We thank the reviewer #2 for the constructive comments on our manuscript. Below, we answer to each of them. In black, are the reviewer comments and in red our responses and in italics, the additional text we propose to add in the revised manuscript.

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-

Main comments

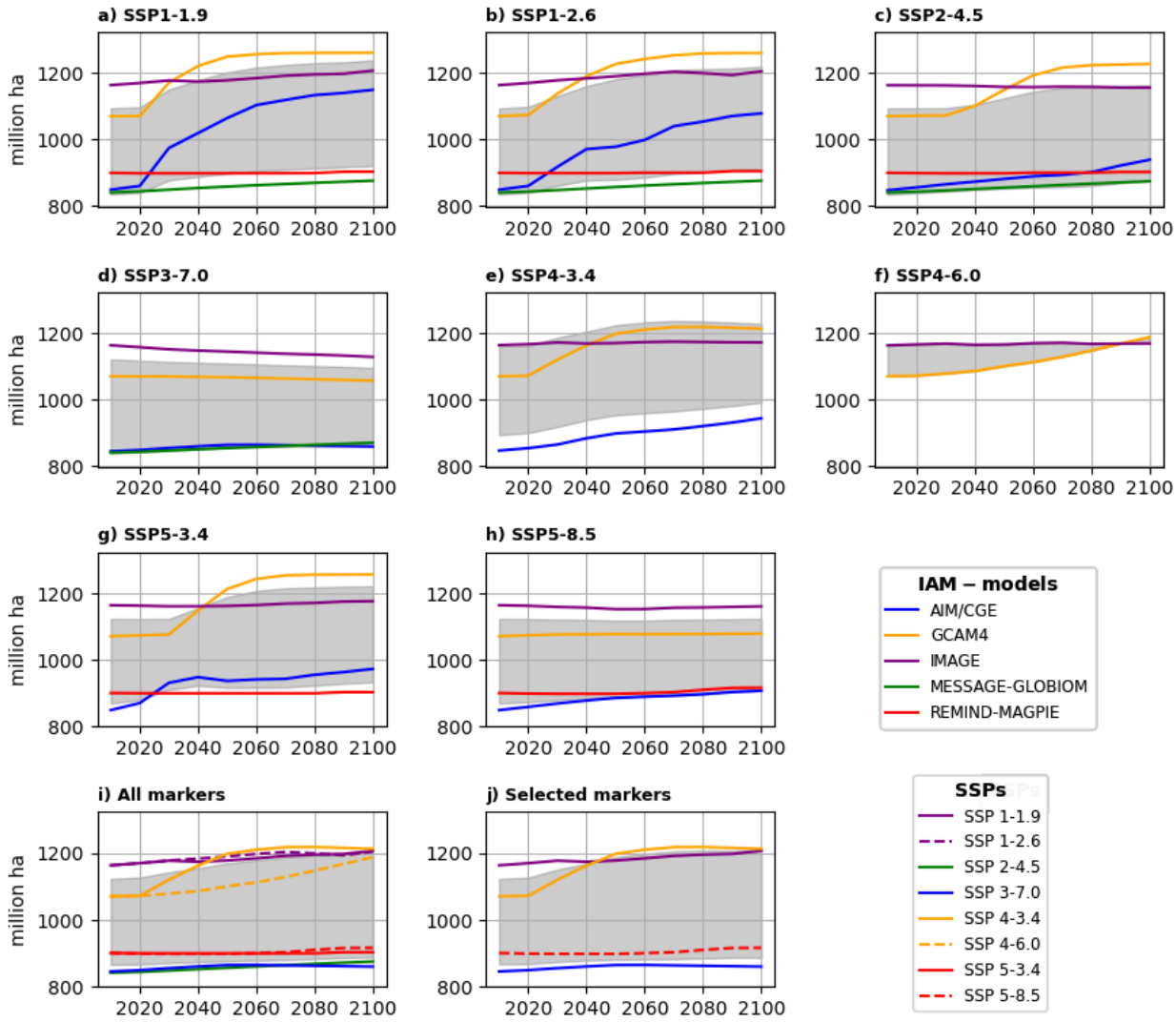
1) Inter SSP spread vs inter IAM spread- I understand that the authors have used the "marker" scenarios for selected SSP scenarios as the inputs to the ESM since those are the only ones available. However, I'm not sure about the places where the authors conclude that the Inter SSP spread for the marker 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)?

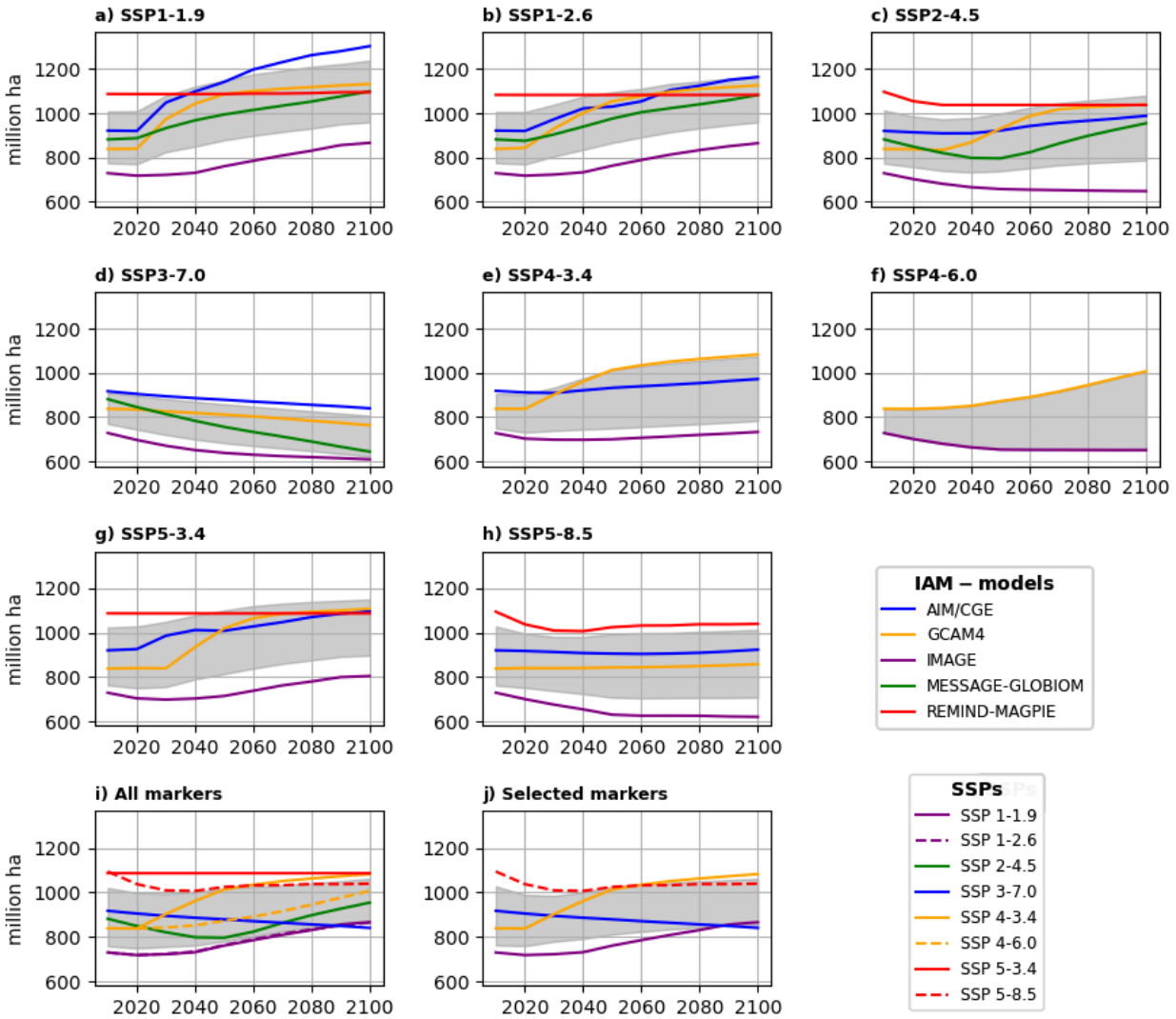
We agree on the "conceptual" difference between the inter IAM spread and inter SSP spread for the marker. Yes, the IAM spread is largely induced by different modelling frameworks, while the SSP spread correspond to different socio-economic storylines. What we wanted to highlight is that, although they have different origins, these two spreads are of similar magnitude when looking at IAM's variables used directly or

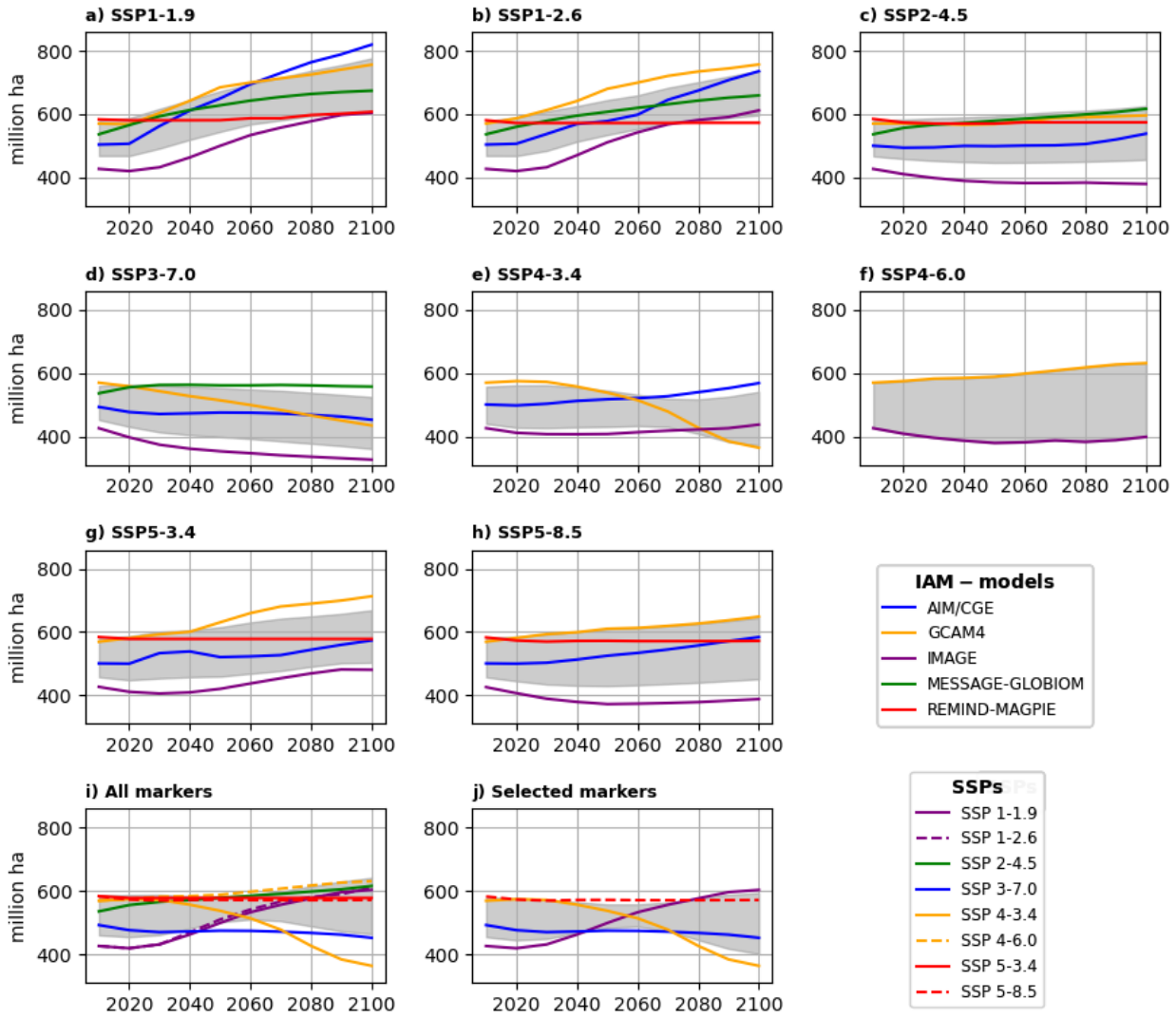
indirectly to constrain land surface models. In the manuscript, we showed comparisons between inter-IAM spread and inter-SSP spread at global scale. In order to ensure that what has been highlighted at global scale remains valid at regional scale, we performed a regional analysis, as suggested by the reviewer. The data we used for processing Figures 1, 2 but also A1, A2 and A3 is IAM output data produced for CMIP6, available on the SSP Database (https://tntcat.iiasa.ac.at/SspD). They are accessible at global scale but also for five aggregated geographical and/or economical regions. These five regions are “Asia” (ASIA), “Latin America” (LAM), “Reforming economies (REF), “Middle East and Africa” (MEA) and countries from the “Organisation for Economic Co-operation and Development” (OECD). We re-processed for the five aggregated regions (see Figures below) the Figure 1 which shows the time evolution (2015-2100) of the forested land area projected by different Integrated Assessment Models (IAM) for different Shared Socio-economic Pathways. The results of this regional analysis show that the inter-IAM spread is significant for any of the five regions and comparable to the selected SSP markers spread. As a consequence, the assumption of using the selected SSP markers spread as a proxy for the inter-IAM spread based on a global analysis remains valid at regional scale. We do not suggest to keep these extra figures as part of the manuscript nor in the Appendix. Nevertheless, we propose to add extra information in the manuscript reporting on this regional analysis.

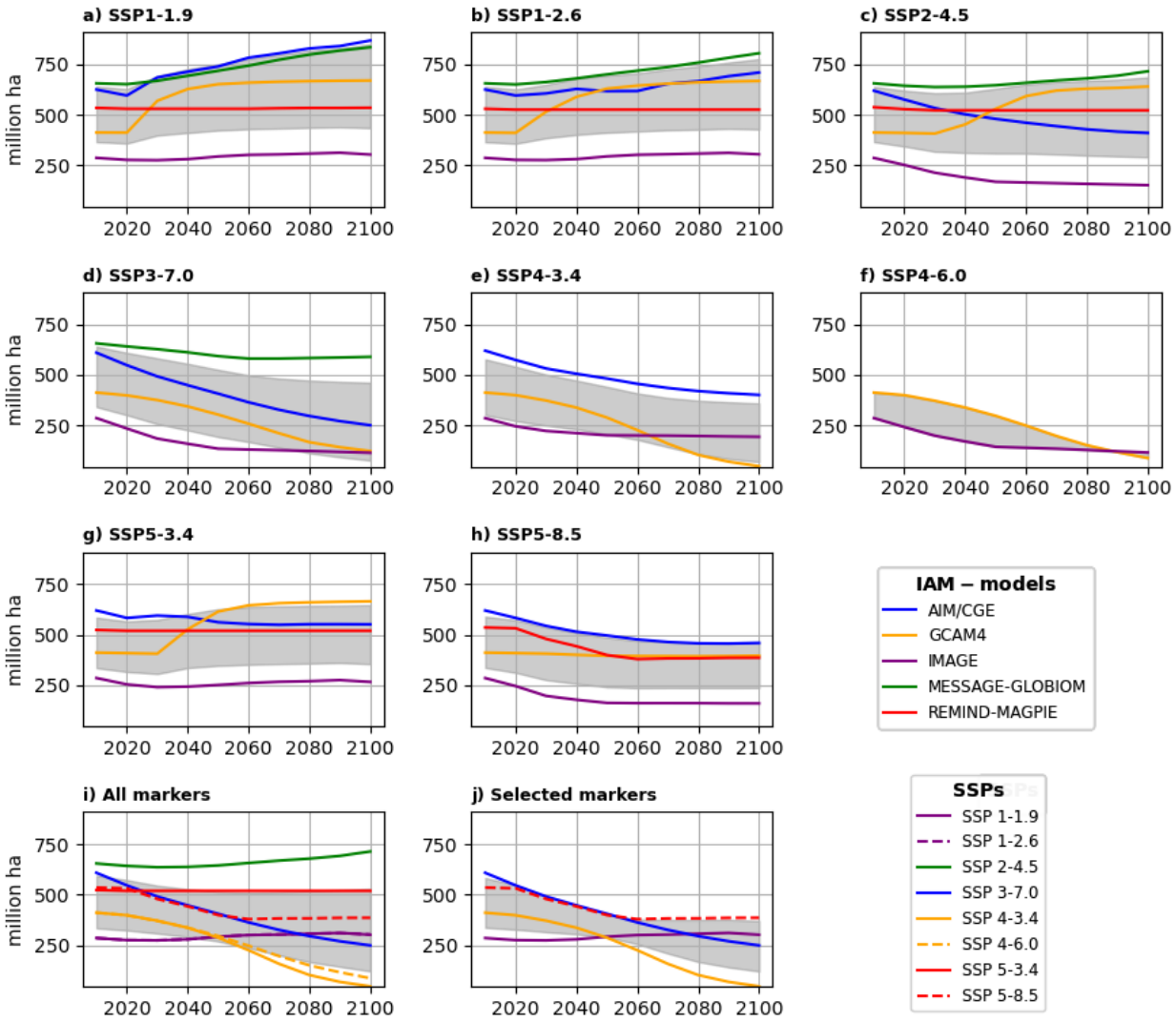
Line 130, we propose to add the following sentence:

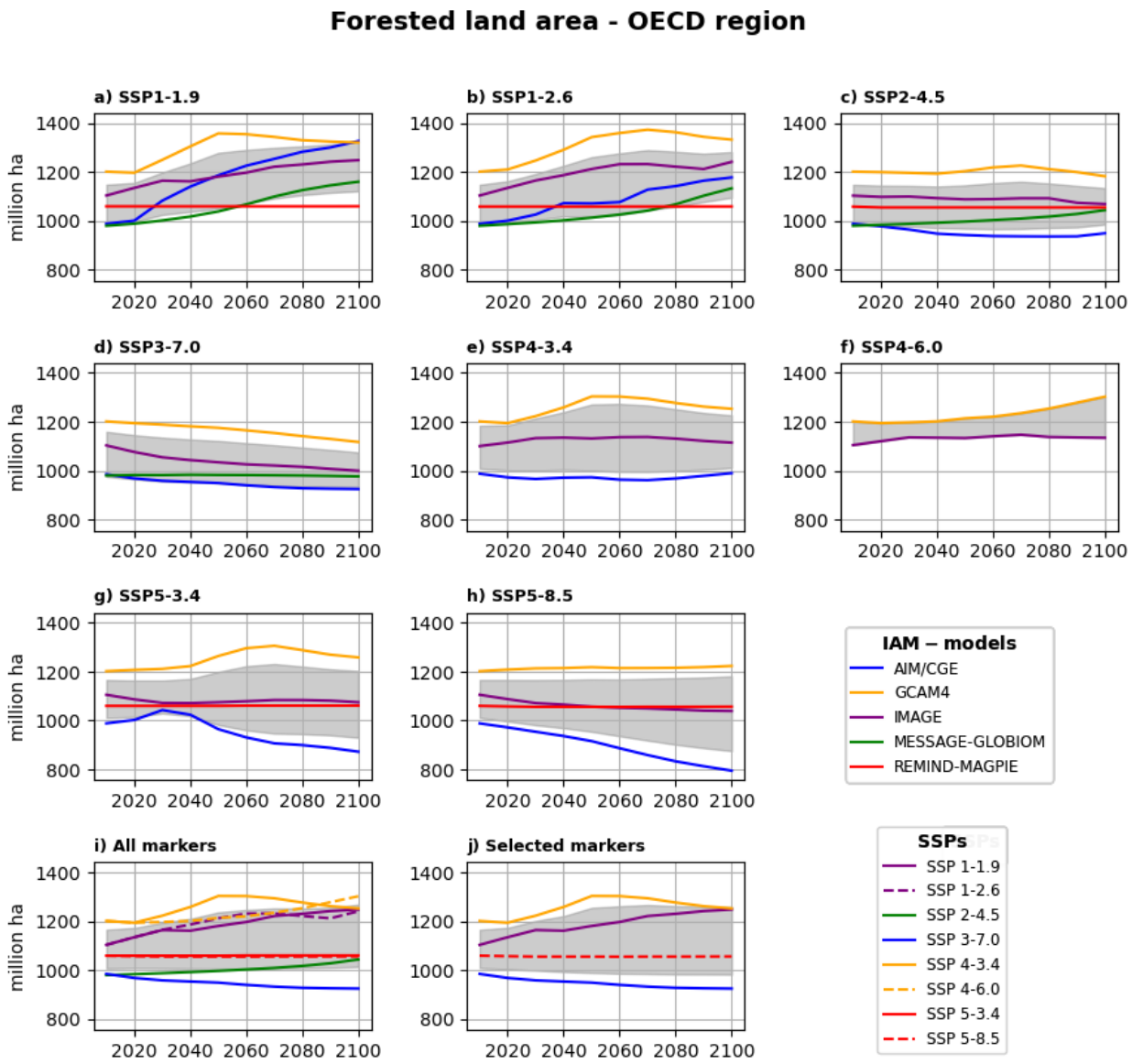
“The comparison between inter-SSP markers and inter-IAM trajectories for the different SSPs is presented at global scale, but the conclusion that the selected SSP markers spread is comparable to the inter-IAM spread for the different SSPs remains valid at regional scale (based on the data available on the SSP Database for five aggregated regions (“Asia”, “Latin America”, “Reforming economies”, “Middle East and Africa” and countries from the “Organisation for Economic Co-operation and Development”*), not shown).*


Forested land area - REF region
a) SSP1-1.9
b) SSP1-2.6
c) SSP2-4.5
d) SSP3-7.0
e) SSP4-3.4
f) SSP4-6.0
g) SSP5-3.4
h) SSP5-8.5
i) All markers
j) Selected markers
million ha
800
1000
1200
2020
2040
2060
2080
2100
IAM – models
AIM/CGE
GCAM4
IMAGE
MESSAGE-GLOBIOM
REMIND-MAGPIE
SSPs
SSP 1-1.9
SSP 1-2.6
SSP 2-4.5
SSP 3-7.0
SSP 4-3.4
SSP 4-6.0
SSP 5-3.4
SSP 5-8.5


Forested land area - LAM region
a) SSP1-1.9
b) SSP1-2.6
c) SSP2-4.5
d) SSP3-7.0
e) SSP4-3.4
f) SSP4-6.0
g) SSP5-3.4
h) SSP5-8.5
i) All markers
j) Selected markers
million ha
600
800
1000
1200
2020
2040
2060
2080
2100
IAM – models
AIM/CGE
GCAM4
IMAGE
MESSAGE-GLOBIOM
REMIND-MAGPIE
SSPs
SSP 1-1.9
SSP 1-2.6
SSP 2-4.5
SSP 3-7.0
SSP 4-3.4
SSP 4-6.0
SSP 5-3.4
SSP 5-8.5


Forested land area - ASIA region
a) SSP1-1.9
b) SSP1-2.6
c) SSP2-4.5
d) SSP3-7.0
e) SSP4-3.4
f) SSP4-6.0
g) SSP5-3.4
h) SSP5-8.5
i) All markers
j) Selected markers
million ha
800
600
400
2020
2040
2060
2080
2100
IAM – models
AIM/CGE
GCAM4
IMAGE
MESSAGE-GLOBIOM
REMIND-MAGPIE
SSPs
SSP 1-1.9
SSP 1-2.6
SSP 2-4.5
SSP 3-7.0
SSP 4-3.4
SSP 4-6.0
SSP 5-3.4
SSP 5-8.5


Forested land area - MAF region
a) SSP1-1.9
b) SSP1-2.6
c) SSP2-4.5
d) SSP3-7.0
e) SSP4-3.4
f) SSP4-6.0
g) SSP5-3.4
h) SSP5-8.5
i) All markers
j) Selected markers
million ha
750
500
250
2020
2040
2060
2080
2100
IAM – models
AIM/CGE
GCAM4
IMAGE
MESSAGE-GLOBIOM
REMIND-MAGPIE
SSPs
SSP 1-1.9
SSP 1-2.6
SSP 2-4.5
SSP 3-7.0
SSP 4-3.4
SSP 4-6.0
SSP 5-3.4
SSP 5-8.5



2) Documentation of IAM processes- 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.

We thank reviewer #2 for the suggestion. Indeed, adding a table with information on the IAMs and the assumptions done about land modelling will be useful. We propose to prepare and add such table in the revised manuscript based on the information we can gather from https://www.iamcdocumentation.eu/index.php/IAMC_wiki#Documentation

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?

Thanks for this suggestion. We propose to add three additional figures as Supplementary information in the revised manuscript, similar to the original Figure 4 but focusing respectively on forested lands, grasslands and croplands. Nevertheless, in order to avoid that the signals represented in these figures are impacted by the change in areas for respectively forest lands, grasslands, croplands, due to land-use changes, we propose to not express the CLCS in 'absolute values' (in PgC) but rather per unit area of respectively forest lands, grasslands and croplands (expressed in kgC m^{-2}). These figures are not presented here as their production requires to get access to output data per vegetation type (PFTs) and specific processing (a longer than initially expected process), but they will be included and discussed in the revised version of the manuscript.

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.

Yes, indeed, it's a good suggestion. We processed the suggested figures which are shown here below. The figure A shows the mean ($\boldsymbol{\mu_{CLCS,TOT}}$) and standard deviation ($\boldsymbol{\sigma_{CLCS,TOT}}$) of the change in carbon by 2100 (relatively to 2014) accounting for all the different CCO2, LUC and NIN trajectories for the total land (CLCS), vegetation (CVCS) and litter+soil (CSCS) reservoirs. These maps correspond to the spatial analysis of the information represented by the white area in 2100 on Figure 4, Figure A11 and Figure A12. The figure B represents the relative impact by 2100 on the CLCS, CVCS and CSCS dispersions of the three drivers (ie. CCO2, LUC and NIN). It corresponds to the spatial analysis of the $\boldsymbol{r_{CVCS,D}}$ variable shown on Figure 4, Figure A11 and Figure A12 with the blue, orange and green stacks.

We propose to add these two additional figures in the core of the manuscript with relevant description of the spatial distribution of each diagnostic.

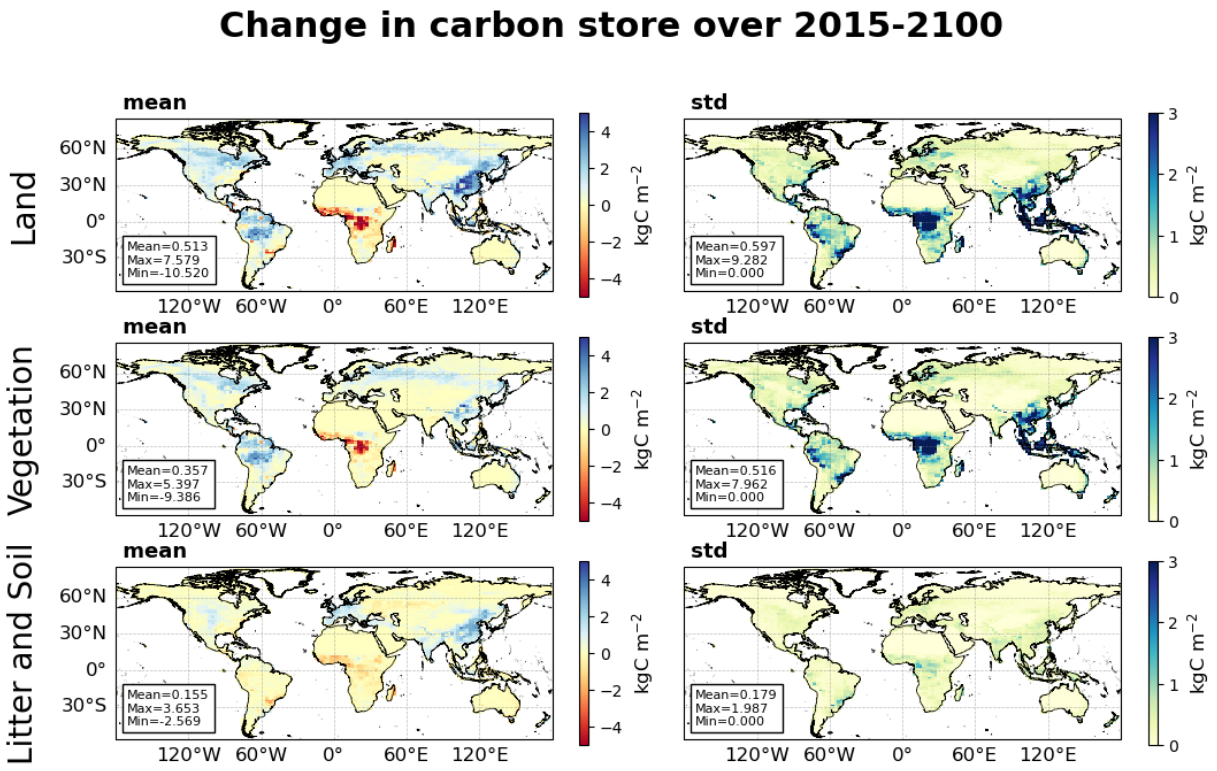


Figure A - Mean ($\mu_{CLCS,TOT}$) and standard deviation ($\sigma_{CLCS,TOT}$) of the change in carbon by 2100 (relatively to 2014) stored in land (CLCS), vegetation (CVCS) and litter+soil (CSCS) accounting for all the different trajectories regarding atmospheric [CO2] and associated climate (CCO2), land-use change (LUC) and atmospheric N deposition and fertilisation (NIN)

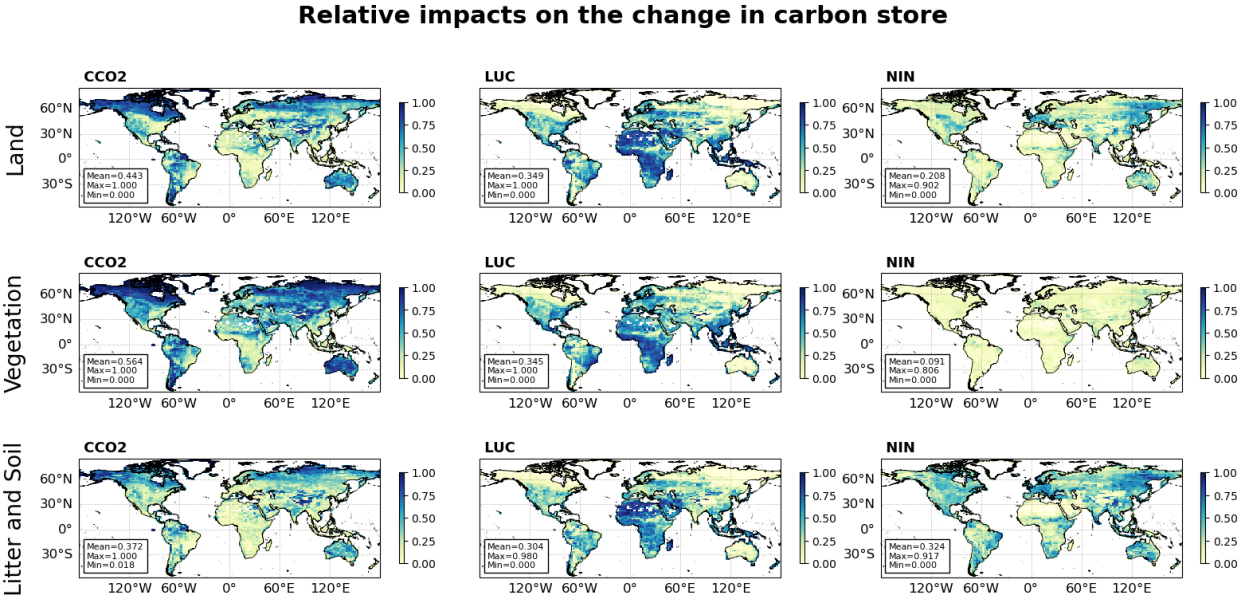


Figure B - Relative impact ($r_{CLCS,D}$ (eq. 11)) of the different trajectories regarding atmospheric [CO2] and associated climate (CCO2), land-use change (LUC) and atmospheric N deposition on the change in carbon by 2100 (relatively to 2014) stored in land (CLCS), vegetation (CVCS) and litter+soil (CSCS)

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.

We agree that the takeaways message for IAM modelers were relatively vague and not discussed enough in the original manuscript. We propose to add a few points in the "summary and conclusion" section at the end:

"In addition, given the large impact of land use change differences between IAMs (for a given SSP) and the significant impact (although lower) of N inputs, we also recommend that the IAM community provides more information on the uncertainties associated to these drivers. For instance, it would be informative to obtain quantitative information on the uncertainty associated to these variables, with a high and a low range trajectory for each driver and whether these uncertainties stand from structural or parametric IAM uncertainties. Information on the degree of correlation between the uncertainty associated to each driver (land use and N inputs) would also help to propagate them in LSMs and ESMs simulations."

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?

Thanks again for the suggestion. We will prepare a flow chart that will look like to the one here below. It is true that there is a step between the LUH2 data and the land-use maps used as input of ORCHIDEE. This procedure is very briefly mentioned in the manuscript at lines 95-96: "The procedure needed for translating the original data for land-use into the fifteen land classes of ORCHIDEE is described in Lurton et al. (2020)." We propose to add the following information: *"In this procedure, information regarding the cropland and pasture areas from LUH2 is preserved while natural land is split into the different unmanaged land classes of ORCHIDEE using data from the ESA CCI Land cover product (ESA, 2022)."*

This procedure is highly model-specific and, as a consequence, may add uncertainty when performing multi-model analysis. When using a single land surface model as we do in our study, we don't think this downscaling add significant uncertainty on the studied variables.

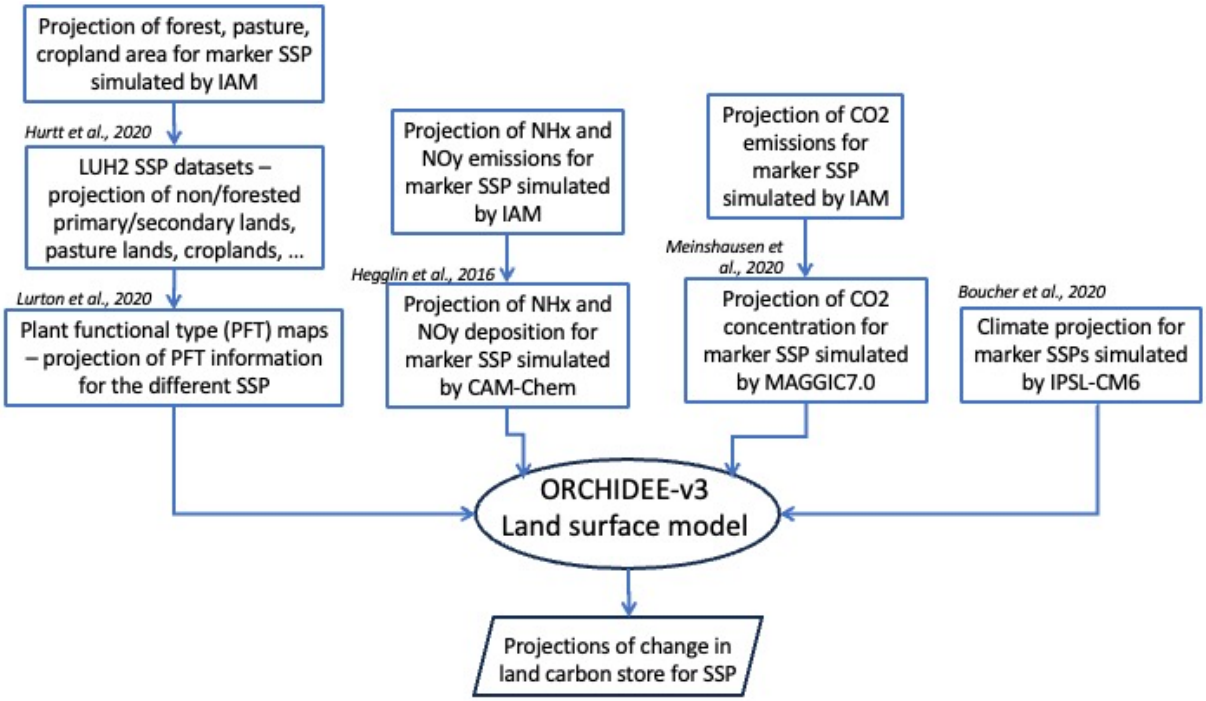


Figure C – Flow chart of the modelling framework highlighting the different input data (rectangles), the land surface model (ellipsoid) used in this study and the main output data produced (parallelogram)

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.

Thanks, the rest of the sentence will be removed.

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."

We'll rephrase the sentence as proposed. Thanks for the suggestion.

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!

We agree that indeed there are some attempts to have more coupled initiative linking IAMs and ESMs. The development of the E3ESM model represents one initiative from DOE (Department of Energy in the USA) to link energy questions to climate projections by ESMs. However, E3ESM only makes a first step in that direction as it does not yet

inlcude all economical drivers of the IAMs. We add the reference to Golaz et al., (2022) in addition to the one to Monier et al. (2018).

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).

Yes, ORCHIDEE-v3 contributed to the Global Carbon Budget over the last four years. We rephrase the sentence at lines 87-88 to include this information: *"It also ranked with a good score for a set of key land variables in a recent model benchmark study (Seiler et al., 2022) as well as in the TRENDY model inter-comparison project* ***as part of the land surface models contributing to the Global Carbon Budget*** *(Friedlingstein et al., 2022)."*

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.

No, indeed, ORCHIDEE runs at the resolution of the climate data, which is here the resolution of the IPSL-CM6 model (i.e. a global resolution of 2.5°x1.27° in longitude and latitude). We will add this information at line 101: *"In this study, ORCHIDEE-v3 ran at the same resolution as the climate input data (i.e. 2.5°x1.27°)."*

References

ESA: ESA CCI Land cover website, https://www.esa-landcover-cci.org/ (last access: 11 March 2022).

O'Sullivan, M., et al. (2022). "Process-oriented analysis of dominant sources of uncertainty in the land carbon sink." Nature Communications 13(1).