Commentary reply:

Dear Dr. Lapham,

Thank you for volunteering your time to provide these thorough comments on this manuscript. In response to your main comment the hypothesis statement can be changed to state:

"We hypothesise that the largest hotspots in the MRD include contributions of biogenic and potentially thermogenic CH_4 due to the complex nature of potential geologic CH_4 sources at depth in the region and the abundance of environmental settings where modern methane is being produced."

Please see below for our responses to individual comments.

Summary: The goal of the paper was to take a first look at the source of the hot spots previously found by aerial surveys using stable carbon isotopes within the Mackenzie River Delta (MRD). The authors state that the MRD has thermogenic gas seepage and biogenic methane atmospheric sources. Given there are so many lakes, this is not surprising, but there should be references for that statement. The authors hypothesize (line 84) that the hot spots come from "thermogenic, biogenic, and mixed sources….". This hypothesis could be strengthened by picking one source based on previous literature. For example, the Kohnert paper clearly suggests that the hot spots are thermogenic because they are so high, but didn't have any detailed source information to support this. This paper does. Or maybe the fact that there are so many lakes emitting biogenic methane means the atmospheric methane would make one hypothesize these hot spots would be biogenic? The strength of this paper is in using stable carbon isotope ratios of methane in air from ground surveys. The paper could benefit from some more details on the sampling sites, the sampling protocols, the assumptions going into the keeling plots, and overall conclusions drawn from the study. Overall, I think the data is interesting, and definitely novel and worthy of publishing. Hopefully the comments below could help streamline the message:

1. The introduction could be streamlined and strengthened. Currently, the text suggests that the MRD has biogenic methane sources, but I couldn't see any references to support that. Maybe work from Lance Lesack's group would be helpful here for in and around Inuvik. On line 60, there is also mention of production of methane in the organic rich active layer but has no reference. There was a recent paper to conduct permafrost incubation studies (Lapham et al., 2021) in Tuk, but that didn't take place in the active layer. In terms of streamlining, the sentence from line 67-68 could be cut; while it is important to measure emissions of methane, since the current study didn't do this, it's not necessary.

Reply: The sentence from line 67-68 can be removed.

The following sentence can be added to the opening paragraph: “Lakes, especially, in the MRD have been shown to be sources of biogenic CH_4 (Cunada et al., 2021; McIntosh Marcek et al., 2021).

The first sentence in the fifth paragraph in the introduction can be changed to read: Migration of CH_4 through discontinuities in the permafrost is common in regions with thin permafrost similar to the MRD as well as production in the organic rich active layer during anoxic conditions (Barbier et al., 2012; Liebner & Wagner, 2007; Lupascu et al., 2012).

2. The study location and methods sections could be reorganized to be sure the proper information is conveyed in each section. For example, the setting was described in section2, and then there was a “study location” in section 3. The methods section should only give the methods used, and results should be reported in the results section.

Reply: The study location section can be moved to section 2 with the exception of the following sentence which should be moved to the Results section:

“Of the five airborne eddy covariance hotspots investigated, atmospheric CH_4 concentrations were significantly above background at four sites (Pingo 1, Pingo 2, Wetland 2, Wetland 3). Only background atmospheric concentrations of CH_4 were observed at Site 9 (Table S1), therefore, it was not included in the main analysis.”

3. Overall figures are sufficient with some revision. For example, figure 1 could be more informative if the walking transects were shown on the pictures, and the direction of wind and location of seeps were also shown. As it is now, without any labels, it’s difficult to see where the seeps are (unless you know), and at Lake 1, unless you know the picture shows the lake is ice covered, it’s hard to know what is happening. The caption says “prominent ebullition” but unless you know what to look for, it’s not clear with the captions. Furthermore, supplemental figure S2 is not mentioned in the text, yet addresses some concerns about wind direction and the location of the transects. If the quality could be improved, or information combined between figure 1 and figure S2, this could help.

Reply: It is our opinion that adding the walking transect data to Figure 1 would be too much information to effectively convey in one Figure. But in response to this comment Figure S2 can be moved to the main results section of the paper and the images improved. The remaining two walking transects can be added as well.

4. The chamber flux data seems to be an add-on. Is it necessary for the message of the paper? If so, more details will be needed (like how the samples were analyzed) and some context of what the fluxes mean in terms of other environments (for the discussion). If not needed, please consider taking out of the paper.

Reply: Although the chamber flux data do not add significantly to the narrative presented in this manuscript we had originally included them because they have considerable value. There is a lack of published chamber measurements in the Mackenzie River Delta as well as the Canadian Arctic. The chamber flux data will be removed from the manuscript.

Detailed comments:

Line 34: add in “oxidation” after production and before transport. I think it’s important with some of the conclusions drawn to get the idea of oxidation into the text earlier.

Reply: "Oxidation” can be added to line 34

Line 51: As numbers, delta values can be high or low, positive or negative, but not heavy or light. Please use “high” or “low” $\delta^{13}C$ values. Be sure to check this throughout and change accordingly.

Reply: $\delta^{13}C$ values can be referred to as “high” or “low” throughout the manuscript

Line 75: “geologic origin”: maybe define what you mean and that it could be made up of thermogenic methane produced deep and migrates, or biogenic or rather, microbial methane produced in the permafrost? See comment from line 224.

Reply: The following can be added to line 75: “(CH_4 produced beneath the permafrost, including thermogenic CH_4 from natural gas reserves that has the potential to migrate through discontinuities in the permafrost)”

Line 78-80: The sentence starting “interestingly, ….” Is a confusing sentence. How can the sources behave differently than the current understanding? Please reword to make more clear.

Reply: This sentence could be changed to read: “Importantly, isotopic signatures have not been extensively used to determine the source of atmospheric CH_4 at hotspots in the outer MRD. Source contributions to atmospheric CH_4 could be different than the current understanding of the region and other, similar Arctic environments.”

Line 117: it would be helpful to have a mark on the map for Tuk.

Reply: The current map in Figure 1 does not encompass Tuktoyaktuk. The field site located in the Tuktoyaktuk coastlands (Pingo 3) is at the southernmost edge of the ecoregion and about 100 km from Tuk.

Lines around 119: describe your sites a little more than just a name. What is "site 9"? There isn't a description in figure 2, and on the figure 1 map, it looks like it's upwind of the hot spot from Kohnert. What were the winds like when you sampled it? Also, the sentence here of "Of the five airborne eddy covariance hotspots….." is a result. It should be moved to that section. In thinking more about the study design, if the idea was to ground truth the Kohnert hot spots, there is a missed opportunity to bring out some novelty of this study. For example, if we look at the "pingo 1" site, the fact that there is a pingo there is important, right? Does that already add information not gained from the Kohnert study? That you observed a pingo there? And what would that mean, what would the observation of a pingo mean for methane emissions? Aren't they by definition conduits of some sort? Or what about pingos being surrounded by wetlands? Additionally, at wetland 3, the fact that there are wetlands characterizing that hot spot is interesting information. I'd almost envision numbering the hotspots sequentially and then giving them their ground feature names as done on figure 1 (this is just a suggestion and maybe not helpful, it just seems interesting what ground features underlay the aerial hot spots). Yet, such an approach really send home the message that is directly inline with your goal, to groundtruth the aerial survey hot spots.

Reply: The following paragraph demonstrating the importance of pingos to CH_4 production can be moved from the discussion to the introduction which will help set up the study design:

"Hodson et al. (2020) found that six pingos in Svalbard had a range of annual flux rates between 76.4 and 364 kg CH_4/year and concluded that pingos require further study due to their potential contributions of CH_4 to the atmosphere. The outer MRD and the Pleistocene deposits of the Tuktoyaktuk Peninsula are home to about 2363 pingos (Wolfe et al., 2021). Release of CH_4 from pingos in the region could represent a significant, unaccounted source of CH_4 to the atmosphere making it a critical area for further study of pingos as a source of CH_4. Migration of CH_4 to the atmosphere from pingos is still poorly understood and additional studies of CH_4 production from pingos will help to improve Arctic CH_4 emission estimates."

- The sentence "Of the five airborne eddy covariance hotspots….." can be moved to the results section.

Table S1: The raw data should be available somewhere for review. Will it be available in a database somewhere, or as a supplemental table here? Also, in this table, for the "source d $\delta^{13}C$-CH_4 values, R^2, and max CH_4" in the fourth column, those are the same values as in figure 1. I'm not sure what this table is adding except to give exact locations. Can you replace this with the raw data, from which you derive the y-intercept from keeling plots? Also, Table S1 gives a "site type" as Polar V. How is the Polar V a site type? Also, you give into in this table for the low R^2 values, what made you pick the R^2 value cut offs you did? For

example, you kept an R^2 of 0.48 but didn't talk about the site with R^2 of 0.434. This sort of thing should be mentioned in the methods.

Reply: This table also serves to show the sites in which we were less confident of a source of CH_4. The following explanation of how the sites were chosen can be added to the supplement:

"An outline of the sites sampled during this study are included in Table S1. Pingo 1, Lake 1, Wetland 2 and Wetland 3 were included in the main analysis despite low R^2 values. The Keeling plot intercept for Wetland 2 and Wetland 3 were low enough that even with a lower confidence in the signature we can still have confidence that it is within the range of biogenic values. Pingo 1 and Lake 1 were included because high CH_4 concentration samples clearly indicated a shift towards a thermogenic source despite the poor fit of the keeling plot. This adds confidence to the interpretation even with a low R^2 value. A few high concentration samples cannot verify the source signature it can indicate that the source has a signature that is higher (thermogenic) or lower (biogenic) that the atmospheric background value."

The site type "Polar V" can be changed to "Airborne EC"

Line 123: how did you determine where discrete point samples were collected? What was the strategy? Upwind, downwind, etc? This is a study location section, is this the best place for that information? I think you should be explicit that the strategy was to target the hot spots, and if you adopt a sample numbering scheme like numbering the hot spots, this strategy will be clear.

Reply: The following can be added to the end of the first paragraph in the sample collection section of the methods (3.2, line 165):

"Walking transect locations were selected by completing one transect up wind and one down wind of the estimated location of the highest flux concentration, in order to obtain background concentrations at each site. Discrete point samples were taken parallel to each walking transect, 3-5 m further away from the center of the hotspot. This sampling method was designed to cover the most area, with the fewest samples, in the shortest amount of time possible. By using this method we were still only able to cover a small fraction of the hotspot (5-10% by area), so samples were collected around potential sources of CH_4, such as pingos or wetlands. This increased the likelihood of pinpointing the source."

Line 125: Is "Lake 1" known as another lake by the community? Is that "shot hole" lake or Swiss cheese? And Channel Seep, is that channel seep 1? There could be reports that have some isotope data reported to help aid you in interpretations.

Reply: Lake 1 is locally known as Swiss Cheese Lake. The Geological Survey of Canada (GSC) has previously sampled Channel Seep but the results were not published. The results of the previous samples collected by the GSC can be added to section 5.2 of the discussion.

Line 126: the "observations of ebullitions seen in open water in summer", were those your observations made in this sampling trip or previous knowledge? Cite previous knowledge.

Reply: The following can be added to the second paragraph of the study location section: "Channel Seep and Lake 1 were previously known to researchers in the field party, holes in the ice were observed from the helicopter while passing over Pingo 3 and Wetland 1 sites during the fall."

Line 126: how close is "as close as possible" to observed ebullitions? Were you on land, upwind, downwind? How long were walking transects, 10m? This discussion in these 3 lines around 130 are more about sample collection. As such, they should be moved to that section of the paper.

Reply: The following can be added to the second paragraph in the sample collection section:

"Point samples at aquatic seep sites were taken as close as possible to observed ebullitions with additional samples taken up to 5 m away from known sources in order to measure source and background CH_4 concentrations. At Pingo 3 and Wetland 1 point samples were taken directly over holes in the ice by throwing a buoy with tubing attached to it onto the water in the open hole in the ice and using a pump to draw air through the tubing into a sample bag. At Lake 1 samples were collected from a boat and positioning the sample inlet directly above seeps. Channel Seep samples were collected by extending a pole with the sample inlet attached to the end out over the seep from the channel bank. All samples were taken from the air less than 10 cm from the seep with the exception of the channel seep sample which was approximately 2 m from the seep. Walking transects and discrete point samples were completed at Pingo 3 and Wetland 1 in the summer of 2021 to compare overall site variation to point source samples."

Lines 131-142: This paragraph seems more high level than where it is situated in the paper. I suggest reorganizing this study location section.

Reply: The Study Location section can be combined with the setting section.

Line 149: Are you missing the word "under"? Permafrost "under" Tuk.....

Reply: This can be edited to read "The permafrost of the Tuktoyaktuk Coastlands..."

Line 154: what is precision of handheld GPS and what model, make? What is the precision of the licor and the picarro CRDS? It's important to mention the cavity ring down spectrometer (CRDS) part of the instrument since that is how the measurement is made. And what standards were used to calibrate the concentration and isotope measurements? The placement of the analysis instruments seems out of place here since this is the sample collection section.

Reply: The section can be renamed "Sample Collection and Analysis

beginning of the section can be rewritten as follows:

"Geolocated air samples were collected in the field and subsequently analysed at the Aurora Research Institute laboratory in Inuvik, Northweset Territories, Canada or at St. Francis Xavier University in Antigonish, Nova Scotia, Canada. CH_4 and CO_2 concentrations and $\delta^{13}C\text{-}CH_4$ were determined using a Picarro G2210i analyser. The Picarro G2210i analyser is accurate to within 1 ‰ $\delta^{13}C\text{-}CH_4$, 0.001 ppm CH_4, and 1 ppm CO_2. All point samples were analyzed for at least 5 minutes and the values averaged, which increases the Picarro G2210i analyser accuracy to 0.1 ‰ $\delta^{13}C\text{-}CH_4$, 0.0001 ppm CH_4 and 0.01 ppm CO_2. Only point samples were used for the determination of $\delta^{13}C\text{-}CH_4$ source signatures. Sample positions were recorded with a Garmin eTrex 10 handheld GPS, which has an accuracy of +/- 3.65 m. Gas mixing ratios were standardized to Ameriflux FB04306 breathing grade air (benchmarked to 0.5 ppb)"

The following can also be added:

"The Li-Cor LI-7810 gas analyser has an accuracy of 0.25 ppb."

Line 156: Please cite the airborne work paper, since it was not done in this study.

Reply: Kohnert, 2017 will be cited here.

Line 158: "photographs of each site…." I think this should be moved to study location, and not sample collection. You are using the photographs to describe the sites, correct? If so, they really set the stage for the setting, which belongs elsewhere.

Reply: This sentence can be moved to the end of the second paragraph in the study location section.

Line 159: "walking transections…" what was pumping rate? What are dimensions of tubing? Is 6mm OD or ID?

Reply: The pumping rate was 20 standard cubic centimeters per minute. 6 mm was the outside diameter, it can be changed to the inside diameter of 4 mm in the text which is more relevant. This sentence can be changed to read as follows: " Walking transects were carried out by filling a 30 m coil of 4 mm inside diameter aluminium Synflex tubing at a constant rate of 20 standard cubic centimeters per minute while walking at a steady pace across the ground or by carrying a Li-Cor LI-7810 gas analyser."

Line 163: "Mixing between sample collection and analysis is limited due to small diameter of tubing". Have you proved that? Or is there a paper you can cite for this? The reason I ask is that the pumping rate is pretty fast, so I would imagine your sample will smear alone the edges of the tubing and mix along the way it's filling. Please give more details as to the accuracy of this approach.

Reply: The method used in this manuscript had been adapted from a study referenced on line 164 (Andersen et al., 2018). The original method used the same type and diameter tubing mounted on a drone and filled it at a similar flow rate (21.5 sccm). The main difference between the two methods is that the original study used an orifice to control the flow while this study used a flow controller. In addition, the authors of the current study tested the method in the lab by filling the lengths of tubing used during the fieldwork with concentrations of CH_4 interspersed with Nitrogen in concentrations between 2.5 ppm up to 10 ppm CH_4. The results showed that there was no distortion on filling the tubing but substantial mixing occurred after 24 hours. In order to prevent mixing during the fieldwork samples were analyzed immediately on return from the field site (within 8 hrs). A description of this experiment can be added to the supplemental methods.

Line 166: Why did you pick 1 meter above ground level? Did you ever try to go down to ground level? Did you see any change in the concentration? Or is 1m desirable because things are more mixed and you are trying not to see a ground signal? What is the thought behind this?

Reply: Because CH_4 source locations were unknown we sampled air at 1 m so that was adequately mixed but still practical to sample. Sampling closer to the ground would have allowed us to sample closer to potential sources but would have reduced our ability to sample sources that were further away from our sample location.

Line 171: Where are the flux chamber measurement data? Also, this section is confusing as written. It looks like 2 chambers were used, the automated one from licor, but I can't tell what was used for Lake 1, using manual extraction of samples. And the dimensions are for a flux chamber, but there is only one, yet it seems two chambers were used? Also, can you discuss how only allowing 1 hour between collars installed and measurement might change your results?

Reply: The soil disturbance caused by collar installation can create a flush of CO_2 (Bahn et al., 2010), therefore, CO_2 fluxes measured during this study may be slightly high because we were unable to wait the recommended 24 hours.

The flux chamber data and corresponding methods can be removed from the paper. Please see main comment 4 above.

Line 178: "Keeling plot analysis". I am not sure this is the right terminology. You analyzed keeling plots to determine the stable carbon isotope signature of the methane source. That phrase, keeling plot analysis, is used several times, so maybe it is the right term but it could be better to say "We constructed keeling plots with the discrete transect data to determine …." And also cite the "common approach" of using keeling plots. I agree that it is common, but I am not sure it is common to take discrete measurements in the horizontal direction versus the vertical direction. Meaning, I thought keeling plots were always done in the vertical collection of air in a forest canopy, for example. If that is not true, it's probably still making a note of this since it does seem a bit novel to use this technique for the walking transects. Or maybe there are papers to show this approach used in this way.

Reply: While the use of keeling plots is common, they are used with a variety of sampling techniques to identify temporal and spatial shifts in ^{13}C for CH_4 and CO_2. It may be more applicable here to say that they are broadly used and give some examples of similar uses. While this particular method may not be common, it would be a stretch to call it novel.

The first paragraph in section 3.3 could be changed to read:

"Keeling plots were constructed from the discrete point samples and used to determine the stable carbon isotope signature of the CH_4 source at each site. Keeling plots are broadly used to determine a source of carbon entering the atmosphere by measuring the change in $\delta^{13}C\text{-}CH_4$, or fractionation, that occurs as more carbon from that source is added (Kohler et al., 2006). The Keeling plot method has previously been used to measure spatial variation of $\delta^{13}C\text{-}CH_4$ in anthropogenic (Chamberlain et al., 2016; Zazzeri et al., 2015, 2017) and natural sources (Skorokhod et al., 2016)."

Line 193: Do you have the bubble isotope values from historical data by the GSC to compare to your point measurements?

Reply: Yes, we have access to unpublished data from the GSC for lake 1. The following can be added to section 5.2 in the discussion:

"Analyses of a seep gas samples from this lake carried out in 2008 yielded values of -290 ‰ $\delta D\text{-}CH_4$/ -45 ‰ $\delta^{13}C\text{-}CH_4$ and -230 ‰ $\delta D\text{-}CH_4$/ -37‰ $\delta^{13}C\text{-}CH_4$ (S.R. Dallimore, personal communication, January 12th, 2023) This is well within the thermogenic isotopic field as determined by Whiticar (1999)."

Line 197: Why is walking transect data shown as average data? The maximum value of 12ppm is very interesting and seems important to know where you were in comparison to the "wetland". Is it possible to do this from the GPS location data you obtained?

Reply: Yes, the raw data for the walking transects could be added to the supplement

Line 203: The sentence of "estimates of source…." Seems a bit premature. Since this is the methods section, could you first say that the keeling plots are shown in figure 3, and show intercepts of X, Y, Z, which indicate the source of the methane? And also give the R2 values? As it is now, you don't mention figure 3, so it's unclear where these numbers come from. The figure 3 caption mentions a "grey region" but there are no grey regions on the figures. And finally, there is a formatting issue with the equation written on the figures. It is also important to mention the cut off you used for the R2 values.

Reply: The sentence on line 203 could be changed to read: "Source stable carbon isotope signatures ($\delta^{13}C\text{-}CH_4$) were derived from Keeling plot Y intercept values (Figure 3) and were 53.0 ‰ for Pingo 1, -63.6 ‰ for Pingo 2, -78.4‰ for Wetland 2, and -71.9 ‰ for Wetland 3."

The plots will be updated with grey regions and the extra 'x' can be removed from the figure.

Line 208: "Keeling plot values" is not quite accurate. Maybe say "keeling plot y-intercepts". It's interesting the seasonal component of these values. Is seems reasonable to think that during the winter, there isn't as much methane oxidation, which leads to the lower values. I think you mention that in discussion.

Reply: Keeling plot values can be changed to "keeling plot y-intercepts."

Line 211: "Flux rates" isn't accurate. A flux is a concentration per area per time, a rate is distance per time. I think you just mean fluxes here. It also seems like the chamber fluxes are an afterthought since the fluxes aren't given here. And they are put in a supplemental table. Are they needed?

Reply: Flux rates can be changed to "fluxes". Please see main comment 4 above.

Lines 215-218: change "values" to "concentrations".

Reply: values can be changed to "concentrations"

Line 217: take out "were". What is an "observation" in this context? There wasn't mention of observations before now. Where does the 2013 number come from? Do you mean the discrete measurements? Same question for the 1850 observations at pingo 1. This section is a bit confusing since it's also written like results, but yet in the discussion section.

Reply:

The following sentence can be moved to the results section: “During the walking transects concentrations above 2.5 ppm were recorded for 1056 of 1850 measurements at Pingo 1 and for 285 of 2013 measurements at Pingo 2.”

The paragraph starting on line 215 can be rewritten to read:

“The highest CH_4 concentrations for walking transects co-located within airborne eddy covariance CH_4 hotspots were obtained in the north-western part of the outer MRD. The elevated values measured over a dispersed area within the eddy covariance hotspots provides a basis to speculate on the possible sources for the hotspots. Estimates of source stable carbon isotope signatures ($\delta^{13}C$-CH_4) derived from Keeling plots were -53.0 ‰ for Pingo 1 and -63.6 ‰ for Pingo 2 with reasonable confidence in these determinations as they were derived with multiple isotopic measurements for each Keeling plot. These signatures are substantially enriched in ^{13}C compared to typical biogenic sources and relatively close to our assumed threshold of -50 ‰ based on thermogenic gas found in the Taglu hydrocarbon reservoir. We conclude, therefore, a geologic source for the methane for each site is made up of a mixture of thermogenic and biogenic gas from depth, perhaps with a dominance of thermogenic methane. However, while elevated values for the walking transects were observed in close proximity to the pingo features, we note that for both sites the highest values were not on the features themselves, but a short distance away in the low lying shrub tundra terrain surrounding the pingos.”

Line 224: For the general reader, it might help to define geologic source in the introduction to put this conclusion in more context.

Reply: The following phrase can be added to line 26 of the introduction to define Thermogenic as used in this paper: “The area is characterized by thin and destabilizing permafrost (Burn & Kokelj, 2009), high organic content soils (Schuur et al., 2008), vast amounts of deep thermogenic methane, originating from fossil hydrocarbon reservoirs (Collett & Dallimore, 1999) and over 49,000 lakes…”.

This is the same definition used by Walter Anthony et al. (2012) .

Line 240: Can you give values for the pingo 1 and 2 site in the text? It would help the reader not have to flip back to the figures.

Reply: The values of -53.0 ‰ for Pingo 1 and -63.6 ‰ for Pingo 2 can be added to the text here.

Line 241: Is this new data? I didn’t see the reporting of the methane concentrations over the pingo features themselves. And this sentence is also a bit confusing as to what you

mean. Did you do 2 transects for Pingo 1? Seems like supplemental figure S2 (top right) could be helpful to show what you mean here. You could refer to that figure here, but that figure quality needs to be improved.

Reply: The sentence on line 241 can be rewritten to read: "A point of interest, however, is that the highest CH_4 concentrations at sites Pingo 1 and Pingo 2 were measured 200-400 m (Figure 2) away from the pingos and were only as high as 2.2 ppm directly over the pingos (Table S3)."

Figure S2 can be moved to the results section (now Figure 2) of the main paper and the images improved and the raw data from the walking transects has been added to the supplement (Table S3).

Line 243: Only wind speed is reported in table 1. Wind direction is also key that would be important to show in that table. Or did you always collect samples downwind? Do you see a correlation with wind speed? I would think that the higher the wind speed, the further away the source of that gas could be.

Reply: Samples were collected upwind and downwind of any features so that we would be certain to pick up background and peak concentrations if the feature were a source. Wind speed and direction is shown of Figure S2, which can be moved to the main manuscript. We have refrained from trying to make correlations with wind speed because we do not have high-rate wind measurements. The following sentence could be added to the sample collection section of the methods:

"If features that represented potential sources such as pingos or wetlands were present, than walking transects were taken upwind and downwind of the feature."

Paragraph starting at line 254: This is a great reason you chose to sample pingos. Could you move it to the introduction to help set up the "why" for your study? After reading the paper again, it seems you didn't set out to study pingos, per say, but you found those pingos at the ground features under the aerial hot spots. If you present these ground features as part of the results, I don't think you need to describe why you chose pingos to study, but instead, it will be clear why you sampled them.

Reply: This paragraph could be moved to the third paragraph in the introduction.

Line 262: "these sites had no obvious geologic…." What sites are being referred to here: wetland 1, 2 and 3? If so, is there a hot spot at wetland 1? It's not obvious on the map. And wetland 3 is very close to swiss cheese seeps, correct? Seems like a potential geologic source.

Reply: The sentence on line 262 can be removed.

There is a typo in line 261, three should be two, referring to Wetland 2 and Wetland 3 which are discussed in this paragraph. This has been corrected. Wetland 1 was not identified by the arial eddy covariance study, therefore it does not show up on the map in Figure 1.

Wetland 3 is indeed close (2.5 km) to Swiss Cheese Lake (Lake 1 in this study). This does show that there is potential for geologic sources in the area but not necessarily at the site. Permafrost conditions, for example, could be very different than Swiss Cheese Lake which is much deeper and more likely to have talik formation underneath which increases the likelihood of geologic sources at that site.

Line 268: Can you add in a sentence after "....Wetland 3."? Please consider adding in: "Our data is consistent with knowledge that wetlands produce significant methane from microbial degradation. This carbon is also probably recent in age versus geologic methane." And you can give some citations for that.

Reply: The following sentence can be added: "This is consistent with knowledge that wetlands can produce significant amounts of biogenic CH_4 (Andresen et al., 2017; McGuire et al., 2012; Wik et al., 2016)"

Line 269: For the lack of signal at site 9, were you downwind of the wetland?

Reply: Yes, the wind was very light, below 3.5 km/h and we sampled upwind and downwind of the wetland. The site was actually quite dry and the wetland had been reduced to a few metres across which would likely have reduced the emissions. Older satellite image shows a clearly larger wetland so the wetland was likely deeper in the past.

Line 273: Can you give reference for this?

Reply: Chanton et al. (2005) can be cited here.

Line 288: What is the evidence for thermogenic methane at this site? Is there any reason to think that the seep could be thermogenic? -53 from the keeling intercept still seems quite low for thermogenic. It just seems that this is most likely an oxidation signal. But as you say, it is still possible there could be thermogenic.

Reply: The authors may have understated the possibility of oxidation at this site during the summer to create the signature of – 53‰. The paragraph can be reworded as follows to better illustrate the two possibilities at this site:

Discrete sampling at Wetland 1 yielded $\delta^{13}C\text{-}CH_4$ Keeling plot source signature of -88.3 ‰ when sampled in October during freeze up and -53.4 ‰ during the summer. In simple terms, this suggests a biogenic source when sampled in October but a more complex scenario during the summer. While the sampling was carried out at the same location,

methane ebullition was seen while sampling during the fall, but not during the summer. Biogenic production can persist late into the cold season (Zona et al., 2016) so it is not surprising to see high-rate biogenic production during freeze up. The lack of ebullition flux at the same site during the summer and the different Keeling plot estimate suggest methane flux in this wetland setting varies seasonally. The Keeling plot source signature of -53.4 ‰ during the summer could be caused from either oxidation of a biogenic source or contributions of both biogenic and thermogenic sources. Seasonal shifts in lake-produced CH_4 stable carbon isotope signatures potentially due to oxidation are known to occur but are typically observed during winter beneath ice cover (Ettwig et al., 2016; Michmerhuizen et al., 1996), or the transition from the ice covered to open water periods in the spring (McIntosh Marcek et al., 2021). Similar observations for seasonal variability in terrestrial sources are not well documented in the literature, although the Wetland 1 site was dominated by sedge vegetation with areas of standing water and transport of CH_4 from anaerobic soils with sedge vegetation has been observed to bypass the aerobic zone, limiting oxidation during the growing season (King et al., 1998; Olefeldt et al., 2013). Therefore, it is possible that there were contributions to the atmosphere from biogenic and thermogenic sources at Wetland 1, but oxidation of biogenic CH_4 during the summer cannot be ruled out as the reason for the signature derived during the summer sampling.

Line 294: I believe the location of Lake 1 is the same as "swiss cheese" that has been visited by the GSC before. Are there reports that report the bubble signature isotope value? It might be informative in your discussion of your values.

Reply: Yes, it is the same location. We have access to data from the GSC from seep gas analysis at the lake that is not published. The following sentence can be added here.

"Analyses of a seep gas sample from this lake carried out in 2008 yielded values of -290 ‰ δD-CH_4/ -45 ‰ δ^{13}C-CH_4 and -230 ‰ δD-CH_4/ -37‰ δ^{13}C-CH_4 (S.R. Dallimore, personal communication, January 12th, 2023) This is well within the thermogenic isotopic field as determined by Whiticar (1999)."

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