Project: 876

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

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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-ESM.

In the following section we summarize the progress on the analysis of the simulations that were performed for the projects ComparCE and CE-Land, where we study 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 projects ComparCE2 and CE-Land+ as requested for this allocation period could not be started so far, since the baseline model experiments to be used are not available, as described below (sections 3 and 4). However, progress has been made on the development for the basis of the CE-Land+ simulations (section 4) and on the development of a portfolio scenario and the implementation of a detection and attribution method (section 5). Furthermore, we have used some computational resources to contribute to the Carbon Dioxide Removal Model Intercomparison Project (CDRMIP, section 6).

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

The findings described in last year's report on the comparison of the CE methods SRM, AFF, and AOA and on the comparison of the SRM and AOA termination scenarios have been refined and published in two peer-reviewed articles (Sonntag et al, 2018, and González et al., 2018). The results on the comparison of AFF and HBPs (Mayer, 2017) are being prepared for publication in a peer-reviewed scientific journal.

3. ComparCE2 simulations

The simulations that were planned for this reporting period could not be performed until now, since the pre-industrial control experiment with freely evolving atmospheric CO₂ concentration (experiment *esm-piControl*) using the CMIP6 model version of MPI-ESM and the forcing data for the future scenarios are not available yet. Instead of performing the planned experiments with the outdated CMIP5 version of MPI-ESM, we decided to still wait for the CMIP6 experiments to finish, since the CMIP6 version 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, CDRMIP), the plan still is to use the CMIP6 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 and historical simulations are now being performed, we are confident that we can start the requested simulations soon.

4. CE-Land+ simulations

During 2017, we performed land-only site-level simulations for the INTERFACE – Altered Rainfall Modelling Experiments on grassland. JSBACH and 13 other land surface models were found to reproduce well observational data in that the spatial slopes derived from modeled primary productivity and precipitation across sites were steeper than the temporal slopes obtained from interannual variations. However, most models were overestimating the negative drought effects (Wu et al., 2018). To understand this behavior better we performed additional simulations for 10 sites also including forests and shrubs provided by the ongoing INTERFACE2 study. These

simulations were conducted with an early CMIP6 version of the model including the nitrogen cycle. Such site-level studies are important to assess JSBACH's PFT responses to above- versus below-average precipitation periods. Building up on these results, we are currently improving JSBACH's performance in simulating evapotranspiration for which several regional, land-only simulations are being conducted. This provides the basis for the development of our new forest mortality scheme following Anderegg et al. (2015). Since the goal still is to assess the impact of a new forest mortality scheme in JSBACH within the CMIP6 version of MPI-ESM, we request the same resources as last year for this project.

5. Detection & attribution of CE in a portfolio scenario

Detection and attribution (D&A) of CE has been studied so far only for stratospheric aerosol injection (Bürger and Cubasch, 2015; Lo et al., 2016). Compared to the classical climate change D&A, in the case of CE only pseudo-observations are available and the background climate is contaminated by other anthropogenic drivers. D&A may be further complicated in the case of a combination of different CE methods, since the detectability of the single CE methods may be affected by each other or the combined signal may not be attributable to a single forcing. Since individual CE methods have been found to have either limited potential or come with high risks and large side-effects (e.g., Sonntag et al., 2018; González et al., 2018), we anticipate individual CE methods to be applied, if at all, as part of a portfolio of various CE methods. Among the most discussed portfolio scenarios are those that combine SRM with CDR or strong mitigation such that the SRM deployment is moderate and temporary (Keith and MacMartin, 2015; Tilmes et al., 2016). We build on these scenarios and combine a high- CO_2 emission scenario with AOA leading to an overshoot in temperature and combine this with SRM to "cut off" this temperature peak. We are currently implementing this scenario and will use the remaining computing resources for this allocation period to run the scenario using the MPI-ESM CMIP5 version. We have implemented a regularized optimal fingerprinting method (Ribes et al., 2013), have applied it to the existing SRM and AOA scenarios, and will apply it to the portfolio scenario. The pre-processing of the data for this D&A algorithm has been done using the allocated computing resources for this period.

6. Contribution to CDRMIP

The Carbon Dioxide Removal Model Intercomparison Project (CDRMIP, Keller et al., 2018) brings together Earth system models in a common framework to explore the potential, risks, and challenges of different types of proposed CDR. Since this scope fits perfectly into the scope of our project, we contribute to this MIP with MPI-ESM simulations. First test runs for the CDRMIP Tier 1 experiment *1pctCO2-cdr* have been finished successfully. This experiment is designed to investigate CDR-induced climate "reversibility". It starts from the end of the CMIP6 DECK experiment *1pctCO2* and uses a decreasing CO₂ concentration with 1% per year down to the pre-industrial level. The final run for this experiment has not been done yet, since it is not clear yet if the available experiment *1pctCO2* will be the official CMIP6 DECK version.

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