MPI-ESM Large Ensemble simulations reproduce decadal carbon trends in the Southern Ocean

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Preamble

Observations-based estimates report large decadal variations in the Southern Ocean carbon sink [LeQuéré et al. 2007, Landschützer et al. 2015]. Sparse observational data lack the ability to show the dynamics of internally varying processes, which demands for the evaluation with models.

Forced ocean models reproduce this internal variability. However, all coupled earth-system-models fail. By analyzing a historical large ensemble of 100 simulations based on Max Planck Institute's Earth System Model (MPI-ESM), we assess modeled internal variability of the Southern Ocean carbon sink.

Here we analyze what drives internal variability and focus on negative carbon sink trends unforeseen just from atmospheric forcing alone.

Internal Variability of the SO carbon sink

- Largest internal variability in outgassing area
- Internal decadal (1σ) variability: ±0.4 PgC / decade
- Detection of positive and negative decadal carbon sink trends similar to those in the 1990s and 2000s in [Landschützer et al. 2015]
- [Landschützer et al. 2015] range within MPI-ESM LE range

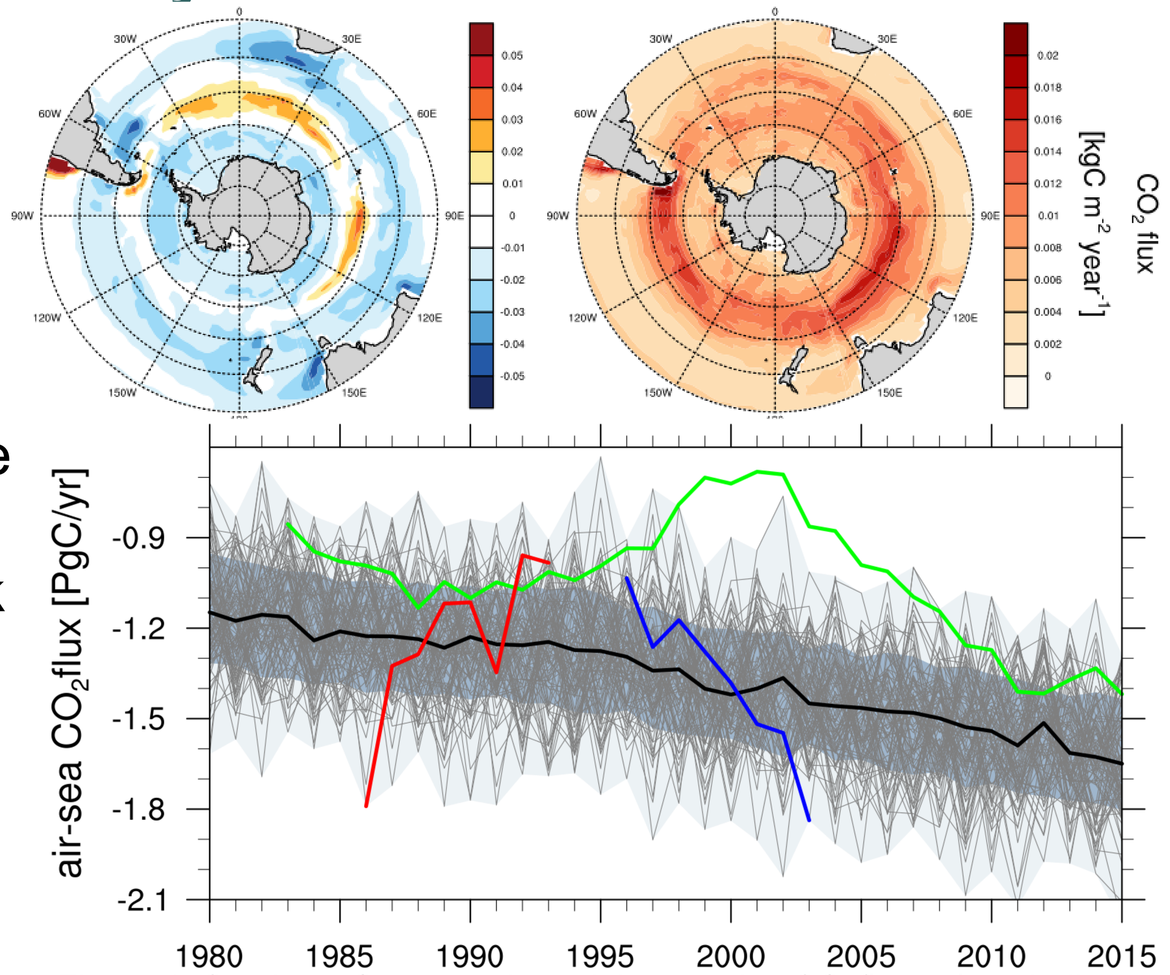

Figure 1: Southern Ocean carbon sink; negative CO_2flux values indicate oceanic carbon uptake: (a) CO_2flux climatology in MPI-ESM, (b) internal variability in CO_2flux, (c) evolution of the Southern Ocean carbon sink south of 35°S, green line from Landschützer et al. 2015, red line negative carbon sink trend, blue line positive carbon sink trend

Winds drive internal variability .

- Latitudes of largest variability 50-60°S
- Stronger winds drive CO_2 outgassing
- Weaker winds drive CO_2 uptake
- Opposing response in biology and circulation to weaker winds

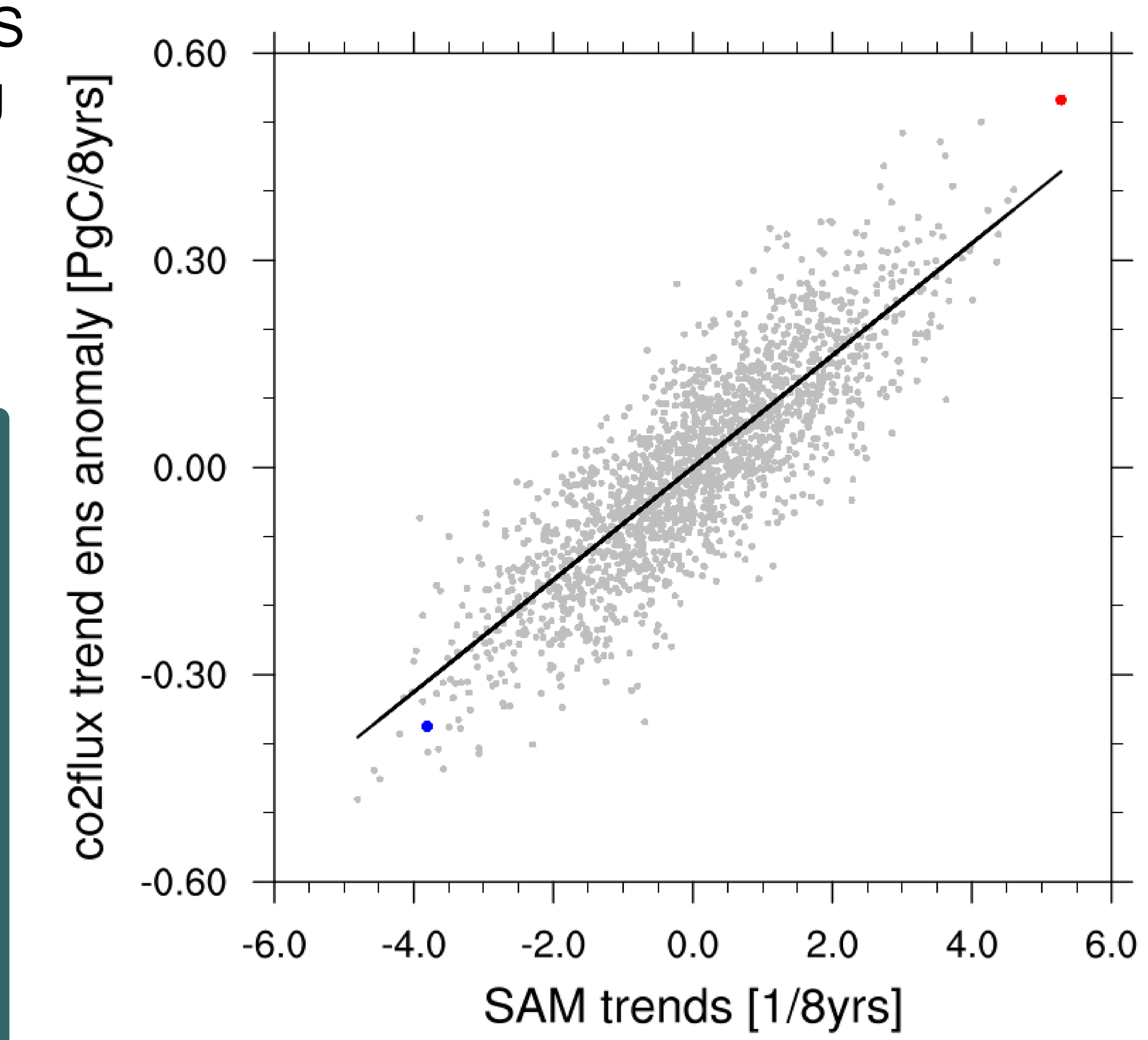

Figure 2: Relation of trends between 1980 and 2005 in SAM index and CO_2flux links the carbon sink to wind strength at 50-60°S.

Conclusions

- Southern Ocean carbon sink variability driven by strength and position of westerly winds
- Decadal carbon sink trends similar to 1990s and 2000s reproducible in coupled ESM
- 3rd conclusion

Methods

- MPI-ESM1.1 with a prognostic carbon cycle
- 100 ensemble members have slightly different initial conditions from pre-industrial control run
- historical forcing from 1850 to 2005
- extension under the RCP4.5 scenario to 2100
- Biogeochemical model from [Ilyina et al. 2013]

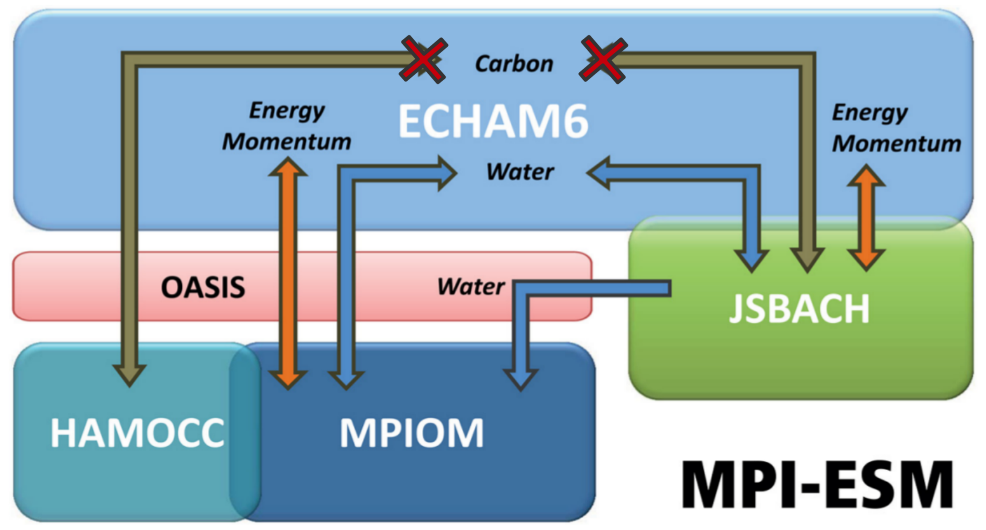

Figure 1: MPI-ESM with a prognostic carbon cycle

Trends in biology

- Opposing summer trends in CO_2flux and primary production
- No change in nutrient limitation
- Deeper mixing inhibits primary production

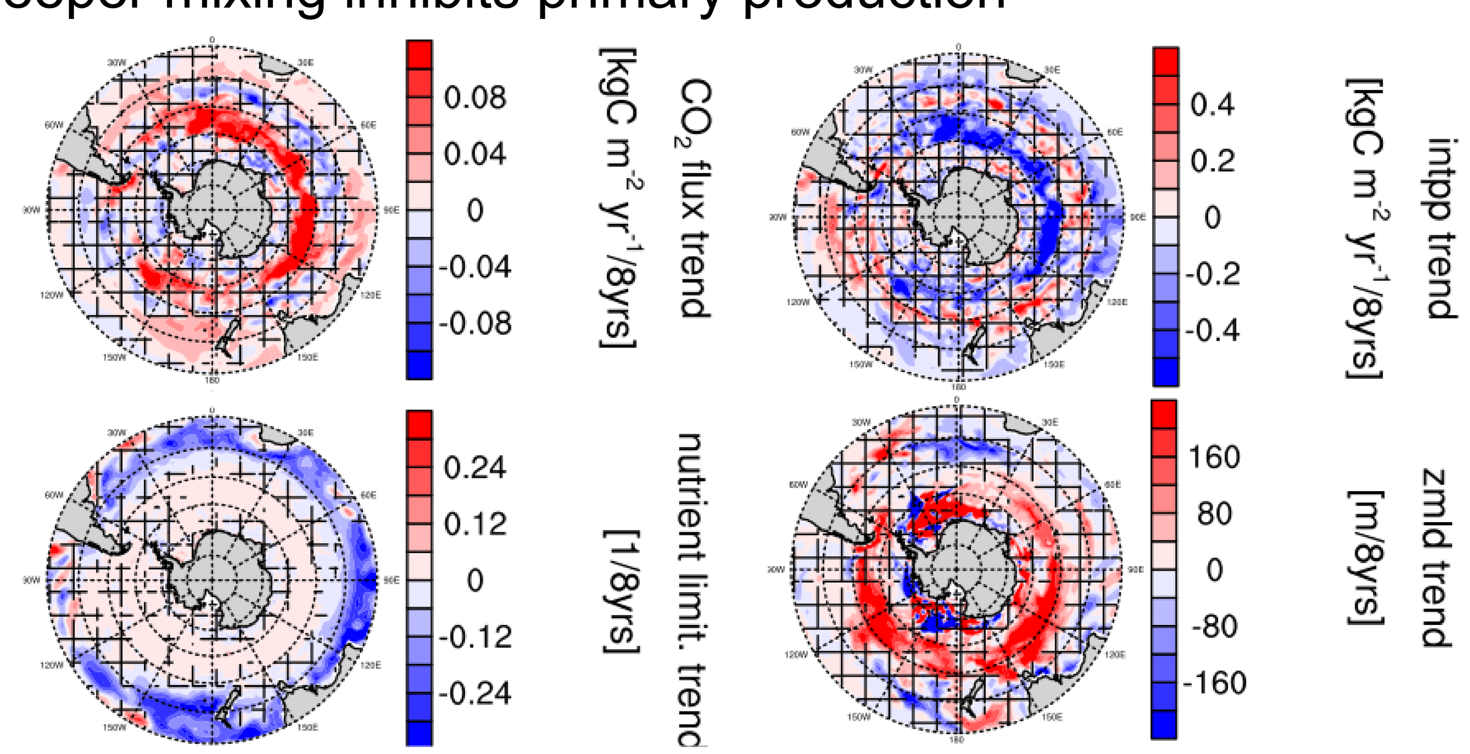

Figure 3: Trends in austral summer in Southern Ocean: (a) CO_2flux , (b) vertically integrated primary production, (c) nutrient limitation and (d) mixed-layer depth

Trends in circulation

- Intensified upper-ocean overturning circulation
- Increased upwelling of carbon-rich deep waters
- Increased Ekman northward transport
- Increased Ekman subduction
- Similar upper-ocean overturning circulation trends as in [DeVries et al. 2017]

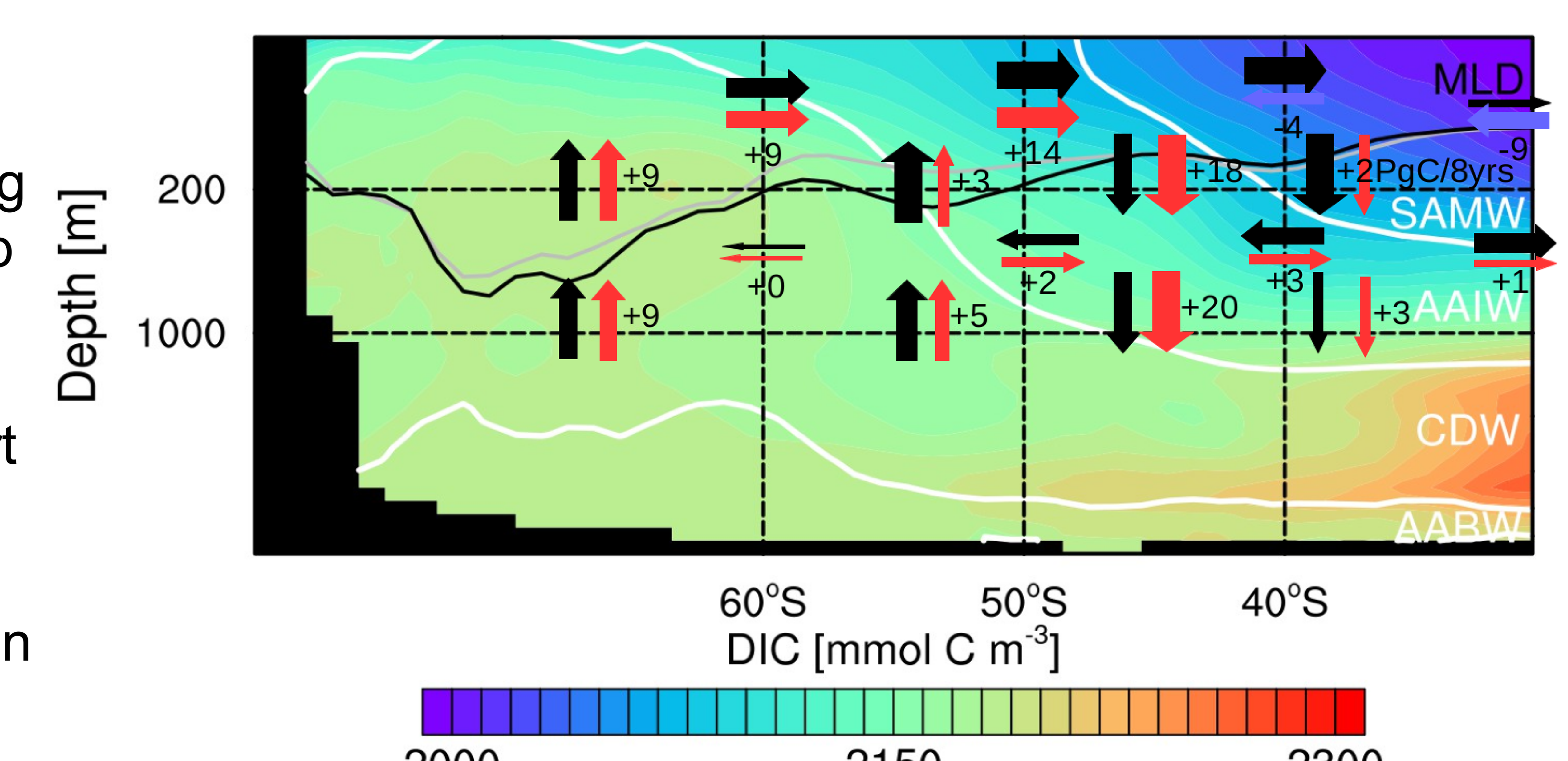

Figure 4: Trends in upper-ocean overturning circulation in the zonal Southern Ocean show how increasing westerly winds intensify the overturning. Black arrows indicate mean advection of carbon, red arrows show intensification in carbon advection, blue arrows show decline, white lines are isopycnals separating Southern Ocean water masses

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