Physical drivers of the Southern Ocean carbon sink in the past 60 years: simulations with a high-resolution ocean model

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Motivation

The **Southern Ocean's carbon sink** underwent pronounced **decadal fluctuations** in recent decades, but the underlying mechanisms are still not fully understood [*Landschützer et al., 2015*]. The **aim of this study** is to assess the physical drivers of Southern Ocean CO_2 uptake in past decades using the newly-developed high-resolution ocean biogeochemistry model ORION10-MOPS (Fig. 1)

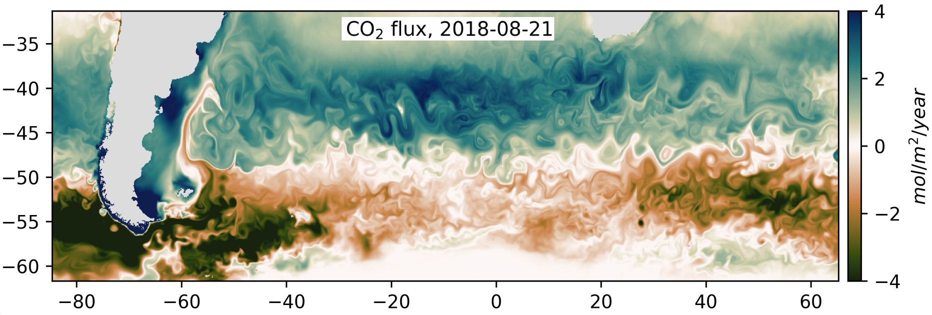
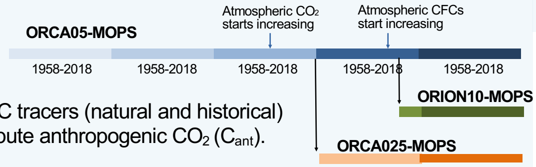


***Fig. 1**: Five day mean simulated CO_2 flux into the ocean in mol/m²/year on 21.08.2018 from ORION10-MOPS (spin-up).*

Modeling strategy

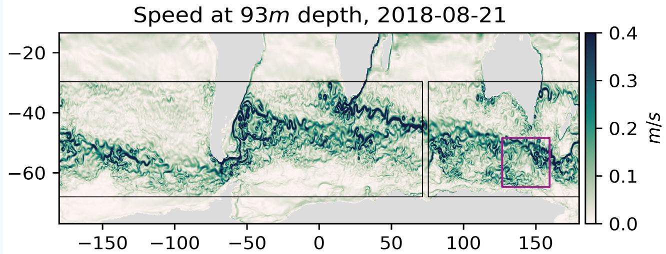
Ocean model NEMO-LIM2 including CFC-12 and the biogeochemical model MOPS [*Kriest and Oschlies, 2015*]

1) ORCA05, 2) ORCA025, 3) ORION10 (1/10° nest from 68°S to 30°S). All forced by JRA55-do forcing [*Tsujino et al., 2018*].



Two DIC tracers (natural and historical) to compute anthropogenic CO_2 (C_{ant}).

***Fig. 2**: Five day mean speed at 93m from ORION10-MOPS. The black lines indicate the boundaries of the 1/10° nest.*



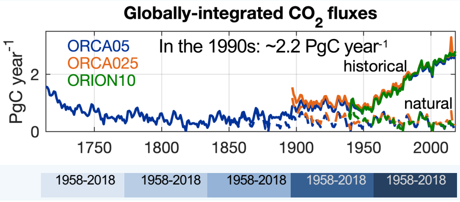
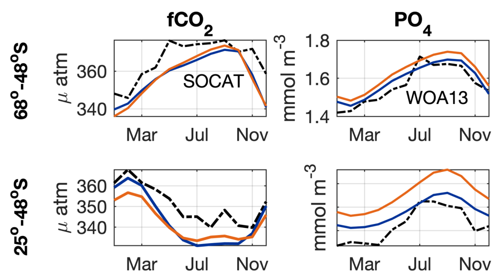


Fig. 3: Globally integrated air-sea CO_2 fluxes into the ocean from the model hierarchy

Model assessment

Fig. 4: Seasonal cycles (2000-2018 average) of surface fCO_2 and PO_4 in model and observations [Bakker et al., 2016; Boyer et al., 2013]. Blue line: ORCA05, orange line: ORCA025. Top: 48°S-68°S, Bottom: 25°S-48°S



Southern Ocean ventilation and carbon uptake in the past decades

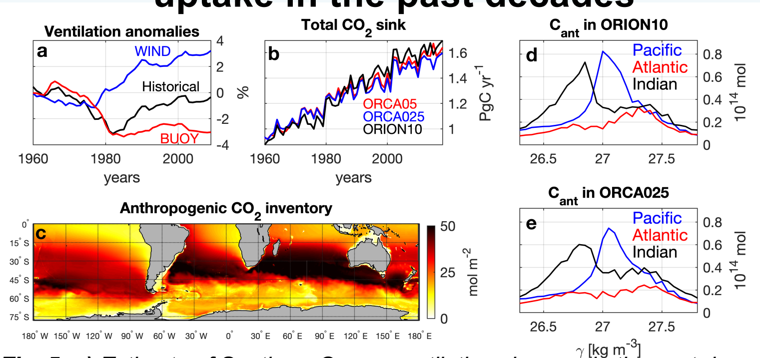


***Fig. 5: a)** Estimate of Southern Ocean ventilation changes in the past decades in a historical experiment (black line) and in the two sensitivity experiments WIND (blue line, where only wind stress is interannually varying) and BUOY (red line, where only air-sea buoyancy fluxes are interannually-varying) performed with ORCA025 [Patara et al., in review on Journal of Climate]; **b)** time series of annually-averaged CO_2 fluxes integrated south of 30°S in ORCA05, ORCA025 and ORION10, **c)** anthropogenic CO_2 (C_{ant}) inventory integrated over the water column in ORION10, **d-e)** C_{ant} integrated in different basins and vertically in 0.05 neutral density bins in **d)** ORION10 and **e)** ORCA025. Panels **c-e)** show temporal averages over 2000-2009.*

Summary and outlook

1. The model hierarchy captures the **observed mean, seasonality and temporal evolution** of the surface fCO_2 and air-sea CO_2 fluxes.
2. The models show a **multi-decadal cycle of Southern Ocean ventilation** (decrease until the 1980s, increase afterwards) driven by opposing effects of wind stress and buoyancy forcing → *what is the effect on anthropogenic CO_2 uptake?*
3. The model hierarchy shows a steady **increase in the Southern Ocean carbon sink over past decades, with a stalling in the 1990s** → *what are the physical drivers?*
4. With respect to lower-resolution models, in ORION10 the trend in total carbon uptake is steeper and the uptake of C_{ant} in mode waters is higher. → *How do **ocean mesoscale eddies influence the carbon uptake**?*

References
Bakker, D.C.E. et al. (2016), A multi-decade record of high-quality fCO(2) data in version 3 of the Surface Ocean CO2 Atlas (SOCAT), Earth System Science Data; **Boyer**, T.P. et al. (2013): World Ocean Database 2013, NOAA Atlas NESDIS 72, S. Levitus, Ed., A. Mishonov, Technical Ed.; Silver Spring, MD, 209 pp., http://doi.org/10.7289/V5NZ85MT; **Follows**, M.J., Ito, T., Dutkiewicz, S. (2006): On the solution of the carbonate chemistry system in ocean biogeochemistry models, Ocean Modelling, 12 (3-4), 290-301; **Kriest, I., and A. Oschlies** (2015), MOPS-1.0: towards a model for the regulation of the global oceanic nitrogen budget by marine biogeochemical processes, Geosci. Model Dev., 8, 2929-2957, doi:10.5194/gmd-8-2929-2015; **Landschützer**, P. et al. (2015), The reinvigoration of the Southern Ocean carbon sink, Science, 349, 1221, doi: 10.1126/science.aab2620; **Orr**, J. C. and Epitalon, J.-M.: Improved routines to model the ocean carbonate system: mocsy 2.0, *Geosci. Model Dev., 8*, 485-499, doi:10.5194/gmd-8-485-2015, 2015; **Tsujino**, H. et al. (2018) JRA-55 based surface dataset for driving ocean-sea-ice models (JRA55-do). Ocean Modelling, 130, 79-139, doi:10.1016/j.ocemod.2018.07.002;

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