Reviewer #1

General comments

The manuscript by Wang et al describes model development within a specific peatland branch (SPRUCE) of the land component of the E3SM model, ELM. The manuscript displays a substantial work with both model development, parameter optimization/calibration, sensitivity analysis and analysis of implications for model simulations in comparison to older versions of the model. In total there are four model setups are run, with the new and old model structures as well as with default and optimized parameters.

The topic is relevant and the modelling approach is reasonable from a theoretical perspective, although I am a bit concerned over the amount of new parameters introduced (37 in total). The paper do discuss the problem of equifinality, however, I would like a deeper discussion on constricting the model parameters or parameter ranges, either through observations or theoretical reasoning.

Thank you for the overall encouragement.

We clarified the rationales behind the perturbation ranges of the parameters in the revised manuscript Sect. 2.7.1, lines 435 and 463-492, in response to "Specific comments – Section 2.2" below.

We added a Sect. 4.3.2 to the Discussion (revised manuscript lines 1062-1102) to discuss how to better constrain the model parameters or parameter ranges than the C-flux based optimization in the current study. Here is a brief summary of the discussion:

- The most sensitive and therefore important parameters to constrain are the uptake rate constants and half-saturation points in revised manuscript Eqs. 2-4 (original Eqs. 1-3). Experimental observations are concentrated in temperate regions and crop species and exhibit high cross-species uncertainty. Therefore, those observations are more useful for large-scale than site-scale simulations. In site-scale simulations where uncertainty is high, total plant NP uptakes, estimated from paired NPP and whole-plant C:N and C:P measurements, can be a reasonable proxy constraint. Well-validated qualitative understandings (e.g. mycorrhizal roots generally have higher rate constants for inorganic NP on a per unit fine root biomass basis than uncolonized roots) can be used to shrink the parameter search space.
- Other sensitive parameters are related to mycorrhizal colonization and their exchange of NP and C with the plant host. Past observations suggest these quantities range 0-100%, and the high uncertainty is supported by SPRUCE-observed colonization fractions (revised manuscript Fig. S10, original Fig. S8). On the other hand, large-scale environmental gradients are found to affect mycorrhizal activity. Therefore, multi-site model-data integration can be employed to capture the broad pattern while avoiding overfitting.
- Root morphological parameters are observed at SPRUCE and have global database available (e.g. the Fine-Root Ecology Database). Empirical data together with covarying

relationships based on root economics theory can provide good constraints for ELM-MYCI in future extensions.

The analysis puts a lot of emphasis on the sensitivity of the different model setups, which is of course a sound approach, however, I feel that the analysis is sometimes overly complicated for a model setup such as this. The focus on sensitivity leads to a lot of relative figures where internal variables are compared to each other, e.g., N acquisition per GPP. While relative values can be informative, absolute values are also important for judging the performance of the model. A simple time-series or scatterplot comparing the different setups against observed data would help. That would also help the interpretation of other metrics such as the normalized values presented in figure 2. I would recommend to move some of the figures of sensitivity, e.g., Figure 7, to the supplementary materials and add a simple figure (time-series or scatterplot) showing absolute values in comparison to observational data.

Thank you for pointing out the problem.

The N acquisition per GPP figure (original Fig. 4) was a mistake – please see previous AC1: 'Correction on Fig. 4', Yaoping Wang, 12 Dec 2025 and we apologize for not having noticed it before submission. The figure was always intended to show absolute N and P acquisition values. The revised manuscript now has the correct original Fig. 4 (revised manuscript Fig. 6). The descriptions and caption in the original manuscript are correct.

We converted the original Fig. S5, which compared mean and temperature sensitivity enclosure-by-enclosure, into a time series plot (revised manuscript Fig. S7) that shows the raw annual observed and modeled data points with root mean squared error metric. Because there are 11 plots, multiple variables per plot, and four model setups, we found it more readable to display the time series in heat map format (like the original Fig. S6 [revised manuscript Fig. S8]). We edited the original Fig. S6 (revised manuscript Fig. S8) to also display root mean squared error like the revised manuscript Fig. S7.

We kept the original Fig. 1 (revised manuscript Fig. 2), because we want to disclose the uncertainty information, i.e. the denominators in the calculation of RAE (Eq. 4), to the reader. But we displayed the newly added Fig. 3, which shows out-of-sample evaluation on C fluxes (see below response to “Section 2.5.1” comment), in scatterplot format similar to the original Fig. 2 (revised manuscript Fig. 4). We kept the original Fig. 2 (revised manuscript Fig. 4), because the comparison can only be performed in normalized terms, as explained in the figure caption. We moved the original Fig. 7 into the SI (revised manuscript Fig. S12).

In general, the paper is well written with an easy structure which is easy to follow. I have reviewed the text and some of the supplementary materials and have some comments that I would like to see resolved. After some revision I think this paper is suitable for publication within GMD.

Specific comments

Section 2.2. This section is generally well written however, I feel like the conceptual idea should be helped by a simple conceptual diagram. Also, I believe that the parameter values should be displayed in the main text and not “hidden” in the supplementary materials. At least the 18 parameter values selected for calibration should be shown along with their default values, calibration ranges, and justification of ranges (if available).

Thank you for these suggestions. We added a simple conceptual diagram to illustrate the nutrient competition relationships between plants and soil decomposition in the original and modified models (Fig. 1 in the revised manuscript). We also moved the table of calibrated parameters from the SI into the main text Table 1. We described the parameter ranges and justifications in the revised manuscript Sect. 2.7.1, lines 435 and 463-492.

Section 2.5.1. The RAE is described here as a metric for calibrating the model and assess the optimal parameter combination. While I have not come across this metric before, it seems like a suitable metric to me. However, it is also used later as an evaluation metric (e.g., section 3.1.1), which seems like a breach of good calibration/validation practice. It is also unclear to me whether the same data was used for calibration and validation.

Thank you for pointing out the problem. The calibration and evaluation in the original Fig. 1 were done using RAE on the same data, but additional non-calibration data (observed annual maximum LAI, pretreatment peat CNP contents, pore water nutrient concentrations, resin-exchange nutrients) were used for model evaluation. We clarified the situation in the revised manuscript by splitting the original data description into a Sect. 2.5 Model calibration data and a Sect. 2.6 Model evaluation data.

To further mitigate the problem of calibration-validation overlap, we added post-calibration C fluxes for model evaluation (revised manuscript Fig. 3), and root mean squared error values for individual variables as an evaluation metric (revised manuscript main text Fig. 3, SI Figs. S7-S8). The post-calibration C fluxes data include aboveground NPP of the two tree species in 2022, the aboveground NPP of the shrubs in 2023, and the growing season NEE of the shrub-moss community in 2023. These new data are described in detail in the revised manuscript Sect. 2.6.1 and SI Sect. 1.3.

Technical comments

L305 “are not overemphasized” is written twice.

Figure 4. The unit description on the y-axis lacks a closing bracket.

Thank you for noticing these two issues. They are fixed in the revised manuscript (line 453 and revised manuscript Fig. 6).