Antarctic Alarm Bells?

Recent Reduced Abyssal Overturning and Ventilation in the Australian Antarctic Basin

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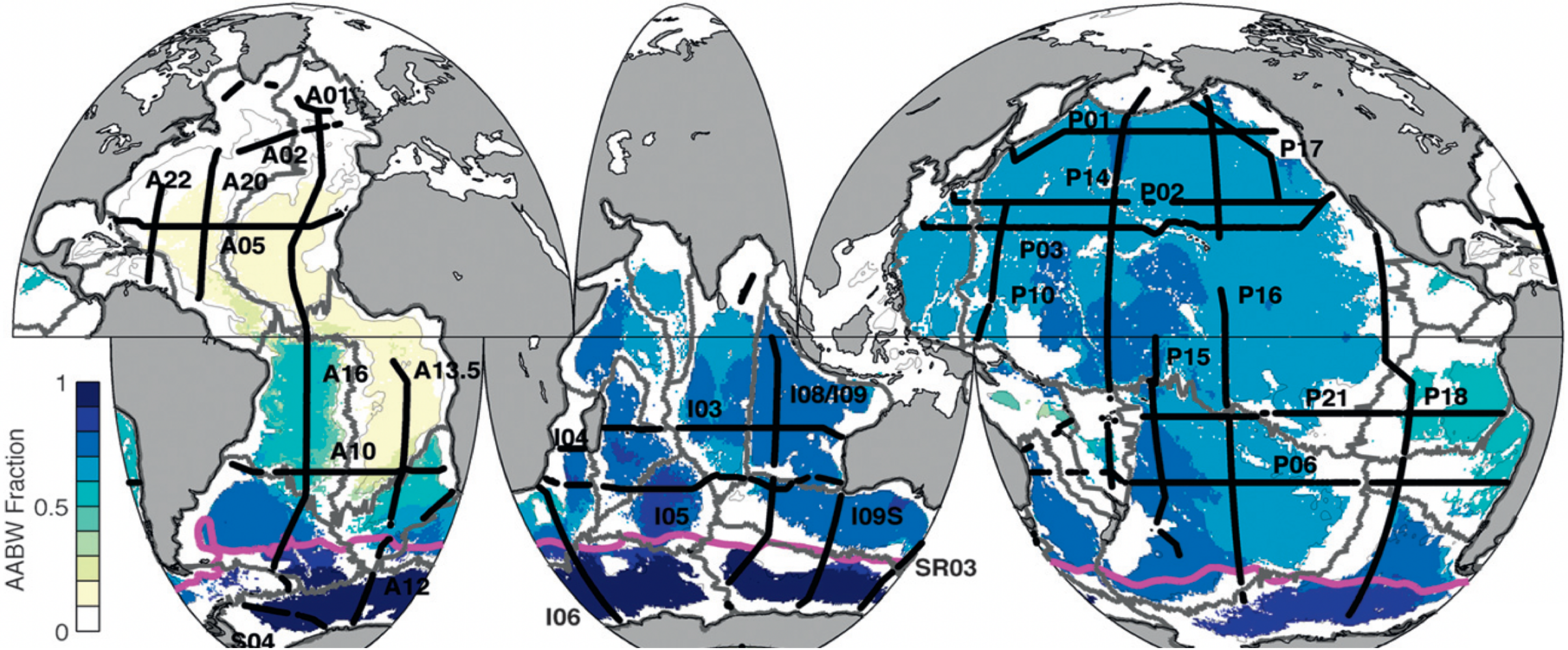
Steve Rintoul, Matt England, Melissa Bowen
+ all the scientists who have collected data over the last 30 years

Water formed around Antarctica fills global ocean

Antarctic Bottom Water (AABW) fills the ocean, forming **40%** of its volume (Johnson, 2008).

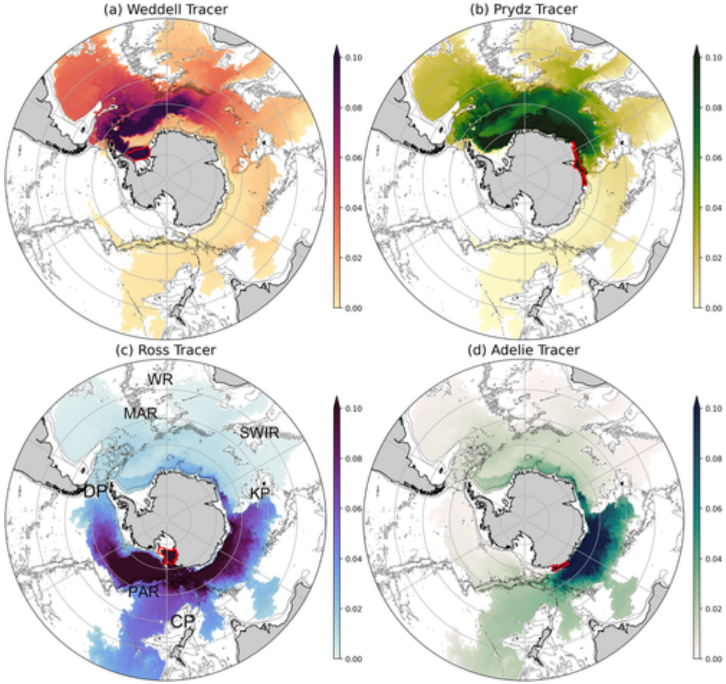


Antarctic Bottom Water (AABW) fraction below 4000 m. After Johnson (2008) & Purkey and Johnson (2010).

4 Antarctic coastal regions drive global processes

AABW is derived from waters created at only

4 sites:



Tracing AABW source water (61 years of model integration).
Solodoch et al., (2022).

4 Antarctic coastal regions drive global processes

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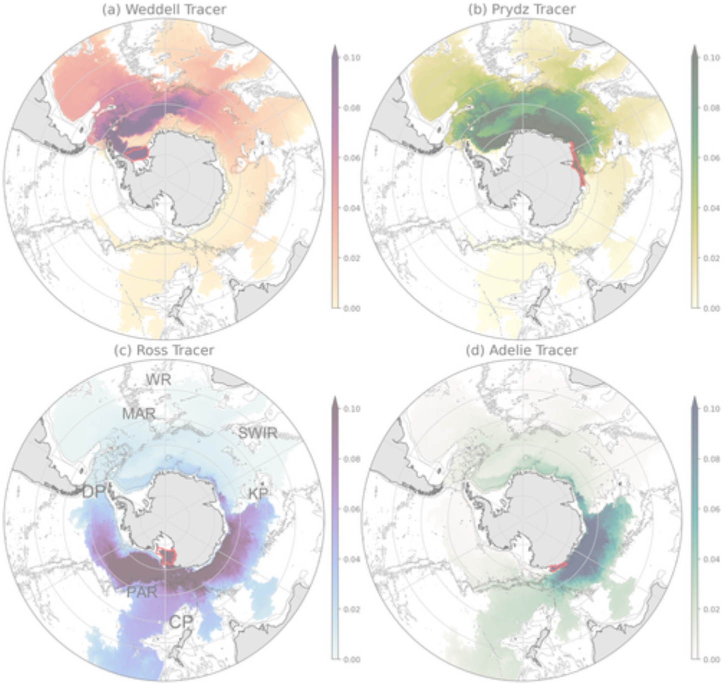
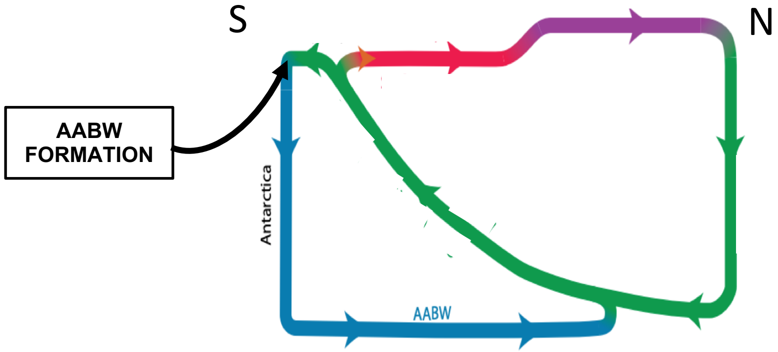


Tracing AABW source water (61 years of model integration). Solodoch et al., (2022).

Transport of AABW away from these sites:

1. Drives the **lower component of the global overturning circulation.**
2. **Ventilates** the deep ocean by replenishing its oxygen.

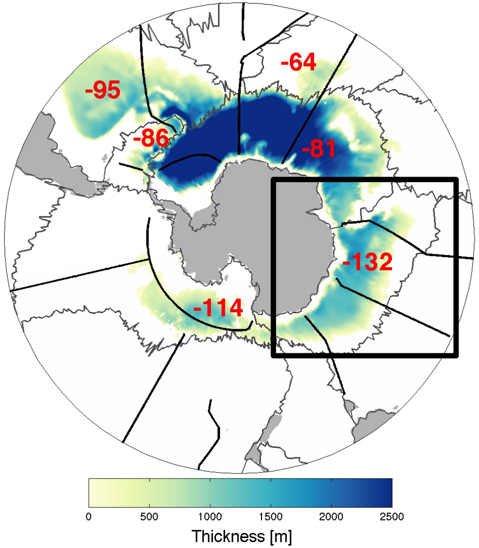


2D schematic of overturning circulation. After Talley et al., (2013).

Freshening and contraction…

Between 1980's and 2000's, AABW has been:

- **freshening** (e.g. Purkey and Johnson, 2013).
- **contracting** (e.g. Purkey & Johnson, 2012).

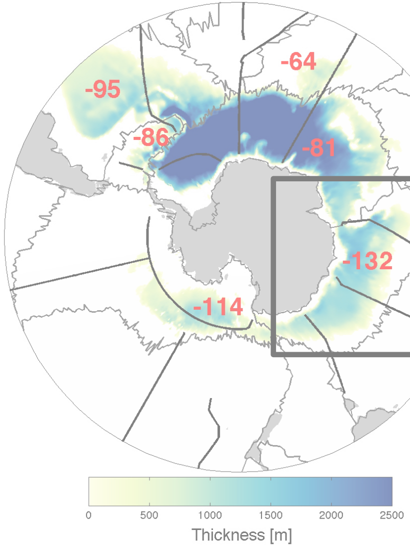


Thickness (shading) and thinning rate in m/decade (red text) of AABW. After Purkey et al (2012).

Freshening and contraction… but oxygen unchanged. Why?

Between 1980’s and 2000’s, AABW has been:

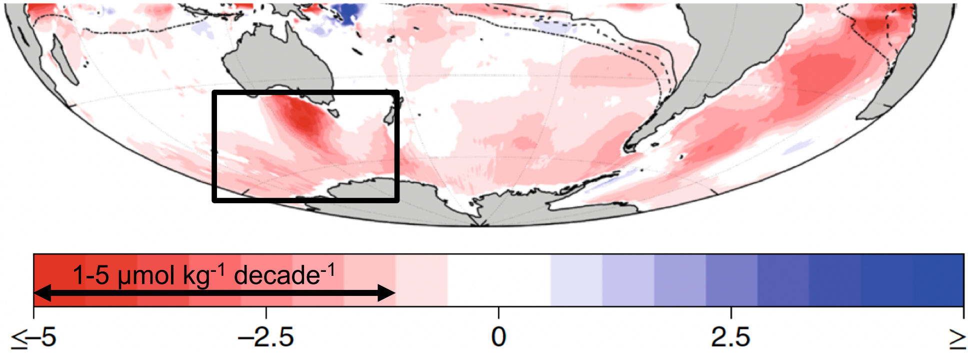
- **freshening** (e.g. Purkey and Johnson, 2013).
- **contracting** (e.g. Purkey & Johnson, 2012).



Thickness (shading) and thinning rate in m/decade (red text) of AABW. After Purkey et al (2012).

… but, **despite** basinwide abyssal **oxygen losses** (Schmidtko et al., 2014):

- **oxygen-maximum unchanged** (Van Wijck & Rintoul, 2014).



1960 to 2010 observational estimate of oxygen change in lower ocean (1200 m to seafloor). After Schmidtko et al., (2017) and Oschlies et al (2018).

Gaps in our understanding

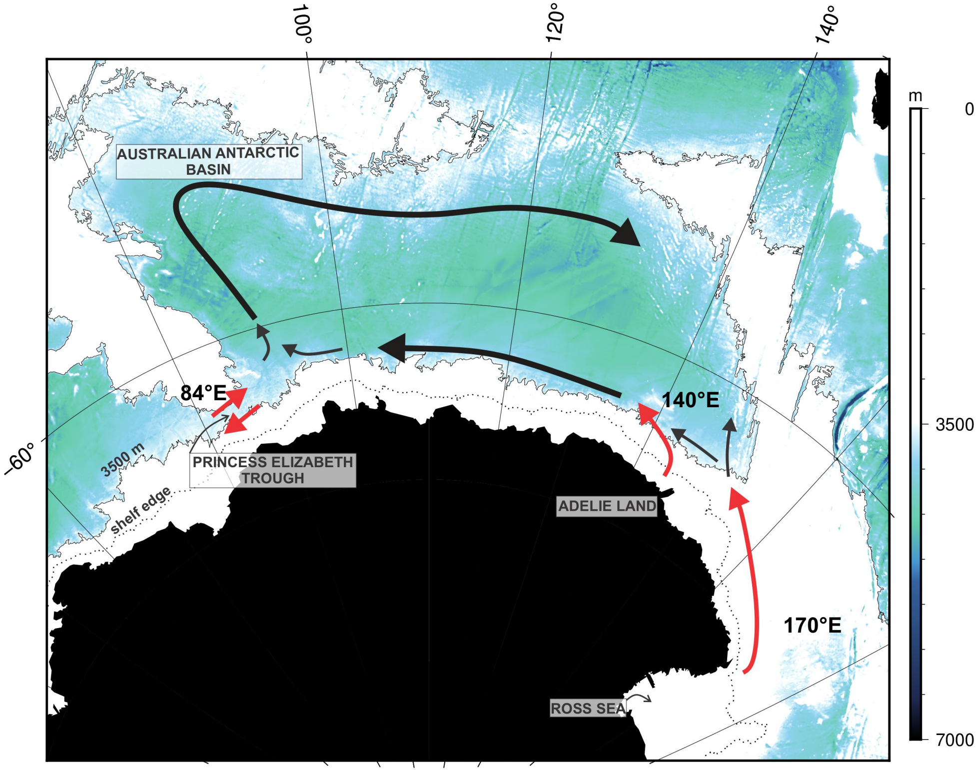
1. **What are the physical mechanisms driving changes in AABW?**
    1. Decrease in production rate (e.g. Johnson et al., 2008; Purkey and Johnson 2012).
    2. Changes in source water properties with little production rate changes (e.g. Azaneau et al., 2013; van Wijck and Rintoul 2014)

2. **Do the same physical mechanisms apply around Antarctica?**

3. **Are the observed trends in AABW natural or anthropogenic?**

Well-ventilated and well-observed Australian Antarctic Basin.

Three bottom waters enter basin via bathymetric gateways



Abyssal circulation in the Australian Antarctic Basin.

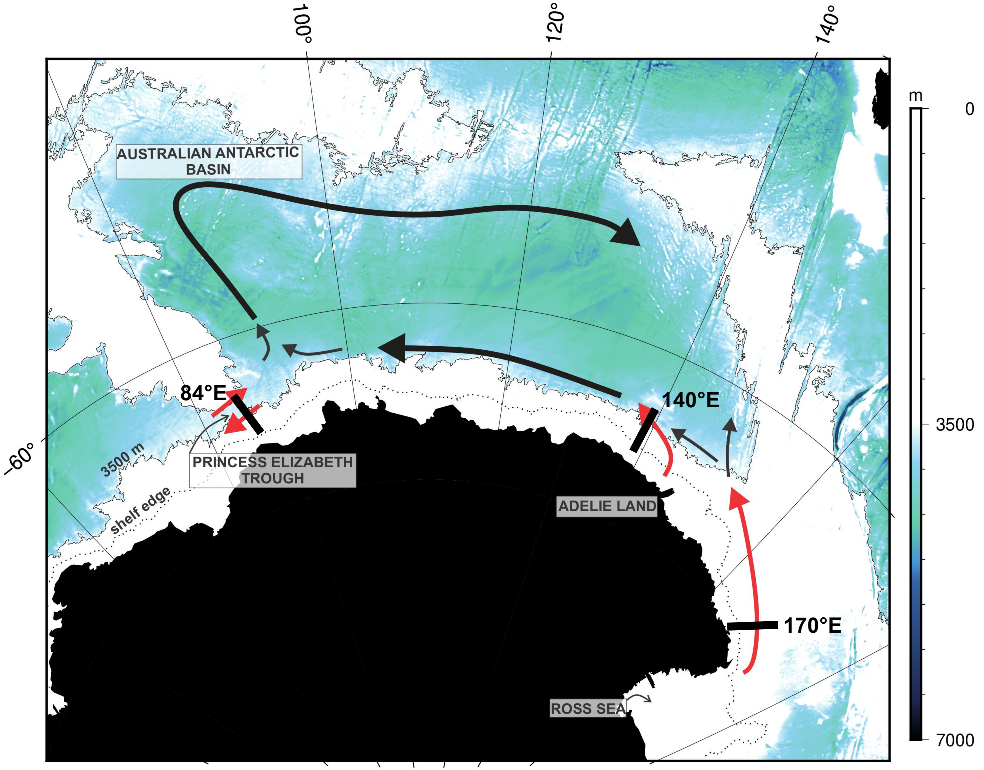
Well-ventilated and well-observed Australian Antarctic Basin.

Three bottom waters enter basin via bathymetric gateways that have been **decadally monitored with repeat hydrographic sections**

╲ **Repeat Hydrographic Cross-sections**

-> Thickness

-> Properties

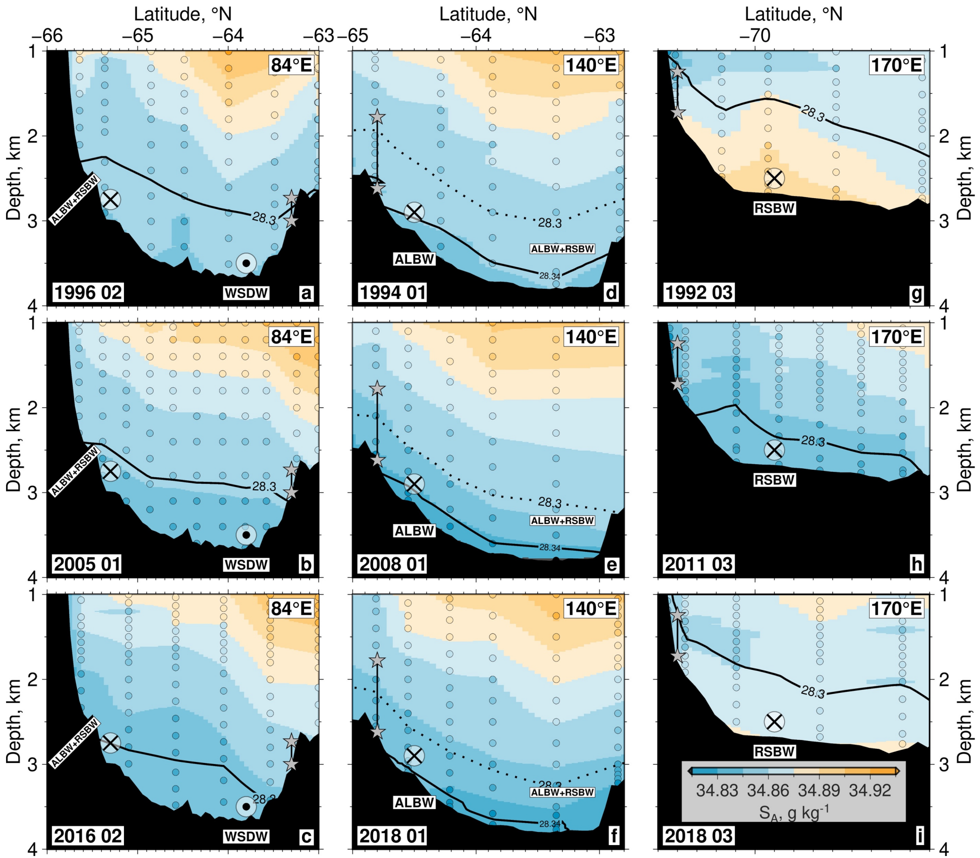


Abyssal circulation in the Australian Antarctic Basin.

Bottom waters are generally freshening

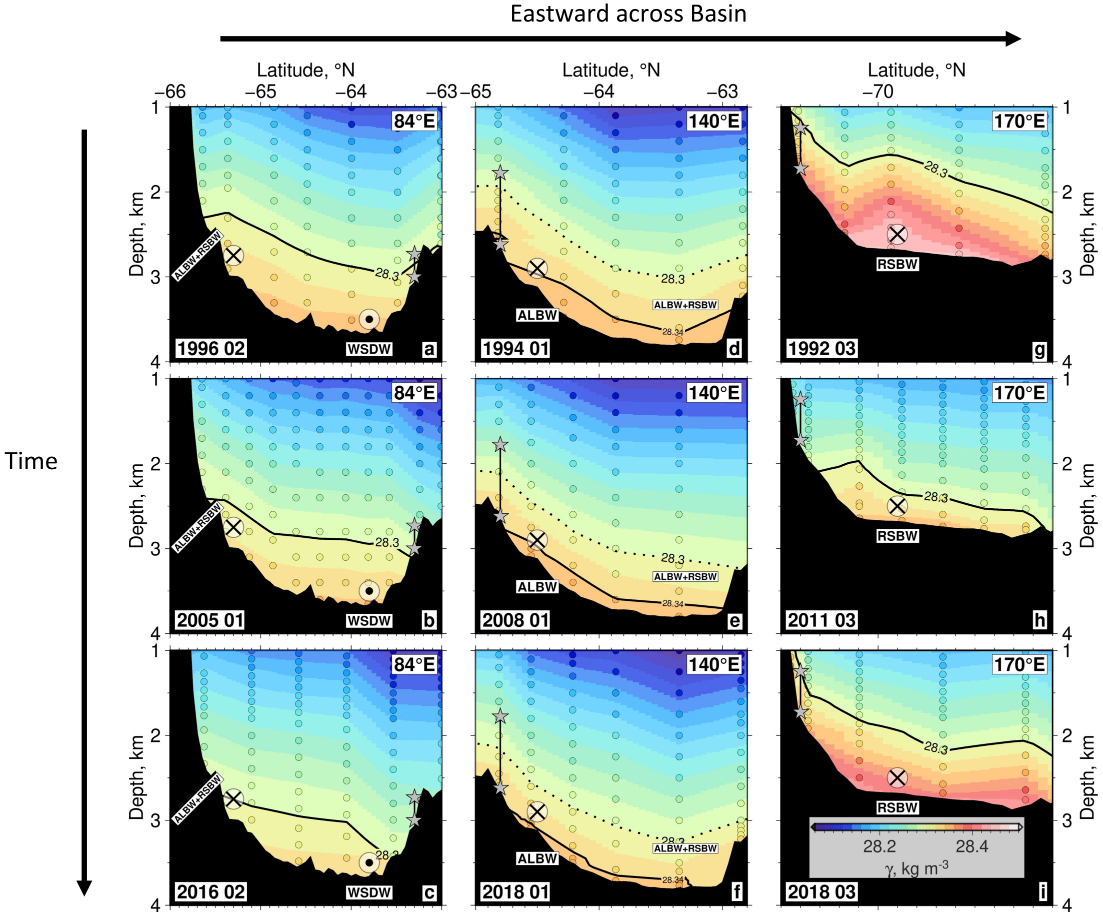
Eastward across Basin

Time



*Latitude-depth sections of **absolute salinity**.*

Bottom waters are generally becoming lighter

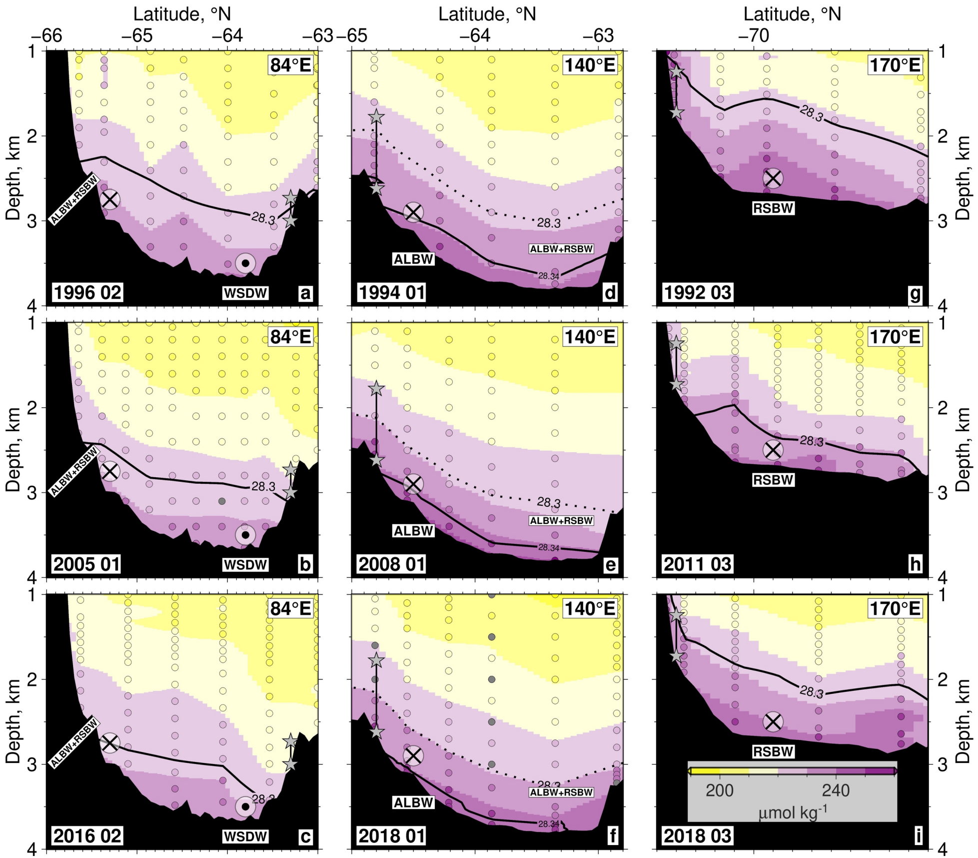


*Latitude-depth sections of **neutral density**.*

Bottom waters show little change in oxygen concentration

Eastward across Basin

Time



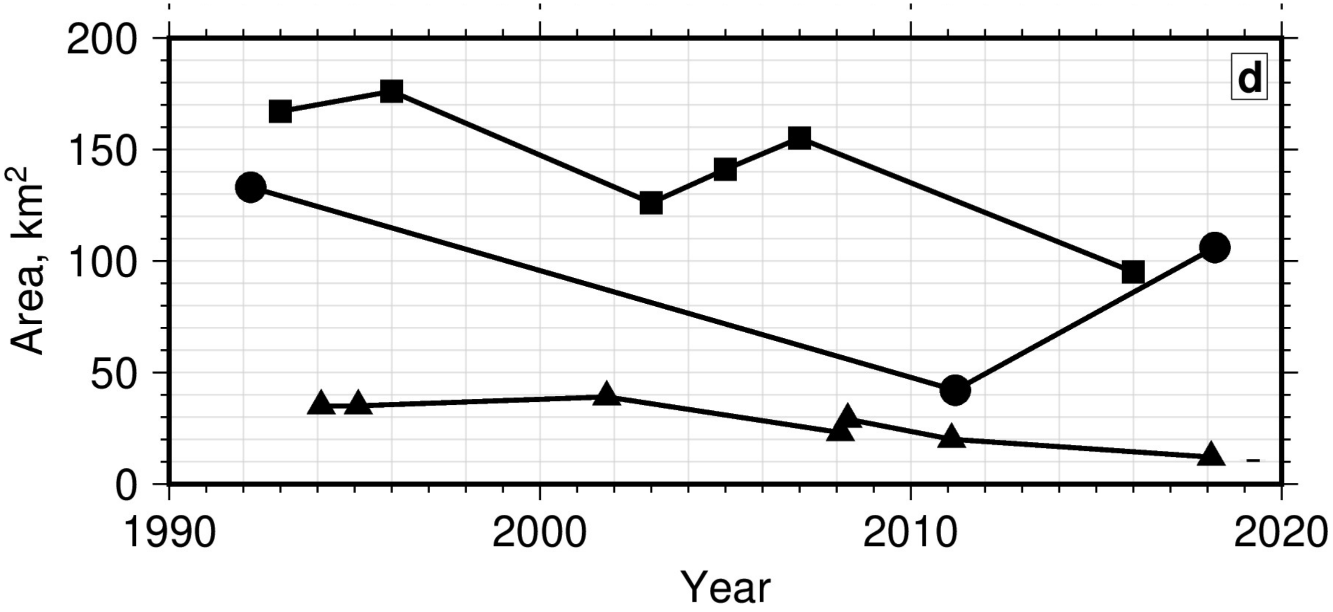
*Latitude-depth sections of dissolved **oxygen concentration**.*

Hydrographic sections reveal area-density relationship

As each bottom water freshens, their heaviest density classes are lost causing a basinwide

thinning rate of 115 ± 30 m decade^{-1}

Bottom water area is related to variability in density, specifically salinity.



Change in area of AABW flowing into Australian Antarctic Basin at gateway.

Well-ventilated and well-observed Australian Antarctic Basin.

Three bottom waters enter basin via bathymetric gateways that have been **decadally monitored with repeat hydrographic sections** and have **well-placed moorings**.

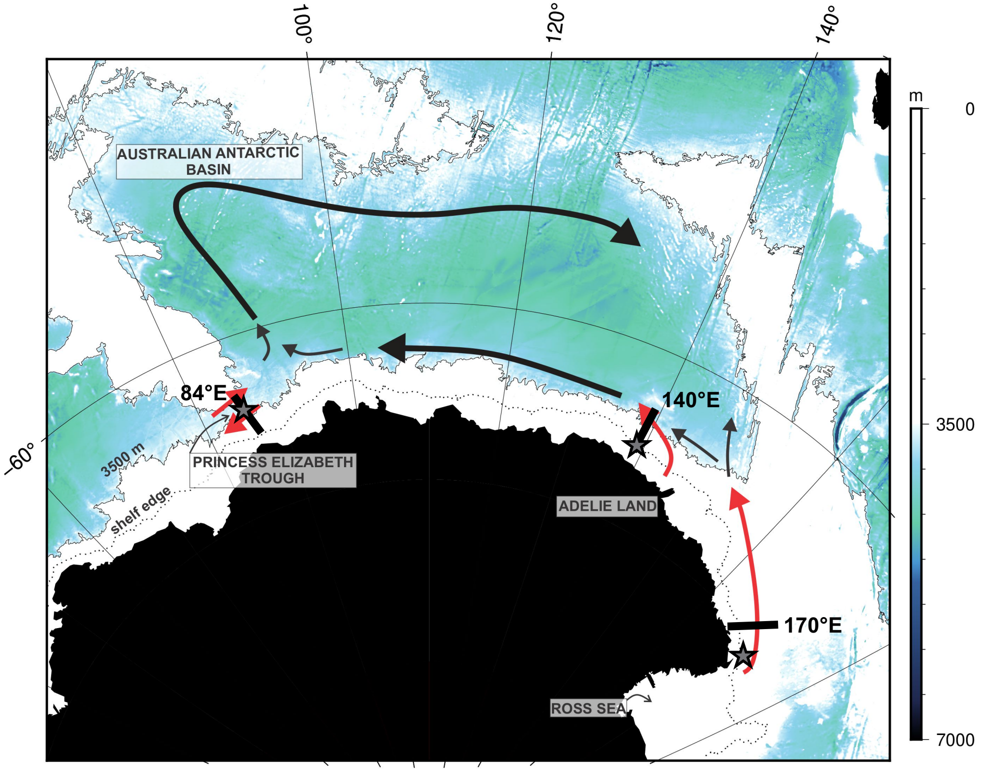
╲ **Repeat Hydrographic Cross-sections**

-> Thickness

-> Properties

★ **Moorings**

-> Time series of absolute speed and properties

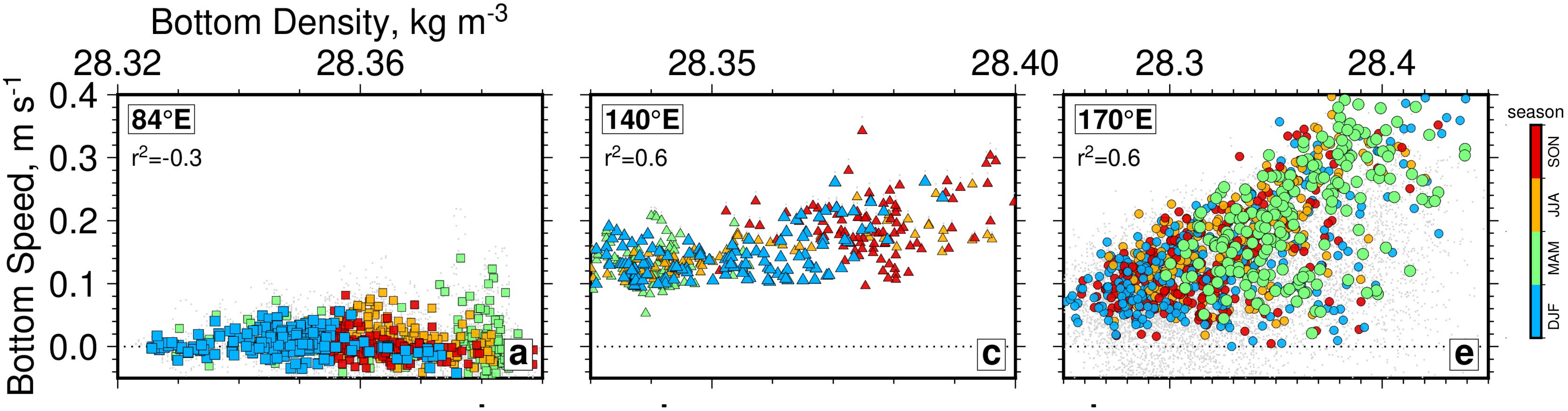


Abyssal circulation in the Australian Antarctic Basin.

Moorings reveal speed-density relationship

Moorings reveal that:

Bottom water speed (and shear) depends on location, season, and density



Bottom water speed and density from mooring data.

Well-ventilated and well-observed Australian Antarctic Basin.

Three bottom waters enter basin via bathymetric gateways that have been **decadally monitored with repeat hydrographic sections** and have **well-placed moorings**.

╲ **Repeat Hydrographic Cross-sections**

-> Thickness

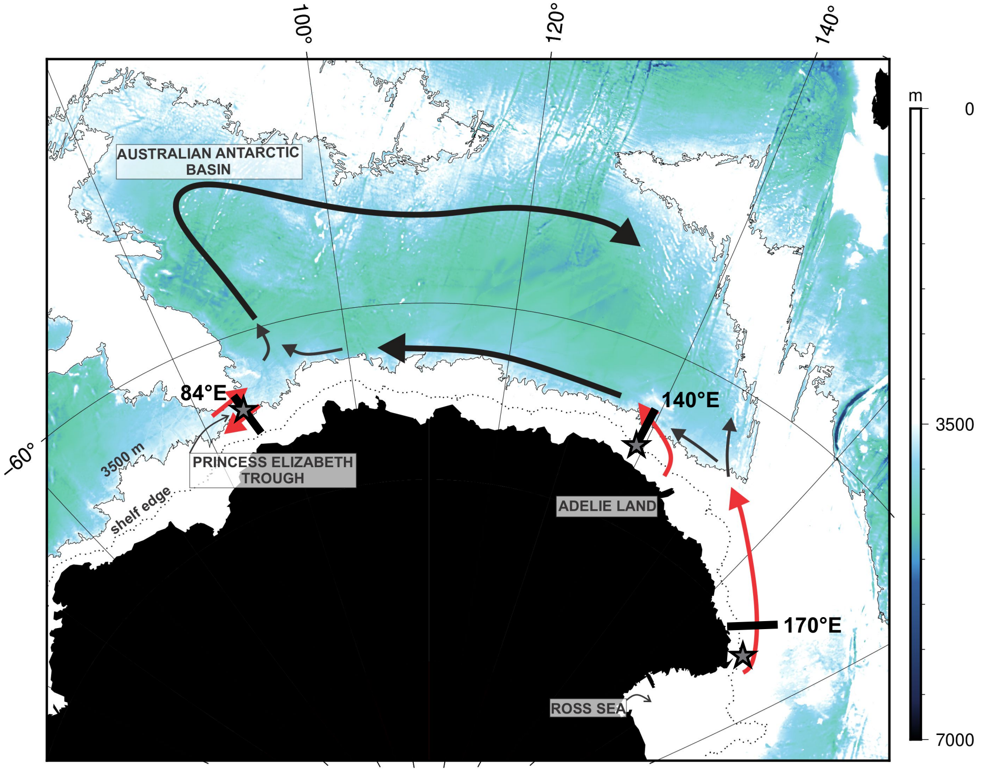
-> Properties

★ **Moorings**

-> Time series of absolute speed and properties

╲ **Model Output** (fills in data gaps)

-> 3D velocity fields



Abyssal circulation in the Australian Antarctic Basin.

Joint mooring-model-hydrographic method

For each location and time, volume transport is given as: $\int [v(t_n) \cdot \mathcal{F}(t_n, y)] \times H(t_n, y) \quad dy$

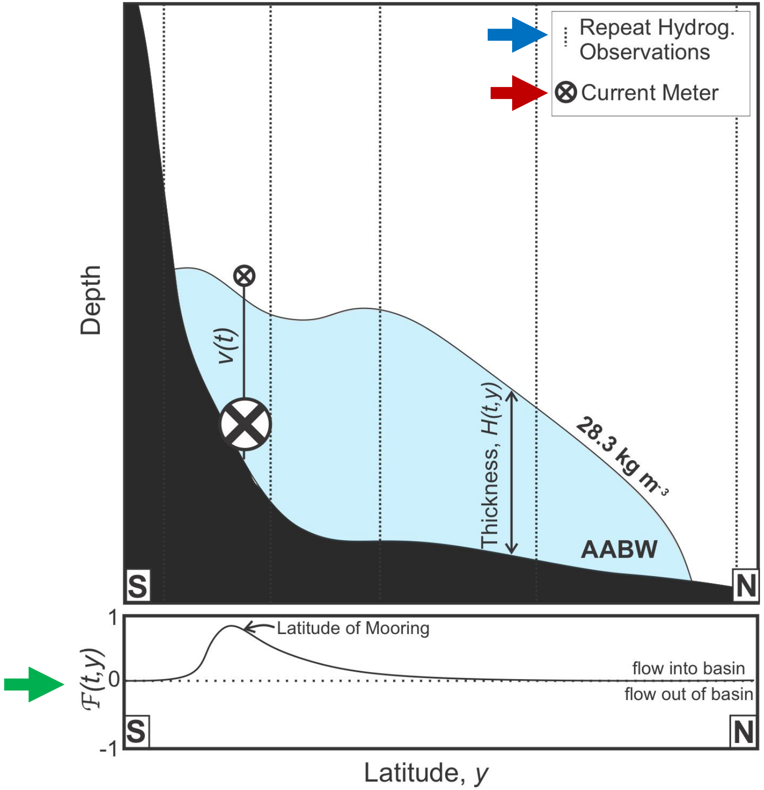
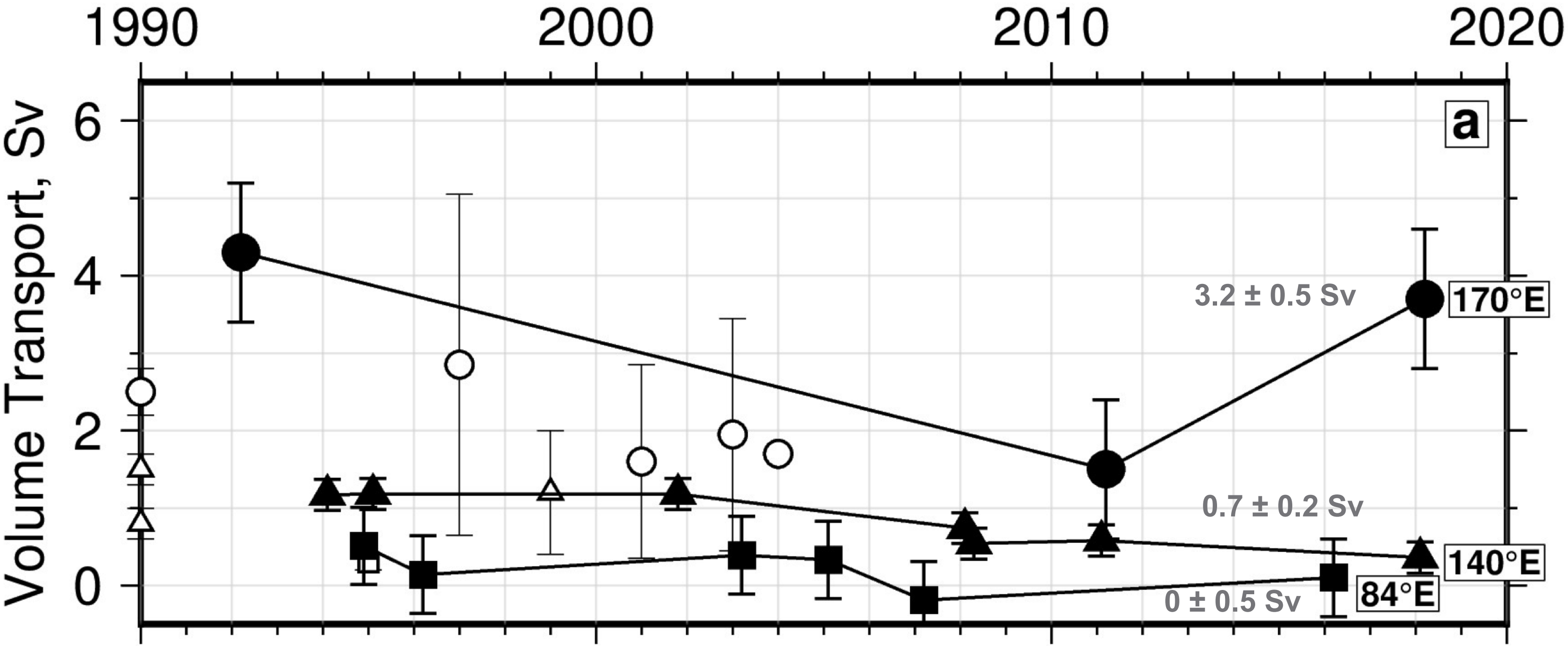


Diagram showing joint mooring-model-hydrographic-method.

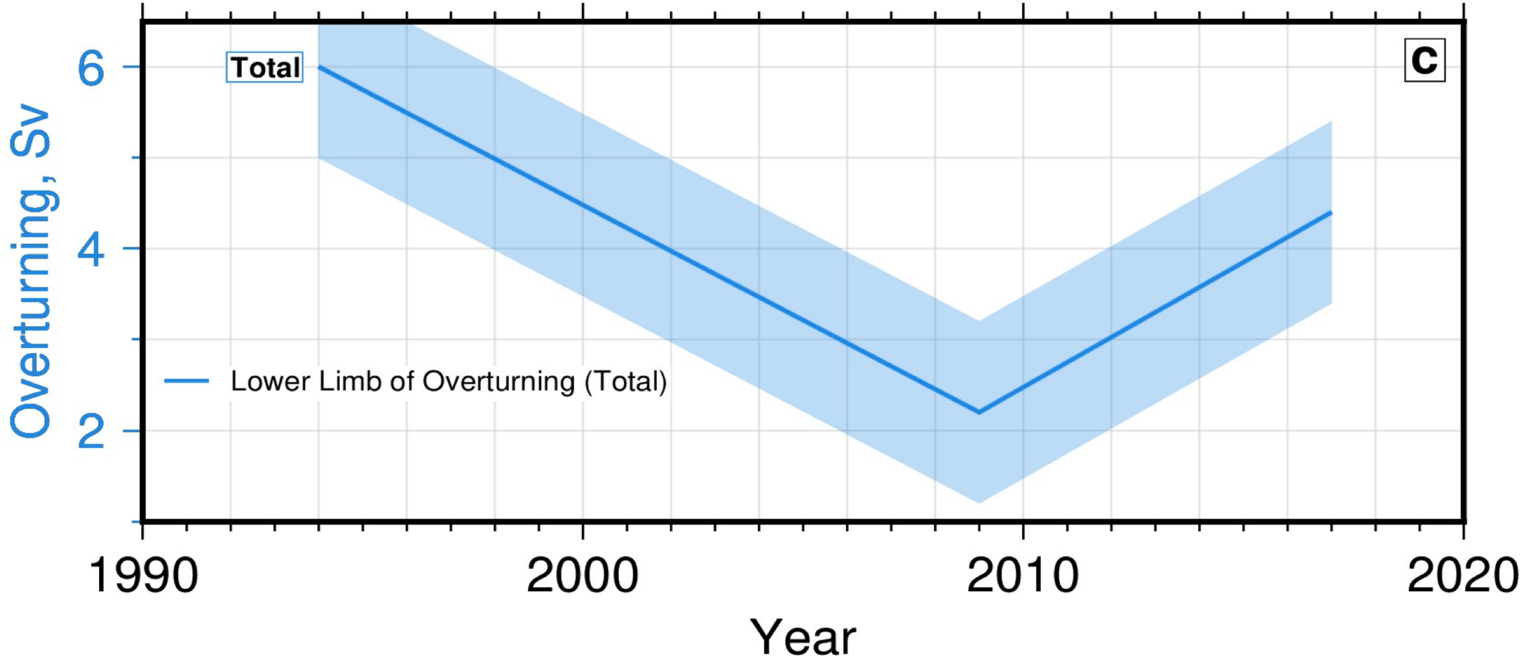
Ross Sea Bottom Water shows the greatest mean and change



Decadal variability of lower limb of overturning circulation between 1990 and 2020. RSBW = circles.

A measure of the lower limb of the overturning circulation

Ross Sea Bottom Water drives the lower limb of overturning circulation in the Australian Antarctic Basin**.**

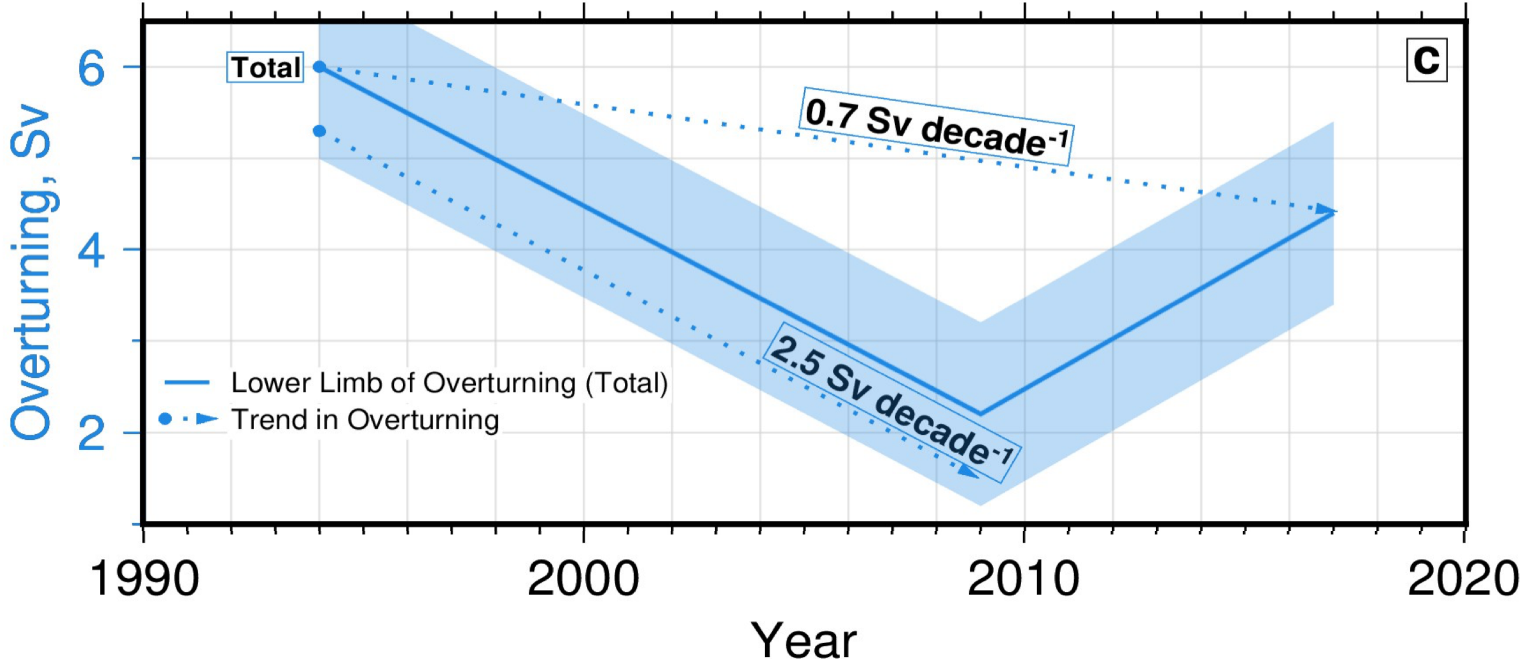


Decadal variability of lower limb of overturning circulation between 1990 and 2020.

Overall slowdown of lower limb of overturning circulation

Observed slowdown of abyssal overturning of -0.8 ± 0.5 Sv decade^{-1}

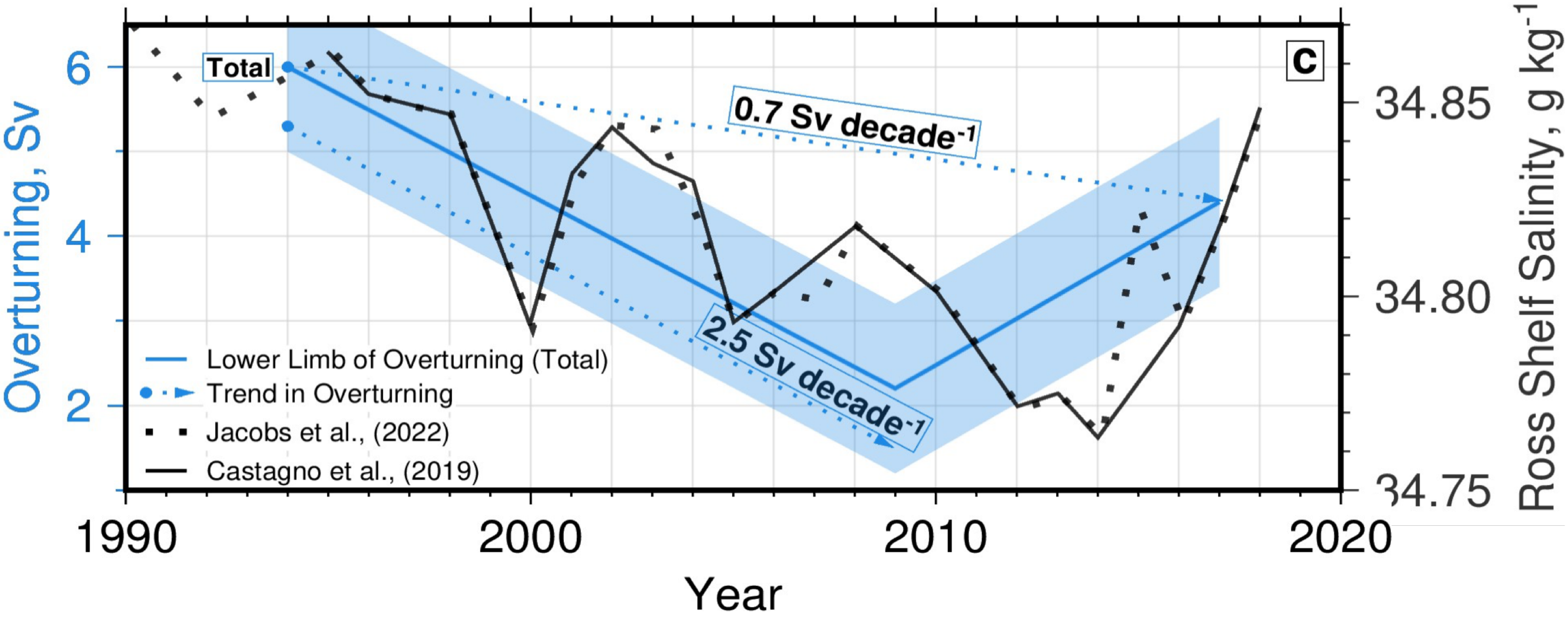
- causes the amount of oxygen reaching the basin to decline by up to **6 ± 1 μmol kg^{-1} decade^{-1}**



Decadal variability of lower limb of overturning circulation between 1990 and 2020.

Co-variation of Ross Sea shelf salinity with overturning

63-year **long-term freshening** trend attributed to increased **glacial melt** (Jacobs et al., 2002; Jacobs et al., 2022), whilst **recent rebound** caused by short-term climatically driven **sea-ice** increase (Silvano et al., 2020).



Decadal variability of lower limb of overturning circulation and Terra Nova Bay shelf water salinity between 1990 and 2020.

Slowdown and recovery of overturning driven by Ross Sea shelf salinity

1. Physical relationship between the density of AABW and its area and speed.
2. Co-variation of Ross Sea shelf salinities with volume transport.
3. Enhanced slowdown of modelled overturning circulation when freshwater input amplified (Heuzé, et al., 2015; Lago and England, 2019).

Shelf water salinity is a key driver of transport changes.

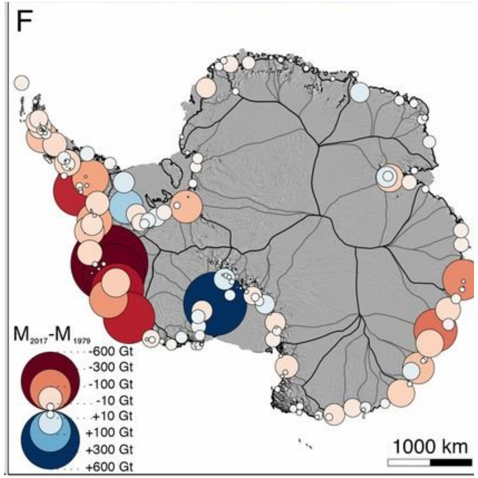
Filling the gaps in our understanding

1. **What are the physical mechanisms driving changes in AABW?**
    - Both: We show that freshening (property change) causes speed and area of bottom water export to decrease (slowdown in production rate of AABW).

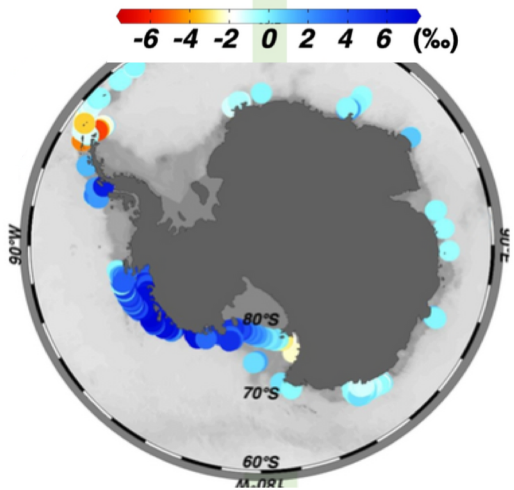
    - Ultimately, salinity/freshwater budget on the Antarctic shelf is key.

Filling the gaps in our understanding

2. **Do the same physical mechanisms apply around Antarctica?**
   - Mechanism (freshening -> slowdown and vice versa) is likely to apply in other regions, irrespective of what drives changes in shelf water salinity (e.g. see Zhou et al., 2023).
   - Impact of glacial melt will vary around Antarctica and is expected to be high in Ross Sea



1979–2017 total change in mass (red = loss). Rignot et al (2019).



2007-2016 glacier-derived freshening (blue = fresher). Pan et al (2022).

Filling the gaps in our understanding

3. Is the trend in AABW natural or anthropogenic?

- What affects salinity can be both natural (e.g. climatic anomalies impacting sea ice production) and anthropogenic (e.g. enhanced glacial meltwater due to warming).

- To completely separate natural variability from long-term changes in Antarctica, we need to:
  1. sustain long-term observational programs
  2. collect more high-resolution regional data
  3. develop and use global models that have ice shelves and realistic freshwater forcing,