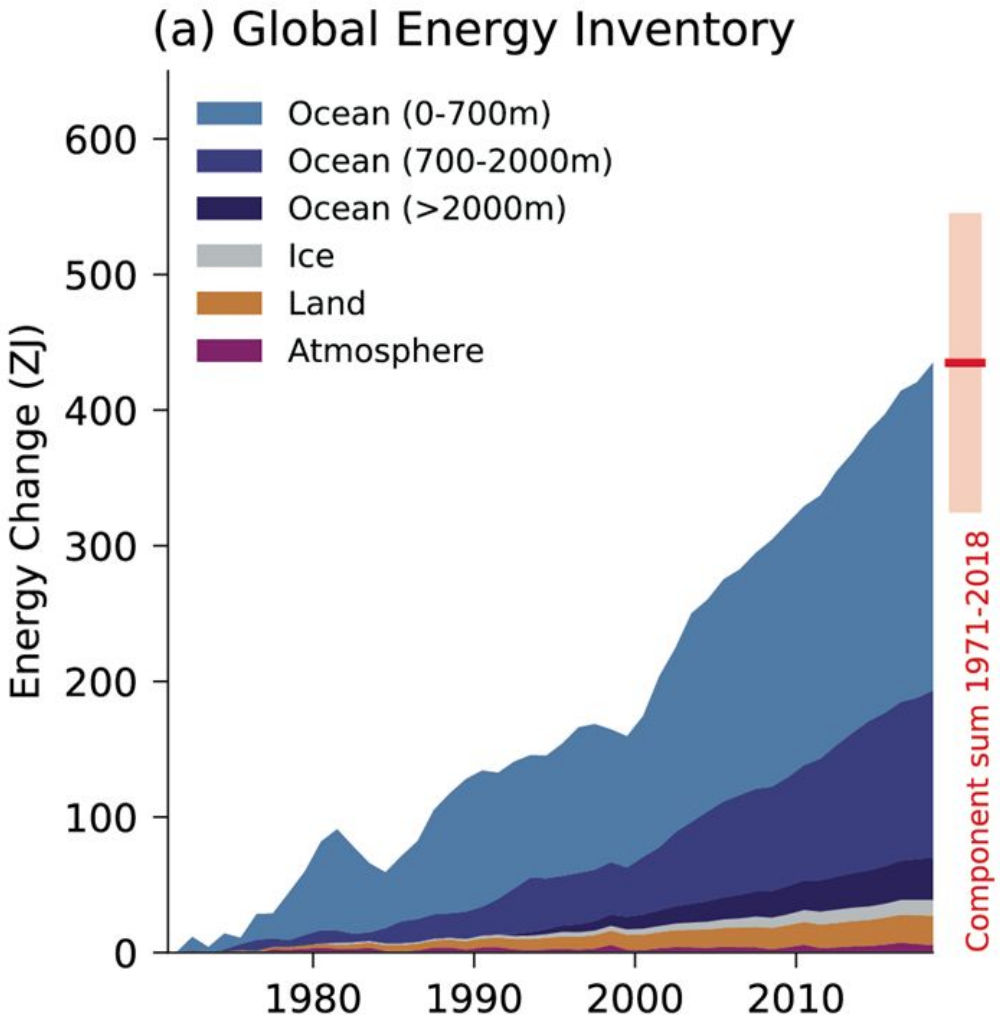
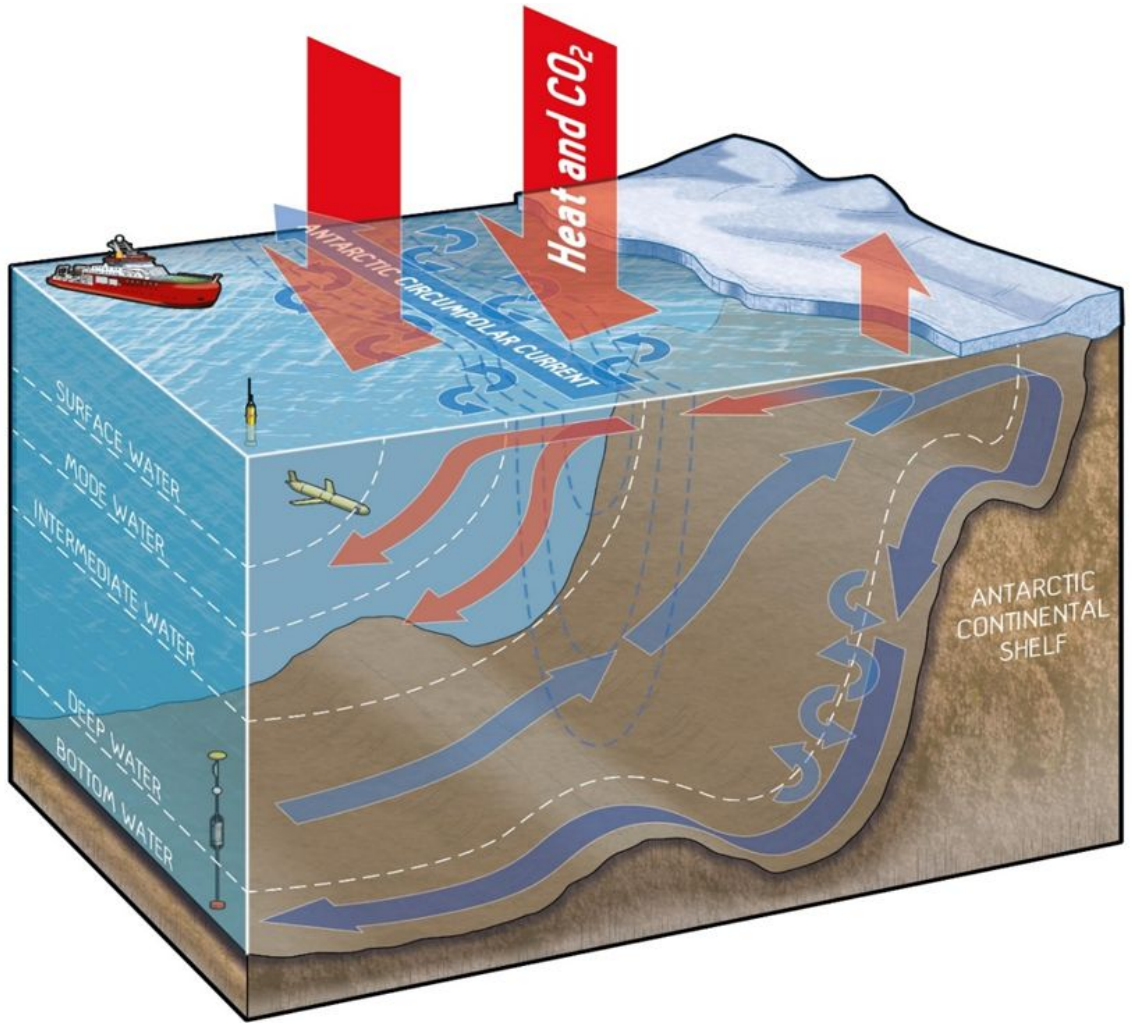
Heat and freshwater

Heat: The Southern Ocean plays a dominant role in ocean warming

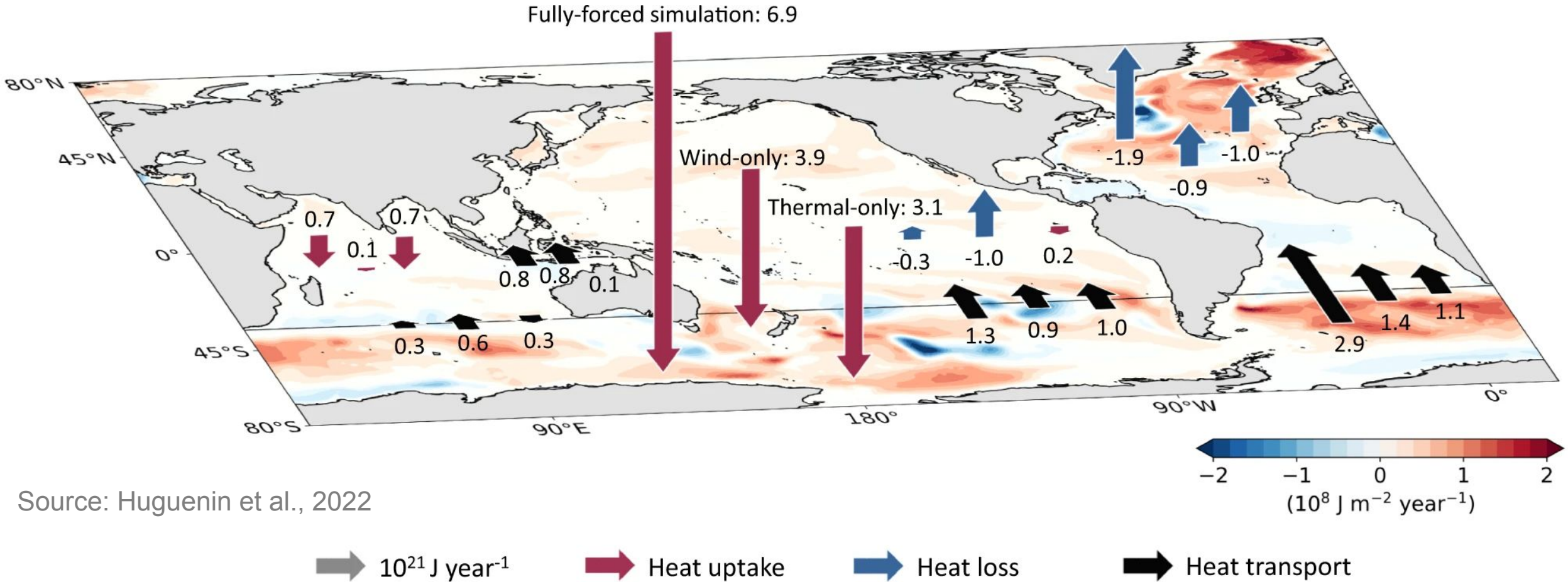


Source: IPCC AR6 2021



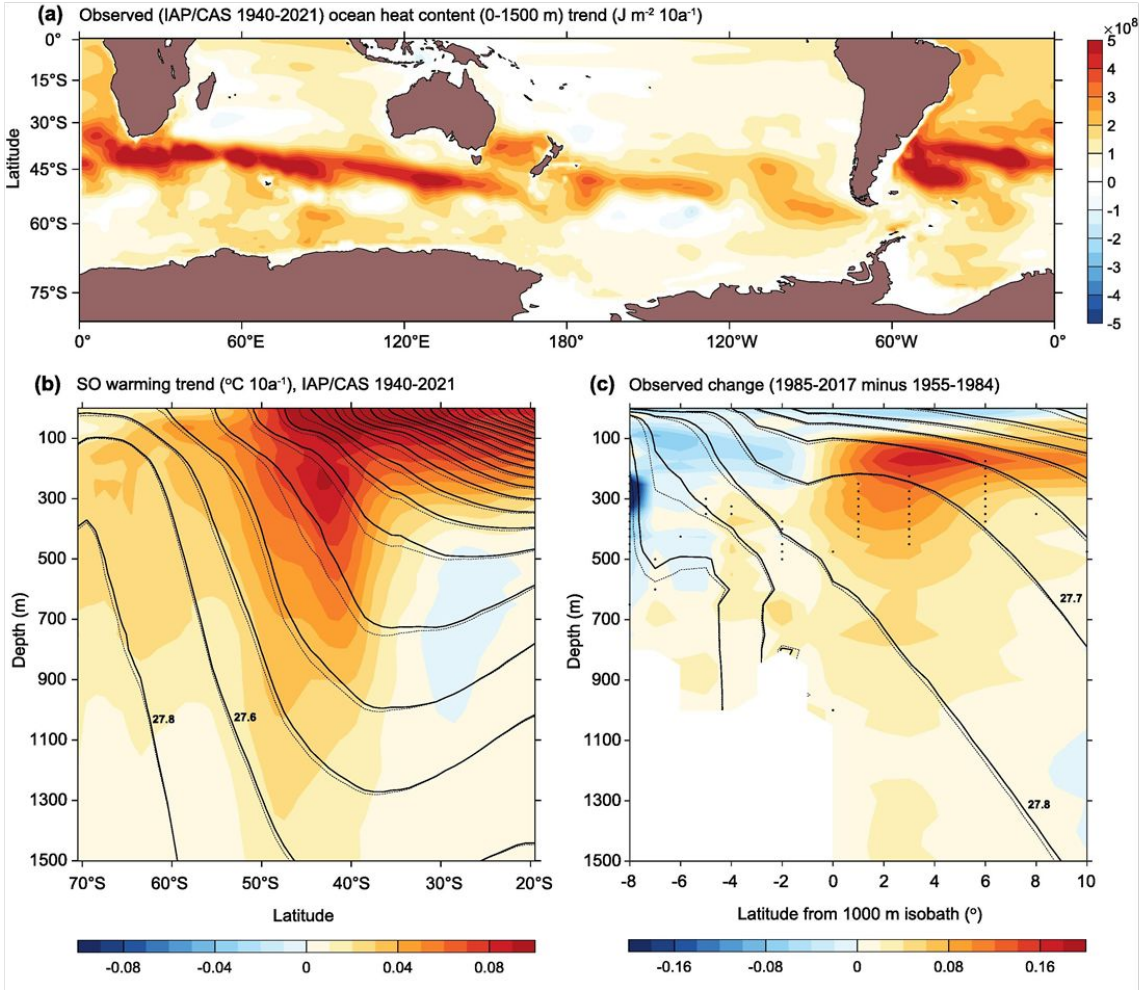
SO dominates global uptake and storage in recent decades

Anomalous global ocean heat uptake, heat loss and heat transport 1970-present in simulations

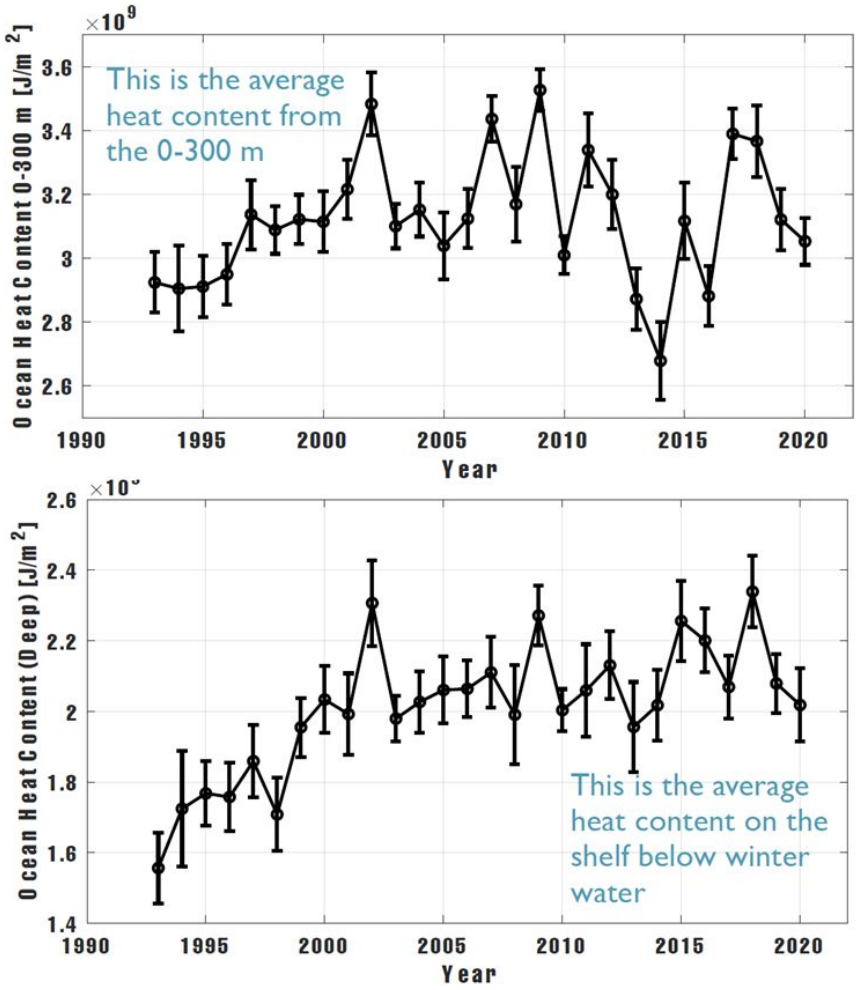


Source: Huguenin et al., 2022

Deep signal of warming, except at surface and near the continent

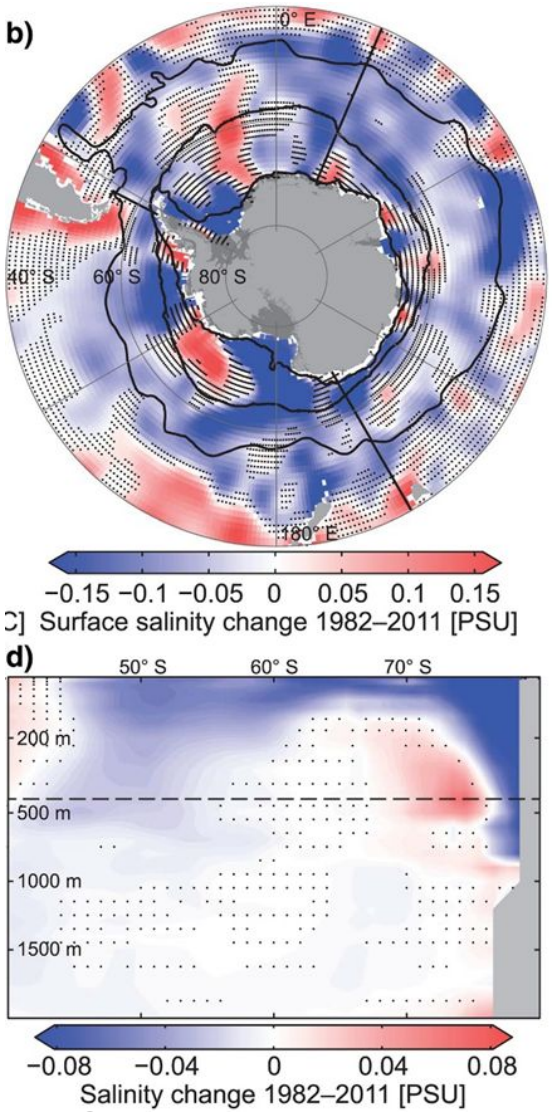


Source: Cai et al., 2023

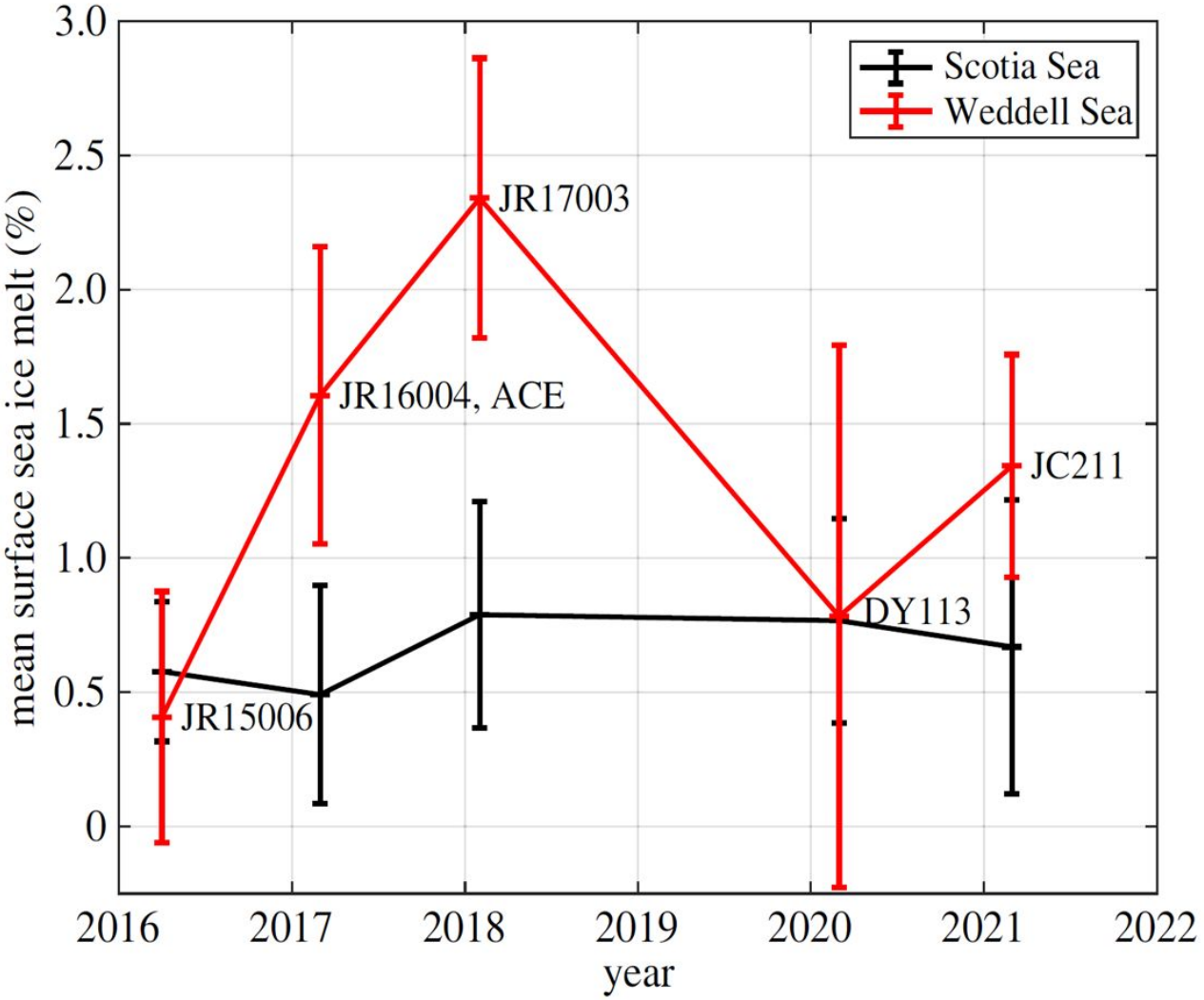


Source: C. Moffat, pers. comms.

Freshwater: Has the polar water cycle become stronger?

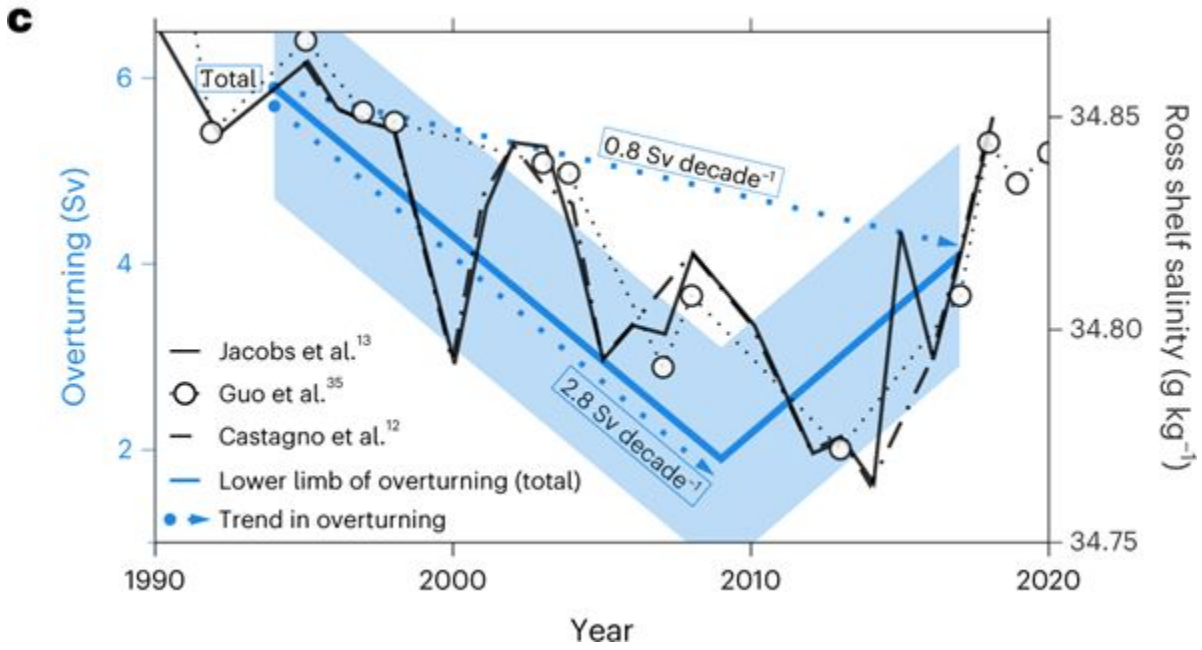


Source: Haumann et al., 2020

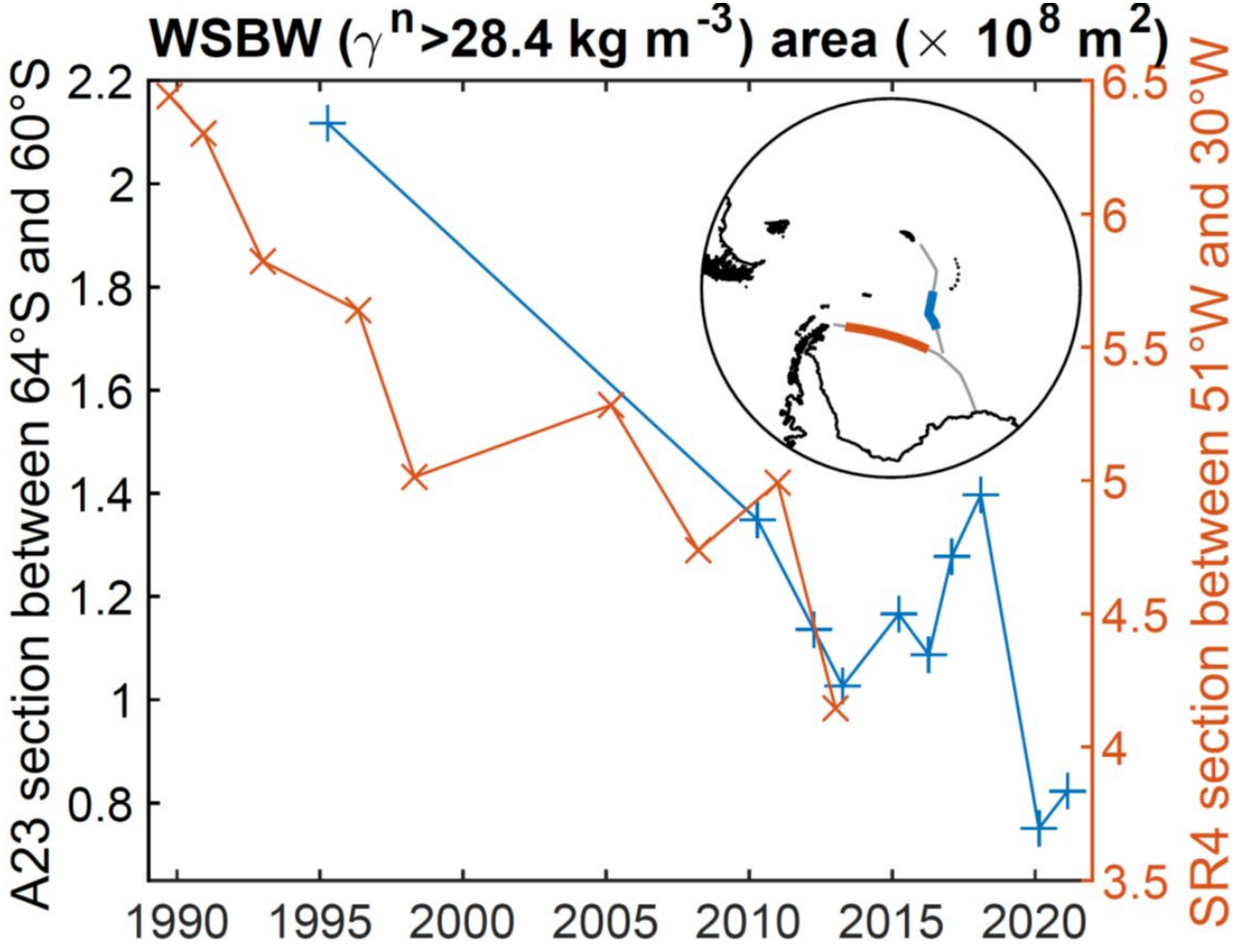


Source: Meredith et al., 2023

Circulation change as a result of freshening, warming, ice distribution?

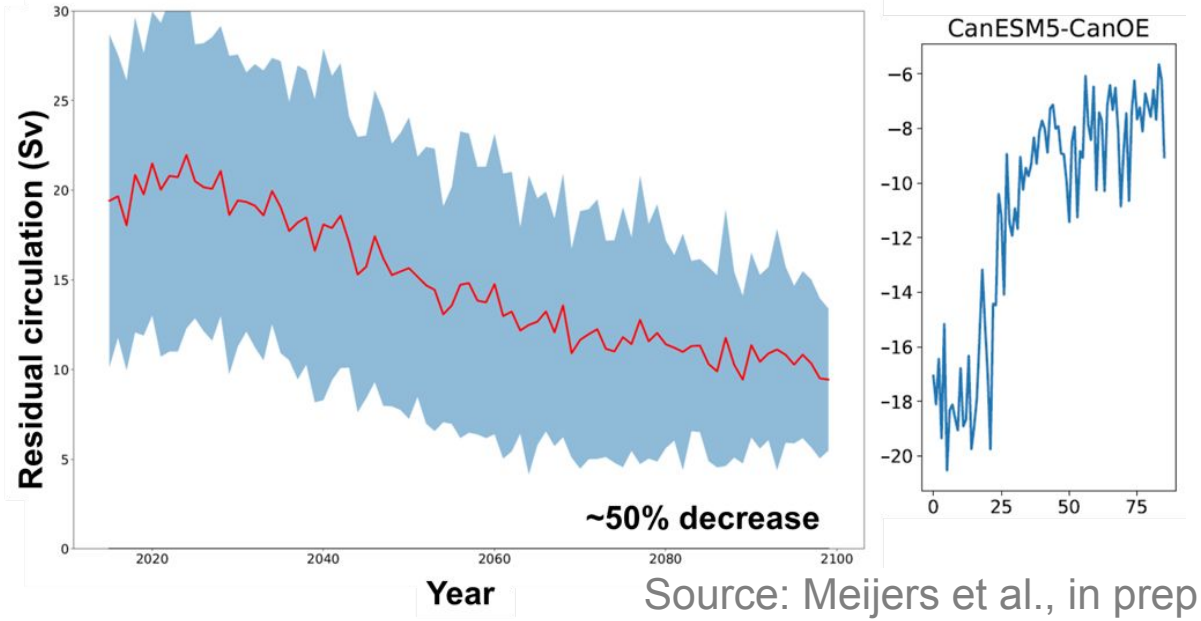


Source: Gunn et al., 2023

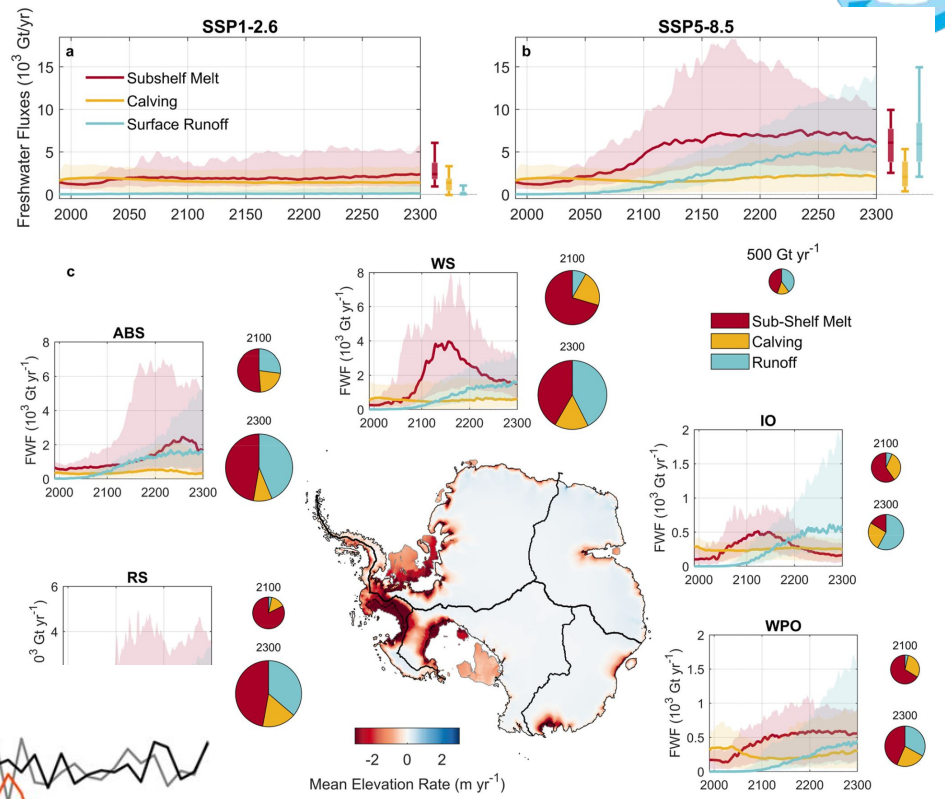


Source: After Abrahamsen et al., 2019

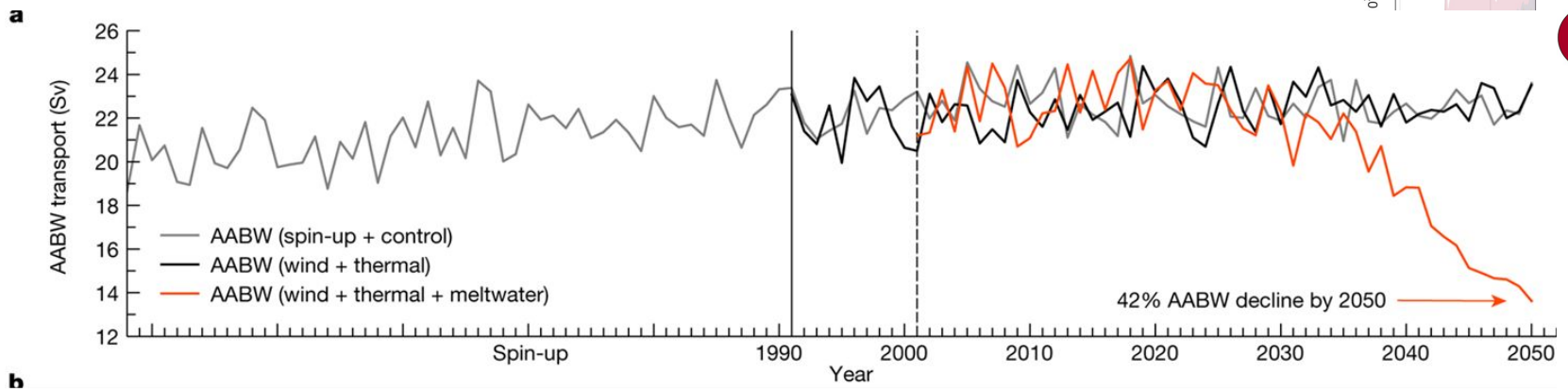
With significant future consequences?



Source: Meijers et al., in prep.



Source: Coulon et al., 2024



Source: Li et al., 2023

Summary

Key questions:

- How is heat transported towards and stored around Antarctica in the ocean and atmosphere?
- How much heat is exchanged between the ice, the ocean, and the atmosphere?
- What are the contributions of moisture transport, salinity transport, precipitation, evaporation, sea ice formation and melt, and ice shelf and iceberg melt to the regions freshwater budget?
- How do changes in these fluxes affect the ocean's stratification, circulation, property storage and export, and how does this feed onto the cryosphere/carbon/BGC/ecosystem and global climate stories (and back)?

International Partners:

Groups: SOFLUX (SOOS), SORP, AniBOS, SOCCOM/PolarArgo, OCEAN ICE, SOFIA, GO-SHIP, MASIS, TRICUSO etc.

Remember why!

"The overarching research priority is improving our ability to model the Southern Ocean system and its response to anthropogenic forcing."

- Bennetts et al., (2024), 'Closing the loops on Southern Ocean dynamics: From the circumpolar current to ice shelves and from bottom mixing to surface waves', Rev. Geophys.

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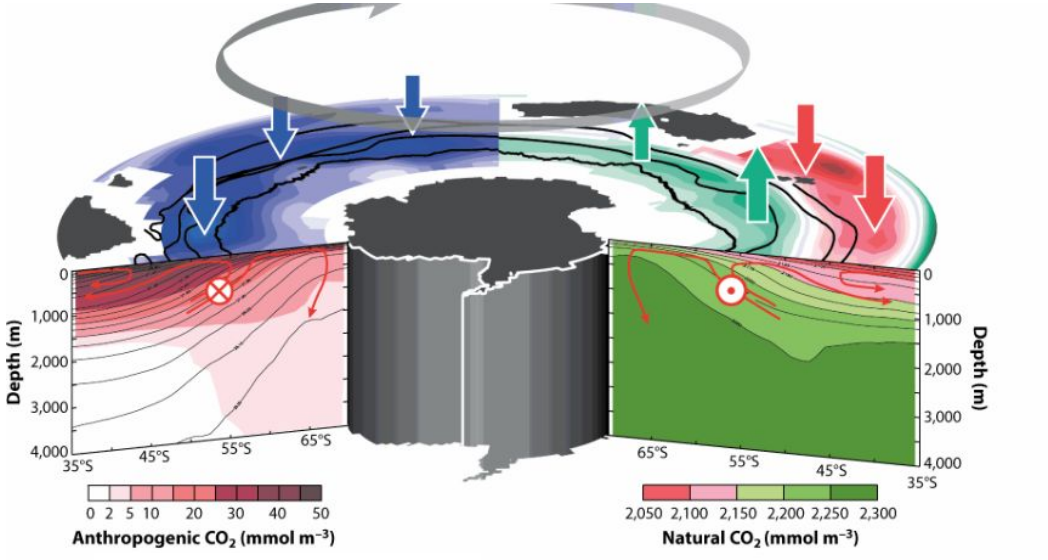
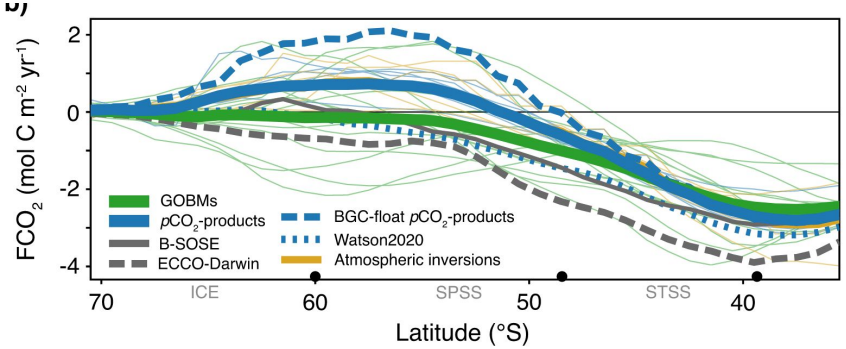
The carbon cycle

The Southern Ocean carbon sink



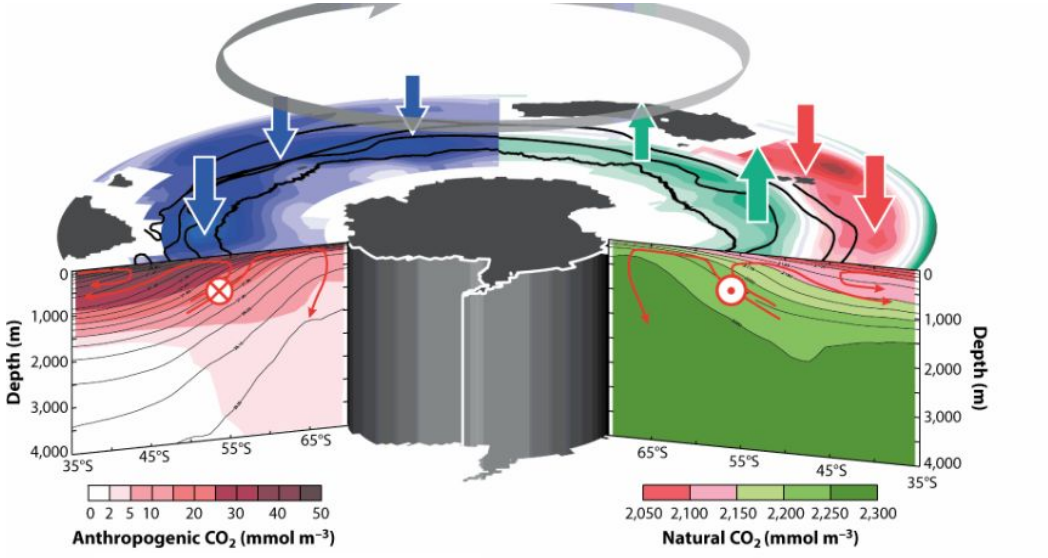
Source: Gruber et al., 2019



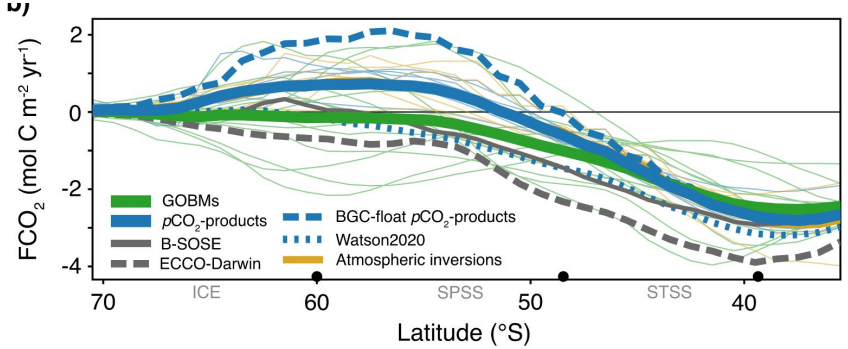
Source: Hauck et al. 2023

- Strong westerly winds and the ACC drive upwelling of deep, carbon-rich waters and surface divergence, shaping the region's role as both a **source** and **sink** of CO_2.
- Upwelling in the Antarctic Zone leads to natural CO_2 outgassing, while subpolar and subtropical regions act as major sinks for anthropogenic CO_2, in part due to the biological carbon pump.
- Biological carbon uptake in summer lead to an enhanced CO_2 drawdown.
- The Southern Ocean remains under-sampled, especially in winter, leading to large uncertainties on the flux.

The Southern Ocean carbon sink



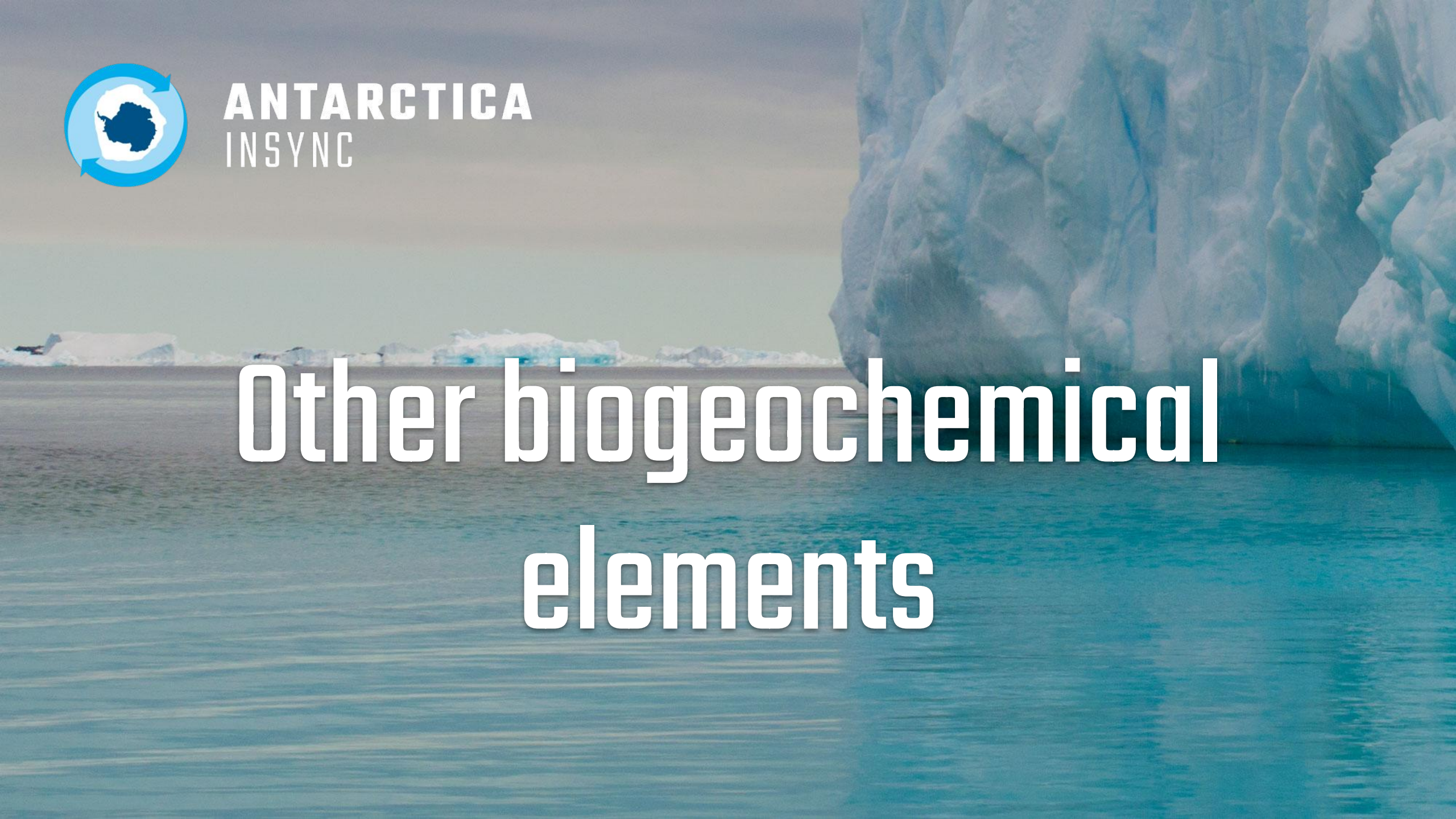
Source: Gruber et al., 2019



Source: Hauck et al. 2023

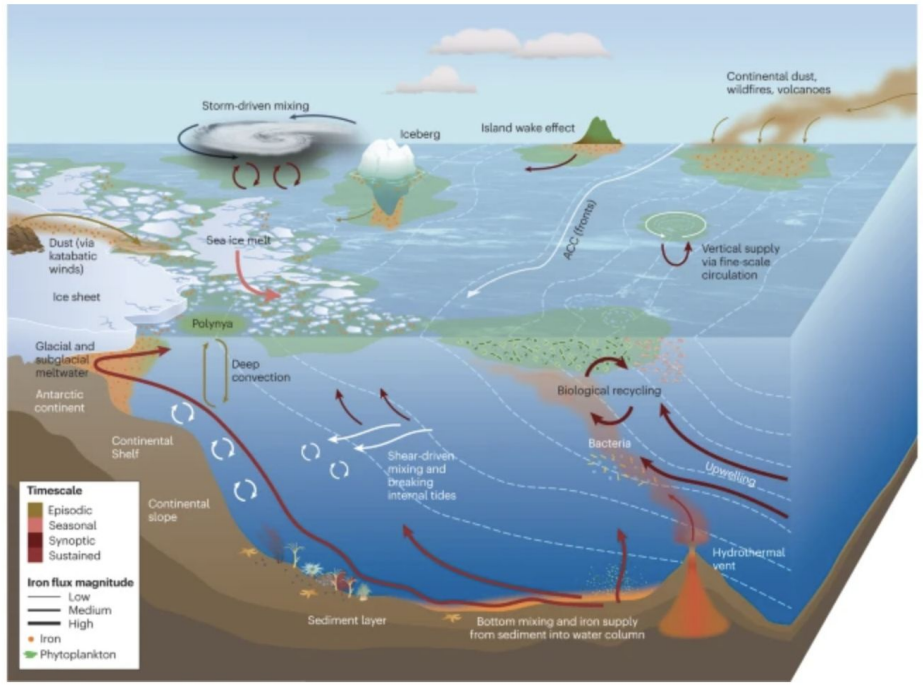
Overarching questions & knowledge gaps

- Is the Southern Ocean a source or a sink of CO2?
- How large are the fluxes, especially in wintertime?
- What are the drivers (both physical and biological)? How do they change on seasonal, interannual and decadal time scales?
- How (and how much) carbon is sequestered in deeper water masses?



Other biogeochemical elements

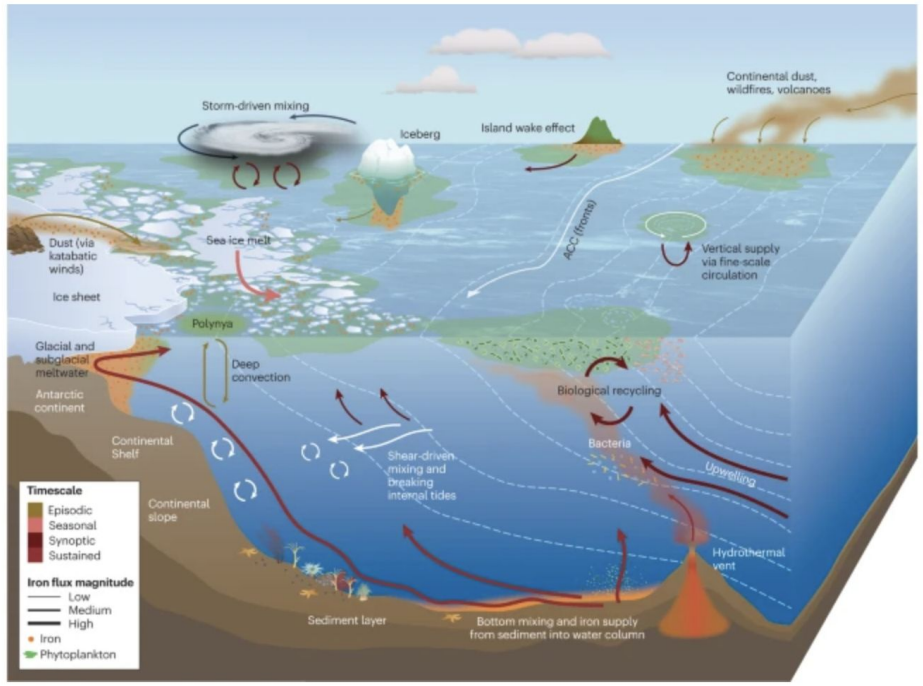
The biogeochemical elements



Boyd et al., 2024

- Micronutrients (**Fe, Mn)** regulate primary productivity, particularly in HNLC regions. Their sources, seasonality and internal cycling remain uncertain.
- Nutrient cycling is critical for productivity and microbial community structure
- GHG (e.g., CH4, N2O) play a key role in climate and ozone layer, role of Southern Ocean is uncertain
- Chemical tracers (e.g., CFCs) and stable isotopes (e.g., $\delta^{13}C$, $\delta^{18}O$) provide insights into physical and biological processes, but long-term time series are limited.

The biogeochemical elements



Boyd et al., 2024

Overarching questions & knowledge gaps

- What are the sources and sinks of nutrients and GHG in the Southern Ocean?
- How do they vary on seasonal and interannual timescales?
- What is the role of *wintertime* processes?
- How are their cycles responding to environmental change?
- What are the relationships between microbial community structures, primary productivity, and nutrient cycling?