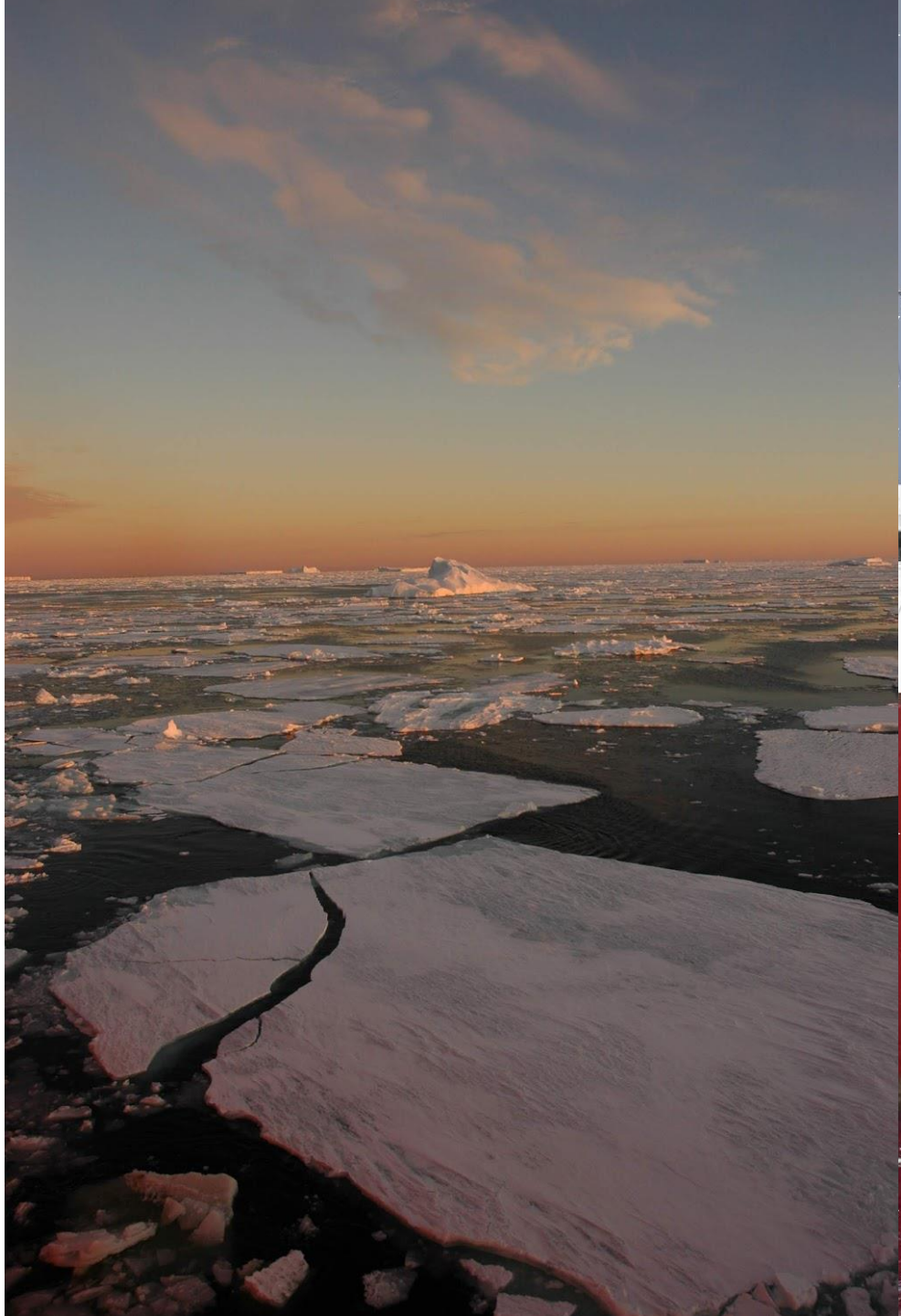
CIRCUMPOLAR OBSERVATIONS AND PROGRAMMES

Andrew Meijers – British Antarctic Survey

SOOS SYMPOSIUM -HOBART 14/08/2023

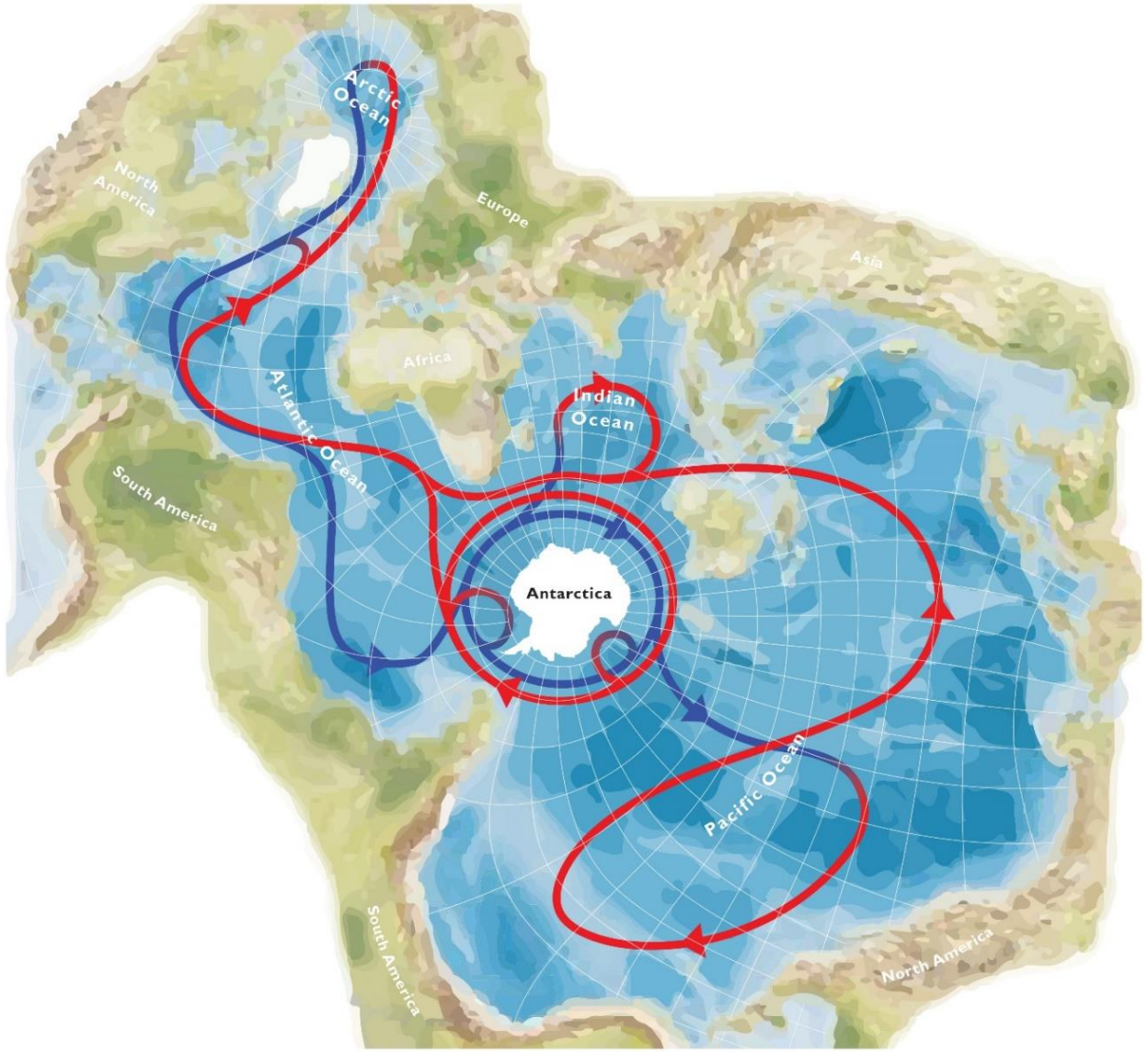
Talk outline

- Thanks to Steve and Eileen.
- Why study the Southern Ocean at all? Our motivations.
- What is happening there now? How is the ocean changing?
- The case for circumpolar *in situ* observations.
- Circumpolar *in situ* programmes:
  - Observing networks.
  - Programmes focused on key science questions – OCEAN:ICE case study.
- SOOS – underpinning circumpolar coordination.
- What next and the case for urgency.



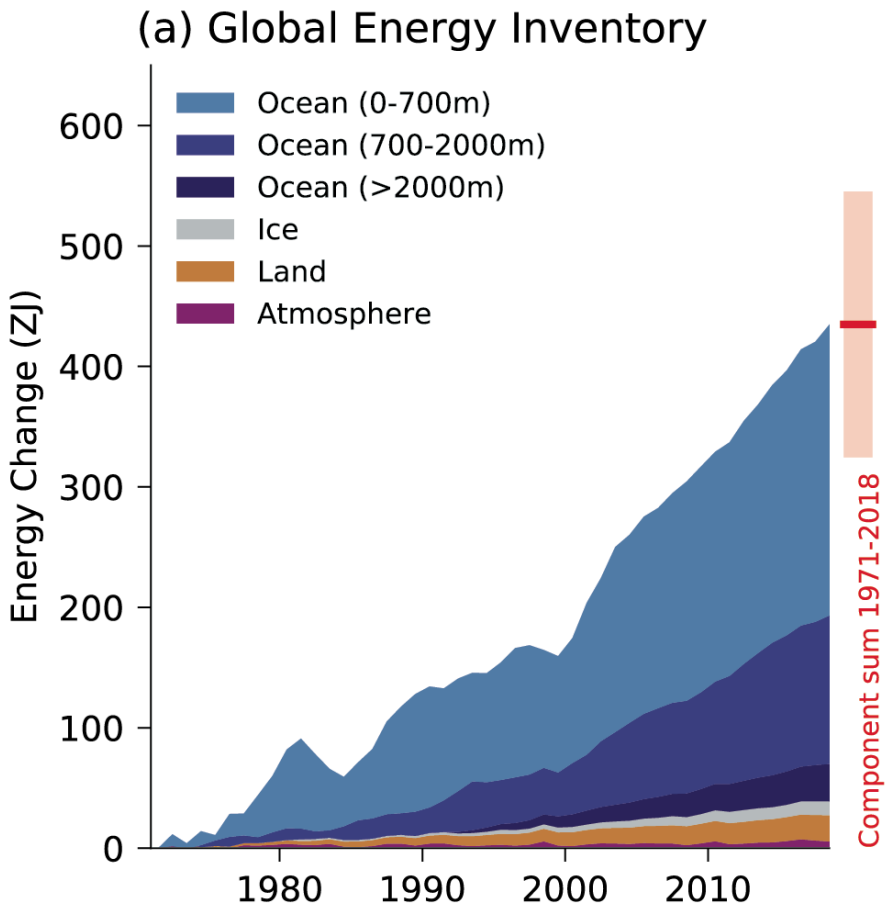
WHY STUDY THE SOUTHERN OCEAN AT ALL?

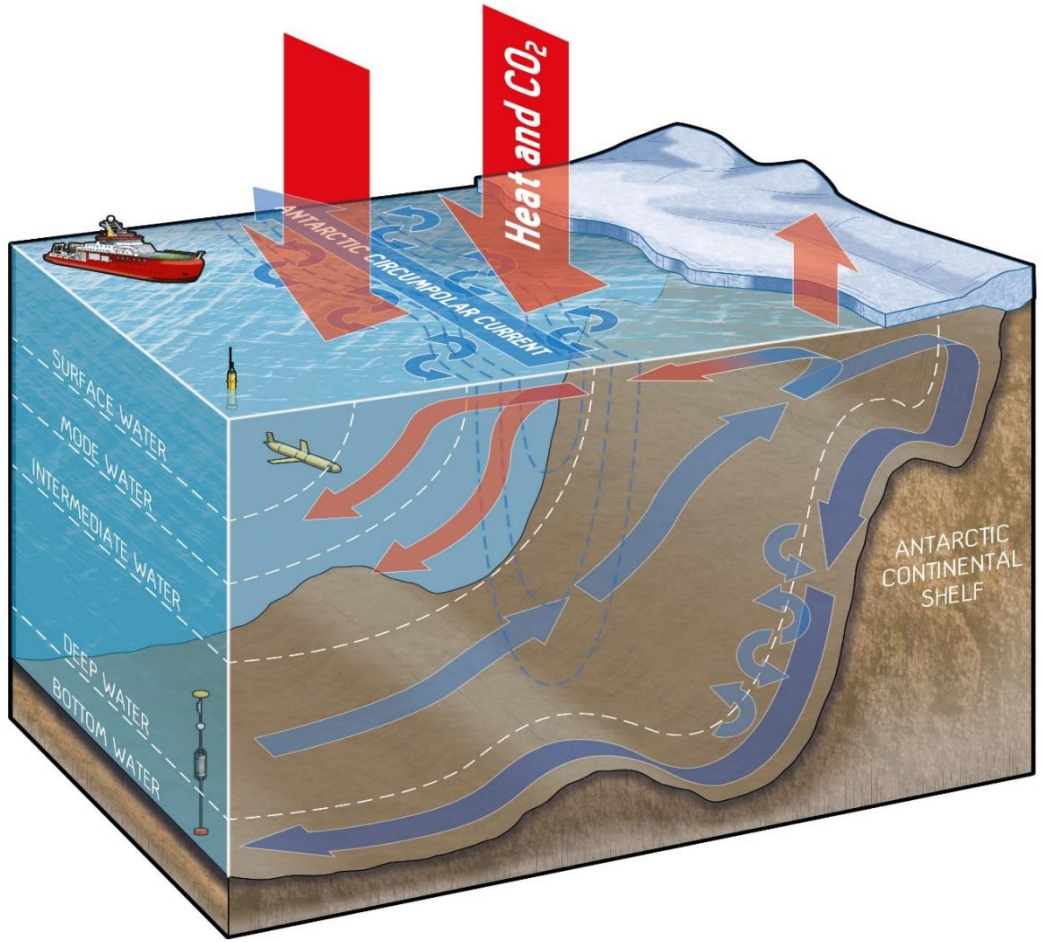
The ocean at the center of the world



British Antarctic Survey
NATURAL ENVIRONMENT RESEAR

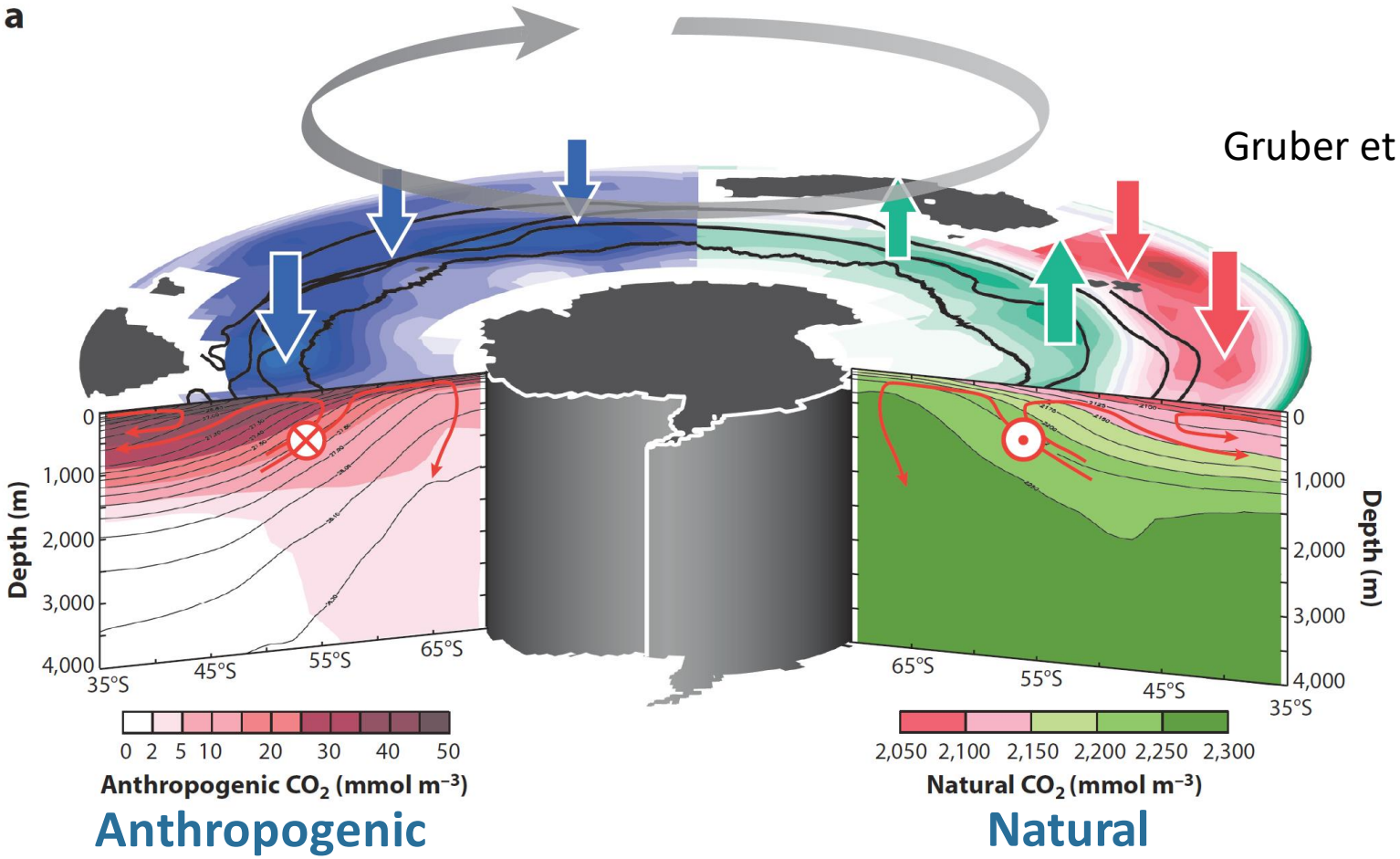
Global warming is ocean warming





- >90% of all anthropogenic heat goes into the ocean, mostly via the Southern Ocean.
- Due to a combination of its unique circulation and uneven hemispheric aerosol forcing.

A major contributor to anthropogenic and natural carbon exchange

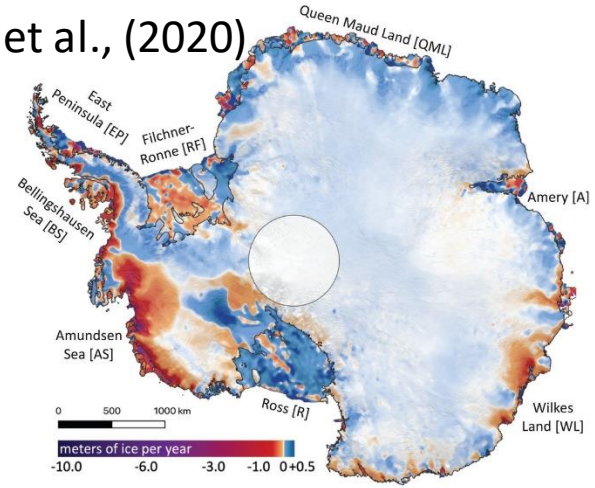


Gruber et al., 2019

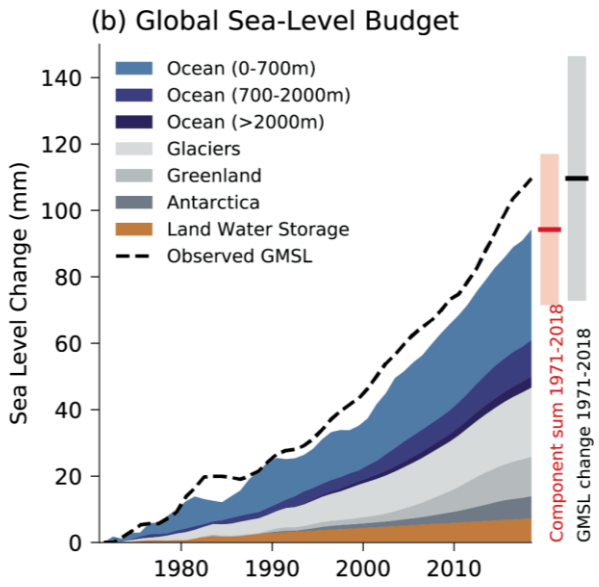
- Overturning circulation brings old natural CO2 to the surface and subducts new anthro. CO2.
- 40% of ocean uptake of antho. CO2 via the Southern Ocean. Also sets acidification patterns.
- Climate service value ~ 225,000,000,000 €/y, based on carbon price 90€/tCO2 (N.Gruber).

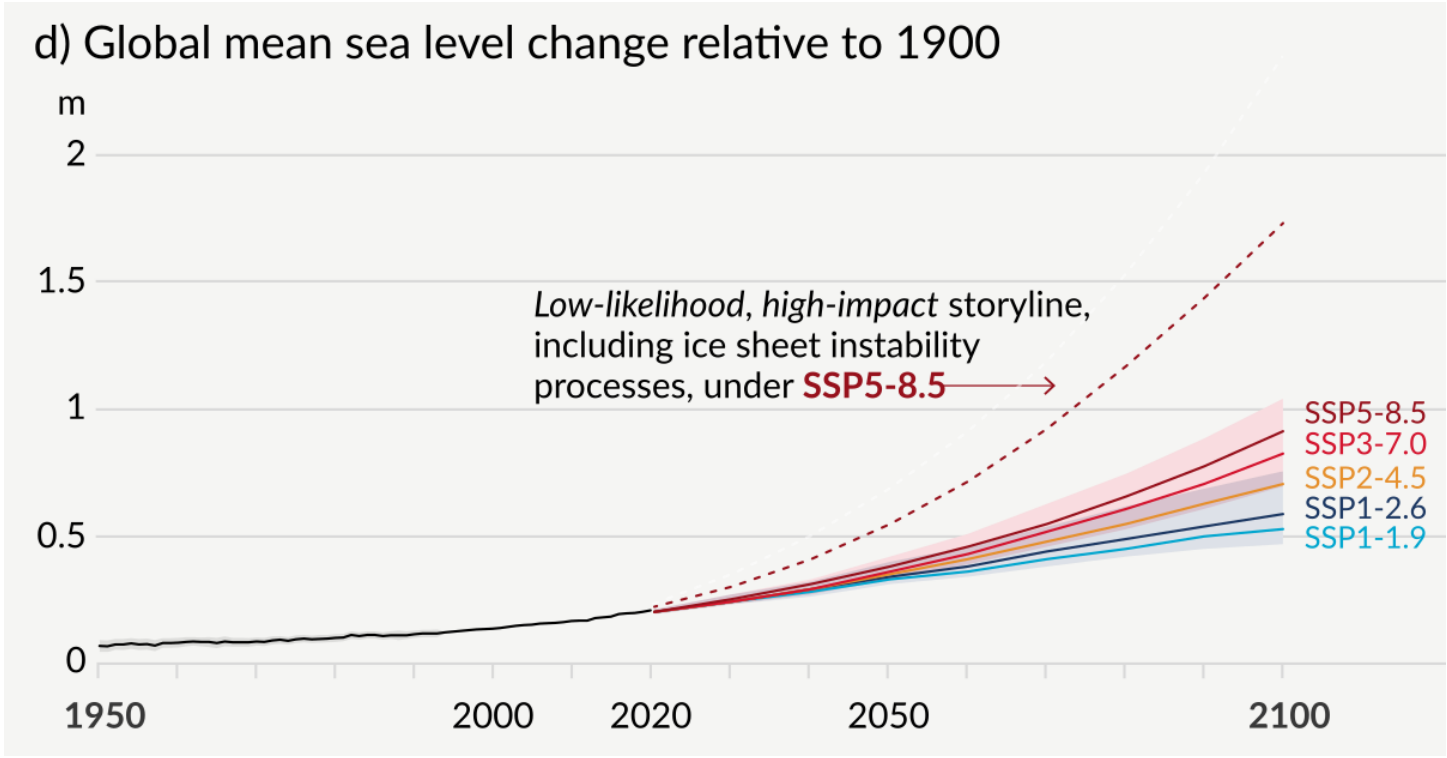
The Southern Ocean is the major driver of ice sheet melt

Smith et al., (2020)



IceSat(-2) Mass loss (2003-19)

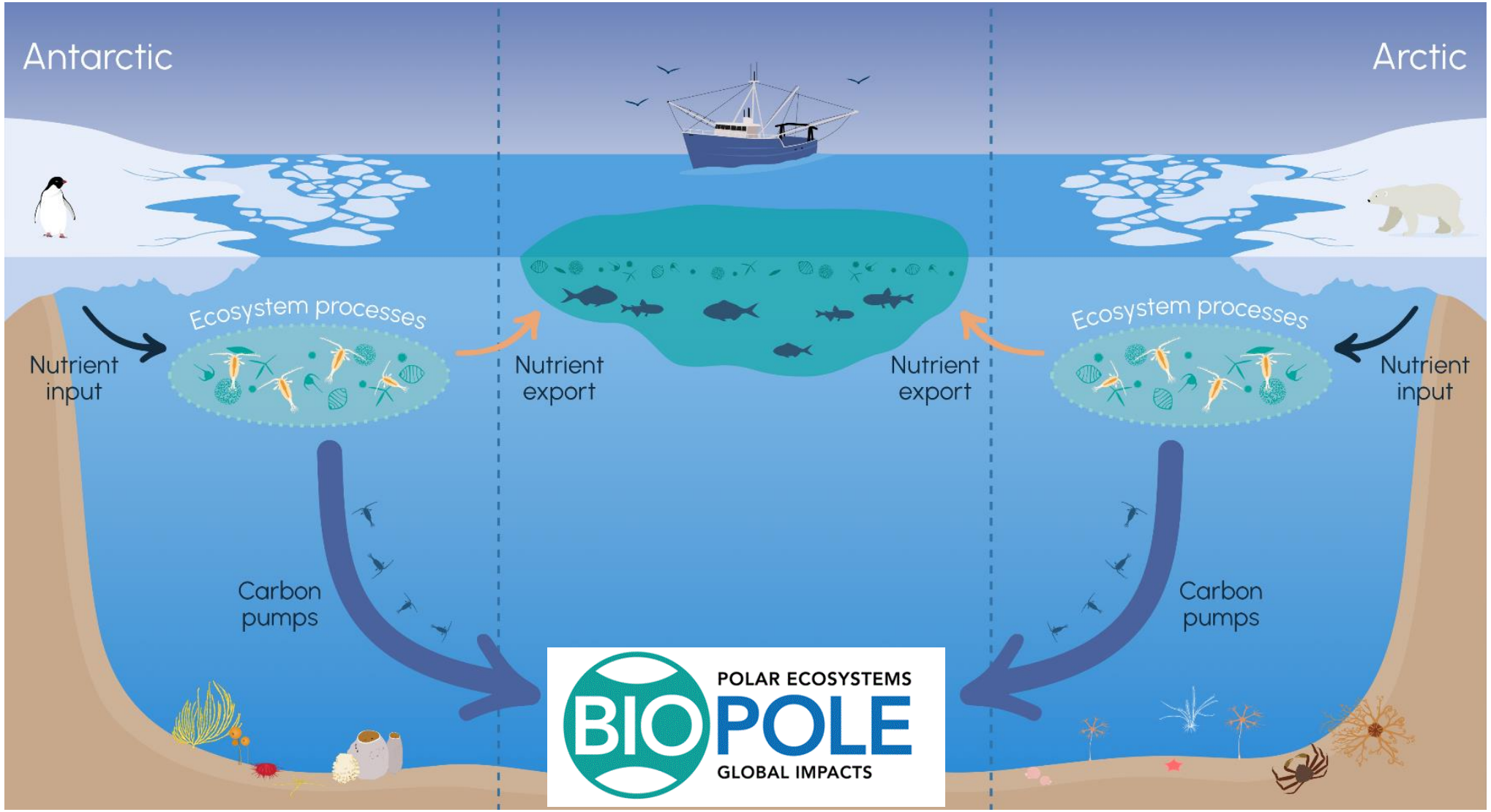




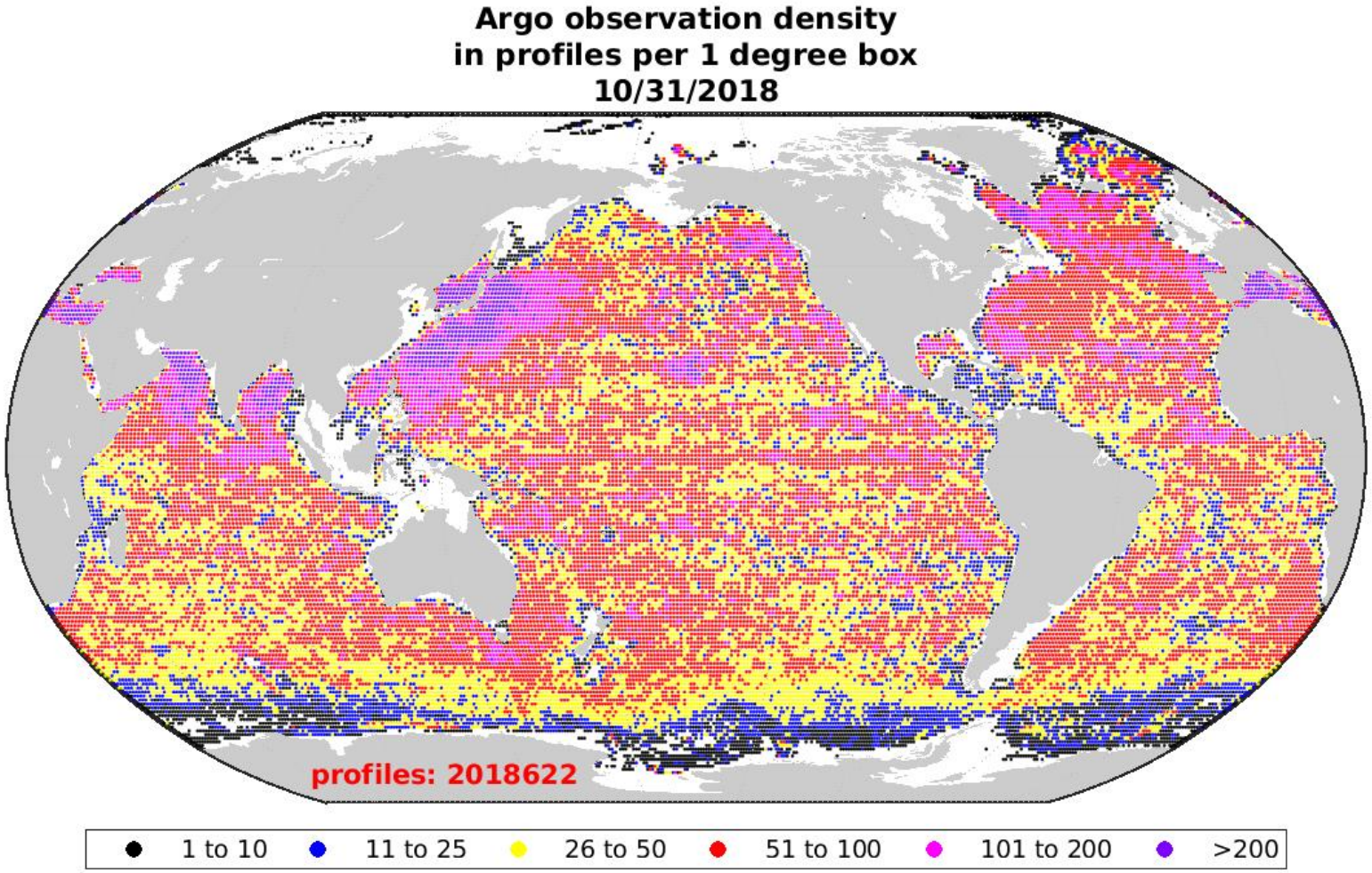
IPCC AR6 (2021), Summary for policy makers high impact storyline from an expert survey and structured expert judgement (i.e. not modelled)

Antarctic response is the single largest future sea level uncertainty

Supports a unique and globally consequential ecosystem



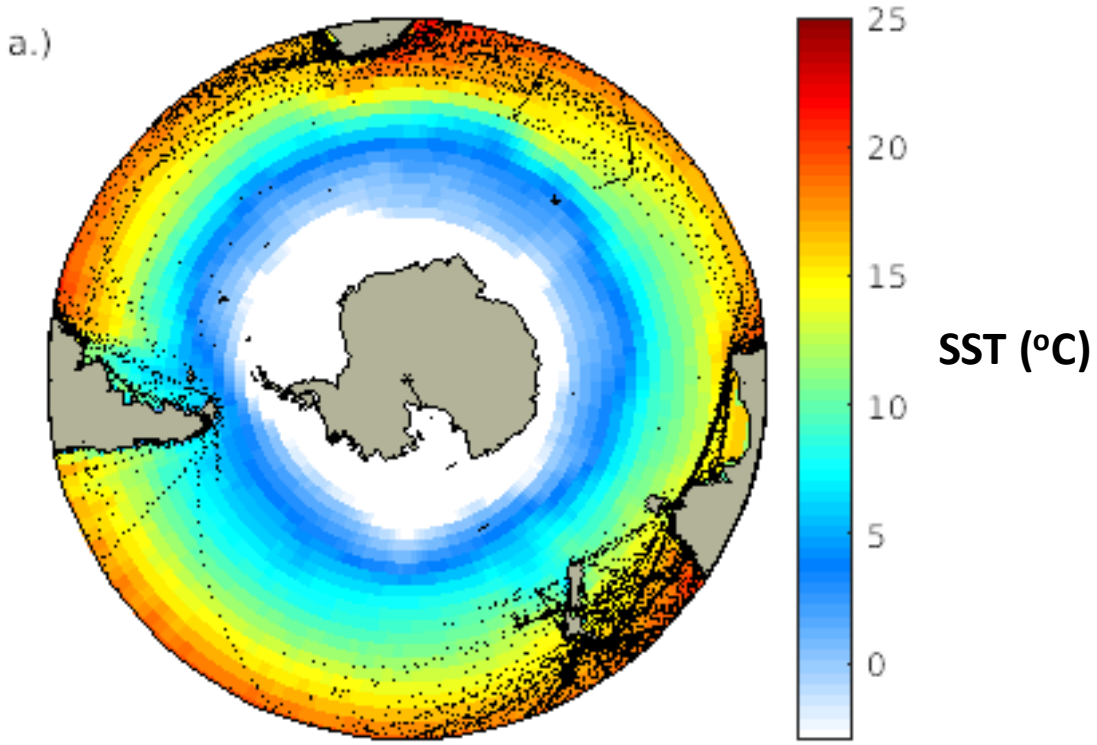
The Southern Ocean is (still) a huge hole in our observing network



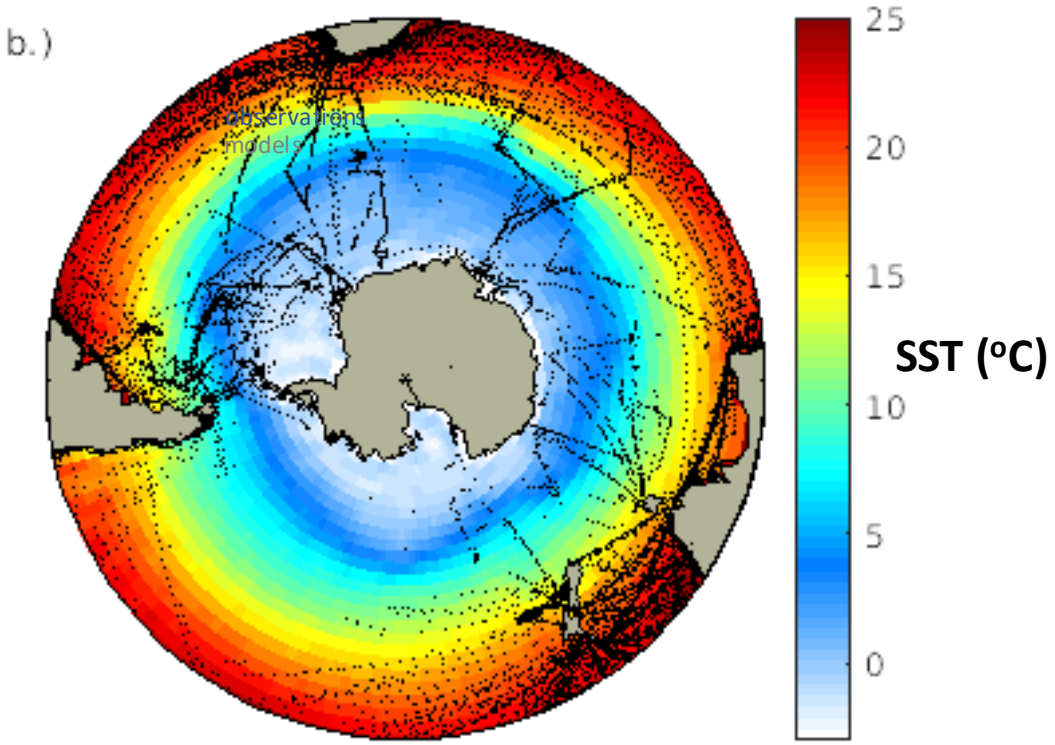
Observations of top 2km of ocean by Argo floats since 2004 (>2 million)

Heat fluxes, absolutely critical to circulation dynamics – unknown in winter

All July Latent Heat Flux Obs. 2000-2004

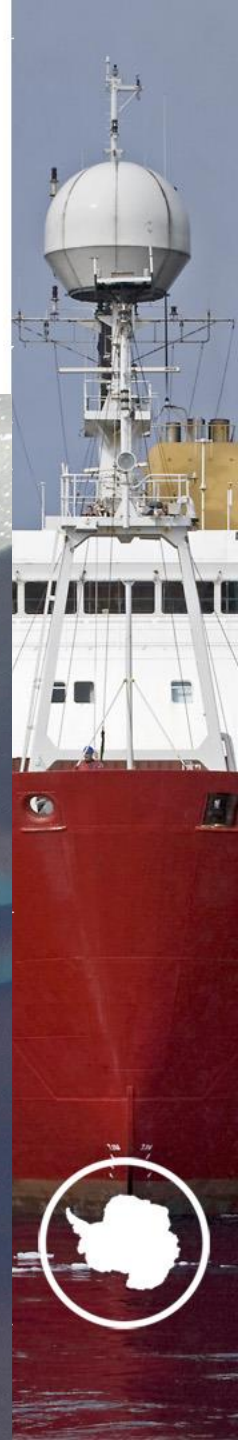


All January Latent Heat Flux Obs. 2000-2004

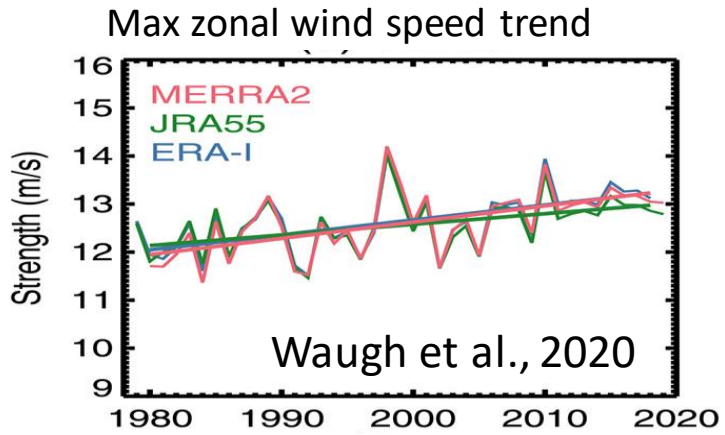


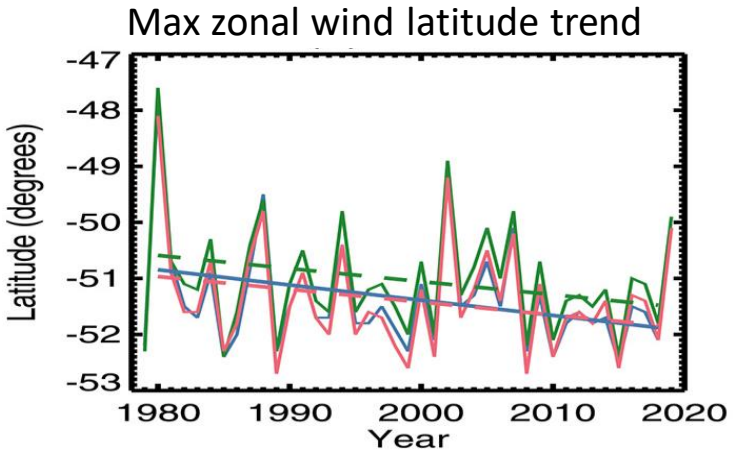
Josey et al., 2023

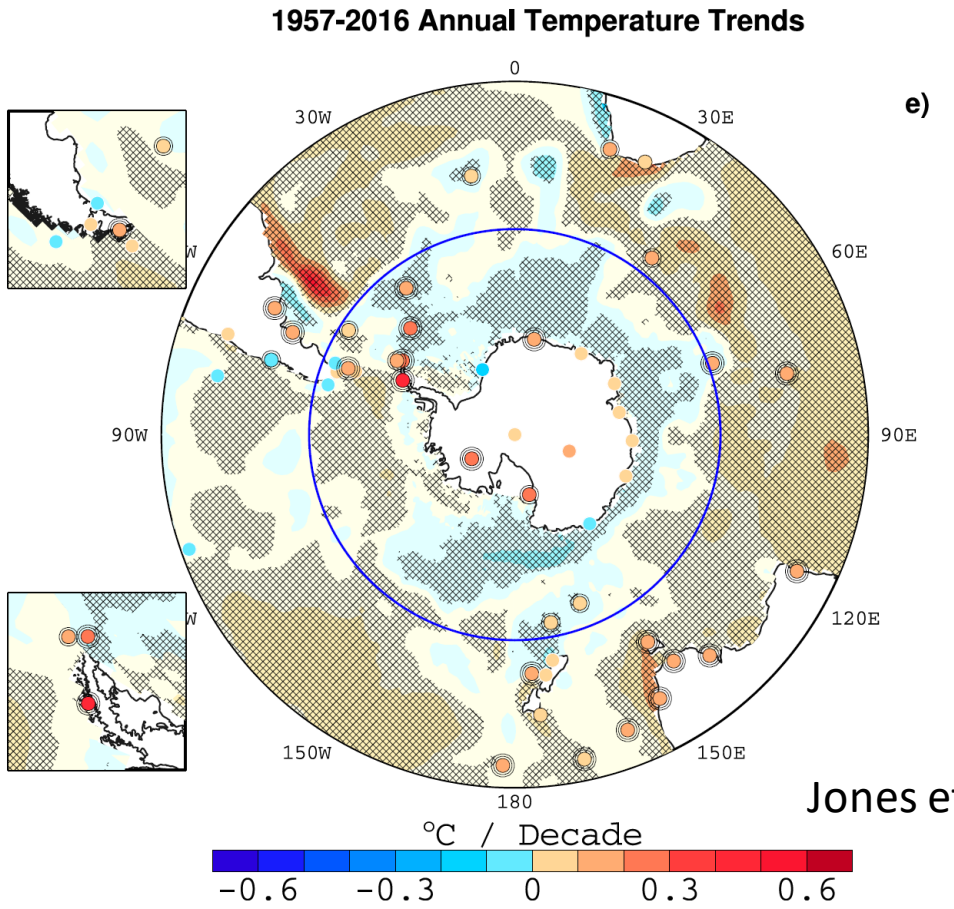
How are things changing in the Southern Ocean?



Changes to winds and surface temperatures



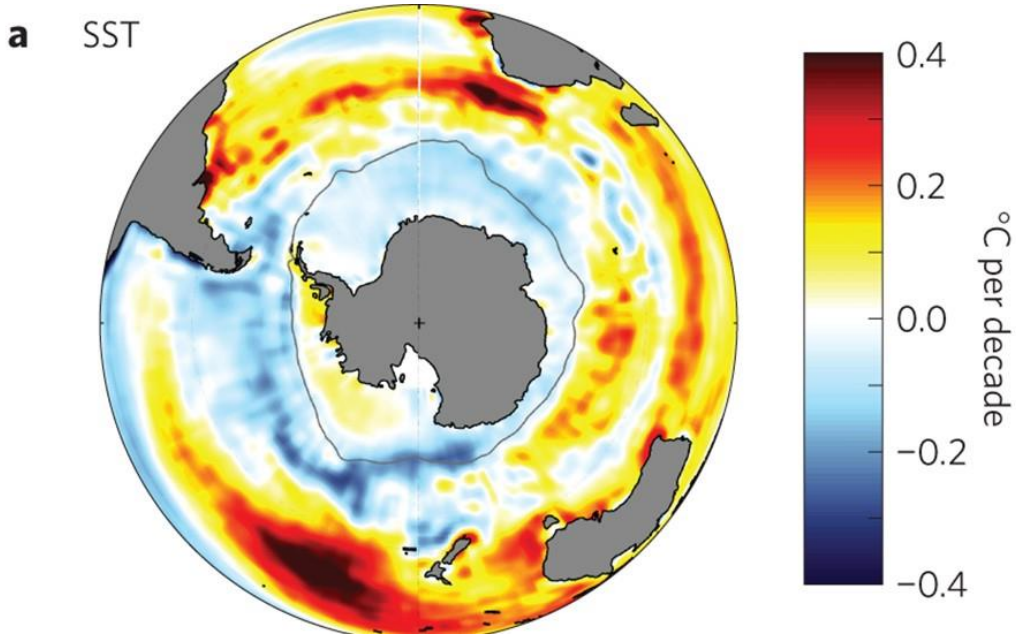




Jones et al., 2019

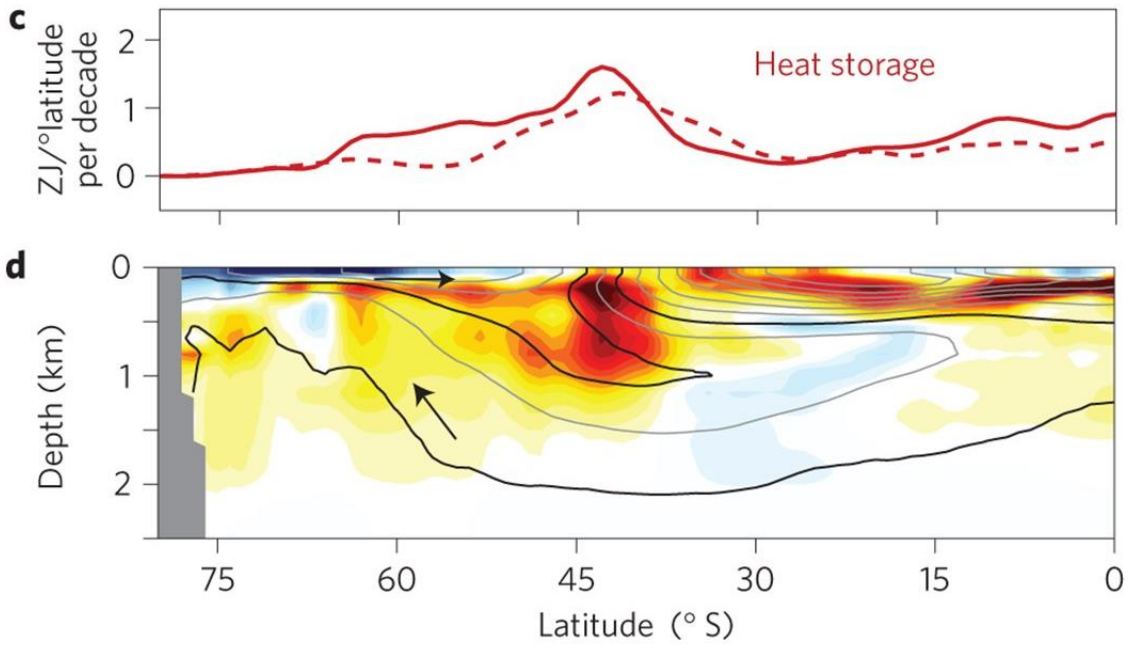
- Winds generally strengthening, with poleward shift of westerly jets.
- Driven by ozone depletion and GHG.
- Surface warming over most of continent, but with strong variability linked to SAM.
- Ocean surface warming in north, cooling in Subantarctic and subpolar waters.

The Southern Ocean is warming (mostly)

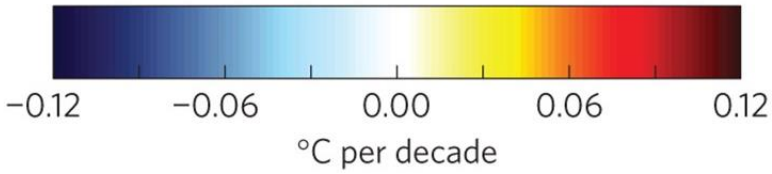


EN4 trends 1982-2012 in SST

EN4 trends 1982-2012 in ocean heat content

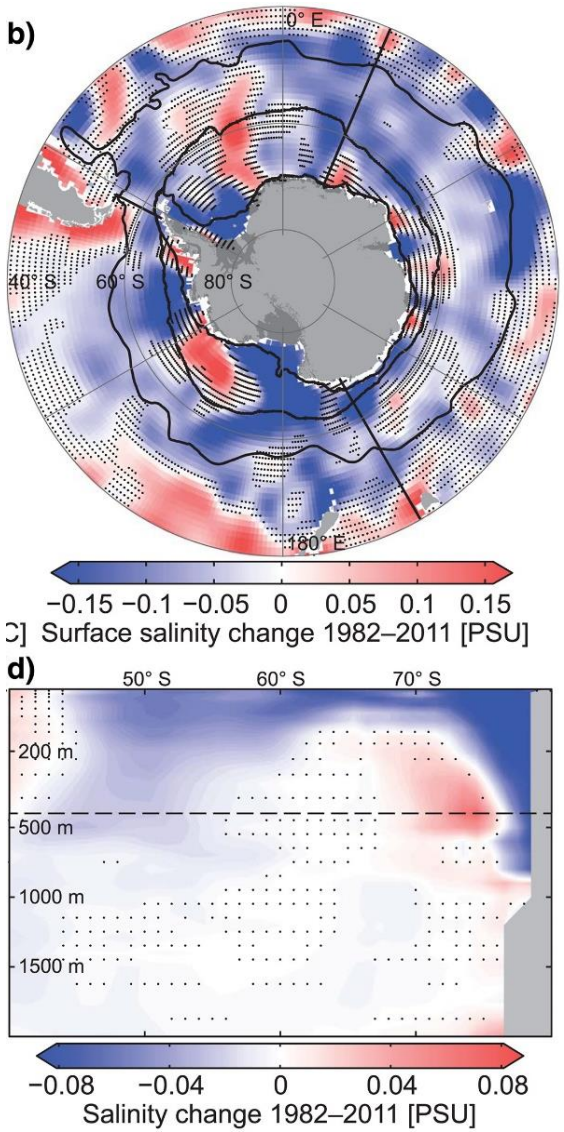


Armour et al., 2016

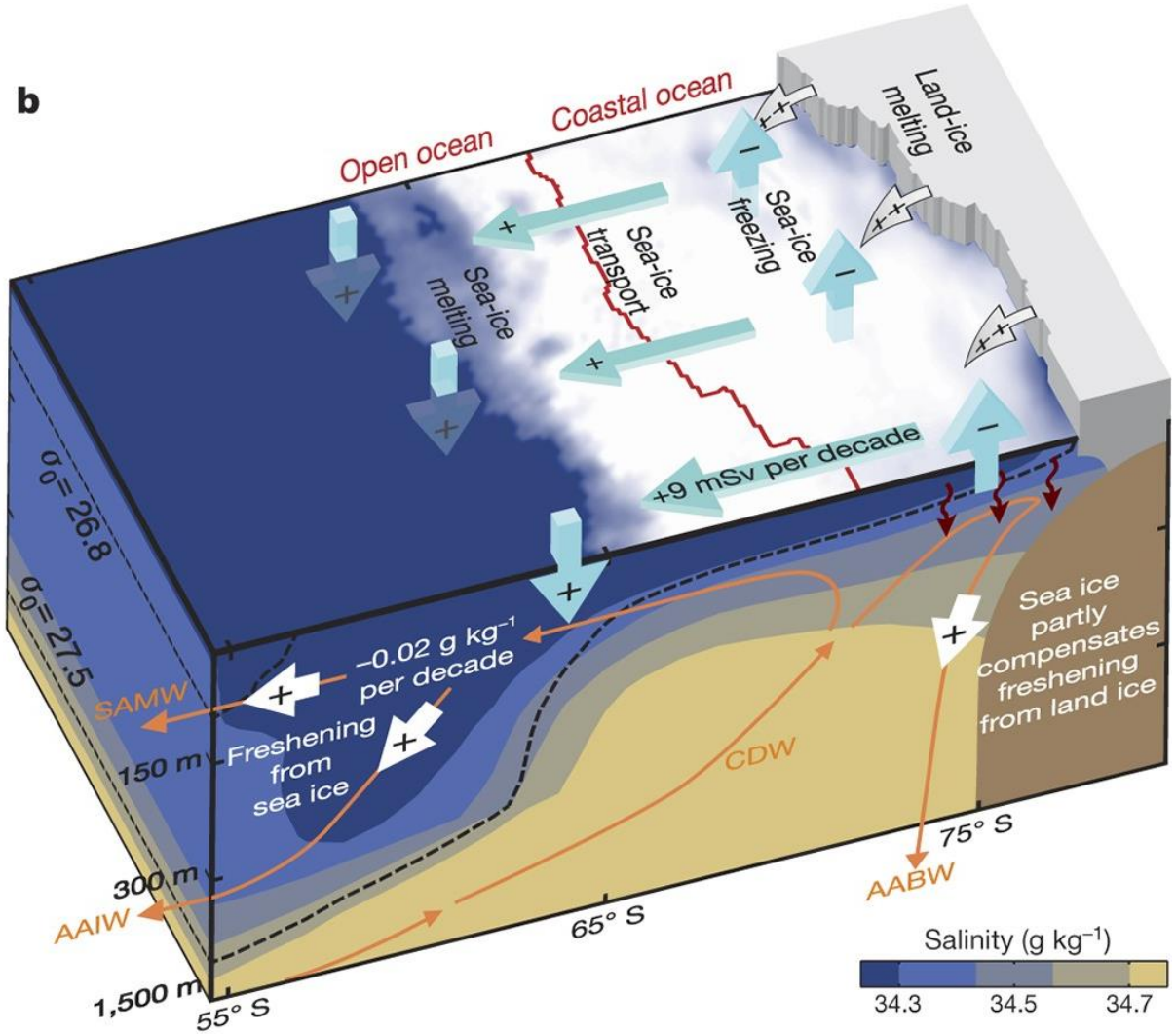


- Warming at all depths below surface.
- Accounts for ~ 1/3 of all recent global ocean warming.
- Ocean surface warming in north, cooling in Subantarctic and subpolar waters.
- Southern trends due to upwelling and surface freshwater stratification.

Strong surface freshening driven by enhanced sea ice export – for how much longer?

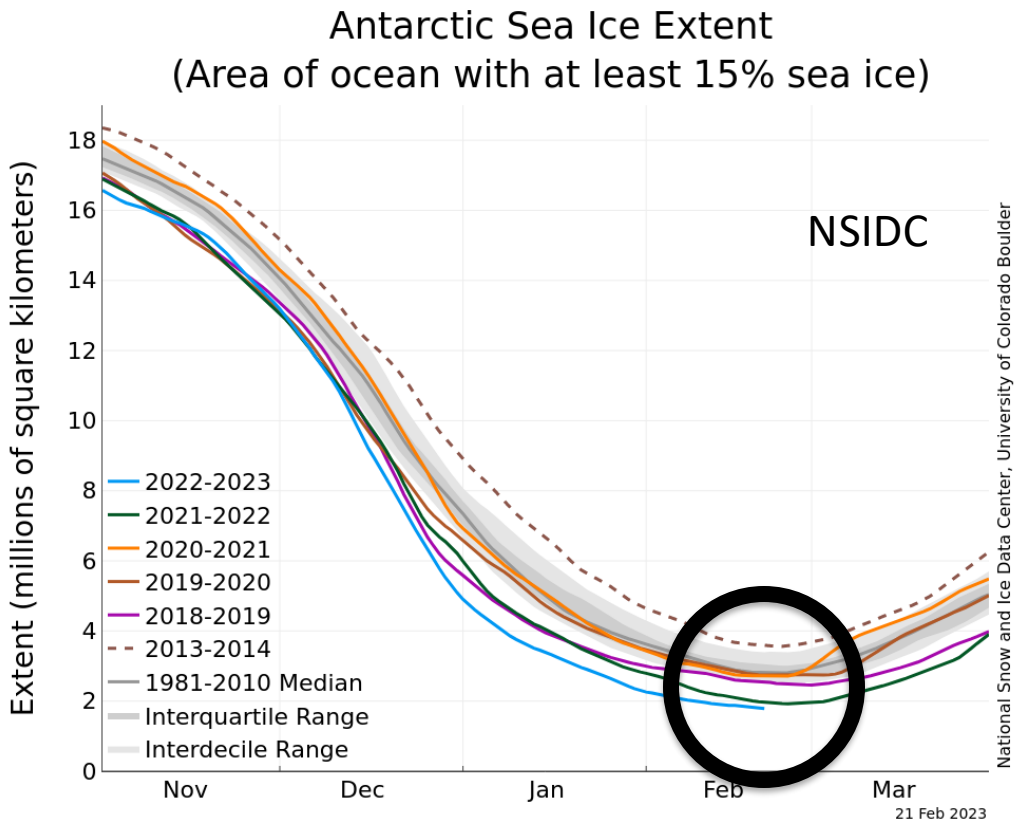


Haumann et al., 2020

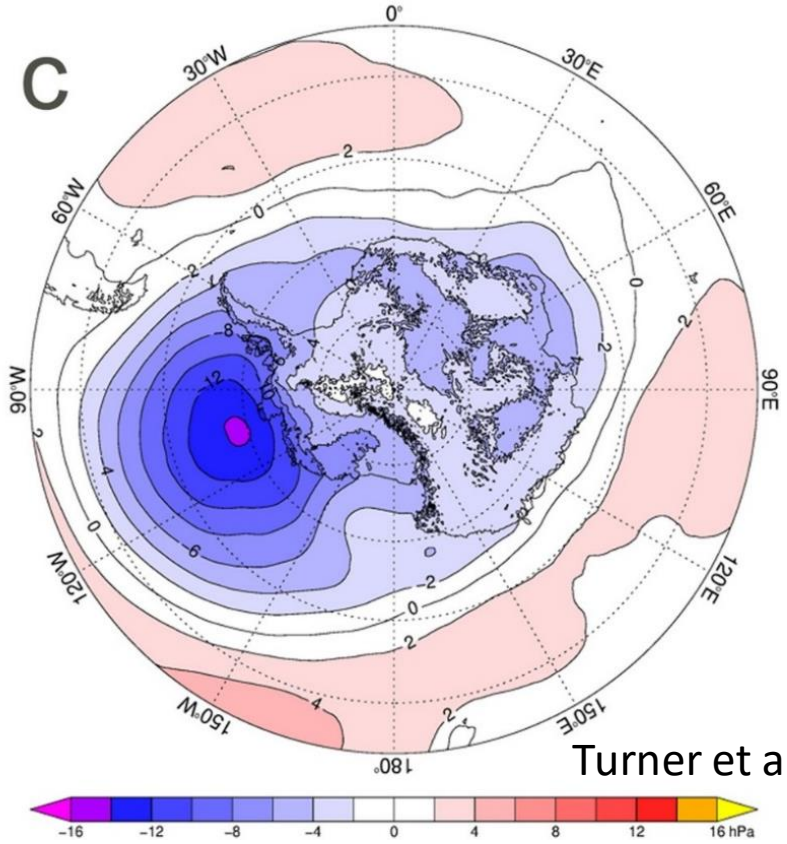


Haumann et al., 2016

Sea ice: Record summer lows



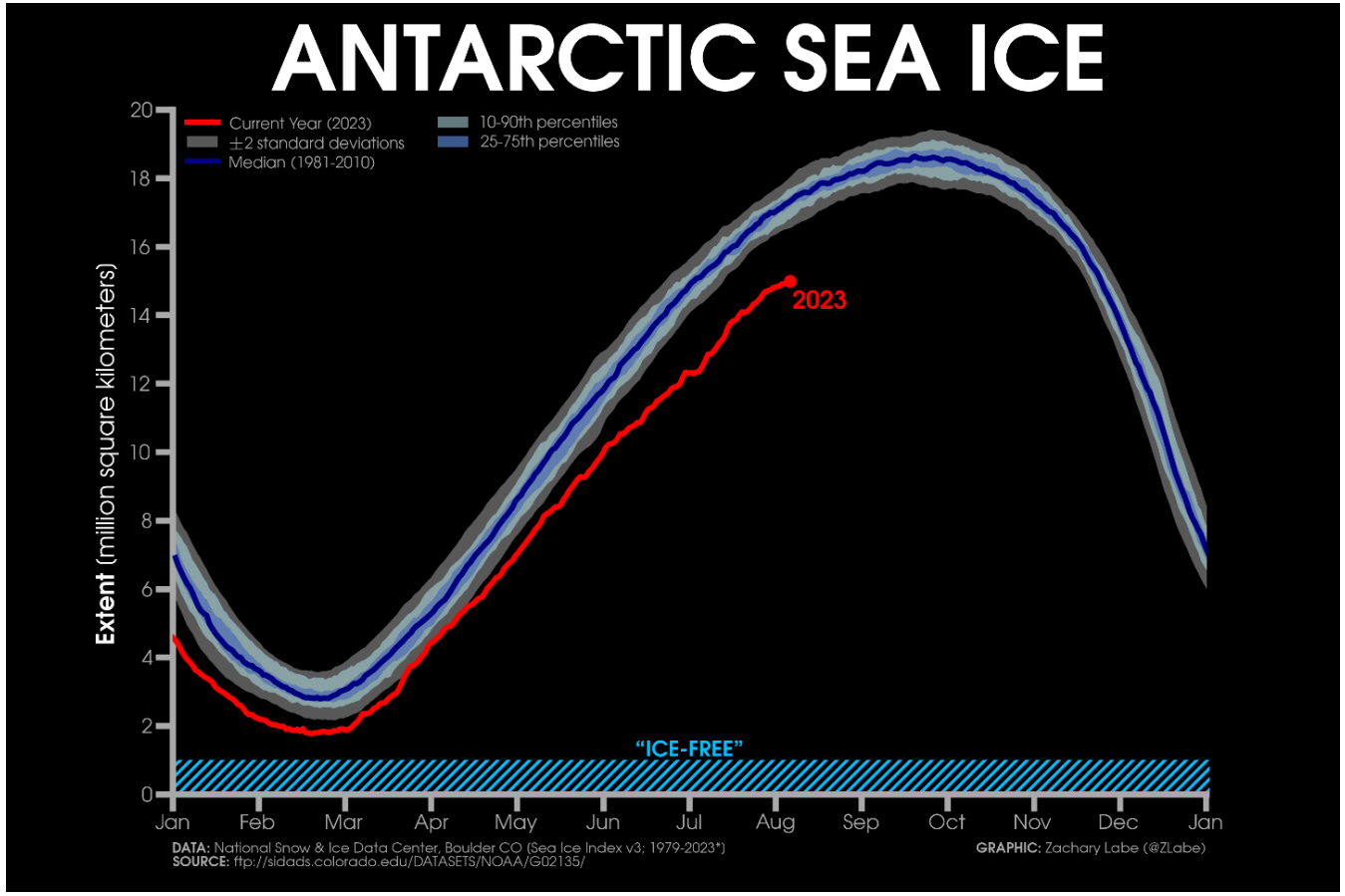
SLP anomaly at SIE minimum 2022



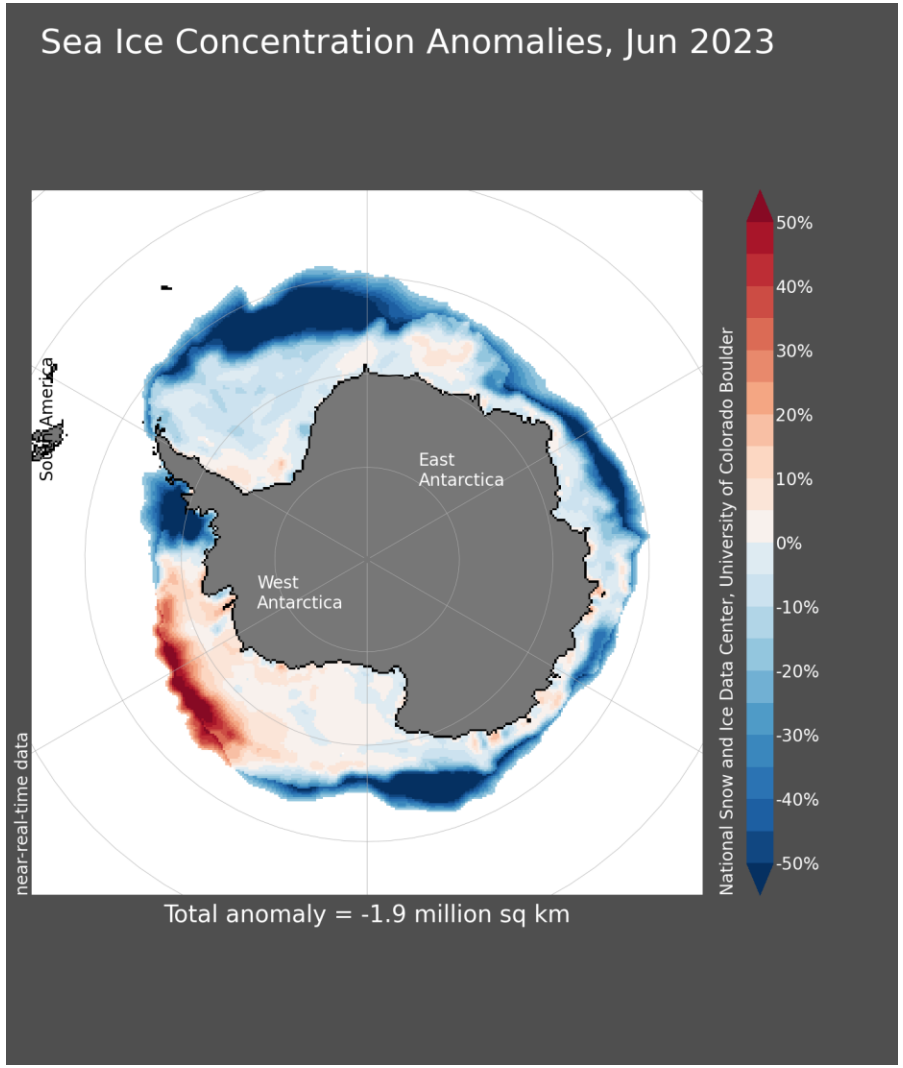
Turner et al., 2022

- Record summer lows in 2022 (Ross Sea dominant) and 2023 (everywhere).
- Strongly linked to deep ASL and wind changes.

Sea ice: The 2023 winter anomaly

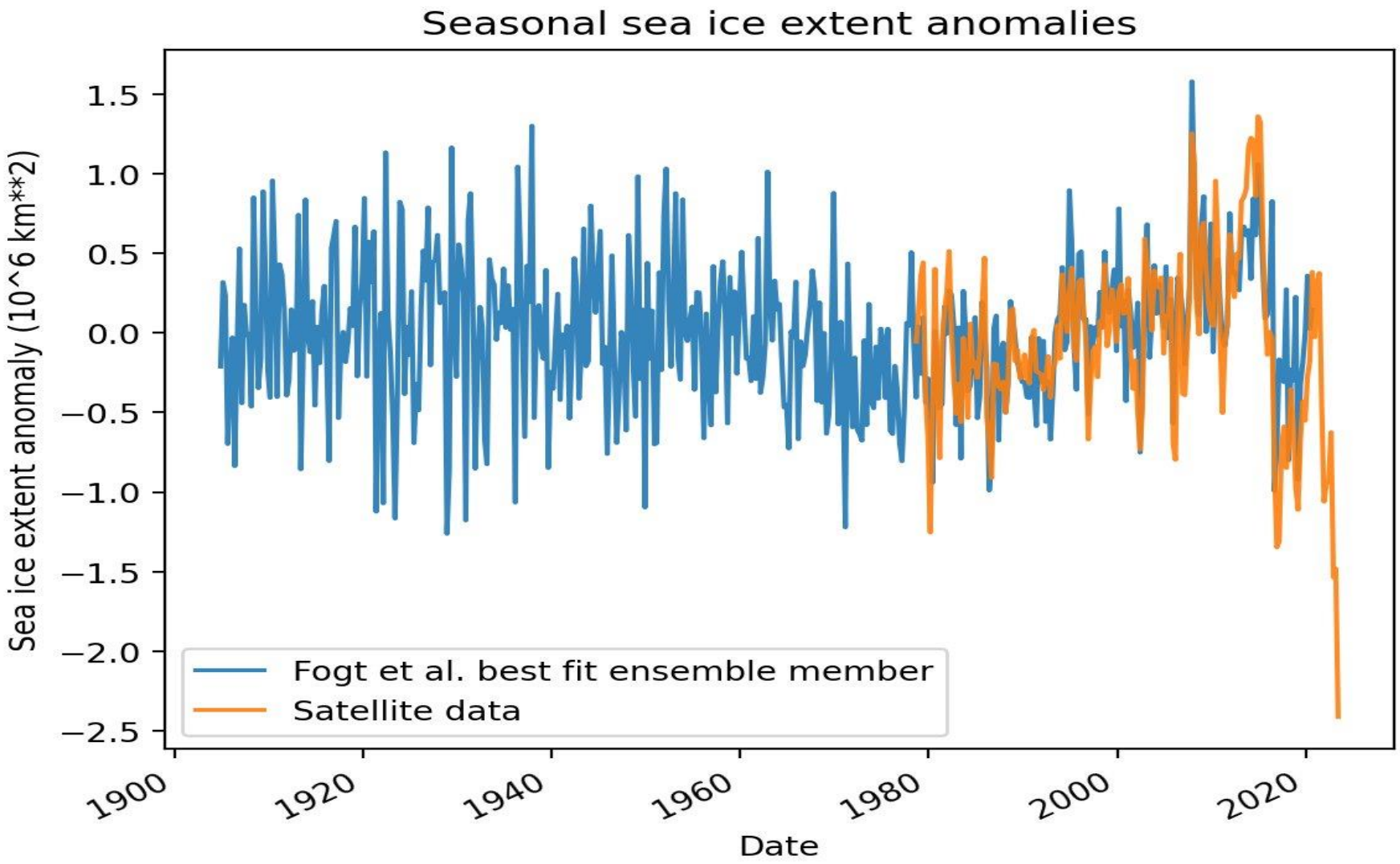


https://zacklabe.com/antarctic-sea-ice-extentconcentration/



NSIDC

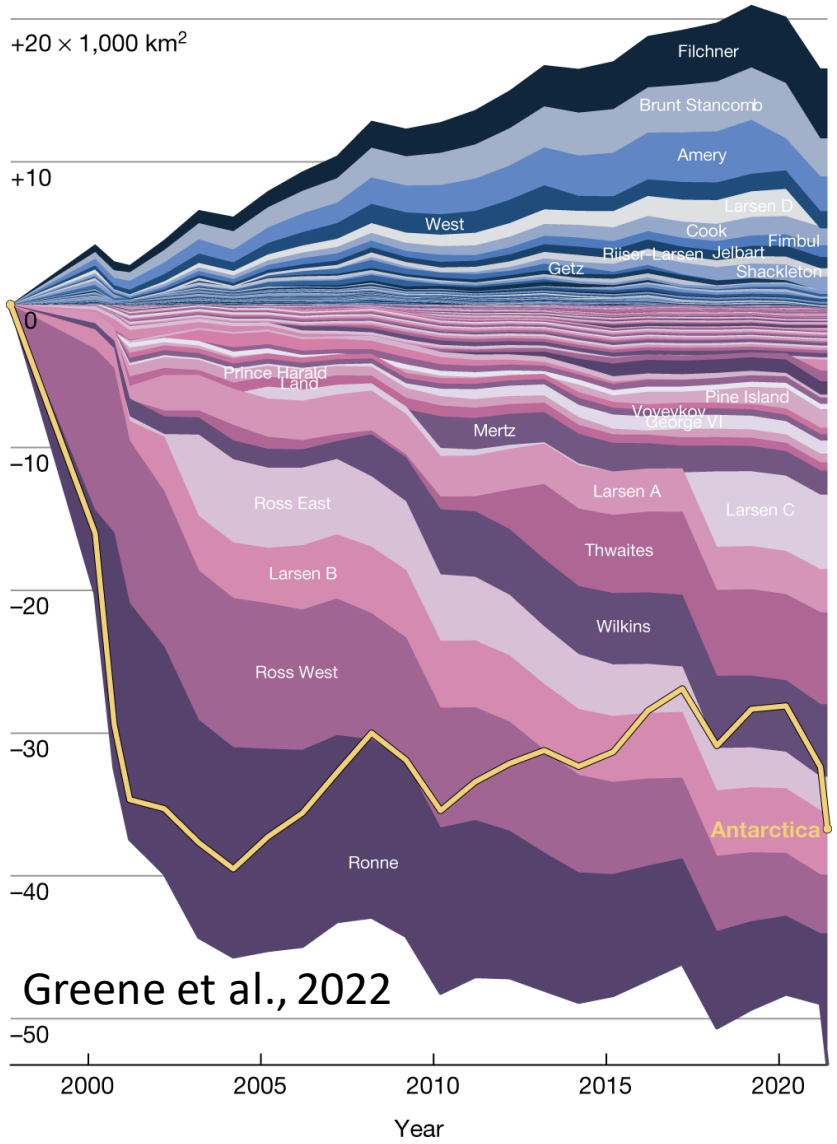
Sea ice: A state change since 2016?

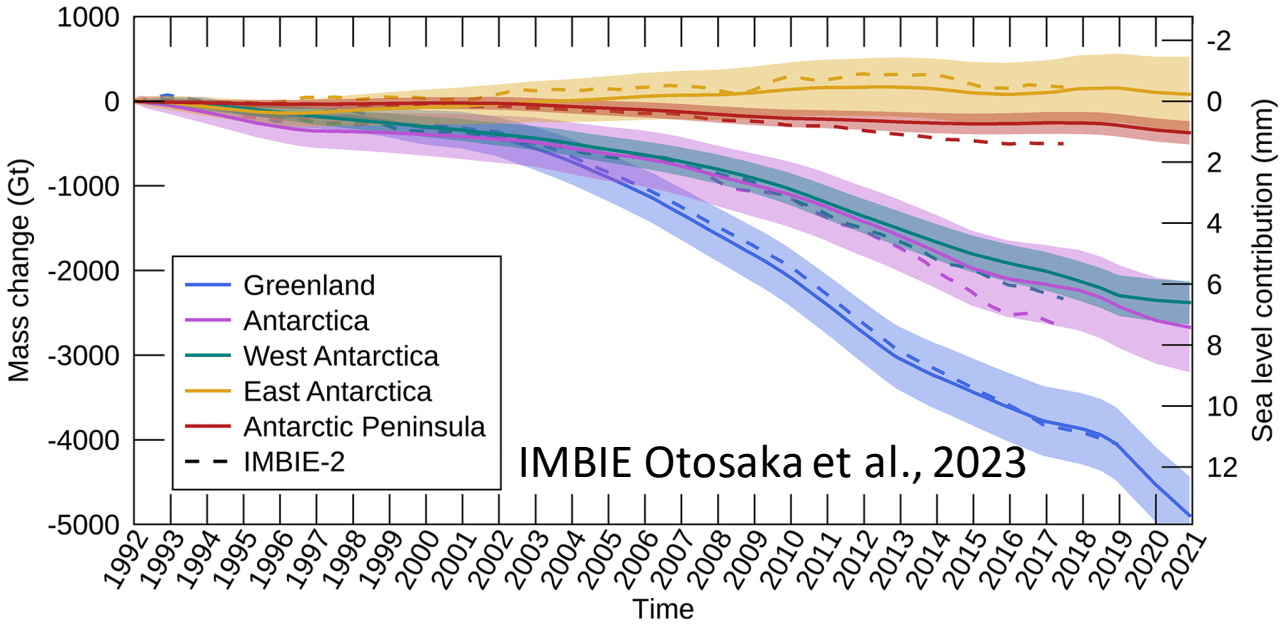


Fogt et al., 2022 Historic reconstruction + satellite observations

Ed Doddridge (Twitter, Aug 23)

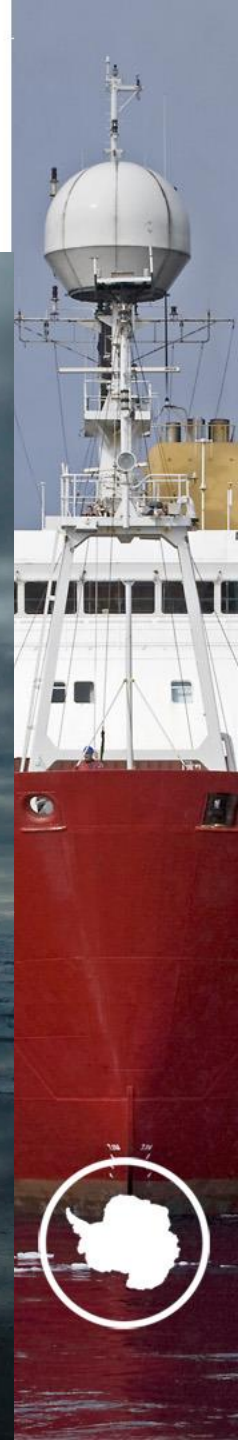
Ice shelves have lost area since 2000, along with ice sheet mass itself



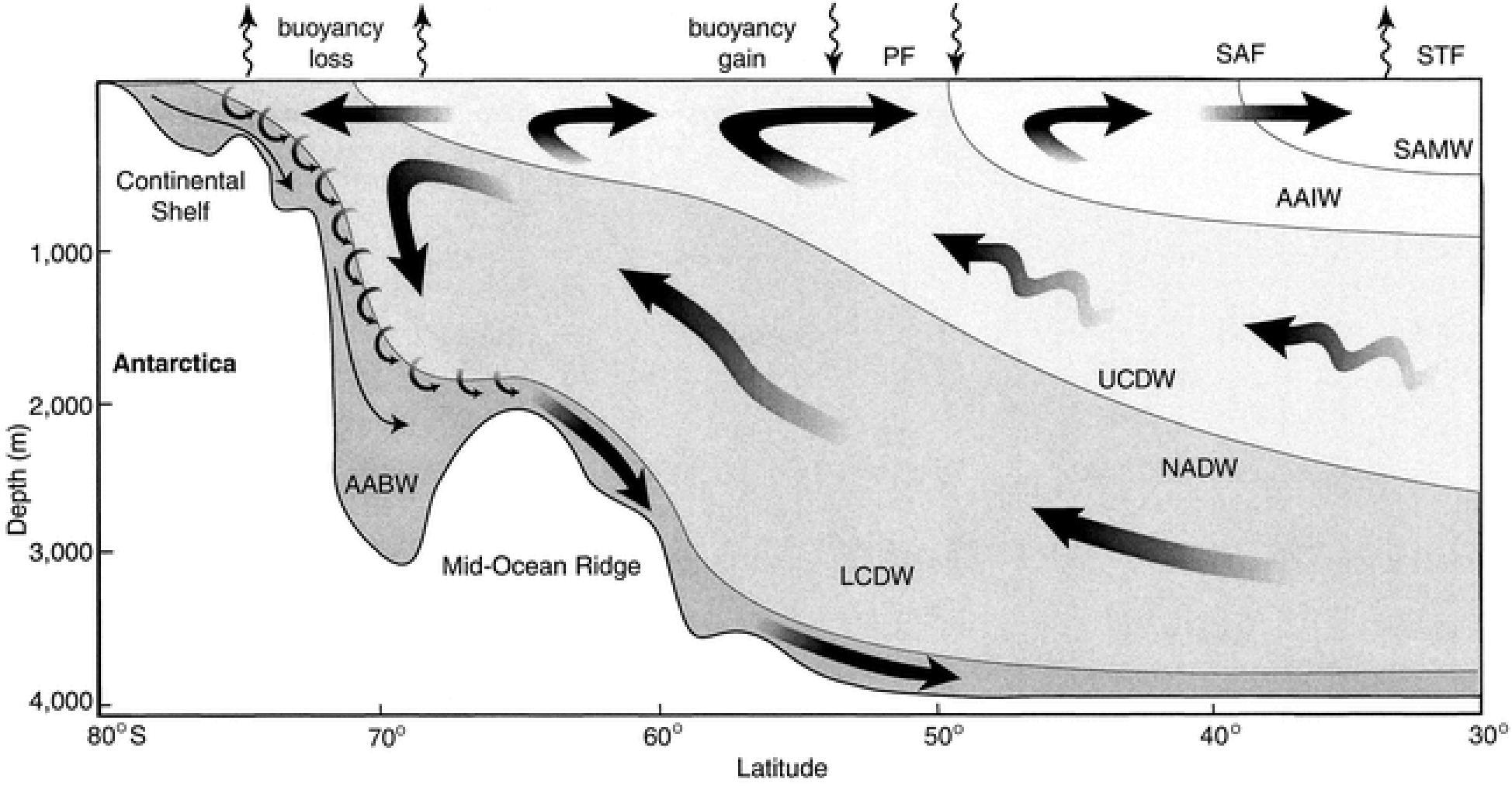


- Ice shelf mass loss equally driven by calving and basal melt thinning.
- Significant interdecadal variability.

THE CASE FOR CIRCUMPOLAR OBSERVATIONS

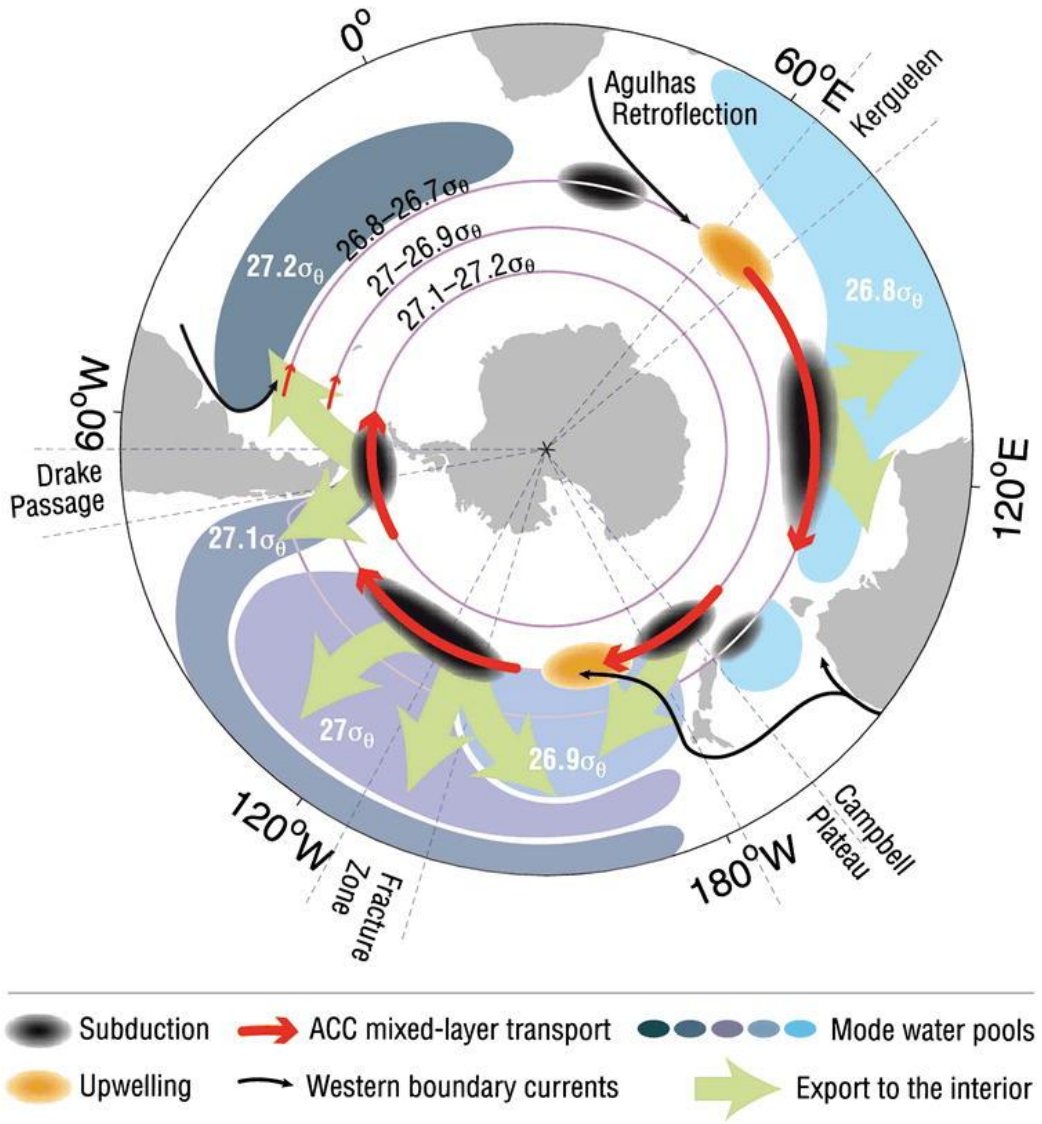


Evolution of our view of the oceans



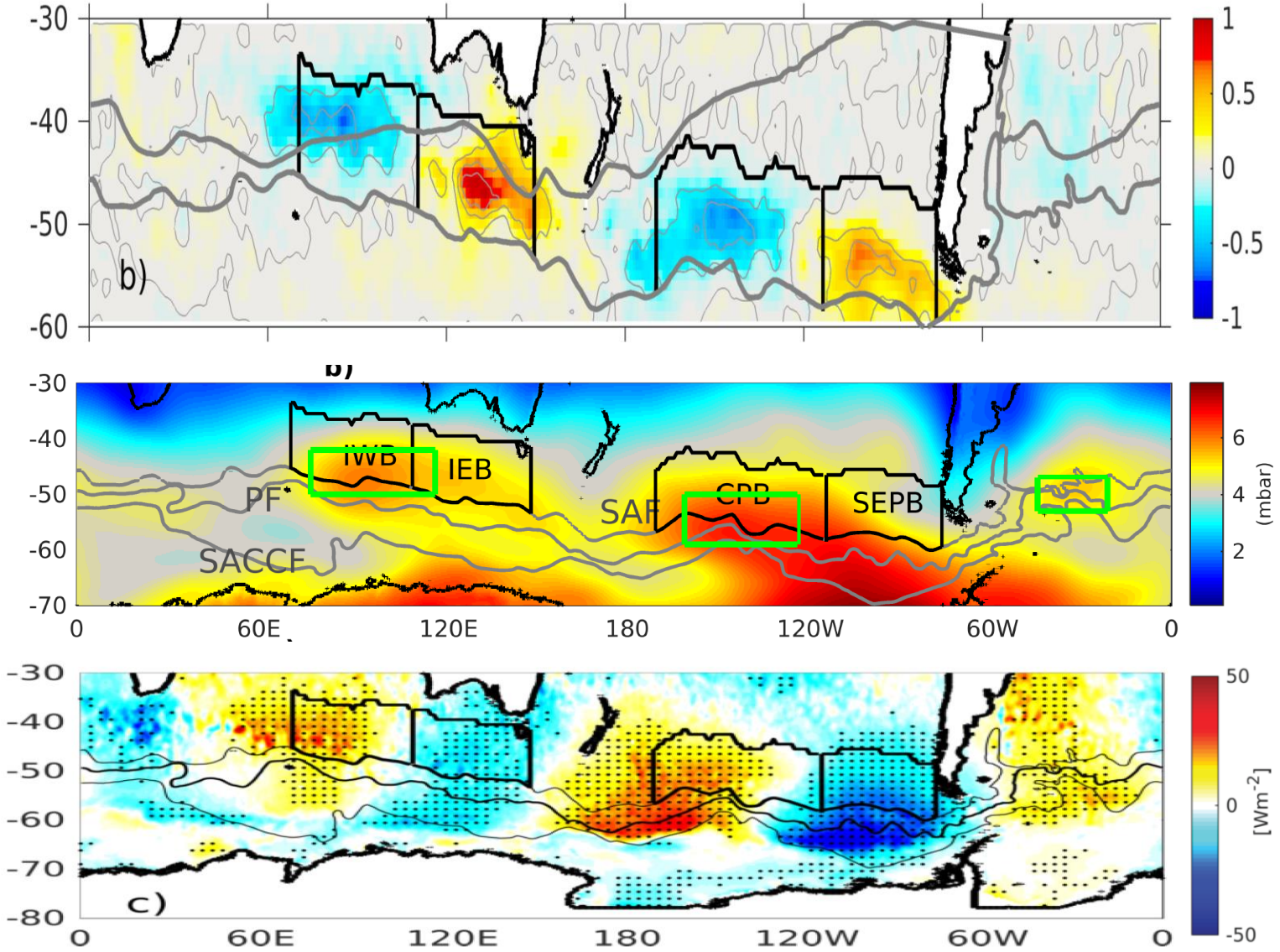
Speer et al., 2000

Subduction via SAMW and AAIW is spatially inhomogeneous…



Sallée et al., 2010

…with significant temporal variability



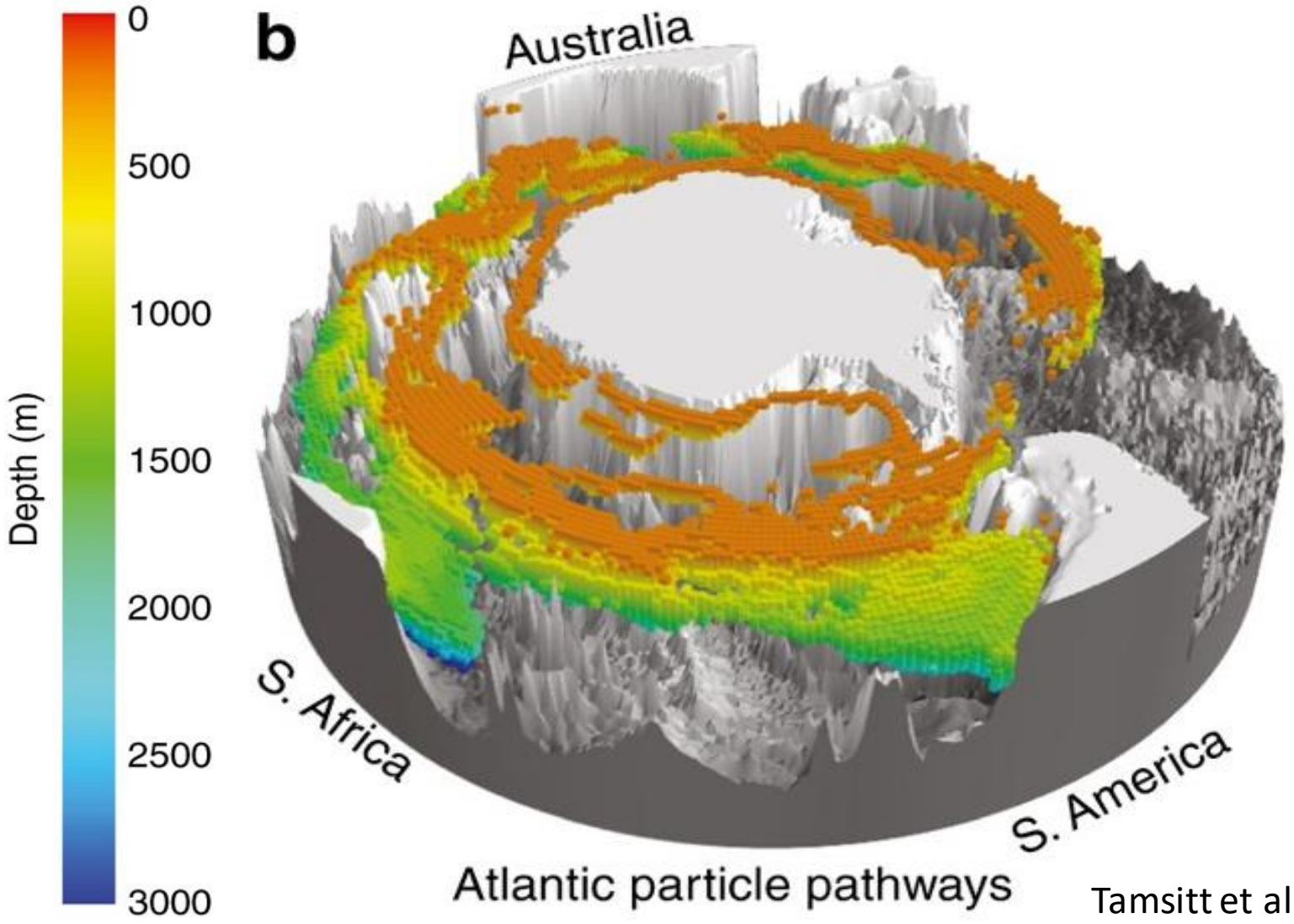
EOF1 of winter mixed layer depth from ORCHESTRA climatology 2005-2019 (King et al.)

Standard deviation of winter MSLP (ERA5)

Regression of net air-sea heat flux regressed onto Pacific box MSLP (ERA5)

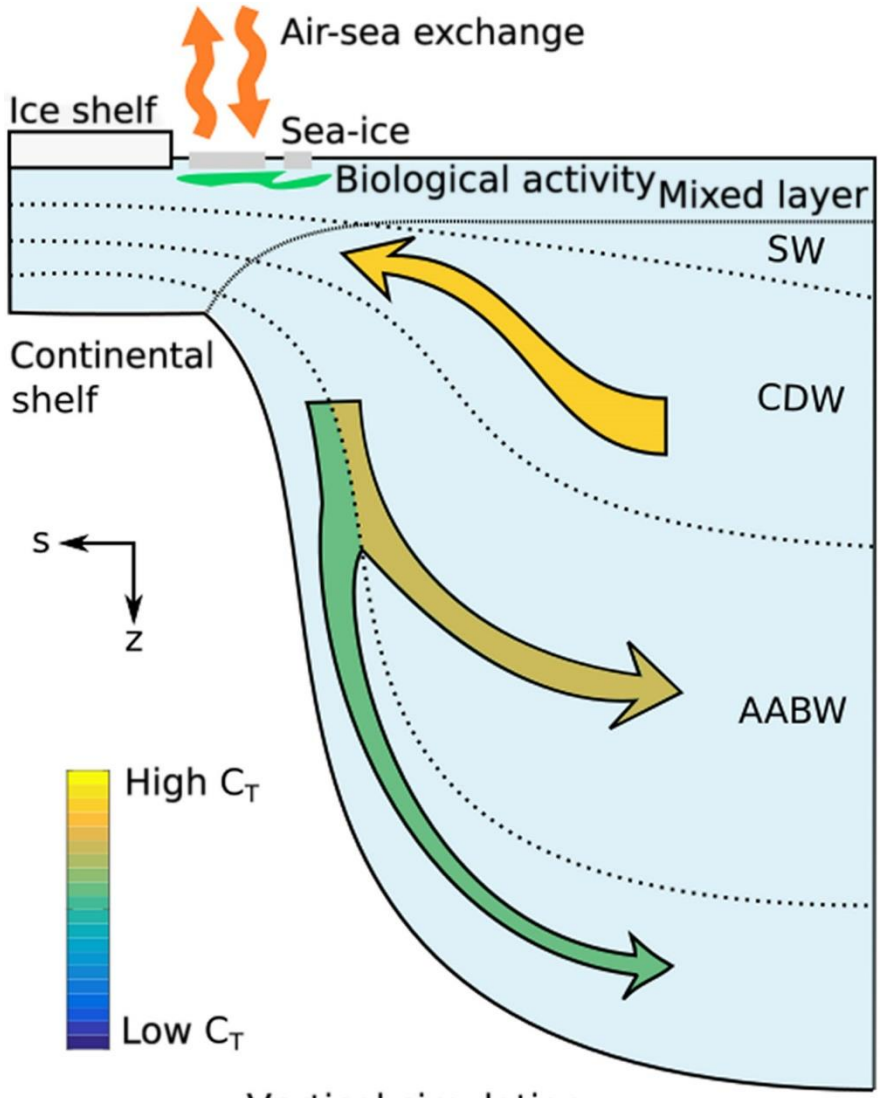
Cerovečki and Meijers 2021

The deeper circulation also must be understood as a 3D circulation



Tamsitt et al., 2017

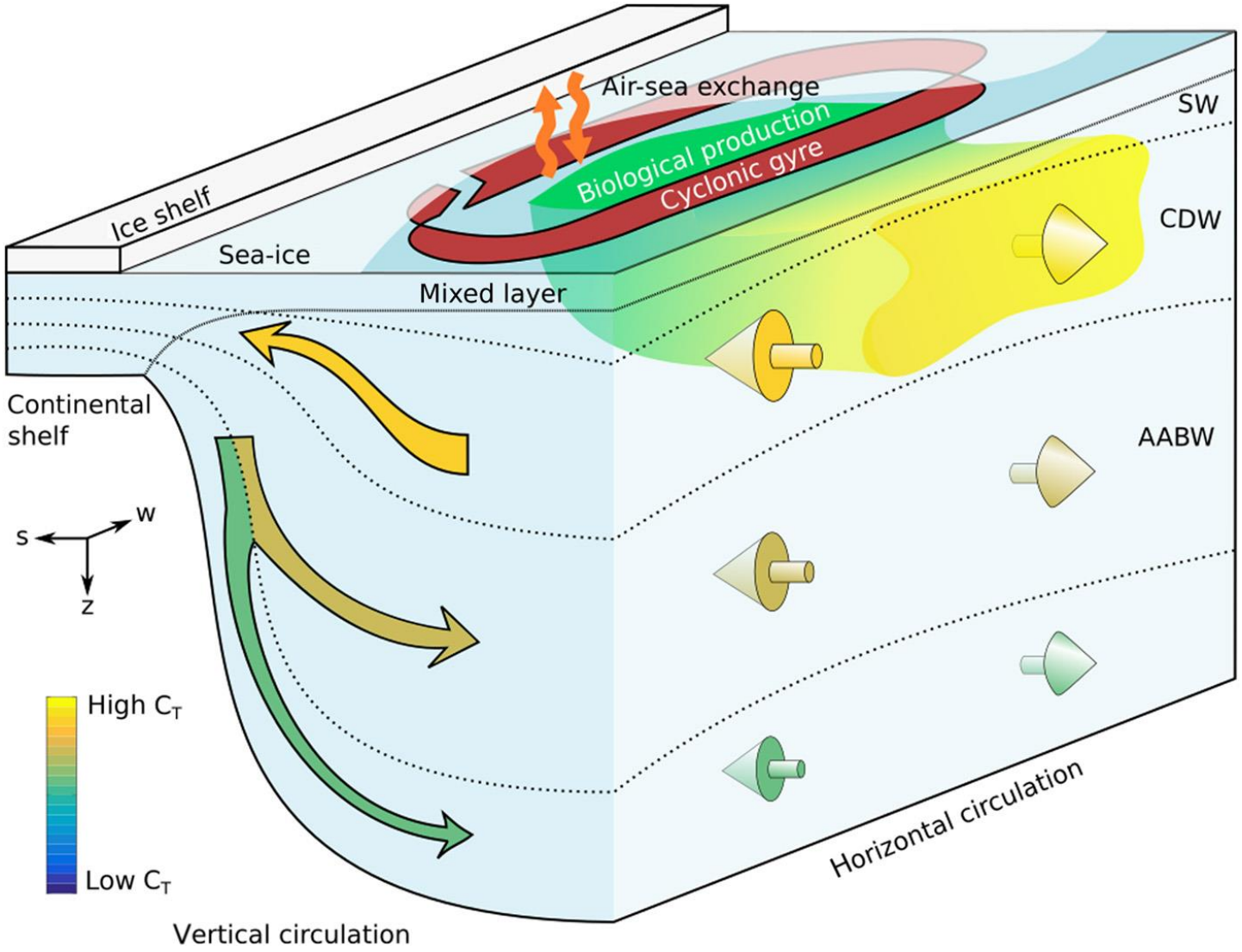
Traditional vertical circulation/biological activity model suggests an ocean CO2 source – unsupported in some regions by observations



Vertical circulation

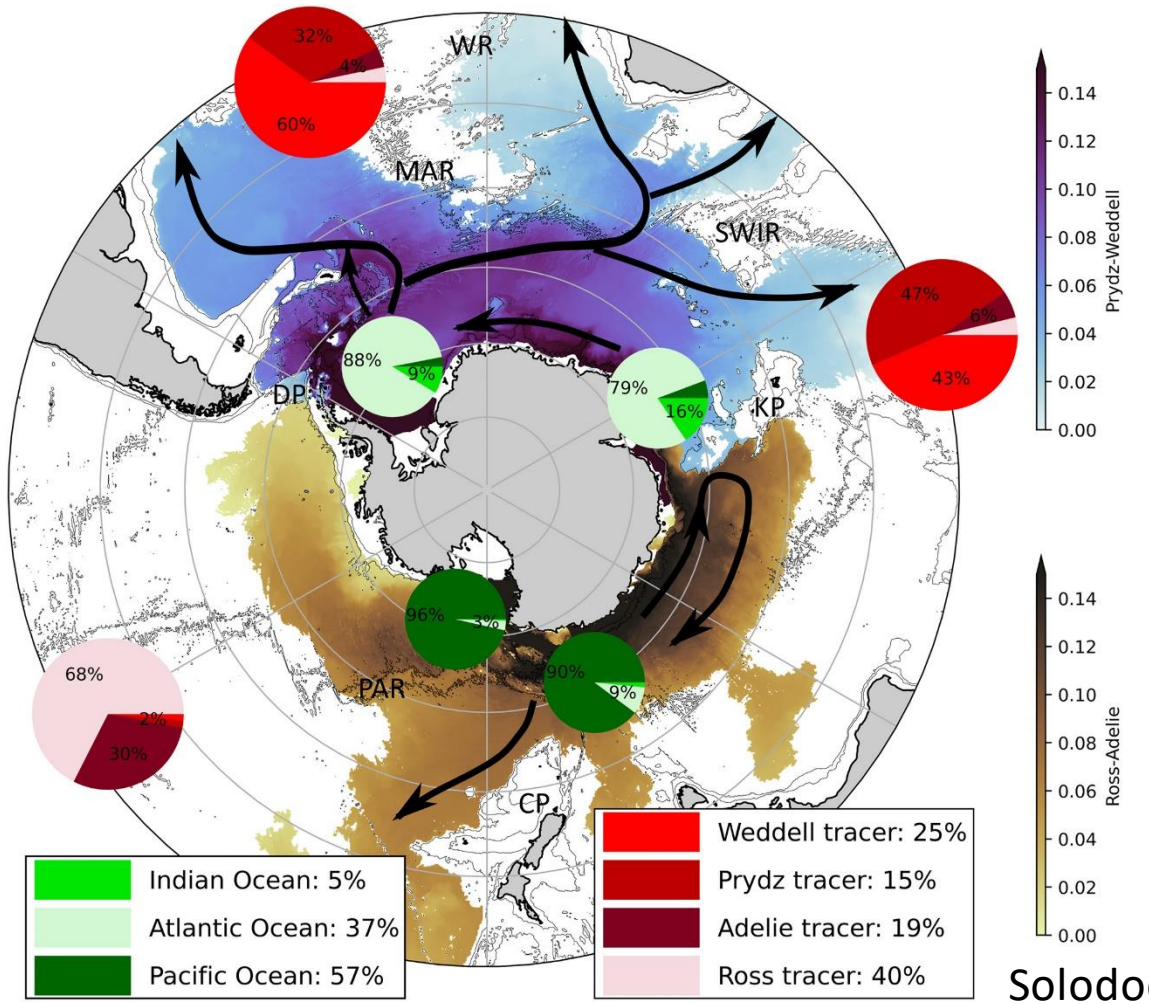
MacGilchrist et al., 2019

The zonal interaction between carbon drawdown/remineralisation and zonal flow is required to understand the Weddell Sea as a natural carbon sink



MacGilchrist et al., 2019

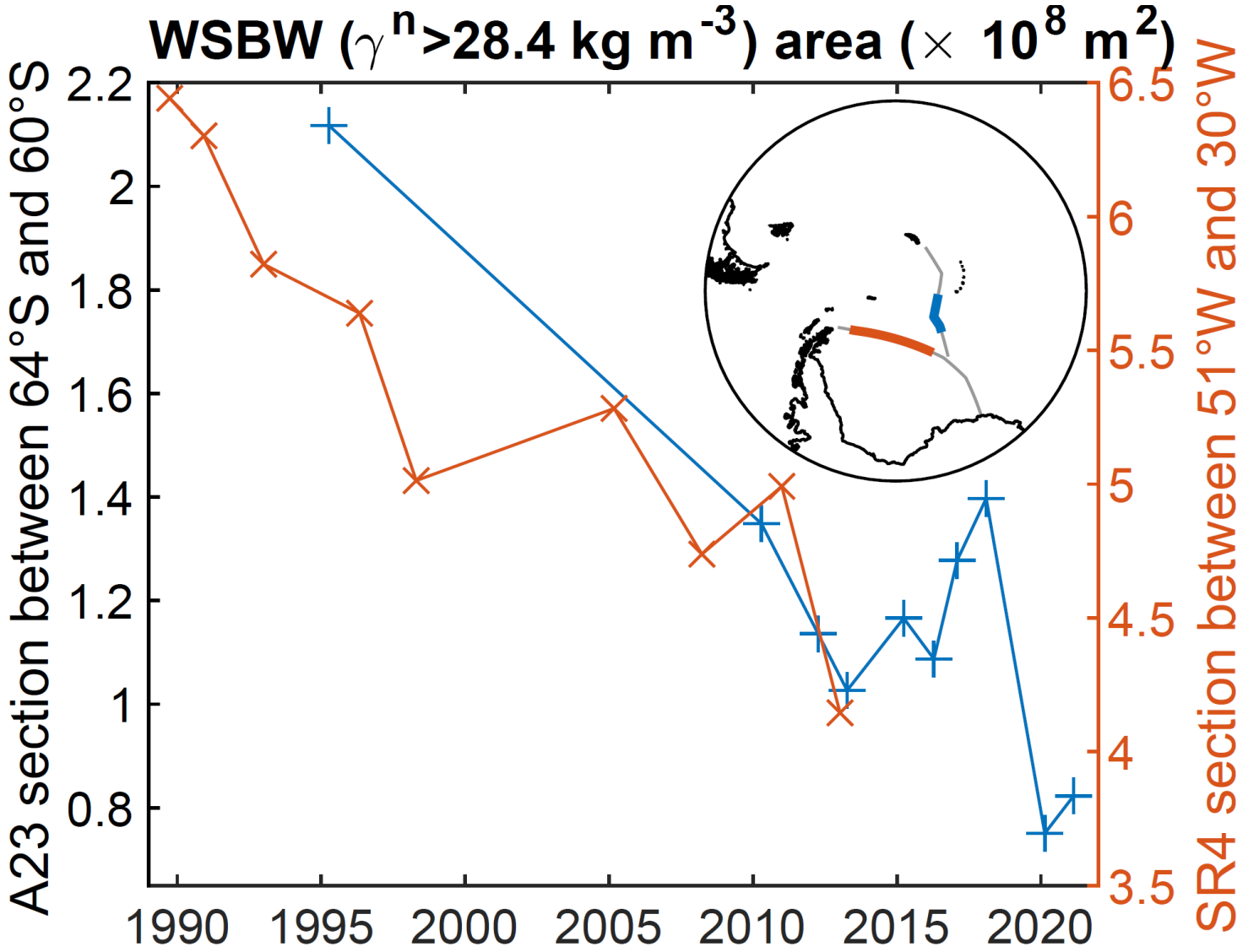
AABW is ~30% of global ocean volume, created only in four regions



Solodoch et al., 2022

- Requires circumpolar coordination and integration of regional monitoring/process studies.

Regional AABW trends vary in their drivers

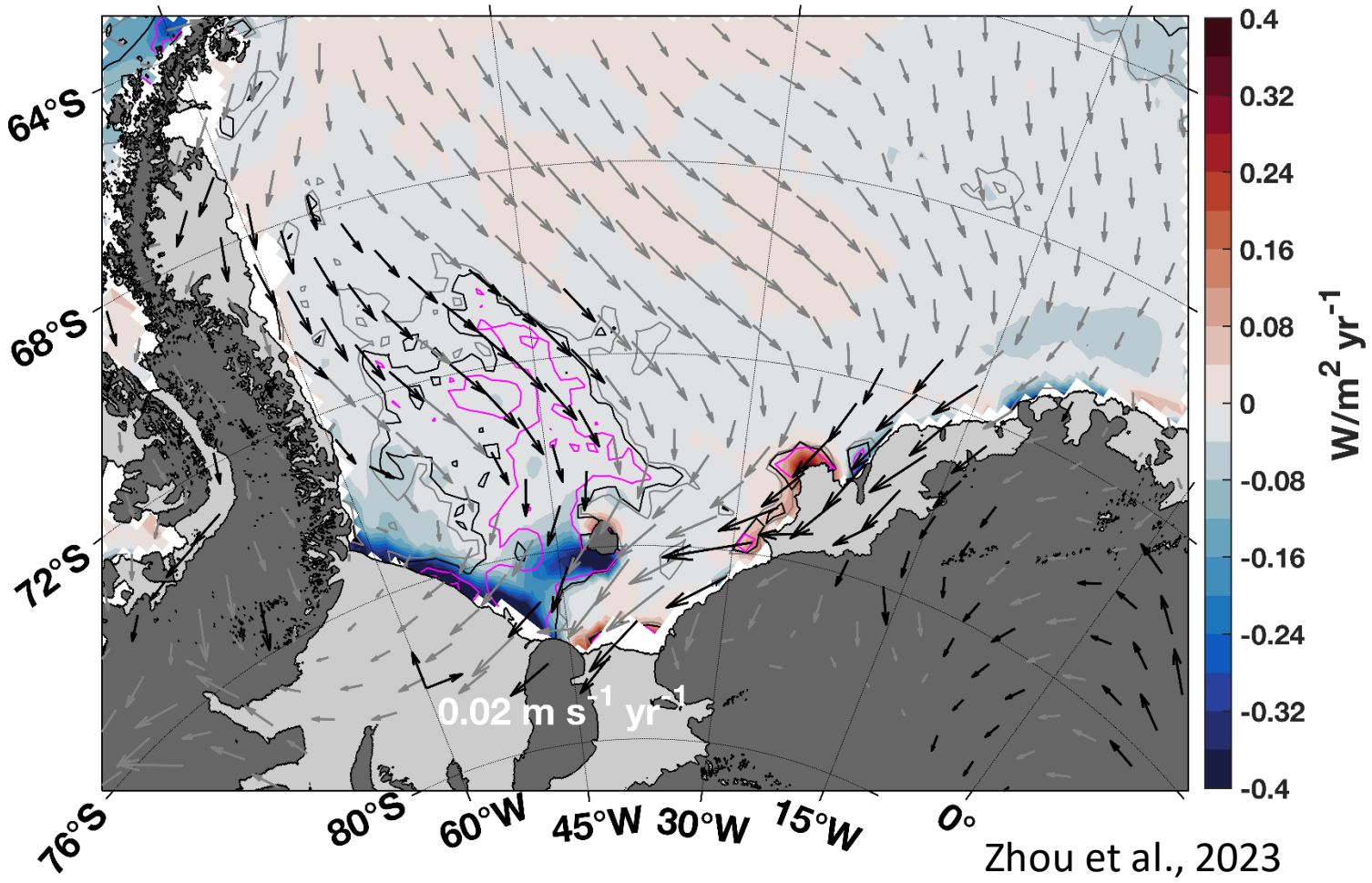


- ~30% reduction in Weddell Sea bottom water volume since 1990.
- Overlies significant interannual variability.

Following Abrahamsen et al., 2019

Increased northerly winds drive reduced AABW formation in Weddell Sea

Trends in sea ice formation rate (colour) and surface wind stress (vectors)

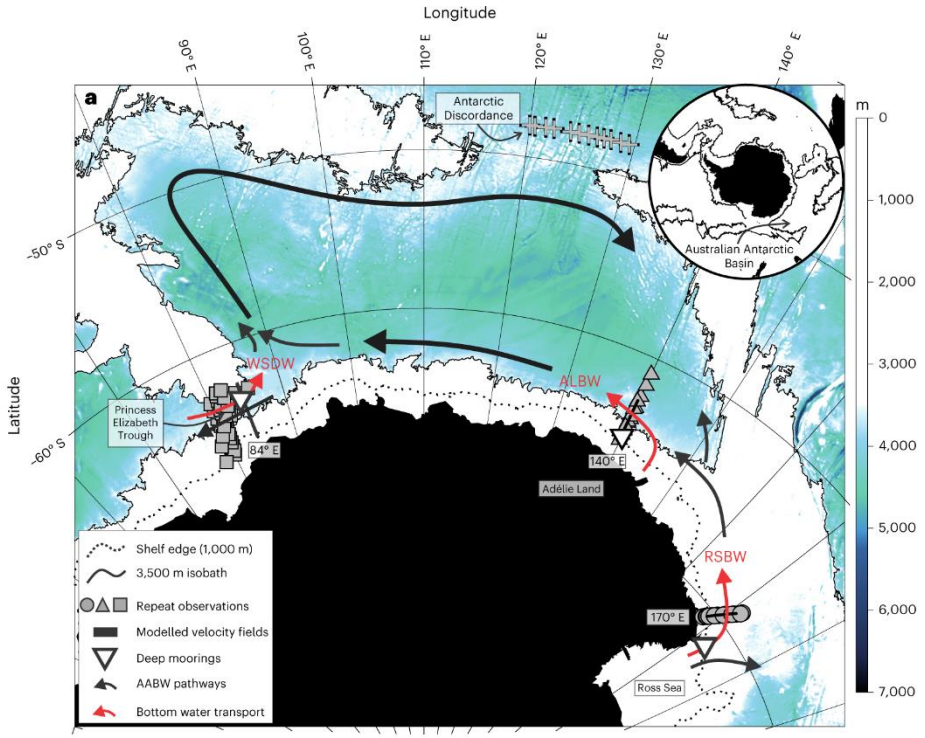


Zhou et al., 2023

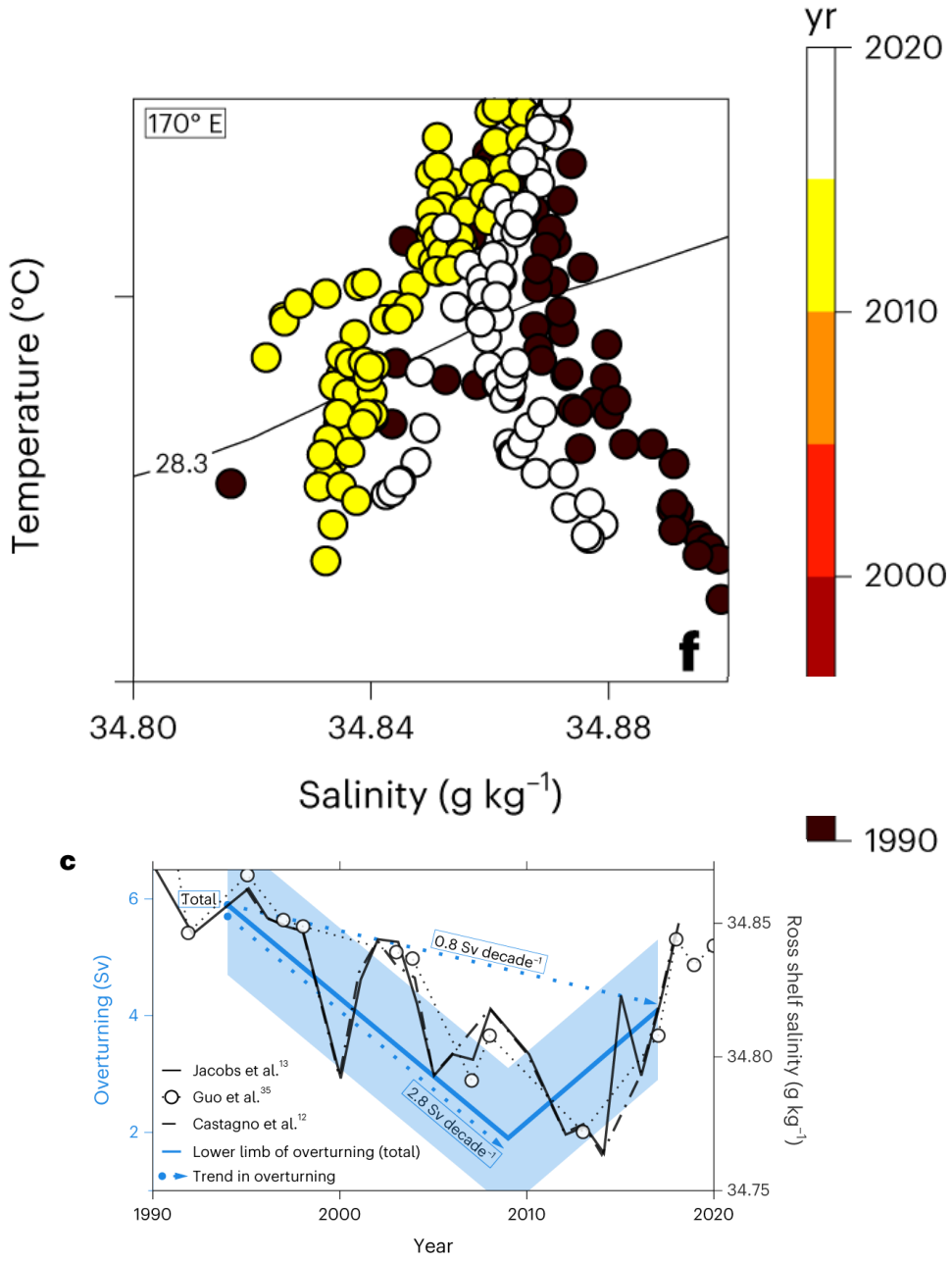
- 30 year trend in northerly winds.
- Drives significant reduction in sea ice formation rates.
- Consequent reduction in dense shelf water formation and AABW export.
- Significant links to ASL variability and Interdecadal Pacific Oscillation.

SO-CHIC
Southern Ocean Carbon and Heat Impact on Climate

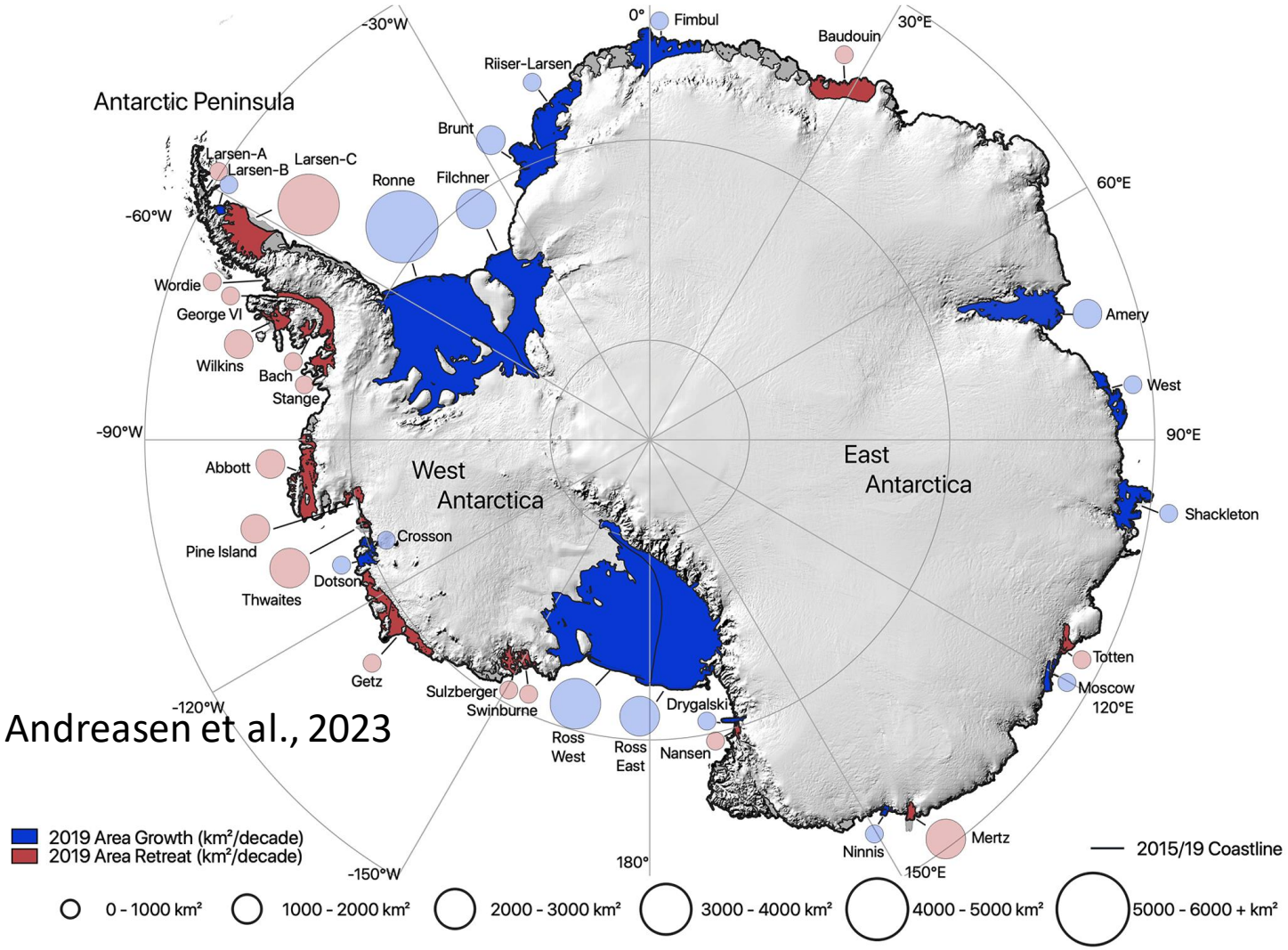
While other AABW trends are attributed instead to ice sheet melt



Gunn et al., 2023



The ice shelves represent even more extreme regionalisation

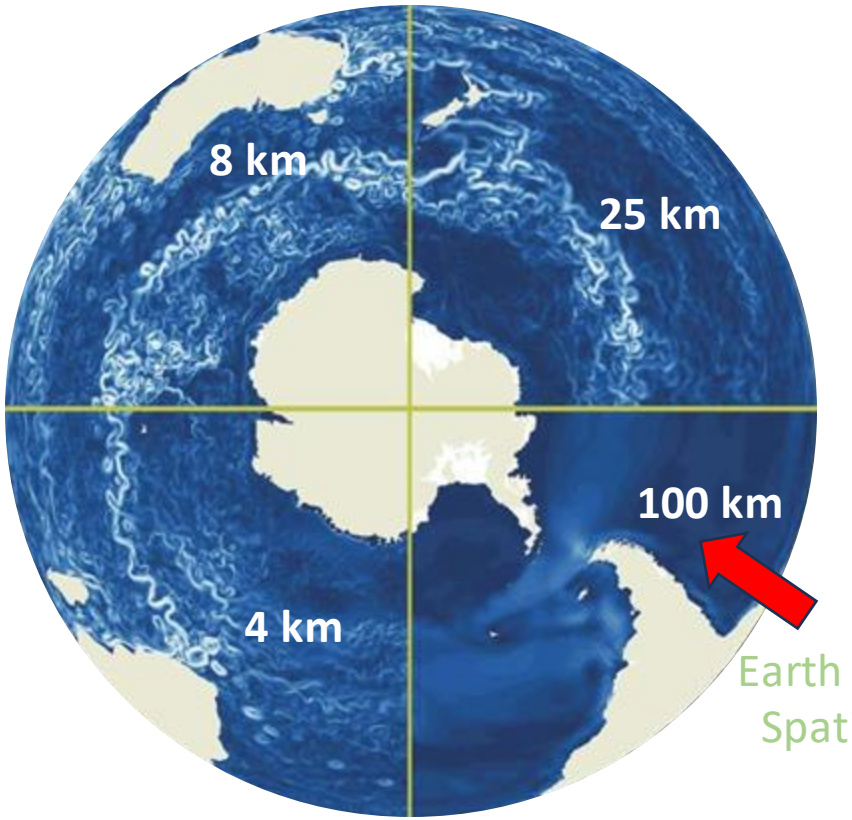


Andreasen et al., 2023

Ice shelf area change 2009-2019

Not enough to just be circumpolar: Scale is critical for important processes

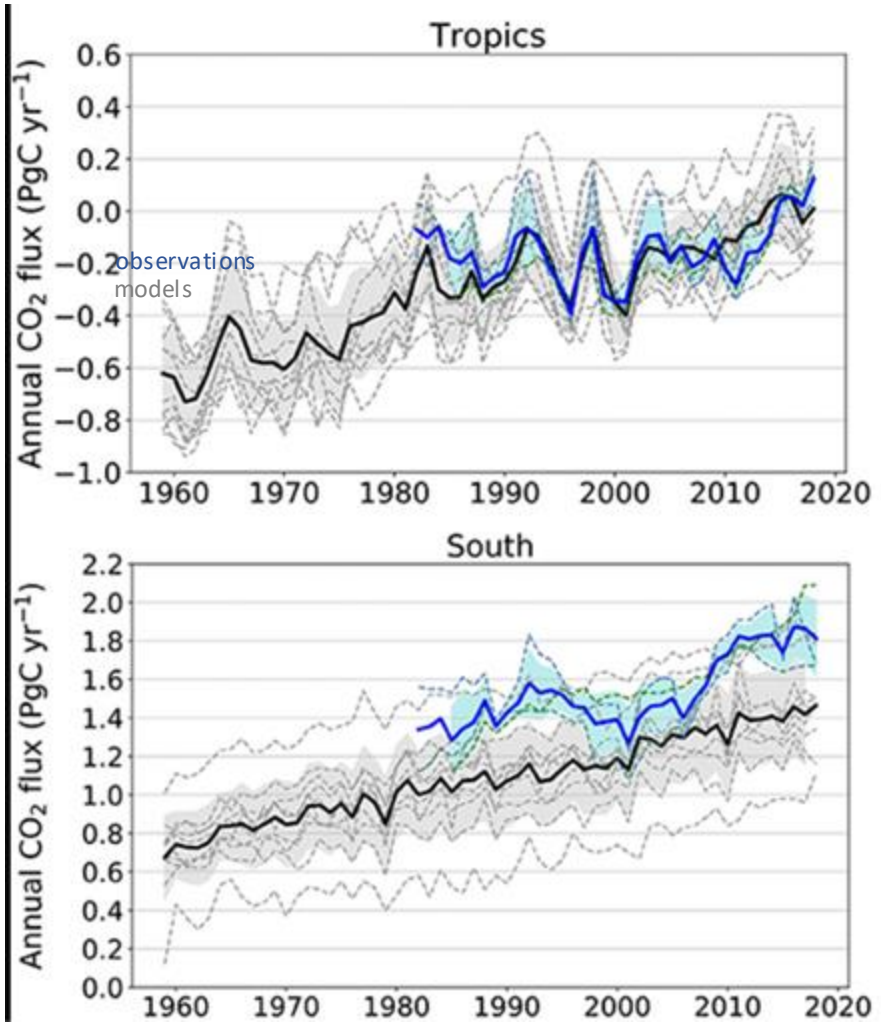
Hewitt and Fox-kemper, 2022



Earth System Model
Spatial resolution

Key Southern Ocean processes are not being resolved in Earth System models

CO2 flux into ocean, models v obs



Hauck et al. 2020

From S. Nicholson and S. Thomalla

A note of caution

"I think this circumpolar thing is the wrong approach. We need to identify the areas that demonstrate the key processes and get them right in models. Then maintain a handful of sites out into the future that keep the models honest. One of the first steps has to be to get the domain well-defined."

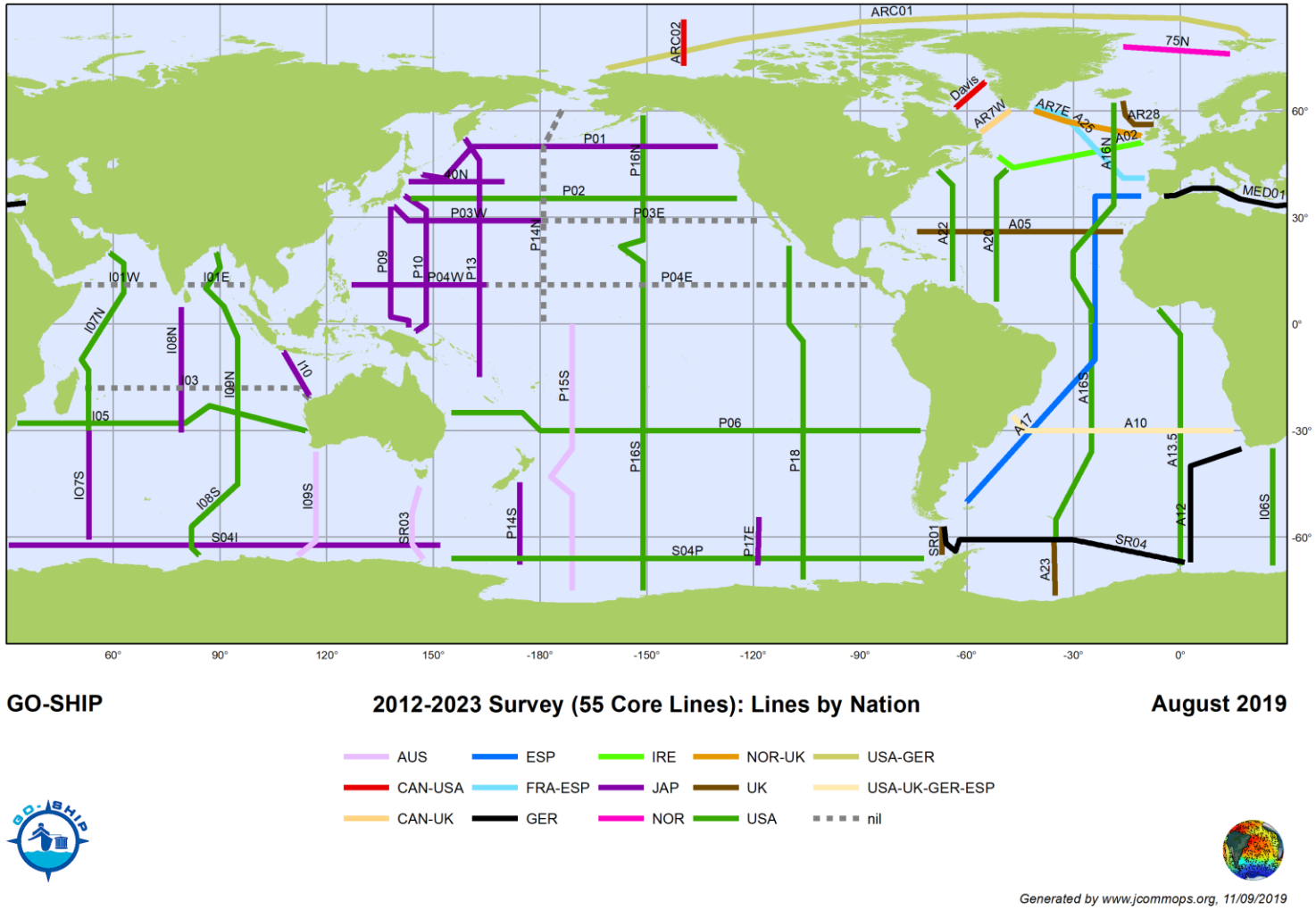
Anon

- Observations need to be made in service to defined scientific or social objectives, as part of a wider plan and integrated with our other toolsets – notably modelling.
- Observations are key to defining process representation in models and assessing model fidelity.
- "Defining the domain" **requires circumpolar observations**…but at what resolution?

CIRCUMPOLAR OBSERVING NETWORKS

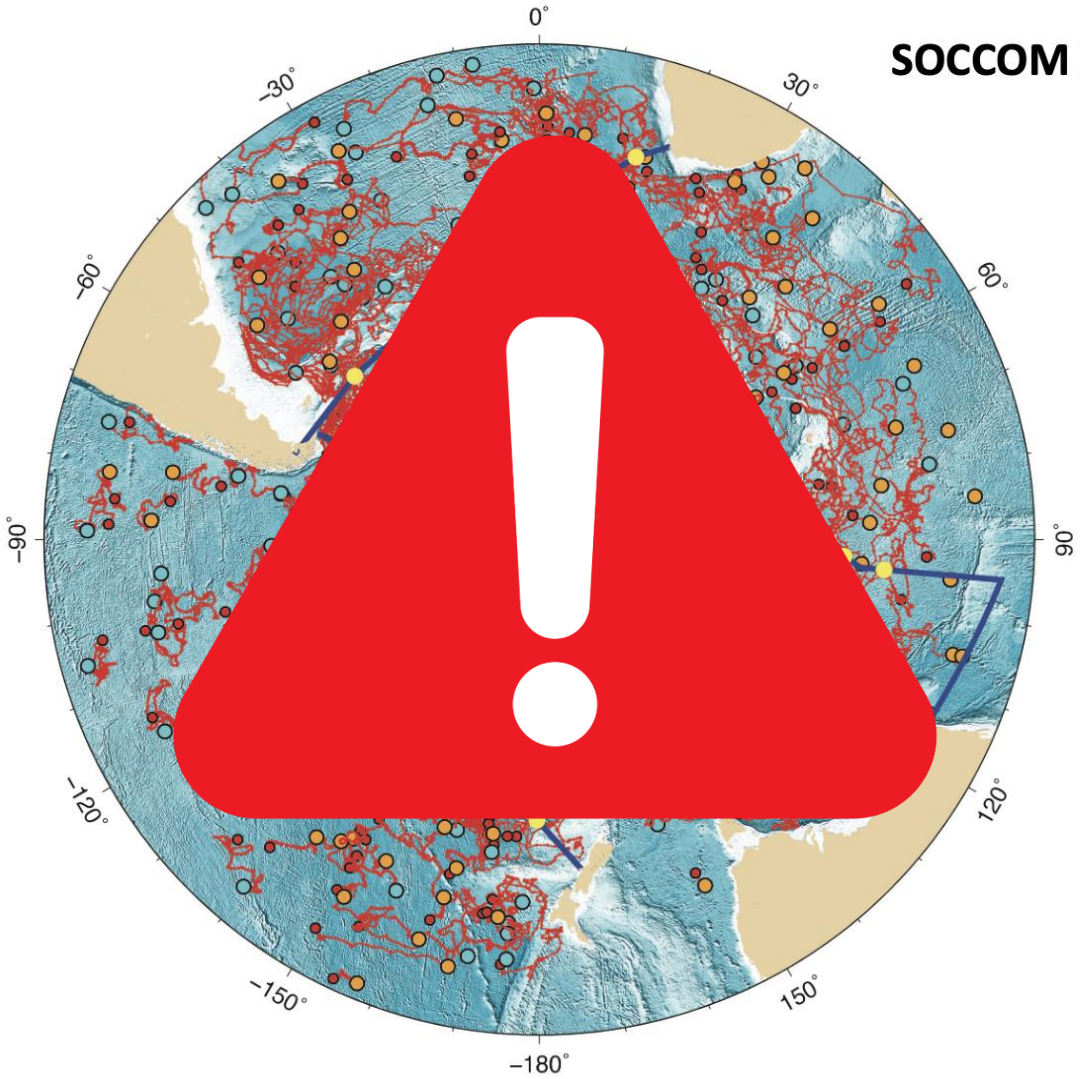
GO-SHIP – Gold standard repeat hydrographic sections

- Resolving decadal signals.
- Reference and standard data.
- Deep observations
- Full BGC.
- Sparse, infrequent and expensive!



Lynne Talley, pers comms.

Argo – SOCCOM – GO-BGC: A revolution in our understanding…and more questions



SOCCOM Floats Year 10 2023-2024

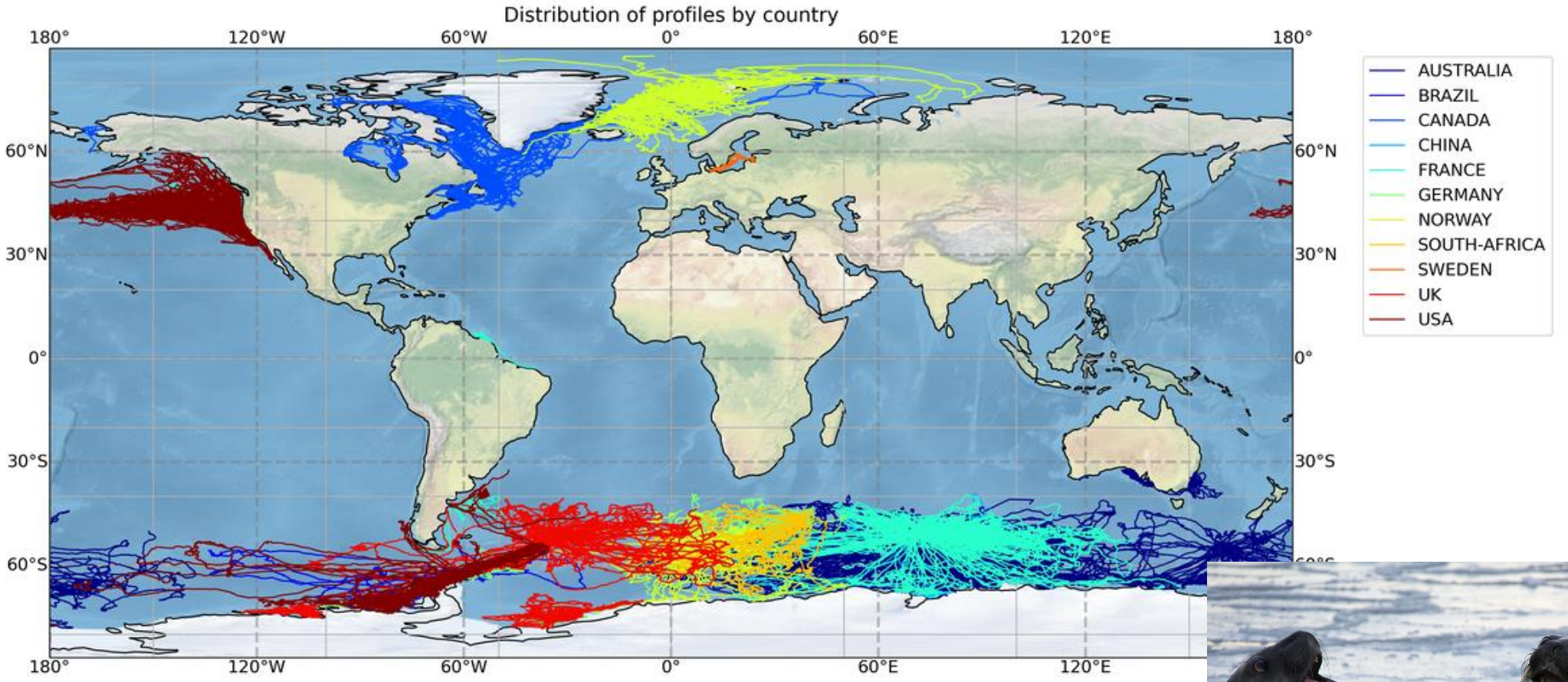
Planned deployments
27 planned
Yellow: Floats
Blue: Sections/stations

Previous deployments
268 deployed; 129 active
Red: trajectories
Orange: current active
Cyan: last dead

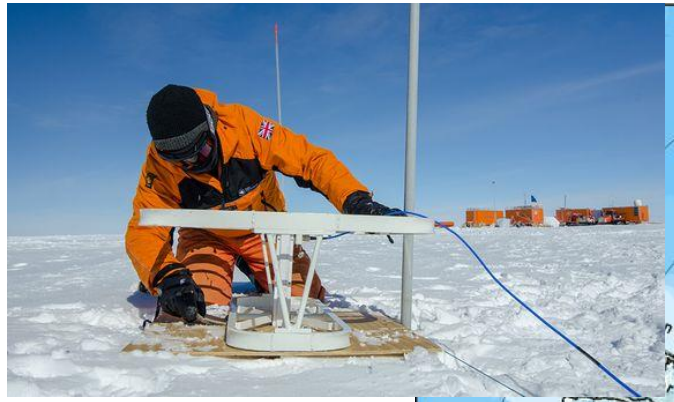
July 28, 2023

Lynne Talley, pers comms.

ANOmal Borne Ocean Sensors (formally MEOP)



Ice shelf monitoring jewellery – NECKLACE and RINGS



Keith Nicholls, pers comms.

CASE STUDY: OCEAN:ICE

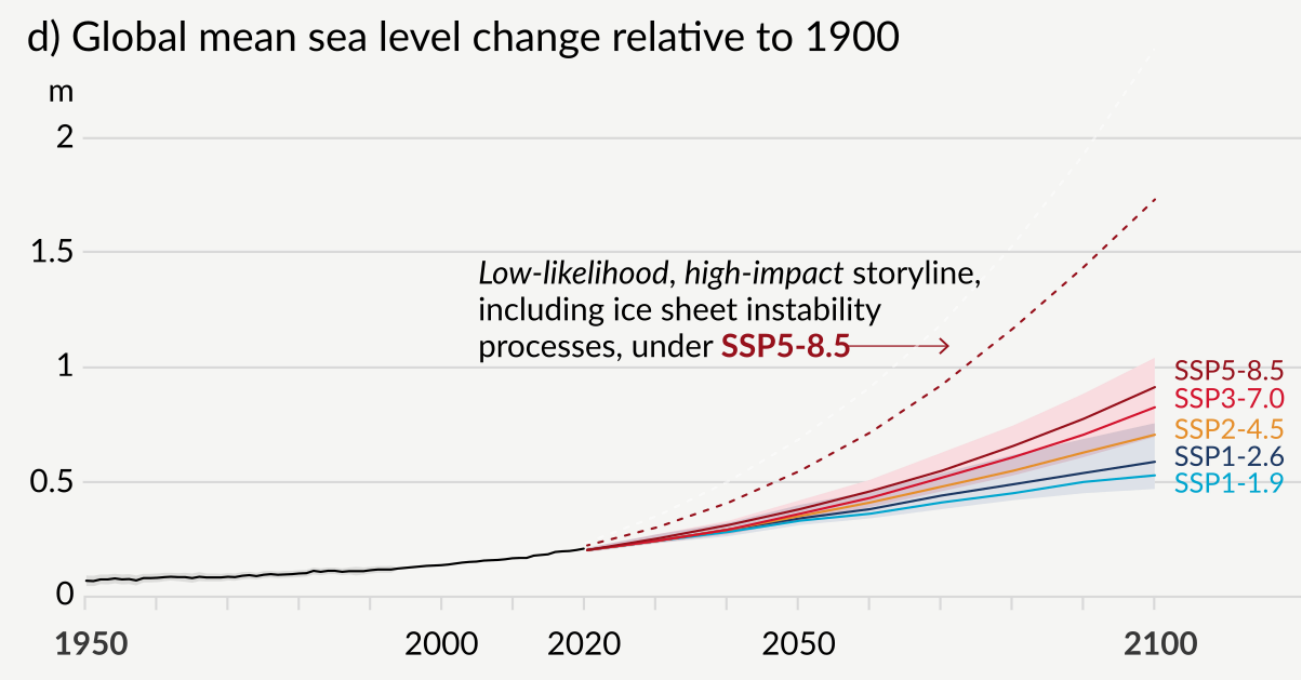
OCEAN:ICE

OCEAN-CRYOSPHERE EXCHANGES IN ANTARCTICA: IMPACTS ON CLIMATE AND THE EARTH SYSTEM

A 4 year (Nov 22) Horizon Europe programme involving 17 centres, ~€8 M funding (inc. UKRI co-funding)

DMI (COORDINATOR), BAS (CO-COORDINATOR) EPB, CNRS, AWI, NORSE, PICR, ETT, U.UTRECHT, U.READING, U.NORTHUMBRIA, U.BRISTOL, U.SOUTHAMPTON, U.BRUSSELS, U.GOTHENBURG, ENS-LMD & NPI

Impact of Antarctic and Southern Ocean processes and feedbacks on planet Earth



IPCC AR6 sea level projections

Circumpolar estimates of ice sheet freshwater flux are a critical unknown for coupled climate modelling, and a barrier to effective inclusion of active ice sheets in CMIP class models, or defining boundary conditions for MIP experiments.

- Key takeaway from IUGG 2023 IACS/IAPSO Joint Commission on Ice-Ocean Interactions discussion meeting

OCEAN:ICE is co-funded by the European Union, Horizon Europe Funding Programme for research and innovation under grant agreement Nr. 101060452 and by UK Research and Innovation

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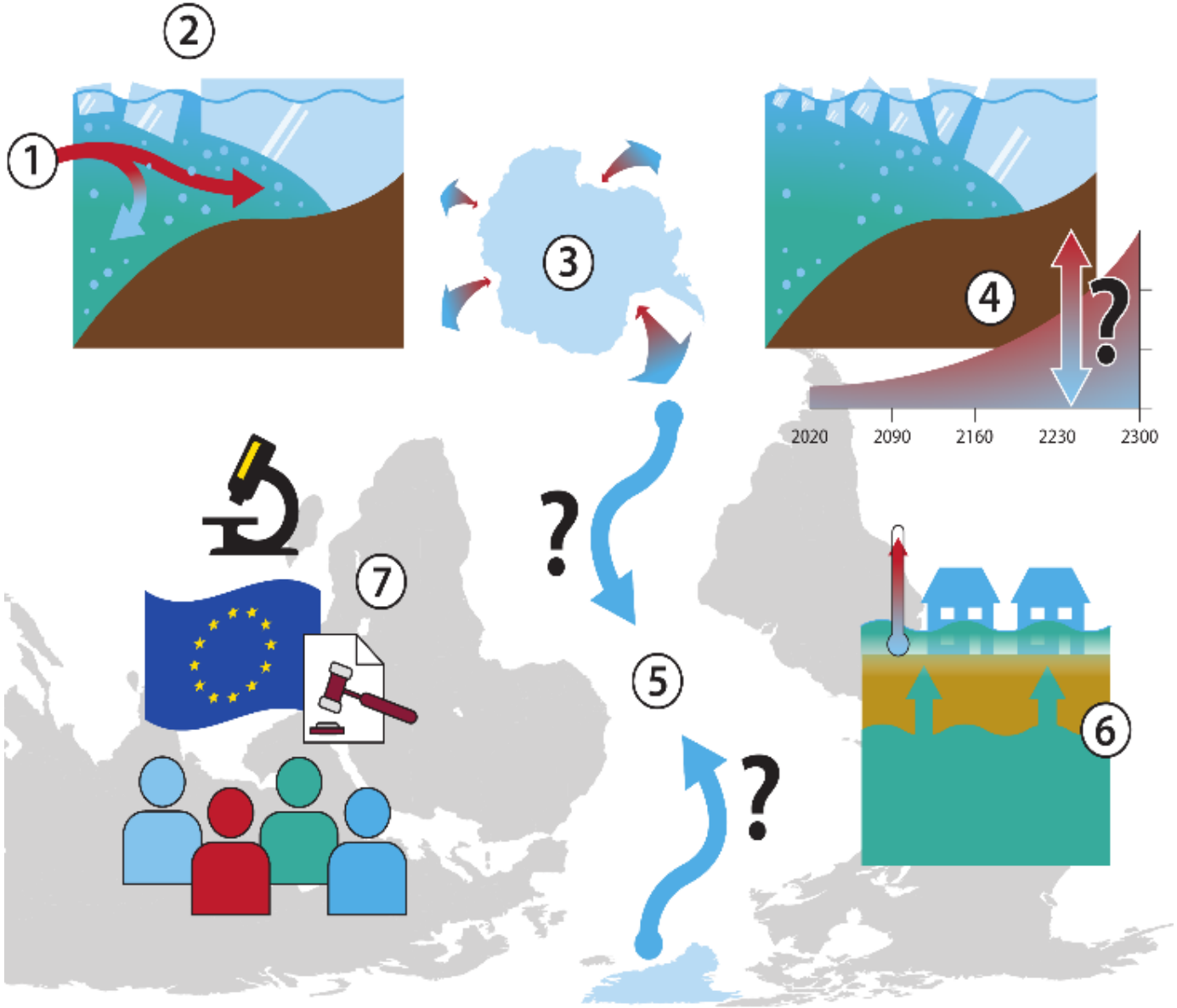
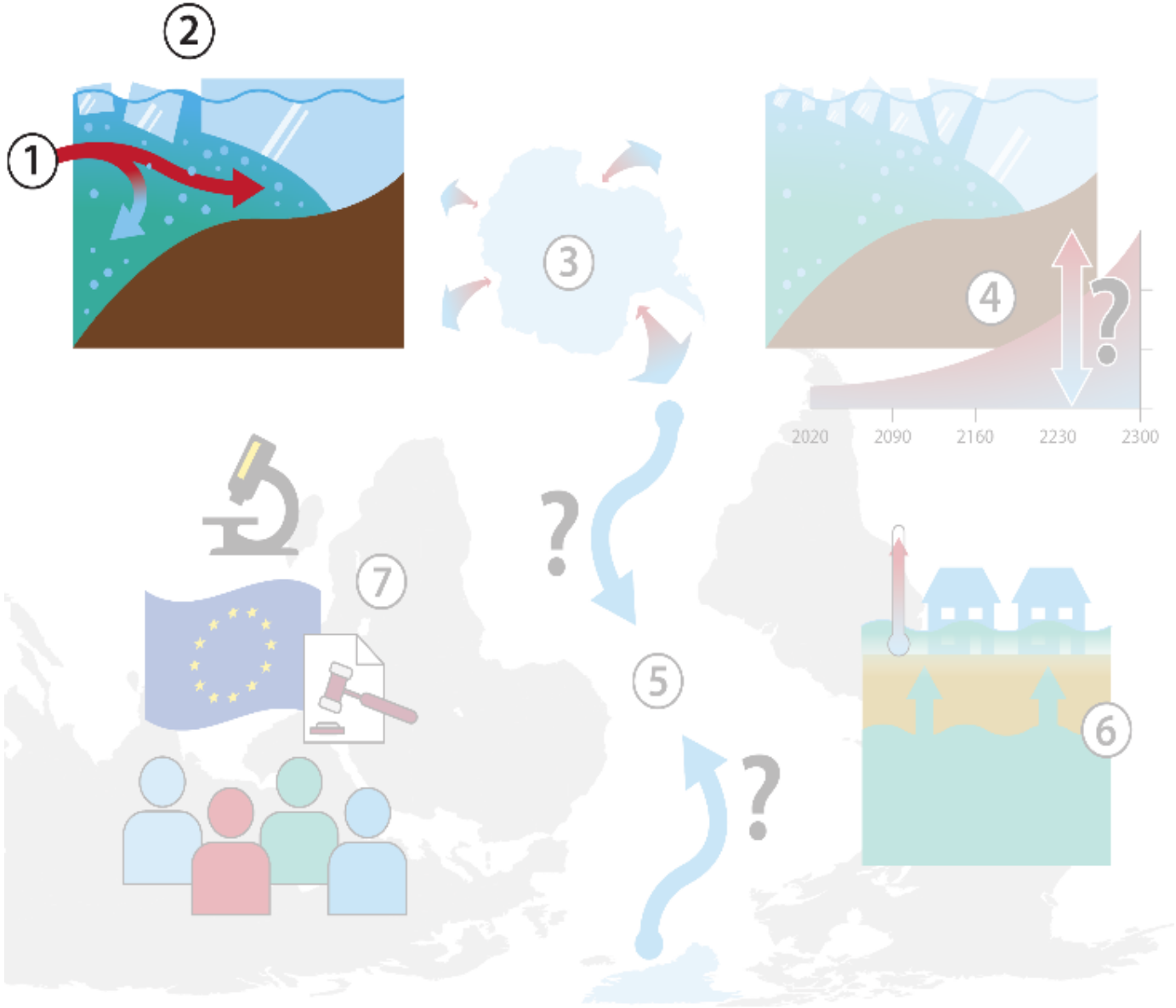


Impact of Antarctic and Southern Ocean processes and feedbacks on planet Earth



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- 2: Ice shelf dynamics, supporting;

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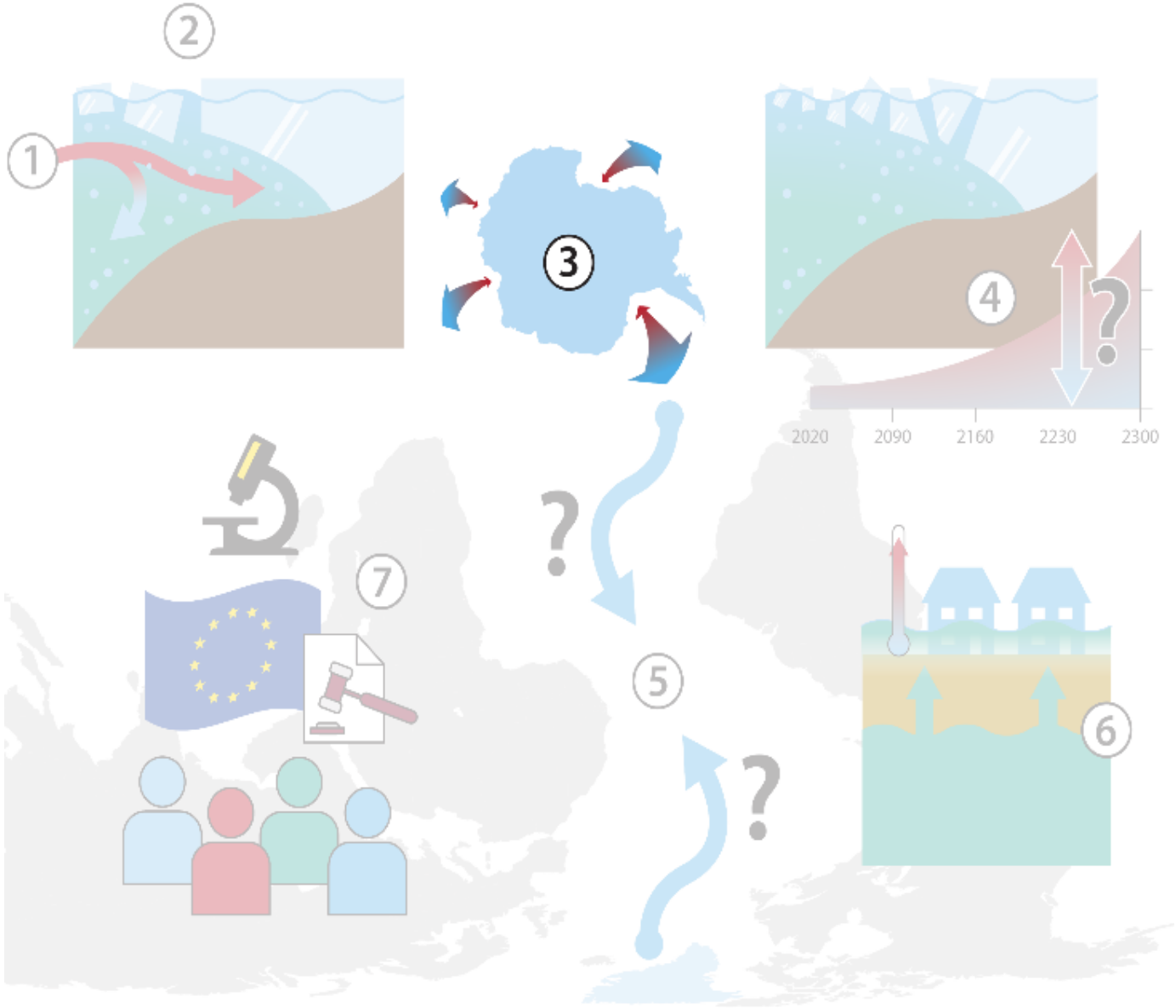

- 1: Examine interaction of subpolar ocean and heat delivery to;
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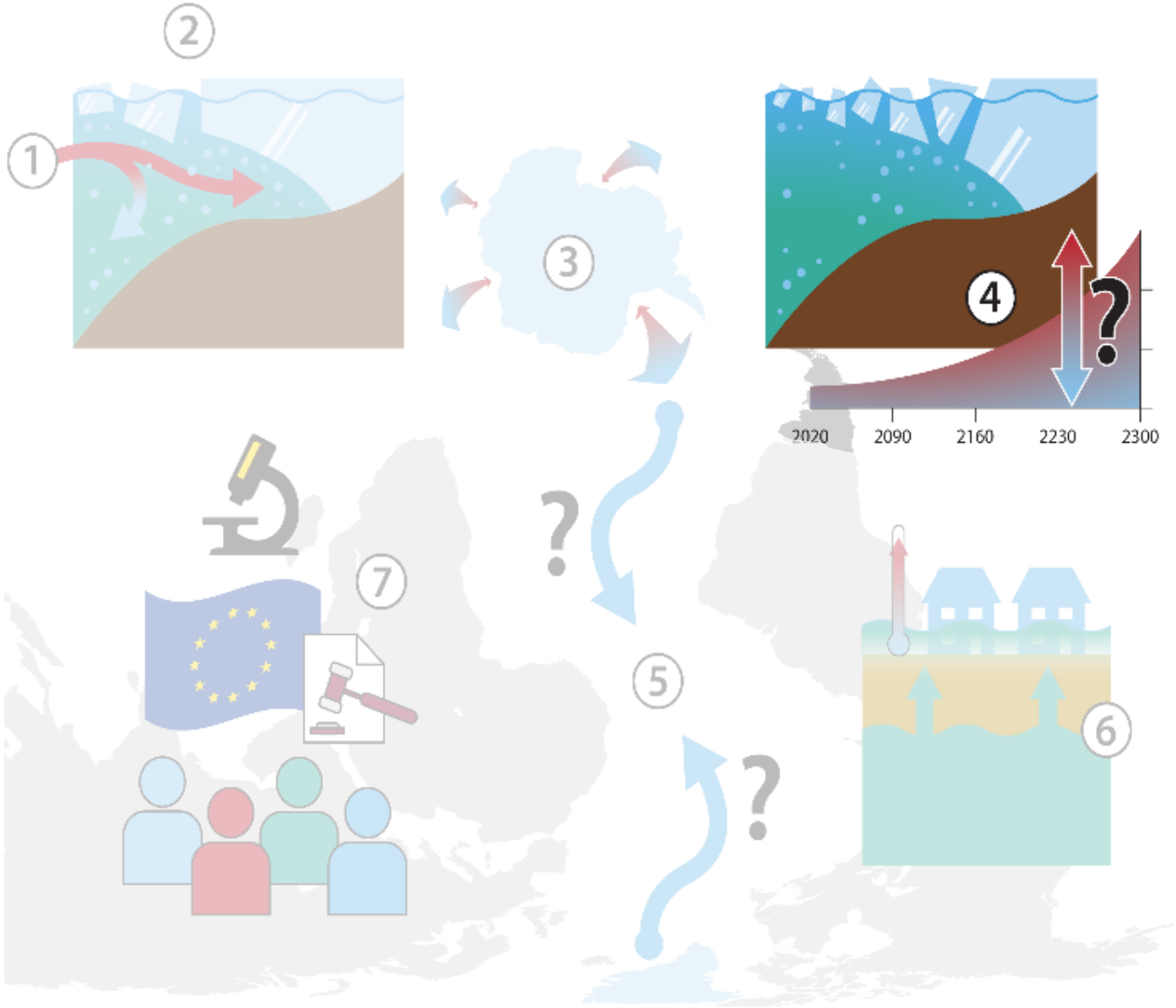

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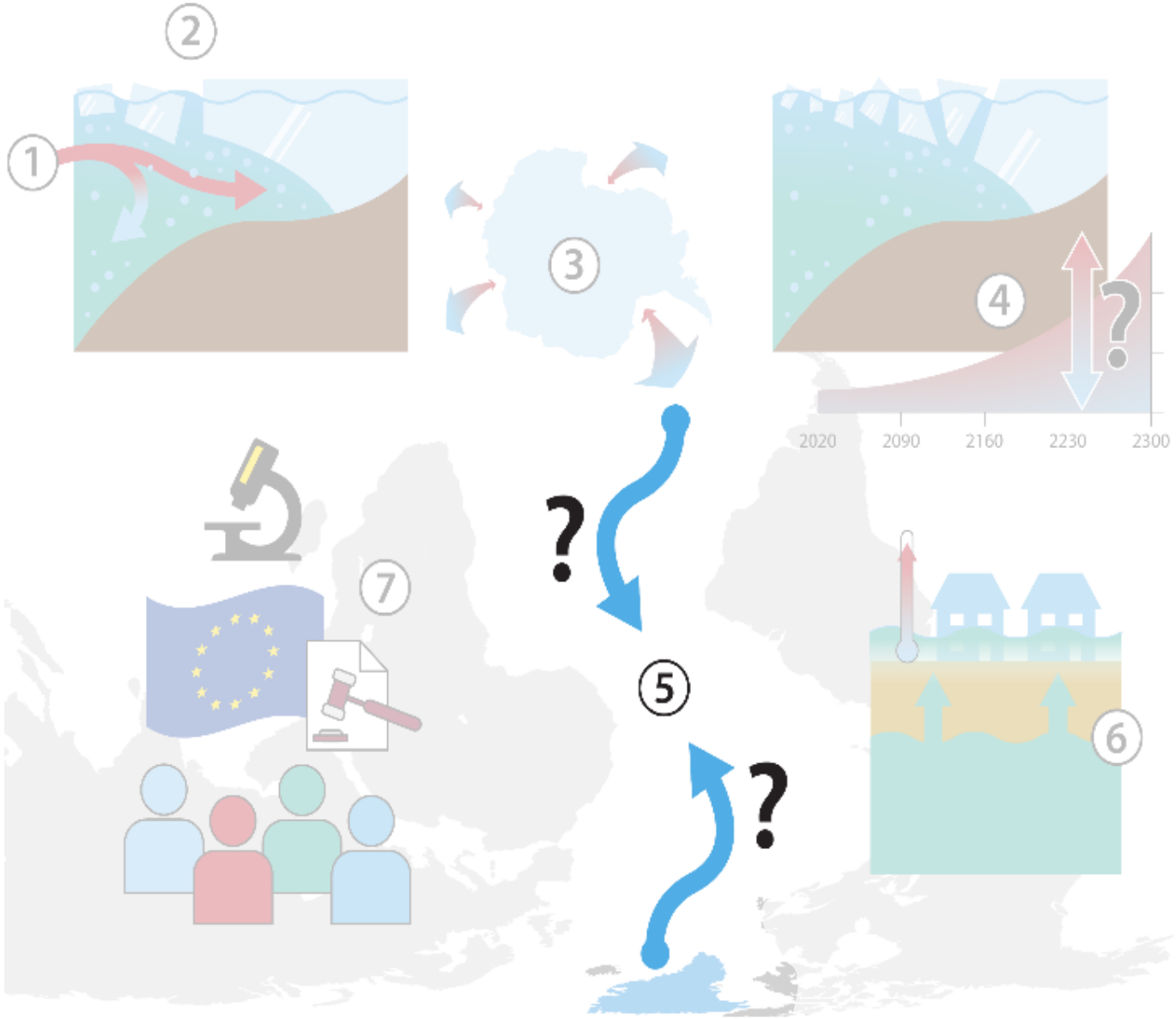

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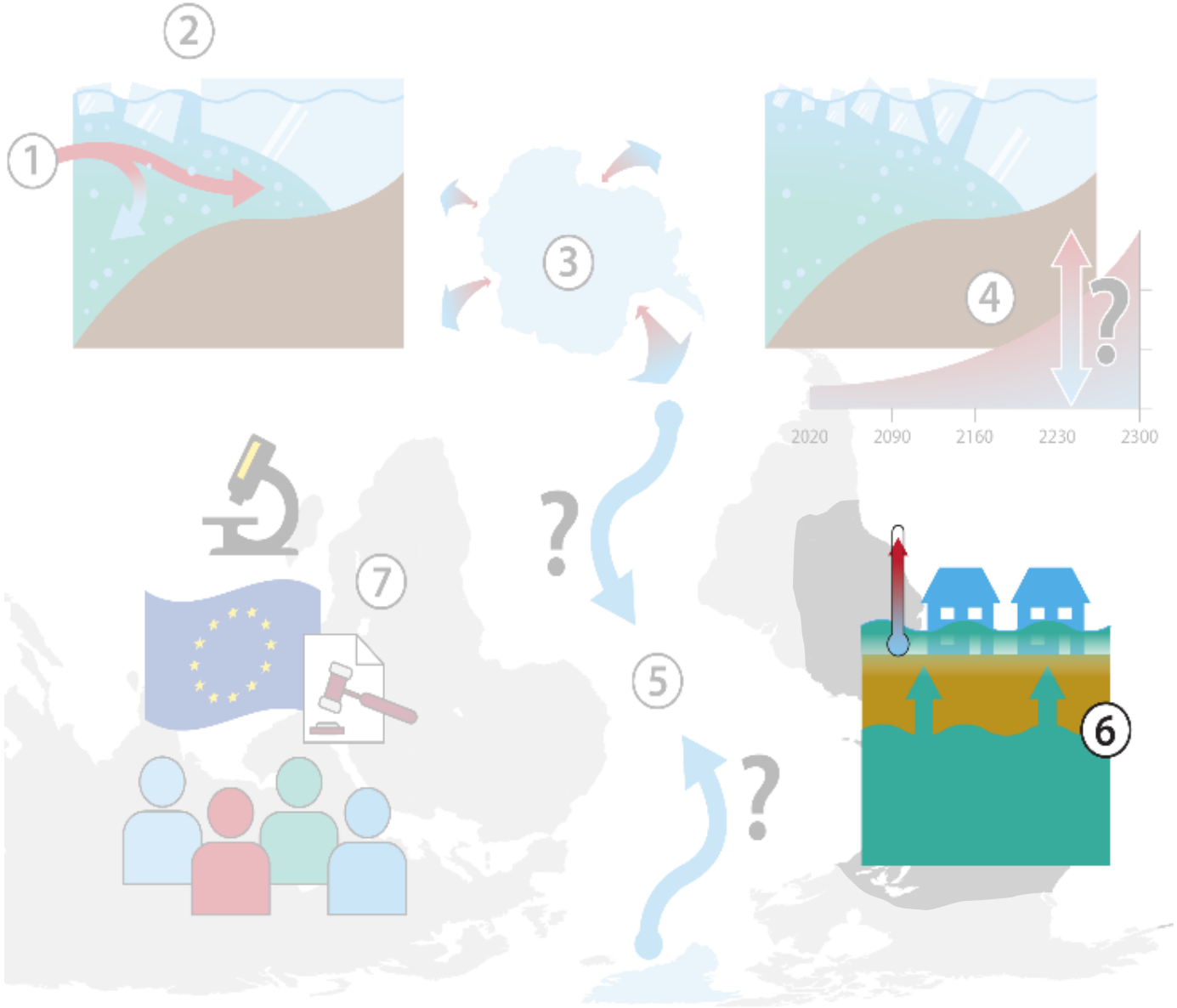

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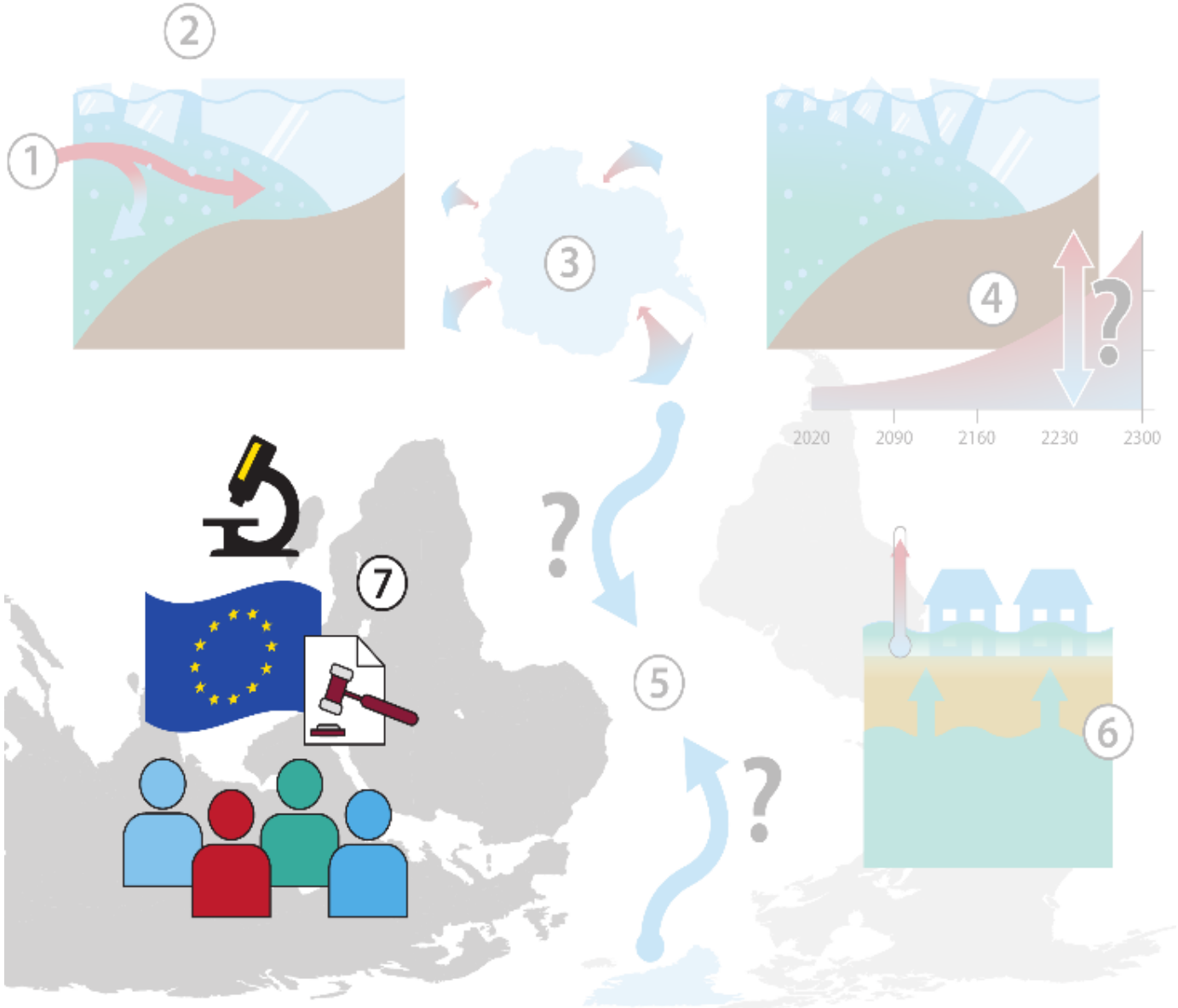

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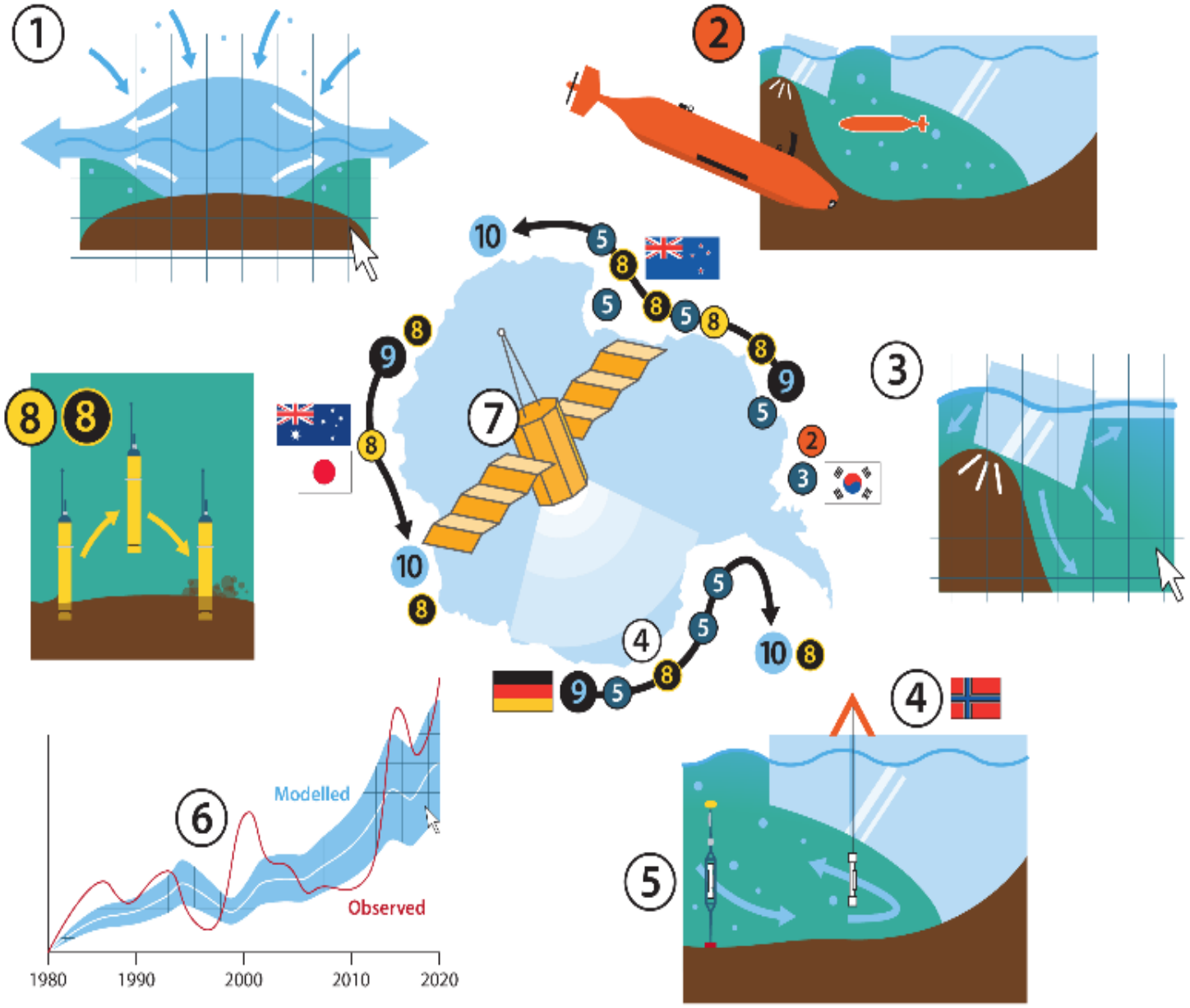
- 6: Modelling of ocean-ice feedbacks and impact on climate; which informs;
- 7: Climate assessments and advice to policymakers and public

Antarctic research elements



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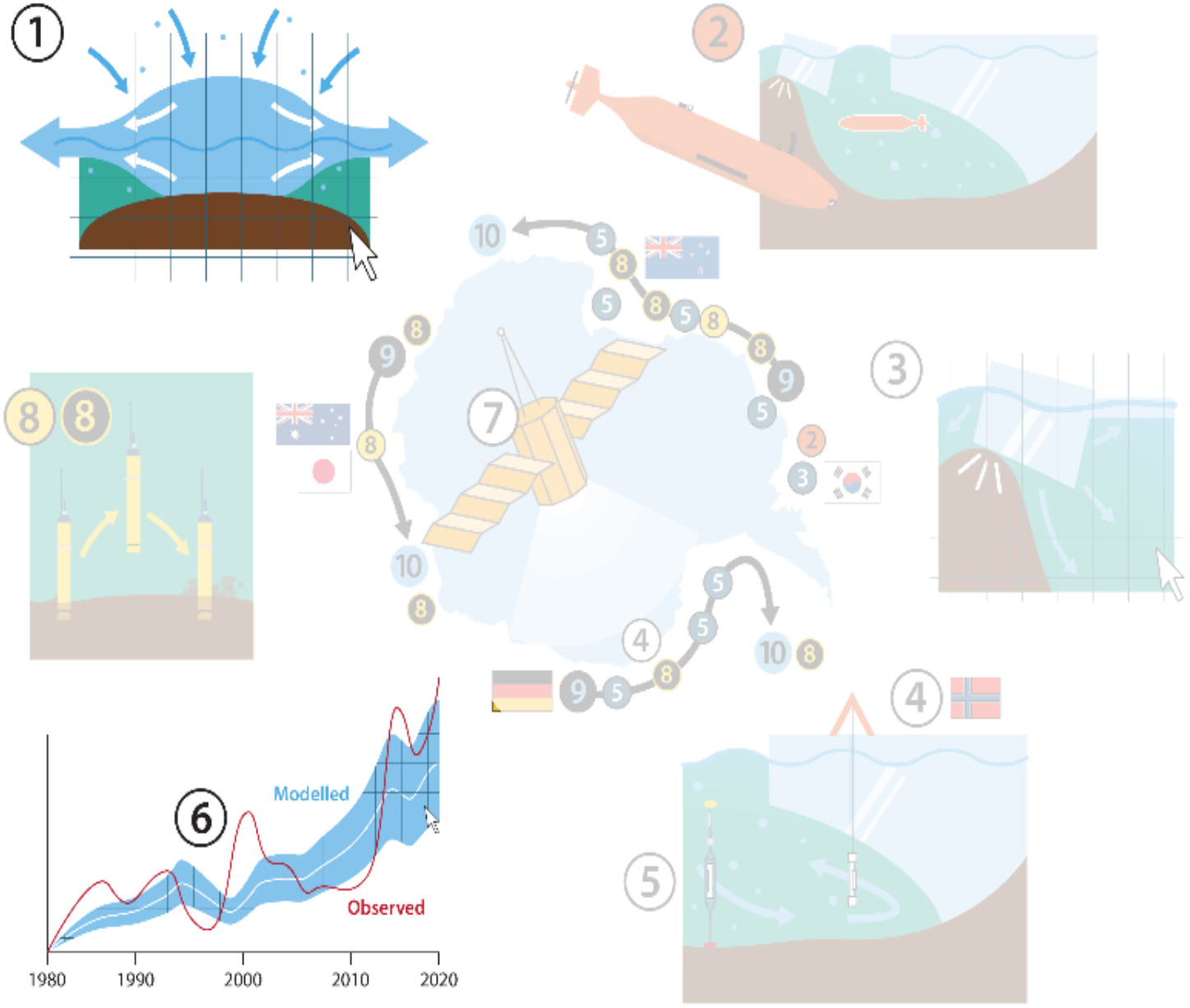
Antarctic research elements



1,6: AIS mass balance and freshwater flux modelling combining surface runoff, blowing snow and basal melt of grounded ice sheet to provide hindcast of recent past and present freshwater fluxes (WP3)

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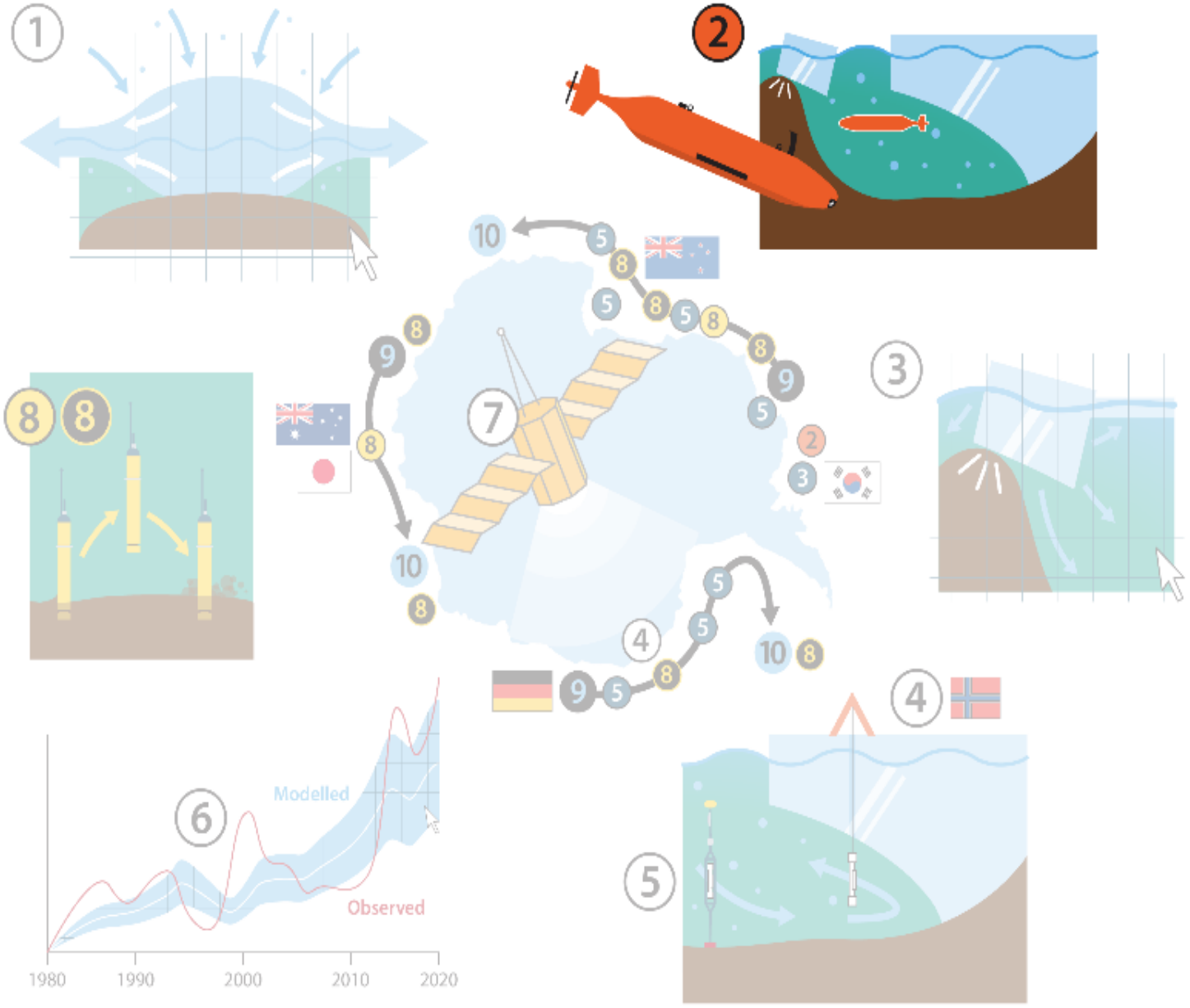

2: AUV deployments beneath West Antarctic Peninsula (warm) ice shelves and around grounded icebergs observing dynamics of heat delivery, basal melt and iceberg-ocean-sea ice interaction (WP2)

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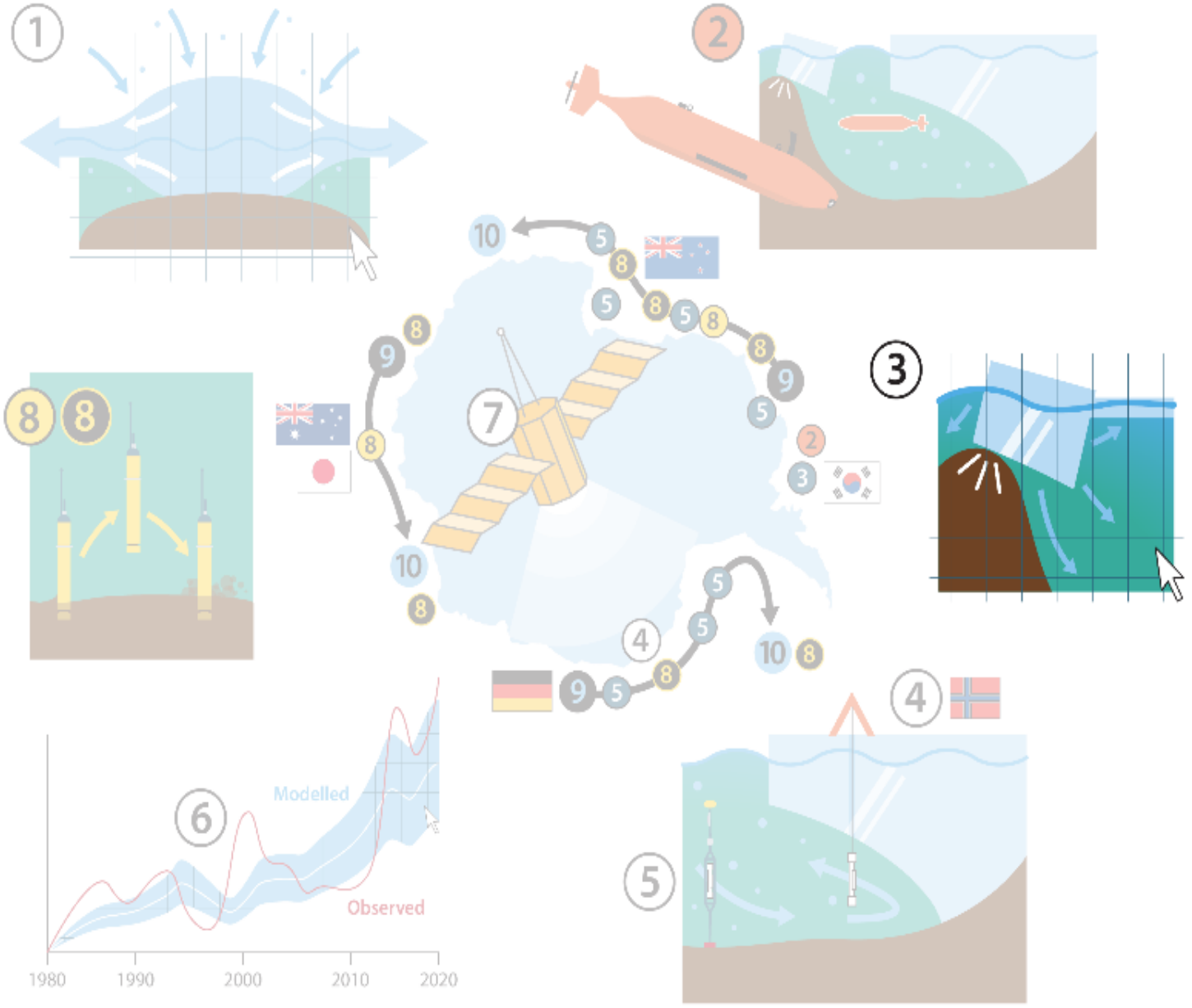

3: Model code development (NEMO) to allow iceberg interaction with bathymetry and sea ice. Improved freshwater distribution, polynya development and ocean feedbacks. Also inclusion of oxygen isotope tracers (WP2).

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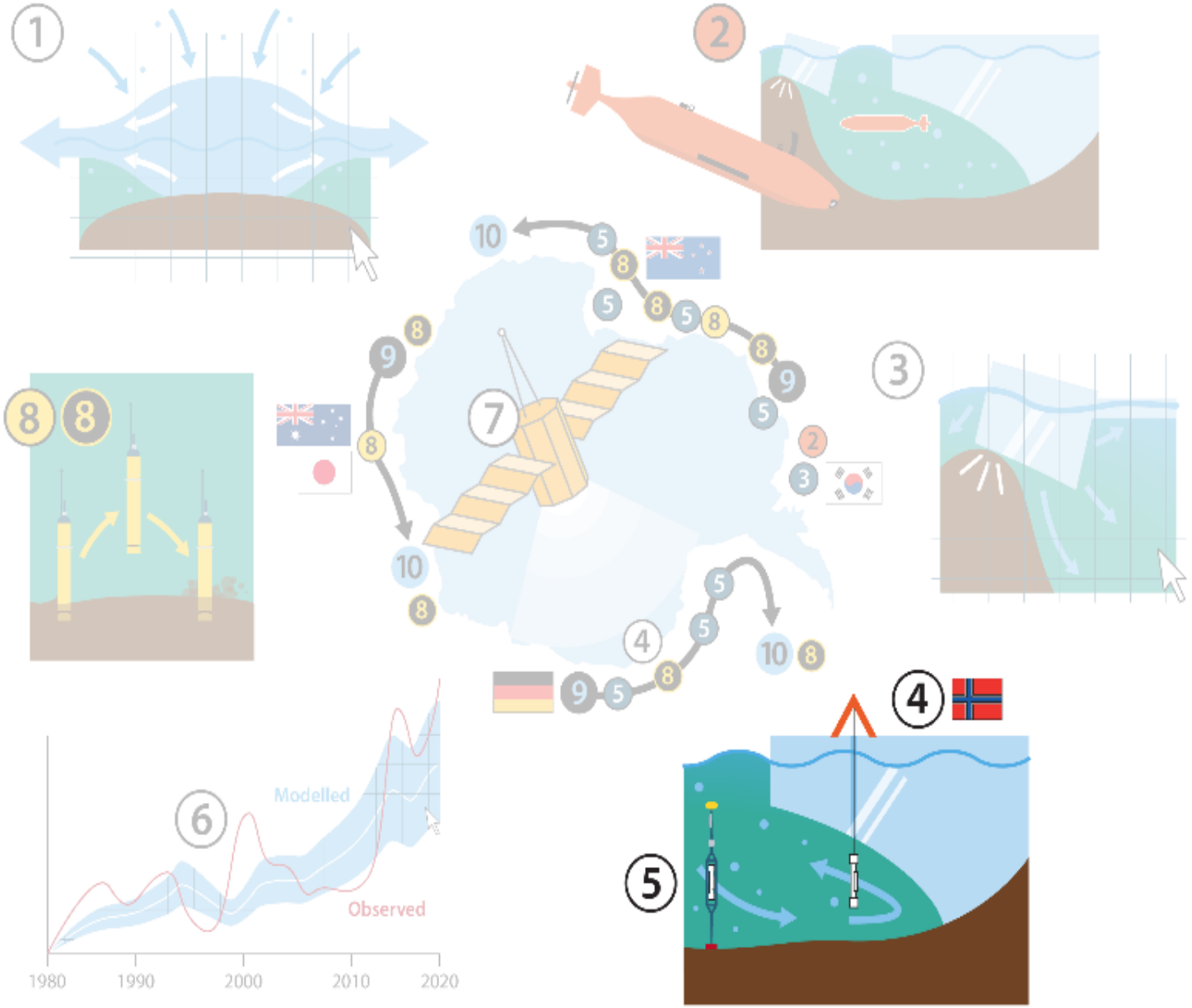

4: Direct measurements of basal melt/refreeze, circulation and mixing beneath Fimbul Ice shelf (cold ice shelf, WP2), including continuous oxygen isotope measurements

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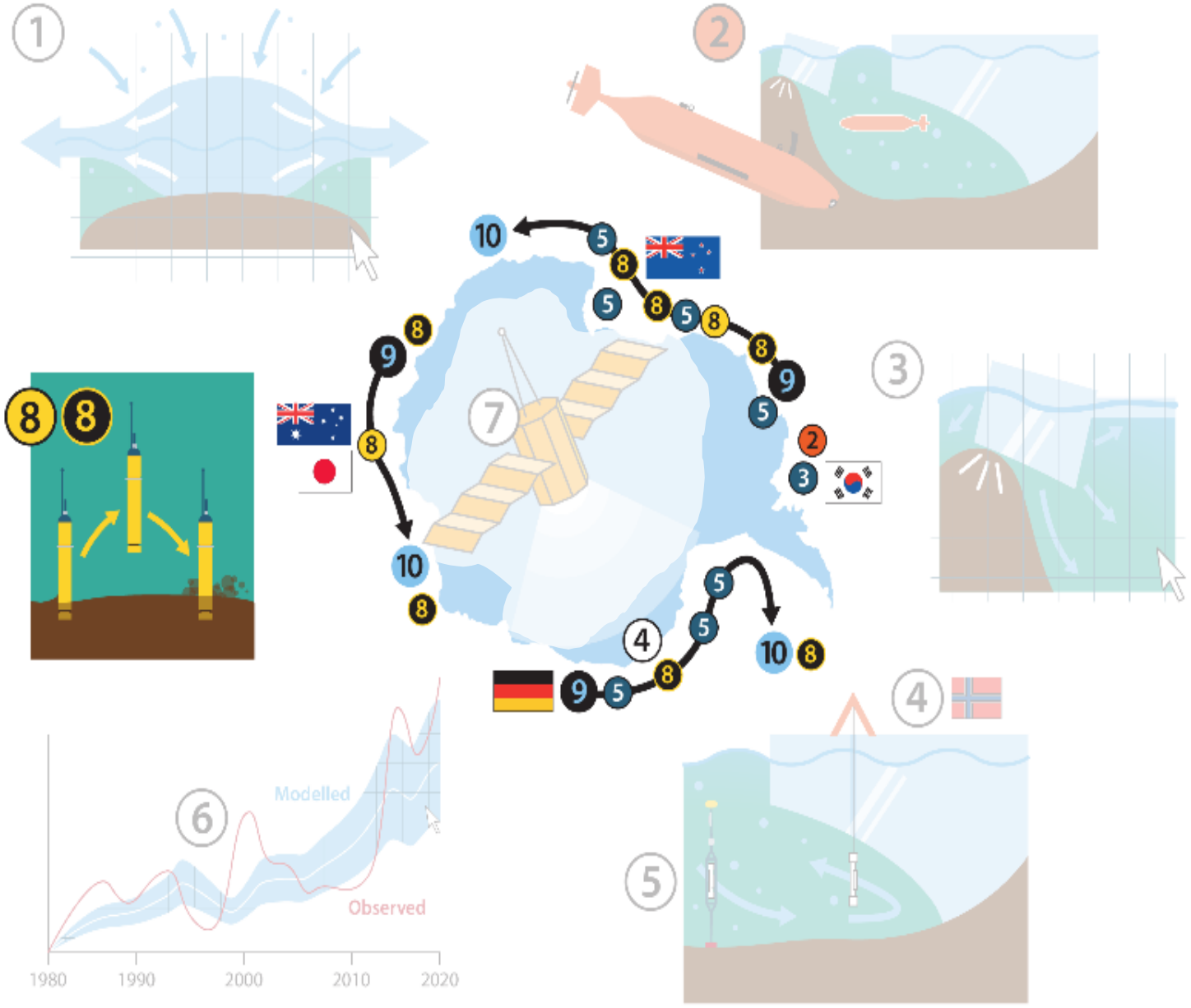

5: Mooring and instrument additions to existing deployments investigating advection between regions of key ocean-ice interaction (9-10) complimented by ‘mud Argo’ (8) virtual moorings where traditional moorings unavailable (WP1). Cf FESOM.

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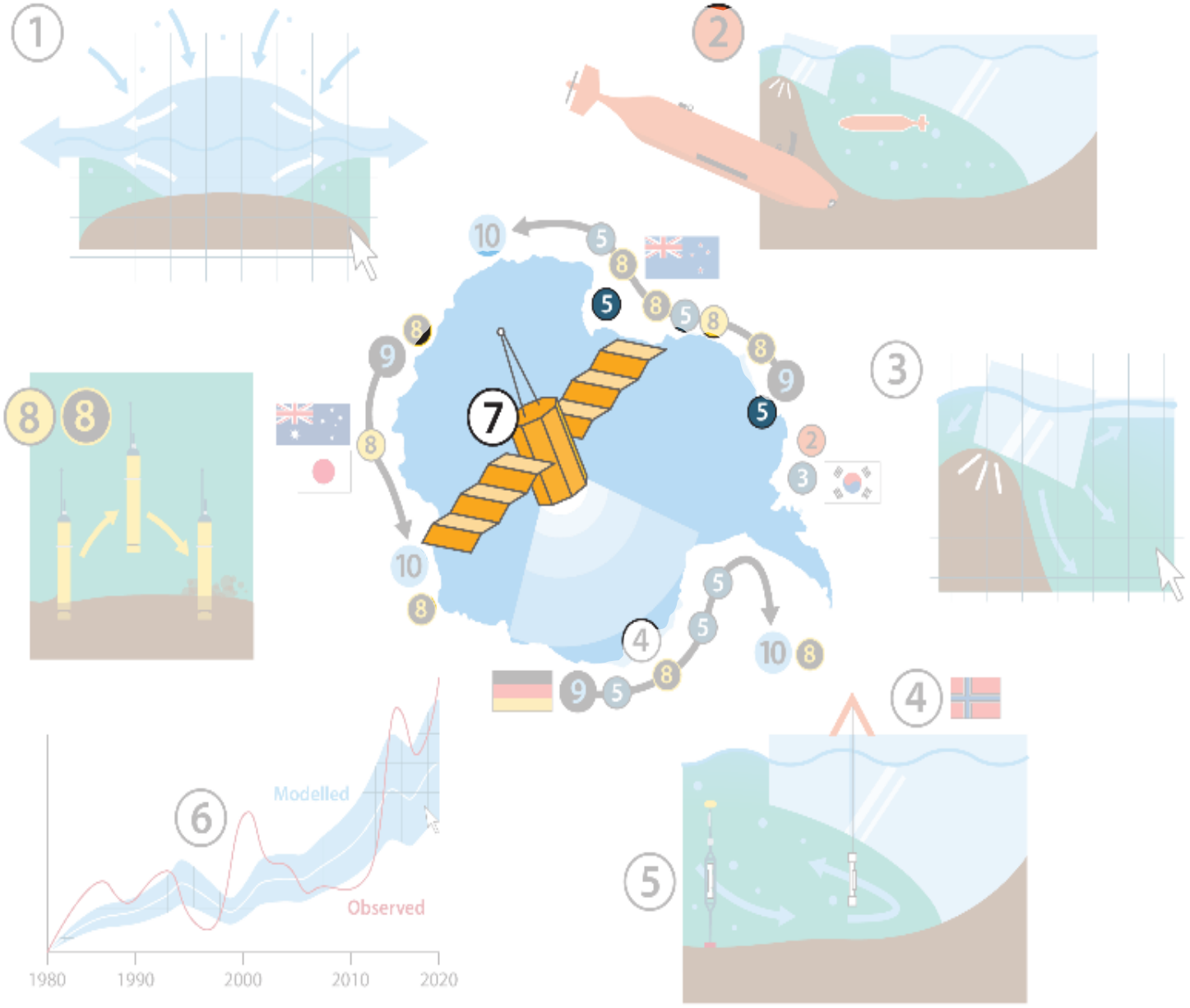

7: EO datasets used to develop new products for of sea ice production (WP1); monitor shelf circulation (WP1); derive melt lake depths over AIS (WP3); and build bespoke consolidated datasets of surface ice damage and calving front locations (WP3).

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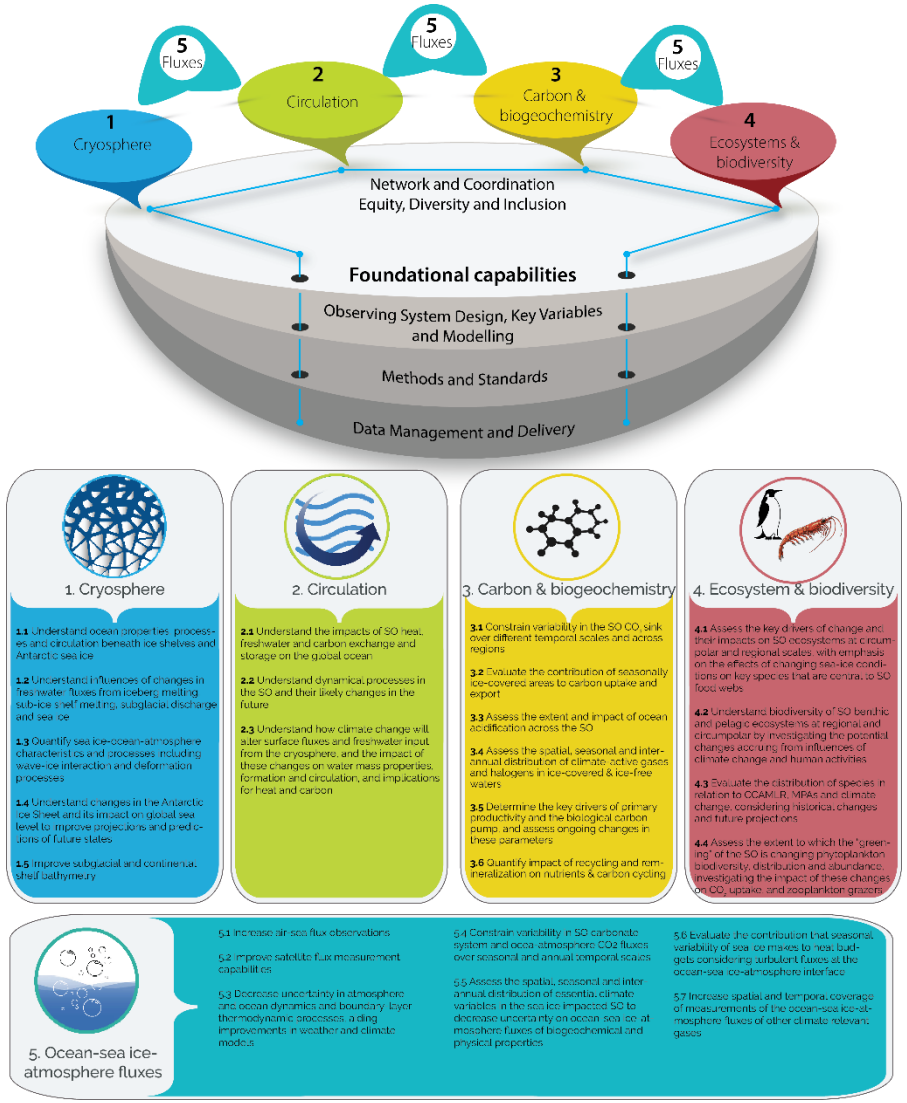
SOOS – UNDERPINNING CIRCUMPOLAR COLLABORATION

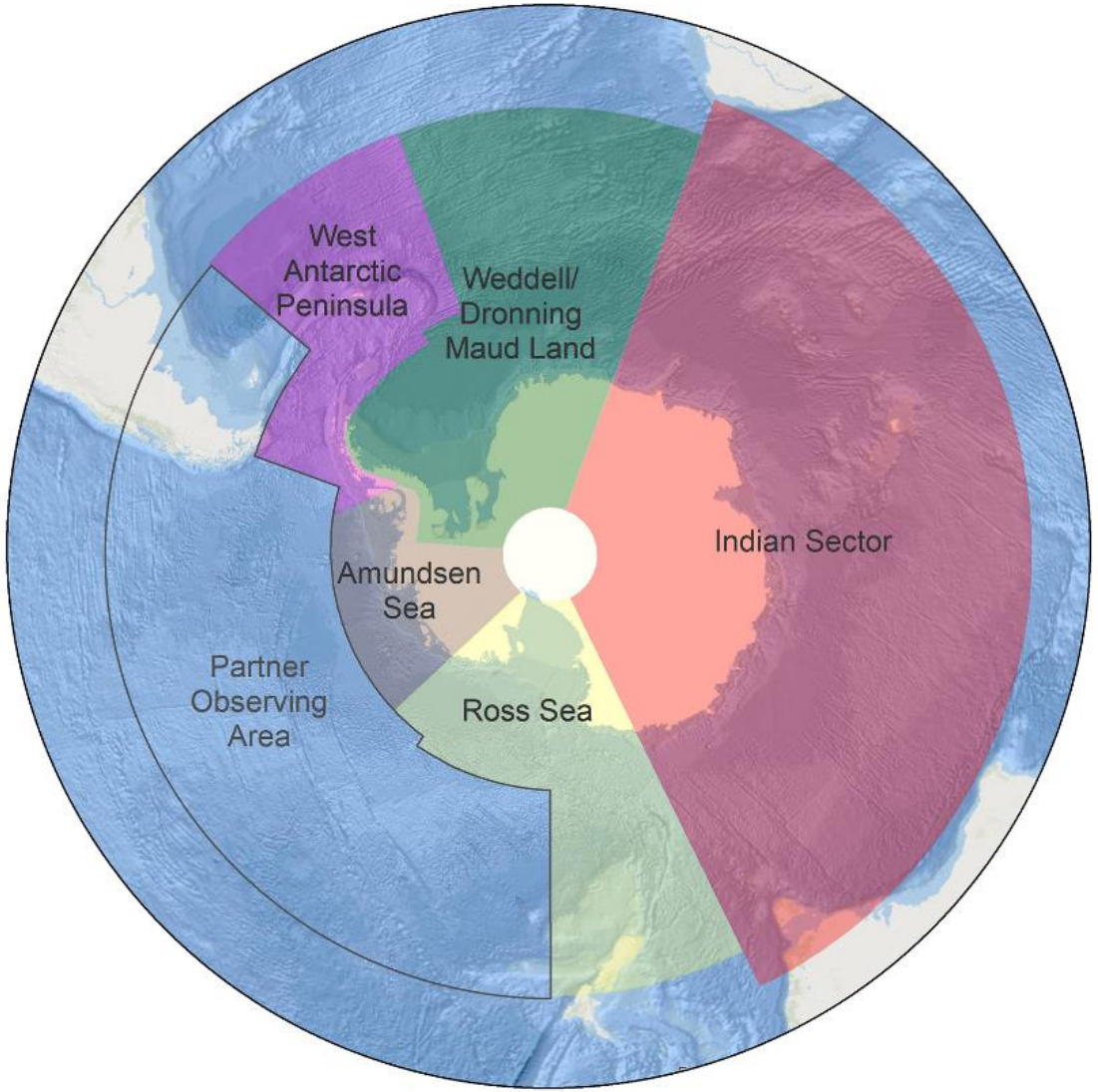
SOOS – coordinating priorities, integrating existing data, and providing forums for collaboration



- A multinational platform for grass roots scientific coordination of scientific priorities, methods and standards, knowledge/data sharing and scientific advocacy.

SOOS 2021-2025 Science and Implementation Strategy

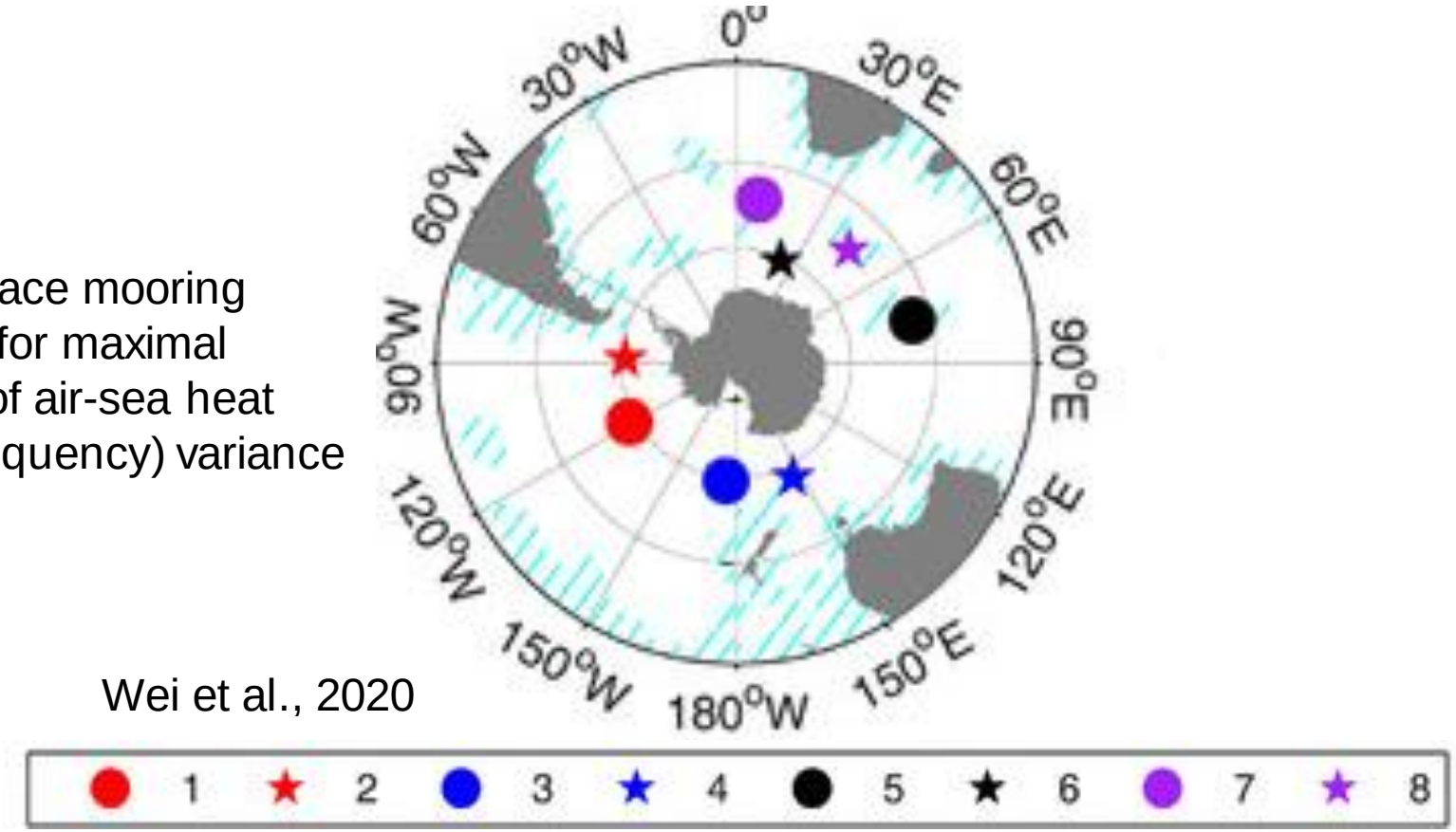
SOOS – coordinating priorities, integrating existing data, and providing forums for collaboration



- SOOS regional working group areas, coordinating activities and supporting collaboration regionally – Get involved!

SOOS *in situ* observation capability working groups

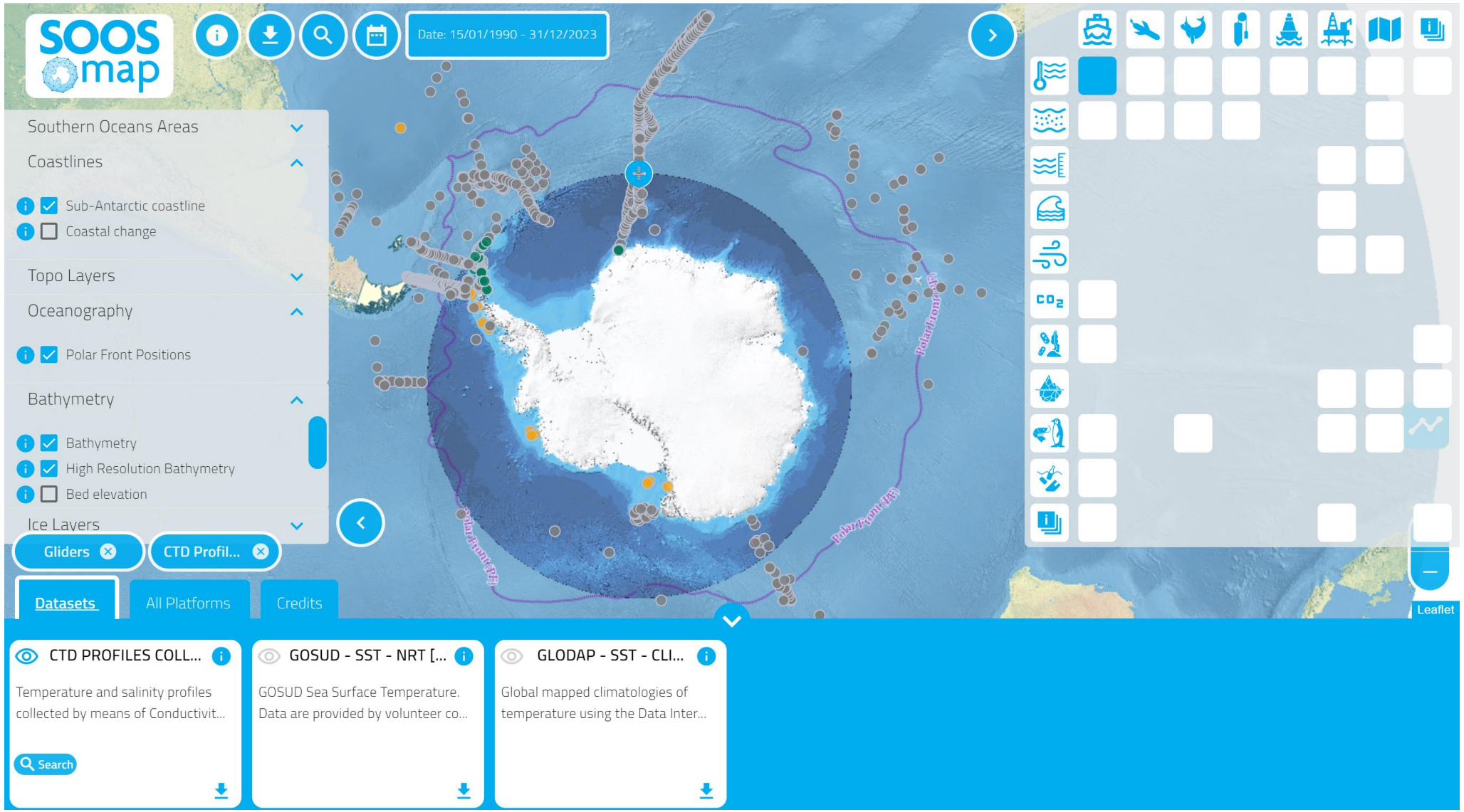
Optimal surface mooring placements for maximal description of air-sea heat flux (high frequency) variance



Wei et al., 2020

- Observing system design (OSD) – prioritising, optimising and coordinating observations.
- Southern Ocean Air-Sea Fluxes (SOFLUX) – A critical data gap.

SOOSmap2: Capturing disparate data streams and consolidating them in one FAIR (Findable, Accessible, Interoperable and Reusable) framework



Summary

- The size and complexity of the Southern Ocean means **coordinated, multi-national efforts are needed** to produce coherent circumpolar assessments.
- Some properties and budgets are now well defined, **but sustained effort is needed** to maintain timeseries/coverage.
- Critical gaps exist, particularly in the **deep ocean, in winter, under the ice, in the carbon cycle and in ice sheet-ocean interactions**.
- **Regional and process studies are important**, but must be done with circumpolar context in mind, and **integrate with other data and models**.
- **SOOS is invaluable** in coordinating scientific priorities, methods and advocacy.

Where next?

- The **autonomous revolution** is here.
- **Challenge in compiling and integrating** high resolution data provided by disparate groups, short term projects and rapidly evolving sensors.
- **A need for (funded!) multinational projects tackling circumpolar science questions.**
- Can the **community define** the critical questions to ask?
    - The CO2 flux model-ship-float disagreement?
    - Sea ice sensitivity to ocean forcing?
    - Air-sea heat, momentum and CO2 fluxes?
    - Ice sheet <-> ocean heat/freshwater fluxes?
- Come to the circumpolar and InSync sessions on Thursday and tell us!

These are pressing questions, and the world is watching us!

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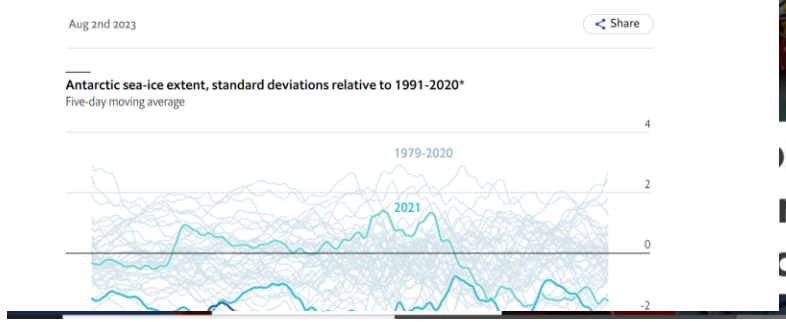
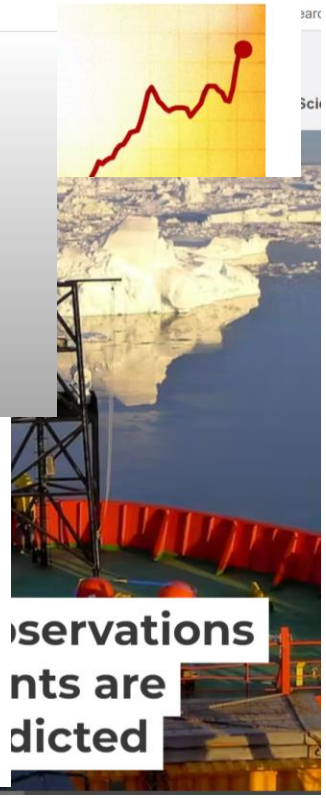
Antarctic Sea Ice Is at a 'Very Concerning' Record Low

winter in Antarctica, when sea ice cover typically grows. But year's sea ice is way behind, reaching record lows with lications for the planet.

The extent of newly exposed ocean is the size of Argentina





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