Feasibilities of carbon dioxide removal portfolios

Simulating carbon dioxide removal portfolios with a fully coupled Earth system model

***A. Oschlies, H.-W. Wey**, GEOMAR Helmholtz Centre for Ocean Research Kiel*

In Short

- In contrast to the prominent atmospheric CO_2 reduction due to CDR, the warming reduction is more uncertain and difficult to detect.
- For the same amount of increase in carbon storage by the two land- and ocean-based CDR, the amount of reduced sink in the counterpart is also similar.
- New experiments are proposed to investigate the practicalities of future CDR deployment, with a total of 41 million core-h computing time and 120 TB of storage being requested.

Carbon dioxide removal (CDR) is indispensable for achieving the Paris Agreement climate target. According to the IPCC Special Report on Global Warming of 1.5° C, 100 to 1000 $GtCO_2$ will need to be removed over the 21st century to meet the 1.5-degree target [1]. However, not a single CDR method is alone deemed sufficient for compensating the residual emissions that are not abatable. Thus, a portfolio of different CDR methods will likely have to be deployed. It is therefore important to understand the effects of different CDR methods on the rest of earth system in terms of both climate and carbon cycle.

In previous project period, we simulated the single application of (i) afforestation and reforestation (A/R) and (ii) ocean alkalinity enhancement (OAE) with the land-ocean-atmosphere coupled model FOCI-MOPS [2,3]. In the OAE experiment, a total of 0.14 Pmol of alkalinity is added to the top layer of ocean over global ice-free region. A set of reference experiments (REF; SSP5-8.5 emission and land use, without CDR) were conducted for comparisons. In the A/R experiment, the land use and land cover follows that of SSP1-2.6, under which the land use is largely regulated. Both of the CDR experiments are applied under a high climate change scenario (SSP5-8.5) with the emission-driven mode permitting interactive carbon cycle. To study the uncertainty posed by internal variability, all experiments were conducted with three ensemble members. By comparing the CDR experiments against the REF experiment, we evaluate the effects of the CDR applied. The experiments were analyzed for contributing to the BMBF project CDRSynTra (https://www.fona.de/en/measures/funding-measures/CDR/cdrsyn_en.php).

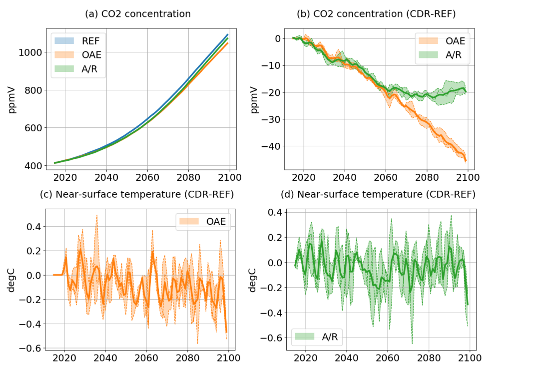

***Figure 1:** The effects of CDR on (a)(b) CO_2 concentration and (c)(d) near-surface temperature. Dashed lines are the three ensemble members and shadings indicate ensemble range. Solid lines indicate the ensemble means..*

Fig. 1 shows the atmospheric CO_2 concentration and temperature of the experiments. The effects of the both CDRs on atmospheric CO_2 are prominent (Fig. 1ab). However, as the emission under SSP5-8.5 is high, the net emission is still positive. In all experiments, the atmosphreric CO_2 concentration increases by more than 400 ppmV from 2015 to 2100. By 2060, the amount of CO_2 removed from the atmosphere is the same for both OAE and A/R (Fig. 1b; about 20 ppmV).

By removing CO_2 from the atmosphere, it is expected that the global mean temperature is lower in CDR experiments than in REF. For OAE, the effect of CDR on temperature is a reduced warming of 0.22 degree at 2060 under SSP5-8.5 emission. For A/R, the reduced warming is 0.12 degree. However, in contrast to the significant effect on atmospheric CO_2 concentration, the effect of CDR on near-surface temperature is much more uncertain. The internal variability of near-surface temperature, represented by the ensemble range of the experiments, is much larger than that of CO_2 concentration. To consider the uncertainty resulting from internal variability, we define that the effect of CDR on temperature (expected to be a cooling effect) is significant if all ensemble members show cooling in the specific year. For OAE , the cooling effect is significant for only 12 years out of the 45 years from 2015 to 2060 (Fig. 1c). For A/R, the cooling effect is even less significant, with only 6 years from 2015 to 2060 being significant (Fig. 1d). In comparison, the effect of CDR on CO_2 concentration is significant for 37 and 40 years for

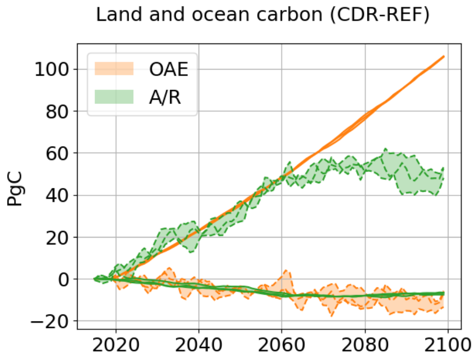

Figure 2: *The differences compared to 2015 in total land and total ocean carbon between the CDR and reference simulations. Dashed lines: Total land carbon. Solid lines: Total ocean carbon. Shading: ensemble ranges.*

OAE and A/R, respectively (Fig. 1b).

Fig. 2 shows the effects of CDR on both total land and ocean carbon. The side-effect of a CDR of reducing the other natural carbon sink is clearly seen. For OAE, by 2060, 48 Pg of carbon is increased in the ocean, with 5 Pg of carbon reduced on land. Interestingly, for A/R, which has a similar amount of carbon increased on land (47 Pg) by 2060, a similar amount of carbon is also reduced in the ocean (8 Pg). That is to say, for a CDR enhancing natural carbon sink, the side-effect of reducing the natural carbon sink of the counterpart is of similar amount for OAE and A/R.

A manuscript based on the results shown here is in preparation for submission to Environmental Research Letters [4].

The experiments conducted in the previous project is highly idealized. While the results have helped us understand the earth system behavior, more realistic experiments for future scenarios are needed. For the follow-up project, we have hence designed a new set of experiments, which include

1. An updated design of the reference simulations
2. A/R experiments with a high forest cover in line with the 1.5 degree target
3. OAE experiments with realistic applying region and varying amount
4. Portfolio experiments where the A/R and OAE are applied at the same time
5. Emission avoidance experiments

In previous project period, the reference simulation is simply the SSP5-8.5 emission with the SSP5-8.5 land use transition. However, as both the CDR and reference experiments have time-varying land use and land cover change, it is not possible to isolate the effects of afforestation. In the follow-up project, as the reference simulations we will use a constant land use scenario (i.e., the land use is kept the same as of the end of the historical simulation) for better isolating the effects of terrestrial-based CDR.

For the OAE experiments, in contrast to the global homogeneous application in the previous project, the alkalinity is now only added to global coastal region. In addition, the amount of alkalinity added is not constant and follows the same trajectory of CO_2 removal reached by the A/R experiment.

To test the linearity of simultaneous application of different CDR options, several combinations of applying OAE and A/R at the same time will be tested. By comparing the results of atmospheric CO_2 concentration and climatic variables (e.g., temperature) from the combined experiments with the single-application experiments, we investigate how linear the climate responding to combined CDR options.

Finally, in addition to the portfolio simulations, we plan to conduct the avoided emission experiments, in which the same amount of carbon removal from the atmosphere by CDR in previous experiments are directly removed from the anthropogenic emission sources. The rationale of the experiments is that it has been pointed out it is difficult to compare different CDR as often a back flux due to altered atmospheric CO_2 concentration is induced [5]. With the avoided emission experiments, we aim to construct a basis for a common framework for assessing different CDR options.

With the new set of experiments, insights into the practicalities of possible future CDR deployment can be provided, which include the issues of detection and attribution under simultaneous deployment of different CDR techniques.

WWW

http://www.geomar.de/en

More Information

[1] IPCC, *Global Warming of 1.5 °C. An IPCC Special Report.* (2018).

[2] Matthes et al., *Geosci. Mod. Dev.* (2020). doi: 10.5194/gmd-13-2533-2020

[3] Chien et al., *Geosci. Mod. Dev.* (2022). doi: 10.5194/gmd-15-5987-2022

[4] Wey et al., *Env. Res. Let.* (in prep.).

[5] Oschlies et al., *Biogeosciences* (2010).

Funding

BMBF project CDRSynTra

DFG Subject Area

313-02