Project: **876**

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

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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 we summarize the progress on the analysis of the simulations that have been 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) (section 2). The simulations for the follow-up projects ComparCE2 have been started, but not finished at this point (section 3). A detection and attribution toolbox has been developed and tested on the experiments made in ComparCE, but not yet applied to the combined SRM and AOA scenario run (section 2, 3). The impact of regional application of AOA has been studied (section 4). Furthermore, we have used some computational resources to contribute to the Carbon Dioxide Removal Model Intercomparison Project (CDRMIP, section 5).

2. Progress on the analysis of ComparCE

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. Therefore a non-stationary detection method is applied using the MPI-ESM grand ensemble (MPI-GE-ESM1.1) in order to evaluate internal climate variability. The results of the detection and attribution method applied to SRM and AOA scenarios (Figure 1) are being prepared for publication.

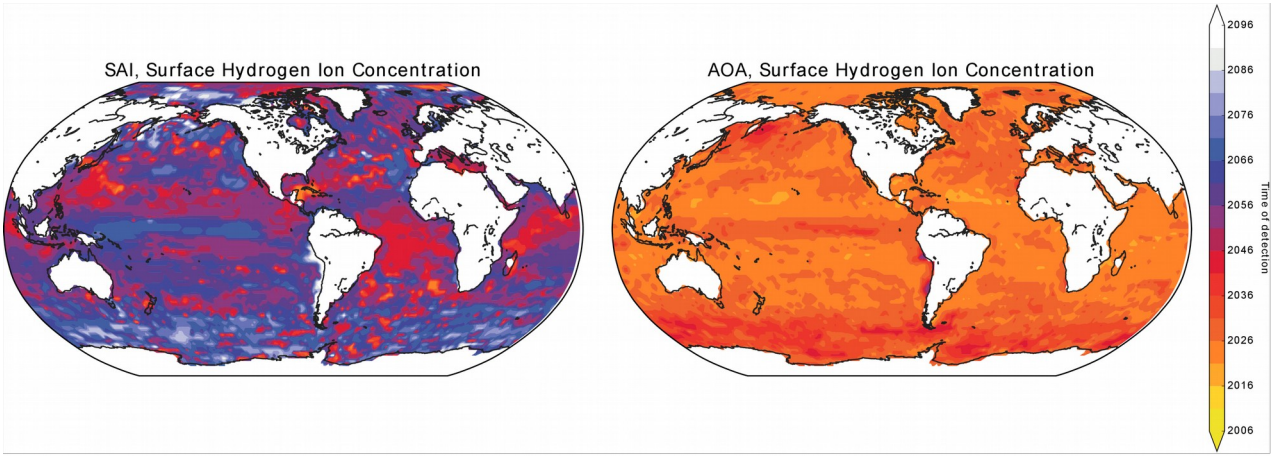

Figure 1: Assuming a non-stationary control climate, local detectability for hydrogen ion concentration (or pH) for SRM (right panel) is later and more inhomogeneous than for AOA (left panel) simulations due to the different time lag between chemical, physical and radiative impacts of anthropogenic and engineering forcing.

3. CE portfolio scenario and ComparCE2 simulations

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 carbon dioxide removal (CDR) or strong mitigation such that the SRM deployment is moderate and temporary (Keith and MacMartin, 2015; Tilmes et al., 2016). Here, a combination scenario was developed that reduces atmospheric CO_2 via AOA from the RCP8.5 to the SSP5-3.4OS scenario and shaves off the peak via SRM to limit radiative forcing at the top of the atmosphere to the SSP5-2.6 scenario, i.e. the target scenario.In this case, D&A of CE 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.

The simulations that were planned for this reporting have been started, but not yet finished. Due to personnel changes within the project, preliminary simulations were performed using allocated computational resources with the CMIP5 model version of MPI-ESM instead of the planned CMIP6 model version, whose simulations needed for the project still were not available before summer. While the individual AOA and SRM forcing runs have been tested and the simulations have been performed, the combination of the two, although implemented, has not yet been run.

4. Regional AOA simulations

In order to evaluate the efficiency of regional AOA in terms of CDR potential, and compared to global application scenarios, simulations of regional AOA have been run stand-alone using HAMOCC6 coupled to MPIOM1.6 similar to the components used in CMIP6. Based on physical properties, 8 different regions were defined that show a different carbon uptake efficiency (Figure 2) depending on the local physical transport of water masses from the surface to depth with the enhanced chemical uptake efficiency through AOA. Based on the results, a global index has been developed that allows to evaluate regional AOA-CDR potential, which should be tested with the coupled MPI-ESM using the CMIP6 model version.

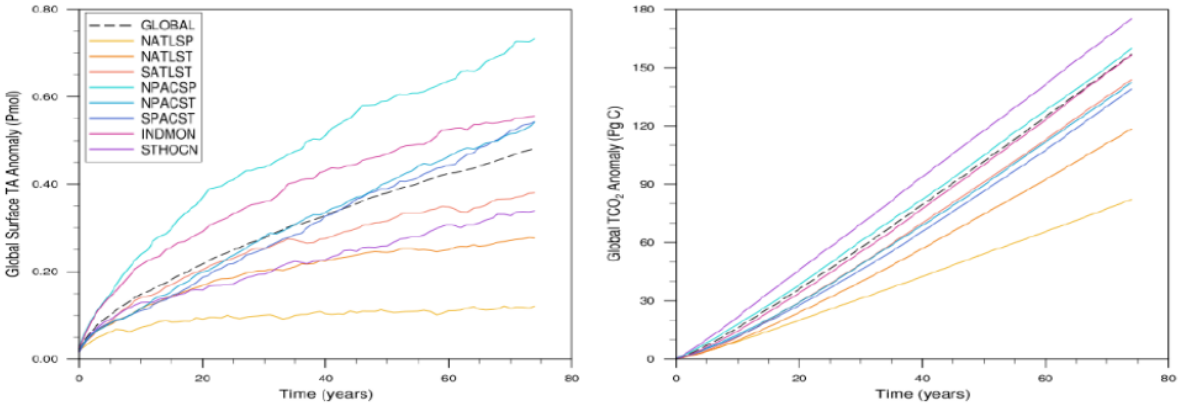

Figure 2: Annual global mean time series of surface ocean total alkalinity (right panel) and global mean DIC column inventory (left panel) for global and regional AOA application.

5. 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. The runs for the CDRMIP Tier 1 experiment *1pctCO2-cdr* have been finished successfully, i.e. at the end of the CMIP6 DECK experiment *1pctCO2,* CO_2 concentration decreases with 1% per year down to the pre-industrial level. The runs for the CDRMIP Tier 1 experiment *CDR-pi-pulse* have not been performed yet.

References

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