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Modeling the physical drivers of the decadal variability of the Southern Ocean carbon uptake

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Observational estimates point to pronounced changes of the Southern Ocean carbon uptake in the past decades, but the mechanisms are still not fully understood. In this study we assess physical drivers of the Southern Ocean carbon uptake variability in a suite of global ocean biogeochemistry models with 0.5°, 0.25° and 0.1° horizontal resolution as well as in a 3-member ensemble performed with an Earth System Model (ESM) sharing the same ocean biogeochemistry model. The ocean models show a positive trend of the Southern Ocean CO_2 uptake in the past decades, with a weakening of its rate of increase in the 1990s. The 0.1° model exhibits the strongest trend in the Southern Ocean carbon uptake. Different physical drivers of the carbon uptake variability and of its trends (such as changes in stratification, ventilation, overturning circulation, and SST) are analyzed. A particular focus of this study is to assess the role of open-ocean polynyas in driving Southern Ocean carbon uptake. Open-ocean polynyas in the Southern Ocean have pronounced climate fingerprints, such as reduced sea-ice coverage, heat loss by the ocean and enhanced bottom water formation, but their role for the Southern Ocean carbon uptake has been as yet little studied. To this end we analyze conjunctly ESM simulations and an ocean-only sensitivity experiment where open-ocean polynyas are artificially created by perturbing the Antarctic freshwater runoff. We find that enhanced CO_2 outgassing takes place during the polynya opening, because old carbon-rich waters come in contact with the atmosphere. The concomitant increased uptake of anthropogenic CO_2 partially compensates the CO_2 outgassing. When the polynya closes, the ocean CO_2 uptake increases significantly, possibly fueled by abundant nutrients and higher alkalinity brought to the surface during the previous convective phase. Our results suggest that open-ocean polynyas could have a significant impact on the Southern Ocean CO_2 uptake and could thus modulate its decadal variability.