

Laurent Biogeosciences Reviews & Response to reviewers:

We thank the two 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 minor revisions to this manuscript.

Notably, we revised the second paragraph in the introduction to explain what we mean by “landscape position”

Reviewer 1:

I have suggested minor revisions that I hope will improve the clarity and readability of the paper.

Line 15: Yedoma samples located in upland and slope position

I still don't understand what you mean by 'slope position'. Is the sample located on a slope of a certain slope angle (ex. Slope with N aspect and slope angle of 20°?)

To clarify, we revised this sentence to read “Yedoma samples from upland and slope cores”,

Line 17: Are the permafrost layer really producing permafrost...change wording.

We clarified this sentence: “The Yedoma samples from the permafrost layer started producing CH4 after six months of incubation.”

Line 23: CH4

Revised as suggested.

Line 36: Formatting issue with citation.

We checked and solved the formatting issues with citation.

Line 40: Formatting issue with citation. Check throughout the document, some citations are underlined. Remove “in their study”, it is redundant.

We checked and solved the formatting issues with citation.

Revised as suggested.

Line 40: In Treat et al. 2018, they discuss landscape type (upland/wetland), not geomorphology.

We revised this sentence to address this point and to define “landscape position”. This now reads:

“Treat et al., (2018) showed that C flux variability was strongly associated to specific landscape types due to differences soil moisture and site drainage in uplands and wetlands that also controlled vegetation communities, which we are referring to here as landscape position.”

Line 42: “Landscape position is highly affected by permafrost thaw, low-lying ice-rich permafrost

areas can turn out waterlogged environments following permafrost thaw, while higher areas can be drained by water run-off." I don't understand this sentence. Do you mean perhaps that the effects of permafrost thaw are different based on landscape position? Instead of "turn out", maybe you mean "turn into" or "become"?

Thanks for pointing this out. We revised the sentence to read:

"Landscape change due to permafrost thaw is also highly affected by landscape position: low-lying ice-rich areas can become waterlogged following permafrost thaw, while higher areas can be drained by water run-off (Osterkamp et al., 2009; Liljedahl et al., 2016)."

Line 51-52: "Studies have shown that C decomposition depends on several"...

Revised as suggested.

Line 54: Treat et al. 2015

Revised as suggested.

Line 55: Please define 'landscape categories'.

Kuhry et al., 2021 defined landscape categories by soil type (peaty wetlands, mineral soils) and the origin of the deposits (peat deposit, alluvial deposit). We added this definition in the manuscript. This sentence now reads:

"For incubation under aerobic conditions, Kuhry et al., (2020) demonstrated that landscape types based on soil type (peaty wetlands, mineral soils) and the origin of the deposits (peat deposits, alluvial deposits) gave a good estimation of SOM lability, and therefore explained differences in CO₂ production better than using only the %C, which is a commonly used metric for C quality across incubation studies (Treat et al., 2015)."

Line 56: Do you mean under anaerobic conditions? ex. Unlike incubation under aerobic conditions, few studies have specifically focused on how ... for estimating CO₂ and CH₄ production under anaerobic conditions.

We split the sentence into two shorter sentences and revised the manuscript as suggested.

Line 57: Once again, you are using the term "landscape position" frequently in this paper without ever explaining what you mean. Please define this term explicitly and clearly in the beginning of the paper. Do you mean slope angle, slope aspect, elevation, landscape cover? In Treat et al. 2015, they define landscape position as: drained lake basin, active floodplain, wetland, lowland, or upland.

Maybe you can use this as an example.

Thanks for this helpful suggestion. We expanded the explanation of landscape position in the second paragraph (line 42) to read:

“Treat et al., (2018) showed that C flux variability was strongly associated to specific landscape types due to differences soil moisture and site drainage in uplands and wetlands that also controlled vegetation communities, which we are referring to here as landscape position.”

Then we used this helpful suggestion in the 3rd paragraph, the sentence on Treat et al’s anaerobic incubation synthesis reads:

“Additionally, Treat et al., (2015) highlighted that CH₄ production differences were partly explained by the landscape position, with differences seen between uplands, wetlands, floodplain soils, lowlands, and drained lake basins”

Line 59: Consider splitting this sentence into two sentences.

Revised as suggested.

Lines 63-65: Please re-read sentences for grammar mistakes and fix.

Revised as suggested.

Line 70: Give general geographic precision of Kurungnakh Island.

We specified the area (Lena Delta) and the country (Russia) of Kurungnakh Island.

Line 96: Fix grammar (tense) mistake.

Revised as suggested.

Line 97: Is a “well-drained upland soil profile” referring to on the upland sample or all three samples? If only the upland sample, this phrase should come directly after the word “upland” or in a separate, clear sentence.

“well-drained soil profile” refers to the upland only. We changed the wording based on your comment.

Line 98: I don’t understand this sentence. Sloping toward which three directions?

Deleted in revision as this didn’t add much information and was confusing.

Line 137: Give exact number of samples which didn’t produce CH₄.

Eleven of the twelve samples did not produce CH₄ for the first two months of incubation. We edited the manuscript based on this comment.

Line 226: Give exact numbers.

We specified that four of the six samples produced CH₄ at the end of the incubation period.

Line 230: Typo. Change to CH₄

Revised as suggested.

Line 232: Typo. °C. This typo appears several times in the rest of the paper. Please double check.

Revised as suggested.

Line 235: Over 363 days? So you have continued monitoring CH₄ production and you eventually did see CH₄ production or are you speculating that one day the samples might start producing CH₄?

Here, we refer to the lag time. We continued monitoring CH₄ and after 363 days, some samples were still in lag phase, e.g., the CH₄ production was still negligible.

Line 251: Typo 4 °C.

Revised as suggested.

Line 256. Typo

Revised as suggested.

Line 271: Statistically significant? If yes give p value, if no, change wording. I believe that the reference is to the incorrect table.

We added the p-value and changed the table.

Line 322: Do you mean to have several headers under the discussion header? 4.1.1. Different behaviors of what between landscape position.

We changed the section headers in this discussion section in the revision:

4.1. CH₄ production in floodplain environment and Yedoma cores across landscape positions

4.1.1. Floodplain core

Line 361: What do you mean by “highly constrained”? I believe you mean to say that community size varies highly “between” sites. What do you mean by “narrowness”?

By “highly constrained” we mean that the methanogen communities strongly depend on environmental factors and can not adapt themselves to any environmental conditions.

“Narrowness” is used in the same meaning as “highly constrained”. Methanogen communities have ecological and phylogenetical functions and it is highly affected by the disturbance of the environment.

Line 364: Typo. 20 °C.

Revised as suggested.

Line 373: Citation missing.

We cited Deng et al., 2015 and Ernakovich et al., 2022 two sentences further for this statement. However, based on your comment we added these two citations after “as well as the thaw disturbance”.

Line 382: Delete “On the first hand”. Very long sentence with grammar mistakes.

We restructured the sentence to make it easier to understand.

Line 428: How much time?

Schaedel et al 2014 showed that the turnover of labile C pool occurred within the first six months of the incubation. We revised the manuscript as suggested.

Line 438: Dwarf dominated tundra? Dwarf-shrub dominated tundra maybe.

Revised as suggested.

Line 461: Typo

Revised as suggested.

Line 464: Landscape position is not the trigger of CH₄ production.

We changed the wording.

Reviewer 2:

This manuscript has significantly improved since the initial version. In particular, the Discussion and Conclusions are more suitably narrowed to the scope of what was studied, and the presentation of the expanded incubation results (up to 1 year) is interesting. The addition of site photos in Supp. Fig. 1 adds important context to the data presented in the paper. I also like the new Figure 4 much better than the old one—not only due to the better annotation of “not detected” and “below detection limit” data, but also the re-grouping of different field samples under the same incubation treatments, which makes it easier to compare different field sites.

However, there are still a few minor revisions needed before publication, mainly related to correcting typos, but also a few minor content revisions. These are:

Thanks for the encouraging and helpful reviews. We’ve adopted the suggestions made here.

General comment: There is inconsistent use of “,” or “.” as a decimal separator.

We carefully changed “,” to “.”.

Li 12-14: Sentence structures could use improvement. Suggested revision: “Here, we used an anaerobic incubation experiment to simulate permafrost thaw along a transect from upland Yedoma to floodplain in Kurungnakh Island. Potential CO₂ and CH₄ production were measured during incubation of active layer and permafrost soils at 4 and 20°C, first for 60 days (approximate length of growing season), and then continuing for one year.”

Revised as suggested.

Li 18: Change “to trigger” to “triggering”

Revised as suggested.

Li 21: Summary is missing opening sentence needed to understand “these gases” in li 22. Copied from tracked changes version: "Climate change is causing increasing temperatures and permafrost thaw, which might lead to increases in the release of greenhouse gases CO₂ and CH₄."

Revised as suggested.

Li 39: Change “differ across Arctic” to “vary across the Arctic”

Revised as suggested.

Li 41-43: Revise this sentence to: “Permafrost thaw is highly affected by landscape position: Low-lying ice-rich areas can become waterlogged following permafrost thaw, while higher areas can be drained by water run-off.”

Revised to read:

“Landscape change due to permafrost thaw is also highly affected by landscape position: low-lying ice-rich areas can become waterlogged following permafrost thaw, while higher areas can be drained by water run-off (Osterkamp et al., 2009; Liljedahl et al., 2016). “

Li 62: change “condition” to “conditions”

Revised as suggested.

Li 63: change “increase of precipitations” to “increasing precipitation”

Revised as suggested.

Li 64: Change “deepen active layer” to “deepening active layer”, and “hence” to “and hence”.

Revised as suggested.

Li ~133-134 (Eq 1 and description): It would make more sense to put this equation above the previous paragraph (i.e. between lines 125 and 126), to be closer to the relevant method text.

Revised as suggested.

Li 163: Change “used a linear regression between each measurement point to” to “a linear regression between each measurement point was used to”

Revised as suggested.

Li 164-165, “calculated with the headspace and the volume of the dry content and normalized per gram soil C”: This wording is unclear. I’m guessing you meant that the headspace concentrations were converted to amounts using the headspace volume and the ideal gas law, and then the gas amounts were normalized to the weight of the dry sample?

Yes, exactly. We’ve revised to clarify:

“The production rate was calculated with the change in concentration of CO₂ and CH₄ over the incubation time. First the measured CO₂ and CH₄ concentrations were converted from ppmv to umol/L using the Ideal Gas Law, then a linear regression between each measurement point was used to calculate the change in concentration over time. The production rate was calculated using the change in concentration over time from the linear regression, then the rates were normalized using the volume of the soil (for differences in the jar headspace) and the weight of the dry soil samples (Robertson et al., 1999). Then these rates were also normalized by the %C found in each sample to look at substrate quality.”

Li 169-170: Going back to my question from the first manuscript version, it sounds like "cumulative" includes the entire time from day 0 to day 67? And what was the result of "calculat[ing] the glucose factor only after glucose addition and see if we have different values" (as mentioned in the Response to Reviews)?

We compared the two calculation methods and we did not see differences in the values. Therefore, we decided to keep the original calculation method.

Li 210: Typo in Table 2? It says the TOC of P17-F is 17.2% (old table version said 0.17).

Thank you for notifying this mistake. We corrected this in revisions.

Table 2: See comment above about the P17-F TOC. In addition, there is an extra decimal point in this sample’s C value, “2..3”. Also more generally, maybe it’s worth adding TN to the table as its own column separate from C/N, since there’s some discussion about it in the text?

We added the TN values to Table 2 and corrected the TOC value of P17-F.

Li 242-243: Specify which temperature this applies to, i.e. “With a cumulative 20°C CH₄ production reaching...”

Revised as suggested.

Li 247-248 "...and the permafrost layer of the same core at 4°C was the lowest": For the P17-F sample, the CO₂ production at 20°C actually looks slightly lower than at 4°C.

You are right. Thank you for your remark. We changed the manuscript based on this comment.

Li 250-251: Change to "At 4°C, the permafrost layers of the Yedoma core P16 and the floodplain core P17 had cumulative production..."

Revised as suggested.

Li 254 & 256: Cite Supp. Fig. 4 here in addition to Fig. 2, since the changes in CO₂ production are easier to see there.

Revised as suggested.

Li 258-260: These values don't seem to match anything in Supplementary Table 2 (except for the 754 value for P17-F-4).

Thank you for notifying this mistake. We revised the manuscript with the correct values.

Li 260-261, "CO₂ production plateaued for all the samples": This doesn't appear to be true for P17-A at 4°C (which shows an uptick at the end)?

You are right. We revised the manuscript with the right values.

Li 269 and 271: The "Table 2" references need to be corrected to "Table 3."

Revised as suggested.

Li 270: The "2.7 ± 2.6 and 2.6 ± 2.1" are slightly different from the values in Table 3.

Revised as suggested.

Li 285-286: Change to "CO₂:CH₄ ratios represent means of total emission after 363 days of incubation."

Revised as suggested.

Li 287: Change "less CH₄ production" to "less GHG production"

Revised as suggested.

Li 296, "0.8 and 9.1": I'm assuming these are absolute amounts (not the glucose factors themselves); what are the units?

Based on your comment, we decided to present the results in different way to make them easier to understand.

“The response factors were low (CH₄ production between 1.2 and 1.7 times higher with glucose addition) and appeared only at 20 °C.”

Li 298, “glucose addition increased CO₂ production at 20 °C by 46%”: For which sample? Or is this an average?

Thank you for pointing this out. As for the previous comment, we changed the manuscript:

“CO₂ production at 20 °C was overall increased by glucose (F= Kruskal-Wallis, df = 1, p < 0.05). The maximum increase of CO₂ production was seen for the permafrost layer of P16 (4.2 times higher with glucose addition).”

Li 302, “core P16-F”: Should this be "P17-A" (see upper left of Fig. 4)?

Revised as suggested.

Li 318: Delete the extra parentheses around “P16”

Revised as suggested.

Li 319: Either delete the “(d.)”, or add panel labels to the figure itself.

We deleted the “(d.)”.

Li 338: Change “did not produce CH₄” to “did not produce appreciable CH₄” (because Fig. 3 still shows a small amount of CH₄).

Revised as suggested and corrected throughout the manuscript.

Li 339: Change “4°C and 20°C” to “4°C or 20°C”

Revised as suggested.

Li 353: Correct the “Table 2” reference to “Table 3”

Revised as suggested.

Li 359: Change “discrepancies” to “variability”

Revised as suggested.

Li 363: The word "narrowness" applied to microbial communities needs more clarification. Therefore (and to correct other grammar), change “by the narrowness” to “due to the ecological and phylogenetic narrowness”.

Revised as suggested.

Li 371: Change “microbial community growth” to “methanogen community growth”

Revised as suggested.

Li 373: Change “were correlated” to “is correlated”

Revised as suggested.

Li 374: Change to “For ecologically and phylogenetically narrow microbial communities, like methanogens, ...” (same reasoning as above; plus other grammar correction)

Revised as suggested.

Li 380: Correct missing period at the end of this sentence.

Revised as suggested.

Li 382: What are these redox features? Also, change “On the first hand” to “On the one hand”.

Oxidation marks were seen in the field and during the subsampling process. We specified in the manuscript.

Li 386: Remove the extraneous comma after “both”. Also change “that did not produce methane” to “which did not produce appreciable methane” (same reasoning as above).

Revised as suggested.

Li 399-405: But the production per gram C would *always* be much higher than the production per gram DW, because the C is only a small percentage of the DW in mineral soils. Therefore, comparisons of production per gram C vs. per gram DW doesn't say anything about the lability of the C. To look at C lability, it only makes sense to compare the per-gram-C production across different samples, because most of the rest of the DW is just inert material. This might mean a re-write of this section; e.g. based on Supp. Fig. 3, you could say that the P17-A sample had the highest C lability because it has the highest production per gram C. But P17-F would still have a similar (or slightly lower) lability compared to the Yedoma soils, so its lability is not especially high.

Thank you for this helpful remark. We re-wrote this section by comparing only the per g C across different samples. It now reads:

“Our rates of CO₂ production per g C were in the same order of magnitude as other Yedoma incubation studies from Kurungnakh Island (Knoblauch et al., 2013, 2018) and nearby Lena Delta River (Walz et al., 2018). These similar results suggest that C in these Yedoma soils is easily available due to the organic-rich characteristics (Strauss et al., 2013). On the other hand, the adjacent samples from the permafrost layers of the floodplain showed CO₂ production g per C similar to the Yedoma cores while, it had the lowest CO₂ cumulative production per gram dry weight of soil. Although floodplain environments in the Lena Delta are considered as a low C pool (Siewert et al., 2016), our results showed that the C in the soils was highly labile and comparable to the lability of Yedoma soils.”

Li 409: Change “as proved by” to “consistent with”

Revised as suggested.

Li 417: Change “limited” to “limiting”

Revised as suggested.

Li 433: Change to “under wet summer conditions, it is likely that there will be rapid C turnover”

Revised as suggested.

Li 443: Delete the extraneous “in CH₄”

Revised as suggested.

Li 448: Change the last part of this line to “soil moisture might increase, and C in Yedoma”

Revised as suggested.

Li 451-452: This sentence needs a few small corrections, as follows: “CH₄ oxidation in overlying surfaces might have inhibited CH₄ production in the active layers of the Yedoma samples (Figure 2; Figure 3), but our methanotroph results did not allow us to draw this conclusion.”

Revised as suggested.

Li 453-457: But CH₄ production in the Yedoma active layers was very low, and occurred only in these anaerobic incubations; whereas in the field the active layers are well-drained and the permafrost is frozen (and therefore not likely actively producing CH₄). Therefore, it seems like in the field there wouldn't be much (if any) CH₄ *to* transport or oxidize. So I'm puzzled by these assertions about CH₄ oxidation and plant transport being important factors in the Yedoma sites, at least while the permafrost is still intact.

We agree with this remark. Based on it, we discussed more in detail the possibility of not having CH₄ production in the Yedoma active layers and removed the parts about oxidation and plant transport that occur in the field but were unfortunately beyond the scope of this experiment.

Li 465: Change “were” to “was”

Revised as suggested.

Li 473: Change to “to better understand changes in redox conditions across the landscape to improve upscaling.”

Revised as suggested.

Supp. Fig. 5: This figure is hard to read due to the line styles having no particular pattern, and some being very similar in appearance (e.g. the active layer 20C and frozen layer glucose 4C are both solid black). My suggestion would be to use the same set of colors as in Fig. 2 to represent the soil layers and incubation temperatures, and dashed / non-dashed lines to indicate presence or absence of glucose.

Thank you for this helpful suggestion. We agree that this figure is hard to read. We revised the figure as suggested.

Supp. Table 2: In the third data column, "Max production rate CH₄ (μg C-CO₂.g C-1.d-1)", it looks like "CH₄" should be "CO₂".

We changed to CH₄.

Supp. Table 3, value "6539.022 ± 1299.21": With these units (mg CH₄-C / g C), this would mean that 6.5 times more CH₄ was produced than there was C in the soil, which is impossible; and also this number is several orders of magnitude higher than the cumulative production in Supp. Fig. 3c. Maybe a misplaced decimal point? Or are the units for this row supposed to be μg instead of mg?

Thank you for this remark. We corrected the units to μg instead of mg.