Internal variability of the Southern Ocean carbon sink in MPI-ESM large ensemble simulations: assessment of westerly wind changes

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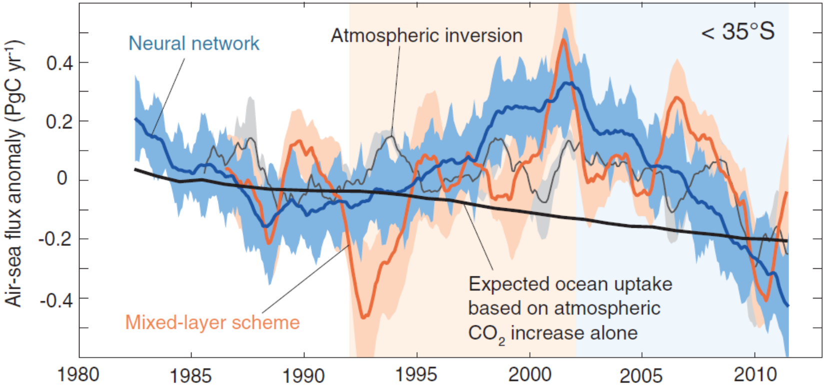
Observations [Landschützer et al., 2015] show an anomalous decadal outgassing trend in the Southern Ocean carbon sink in the 1990s.



Decadal trends of internal variability were not yet explored in coupled earth system models. We use initially perturbed 100-member historical ensemble simulations to assess the variability of the Southern Ocean carbon sink and its underlying processes.

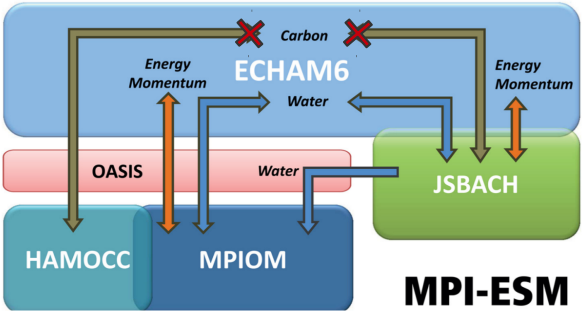


Figure: Schematic view of MPI-ESM1.1 with a diagnostic carbon cycle

Scientific questions

1. How large is the modeled decadal internal variability in the Southern Ocean carbon sink?
2. Do we find similar trends to those observed in the 1990s and 2000s in this large ensemble?
3. Which processes drive decadal internal variability in this large ensemble?

The modeled internal decadal variability is ± 0.36 PgC (2σ ensemble standard deviations). We find positive decadal trends in the Southern Ocean carbon sink similar to observations in the 1990s.

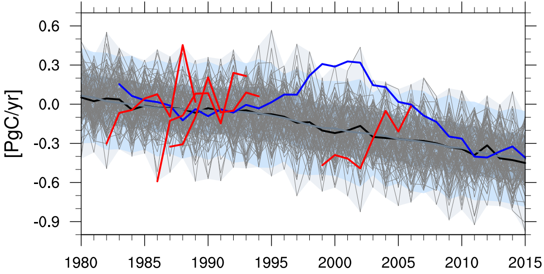


Figure: Evolution of the Southern Ocean carbon sink anomaly south of 35°S. Grey lines show the 100 ensemble members, the black line the ensemble median, the gray shading is the range of the ensemble, the blue shading is the 2σ ensemble spread, the red lines are members of decreasing sink trends, the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

We find westerly winds as the main driver of internal variability in the Southern Ocean carbon sink and analyze the response of biology and ocean circulation.

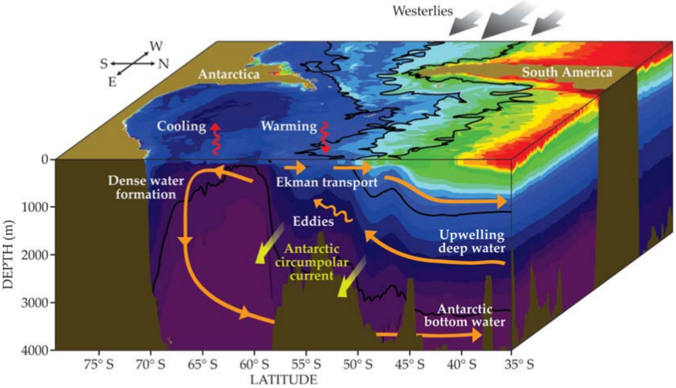


Figure: Dynamics of the Southern Ocean [Morrison et al., 2015]

We find correlations of significant trends in CO_2flux, primary production and mixed-layer depth.

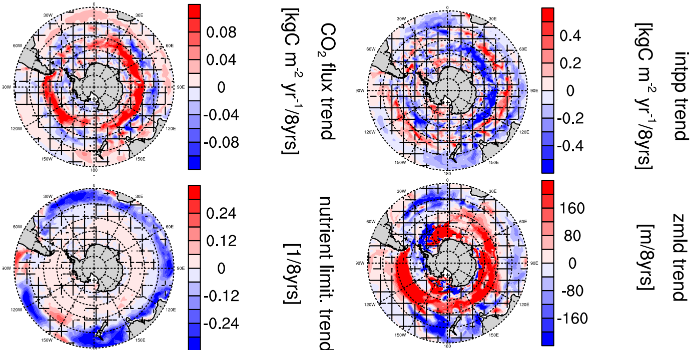
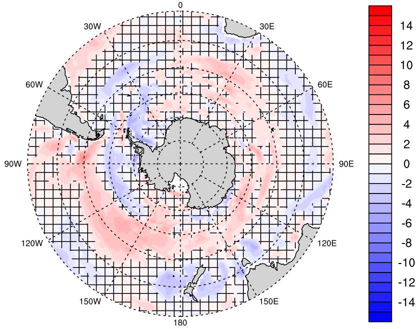


Figure: Southern Ocean austral summer trends over 8 years: CO_2flux (top left), vertically integrated primary production (top right), surface nutrient limitation (bottom left) and mixed layer depth (bottom right); hatched areas indicate where trends were below 95% significance

Light limitation causes the decline in primary production at 50-60°S. Phytoplankton gets mixed deeper into the ocean.



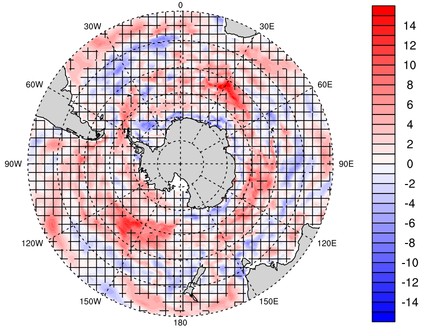


Figure: Trends in [m/8yrs] of average depth of vertical diffusivity due to wind (left) and for phytoplankton average depth (right); hatched areas indicate where trends were below 95% significance

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Deeper winter mixing delays primary production blooms in austral spring and lowers primary production all over the summer.

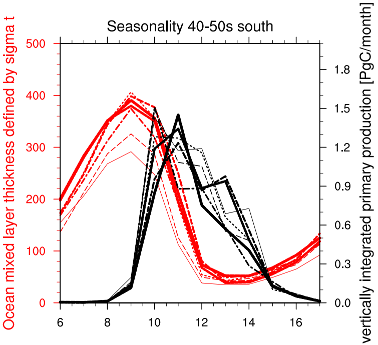

Figure: Seasonality of vertically integrated primary production (black) and mixed layer depth (red) at 50-60°S over 8 years; thicker lines are later years

Previous studies show increasing primary production for increasing winds. Increased upwelling brings more nutrients, but this has no effect on biology in HAMOCC.

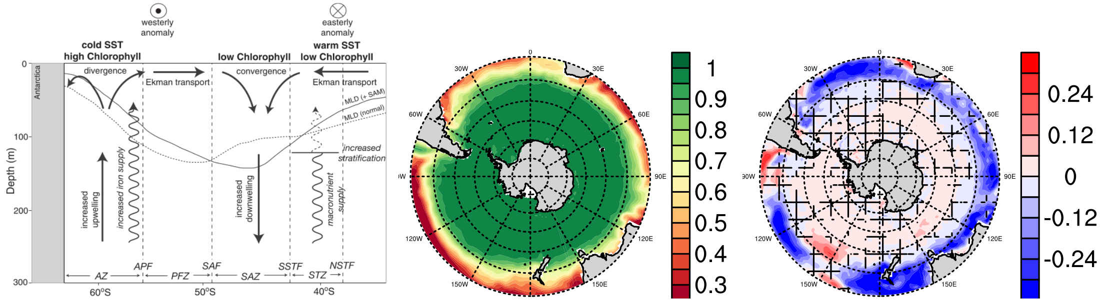

Figure: (left) Schematic view of the upper ocean response to a positive SAM phase [Lovenduski and Gruber, 2005]; (right) surface nutrient limitation function summer mean and trend

related papers: [Lovenduski et al., 2008] [Wang and Moore, 2012] [Hauck et al., 2013]

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Upper-ocean overturning circulation is strengthened by intensified westerly winds. Increased upwelling south of 50°S brings more carbon-rich waters to the surface.

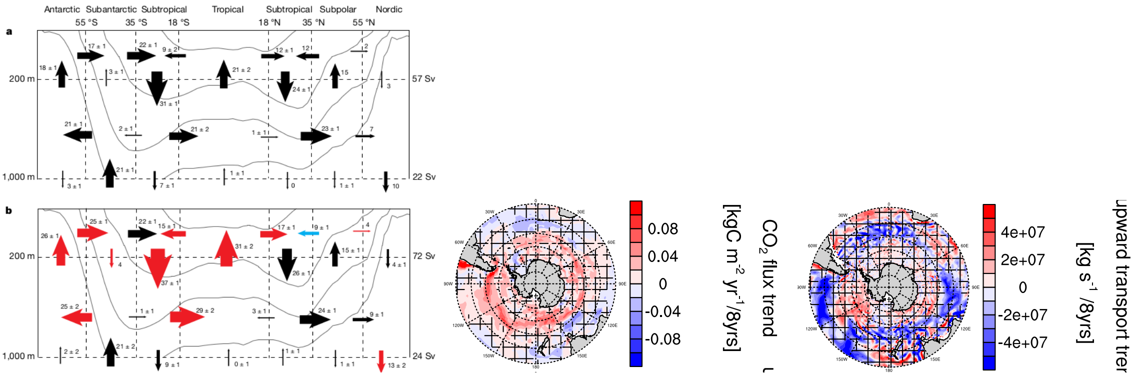

Figure: (left) Upper-ocean overturning circulation (a: normal; b: stronger winds) [DeVries et al., 2017]; (right) trends in winter in CO_2flux and advective upward transport

The strength of westerly winds dominates the internal variability of the Southern Ocean carbon sink. The explained mechanisms apply vice versa for decreasing winds .

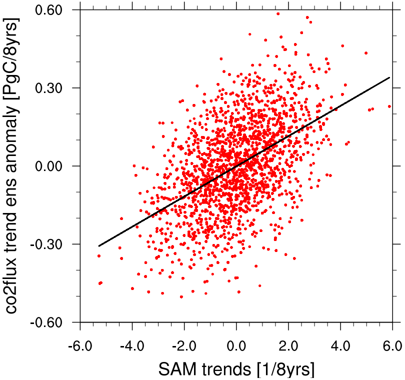

Figure: Southern Annular Mode (SAM) as indicator of wind strength vs. CO_2flux south of 35°S; one data point represents 8-year trends of single realization minus ensemble mean in 8-year periods between 1980 and 2005

Questions now

- Are the research questions answered?
- Can I quantify internal variability as $\pm\, 2\sigma$ ensemble standard deviations?
- Can I call biology a driver of the internal variability of the Carbon Sink or is it rather the response of biology to the westerly winds which are the driver?
- Upwelling nutrients don't change primary production: iron-hypothesis for Southern Ocean doesn't apply in HAMOCC?
- Is this scatter plot useful to show the link between winds and CO_2flux in general?

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