The changing Southern Ocean carbon sink in an ocean full of eddies

CO_2 uptake and export in the subpolar oceans: simulations with a high-resolution ocean biogeochemistry model system

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In Short

- We investigate the physical drivers the ocean carbon uptake from the 1950s to today in the Southern Ocean.
- We developed a high-resolution global ocean biogeochemistry model using two-way nesting in the Southern Ocean.
- First results show decadal changes in the rate of Southern Ocean carbon uptake and an intriguing model resolution-dependence.
- The relative role of wind stress and buoyancy forcing changes will be assessed through dedicated sensitivity experiments.

Background and research aims: The world ocean plays a crucial role in mitigating climate change by taking up about a third of the anthropogenic carbon dioxide (CO_2) emissions. Owing to its cool temperatures and vigorous water mass formation, the Southern Ocean south of 30°S is a prime area for the uptake of carbon (figure 1) and accounts for about half of the ocean uptake of anthropogenic CO_2 [1]. The past decades saw the Southern Ocean rapidly evolving in terms of wind speed, ocean temperature, and salinity [2]. The way in which the Southern Ocean carbon sink responds to the ongoing and projected increases in winds and atmospheric temperatures will have a profound influence on the evolution of the Earth's climate. It is therefore problematic that the mechanisms causing changes in the Southern Ocean carbon sink are still far from being well understood.

Project shk00041 aims at assessing the physical drivers of the Southern Ocean CO_2 uptake over recent decades. A particular focus is on explicitly simulating ocean mesoscale eddies, which are thought to significantly affect the response of the Southern Ocean's carbon sink to climate change and which are typically not resolved by Earth System Models.

Modeling approach: During the first year of the shk00041 project, a hierarchy of global ocean biogeochemistry models at increasing horizontal resolution (from 1/2°, to 1/4°, to 1/10°) was developed. The ocean model is the ocean sea-ice model NEMO-LIM2 [3] and the ocean biogeochemistry model is MOPS [4] which was recently developed to include the inorganic carbon chemistry. The high-resolution ocean model (ORION10-MOPS) resolves ocean mesoscale dynamics by embedding a regionally refined ocean grid at 1/10° in the Southern Ocean (30°S- 68°S) within a global 1/2° ocean grid (figure 1). The models are forced by the JRA55-do [5] surface data set, which provides atmospheric forcing at 3-hourly and 0.5 horizontal resolution based on the Japanese 55-year Reanalysis and which extends from 1958 until today.

Status report for the period 29.07.2019-28.07.2020:

a) Hindcast experiments with the ocean-biogeochemistry model hierarchy

During the second project year, hindcast simulations with the ocean-biogeochemistry model hierarchy were carried out from 1958 to 2018. The simulations show a good match to observations in terms of mean and seasonality. When integrated over the whole Southern Ocean south of 30°S, all models show an increasing CO_2 uptake caused by rising atmospheric CO_2 concentrations. Superimposed to this long-term trend are decadal modulations in the Southern Ocean carbon sink, with a reduced rate of increase in the 1990s and a strengthened rate of increase afterwards. An intriguing feature is the effect of model resolution for the Southern Ocean carbon sink. When compared with the lower resolution models, the eddy-rich ORION10-MOPS shows a steeper trend of total ocean CO_2 uptake. Also, the eddy-rich model shows higher anthropogenic CO_2 inventories especially in mode waters formed in the Indian and Pacific basins. These preliminary results point to the relevant role played by ocean mesoscale eddies in modulating the carbon uptake and storage under changing climate conditions.

b) Southern Ocean ventilation changes driven by wind and buoyancy forcing

We performed a set of ORCA025 experiments including the ventilation tracer CFC-12 under the atmospheric forcing data sets CORE-II [6] and JRA55-do [5]. The effect of changing wind stress and buoyancy forcing for the Southern Ocean ventilation, which is a central process for the global ocean budgets of anthropogenic CO_2, was analyzed over the period 1948-2018. In addition to hindcast and clima-

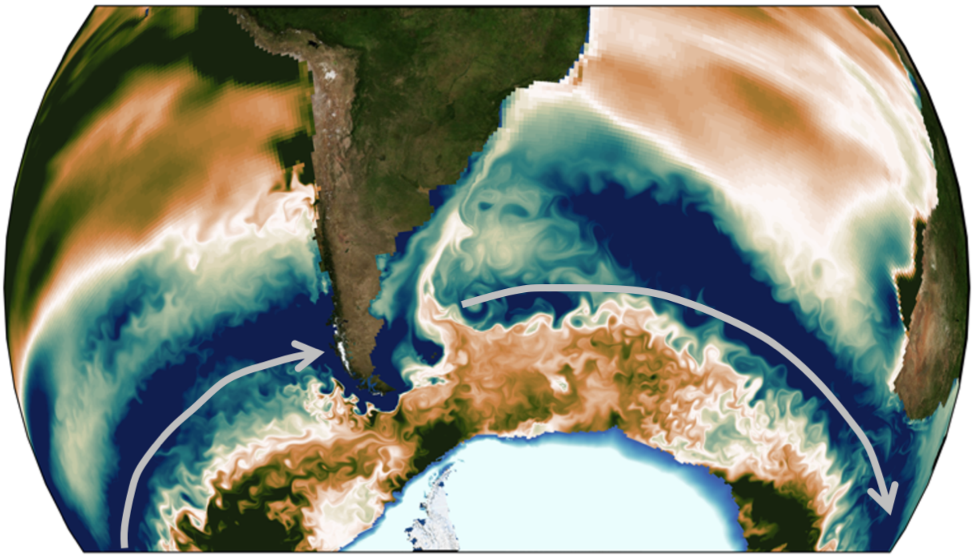

Figure 1: *Snapshot of natural air-sea CO_2 fluxes (reddish colors indicate outgassing) and sea ice from the ORION10-MOPS model (1/10° grid spacing in the Southern Ocean). Arrows show the approximate location of the westerly winds maxima.*

tological experiments, two sensitivity experiments were performed where the interannual variability of either the wind stress or of the buoyancy forcing was suppressed. The simulations uncovered a multi-decadal variation in Southern Ocean ventilation from the 1960s to today, with a decrease until the 1980s and subsequent increase driven by the counteracting effects of wind stress and air-sea buoyancy fluxes. This study suggests that Southern Ocean ventilation can be expected to increase as long as the effect of increasing Southern Hemisphere wind stress overwhelms that of increased stratification.

For the next project year additional simulations are envisaged in order to disentangle the physical drivers of the carbon sink changes, most notably the wind stress-driven changes from the buoyancy-driven changes. To this end, we plan a series of sensitivity simulations where the interannual variability of the wind stress and of the buoyancy forcing are in turn retained or suppressed. Thanks to these simulations it will be possible to more robustly relate the decadal changes in the Southern Ocean carbon sink to the overlying atmospheric forcing. The comparison of the results from the hierarchy of model resolutions will contribute to the development of modelling strategies for the prediction of the 21st century ocean carbon sink under rising CO_2 emissions.

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More Information

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