

Point-to-point responses to comments

We thank the Editor and the reviewers for their careful evaluation of our revised manuscript and for the constructive comments provided. In response, we have substantially revised the manuscript to address the key issues raised in the decision letter and the reviewers' reports. Below, we first respond to the Editor's comments, followed by detailed point-by-point responses to the individual reviewers.

Decision letter:

Dear Authors,

First of all, please accept my sincere apologies for the considerable delay in getting back to you with the reviews. Unfortunately, none of the original reviewers were available to re-assess your work, and it proved very difficult to find new experts willing to evaluate this revised version. I have now received feedback from two new reviewers, both of whom carefully considered the initial reports as well as your revised manuscript.

Although this new version represents a clear improvement, both reviewers concluded that several of the original concerns were not sufficiently addressed. In particular, they found that some of the manuscript's main claims remain insufficiently supported by the model development and analysis presented. Both reviewers emphasize that the paper would benefit from a more transparent and balanced framing—acknowledging the methodological advances achieved while also clearly discussing the remaining limitations. Their comments, which align closely with those made in the first review round and during the interactive discussion, point to several key aspects that require substantial revision: (i) the model is still applied beyond its calibration range; (ii) the quantification and communication of uncertainty should be strengthened throughout; and (iii) the conclusions should more carefully reflect the limited temporal validation range and avoid overinterpreting exploratory results, particularly with respect to the net climate effects of drainage.

Given these constructive but substantial reviews—which are fully consistent in their assessments—I will only be able to reconsider the manuscript for publication after major revisions have been undertaken to reframe the paper along the lines suggested by the reviewers.

Kind regards,

Marijn

Response:

Thank you for your assessment of our revised manuscript and for summarising the key issues that remained insufficiently addressed. In response, we have undertaken a substantial revision of the manuscript to improve its framing, transparency, and interpretation, focusing in particular on the three points highlighted in your decision letter.

First, we have revised the manuscript to more clearly position this study as an exploratory, first-step modelling effort. While long-term drainage simulations are retained, they are now consistently framed as model-based scenarios rather than validated predictions, with explicit clarification of the temporal range over which the model has been evaluated against observations.

Second, we have strengthened both the quantification and communication of uncertainties throughout the manuscript. This includes explicit representation of parameter uncertainty, uncertainty arising from alternative vegetation trajectories following drainage, and a clearer discussion of remaining unresolved processes. Uncertainty ranges are now systematically shown in figures, captions, and the associated text.

Third, we have revised the conclusions to more carefully reflect the limited temporal validation range of the model and to avoid overinterpretation of exploratory results, particularly with respect to the net climate effects of drainage and GWP-based assessments. The statistical emulator is now explicitly described as being derived from short-term sensitivities corresponding to the period over which the model has been evaluated.

In addition, we have added an independent comparison with field observations from a long-term drainage experiment near FI-Sii (Appendix E), which provides complementary support for the model's ability to capture key drainage-induced flux responses under real-world conditions, while remaining consistent with the model's acknowledged limitations.

We believe that these revisions address the concerns raised by the reviewers and yourself and improve the clarity and balance of the manuscript.

Comments from Reviewer #1

Detailed comments:

Report on: Modeling the impact of drainage on peatland CO₂ and CH₄ fluxes and its underlying drivers.

Whilst there are existing site-scale peatland models that simulate drainage in peatlands and its effect on peat Carbon, this paper reports on interesting work to represent peatland drainage in a land surface model (ORCHIDEE-PEAT). However, following its revision, I still have concerns about the approach taken to presenting the model and its results. The paper represents a first step in model development, which the authors acknowledge, and it should be presented as such.

The authors clearly and fully report on the limitations of the new model's limitations when simulating drainage. However, these limitations illustrate that claims about using model predictions as a tool "for estimating drainage effects" are probably not appropriate at this stage. Instead, the limitations should be framed around the steps needed to better represent peatland drainage in a land surface model, what the challenges are, and how they might be addressed.

I agree with the comments from the two previous reviewers and won't repeat those here. However, my concerns (written before reading the previous reviews) were very similar to those already raised. Therefore, in my view, the framing of the revised manuscript should:

- Have greater focus on the drainage module and approach, which I think is still inadequate, since that is the novel addition presented here.
- Consider a different title: e.g. The development and implementation of a drainage module for ORCHIDEE-PEAT.
- Discuss what happens to peatlands when they are drained and what will or won't be simulated here.
- Discuss how other site-scale peatland models simulate drainage and compare them with the approach implemented here. Identify some of the key issues that need to be solved at some time.
- What are the challenges of implementing drainage in a LSM in comparison to site-scale models.
- Talk about the detail needed in the model. Additional complexity isn't always a good thing and can just increase the uncertainty of model predictions. Perhaps the authors can identify how they might tackle this issue.
- Highlight the progress made, and
- talk about and prioritise the next steps in model development.

In my opinion, the manuscript deserves to be published, but not in its current form.

Response: We thank the reviewer for this thoughtful comment regarding the framing of the manuscript and agree that the work presented here represents a first step toward incorporating peatland drainage processes into a land surface model, rather than a fully validated predictive framework.

In the revised manuscript, we have explicitly reframed the scope and intent of the study to emphasize its exploratory nature. In response to the reviewer's overarching concerns regarding model framing and interpretation, in the Introduction (**Lines 142-146**), we clarify that the idealized drainage simulations are intended to investigate key mechanisms, sensitivities, and structural challenges associated with representing peatland drainage in a land surface model, rather than to provide fully validated predictive estimates of drainage impacts.

We have also strengthened the Discussion to address the reviewer's concerns regarding model scope, limitations, and development priorities. In particular, the concluding section of the Discussion (**Lines 782-789**) now explicitly highlights both the progress made by implementing a drainage module within ORCHIDEE-PEAT and the key priorities for future model development, including dynamic vegetation shifts, evolving peat physical and biogeochemical properties, lateral water and carbon fluxes, and improved representation of long-term post-drainage processes.

Finally, the Conclusions, points (2) and (4) (**Lines 808-817 and 822-831**) were revised to ensure that long-term drainage responses and the statistical emulator are consistently interpreted as

exploratory, model-based scenarios rather than validated predictions, with explicit clarification of the temporal scope over which the model has been evaluated against observations.

We hope that these revisions address the reviewer's concern and more clearly position the manuscript as a methodological first step in model development for peatland drainage representation.

Lines 142-146: *“We performed idealized site simulations with virtual drainage in the future under current climate conditions, with different prescribed water table depths, as an exploratory modeling effort to investigate how peatland drainage processes can be represented within a land surface model and to identify key mechanisms, sensitivities, and structural challenges associated with drainage, rather than aiming to provide fully validated predictive estimates of drainage impacts.”*

Lines 782-789: *“Overall, building on the results and limitations discussed above, this study demonstrates that implementing a peatland drainage module within a land surface model is feasible and yields physically consistent responses of CO₂ and CH₄ fluxes to water table drawdown across contrasting sites. At the same time, the results highlight key structural and process-level challenges that remain to be addressed, including dynamic vegetation shifts, evolving peat physical properties, lateral water and carbon fluxes, and improved representation of long-term post-drainage processes. Addressing these challenges represents a clear priority for future model development before such a framework can be applied for robust large-scale predictive assessments.”*

Line 808-817: *“(2) How do fluxes change as a function of drainage duration? We found that a longer drainage period leads to a diminishment of the increase of CO₂ emissions, and to a strengthening of the CH₄ emission reduction over time with longer drainage. The first result for CO₂ is consistent with previous emission factors simulated for peat drained to croplands agriculture (Qiu et al., 2021). Such a model as presented here, if validated against real-world observations, can help provide time-dependent emission factors that may be useful for inventory calculations in the absence of long-term CH₄ emission factor changes from measurements. It should be emphasized that model evaluation against observations is currently limited to the first decade following drainage, and that simulated changes over longer drainage durations represent model-based extrapolations that should be interpreted as exploratory scenarios rather than validated predictions.”*

Line 822-831: *“What factors affect the sensitivity at each site in the model? We found that, in the model world, the initial fluxes, initial water table depth, soil organic carbon, moss fraction and temperature are the key influential factors controlling the sensitivities across sites. These variables have strong covariations in the model, so their effect cannot be isolated individually. The emulator is constructed from sensitivities of modeled GHG fluxes to water table depth derived from the first 10 years following drainage, corresponding to the period over which the model has been evaluated against observations. This finding allowed us to propose an emulator of the modeled sensitivities that could be used to predict flux changes at other sites or over a region. Yet, this is only a model result and testing it against observations would be important in the future to use such an emulator approach for GHG accounting.”*

Comments from Reviewer #2

Detailed comments:

The underlying modeling work has merit as an exploratory analysis of pristine peatland vulnerability to drainage. The framework is interesting, the topic important. The authors have made important improvements since Round 1, including a vegetation sensitivity test, and an expanded discussion of limitations. I appreciate these additions, particularly the improved Discussion section which shows good transparency about model constraints and the Abstract which appropriately acknowledges limitations (lines 41-44).

However, the main concern from Round 1, **about applying the model beyond its calibration range**, is in my view still not adequately reflected in how the results are presented. While the Discussion shows good awareness of limitations, I think the Conclusions do not reflect the same care. This creates a risk that readers will see the results as validated predictions rather than exploratory scenarios.

Response: We thank the reviewer for the clear suggestions and have done our best to address them. See replies below. We are pleased to see that the reviewer is satisfied with the vegetation sensitivity test and we agree that applying our model beyond its calibration range raises unknown uncertainty, which was acknowledged in the conclusions. We now have 1) quantified uncertainty on the model predictions from uncertain parameter values under present conditions using a Monte-Carlo approach (**Lines 221-226**) and 2) uncertainty from future vegetation shifts as the difference of predicted fluxes for different future vegetation. We have acknowledged in the conclusion the existence of 'known unknown' uncertainties, such as parameter changes and missing processes in the future.

Major Comments

1. Lack of uncertainty quantification in results

All figures show only single lines without uncertainty ranges, even though the authors used ORCHIDAS, a Bayesian method (lines 186-189) that gives uncertainty estimates from the calibration. The sensitivity analysis shows how different sites respond differently, but this is not the same as showing the uncertainty around any single site's projection.

More importantly, Appendix D shows that different vegetation assumptions can completely reverse the climate effect, from cooling to warming or the opposite (lines 615-616), yet this critical uncertainty is not shown in any main figure. Without showing uncertainty, the results look more certain than they really are.

Please add uncertainty bands to all projection figures and mention uncertainty bands in the text, e.g. in section 3.8. These could come from the Bayesian calibration and should also show the range across different vegetation scenarios from Appendix D.

Response: We agree with the reviewer that uncertainties should be quantified. Here we define uncertainty as 1) uncertain parameter values under current conditions affecting future predictions, 2) uncertainty in vegetation shift and 3) known unknown uncertainties such as shifts in future parameter values and model structural limitations, including lack of prediction capabilities for changes in organic matter decomposition induced by reduced phenolic compounds during dry conditions - phenols normally inhibit microbial activity and therefore prevent the breakdown of organic matter (Fenner and Freeman, 2011), shifts in molecular composition of SOC and stability from microbe-, plant- and re-derived sources in response to soil warming caused by drainage and future elevated CO₂ (Ofiti et al., 2023) and the suppression of drainage export of dissolved organic carbon during drainage (Rosset et al., 2022).

Regarding 1), we performed 10 Monte Carlo simulations by varying the temperature dependence of CH₄ production, which varies between sites (Q₁₀-CH₄) (Liu et al., 2025), and the oxygen deficit

enhancement of methanogenesis (O_{2m}) (Morel et al., 2019), two parameters that were found to be the most influential controlling CH_4 emissions after performing preliminary sensitivity tests. In all the figures, this parametric uncertainty was calculated by the standard deviation of the 10 simulations with varied Q_{10-CH_4} and O_{2m} and added to the graphs. **Fig. 2** shows the uncertainty on the baseline simulations and **Fig. 4, C1-C3** show the uncertainty on future projections for different water table depths.

Regarding 2), we have considered the simulations in **Appendix D** to calculate the uncertainty on future vegetation change as the min-max range of predicted fluxes across our three vegetation scenarios (unchanged, shift from moss to grass and shrubs, and shift from moss and grass to shrubs). This range was represented as an error bar in all the revised figures (**Fig. 10, D1 to D4**).

Regarding 3), we acknowledged known unknowns from future parameter shifts and unresolved processes in the conclusion with the following text

Lines 850-858: “Finally, although our study explicitly quantified uncertainties arising from parameter calibration and alternative vegetation trajectories, there remain ‘known unknown’ uncertainties associated with potential future parameter shifts and unresolved model structural limitations. These include changes in organic matter decomposition induced by reduced phenolic compounds during dry conditions (as phenols normally inhibit microbial activity and therefore prevent the breakdown of organic matter) (Fenner and Freeman, 2011), shifts in the molecular composition and stability of soil organic carbon from microbe-, plant- and re-derived sources in response to drainage-induced soil warming and future elevated CO_2 (Ofiti et al., 2023), and the suppression of dissolved organic carbon export during drainage (Rosset et al., 2022).”

Reference

Fenner, N. and Freeman, C.: Drought-induced carbon loss in peatlands, *Nature Geosci*, 4, 895–900, <https://doi.org/10.1038/ngeo1323>, 2011.

Ofiti, N. O. E., Schmidt, M. W. I., Abiven, S., Hanson, P. J., Iversen, C. M., Wilson, R. M., Kostka, J. E., Wiesenberg, G. L. B., and Malhotra, A.: Climate warming and elevated CO_2 alter peatland soil carbon sources and stability, *Nat Commun*, 14, 7533, <https://doi.org/10.1038/s41467-023-43410-z>, 2023.

Rosset, T., Binet, S., Rigal, F., and Gandois, L.: Peatland Dissolved Organic Carbon Export to Surface Waters: Global Significance and Effects of Anthropogenic Disturbance, *Geophysical Research Letters*, 49, e2021GL096616, <https://doi.org/10.1029/2021GL096616>, 2022.

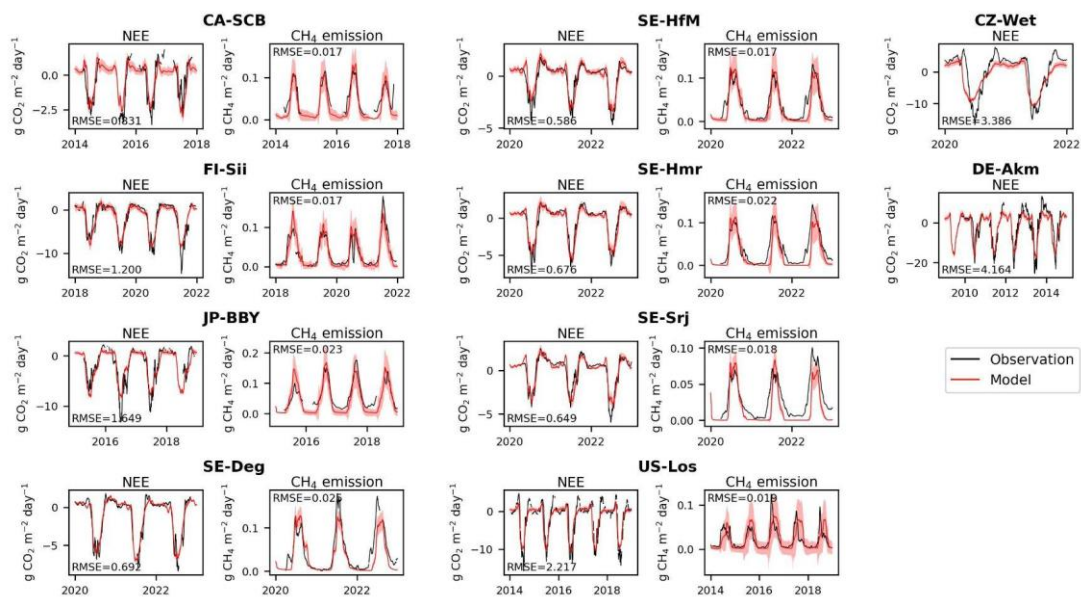


Figure 2. Comparison of model simulations after calibration with observed net ecosystem exchange CO_2

fluxes (NEE) and CH₄ emissions. Sites in panels a-h measured both fluxes and in i-j only NEE. The red shadings in each plot represent the uncertainty (± 1 standard deviation across 10 Monte Carlo simulations; see Methods) in the simulated NEE or CH₄ emission induced by parameter uncertainty.

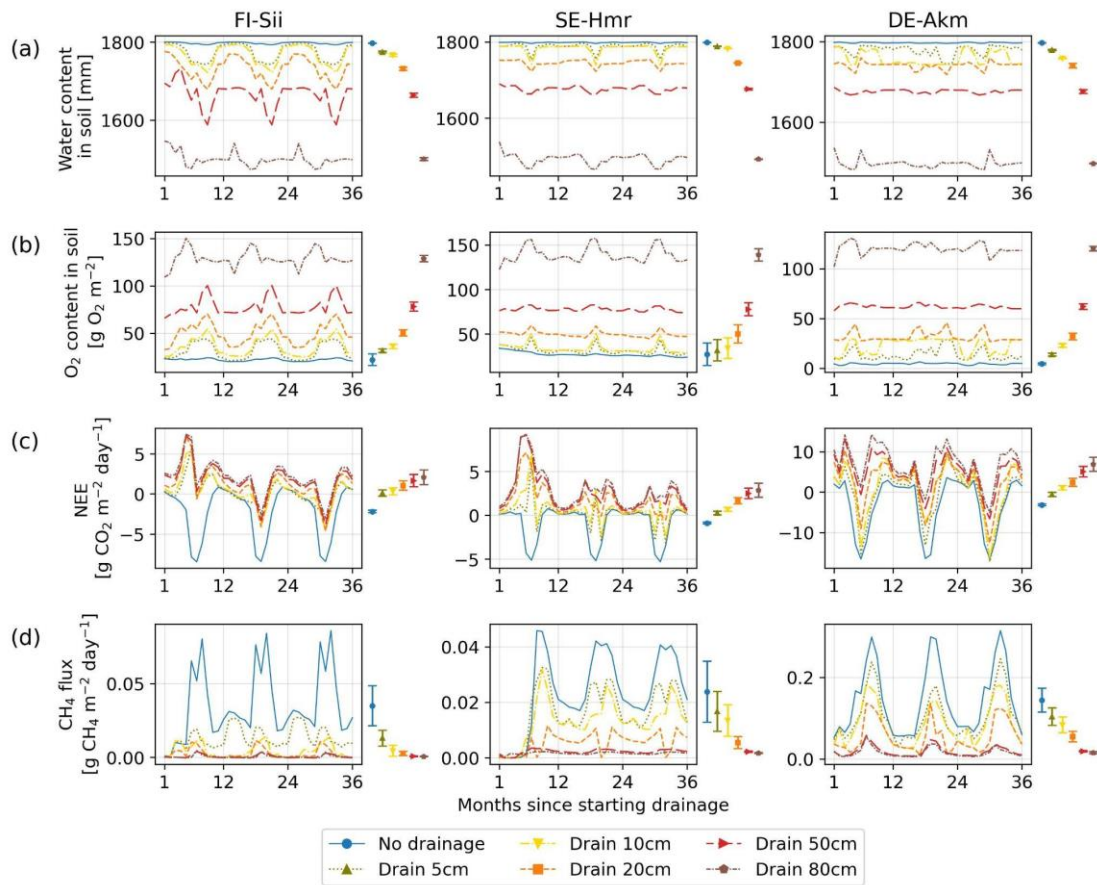


Figure 4. Simulated changes at three sites of (a) soil water content in the whole profile (2m), (b) soil oxygen content, (c) Net Ecosystem Exchange of CO₂ and (d) methane emissions. Different colors indicate different water table depths below the original water level at each site. The coloured bars on the right of each panel summarize parameter uncertainty, quantified as ± 1 standard deviation of the simulated time-mean fluxes computed over the full 50-year drainage simulation from 10 Monte Carlo runs. The coloured dots indicate the time-mean flux simulated using the calibrated parameter set. Note that when a flux (e.g. CH₄) is close to zero, the corresponding parameter-induced uncertainty also approaches zero.

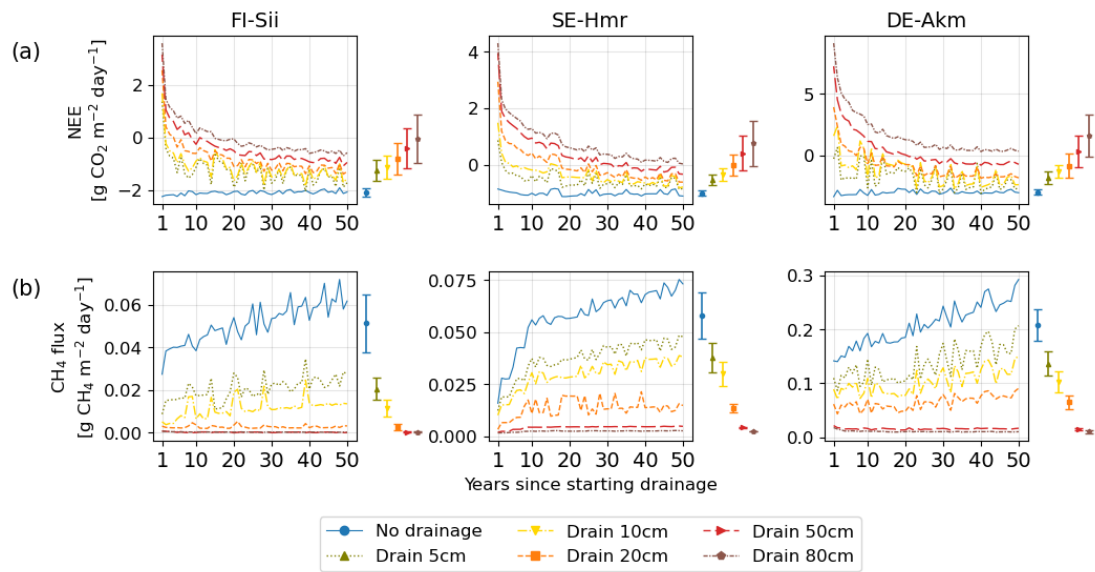


Figure C1. Simulated time series of (a) net ecosystem exchange (NEE) of CO₂ and (b) CH₄ emissions over the 50-year simulation period at the same three sites as in Fig. 4. Different colors and line styles indicate different water table depths below the original water level at each site. The colored bar shown to the right of each panel summarizes uncertainty arising from parameter uncertainty, expressed as ± 1 standard deviation of the simulated time-mean flux over the 50-year simulation period. The colored dots indicate the corresponding time-mean flux simulated using the calibrated parameter set. Note that when a flux (e.g. CH₄) is close to zero, the corresponding parameter-induced uncertainty also approaches zero.

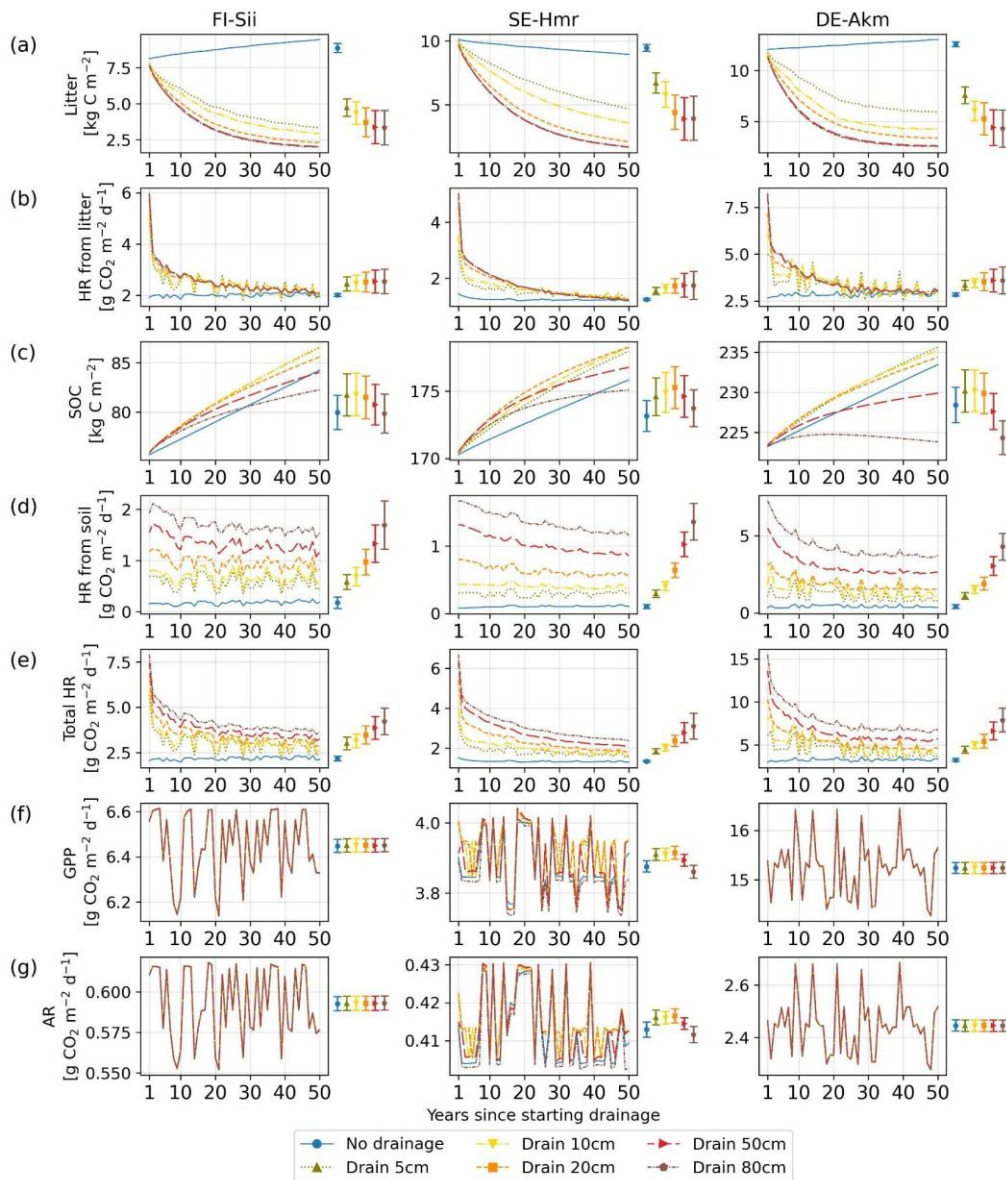


Figure C2. Simulated changes in litter carbon and soil organic carbon (SOC) pools and associated heterotrophic respiration over the 50-year simulation period following the onset of drainage. Shown are (a) litter carbon, (b) heterotrophic respiration (HR) from litter, (c) soil organic carbon, (d) heterotrophic respiration from soil, (e) total heterotrophic respiration (sum of litter and soil components), (f) gross primary production (GPP), and (g) autotrophic respiration (AR) at three sites. Different colors and line styles indicate different water table depths below the original water level at each site. The coloured bars on the right of each panel summarize parameter uncertainty, quantified as ± 1 standard deviation of the simulated time-mean fluxes computed over the full 50-year simulation from 10 Monte Carlo runs. The colored dots indicate the corresponding time-mean flux simulated using the calibrated parameter set. Note that when a flux (e.g. HR) is close to zero, the corresponding parameter-induced uncertainty also approaches zero.

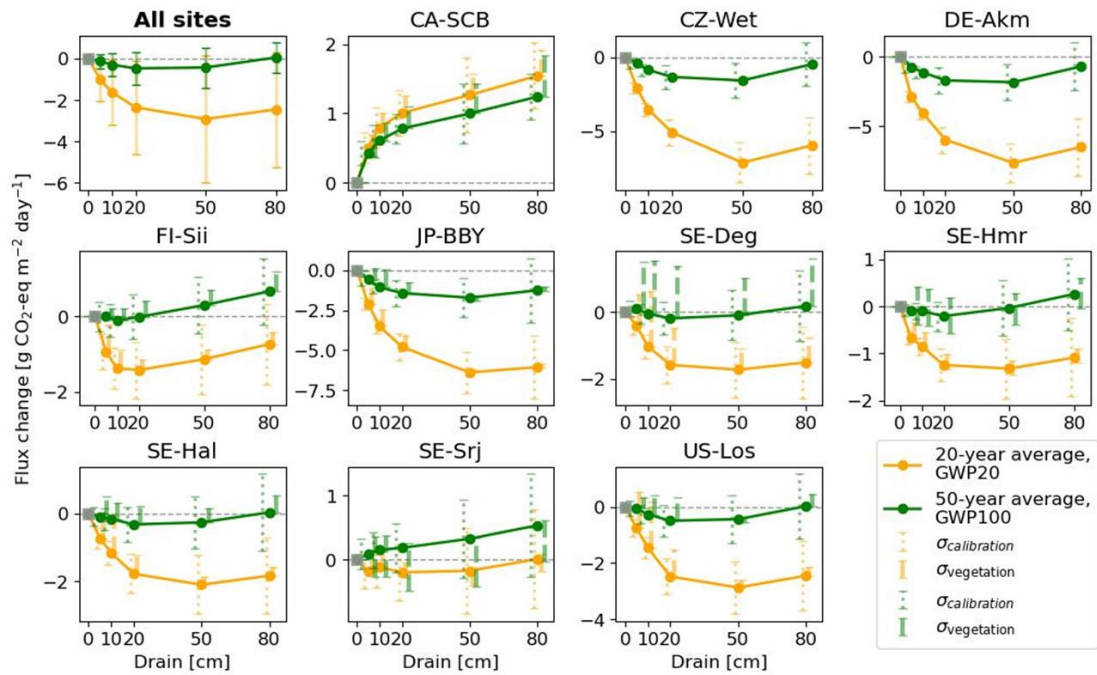


Figure 10. Change in fluxes (relative to undrained) expressed as CO₂-equivalents by drainage level (x-axis), averaged over 20 and 50 years following the start of drainage. CH₄ emissions were converted to CO₂-equivalents using GWP20 for 20-year average (orange lines) and GWP100 for the 50-year average (green line). In the plot with all sites, the error bars parameter calibration uncertainty ($\sigma_{\text{calibration}}$), quantified as ± 1 standard deviation of the simulated time-mean CO₂-equivalent fluxes over the full 50-year simulation period across 10 Monte Carlo runs, and vegetation scenario uncertainty ($\sigma_{\text{vegetation}}$), defined as the minimum–maximum range of simulated responses across alternative vegetation change scenarios (see Appendix D).

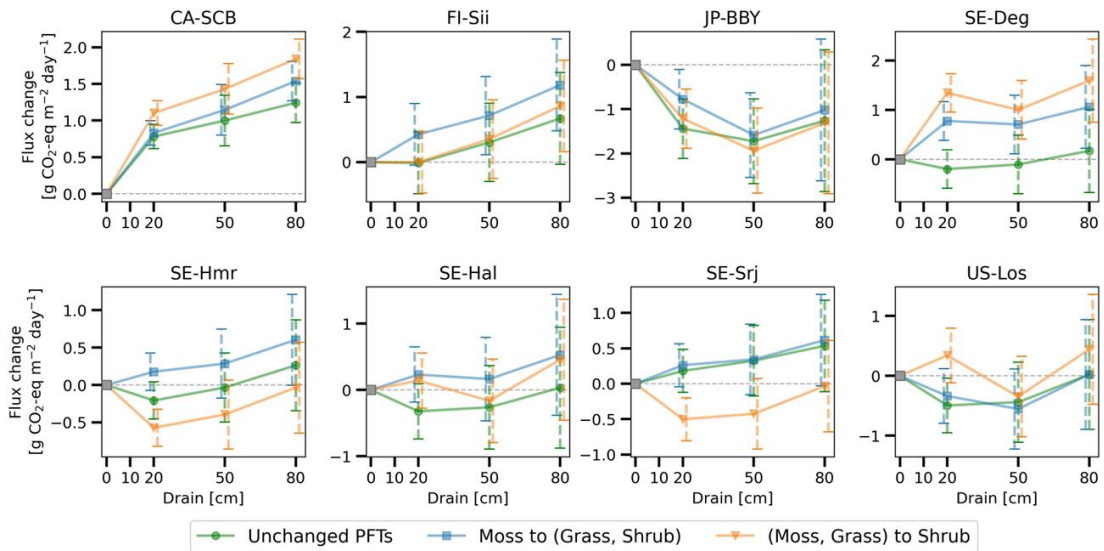


Figure D1 Combined effect of drainage over a 50-year period evaluated using GWP100 under three vegetation scenarios: unchanged plant functional types (PFTs; green), conversion of moss to grass and shrubs (blue), and conversion of moss and grass to shrubs (orange). Error bars show parameter uncertainty (± 1 standard deviation of 50-year time-mean CO₂-equivalent fluxes across 10 Monte Carlo runs). Because all vegetation scenarios use the same baseline-calibrated parameter set and model structure, parameter uncertainty is identical across scenarios, whereas differences among curves reflect vegetation scenario uncertainty.

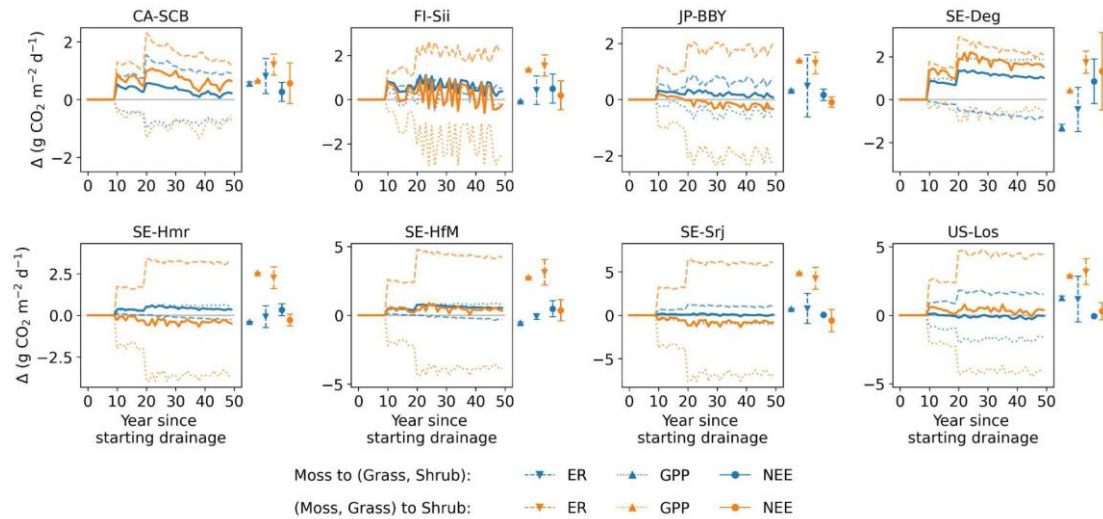


Figure D2. Changes in gross primary production (GPP), ecosystem respiration (ER), and net ecosystem exchange (NEE) under two vegetation change scenarios, relative to the unchanged plant functional type (PFT) scenario, for the 80 cm drainage case. Results are shown for the conversion of moss to grass and shrubs and for the conversion of moss and grass to shrubs. All vegetation scenarios were simulated using the same baseline-calibrated parameter set and model structure; therefore, parameter uncertainty is identical across vegetation scenarios. The coloured bars shown to the right of each panel represent parameter uncertainty, quantified as ± 1 standard deviation of the simulated time-mean fluxes over the full 50-year simulation period across 10 Monte Carlo runs. The colored dots indicate the corresponding time-mean flux simulated using the calibrated parameter set.

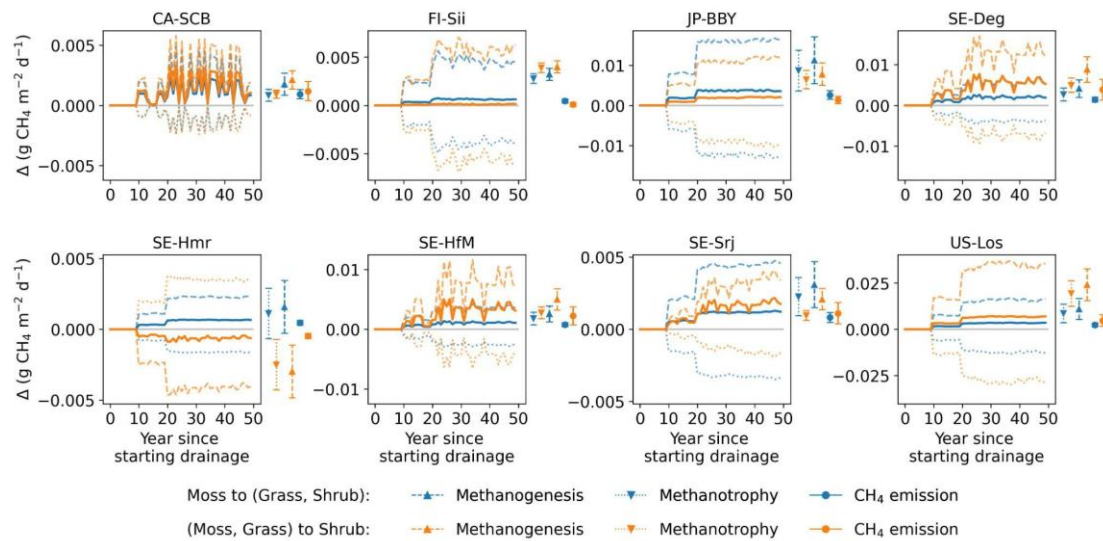


Figure D3. Changes in methanogenesis, methane oxidation (methanotrophy), and net CH₄ emissions under two vegetation change scenarios, relative to the unchanged plant functional type (PFT) scenario, for the 80 cm drainage case. Results are shown for the conversion of moss to grass and shrubs and for the conversion of moss and grass to shrubs. All vegetation scenarios were simulated using the same baseline-calibrated parameter set and model structure; therefore, parameter uncertainty is identical across vegetation scenarios. The coloured bars shown to the right of each panel represent parameter uncertainty, quantified as ± 1 standard deviation of the simulated time-mean fluxes over the full 50-year simulation period across 10 Monte Carlo runs. The colored dots indicate the corresponding time-mean flux simulated using the calibrated parameter set.

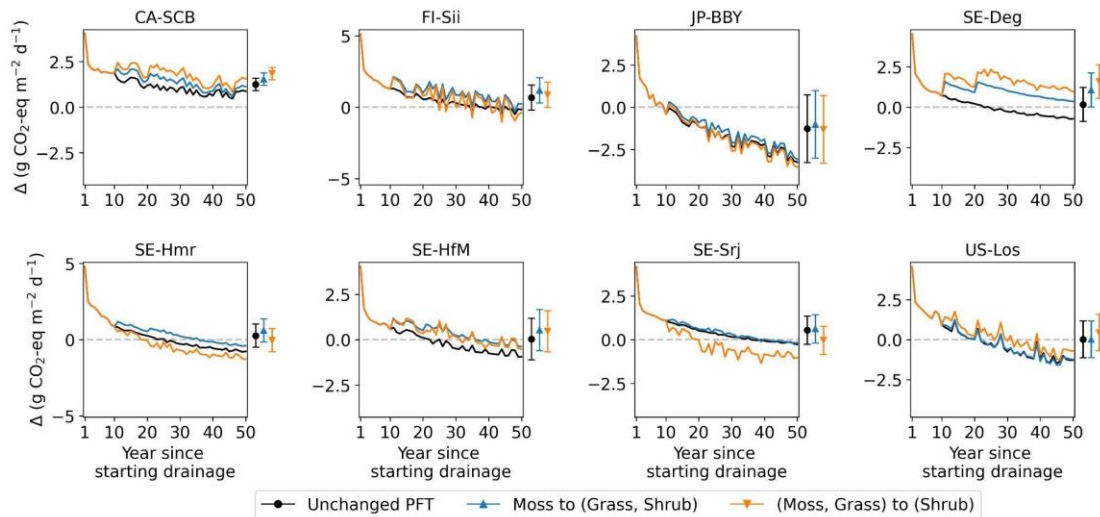


Figure D4. CO₂-equivalent emissions under two vegetation change scenarios for the 80 cm drainage case: unchanged plant functional types (PFTs), conversion of moss to grass and shrubs, and conversion of moss and grass to shrubs. All vegetation scenarios were simulated using the same baseline-calibrated parameter set and model structure; therefore, parameter uncertainty is identical across vegetation scenarios. The coloured bars shown to the right of each panel represent parameter uncertainty, quantified as ± 1 standard deviation of the simulated time-mean CO₂-equivalent fluxes over the full 50-year simulation period across 10 Monte Carlo runs. The colored dots indicate the corresponding time-mean flux simulated using the calibrated parameter set.

2. Temporal validation limits not made clear in conclusions and results

The Conclusions should clearly state that validation covers the first 10 years and that longer projections are model extrapolations with growing uncertainty. This does not mean you need to remove the long-term results, but they should be presented as exploratory scenarios rather than validated predictions. For example, the statement about how "longer drainage period leads to diminishment of CO₂ emissions" (lines 675-678) goes beyond what has been validated.

Also in the results part, I feel like this is not mentioned clearly enough. For instance, the caption of Fig. 6 does not mention at all that it is only showing simulated fluxes after 10 years of drainage. I feel like this is an important information. Same for Fig. 7, 8 and 9. Furthermore, the emulator model depends on this sensitivity analysis of the first 10 years after drainage. This does not come out clearly in the text. Also in the conclusions, please mention that the emulator model is based on the sensitivity of GHG emissions to water table depth after 10 years of drainage.

Response: We agree and have clearly stated in the revised text **Lines 814-817** and **825-828** on a caution for using our emulators formulations, that the validation covers the first 10 years and that uncertainty grows in the future from long-term change involving vegetation and processes unresolved in the model. See our detailed response above. The conclusions were also modified for the emulators.

Lines 814-817: *“It should be emphasized that model evaluation against observations is currently limited to the first decade following drainage, and that simulated changes over longer drainage durations represent model-based extrapolations that should be interpreted as exploratory scenarios rather than validated predictions.”*

Lines 825-828: *“The emulator is constructed from sensitivities of modeled GHG fluxes to water table depth derived from the first 10 years following drainage, corresponding to the period over which the model has been evaluated against observations.”*

In addition, we have performed a simulation for a site near the FI-Sii where a drainage experiment with ~10 cm lower WTD has been conducted for about 40 years (Kwon et al., 2022; Nykänen et al.,

1998). The increased ecosystem respiration and reduced CH₄ emissions in the experiment compared to the control site predicted by our model are in fair agreement with observations, giving support that our model can reproduce real-world drainage fluxes. This was added in the discussion (Lines 776-781) and Appendix E.

Lines 776-781: “Despite these limitations, an independent comparison with field observations from a long-term drainage experiment conducted at a site near FI-Sii shows that the model reproduces the observed increase in ecosystem respiration and reduction in CH₄ emissions under drained conditions reasonably well (Appendix E; Fig. E1). This comparison provides additional support that, within the limits discussed above, the model is able to capture key aspects of drainage-induced greenhouse gas flux responses under real-world conditions.”

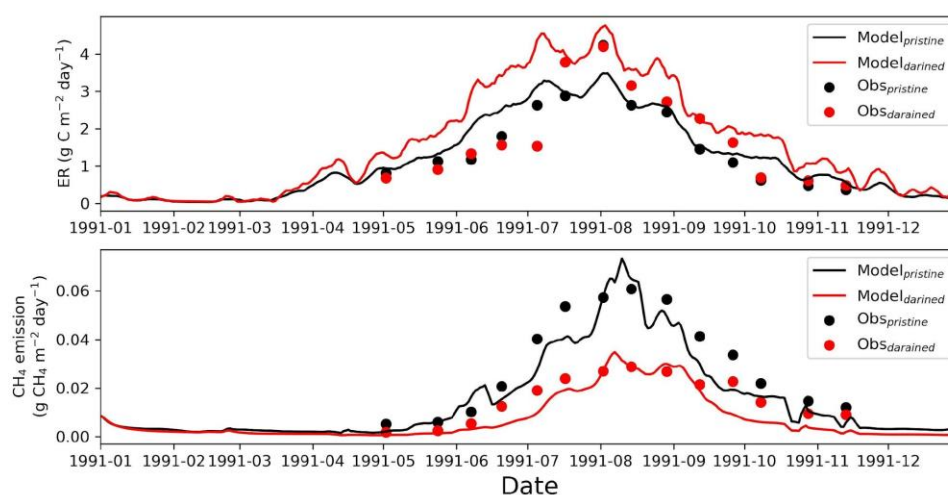


Figure E1. Comparison of observed and modeled ecosystem respiration (ER) and CH₄ emissions of a drainage experiment near the pristine peat site of FI-Sii. The drained conditions are in red, and the controls (pristine peat) are in black. Lines are our simulations, and dots are the observed fluxes.

3. Claims about net climate effects need careful rewording

Conclusion 5 (lines 691-695) states that drainage causes "net cooling" using GWP20 and provides "a more nuanced view than the current paradigm." While you acknowledge this "seems at first glance opposite to meta-analysis results," I think this part should be softened to not appear to overturn well-established findings without strong validation, especially since the net cooling depends on projections that go well beyond the 10-year validation period.

Response: We agree and have softened this sentence.

Lines 842-845: “However, our prediction of a net cooling using GWP20 differs from most previous meta-analysis results and should be interpreted with caution, because it relies on model-based projections extending well beyond the 20-year time horizon associated with the use of GWP20.”

Furthermore, Appendix D shows vegetation scenarios can reverse the sign of climate effects, and even though it is mentioned in the Discussion (lines 606-616) and is absent from the conclusions.

The Conclusion only notes "future work should consider" this (line 703). However, current conclusions about net climate effects already depend on vegetation assumptions. Relegating this to future work is insufficient when the baseline scenario lacks empirical justification.

Response: Agreed and we added a sentence in the conclusion.

Lines 860-853: *“Furthermore, our results show that vegetation shifts represent a major source of systematic uncertainty in our predictions, and that different plausible future vegetation trajectories can reverse the sign of the simulated climate effects, thereby directly affecting the interpretation of our conclusions on net climate impacts.”*

The authors should either provide evidence for why the baseline vegetation scenario is realistic, or present the main results as an ensemble across the vegetation scenarios explored in Appendix D.

Response: In the revised version (Appendix D), we clarified the fact that current vegetation is adjusted to match site observations and because we don't know which future vegetation scenario is more likely to happen, we have now used the mean of the three scenarios and represented the uncertainty from the min-max of our three vegetation scenarios in the revised manuscript.

Lines 1232-1239: *“Site-level current vegetation composition was first adjusted to match available field observations, providing a realistic baseline for model initialization. However, the trajectory of vegetation change following peatland drainage remains highly uncertain, and no single future vegetation scenario can be considered more likely than others. To account for this uncertainty, we evaluated two alternative vegetation change scenarios in addition to the baseline scenario with unchanged plant functional types (PFTs). Results from these three vegetation scenarios were combined to form an ensemble, with the mean response reported in the main analysis and the minimum–maximum range used to quantify vegetation-related uncertainty.”*

At minimum, the conclusions must acknowledge that vegetation uncertainty can qualitatively change the climate impact assessment. This is not a minor sensitivity, because it affects the sign of the main finding.

Response: We completely agree - see our response just above

Minor Comments

4. Figure captions need more detail

Several figure captions lack important contextual information that would help readers interpret the results, as already mentioned above. Another example is Fig. 6 where the validation data are from Evans et al. (2021) are not mentioned in the caption.

Response: Thanks for the comment. We have revised all of the captions carefully to include contextual information.

Figure 2. Comparison of model simulations after calibration with observed net ecosystem exchange CO₂ fluxes (NEE) and CH₄ emissions. Sites in panels a-h measured both fluxes and in i-j only NEE. The red shadings in each plot represent the uncertainty (± 1 standard deviation across 10 Monte Carlo simulations; see Methods) in the simulated NEE or CH₄ emission induced by parameter uncertainty.

Figure 4. Simulated changes at three sites of (a) soil water content in the whole profile (2m), (b) soil oxygen content, (c) Net Ecosystem Exchange of CO₂ and (d) methane emissions. Different colors indicate different water table depths below the original water level at each site. The coloured bars on the right of each panel summarize parameter uncertainty, quantified as ± 1 standard

deviation of the simulated time-mean fluxes computed over the full 50-year drainage simulation from 10 Monte Carlo runs. The coloured dots indicate the time-mean flux simulated using the calibrated parameter set. Note that when a flux (e.g. CH₄) is close to zero, the corresponding parameter-induced uncertainty also approaches zero.

Figure 5. Evolution of modelled emission factors (a) for CO₂ fluxes and (b) for CH₄ emissions for five decades after drainage, displayed for three drainage depths. Negative values in the right plot indicate less CH₄ emissions in the drained condition than in the undrained condition.

Figure 6. Simulated fluxes of (a) Net ecosystem exchange of CO₂ and (b) CH₄ emissions for different water table levels below the original water surface (red points) compared with meta-analysis observations from Huang et al. (2021b) (cyan) and Zou et al. (2022) (brown), and with field measurements from Evans et al. (2021) (yellow) and WET HORIZONS project (purple). The darkest color shading represents ± 1 standard deviation across observed sites, and the lightest shading indicates the minimum–maximum range of the observations. (c) Modeled (red dots) and observed distributions of NEE changes (Δ NEE) for different water table depths of drainage, compared with meta-analysis results, and (d) same for CH₄ emissions changes (Δ CH₄). For consistency with observational datasets, model results were averaged over the first 10 years of simulations, corresponding to the period during which most post-drainage observations were collected.

Figure 7. Sensitivities of (a) net ecosystem exchange (Δ NEE/ Δ WTD) and (b) CH₄ emissions (Δ CH₄/ Δ WTD) to water table depth as a function of the starting water table depth. The starting water table depth is the upper value in Δ WTD used to calculate sensitivities by dividing Δ flux by Δ WTD for all possible negative values of Δ WTD. The analysis is performed based on results from the first 10 years of drainage simulations. The gray shadings represent 95% CI of the regression.

Figure 8. Summary of site-level sensitivities and explanatory variables used to analyze the drivers of drainage responses. (a) Sensitivity of NEE to water table drawdown at each site, expressed as the change in flux per centimeter of deeper water table depth (Δ NEE/ Δ WTD); positive values indicate reduced CO₂ uptake or net emissions with deeper WTD, (b) same as (a), but for CH₄ emissions (Δ CH₄/ Δ WTD); negative values indicate reduced CH₄ emissions with deeper WTD. (c) Initial NEE, (d) initial CH₄ emissions prior to drainage. Additional modeled variables examined for their role in explaining the sensitivities include (e) initial water table depth prior to drainage (negative values indicate water table below the surface), (f) annual mean air temperature, (g) modeled soil organic carbon density (SOC), calculated as the sum of active, slow, and passive pools over the full soil column, and (h) peatland vegetation composition including peatland graminoids, shrubs, mosses. All statistics are based on modeled results from the first 10 years of drainage simulations, consistent with the temporal window used for sensitivity analysis.

Figure 9. Relationships between the sensitivities of (a) net ecosystem exchange (NEE) and (b) CH₄ emissions to water table drawdown and selected site-level variables, including initial NEE, initial CH₄ emissions, initial water table depth (WTD), air temperature, soil organic carbon content (SOC), and the moss index (MI). Solid lines show fitted regression relationships across sites, and gray shaded areas indicate the 95% confidence interval of the fitted regression. The moss index represents the relative cover fraction of mosses compared to vascular plants. The analysis is based on modeled results from the first 10 years of drainage simulations.

Figure 10. Change in fluxes (relative to undrained) expressed as CO₂-equivalents by drainage level (x-axis), averaged over 20 and 50 years following the start of drainage. CH₄ emissions were converted to CO₂-equivalents using GWP20 for 20-year average (orange lines) and GWP100 for the 50-year average (green line). In the plot with all sites, the error bars parameter calibration uncertainty ($\sigma_{\text{calibration}}$), quantified as ± 1 standard deviation of the simulated time-mean CO₂-equivalent fluxes over the full 50-year simulation period across 10 Monte Carlo runs, and vegetation scenario uncertainty ($\sigma_{\text{vegetation}}$), defined as the minimum–maximum range of simulated responses across alternative vegetation change scenarios (see Appendix D).

5. Statistical emulator presentation

The emulator (Section 3.7) is trained on model outputs with acknowledged limitations using a small sample size (10 sites, 6 predictors, acknowledged multicollinearity). While the Abstract appropriately uses cautious language ("may offer a simplified tool," lines 43-44), the authors should consider whether this tool requires more extensive validation before presentation, or whether it should be more explicitly framed as exploratory given the acknowledged limitations of the underlying model.

Response: We agree with the reviewer that the emulator is trained on a limited dataset and on model outputs with acknowledged uncertainties. We have therefore revised Section 3.7 to more explicitly frame the emulator as an exploratory, proof-of-concept tool rather than a fully validated predictive model. Specifically, we clarified its intended use and limitations in the section title and text, and softened the interpretation of the cross-validation results accordingly (**Lines 605-607**). The Abstract already uses cautious language, which we retained and further aligned with this framing.

Lines 605-607: *“Given the limited number of sites and the acknowledged limitations of the underlying process-based model, the emulator presented here is intended as an exploratory, proof-of-concept approach rather than a fully validated predictive tool.”*