Review of "Holocene land cover change in North America: continental trends, regional drivers, and implications for vegetation-atmosphere feedbacks" by Andria Dawson, et al.

This manuscript describes a study to reconstruct land cover for the Holocene over North America. As part of the LandCover6k initiative, the methodology follows a standardized procedure: first pollen records from sedimentary archives are synthesized and samples are assigned ages using up-to-date age-depth models. Then, pollen spectra are simplified and decimated to include specific taxa, and relative abundances of these taxa are passed to the REVEALS pollen-landscape model. REVEALS generates quantitative estimates of land cover for specific taxa that can be further generalized into broad groups of plant functional cover, e.g., broadleaf deciduous or needleleaf evergreen trees. These point-based data are then interpolated to a continuous 1-degree grid covering the study area. The work presented here complements similar activities undertaken for other parts of the Northern Hemisphere and ongoing work in the tropics and elsewhere. The authors present the results of the synthesis in the form of gridded maps and synthetic timeseries covering the entire North America spatial domain, and for specific regions that they analyze in further detail.

Overall, this is an excellent study that is rigorous in its methodology, interesting and in some ways novel in terms of results, and honest about shortcomings. The authors helpfully provide a roadmap for future research including on improving the land cover reconstructions and recommendations for research that could employ the maps and other datasets produced here. There are a few issues that should be clarified before publication, and ultimately this paper and the associated datasets will make a valuable contribution to the journal and support range of fields in further study.

We thank Reviewer 2 (Dr. Jed Kaplan) for these comments. We consider ourselves fortunate to receive two detailed, thoughtful, and constructive reviews of our ms.

General comments

While changes in ice cover were considered, it appears that sea level changes (and proglacial lakes) were ignored in this study. This is a major limitation of the spatial analyses and at the very least should be justified. It's a bit strange because these paleogeographic changes are considered in previous, similar studies by some of the same authors (e.g., Williams, 2003; Williams et al., 2004). The early Holocene is characterized by very large proglacial lakes at the margin of the Laurentide Ice. More importantly were the postglacial isostatic adjustments that lasted throughout the Holocene. For example, the Hudson Bay Lowlands were submerged until after 5ka and low-lying areas of the Atlantic coast and Florida had significantly more land area exposed in the early Holocene. Data on sea level changes, for example from the PAGES PALSEA activity would be worth considering, and citing in an explanation of why these were not part of the current study.

Thank you for this comment. We will add proglacial lakes to our mapping and areal analyses, since these lakes were still widespread in portions of the study during the early Holocene. We

will cite recent reconstructions of sea level change (from PALSEA or other efforts) while noting that for the Holocene time period and continental-scale study presented here, these sea level effects are not expected to have a major effect on our reconstructions.

In the interpolated maps, the parts of the study domain that show no data I assume are because the “confidence region” (CR) was greater than the threshold of 9, for example in much of Mexico in the early Holocene. It would be helpful to see the CR maps themselves included among the supplementary figures. Looking at Figure 1, there are only 3 or maybe 4 sites in all of Mexico, so it is hard to understand, especially given the climatic and topographic diversity of Mexico, that there is much power in the interpolations over that space.
We agree that this would be helpful, and we will add maps of uncertainty for all time periods shown in the manuscript (see also response to Reviewer 1).

We will set a fixed domain size and exclude grid cells in the Mexico region in our analysis given the lack of records for this region. Setting a fixed domain size in Mexico removes confounding effects that may arise from the changing number of included grid cells.

All of the data products presented here (point-based and gridded maps) must be freely released on zenodo.org or other open-access data repository that provides a DOI upon final publication of the paper. The gridded maps should be provided in the earth system modeling-standard netCDF format.
We agree and will do this. Reviewer 1 raised the same point.

A few notes on presentation

As “land use” is generally accepted to be an activity that is unique to humans, it is not necessary to qualify the term with “human land use” or “anthropogenic land use” in the manuscript. In the interest of conciseness, please just use “land use” alone throughout the manuscript, or maybe define it once at the beginning of the text.
This is a good point, and we will edit the manuscript accordingly.

I found the constant switching back and forth between scientific names and common names for taxa distracting and sometimes confusing. Use of both nomenclatures even occurs in a single sentence (e.g., lines 435-436). I ask the authors to pick one nomenclature system and stick with it throughout the entire manuscript.
We will make this change.

Please use a thinner line thickness in all of the maps presented in the manuscript and supplement. The heavy line weight around the ice sheets and coastline distracts from the content. Perhaps the ice sheets could be plotted in a blue or brighter, contrasting color as polygons, without any outline at all.
We will revise the ice and coastline colors accordingly.

Specific comments

Lines 48-49
It is not at all clear how changes in the abundance of hemlock could have been significant enough to have a biogeophysical feedback to climate; see further comments below.
We address this point below.

Lines 168-169
Please explain briefly how relative abundances are calculated when some taxa are ignored? Is there an "all other taxa" bin? Or are only abundances relative to the considered taxa included? What happens when a taxon that is considered to be important in terms of land cover, even locally, is not part of those used in the REVEALS model?
We will address this in our revisions to the Methods section. The standard REVEALS workflow does not include an "all other taxa" bin. This is because of the variability in PPEs and fall speeds among taxa that would be included in such a bin. In this work, we first translated the Neotoma taxonomy to the Whitmore taxonomy (ref); this resulted in a list of 47 taxa. We identified the taxa that were most abundant and indicators of land cover type, of which there were 33. There were corresponding PPE and fallspeed values for all of these taxa. The set excluded results in a total of about 0.5% of the total pollen grains counted (for North American Holocene). We will add some text to clarify these decisions, and include a list of the taxa that were excluded in the supplement.

Line 235
Approximately how does the grid resolution of the 1x1 degree interpolated surface compare to the 10,000km2 area represented by a REVEALS reconstruction noted on line 179? Naturally it changes by latitude, but it would be helpful to put a comparative statement here.
We will add some text that discusses the area that REVEALS reconstructions represent, in the context of our grid cell size.

Lines 254-255
Here where CR is introduced, it would be good to call out supplementary figures here showing this value in map form for all periods.
As indicated above and in our response to Reviewer 1, we will add maps of reconstruction uncertainty to the supplementary information.

Lines 260-261
I understand that the LandCover6k grid was specified as 1x1 geographic degrees, but wouldn't it have made more sense to do the original work on an equal-area grid and then only reproject the data in a final step? At the very least it would have made interpretation of the maps more straightforward, and would be similar to earlier work (Williams, 2003; Williams et al., 2004).
Our primary goal was to maintain consistency with the other LandCover6k papers. We'll publicly share the results (as NetCDF files) in 1x1 degrees, but in our data visualizations, we'll reproject maps to Albers equal area, using the same projection parameters as in the earlier papers by Williams et al.

Figure 1
Could you plot the 1x1 degree graticule on this map using a very thin line in an unobtrusive color? It would make interpretation of the grid resolution of the other maps easier.
We'll experiment with adding this graticule, and will keep it as long as figure legibility is maintained.

Figure 1
Given the very high density of sites, it seems strange that nearly all of Minnesota is not included in any of the regional boxes. The choice to exclude this area deserves some explanation.
Our selection of regions was not intended to be comprehensive (this would have made for a very long and dull paper). Rather, we picked selected regions, based on a) whether we saw an interesting trend in land cover to which we wanted to call the reader's attention and/or b) describing changes in the west, which has been less intensively studied. Other regions certainly could have been chosen, and Minnesota definitely has its merits. We will add a brief note about these criteria to the manuscript.

Figure 2
Use a thinner line weight, or no line at all for the ice sheet outline (as noted above).
We will revise the map color scheme accordingly.

Figure 2
To aid in quickly interpreting the plots and to provide better consistency with the rest of the figures, please plot the land cover fractional surfaces in the same colors as used in Fig. 3 and the other timeseries plots. That is to say, plot the first column of maps in shades of green, the second in shades of blue, and the third in shades of orange.
We recognize that this would likely make it easier to link the time series figures with the land cover maps, but one of the primary objectives of the map series is to compare land cover across the maps. Using different colors in land cover maps would make this difficult, and would require three legends instead of one. Given this, we would like to keep the single color scheme for the maps.

Figure 2
As noted in the supplement the three interpolated surfaces sum across to 100% in each row, and there is no "missing" fraction that represents bare ground. In the Arctic and in desert areas, the landscape is not 100% vegetated. This information should not be buried in the supplement, and needs to be clearly noted when the main figures are presented in the figure caption and body text. It should further be noted as a limitation and explained why this is not the case in the main manuscript text.
Agreed, we will clarify this in the main text.

Line 311
Given that there are only 3 sites in Mexico, is the spatial domain of the study justified? Wouldn't a maximum distance buffer around nearest site be better - e.g., up to 100 km apart (corresponding to the REVEALS indicative catchment area)? As noted above there is a distance

filter on the grid based on the CR value, but it would be interesting to see how this translates into distance from a site. Some statistics, such as the max distance from any site in the interpolation, would be helpful, even if only in the supplementary materials.
We will establish a standard spatial domain and reduce the size of the study domain to omit grid cells for which there are reconstructions only in a few time periods (e.g. Mexico, and perhaps several other coastal grid cells) .

Line 320
The number of gridcells contributing to the curves presented in Figure 3 changes based on ice area, apparently not sea level, but also CR value. Can we see an additional curve on this figure showing the total area in the spatial domain contributing to the cover estimate?
By establishing a standard domain size (see responses above), we will not need to include a curve representing changes in domain size over time.

Lines 435-436
In this sentence, and others, please just choose one form of plant nomenclature or the other, and stick with it.
Will do.

Lines 541-543
"… desert, steppe, and other open-land arid ecosystems are likely to be underrepresented in these reconstructions, due to a scarcity of dryland sites" yet the interpolated maps and timeseries curves imply continuous vegetation cover (without bare ground), if I understand correctly. This limitation of the methodology should be further described and justified.
We will make this edit.

Line 566
Is there really nothing to say here about sea level dynamics over the period?
We will add to this paragraph a brief mention of sea level changes over this time period.

Line 625
I suggest a small rewording of this sentence to: "During the late Holocene, the growth of Indigenous populations and intensification of land use in the Americas had increasing effects on land cover. Understanding the interactions among…"
We'll consider this rewording while reviewing this section to address, e.g., the next comment.

Line 632
Evidence for dense populations and land use in North America are dismissed here, yet a number of examples of this are provided in the following paragraph. This sentence could be reworded to better tie to what is coming next.
We'll look into ways to reword this sentence.

Paragraph starting on line 660

What is the purpose of this paragraph? Can it be tied back to the data presented in the current study?
We'll add a sentence or two that ties this paragraph back to the results. The general goal of this paragraph is to at least briefly note the major effects of EuroAmerican land use, without going deep into this topic, as previous papers have covered this topic well.

Section starting on line 668 (4.1.1)
This section needs to be tied back more clearly to the findings in the current study, at least speculatively. The section reads like a review paper now and there is nothing new in here.
Per comments from Reviewer 1, we plan to keep this paragraph, while somewhat shortening its treatment of biogeophysical feedbacks and adding some text on carbon cycle feedbacks. Part of the goal of this section is to broadly introduce the themes that follow; we'll look for ways to strengthen this connection.

Line 675-676
The full name of the "TEMPO" acronym could be removed here and just put in the bibliography.
Will do.

Paragraph starting on line 707
This paragraph does a very good job of explaining how the data synthesized in the current study ties back to previous work. It should be a model for how section 4.1.1 could be improved.
Thank you.

Line 715
"Great Plains"
We will fix this..

Line 728-731
It is not clear from this section or from the maps or timeseries how large, in absolute terms, the coverage of T. Canadensis could have ever been. The paragraph seems to insinuate that it could have been abundant enough to make a majority proportion of forest cover, therefore having a strong influence on, e.g., albedo. But… (see next comment)
See response to the next comment.

Lines 731-732
Am I missing something because I don't see a shift in the dominance in Fig. 4, which is always more than 50% summergreen trees and shrubs, with evergreen less than 30% cover fraction throughout the Holocene. Are you arguing that ETS forests were conifer-dominated? Otherwise, the albedo changes would have been very subtle, especially since T. Canadensis can persist in the understory for a century or longer and so while it is there and producing pollen, it will have no influence on summer albedo and relatively little on winter.
Yes, please note the interesting difference between Figure 4b and 4a. The time series in Figure 4b show little change, as Reviewer 2 notes, but they are averaging across a broad area. Figure 4a shows that there is a very large effect associated with the hemlock collapse, with 40%

changes in evergreen cover, but that these changes are concentrated in the eastern part of the study domain. Hemlock is a late-successional shade-tolerant tree and tends to be a canopy dominant in areas of low disturbance. We stand by our inference that this single-species collapse could have had a major effect on land-atmosphere interactions at regional to subregional scales, and perhaps more broadly, depending on how the teleconnections played out.

More broadly, this topic is a good example of how different phenomena are operating at different scales - one of the main points of this paper.

Lines 741-743
Looking at the summary figures, these changes must have all be very subtle. If not, then some further quantitative information should be highlighted here.
Based on the summary figures, the changes represented here are about 5% at a continental scale, which is worth reporting and discussing, because of the large spatial extent involved. (A global mean temperature increase of 2C is a big deal; a 2C increase locally not as much.) This is another topic that is a good example of how different effects manifest at different scales. The hemlock collapse was very large but at subregional to regional scales; this is a smaller change but across a much larger spatial domain.

Line 747
Broadleaf summergreen trees have greater maximum evapotranspiration rates than needleleaf evergreens and this effect should also be mentioned here as it is probably more important than the summertime albedo differences.
Agreed, we will mention this.

Line 753
I am not convinced that there is anything more than “relatively subtle shifts in the proportions of summergreen and evergreen trees and shrubs” shown in the data presented here.
See response above, for comment on L741-743.

Line 775-776
If “… REVEALS estimates are sensitive to parameter choices…” then why didn't you not just explore a larger parameter space and make a range of reconstructions? Instead of just one? Seems like it would be an easy change and could lead to the preparation of a range of maps or uncertainty fields.
In this manuscript, we are focusing on the REVEALS protocol and a careful review of the resulting reconstructions. We believe that adding a sensitivity analysis of REVEALS parameterizations is beyond the scope of this paper.

Line 784-785
The sentence mentions that “…this approach does not mechanistically represent the underlying processes that link pollen to vegetation”. The GMRF method also does not account for soil, slope, aspect, and other edaphic controls on vegetation cover. This should be mentioned.

We will make this change.

Line 828-830
Here it is admitted that the changes in "… continental-scale fractional forest cover were broadly stable." This statement does not seem to support the idea that biogeophysical feedbacks between land and atmosphere would have been very important, in contrast to what is insinuated earlier in the manuscript. Some further explanation would be helpful here.
As noted above, different effects manifest at different scales, and this manuscript is designed to report phenomena across scales. During revisions, we will review all statements and sections to ensure that they are clearly associated with the appropriate scale of inference.

References
Williams, J. W. (2003). Variations in tree cover in North America since the last glacial maximum. Global and Planetary Change, 35(1-2), 1-23. doi:10.1016/S0921-8181(02)00088-7
Williams, J. W., Shuman, B. N., Webb, T., Bartlein, P. J., & Leduc, P. L. (2004). Late-Quaternary Vegetation Dynamics in North America: Scaling from Taxa to Biomes. Ecological Monographs, 74(2), 309-334. doi:10.1890/02-4045