Comparative assessment of land-, ocean-, and atmosphere-based climate engineering using the Max Planck Institute Earth System Model

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Previous model studies on potential impacts of climate engineering (CE) have focused mainly on comparing effects of individual CE methods as simulated by different climate and Earth system models. Here we assess land-, ocean-, and atmosphere-based climate engineering measures with respect to their mitigation potential, side-effects on the Earth system, and uncertainties. For the first time a comprehensive Earth system model with prognostic carbon cycle is used to consistently compare two carbon dioxide removal methods – afforestation and ocean alkalinity enhancement - and solar radiation management by stratospheric sulfur injection. We perform simulations using the Max Planck Institute for Meteorology Earth System Model (MPI-ESM), each including one of the three CE methods and all forced by anthropogenic CO_2 emissions according to the Representative Concentration Pathway (RCP) 8.5. Our results show that the different CE methods differ vastly in terms of climatic effects, driven by different target variables - CO_2 reduction for afforestation and ocean alkalinity enhancement, radiative forcing for solar radiation management. We find that mitigating feedbacks may emerge: as a response to the solar radiation management temperatures are reduced leading to a reduction of CO_2. In addition, unintended side-effects become clear: For example, global terrestrial net primary production (NPP) is substantially reduced due to ocean alkalinity enhancement, while afforestation has no large net effect on global NPP due to counteracting effects of reduced CO_2-fertilization and larger forest area. Lastly, regional patterns of climate change differ despite similar global mean changes in our simulations, highlighting the need for sufficient spatial resolution in evaluating consequences for adaptation.