Response to reviewer #3

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

Review:

In the manuscript 'The Carbon Dioxide Removal Model Intercomparison Project (CDR- MIP): Rationale and experimental design' the authors document the experimental de- sign for a suite of coordinated experiments, designed to explore potential, risks and uncertainties in Earth System response to carbon dioxide removal (CDR) from the atmosphere. The authors provide a sound and detailed motivation for this suite of coordinated experiments, emphasizing connection with other model intercomparison exercises.
I much appreciate this paper, which is not only highly relevant in the context of UNFCCC COP21 objectives. IT is also relevant for some WCRP grand challenges topics such as reducing uncertainties in climate sensitivity and constraining climate-carbon cycle feedbacks. Therefore, I recommend acceptance of this manuscript after some minor revisions listed below.

General comments:

1) Some sections are really long to read. I would therefore recommend to bring upfront important message.

To address this comment and those by other reviewers we have shortened several sections, e.g., Section 3.1, 4.2, and 4.3, and spent a considerable amount of time reducing repetitions, e.g., by condensing the multiple model output frequency sections into one. Hopefully, these improvements have made the text more readable and brought the important messages to the forefront.

2) Some experiments seem to complement existing MIP coordinated simulation while some other don't. It would be convenient to clearly state why those later are independent (or new) from existing experiments.

As also suggested by another reviewer we have revised the section describing the relationship to other existing MIPs. In doing this we state up front that, " There are no existing MIPs with experiments focused on climate "reversibility", direct CO_2 air capture (with storage), or ocean alkalinization." *before describing the links that exist between CDR-MIP and other MIPs. This should clarify how CDR-MIP experiments differ from and are complementary to other existing MIP experiments.*

3) There is no documentation or information on how this MIP will address the role of the internal climate variability. As I read the present ms, it seems that exp produce a sufficient signal-to-noise ratio. However, for some exp, especially those in emission-driven simulations

recommendation and sensitivity relative to the ensemble size seems required.

We do recommend that groups conduct 3 ensemble members (Section 3.3) to deal with variability. However, for CDR-MIP, interannual variability is likely to be a larger issue than internal model variability. Pervious studies such as Hewitt et al., (2016) that looked at this issue with a focus on the carbon cycle, which is especially relevant for CDR-MIP, found that when comparing simulations of CMIP5 scenarios for land-carbon fluxes, the model spread was so big that it was the primary source of uncertainty. While for ocean carbon uptake, the variance attributed to differences between representative concentration pathway scenarios exceeded the variance attributed to differences between climate models. In most models "internal variability" (assuming this means "sensitivity to perturbed initial conditions") was fairly small – especially on decadal scales. Interannual variability of carbon fluxes was high, but tended to even out on >5 year timescales. Based on this knowledge, we recommend that modelling groups perform at least three ensemble members to reduce this uncertainty related to variability, but leave it up to each group to determine how much of an issue this is and whether it requires more or fewer runs. Thus, section 3.3 states that, " We encourage participants whose models have internal variability to conduct multiple realizations, i.e. ensembles, for all experiments. While these are highly desirable, they are neither mandatory, nor a prerequisite for participation in CDR-MIP. Therefore, the number of ensemble members is at the discretion of each modeling group. However, we strongly encourage groups to submit at least three ensemble members if possible."

Specific comments (note that in the pdf of original comments the symbols Âa˘ were present):

L52: It could be nice somewhere to refer to the IPCC definition of mitigation.

We have added the sentence " To do this a massive climate change mitigation effort to reduce the sources or enhance the sinks of greenhouse gases (IPCC, 2014b) must be undertaken." *to the second paragraph in the introduction.*

L59: impacts= climate impacts?; efficacy refer to technological scalability here? I don't think CDR-MIP address this very specific point.

*"Impacts" has been changed to "climate impacts". No we did not mean efficacy from a technical viewpoint. To clarify what CDR-MIP focuses on we have added text to point out that we are referring to, "*atmospheric CO_2 reduction efficacy".

L81: please indicated what is the reference period used to defined the prein- dustrial level.

We are referring to the year 1850 and have added this information to the sentence.

L85: rather use "attributed to anthropogenic...".

*We have added the words "*attributed to*" to this sentence.*

L91: limiting warming= limiting anthropogenic warming

Change made.

L116: please indicate that these are all models(=IAMs) results and are hence speculative. . .

*Done, we now state that "*All future Integrated Assessment Model (IAM) scenarios indicate...*".*

L135-141: "help to mitigation" and "potential effectiveness" are redundant. The last point need to be clearer. As I understand the various foci of CDR-MIP, there are: - Effectiveness - Risks and benefits including avoided impacts - Related carbon cycle –climate feedbacks

We have eliminated the redundant bit from point (ii) by deleting the word "effectiveness". We have also tried to clarify point (iii) by changing it to read, " To inform how climate and carbon cycle responses to CDR could be included when calculating and accounting for the contribution of CDR in mitigation scenarios, i.e., so that CDR is better constrained when it is included in IAM generated scenarios."

L235: issue of permanence has to be taken with cautious here. Indeed, CDR-MIP is designed for ESM, EMIC and boxmodel. Those models are not designed to address carbon storage leakage (fit for purpose). They can only document the response of the Earth system when a leakage occurs.

Yes, thanks for pointing this out as it is an issue. In some models permanence cannot really be calculated. However, for models with more complex components some questions about permanence can be evaluated. For example, if a forest is planted and takes up carbon (afforestation forcing), and then at some point experiences dieback or carbon loss due to a warmer drier future climate (as internally calculated), some of the sequestered carbon may be released again. Or if we add alkalinity to the ocean and then stop adding it at some point, we can evaluate if any of the carbon that was sequestered is released again. We have added a statement to address this issue. Question 4 now reads, " For methods that enhance natural carbon uptake, e.g., afforestation or ocean alkalinization, where is the carbon stored (land and ocean) and for how long (i.e. issues of permanence; at least as much as this can be calculated with these models)?"

L273: Please refer to {Smith:2015}

Done.

L386: CMIP5, are you sure?

Yes, at least some of them are.

L654 doubtful = unrealistic

Word substitution made.

L663: Why C1 doesn't rely on abrupt 4xCO2 rather than 1%CO2.

We considered several designs for C1 such as an abrupt 4xCO2 perturbation. However, after much discussion we decided upon a 1%CO2 experiment because it will better capture the slow ocean response to perturbations.

L841: As I read it: there is a removal of 100Gt in one year. Are you expecting a pulse removal (1 model time-step) are a smoothed removal during one year? Besides, do you expect a spatial structure of the CO2 removal?

Thank you for pointing out that we missed these details. This is an instantaneous removal of CO_2. We do not expect a spatial structure for the CO_2 removal and will leave it up to modelling groups where CO_2 is spatially distributed to find the best way to uniformly remove CO_2 from their atmosphere. We have added text so that this section now reads, " with 100 Gt C instantaneously (within 1 time step) removed from the atmosphere in year 10. If models have CO_2 spatially distributed throughout the atmosphere, we suggest removing this amount in a uniform manner."

L1043-1047: Why not relying on a constant afforestation? LUMIP T1 exp is a constant deforestation. It would have been a complementary model experiments here.

We had considered doing such a simulation in our numerous discussions on how to devise an afforestation simulation for CDR-MIP. The main reason that we did not do an afforestation simulation to compliment the LUMIP deforestation simulation is that the deforestation simulation is CO_2 concentration-driven and we wanted to have a CO_2 emission-driven simulation so that we could quantify climate-carbon cycle feedbacks. The esm-ssp585- ssp126Lu *was then our best choice, especially since other groups would be performing emission-driven SSP5-8.5 simulations as part of C4MIP and ScenarioMIP.*

L1437 2.8◦ longitude by 1.6◦ latitude

Typo corrected.