Image courtesy: NASA

Overview of processes: current state of the art and gaps

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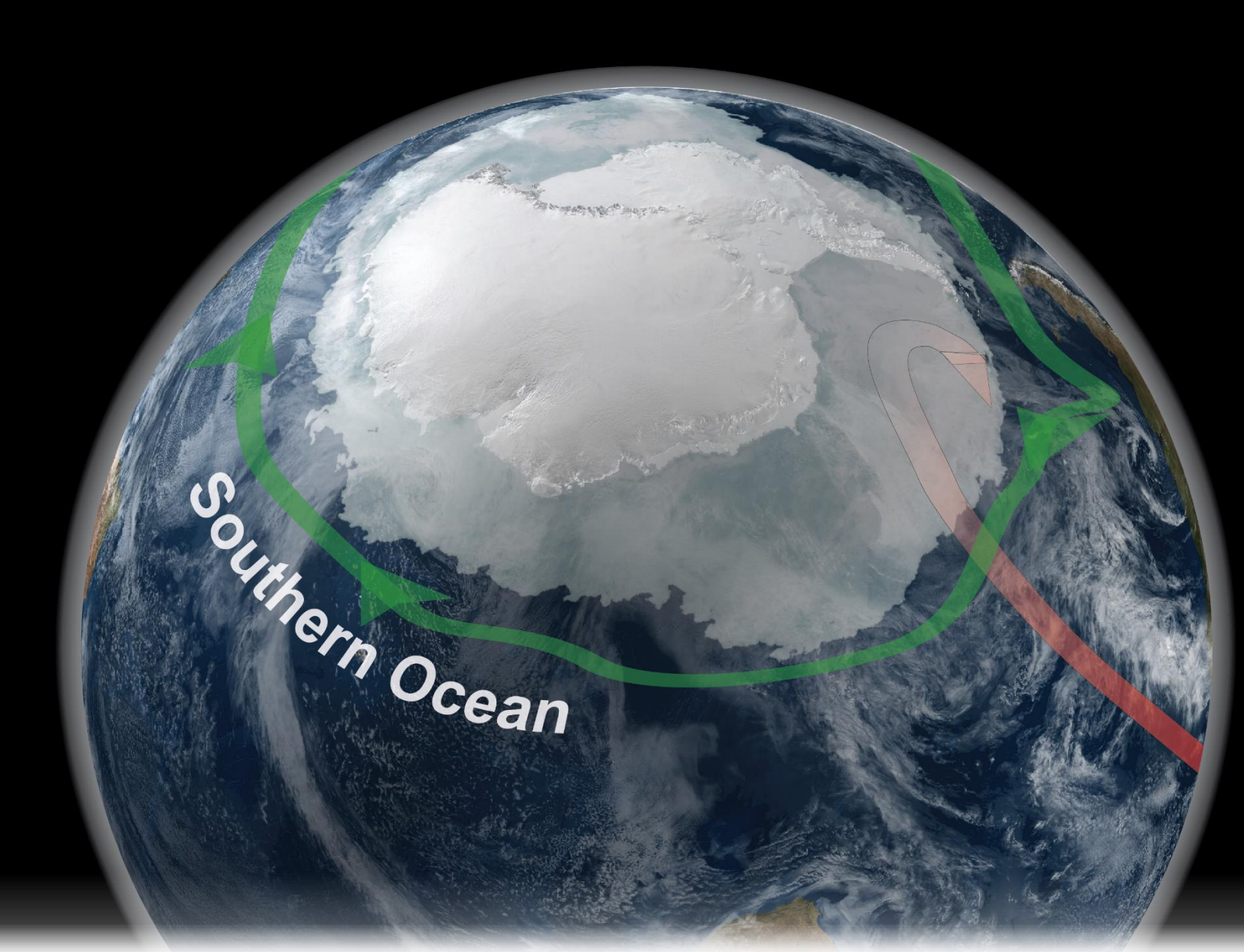
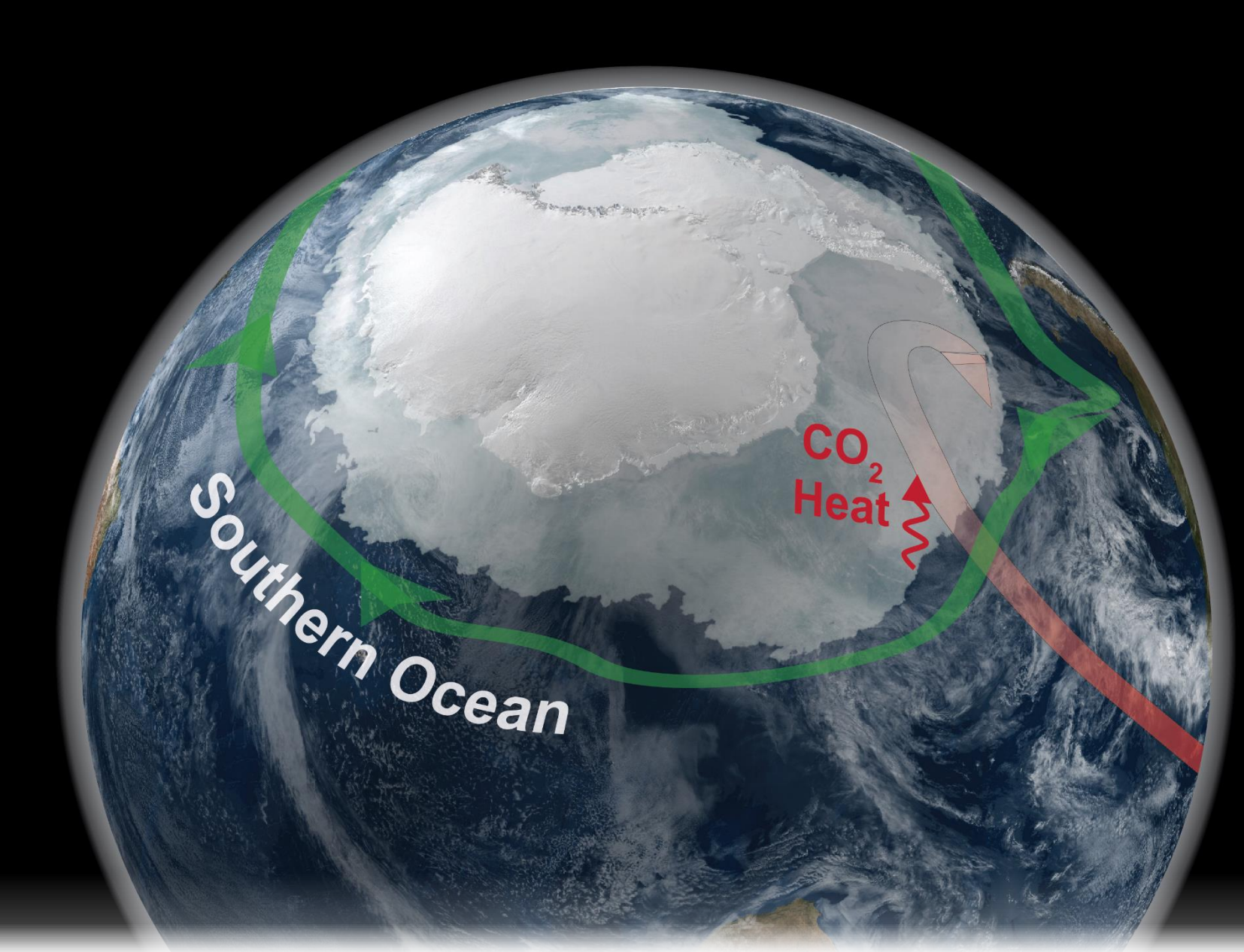
How satellite measurements can help in better understanding dense water formation in the Southern Ocean and its impacts on the global circulation and climate

Image courtesy: NASA



Returns up to 80% of all deep water to surface

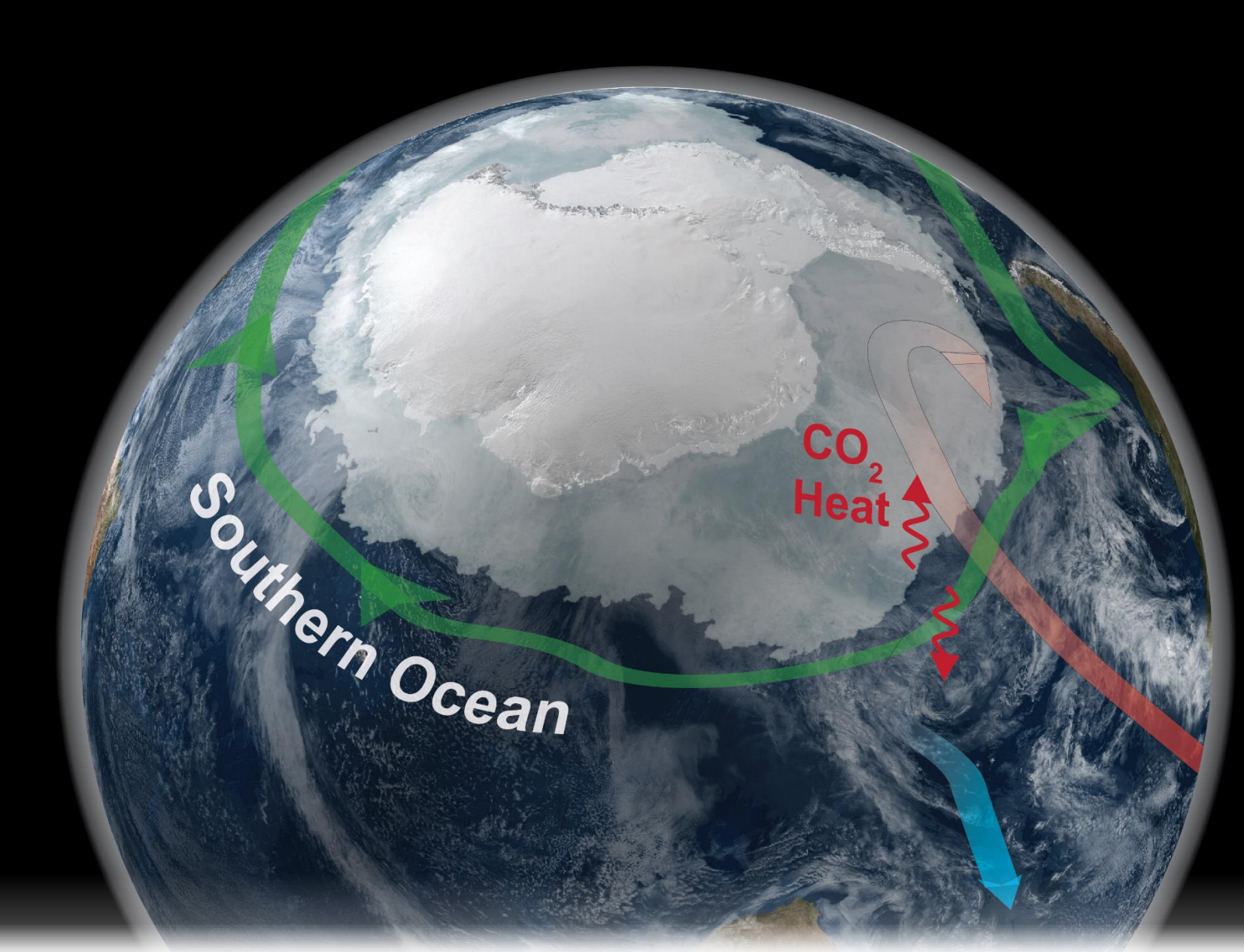
Image courtesy: NASA



Returns up to 80% of all deep water to surface

Releases heat and CO_2 to the atmosphere

Image courtesy: NASA

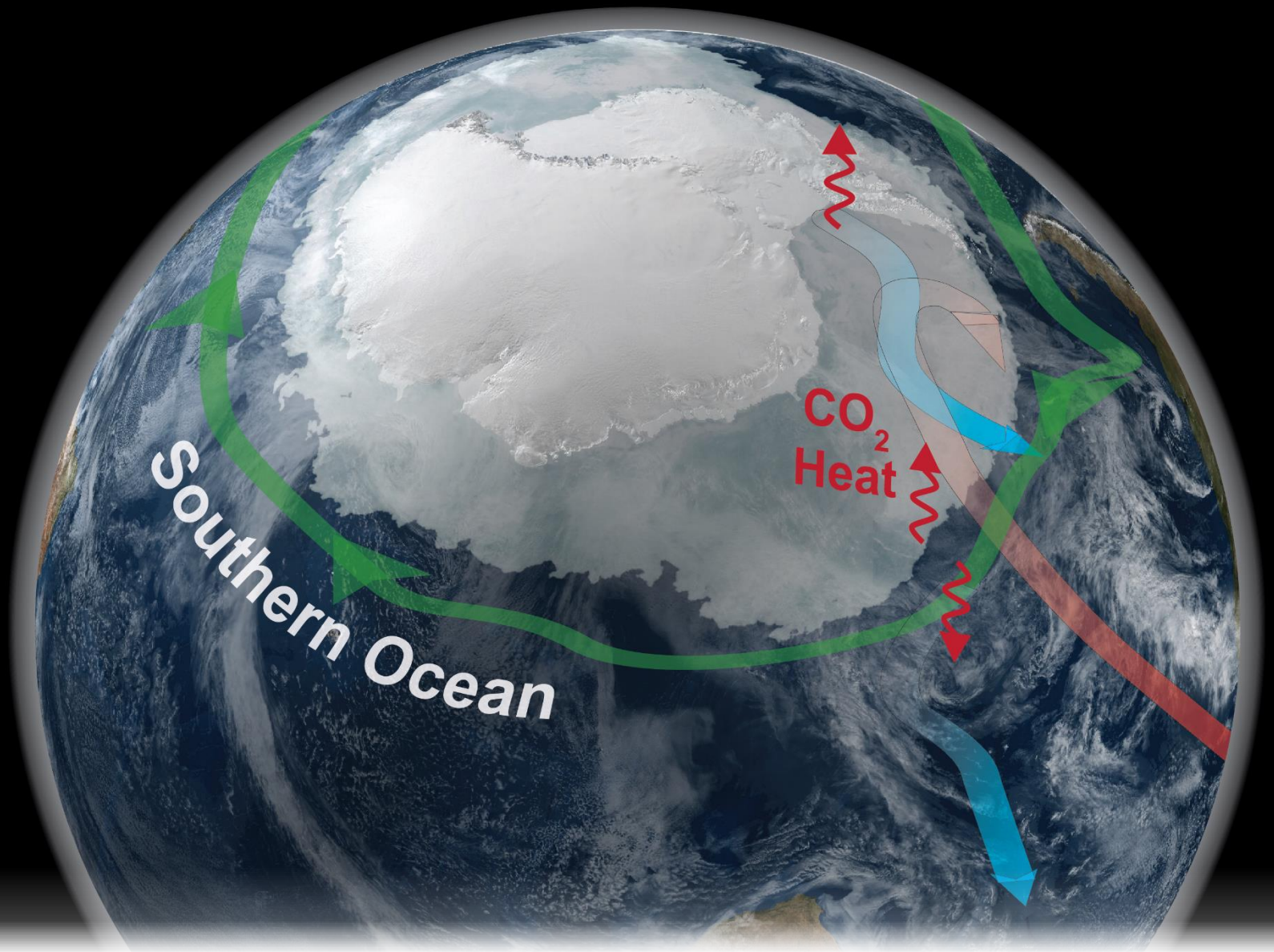


Returns up to 80% of all deep water to surface

Releases heat and CO_2 to the atmosphere

Subducts large amounts of anthropogenic CO_2 (13%) and heat (68%)
→ Slowing-down global warming

Image courtesy: NASA



Returns up to 80% of all deep water to surface

Releases heat and CO_2 to the atmosphere

Subducts large amounts of anthropogenic CO_2 (13%) and heat (68%)
→ Slowing-down global warming

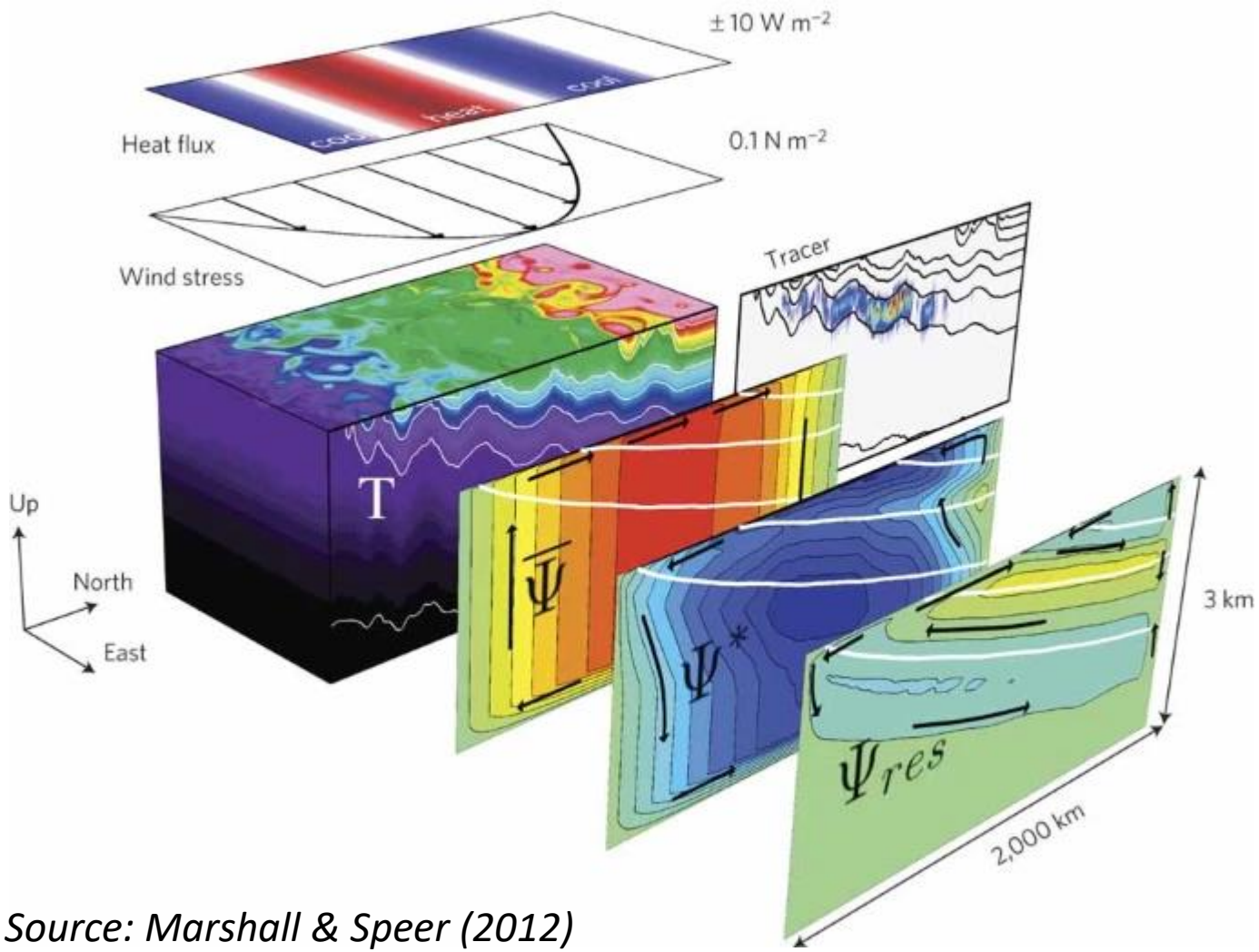
Loses heat around the continent and melts ice shelves
→ Contributing to sea-level rise

Forms Antarctic Bottom Water that ventilates the deepest parts of the global ocean

Image courtesy: NASA

Southern Ocean as an important component of the global overturning circulation

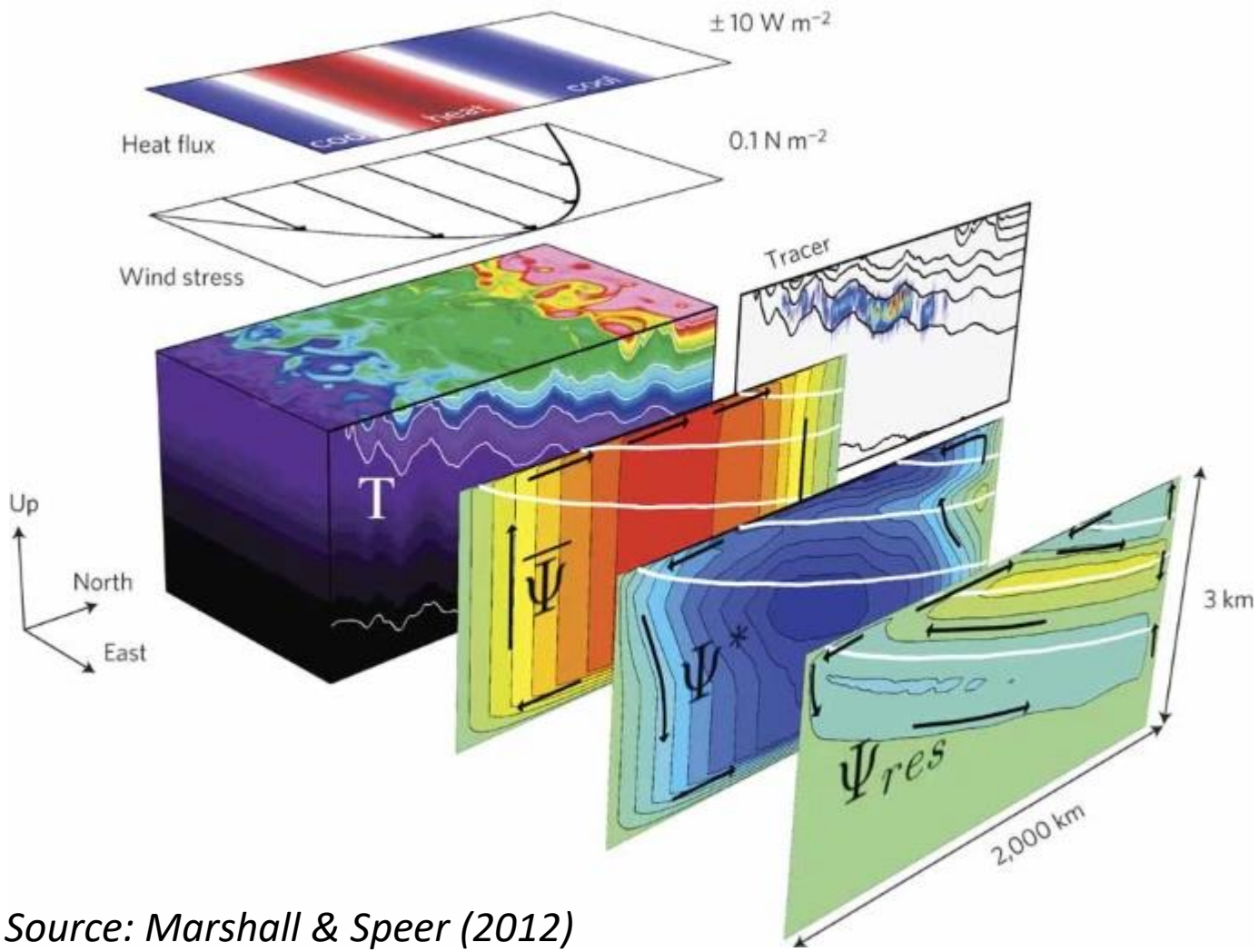
Westerly winds fuel upwelling of global deep waters



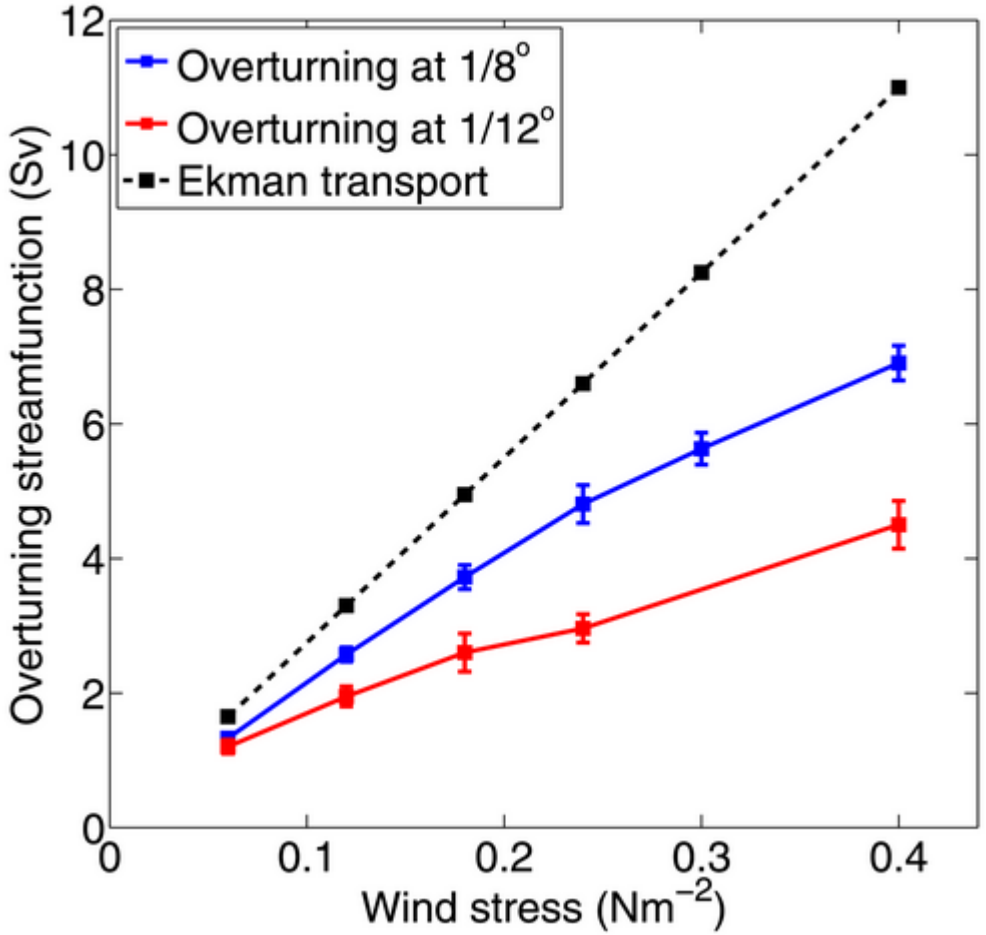
Source: Marshall & Speer (2012)

Southern Ocean as an important component of the global overturning circulation

Westerly winds fuel upwelling of global deep waters & important role of mesoscale eddies

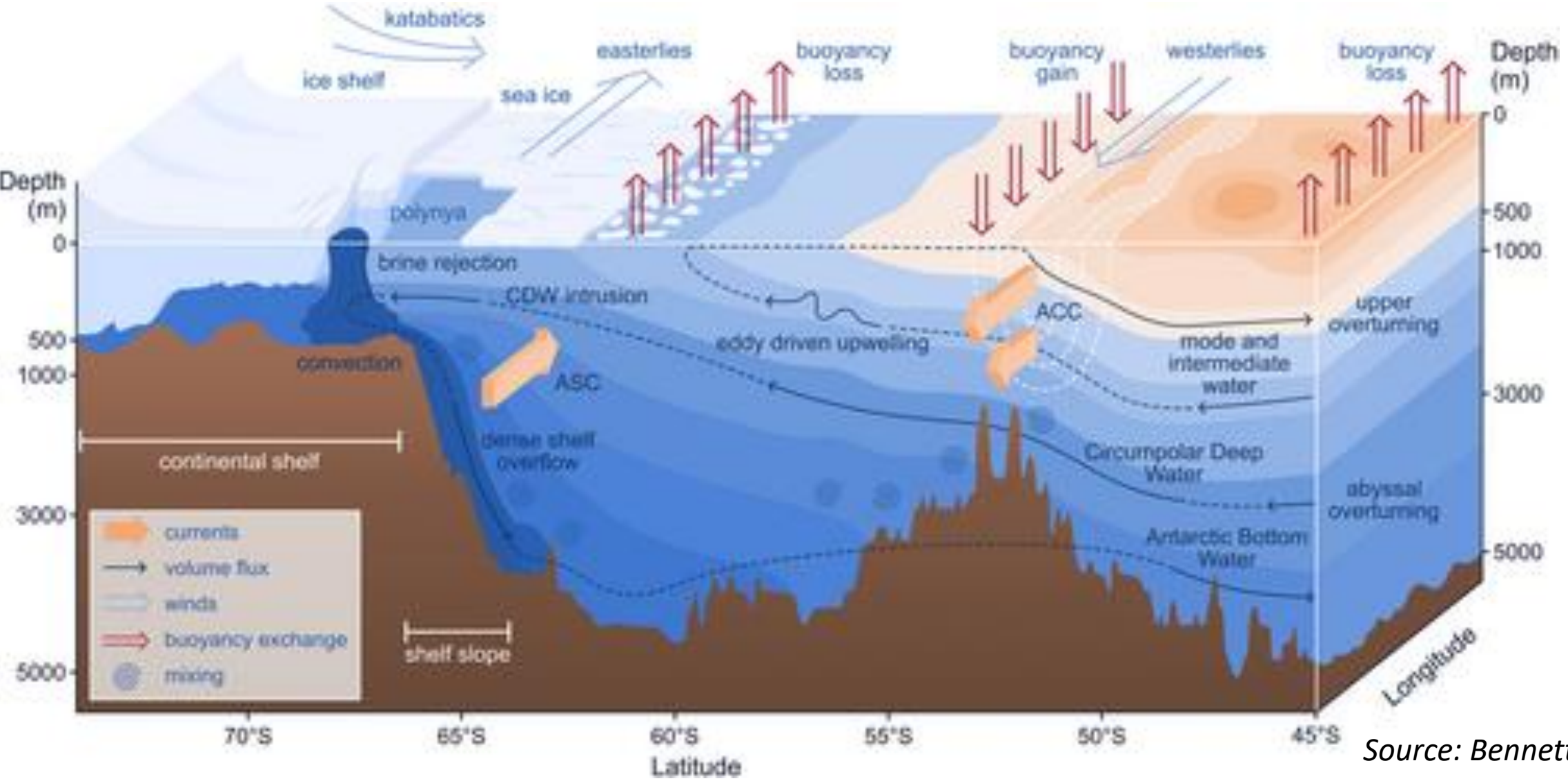


Source: Marshall & Speer (2012)



Source: Morrison & Hogg (2013)

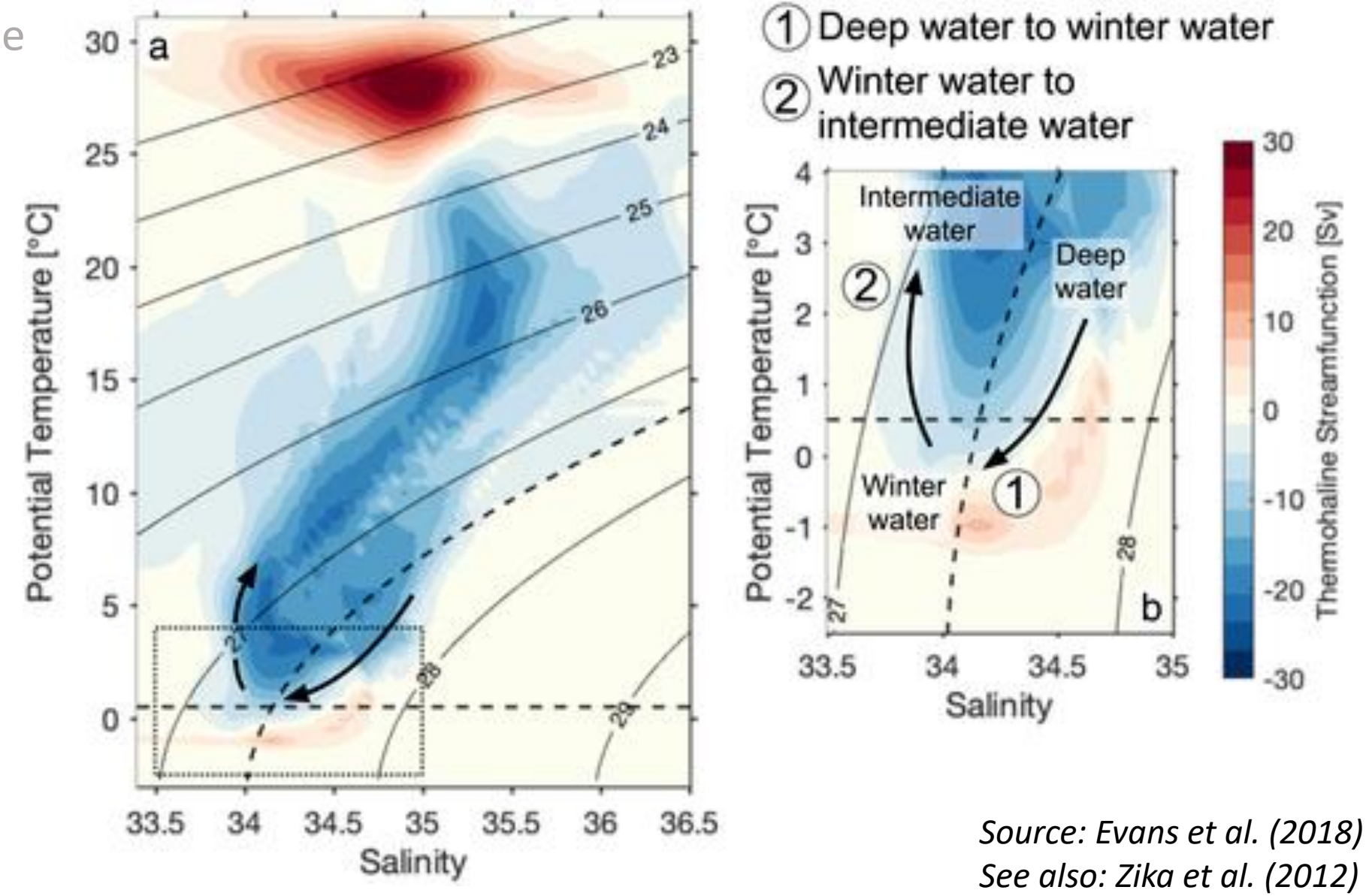
Important role of heat and freshwater fluxes



Source: Bennetts et al. (2024)

Important role of water mass transformation through heat and freshwater fluxes

Strong seasonal dependence

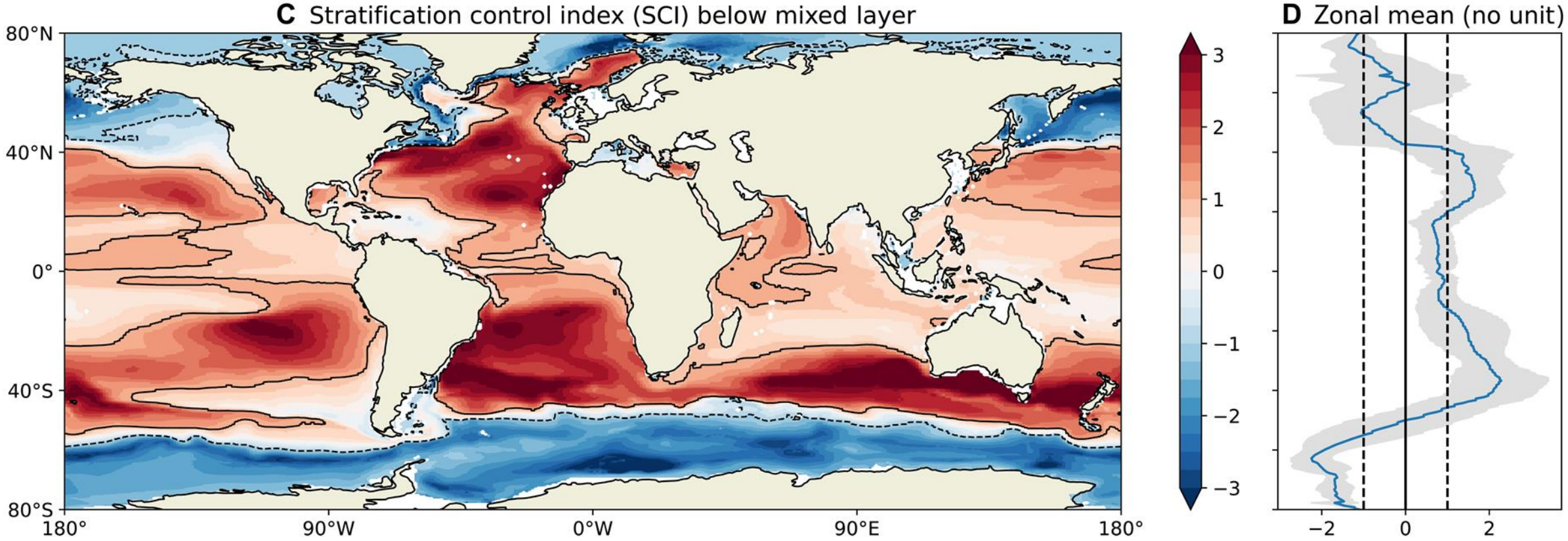


Source: Evans et al. (2018)

See also: Zika et al. (2012)

Critical role of salinity and freshwater in polar oceans

Density stratification dominated by freshwater fluxes



Source: Roquet et al. (2022)

See also Stewart & Haine (2016), Carmack (2007)

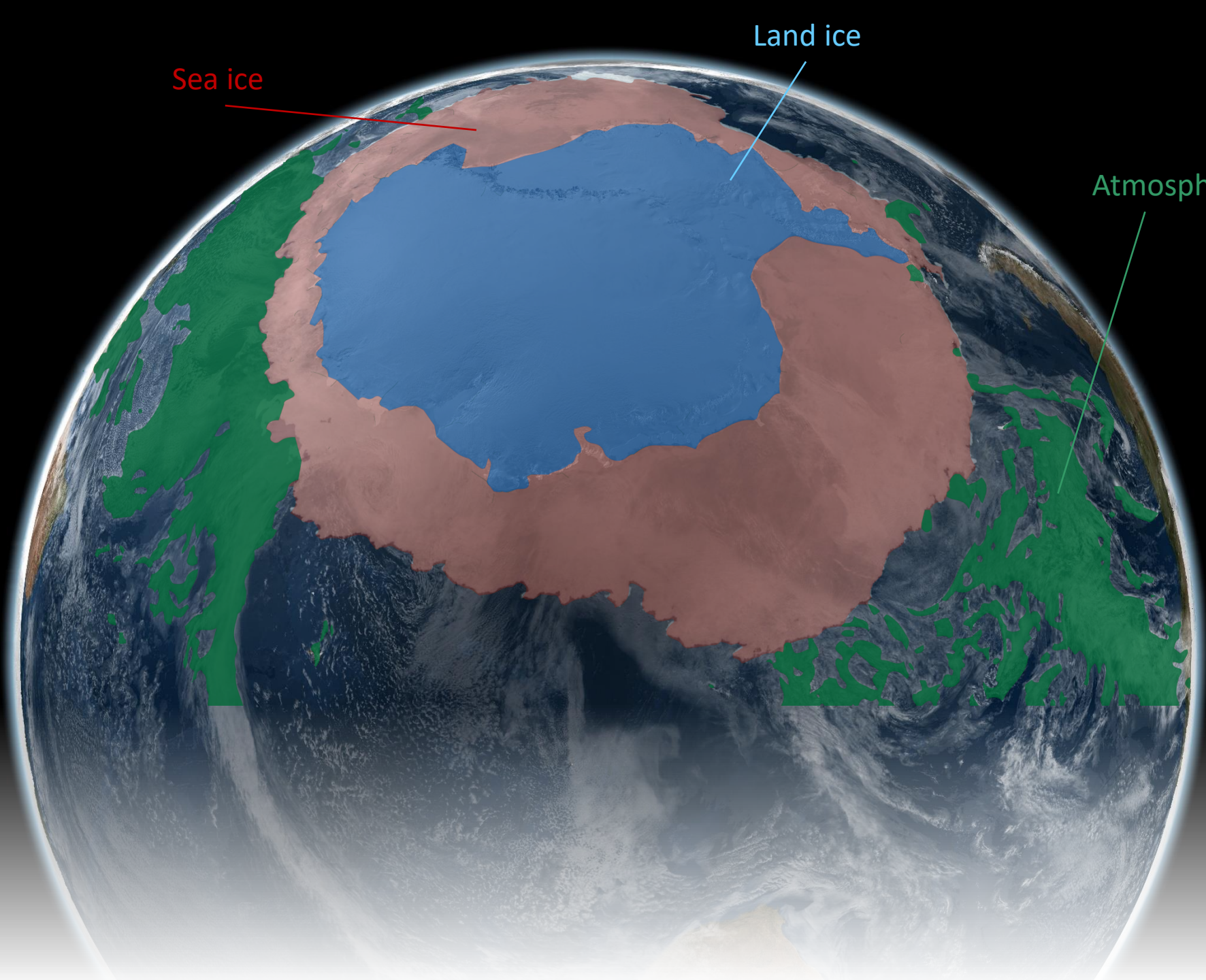
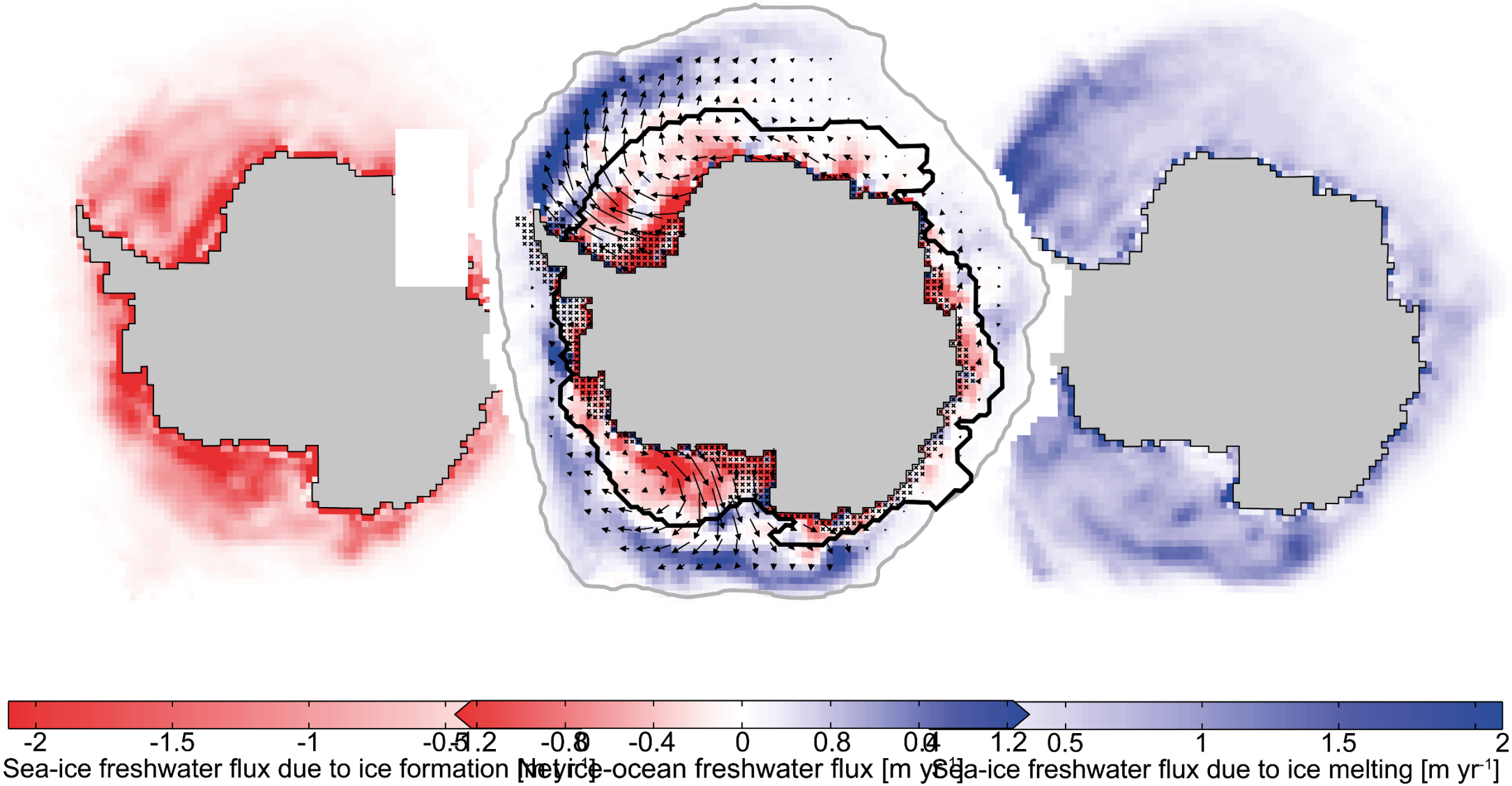


Image courtesy: NASA

Observation based sea-ice freshwater fluxes

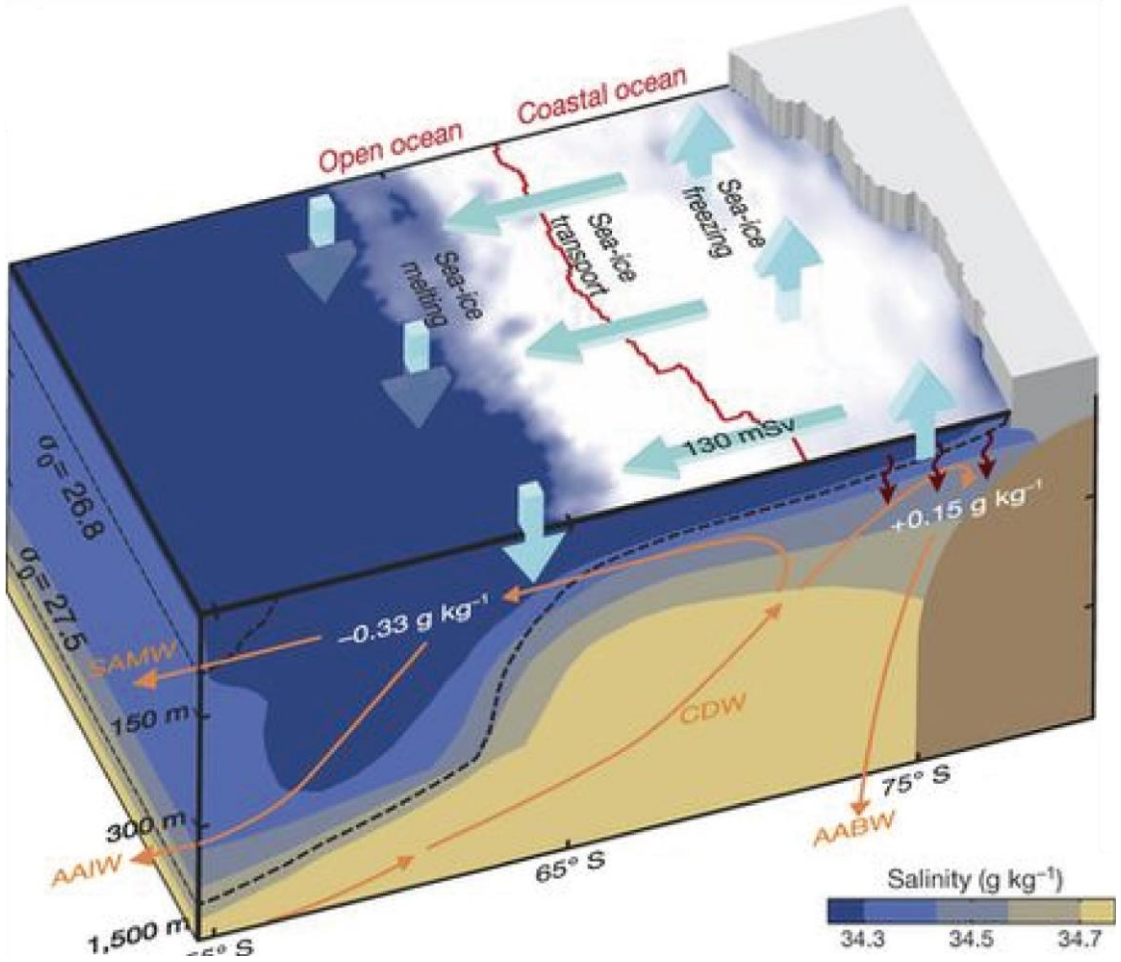
Sea-ice formation, melt & transport (1982-2008)



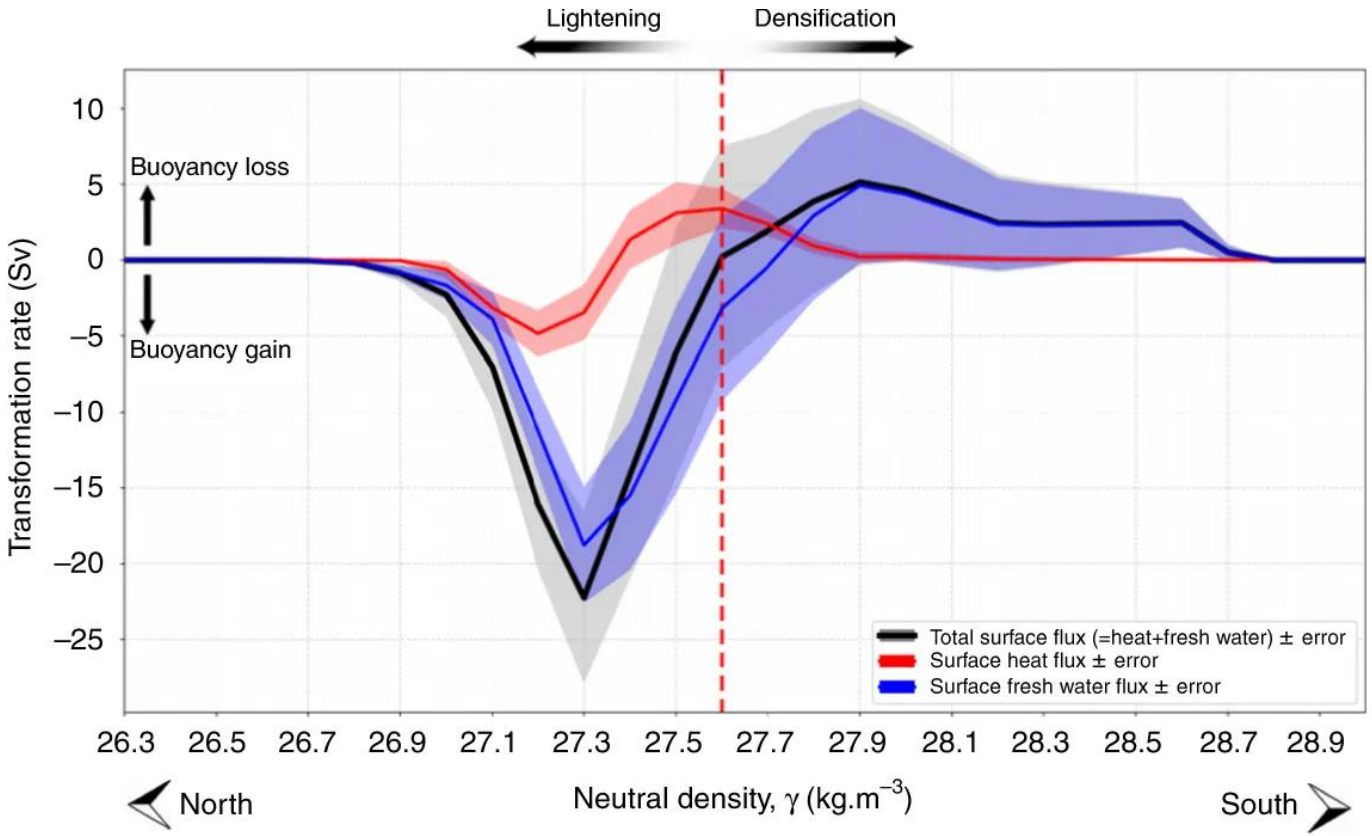
Haumann et al. (2016)

Sea-ice freshwater fluxes driving Southern Ocean salinity and water mass transformation

Antarctic sea ice plays a critical role in the global climate system through its influence on ocean circulation and stratification

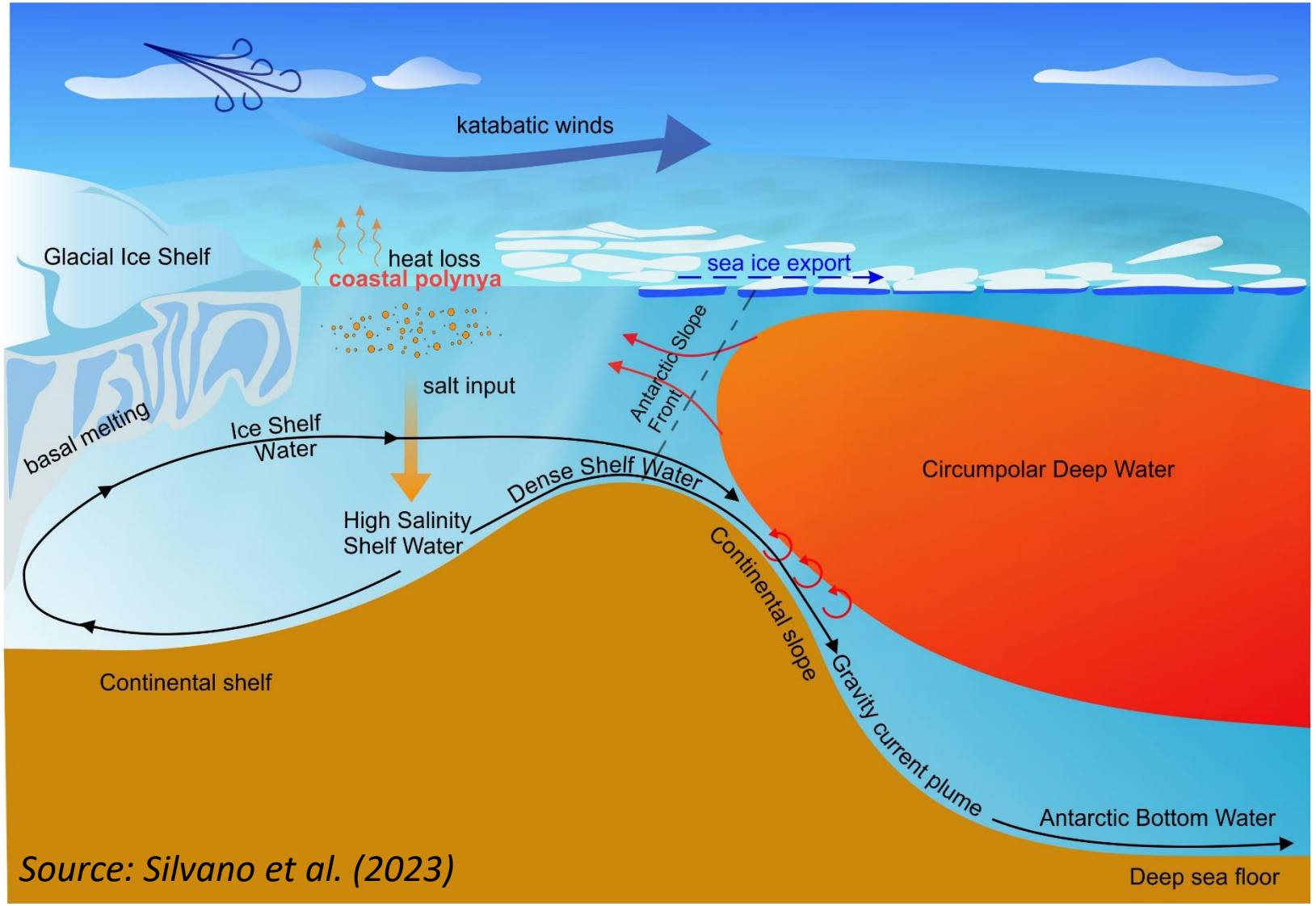


Source: Haumann et al. (2016)

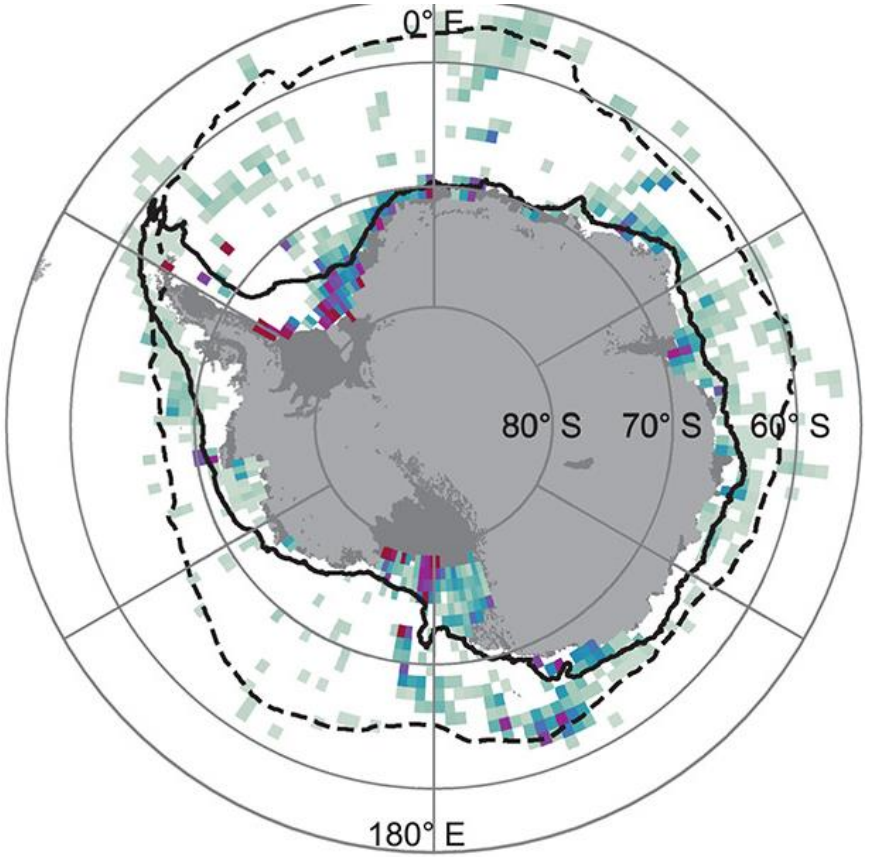


Source: Pellichero et al. (2018)
See also: Abernathey et al. (2016)

Role of sea ice formation and ice shelf interactions in dense shelf water production



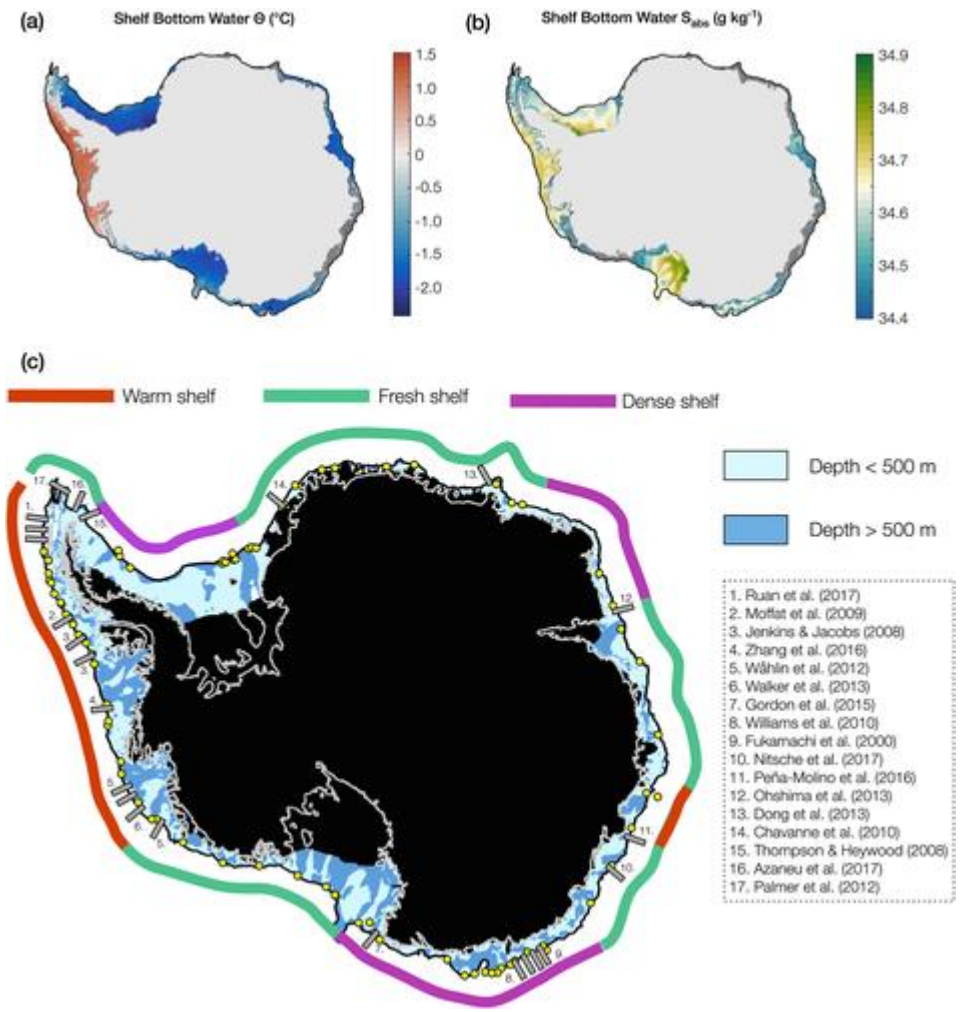
Source: Silvano et al. (2023)

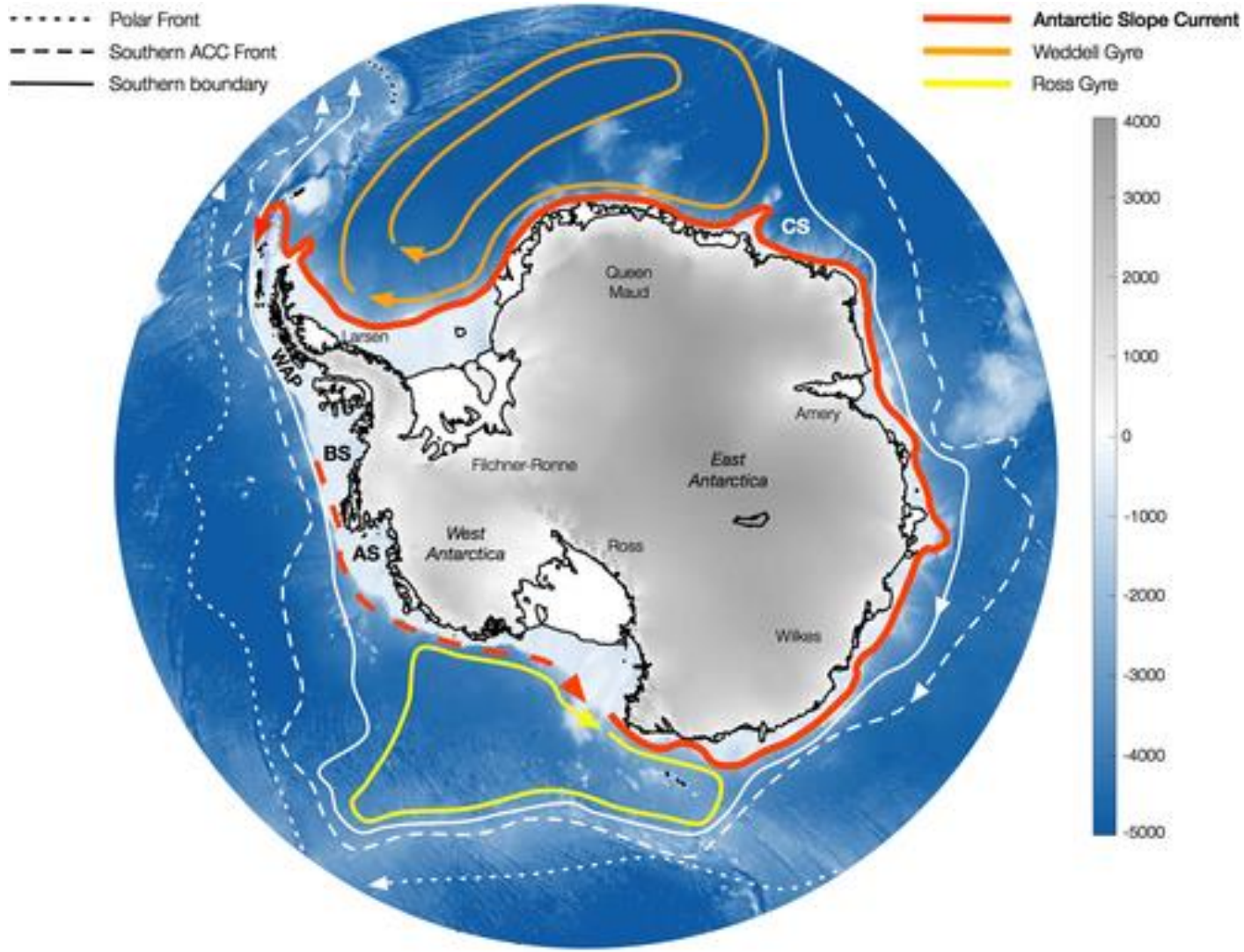


Source: Haumann et al. (2020)

Strong zonal variability

Water mass transformation & dense water formation are spatially and temporally dependent

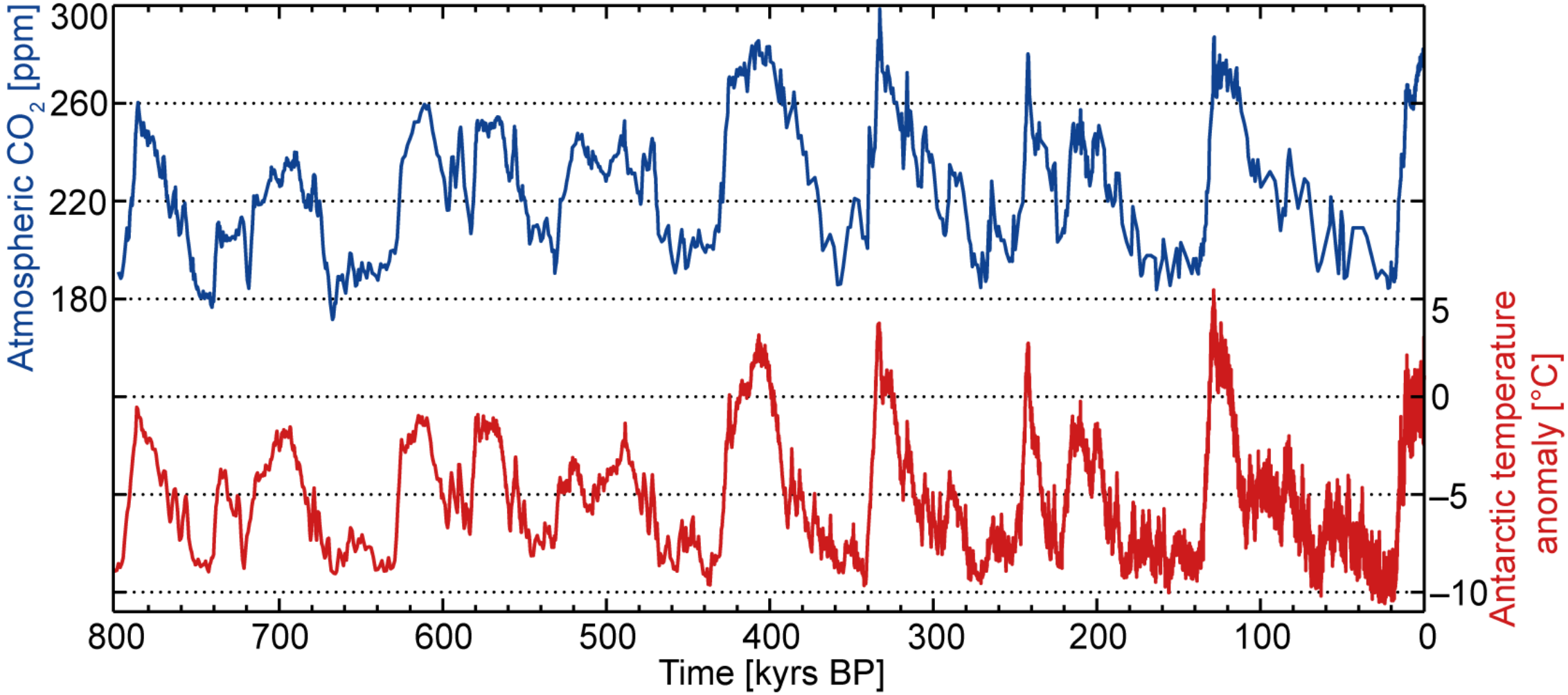




Source: Thompson et al. (2018)

Global relevance

Destruction and formation of water masses controls global carbon and energy balance on long time scales due to heat and CO_2 exchange between the atmosphere and the deep ocean



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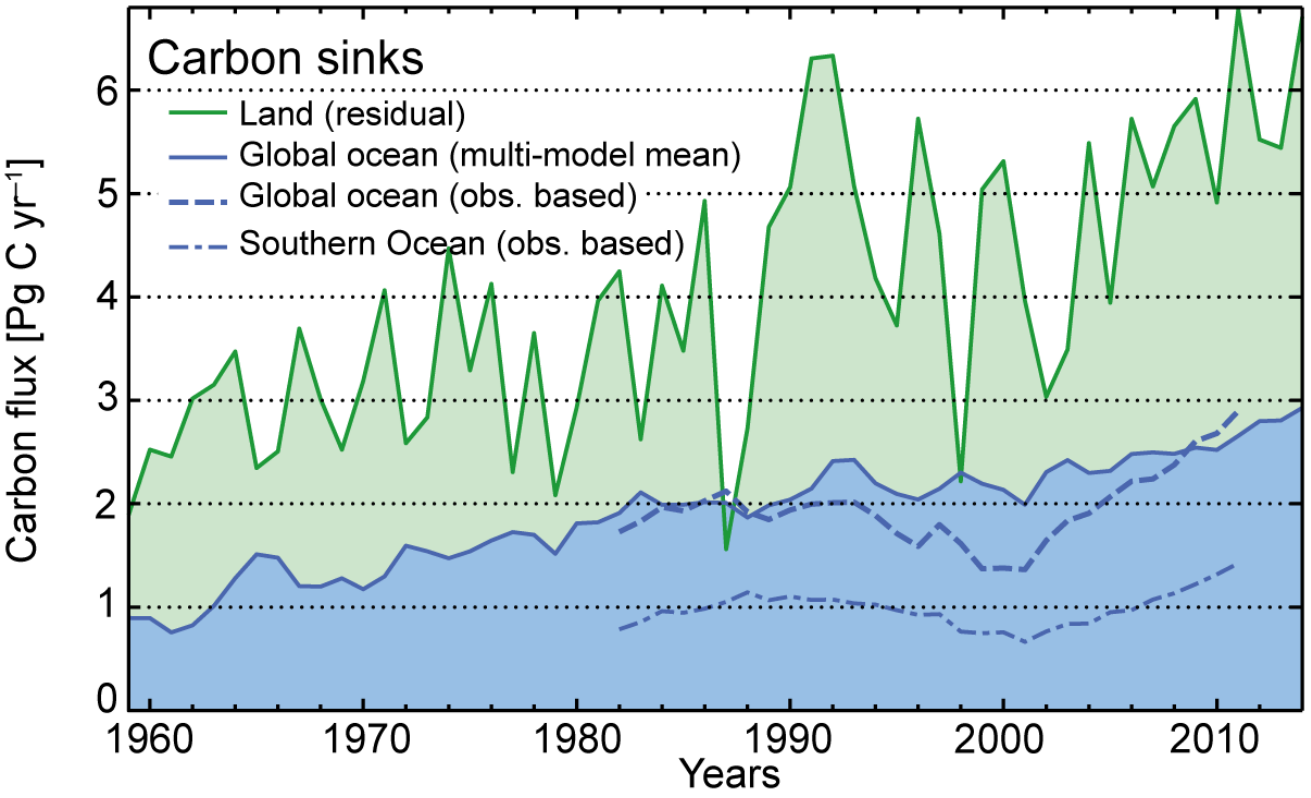

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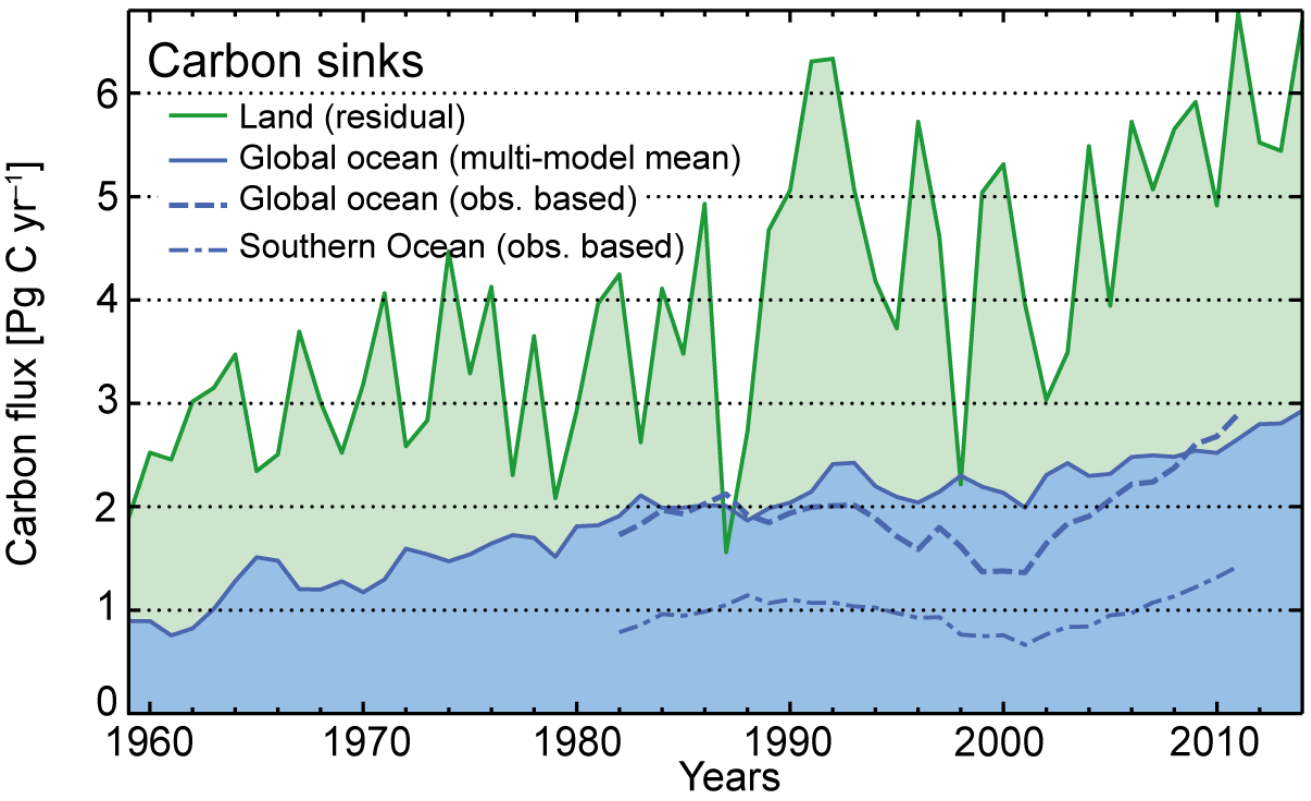
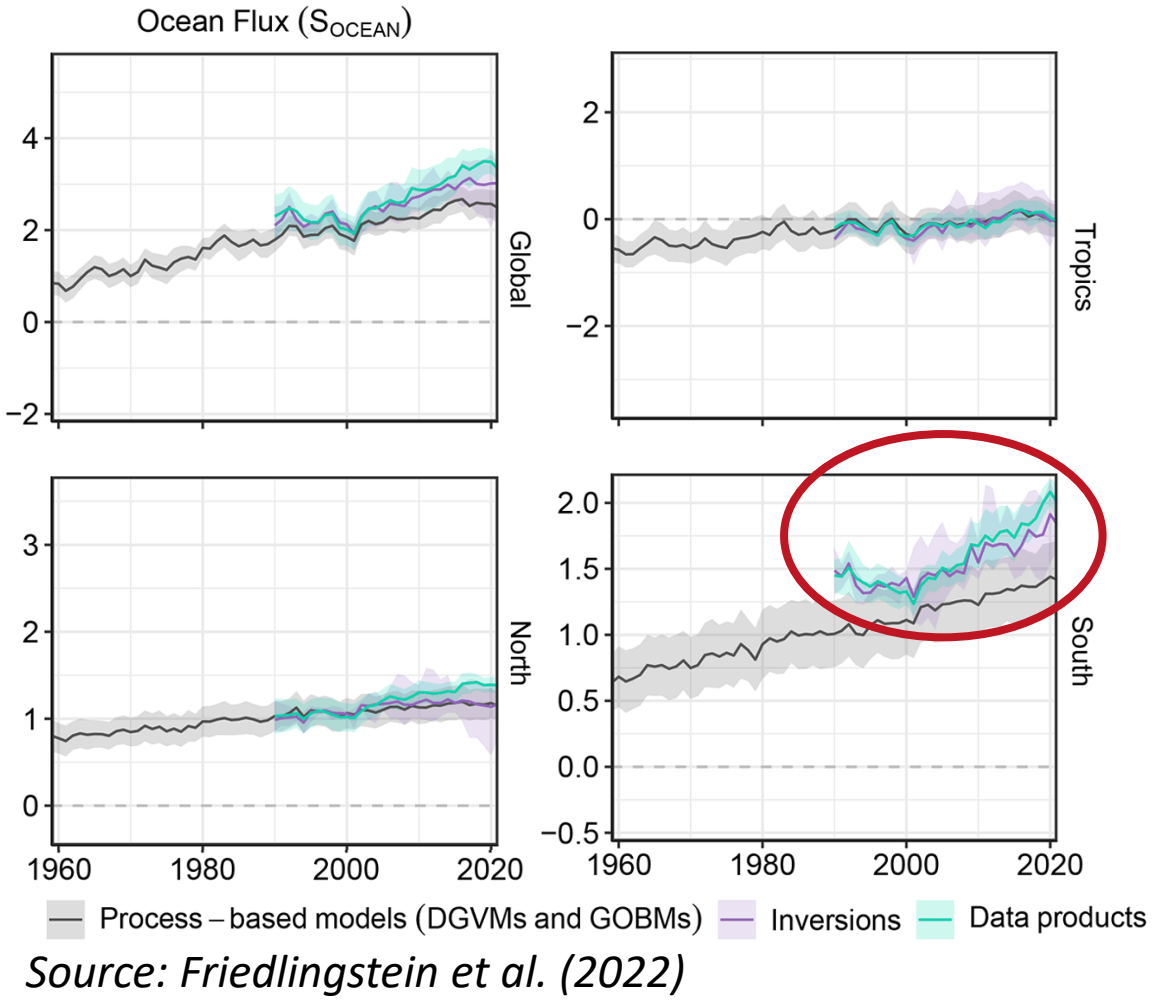




Source: Friedlingstein et al. (2022)

→ Remains one of the largest uncertainties in the global carbon budget

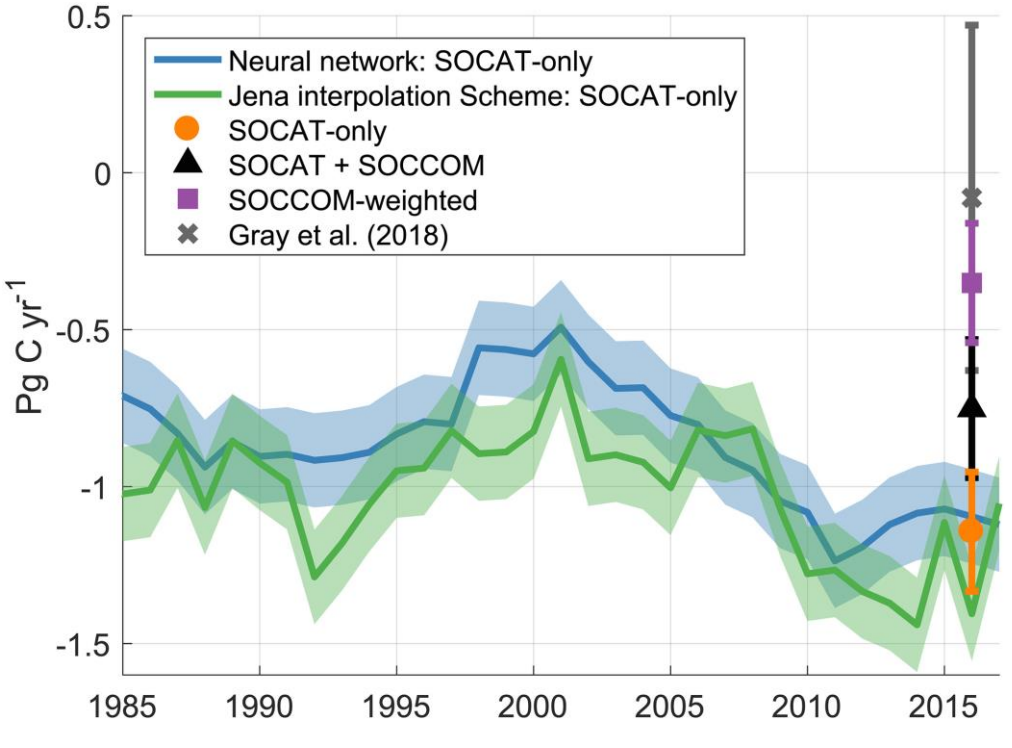
Take-home messages

- While winds fuel the overturning circulation in the Southern Ocean, work over the recent decade(s) highlights the importance of heat and freshwater fluxes in driving water mass transformation
- The destruction of upwelling deep water and formation of new water masses is a key process for climate as it can alter the global energy and carbon balance, in particular in a changing climate
- Key knowledge gaps include
    - the water mass transformation in the sea ice covered ocean, in particular in winter
    - and the spatial and temporal variability of the destruction of upwelling deep water and the formation of new bottom, dense, intermediate and mode waters

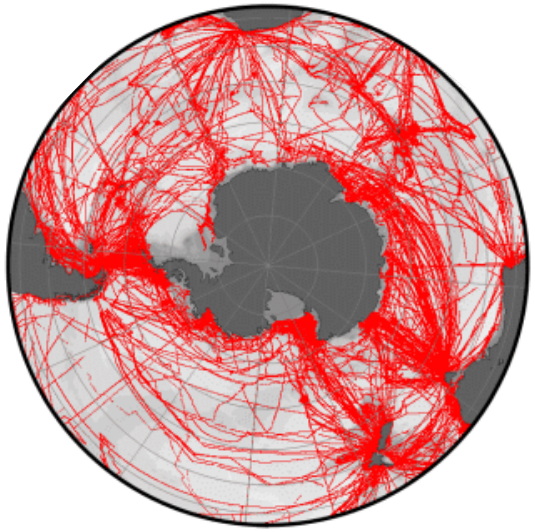
High-Priority Research

Budgets of heat and carbon and their changes (also in response to the human impact)?

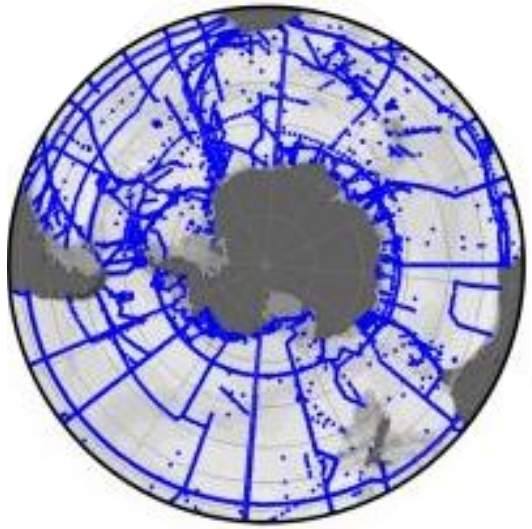
- It is critical to sustain both BGC-Argo array and shipboard measurements in order to understand the Southern Ocean carbon budget in the long-term
- Repeat hydrographic sections need to be sustained and reassessed (incl. the freshwater budget)
- International coordination needs to be strengthened to get a better circumpolar understanding, especially in winter



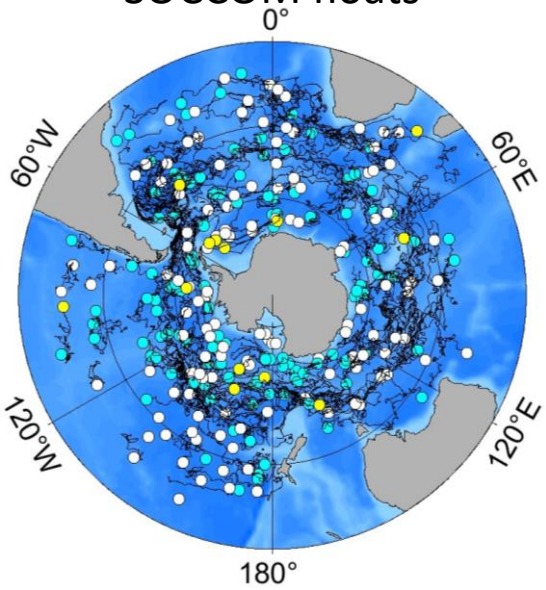
SOCAT surface pCO_2



GLODAP sections



SOCCOM floats



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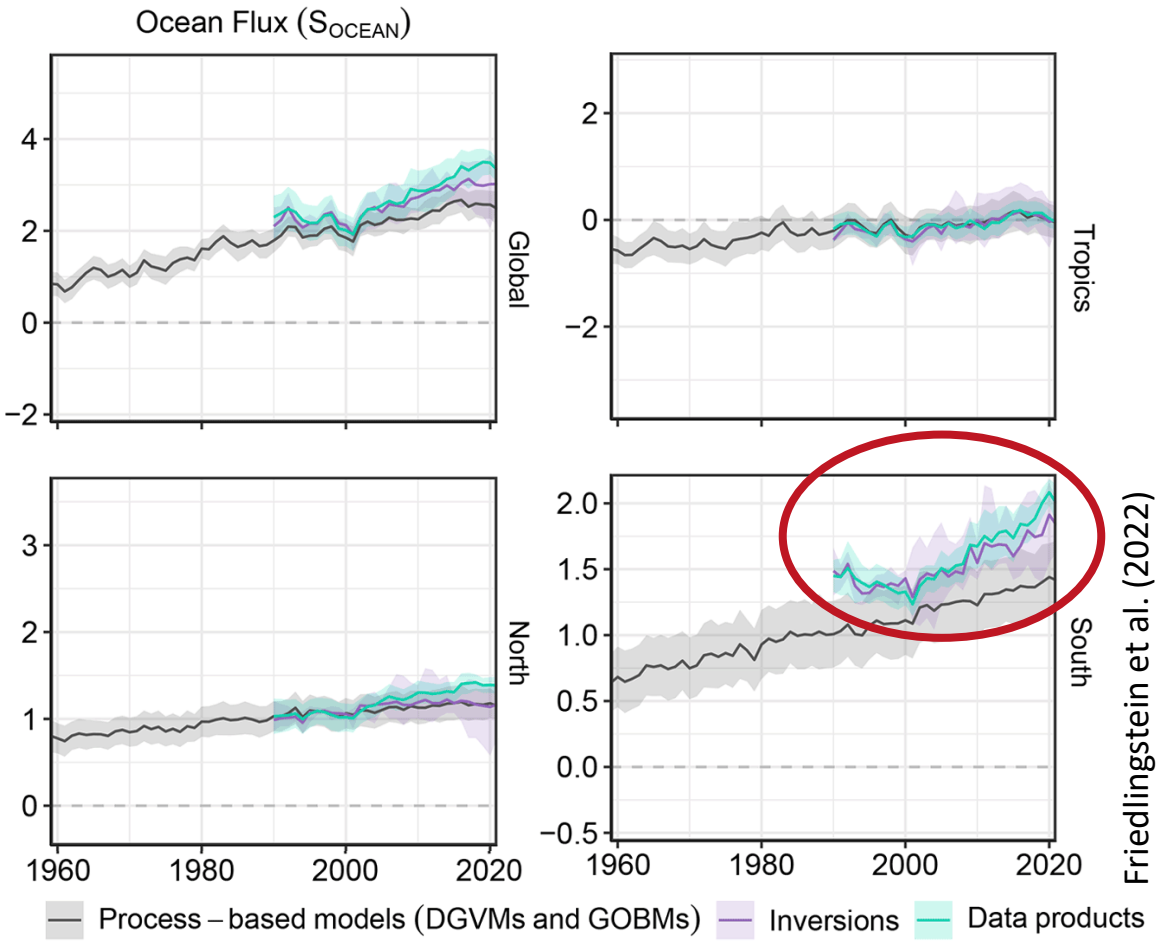
Closing the gap between observations and models

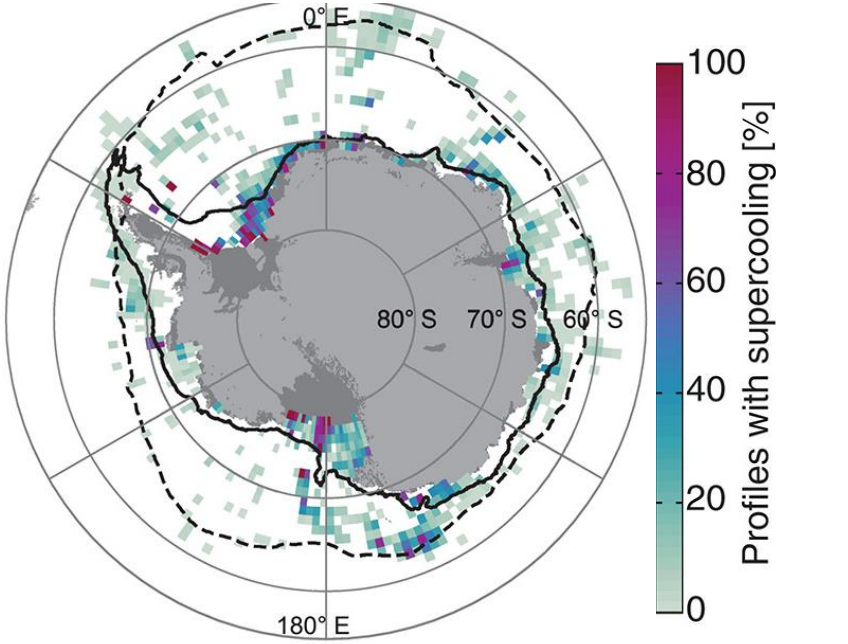
- Strengthen integrated modeling, remote sensing, and field observation efforts (data assimilation, machine learning)
- Prioritize data that improves model parameterization, in particular mixing and biogeochemical processes (production, sinking, remineralization and dissolution)
- Strengthen observational efforts in **“blind-spots”**



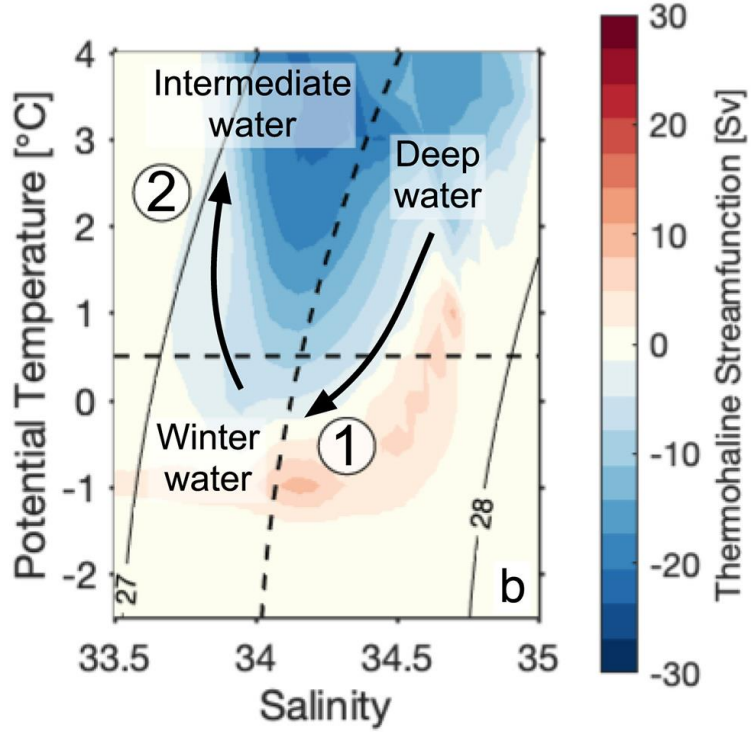
Blind-Spots

What happens under and around the sea ice in winter?

- Further advance efforts to collect data from the seasonally ice-covered ocean in winter
- Focus on upper ocean processes to understand how deep waters are ventilated and affect surface fluxes
- Ship and autonomous capabilities directly under sea ice need to be strengthened
- Develop coupled platforms to measure atmosphere, ice, and ocean properties



Haumann et al. (2020)



Evans et al. (2018)

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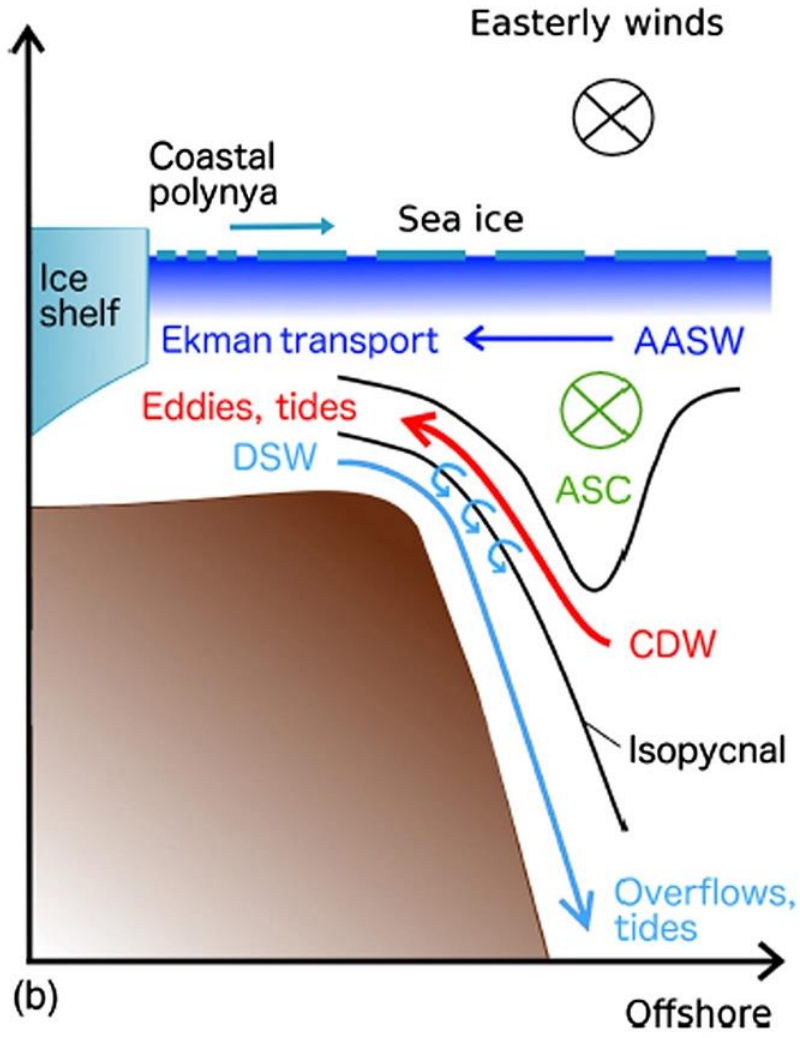
How is heat reaching the continental margin and how is Antarctic meltwater escaping the coast?

- Better understand the dynamics of coastal currents and the exchange between the continental shelf and the open ocean through targeted campaigns
- We need more high-quality salinity data and ocean freshwater tracer observations (seawater isotopes, noble gases, etc.)



Thompson et al. (2018)