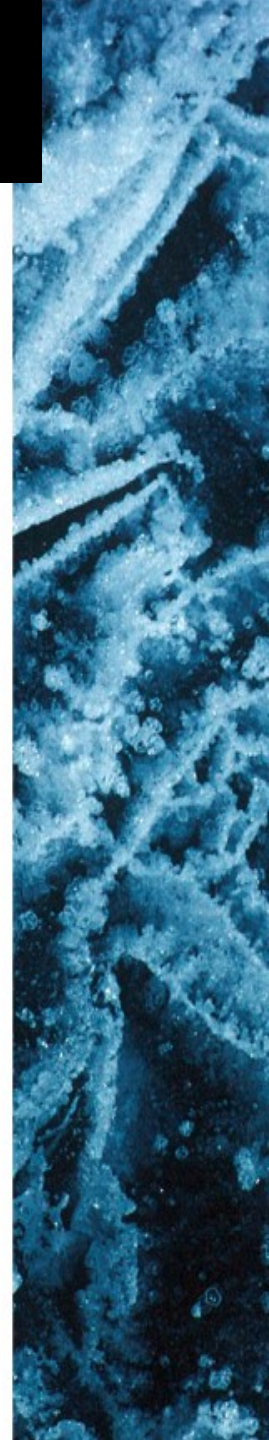
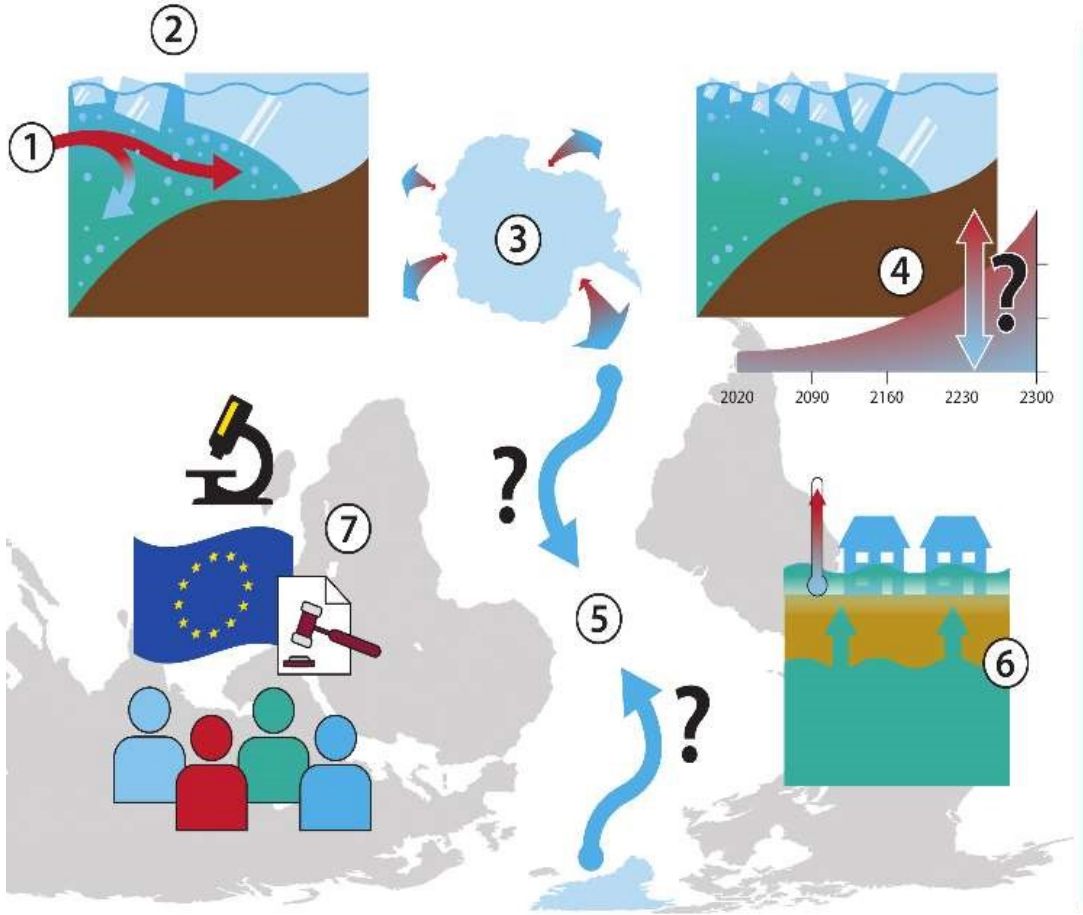
WP5 – Ice sheet impacts on global ocean circulation

ELAINE MCDONAGH & PETRA LANGEBROEK



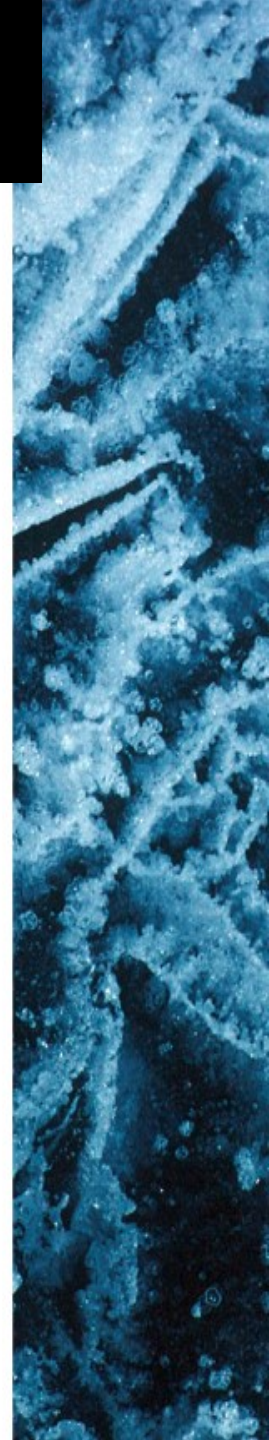
How sensitive is **ocean circulation** to changes in **freshwater fluxes** from the Greenland and Antarctic **ice sheets** ?



1. Ocean processes around Antarctica (WP1)
2. Antarctic ice sheet-ocean interactions (WP2)
3. Antarctic ice sheet modelling and freshwater fluxes (WP3)
4. Future fluxes and stability of Antarctic ice sheet (WP4)
5. Ice sheet impact on global ocean circulation (WP5)
6. Ice sheet-ocean-climate impacts and tipping points (WP6)
7. Scientifically and socially relevant impacts and dissemination (WP7-9)

How sensitive is **ocean circulation** to changes in **freshwater fluxes** from the Greenland and Antarctic **ice sheets** ?

Ocean and Earth System Models



Freshwater perturbations in ocean model NEMO and Earth System Model NorESM

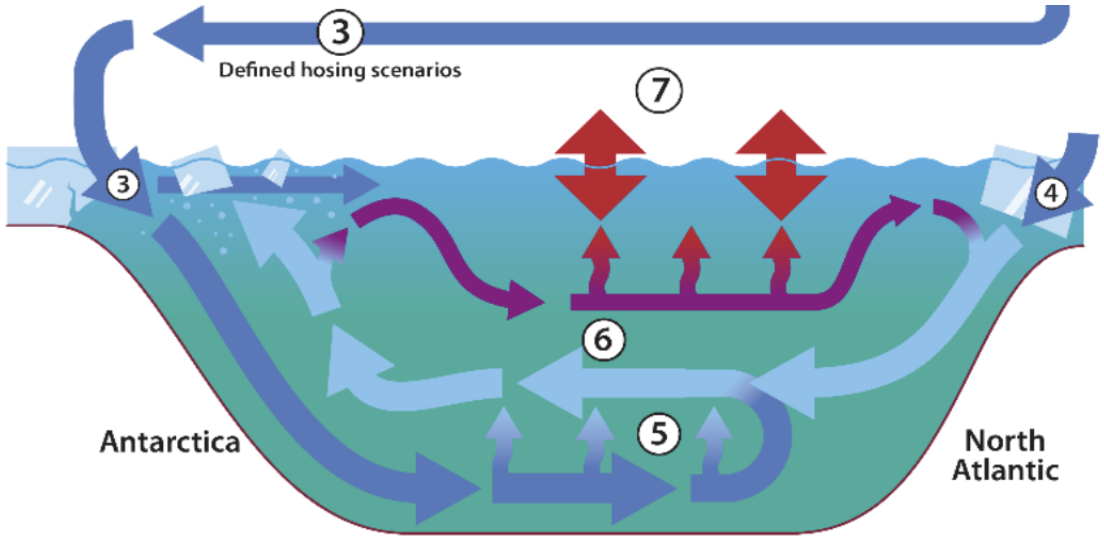


Figure 1.5: AIS freshwater flux projections and uncertainty and ocean model forcing. Section 1.2.4.3.

Freshwater perturbations

Casimir de Lavergne

Strategy:

› Long NEMO simulations at 1º resolution under climatological forcing plus freshwater perturbations.
› Passive tracers to tag and track northern and southern sourced deep waters.
› Analyse circulation and tracer changes due to freshwater perturbations.

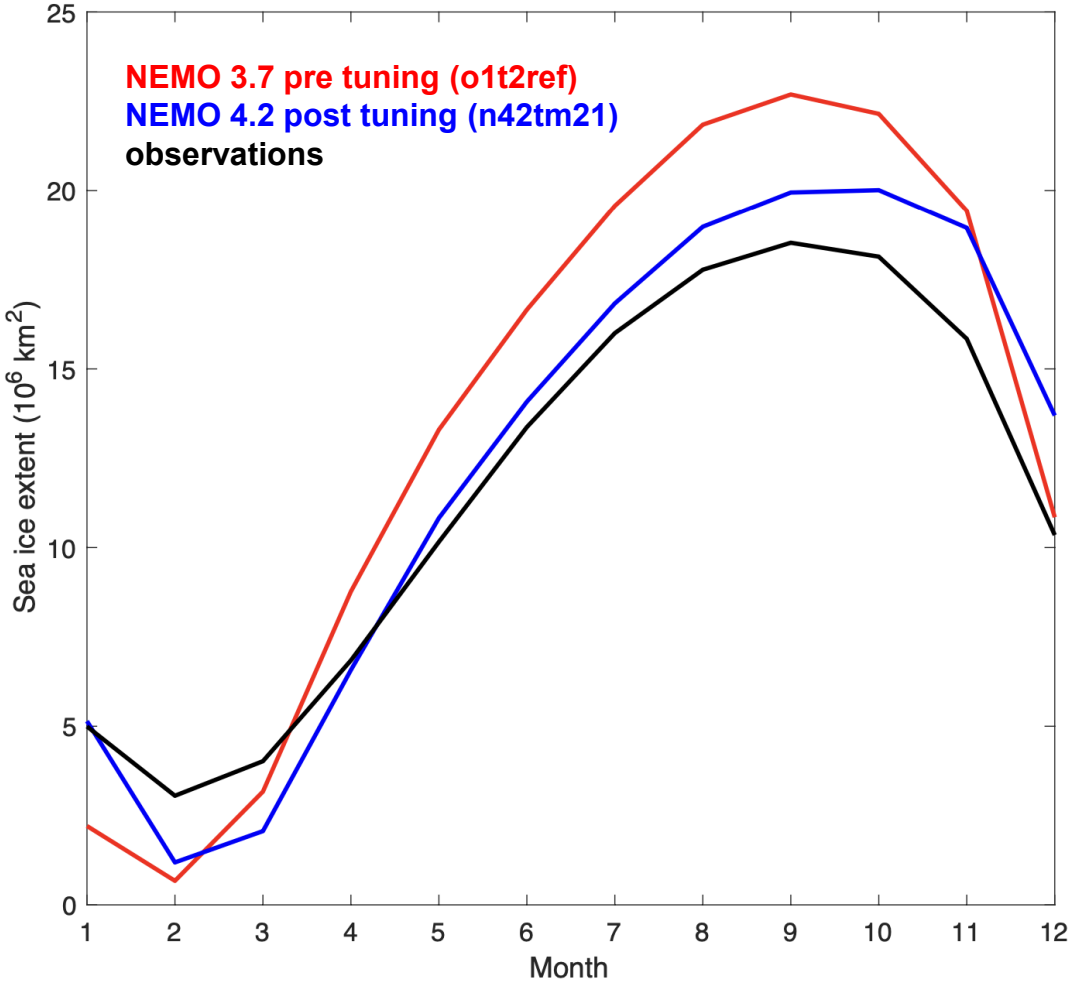
Methodology:

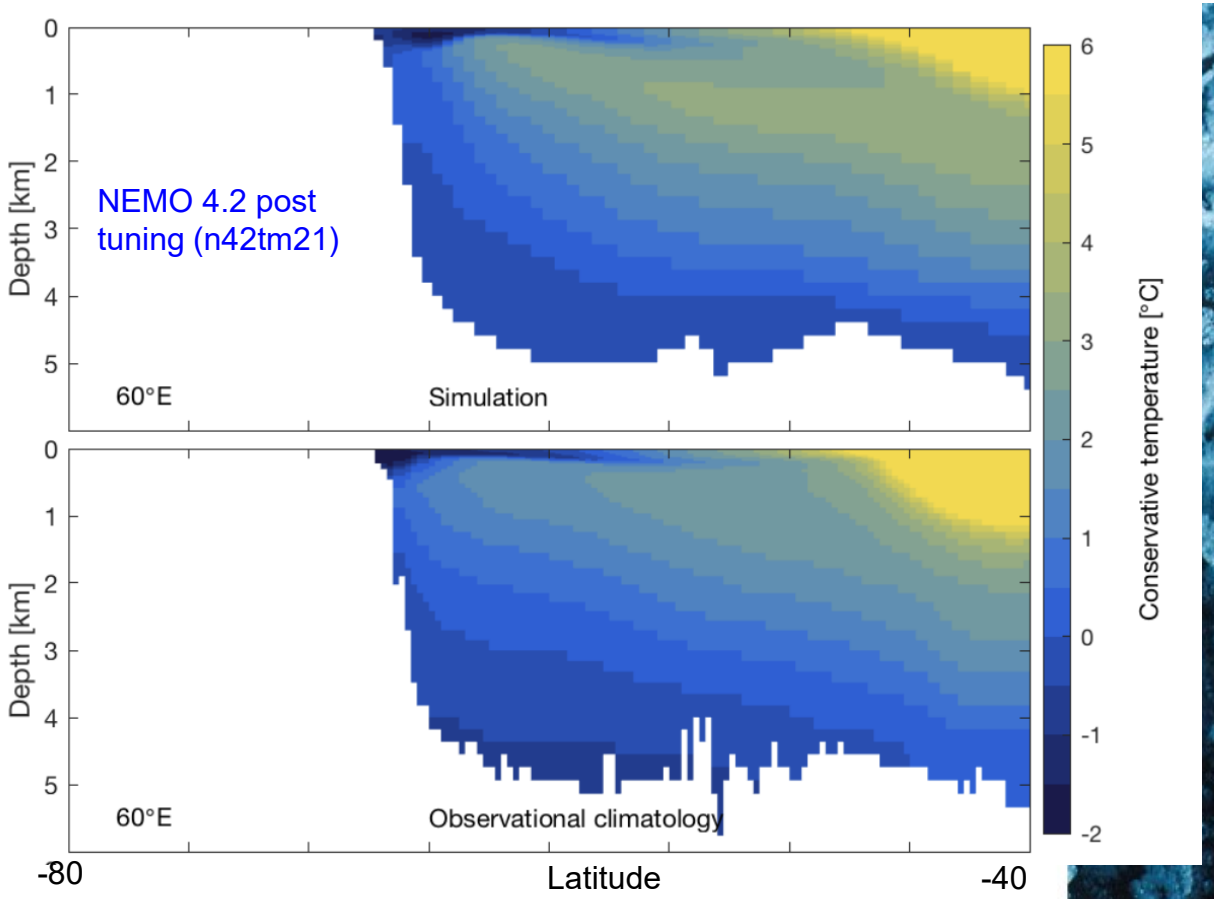
› Start from near-equilibrated NEMO simulations with COREII normal year forcing (and SSS restoring).
› Add several numerical dyes in deep water formation regions. Spin up the dye tracers offline.
› Convert the SSS restoring into a flux forcing.
› Run the model with online dye tracers for a few hundred years to obtain steady distributions.
› Run with the freshwater flux perturbation following some (extended) scenarios of ice sheet mass loss.
› Add dye tracers that track the new freshwater sources.

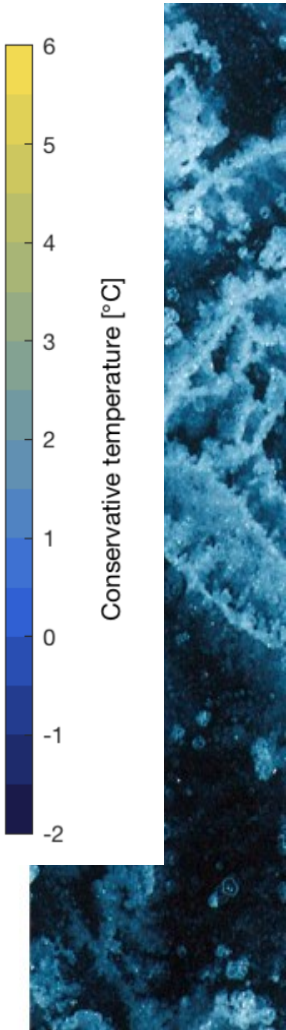
→ D5.7: Report on initialisation and verification of NEMO configuration (M30, CNRS)

Improvements & tuning

Casimir de Lavergne







→ *D5.7: Report on initialisation and verification of NEMO configuration (M30, CNRS)*

Casimir de Lavergne

Improved Southern Ocean in NEMO 1° global ocean model

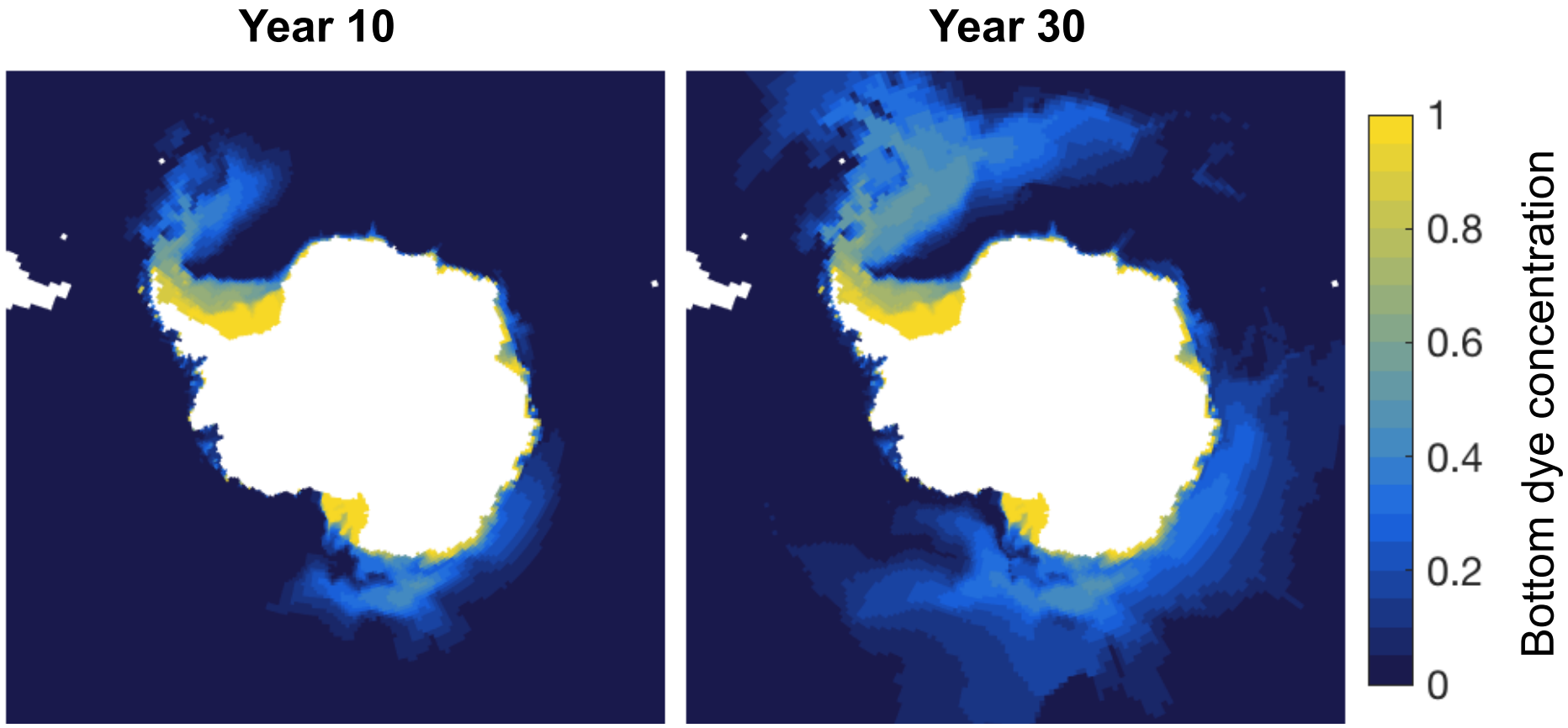
Casimir de Lavergne

S. Rathore, G. Madec, J.-B. Sallée,
A. Nasser, C. Ethé, M. Vancoppenolle

OCEAN:ICE General Assembly — October 25, 2023

A 1° NEMO configuration with shelf-formed AABW

A dye released uniformly at the surface sinks at shelf formation sites, then down the continental slope:
the model forms and exports Dense Shelf Water.

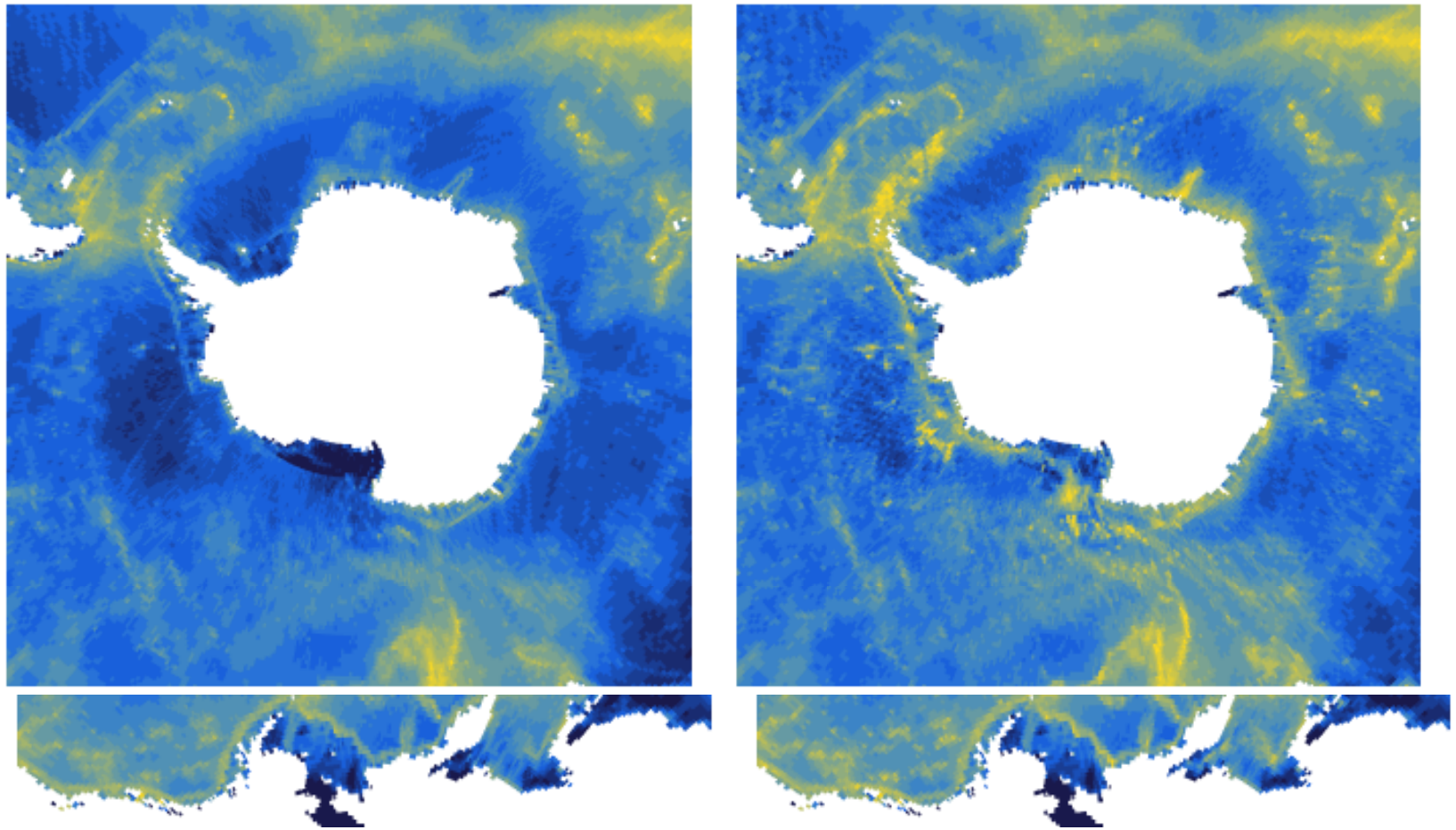


An improved tidal mixing scheme

Mixing by sub-inertial internal tides has been added. It is substantial in the Southern Ocean.

de Lavergne et al. 2020

+ sub-inertial internal tides

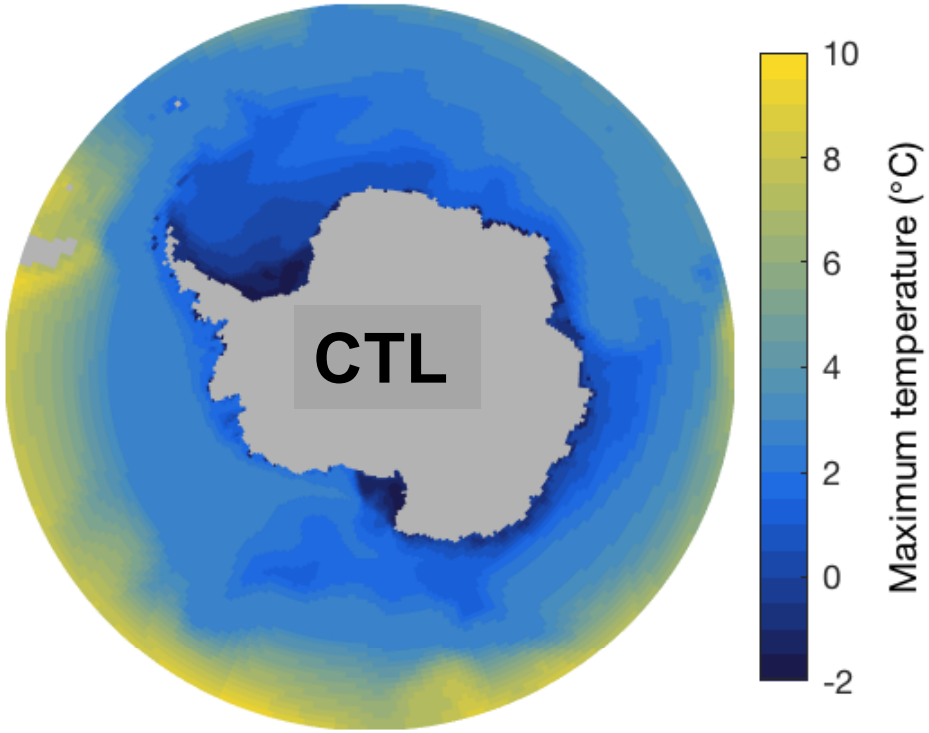


Power available for mixing in each water column ($\log_{10}$[W m^{-2}])

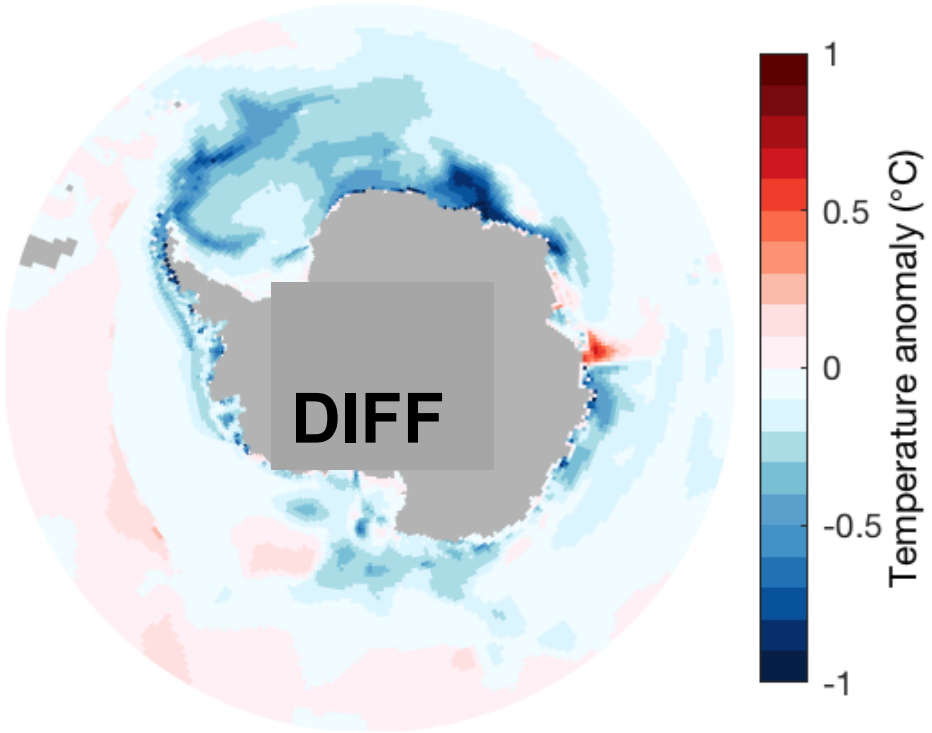
Sub-inertial tides reduce heat reaching Antarctica

Mixing by sub-inertial internal tides cools down Circumpolar Deep Water around Antarctica, with implications for ice-shelf melt.

Max T(z) in control run



Impact of added mixing by sub-inertial tides



Conclusions

- It is possible to simulate AABW formation on the shelves at 1° resolution (at least in NEMO 4.2).
  - ➢ Including with coarse climatological forcing

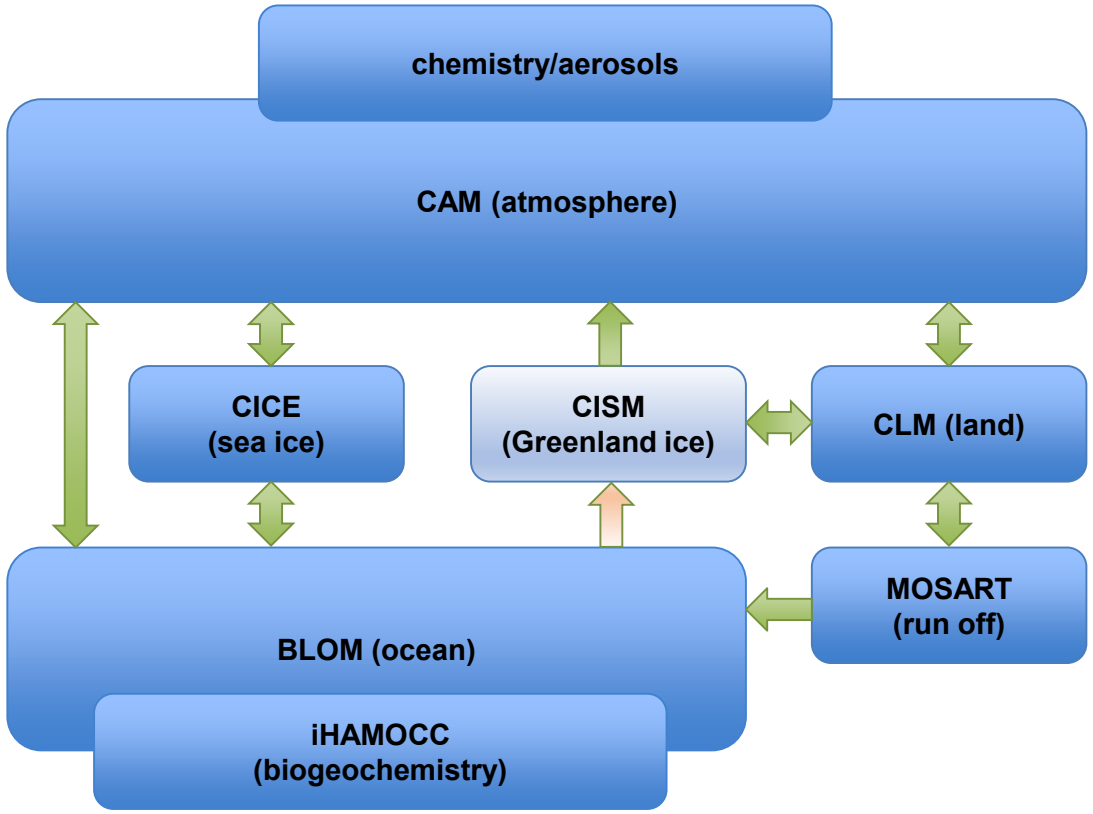
- Compared to ACCESS-OM-0.1, this 1° model has stronger AABW dilution and a coarser ASC, yet a better abyssal MOC and better vertical mixing.
  - ➢ Good tool to assess long-term sensitivity of AABW

- Mixing by sub-inertial internal tides tends to shield Antarctica from CDW heat.
  - ➢ Could change ice-shelf sensitivity to warming/hosing

Freshwater perturbations

Petra Langebroek

David Chandler



NEW: interactive Greenland ice sheet

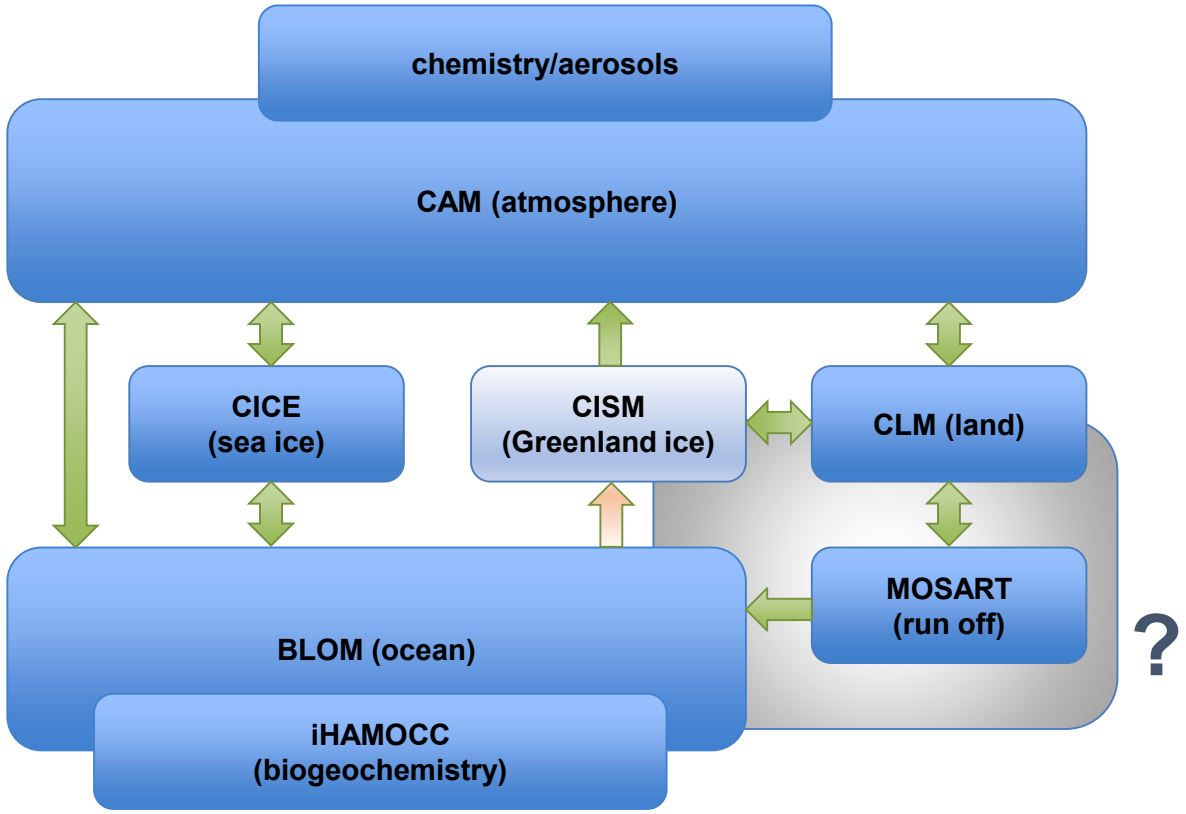
- Atmospheric circulation changes due to changes in ice sheet topography
- Surface mass balance – height feedback
- Ocean thermal forcing, sub-shelf and frontal melting: Not yet, but addressed in Norwegian project (Heiko Goelzer)

NorESM2: Seland et al. 2020 CESM2: Danabasoglu et al., 2020

Freshwater perturbations

Petra Langebroek

David Chandler



NEW: interactive Greenland ice sheet

- Atmospheric circulation changes due to changes in ice sheet topography
- Surface mass balance – height feedback
- Ocean thermal forcing, sub-shelf and frontal melting: Not yet, but addressed in Norwegian project (Heiko Goelzer)
- **OCEAN:ICE** Freshwater fluxes influence the ocean circulation. HOW/MUCH?

→ *D5.8: Report on Greenland ice sheet freshwater implementation in NorESM (M30, NORCE)*

Freshwater perturbations in ocean model NEMO and Earth System Model NorESM

From WP4

From NorESM

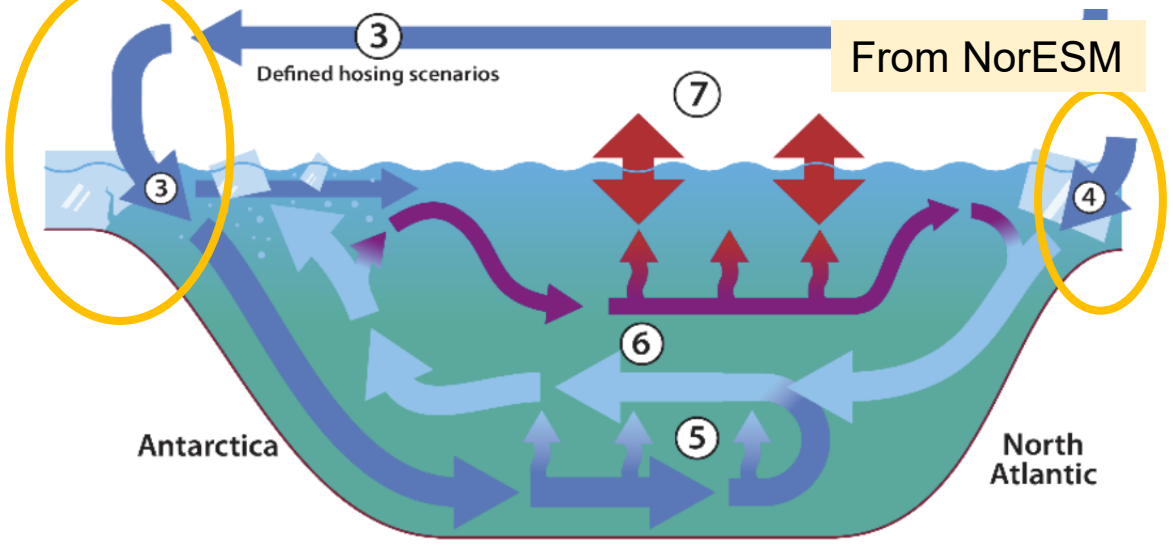


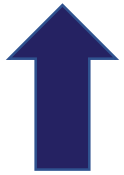
Figure 1.5: AIS freshwater flux projections and uncertainty and ocean model forcing. Section 1.2.4.3.

→ *D5.9: Report on impact of glacial freshwater forcing on ocean circulation in NEMO & NorESM (M42, NORCE&CNRS)*

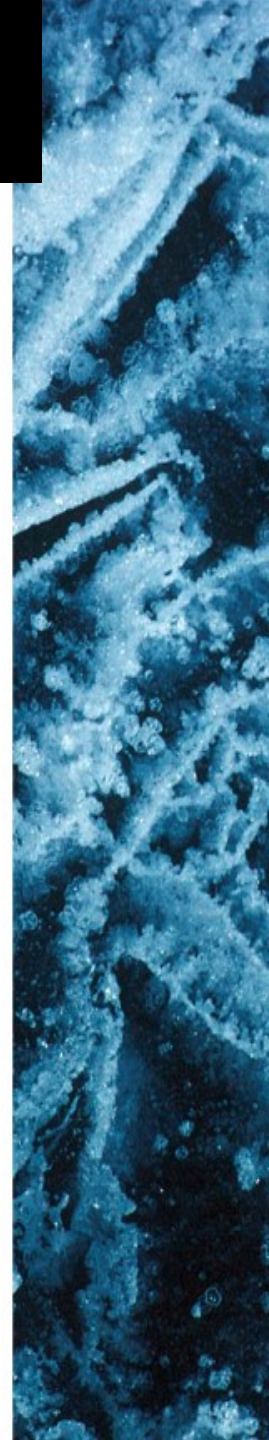
How sensitive is **ocean circulation** to changes in **freshwater fluxes** from the Greenland and Antarctic **ice sheets** ?

OCEAN:ICE

Ocean and Earth System Models



Gridded data / Data matrix



Surface water isotope reconstruction

Ocean Memory and Water Mass Archeology –

Reconstructing freshwater forcing

Elaine McDonagh

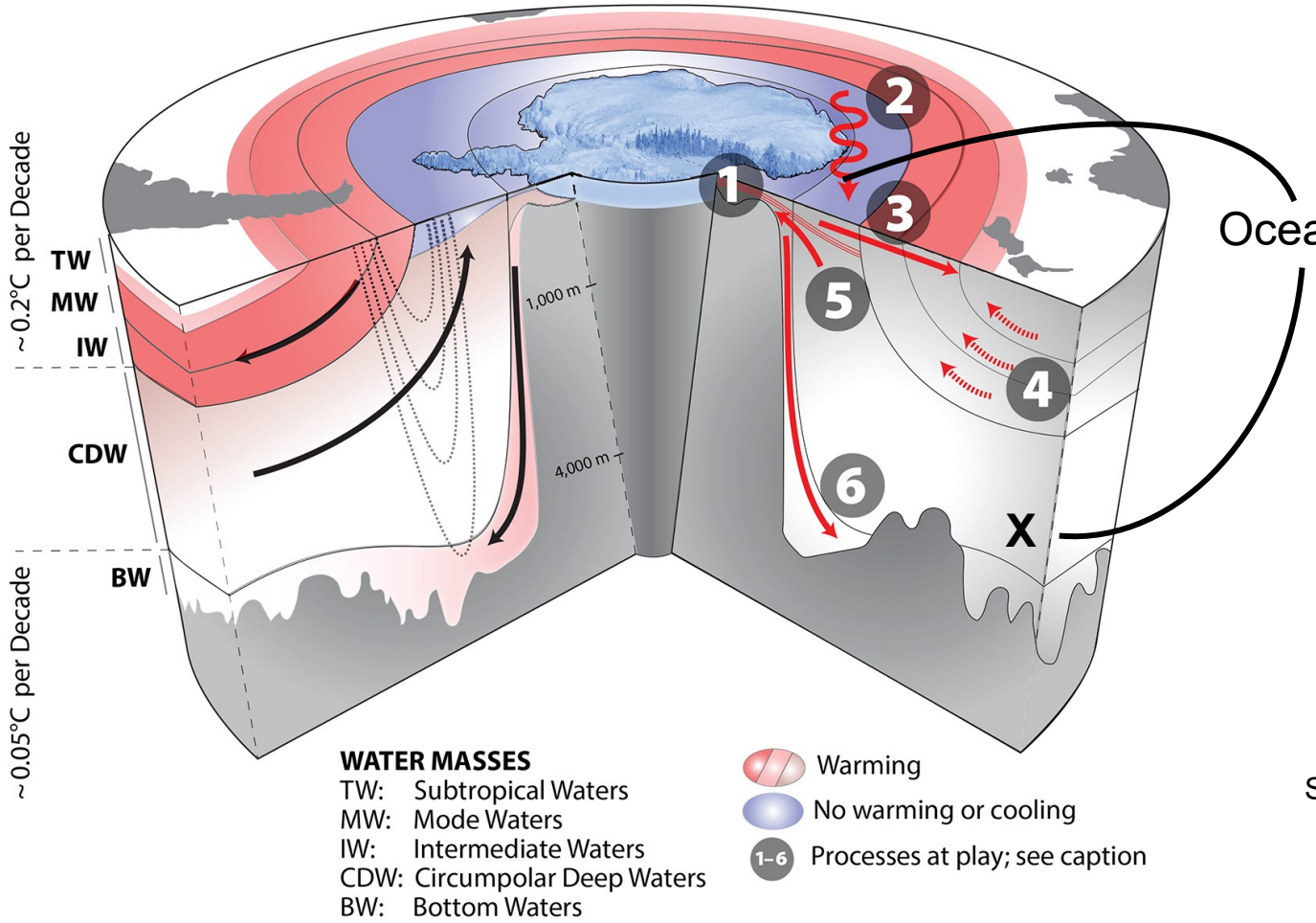
Jake Gebbie

Xabier Davila

Brynn Hamilton.

Mike Meredith

Mathilde Helbert



Total Matrix Intercomparison (TMI)

Ocean Memory

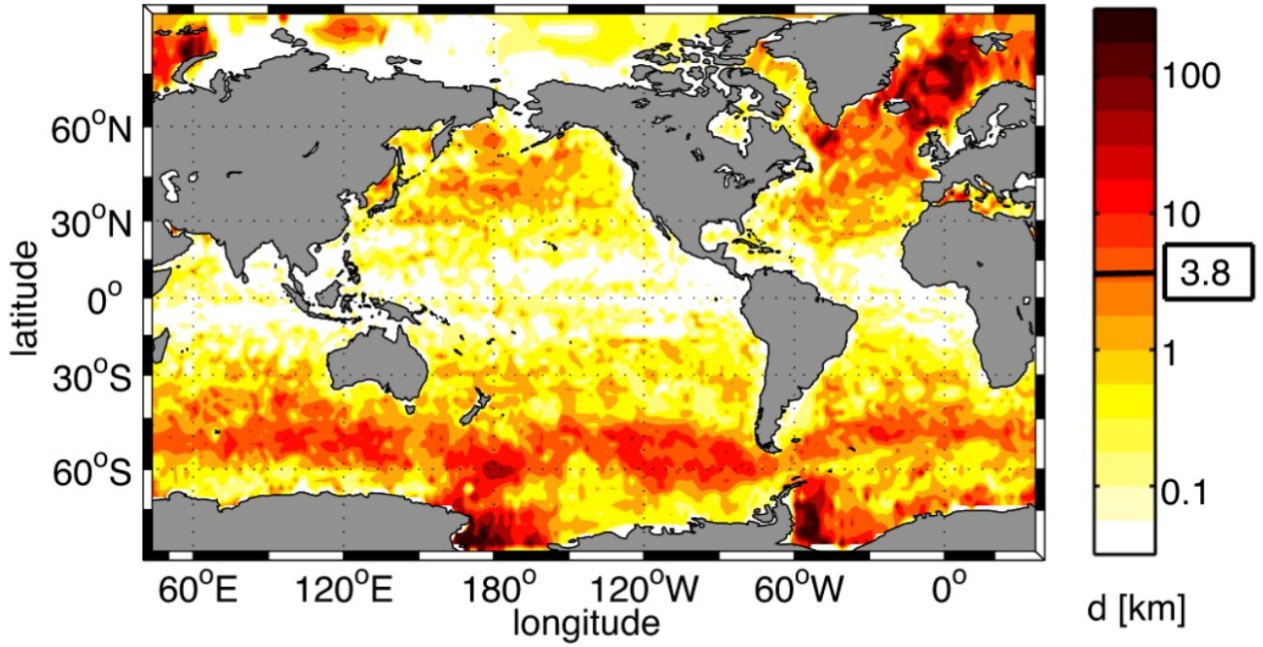
- Salinity
- Temperature
- $\delta^{18}O$

Salle (TOS)

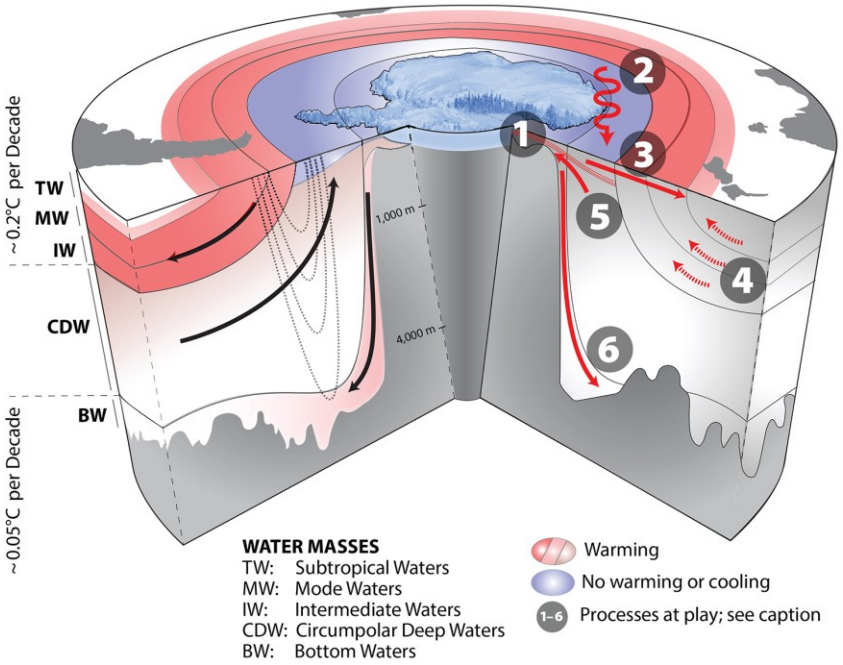
Total Matrix Intercomparison - Gebbie & Huybers (2010, 2012)

- A **steady state**, offline, **inverse 3D** ocean circulation model.
  - State estimate of the modern ocean circulation.
- Provides water mass **pathways** and **transport timescales**.
- By inverting ocean circulation, one can reconstruct the surface boundary condition for any ocean interior point.

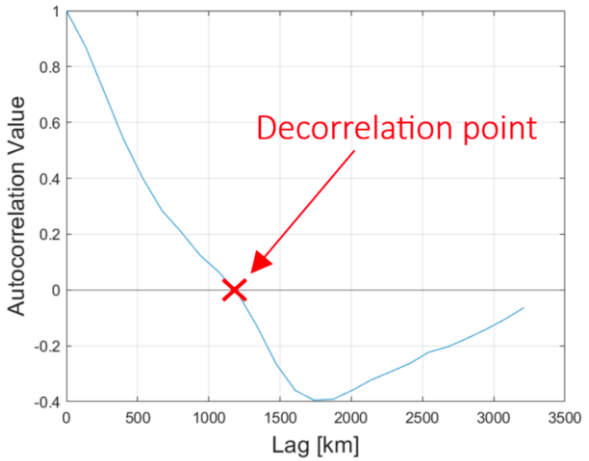
"How is the ocean filled?"

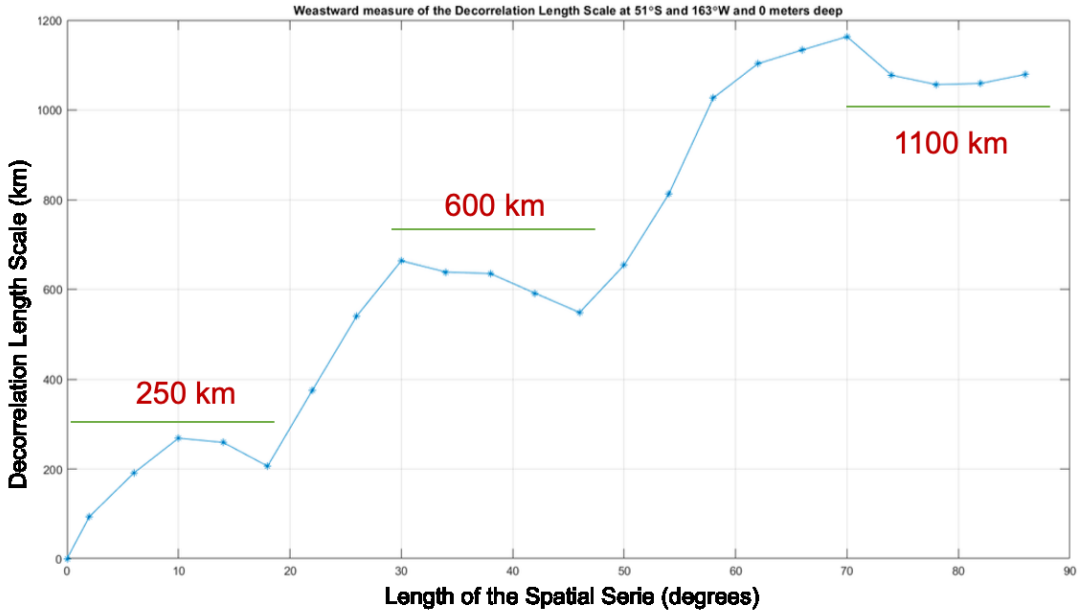


Gebbie & Huyber (2011)



Decorrelation lengthscales



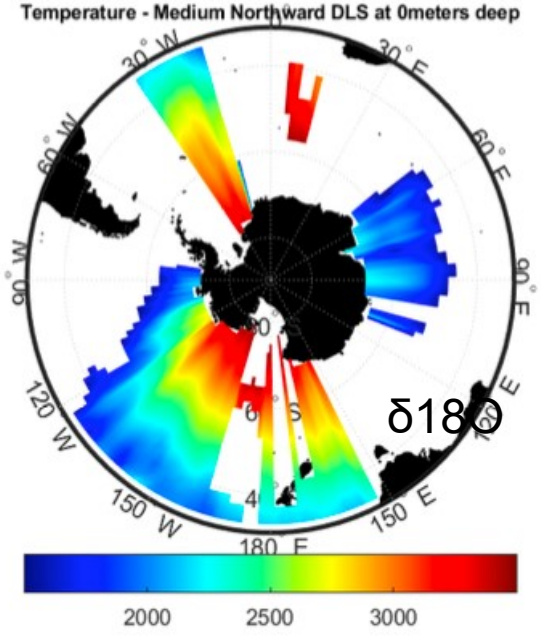


Typically three length scales

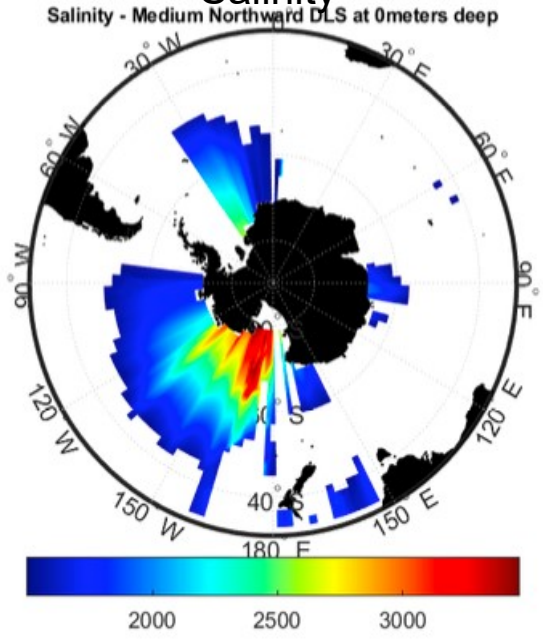
Mathilde Helbert

Decorrelation Length Scales – Northward (1500 – 3000 km)

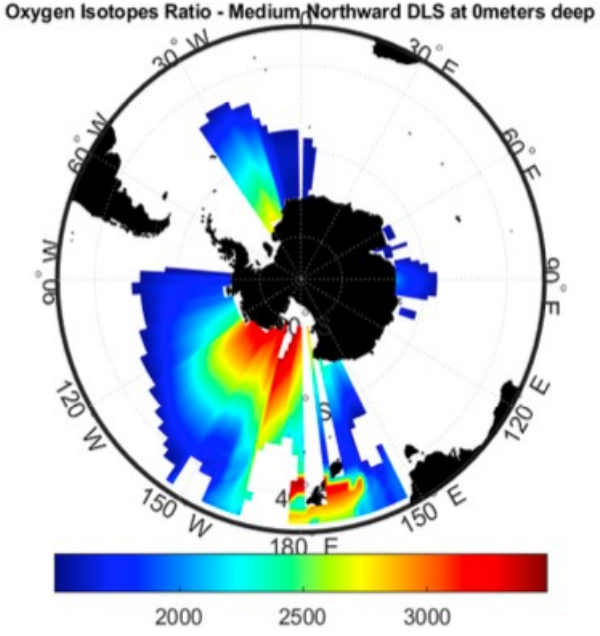
Temperature



Salinity



δ18O



So far:

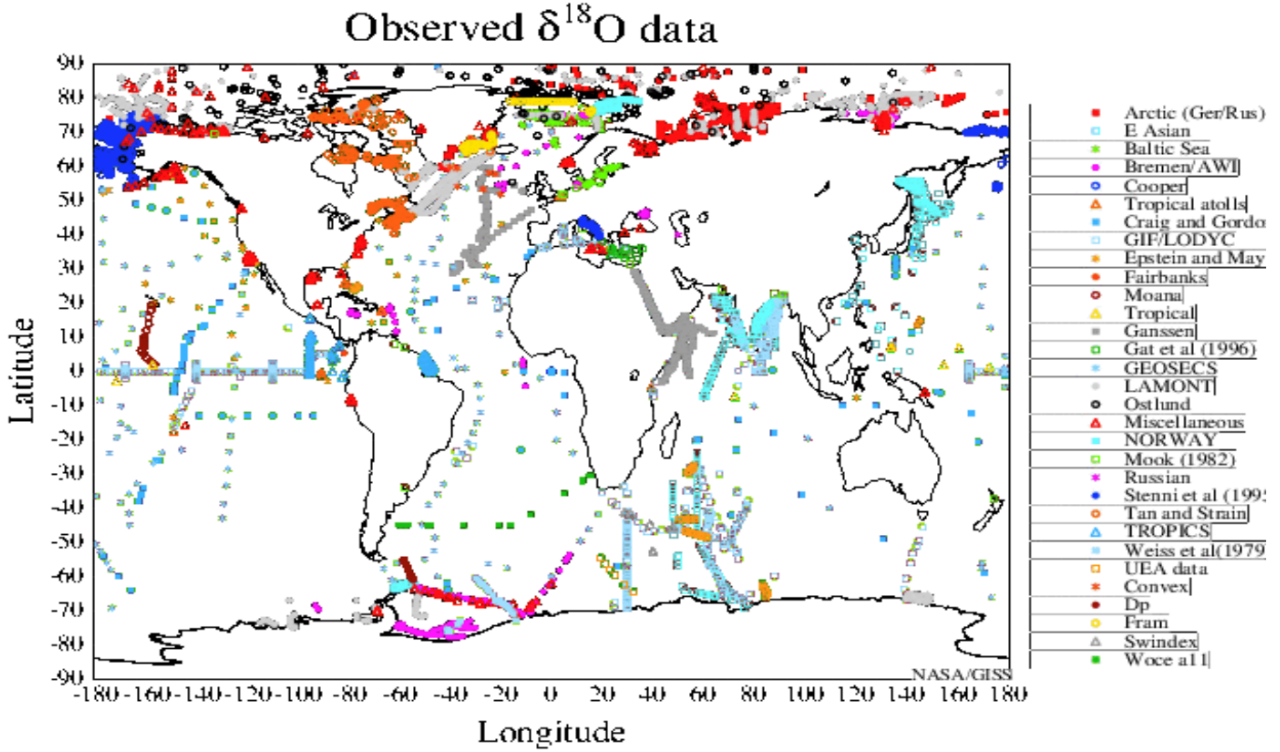
δ18O has similar structure to salinity.

To come:

- Spectral Analysis to understand the strength of the signal regarding the decorrelation length scale.
- Use of self-organizing maps to detect coherent structures to be used during the **data inversion**

The Plan: Water Mass Archeology

- Compile existing observations of $\delta^{18}O$.
- Construct salinity, temperature and $\delta^{18}O$ water-column time-series informed by:
  - Correlation length scales.
  - Spectral Analysis.
- Reconstruct the surface boundary conditions according to the TMI pathways
  - Following the method by Gebbie (2012)



Schmidt et al. (1999)

→ *D5.5: Report on temporal and spatial length scales in δ18O observations (M18, NORCE, UKRI-BAS)*
→ *D5.6: Reconstruction of global surface δ180 and salinity (M30, NORCE, UKRI-BAS)*

How sensitive is **ocean circulation** to changes in **freshwater fluxes** from the Greenland and Antarctic **ice sheets** ?

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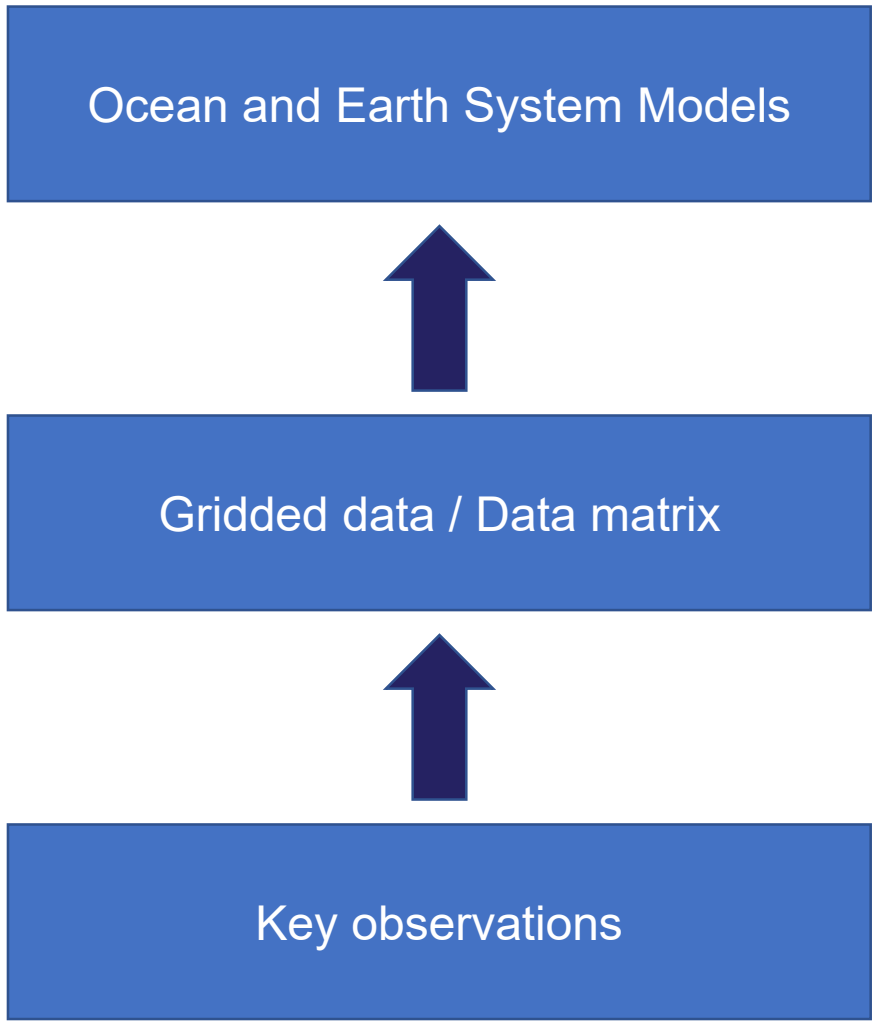
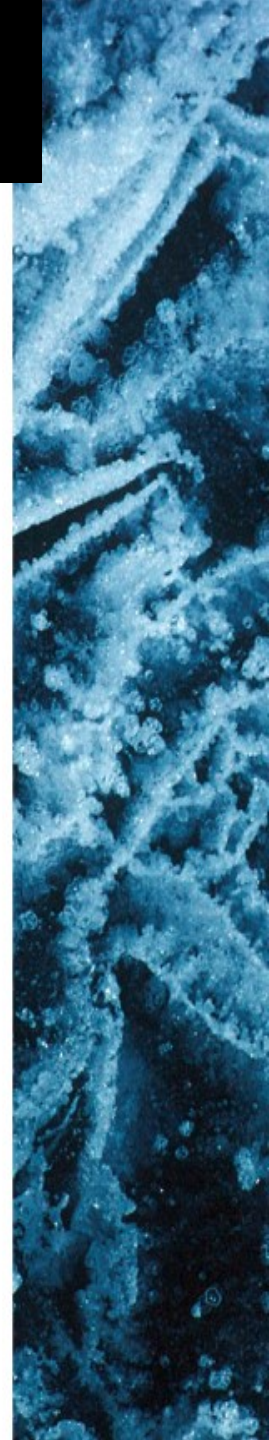
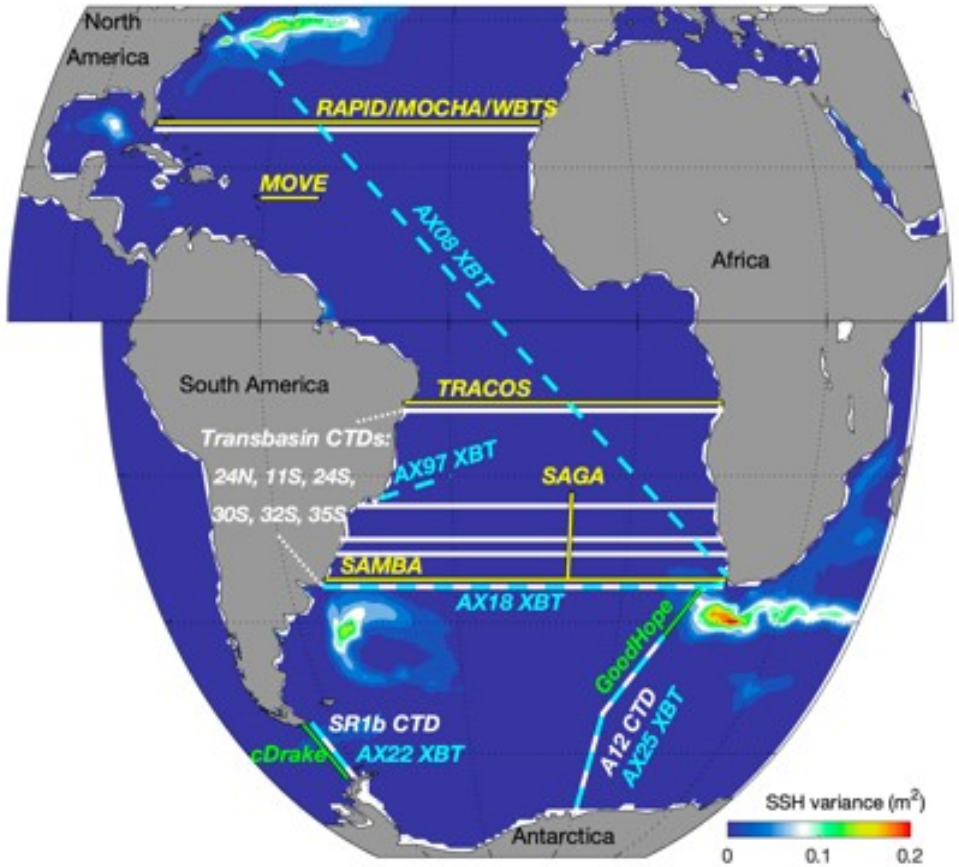


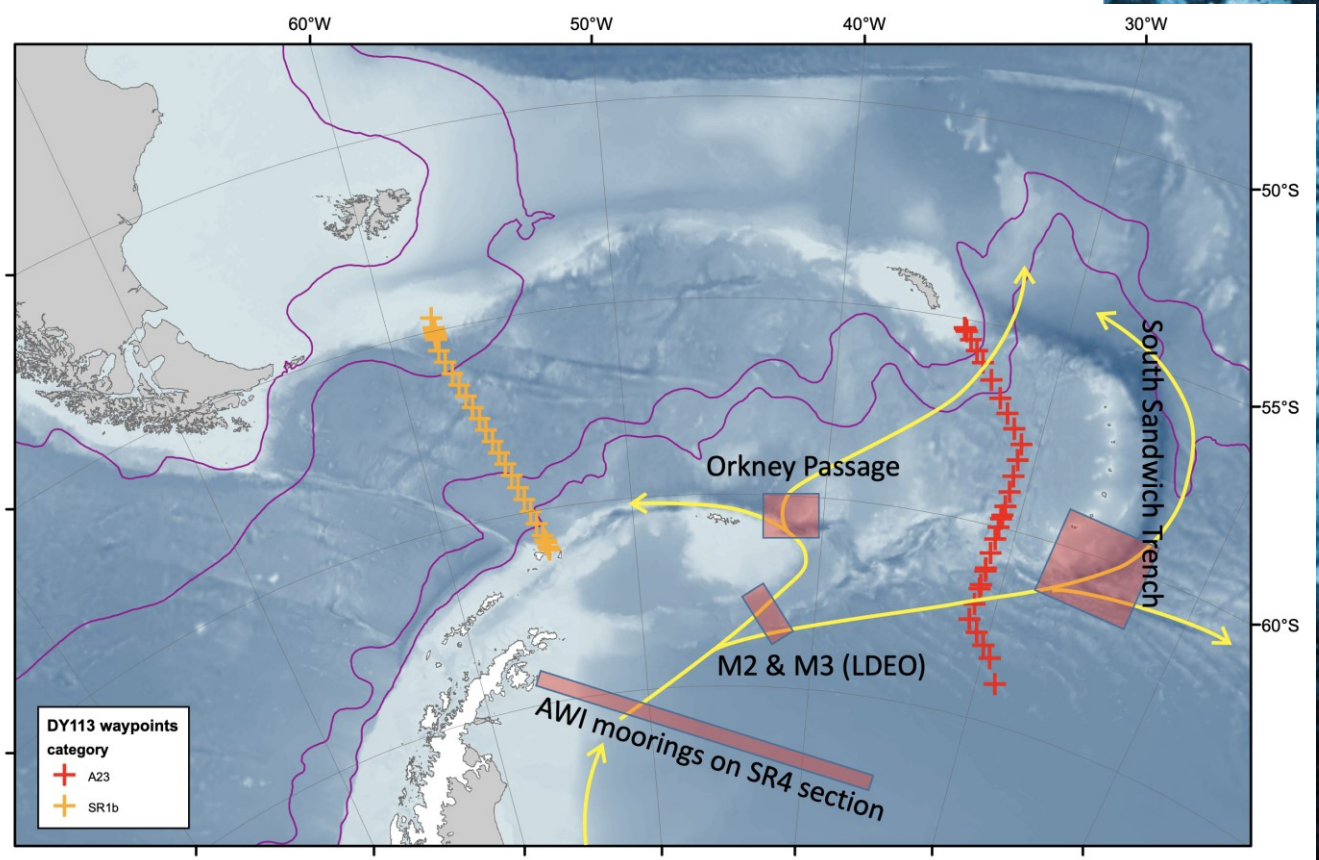


Key observations: focus on AABW export

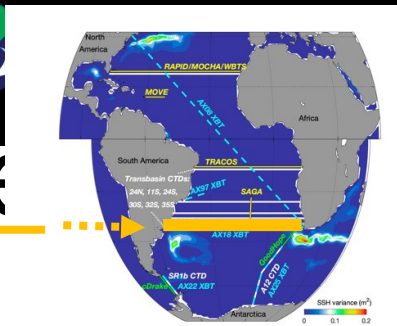
South Atlantic MOC Basin-wide Array (SAMBA)



Orkney Passage & South Sandwich Trench



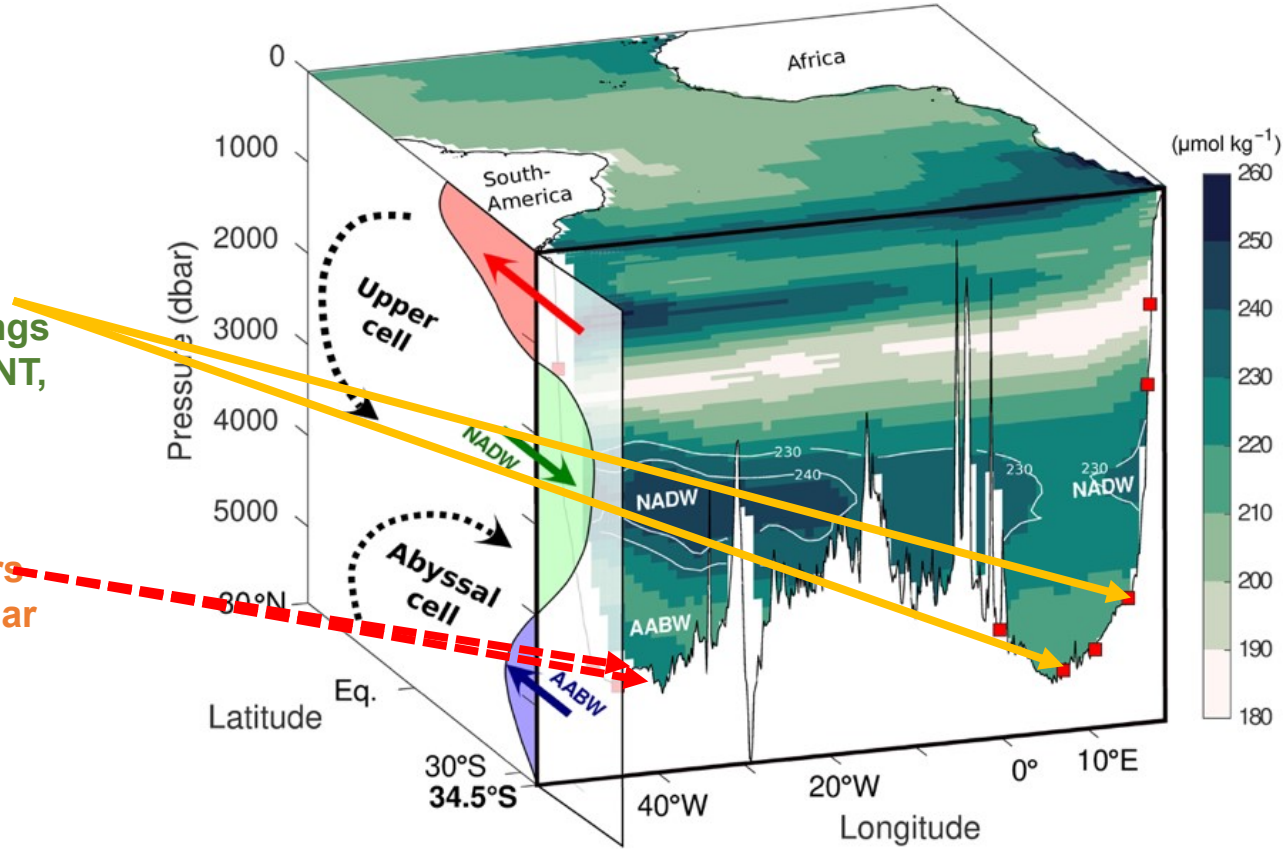
OCEAN:ICE @ the SAMBA line



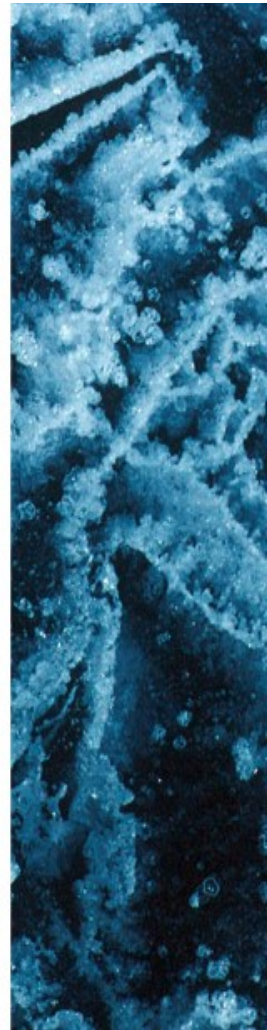
Sabrina Speich

Focusing on the Abyssal cell of the AMOC at 34°S

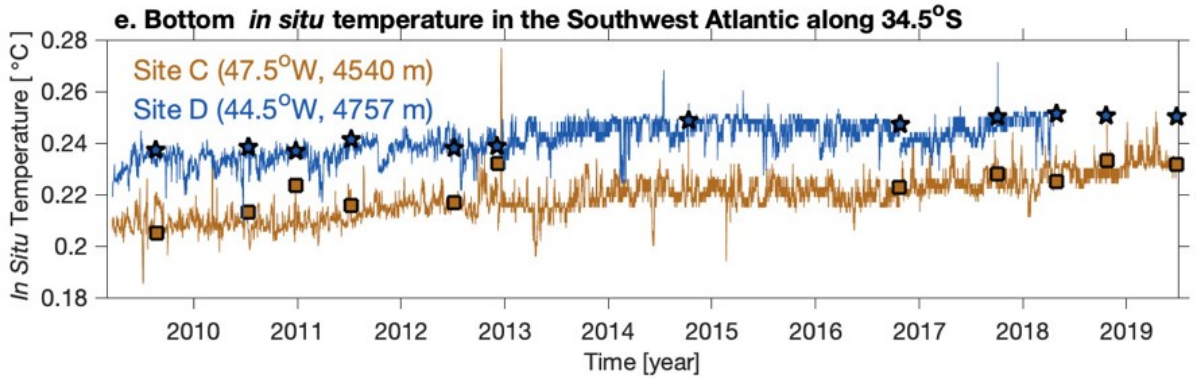
- Adding complements to SAMBA (~~6~~ 4 MicroCATS in bottom waters)
  - **2 deployed early this month on PIES moorings @SAMBA-EAST by DEFF (Dr. Tarron LAMONT, Cape Town, South Africa)**
  - **2 to be deployed on 2 PIES moorings @SAMBA-WEST by SHN from Argentina (Drs Charo and Chidichimo, Buenos Aires and Mar de la Plata) hopefully in December 2023**

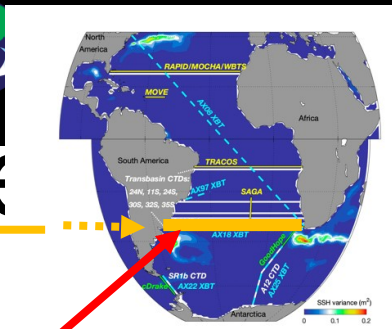


Manta et al., 2021



OCEAN:ICE @ the SAMBA line





While waiting for the MicroCATS time series we will, in 2024 :

Hiring a Master student and later a postdoctoral researcher for

› Analyzing historical & SAMBA observations, as well as reanalysis data to detect changes in salinity and if these changes are correlated with the observed temperature changes in SAMBA-WEST; Are similar changes observed in SAMBA-EAST where deep and bottom waters are “older” and more mixed?

- New CTDs and available Bottom Temperature timeseries for SAMBA-EAST (never investigated before) and SAMBA-WEST to be analyzed
- Historical cruises in the region (WOCE, repeat GO-SHIP)
- Deep Argo floats in the western basin
- European ocean reanalyses products

→ D5.3: Calibrated, quality-controlled dataset of near-bottom sensors on SAMBA array (M36, ENS-LMD)
→ D5.4: Paper on deep and bottom water masses from SAMBA observations (M44, ENS-LMD)

Orkney Passage & South Sandwich Trench

OCEAN:ICE

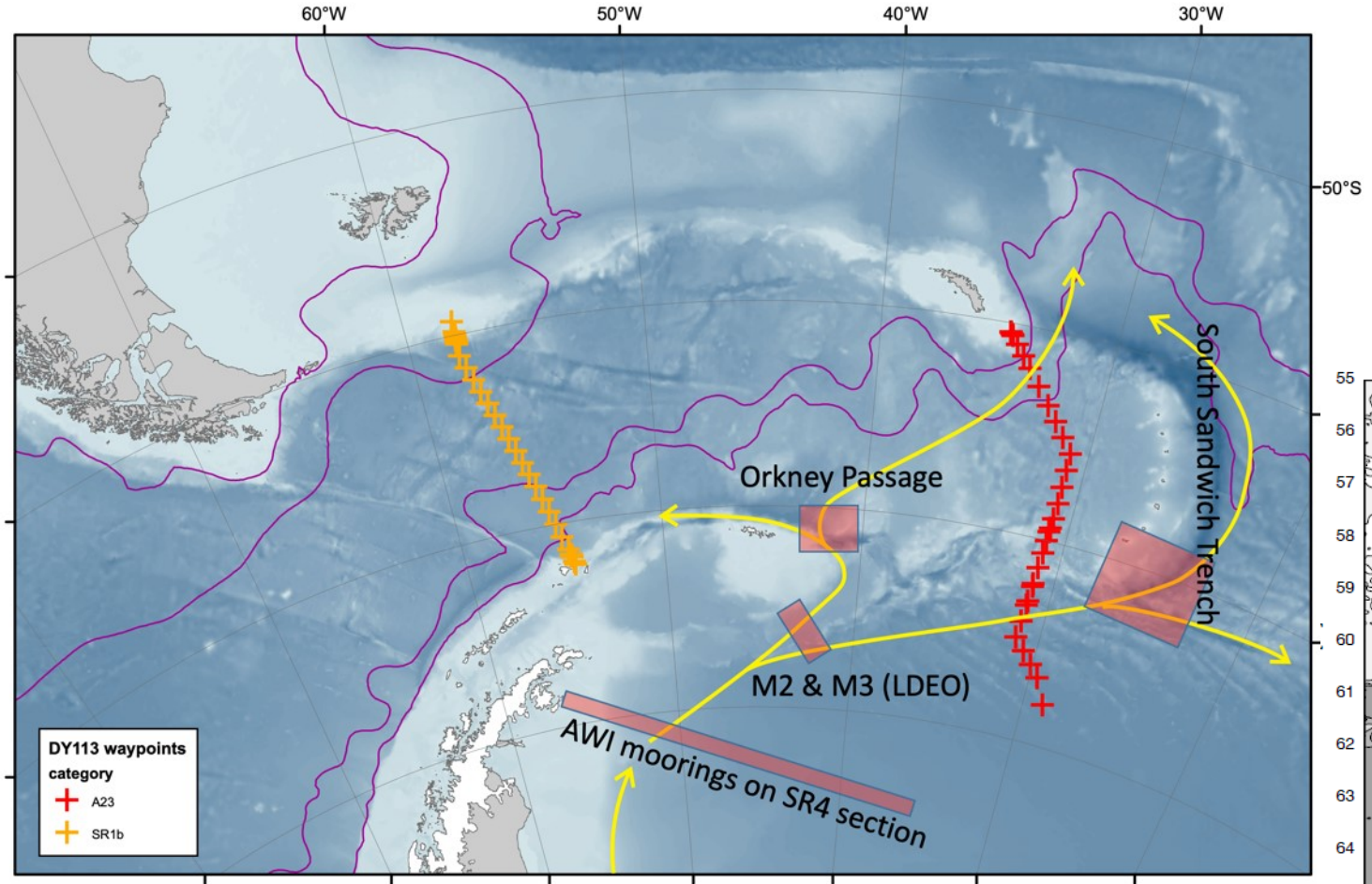



Povl Abrahamsen

Mike Meredith

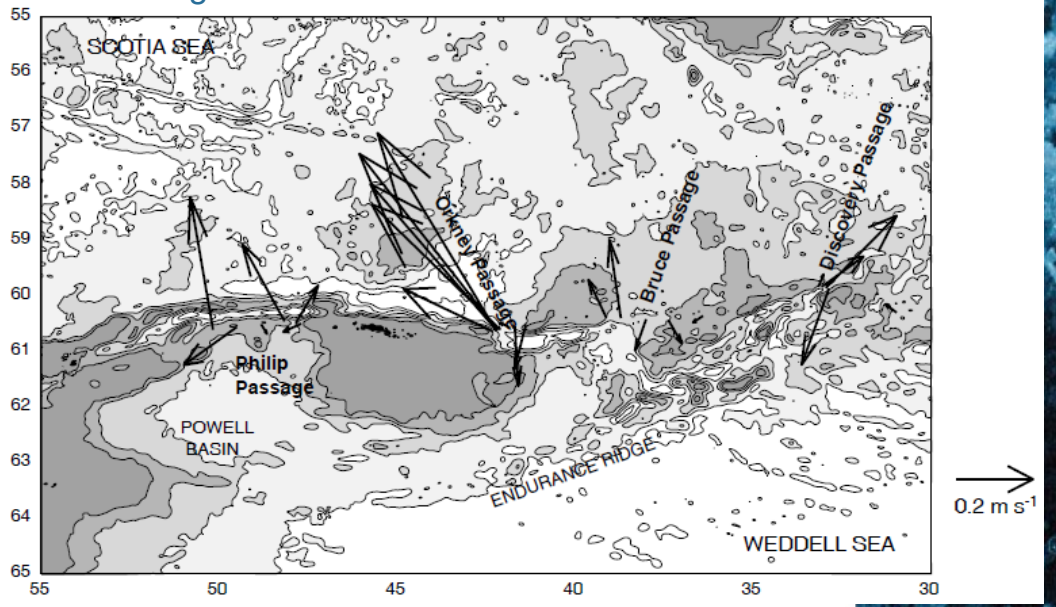
Alberto Naveira Garabato

Chris Auckland



Key region for export of Weddell Sea Deep Water, a precursor to Antarctic Bottom Water

Strong northward currents



Naveira Garabato et al., 2002

Orkney Passage & South Sandwich Trench

What happened in 2022-2023

- Cruise DY158: BAS Ecosystems and Polar Oceans cruise on RRS *Discovery*
  - Departed Montevideo 22 Dec 2022
  - Krill work near South Georgia
  - A23 section repeat
  - Orkney Passage/M2/~~M3~~ mooring recovery and turnaround
  - A little opportunistic circuit of iceberg A-76A with water sampling along the front!
  - Arrived Stanley 29 Jan 2023

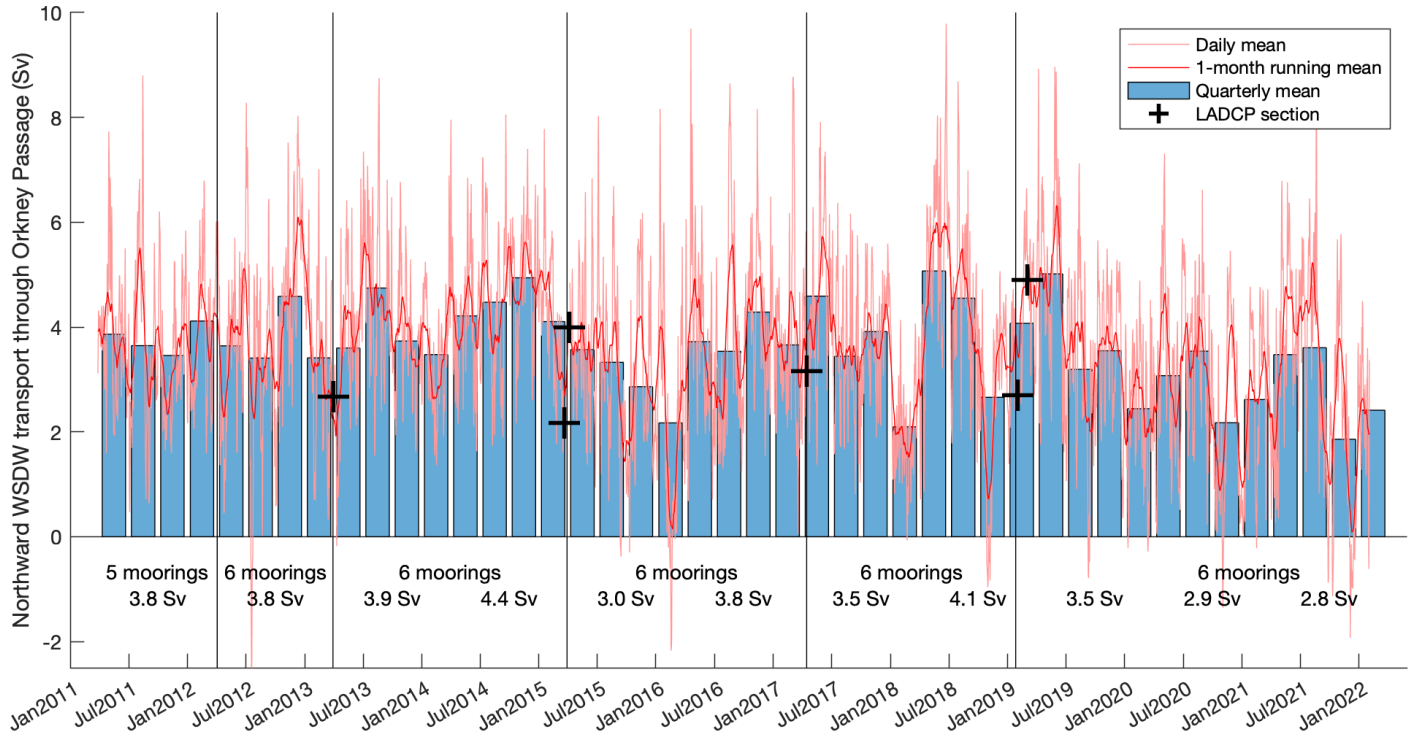
- 6 moorings in Orkney Passage recovered
- 4 moorings redeployed
- M2 redeployed
- Could not reach M3, but RRS *Sir David Attenborough* managed to recover and redeploy it!

- Surplus instrumentation and releases returned to UK for use in South Sandwich Trench

Orkney Passage & South Sandwich Trench

Orkney Passage

- Time series of WSDW export through Orkney Passage now covers 2011-2022
- Batteries ran out on current meters in early 2022, though water mass properties continued into 2023
- Average WSDW export is 3.6±1.7 Sv
- High variability, some reversals
- See posters from Auckland et al. and Abrahamsen et al.



Orkney Passage & South Sandwich Trench

Plans for 2023-2024

- Original plan to deploy on S. A. Agulhas II on SANAE cruise (Dec 2023-Feb 2024)
- This unfortunately cannot happen
- Mooring equipment has been purchased and is ready to ship from BAS
- Four Microcats are in Cape Town

- Through contacts in the Government of South Georgia and the South Sandwich Islands, we have begun discussions with a fishing company to determine whether it might be feasible to deploy the moorings in March 2024. We are still awaiting an answer.
  - Risk: If we cannot deploy this season, MS9 (deployment of moorings) will be delayed considerably. Possible knock-on delays to MS10 (recovery), D5.1 (dataset) and D5.2 (paper)
- If this can go ahead, it leaves a very short time for organizing environmental permitting, shipping, etc.

Orkney Passage & South Sandwich Trench

Plans for 2024-2025

- Mooring cruise to Orkney Passage/M2/M3 on RRS Sir David Attenborough through BIOPOLE
  - Requested dates: Jan-Mar 2025
  - Risk: ship time constraints/technical readiness of ship
- Still to be determined whether we might be able to deploy or recover moorings in South Sandwich Trench (depending on the outcome of this season) or whether other ships will be required for this purpose.

Plans for 2025-2026

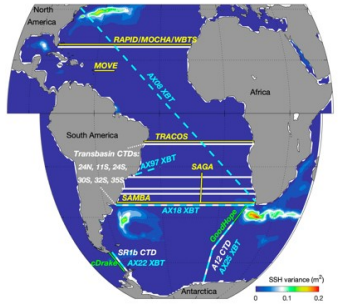
- None at present – though if SST moorings are deployed in 2025, we will need to recover this season if we have any hope of delivering our deliverables before the end of the project...

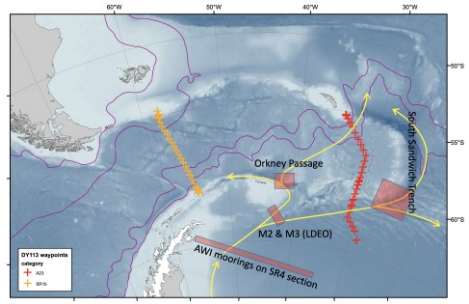
→D5.1: Calibrated, quality-controlled mooring dataset from South Sandwich Trench (M36, UKRI-BAS)
→D5.2: Paper on South Sandwich Trench data, incl. Orkney Passage comparison (M45, UKRI-BAS)

WP5 – Ice sheet impacts on global ocean circulation

New key observations

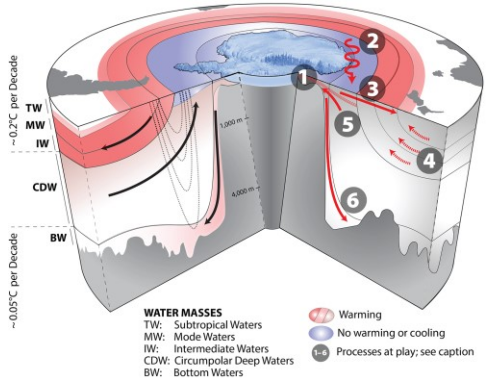
› Currents, temperatures, salinity, etc. at Orkney Passage, South Sandwich Trench & SAMBA





Data matrix

› Using state-of-the-ocean to reconstruct surface boundary conditions (meteoritic water and sea ice)



Ocean and Earth System modelling

› Understanding of impact of freshwater on ocean circulation, using NEMO and NorESM

THANK YOU!

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