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Comment on bg-2021-121

Anonymous Referee #1

Referee comment on "Model simulations of arctic biogeochemistry and permafrost extent are highly sensitive to the implemented snow scheme in LPJ-GUESS" by Alexandra Pongracz et al., Biogeosciences Discuss., https://doi.org/10.5194/bg-2021-121-RC1, 2021

General comments

The paper describes the implementation of a dynamic, multilayer snow scheme in the dynamic vegetation model LPJ-GUESS. The multilayer model's performance is compared to the single layer model's performance by evaluating the models' output with respect to observations of snow depth and soil temperature at the site level, soil temperatures and soil-air temperature difference on the regional scale, and dominant vegetation type distribution on the pan-arctic scale. The two models are also compared to each other with respect to soil temperatures and carbon cycle dynamics on a pan-arctic scale. The study therefore presents a thorough overview of the effects of switching to the new snow scheme, and in particular goes into detail on the causal relationships of the model's effect on carbon cycle dynamics. Interesting points are drawn out, such as the effect of snow in springtime on summer temperatures, and how the new scheme has an opposing effect on summer and winter soil temperatures. The study will be useful both for users of LPJ-GUESS, and those considering the impacts of dynamic snow schemes on model biogeochemistry. While the paper shows that the implemented 'dynamic' snow scheme is a clear improvement over the 'static' snow scheme's configuration, the paper would benefit from and should include more discussion of what is responsible for the improvement in soil temperatures. In particular, comparison of the modelled snowpack conductivity and snow density between the two schemes should be included, as well as looking at the effect of changes in soil moisture content - an indirect effect of changing the snow scheme but a key control on soil conductivity and summer soil temperatures. Fortunately, some of this material is already in the supplement.

Specific comments

Analysis

As previously mentioned, while cause and effect has been gone into in detail for the carbon cycle, similar detail has not been afforded to the changes in soil temperature. I would recommend that the discussion of snowpack dynamics in S2.1 be moved to the main text and expanded, as the effect of the model on snow density is perhaps the primary cause of the resulting changes to the modelled insulating effect of snow, and hence the ground thermal and biogeochemical changes, and there is currently very little quantitative discussion of the effect of the model on snow density and insulating factors.

Another primary control on soil temperatures is soil water content, particularly in the upper layers of the soil. Figure S11 shows that changing to the new scheme has an effect on July soil water content. Visually there is correlation between areas that have become drier in July as a result of the new scheme and those with reduced summer temperatures. This could be due to the soil being less conductive due to being drier, though there could also be the opposite causal relationship. In either case, I would recommend moving part of S11 into the main text and including some discussion of the relation between soil moisture and soil temperatures.

Regarding the cause of the improvement in soil temperatures, it is not entirely clear that it is the dynamic and multilayer nature of the new scheme that is responsible. In figure three, for the static scheme, all sites seem to have reasonable snow depths but too low soil temperatures. This could indicate that one or more parameters in the original static scheme are set incorrectly, and that changing these would result in a similar level of improvement as changing the snow scheme. For example, the snow conductivity parameter could be set too high. While the investigation of adjusting these parameters would be a lot of work, comparing the total snowpack conductivity between the two schemes, perhaps on a new panel in figure 3, or alongside figure S3a would enable insight as to whether the original configuration is at least partly at fault.

Regarding the biogeochemistry, the effect of the new scheme on the modelled soil carbon is of course of key interest, and it would be nice to have more of an idea of how the model compares with observations. Line 395 says "The spatial pattern… [of soil carbon] is well captured by our simulations." This, however, is not backed up by comparison to observations. It is also not mentioned if this is an improvement over the original scheme. As mentioned in the text, comparison of the total soil carbon pool with observations is restricted by LPJ-GUESS not modelling peatlands and considering organic matter to be in the top 0.5 m of the soil. While not essential for this paper, it would be nice to compare the modelled and observed soil carbon for areas where the soil depth is only 0.5 m, or perhaps more realistically compare the model to the carbon content in the upper 0.5m of the soil, which may be something for which you can find an estimate.

Other points

Title and abstract – While your title reflects the key scientific application of the paper, I feel that a more appropriate summary would be 'The physical and biogeochemical effects of implementing a multilayer snow scheme in LPJ-GUESS', as your paper doesn't really aim to be a sensitivity study. At any rate, I would advise you to consider including the

name of your model (LPJ-GUESS), and what you are specifically doing (introducing a multilayer snow scheme) in the title. If however the main aim is to answer specific scientific questions, these should be set up clearly in the introduction, and answered in the end. Currently, I think your abstract is a good summary of your paper, but it could do with some quantitative statements. Indeed, more quantitative statements would generally be welcome throughout the text when making comparisons.

The implementation of the dynamic snow scheme is on the whole clear, however, in line 144 it says: "The computational cycle ends by rearranging the layers based on the depth thresholds, taking into account the potential liquid water content." More detail on how this is done is needed here to make your method reproducible. It would also be beneficial for readers unfamiliar to LPG-Guess to have a really brief overview (even a few sentences) on how soil thermodynamics and soil carbon are accounted for in the introduction to LPJ-GUESS at the start of section 2. For example, does the model have layers of soil, how deep is the soil, what permafrost processes are simulated?

Section 5 - I'm not entirely sure as to the distinct purposes of each paragraph in the conclusions, maybe this could be made clearer?

Will you be including a code/data availability statement?

Plots & tables

Plots are generally clear, however, colour bar scales should be altered for some plots to improve readability and to facilitate comparison. For example, in figure 8 it's very hard to see the distribution of winter respiration rate; maybe a different scale could be used? Also, the choice of two different scales for Figure 8a and Figure 8b make summer and winter difficult to compare, as well as making it appear as though there is more change in summer, while this might not be the case.

Figure 12 is nice, however, there are a few things that could make it clearer. Firstly, to my eyes, the colorbar has a clear distinction between red (increase) and grey (neither increasing or decreasing), but a not-so-clear distinction between grey and blue (decrease). This results in it not being clear, for example, whether Ra for permafrost in winter is negative, neutral or even slightly positive but still very small. Maybe this could be made clearer with a separate colour in the middle, or a clearer changeover in the middle between red and blue. Also, the acronyms in this figure may not be immediately obvious to people who haven't read the text, so would be good to include in a key / the figure caption. Finally, I'm not sure I quite get the different box borders.

Figure 4 – The bottom right panel (delta T vs snow depth for the static scheme) seems wildly different to the observations and the dynamic scheme. Is the scale on the y axis

wrong? On a separate note, it seems odd that there is so little variation in soil temperature with snow depth for the static scheme, so again I wonder if the static scheme has been set up with a poor value for the thermal conductivity and density. Again, it would be nice to compare these between schemes and go into why the new scheme has the effect it does.

Line 163 / Table S1 - Relatively little information is given in table S1 about these sites. I would say that including the coordinates of sites is essential. Climatic indicators would be nice. Site observations need to be referenced.

Technical corrections

Line 18 - The sentence "These developments contribute to a better understanding of the Arctic's role in the global climate system" may be overstating things?

Line 28 – Since CO_2 and methane is already being released, perhaps the sentence should talk about an increase in the release, or the change in the net warming effect?

Line 34 – It would be nice to quantify what "varies widely" means here.

Line 54 – Maybe specify what these "key physical processes" are here.

Line 59 – (Style) Maybe simplify to 'improve LPJ-GUESS's simulation of the insulating effect of snow'.

Line 61 – (Style) Change 'this' to 'the'

Line 64 – (Style) You switch to future tense here.

Line 65 – I'm not sure what you mean by "We address the changes… ".

Line 73 – (Style) ", about 60° latitude," would be more suited to being in brackets rather than a double comma.

Equation 2 – It might be nice to mention what precipitation is doing in this equation.

Line 94 – It might be nice to mention the limitations of this assumption.

Line 99 – How are parameters a, b and c determined?

Line 103 – Is this minimum density often reached? Also, what is the physical mechanism which would impose this limit in reality?

Line 109 – Specify which physical properties are combined with the soil layer properties in this case.

Line 110 – (Style) "In case all five layers are exceed…" should be 'In the case where all five layers exceed…"

Equation 5 – I'm not sure if ρ_0 has been defined yet.

Line 144 – Is a daily timestep used then?

Line 165 – Are overlapping time periods used?

Line 169 – How many Russian sites are there?

Line 178 – "the influence of snow" -> 'the effect of changing the snow scheme'

Lines 187-190 – You are making the point the improvement in soil temperatures does not seem to be to do with improvements in snow depth. The logical conclusion is that it is the properties of the snow which have changed. This should be mentioned here. An analysis of where the change lies naturally follows this figure and should be discussed. While you may not have the level of detailed observations as in figure S2 for all sites, a new figure or panel similar to figure 3 comparing the difference in average thermal conductivity (and possibly density) of the snowpack between schemes, would allow this essential analysis.

Lines 192/3 says that "there is a smaller variance of modelled values of snow depth and soil temperature using the Dynamic snow scheme". This is true for soil temperatures, but not really the case for snow depths. On a separate note, would it be helpful to have the statistics covering just the winter period? The lower boundaries of the statistics may become more useful if this were the case.

Figure 3 – see point about snow densities/conductivity in the static scheme, also, is the soil wet enough for the static scheme in Abisko?

Line 203 – Still wondering how many sites there are in total.

Line 204 – "…has a better skill…" -> "has better skill"

Line 213 – "…has an improved skill to simulate…" - > "…has improved skill in simulating…"

Line 232 - Hypotheses need to be introduced, then tested. You have not introduced this as a hypothesis anywhere.

Line 223 – This appears to read that implementing a compaction process in the model causes the snow depth to be greater. Are you sure that this is the case?

Line 240 – much closer!

Line 247 – Figure S3a shows the *temperature* is increasing rapidly in the static scheme *before* snow melt, though you could possibly say this for the dynamic scheme, or for water availability rather than temperature.

Lines 253/4 – The sentence "…the largest changes in snow depth, temperature and maximum ALD coincide' is only sometimes true, as can be seen from the figures. Temperature and ALD are of course directly linked but, again, most of the change in the insulative effect is not from snow depth change, and a large part of the summer temperature difference is from difference in moisture.

Line 261 – exists -> exist

Lines 262/3 – can you mention why changes in soil carbon sometimes do not coincide with soil temperature changes?

Line 264 – A small point: changes in soil temperature of course do influence soil carbon (you have assumed a rate of respiration change after all), so could this sentence be more specific?

Line 266 – Could you be more specific about how the normalisation is done?

Figure 10 - Even though you are primarily comparing schemes, it would still be nice to show the absolute NEE from figure S9 in the main text so that the differences in the schemes can be compared to the absolute values i.e. would it be enough to flip the ecosystem from a source to a sink or is this a small effect. Maybe this could be talked about in the main text as well?

Line 294 – "no vegetation" -> "mostly bare soil" (as we are comparing the *dominant* type of vegetation).

Figure 12 - why is NEE decreasing for summer permafrost?

Line 320 – why does nitrogen mineralisation decrease in the winter? (this seems to be the opposite effect of what is expected from figure 12).

Section 3.4 - This section could possibly so with a little more explanation to guide the reader through the cause-and-effect of what is quite a complex diagram.

Lines 322/3 – strong heat transfer results in insufficient insulation?

Line 325 – maybe cross-reference figure S3.1 here? You could even split figure S3.1 into permafrost and non-permafrost panels.

Line 333 - the sentence starting "By altering..." could be rephrased to make its relation to the preceding sentence clearer.

Line 356 - delete the first comma in this sentence and change second comma to ', and also'

Line 356 – There's a bit of switching between present and past tense in this paragraph.

Line 358 – You've used the phrase 'improves the simulation of soil thermodynamics' (or similar) a few times now. It's a little picky, however, you haven't actually changed how the soil thermodynamics work, but you have improved the soil temperatures.

Line 358 – "can be applied for in depth analysis across the Arctic" is a bit vague.

Line 364 – Does this need confirming?

Lines 363 to 369 seem like they belong in the introduction.

Line 371 – A 'however' at the start of the sentence 'Considering the presence of permafrost..' may help the logical flow with the preceding sentence.

Lines 374 & 375 – I'm simplifying slightly, but this reads as 'respiration increases because respiration increases'?

Line 376 – 'can be attributed to' -> 'due to'

Line 377 - It would be nice to have a total for this, or at least some numbers! Maybe cross reference figure S3?

Line 384 – Could you give some numbers here?

Line 386 - In most areas? Also, what does significantly different mean here? Maybe just compare the two, or say the total difference it makes in each case?

Line 388 – "We found that the soil carbon pool is lower…" -> 'We found that using the

dynamic model decreases the soil carbon pool...'

Line 421 – Hypotheses need to be introduced, then tested. You have not introduced this as a hypothesis anywhere.

Line 422 – is the word "significant" justified here?

Line 453 "and outside of" -> 'but especially outside of'

Line 453 "The differences between the simulations were larger within permafrost underlain areas." – This is true for the physical variables, but not the case for, say, NEE.

Line 465 – add reference.

Line 478 - Apart from the tunga-taiga boundary & dominant veg types, I'm not sure you've done much comparison of the biogeochemical variables with observations, so can you say that you have decreased the uncertainty?

Lines 476 to 482 perhaps have a bit of repetition.

Supplement:

S2.1 – Again, I feel like this should be in the main paper, as it's important to know that you can get the density right, and that's not really covered much elsewhere.

S3.1 – It would be great to have an average thermal conductivity on here. Also, what area does this cover?

Figure S9 - having got used to red = positive, blue = negative, it would be nice if this was also used for the Summer absolute NEE.

Figure S11 – Again, water content is a key control on summer soil temperatures - you can

see the impact of the patches which are now drier on the summer soil temperatures - they don't warm up as much. Some comparison of this to changes in soil temperatures may be important in the main text.

S3.5 – “Fig. ??” - broken link?

Figure S12a - It would be nice to show percentages for each of the pathways, especially since the fraction that remains unchanged is not shown. It might have been nicer to show the change in areal coverage (which would include the areal changes within sites of each PFT) rather than the change in the number of sites where that type dominates. However, it’s probably not worth reanalysing for this plot.