

Response to reviewers: “Heterogeneous CO₂ and CH₄ content of glacial meltwater from the Greenland Ice Sheet and implications for subglacial carbon processes” (Pain et al.)

Editor comments

L11-14: an extremely long sentence featuring too many ‘and’s. Please divide the sentence for easier digestion.

Agreed-- we have changed the sentence to: “We evaluate subglacial discharge from the Greenland Ice Sheet for carbon dioxide (CO₂) and methane (CH₄) concentrations and $\delta^{13}\text{C}$ values in order to evaluate subglacial CH₄ and CO₂ sources and sinks using geochemical models. We compare discharge from southwest (a sub-catchment of the Isunnguata Glacier, sub-Isunnguata, and the Russell Glacier) and southern Greenland (Kiattut Sermiat).” (lines 11-14)

L14: erroneous semicolon – should be a colon, or just a comma.

Corrected

L16: ‘meltwater in southwest sites’ – should this be ‘from’ or ‘at’?

Changed to “from”

L64: not sure this sentence is necessary: the majority of our readers know that there are no other ice sheets remaining in the northern hemisphere. If you choose to retain, either Northern should not be capitalised, or both Northern and Hemisphere should be capitalised (I think the latter?).

We opted to keep this in the manuscript as it reinforces the point that the current landscape of Greenland can be used to understand larger deglaciation events such as that which occurred since the LGM. We have changed to Northern Hemisphere

L91: typo

Corrected

L119: spacing error prior to ref

Corrected

P12: two paragraphs beginning with ‘While’, and multiple sentences beginning the same – suggest rewording one or two for readability.

Wording has been changed in two instances (lines 346 and 365)

L500: typo - missing space

Corrected

Reviewer 2 comments

Title – correct to ‘heterogeneous’

Corrected

Abstract – verb still missing in sentence at lines 20-22

Corrected

Intro

57 and elsewhere please specify if Graly et al 2017a or b

Graly 2017a was incorrectly included in the reference list, so now there is only one Graly 2017 reference.

62-64 relevant work should be cited here, eg the recent review by Wadham et al (2019)
70 Musilova et al (2017) did not study subglacial microbial activity; this reference is irrelevant here

Citations have been added

Methods

91 typo in ‘the Qinnguata Kuussua’

Corrected

97 mentioning the Isunnguata catchment size is irrelevant and potentially misleading here and should be removed

We feel that it is important to contextualize the regional hydrology and describe the glaciers provided in the map, therefore have opted to keep this number. The use of the term sub-Isunnguata throughout the manuscript reinforces that this is a sub-catchment of the Isunnguata, and the difference between the catchment areas is described in lines 96-97.

102 The estimate of the Russell Glacier catchment size of 300 km² has remained in the text. This is questionable and I strongly advise the authors to remove it or to add this is probably exaggerated (van de Wal and Russell 1994).

We have added language to communicate this uncertainty in lines 101-102 and added this citation.

Results

277-278 The correlations between Sub-IS discharge and $\delta^{13}\text{CCH}_4$, ϵC , and fox are weak and the data points certainly do not suggest linear relationships (Fig 5bcd). The relevant discussion should be toned down accordingly (see below).

We now describe the correlations as weak (lines 277-278)

Discussion

337-339 This explanation is confused. Methane production requires a very negative redox potential and any external terminal electron acceptors brought in by meltwater (O_2 , NO_3^-) would inhibit it and lead to CH_4 oxidation instead. The EAs for methanogenesis are either CO_2 (for the hydrogenotrophic pathway) or acetate (acetoclastic methanogenesis is a disproportionation). Please remove or rephrase this.

Thank you for pointing this out-- this was an important error in the text. We have modified the text to reflect this: "If limited by residence time, a hydrologic link between glacial hydrology and subglacial biogeochemistry would be established because supraglacial discharge delivers terminal electron acceptors to the ice bed and would limit methanogenesis." (lines 337-339)

354-356 If CH_4 is stored under the ice sheet no fractionation is likely to occur. Therefore, it is impossible to decide whether the released CH_4 comes from active methanogenesis or old reservoirs, based only on $\delta^{13}\text{CCH}_4$. Please remove or rephrase this.

We have rephrased as follows: "The similar isotopic ratio between our samples and that measured in active methanogenic communities could indicate that similar methanogenesis pathways occur across this region, or that the $\delta^{13}\text{C-CH}_4$ of stored subglacial CH_4 has not been fractionated by oxidation or transport in the peak melt season when we observe these depleted $\delta^{13}\text{C-CH}_4$ values." (lines 352-354)

367 While I agree it is unlikely that the extent of outgassing would vary significantly between sampling times, it may be affected by discharge due to changes in turbulent flow. Please change to 'outgassing would not fully explain temporal differences'.

This change has been made.

372-374 This paragraph is based on the weak correlations shown in Fig 5 (see above) and should be toned down.

We now acknowledge the weak correlation here (line 373)

392, 415 please remove the sermiat/glacier pleonasms

This change has been made.

423-8 unfinished sentences, please rephrase

Typos have been corrected.

491-498 More recent and appropriate literature should be referred to. For example, microbial sulphide and thiosulphate oxidation in the subglacial environment have been quantified by Boyd et al 2014 and Harrold et al 2016, respectively; the presence of growth substrates as a factor for CH₄ production in subglacial samples has been shown experimentally by Stibal et al 2012; Wadham et al 2010 provided a thorough overview of subglacial weathering and the role of microbial processes in it.

These references are now included (lines 489, 491).