Project: **876**
Project title: **ComparCE2; Comparing land, ocean, and atmosphere based climate engineering measures with MPI-ESM simulations**
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Report period: **2020-01-01 to 2020-12-31**

1 Project Overview

Today's climate change is driven by extensive CO_2 emissions, mostly from the burning of fossil fuels. However, reducing CO_2 emissions alone may no longer be sufficient, and carbon dioxide removal strategies (CDR) and solar radiation management (SRM) may need to be deployed. Studies so far have concentrated on the analysis of single climate engineering (CE) measures, but an informed discussion of benefits and disadvantages needs a comparative analysis of a large suite of CE measures. This issue is tackled in the project ComparCE2 funded by the DFG within the priority program on "Climate Engineering" (SPP 1689; www.spp-climate-engineering.de), which is the respective follow-up project of ComparCE. 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 summarise the progress on the analysis of the simulations that have been performed for the projects ComparCE, where we study CE methods deployed in separation and compare the effects of the different methods: solar radiation management (SRM) by sulfate aerosol injection, and artificial ocean alkalinization (AOA). The simulations for ComparCE2 have been finished. However, the envisaged runs of a combination AOA-SAI scenario were abandoned. A detection and attribution toolbox has been developed and tested on the experiments made in ComparCE, and applied to the SRM and AOA scenario runs . The impact of regional application of AOA has been studied. Furthermore, we have used some computational resources to contribute to the Carbon Dioxide Removal Model Intercomparison Project (CDRMIP).

2 Report on Computational Time 2020

Detection and attribution of stratospheric aerosol injection (SAI) and artificial ocean alkalinisation (AOA) in MPI-ESM In order to monitor the success of individual CE measures, the detectability of CE signals need to be ensured as well as the ability to attribute these signals to their cause. The unique scenario design in []Gonzalez2016 and [7] allows to quantitatively compare the detectability of atmosphere-based and ocean based CE measures, namely SAI and AOA-driven changes in not only global, but also local near-surface air temperature and pH signals (as shown in Figure 3). The advantage for detecting these engineered signals in the climate system is that the start date of the additional external forcing is well known. For the first time, [3] uses single-model estimates of the externally forced response based on the MPI-ESM and single-model estimates of internal variability provided by the Max Planck Institute Grand Ensemble (MPI-GE) in a regularized optimal fingerprinting approach [6]. By that, potential bias associated with sampling uncertainty in the CMIP5 database is overcome and non-physical detection and attribution results associated with inter-model differences of response patterns to forcing may be avoided.

With ongoing emissions of greenhouse gases, the assumption of a stationary background climate state may no longer hold and a transient background climate state may better reproduce internal variability changes over time. Confirming work by [1] and [5], the results show that detectability timescales are sensitive to the choice of null hypothesis. In general, detection can be claimed earlier and the results are more robust while working with a transient background climate state instead of a stationary null hypothesis. The shift in the detectability pattern between the two null hypotheses indicates that the underlying assumption of the detection and attribution method that any observed change in climate is a linear combination of externally forced signals and noise, fails on local scales.

In general, the results show that detection is impeded, if 1) signals are small, 2) internal variability is high, or 3) multiple externally forced signals have an indistinguishable response pattern. However, the failure to detect CE forcing cannot be interpreted as that no influence exists through SAI or AOA globally or locally, but rather that the forced responses to either forcing are not detectable above the internal variability. [3] conclude that, locally, detectability of a single CE measure is limited in a region prone to large internal variability, which implies for a combination of small-scale measures that detecting individual responses may be ineffectual.

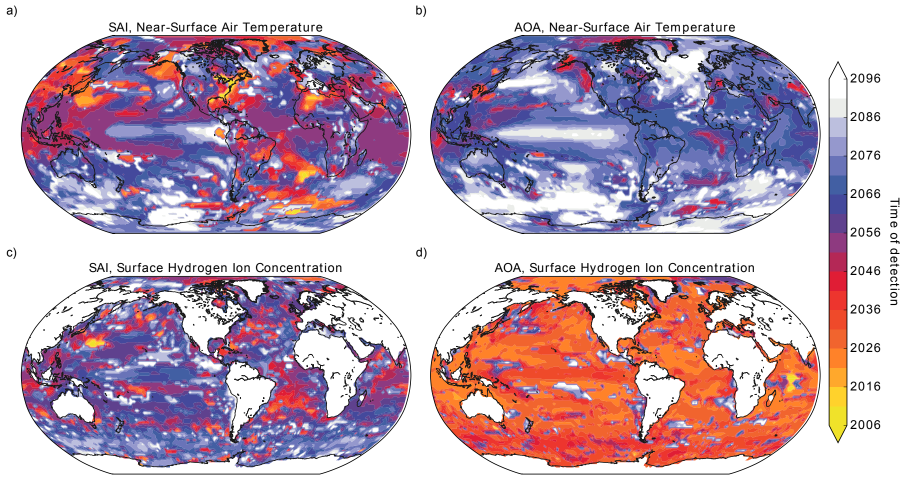

Figure 1: Local detectability for temperature (panels a, b) and hydrogen ion concentration (panels c, d) for SAI (panels a, c) and AOA (panels b, d) simulations. Regularised optimal fingerprinting was applied to every grid point assuming a non-stationary control climate. From [3].

The Sensitivity of the Marine Carbon Cycle to Regional Artificial Ocean Alkalinisation In order to evaluate the efficiency of regional AOA in terms of its CO_2 removal potential compared to a global application, simulations of regional AOA have been run stand-alone using HAMOCC6 coupled to MPIOM1.6 similar to the components used in CMIP6. For that, 8 different regions were defined that represent different physical regimes and biogeochemical sensitivities, in which total alkalinity is enhanced at a rate of 0.25 Pmol a^{-1} in 75-year simulations. The enhanced carbon uptake potential due to AOA ranged between 82.14-175.18 Pg in the experiments with substantial regional differences [2]. The different carbon-uptake potentials are associated with redistribution of surface alkalinity by the large-scale circulation across areas of different carbon-uptake efficiencies. The background concentration of dissolved inorganic carbon and total alkalinity determined the sensitivity of the CO_2 system in seawater to alkalinisation, globally, but especially on regional scales. The results reveal that regional alkalinity enhancement has the potential to exceed carbon uptake through global AOA [2].

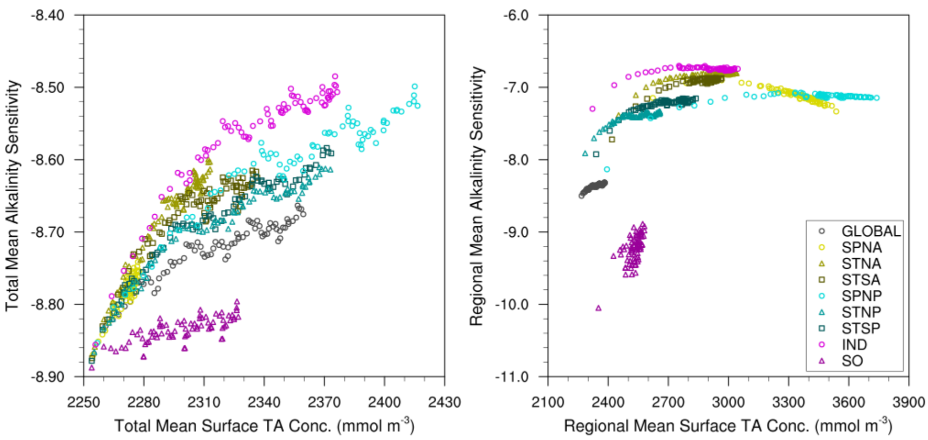

Figure 2: The total annual mean surface alkalinity sensitivity against the total annual mean surface total alkalinity (left panel) and the regional annual mean surface alkalinity sensitivity against the regional annual mean surface total alkalinity for the global and different regional artificial ocean alkalinisation experiments (right panel). From [2].

Contribution to CDRMIP The Carbon Dioxide Removal Model Intercomparison Project [4, CDRMIP] 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 contributed to this MIP with MPI-ESM simulations. The runs for the CDRMIP Tier 1 experiments 1pctCO2-cdr and CDR-pi-pulse have been finished successfully. Remaining computational time will be used for cmorization of all data.

References

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