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Carbon feedbacks in the high-resolution transient Holocene simulations using the MPI Earth system model

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One of the interesting periods to investigate interactions between climate and carbon cycle is the Holocene, when, despite of the relatively steady global climate, the atmospheric CO_2 concentration grew by about 20 ppm from 7 kyr BP to pre-industrial. We use a new setup of the Max Planck Institute Earth System Model MPI-ESM1 consisting of the latest version of the atmospheric model ECHAM6, including the land surface model JSBACH3 with carbon cycle and vegetation dynamics, coupled to the ocean circulation model MPI-OM, which includes the HAMOCC model of ocean biogeochemistry. The model has been run over the Holocene period of the last 8000 years under the forcing data sets of orbital insolation, atmospheric greenhouse gases, volcanic aerosols, solar irradiance and stratospheric ozone, as well as land-use changes. In response to this forcing, the land carbon storage increased by about 60 PgC between 8 and 4 kyr BP, stayed relatively constant until 2 kyr BP, and decreased by 90 PgC by 1850 AD due to land use changes. The ocean carbon storage increased in this simulation by 150 PgC, leading to a deficit of ca. 190 PgC in the coupled land-ocean-atmosphere system. If the atmospheric CO_2 concentration were interactive in this experiment, the atmospheric CO_2 increase during the Holocene would be much smaller than in the ice-core reconstructions. Therefore, we also performed a simulation with the interactive atmospheric CO_2 in a "nudged" setup. In this case, we reduced the ocean surface alkalinity when the simulated CO_2 concentration dropped below the target (ice-core CO_2). This simulation resulted in the atmospheric CO_2 concentration closed to reconstructed and the ocean being a source of about 40 PgC by the end of the simulation. A plausibility of this approach to make ESM's ocean outgas CO_2 under rising atmospheric CO_2 concentration will be discussed.
We also investigated dynamics of carbon reservoirs during periods of strong volcanic eruptions. In response to the eruption-caused cooling, the land initially stores more carbon as respiration decreases, but then it releases even more carbon due to productivity decline. This decadal-scale variability helps to quantify the land and ocean carbon feedbacks during the past periods when the temporal resolution of the ice-core CO_2 record is not sufficient to capture fast CO_2 variations. From a set of Holocene simulations with prescribed or interactive atmospheric CO_2, we get estimates of climate-carbon feedback useful for future climate studies.

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