To Review No. 2

Reviewer 1 has provided a thorough and insightful evaluation of the manuscript, highlighting several key issues that warrant attention. I won't repeat all their points here, but I would like to express my full agreement with their assessment.

That said, I also share Reviewer 1's view that the paper addresses an important topic—modeling peatland drainage and its effects on greenhouse gas emissions. This is a valuable area of research that deserves continued development. The modeling approach appears to perform quite well under pristine conditions, especially where the water table depth (WTD) remains above -20 cm in the calibration datasets. In that respect, the paper serves as a strong example of model development. It may also serve to inform of what may happen to pristine systems as these are affected by warmer and drier climates.

However, the system being modeled—drained peat soils—is highly complex. These soils behave quite differently from mineral soils or even undisturbed peatlands. Lessons from better-studied systems may not always transfer well, especially for peatlands that have been drained for long periods.

My primary concern lies in some of the claims made based on this model. These are bold conclusions, and in such cases, it's essential to ensure that they are supported by robust evidence. At present, I'm not fully convinced that the data and analysis sufficiently back these claims.

There are many innovative aspects in the manuscript, but the results hinge critically on the assumption of a slow SOC pool in deeper peat layers. As Reviewer 1 has pointed out (and I had also intended to reference), this assumption may not reflect reality. In fact, evidence suggests that in agricultural peatlands, decomposition rates often increase over time as the peat becomes more degraded. This point should be reconsidered in future model iterations.

Thank you very much for your time and effort in reviewing our manuscript, and for your constructive feedback. We fully agree that the drained peatland system is highly complex and that conclusions based on current model outputs must be interpreted with caution. The model still has many shortcomings and needs to develop more. Our aim was to take an initial step toward simulating how a pristine peatland would respond to drainage, as a first move toward more realistic modeling of drained peatland dynamics, not to draw any broad or definitive conclusions. We have moderated the strength of our conclusions accordingly.

Regarding the SOC decomposition dynamics, we share your concern. As noted in our response to Reviewer 1, the model does not currently simulate progressive changes in SOM quality or associated increases in reactivity due to degradation. Instead, decomposition is governed by fixed turnover times across conceptual carbon pools. We recognize this as a key limitation and have added a statement to the Section 4 - Discussion to highlight the need for future model improvements in this area.

In revised manuscript:

Additionally, it was found that highly decomposed peat due to drainage can be more vulnerable to further breakdown (Säurich et al., 2019), which is influenced by both peat properties and nutrient status. Yet, our current model does not explicitly track the progressive degradation of individual SOC components or incorporate nutrient feedbacks to diagnose their corresponding reactivity. Decomposition could be calculated based only on a fixed residence time which is a parameter calibrated under pre-drained conditions. Simulating peat properties and their feedbacks as dynamic variables would require further model development.

In the revised manuscript, we (1) added further clarifications and explanations to improve the manuscript based on reviewers' feedback, (2) included a sensitivity experiment to assess the potential impact of vegetation change, and (3) introduced an additional scenario of 80 cm drainage.

I'd also like to raise a few additional considerations:

1. Drainage depths used in the model runs: The levels tested (-5, -10, -20, and -50 cm) seem quite shallow. Only the -50 cm scenario might resemble an initial drainage condition. Including deeper, more representative drainage levels could provide more realistic insights.

We added a drainage of 80cm in the revised version. All the figures and statistics were updated accordingly.

2. Dynamics of managed drainage systems: In real-world settings, drainage in peat soils is often actively maintained over time—ditches are deepened, compacted soils are re-drained, etc. This means that drainage may reach progressively deeper peat layers, encountering different SOM characteristics than those present at the start. The model could reflect this temporal change more explicitly.

Thank you for highlighting this important aspect of managed drainage systems. While we did acknowledge in the Discussion that subsidence may cause the peat surface to lower over time - bringing it closer to the water table - we did not explicitly consider the common practice of actively maintaining drainage efficiency by deepening ditches or re-draining compacted soils. We agree that this practice can result in progressively deeper drainage over time, potentially exposing peat layers with different SOM characteristics than those initially affected. Capturing such dynamic feedback would require additional model developments, particularly in representing peat structural changes, compaction, and adaptive ditch management strategies. We acknowledge this as a further limitation and have clarified this point in the revised Discussion.

In revised manuscript:

Additionally, in managed systems, drainage is often actively maintained over time - such as by deepening ditches - to preserve drainage efficiency. This practice can lead to a progressive lowering of the effective water table, further exposing deeper peat layers with different SOC characteristics. Incorporating such dynamics would require modelling not only peat subsidence, as already noted, but also adaptive ditch management, which is not yet represented in the current model framework.

3. Use of GWP for interpreting results: While GWP is commonly used in policy contexts, it may not always capture the complexity of peatland carbon dynamics—particularly the long-term CO_2 storage versus CH_4 emissions trade-off. Radiative forcing models might offer a more nuanced picture and could be used to contextualize the GWP results more effectively.

We totally agree with this opinion. In fact, we were going to do that: using a radiative forcing model to evaluate the net climate impact instead of GWP. However, we found this manuscript already long and did not want it to have more content. So we used GWP for now and considered the run with radiative forcing model as a potential follow-up to this study.

A few minor suggestions:

Please clarify whether the point data in the figures represent actual site measurements or model outputs.

It's done.

In line 495, it seems there may be a typo in the equation: should it be intNEE rather than $intCH_4$?

It was indeed the initial CH4. Initial CH4 was found to have a strong relationship with NEE sensitivity.
Anyway, with the 80cm drainage updated, the equation changed now (although initial CH4 is still highly related to the NEE sensitivity).

<u>In revised manuscript:</u>

$$S_{NEE} = 0.022 - 0.013\, NEE_{init} - 0.025\, MI \qquad (3)$$

(R2 = 0.92, p< 0.001)

$$S_{CH4} = 0.045 - 14.426\, CH4_{init} \qquad (4)$$

(R2 = 0.998, p< 0.001)

With a more realistic representation of drained peat soils, this modeling framework has strong potential to inform both research and policy. I hope these suggestions are helpful and supportive of the manuscript's continued development.