Review for "Projected changes in land carbon store over the 21st century: what contributions from land-use change and atmospheric nitrogen deposition?"

Summary- In this study, the authors present an analysis of land carbon store (or CLCS) for different scenarios where different variables projected by Integrated Assessment Models (IAMs) are used as forcings for a land surface model – ORCHIDEE-v3. Specifically, the authors present results for variation in the CLCS results associated with changing values of CO2 concentrations , changing values of land use and changing values of N deposition. The authors have found that there is significant regional heterogeneity when it comes to the sensitivity of CLCS change to change in aforementioned factors.

Coupling of IAMs and ESMs is a topic of rising importance and is indeed gaining more attention as a part of the CMIP exercises. Moreover, the projections of variables such as nitrogen deposition in IAMs are relatively under studied and are therefore important to quantify via coupling with ESMs. Such coupling exercises can indicate what IAMs are missing. Therefore, this is clearly an important topic and an important question.

I largely followed the paper and its findings. However, I had some questions regarding the findings themselves and regarding the methodology. I recommend publication after the authors respond to the comments-

<u>Main comments</u>

1) **<u>Inter SSP spread vs inter IAM spread-</u>** I understand that the authors have used the "marker" scenarios for selected SSP scenarios as the inputs to the ESM since those are the only ones available. However, I'm not sure about the places where the authors conclude that the Inter SSP spread for the marker scenarios is similar to the inter IAM spread. The Inter IAM spread is largely the result of parameterizations and modelling choices (e.g., AIM is a CGE model while GCAM is a partial equilibrium model). The SSPs are socio-economic storylines on the other hand. Comparing the two seems like an apples to oranges question to me. I agree that the authors have concluded by saying more scenarios need to be made available (other than these marker scenarios). However, it still seems unconvincing to me to treat the marker spread as the IAM spread. Also note that the way land use, nitrogen and carbon cycle is modelled may be very different from IAM to IAM. Can the authors produce the spread for a region or two to assess the robustness of their assumption (as opposed to the global spread for the selected variables)?

2) **<u>Documentation of IAM processes-</u>** I believe this paper would benefit by a table which documents which IAMs are used in which marker scenarios and a summary of the assumptions used by the IAM for the land use change and N deposition modelling. The description does not have to be extensive, and the idea here would be that the reader would know what overall assumptions are going into these marker scenarios for the selected variables.

3) **PFT driven differences-** The other reviewer alluded to this as well, but it seems that there may be fundamental land type (or PFT)driven differences across scenarios. Can the authors document how the CLCS from individual or aggregated land types looks across scenarios? Can the authors also add a figure which shows the responses across different land types?

4) **Spatial results-** The regional heterogeneity is indeed interesting. I wanted to know if it was possible to show the mu or sigma values calculated as a map to identify hotspots for different variables. Basically, Figure A11 shown as a map with 3 facets (CCO2, LUC and NIN). This would really be an interesting analysis and also help pull out some within region dynamics. I also believe this is one of the bigger advantages of this coupling exercise.

5) **Takeaways for IAM modelers-** I apologize if this sounds vague. But can the authors frame some takeaways for IAM modelers other than the important point that more IAM scenarios need to be made available at a fine resolution? Sensitivity analysis such as these are often used to indicate areas where IAMs are weak and should produce better results or future focus areas for IAMs. Can the authors broaden the discussion to include some takeaways? One obvious one is that modelling of nitrogen deposition can have a significant impact on CLCS storage in some regions. Perhaps there are few more points that can be used.

6) **Description of methodology-** This manuscript would benefit from the inclusion of a flow chart which shows the inputs and the outputs. For example, IAM marker scenarios are inputs to the ORCHIDEE model. Also, there is a step where the LUH2 data (IAM marker scenarios) are further transformed to match ORCHIDEE's PFTs, correct? Can this be described in more detail? Did this downscaling add more uncertainty?

Minor points

1) **Page 1 Line 14-15-** This is a bit awkwardly worded. Perhaps you can cut the sentence at " More precisely, only one IAM output is used as representative of a single SSP". I'm not sure what the rest of the sentence adds.

2) **Page 2 Line 34-35-** " In the following, and by simplicity, we refer to these eight scenarios as SSPs" can be " Here forward we refer to these scenarios as SSPs for simplicity."

3) **Page 3 Line 64-66-** Note that recently there have been two way coupling exercises to couple IAMs and LSMs to address such uncertainties. See the E3SM exercises (https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2022MS003156) as an example. This can probably be cited to ground the current study better. Note I am no way related to the study mentioned here!

4) **Page 3 Line 77-78-** Is ORCHIDEE a part of the Global Carbon Project suite of models? I see that the Fridgelstein paper is cited later, but perhaps that can be explicitly mentioned as well (If that is true).

5) **Page 3 Line 91-92-** What resolution does ORCHIDEE operate at? Is it the same resolution as LUH2 or is it something different? That can be mentioned somewhere.