Project: **876**

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

Project lead: **Christian Reick,** Tatiana Ilyina, Julia Pongratz, Hauke Schmidt

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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 for an informed discussion of pro's and con's it 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 ("Schwerpunktprogramm") on "Climate Engineering" (SPP 1689; see 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 such 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 three CE methods in separation and compare the effects of the different methods: solar radiation management by sulfate aerosol injection, afforestation, and ocean alkalinity enhancement. 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.

2. Progress on the analysis of ComparCE simulations

2.1 Afforestation: Our study on the potential of afforestation showed that the carbon sequestration potential of natural forest regrowth on abandoned agricultural land, as described in the RCP4.5 scenario, is larger than had been estimated previously. This is due to the combined effect of land use changes and the enhanced carbon uptake of the terrestrial biosphere in a warm and high-CO_2 world. The results have been published in Sonntag et al. (2016) and indicate that the potential of reforestation as a CE tool depends on the background climate and CO_2 levels, which is an aspect important to consider in the portfolio-scenarios simulations to be performed in the following allocation period.

2.2 Ocean alkalinity enhancement: In our study on ocean alkalinity enhancement we found that atmospheric CO_2 concentration reaches RCP4.5 levels when adding 114 Pmol of alkalinity to the surface ocean under RCP8.5 CO_2 emissions. In this scenario 940 Gt of carbon are removed from the atmosphere and the global warming is reduced by 1.5 K within this century compared to the RCP8.5 baseline scenario. This global warming reduction reduces the loss of sea ice and high sea level rise. Seawater pH and the carbonate saturation state rise substantially above levels of the current decade. The results have been published in Ferrer Gónzalez and Ilyina (2016) and indicate that the mitigation potential of ocean alkalinity enhancement comes at a price of an unprecedented ocean biogeochemistry perturbation with unknown ecological consequences.

2.3 Comparison of CE methods: Our results concerning the comparison of the three CE methods show that driven by different target variables – reduction of atmospheric CO_2 for afforestation and ocean alkalinization, radiative forcing for solar radiation management – the different CE methods differ vastly in terms of climatic effects. We find that mitigating feedbacks may emerge: as a response to the solar radiation management temperatures are reduced leading to a reduction of atmospheric CO_2. In addition, unintended side-effects become clear: For example, terrestrial net primary production (NPP) is substantially reduced due to ocean alkalinization, while afforestation has no large net effect on terrestrial NPP due to counteracting effects of reduced CO_2 fertilization and larger forest area. We also identify challenges arising when aiming at a comparative assessment of different CE methods. One reason complicating comparability of CE methods is the fact that the potential of a certain method may depend on the background state of the Earth system, e.g., we find that the CDR potential of reforestation depends on climate and CO_2. Another reason is that the scenario design already sets targets and potentials of the studied CE method. Overall, our study contributes to a better understanding of how different CE methods affect the components of the Earth system and of why a comprehensive assessment of CE is difficult. These findings are covered in a manuscript that is being prepared for publication (Sonntag et al., in preparation).

3. Simulations performed in this reporting period

The simulations that were planned for this reporting period were anticipated to be performed in the second half of 2016. However, the model version to be used for the simulations is the CMIP6 version of MPI-ESM, which is not available yet. To use synergies with CMIP6 historical and future 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 synergies has also been asked for in the remarks by the reviewers of the previous proposal.

To avoid loosing time waiting for the CMIP6 version of MPI-ESM, we decided to use the granted computing resources for advancement towards another milestone of CE-Land, namely the further investigation of the CE potential of herbaceous biomass plantations (HBPs) using the CMIP5-version of MPI-ESM. The simulations used the RCP8.5 CO_2 emissions and a modified RCP4.5 land-use in which most abandoned crops and pastures were converted to HBPs. The areas chosen for biomass establishment correspond to areas that are afforested in the original RCP4.5 and the hybrid scenario described in Sonntag et al. (2016), thus ensuring comparability between land-use scenarios within the projects. Four different scenarios were simulated which explore two different management options and two different cases for fossil-fuel substitution. Management options differed in amount of harvestable material produced (either 55% or 71% of total plant carbon). Fossil-fuel substitution options simulated one case with no fossil-fuel substitution (0% fossil-fuel substitution) and one case where all harvested carbon substituted fossil fuels (100% fossil-fuel substitution). Each management option was paired with each fossil-fuel substitution option. Preliminary results indicate that even without fossil-fuel substitution, RCP4.5 land-use with HBPs reduces CO_2-concentrations and temperatures compared to the RCP8.5 baseline (Fig. 1), which highlights the importance of land-use choices for the global climate. HBPs with fossil-fuel substitution reduce CO_2-concentrations and temperatures even compared to afforestation. Fossil-fuel substitution by HBPs becomes effective relatively rapidly and exceeds carbon bound by afforestation in most areas where they are planted. Management only impacts CO_2-concentrations in combination with fossil-fuel substitution.

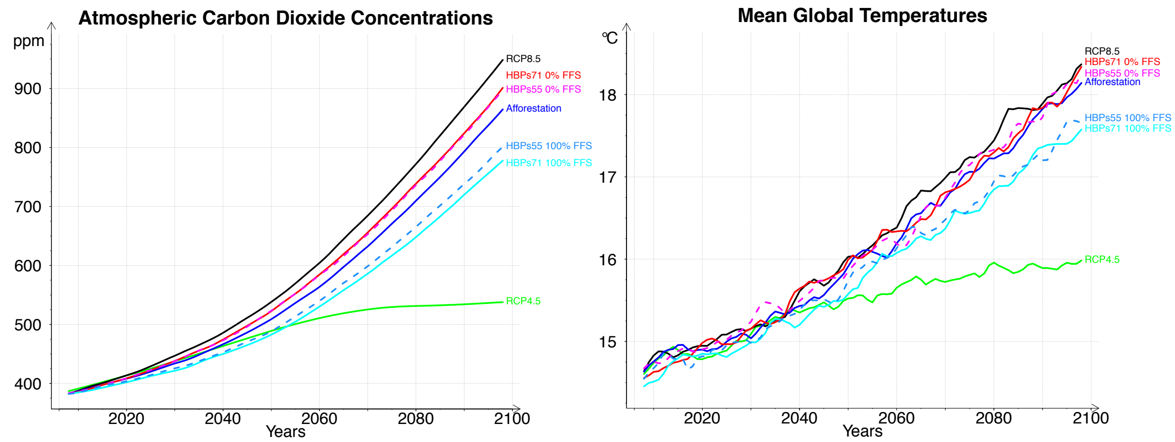

Figure 1: Global annual mean atmospheric CO2 concentrations and surface air temperatures for the 4 different scenarios with herbaceous biomass plantations, the afforestation scenario, and the RCP8.5 and RCP4.5 simulations for comparison.

References

Ferrer González, M., and T. Ilyina (2016), Impacts of artificial ocean alkalinization in the Earth system, Geophysical Research Letters, 43(12), 6493–6502, doi:10.1002/2016GL068576.

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