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Internal variability of the air-sea CO_2 flux in the MPI-ESM large ensemble simulations

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Observations-based studies indicate pronounced decadal variations of the ocean carbon sink. These variations are driven by the internal variability of the earth system superimposed on the linear trend of the ocean carbon sink in response to the increase of anthropogenic carbon emissions. Previous modeling studies based on large ensemble simulations showed a prominent role of internal variability of the climate system. They also show that it is challenging for earth system models (ESMs) to capture multi-year trends in the ocean carbon sink and so the temporal and spatial evolution of the internal variability is still poorly understood. Moreover, it is unknown what ensemble size is required to capture the internal variability of the ocean carbon sink.

We investigate the internal variability of the carbon flux into the ocean in the context of the observed variations on decadal time-scale using large ensemble simulations based on the Max Planck Institute's ESM (MPI-ESM). The ensemble spans the period of 1850-2100 including 100 historical simulations extended by the RCP2.6 and RCP4.5 scenarios and 68 members of the idealized scenario of 1% per year increase of atmospheric CO_2 to quadrupling. The ensemble is generated by starting the simulations from different years of the pre-industrial control simulation. In this way, we can determine the forced variability as the ensemble mean signal and the internal variability is the difference between single ensemble simulation and the ensemble mean.

Our results reveal that the internal variability of the air-sea CO_2 flux is as large as the forced trend on decadal time-scales, and the largest variability is found in the 50-65°S band of the Southern Ocean. The ensemble produces both positive and negative 10-year trends of the carbon flux into the ocean as suggested by observations. It implicates the strong role of internal variability of the natural system and the potential of the MPI-ESM's large ensemble to capture some modes of this variability.

We calculate how many ensemble members are needed to disentangle the forced signal from the internal variability. We use the 100-member ensemble mean as a reference and calculate the spatial correlation of the ensemble mean trends for a different number of ensemble members with the reference field. Our results suggest that more than 40 members are required to reproduce the forced decadal trend pattern in MPI-ESM. This number varies in different ocean regions. Furthermore, the internal variability of the oceanic carbon uptake is not steady. It increases with increasing background atmospheric CO_2 concentration.