Responses to reviews for manuscript **Global Rules for Translating Land-use Change (LUH2) To Land-cover Change for CMIP6 using GLM2**

To Reviewer #1:

Reviewer 1: This is a revision of a previously reviewed manuscript. The authors have done a good job addressing the reviewer comments (which was not a trivial task), but there are still a few things that need clarification before publication. I don't have any major concerns. Please see the comments below for details.

Response: Thanks for all comments. We have made some clarifications accordingly. Please see our point-by-point response below.

Reviewer 1: page 3, lines 19-23: It isn't clear what "inconsistent land-cover translation" means here. Inconsistent with LUH? Inconsistent across ESMs/DGVMs?
It seems that the meaning here is leaning toward inconsistency across ESMs/DGVMs, but both inconsistencies are relevant. So I suggest clearly specifying both.
And "globally consistent" is also ambiguous. A rule that is global in spatial extent? Or a rule that is applied consistently by different folks around the globe? Again, it seems like the latter makes more sense here. That it is a global rule is different issue that also generates uncertainty.
Also, "eliminate added uncertainties" is an overly ambitious claim.
Maybe try "Consistent application of a specified rule for translating…could reduce uncertainties from translation inconsistencies in studying…"

Response: 'consistent' here means ESMs/DGVMs are suggested to use the same rule to translate the given land-use change dataset such as the LUH2. We agree with your suggestion and changed the lines to "*Therefore, consistent application of a specified rule for translating land-use products could reduce uncertainties from translation inconsistency in studying land-use effects through ESMs and DGVMs*".

Reviewer 1: page 4, lines 14-16: Please clarify the relationship to LUH2. These GLM2 runs generate and track the exact same LUH2 data as before, and the additional translational tracking does not affect the LUH2 land use transitions. The translation and tracking of vegetation carbon is an additional capacity.

Response: Very good point. We have added this clarification into the first paragraph of section 2.3. It is "*Note that the modified GLM2 still generate and track the exact same land-use transitions of the LUH2 and has the additional function to track associated land cover change in terms of forest cover and vegetation carbon.*"

Reviewer 1: page 5, lines 17-20 Does this mean that the constant spin-up climate is a 100-year average?
How were the stocks and fluxes calculated during the translation simulations?

Did the spin-up produce a spatial, but temporally static, look-up table for use by the simulations, or was it just for initial conditions?
Or are the simulations also driven by some form of static or time-varying climate that determines carbon fluxes and stocks?
It appears later on page 7 that the spinup contributes to parameters for eq. 7. This should be clarified here.

Response: Yes, the 100-year averaged temperature and precipitation are used and remain constant during the spin-up. They are spatially varied but temporally static. Besides, the GLM2 use them to estimate fluxes and stocks (NPP and B(t) at Eq.7), which is explained at the first paragraph of section 2.3. For better clarification, we have changed the description of climatology generation as "*The annual temperature and precipitation maps from MSTMIP were averaged over 1901 and 2000 to generate the spatially varied and temporally static climatological temperature and precipitation, which was then used to spin up the GLM2 globally at 0.25x0. 25° resolution for 500 years.*". Besides, we also added explanation at the paragraph after Eq.7 "*Note that B_0 and NPP_0 are estimated by a statistical model in GLM2 using climatological temperature and precipitation and are constant over simulation period from 850 to 2015.*"

Reviewer 1: page 5, line 30
Is the type of vegetation remaining in the land use categories (5-8) tracked? Or is it just the biomass value that characterizes the vegetation?
Is it assumed that land use categories have no biomass (and no change over time in biomass) if the vegetation has been cleared (this is answered on page 10)?

Response: vegetation remaining in land-use categories 5-8 is indeed tracked. This vegetation has three pathways: 1) If its land-use type remains the same, its biomass will not grow as explained at the second paragraph of section 2.5, and 2) if it is converted to another type of 5-8, like from crop to managed pasture, its biomass will be cleared; 3) if it is converted back to secondary forest or non-forest, its biomass will continue growing, tracked by Eq.7.

Land-use categories 5-8 have biomass only if they have vegetation that came from primary/secondary land and was not cleared due to translation rule.

Reviewer 1: page 6, lines 11-14. Is this correct for gamma? It seems like it should be the opposite: a 1 value for "O" such that the land use type gains vegetation when no clearing occurs. Clearing means that no vegetation would be gained.

Response: we have modified Eq.2 and replaced γ_{ij} by (1-γ_{ij}). In this way, gramma is still 1 for X and F indicating no vegetation could be gained in Eq.1, and gramma is still 0 for O indicating amount of a_{ij} vegetation could be gained.

Reviewer 1: page 7, lines 3-4. This needs clarification, as gamma isn't the same as for the reverse of transitions to land use categories. For example, any transition to land use from primary or secondary would generate a loss of vegetation in primary or secondary land, regardless of clearing, which would mean that gamma is always one for eq. 5; the lost vegetation fraction would either be in a land use category, or it has been cleared.

Response: yes, you are right. Any land-use transitions from primary or secondary would result in vegetation loss in primary and secondary. The lost vegetation could be remained in cropland, pasture or rangeland if translation rules indicate O, or be removed if the rules indicate X/F. We have corrected it by removing γ_{ji} from Eq.5.

Reviewer 1: page 11, line 12. reference table 4

Response: change made.

Reviewer 1: page 11, line 13. I suggest being specific here, as table 4 shows the results. You don't need the e.g. clause, and you should state that 5 of 8 countries have values within range for rules 1-3 and 4 out of 8 for rule 4 (if i counted correctly)

Response: Good point. We have changed the line to "*The forest cover estimates from Rules 1-4 are generally well within the range of diagnostics. For example, 6 of 8 countries have estimates within the range for Rule 1, 2, and 3, and 5 of 8 countries for Rule 4*."

Reviewer 1: page 11, line 16. It isn't clear what you mean here by larger difference and what these differences are. I assume you mean differences between rules 1-3 and rule 4.

Response: The difference is between Rule1-3 and Rule 4. We have rephrased it as "*China and Brazil are the two countries where Rules 1-3 and Rule 4 have relatively larger difference between their estimates, the difference between Rule 1, 2, 3 and Rule 4 are 1.17 million and 1.08 million for China and Brazil respectively*."

Reviewer 1: page 12, line 22. I am not sure that this metric evaluates the heterogeneity. I suggest something like "…best capture carbon density globally…)

Response: It is changed to "According to this comparison, Rules 1-3 best capture the carbon density globally (Figure 8)."

Reviewer 1: page 13, lines 10-11. I suggest rephrasing rangeland part, as currently it isn't clear what the rule does when establishing rangeland. Rather than switching to leaving vegetation, state that for rangeland the rule clears all vegetation only if source land is forest.

Response: Those lines have been changed.

To Reviewer #3:

Reviewer 3: I appreciate that the authors reconsidered the wording throughout the manuscript and added analysis, now presenting a more nuanced discussion of their approach to test different rules for the translation between LUH2 land-use and land-cover for ESMs. However, their main conclusion (=recommendation of rule 1) is not covered by the results of the analysis and sufficient justification for the exclusive recommendation of this rule is still missing. The framing of the manuscript still indicates the opposite, e.g. by the following statement in the abstract:

'Examinations at global, country, and grid scales indicate that the recommended translation rule for CMIP6 models is 1) completely clear vegetation in land-use changes from primary and secondary land (including both forested and non-forested) to cropland, urban land, and managed pasture; 2) completely clear vegetation in land-use changes from primary forest and/or secondary forest to rangeland; 3) keep vegetation in land-use changes from primary non-forest and/or secondary non-forest to rangeland. This confirms the translation rules suggested earlier in the HYDE dataset underlying LUH2.'

(1) The examinations across scales do not exclusively indicate rule 1 (instead rules 2 and 3 are equally likely), which the authors also state in the manuscript and in the reply to the reviewers.

(2) The examinations do not confirm the translation rule suggested by HYDE. Instead, the earlier suggestion from HYDE is used as (the main) justification to pick rule 1 instead of rules 2 or 3.

One way out would be to be very clear about the fact that rule 1 is only recommended to achieve consistent implementation in future simulations (i.e., it would require to be a major point in the discussion and also in the abstract) and this recommendation is NOT a result of the analyses in this manuscript (as these show that with the same arguments also recommendation of rules 2 and 3 could be justified).

In this context, the manuscript would also benefit from a more critical discussion about the downsides of a consistent 'translation rule' (which is not necessarily supported by available data). In my opinion, it is reasonable to aim at a standardized translation between LUH transitions and ESM land cover. But such a standardization always comes at the cost of omitting uncertainties, instead of actually reducing them. If, for example, the 'added uncertainty of 43 PgC in CMIP6' (as stated in the discussions) is avoided by implementing a consistent 'translation rule' this does not necessarily mean that the uncertainty is not there anymore; it might be just not depicted in the ESM results anymore. Only if the authors could show by their analysis that one rule performs significantly better than others, this would be an indication for actually 'reducing' uncertainties.

If the authors do not want to put more emphasis on the consistency aspect and/or highlight the limitations of their results (i.e., basically we do not know about the 'correct' rule), they would need to show with their analysis that rule 1 outperforms the other rules.

In sum, I think it is a useful study/analysis and worth to be published, but requires more nuance in the presentation of results, limitations, and derived conclusions.

Response: We have rephrased the abstract and major content of discussion section according to your suggestions and reworded statements about uncertainty. We do think standardization of land-use data and translation to land-cover is very important and beneficial to model simulations and evaluations in CMIP6, and this is the major point of this study. Therefore, this study discusses possible impacts of translation rule choices on land cover and aims to provide insights into LUH2 implementation for CMIP6 models. Our evaluations suggest Rule 2 gives closer estimates of vegetation carbon to diagnostics than Rule 1 and Rule 3. However, given uncertainties in vegetation carbon diagnostics, we think certainly differentiation of Rules 1, 2 and 3 is difficult in this study. We have discussed limitations at discussion section and revised the statement that a consistent translation rule could eliminate added uncertainty in LULCC emissions. Please see the point-by-point response below.

Reviewer 3: P3 L1-3 The authors did not address the comment on the (non-)existence of 'global transition rules'

Response: We do agree that a global rule may not exist, and implementation of such rule is very likely to oversimplify the translation between land-use changes and land-cover changes. We have stated in discussion section that global rules may result in errors in land-use translation and discussed the possibility of spatially or temporally varied rules.

Reviewer 3: P3 L5-7 What is the basis for this statement, if it's not supported by literature? Some previous analysis? I think without a reference it is a misleading statement.

Response: we have rephrased this paragraph.

Reviewer 3: P4 L1-5 I am sure there are suitable legend translations for ESA CCI land cover as well and it's one of the most up-to-date datasets, but indeed it's not a critical issue.

Response: It will be very interesting and valuable for future work to evaluate these rules with ESA CCI product.

Reviewer 3: P4 L28 While I see that it is difficult to link biomass density to tree density as the authors state, I think it would be worth to give an indication which one of the forest definitions in the literature (and also the ones in the reference maps used for comparison) is closest to this 2 kgC/m^2 definition. This definition has the potential to affect the results and deserves some attention.

Response: It is difficult to indicate which forest definition is closest to 2 kgC/m_2, because only one definition is used to derive satellite-based tree-cover to forest cover, namely the 30% threshold. Detailed discussion of the threshold choices is beyond the scope of this study and it is well discussed in Sexton et al 2016 (already cited). Besides, we think comparisons in Fig.3, Fig.4

and Fig.S1 could suggest which reference map best matches the 2 kgC/m² definition. We also pointed out at the last paragraph of section 3.2 that our estimates are closer to GFC than others.

Reviewer 3: P5 L1 The intention to include rules 5-9 is still not clear. Although it might be useful for test/sensitivity runs (also for the ESM community), I think it doesn't make sense to include them if the main purpose of the manuscript is to derive a realistic/recommended translation rule (where these rules by definition are not useful). In the results (incl. tables and figures) they are hardly revisited and rather add confusion to some of the results. In my opinion, the authors should decide to either include all rules in all results/tables/figures or stick to rules 1-4. To concentrate on a different set of rules at different sections of the results is confusing.

Response: As we emphasized at the last paragraph of section 2.2, inclusion of Rules 5-9 could be used to infer individual contribution to land cover change from cropland, pasture and so on, and inclusion of them does not mean they are realistic to be implemented. We still think inclusion of Rules 5-9 will be helpful to answer questions like what likely impacts on forest/carbon from Rules 5-9 are implemented and why we recommend not to use these Rules. We also have added forest cover and carbon density maps of Rules 5-9 to the figure. S6 and S7 are for completeness.

Reviewer 3: P10 L9-11 I see the authors intention to include the whole range of currently available forest reference maps. However, it would be still useful to give an indication which one is closest to the GLM2 forest definition. If we would know, for example, that one of the products has a similar forest definition, this could increase the confidence/justification for one of the rules.

Response: We have added such an indication in terms of spatial pattern at the last paragraph of section 3.2. The reason why to include multiple maps as reference is there is no such a map that undoubtedly has the closest definition with the GLM2. First, all reference maps define forest based on tree cover rather than the GLM2 uses biomass. Second, Figure 2 and 4 suggest different closest maps. The GLC2000 has the smallest difference from the GLM2 in terms of global forest area in Figure 2, but the GFC gives the smallest AAD in Figure 4. Besides, the evaluation of rules is not affected without indication of such reference map. For example, Figure 4 shows Rule 1, 2, and 3 consistently produce the smallest overall difference among Rule 4 and other rules regardless of which satellite-based forest cover is chosen as the reference.

Reviewer 3: P1 L30 Reference biomass is also close for rule 2 and 3.

Response: The abstract has been rephrased.

Reviewer 3: P1 L30 Should it be: '[…] regions with forest cover larger than 50%'?

Response: The abstract has been rephrased.

Reviewer 3: P2 L16 As there is now already a carbon budget update, it might be good to use the latest values/reference. Friedlingstein, P. et al. 2019. Global Carbon Budget 2019. Earth Syst. Sci. Data 11, 1783–1838. https://doi.org/10.5194/essd-11-1783-2019

Response: change made.

Reviewer 3: P3 L7-9 It is not only the lack of a globally consistent rule, but also the fact that the existence of such a global rule is very unlikely and a large simplification (see original comment P3 L1- 3).

Response: This paragraph has been rephrased in a way of emphasizing importance of consistent rules across models and standardization of LULCC data. We do agree that a global rule is very likely to over simplify the translation between land-use changes and land-cover changes, and we also think particular areas may need different rules. Therefore, we have discussed the possibility of spatially or temporally varied rules and noted readers the simplified rules designed in this study could result in errors at the third paragraph of section 4.

Reviewer 3: P3 L21-23 But also obscures the uncertainty from the lack of process understanding and lack of dedicated spatially explicit treatment.

Response: These lines have been changed as "*Therefore, a consistent rule across models for the LUH2 translation is needed with potential to reduce impacts of LUH2 use inconsistency on studying land-use effects through CMIP6*".

Reviewer 3: P3 L25 'which are then integrated'

Response: change made.

Reviewer 3: P9 L20 'accounted for in bookkeeping model based studies'

Response: change made.

Reviewer 3: P9 L29 'should be close to diagnostics'

Response: change made.

Reviewer 3: P9 L31-33 It's not 'other criteria, such as …', but the only one that is used in the end to identify the recommended rule.

Response: changed as **"**Finally, if several rules have a reasonably good fit to these three diagnostics, other criterion, namely the definition characteristics for managed …**"**

Reviewer 3: P10 L17-19 I don't understand what the authors intend to say here?

Response: removed to avoid confusing.

Reviewer 3: P11 L2-4 Due to these large discrepancies it would be even more helpful to guide the reader with some information about which forest definition (of the reference maps) is closest to the GLM forest definition. (see original comments P4 L28; P10 L9-11).

Response: we have made such indication at the last paragraph of section 3.2.

Reviewer 3: P11 L17-18 And are within the range for Brazil, US, Congo, Indonesia, Peru.

Response: added "are within range for Brazil, Democratic Republic of the Congo, Indonesia, and Peru". Rule 7 is outside the range for US.

Reviewer 3: P12 L6-14 All the realistic rules (1-4) reduce the pasture anomaly. Is this then just the difference between LUH1 and LUH2 or really a characteristic of the individual rules?

Response: improvement of LUH2 itself primarily reduces the anomalous emissions by 6 Pg C, and choice of some rules could further reduce the emissions. We also clarified this by adding "*Rule 1 reduces anomalous emissions by 6 Pg C, indicating the sole contribution of the LUH2 to mitigate pasture anomaly*".

Reviewer 3: P13 L3-5 On average and globally. The regional and gridded comparisons (Table 4, Supplements) indicate that this might not hold at the country and grid level. Misleading statement.

Response: These lines have been changed.

Reviewer 3: P13 L6-8 It's actually hard to say if it is 'better' given all the uncertainties in these comparisons.

Response: changed 'better' to 'closer'.

Reviewer 3: P13 L14-16 Which is also true for rule 2 and 3.

Response: this paragraph has been re-organized.

Reviewer 3: P13 L23-25 The uncertainty is not really reduced by implementing a consistent rule, as long as we do not know, which rule is ‘correct’. It’s just omitted from evaluation.

Response: this paragraph has been re-organized.