Response to the editor

Dear Yi,

your revised manuscript has now been seen by another reviewer who has some additional comments. Please respond to the comments and also make sure that you follow the GMD policy that model code and data has to be archived in a persistent repository and that the version number is included in the title.

Best

Marko

[Response] Thank you very much for your time and effort in handling our revised manuscript. We have carefully addressed the reviewer's additional comments and revised the manuscript accordingly. In compliance with the GMD policy, we have archived the model code in a public Zenodo repository: https://zenodo.org/records/15306029, and have archived all datasets used in the study, along with the processing scripts and code for generating the results and figures, in a separate Zenodo repository: https://zenodo.org/records/15371113. Both repositories are cited in the manuscript to ensure full reproducibility. Additionally, we have included the model version number in the title, as required.

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General comments

Peatlands are one of the largest C reservoirs on land that actively interacts with the atmosphere. Peats as organic soils (histosols) are often much deeper than mineral soils types and have very different formation process due to waterlogging conditions. So more realistic treatment of peatlands is critical. Also, most organic carbon in Yedoma deposits have not been incorporated through soil forming processes such as roots or pedoturbation. The study incorporates and integrated these two "special" land surface units (peatlands and Yedoma deposits) using a new spin-up scheme into a popular land surface model (ORCHIDEE). This represents an important progress towards modeling deep land carbon for many applications in the future.

I have read the revised manuscript and authors' responses to previous round of reviewers' comments. In general, I think the manuscript is much improved.

[Response] Thank you very much for taking the time to review our revised manuscript and for your encouraging feedback on both the manuscript and our previous responses. We sincerely appreciate your detailed, thoughtful, and constructive comments, which have helped us improve the clarity of the paper greatly. We have carefully revised the manuscript following your suggestions. Please find our point-by-point responses to your major and detailed comments below.

Major comments

I do have a few additional questions that the authors may wish to consider.

1. *When describing Yedoma deposits, the authors refer them either as Yedoma deposits or soils. During the late Pleistocene when the Yedoma was actively formed, it should be referred as Yedoma deposits, as there was almost no soil formation process. Most or all organic matter was buried through sedimentation processes, such as aeolian (wind-blown), alluvial (by water), colluvial (by gravity) or nival processes (through snow/meltwater). However, during the Holocene, Yedoma deposits are presumably no longer actively accumulating, so soils could be formed on these deposits. For the purpose of this study, in most occasions it should refer as Yedoma deposits. I feel that the authors should clarify this distinction.*

[Response] Thank you for this thoughtful suggestion. Our model was indeed designed to reflect the distinction between "Yedoma deposits" and "Yedoma soils": during the late Pleistocene, carbon accumulates in Yedoma deposits through the sedimentation processes. In the Holocene, these processes are turned off, allowing conventional soil formation and carbon accumulation to occur on top of the existing deposits. As our study focuses more on the carbon accumulation processes during the late Pleistocene, we now consistently use the term "Yedoma deposits" throughout the revised manuscript, as suggested by the reviewer.

2. *During the Yedoma formation period before the Holocene, there should be multiple PFTs that had grown on these deposits from the boreal to arctic regions when the weather/climate permits, as perhaps implemented in Zhu et al. (2016), despite that the organic matter did not necessarily enter the "soil" profile through pedoturbation or other soil forming processes, but instead through burial and sedimentation processes. Perhaps during the Holocene, the process should be similar to other conventional PFTs (see comment above). On that point, I'm not sure what does the term fi(z,t) (that is, "the OC input to pool i") in equation 2 refers to: burial/sedimentation as for Yedoma deposits or root or litter input as for soils on Yedoma deposits parent materials.*

[Response] In our simulation of Yedoma formation during the late Pleistocene, we use the dynamic global vegetation model in ORCHIDEE-MICT, as in Zhu et al. (2016), to allow multiple PFTs to grow wherever climate conditions permit. These PFTs provide organic matter, which is buried directly via sedimentation processes (as represented in Equation 2), rather than being incorporated through soil-forming mechanisms like pedoturbation. At the beginning of the Holocene, we transition to a single Yedoma PFT that inherits the total carbon previously accumulated by all PFTs in the Yedoma deposits. From that point on, sedimentation processes are turned off, and conventional soil formation continues on top of the existing deposits. This setup enables us to distinguish the future response of Yedoma-affected regions from that of conventional vegetation types like trees and grasses, as well as peatland PFT.

Regarding Equation 2: the term *fi(z, t)* refers to the input of organic carbon (OC) into pool *i*, typically from root and litter inputs. In conventional soils, these inputs are incorporated into the soil profile and transported downward through soil-forming processes. By contrast, during Yedoma formation, the same organic inputs are buried through sedimentation rather than pedogenic processes. This burial is captured by the sedimentation term "$u(t)\frac{\partial C_i(z,t)}{\partial z}$" in Equation 2.

3. *Why the very different peatland initiation scheme/timings in the old and new spin-ups generate very similar total C stocks in peatlands? Are these simply coincidence or constrained by mass conversation or the net result of compensation of different peat C processes (such as NEP, decomposition, and various decomposition rates of different C pools)?*

[Response] Thank you for this great question. We also initially expected notable differences in total peatland carbon stocks, given that the new spin-up, which incorporates observation-constrained peatland initiation timing, substantially shortens the duration of peat carbon accumulation, particularly for peatlands younger than 13,500 years (Fig. S1). However, the total carbon stocks in peatlands remain similar between the old and new spin-ups. This is primarily due to the mass conservation constraint in ORCHIDEE-MICT, which we have explained in Section 4.1.

First, we do find that the shorter accumulation period in the new spin-up leads to a reduction of 20 Pg C (7%) in deep (>3 m) peat carbon and a 35 Pg C (43%) decrease in the passive SOC pool (the slowest-turnover carbon pool) (Table 3), particularly in younger peatlands (Fig. 6). Peat depths also become 1–5 m shallower, especially in the Boreal region (Fig. S5f), where total peat SOC decreases by 53 Pg C (18%) in the new spin-up compared to the old.

However, this loss is largely compensated by an increase in Arctic peatland carbon stocks, 49 Pg C (15%) higher in the new spin-up. This compensation arises from the model's mass conservation requirement: as peat PFTs expand during the Holocene, SOC from shrinking conventional PFTs (e.g., trees and grasses) is redistributed to the expanding peat PFTs. In Arctic regions, where conventional PFTs already store substantial SOC (up to 3 m depth; see Fig. 7 and Fig. S4), this inherited SOC results in even higher stocks and deeper profiles in the new spin-up (Fig. S5). By contrast, mid-latitude peatlands, where conventional PFTs store less SOC, receive less inherited carbon, leading to fewer disruptions to the impacts of constrained peatland initiation timing on peat carbon accumulation.

In summary, while the model's mass conservation constraint drives a regional compensation in total peat carbon stocks, the revised peatland initiation timing still plays a critical role in shaping the vertical distribution and turnover characteristics of peat carbon pools, especially in the Boreal region. The reductions in deep SOC, passive SOC, and peat depth under the new spin-up may alter the future vulnerability and response of peat carbon to climate change.

Some detailed comments:

I have some editorial edits and suggestions to help improve the clarity of the manuscript. Specific comments:

Line 19: change to "... peatlands (formed mostly during the Holocene)..."

[Response] Done.

L23: not soil layer in Yedoma deposits. See comment above.

[Response] Thanks. We have revised the sentence as "... that deposited deep carbon in **the layers of peatlands and Yedoma deposits.**".

L62-63: perhaps better called it "deposits", rather than "sediments"

[Response] Revised as suggested.

L68: not Yedoma soils, but Yedoma deposits

[Response] Revised.

L108: Yedoma deposits
[Response] Revised.

L145: change "sedimentation" to ""sedimentation"" (with quotation marks), as it is an accumulation process by plants living on peatlands, not really sedimentation process
[Response] Revised as suggested.

L160: change to "downward movement rate"?
[Response] Revised.

L165: "Strauss et al. (2013)"
[Response] Revised.

L216 Table 1: Change "period" to "Duration"?
[Response] Revised as suggested.

L238: at the end add "smaller … extent of Yedoma deposits south of 60 N"
[Response] Thank you. We have revised the sentence slightly beyond the suggestion as: "**…given that no Yedoma deposits are found south of 60°N (Fig. 2; Strauss et al., 2021).**" According to the Yedoma deposit map in Strauss et al. (2021), "no" is more accurate than "smaller", as there is no documented extent south of 60°N.

L242: add "," after land surface model"
[Response] Added.

L244 Table 2: change "Epoch" to "Period" and "Period" to "Duration" on both table heading lines. "Epoch" is official chronological term in geology stratigraphy, such as "Holocene Epoch".
[Response] Revised as suggested.

L260: change "benthic mosses" to "mosses"
[Response] Done.

L268 and elsewhere in this paragraph and in the manuscript: change "epochs" to "periods". See comment above.
[Response] Revised throughout the manuscript.

L271: change "…time in kyrs from 16 to 9" to "…time from 16 to 9 kyrs"

[Response] Done.

L290: Figure 3a: vertical axis label units to "Number per kyr" and "Mkm2 per kyr"

[Response] Revised as suggested.

L298 and line 304: change to "Xi et al. (2014)" (no comma)

[Response] Done.

L307: change "forest" to "tree"

[Response] Revised.

L316: "Results and evaluation" is a little weird. Change to "Results and interpretations"?

[Response] Thanks for the suggestion. We have revised the heading as "**Results and interpretation**".

L340: change to "kg per m2". Also, "…depth of total organic carbon" is not an accurate expression. Change to "…depth of Yedoma deposits" or "…depth of OC-rich Yedoma deposits"? Deposits have depth, but OC doesn't.

[Response] Revised to "kg per m2" and "...depth of Yedoma deposits".

L343-344: see comment on line 238. Add "south of 60 N"

[Response] Following our response to your comment on line 238, we revised the sentence as: "**…given that no Yedoma deposits are found south of 60°N (Fig. 2; Strauss et al., 2021).**"

L345: change "peat" to "peatlands"

[Response] Done.

L351-352: change "for" to "from conventional PFTs…", and also elsewhere?

[Response] Revised throughout the manuscript.

L355: in the figure panel (b) and (d) X-axis label: change "Simulation year" to "Simulation time"?

[Response] Done.

L364: change to "accumulate a total soil carbon stock of 1239 Pg C…"

[Response] Done.

L365: to "present-day Yedoma extent"

[Response] Done.

L379: "in the new spin-up than the old spin-up"

[Response] Done.

Table 3:

Left column: change to "Total OC stock", to "By depth interval (m)"

[Response] Revised as suggested.

L417 Figure 7 caption: these are not "soil types". Change to "comparison of simulation results from the old and new spin-ups"?

[Response] Thank you for pointing this out. We have revised the caption as "Carbon accumulation for three **PFT classes** after the peat simulation from the old and new spin-ups." While we appreciate the suggested caption, we felt that "comparison of simulation results from the old and new spin-ups" was too general and did not clearly convey the figure's focus on PFT-specific carbon accumulation.

L460: The 4.1 heading sounds too similar to "Results and evaluation/interpretation" section. Should focus on some more integrated and more important topics to discuss, rather than still on differences and interpretations of new and old spin-ups…

[Response] Thanks for the suggestion. We have revised the heading to a more focused title: "**Effects of SOC insulation on soil carbon accumulation**".

L504: The discussion on the SOC-Tsoil feedback is really good! It would be really useful to partition of relative contributions of different processes and mechanisms, including peat-T feedback, partition of OC pools (passive vs slow vs fast)/turnover times, perhaps in future analysis.

[Response] Thank you for your positive feedback. We also consider this an important direction for our future analysis.

L548-449: not only for peatlands. If the simulations use realistic paleoclimate input data sets, you would expect changes in PFTs at different time during the last 20 kyrs, even if there were no feedbacks between vegetation and climate through online simulations with ESM. This limitation should perhaps be mentioned here.

[Response] Thank you for this helpful suggestion. We have mentioned this point in the revised discussion "Coupling with paleoclimate models (e.g., Kleinen et al., 2012, 2016; Treat et al., 2019) or using available datasets such as TraCE-21ka (He et al., 2013), **along with incorporating the dynamic**

evolution of conventional PFTs (e.g., trees, grasses, and croplands) over the last 20,000 years, would enable a more realistic simulation of carbon accumulation in peatlands and conventional soils." (L548-551)

L554-555: incomplete sentences. Change to "…in peatlands, omitting…"
[Response] Revised as suggested.

L559-560: ...presents a new spin-up protocol…by representing deep carbon …. Peatlands more realistically in the ORCHIDEE,,,"
[Response] Revised as suggested.

L563: change to "after observation-constrained peat initiation time…"
[Response] Revised.

L566: "226 Pg larger that the old…"
[Response] Revised.

L563-564: "a model version for simulation of deep land carbon….transition and for projection of land carbon response to future warming"
[Response] Thank you. We have revised this sentence as suggested.

References

Strauss, J., Laboor, S., Schirrmeister, L., Fedorov, A. N., Fortier, D., Froese, D., Fuchs, M., Günther, F., Grigoriev, M., Harden, J., Hugelius, G., Jongejans, L. L., Kanevskiy, M., Kholodov, A., Kunitsky, V., Kraev, G., Lozhkin, A., Rivkina, E., Shur, Y., Siegert, C., Spektor, V., Streletskaya, I., Ulrich, M., Vartanyan, S., Veremeeva, A., Anthony, K. W., Wetterich, S., Zimov, N., and Grosse, G.: Circum-Arctic Map of the Yedoma Permafrost Domain, Front. Earth Sci., 9, https://doi.org/10.3389/feart.2021.758360, 2021.

Zhu, D., Ciais, P., Krinner, G., Maignan, F., Jornet Puig, A., and Hugelius, G.: Controls of soil organic matter on soil thermal dynamics in the northern high latitudes, Nat. Commun., 10, 3172, https://doi.org/10.1038/s41467-019-11103-1, 2019.