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Coupled Model Simulations of Carbon Dioxide Removal via Ocean Alkalinity Enhancement and Large-scale Afforestation and Reforestation

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All Shared Socioeconomic Pathways (SSP) of future climate scenarios that are well below 2 °C warming require the application of carbon dioxide removal (CDR) technologies. While the mitigation potentials of different CDR methods have been proposed, the climate impacts have only been studied to a limited extent with the Earth System Models (ESMs). As part of the CDR Model Intercomparison Project (CDRMIP), we utilize here the land-ocean-atmosphere coupled FOCI-MOPS model to study the potential reversibility and impacts of different proposed CDR methods. FOCI-MOP is an integration of the marine biogeochemical model, Model of Oceanic Pelagic Stoichiometry (MOPS), in the Flexible Ocean and Climate Infrastructure (FOCI) ESM. Two CDR methods are studied under highly-idealized scenarios: a marine-based CDR of ocean alkalinity enhancement, and a land-based CDR of afforestation and reforestation, given their large theoretical mitigation potentials. In both experiments, the CDR methods are applied under the high CO_2 emission scenario (SSP5-8.5). In the experiment of ocean alkalinity enhancement, alkalinity is added to ice-free ocean at a rate of roughly 0.14 petamole per year. In the experiment of afforestation and reforestation, the land use follows the scenario with high levels of afforestation and reforestation (SSP1-2.6). We look into the efficiency and the side-effects of CDR methods. In addition, we investigate whether the hysteresis behavior exists as well as the non-reversible aspects of the applied CDR, including ocean deoxygenation as well as the respective impacts on both terrestrial and marine primary production. Finally, as models are largely different in their structures and representations of terrestrial and marine biogeochemistry, we compare our results to results from other models participating in CDRMIP for assessing the modeling uncertainty. The results presented here are helpful for a more realistic application of CDR portfolio and provide insights on a mitigation pathway toward a net-zero world in the future.