

Biogeosciences Discuss., author comment AC3  
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## Reply on RC3

Mélissa Laurent et al.

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Author comment on "Relationships between greenhouse gas production and landscape position during short-term permafrost thaw under anaerobic conditions in the Lena Delta" by Mélissa Laurent et al., Biogeosciences Discuss.,  
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Laurent Biogeosciences Reviews & Response to reviewers:

*We thank the three reviewers for their helpful comments and suggestions, which help to improve our manuscript. In response to the thoughtful and constructive comments from the reviewers, we made major revisions to this manuscript throughout all sections and most figures. A summary of these changes is given here, as well as the detailed response to reviewers below. The major changes include:*

- *Most of the reviewers pointed out that the results would be more relevant and interesting if the incubation time was longer in order to overcome the lag time before methane production that we observed. Unexpectedly, our results showed that after two months of incubation at 20degC, under anaerobic conditions, only one sample layer produced CH<sub>4</sub>. We originally focused on a short-term incubation because we believe that it is essential to quantify C production under realistic timescale of a growing season (~60 days) in Kurungnakh Island because the aim of this study was to quantify the C production during the growing season under wet conditions communities and identify factors (microbial abundance, substrate availability) that would limit CH<sub>4</sub> production in this case study site. However, since only the active layer of the floodplain started producing CH<sub>4</sub>, we decided to keep the incubation running to see whether the other cores would produce CH<sub>4</sub>.*
- *We've included this additional incubation data from days 68 to 363 of the extended experiment. We incorporated additional incubation data into the revised manuscript throughout and have produced a new figure with the cumulative production over a 363-day period. The revised manuscript now shows anaerobic CO<sub>2</sub> and CH<sub>4</sub> production over a 363-day period.*

*To summarize the results from this longer incubation period, the floodplain core produced CH<sub>4</sub> within the first 60 days due to the already established methanogen communities, as we showed in the initial manuscript. After 6 months of incubation, the permafrost layers from the Yedoma cores started producing CH<sub>4</sub>. This important result was not included in the earlier manuscript version with the shorter incubation time, as noted by all the Reviewers. Old Figure 4 shows that the permafrost layer in P15 and P16 has a lower methanogen concentration than P17-A, so we attribute the difference in lag time primarily due to the time required for the Yedoma samples to activate the methanogen communities and to produce CH<sub>4</sub>. We hypothesize that the lack of methanogens in the P16-A and*

*P15-A could be due to the dry condition induced by the landscape position. This indicates that methanogenesis is unlikely established after permafrost thaw in these sediments unless colonized by methanogens and the lack of response of CH<sub>4</sub> to the glucose addition and continued anaerobic CO<sub>2</sub> production also reduces the likelihood that substrate availability limits CH<sub>4</sub> production despite the lower C abundance compared with the floodplain soil (Table 1).*

*Additionally, the results section has been clarified to distinguish missing versus zero data within the microbial dataset.*

- *The introduction has been revised to address the concerns of the reviewers, to be more precise and specific about permafrost carbon, the permafrost carbon feedback, and earlier incubation studies. We both narrow the focus to findings from earlier incubation experiments and elaborate on the specifics of the findings regarding the landscape position. In detail, we include a definition, discuss what differs across landscape positions, and expand on the links between microbial abundance and CO<sub>2</sub> and CH<sub>4</sub> production.*
- *We substantially revised the methods section to include more details addressing the criticisms of the reviewers and clarified terminology throughout the manuscript (e.g. "production").*
- *We substantially revised the discussion in order to address the criticism from the reviewers about the overly broad implications of this study despite the limited number of permafrost cores. It is now substantially shorter. We remove Figure 5 (the conceptual diagram) in the revisions. We clarify throughout the manuscript that this is a case study based on permafrost cores from Kurungnakh Island, Siberia, Russia. We shortened and narrowed the discussion to a case study, which aims to understand and quantify the potential C production in this limited region by integrating information about the influence of landscape position, microbial data, and, soil parameters to understand the factors controlling C production in this site within the Yedoma dominated region. We would like to note, however, the importance of these particular permafrost cores collected at a remote field site in Arctic Siberia, and this data given that it is no longer possible to re-sample at these sites in the foreseeable future.*

### **Reviewer 3:**

This manuscript presents data from a short-term anaerobic incubation study. The authors present results from six individual samples from three different locations. The goal of the study is to understand the potential effects of temperature, "landscape position", and the addition of glucose to CH<sub>4</sub> and CO<sub>2</sub> production from the soil samples. The premise of the study is interesting and timely.

However, the incubation time of the experiment appears to have been too short, as the methanogens were still in lag-phase. Based on the information presented in the study, I found the links between their results and conclusions unconvincing.

*As explained in the main response, we aimed to simulate wet summer conditions during the growing season. Our results showed that after two months of incubation, only the active layer of the floodplain produced CH<sub>4</sub>. The absence of CH<sub>4</sub> production for the other active layers at 20degC was unexpected. The lack of methanogens and CH<sub>4</sub> production after two months show that the methanogen communities were not established. Even though most of our samples did not produce CH<sub>4</sub> within the 2 months, we still believe it is necessary to capture the behaviour of these samples for C production during the growing season. We continued to measure this incubation experiment after the two months presented in this study, as mentioned in the overall summary above. These additional measurements from days 68 to 363 have been added to the study in response to this concern, raised both here and by the other reviewers.*

I think this could be improved by adding more details and specificity to the methods section, in particular.

*We have substantially revised the methods based on these comments to add further details.*

More details about the "landscape position" of the sample site would be helpful (i.e. slope, aspect, vegetation cover, etc). I think it would be helpful to consider the scope of the experiment when formulating conclusions.

*There is a table with descriptions of the three different sites (see supplementary table 1) in the supplemental materials. In the revisions, we have added pictures of the sites and more details regarding the distance to the rivers surrounding the sample sites. In addition, during the revision, we clarified throughout the manuscript that this is a case study in the Lena River Delta, proposed a hypothesis that these trends may occur at other sites within the permafrost region, and generally narrowed the scope of the discussion and conclusion.*

Six samples (from three locations) were incubated for ~70 days. While interesting, there are not enough data points presented in this study to draw meaningful conclusions for permafrost landscapes as a whole.

*As mentioned above, our study is a case study of Kurungnakh Island. We worked with three cores, but we analyzed these cores at two depths with laboratory replicates and incubated them at two different temperatures. We would like to point out that there is still a lack of data regarding incubation studies in Siberia, and only a few studies have worked with the active layer and permafrost layer, and two incubation temperatures. Finally, to establish a pan-Arctic dataset and compare data across the Arctic, smaller studies are essential. Nevertheless, we agreed that it is not possible to draw conclusions for permafrost landscapes and use this case study to generate a hypothesis that the landscape position is an important control on the potential for methane production with permafrost thaw in the broader permafrost region.*

I strongly suggest that the authors simplify the sentence structure throughout the article. I think that the article can be substantially shortened by removing redundancy and superfluous information/sentences. Most instances of conjunctive adverbs (however, finally, on the other hand, likewise, etc.) should be removed.

*Thanks for this feedback. Overall, we found the specific comments from reviewer 3 to be really constructive and helpful particularly in the discussion section. We have carefully revised the manuscript to simplify the sentence structure throughout and to focus it on the question of potential CO<sub>2</sub> and CH<sub>4</sub> production across different landscape positions in this permafrost landscape.*

Also consider the difference between GHG "emissions" and "production" and change your wording accordingly.

*We changed "emission" by "production" when necessary and reworked the sentence structure.*

**Line 10:** "release more greenhouse gases". More compared to what? I suggest you remove "more" or be more specific.

*Removed during revisions in order to simplify and be more precise.*

**Line 11:** "to address the large heterogeneities of GHG releases". Spatial heterogeneities? Temporal heterogeneities? I suggest you be more specific here.

*Removed during revisions as above.*

**Line 11:** I suggest you reformulate this sentence. Your study is not really addressing "large heterogeneities of GHG releases". You are trying to understand what the relationship might be between GHG emissions and soil parameters and what factors might be causing large 'spatial' heterogeneities in GHG emissions from permafrost landscapes.

*Removed during revisions in order to simplify and be more precise.*

**Line 13:** Two depths? Do you mean sediment from two depths from three Lena Delta cores? I suggest you be more specific/clarify.

*From each core, samples were collected at two depths. We specified by replacing "two depths" by "Active layer and permafrost layer samples from three cores..."*

**Line 15:** "Samples from located in upland or slope positions". Typos here.

*Revised as suggested.*

**Line 16:** Same typo as above "from located in"

*Revised as suggested.*

**Line 18-19:** I suggest you rewrite/simplify this sentence and make it easier to read.

*Revised as suggested.*

**Line 20:** In addition, our study **identified** different CO<sub>2</sub> production...

*Revised as suggested.*

**Line 23:** Suggestion: Climate change is causing increasing temperatures and permafrost thaw, which might lead to increases in the release of greenhouse gases CO<sub>2</sub> and CH<sub>4</sub>.

*Revised as suggested.*

**Line 36:** "Due to the low temperatures, the organic matter..."

*Revised as suggested.*

**Line 36:** The statement that all permafrost soils act as a C sink is misleading. Check out:

Elder et al. 2021 <https://doi.org/10.1029/2020GB006922>; Anthony et al., 2021 <https://iopscience.iop.org/article/10.1088/1748-9326/abc848/meta>; etc.

*Removed during revisions.*

**Line 40:** Consider using an oxford comma throughout the article. It is the standard and will really improve the clarity of your sentences.

*Thank for your comment.*

**Line 47:** The paragraph beginning on line 47 is two sentences long. Consider merging it with the preceding paragraph.

*Removed during revisions as above.*

**Line 53:** Consider rewriting this sentence to reduce the number of commas and clauses. Currently, it is difficult to read.

*Removed during revisions as above.*

**Line 57:** Consider eliminating both instances of “able to produce”. It is not necessary (i.e., not all soils produced the same quantity of CH<sub>4</sub>...)

*Removed during revisions as above.*

**Line 59:** Suggestion: “Even though several factors controlling C decomposition have been ...”. I would consider rewriting this sentence to make it more neutral.

*Removed during revisions as above.*

**Line 61:** What do you mean by “a single temperature”. As opposed to temperature profile with depth? Can you be more specific?

*Removed during revisions as above.*

**Line 62-63:** Suggestion: “Therefore, the relationships between different temperatures, landscape positions, and C production under anoxic conditions are not well understood.”

*Removed during revisions as above.*

**Line 62:** Consider defining “landscape position”. It is not clear to me what you mean by this term. Can you be more specific? Same for “different temperatures”. Do you mean the natural spatial heterogeneity of ground temperature in permafrost landscapes (i.e., cooler temps under forest cover, temperature profiles with depth, etc.)?

*In the revision, we defined landscape position as a specific geomorphology component of the landscape (e.g. upland, mid-slope, floodplain, as shown in Fig 1b), which affects factors like soil moisture and site drainage. As well, we specified that “temperature” stands for the temperature of permafrost thaw.*

**Line 64:** consider replacing “form” with “type” and “amount” with “quantity”

*Removed during revisions as above.*

**Line 64:** released

*Removed during revisions as above.*

**Line 72:** Consider adding Hughes-Allen et al., 2021 to the list of references as it discusses specifically differences in GHG emissions from different types of thermokarst lakes. <https://doi.org/10.1002/lno.11665>

*Thank you for the reference but we now have removed this paragraph to focus on incubations.*

**Line 77:** I think you are overstating the lack of studies/info here. A quick google search turned up many studies from the last three years describing both experimental studies and in-situ analyses.

*Removed during revisions as above.*

**Line 84:** Typo. "King"

*Removed during revisions as above*

**Line 84:** Consider finding a different term for "C control". It's not clear what you mean here.

*Removed during revisions as above.*

**Line 85:** Typo. Citation doubled "Koch, Knoblauch, et Wagner 2009".

*Revised as suggested.*

**Line 86:** You start discussing methods here without yet discussing the objectives of your study. Consider reordering these sentences/paragraphs.

*We revised the introduction to address the objectives of the study first.*

**Line 88:** You mention landscape positions often, but again, you never define this variable. Please consider defining/being more specific.

*Thanks for this critique. We now clearly define this and focus on this aspect in the revised introduction.*

**Line 89:** Define "short term". Days, weeks, months?

*Removed during revisions as above.*

**Line 93:** microbesif microbial community composition? Quantity of microbes? Please be more specific.

*Removed during revisions as above.*

**Line 107:** I suggest you make "The soil sampling was carried out..." the beginning of a new paragraph.

*Revised as suggested.*

**Line 107:** I strongly suggest that you break up this sentence into two shorter sentences. End the first sentence where the colon is.

*Revised as suggested.*

**Line 109:** You can remove "after excavating the active layer"

*Revised as suggested.*

**Line 112:** Does "with a well-drained upland soil profile" apply to the topography of all three sites? The sentence should be restructured so that it ends with "respectively".

*"well-drained upland soil profile", applies for the upland and the slope.*

**Line 110-113:** You mention twice that the cores were chosen based on their location within the local topography. I think you can reorder/rework these sentences to make it flow better.

*As suggested, we reworked the sentence construction.*

**Line 115:** replace "another" with "one"

*Revised as suggested.*

**Figure 1:** I suggest that you add Figure sublabels (i.e., a, b) so that you can reference them in the figure caption.

*Thanks for the suggestion. Revised as suggested.*

**Line 127:** "Electrical conductivity and pH were measured from pore water for better comparison between samples." Better comparison compared to what? A different type of method? This sentence isn't super clear to me.

*We revised this sentence in the new version.*

**Line 128:** I think this equation would be more readable if it was presented in normal equation form (i.e., inline equation)

*Revised as suggested.*

**Line 131:** how many samples is one series?

*The instruments can both analyse 90 samples for one series. For each analyse (TC and TN), the samples were measured together. We revised as this clearly caused confusion.*

**Line 132:** Can you describe the relationship?

*Thank you for pointing this out. First, we apologize for the wrong reference, which may have caused this confusion. We corrected the reference by "Fuchs 2019". In his thesis, Fuchs determined the bulk density and the water content of one thousand samples from the Lena Delta. To calculate the bulk density, he divided the dry weight of a sample by its initial volume. With the data from the bulk density and the water content, they established a transfer function to determine the bulk density of a sample when the volume is unknown. As we explained in the manuscript, we did not calculate the bulk density, but estimated it according to this transfer function. In addition, the samples used for this study come from the same area as the samples used to establish this correlation. We changed the manuscript and explained the bulk density estimation in more details.*

**Line 135:** I suggest that you use "organic material" rather than "organics".

*Revised as suggested.*

**Line 136:** I suggest that you remove "In the end".

*Revised as suggested.*

**Line 142:** I suggest that you keep the passive voice here that you are using throughout the methods. For example, "Sterilized tap water was added to samples with a moisture content of less than 30% to limit the effect of gas dissolution (Henry's Law).

*Revised as suggested.*

**Line 152:** I suggest you say, "The effects of glucose are usually observed within less than 48h".

*Revised as suggested.*

**Line 153:** How are you measuring the gas? And do you mean one week as in 7 days or one working week as in days.

*Described in the following section.*

**Line 156:** Ok now I see the gas section. Maybe just add that it is describe in the following section.

*Revised as suggested.*

**Line 162:** I suggest that you eliminate "Finally"

*Revised as suggested.*

**Line 172:** I suggest that you keep the tone neutral here. Eliminate "We decided". Just explain what you did.

*Revised as suggested.*

**Line 170-175:** I think this paragraph can be cleaned up to be more specific and easier to understand.

*Based on your comment, we simplified and made this paragraph more understandable.*

**Line 202:** check spelling Kuskal-Wallis

*Revised as suggested.*

**Line 207:** I suggest "All soil samples, except P15-F, had a pH between 6.5-7.5."

*Revised as suggested.*

**Line 211:** Do you mean TOC **weight percent**?

*Yes, we specified this in the method section.*

**Line 242:** ...CH<sub>4</sub> production at **either** 4°C **or** 20 °C

*Revised as suggested.*

**Line 242:** CH production rates were **consistently** below...

*Revised as suggested.*

**Line 249:** I don't think you mean emissions here, rather production

*Revised as suggested.*

**Line 255:** Very long sentence. I strongly suggest that you rewrite it to focus on succinctness and clarity.

*We reworked the sentence construction to have something more succinct and easier to read.*

**Results section:** Limit the results section to the actual results. Currently, you are mixing in some discussion elements. These should really be saved for the discussion section.

*Revised as suggested.*

**Line 296:** Error in figure cross reference

*Thank you for the remark. We corrected the cross reference.*

**Line 325:** I suggest you write 1-2 overview discussion sentences rather than restating the results section.

*Thanks for this feedback, we incorporate this in the newly revised discussion section.*

**Line 325-330:** This section is really heavy on words like “nevertheless, likewise, however, etc.” These should be used more sparingly for easier reading. I also believe that you can reduce this paragraph to two sentences.

*Thanks for your comment. We revised the manuscript according to your comment.*

**Line 330-339:** Very nice paragraph and interesting. Can you expand more here, especially the relationship between C and N and anaerobic CO<sub>2</sub> production?

*C mineralization is mainly controlled by the bioavailability of the OM and microbial communities. Under anaerobic conditions, diverse microbial communities are able to decompose the OM to CO<sub>2</sub>. Therefore, the CO<sub>2</sub> production is mainly controlled by the quality (N) and the quantity (TOC) of the OM. Here, our results followed the trend of the TOC contents.*

**Line 340:** Can you clarify the sentence?

*We expected a large increase of CO<sub>2</sub> production rate after the glucose addition. However, only a slight increase of CO<sub>2</sub> production was observed at 20degC for P15 and P16. Therefore, we tried to understand why the CO<sub>2</sub> production did not increase after the glucose addition.*

**Line 351:** what is lysis?

*In this case, lysis means decomposition. We replaced this word in the manuscript as it caused confusion.*

**Line 352:** A concluding sentence would be nice/helpful to wrap up the ideas you present in the preceding section.

*Thanks, we revised the discussion to pay careful attention to the sentence and paragraph construction.*

**Line 363:** I think it would be helpful to define lag time much earlier in the paper.

*We defined “lag time” after the first use, e.g. section 3.2.1. but because it is important, we discuss this further in the revised introduction.*

**Line 373:** I don't think it's appropriate to make this leap from your study to this general statement that glucose availability is not a driving factor for CH<sub>4</sub> production in mineral soils.

*That is true. We removed this sentence in the revision.*

**Line 380-382:** Interesting ideas. Can you expand more here, especially on topographic position? I am not seeing the link between topographic position and the results/factors influencing CH<sub>4</sub> CO<sub>2</sub> production that you discuss in this section.

*In this section we discuss the behaviour of CH<sub>4</sub> production under anaerobic conditions. Here, we explain that the lack of CH<sub>4</sub> production for P15 and P16 was mainly due to no established methanogen communities. If the methanogen community was small, but established, we would expect to have community growth after the glucose addition. However, since nothing happened, we concluded that this result was an additional support to our hypothesis, e.g., the absence of CH<sub>4</sub> production for those samples was because the methanogen was not active (or not active enough). We explain this lack of activity with the actual environmental conditions of sample sites due to the landscape position (cf section 4.2). Based on this feedback, we discuss this point more thoroughly in the revised discussion*

**Line 385:** There are many newer available articles which discuss this subject. Check out

Roy Chowdhury, Taniya & Berns, Erin & Moon, Ji-Won & Gu, Baohua & Liang, Liyuan & Wullschleger, Stan & Graham, David. (2021). Temporal, Spatial, and Temperature Controls on Organic Carbon Mineralization and Methanogenesis in Arctic High-Centered Polygon Soils. *Frontiers in Microbiology*. 11. 10.3389/fmicb.2020.616518.

*Thank you for the reference, we added more recent references.*

**Line 400-405:** Rather than summarizing the Herbst study so specifically, can you give a more general summary and explain how their result relate to yours and why they might differ?

*Yes, that is a good idea. Overall, Herbst et al. (2022) uses samples collected in the same area as ours but exclusively from floodplain soils, and did very similar incubation experiments using anoxic conditions at 20 C. Therefore, we consider this study as a comparison to complete our dataset. The results of Herbst (2022) showed rapid establishment of methanogen communities in floodplains. The lower production rate might be due to lower TOC and TN contents.*

**Line 406:** I suggest "confirm" rather than "are in line with"

*Revised as suggested.*

**Line 410-415:** I think this paragraph can be streamlined and made more concise. Please be specific about how the results/conclusions of the studies you discuss are related to your results.

*Thanks for this suggestion. We revised this paragraph to focus on the results from this study, including references to the figures showing these results, the conditions observed in the field. Then we use the observations from other field-based measurements as a comparison. The in-situ measurements show similar trends to what we observed in our incubations. We also compare their explanations for these high CH<sub>4</sub> fluxes to our findings.*

Please also note the supplement to this comment:

<https://bg.copernicus.org/preprints/bg-2022-122/bg-2022-122-AC3-supplement.pdf>