Growing-season variability and environmental controls of CH_4 and N_2O fluxes across high-latitude terrestrial ecosystems (Niemi et al.)

General comments

This manuscript presents a substantial and potentially valuable dataset on the variability of CH_4 and N_2O fluxes during the growing season of two consecutive years across contrasting eight high-latitude land cover classes of subarctic and boreal Northern Finland. The combination of flux measurements at wetland and non-wetland sites for the two greenhouse gases (GHGs), along with the fitting of linear mixed-effects models to examine the relationships between GHG fluxes and environmental variables, reflects interesting field work and has identified important variables for improving our understanding and modelling of both GHGs. The key findings, the seasonal trend, the relationship with land cover classes, and the correlation factors (through not decisive) provide valuable insights.

The topic is timely and clearly relevant to high-latitude terrestrial ecosystems, and the study has the potential to make a useful contribution once presentation is revised. The manuscript can be improved, in particular, by 1) enhancing its presentation: in the result section, an analysis of statistical significance should be used to demonstrate how and whether the research questions posed can be answered using statistical methods; and by providing a more detailed description and presentation of the results, including additional information. It could be further strengthened 2) by highlighting the research gaps, connecting key findings to scientific context, and clarifying the implications of the research.

Specific comments

Abstract

Line 32-36: Give clear terminology of land cover classes and use always the same terms. E.g. use “dry land cover classes” (dry tundra: bare, shrub tundra), forest sites and “wetland land cover classes”: tundra wetland, bog, fen, permafrost bog) throughout the manuscript. In line 34-35 it is not clear that wetlands include fens and permafrost bogs.

Line 35: Are this means or medians? In the result section (line 309…), means are given, but in Figure 2 only medians are shown. Please use the option that is more appropriate for the data records and is consistent throughout.

Introduction

Line 55: Add literature: Climate effect on CH4 and N2O

Line 65-70: Introduce definitions: peatland: fen, bog, permafrost bog in connection with wetland and dry tundra in comparison to wet tundra and forest ecosystems. Add numbers: what is less carbon, vast extend?

Line 74: When giving global warming of N2O also add it for CH4

Line 76: What is the definition of wetlands here? Clarify here. What is the difference to line 65 where peatlands are described as methane source? Is there a general difference in carbon content (< Corg. threshold?)

Line 79: Give definition of tundra and dry tundra.

Line 93-94: Give clear terminology of land cover classes (see Abstract).

Line 99: More precise. 8 land cover classes at two research sites in Northern Finland?

Material and Methods

Fig. 1: Please show different land cover classes e.g. with different colors or symbols on map.

Line 110-125: Please describe in which areas were which land cover types found or all 8 types in both areas?

Line 125: Those are not soil conditions, but rather the source material for soil formation. Can you tell us more about the soils? Was there an organic layer, and how thick was it? The organic layer thickness (OLT) might had an influence on GHG.

Line 141: Please give information how many measurements at each land cover site and the growing season temperature and precipitation. Were these years comparable to one another, or were they particularly dry or wet compared to the long-term average? This might be important for the differences in N2O fluxes between 2024 and 2025.

Line 146: Use always the same terminology “shrub” tundra instead of “shrubby”, only permafrost bog instead of palsa.

Line 148: Please explain, “with some minor changes to more accurately describe our research sites”, which parameters? Vegetation, soil, moisture?

Line 151-152: What are you expecting for the organic layer?

Line 153: Introduce the main groups: dry tundra, forest and wetland and then further differentiate.

Line 153: Add literature for the statement.

Line 154: Have you described the vegetation or is this specified in the land cover classification used by the others?

Line 167: Did you measure permafrost to differentiate the permafrost bog from bog?

Line 178: How shallow and does “no peat” mean no H horizon, but instead an O horizon? Give more information and be more precise?

Line 180: What is the meaning of very dry? In Fig. 3, tundra wetlands had the highest soil moisture.

Line 211: The calibration function can only be used for mineral soil and normally the VWC of organic soils or high OLT will be underestimated using this technique. Please verify or discuss.

Line 227: More precise. Did you measure pH values in H2O or CaCl2?

Line 266: How many measurements were removed in %? Please indicate the number of measurements in which the detectable average flow rates for both gases were exceeded.

Line 274: Which p values were considered statistically significant?

Results

Line 309-320 and line 335-343: Here means are given, but in Figure 2 only medians are shown. Use clear terminology for land cover classes. Statistical analyses about significant differences within land cover classes and between land cover classes are missing. Please indicate, if significant different or not with p values and indicate in Figure 2. Only by indicating the statistical significance can we determine whether the first (section 3.10) and second (section 3.11) research questions can be answered.

Line 322-330: Here, too, there is a lack of statistical support for the statements. Is there a significant difference within the land cover class between months? Please also indicate whether the CH4 measurements differed between the two years, even if this is not crucial to answering the research question. However, this information will be provided later for N2O.

Line 344-345: It would be interesting to include a figure in the appendix to illustrate this point (e.g. with different colors for land cover classes)

Line 347: Please give more information. Especially for the wetland land cover classes; there might be lower N2O uptake in June and increasing during the season. Please describe, if this probable statement is right and test, if statistical relevant. Please show measured differences between years. Does Figure 7c show only predicted N_2O values, or does it also include measured values?

Line 353-370: Statistical proofs of the given statements are missing. Please give p values for all comparison statements, also in Figure 3. Are the values given in the text means or medians?

Line 367-370: Be more precise. Please consider pH classification, normally very acidic means pH in CaCl2 between 4.0-4.6 depending on the classification system, therefore the pH value of tundra wetlands is only slightly acidic.

Line 398: Contrary to this statement, I can see a high effect of temperature and only a low effect of pH in Figure 7b & 7d. Please explain.

Line 400: Please discuss later the influence of temperature and moisture on N2O fluxes between the years. Was the year 2025 wetter?

Discussion

Throughout this chapter, please explain how you answered the question and whether your findings were supported by statistical tests. Structure your text so that you answer one question with another. Draw comparison to literature, try explaining reasons behind them and highlighting possible future implications (e.g. warming, change of land cover area size).

Line 407-410: Please indicate at the beginning whether you were generally able to answer the three research questions. In this paragraph, you only gave a statement to the third question.

Line 412: Clear terminology, so you can begin with “Dry land cover classes”. Was there a statistical difference between the land cover classes and can the classes be used to predict fluxes for CH4 and N2O?

Line 417: Please indicate whether and how you answered your second question?

Line 433: References are missing

Line 447: Please provide more detailed data on the gas fluxes reported in the literature, as opposed to your own gas fluxes

Line 461: Is this threshold value specified in the literature?

Line474: How about discussing the temperature sensitivity of both processes here, specifying the Q10 value?

Line 484-485: To better understand this, it would be helpful to see in Figure 5c which values are measured (e.g., represented by points) and which are simulated.

Line 490: See comment to line 367-370: Please provide a more detailed classification.

Line 510: References are missing

Line 506-517: Please discuss also detection limit of N2O with Licor.

Line 581-529: Please provide more detailed data on the positive and negative N2O gas fluxes reported in the literature, comparing them to your N2O emission data. Please discuss reasons, why there is production of N2O at the dry sites. Was there a statistical difference between land cover classes and can you therefore confirm your first hypothesis?

Line 523: uniform terminology for “non-wetland” write e.g. “dry land cover classes”

Line 554: Is there also a correlation between CH4 uptake and N2O emission (results line 344-346)? Please discuss reasons?

Appendices

Please indicate the number of measurements for each line in the tables.

Table A2: Given the differences in N2O values between the two measurement years, it would be interesting to see the results of each year

Technical corrections

Line 58: Citation: Name is wrong “Biskabjorn”. Please check the references throughout the manuscript for accuracy.

E.g., Line 67 & line 501: Citation: Kübert et al., and Weslien et al., are missing in reference list. Please check the references throughout the manuscript for accuracy.

Line 70: GPP: Write out the full term before using the abbreviation

Line 162: Before using abbreviation, introduce first in line 155 with “()”.

Line 200: Is that a value without a unit?

Line 254: “c” is given in ppm but final unit is mg or µg. So please write that you also converted this.

Line 348: Move the point “.” out of the bracket “)”

Fig. 5, 7: Units are missing for fluxes.

Fig. 7a: Please give points and no line between points.

Line 397: Please write in capital letters for Figure abbreviations in the whole manuscript (“Fig. 1”)