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Solid, interesting study; needs some further discussion of omitted processes and improved presentation

Anonymous Referee #1

Referee comment on "Nitrogen restricts future sub-arctic treeline advance in an individual-based dynamic vegetation model" by Adrian Gustafson et al., Biogeosciences Discuss., https://doi.org/10.5194/bg-2021-169-RC1, 2021

This manuscript describes a modeling study to understand the climatic and biogeochemical controls on vegetation change in sub-arctic Sweden. The authors parameterized the LPJ-GUESS dynamic vegetation model with the principle plant types found in their study area around Abisko, Sweden. Using a very high resolution local gridded climatology and downscaled GCM output, the authors then ran LPJ-GUESS in a historical and series of future climate scenarios, and in a range of sensitivity tests controlling for different processes including CO2 fertilization and nitrogen cycling. The authors conclude that while climate has an overarching control on vegetation composition and position of the treeline, nitrogen availability exerts a very important influence on vegetation dynamics.

In general, this study is well designed and the methodology and sensitivity tests follow generally accepted protocols for dynamic vegetation modeling experiments. The manuscript is well written and easy to follow. The presentation could be improved, in particular the figures, and I do have a few scientific comments that should be addressed, but overall this manuscript should be suitable for publication in Biogeosciences after moderate revision.

General comments

I would like to see more discussion of the processes that were not included in the model, concentrating on the following:

1. Seed dispersal limitations to vegetation change: A great deal of modeling work has gone in to understanding the role of seed dispersal in limiting plant migration rates, particularly along vertical gradients similar to the principle one at Abisko. The pioneer in this research has been Heike Lischke with her TreeMig Model (Lischke et al., 2006), which

has been applied to the Arctic (Epstein et al., 2007), and some representation of dispersal and migration has even been incorporated into a version of LPJ developed in part by your colleagues in Lund (Lehsten et al., 2019). Of course, dispersal limitations are not the whole story of what limits plant migration (Scherrer et al., 2020). Nevertheless, some further discussion on this topic and additional citations would be welcome in this manuscript, as it is effectively missing at the moment.

2. Permafrost effects: While it is mentioned that the study area lies in the permafrost zone, it is not really discussed how changing permafrost dynamics; deepening of the active layer, changes in effective rooting depth, changing water table depth, etc. affects vegetation. At the ultra-high resolution used in the model simulations, it might be important to account for how ground freezing and soil vertical and horizontal movement caused by frost (or lack of it in the future) could affect survival and competition among the various plant functional types simulated. While I appreciate that a full treatment of permafrost dynamics may be beyond the scope of the present study, it would be good to have some further discussion/speculation of how this process could influence the results and conclusions of the modeling work performed here.

3. Slope and aspect effects: It is mentioned that the study area is hilly or even mountainous; at the resolution of the model, how were slope and aspect handled? Particularly in a high-latitude situation with low sun angle, slope and aspect must be very important in influencing the surface radiation budget, soil temperature, and snowpack dynamics. If slope and aspect were not considered in this study, some explanation of why is required, and similarly to the point above, the authors should include some discussion of the potential effects that this could have on their results. Furthermore, as the resolution of the modeling approaches micrometerological scale, it would be helpful to have some further discussion of how the lakeshore climate may be different from areas further away, e.g., with respect to wind speed and the radiative environment.

4. Linked to the point above on slope and aspect, I would have liked to see some more discussion of the spatial heterogeneity of the snowpack. Again, at the model resolution and over the spatial domain considered, I would imagine that the formation of snowdrifts and other snowpack variation is important for soil temperature and moisture, plant survival, and N cycling. Numerous studies have demonstrated that wind and slope/aspect have a strong influence on the depth and density of snow in snowdrifts and on the rate and timing of snowmelt. This spatial heterogeneity in snowpack depth and melt rate affects winter surface temperatures and therefore survival of plants at and above the treeline, and growing season soil moisture (there are many studies on this topic but one example isWalker et al., 1999). Again, while a full treatment of snowpack heterogeneity might be beyond the scope of the study, some more discussion of this important process, and how it might influence the region around Abisko specifically, is warranted.

5. Given the overall importance of N cycling for the results of this study, it would be helpful to have an overview of the N module in LPJ-GUESS. In particular, I would like to understand how biological N fixation is represented and if certain PFTs (e.g., something representing Alnus spp.) can be advantaged in nitrogen poor settings because they are capable of enhanced N fixation especially with warmer temperatures.

Specific comments

Line 148

It is mentioned that three replicate patches in each gridcell are used for LPJ-GUESS. It is worth going in to a little more detail here to justify this choice of the number of replicate patches. As I understand, each patch in LPJ-GUESS is meant to represent an area of 0.1 ha. With a 50m grid (cells of 0.25 ha), three replicates effectively makes an explicit representation of the entire gridcell, no?

Line 153

Further to my general comment above, please explain how slope and aspect are incorporated into this gridded climatology.

Line 157 and Fig S1.1

From looking at the figure I don't really see how temperature is "more variable" with increase in elevation. Perhaps some descriptive statistics would be more useful here.

Line 167-169

Soil edaphic controls on vegetation are an important part of treeline and subarctic biogeography; it is even mentioned on this line. So why not make any attempt to account for spatial variation in soils? Although the spatial resolution is still a bit coarse, why not use the pedometrics-based Soilgrids250 (Hengl et al., 2017) instead of simply prescribing the same soils everywhere? Could you have done some sensitivity tests to quantify the model response of vegetation distribution and treeline to different soil physical properties?

Line 418

Where are these transects? Call out the supplementary figure here or even better refer to an overview map (see comment below). How were the locations and orientations of these transects chosen?

Comments on the presentation

I would appreciate seeing an overview map or aerial photo of the study area showing topography and the location of the lake, any rivers, and settlements, roads, etc. I would also like to see at least an inset map showing the location of the study area within Europe and Sweden.

Fig. 2

What is the white area in these maps? Why are the colors used for the PFTs in Fig. 2a not the same as those used in Fig. 3? Please harmonize. Please add a scale bar to these figures, and perhaps one or two longitude and latitude tick marks/labels. As many readers look only at the figures, or the figures first, it would be helpful to spell out the PFT names in the figure legend here instead of making the reader refer back to an additional table or text to decode these.

Fig. 3

Harmonize the colors with Fig. 2a

Fig. S1.1

The figure caption appears to be cut off

Supplement S1 Table 1

What is reported in the column "Reported (van Bogart et al. 2011)"? What are these units of?

Fig. S1.4

What is the gray scape in plotted in the background of the map? What is the white area?

Fig. S1.6e

What is the principle control on annual shortwave radiation? Is it cloud cover? This could also be discussed in the main text.

References

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