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Natural processes behind the CO_2 sink variability in the Southern Ocean during the last three decades

Elif Yilmaz[1], Raffaele Bernardello[2], and Adrian P. Martin[3]
[1]Barcelona Supercomputing Center, Barcelona, Spain (elif.yilmaz@bsc.es)
[2]Barcelona Supercomputing Center, Barcelona, Spain (raffaele.bernardello@bsc.es)
[3]National Oceanography Centre, Southampton, United Kingdom (adrian.martin@noc.ac.uk)

Anthropogenic activities during the past two centuries have caused an increase in atmospheric CO_2 which has driven a linear increase in oceanic CO_2 uptake. The Southern Ocean (SO, < 35□S) is one of the major uptake areas for anthropogenic CO_2, responsible for ~40% of ocean CO_2 sink. Apart from the linear increase in the CO_2 sinking trend, in the SO pronounced variations have been observed in recent decades, driven by natural processes, but the exact mechanisms behind them are still debated. Aiming to fill this knowledge gap, we investigated the natural drivers of CO_2 flux variations in the SO using existing observation-based datasets between the years 1982-2019. We removed the long-term linear trend in the time series of CO_2 flux and other indexes to focus on decadal variations. We found that two mechanisms explain the interannual to decadal variations in the SO: Ekman upwelling and eddy kinetic energy, by their controls on different components of surface pCO_2 variations. The pattern of variability in Ekman upwelling during the time period studied was markedly circumpolar, and the time series of its 1st principal component was strongly correlated with the detrended SAM Index ($r=0.81$, $p<0.05$). Similarly, leading EOF maps of CO_2 flux anomalies and the components of surface pCO_2 changes (i.e., nonthermal and thermal) show that their variations were dominantly symmetric. As previously shown, weakening of SO CO_2 sink in the 1990s coincides with intense positive SAM episodes. Following the late 1990s, the intensity of SAM decreased, which strengthened the CO_2 sink in the early 2000s. At the same time, the relative contribution of the thermal component grew south of the Polar Front, indicating positive temperature anomalies during this period. Such warming events, following intense and recursive SAM episodes were reported before and were attributed to the increased mesoscale eddy activity in the region. In agreement with these studies, our results show that eddy kinetic energy increased after intense SAM periods with a lagged response of ~2 years, and a positive temperature anomaly in low frequency was observed following these peaks. This warming prevented the CO_2 uptake rate from reaching immediately to its potential strength in the absence of strong westerlies, and explains the growing effect of the thermal pCO_2 component.