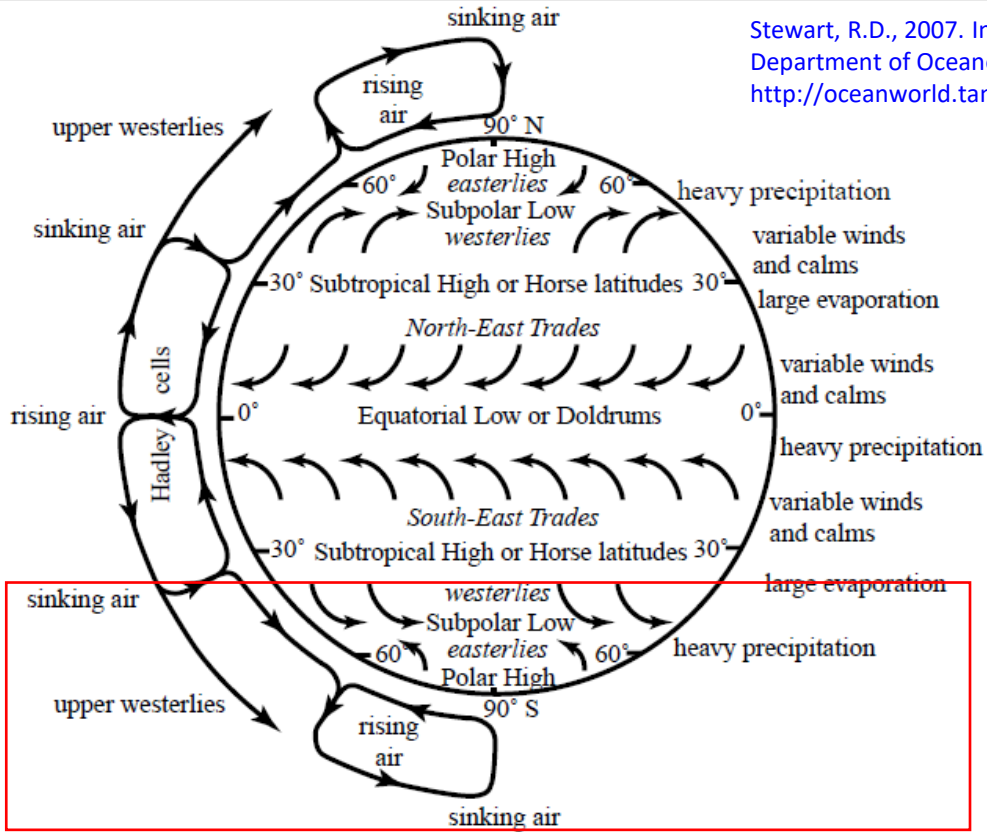
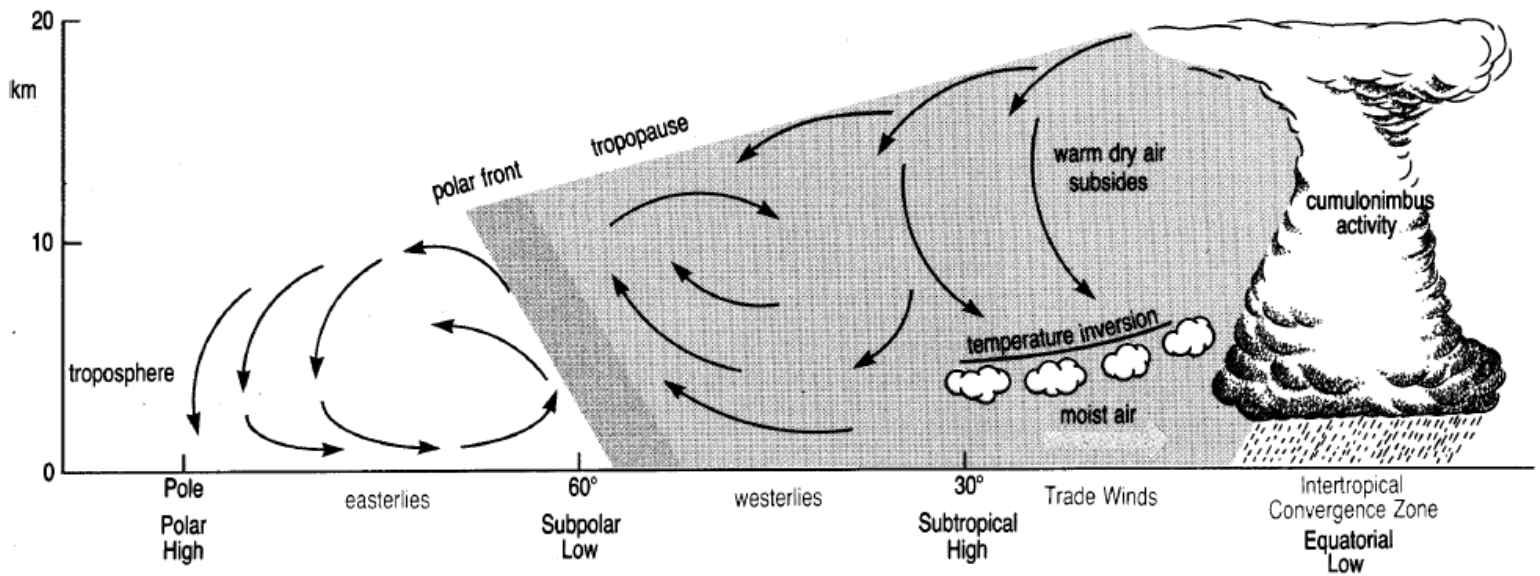
Simplified schematic of Earth's atmospheric circulation driven by solar heating in the tropics and cooling at high latitudes.



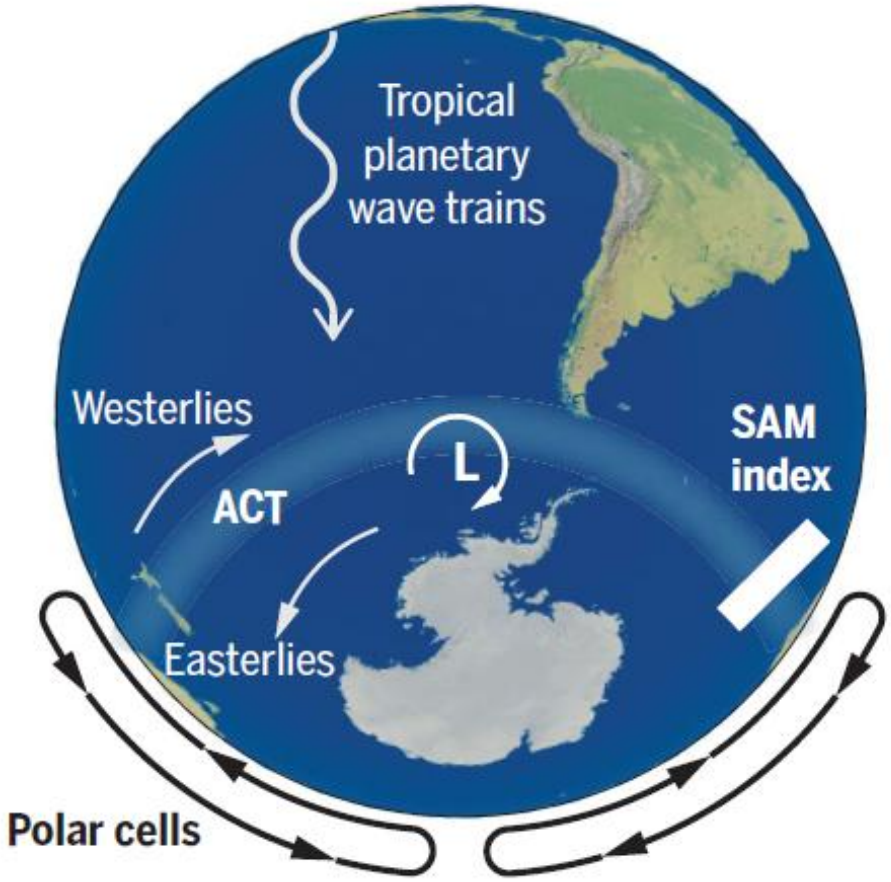
Stewart, R.D., 2007. Introduction To Physical Oceanography. Texas A & M University, Department of Oceanography, 345 pp. http://oceanworld.tamu.edu/resources/ocng_textbook/PDF_files/book_pdf_files.html

The winds are influenced by Earth's rotation

Cross-section through the atmosphere showing the two major cells of meridional circulation



The role played by the atmospheric-ocean teleconnections to modulate the heat transfer to high latitudes



The approximately east-west oriented atmospheric Antarctic Circumpolar Trough (ACT) supports a band of **westerly winds to the north of the trough, and easterlies to the south.**

Coriolis force causes the westerlies and easterlies to drive the upper ocean waters to the north and south, respectively, **creating a divergence of surface waters** all along the ACT.

This creates an upwelling of the subsurface water which rises above the depth of the continental shelf break in places and allow the possibility of it crossing onto the shelf and interacting with the Antarctic Ice Sheet

Stephen R. Rintoul, Chris Hughes and Dirk Olbers
OCEAN CIRCULATION AND CLIMATE ISBN 0-12-641351-7

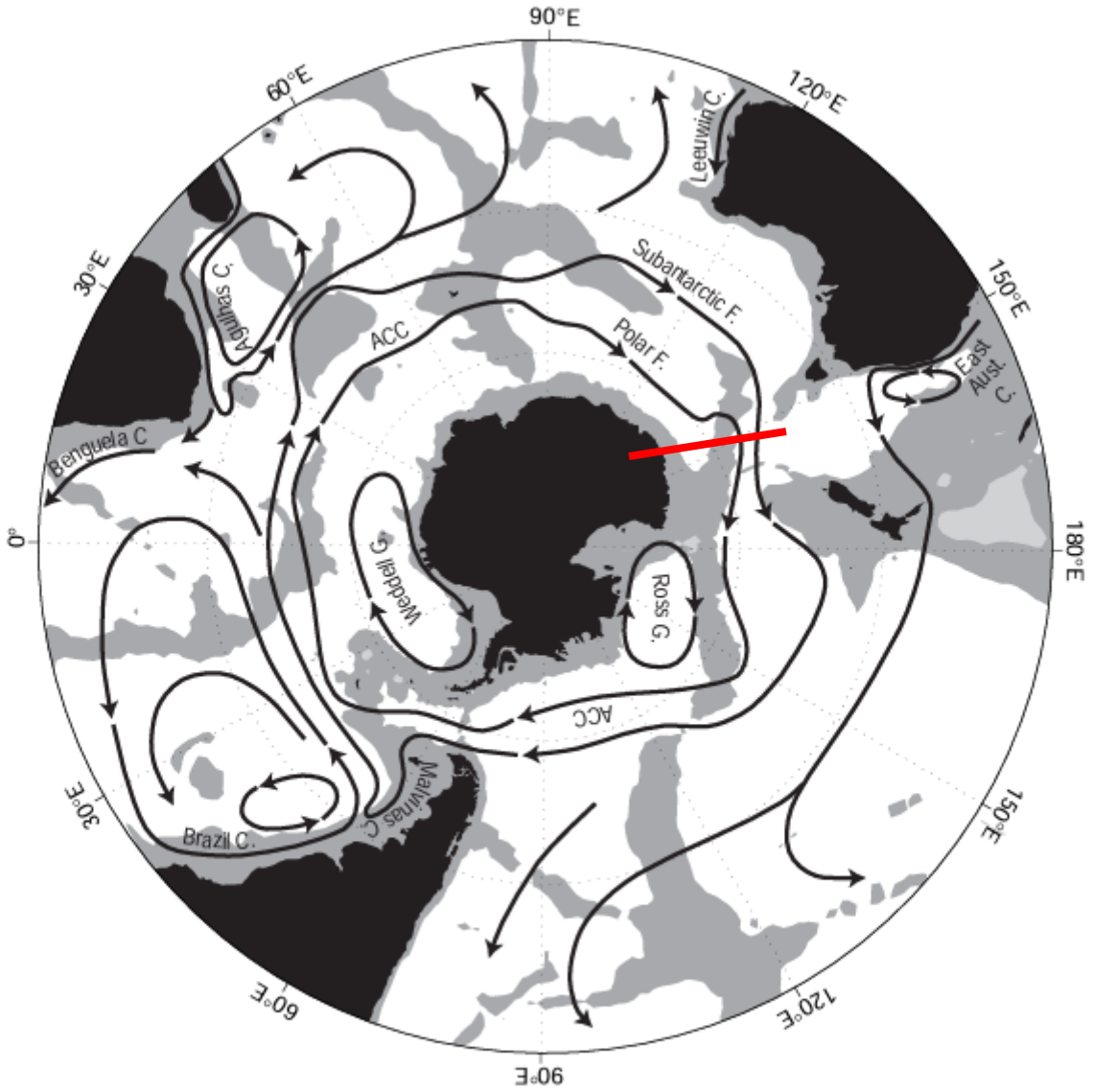


Fig. 4.6.1 Schematic map of major currents in the southern hemisphere oceans south of 20°S. Depths shallower than 3500 m are shaded. The two major cores of the Antarctic Circumpolar Current (ACC) are shown, the Subantarctic Front and Polar Front. Other abbreviations used are F for front, C for Current and G for gyre.

Antarctic Slope Current

Antarctic Circumpolar Current

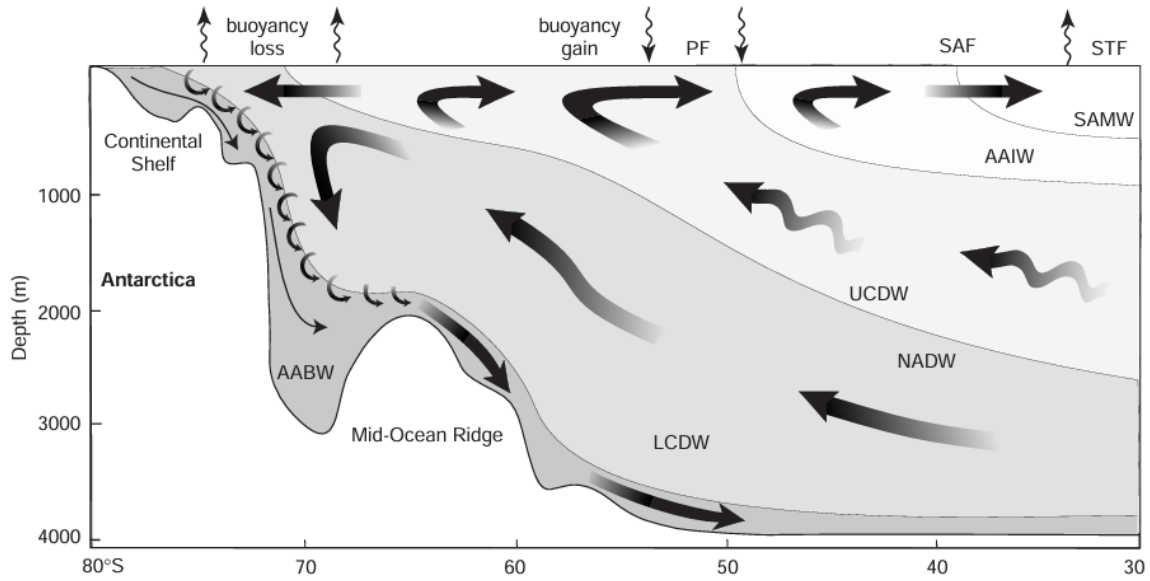


Fig. 4.6.2 A schematic view of the meridional overturning circulation in the Southern Ocean (from Speer *et al.*, 2000). An upper cell is formed primarily by northward Ekman transport beneath the strong westerly winds and southward eddy transport in the UCDW layer. A lower cell is driven primarily by formation of dense AABW near the Antarctic continent. PF, Polar Front; SAF, Subantarctic Front; STF, Subtropical Front; AAIW, Antarctic Intermediate Water; UCDW, Upper Circumpolar Deep Water; NADW, North Atlantic Deep Water; LCDW, Lower Circumpolar Deep Water; AABW, Antarctic Bottom Water. SAMW: Sub Antarctic Mode Water

Stephen R. Rintoul, Chris Hughes and Dirk Olbers
OCEAN CIRCULATION AND CLIMATE ISBN 0-12-641351-7

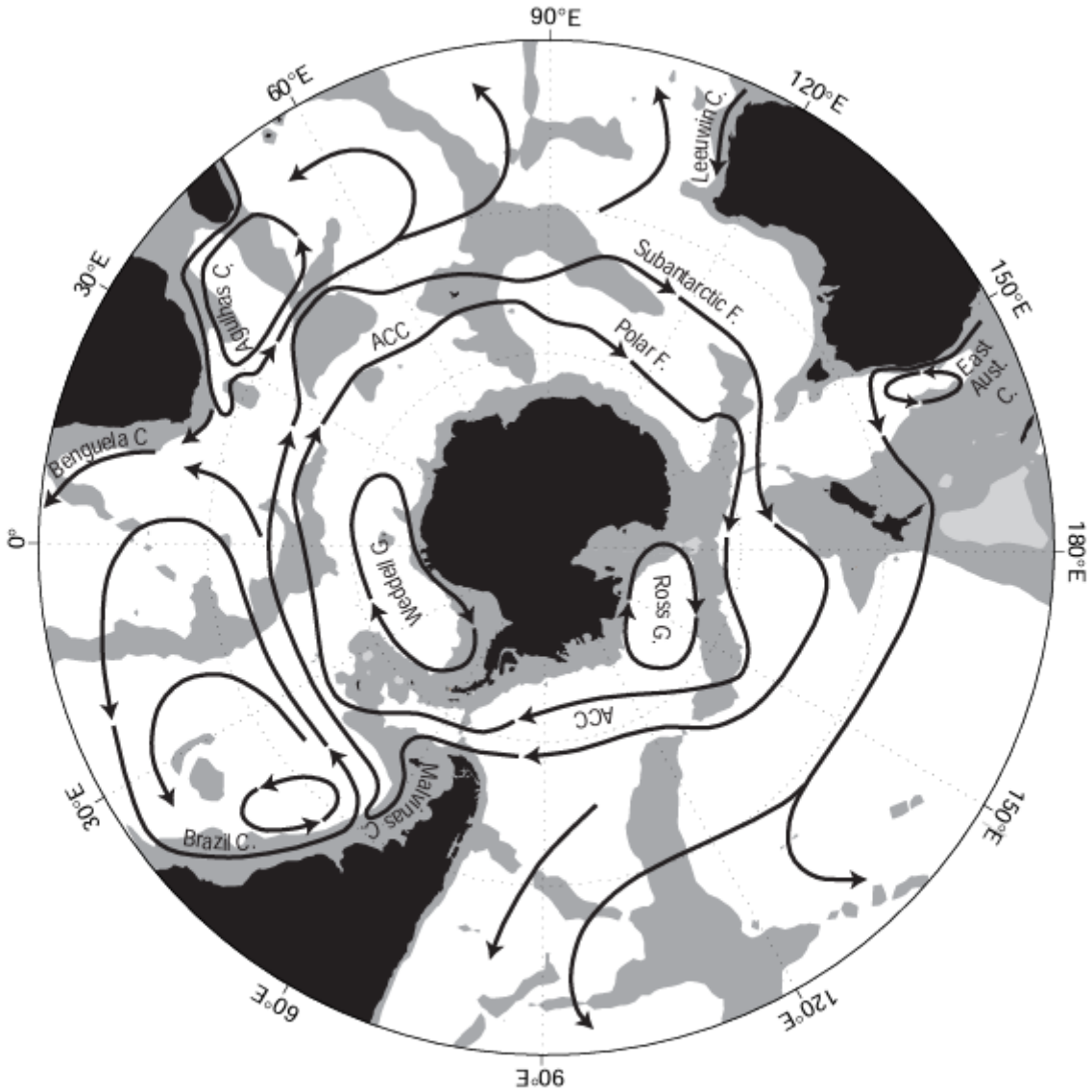
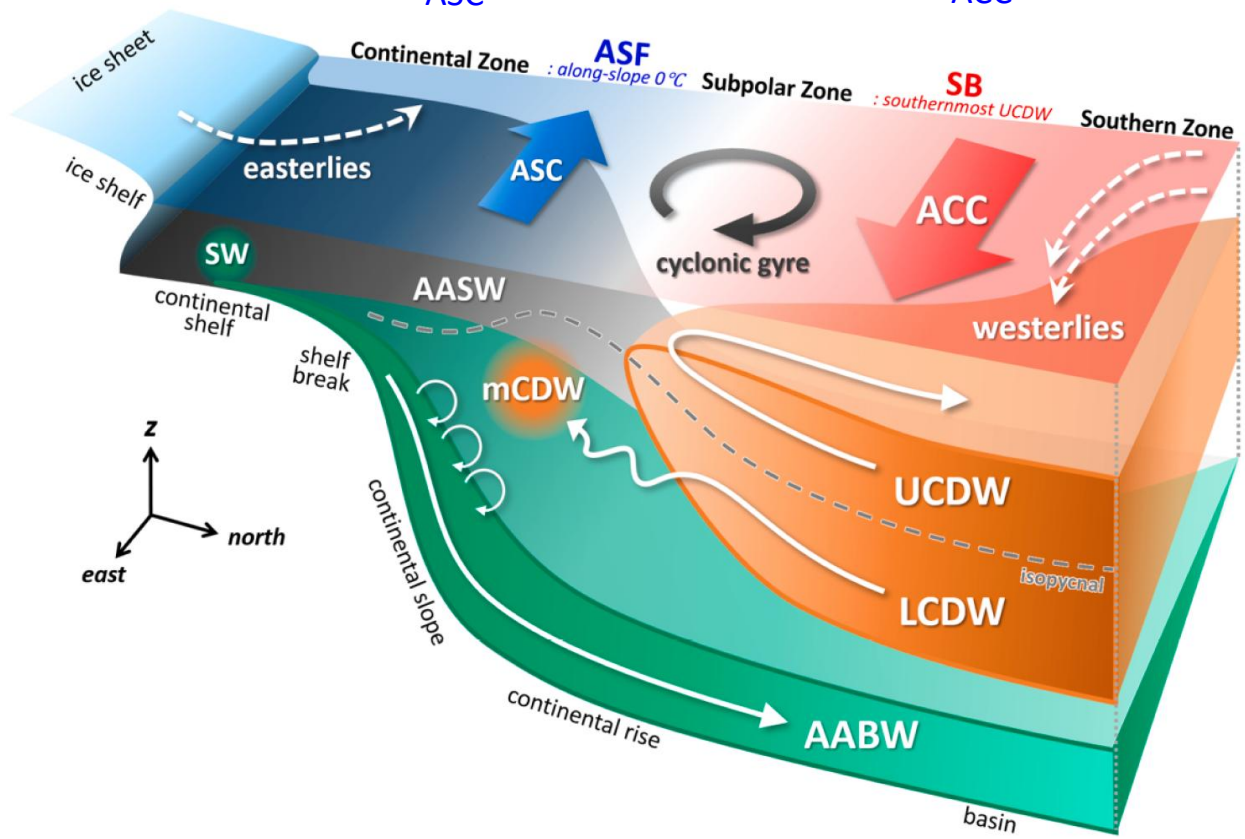


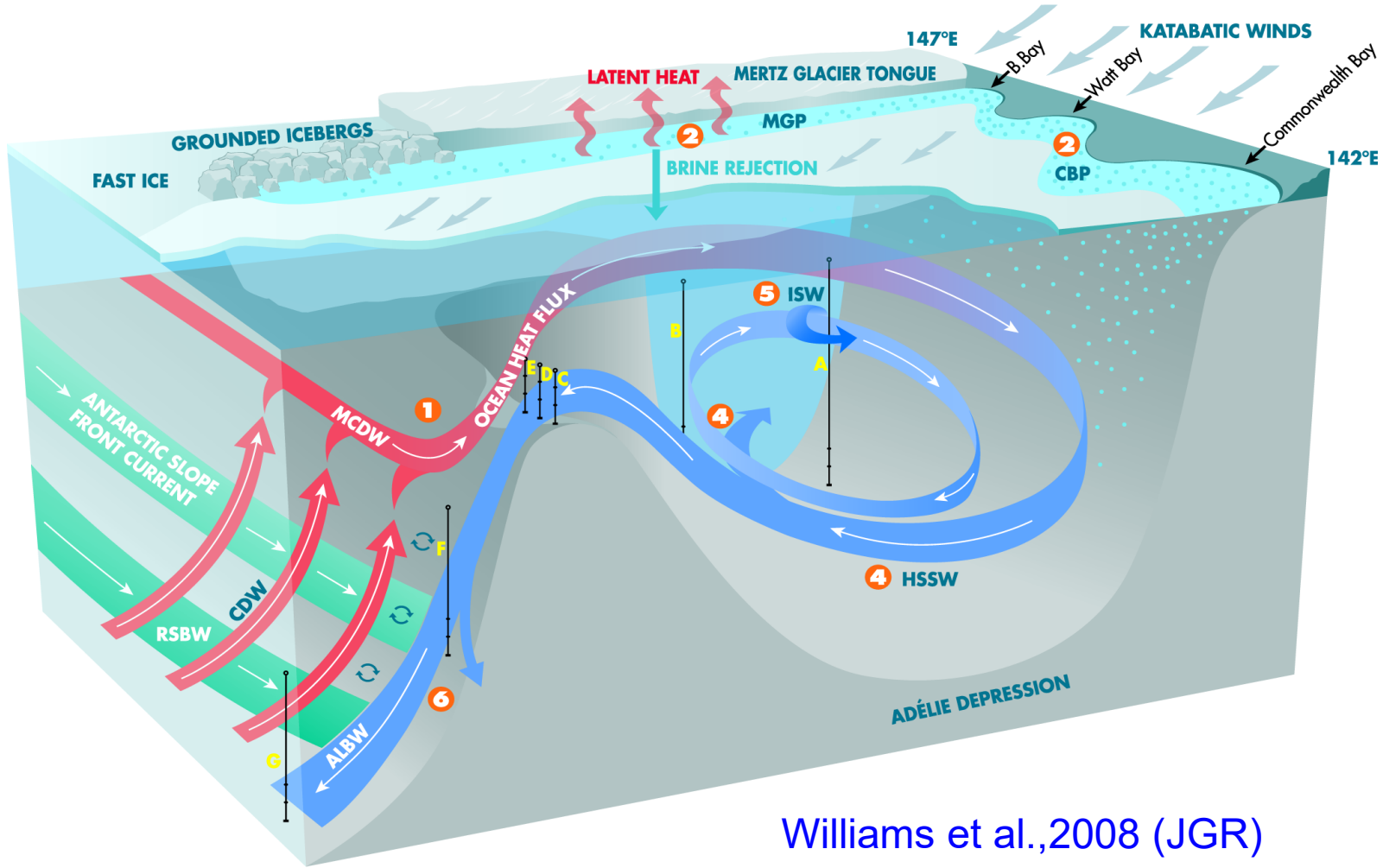
Fig. 4.6.1 Schematic map of major currents in the southern hemisphere oceans south of 20°S. Depths shallower than 3500 m are shaded. The two major cores of the Antarctic Circumpolar Current (ACC) are shown, the Subantarctic Front and Polar Front. Other abbreviations used are F for front, C for Current and G for gyre.

Antarctic Slope Current
ASC

Antarctic Circumpolar Current
ACC

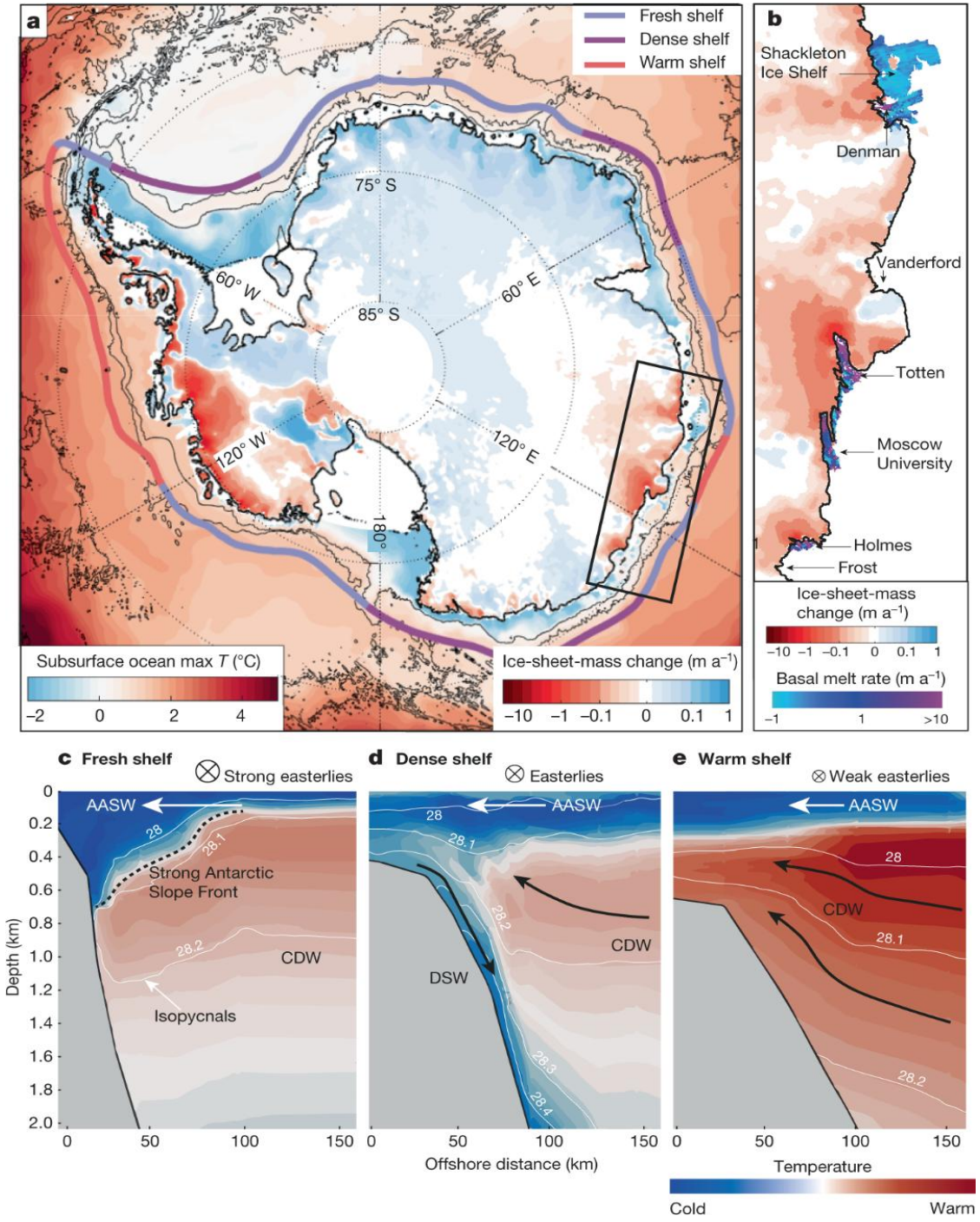


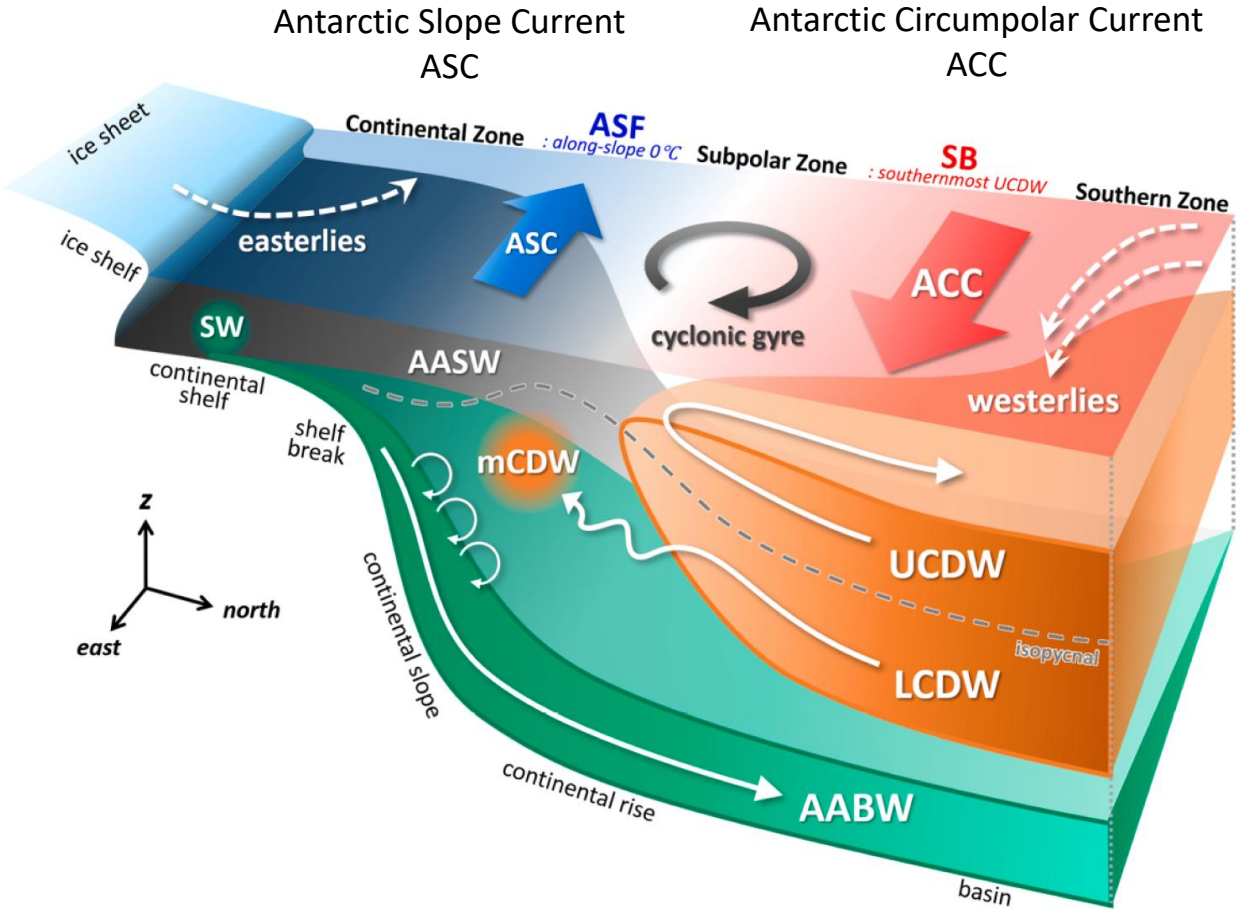
Yamazaki et al.2024



Williams et al.,2008 (JGR)



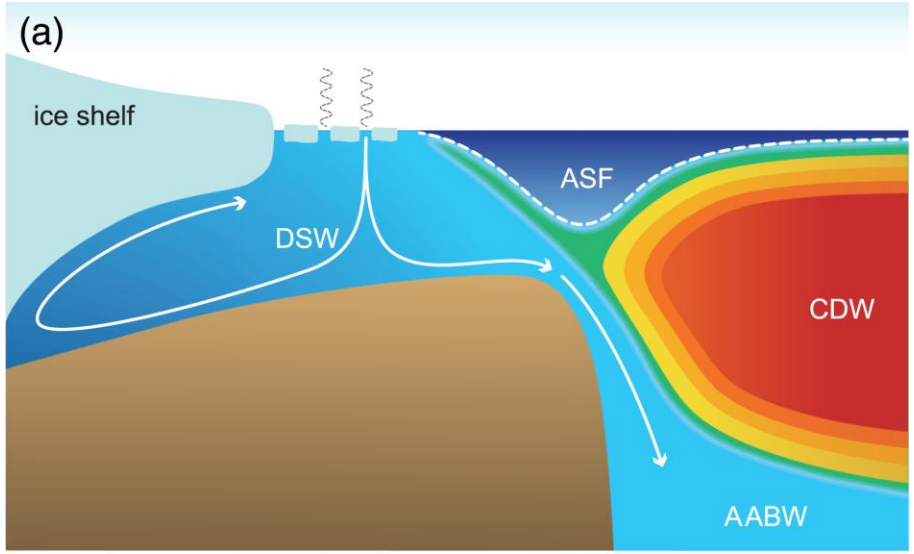




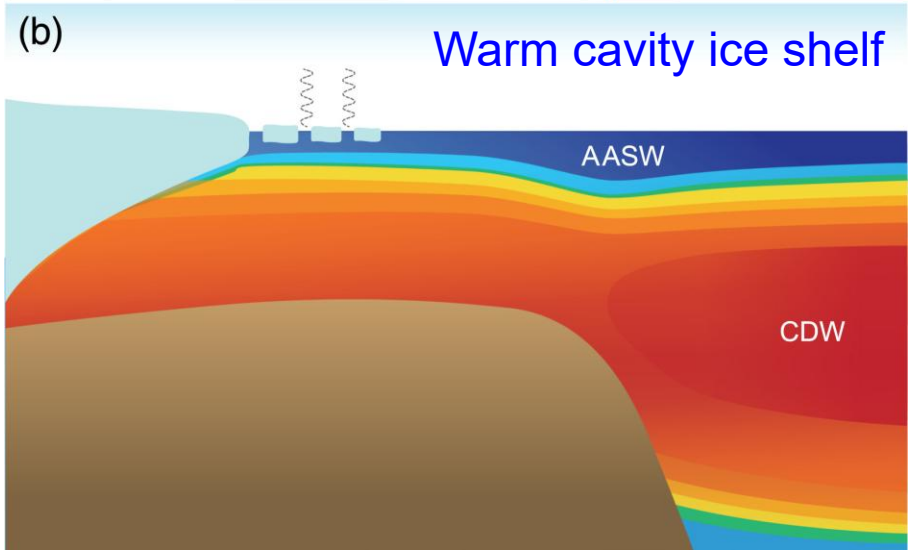
Yamazaki et al.2024

Stockes et al., 2022

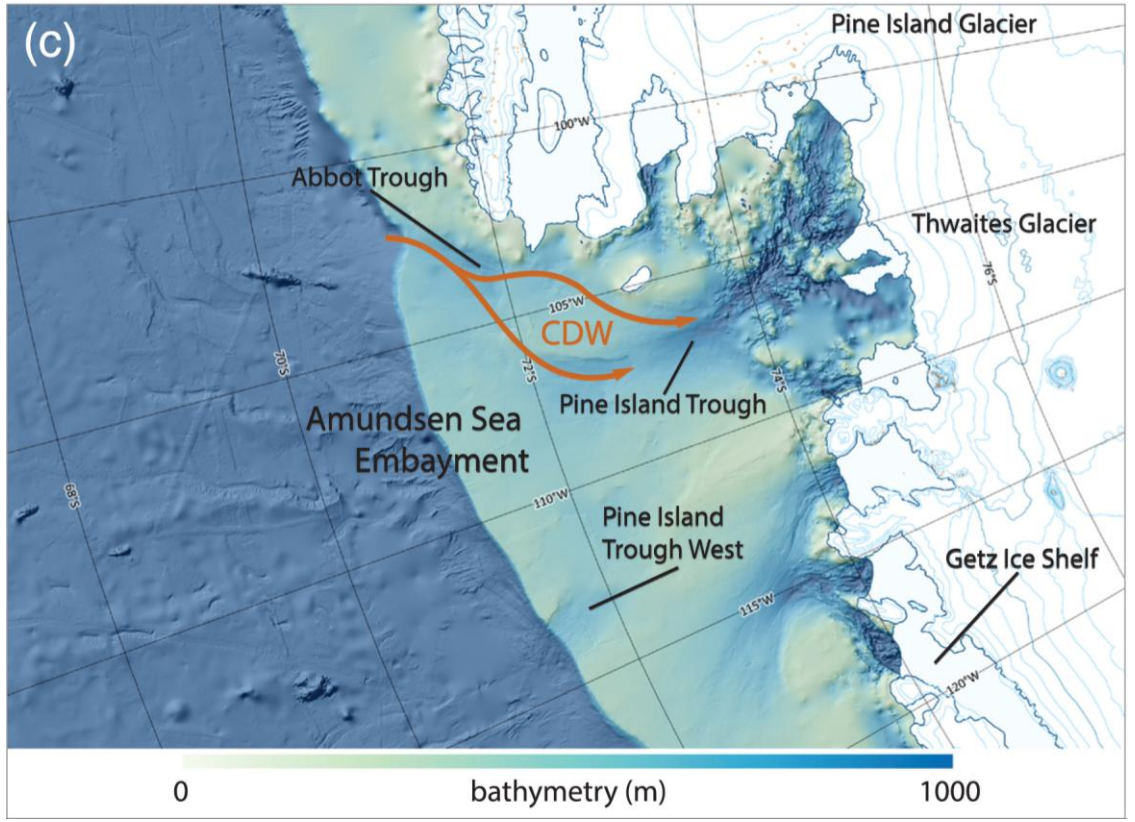
Cold cavity ice shelf



Warm cavity ice shelf

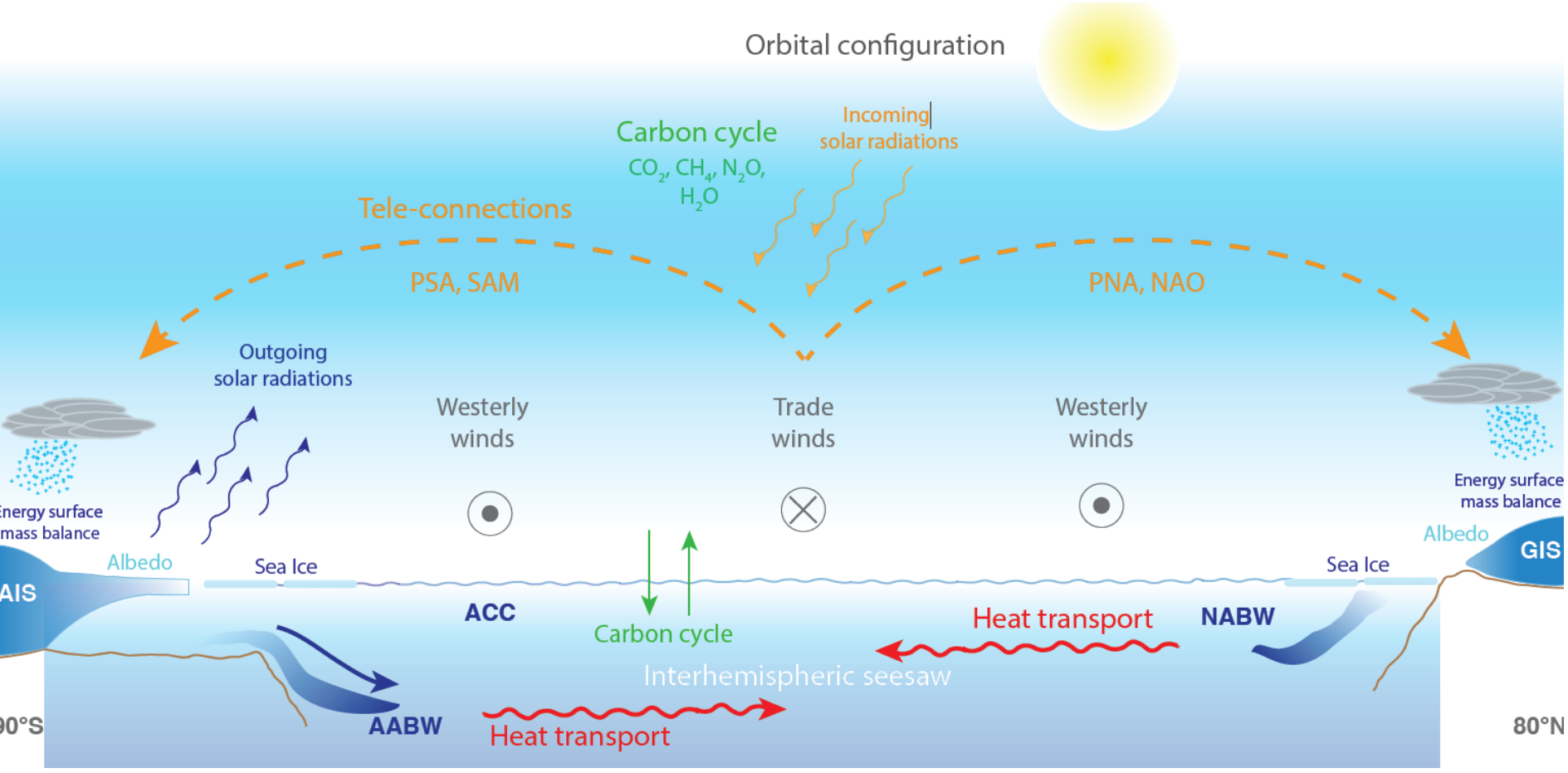


Troughs and depressions at the shelf break can facilitate access of oceanic heat on to the continental shelf and further to the coast



Noble et al., Reviews of Geophysics, Volume: 58, Issue: 4, First published: 15 August 2020, DOI: (10.1029/2019RG000663)

The orbital changes defines the amount of insulation to the polar regions



SAM: Southern Annular Mode
PSA: Pacific South-American oscillation
ACC: Antarctic Circumpolar Current

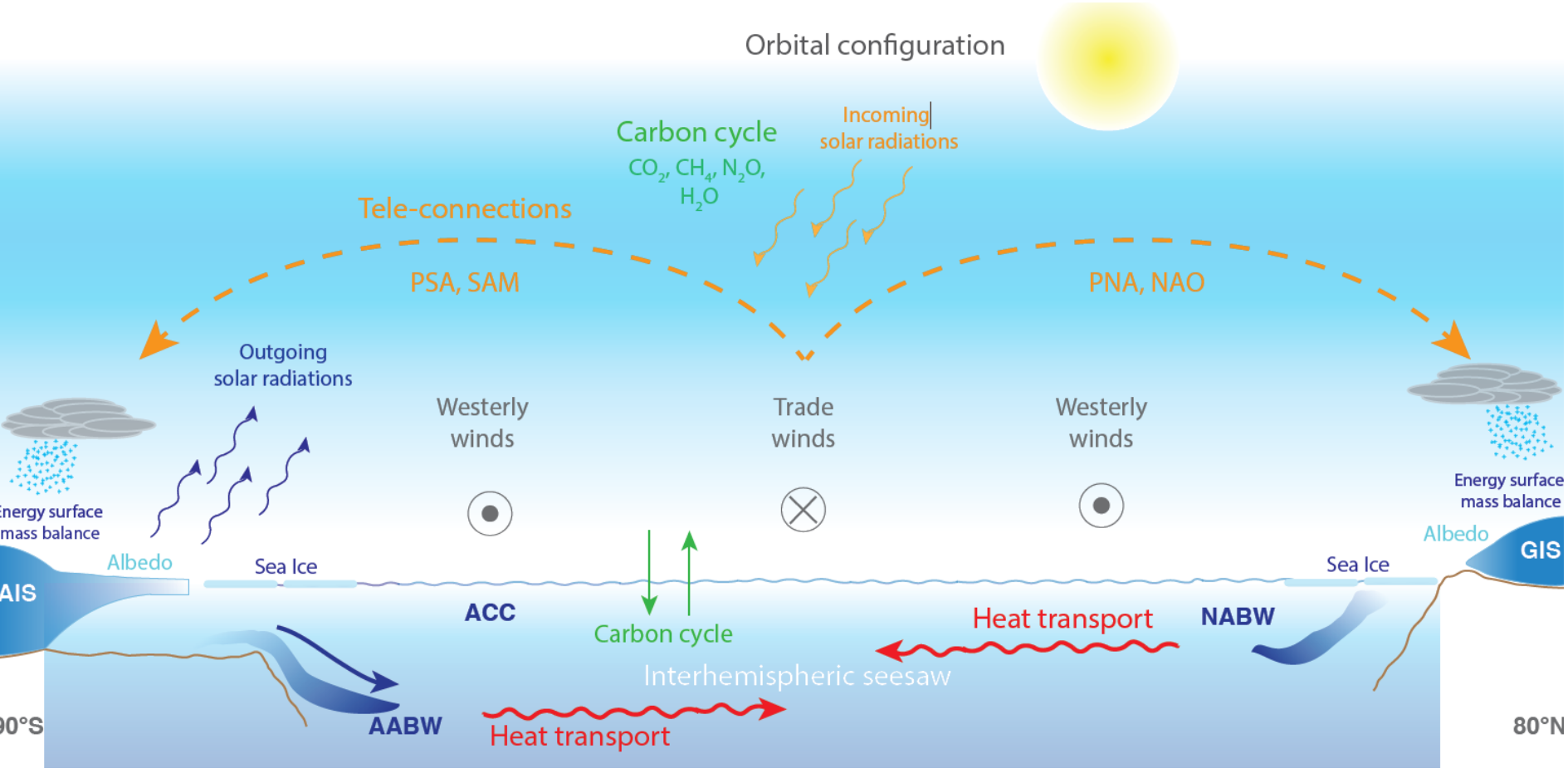
Colleoni et al., 2018 modified

Earth axis inclination (**obliquity**, 41,000 Kyr cycles) affects the strength of the seasons.
Least inclination = largest thermal gradient from low to high latitude.

Precession (23 and 19 kyr cycles) causes solstices (longest day in summer, and shortest in winter) to occur at different points in Earth's orbit, and thus affects the intensities/lengths of the seasons

Eccentricity (100 and 400 kyr) cycles) changes the shape of orbits modulates the amplitude of precession, and thus influencing the total annual/seasonal solar energy budget

Changes in cryosphere affect the Earth System



SAM: Southern Annular Mode
PSA: Pacific South-American oscillation
ACC: Antarctic Circumpolar Current

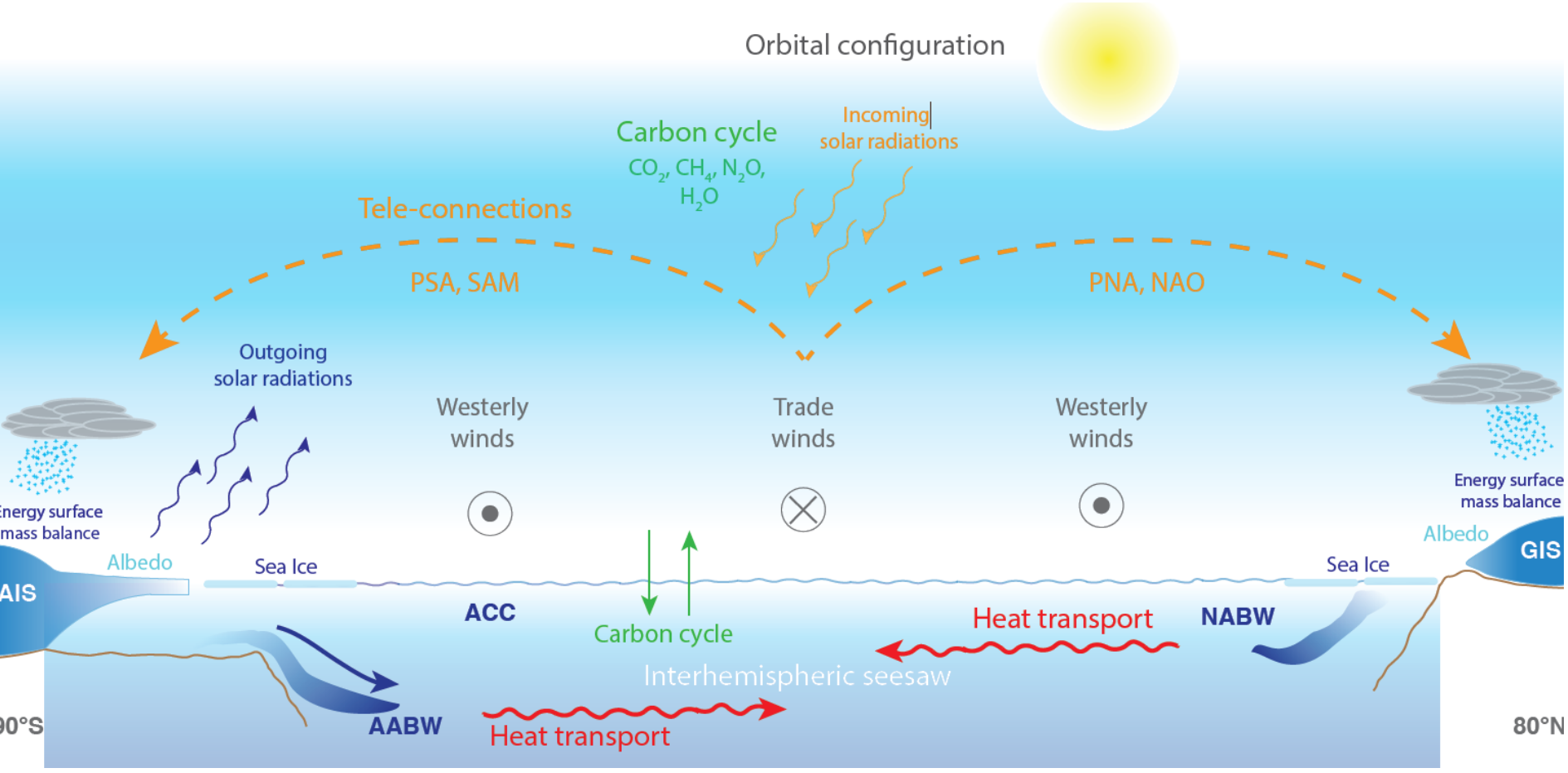
Colleoni et al., 2018 modified

Variations in polar ice cover and ice sheet volume directly affect Earth's absorption of solar energy through changes in **planetary albedo**

shifts in atmospheric and oceanic currents associated with high latitude processes influence the way **heat and marine nutrients are redistributed around the planet,**

=> form a significant control on global carbon cycling through time

Changes in cryosphere affect the Earth System



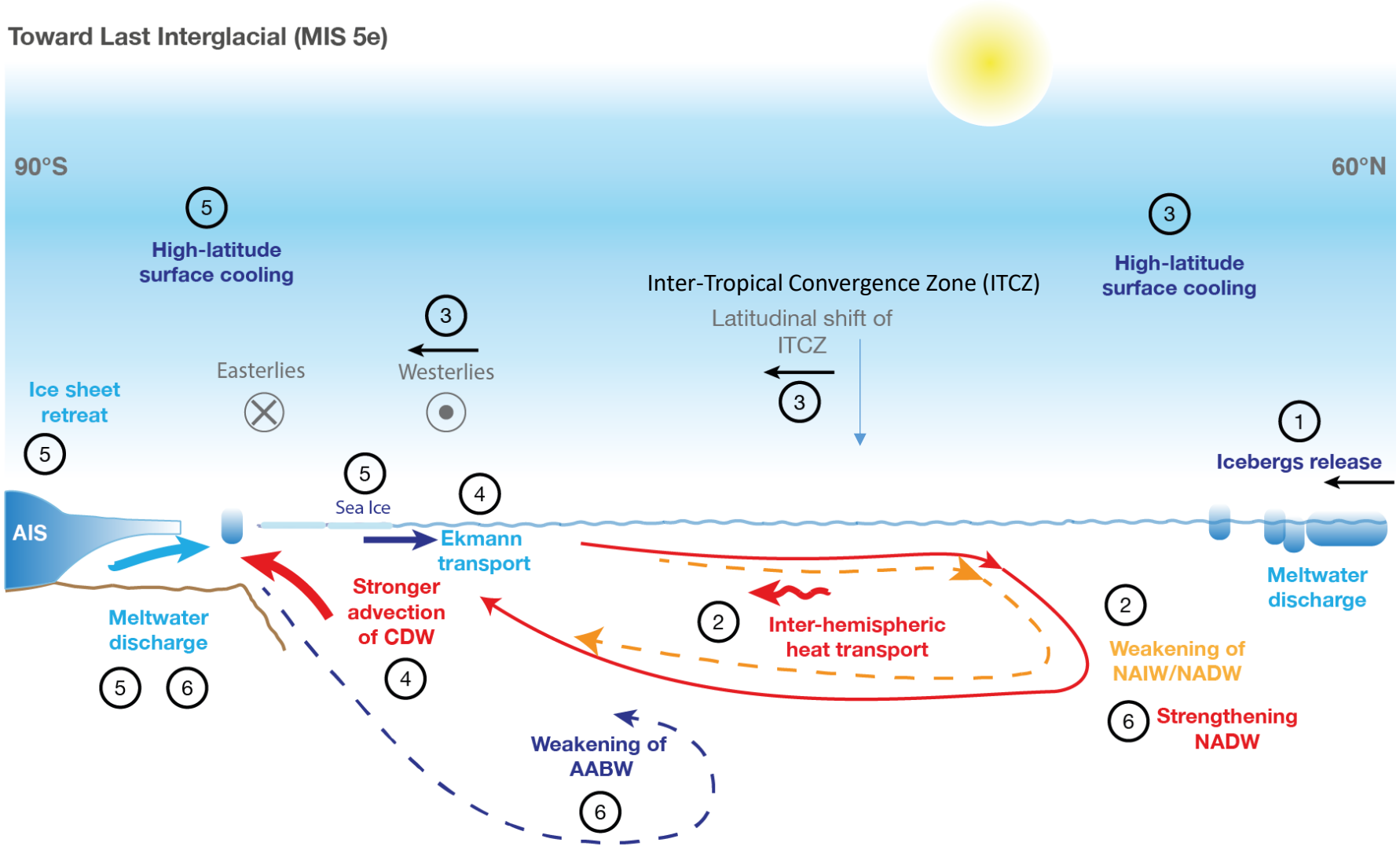
SAM: Southern Annular Mode
PSA: Pacific South-American oscillation
ACC: Antarctic Circumpolar Current

Colleoni et al., 2018 modified

Ocean warm water incursion in the continental shelf causes:
ice melting with fresh water release
⇒ sea ice extension increase
= **stabilizing effect?**

Antarctic Bottom Water production decrease causes:
slow down of global circulation
⇒ less latitudinal heat/salty gradient
= **stabilizing effect?**

Impact of freshwater at global scale: bipolar seesaw



Antarctic Ice Sheet
Ice volume= 27×10^6 Km^3

Equivalent global sea level= 58.3 m (~22.6 m of marine based ice)

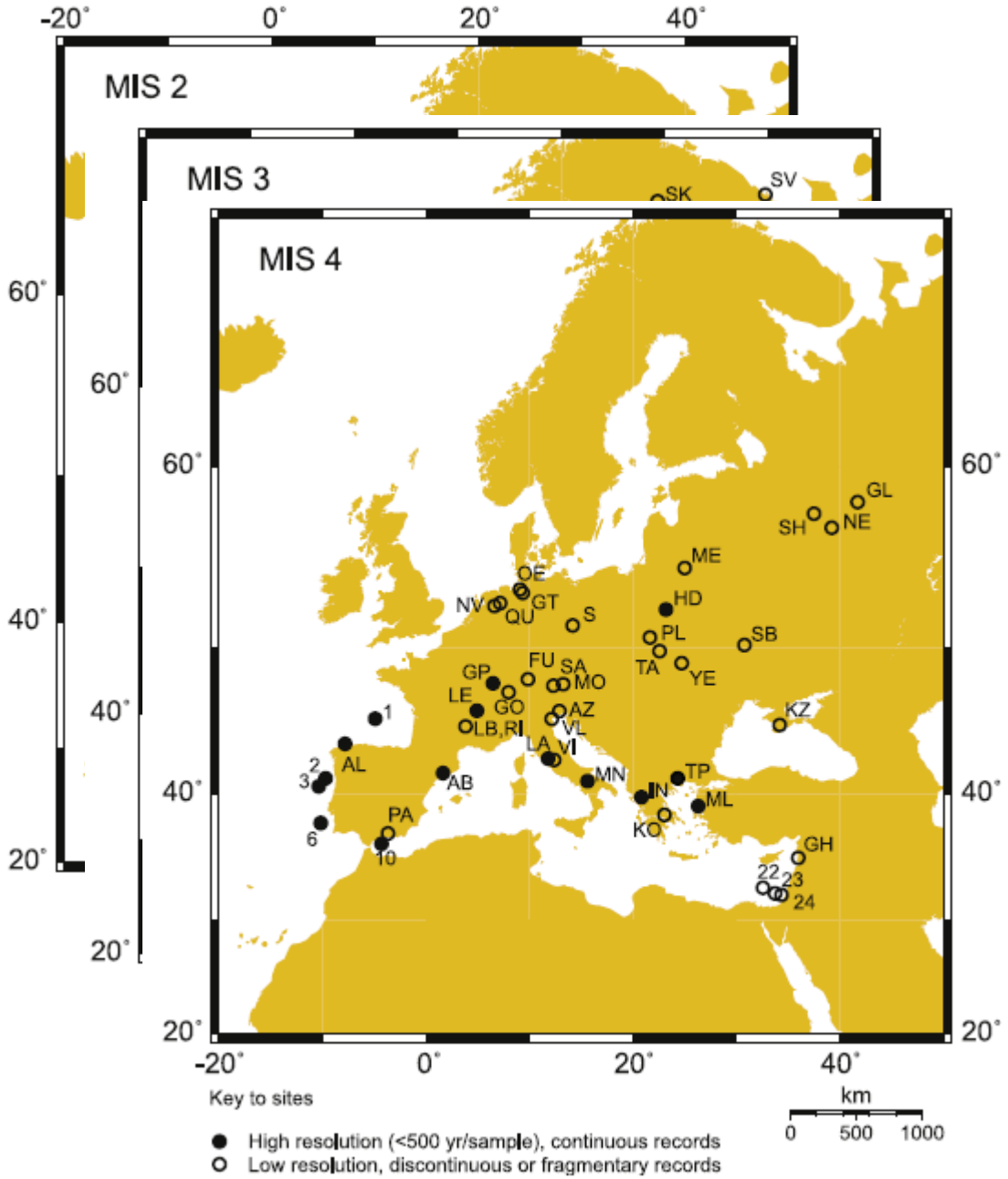
1 e.g. Heinrich 11 event (B135 and 130 ka);

Greenland Ice Sheet
Ice volume= 2.85×10^6 Km^3

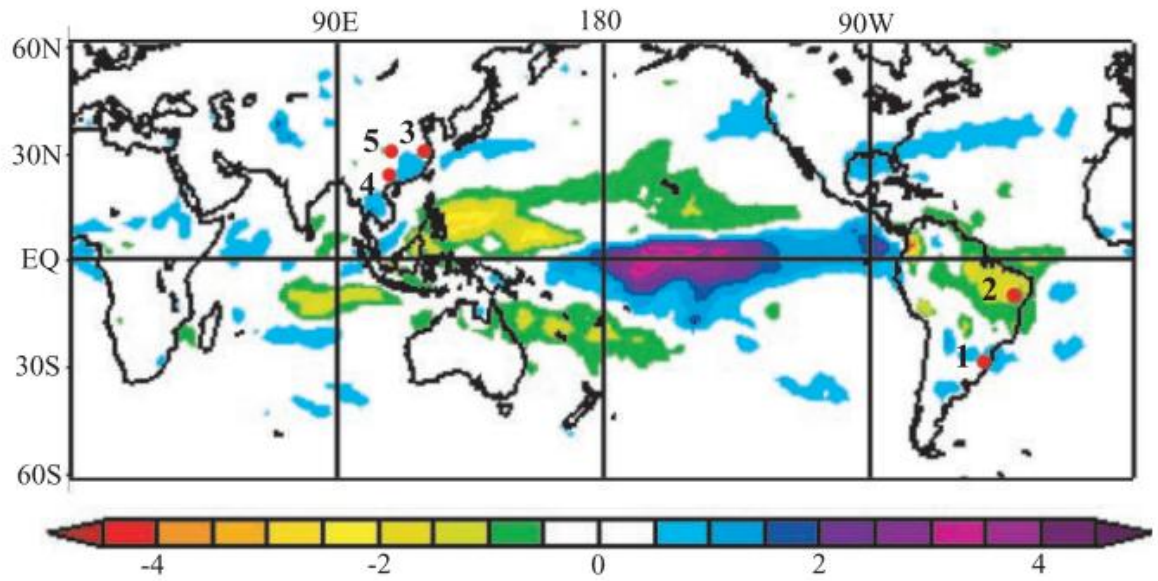
Equivalent global sea level= 7.2 m

Taylor et al. 2020 Colleoni et al. 2022

Millennial-scale variability during the last glacial in vegetation records from Europe (Fletcher et al. 2010) - pollen

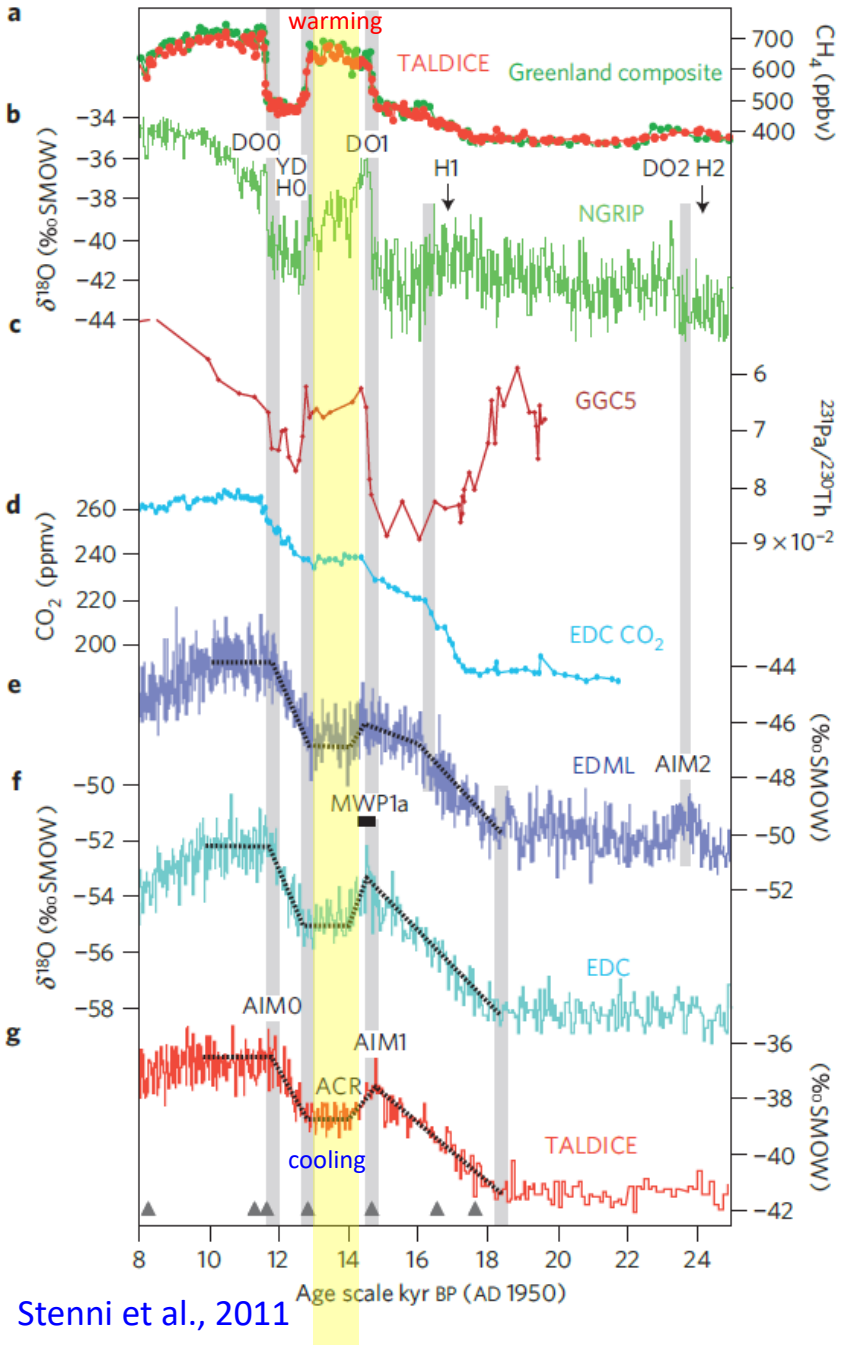


Millennial-scale precipitation changes in southern Brazil over the past 90,000 years (Wang et al. 2007) - speleothems record



"millennial-scale events seem to be strongly modulated by AMOC changes and associated Inter-Tropical Convergence Zone migration. Through air-sea dynamics, abrupt climate events initiated in the North Atlantic eventually telecommunicate to the low latitudes."

Asynchronous temperature changes between Greenland and Antarctic ice core records during the last glacial period

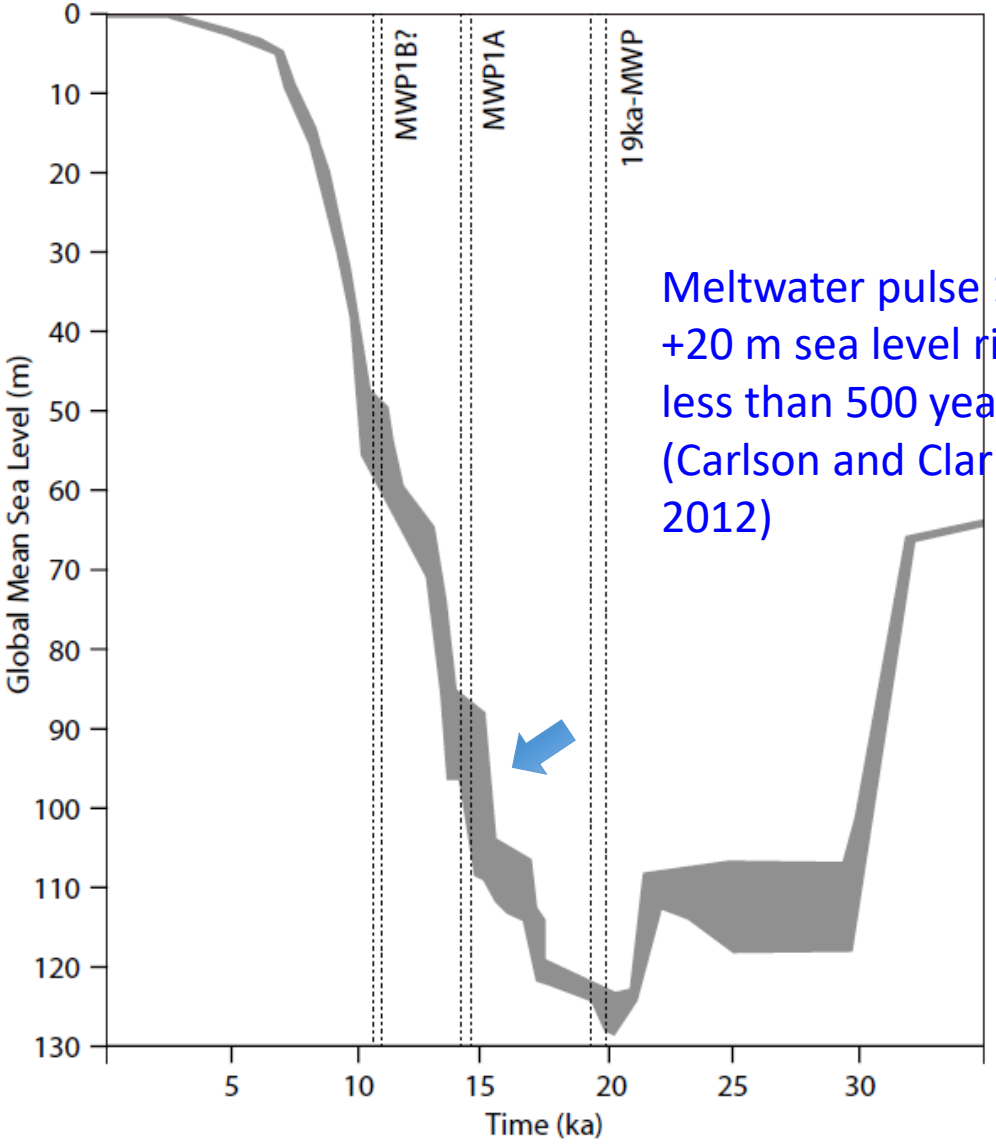


Stenni et al., 2011

the Antarctic Cold Reversal (ACR) is synchronous with the Bølling/Allerød warming in the Northern Hemisphere 14,600 years ago.

The Bølling/Allerød is coincident with the occurrence of meltwater pulse 1A (MWP-1A) that caused a rapid sea level rise of about 9-20 m at a rate of 4 m/100 yr.

Average sea level record from Great Barrier coral Reef (ODP exp. 325)

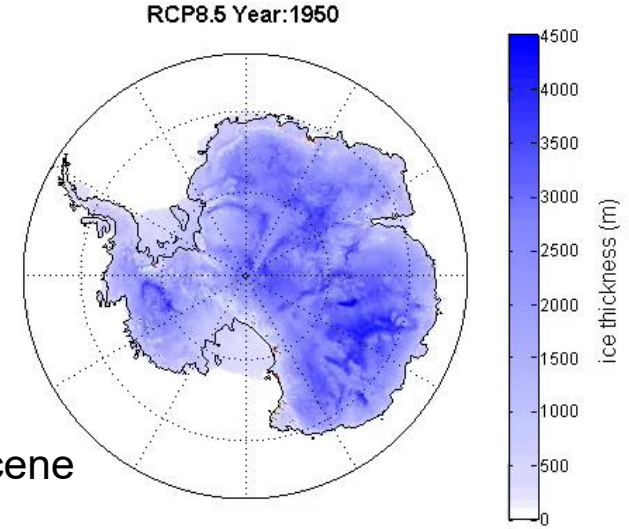


Meltwater pulse 1A = +20 m sea level rise in less than 500 years (Carlson and Clark, 2012)

Yokoyama et al. (2018 and 2019)

there remains ~**22.6 m sea level** equivalent of marine based ice currently in Antarctica, much of which is potentially sensitive to marine ice sheet instability and rapid retreat

Global average sea level projection

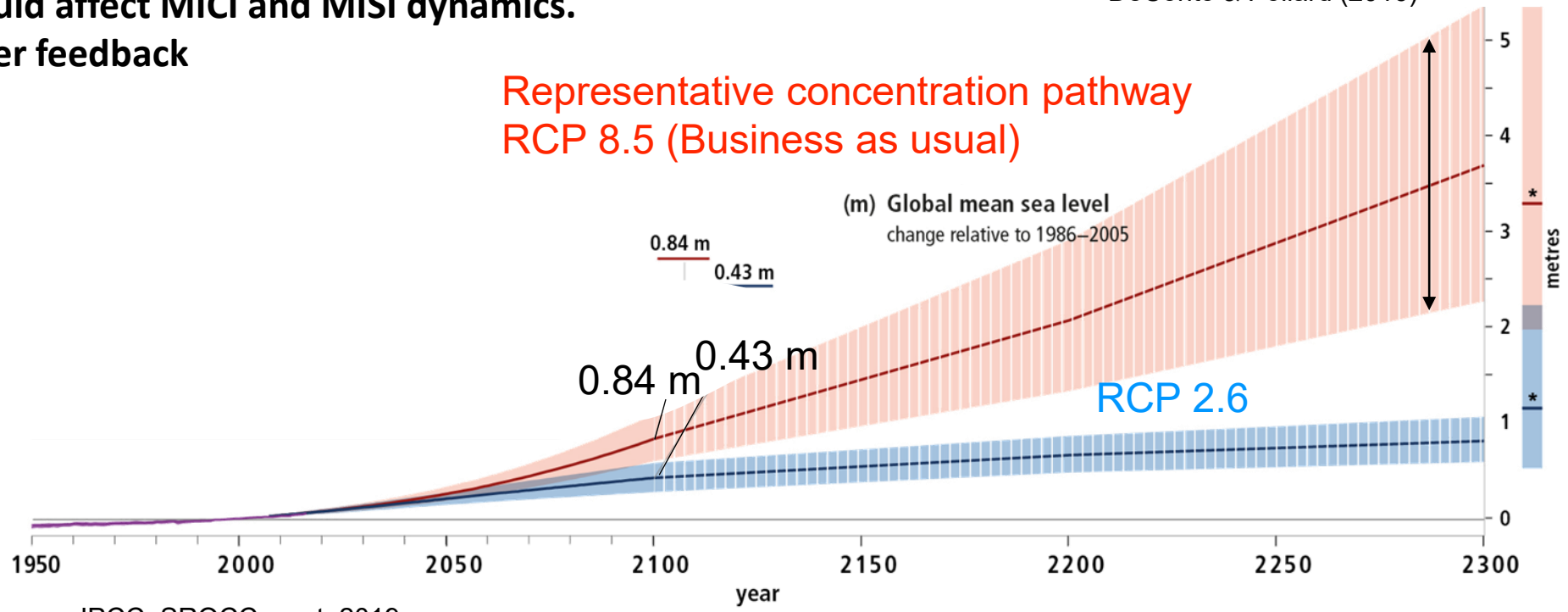


DeConto & Pollard (2016)

Model constraints from observations:
+3.6-7.4 m SLE for the Last Interglacial LIG (**128 ka**) Pleistocene
+10-20 m SLE for the mid Pliocene Warm period mPWP (**3.3 Ma**) Pliocene

not GIA that could affect MICI and MISI dynamics.
No ice meltwater feedback

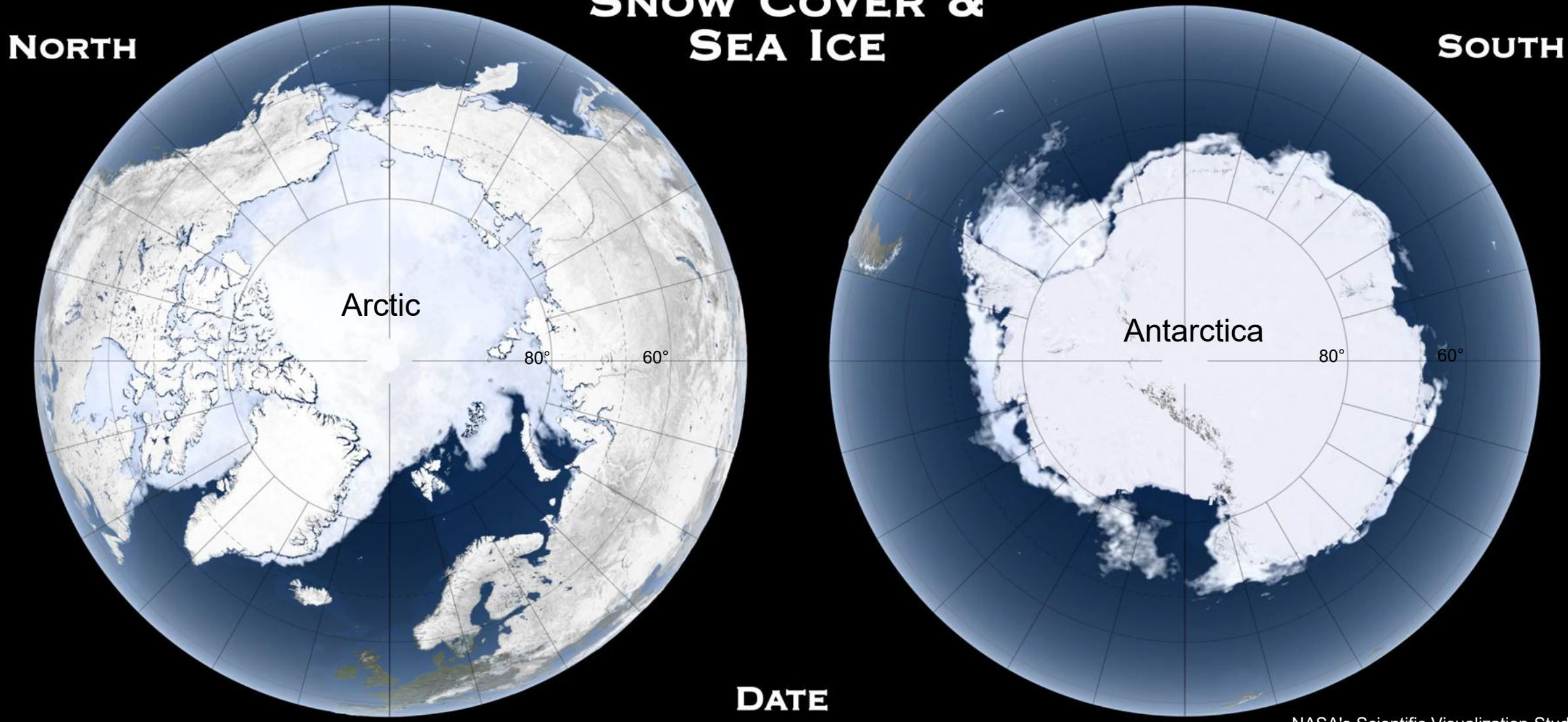
Representative concentration pathway
RCP 8.5 (Business as usual)



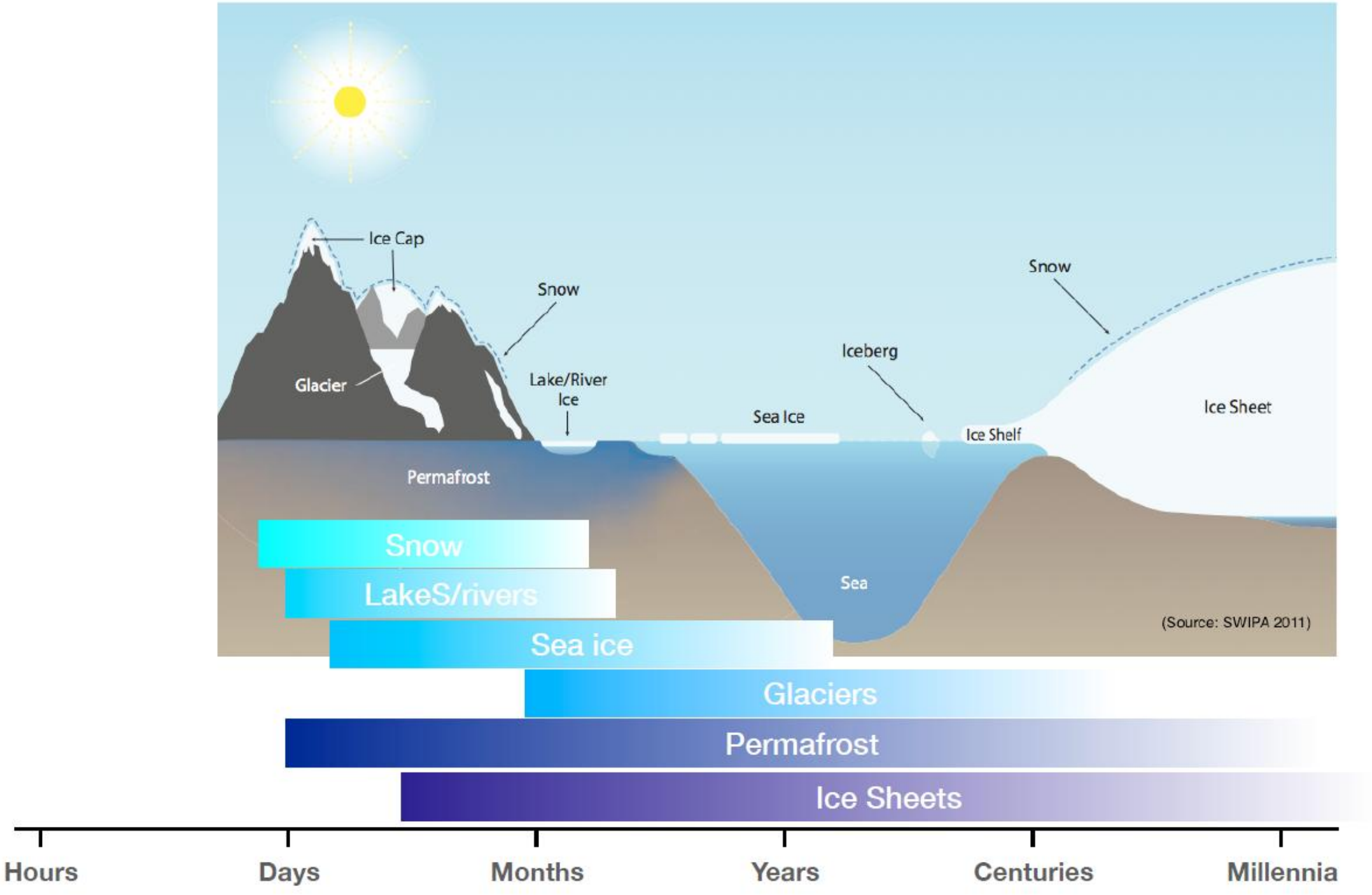
Large uncertainties

Source: IPCC, SROCC, sept. 2019

Snow Cover & Sea Ice



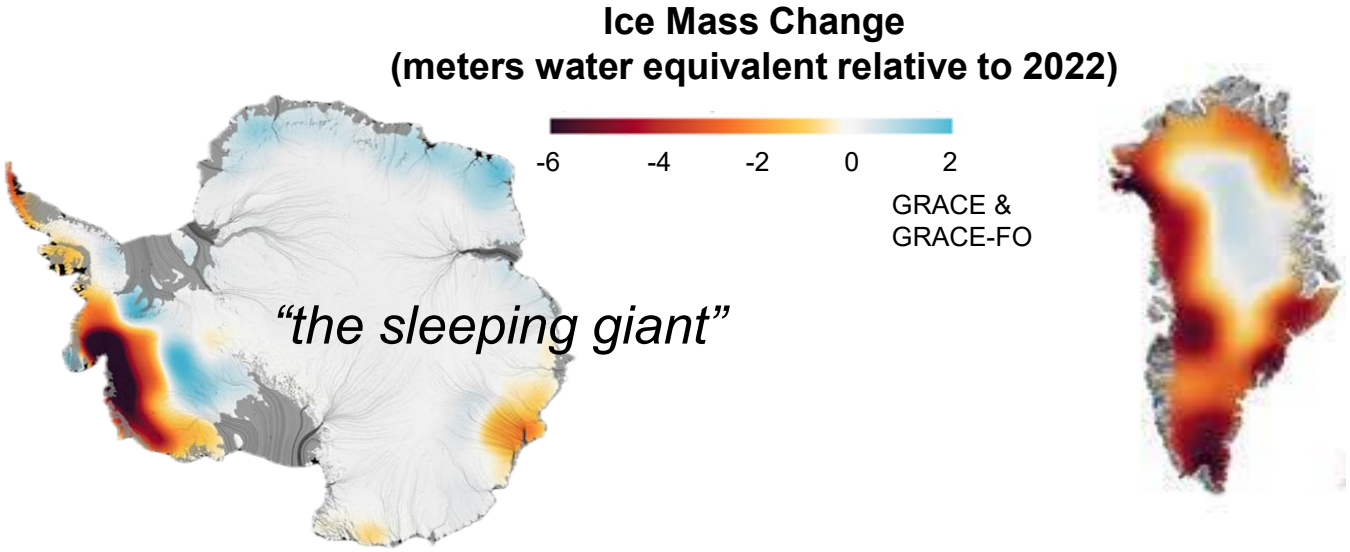
NASA's Scientific Visualization Studio


Ice Cap
Snow
Glacier
Lake/River Ice
Sea Ice
Iceberg
Snow
Ice Shelf
Ice Sheet
Permafrost
Sea
(Source: SWIPA 2011)
Snow
LakeS/rivers
Sea ice
Glaciers
Permafrost
Ice Sheets
Hours
Days
Months
Years
Centuries
Millennia

Ice sheets

Total ice volume ca. 58 m

Total ice volume ca. 7 m



0.43 mm/year

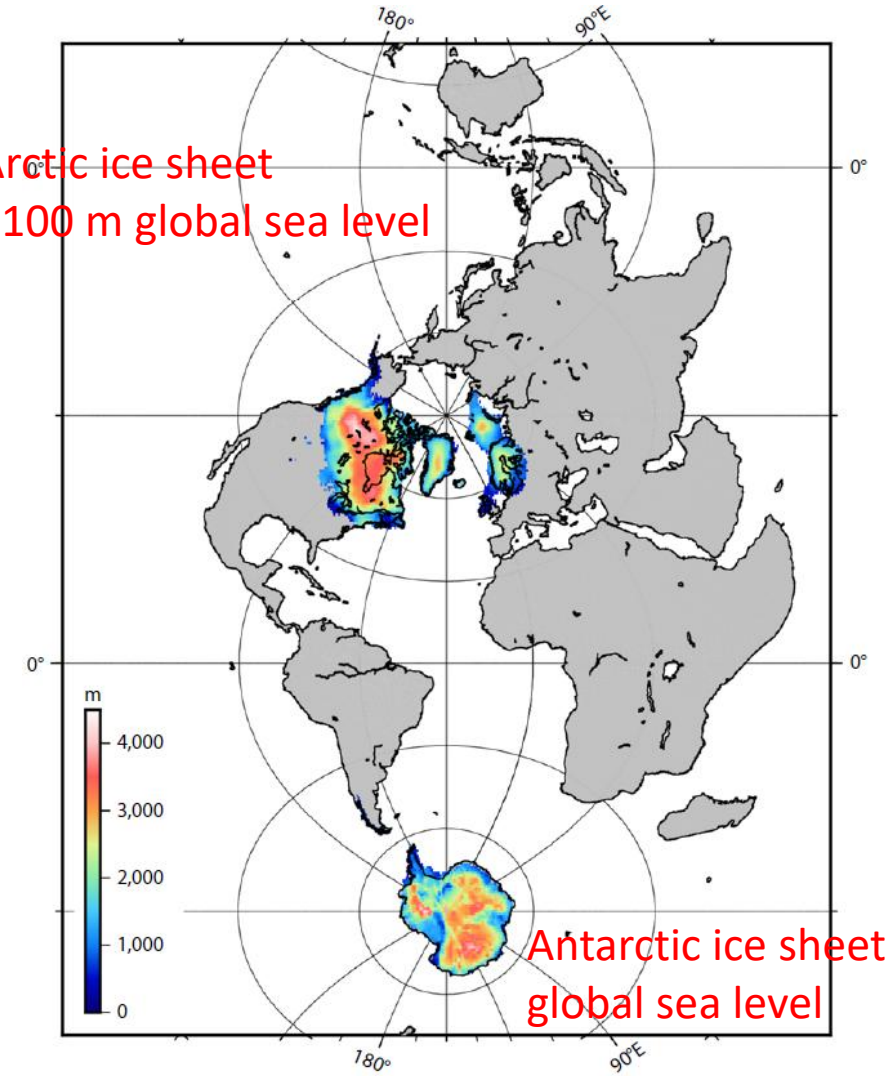
0.77 mm/year

Total sea level contribution
+1.2 mm/year
average 2006-2015





Polar ice sheet extension during the last glacial maximum 21,000 years ago

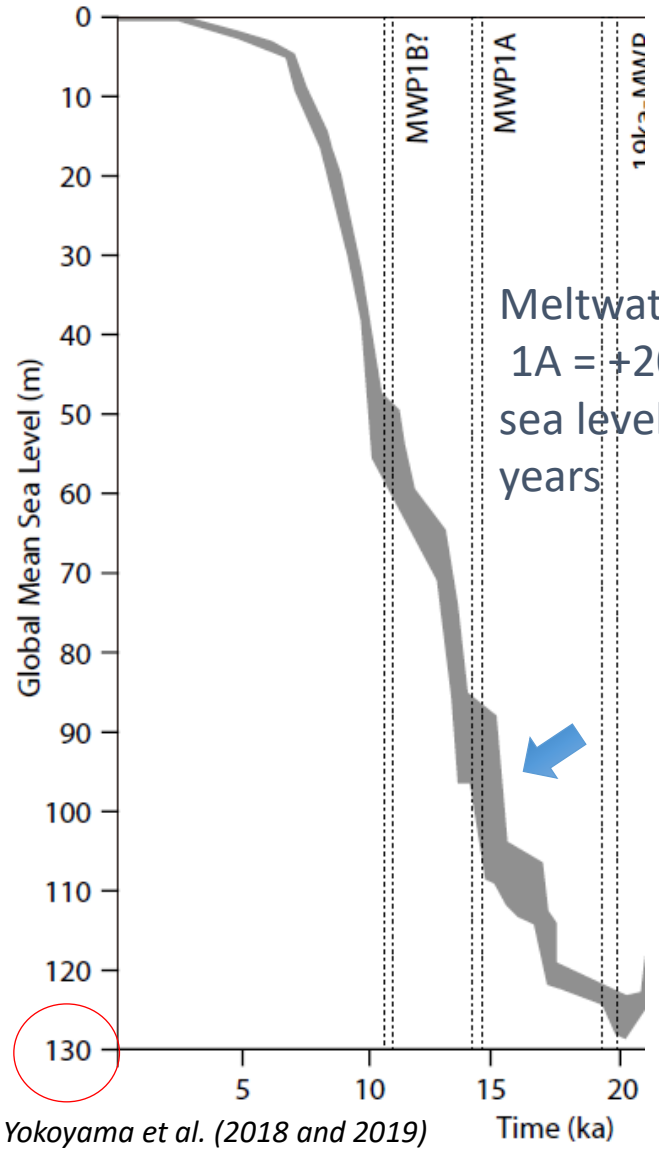


Arctic ice sheet
+100 m global sea level

Antarctic ice sheet +30 m global sea level

Peltier et al., 2015, Yokoama et al., 2019

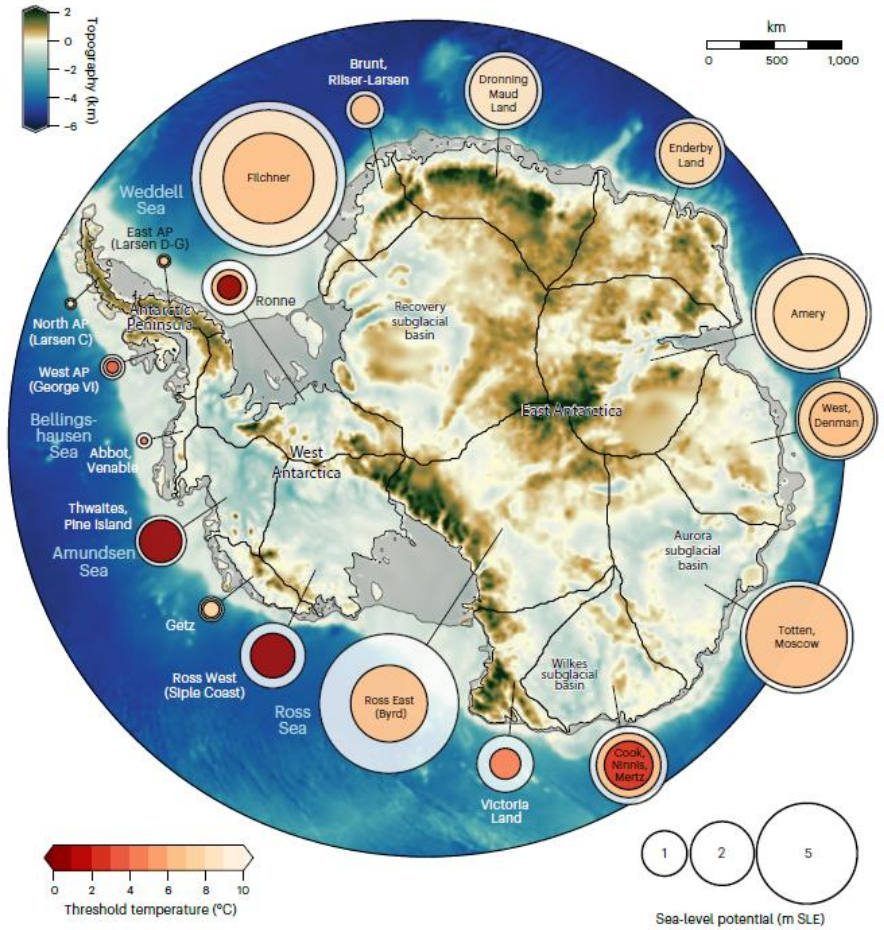
Aaverage sea level as recorded in the Great Barrier coral Reef (ODP exp. 325)

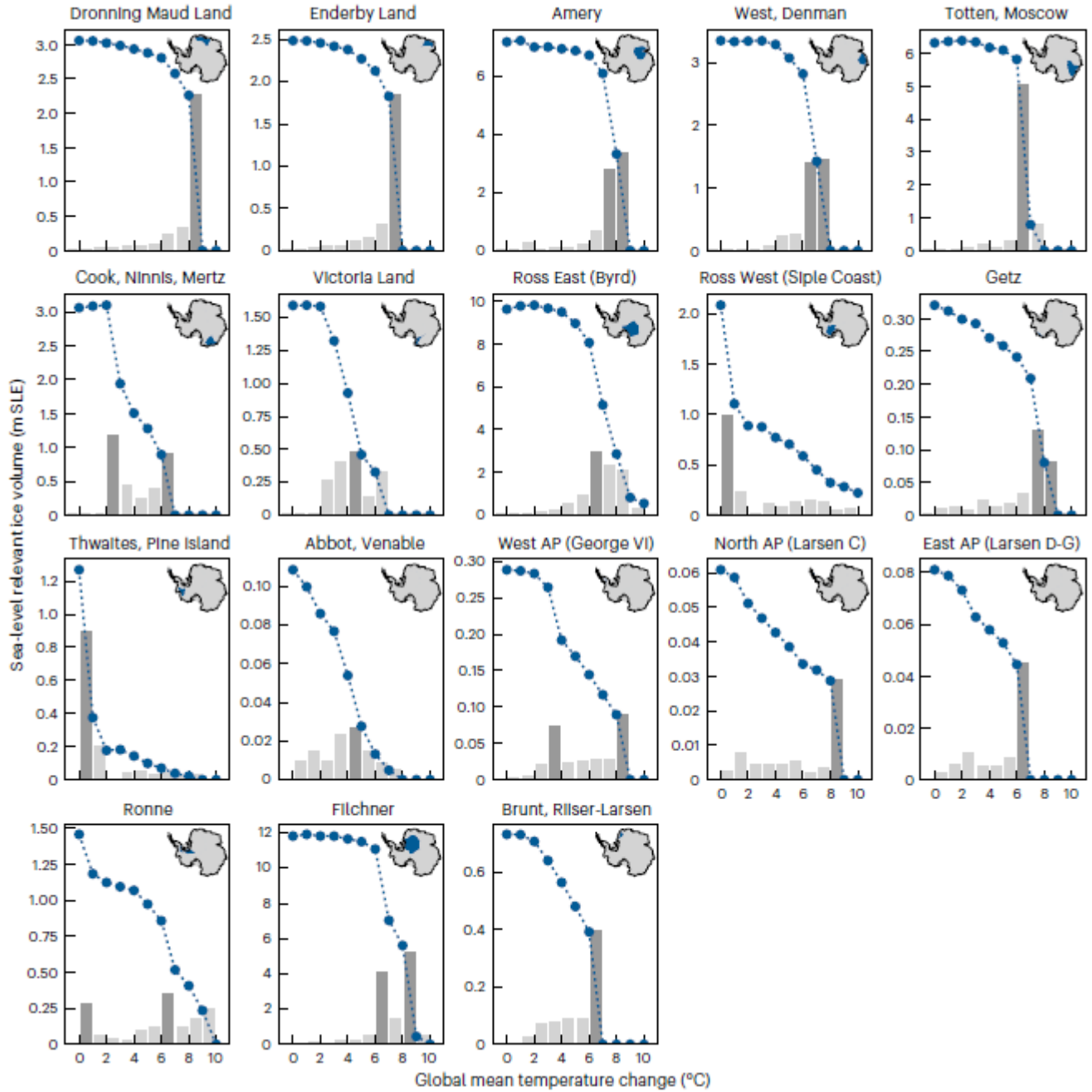


Meltwater pulse 1A = +20 m global sea level rise in 340 years

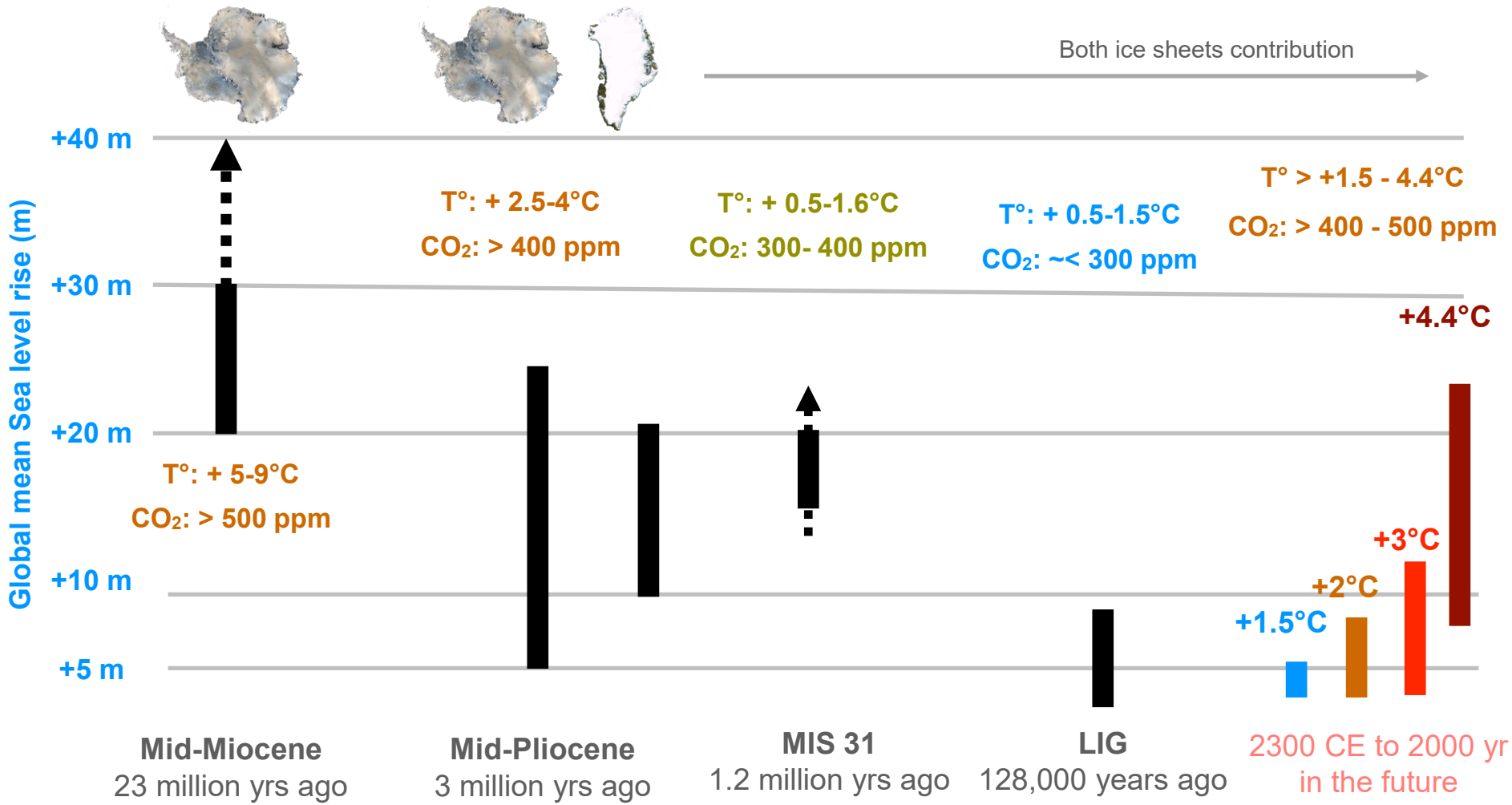
Yokoyama et al. (2018 and 2019)

How fast and when will the remained present day ice sheet melt?





Winkelmann et al., 2026



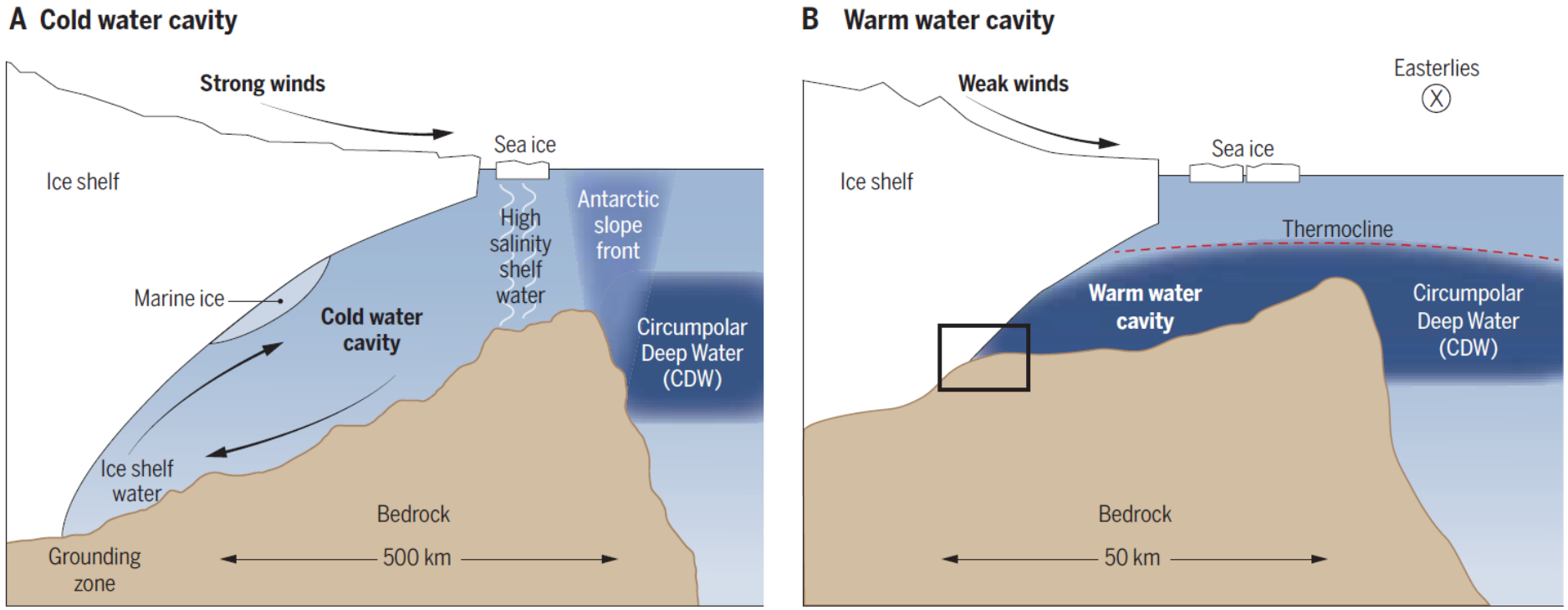
Colleoni et al., in preparation after Colleoni et al. (2022)

Ice is melting: what is the main driver? Atmospheric or ocean warming?



Nansen Ice Shelf, Lat: -75.039°/Lon: 163.512°, January 13, 2014 at 09:10 AM (Local time at Terra Nova Bay). Courtesy Dr. Won Sang Lee, Principal Research Scientist, KOPRI

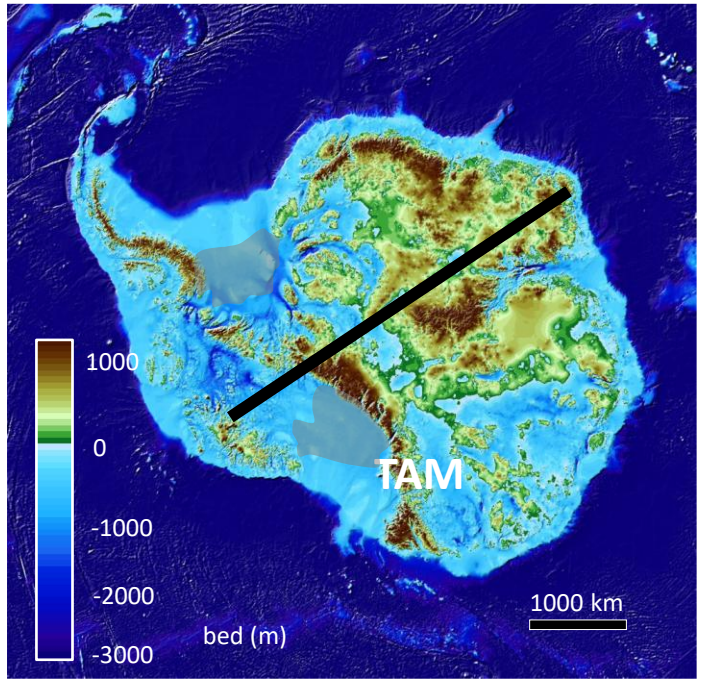
https://www.youtube.com/watch?v=dAOBbXQys78

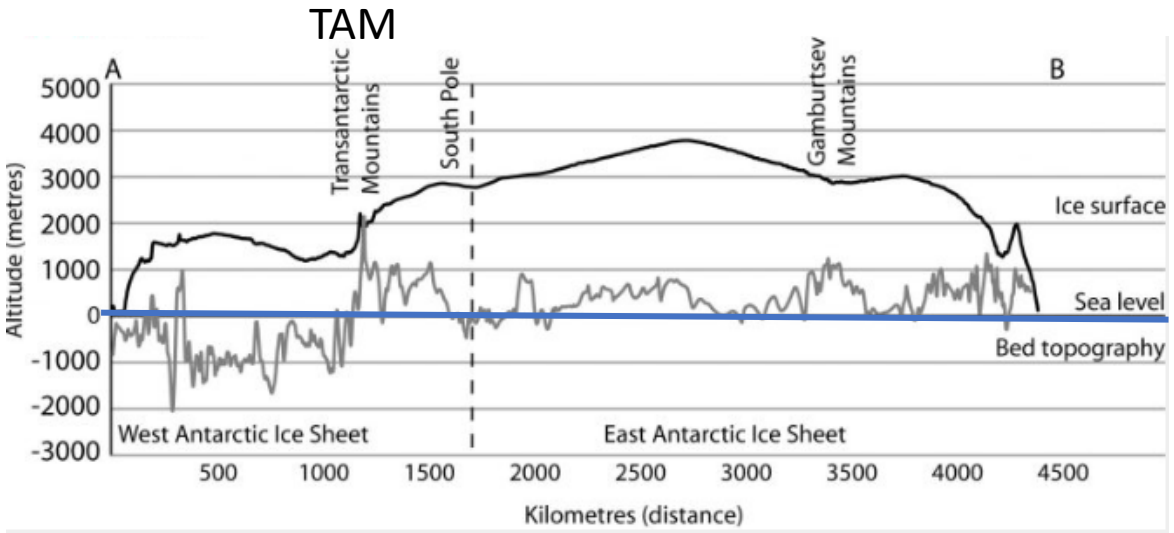


Holland et al., 2020

Topography and bathymetry

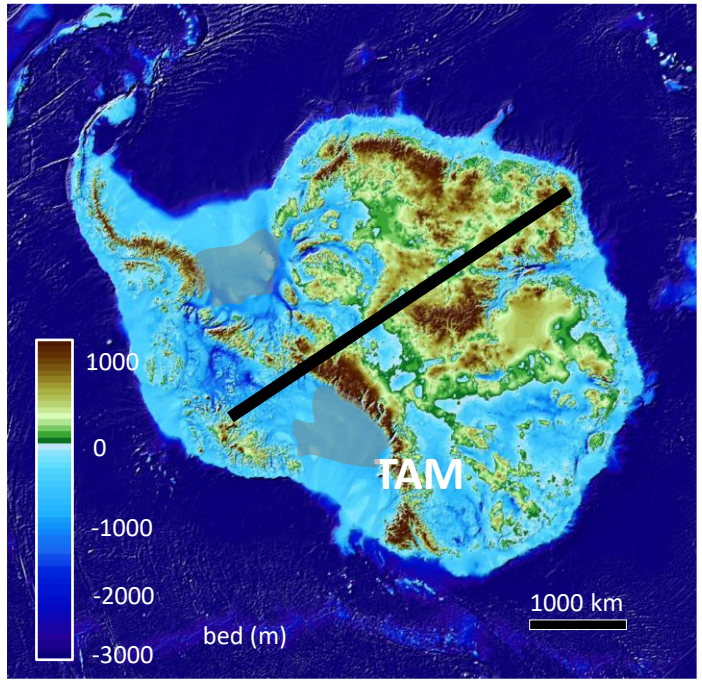
Morlinghen et al., 2019, Dorschel et al., 2022



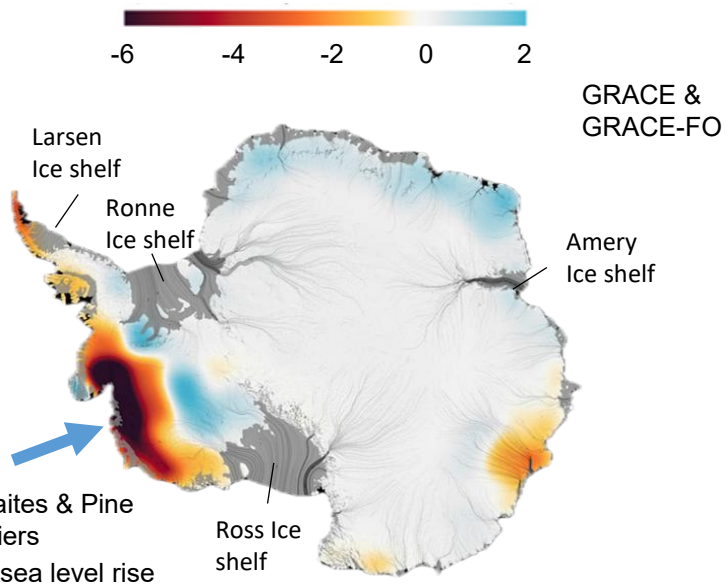


Topography and bathymetry

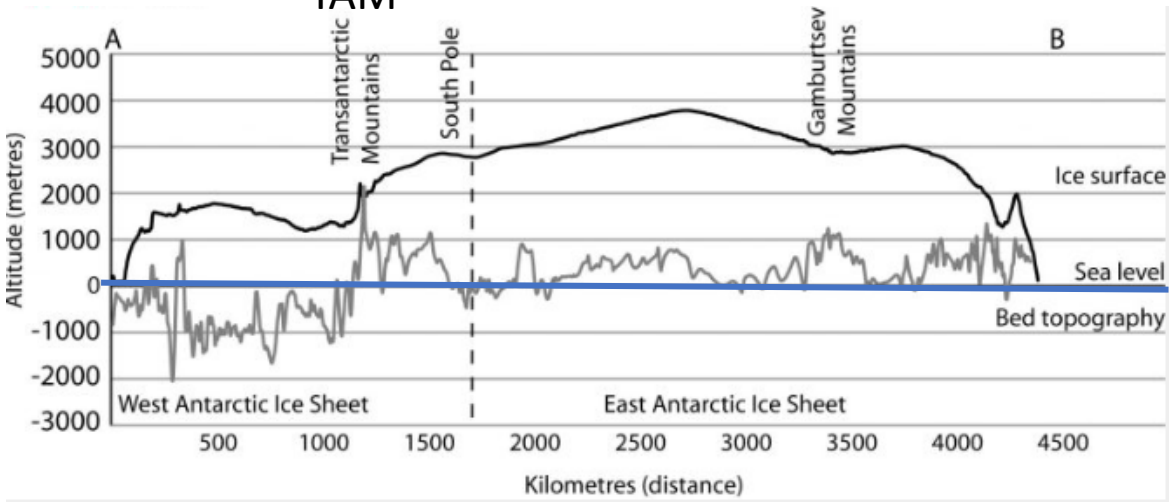
Morlinghen et al., 2019, Dorschel et al., 2022



Ice Mass Change
(meters water equivalent relative to 2022)



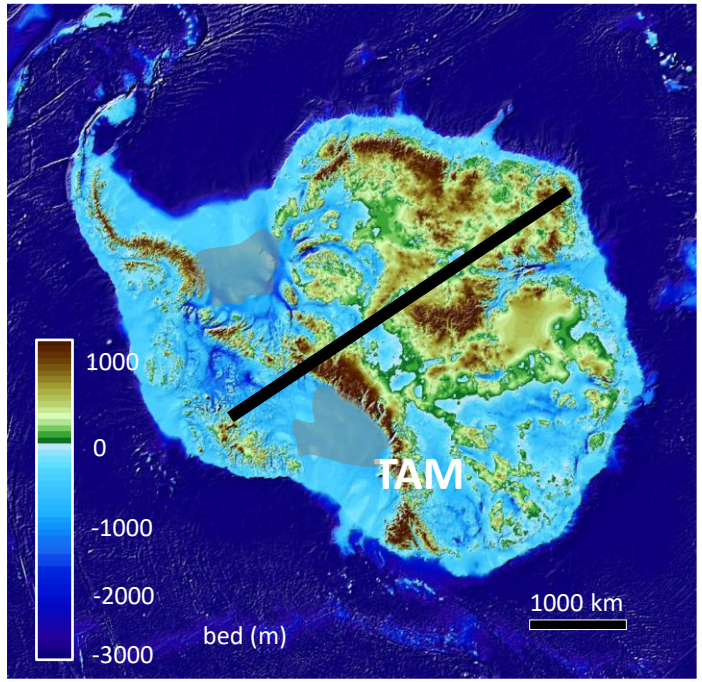
TAM



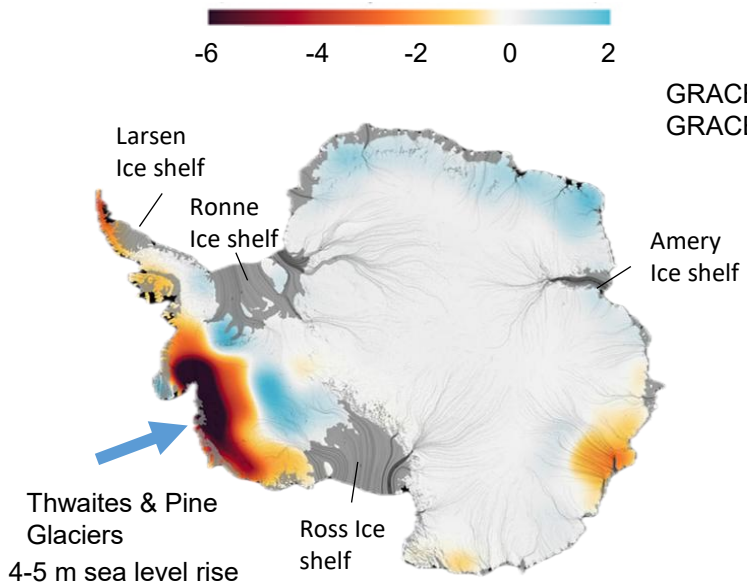
Paleoceanographic reconstruction of polar marine environment : why and how

Topography and bathymetry

Morlinghen et al., 2019, Dorschel et al., 2022

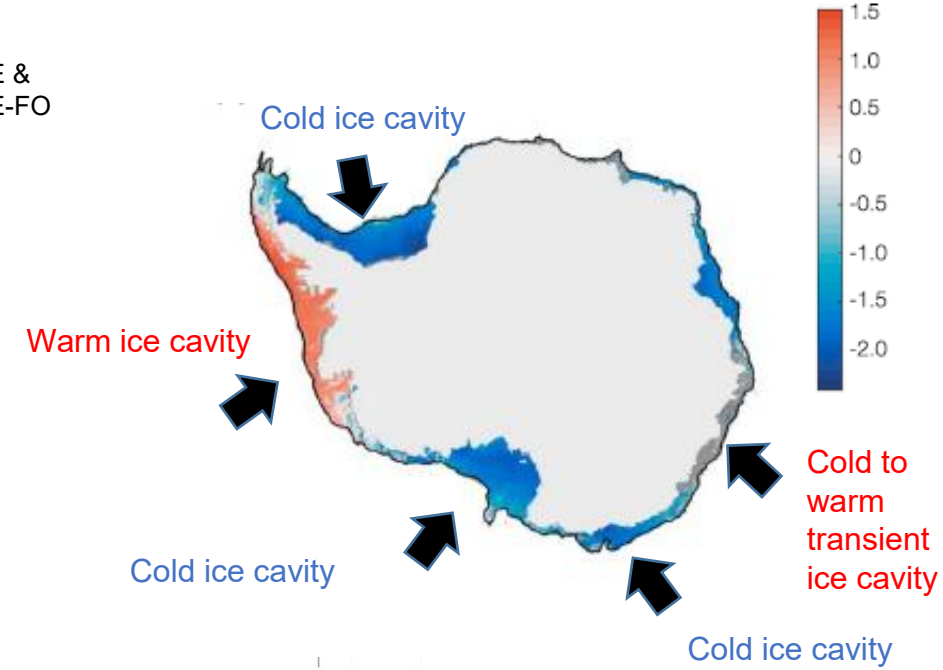


Ice Mass Change (meters water equivalent relative to 2022)

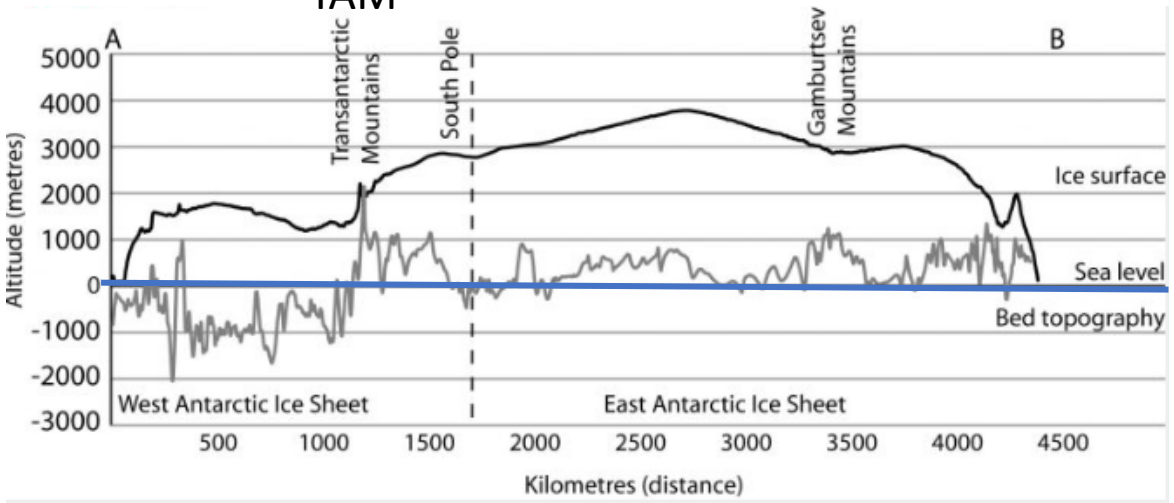


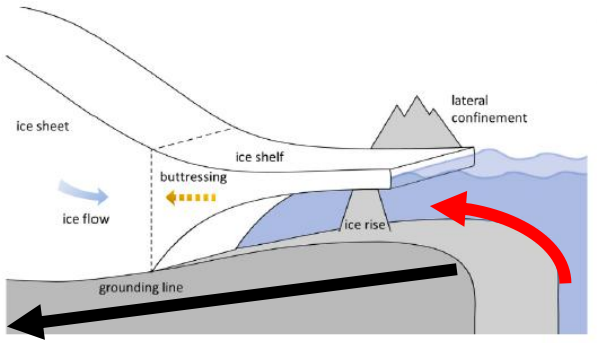
Continental Shelf bottom water temperature (°C)

Thomspon et al., 2018



TAM





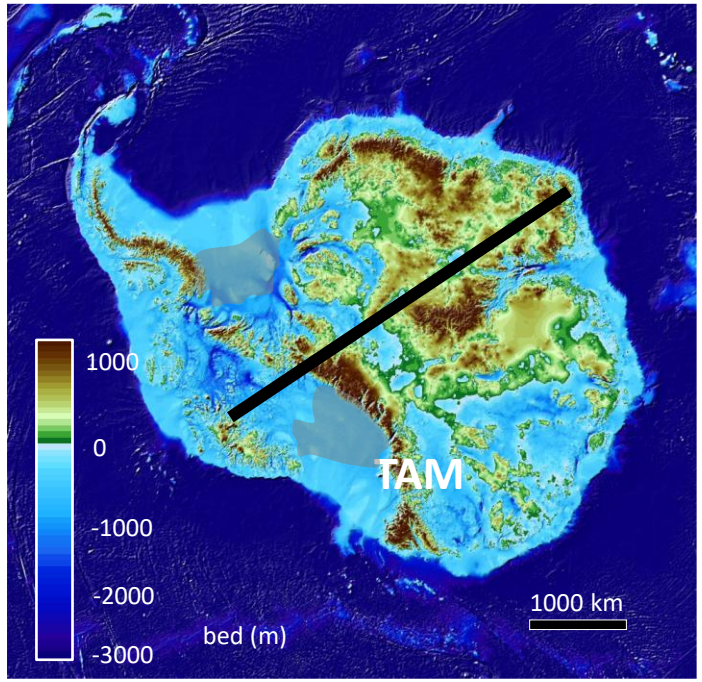
[Credit: Ronja Reese & Maria Zeitz]

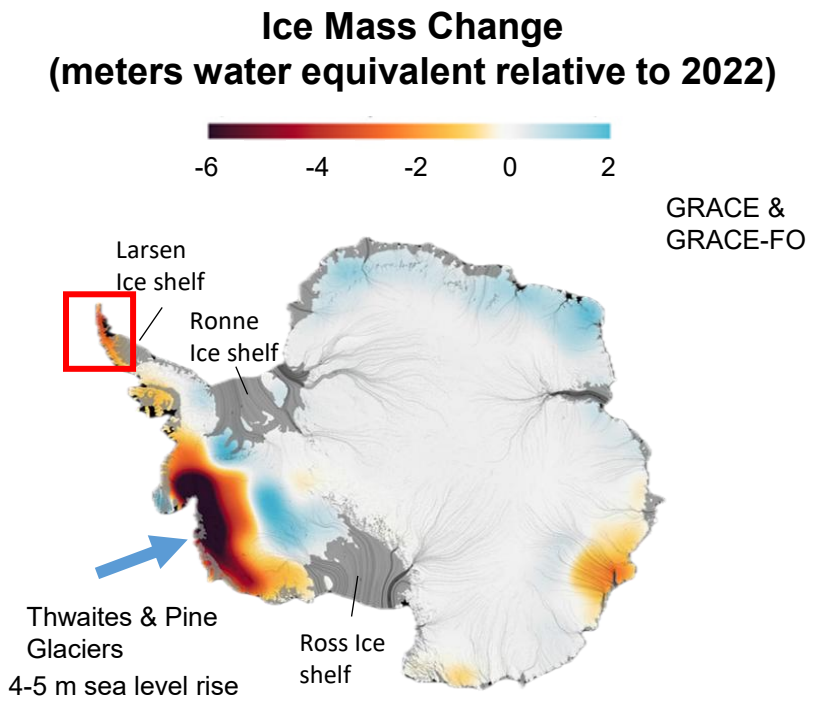
Circumpolar deep water

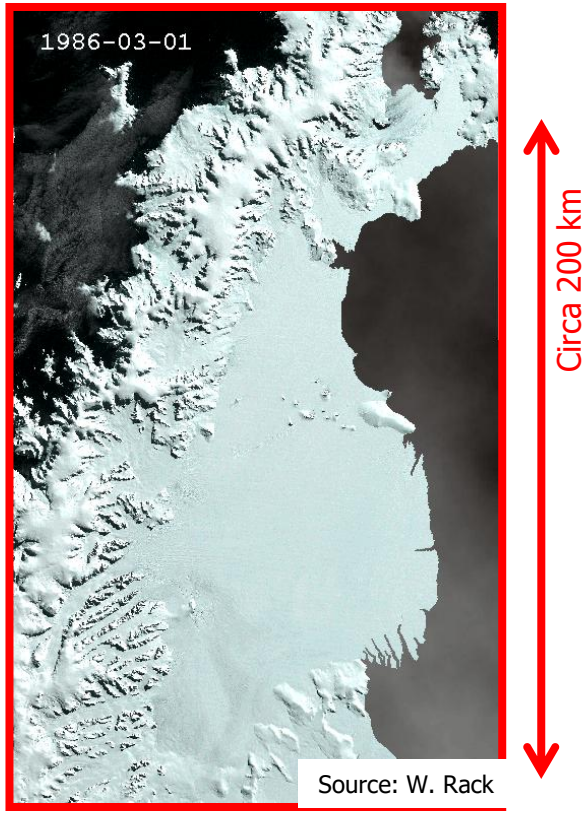
Landward deepening subglacial bed

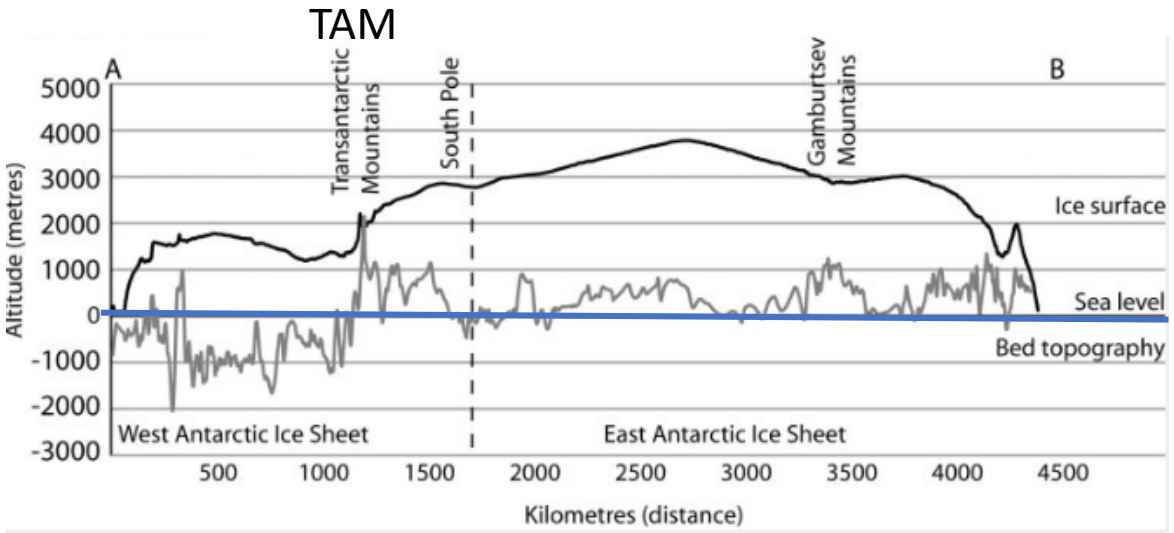
Paleoceanographic reconstruction of polar marine environment : why and how

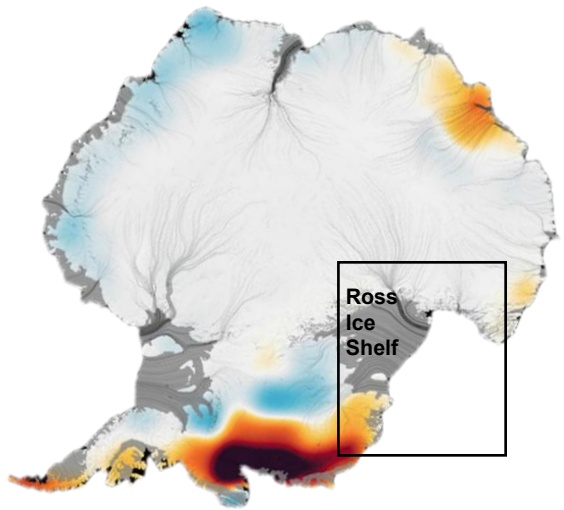
Morlinghen et al., 2019, Dorschel et al., 2022











HSSW = High Salinity Shelf Water
ASC = Antarctic Slope Current
CDW = Circumpolar Deep Water
MCDW = Modified Circumpolar Deep Water
AABW = Antarctic Bottom Water
ISW = Ice Shelf Water

HSSW southward dispersion

HSSW formation

HSSW overflow

ISW overflow

Victoria Land

Joides Basin

Ross Ice Shelf

Hayes Bank

Glomar Challenger Basin

Little America Basin

Houtz Bank

Pennell Bank

Central Basin

Iselin Bank

AABW (Ross Sea saltier source)

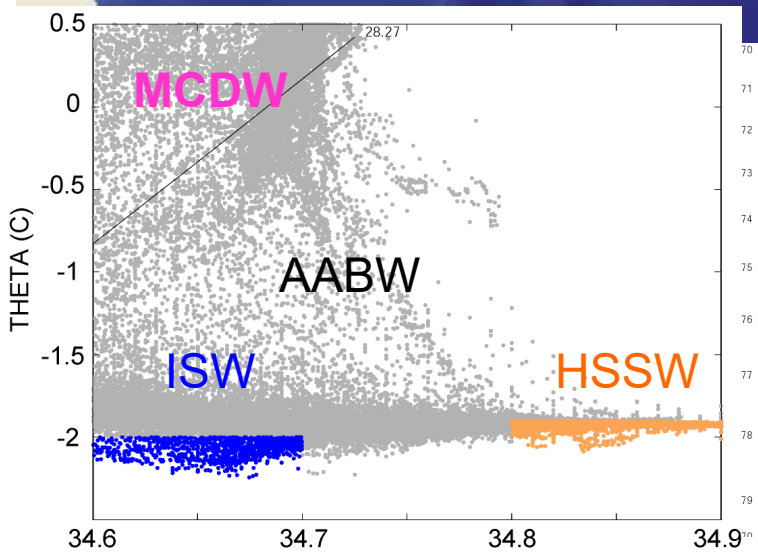
AABW

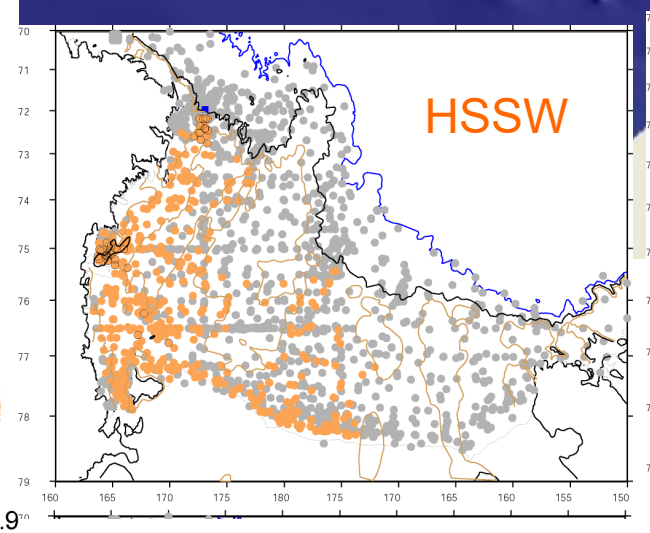
ASC

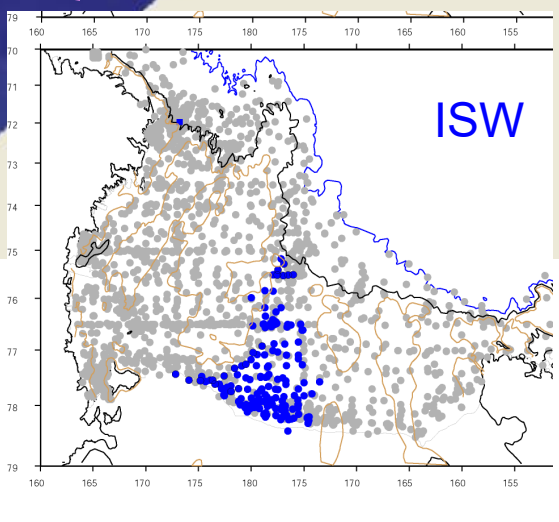
MCDW

Southern branch of the Ross Sea Gyre (CDW)

AABW (Ross Sea colder source)







Jacobs et al., 2002
Orsi et al., 2009
Bergamasco et al., 2002

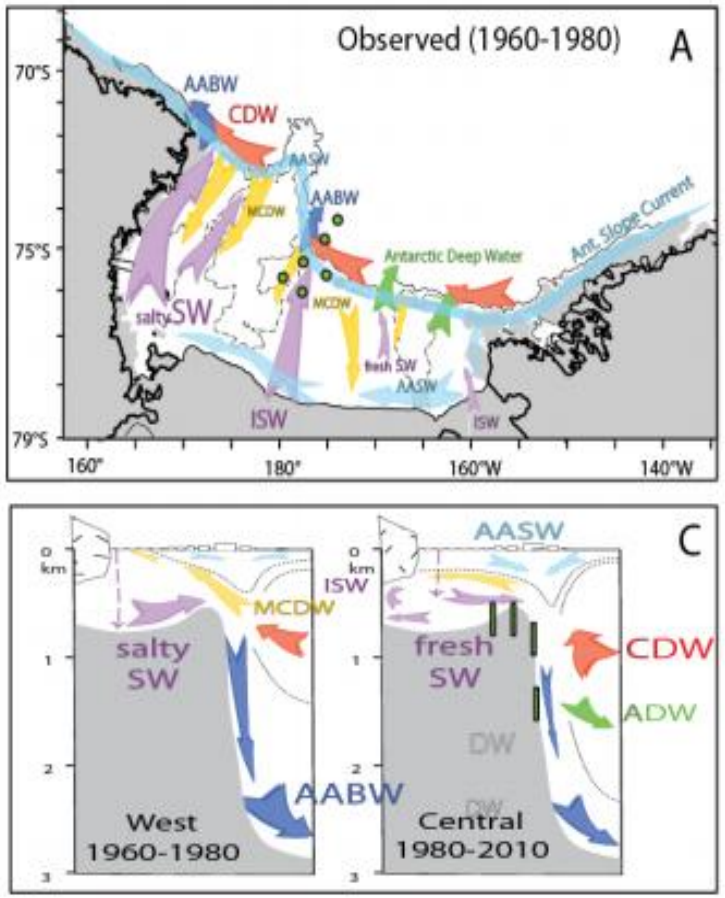
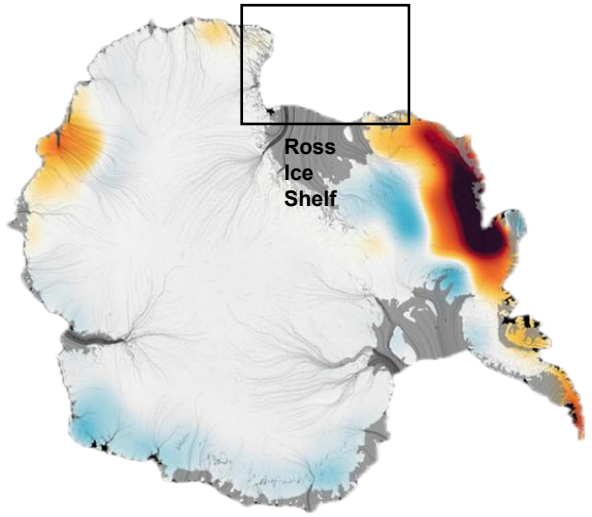
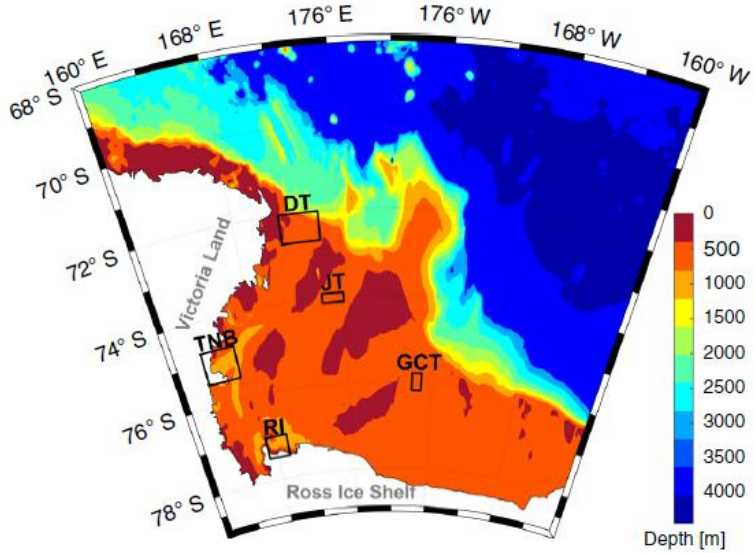
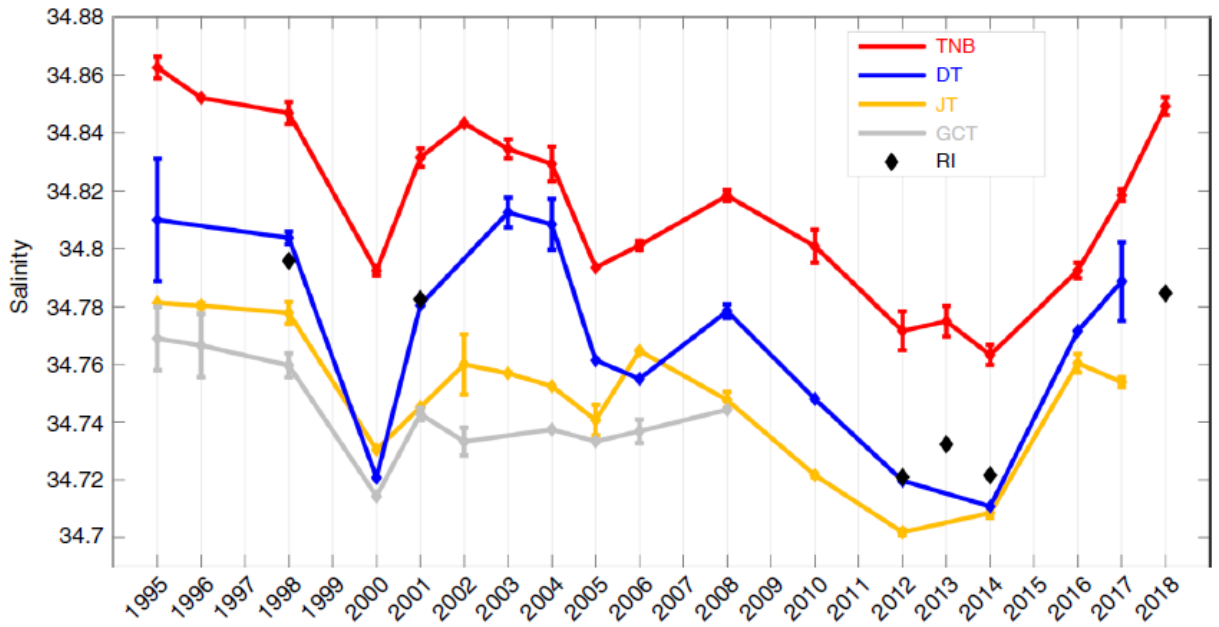


Figure modified from Smith et al. (2012).



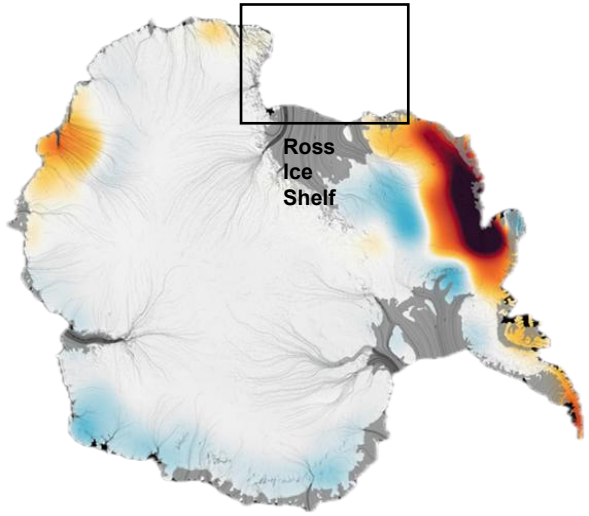


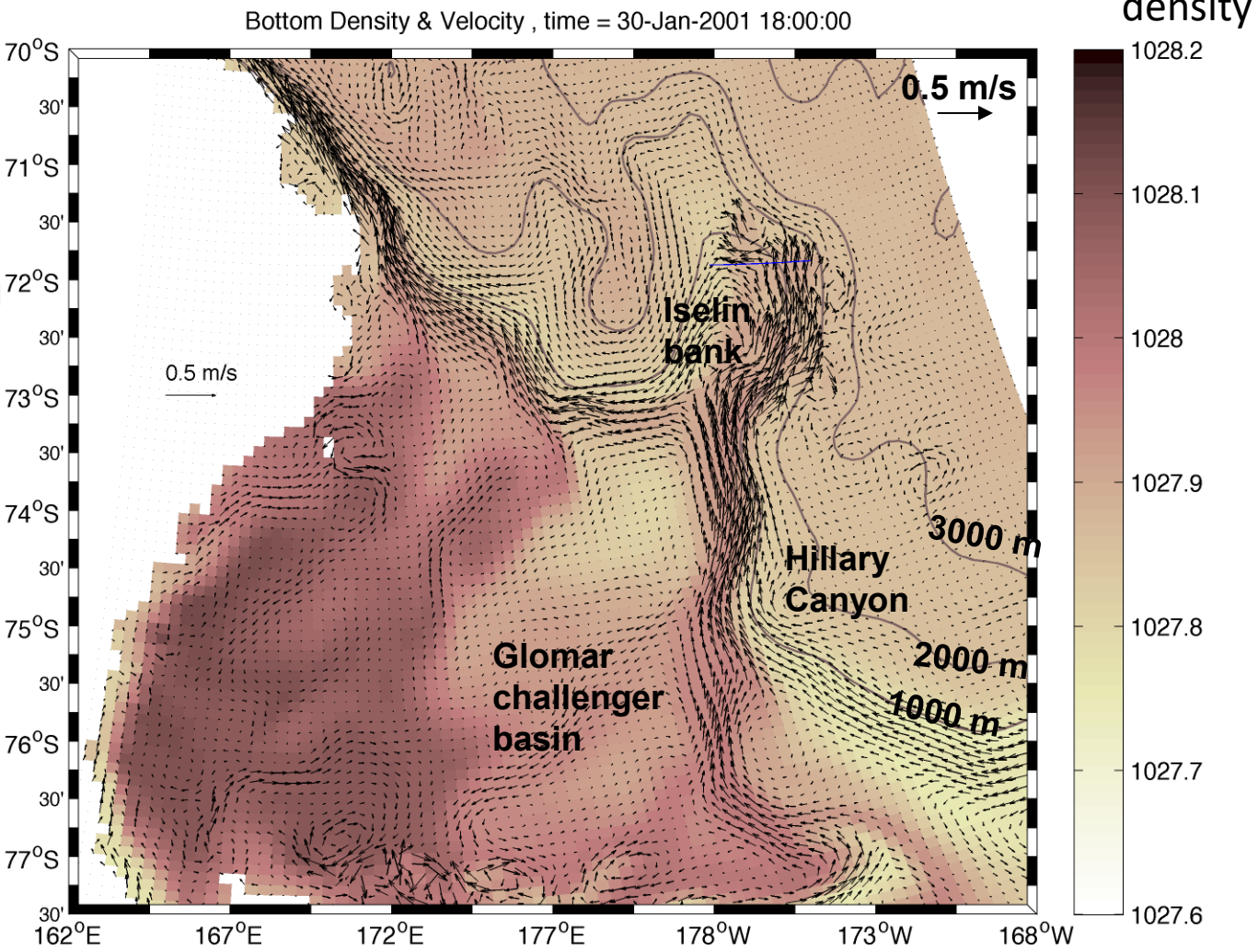


Castagno et al., 2019

General Circulation modeling ROMS 2.1

A. Bergamasco CNR-ISMAR

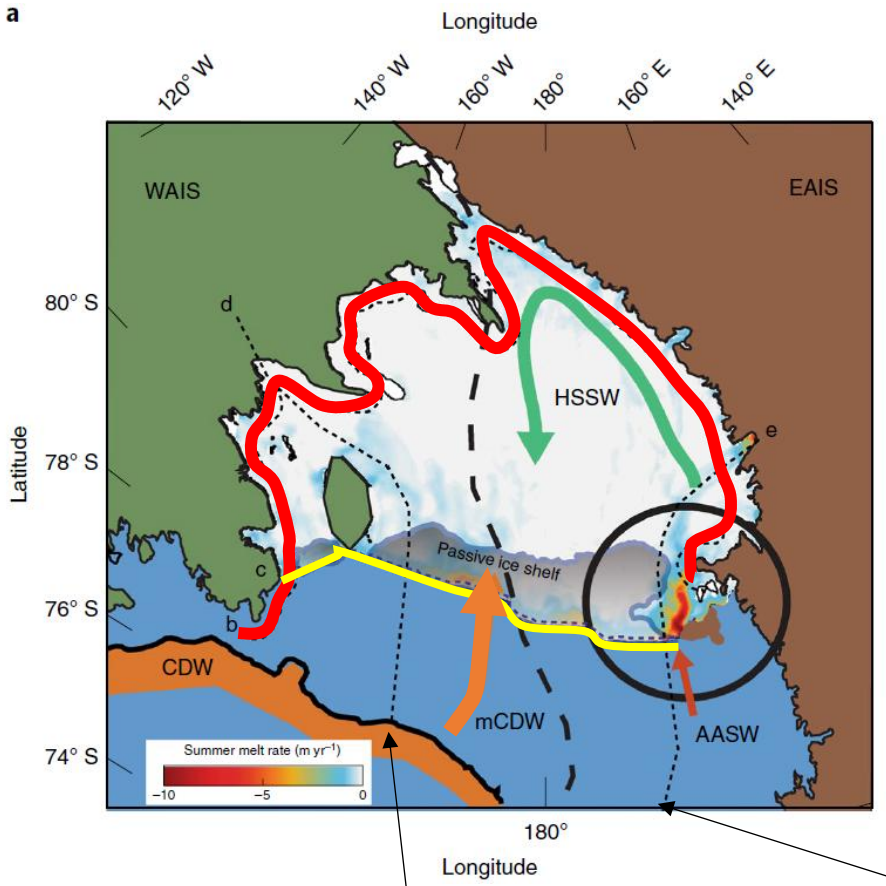


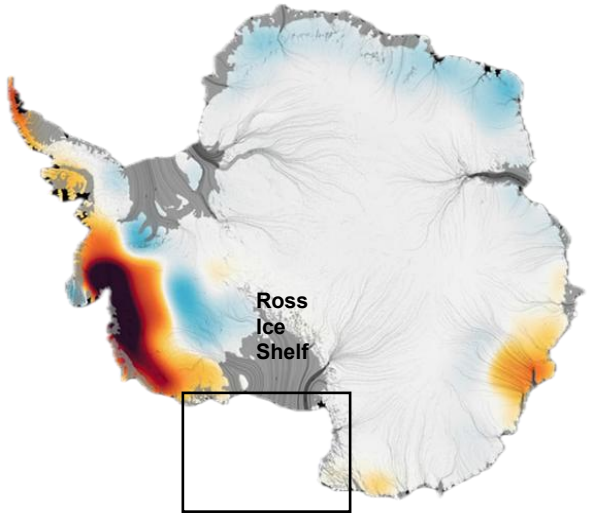


The model considers sea ice dynamics and thermodynamics and hydrographic measures (January 2001)

andrea.bergamasco.cnr@gmail.com

Tinto et al., 2019

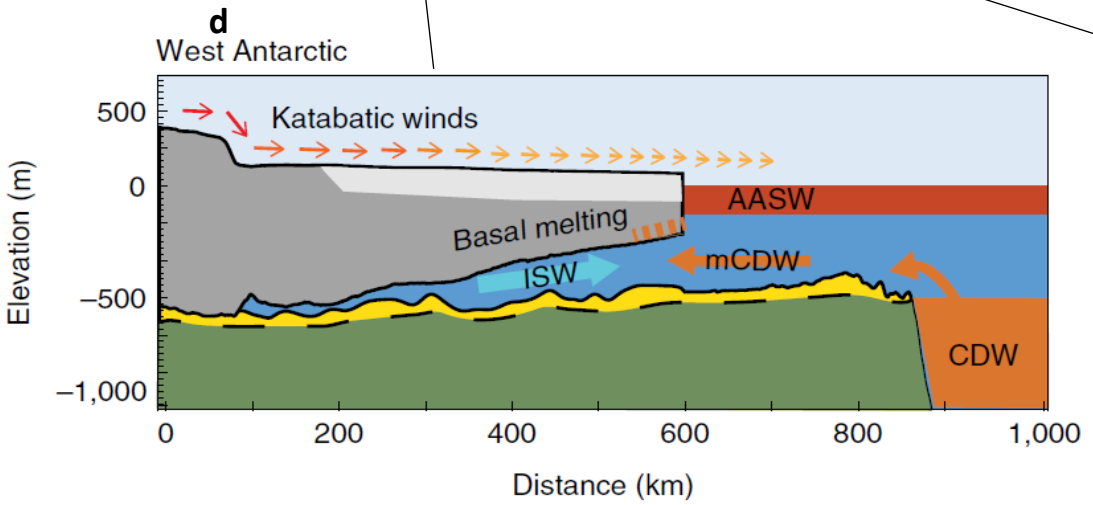


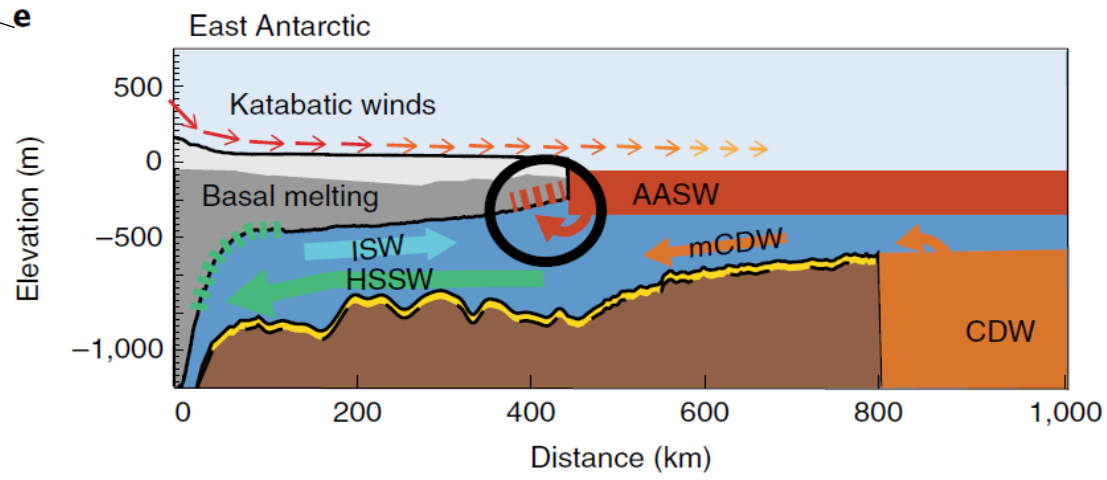


CDW Circumpolar Deep Water T > 1.0°C; S<34.7
Modified Circumpolar Deep Water T < −1 °C; S<34.6
AASW Antarctic Surface Water= T>−1.5°C ; S<34.2
HSSW High Salinity Shelf Water= T>−1.5°C ; S<34.9
ISW Ice Shelf Water= T>−2°C ; S<34.7

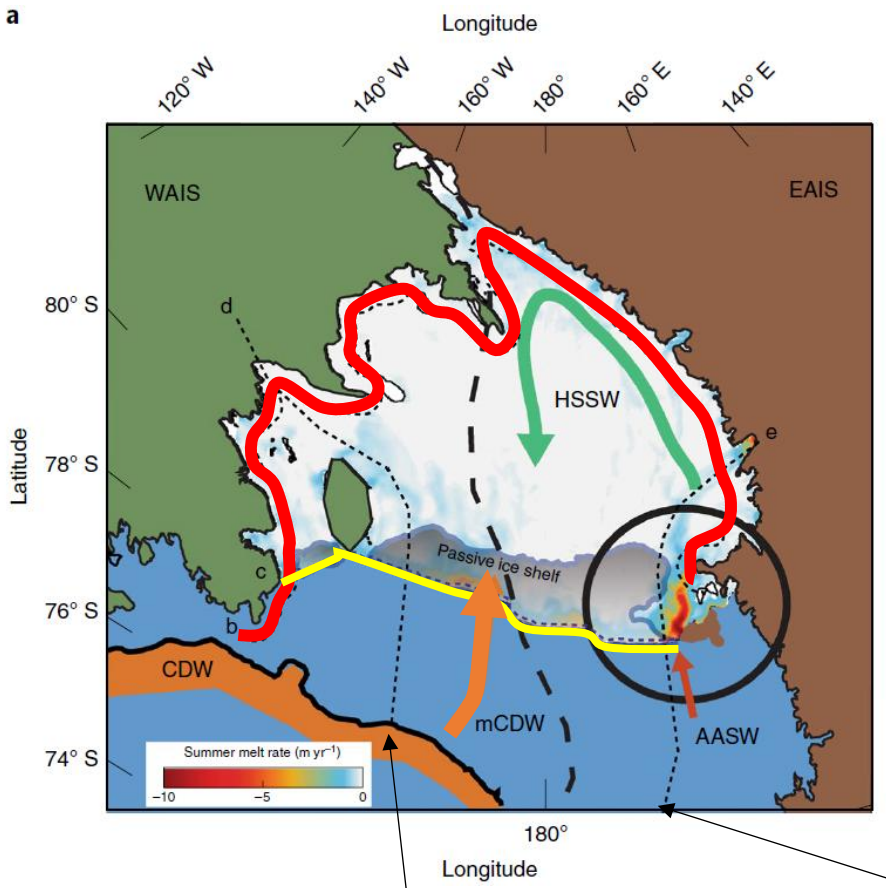
Jacobs et al., 2002
Orsi et al., 2009
Bergamasco et al., 2002

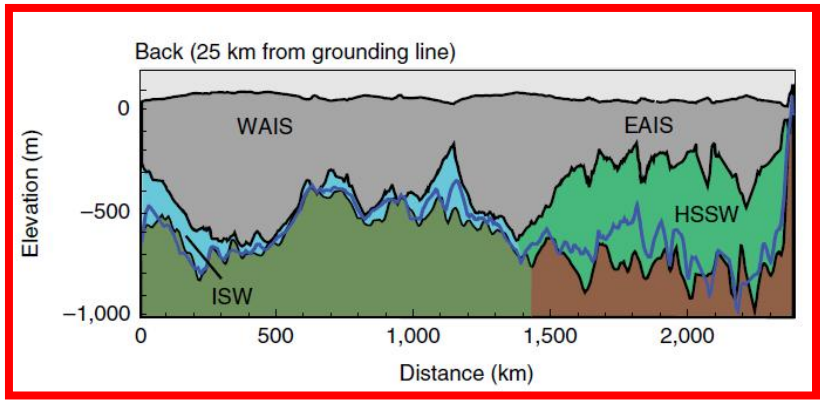
The Ross Sea today

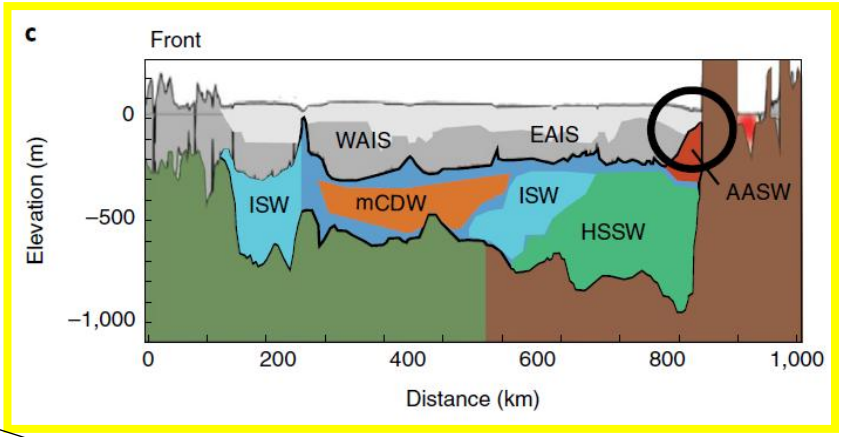




Tinto et al., 2019



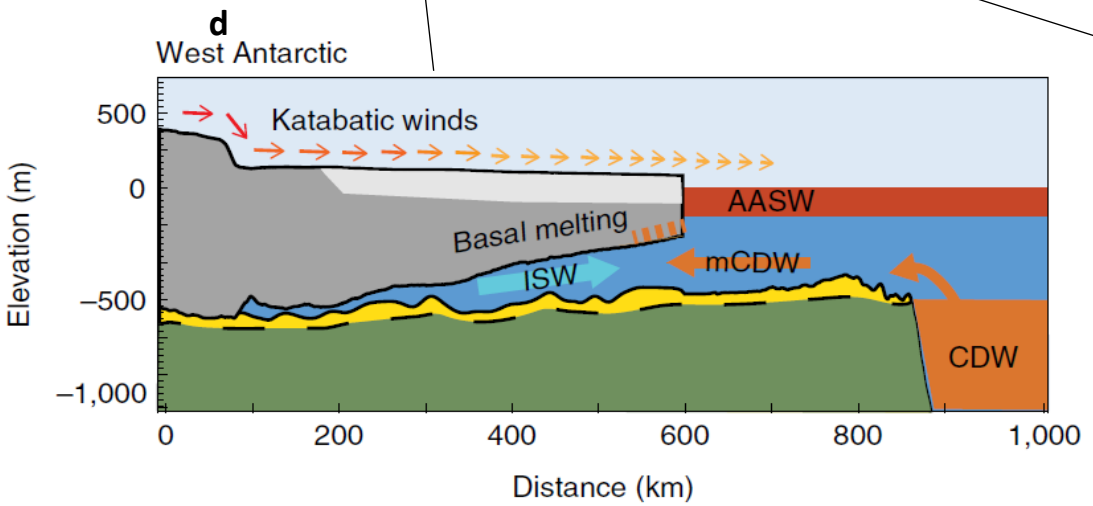


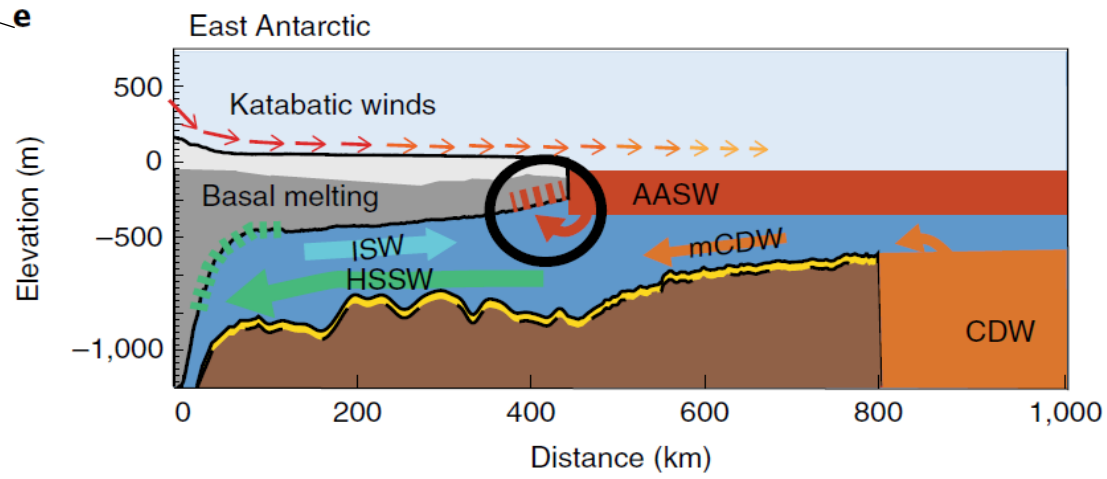


CDW Circumpolar Deep Water T > 1.0°C; S<34.7
Modified Circumpolar Deep Water T < −1 °C; S<34.6
AASW Antarctic Surface Water= T>−1.5°C ; S<34.2
HSSW High Salinity Shelf Water= T>−1.5°C ; S<34.9
ISW Ice Shelf Water= T>−2°C ; S<34.7

Jacobs et al., 2002
Orsi et al., 2009
Bergamasco et al., 2002

The Ross Sea today





AGU PUBLICATIONS

Paleoceanography and Paleoclimatology

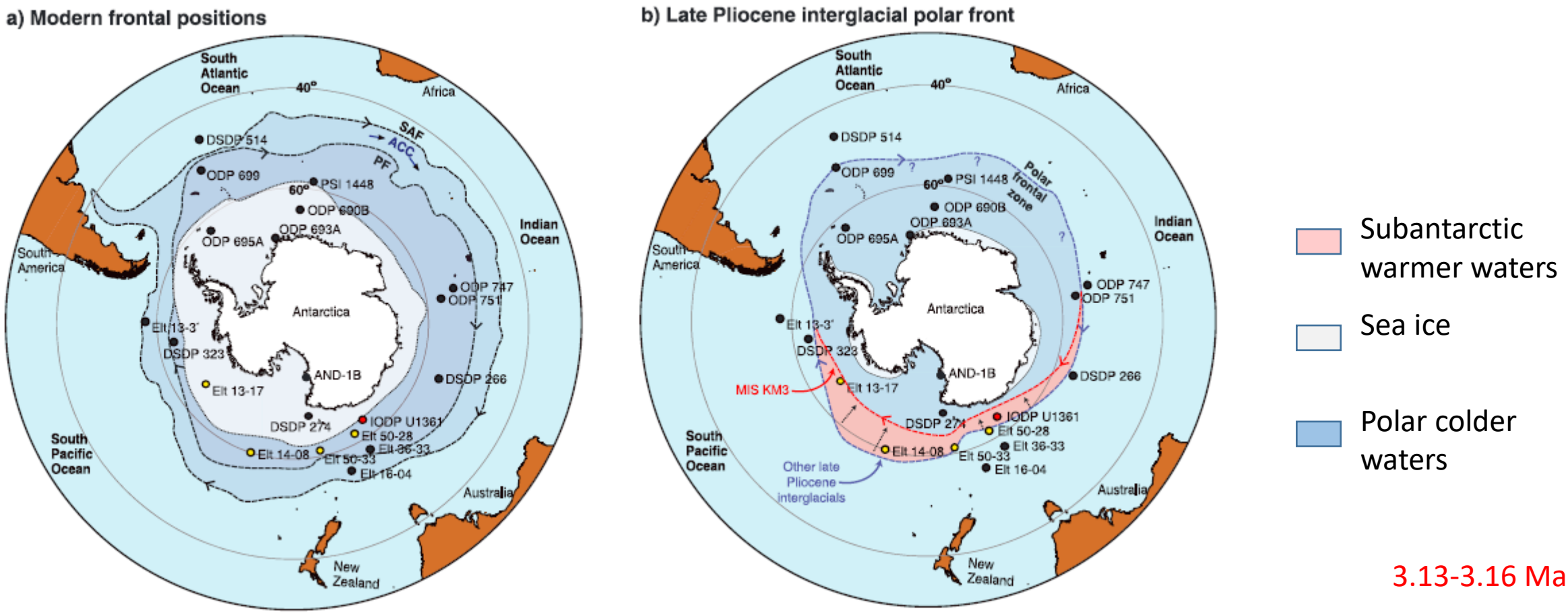
RESEARCH ARTICLE
10.1002/2017PA003225

Polar Frontal Migration in the Warm Late Pliocene: Diatom Evidence From the Wilkes Land Margin, East Antarctica

B. I. Taylor-Silva[1] and C. R. Riesselman[1,2]

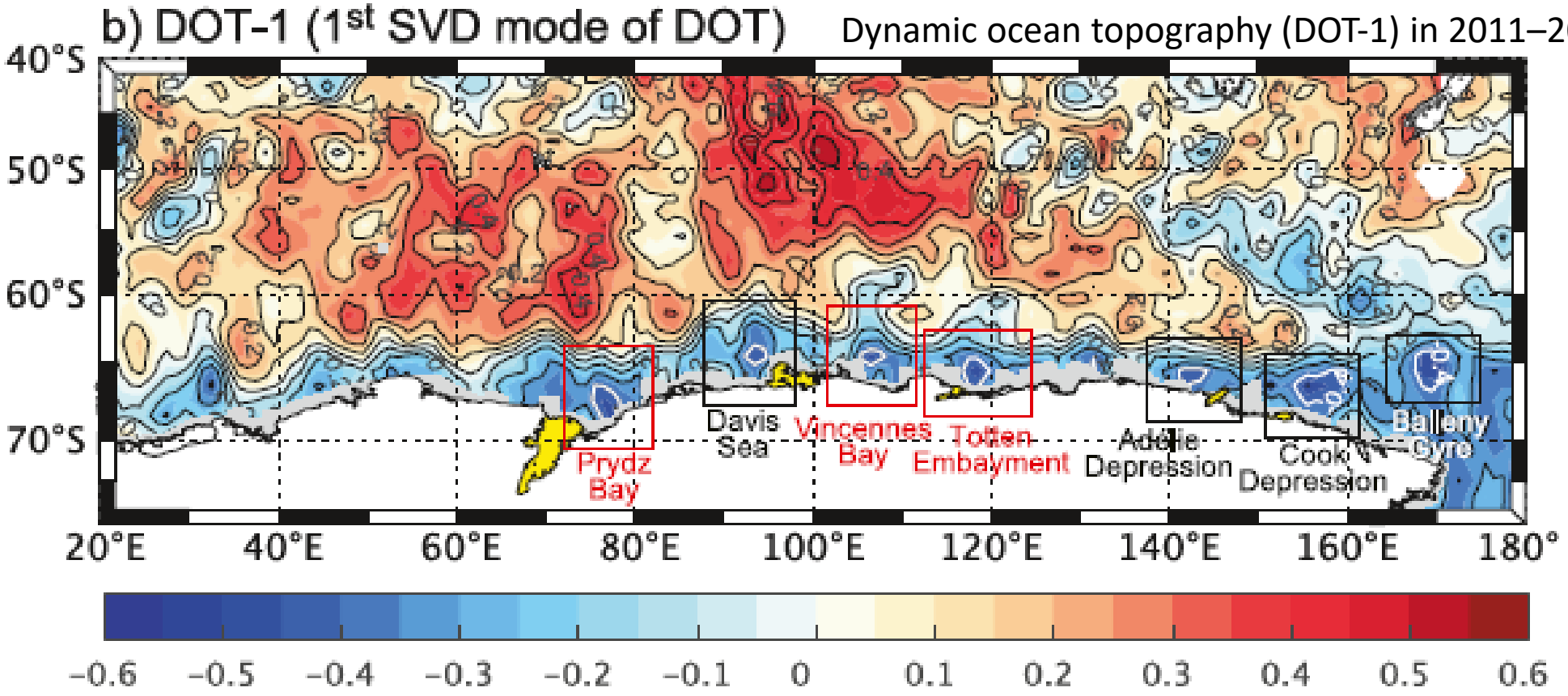
[1]Department of Geology, University of Otago, Dunedin, New Zealand, [2]Department of Marine Science, University of Otago, Dunedin, New Zealand

Key Points:
- Pliocene cooling on the Wilkes Land margin was interrupted by an excursion to warmer subantarctic conditions during the unique MIS KM3
- Revisiting published records shows that the KM3 excursion was produced



3.13-3.16 Ma

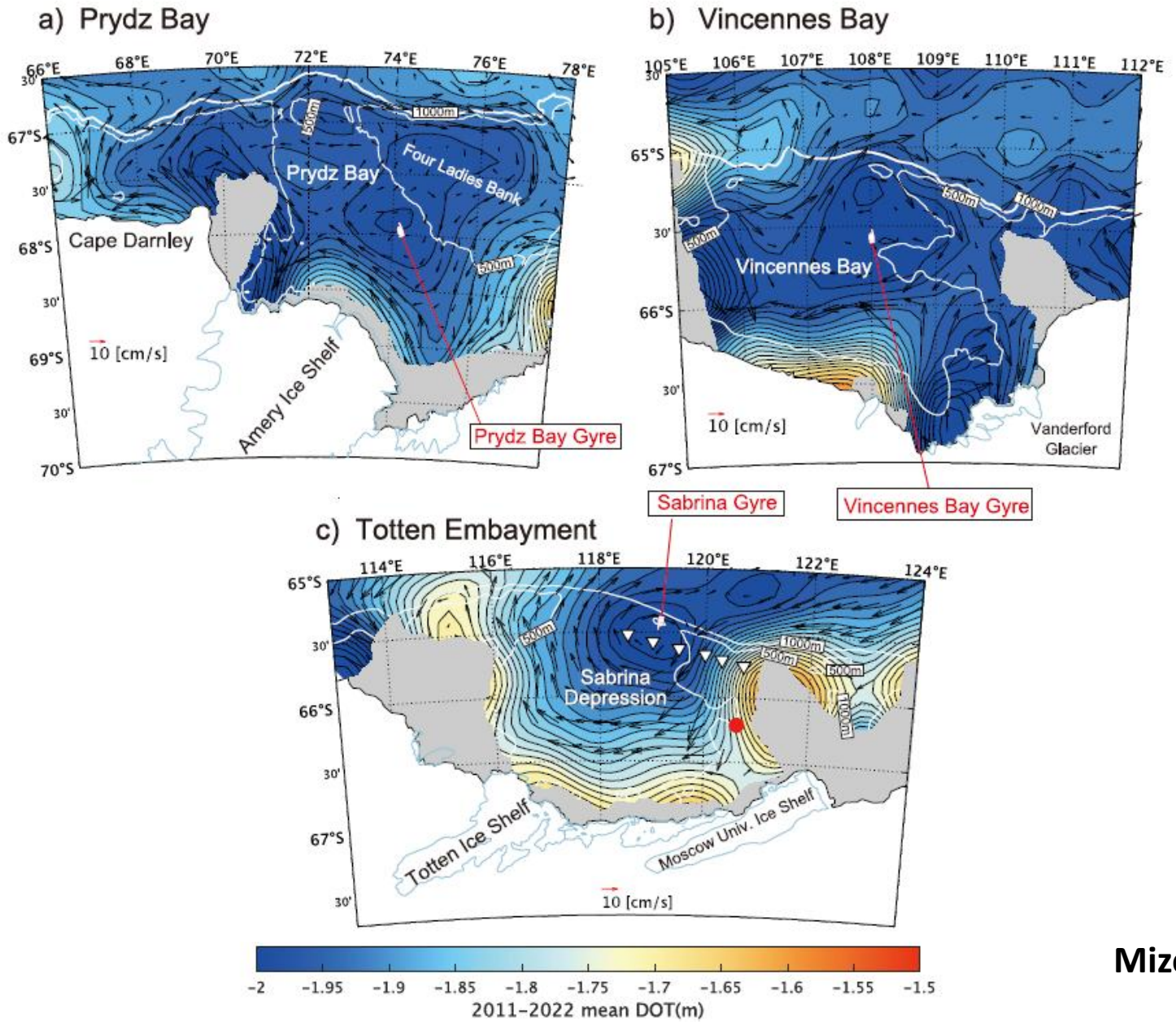
Clockwise gyres form along the East Antarctic coastal margins with deepening coastal sea levels



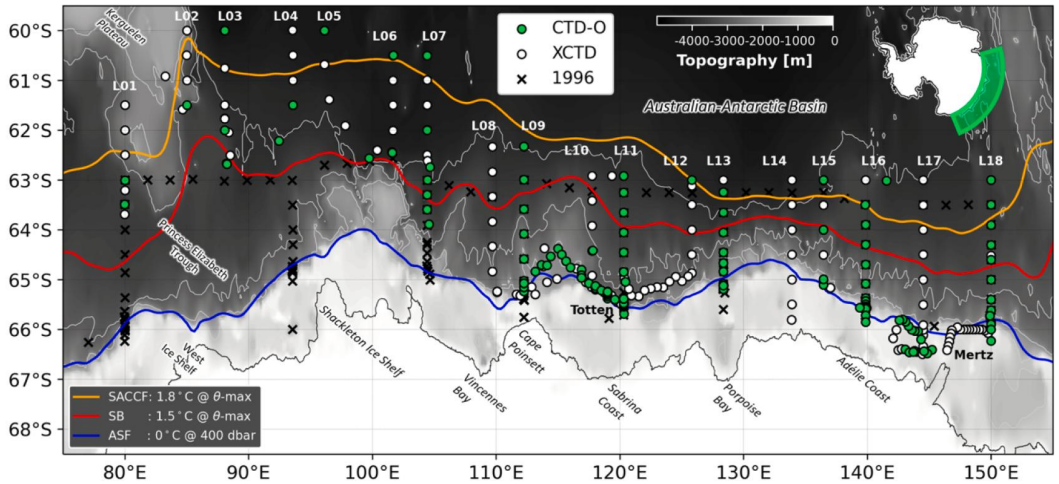
DOT: the difference in elevation between the actual sea surface and the geoid (the theoretical reference surface linked to the Earth's gravitational field).

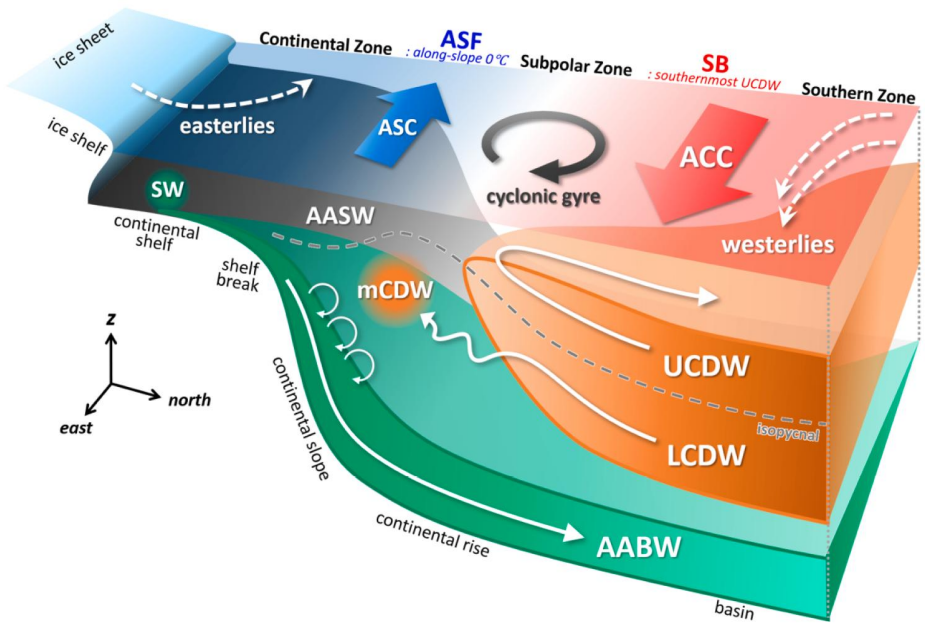
Mizobata et al., 2025

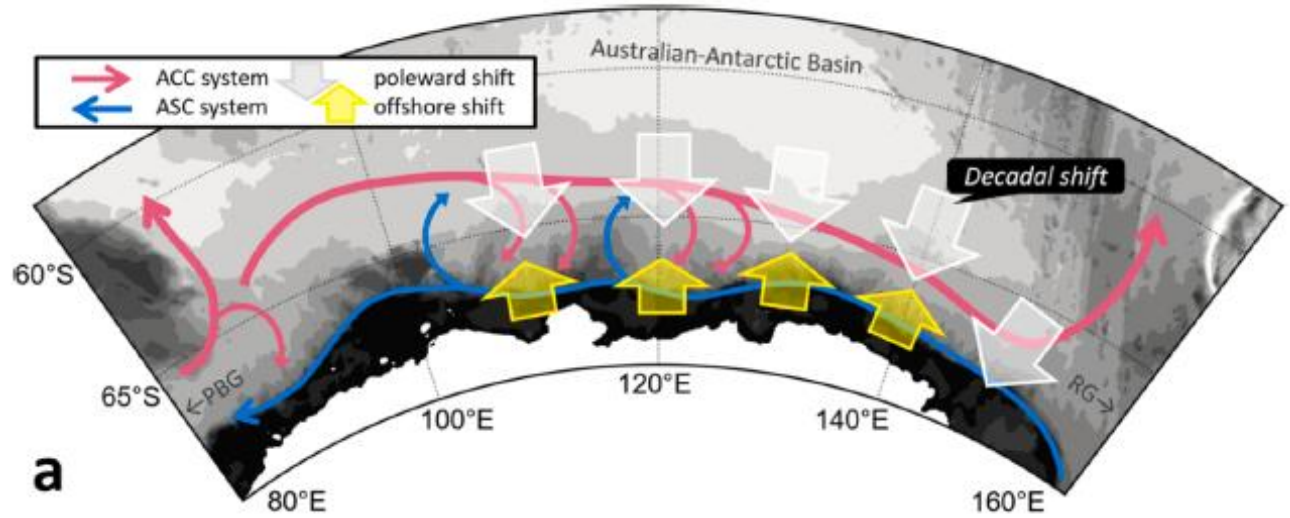
Clockwise gyres form along the East Antarctic coastal margins with deepening coastal sea levels

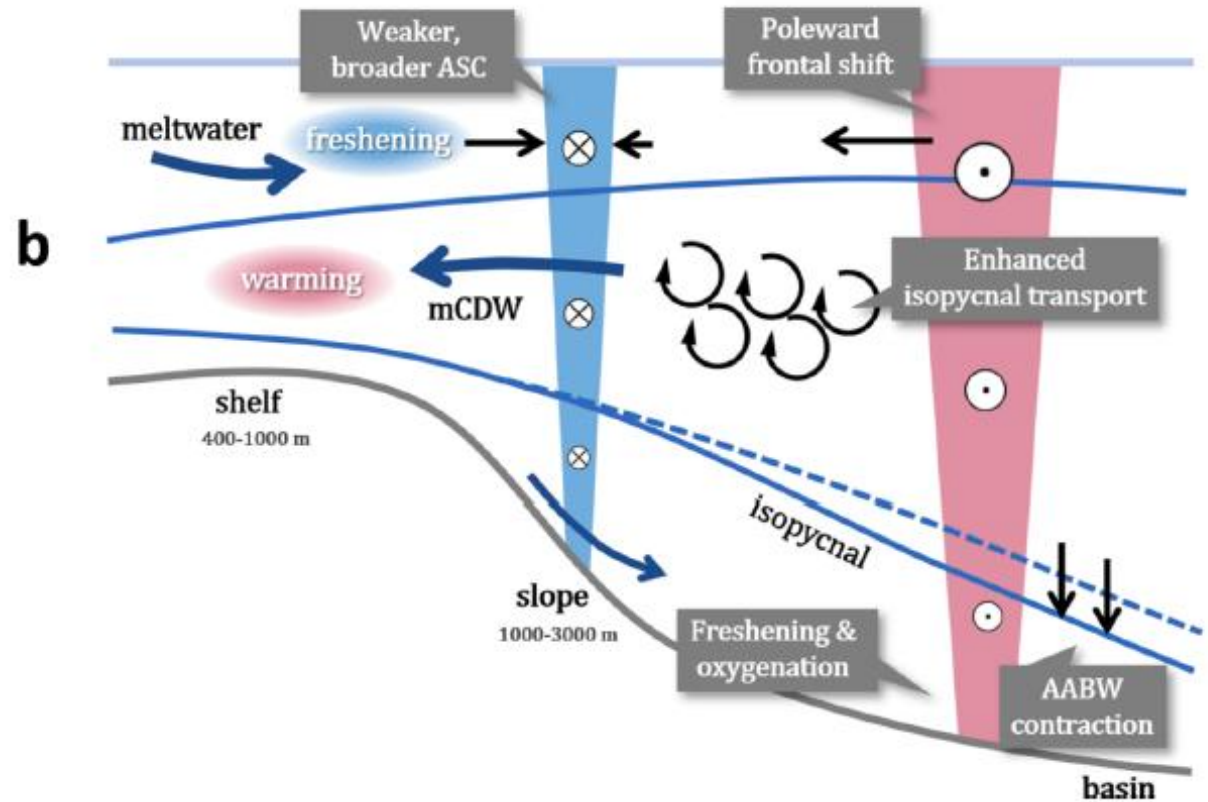


Mizobata et al., 2025

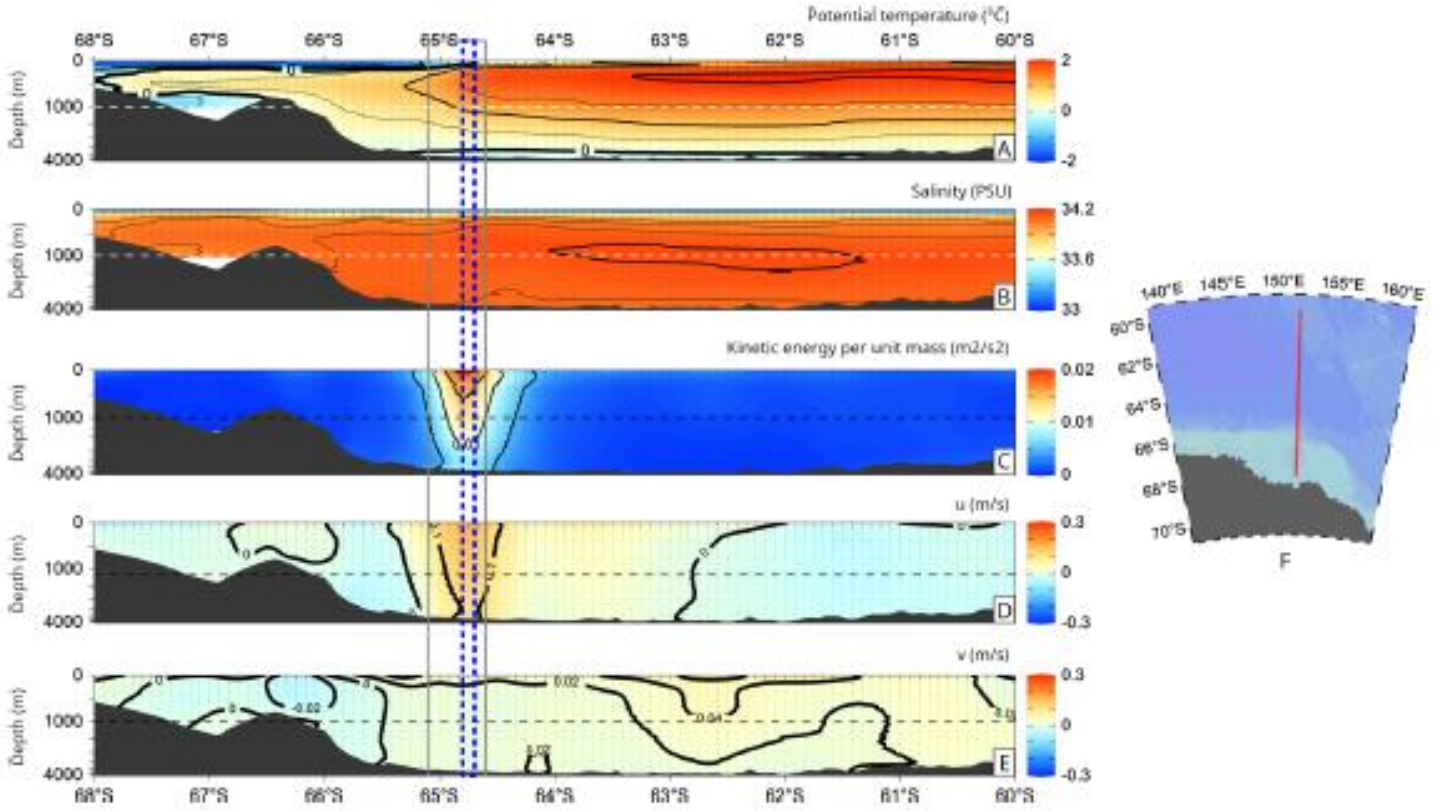


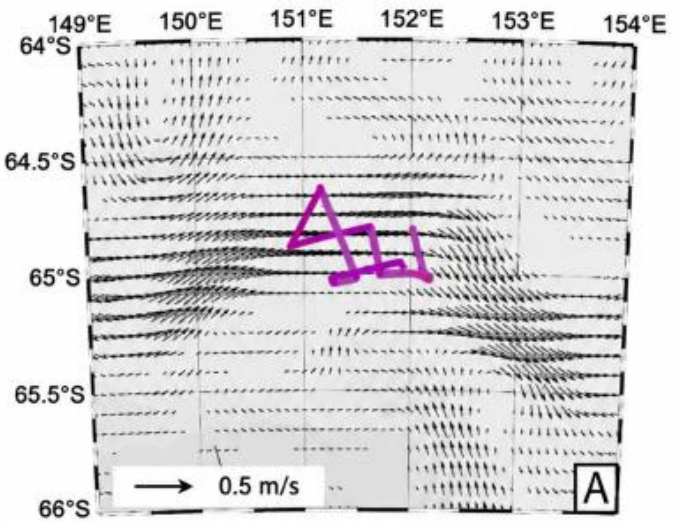


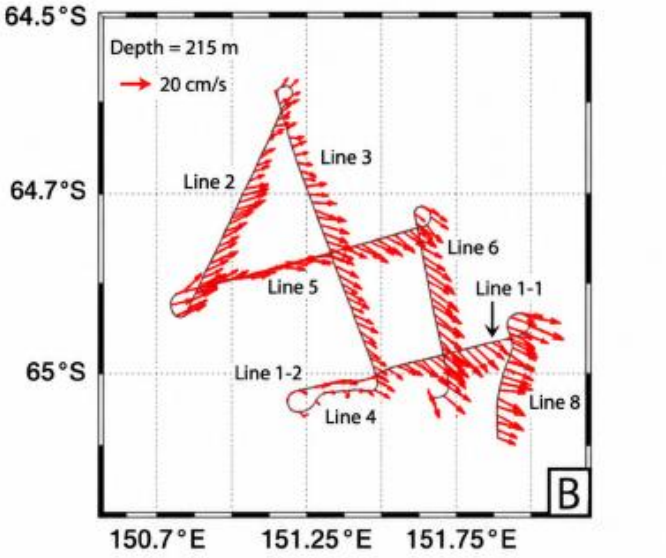




Yamazaki et al.2024

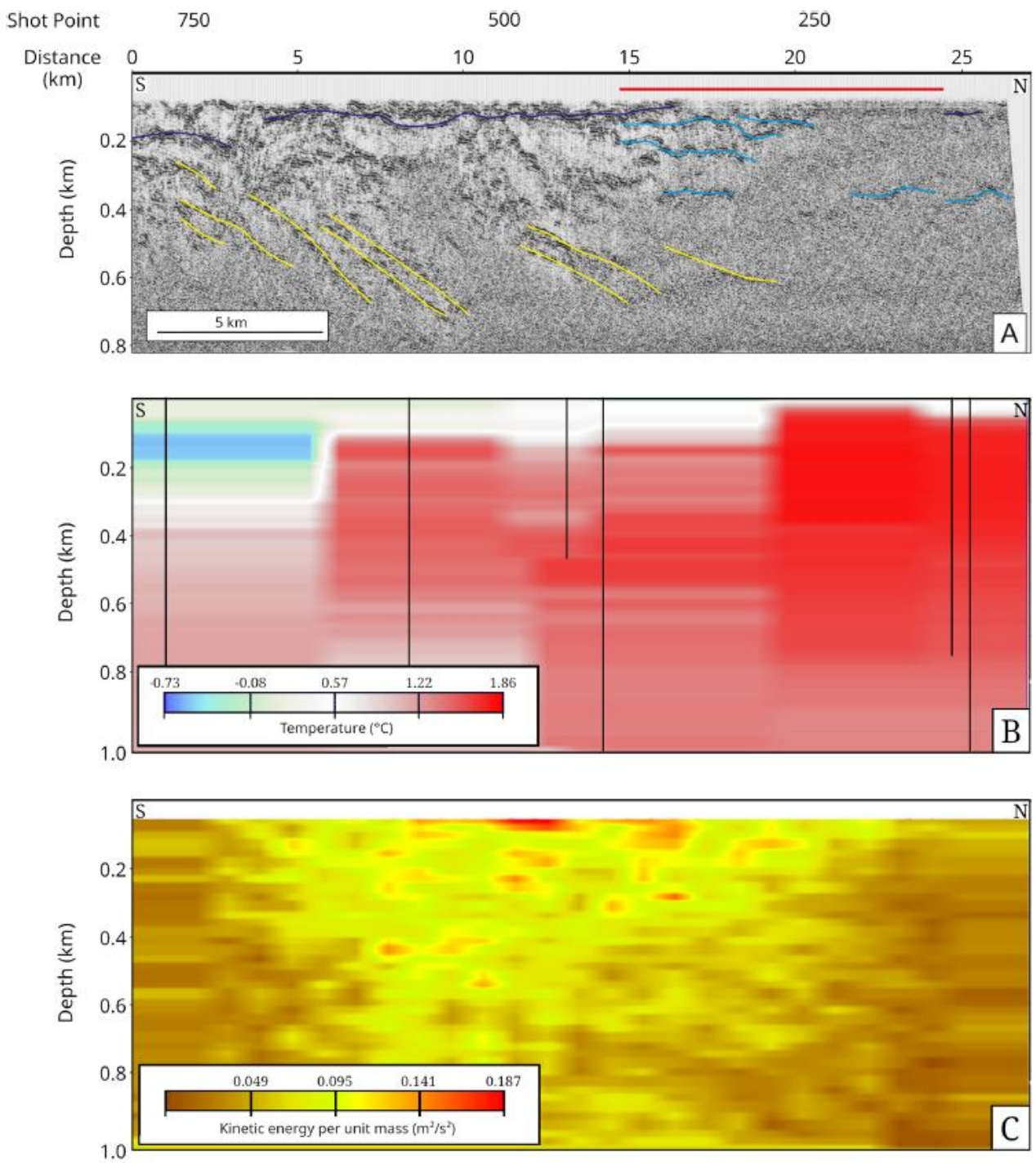


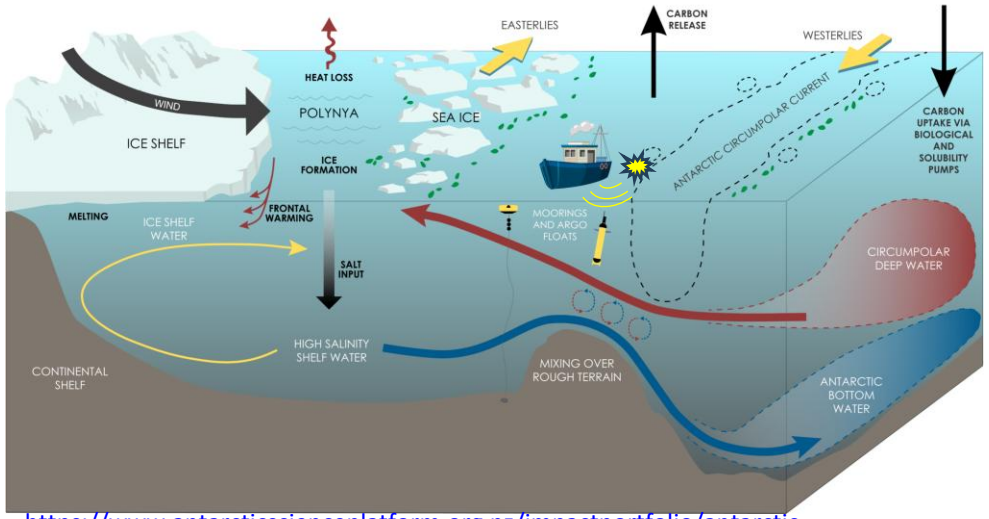




Full depth meridional section at 151.5°E of the GLORYS model data.
The grey rectangle indicates the area of the seismic survey.
The dashed blue rectangle indicates the latitudinal band containing the souther boundary of the ACC,
The dashed horizontal lines mark the 1000 m-limit of the MCS data.

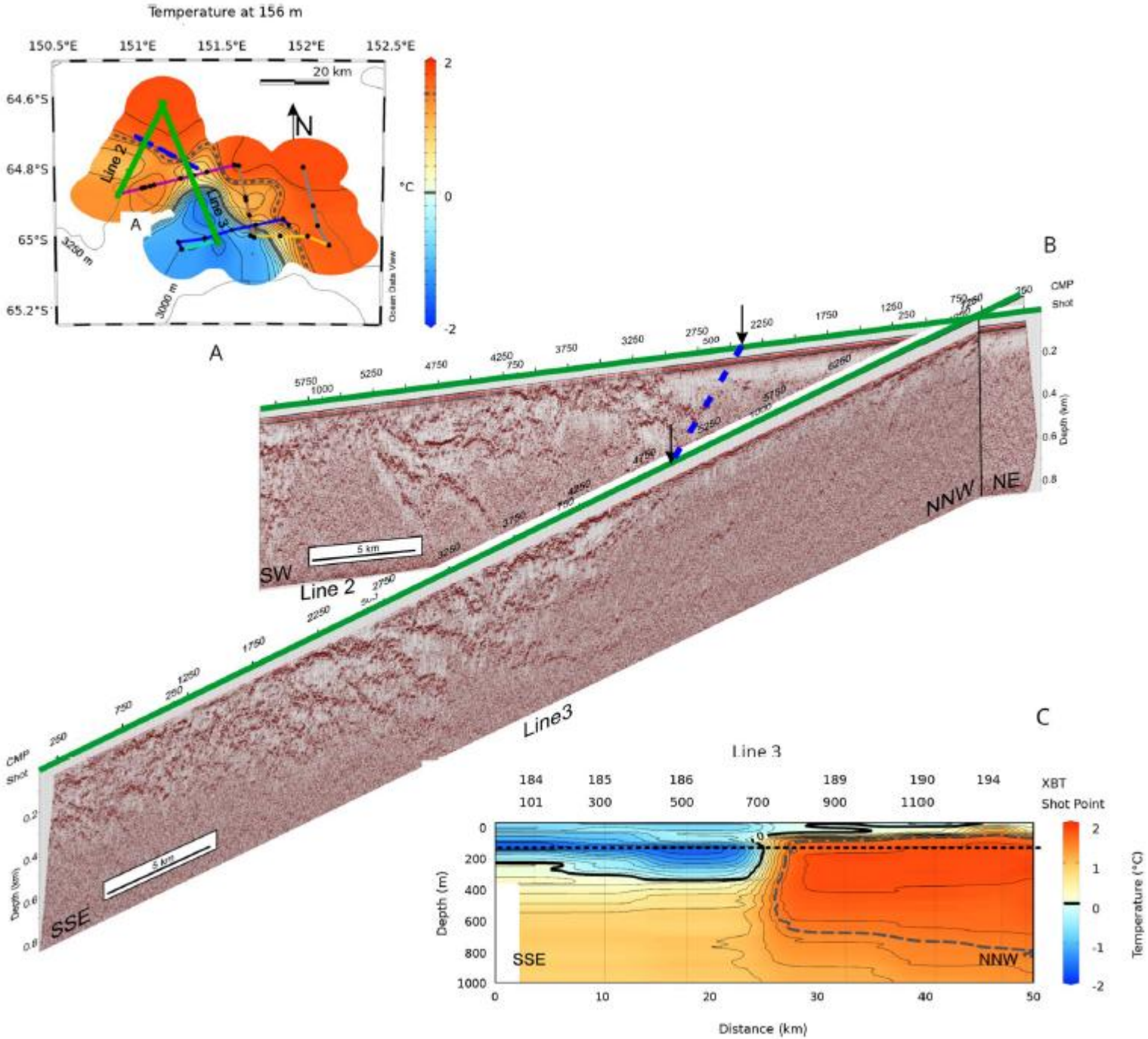
Ferrante et al., 2026 Marine Geophysical Research
https://doi.org/10.1007/s11001-026-09635-5



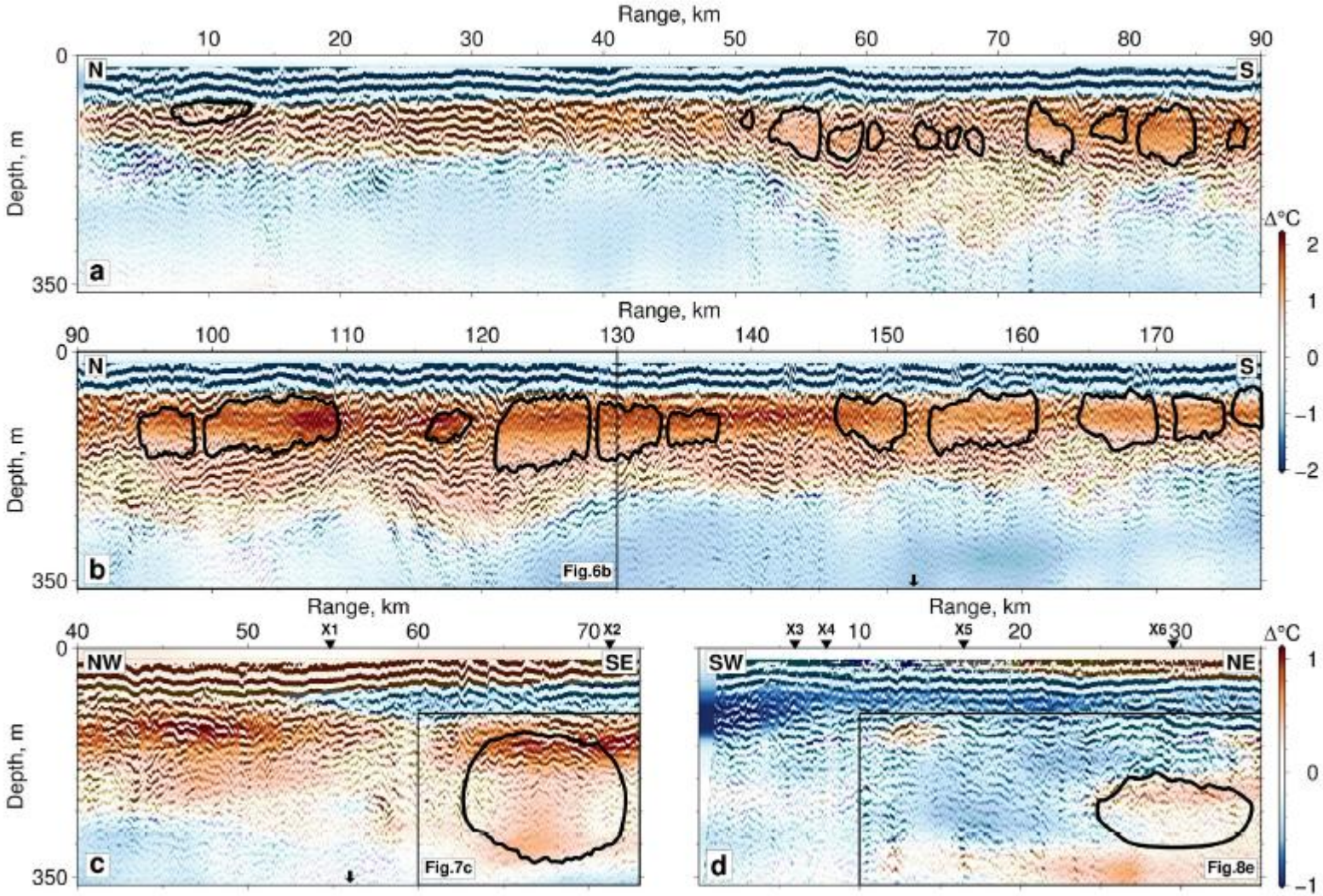


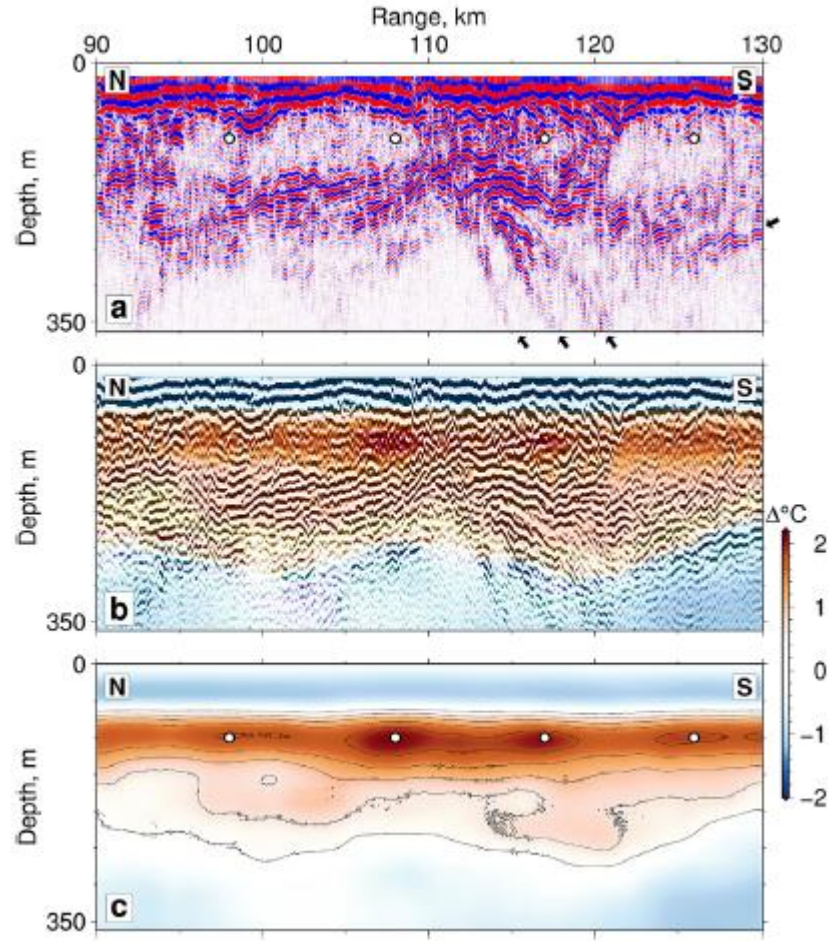
https://www.antarcticscienceplatform.org.nz/impactportfolio/antarctic-bottom-water-and-the-ross-sea-a-gateway-to-global-ocean-circulation

Ferrante et al., 2026 Marine Geophysical Research
https://doi.org/10.1007/s11001-026-09635-5

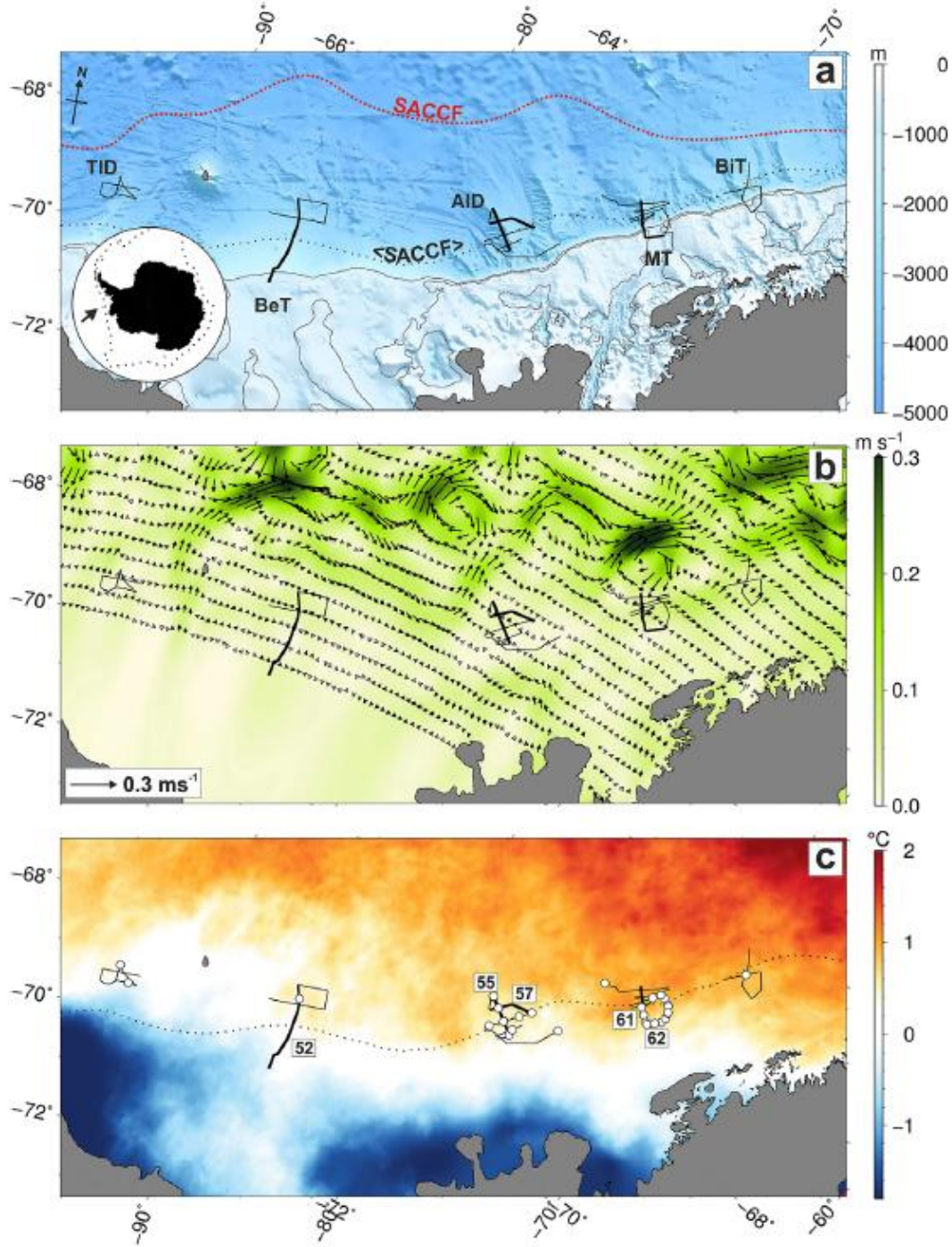


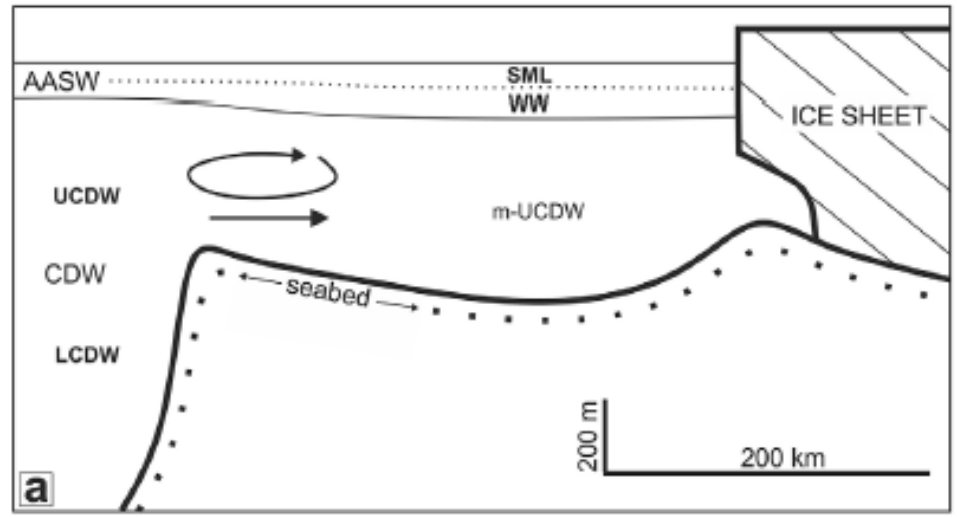
Ferrante et al., 2026 Marine Geophysical Research
https://doi.org/10.1007/s11001-026-09635-5





Gunn et al., 2018





Gunn et al., 2018