Project: **876**

Project title: **Comparing land, ocean, and atmosphere based climate engineering measures with MPI-ESM simulations (ComparCE)**

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1. Introduction

The main aim of the ComparCE project is an objective and comprehensive assessment of the potential impacts, side-effects and uncertainties of various Climate Engineering (CE) measures. The strategy for assessing Earth system impacts is to simulate the implementation of three frequently discussed CE suggestions in two Earth System Models (ESM) of very different complexity, the intermediate-complexity UVic ESCM, and the comprehensive Max-Planck-Institute Earth System Model MPI-ESM. While UVic allows for the simulation of a large number of sensitivity simulations, the use of the MPI-ESM is necessary to investigate the robustness of the results obtained with the UVic that could be questioned in particular due to the very idealized representation of the atmosphere in the latter model. In this report we will concentrate on results obtained with the MPI-ESM as only those simulations were requiring the use of the HLRE (DKRZ) computers.

2. Intercomparison of three CE methods

The three studied CE techniques include SRM as sulfate aerosol injection (CE-atmos), afforestation (CE-land), and ocean alkalinity enhancement (CE-ocean). For all experiments the GHG forcing and the land use changes of RCP8.5 were taken as baseline scenario. In order to allow for a consistent intercomparison of CDR and SRM methods, and in contrast to e.g. the GeoMIP, a model version with prognostic CO_2 was used. Similar to Niemeier et al. (2013), for the CE-atmos experiments an amount of stratospheric sulfate, which increased with time, was prescribed in order to limit the top of the atmosphere radiative forcing to that of the RCP4.5 scenario. For CE-ocean, alkalinity was added annually to the ocean surface layer to enhance ocean carbon uptake and reduce atmospheric CO_2 to those of the RCP4.5 scenario (Ferrer-Gonzalez and Ilyina, 2015). In the CE-land experiments, the RCP8.5 land use changes were replaced by those of RCP4.5 scenario, which prescribes massive afforestation. While for many of the analyzed Earth system variables the behavior of the MPI-ESM simulations was similar to earlier studies (Keller et al., 2014), some properties such as the global terrestrial net primary production (NPP) showed some unexpected behavior. For example, the lowest terrestrial NPP was found in the CE-ocean simulation, resulting from reduced CO_2-fertilization at still substantial heat stress (Fig. 1). Our preliminary analysis of the effects of termination of CE-ocean and CE-atmos suggest that the Earth system variables revert back to unmitigated values, albeit at different rates. As the rate of change is critical for the impacts of climate change on marine and terrestrial ecosystems, this potential risk of termination has to be addressed in a comprehensive CE assessment.

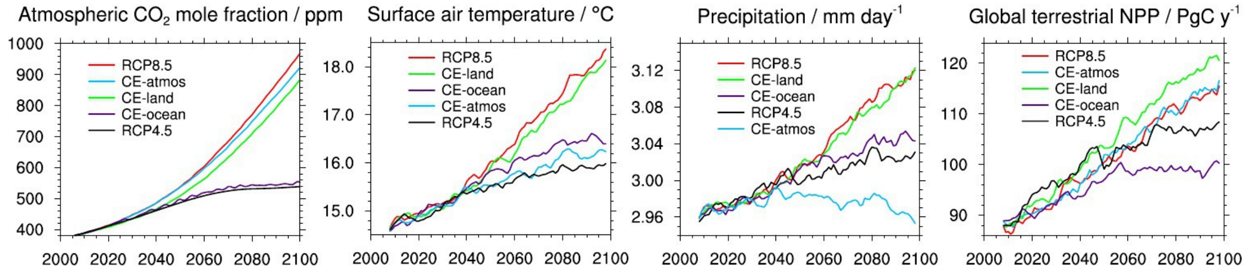

Figure 1: Time series of different global mean Earth system variables from MPI-ESM simulations for the RCP scenarios 4.5 and 8.5, and the CE scenarios for afforestation (CE-land), ocean alkalinity enhancement (CE-ocean) and sulfate aerosol injection (CE-atmos).

3. The role of afforestation for climate change in different CMIP5 RCP scenarios

The CE-land experiments provided the unique opportunity to disentangle effects of different GHG concentrations and different land use scenarios in the scenarios RCP4.5 and RCP8.5. We find that the CO_2 concentration in the atmosphere is reduced by about 85 ppm by the end of the century in the CE-land experiment relative to the control run. This value is higher than previous estimates (e.g., House et al., 2002), mostly because of the effects of a changing climate and changing atmospheric CO_2 on the terrestrial carbon sequestration potential, which had not previously been accounted for. The reduced CO_2 concentration leads to annual mean temperatures being lower by about 0.27°C in the global mean and up to more than 2°C regionally in the model. Thus, we conclude that the mitigation potential of reforestation is higher than previously thought. The results have also shown that afforestation effects depend on the climate state under which afforestation is performed, a feature that is not well understood, yet, and that may make an assessment of combined portfolios of mitigation, adaptation and CE efforts particularly challenging.

4. The dependence of effects of alkalinity enhancement on the ocean state

The background physical and biogeochemical state of the ocean may also impact the mitigation potential of ocean-based CE. In the case of CE-ocean a previous study (Ilyina et al., 2013) illustrated that alkalinity addition in surface waters, which would be longer in contact with the air above, showed to be more effective in lowering atmospheric CO_2 and had the largest mitigation effect on seawater pH, both on the global scale and regionally. In contrast, alkalinity enhancement in deep water formation regions showed to be least effective because alkalinity is rapidly transported into the deep ocean. On long time scales (i.e. >1000 years), the impact on atmospheric CO_2 and ocean pH only depends on the amount of alkalinity added, but regional differences may be substantial over several hundred years.

References

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