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The role of internal variability for decadal carbon uptake anomalies in the Southern Ocean

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The Southern Ocean is a major sink for anthropogenic CO_2 emissions and hence it plays an essential role in modulating global carbon cycle and climate change. Previous studies based on observations (e.g., Landschützer et al. 2015) show pronounced decadal variations of carbon uptake in the Southern Ocean in recent decades and this variability is largely driven by internal climate variability. However, due to limited ensemble size of simulations, the variability of this important ocean sink is still poorly assessed by the state-of-the-art earth system models (ESMs).
To assess the internal variability of carbon sink in the Southern Ocean, we use a large ensemble of 100 member simulations based on the Max Planck Institute-ESM (MPI-ESM). The large ensemble of simulations is generated via perturbed initial conditions in the ocean and atmosphere. Each ensemble member includes a historical simulation from 1850 to 2005 with an extension until 2100 under Representative Concentration Pathway (RCP) 4.5 future projections. Here we use model simulations from 1980-2015 to compare with available observation-based dataset.
We found several ensemble members showing decadal decreasing trends in the carbon sink, which are similar to the trend shown in observations. This result suggests that MPI-ESM large ensemble simulations are able to reproduce decadal variation of carbon sink in the Southern Ocean. Moreover, the decreasing trends of Southern Ocean carbon sink in MPI-ESM are mainly contributed by region between 50-60°S. To understand the internal variability of the air-sea carbon fluxes in the Southern Ocean, we further investigate the variability of underlying processes, such as physical climate variability and ocean biological processes. Our results indicate two main drivers for the decadal decreasing trend of carbon sink: i) Intensified winds enhance upwelling of old carbon-rich waters, this leads to increase of the ocean surface pCO_2; ii) Primary production is reduced in area from 50-60°S, probably induced by reduced euphotic water column stability; therefore the biological drawdown of ocean surface pCO_2 is weakened accordingly and hence the ocean is in favor of carbon outgassing.

Landschützer, et al. (2015): The reinvigoration of the Southern Ocean carbon sink, Science, 349, 1221-1224.