Prof. Dr. Nicolas Brüggemann
Associate Editor
Biogeosciences

August 4, 2023

Dear Prof. Dr. Brüggemann,

Thank you for the constructive comments on our manuscript "Technical note: Skirt-chamber – An open dynamic method for the rapid and minimally-intrusive measurement of greenhouse gas emissions from peatlands" (BG-2023-37).

In the revised version, we have addressed all the comments and suggestions provided by you and the reviewers. This valuable input has significantly improved the overall quality of our work. We sincerely appreciate the time and effort you and the reviewers dedicated to our manuscript.

We hope the revised manuscript meets the standards for publication in *Biogeosciences*, and we extend our gratitude for your support throughout the process.

Sincerely yours,

Frédéric Thalasso
Armando Sepúlveda Jáuregui

Comments from the Editor, Dr. Nicolas Brüggemann

L100-126: Your mathematical approach only works correctly:
1. If there are (as you state in L119) stable environmental conditions, particularly regarding the wind speed. Your high variation of θC in the field (L231) indicates that you had quite variable wind conditions. Please discuss the impact of variable wind speed on your mathematical approach and the results obtained with it.

Our response: This is a fine observation, and we agree with it, although only partially. Indeed, our methodology does not require fixed C_B, C_C, and θ_C values. Fluctuations around a mean value are acceptable, as long as no significant trend or change over time occurs. However, we fully agree that this was missing in our previous version of the manuscript. Please note that the observed variations of θ_C (reported on L231) is over different days and over different terrains. To attend this comment, we made several modifications in our manuscript:

First, in the Material and Methods section, we added (L126): "In these mass balance equations, it is important to stress that, during field operation with varying wind speed and irradiance, it is not a strict requirement for C_B, C_C, and θ_C to remain absolutely stable or fixed.

Instead, they can fluctuate around a mean or average value as long as no significant trend or change over time is observed. Thus, it is crucial that each measurement step is sustained for several minutes to allow for the determination of mean values, as was done in the present work. More details and the step-by-step field methodology are described in section 2.3.".

Second, in the results and discussion section 3.2, we added (249): "Overall, θ_C was estimated at 30.74 ± 22.70 s during the entire field campaign. Reminding that $\theta_C = V_C/Q_L$, the equivalent gas flow rate exchange between the chamber and the environment (leak flowrate) was 0.67 ± 0.49 L s^{-1}. The variations in θ_C observed over the entire field campaign were likely influenced by weather conditions, particularly wind variations, as well as the variable ground surface with different plant covers and, consequently, different permeabilities (see Table S2).".

Then in section 3.6, we discuss the impact of external conditions on our measurements, as follows (L386): "First, the mass balance of the skirt-chamber (Section 2.1) is sensitive to varying wind speed and solar irradiance, affecting θ_C, C_B and C_C. To this regard, it should be noted that it is not a strict requirement for C_B, C_C, and θ_C to remain absolutely stable or fixed, as long as these parameters fluctuate around a mean value with no significant trend or change over time, and that each measurement step is sustained for several minutes. During our experiments, we conducted quadruplicate measurements of known CH_4 samples at six distinct concentrations (Figure 3), and the results indicated a mean CV of 7.1 ± 5.0%. This suggests that external conditions, not related to ecosystem emission variability, had a relatively limited impact on measurements. The validity of this finding was further confirmed through quintuplicate ecosystem flux measurements ($F_{CH4,2}$), which showed a CV of 10.3% at a relatively high emission hotspot and a CV of 74.6% at a relatively low emission spot. This indicates that the variation in parameters estimation was primarily due to fluctuations of ecosystem emissions, rather than changing environmental conditions. However, we acknowledge that varying environmental conditions might still have some impact, and we hypothesize that using a wind shield in close vicinity to the chamber might reduce the influence of wind gusts and to improve the accuracy of the method, which should be tested.".

Regarding a second comment from Dr. Brüggemann on the same "method validity":
2. If there is only negligible diffusion of your injected CH4 into the soil/peat. The fact that you get two different values for CB,CH4 might indicate that you have substantial diffusion of CH4 into the soil column and back diffusion during the subsequent measurement period. Please comment on that point.

Our answer: This is very important point, and indeed potential diffusion of injected CH_4 into the soil/peat is a key-point of method validity. To this regard, we do not believe this has a significant impact on our measurement, mostly because during testing with the injection of a known amount of CH_4, we recovered all the CH_4 injected. This was missing in our previous version of the manuscript, and we corrected this missing information, as follows (L262): "The results obtained are presented in Figure 3, showing that R^2 was 0.997 and the slope of the mass of CH_4 detected vs. the mass injected was 0.977. The equivalency between the mass of CH_4 injected and detected indicates, first, that the mass of CH_4 injected was recovered without being lost due to diffusion into the ground. Indeed, it is essential to note that the transitory and artificial increase of C_C after pulse injection, has the potential to modify the concentration gradient between the chamber and the soil, as previously suggested (Kutzbach et al., 2007; Juszczak, 2013), and to promote CH_4 diffusion from the chamber to the soil, leading to potential biases in θ_C determination. The consistency between the mass of CH_4 injected and detected also suggests that the mass balance of the skirt-chamber (Eq. 3) correctly describes the behavior of the skirt-chamber and that any amount of gas reaching the chamber is correctly accounted for, validating the method.

How often did you inject CH_4 to your chamber? Before each measurement? Please specify in the Materials + Methods section.

Our response: Thank you, this was explained in Section 2.3. However this should be made clearer. Thus, we modified two key sentences, as follows:

(L165) Each flux measurement involved a four steps protocol (Table 1).

(L171) Step 3, a pulse of 1 mL of standard CH_4 (99.99%, Linde, Chile) was injected once with a plastic syringe through a septum connected on the waste line of the UGGA (returning to the chamber).

L168: Measuring dark respiration immediately after a light or illuminated period might lead to overestimation of plant respiration due to the process of light-enhanced dark respiration of living plant tissue. Please take this into account for your respiration estimates.

Our response: Thank you for bringing this important point to our attention. We acknowledge that measuring dark respiration immediately after a period of illumination might lead to an overestimation of plant respiration due to the process of light-enhanced dark respiration (LEDR) in living plant tissues. This phenomenon has been well described in the literature. In our study, we adhered to a standard protocol for measuring dark respiration, ensuring our analysis was consistent with the methodology commonly employed in similar studies in peatland ecosystems. By limiting the dark periods to just 5 minutes, we aimed to reduce the potential influence of LEDR, a phenomenon that typically peaks between 10 to 20 minutes and is strongly influenced by light levels without a clear pattern. Nonetheless, we recognize that the possibility of LEDR affecting our respiration estimates exists, and isotopic measurement analysis must be considered in future developments to fully address this concern. In order to include this topic in our revised manuscript, we include the following:

(L426) "Fifth, in the literature, it is well documented that measuring dark respiration immediately after a period of illumination might lead to an overestimation of plant respiration due to the process of light-enhanced dark respiration (LEDR) in living plant tissues (Atkin et al., 2000; Barbour et al., 2007; Werner et al., 2011). In our study, we adhered to a standard protocol for measuring dark respiration in peatland ecosystems, aligning our analysis with the methodology commonly employed in similar studies (Shaver et al., 2007; Järveoja et al., 2018, 2020; Capooci and Vargas, 2022; Rankin et al., 2022; Virkkala et al., 2022; Ilyasov et al., 2023). By limiting the dark periods to just 5 minutes, we aimed to reduce the potential influence of LEDR, a phenomenon that typically peaks between 10 to 20 minutes (Barbour et al., 2007; Atkin et al., 2000) and is strongly influenced by light levels, without displaying a clear pattern (Barbour et al., 2007). Nevertheless, we recognize that the possibility of LEDR affecting our respiration estimates exists in our experimental approach, and as such, the results presented in this study should be considered with appropriate caveats. Despite these considerations, we believe that our discrete gas flux measurements effectively capture the spatial variability of peatland emissions across the microtopography, an issue of significant importance in these ecosystems as discussed by Capooci and Vargas (2022).".

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L155 + 168: Change "to measured" into "to measure".
L170: It should read CB,CH4,2 here.
L172: The last should also read CB,CH4,2 here.
L181: Write "concentration in the chamber".
L295: Write "Southern Patagonia".
L311: Write "in its present configuration".
L318: Wrong numbering of section, 3.5 occurs twice.
L331: Sentence starting with "Repeatability" is truncated. Formulate full sentence.

<u>Our response</u>: We are grateful for these detailed revisions. All these errors have been corrected. L331 (previous line numbering) has been changed to "Regarding repeatability, R_{CO2} was also evaluated with measurements at 16 locations divided in four transects of 3 m, on three occasions, i.e. 2 and 12 days after the first measurement (Table S1).

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<u>Comments Reviewer 1</u>

1. L32: In this comment, Reviewer 1 suggests we include more detailled information on CH_4 emissions.

<u>Our response</u>: We appreciate this observation and we enhanced this section as follows (L30): "At present, peatlands act globally as carbon sinks, sequestering 0.1 GtC y^{-1} (Frolking et al., 2011). "However, peatlands are also among the largest greenhouse gas emitters to the atmosphere (IPCC, 2021), including carbon dioxide (CO_2) as product of the ecosystem respiration and methane (CH_4) produced through anaerobic processes. Consequently, peatlands can behave as carbon sink or net sources through time at different time scales (e.g.,

diurnal, seasonal, decadal, millennial) and spatial scales (i.e., site, watershed, region) (Ding et al., 2004; Günther et al., 2014; Cobb et al., 2017; Swails et al., 2021)".

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2. Around L313-316, L319-322: Reviewer 1 has noted that these sections must clarify the gas exchange under these specific configurations (i.e. with a plastic cover that is not totally transparent and in presence of a dark screen).

Our response: Thank you for pointing that out. We modified L313-316 section as follows (L336): "These results provide strong evidence that the skirt-chamber, in its present configuration, inaccurately estimated the CO_2 exchange between the peatland and the atmosphere, primarily due to the highly fluctuating CO_2 concentrations combined with relatively low CO_2 emission/capture rates. Indeed, in contrast to $C_{B,CH4}$, $C_{B,CO2}$ exhibited high dependence on solar irradiance, which was rapidly changing during the field campaign. Therefore, our first suggestion would be to deploy the chamber under more stable irradiance conditions possible. Furthermore, the skirt-chamber tested utilized a transparent plastic film over a basket made of sparsely interwoven steel wires, resulting in limited light penetration to the ground, estimated at 54 ± 8%. Hence, our second suggestion would be to optimize incoming irradiance to better mimic the actual conditions existing in the field. This could be achieved through a more transparent chamber design, ensuring that the photosynthetic activity within the chamber closely approximates the conditions that the plants would experience under natural conditions, without a chamber.".

The second section (L319-322) was changed as follows (L347); "As illustrated on Figure 2, when covering the skirt-chamber with a dark screen, i.e. when photosynthetic activity was inhibited, an increase of the CO_2 concentration within the skirt-chamber was standardly observed, reaching a new steady state at $C_{D,CO2}$, corresponding to the ecosystem respiration.".

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3. Around L359-360: Reviewer 1´s note implies the necessity to compare the skirt-chamber and standard static chamber in our concluding remark.

Our response: We agree with this comment, and we modified this section, as follows (L438): "Compared to standard chambers, i.e. non-steady-state chambers (closed systems) that are inserted/embedded into the ground with a collar, the skirt-chamber offers several key advantages. These include minimal soil disturbance, a smaller chamber size, and the absence of a collar, which allow rapid measurements in multiple locations, thus enabling improved spatial resolution, as well as improved portability, making it advantageous for fieldwork in remote locations. Furthermore, the design of the skirt-chamber may help regulate the temperature increase within the chamber, thanks to constant gas exchange with the exterior that reduces heat accumulation. Contrastingly, standard chambers, and in particular automatic chambers, offer an incomparable temporal resolution, with minimal field workload. Thus, we conclude that the skirt-chamber concept is a new alternative tool, with specific advantages, that could be advantageously combined with the existing methods, to improve our understanding of greenhouse gas emissions and of the factors controlling them in peatlands".

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Comments Reviewer 2

1. On the line 138 it is stated that "The peatland was not flooded but the water table was close to the surface, i.e. 0.1−0.6 m." Did you measure the water table at/next to each measurement point or how was the water table measured? The studied peatland seems not to be relatively wet as the highest water table measured is around -10 cm. However, the campaign was conducted at the end of the summer, which I assume can be drier compared to spring and autumn. Is there a lot of seasonal variation in the water table? I am wondering about this because one of the greatest advantages of the skirt-chamber is that it can be used without collars in remote areas. However, there can be both high spatial and temporal variation in water tables in peatlands. It this study, skirt-chamber was tested only on non-flooded conditions. How do you think the skirt-chamber would perform on wet surfaces and would it affect the measurements somehow?

Our response: This comment is important, as it highlights the relevance of the water table as a dominant factor in the greenhouse gas dynamics in peatlands. In our study, we manually measured the water table using a groundwater monitoring well, which consisted of a plastic 2-inch perforated tube. This tube was strategically installed two days before our measurements, in the proximity of our measurement locations. The relative height of each measurement point to the water table was determined using a water level hose.

We tested the skirt-chamber in March 2022, during which precipitations are usually higher than the other months of the year. The peatland, where our research was conducted, was equipped with eight piezometer probes, installed since April 2022. These probes showed moderate variation and, so far, we have not found flooded areas. Regarding the potential of the skirt-chamber to be used on flooded area, we did not test that approach, but we do not anticipate any potential issues.

To attend these comments, we included three amendments to our manuscript:

1. We incorporated in the Material and Methods Section a description of the methodology used for the water table measurements, as follows (L143): "The peatland was not flooded but the water table was close to the surface, *i.e.* 0.1−0.6 m. The water table depth was manually measured using a groundwater monitoring well, which consisted of a plastic 2-inch perforated tubing installed two days before our measurements, in close proximity to our measurement site. The height of each measurement point, relative to the water table, was determined using a water level hose.".

2. We included a brief discussion on the possible application of the skirt-chamber in flooded areas, as follows (L409): "Third, in this study, we exclusively tested the chamber under non-

flooded conditions. However, it is expected that the chamber would function effectively when used in flooded areas, where a water layer would provide a seal between the chamber and the ground. In such cases, the chamber would likely operate similarly to a standard closed chamber without any leakage, which could be confirmed through pulse injection. However, the latter should be experimentally tested.”.

3. We included a climatogram (Figure S2) in supplementary material, showing moderate variations in precipitation as well as temperature changes over seasons, indicated as follows (L146): “The campaign took place on March 3−24, 2022, which corresponds to the end of summer season and to a month with relatively warm temperatures and high precipitation levels (Figure S2). To minimize the impact of operators on the peatland superficial structure, operators were using snowshoes and each measurement spot was marked prior to measurements, with a plastic ring of the same size than the chamber, to avoid stepping over the location.”.

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2. Related to my first comment, I am curios whether you observed any ebullition during your measurements and needed to discard some of them because of it? Ebullition can happen anywhere in a peatland but is more common on wet surfaces. In the studied peatland it is said to also be bare peat without a living Sphagnum moss cover in some locations. In my experience, these kinds of bare peat surfaces characteristic to some bogs can be very wet and challenging to measure because of ebullition. Did you measure any bare peat locations? I like that you paid attention to only causing minimal disturbance for the peatland (snowshoes, marking the measurement spots beforehand), but as there were no boardwalks in the studied area, it is always possible to cause some disturbance and trigger ebullition when stepping close to the measurement spot for closing the chamber etc. Please, add a note to the manuscript about how many measurements (if any) were discarded because of some disturbance.

Our response: This is also a very important comment. We were expecting “ebullition like” events in our study, but we did not observe any clear event of that nature. We agree with the Reviewer 2 hypothesis that this could be attributed to measurements only under non-flooded conditions. We included a short discussion on that point, as follows (L413): “Fourth, another feature of the skirt-chamber is that it does not allow for the segregation of diffusive and ebullitive fluxes, well-documented in the literature (Baird et al., 2009). During our measurements, we did not observe sudden peak increases in CH_4 or CO_2 concentrations, which would be expected if bubbles were reaching the surface. Rather than dismissing ebullition, we hypothesize that this absence of peak concentrations was due to the measurements being conducted under non-flooded conditions. In such conditions, any bubbles reaching the acrotelm of the peatland would probably diffuse at a moderate rate through the organic material layer instead of being suddenly released to the gas phase. In this study, emissions were measured based on mean CH_4/CO_2 concentrations during steady states, which encompassed some variations potentially associated with ebullition or other temporal effects. Therefore, the results obtained with the skirt-chamber reflect total emissions, and an alternative strategy should be employed to separate ebullitive fluxes.”.

3. On the line 85 it is said that you measured the CO_2 and CH_4 fluxes "…at different vegetation covers and terrain.". How did the measurement locations differ in their vegetation? Did you conduct any vegetation measurements, such as cover estimation per species, for each spot? If so, could you add this information in the supplementary material?

Our response: Certainly, this is a nice add-on. We included a short methodology on that point, as follows (L190): "At the end of each measurement, before removing the chamber, plastic rulers were placed around the base of the chamber to mark the covered area. A photograph was taken and used to identify the extent of the area covered by the major plant species where fluxes were measured. These scaled photographs were analyzed using the Fiji software (Schindelin et al., 2012). The cover percentage of each individual species or group of species was determined using the freehand selection tool.".

Additionally, we included the vegetation cover, in an additional Table S2 (similar to Tables 2 and S1). This Table S2 gives the percentage of the vegetation cover, for seven classes observed; (i) *Sphagnum magellanicum*; (ii) Ericaceae species (*Empetrum rubrum* and *Gaultheria pumila*); (iii) *Tetroncium magellanicum*; (iv) *Nothofagus antarctica*; (v) *Polytrichum spp*.; (vi) Lichens (*Cladonia arbuscula* and *Coelopogon epiphorellus*); (vii) exposed peat surface.

4. How much did the temperature inside the chamber increase during measurements? On the line 147 it is said that there was light/temperature data logger inside the chamber, but you do not present or discuss the temperature in any way. A transparent light chamber, such as the skirt-chamber, acts easily as a little greenhouse, especially when the weather is sunny. In my experience, temperature inside the chamber can increase several degrees in sunny conditions already during a short chamber closure (2-4 minutes) when measuring with the static chamber method, and thus I have used a cooling system in my static chamber measurements when needed to keep the temperature in the chamber as close to the ambient temperature as possible. As the skirt-chamber does not have a cooling system and the total chamber closure is relatively long (15-17 minutes), 10-12 minutes of which in light conditions, it can potentially result in significant temperature rise and moisture condensation in the chamber, which alter the conditions during a measurement. Temperature affects the activity of both CH4 producing and consuming microbes, photosynthesis and respiration rates of plants, evapotranspiration, solubility of the gases, etc. Therefore, it is important to take temperature into account in flux calculations based on the static chamber measurements. In your flux calculations based on the open dynamic skirt-chamber temperature is not included. Could you elaborate on that? Please, also add information about the temperature inside the chamber in the supplementary material if possible.

Our response: We agree that this discussion is important and regret its omission from our previous manuscript version. This omission was corrected with a new description in the

Results and discussion section, as follows (L398): "Second, during chamber deployment, we typically observed moderate temperature increases, as exemplified in Figure S3, ranging from 0 to 4.25 °C with a mean of 0.83 ± 1.30 °C above the ambient air temperature, over the chamber deployment time. The slope of the temperature increase ranged from 0 to 0.63 °C min^{-1}, with a mean of 0.09 ± 0.15 °C min^{-1}. This temperature increase was positively correlated with sun irradiance, with a Pearson correlation factor of $r(130) = 0.712$ ($p < 0.05$). The correlation between the temperature change rate ($dT\ dt^{-1}$) and sun irradiance (I) was described by the equation $dT/dt = -0.178 + 2.54 \times 10^{-5}\ I$. In some cases, a decrease in temperature was observed, associated with a sudden decrease in sun irradiance, and this cooling effect was systematically observed after the dark screen was placed on the chamber for respiration measurement (step 4). We attribute the relatively moderate temperature increases to two main factors. First, as a characteristic of the skirt-chamber, there is a constant gas exchange with the exterior, thus reducing heat accumulation within the chamber that would be observed in a closed chamber. Second, the light intensity was moderated due to the relatively low latitude of the Navarino Island (54.9396°S) and the lack of transparency of the chamber (as discussed in Section 3.4).".

This discussion was also complemented with a new Figure S3:

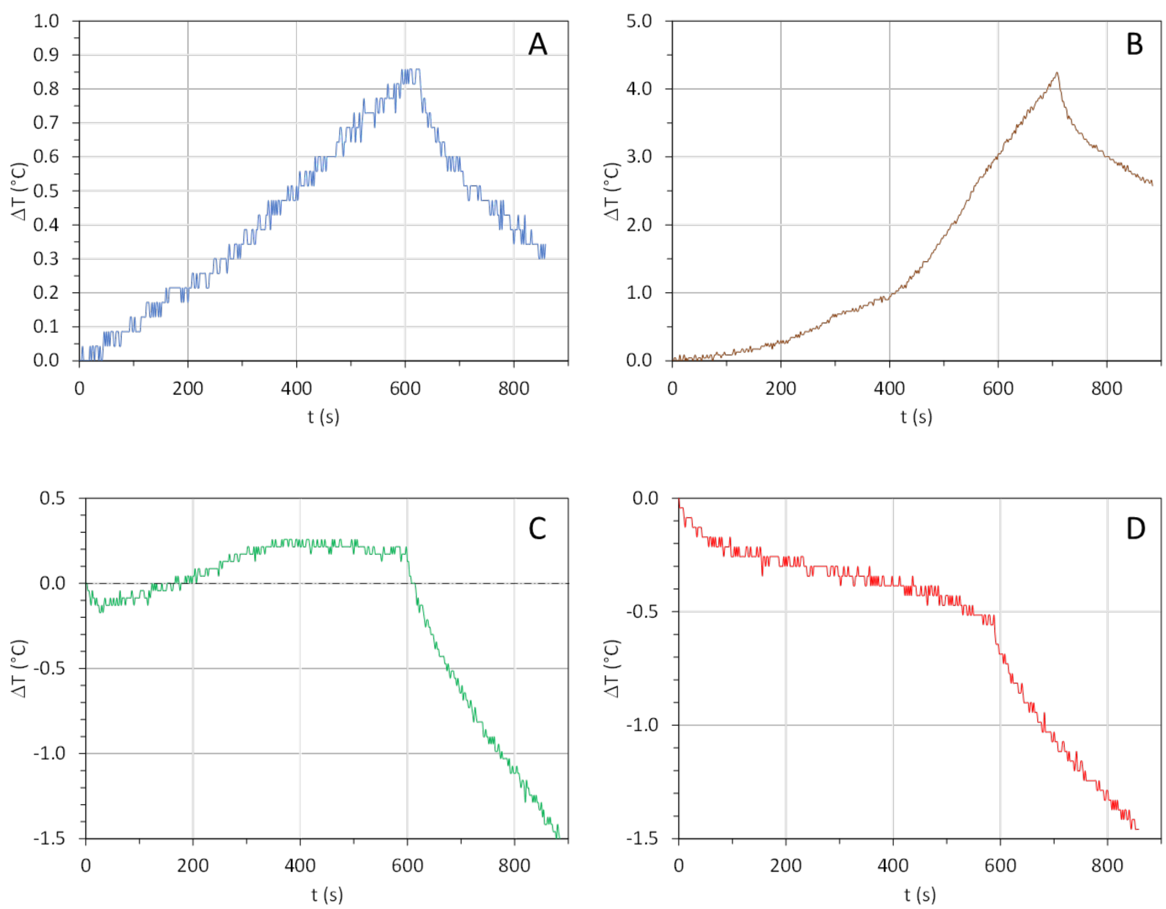

Figure S3: Examples of temperature behavior observed within the chamber during its deployment. The observed decrease at $t > 600$ s corresponds to Step 4 (dark screen deployment).

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