

Reviewer 1

Responses to the reviewers are shown in red.

General comments:

The paper presents the modelling of the methane dynamics into the LPJmL6 land surface model which includes already a representation of the energy, water, carbon and nitrogen cycles. For that purpose, a modelling of the water table depth and wetland extent were included based on the CTI-TOPMODEL framework. Methanogenesis and methanotrophy were parameterized, land use and rice management effects alongside inundation-tolerant vegetation were also represented. Model results evaluated against global datasets show consistent and realistic fluxes, showing the potential of the developed framework to support climate-mitigation strategies.

The paper is well-structured, well-written and easy to read. The parameterisations developed and the results are clearly presented, the figures are of good quality. The paper falls within the scope of GMD and presents a very rigorous and substantial advance in the modelling of the soil methane processes. Therefore, I recommend its publication after the authors address my main concerns.

We thank the reviewer for the positive and constructive feedback. We appreciate the recognition of the novelty, rigor, and clarity of our work, as well as its relevance for GMD.

We are working on a revision in which we have carefully addressed all concerns as listed below. Corresponding revisions will be made in the manuscript.

Specific comments:

- The introduction should present the state of the art of the soil methane processes in Earth System Modeling, especially the previous works which focused on the representation of methane cycle in land surface models. All the bibliography on this topic is missing in the present paper.

We thank the reviewer for this comment. We revise the introduction by adding a concise paragraph on previous process-based representations of soil and wetland CH₄ processes in land surface and Earth system models. Thereby we briefly summarize earlier work on CH₄ production, oxidation, and transport pathways and their implementation in models such as LPJ-WHyMe, ORCHIDEE-based methane formulations, CLM4Me, WETMETH, and WETCHIMP/WETCHIMP-WSL intercomparison studies.

- It is important to validate the model on local fluxes. A comparison against site measurements of carbon and methane fluxes is required to show the model performances and give error metrics.

We agree that site-level validation provides an important constraint on simulated carbon and methane fluxes. The manuscript already includes a site-level evaluation of carbon fluxes using NEE measurements, shown in Fig. 7, together with error metrics. In response to the reviewer's

comment, we provide a supplementary comparison of simulated CH₄ fluxes against available methane flux tower observations to evaluate model performance for local-scale methane exchange.

- To better highlight the performances of the model developed, a spatial representation of the methane emissions need to be added (not only latitudinal averages as done here). Maps should be added to present the spatio-temporal variability of the fluxes. A presentation of the contributions of the various processes and ways of transportation would be interesting also.

We agree that latitudinal averages alone do not sufficiently describe the spatial structure of simulated CH₄ emissions. In response, we aim to add a new spatially more detailed comparison of wetland CH₄ emissions. A new figure corresponding to the latitudinal profiles shows maps of LPJmL6-simulated wetland CH₄ emissions, the WetCHARTs ensemble median, and the anomalies between them. This allows the reader to assess both the zonal agreement and the regional spatial deviations between LPJmL6 and the observation-based ensemble.

This analysis shows that LPJmL6 reproduces the broad latitudinal distribution of wetland CH₄ emissions reasonably well, including the dominant tropical maximum. However, the spatial anomaly map also shows that similar latitudinal totals can arise from different regional emission patterns. We discuss these differences explicitly, noting that the comparison is made against the WetCHARTs ensemble median and that the ensemble spread reflects substantial uncertainty in wetland extent and CH₄ flux estimates. We also discuss limitations related to the coarse model resolution, which restricts the representation of narrow floodplains and riparian wetlands, and the absence of explicit bank infiltration and river--floodplain exchange processes in the current model version.

Regarding the requested presentation of the contributions of the various processes and transport pathways, these diagnostics are already included in the manuscript in Sect. 5.3 and Table 3. There, we report the global CH₄ budget separated into atmospheric flux pathways, including diffusion, plant-mediated transport, ebullition, and fire emissions, as well as source categories such as natural wetlands, rice fields, grasslands, and other croplands. We also provide soil CH₄ oxidation and the resulting net methane sink. We have revised the text to make this connection clearer and to emphasize that these data provide a process-level comparison of the different emission pathways and source categories.

Technical comments:

- Line 75: grid cell mean water table depth: is it the annual mean? Precise please.

Here, the grid-cell mean water-table depth refers to the annual mean water-table depth simulated for the 0.5° grid cell. Since the saturated area is derived annually in our implementation, we have clarified this in the text.

- Table 1, 2 and 3 should be moved to an annex or supplementary document

We move Tables 1, 2, and 3, and also Table A1, to the Supplement. We also address the few editorial suggestions you made.

- Liner 169: equation number is missing

We have added the missing equation number.

- Line 181: Remove the article “the” at the beginning of the line

We have removed the article “the” at the beginning of the line.