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

To Reviewer #1:

Reviewer 1: The authors present an analysis of how various land conversion rules affect forest area and biomass carbon over the historical period, when applied to the LUH2 land use data. The results are compared with several available data sets, and they find that while a few different rules may be reasonable, the rule corresponding to definitions of source land use data appears to be the most reasonable one to use. They conclude by recommending full clearing of vegetation for cropland, urban, and managed pasture and clearing only for rangeland, when applying LUH2 data to ESMs and DGVMs.
Overall response I, and I think many others, will be happy to see these results published. This is a necessary step toward improving estimates of LULCC effects on the earth system. The paper is relatively clear, but some additional clarification and discussion are needed. Please see the details following these main concerns:

Response: Thank you very much for your comments which are very conductive to improve the manuscript. We have carefully revised the manuscript accordingly. Note that 'transition rule' has been renamed as 'translation rule' throughout the manuscript to avoid confusion with LUH2 land-use transitions. Please see our point-by-point response below.

Reviewer 1: 1) The methods describing how vegetation fraction and land-use fraction are tracked (section 2.3) are not complete.

Response: Please see details in relevant comment below.

Reviewer 1: 2) While there is some discussion of "forest area" vs "forest/tree cover," it is still unclear which metric is being used and discussed in the comparisons.

Response: Only forest cover/area were simulated and compared between model and reference datasets. We have clarified what metrics are used at the last paragraph of section 2.5.

Reviewer 1: 3) Please include discussion of the analytical rule results. You present the numbers, but do not tell us what they mean in terms of how particular transitions affect forest area and carbon dynamics.

Response: We have added discussions of Rules 5-9 at results section.

Reviewer 1: 4) It would be useful to see regional comparisons for carbon.

Response: Regional comparisons of carbon density estimate has been added as Figure S4.

Reviewer 1: Specific suggestions and comments: Abstract page 1, line 23: “optimal” is a strong word here for a global transition rule. “most reasonable global transition rule. . .” may be more appropriate

Response: We have changed ‘optimal’ to ‘recommended’.

Reviewer 1: page 1, line 23: “optimal” is a strong word here for a global transition rule. “most reasonable global transition rule. . .” may be more appropriate

Response: We have changed ‘optimal’ to ‘recommended’.

Reviewer 1: page 2, lines 9-10: this is a misleading statement not supported by the inappropriate reference (which is also quite old). it isn’t necessarily the case that recovering or planted or re-planted forest has lower potential biomass many plantations or managed forests have higher growth rates than unmanaged forest, and in time could easily match or outgrow unmanaged biomass levels furthermore, the reference is about available land for afforestation, and does not compare afforested stands with corresponding primary stands. there are several recent papers that estimate carbon sequestration potential of forests. here is one example: griscom et al 2017: natural climate solutions in PNAS, oct 31 2017 vol 114 no 44 11645-11650

Response: We have revised these line as “*Afforestation/reforestation, in contrast, recovers forest which accumulates carbon but sequestration potential are constrained by water and nutrient availability (Smith and Torn, 2013)*”, and the reference discusses ecological limit on sequestration potential of afforestation/reforestation.

Reviewer 1: page 2, lines 18-22: awkward sentence that is difficult to read. split it up and bring the examples out of the parentheses

Response: It has been revised as “*For this purpose, LULCC reconstructions enter Earth System Models (ESMs) (Lawrence et al., 2016), Dynamic Global Vegetation Models (DGVMs) (Le Quéré et al., 2018) and bookkeeping models (Hansis et al., 2015) to quantify biogeochemical and biophysical impacts of historical land-use change …* ”.

Reviewer 1: page 5, lines 22-23: are there other factors not taken into consideration? is the climatology constant or does it vary with time? be specific here - state exactly what factors are or are not included

Response: The climatology is produced by averaging temperature and precipitation of MSTMIP 1901 and 2000 and remained as constant over the spin up period. We have reorganized these lines.

Reviewer 1: page 5, lines 26-29: what tree density or how much tree canopy cover will give 2 KgC/mˆ2? what defines potential forest area in the two comparison studies?

Response: It is difficult to link biomass density to tree density as their relationship may strongly vary with tree species and also locations, and there are many different definitions of forest in the literature. The threshold value of 2 kg C/m_2 potential biomass was used for consistency with prior studies and GLM2/LUH2 (see references below).

Hurtt GC, Pacala SW, Moorcroft PR, Caspersen J, Shevliakova E, Houghton R, Moore B (2002) Projecting the Future of the US Carbon Sink. Proceedings of the National Academy of Sciences of the United States (PNAS)/ 99(3): 1389-1394.

Hurtt GC, Frolking S, Fearon MG, Moore B, Shevliakova E, Malyshev S, Pacala SW, Houghton RA (2006), The underpinnings of land-use history: three centuries of global gridded land-use transitions, wood harvest activity, and resulting secondary lands. Global Change Biol 12:1208–1229

G. C. Hurtt, L. P. Chini, S. Frolking, R. A. Betts, J. Feddema, G. Fischer, J. P. Fisk, K. Hibbard, R. A. Houghton, A. Janetos, C. D. Jones, G. Kindermann, T. Kinoshita, Kees Klein Goldewijk, K. Riahi, E. Shevliakova, S. Smith, E. Stehfest, A. Thomson, P. Thornton, D. P. van Vuuren, Y. P. Wang (2011) Harmonization of land-use scenarios for the period 1500–2100: 600 years of global gridded annual land-use transitions, wood harvest, and resulting secondary lands. Climatic Change 109:117–161

Reviewer 1: page 6, lines 5-28: These equations are incomplete, and therefore confusing. Transitions from types 5-8 to 5-8 are not included for f-gained. As such we do not see that these types of gains account for the f/l ratios of the losing types 5-8. Transitions from types 1-4 to 1-4 are not included for losses or gains. Doesn't harvest move primary to secondary land? Are there any gamma factors for these transitions? Also, wouldn't abandoned ag land move to secondary first, then from secondary to primary? For this path from ag to secondary to primary, how is the abandoned ag vegetation fraction tracked over time?

Response: As the example of forest-pasture transition (the 2nd paragraph of section 2.3) explains, vegetation remaining in pasture will be cleared when the land is further changed to non-primary and non-secondary land. Similarly, vegetation remaining in cropland, rangeland or urban will also be cleared when the land is changed to cropland, pasture, rangeland and urban. Therefore, vegetation fraction could only be gained from land use changes from type 1-4. This is why $f^{gained}(i,t)$ in Eq.2 only includes land use changes from types 1-4. To avoid confusion, we clarify this before Eq.2.

Wood harvest from primary land does move vegetation to secondary, and there is no gamma factor for it. We have fixed the Eq. 5 and 6. Note that vegetation in cropland, pasture or rangeland could be back only to secondary land, there Eq.6 only apply to forested and non-forested secondary land. We have clarified this at the paragraph before Eq.4.
Besides, regarding the path you gave, the first part from abandoned ag to secondary is tracked in the Eq. 3 and 6, but the rest part that from secondary to primary is invalid in LUH2 according the definition of primary land in LUH2. Specifically, primary will not be reconverted once any land-use changes occur, thus your path will stop as secondary land.

Reviewer 1: Furthermore, there are corresponding equations for l(i,t+1), correct? But they are different because they track the land use transitions upon which the vegetation changes (without the gamma parameter that alters vegetation cover). This distinction and relationship between the two needs to be made clear.

Response: $l(i,t)$ is land-use fraction from LUH2 for type *i* at time *t*. This is no need to track land use fractions as LUH2 provides time series for them. Changes are made at the paragraph after Eq.3.

Reviewer 1: page 6, lines 20-21: f(i,t) could also be equal to l(i,t)

Response: Yes, we have revised it as "*this fraction is larger than or equal to its vegetation fraction* $f(i,t)$*.*"

Reviewer 1: page 6, lines 22-23: "these" is confusing. maybe delete "these" and make "land-use" at the end plural.

Response: We have rephased the whole paragraph that describes how vegetation in primary and secondary land is tracked.

Reviewer 1: page 7, line 21: considering annual creation and discard of wood products and decay in landfills, these emissions can grow to be quite large over time.

Response: We agree that emissions from wood product could be very large. However, we think using biomass change as proxy of land-use change emissions in this manuscript has already included the emissions you mentioned, since wood products accumulate carbon from harvest, deforestation and other activities, and this accumulation could be reflected in vegetation carbon changes.

Reviewer 1: page 7, lines 22-32: This does not appear to account for different areas of secondary land within a grid cell with different ages. Similarly to my comment above, if cropland is abandoned and has half natural secondary veg and half crop veg, there can be at least three

different ages of secondary land in the cell. The number of different ages will grow with each transition. How is this dealt with? When does secondary become primary land again? Does primary land always have biomass density of B0?

Response: GLM2 does not account explicitly for the complete age distribution within secondary lands. When a fraction of secondary is newly created either from abandoned cropland or from harvested primary land, the mean age of the secondary land will be re-computed, and then it increases year by year to track biomass growth. Besides, primary land always has B_0, and once land use change occurs, it will never come back to primary land because of the primary land definition. We added description at the 2nd paragraph of section 2.4 to clarify the computation of mean age.

Reviewer 1: page 8, line 25: do you expect a 30% tree cover threshold to correspond with GLM's 2 KgC.mˆ2 threshold? Also, are the >30% pixel areas used for the values in table 2, or are the values in table 2 pre-threshold tree cover fractions that were calculated?

Response: Threshold value of 30% is discussed in Sexton et al., 2016 and its resulting forest area is comparible to FAO report. This value was used to convert tree cover to binary maps of forest and non-forest at 1km resolution, then we counted the forest area based on the 1km binary maps and reported global forest area of satellite-based dataset in Table 2. We have clarified this at the 2nd paragraph of section 2.5.

Reviewer 1: page 10, lines 4-28: What numbers are you comparing here and in figures 3-4 and table 4? Are the six-dataset numbers the tree cover or the forest with cover >30%? What does GLM's biomass threshold represent in relation to these metrics? Also, there are a couple of other tree cover estimates that are much lower: see meiyappan and jain 2012 frontiers in earth science 6(2):122 and Li et al 2018 earth system science data, 10:219.

Response: Only forest area/cover with a tree-cover threshold >30% of six satellite-based datasets are used in section 3.2 "Forest cover evaluation". We have clarified what metrics are used for evaluation at the last paragraph of section 2.5.

The lower global forest area estimates of meiyappan and jain 2012 may due to definition of forest, as they state in the second paragraph of section 4 "Comparisons with other studies". Moreover, the values of their test-case in the Table 5 is very comparable to the Table 2 of our manuscript.

The inclusion of six datasets as diagnostics in our manuscript is to avoid biased evaluation because of choosing a particular dataset. It will be very helpful to investigate the causes why satellite datasets report different forest cover, but it beyond the scope of our manuscript.

Reviewer 1: page 11: Can you make regional comparisons of LULCC emissions with info from the sources in table 3?

Response: As most of studies in Table 3 do not provide regional or gridded estimates, it is difficult to compare the regional LULCC emissions. However, we do compare the emissions from pasture and rangeland expansion for Rule 1-4 at different regions in Figure 6.

Reviewer 1: page 11, lines16-25: It would be helpful to see regional comparisons of carbon stock here.

Response: we have added Figure S4 for comparing carbon density at different latitudinal bands.

Reviewer 1: page 12, lines 11-13: up to this point you report that rules 1-3 have the same forest area dynamics, which makes sense because forest is always cleared in all three rules. but here you state that there are differences between rules 1 and 2 for forest area. please clarify why this is the case, and if they are different it needs to be noted early on, even if the differences are negligible.

Response: Rule 1,2, 3 should have the same forest area and only differ in carbon density, we have reorganized the results, discussion and conclusions section.

Reviewer 1: page 12, lines18-30: This is repetitive of your methods. It would be more useful to have discussion of the alternative rules, which you include in your figures/tables, but do not comment on at all.

Response: We have reorganized the discussion and conclusions, also analyzed Rules 5-9 at results section.

Reviewer 1: Figure 2 Only the results for rules 1-4 are shown, not all 9 as in the caption

Response: Right, we have fixed it.

Reviewer 1: Table 5 Do you mean compared with studies from table 3?

Response: Yes, it should be 'Table 3'. Change made.

Reviewer 1: Figures 5 and 6 I don't see the black dashed line. is it hidden?

Response: As Rules 1 and 3 have same treatment for land-use changes from primary and secondary land to managed pasture, the resulting emissions are very closed to each other, thus back dashed line almost completely overlapped blue dashed line. We have recreated Figures 5 and 6 by splitting each rule into individual plot.

Reviewer 1: Figure 8 I suggest plotting them in rule # order - rules 1 and 2 appear to be switched

Response: Change made.