Response to reviewer #1

>> The reviewer's comments are in bold. <<
>> Responses are in italics. <<
>> New text is in plain type. <<

Review Keller et al. 'The Carbon Dioxide Removal Model Intercomparison Project (CDR-MIP): Rationale and experimental design'

This manuscript presents a motivation and description of the experimental design of a planned carbon dioxide removal model intercomparison project. The manuscript touches upon a much discussed but so far little investigated area: how will the Earth system react to large scale removal of carbon from the atmosphere by different processes? This is an important initiative that will serve the community well and I find the article worthy of publication in Geoscientific Model Development. The motivation and experimental protocol is outlined well but for clarity I recommend some changes listed below.

#1 Section 1.2 CDR-MIP Scientific Foci[Page 6] The first and second motivation seem to address the same question and could maybe put together.

Thank you for the suggestion. We agree that they are similar and have combined these motivations.

#2 Section 2 Background and motivation[Page 9, lines 270-273] sentence unclear, rephrase

Sorry if this is unclear. We have tried to clarify the sentence by rephrasing it to be:

" BECCS is thus, constrained by some environmental limitations (e.g., suitable land area), but because the carbon is removed and ultimately stored elsewhere, it may have a higher CDR potential than if the same deployment area were used for a sink-enhancing CDR method like afforestation that stores carbon permanently above ground and reaches a saturation level for a given area."

[Page 10, line 315] Maybe shortly name some examples for other side effects than regional albedo changes.

We have added a few more examples and slightly changed the sentence order so that the order is logical. This section now reads:

" Some significant side effects are caused by the spatial scale (e.g., millions of km^2) at which many methods would have to be deployed to have a significant impact upon

CO_2 and global temperatures (Boysen et al., 2016; Heck et al., 2016; Keller et al., 2014). Side effects can also potentially alter the natural environment by disrupting biogeochemical and hydrological cycles, ecosystems, and biodiversity (Keller et al., 2014). For example, large-scale afforestation could change regional albedo and evapotranspiration and so have a biogeophysical impact on the Earth's energy budget and climate (Betts, 2000; Keller et al., 2014). Additionally, if afforestation were done with non-native plants or monocultures to increase carbon removal rates this could impact local biodiversity."

#3 Section 3.1 Relations to other MIPsI acknowledge the fact that with the variety of existing MIPs it is not easy to set a new MIP into relation to them. This subsection, however, is generally not very clear to the reader and a bit lengthy with repetitions of statements and needs focusing.

We have tried to improve this section. Hopefully it is now more clear and concise without repetitive statements. The section now reads:

" We highly recommend that participants in CDR-MIP also conduct experiments from other MIPs. CMIP6 and CMIP5 experiments, analyses, and assessments both provide a valuable baseline and model sensitivities that can be used to better understand CDR-MIP results. Further, to maximize the use of computing resources CDR-MIP uses experiments from other MIPs as a control run for a CDR-MIP experiment or to provide a pathway from which a CDR-MIP experiment branches (Sections 3.2 and 4, Tables 2- 7). Principle among these is the CMIP Diagnostic, Evaluation, and Characterization of Klima (DECK) and historical experiments as detailed in Eyring et al. (2016) for CMIP6, since they provide the basis for many experiments with almost all MIPs leveraging these in some way.

Here, we additionally describe links to ongoing MIPs that are endorsed by CMIP6, noting that earlier versions of many of these MIPs were part of CMIP5 and so provide a similar synergy for any CMIP5 models participating in CDR-MIP.

Given the emphasis on carbon cycle perturbations in CDR-MIP, there is a strong synergy with C4MIP which provides a baseline, standard protocols, and diagnostics for better understanding the relationship between the carbon cycle and the climate in CMIP6 (Jones et al., 2016b). The C4MIP emissions-driven SSP5-8.5 scenario (a high CO_2 emission scenario with a radiative forcing of 8.5 Wm^{-2} in year 2100) simulation, esm-ssp585, is a control run and branching pathway for several CDR-MIP experiments. CDR-MIP experiments may equally be valuable for understanding model responses during related C4MIP experiments. For example, the

C4MIP experiment ssp534-over-bgc is a concentration driven "overshoot" scenario simulation that is run in a partially coupled mode. The control run required for analyses of this simulation is a fully coupled CO_2 concentration driven simulation of this scenario, ssp534-over, from the Scenario Model Intercomparison Project (ScenarioMIP). The CDR-MIP experiment, C2_overshoot, which is a fully coupled CO_2 emission driven version of this scenario, will provide additional information that can be used to extend the analyses to better understand climate-carbon cycle feedbacks.

The Land Use Model Intercomparison Project (LUMIP) is designed to better understand the impacts of land-use and land-cover change on the climate (Lawrence et al., 2016). The three main LUMIP foci overlap with some of the CDR-MIP foci, especially in regards to land management as a CDR method (e.g., afforestation/reforestation). To facilitate land-use and land-cover change investigations LUMIP provides standard protocols and diagnostics for the terrestrial components of CMIP6 Earth system models. The inclusion of these diagnostics will be important for all CDR-MIP experiments performed with CMIP6 models. The CDR-MIP experiment on afforestation/reforestation, C3 (esm-ssp585-ssp126Lu-ext), is an extension of the LUMIP esm-ssp585-ssp126Lu simulation beyond 2100 to investigate the long-term consequences of afforestation/reforestation in a high-CO_2 world (Section 4.3).

ScenarioMIP is designed to provide multi-model climate projections for several scenarios of future anthropogenic emissions and land use changes (O'Neill et al., 2016), and provides baselines or branching for many MIP experiments . The ScenarioMIP SSP5-3.4-OS experiments, ssp534-over and ssp534-over-ext, which prescribe atmospheric CO_2 to follow an emission overshoot pathway that is followed by aggressive mitigation to reduce emissions to zero by about 2070, with substantial negative global emissions thereafter, are used as control runs for the CDR-MIP CO_2 emission driven version of this scenario. Along with the partially coupled C4MIP version of this experiment, these experiments will allow for qualitative comparative analyses to better understand climate-carbon cycle feedbacks in an "overshoot" scenario with negative emissions (CDR). If it is found that the carbon cycle effects of CDR are improperly accounted for in the scenarios, then this information can be used to recalibrate older CDR-including IAM scenarios and be used to better constrain CDR when it is included in new scenarios.

The Ocean Model Intercomparison Project (OMIP), which primarily investigates the ocean-related origins and consequences of systematic model biases,

will help to provide an understanding of ocean component functioning for models participating in CMIP6 (Griffies et al., 2016). OMIP will also establish standard protocols and output diagnostics for ocean model components. The biogeochemical protocols and diagnostics of OMIP (Orr et al., 2016) are particularly relevant for CMIP6 models participating in CDR-MIP. While the inclusion of these diagnostics will be important for all CDR-MIP experiments, these standards will be particularly important for facilitating the analysis of our marine CDR experiment, C4 (Section 4.4)."

#4 Section 3.5 Model driftShortly state acceptable model drift as described by Jones et al. (2016b) (as done on Page 26, lines 832-839).

Done. Text has been added stating that, " This means that land, ocean and atmosphere carbon stores should each vary by less than 10 GtC per century (long-term average ≤ 0.1 Gt C yr^{-1}). We leave it to individual groups to determine the length of the run required to reach such a state."

#5 Model output frequency subsections in section 4 (4.1.2, 4.2.2, 4.2.4,4.2.6, 4.3.2, 4.4.2) Combine these subsections into one and refer to Table 8 for details to avoid extensive repetition.

Thanks for the suggestion. These sections have been combined and placed into Section 5.

#6 Section 4.2 Very lengthy to read. Shorten and focus.

We have deleted two large sections of text that were repetitions of what had been stated in Sections 2 and 3.1. This should shorten and focus the section.

#7 Section 4.2.1[Page 26, lines 832-839] move to section 3.5 and remove here.

Done.

#8 Section 4.3Same as #6, try to shorten and focus.

We have deleted a large section of text to shorten this section down to two, more focused paragraphs.

#9 Section 7 Code and/or data availability[Page 41] To avoid repetition, combine this section with section 5.4 into one.

We had originally done this, but the journal explicitly requires that we have section

on "Code and/or Data Availability", which is why we added this section at the request of the Journal after uploading our original manuscript. However, we do agree that some information is repetitive and have tried to change text in other sections to refer to this one if possible.

Minor comments

[Page 7, lines 206-207 and 222-225] repetition

The sentence that was on lines 206-207 had been deleted to avoid repetition.

[Page 7, lines 223-224] clarify: a good test for what?

We have deleted this sentence since it repeats, in a less clear manner, what was said in the introductory paragraph to this section where we state that, "CDR-MIP results may also be able to provide information that helps to understand how model resolution and complexity cause systematic model bias. In this instance, CDR-MIP experiments may be especially useful for gaining a better understanding of the similarities and differences between global carbon cycle models because we invite a diverse group of models to participate in CDR-MIP".

[Page 18, line 577] 'not mandatory, nor a prerequisite' replace 'not' with 'neither'.

Corrected.

[Page 19, lines 621-622] In 'limiting the number experiments' add 'of'.

Corrected.

[Pages 20-21, lines 658-661] Remove sentence 'Moreover, since many...'

Done.

[Page 21, lines 668-669] Remove sentence 'Note that piControl...'

Done.

[Page 28, lines 911-912] Remove sentence 'EMICs and box models...' and include this information in subsection about model output frequency (see #5).

Done.

[Page 29, lines 922-924 and 936-937] Remove sentence 'EMICs and box models...'

Done.

[Page 45, line 1437] '2.8° longitude by 1.6° longitude' do you mean '2.8° longitude by 1.6° latitude'?

Yes, this has been corrected.

Tables

[Tables 2-7] Including a column with the name of the preceding run from which the experiment is to be started will increase clarity.

Thanks for the suggestion. A new column called "Initialized using a restart from" has been added to each of these tables.