Emergent constraints on the Southern Ocean anthropogenic carbon uptake

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4C Climate-Carbon Interactions in the Current Century

FNSNF Swiss National Science Foundation

SCIENCE ADVANCES | RESEARCH ARTICLE

OCEANOGRAPHY

Southern Ocean anthropogenic carbon sink constrained by sea surface salinity

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The ocean attenuates global warming by taking up 20 to 30% of anthropogenic carbon emissions. Around 40% of this ocean anthropogenic carbon sink is located in the Southern Ocean. However, Earth system models struggle to reproduce the Southern Ocean circulation and therefore its anthropogenic carbon uptake. Here, we identify a tight relationship across two multimodel ensembles between present-day sea surface salinity in the subtropical-polar frontal zone and the past and future anthropogenic carbon uptake in the Southern Ocean. Observations and model results constrain the cumulative Southern Ocean anthropogenic carbon uptake over 1850–2100 by phase 6 of the Coupled Model Intercomparison Project (CMIP6) model ensemble to 158 ± 6 petagrams of carbon under the low emissions scenario Shared Socioeconomic Pathway 1-2.6 (SSP1-2.6) and to 279 ± 14 petagrams of carbon under the high emissions scenario SSP5-8.5. The constrained Southern Ocean anthropogenic carbon sink is 14 to 18% larger and 46 to 54% less uncertain than the unconstrained CMIP6 estimates. This constraint demonstrates the importance of the freshwater cycle for the Southern Ocean circulation and carbon cycle.

Image by Oscar Schofield

The importance of the Southern Ocean for C_{ant} uptake

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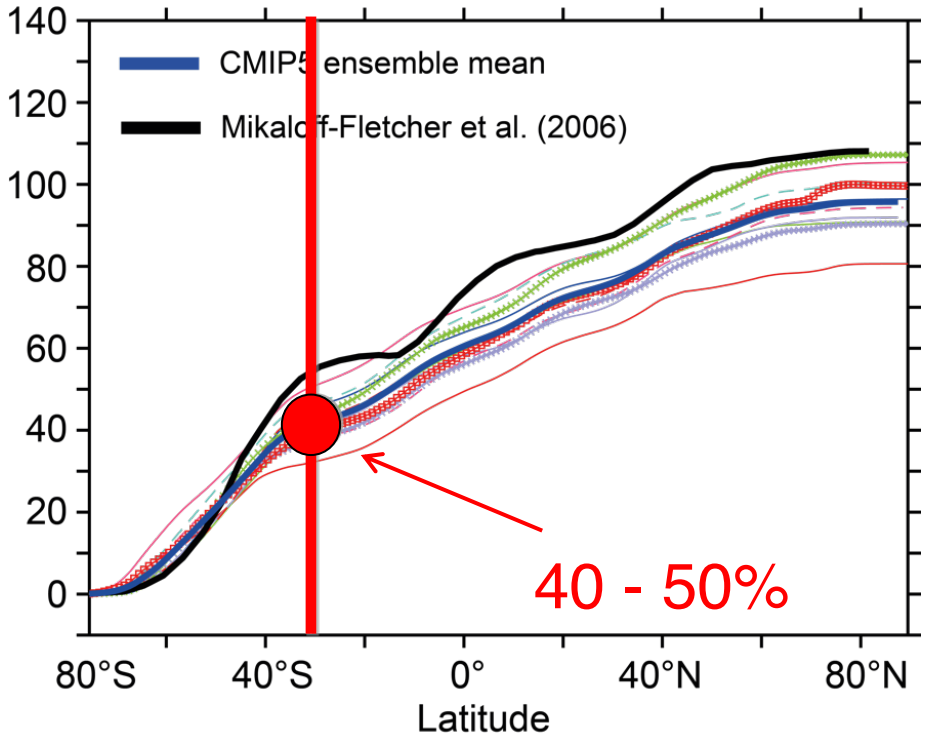
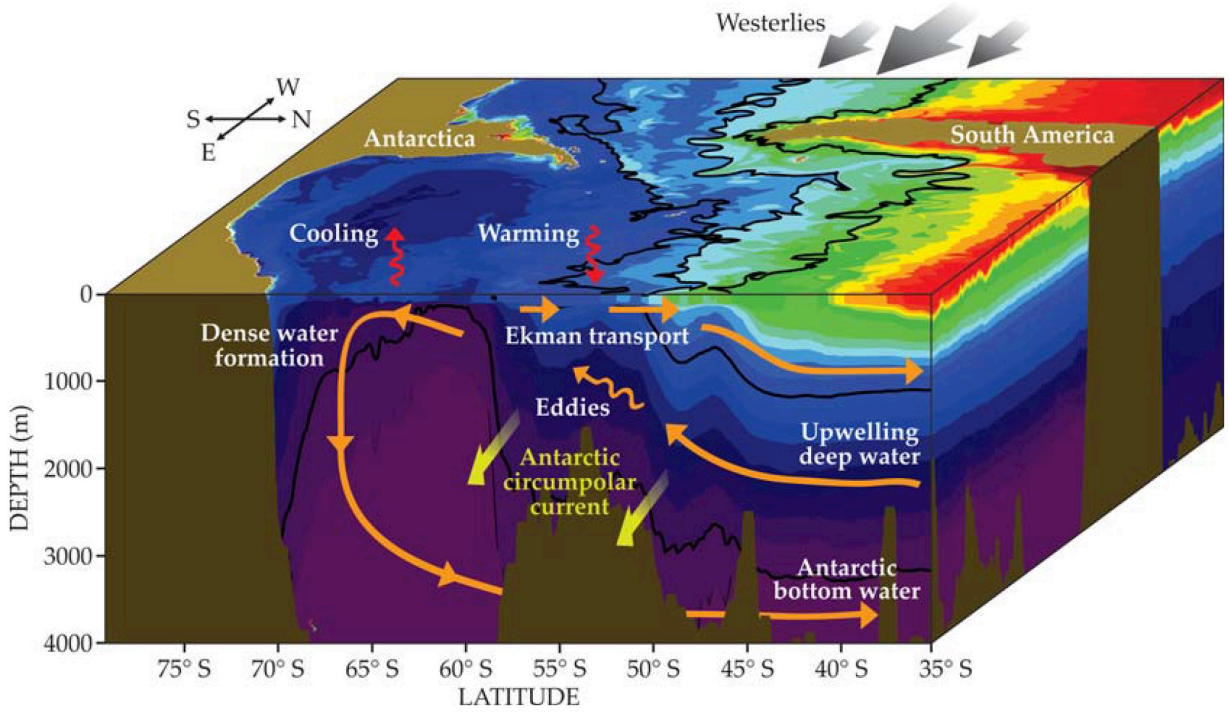
Cumulative C_{ant} uptake (Pg C): 1850 - 2005





Frölicher et al. (2015, Journal of Climate)

Morrison, Frölicher, Sarmiento (2015, Physics Today)

Future Southern Ocean C_{ant} sink is highly uncertain

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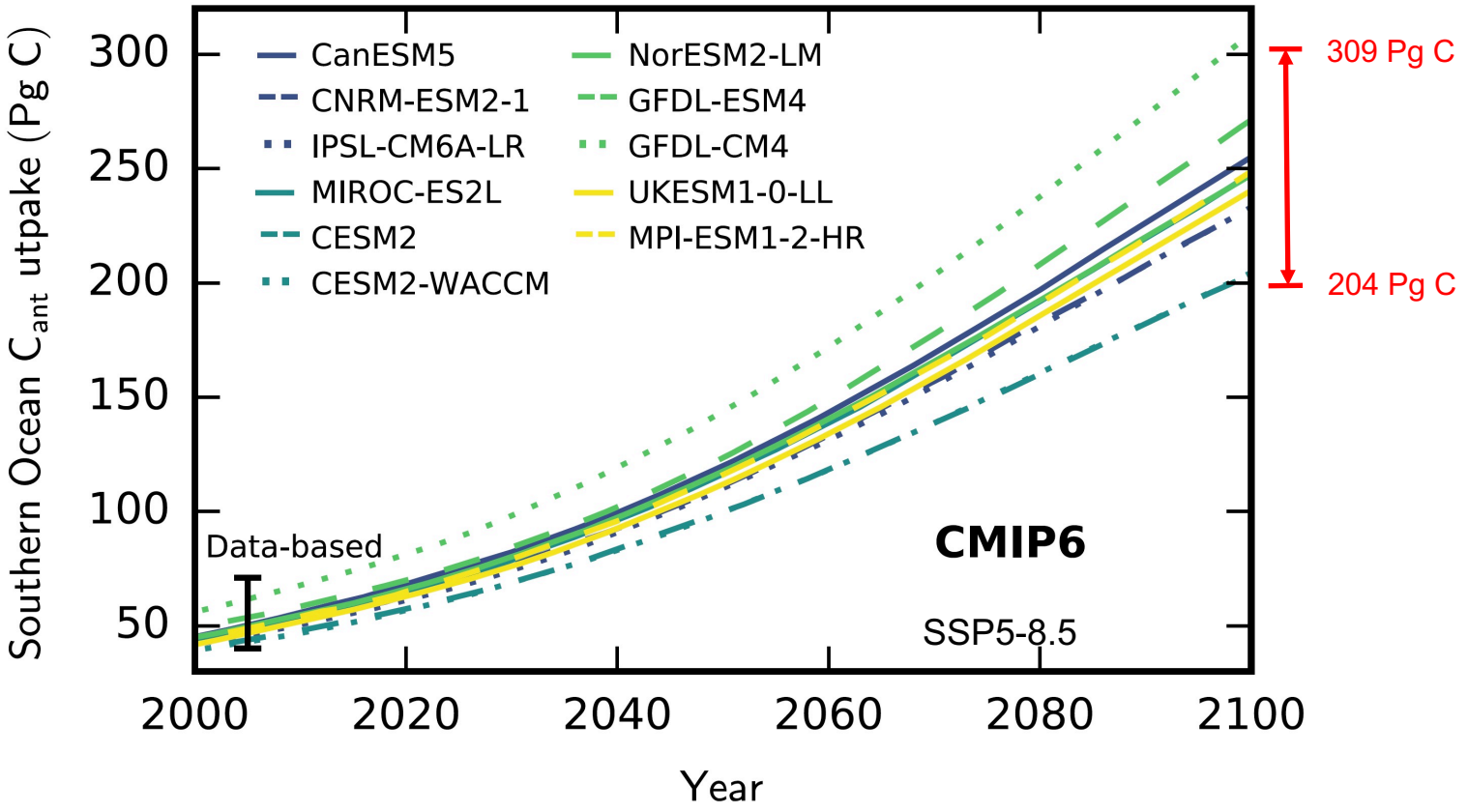

Uncertainties in CMIP6 ESMs remain large despite model development and increased horizontal and vertical ocean model resolution

→ Emergent constraints offer an opportunity to reduce these uncertainties

Terhaar, Frölicher, Joos (Science Advances, in press)

Higher present-day sea surface salinity → more future C_{ant} uptake

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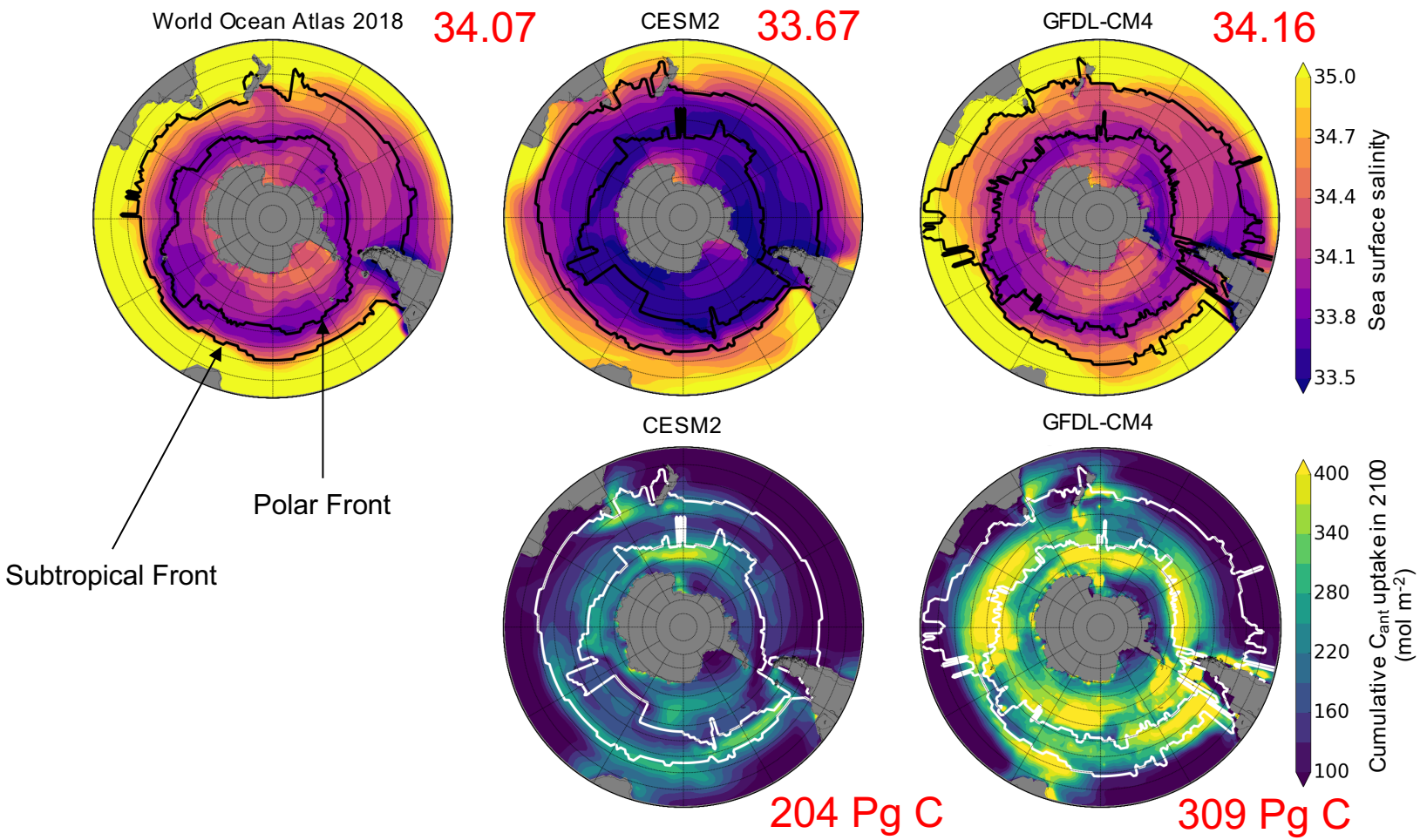

- CMIP6 ESMs that simulate low salinity between Polar Front und Subtropical Front simulate small C_{ant} uptake
- CMIP6 ESMs with high salinity simulate large C_{ant} uptake

Terhaar, Frölicher, Joos (Science Advances, in press)

Sea surface salinity is a physically supported indicator of the formation rate of SAMW and AAIW

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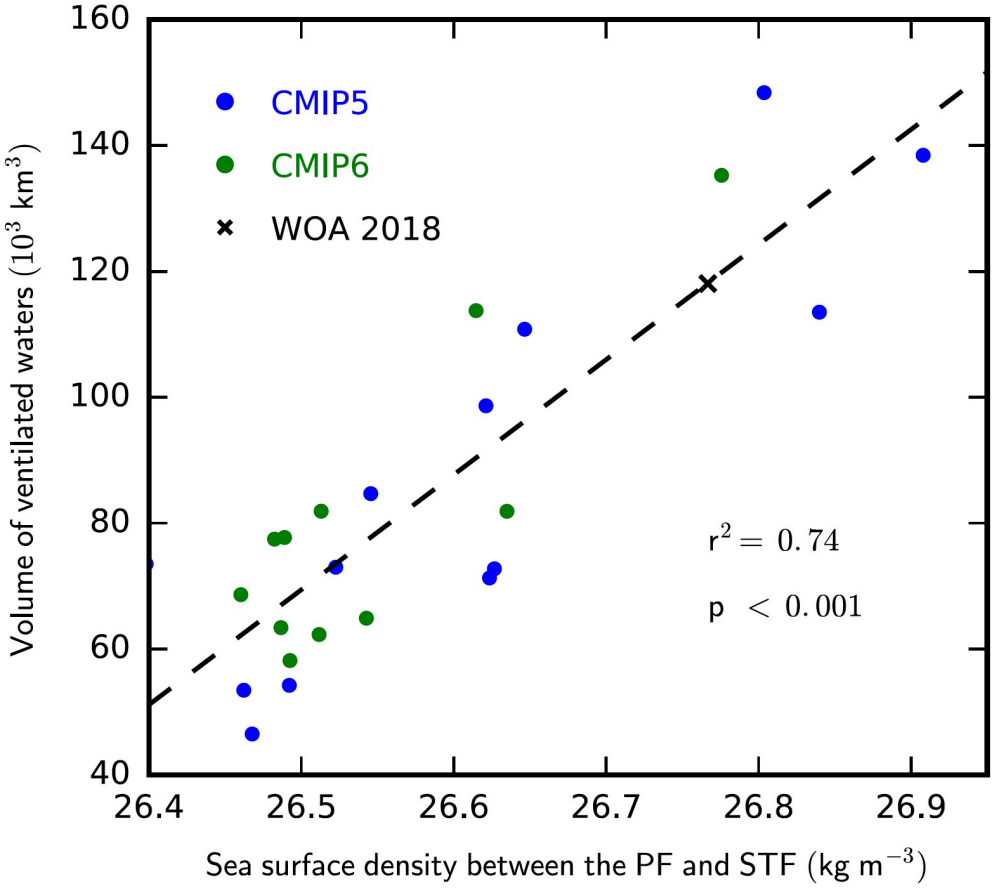

- Heavier surface waters (high salt = high density) penetrate deeper and occupy larger volume below the surface than lighter waters
- Volume of SAMW and AAIW increases with increasing sea surface density

Terhaar, Frölicher, Joos (Science Advances, in press)

Emergent constraint on the cumulative Southern Ocean C_{ant} uptake in CMIP6

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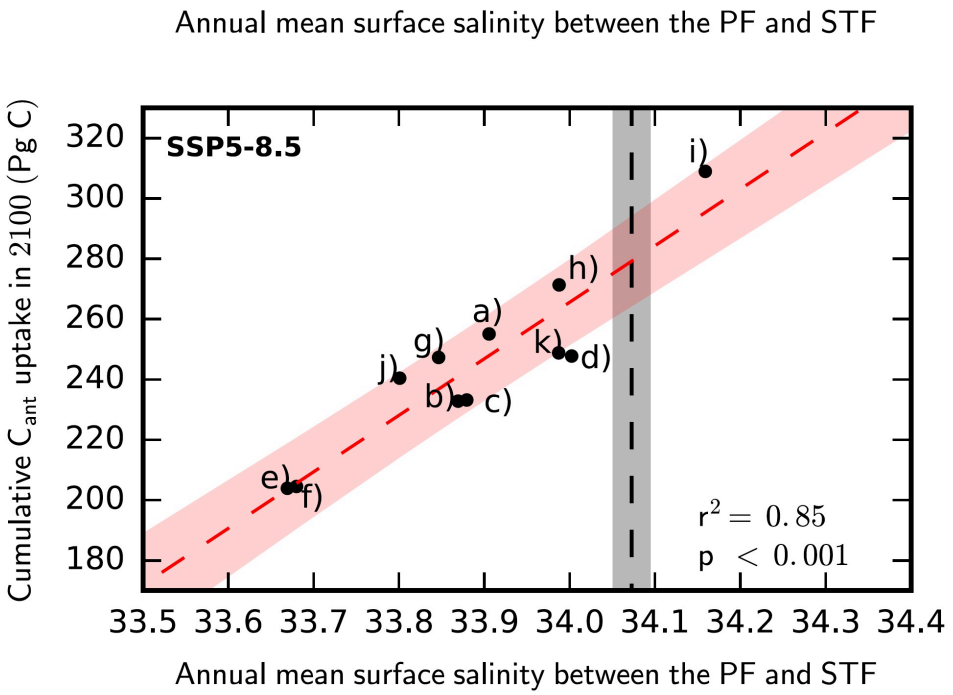

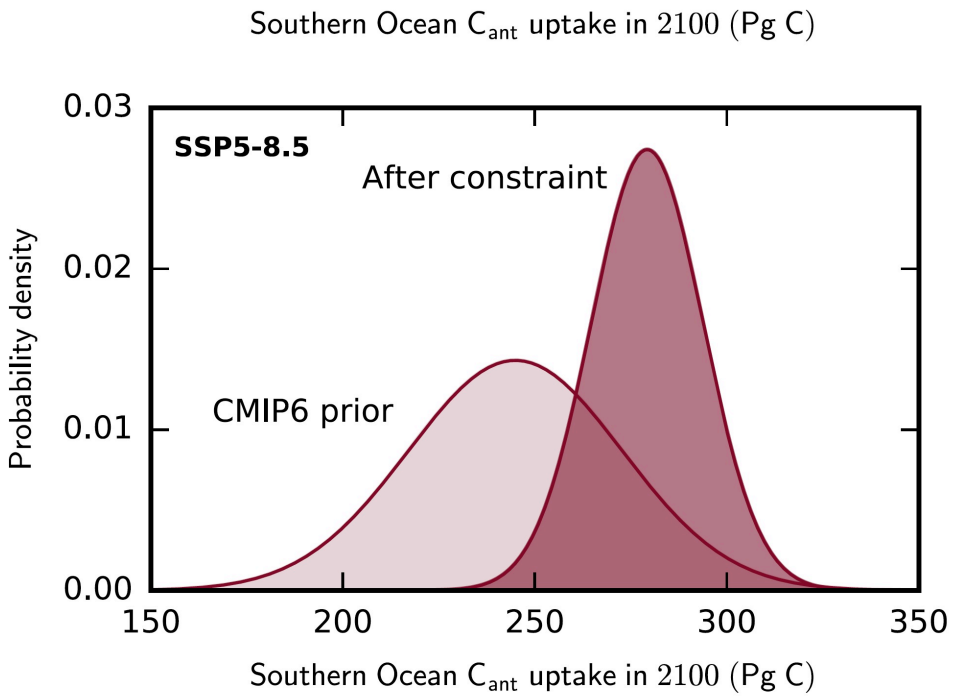

- The constrained Southern Ocean C_{ant} sink is 46-54% less uncertain than unconstrained estimate
- Low model bias in salinity causes underestimation of Southern Ocean C_{ant} sink by 14-18%
- Emergent constraint also holds across CMIP5 models and under different future emissions scenarios

Terhaar, Frölicher, Joos (Science Advances, in press)

Conclusions and further analysis

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- Correct representation of the freshwater cycle in the Southern Ocean is crucial for simulating the circulation and the associated ocean C_{ant} uptake.
- There is a tight relationship across two multi-model ensembles between present-day sea surface salinity in the subtropical-polar frontal zone and the past and future C_{ant} uptake in the Southern Ocean.
- The constrained Southern Ocean C_{ant} uptake is 14 to 18% larger and 46 to 54% less uncertain than the unconstrained CMIP6 estimates.
- The effects of mesoscale eddies and changes in freshwater input from Antarctic ice melt need to be quantified in subsequent studies when such (high-resolution) models become available.