Project: **876**

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

Principal investigator: **Sebastian Sonntag**

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1. Introduction

Today's climate change is driven by extensive CO_2 emissions, mostly from the burning of fossil fuels. Supposing that under the current global political situation these CO_2 emissions continue to increase, different climate engineering measures to mitigate climate consequences of these emissions have been proposed. Studies so far have concentrated on the analysis of single climate engineering (CE) measures, but an informed discussion of pro's and con's needs a comparative analysis of a large suite of CE measures. This issue is tackled in the projects ComparCE2 and CE-Land+ funded by the DFG within the priority program on “Climate Engineering” (SPP 1689; www.spp-climate-engineering.de), which are the respective follow-up projects of ComparCE and CE-LAND. The projects aim at providing a basis for a comparative analysis by simulating different types of CE measures within the same model, the MPI Earth System Model (MPI-ESM).

In the following we summarize the progress on the analysis of the simulations that have been performed for the projects ComparCE and CE-Land. In these simulations we study four CE methods deployed in separation and compare the effects of the different methods: solar radiation management (SRM) by sulfate aerosol injection, afforestation (AFF), herbaceous biomass plantations (HBPs), and artificial ocean alkalinization (AOA). The simulations for the follow-up project ComparCE2 as requested for this allocation period could not be started so far, since the model version to be used is not available yet, as described below (section 3).

2. Progress on the analysis of ComparCE and CE-Land simulations

2.1 Comparison of SRM, AFF, and AOA: We have refined and extended our study on the comparison of the three CE methods SRM, AFF, and AOA. We find that as a response to SRM the land carbon uptake is enhanced due to reduced soil respiration leading to a reduction in atmospheric CO_2. In addition, we find that terrestrial net primary production (NPP) is substantially reduced in the AOA scenario due to a strong CO_2 reduction and decreased forest area in this scenario, whereas SRM has almost no net effect on terrestrial NPP due to counteracting effects of decreased water stress in low latitudes and weaker boreal forest expansion. We also identify challenges arising in a comparative assessment of different CE methods: the quantitative results depend on details of the CE scenarios and on the underlying models, and an interpretation of relative efficiency depends on the choice of variables that are analyzed. Furthermore, we show that normalizations allow for a better comparability of different CE methods. For example, we find that more carbon needs to be removed from the atmosphere for AFF compared to AOA to achieve the same global warming reduction (Fig.1). These results are covered in a manuscript that is currently in revision (Sonntag et al., in revision).

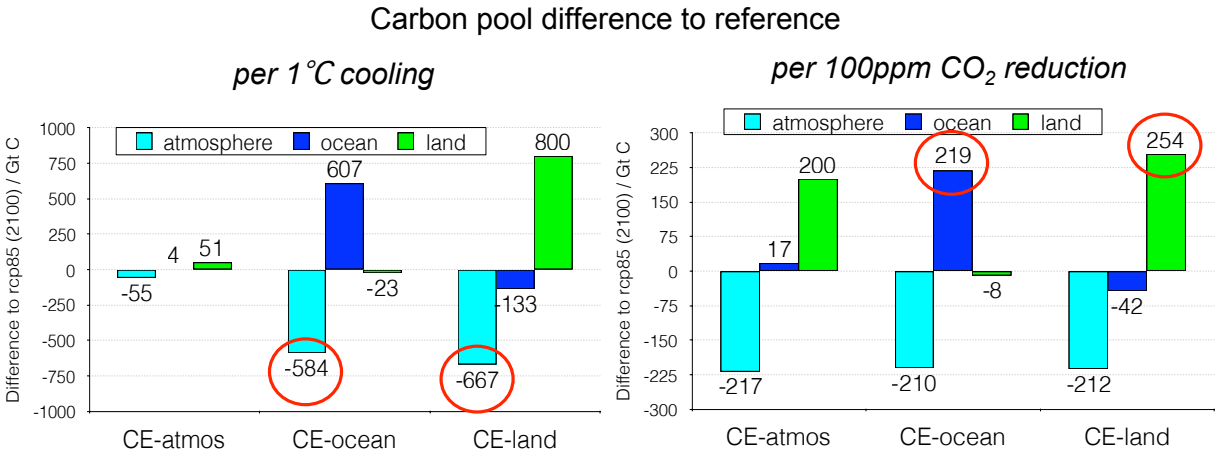

Figure 1: Global annual (year 2100) mean carbon pool differences between the experiments simulating SRM (CE-atmos), AOA (CE-ocean), and AFF (CE-land) and the reference RCP8.5 experiment for the total atmospheric, ocean, and land carbon, scaled by the corresponding differences in surface air temperatures averaged over the years 2081-2100 (left) and scaled by the corresponding differences in atmospheric CO_2 concentrations.

2.2 Comparison of SRM and AOA termination scenarios: Within the project ComparCE additional SRM and AOA scenarios had been performed which simulate a sudden termination of these methods in the year 2070. That is, the respective CE deployment is simulated from 2006 to 2070 and then the simulation is continued until 2100 without CE deployment. We compare the results of the AOA and SRM scenarios, both terminated in 2070 and continued until 2100, regarding the environmental effects of the CE deployments on multi-decadal rates of change and on seasonal variability. We find that local rates of surface warming after termination of SRM largely exceed those of the reference scenario RCP8.5 in line with previous studies. After termination of AOA, rates of surface warming are in general similar to those of the RCP8.5, but their spatial patterns differ: At high Northern latitudes, local rates of surface warming exceed those of the RCP8.5, and some regions reach trends as large as in the terminated SRM scenario. We also find that large-scale AOA and SRM scenarios do not present regional differences in their effects on the seasonal variability of surface temperatures, despite the different forcings that are modified by these methods. We find that alkalinity addition might cause rapid variations in the seawater chemical environment where vertical mixing is limited and that after termination of AOA, rates of ocean acidification locally exceed those associated with the reference RCP8.5 scenario. These results have been published in a PhD dissertation (Ferrer González, 2017) and are currently being prepared for publication in a peer-reviewed journal.

2.3 Comparison of AFF and HBPs: Within the project CE-land four scenarios involving herbaceous biomass plantations (HBPs) have been performed exploring two different management options and two different cases for fossil-fuel substitution. Comparing the effects of HBPs and afforestation (AFF) on the climate, we found that AFF is more effective at mitigating the climate than HBPs as long as HBPs were used for energy production only. When used for fossil-fuel substitution, HBPs reduced carbon dioxide concentrations by the end of the century by 150-170 ppm and temperatures by 0.8-1.0°C compared to the RCP8.5 scenario while AFF reduced these values by 85 ppm and 0.4°C respectively. HBPs became more effective than forests within 30 years in most areas of the globe assuming a 100% fossil-fuel substitution level. They retained this rapid increase in effectiveness in many areas even when current technological limits of 30-70% substitution levels were accounted for. While albedo differed between AFF and HBPs, overall biogeophysical differences between the two land-use types were negligible with respect to their effects on the climate. These results have been published in a PhD dissertation (Mayer, 2017) and are currently being prepared for publication in a peer-reviewed journal.

3. ComparCE2 simulations

The simulations that were planned for this reporting period could not be performed until now, since the CMIP6 model version of MPI-ESM to be used for the simulations has not been available yet. Instead of performing the planned experiments with the outdated CMIP5 version of MPI-EMS, we decided to still wait for the CMIP6 version, since it includes major improvements regarding the representation of climate and carbon cycle processes, e.g., the representation of soil carbon decomposition and carbon-nitrogen interactions (Goll et al., 2017). To use synergies with CMIP6 historical and future DECK experiments and to allow for better comparison of our simulations with those performed within CMIP6-endorsed MIPs (C4MIP, GeoMIP, LUMIP, ScenarioMIP), the plan still is to use the CMIP6 model version of MPI-ESM. Using such synergies has also been asked for in the remarks by the reviewers of a previous proposal. Since the CMIP6 DECK simulations are now being performed, we are confident that we can start the requested simulations soon.

References

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