Referee 2

Thanks for your very helpful comments and suggestions. Please find below our answers for each general and technical comment.

The authors present a study on the evaluation of nine different scenarios of methane (CH4) wetland emissions in the Arctic, obtained by varying two parameters of the JSBACH land surface model: Q10 and fCH4. These scenarios were evaluated using an inverse modeling approach by analyzing the necessary adjustment of the model between prior and posterior CH4 fluxes.
The authors found that a Q10 value of 1.8 generally produced the best prior emission scenario in the pan-Arctic region. However, at a regional scale, the optimal parameter set-ups varied, highlighting the importance of using specific parameters of different regions.
In my opinion, this study has been well prepared and carefully thought out, and no major adjustments are required. However, there are three aspects of the description of the study set-up and manuscript structure that could be improved:
Authors: We thank the reviewer for this positive overall assessment of our study.

1. I would suggest revising the introduction and condensing the information provided slightly. While it is interesting to read, I think it could be shortened slightly to focus more on the research questions being discussed.
Authors: We will revise and improve the clarity and focus of the introduction, as suggested by the reviewers. We will also emphasize the research questions addressed in this study.

2. I would also suggest describing the observation network used more extensively, and properly acknowledging the institutions that provided the observations. In my opinion, the terms currently used in the study, such as "different databases" or "several global and regional networks", are insufficient. Additionally, the limitations of the in situ network, such as the lack of observation sites in Siberia, should be discussed earlier in the manuscript, as these can have a significant impact on posterior CH4 emissions.
Authors: Thanks for the suggestion. We agree with the reviewer about how important is to properly describe and acknowledge the data providers. We will add a more detailed description of the data used (including a supplementary table with a list of stations used in the inversion) and discuss about the limitations of the in situ network.

3. Please provide a more thorough description of the inversion set-up in section 2.3, as several aspects have not been sufficiently described so far. For example, how did you define the transport error, and which uncertainties were used for the prior emissions? Did you optimize the total CH4 fluxes, or were the fluxes optimized by source category? This is unclear from the description. How were the initial concentrations defined? You could also potentially include one or two more sentences describing the transport model used.
Authors: We thank the reviewer for this suggestion, and we agree that providing more information about the inversion setup is important for strengthening the paper. We will review the inversion setup in Section 2.3 to better describe the model setup and address the points made by both reviewers. The Jena CarboScope is a linear Bayesian framework that infers surface-atmosphere CH_4 fluxes by combining prior flux estimates with atmospheric CH_4 mole fraction measurements and accounting for their respective uncertainties based on observed atmospheric mole fractions. The flux vector f represents the net flux per grid cell per time step. The Jena CarboScope enables f to be represented as the sum of different flux components, each

of which is modelled independently using its own statistical linear flux model. These independent a priori error covariance structures allow deviations from the prior flux estimate to be attributed to specific components during the inversion process. In this study, the a priori shape uncertainty was defined as 100% of the prior flux for each flux category. All flux categories were optimized, assuming spatial correlation lengths of ~500 km. Temporal and spatial fluxes are optimized within a Bayesian inversion framework that minimizes a cost function combining prior and observational constraints. The solution is obtained analytically using the linear Bayesian approach, which yields maximum posterior flux estimates and their associated uncertainties. Details of the cost function formulation and solution method can be found in the CarboScope technical report (Rödenbeck, 2005).
In addition, we will also include that the transport model used in CarboScope is the TM3 global atmospheric tracer model, an Eulerian transport model that solves the continuity equation (and parametrizations of boundary layer and convective mixing) for atmospheric tracers in a three-dimensional grid over the globe (Heimann and Körner, 2003). The model has a spatial resolution of approximately 3.8° latitude by 5° longitude, with 19 vertical layers, and it is driven by meteorological inputs from the NCEP reanalysis dataset (Kalnay et al., 1996). Flux inversions were conducted at the TM3 spatial resolution and a daily temporal resolution. Since the model is initialized with a homogeneous background concentration of the tracer, it is run for at least one year before to the period of interest to avoid any impact resulting from the model spin-up. To account for model-data mismatch, including the representation error of the measurements within the transport model, each station is assigned a weekly error value based on how well the atmospheric transport model can capture local atmospheric dynamics. For example, mountain sites and stations near shores samples are assigned a smaller error of 15 ppb, whereas surface sites in regions with complex circulation patterns receive a larger error of 30 ppb.

Specific comments

P1, L17: Would it be possible to already give a short definition of what the Q10 value indicates in the abstract?

Authors: Yes, we will add it to the abstract.

P4, L123 and P5, Fig.1: I would consider renaming the "Europe" region "Europe and Greenland", given that Greenland constitutes a substantial part of this region (even though it belongs to Denmark, it is politically independent and not on the European continent).

Authors: We thank the authors for this suggestion. We will edit the manuscript renaming the "Europe" region to "Europe including Greenland".

P4, L127: It would be good to mention here that you are using in situ data for the inversion, since "data coverage" could also include satellite data.

Authors: We will clarify that.

P6, L168-169: of your choice? Out of curiosity, is the capped fraction of 0.5 a default of the model or a setting

Authors: It reflects empirical evidence that methanogenesis typically contributes less than half of total anaerobic carbon mineralization, because more energetically favorable anaerobic pathways (e.g., iron, sulfate, and nitrate reduction) generally dominate carbon flow (Bridgham et al., 2013).

Bridgham, S.D., Cadillo-Quiroz, H., Keller, J.K. and Zhuang, Q. (2013), Methane emissions from wetlands: biogeochemical, microbial, and modeling perspectives from local to global scales. Glob Change Biol, 19: 1325-1346. https://doi.org/10.1111/gcb.12131

P7, L184: How did you define the ranges of Q10 and fCH4? Are these based on experience and/or other studies?
Authors: The range values tested in our sensitivity experiments was based on previous studies and literature review. As summarized by Moser et al. (2026), the majority of models set the temperature sensitivity of CH_4 production to be between 1.5 and 4, typically using a central value of around 2.

P7 and P8, Section 2.4: Would it be possible to summarize the described calculations for the evaluation in one or multiple equations?
Authors: We thank the reviewer for the suggestion. Although it is technically possible to summarize the evaluation using equations, our methodology involves ensembles, spatial averaging, and temporal aggregation. Condensing these steps into a few equations could make the workflow more abstract and difficult for readers to follow. Therefore, we chose to present the calculations descriptively to maintain clarity and accessibility.

P11, L290-L 196: Did the inversion optimize the total CH4 emission or was each emission category optimized separately? In the first case, how were the wetland emission obtained? (See also general comment 3)
Authors: We optimized each CH_4 emission category separately. We will review the Section 2.3 to include a more detailed description of the inversion methodology and to clarify this.

P13, Figure 3a: So these are the total CH4 emissions from all sources using mean values of all 9 emission scenarios? "using different values of Q10 parameter and baseline fCh4 fraction" is a bit vague and could indicate, that only specific scenarios were used. Also it could be beneficial to plot a pattern in either the prior or the posterior bars since the color difference not always clear (e.g. https://matplotlib.org/stable/gallery/shapes_and_collections/hatch_style_reference.html)
Authors: We will revise the figure caption to clarify that the values shown represent only the wetland CH_4 emissions from all nine inversion scenarios. Additionally, we will improve the figure by adding a pattern to visually distinguish prior from posterior emissions.

P14, L353-L354: I think it could be helpful to also provide exemplary maps of the prior fluxes (not just the model adjustment) to better visualize expressions such as "which showed that in high-emission areas, for example the Western Siberian Lowlands..."
Authors: We will add the prior and posterior flux maps as a supplementary figures.

Technical corrections
P3, L84-L85: Please check grammar, e.g. "One big research question now is how high the Q10 value should be for this temperature dependency of the CH4:CO2 production ratio. In order to answer this question, we employ..."
P8, L221-L222: Please check grammar, e.g. "Previous studies have used atmospheric inversion models to evaluate different bottom-up estimates and determine which best reproduces observed atmospheric CH_4 data..."
P8, L239: Better: maps were created
P12, L325: Please check grammar: "...best agreed well with..."

Authors: Thanks for pointing this out, we will check the grammar and do the technical corrections.