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Biogeosciences Discussions

Interactive comment on "The importance of freshwater systems to the net exchange of atmospheric carbon dioxide and methane with rapidly changing high Arctic landscapes" *by* Craig A. Emmerton et al.

Anonymous Referee #1

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General comments on the overall quality of the paper

In this study, authors examine CO2 and CH4 exchange between four common freshwater systems located in the high Arctic watershed of Lake Hazen, Elsmere Island, Nunavut, Canada. This study aims to measure net exchange of CO2 and CH4 between atmosphere and common high Arctic freshwater ecosystems. In previous studies, authors investigated CO2 and CH4 net exchanges from terrestrial ecosystems (e.g. polar semi-desert, meadow wetlands, uplands) in the watershed of Lake Hazen. In this study, authors also aim to contextualize their new findings about freshwater systems in Lake

Hazen watershed with both their previous results and literature.

The scientific context and questions are well defined but specific issues about High Arctic landscapes could be clarified. What are the conditions and issues in High Arctic environments that differ from Low Arctic and Sub Arctic regions? The objectives are well exposed and correspond to data showed by authors. However, because of too general sentences and a lack of references, the answer of the second objective (contextualization) is not well developed and not accurate enough.

The authors present interesting data about CO2 and CH4 concentrations and exchange with atmosphere in freshwater systems in a high Arctic watershed. Measurements have been performed during summers from 2005 to 2012 in four freshwater ecosystems: evaporative ponds, meltwater ponds, shoreline ponds and Lake Hazen shoreline. These four freshwater systems were identified using a hierarchical clustering analysis based on gas concentrations and biogeochemistry data.

The main findings from this study are: Mean CO2 concentrations and atmospheric exchanges were statistically similar between freshwater systems. The three types of ponds were weak CO2 emitters. Shoreline ponds exhibited the highest dissolved CH4 concentrations and fluxes to the atmosphere. However, because shoreline ponds cover a small area, their contribution to overall CH4 emissions was weak. Other ponds and the Lake Hazen shoreline showed similar CH4 concentrations and fluxes, which were weak. The same authors evidenced in previous studies that polar semi-desert ecosystems were weak sink of atmospheric CO2 but they significantly consumed CH4. Alternatively, meadow wetlands were important sink of CO2 and weak emitter of CH4. Considering their cover surface, all freshwater systems did not significantly contribute to total net C exchange from Lake Hazen watershed.

This study showed interesting results about the weak CO2 and CH4 emissions and uptake from freshwater systems in High Arctic region. These results are crucial to better constrain the assessment of future carbon feedback from permafrost environments

with climate change. Furthermore, high values of CH4 concentrations and fluxes in shoreline ponds are important considering likely evolution of both the water level and the biogeochemistry of Arctic lakes.

From my point of view, the main result is the seasonal flooding of Lake Hazen that led to strong increase in CO2 and CH4 emissions from ponds bordering the lake while other ecosystems were weak CH4 emitter. The highlighted processes are interesting and important although more evidences of the impact of biogeochemistry change on CH4 emissions would be necessary.

The second part of the discussion infers about the evolution of carbon exchange from freshwater systems in warmer and wetter conditions due to climate change. This section (paragraph 4.3) should be strongly modified. The current discussion section is too general and not adequately based on the findings from this study. There is a strong lack of references in this section (only four, an one auto-citation). Authors should develop a more specific and accurate discussion using more references.

Despite the importance of data, authors are strongly recommended to do a major revision before acceptation by 1) better investigating the biogeochemical processes responsible of contrasted CO2 and CH4 concentrations and fluxes among ponds and 2) strongly improving the discussion.

Scientific questions and issues

- I would recommend changing the title that does not reflect the main findings

- The number of samples should be indicated. The standard deviation of the mean should be indicated. How are representative the different measurements considering the differences in quantity of samples? How evolved the number of samples during time from 2005 to 2012? How many samples per site did you use to build the dendrogram?

- Are the ponds permanent throughout the year? Do you consider these freshwater systems as ponds of small lakes?

- What is the geologic substrate and the soil nature in the watershed? It may help to discuss your interesting results.

- Place the section 'numerical analysis' currently located in the supplementary data in the main manuscript.

- Authors studied both spatial and temporal variability. The two perspectives are not clearly exposed. I would recommend separating results about spatial variability from temporal evolution of gas concentrations and fluxes. The robustness of the spatial variability should be better explained by improving Figure 2 and Table 2. The available samples/data and the significance of differences in biogeochemical composition should be added. Some temporal trends should be better illustrated and explained (Figure 3).

- This manuscript reproduces and repeats some results already presented in Emmerton et al. (2014). Results from previous studies should be removed from the abstract and from the result section.

- Most of the figures should be modified in order to clarify the main information. Concentrations and fluxes bar plots should be separated; vertical scales should be changed. Some figures in supplementary data could be placed in the main manuscript such as Figure S2.

- Authors highlighted interesting biogeochemical processes, which could be better evidenced.

- This manuscript requires a substantial improvement of the section 4.3. Scientific arguments should be more specific and based on the findings from this study.

Technical corrections

In the introduction:

From l 35-36: The paragraph seems to be general and does not provide precise information about the weight of each process or where do they mainly occur? Is there a

latitudinal gradient from Sub-Arctic to Low-Arctic and High-Arctic.

l 41-42: Check sentence structure

l 45-46 and l51: The freshwater systems cover more than 50% of area in northern regions but less than 5% in polar semi-desert landscapes? Authors may better explain this important difference between the general point of view and specific semi-desert landscapes, and could describe the latitudinal/landscape gradient?

l 61-62: Control the relevance of chosen references, particularly Peterson et al. (2002) about permafrost thaw and Manabe et al., (1994) about growing seasons.

l 68: the reference (Antony et al., 2014) does not correspond to the sentence about polar semidesert.

l 68-70: Sentence is not clear, check its structure

l 70: although it is uncertain how rapid climate change will alter the C cycle in northern landscapes, this study does not provide strong information about its evolution.

In Methods

Figure 1: the figure should be modified. The general maps are too small and thus not useful, the north arrow and the scale are also too small and not visible. Even on a half page, pond and lake pictures are small and don not provide any information. Authors may choose some of the pictures to illustrate the differences among landscapes/freshwater systems.

l 100: Sentence structure

l 102: how many samples were collected each year and what would be there contribution to mean values? If there is temporal heterogeneity in sampling, mean values may differ with both spatial and temporal evolution.

From l 103: how many samples did you analyse for dissolved CO2 and CH4 and how

many did you use to calculate fluxes?

l 135: same title for 2.3 and 2.2 In general how are analysis and calculation representative?

From l 160: do differences in sampling frequencies have consequences to compare dissolved gas concentrations and fluxes to biogeochemical functioning? For example, for the ponds 10, 11, 16, chemical analyses were only performed on samples collected from 2010. In 5 years, pond conditions may have significantly changed with the important climate change in this region.

In Results

Figure 2: Not useful, could be put in supplementary data. Moreover, what represent the numbers between brackets? If they represent the number of samples, how authors can compare some sites with 15 samples and some sites with only 1? Noteworthy is the close relationship between Shoreline and Meltwater ponds, closer than Lake Hazen shoreline.

Table 2: How many samples for each pond type (not lake type)? Standard deviation should also be added. Authors my also provide mean and SD of the different physical and chemical parameters for each pond in order to compare with group values (in supplementary data for example). TDN could be added.

l 189: Illustrate the sentence 'without extremes during the growing season' with a figure;

l 195: Ammonia is not only produced in anoxic conditions, 'reduced ions' could be rephrased as ammonia or nutrient or inorganic ions, mineralization products. . .

l 196: How the Table S4 shows the increase in concentration of NH4 with chemical change during the onset of flooding?

l 196: Both spatial and temporal aspects are used in cluster analysis. This may not be representative due to the discrepancy in sampling.

l 200-201: Inference from results that may be placed in discussion

Figure 3: The figure is not clear, seasonal trends are not clear, differences among sites and years are difficult to see. Scales of vertical axes could be modified according to maxima and minima values, especially for CH4 in meltwater ponds and lake Hazen shoreline. Lines between dots for Evaporative ponds should be removed; authors do not know what occur between their measurements. Evaporative ponds exhibit significantly less measurements than other sites. Results from this figure are not well explained and explored. Only cited twice at the beginning of 3.2.1 and 3.2.2, but not any arguments are based on this figure. Authors do not develop the seasonal trend of dissolved CO2 ad CH4. Comparison between years would be better highlighted using bars plots or a simple table.

Figure 4: Unclear, concentrations and fluxes should not be placed together in the same graph. Comparison between concentrations and fluxes in ponds are difficult. I advise to place dissolved gas concentrations in a graph and fluxes in another.

l 205-206: Although dissolved CO2 concentrations showed non-significant differences, authors compared these values between system types.

l 209: same comment as line 195.

l 221-222: CO2 and O2 correlation and relationship with water temperature not well showed in the Figure 5. Correlation coefficients may be placed in the main manuscript.

l 233-234: The sentence is not clear.

l 245-246: Still not any significant differences among pond types, but authors compared shoreline ponds values to other systems (l 255).

l 269-273: These are not results from this study, should be placed in discussion.

l 277: Is the assumption of generalization relevant and representative of the mean lake composition?

Figure 6: CO2 and CH4 fluxes should be separated. Vertical scales should be modified, for most ecosystems CO2 flux values cannot be read. Figure 6b may be change to a table. Although units were different, CO2 and CH4 fluxes have been already shown in Figure 4. This figure should be modified.

In the discussion

l 300: 'other compounds' is not clear

l 302: 'considerable' is a bit excessive considering dissolved CO2 concentrations

l 303: Are there evaporates in Lake Hazen watershed? Do you think weathering of carbonates is higher in Evaporative lake than in other systems (pH almost similar in all ponds)? Can DIC be released from surface water exhibiting pH around 8.3? This sentence is too general, higher CO2 concentration originates from higher microbial decomposition or as you write after due to concentration effects.

l 311: Do you have evidence of pond stratification other than correlation between CO2 and CH4 concentrations?

l 315: Associations may be replaced by correlations.

l 316-318: How do you evidence that productivity of microbial decomposition where not the main drivers? Both primary productivity and microbial activity could increase with temperature during the day and lead to diurnal O2 and CO2 concentration trends following temperature.

l 320-321: rephrase 'pre to post-flooding mean chl-a concentrations of 1.2 to 0.4 μg l-1)

l 324: 'reduce compounds' could be rephrase as nutrients or ammonia/nitrates, ammonia is not only produced in reduce conditions.

l 325-326: The sentence is not clear. Moreover, how diurnal O2 and CO2 concentration trends suggest that primary productivity was consistently occurring in Shoreline while

you seem to suggest the opposite l 316-318?

l 336-340: How can you evidence that SO42- production outcompeted CH4 production? Maybe the locations of SO42- and CH4 productions were different or the anoxia could not sustain methanogenic bacteria activity. Do you have measurements of dissolved O2 or redox potential in the ponds?

l 344-345: The sentence is not clear, rephrase.

l 354-355: Are you sure (to your knowledge)?

Table 3 (l 357): Considering the intense Arctic change these last 25 years, how the compilation of data of CO2 and CH4 fluxes throughout more than twenty years can be relevant? Moreover, CO2 and CH4 fluxes may mostly differ according to soil nature, moisture, vegetation, microtopography or local climate conditions and not as a function of large latitudinal regions. I do not think this table provide useful and accurate information. Few words about the comparison between the measurements from this research and other studies would be enough. The main information provided by the table is also not clear.

Paragraph 4.3: This paragraph is too general; no specific point from your study is developed. Only few references are used to support your discussion (4 references, of which one is an article from authors). This entire paragraph should be modified: the discussion should be more based on your results, a specific and original point of view should be developed and your findings better compared with more articles.

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