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The impact of recent climate change on the global ocean carbon sink

Background

In recent decades, the rise in atmospheric CO_2 has caused growing oceanic CO_2 uptake. Yet, global warming, winds and other climate change also affect the ocean carbon uptake.

Research questions

- How large are the effects of atmospheric CO_2 and recent climate change on the air-sea CO_2 flux?
- How do changes in winds, temperature and other factors explain the climate effect on the ocean carbon uptake globally and regionally?

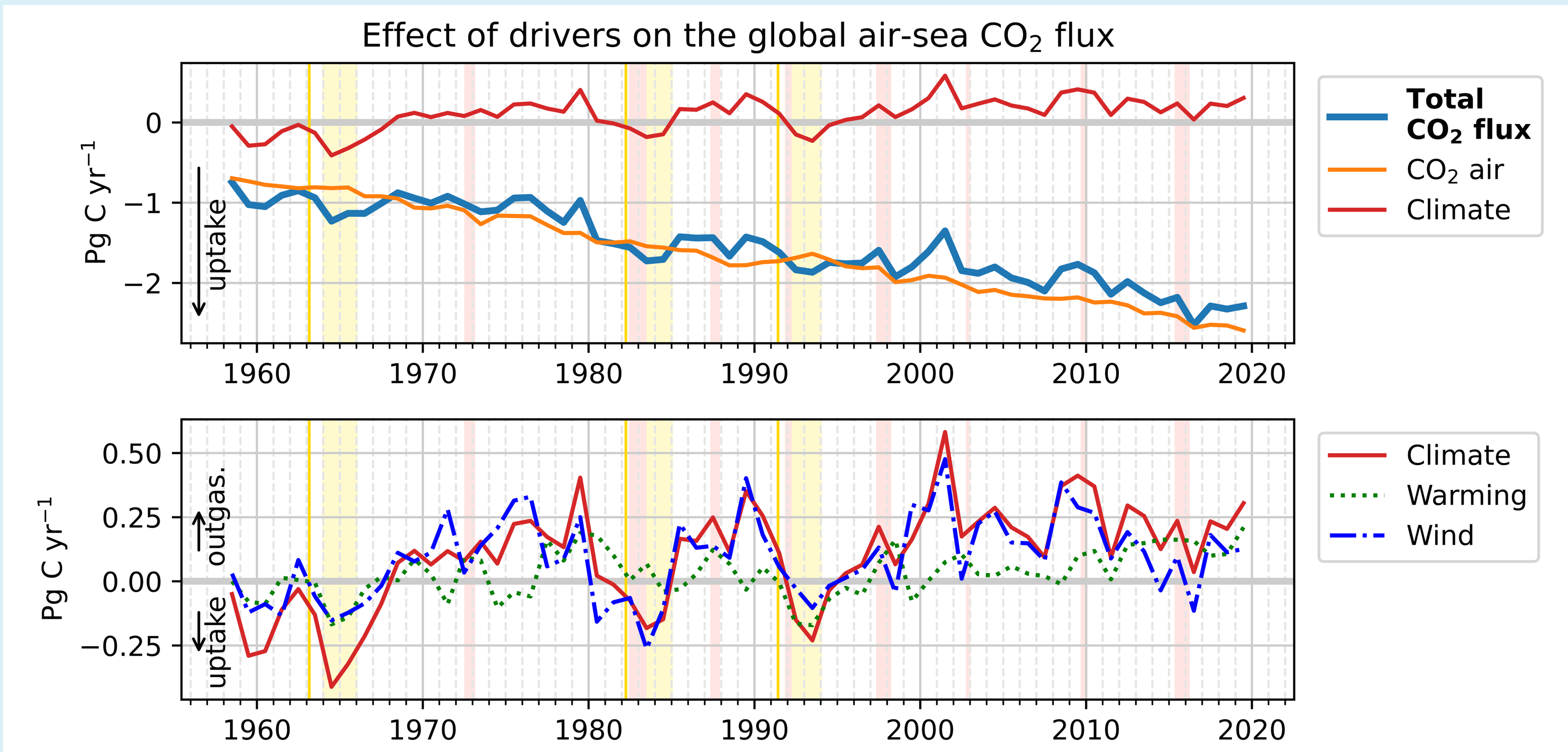
Take-away messages

- Climate change reduced the time-mean ocean carbon uptake 2000-2019 by 13%.
- The most important driver (9%) were changes in the transport of DIC by the wind-driven ocean circulation.
- The effect of global surface warming (5%) depends on the strength of DIC transport between the deep and surface ocean.

Model and methods

We use the global ocean biogeochemistry model FESOM1.4-REcoM *(1,2)* to quantify the effects of atmospheric CO_2 and climate change on the air-sea CO_2 flux 1958-2019. Based on six simulations, we disentangle the effects of winds, global warming, other climate and atmospheric CO_2 online.
We also estimate the direct effects of the following variables offline based on a linear approximation following *(3)*: wind velocity, sea surface temperature, sea-ice concentration, salinity-normalized alkalinity (sAlk), salinity and freshwater fluxes (S+FW) and salinity-normalized DIC (sDIC).

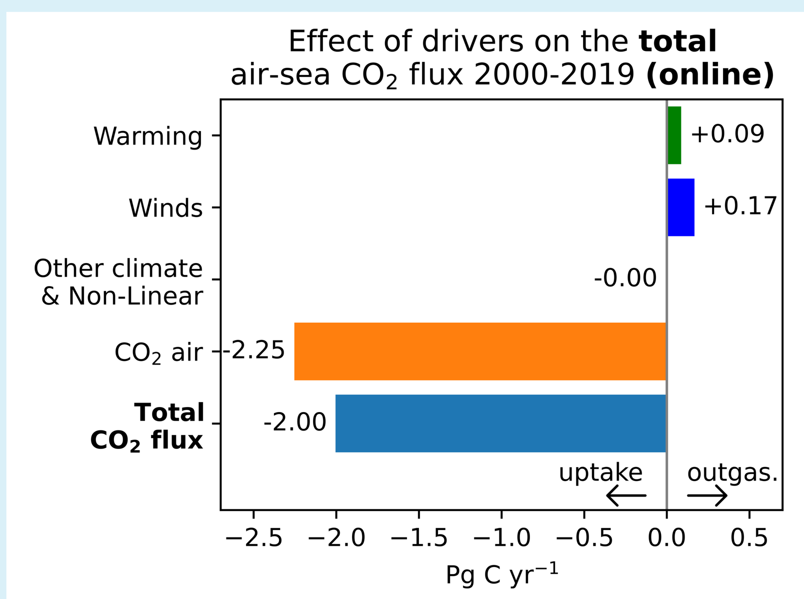
Global air-sea CO_2 flux

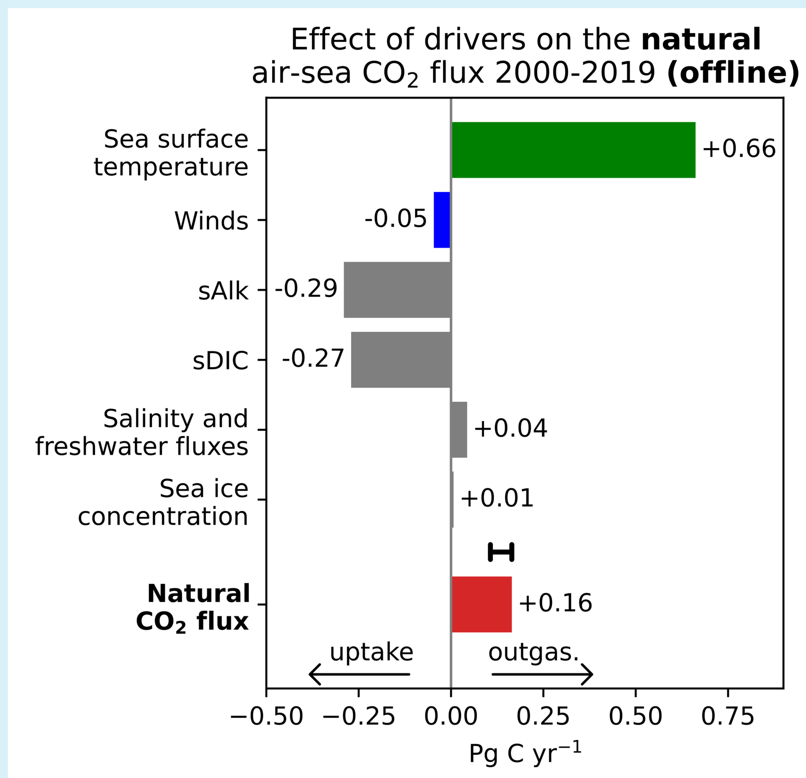


In recent decades, the increase in atmospheric CO_2 has dominated the global ocean carbon uptake. However, meteorological effects, in particular winds, control interannual variability and reduced the trend 1958-2019 by 27%.

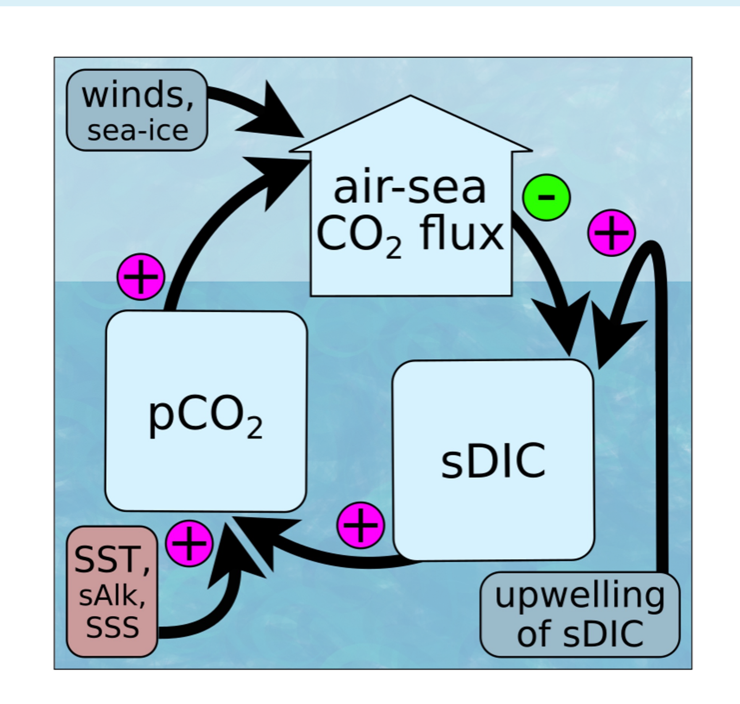
Online and offline estimate of climate effects

Changes in winds reduced the global ocean carbon uptake 2000-2019 by 0.17 Pg C yr^{-1} according to the online approach. The linear estimate fails to capture the wind-driven redistribution of sDIC and sAlk by the ocean circulation. Furthermore, the linear approximation overestimates the effect of warming due to neglected feedbacks (see 'Effect of warming').





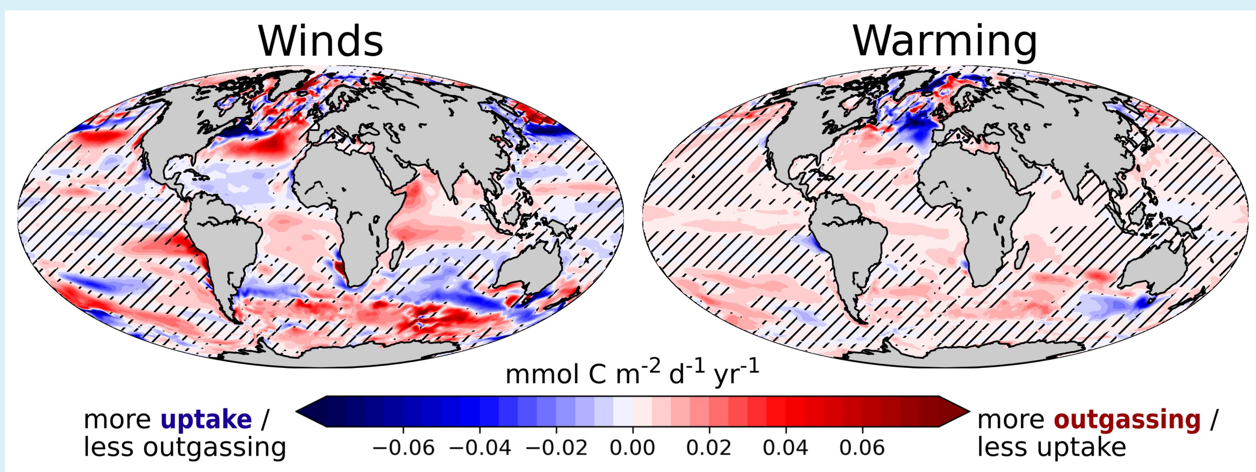
Effect of warming on natural carbon



A negative feedback between the air-sea flux and surface sDIC concentration diminishes warming-driven outgassing of natural carbon. However, where natural carbon is supplied from depth, warming efficiently leads to outgassing.

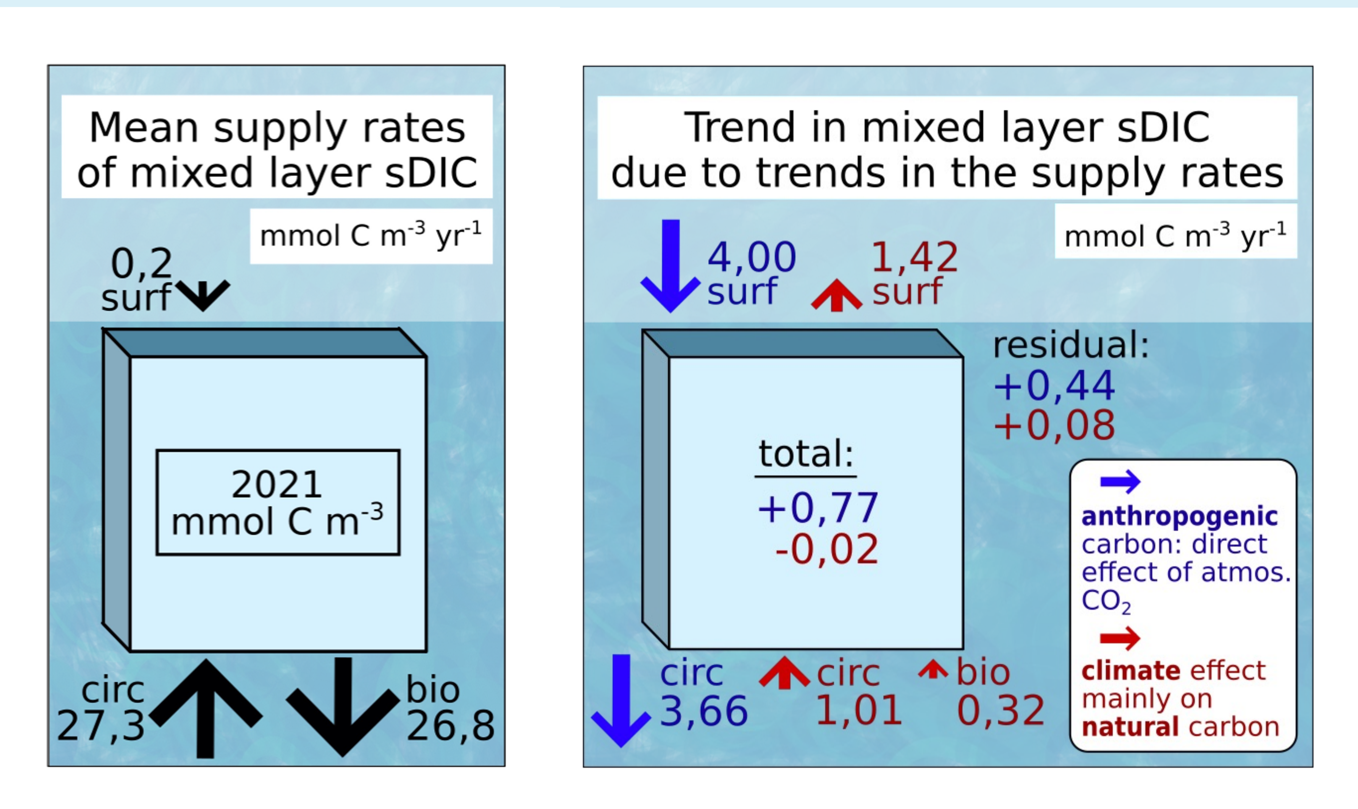
Regional impact

on the air-sea CO_2 flux trend 1958-2019



Changes in the mixed layer sDIC budget

In the multidecadal mean, downward biological flux of carbon and primarily upward sDIC transport by the circulation are almost in balance. However, even small changes affect the mixed layer sDIC concentration and are thus strongly linked to the air-sea CO_2 flux.



While the amount of anthropogenic carbon that is transported downward with the circulation is increasing, changes in the transport of natural carbon are in the opposite direction. The reason are wind-driven changes, such as an increase in upwelling of DIC in the Southern Ocean *(4)*. Furthermore, the amount of natural carbon being transported downward by the circulation decreases because of warming-driven depletion of natural carbon at the surface.

1 **Wang et al. (2014).** The Finite Element Sea Ice-Ocean Model (FESOM) v.1.4: Formulation of an Ocean General Circulation Model. *Geoscientific Model Development, 7(2),* 663–693. doi: 10.5194/gmd-7-663-2014 2 **Schourup-Kristensen et al. (2014).** A Skill Assessment of the Biogeochemical Model REcoM2 coupled to the Finite Element Sea Ice Ocean Model (FESOM 1.3). *Geoscientific Model Development, 7(6),* 2769–2802. doi: 10.5194/gmd-7-2769-2014 3 **Lovenduski et al. (2007).** Enhanced CO_2 Outgassing in the Southern Ocean from a Positive Phase of the Southern Annular Mode. *Global Biogeochemical Cycles, 21(2).* doi: 10.1029/2006GB002900 4 **Panassa (2018).** Role of Mixed Layer Depth and Subduction Processes for the Southern Ocean Carbon and Nutrient Cycles (PhD Thesis). *University of Bremen.* https://media.suub.uni-bremen.de/handle/elib/1427.

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