Internal Variability of the Southern Ocean Carbon sink

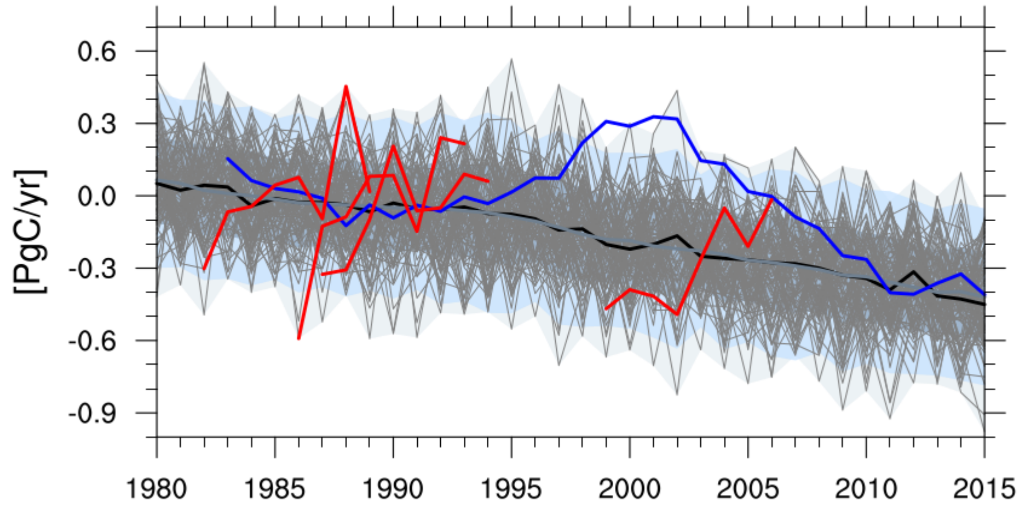
Journal Club

Discussion based on Landschützer et al. 2015

Why do I present this?

- MSc Thesis on internal variability of Southern Ocean Carbon Sink
- Southern Ocean is big contributor to Global Carbon Cycle and focus area of new WCRP Grand Challenge on carbon feedbacks
- Use MPI-ESM Large Ensemble
- Peter’s neural network is a powerful upgrade on SOCAT database

Southern Ocean carbon sink is varying



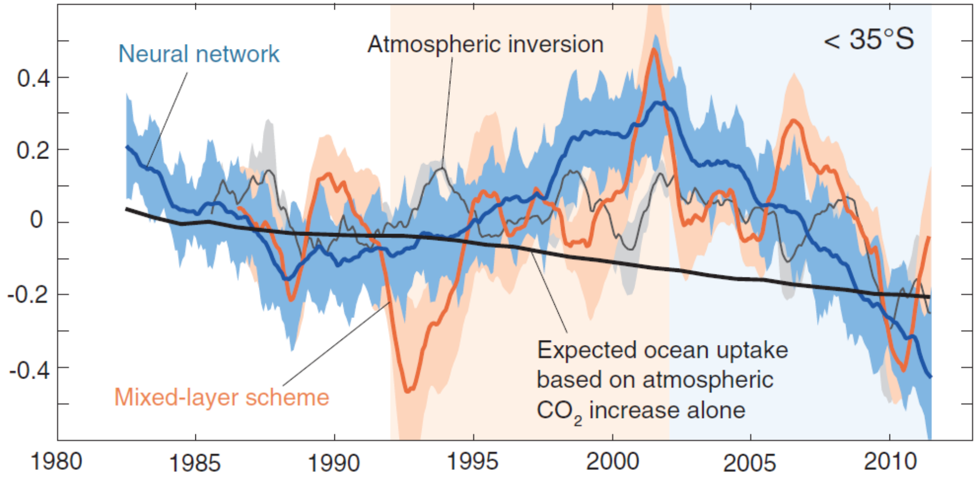


Figure 3: Evolution of the Southern Ocean carbon sink anomaly south of 35°S. Grey lines show the 100 ensemble members, the black line the ensemble median, the gray shading is the range of the ensemble, the blue shading is the 2σ ensemble spread, the red lines are decreasing sink trend candidates, the blue line is the SOM-FFN observation-based estimate (Landschützer et al., 2015); negative values indicate anomalous uptake with respect to the 1980s

Results: pCO_2 trends

- symmetric pCO2 trends
- pCO2 separation by Takahashi (2002)

$$(pCO_2 \text{ at } T_{\text{mean}}) = (pCO_2)_{\text{obs}} \times \exp[0.0423(T_{\text{mean}} - T_{\text{obs}})],$$

$$(pCO_2 \text{ at } T_{\text{obs}}) = (\text{Mean annual } pCO_2) \exp[0.0423(T_{\text{obs}} - T_{\text{mean}})],$$

- asymmetric thermal responses
- asymmetric SLP, but **no reversal**

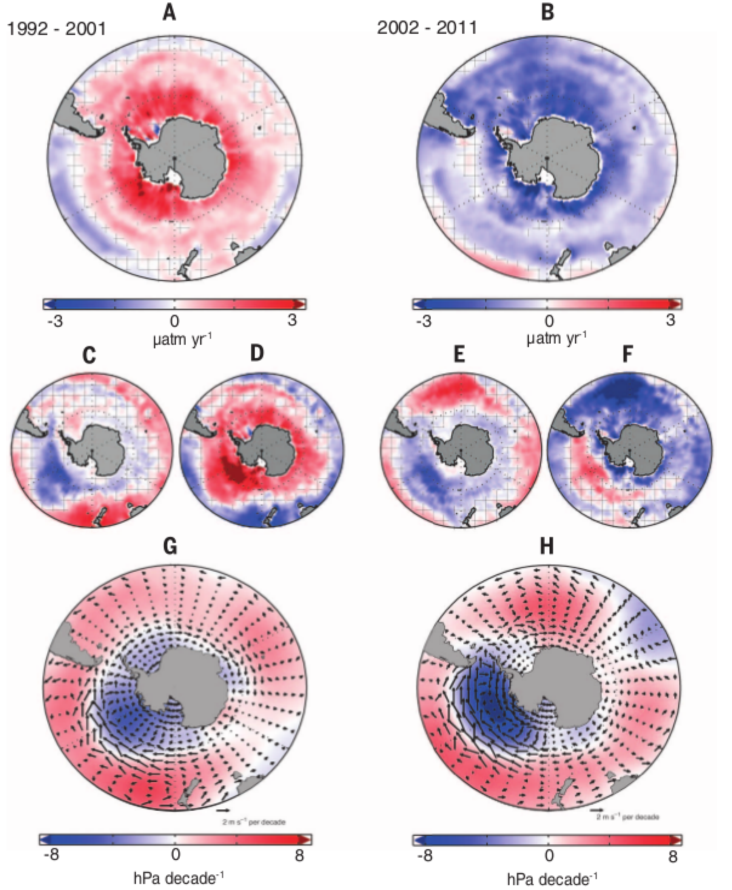
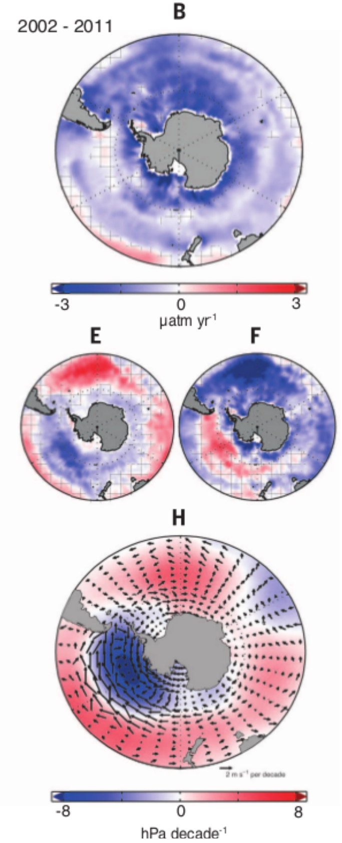


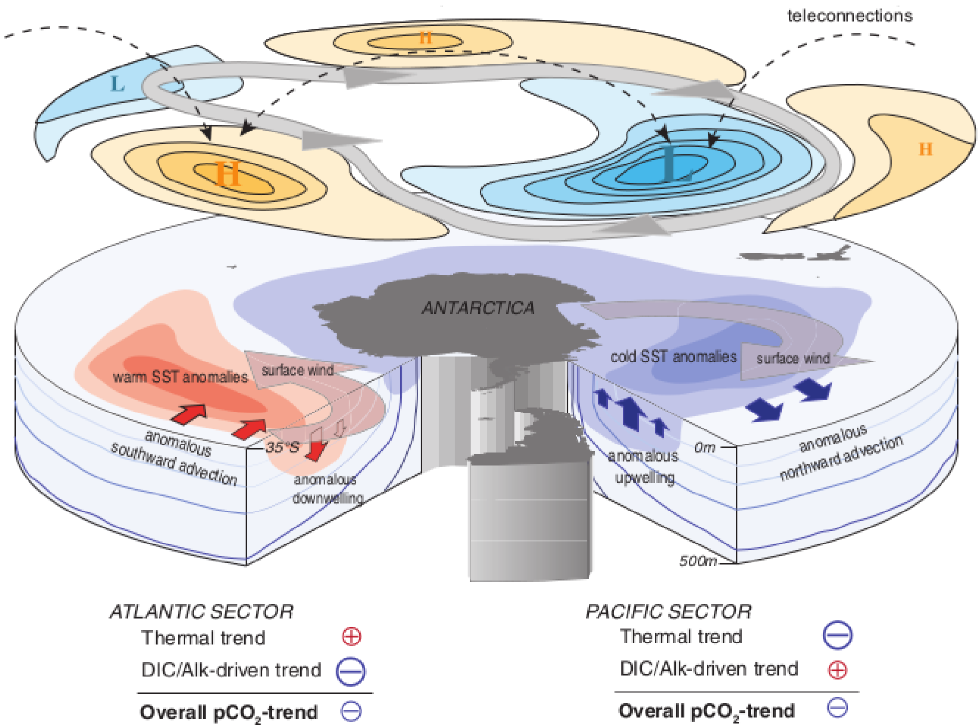
Fig. 2. Trends in ΔpCO_2 based on the neural network output and its two components for the two analysis decades: 1992 through 2001 and 2002 through 2011. (**A**) Linear trend in ΔpCO_2 for the 1990s. (**B**) As (A) but for the 2000s. Linear trend in (**C**) thermal pCO_2 and (**D**) nonthermal ΔpCO_2 for the 1990s. (**E**) and (**F**), as (C) and (D) but for the 2000s. Positive (red) ΔpCO_2 trends indicate a faster increase of pCO_2 in the surface ocean than in the atmosphere (i.e., a decreasing sink) and vice versa for positive (blue) trends. Hatched areas indicate where the linear trends are outside the 5% significance level ($P \geq 0.05$). (**G**) and (**H**) illustrate decadal trends of sea level pressure (shading) and 10-m wind (vectors) from 1992 through 2001 (G) and 2002 through 2011 (H) based on data from the ERA-Interim reanalysis (20).

Results: explanation

- 1990s: strengthening winds, more upwelling, “confirmed” [Le Quere, 2007]
- 2000s: no reversal of winds, but why decrease?
  - Temperature effect on CO2flux
  - upwelling anomalies from SLP anomalies
  - assymetric response in T, but symmetric in total

Southern Ocean carbon sink in the 2000s





Implications

- Oceanic carbon sink more variable and sensitive than previously suggested
- last sentense unclear: „This also suggests that should current climate trends reverse in the near future, the Southern Ocean might lose its recently regained uptake strength, leading to a faster accumulation of CO2 in the atmosphere…“
- → We don’t know for sure where we go

Papers

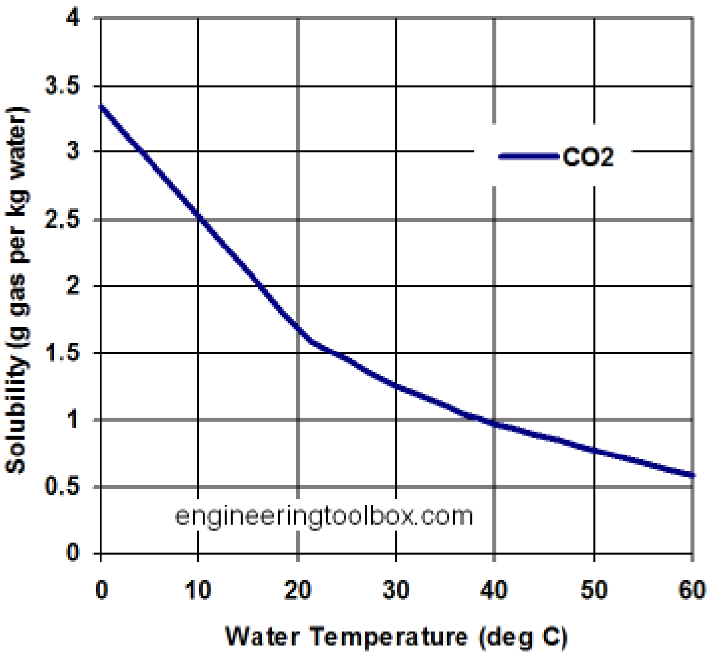
- Le Quéré et al., (2007): Saturation of the Southern Ocean CO2 Sink Due to Recent Climate Change, *Science, American Association for the Advancement of Science*, 316, 1735-1738
- Lovenduski et al., (2008): Toward a mechanistic understanding of the decadal trends in the Southern Ocean carbon sink Global Biogeochem. Cycles, 22
- Landschützer et al., (2016): Decadal variations and trends of the global ocean carbon sink, *Global Biogeochemical Cycles, Wiley-Blackwell*, 30, 1396-1417
- DeVries et al., (2017): Recent increase in oceanic carbon uptake driven by weaker upper-ocean overturning, *Nature, Springer Nature*, 542, 215-218

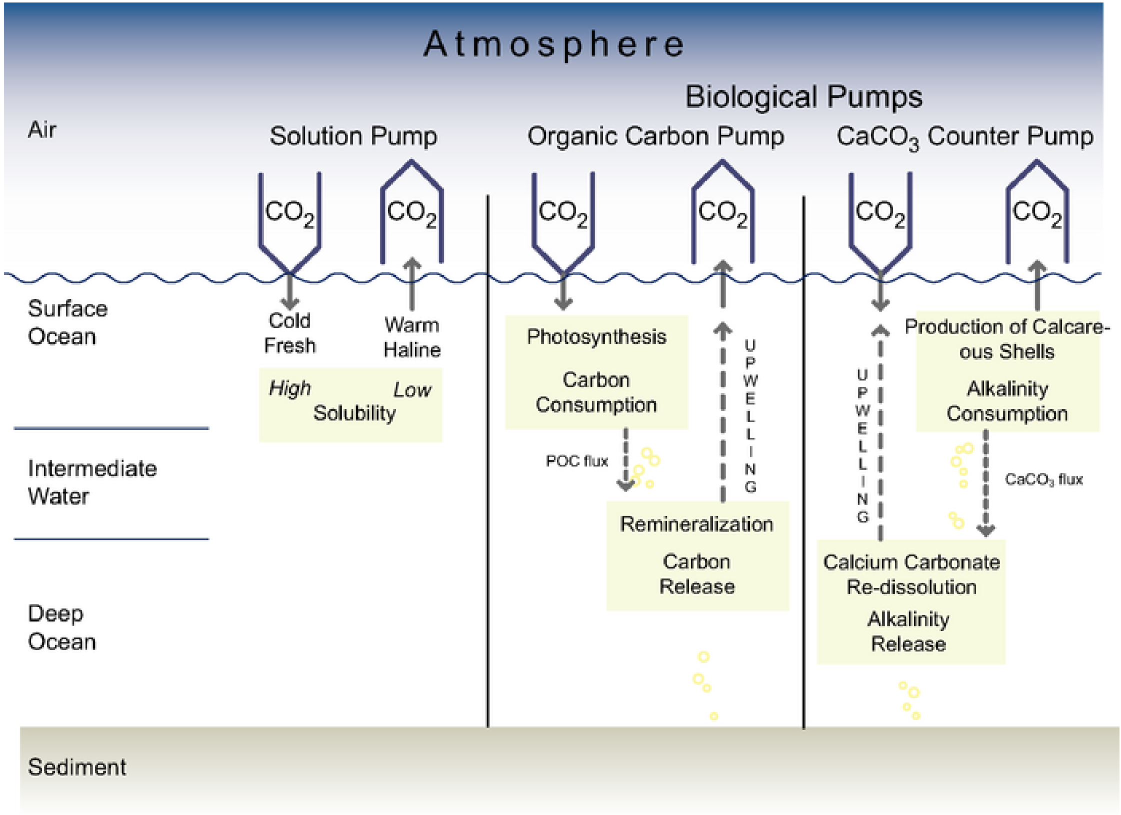
Backup slides

Method

- pCO2: Neural network on SOCAT (Surface Ocean CO2 Atlas) database, because sparse observations
- SLP/winds: ERA-interim reanalysis
- T: NOAA Optimum Interpolation

„pumps“ regulate carbon





Southern Ocean Circulation

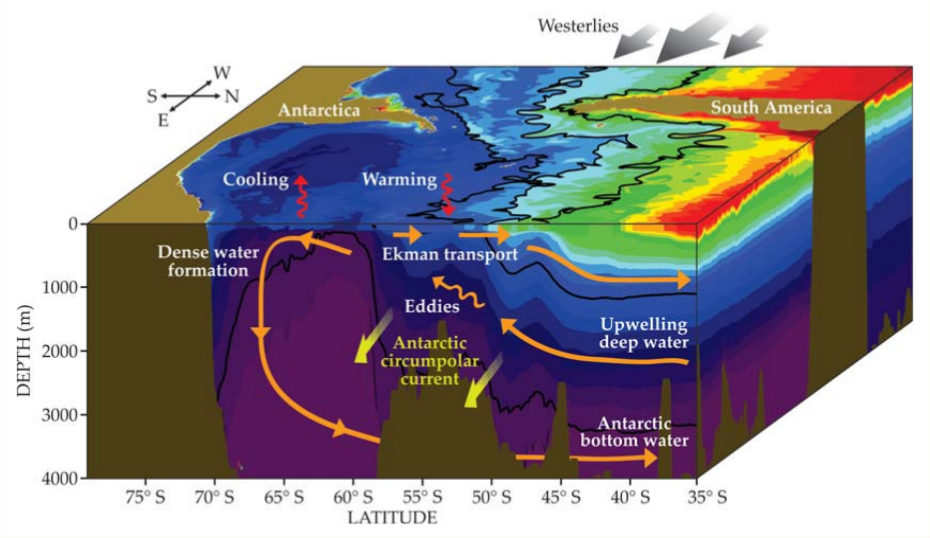
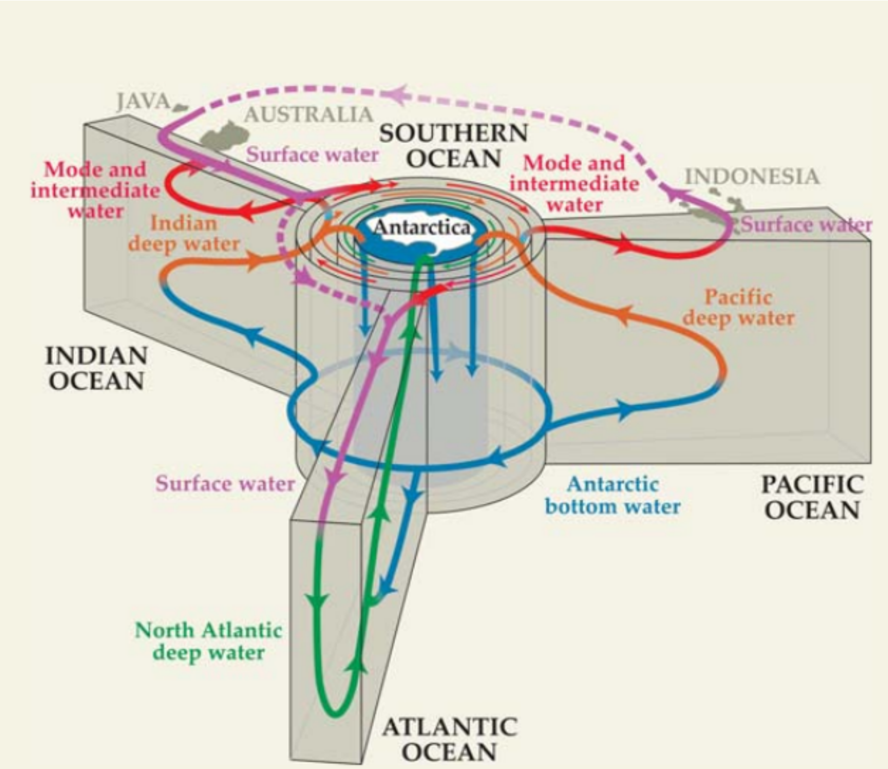


Figure 1. Dynamics in the Southern Ocean. The westerly winds combine with the Coriolis force to drive a northward flow, known as the Ekman transport, at the ocean's surface. The Ekman transport shifts the light surface waters northward, thereby tilting the density contours—shown as colors ranging from red (surface light water) through blue (deep dense water)—up from the horizontal. The latitudinal variation in the westerlies creates a divergence in the Ekman transport, which causes water to upwell along the sloping density layers from the deep ocean to the surface. (Eddies and the flow of the strong eastward Antarctic circumpolar current over topographic ridges also influence the upwelling, as outlined in box 2.) Upon reaching the upper ocean, the upwelled waters split into two pathways: Water that reaches the surface close to Antarctica's sea ice is cooled, sinks along the continental shelf, and is transformed into dense bottom water; water that surfaces north of the sea-ice edge is warmed and flows northward with the Ekman layer.[4]



SO Circulation for CO2 sink

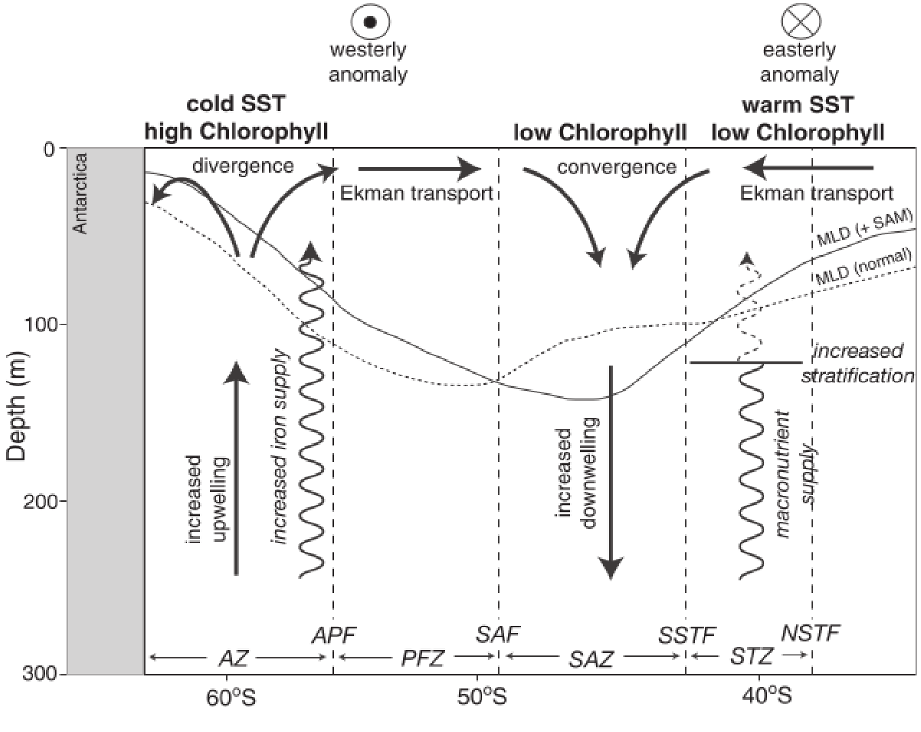


Figure 2. Schematic illustration of the upper ocean response to a positive phase of the SAM.

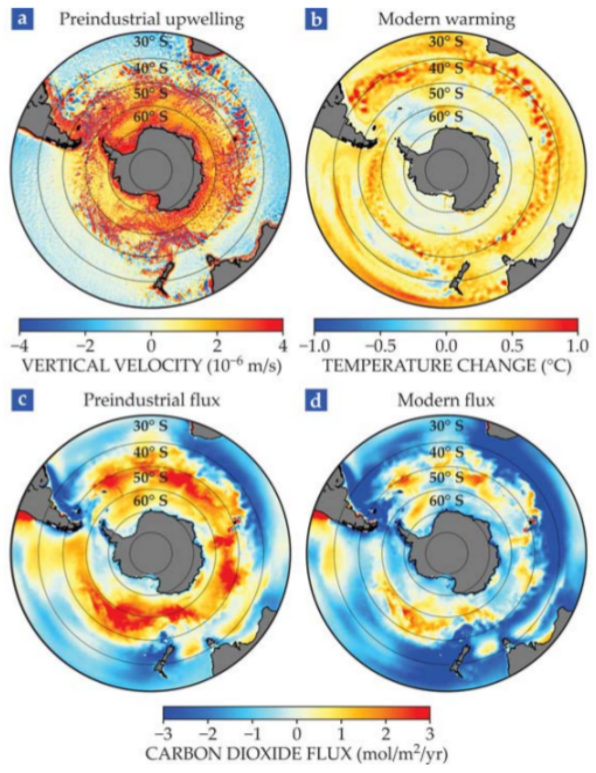
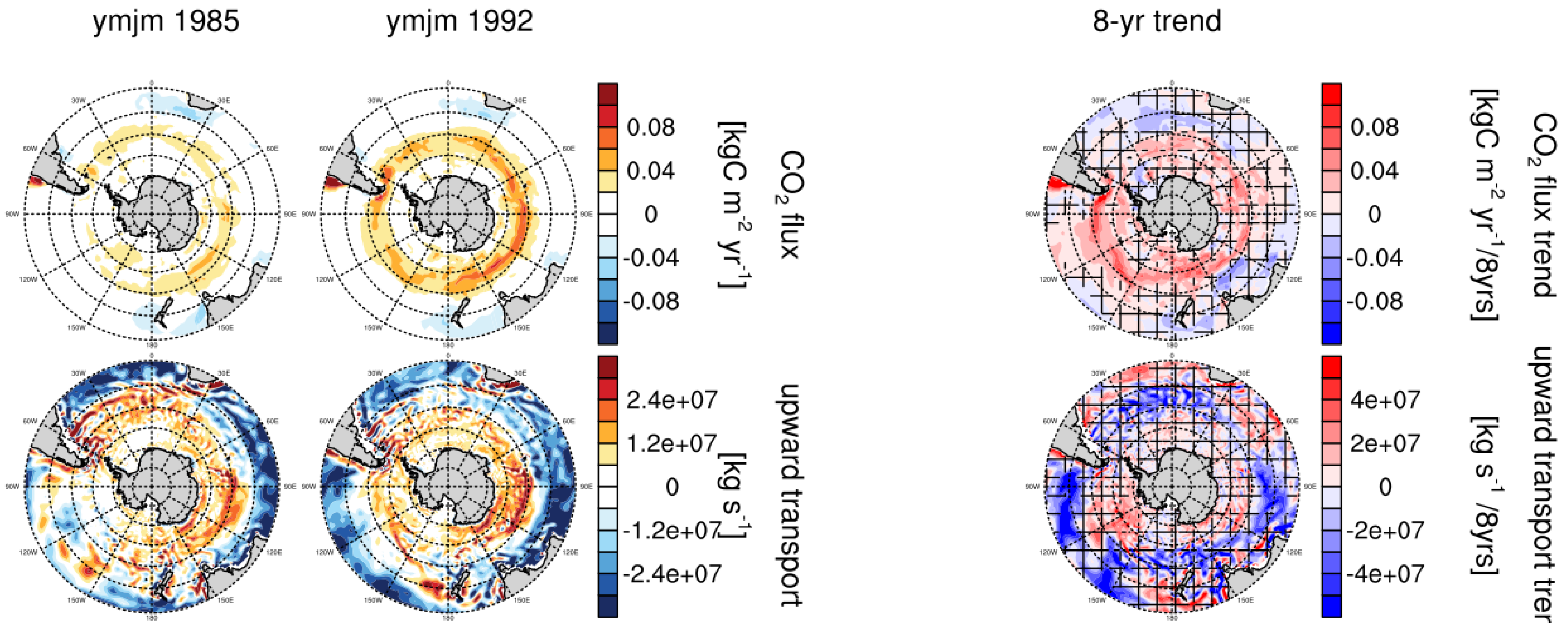


Figure 2. Simulations based on a high-resolution climate model.[17] **(a)** The vertical component of velocity averaged over the upper 200 m of the ocean, using a preindustrial simulation. Upwelling is positive (red), and downwelling is negative (blue). **(b)** Ocean warming averaged over the top 1 km when the concentration of atmospheric carbon dioxide is 400 ppm and assumed to increase at 1% per year since preindustrial times. **(c)** The air–sea flux of CO_2 during preindustrial times. **(d)** The air–sea flux of CO_2 when the atmospheric concentration is 400 ppm. Positive fluxes (red) indicate the outgassing of CO_2 from the ocean to the atmosphere, and negative fluxes (blue) indicate carbon uptake by the ocean.

Southern Ocean MPI-ESM LE m=178 positive 8-year winter trend 1985-1992



Summer trends MPI-ESM LE

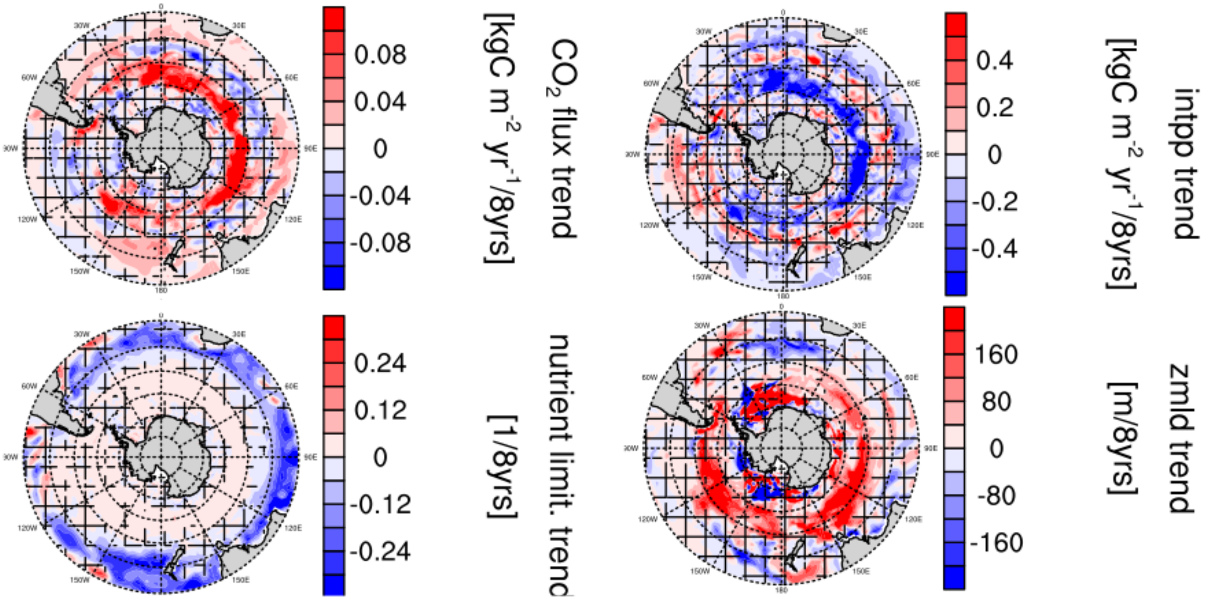


Figure 5: Southern Ocean austral summer trends per per 8 years: CO_2flux (top left), vertically integrated primary production (top right), nutrient limitation (bottom right) and mixed layer depth (bottom left); hatched areas indicate where trends were below 5% significance

DeVries (2017)

- Inverse modeling
- Enhanced upper ocean circulation in 2000s
- Nothing about reasons for this change

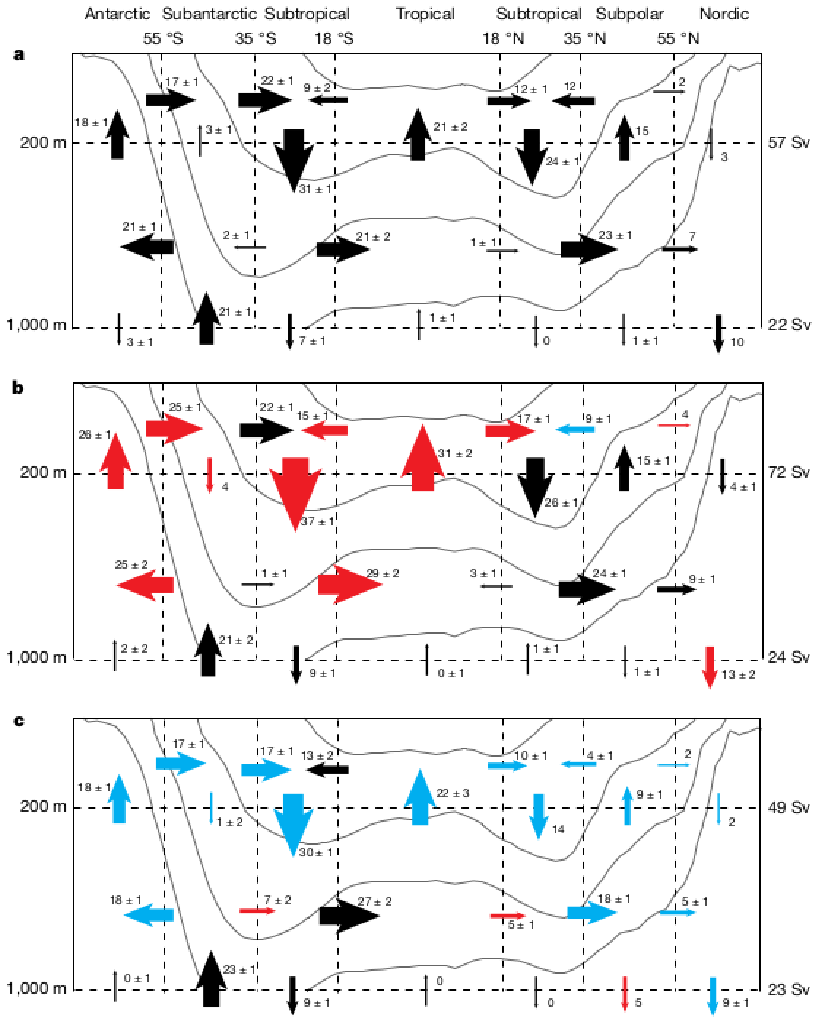
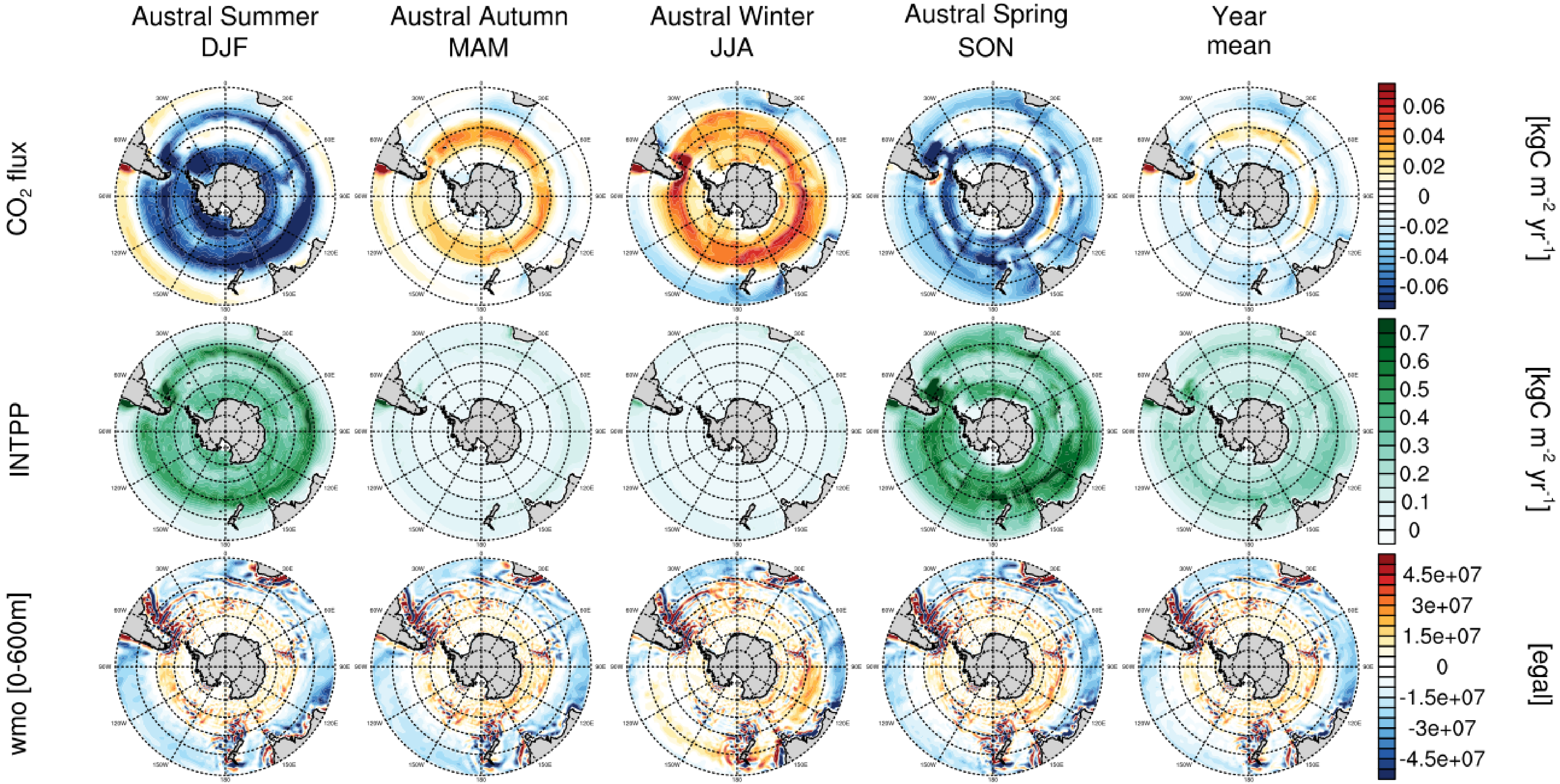
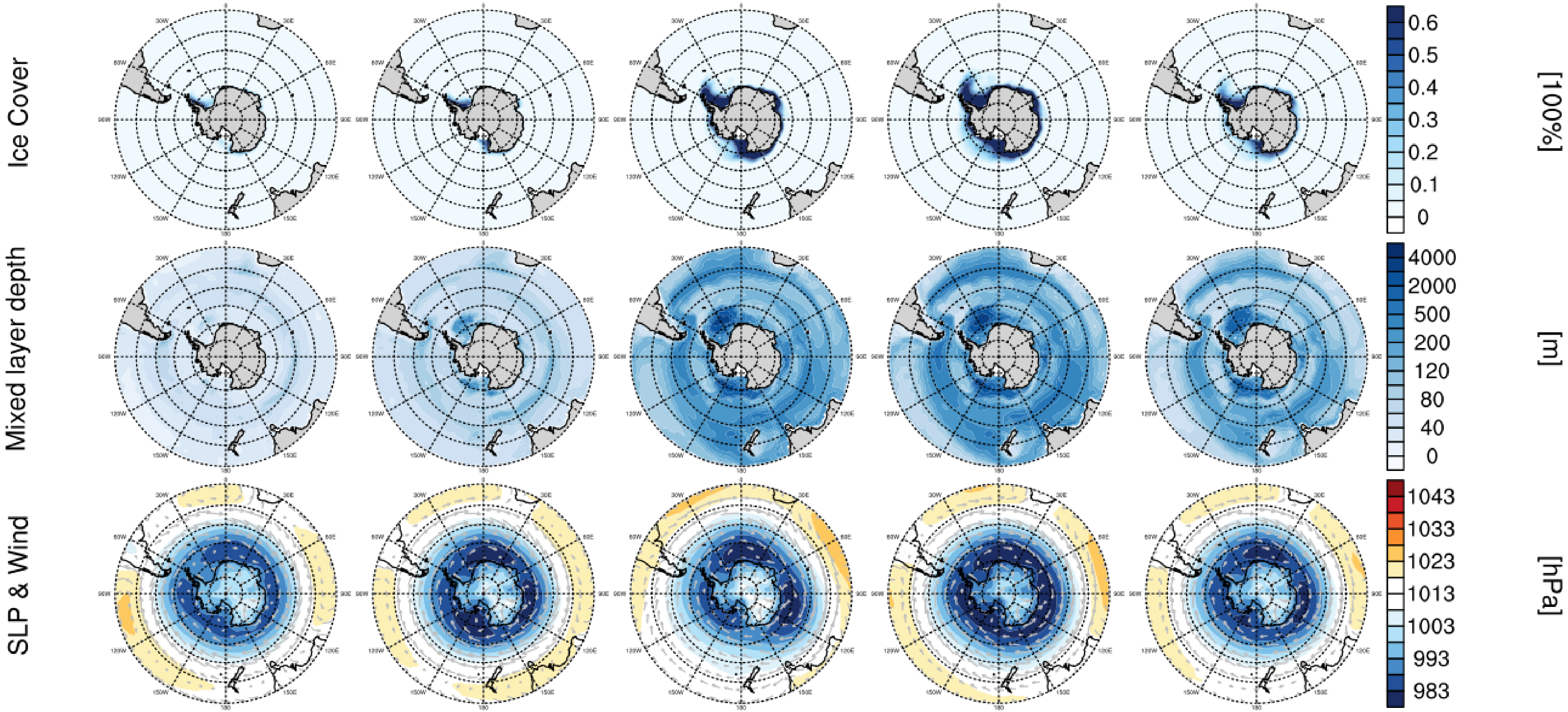


Figure 1 | Upper-ocean overturning circulation during the last three decades. Volume transports are shown in units of Sverdrup (Sv; $10^6\ m^3\ s^{-1}$) for the 1980s (1980–1989) (**a**), 1990s (1990–1999) (**b**) and 2000s (2000–2010) (**c**). Red (blue) arrows indicate an increase (decrease) in the magnitude of the transport relative to the previous decade. Thin grey lines indicate the mean position of isopycnals with density $\sigma_0 = 25.4\ kg\ m^{-3}$, $26.6\ kg\ m^{-3}$, $27.2\ kg\ m^{-3}$ and $27.6\ kg\ m^{-3}$. Uncertainties are standard deviations calculated from a suite of five different data-assimilated circulation models (Supplementary Table 1). To the right of each diagram is the total exchange of waters across each depth horizon. The 200-m depth roughly corresponds to the base of the surface mixed layer, while the 1,000-m depth corresponds to the base of the mesopelagic layer.

Seasonal Overview Southern Ocean 1986-2005 MPI-ESM GR15 LE ensmean




Ice Cover
Mixed layer depth
SLP & Wind
0.6
0.5
0.4
0.3
0.2
0.1
0
[100%]
4000
2000
500
200
120
80
40
0
[m]
1043
1033
1023
1013
1003
993
983
[hPa]