

We thank the reviewer for the thoughtful and constructive feedback provided on our manuscript entitled "*Spatiotemporal Variability and Environmental Controls on Aquatic Methane Emissions in an Arctic Permafrost Catchment*." We have carefully addressed all comments, revising the manuscript where appropriate and providing clarifications where necessary. Below, we provide detailed, line-by-line responses with the full reviewer comments included. Measurements

Line 25 (Fox-Kemper et al., 2021)

Reviewer Comment: "Line 25 (Fox-Kemper et al., 2021)."

Response: We thank the reviewer for catching this. A missing parenthesis was added to the reference citation on **line 27**.

Line 40 (Saunois et al., 2016 → 2025)

Reviewer Comment: "The reference to 'Saunois et al., 2016' can be updated in 2025."

Response: We thank the reviewer for pointing this out and for noting the updated reference. The citation has been updated to Saunois et al. (2025) on **line 41**.

Line 64 — Sentence rephrasing for readability

Reviewer Comment: "Methanotroph and methanogen microbial assemblages along an upland-wetland environmental gradient were..." I suggest rephrasing this sentence to improve readability.

Response: We thank the reviewer for this excellent suggestion. The sentence has been rephrased for clarity and parallel structure on **lines 64-67**:

"Sedimentary processes in lakes promote carbon storage, whereas methanotrophic and methanogenic microbial assemblages along an upland–wetland environmental gradient regulate CH₄ consumption and emission, respectively."

Line 104 — Figure 1 clarity

Reviewer Comment: "I suggest outlining the specific locations of wetlands, rivers, and tributaries in Fig. 1."

Response: We appreciate this helpful recommendation. We have revised the Figure 1 to highlight these areas and the caption was also updated to specify spatial features on **lines 112-117**:

"The blue circle indicates streams fed by snowmelt and the turquoise circle indicates the outlet of the lake. The red circle indicates the warm spring area which forms a wetland type ecosystem. Points inside the black circle north of the lake indicate measurements taken from the Red River and its stream tributaries."

Line 121 — Chamber material and sealing performance

Reviewer Comment: "Semi-transparent plastic material. This is one of my concerns in the paper. Could you please give detailed information about this chamber, e.g., sealing performance? This raises my concern because the plastic material is not a 'regular' material in detecting trace gases. This may cause systematic error when calculating methane fluxes by using linear fitting. In addition, the data between 2023 and 2024 were collected by using different chamber types, which weakens the results and discussion when comparing these two years of data."

Response: We thank the reviewer for this important observation. We have added a detailed clarification in Section 2.2 on **lines 128-133**:

"The semi-transparent plastic chamber used a circular foam floater that was wrapped around the outside of the chamber, allowing 2cm of the chamber to be below the water surface, forming a 100% airtight seal. The West Systems chamber was inserted into a closed-cell foam floater, where the seal was created once the chamber was inserted into the floater. Despite differing chamber

materials and flotation devices, median fluxes between 2023 and 2024 were identical at $5.0 \text{ nmol m}^{-2} \text{ s}^{-1}$, confirming comparability across years.”

Wind speed and flux uncertainty

Reviewer Comment: “Another concern is that the calculation fluxes were not revised for the real wind speed. I know this is difficult based on current data, but a discussion on how the wind speed would disturb the water surface and methane emission should be included. Besides, an uncertainty evaluation of chamber-based flux should also be included so that it is convenient to compare with the fluxes reported in other areas.”

Response: We thank the reviewer for these valuable points. The following additions have been made:

Section 2.2 (Data Collection) lines 149-154:

“While floating chambers isolate the headspace from light wind disturbance, increased surface turbulence may influence gas exchange in the open space of the chamber (Vachon and Prairie 2013). Our approach captures diffusive exchange under mostly calm-water conditions (i.e., wind speed up to $\sim 4 \text{ ms}^{-1}$), but we acknowledge that regional wind-driven mixing may contribute to flux variability beyond our individual chamber footprints.”

Section 2.3 (Flux Algorithm & Ebullition Detection) lines 206-218:

“Because fluxes were derived from high-frequency (1 Hz) concentration data fitted using a GAM with a strict acceptance threshold of $R^2 \geq 0.99$, analytical uncertainty in the rate-of-change estimation is negligible. Conventional uncertainty propagation (e.g., based on regression slope error or replicate chambers) is not meaningful in this context because the GAM approach fits a smooth curve through hundreds of data points per deployment, effectively minimizing noise and preventing poor-quality fits from contributing to the final flux values. This ensures that the dominant source of variability in the dataset reflects true environmental heterogeneity rather than analytical error. Furthermore, because the chamber headspace was fully sealed and isolated from external turbulence, wind-induced variability—which often motivates uncertainty corrections—is mechanically removed from the flux calculation process. For these reasons, we report spatial variability (e.g., medians, ranges, and interquartile spread) rather than analytical uncertainty, as it provides a more ecologically relevant representation of flux variability across the catchment.”

Line 138 — Frequency of chamber measurements

Reviewer Comment: “Did the 707 chamber measurements take place twice (2023 and 2024) or several times on different days? I think this information is important to evaluate the significance of this study, though I found some of it in the figures.”

Response: We thank the reviewer for this question. The following clarification was added to Section 2.2 on **line 147-148**

“Overall, we made 707 chamber measurements, *representing ~10-15 chamber placements taking place daily...*”

Line 197 — Typographical error

Reviewer Comment: “Typo after the word ‘ebullition.’”

Response: We thank the reviewer for spotting this. The typographical error has been corrected and clarified as versus instead of v., on **line 224**.

Line 205 — Dissolved oxygen (DO) concentration method

Reviewer Comment: “How did you measure the DO concentration? At a one-minute frequency, I suppose a probe was used. The method, precision, and uncertainty should be clarified.”

Response: We thank the reviewer for the helpful suggestion. The following details have been added to Section 2.5:

Section 2.2 (Data Collection) lines 155-156:

“...water parameters were collected in 2024 using a Aquatroll 600 water sonde (see section: Decoding Methane Drivers).”

Section 2.4 (Lake and Stream Metabolism) lines 234-235:

“...(DO) collected at a one-minute frequency during chamber measurements (DO sensor accuracy: $\pm 0.1 \text{ mg L}^{-1}$; resolution 0.01 mg L^{-1}).”

Line 223 & 244 — Section numbering correction

Reviewer Comment: “Should be section 2.6 instead of 2.4” and “Should be section 2.7.”

Response: We thank the reviewer for catching these numbering inconsistencies. They have been corrected in the revised manuscript.

Line 256 — Soil temperature measurement depth

Reviewer Comment: “Why did you use the soil at 40 cm but not at the surface or top 10 cm to match the soil volumetric water content’s standard?”

Response: We thank the reviewer for this insightful comment. The following clarifications have been added on lines 294-296:

“We used catchment soil temperature at 40 cm to represent subsurface active-layer conditions that influence deeper thermal dynamics, groundwater inflow, and delayed soil heat retention through the thaw season.”

lines 299-301

“Additionally, we used VWC at 10 cm depth because it was the most complete and continuous dataset across the measurement depths, and highly correlated with VWC at 20cm, 30cm and 40cm.”

Line 270 — Predictors count inconsistency

Reviewer Comment: “‘7 of the 21 weighted predictors.’ This was inconsistent with that in Fig. 3, which says 8 of the 21 of the weighted predictors. Please check.”

Response: We thank the reviewer for noticing this inconsistency. The text in Fig 3. has been corrected to “7 of the 21 weighted predictors on lines 345-346.

Line 335–338 — KDE explanation placement

Reviewer Comment: “The discussion jumped from different figures, weakening the flow. In addition, these sentences were saying the advantages of KDE, which I think is not suitable in the Discussion, but in the Method.”

Response: We thank the reviewer for this valuable recommendation. The KDE methodological explanation has been moved to Section 2.4 (Spatial Flux Evaluation, lines 257-259), leaving only interpretive references in the Discussion.

Additional Clarifications:

- Clarified that all BRT models were trained using 2024 data only on **lines 279-280**.

Final Note:

We sincerely thank Reviewer 1 for the thorough and constructive comments. These suggestions have substantially improved the clarity, rigor, and overall presentation of the manuscript.