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Carbon cycle feedbacks in an idealized and a scenario simulation of carbon dioxide removal in CMIP6 Earth system models

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Limiting global warming to 1.5°C by the end of the century currently seems to be an ambitious target which will potentially be accompanied by a period of temperature overshoot. Achieving this climate goal might require massive carbon dioxide removal on large scales. Regardless of the feasibility of such removals, their effects on biogeochemical cycles and climate are not well understood. Changes in atmospheric CO2 concentration ([CO2]) and climate alter the CO2 exchange between the atmosphere and the underlying carbon reservoirs of land and ocean. Carbon-concentration and carbon-climate feedback metrics are useful tools for quantifying such changes in the carbon uptake by land and ocean, currently acting as a sink of carbon. We investigate the changes in carbon feedbacks under overshoot scenarios that could influence mitigation pathways to achieve the temperature goal. An ensemble of Coupled Model Intercomparison Project 6 (CMIP6) Earth system models that conducted an idealized ramp-up and ramp-down experiment (1pctCO2, with increasing and later decreasing [CO2] at a rate of 1% per year) has been used and compared against a scenario simulation involving negative emissions (SSP5-3.4-OS). The analyses are based on results from biogeochemically coupled (where land and ocean respond to rising CO2 levels but the climate is kept constant) and fully coupled simulations. For the positive emission phases, the model-mean global average carbon-climate feedback looks roughly similar between the SSP5-3.4-OS and the 1pctCO2 simulations, with a gradual monotonic decreasing behavior in absolute values which translates to a reduction in land and ocean uptakes. The carbon-concentration feedback in SSP5-3.4-OS is larger than in the 1pctCO2 simulations over the ocean. Both the ocean and land simulate an increase in carbon uptake during the ramp-up, while during the ramp-down, their uptakes show a hysteresis behavior. This feature is more prominent in the idealistic 1pctCO2 experiment with a higher [CO2] growth rate and without land use change effects than in the more realistic SSP5-3.4-OS scenario. Also, the time evolution of the global annual carbon-concentration and carbon-climate feedbacks seem to be very similar over natural land areas. In addition, changes in carbon fluxes are compared over the high latitude permafrost and non-permafrost regions in the Northern Hemisphere. Over land, the carbon-

concentration feedback metric is decomposed into different terms to investigate the contributions from changes in live vegetation carbon pools and soil carbon pools. This indicates that the feedback is dominated by the residence time of carbon in vegetation and soil. Furthermore, building on previous studies, feedback metrics are also calculated using an alternative approach of instantaneous flux-based feedback metrics to further compare differences between models. The difference between the two approaches can be seen more obviously in the geographical distribution of the two feedbacks, especially for the negative emission phases of the 1pctCO2 experiment.