General comments

The authors Aurich et al. present a new design to measure vertically CO_2 concentration (or pCO2) in lakes. The authors present a smart idea which addresses a critical issue in understanding CO2 gradients in near-surface layers of water bodies.

Response: Dear Reviewer, thank you for reading and commenting on our manuscript. We appreciate your thoughtful and constructive feedback. As your general comments already raise several specific points, we have addressed them individually below. We believe that incorporating your suggestions and discussing the raised concerns has improved the manuscript.

However, I have some concerns with the design and practical use. For example, the authors claim in the text (line 69), that manual sample disturb the layer being sampled. However, the FME floating would also induce artificial disturbance in the upper 3 cm layer being sampled. I think that is not something which can be totally avoided, but needs to be addressed.

Response: Thank you for the comment. Avoiding turbulence is a very important factor in this entire study. We agree that deploying the FME does have an influence on the turbulence regime at the water surface, since it is physically present. Some degree of disturbance is unavoidable, but we consider it minor under the conditions investigated.

However, in the situations we investigated, the FME was floating without visible movement and did not introduce visible turbulence. We assume, that turbulence at the surface may be slightly altered, but not significantly under situations of minimum turbulence. But, even if the FME introduces or alters turbulence to the top 3 cm, the benefit of measuring CO_2 concentrations at this depth and temporal frequency likely outweighs any small error introduced.

We also think that if the FME would introduce bias, the it would likely result in a negative error. Since more turbulence would destroy/decrease the concentration gradient. Therefore one would still underestimate the CO_2 concentrations.

The fact that FME can only be deployed at very calm conditions – as silicone tubes may get in contact with atmospheric CO2 – raise the question on how practical the technique is?

Response: The FME is designed to be used in calm conditions, where reduced turbulence makes it difficult to measure representative CO_2 concentration by using conventional probes. The less calm the conditions become, the more mixed the water becomes, allowing the use of conventional probes less close to the water surface. The technique is therefore most practical for this use case.

What the good depth without running into the risk to “contaminate” data with atmospheric CO2?

Response: Adjusting to a good depth and making sure to avoid atmospheric contamination was an important part of the test. During setup, the FME was adjusted carefully to a position just below the water surface, while visually confirming that no part of the tubes touched out of the water. The deployment depth was then measured. Under the conditions investigated, the typical sampling depth was approximately 1cm. This procedure minimized the risk of atmospheric contamination. We recommend this procedure to the users too, and will add it to the manuscript.

A more sophisticated design with adjustable depth deployment, pressure sensor and multiple FME (rather than two depths) is actually needed. The design presented here is rather simplified.

Response: The depth adjustment is already possible in the current setup. We will clarify this in the methods section.

We agree that further additions, such as pressure sensors, temperature probes, or additional simultaneous measurement depths may be valuable upgrades in future deployments. However, the aim of this study was to develop and validate a simple, robust and easy to deploy device for resolving near-surface CO_2 gradients at high temporal resolution.

Details

The authors did the experiments using CO2-supersaturated water (950 and 3000 ppm, and I am wondering how the FME performs under more natural saturation levels (~ 380-480 ppm)?

Response: Thank you for the comment. We presented tests in elevated concentration levels, because these were the conditions that we observed in-situ in a previous publication (Aurich et al. 2025). The purpose of the experiment was to show the ability of the FME to resolve concentration differences in close vertical proximity (only ~25cm distance). In typical field deployments, this distance would be considered neglectable. The experimental design of filling with supersaturated water and letting the CO_2 gas out was a practical decision, with high probability of successesfull formation of concentration differences.

Further, to show that the working principal of the FME works, a large and easily to detect difference was helpful. We could also be sure that concentration differences - measured with the FME - between the two depths were actual differences, without running into the danger of sensor inaccuracies being possibly larger than the concentration differences.

Line 44: Some of the literature refers to estimating k over the ocean. I suggest to explicitly say so, and make clear which ones refer to lake studies

Response: We will clarify that in the manuscript.

Line 61: remove comma after reference

Response: The comma was removed.

Line 65: Please re-phrase “safe depth”

Response: We agree that “safe” was not the very clear. We decided to replace it by the word “representative”, after also discussing “appropriate” and “optimal”.

Line 84: replace by “calm surface conditions in lakes”

Response: We replaced it.

Line 108: Provide more detaisl on the NIR analyzer in terms of performance (accuracy, calibration setup….)

Response: We will revise the description of the instruments used and add calibration data and accuracies measured before the experiments.

Line 139: How was the AMT standard probe was calibrated, and what is a typical accuracy?

Response: This is an important point that was not described sufficiently in the original manuscript. We have now added information on the calibration procedure of the AMT standard probe and its typical measurement accuracy to the revised manuscript. The probe was calibrated according to the manufacturer's instructions. According to the manufacturer, the measurement accuracy is ±0.06 mg L^{-1} CO_2 in the range 0–5 mg L^{-1} CO_2 and ±2% of the measured value in the range 5–8 mg L^{-1} CO_2.

Line 145: How did the authors ensure that the aquarium pumps efficiently avoided the buildup of a gradient for the calculation of the error between both FME?

Response: The pumps were installed in two places of the pool, facing with the outlet upward. This created a visible overturn. The pumps had a combined pumping volume of 600 L/h, and we could see the concentrations of the two depths converge rapidly (figure 5).

Line 149: Authors refer to the "same depths", which strictly speaking was not the case as indicated in the following sentence by writing "proximity".

Response: The exact same depth was not possible to achieve in that experiment. Due to the size of the pool, we installed one FME on the other. Therefore, they were measuring within the same centimeter range. We will replace "close proximity" to avoid confusion.

Figure 3A: I do not understand why a concentration of 950 ppm was measured as in the method section a concentration of 3000 ppm was referred to. The authors should also explain how the access the "true" CO2 concentrations as reference values. I assume that pool of water was outgassed "naturally", but a reference value would be beneficial to assess the "sampling efficiency".

Response: We understand the confusion. The data for plot A in figure 3 was measured when the CO_2 degassed from the pool overnight, after the initial filling. Before this, we we were checking the setup and equipment. After those measurements, we emptied and refilled the pool to measure the data for plot B in figure 3.

Figure 4b: Is the steep increase at 2cm between 6:00 and 9:00 real or artifact from pressure buildup? There seems to be also small increase by switching from 29 to 2cm, at the each beginning of the black line sections.

Response: The small increases occur due to the pressure in the system during switching. Since we used a closed loop system with only one analyzer, every switch meant closing the loop for the analyzer for a second. This caused the pump to build up pressure, which caused those noisy measurements.

Figure 5: It would help readers to indicate in the plot when the aquarium pumps were turned on.

Response: It is highlighted by the dashed vertical line in the graph.

Line 180: Authors refer to a standard CO2 probe shown in Figure 2B, but that is not visible or clearly indicated.

Response: We will add rectangles to the figure to increase visibility of the features shown.

Line 182: equilibrated faster to the in-situ concentration than what?

Response: Faster than the standard CO_2 probe (AMT probe). We added it to the text.

Figure 6. The authors should show data from FME at 25cm depth to compared with the standard CO2 probe.

Response: We will perform an additional pool experiment with the FME and the AMT probe at same depth. We will measure the CO_2 concentrations at equilibrium with the air and verify measurements by taking samples to be analyzed using a gas chromatograph. Data derived from this experiment will be added to a revised version of the manuscript.

Line 194: Use the acronym FME

Response: We changed it in the text.

Line 194; Measuring at two depths cannot be referred to as "high vertical resolution". The paper represents two points with depth only.

Response: Thank you for your comment. The phrase "high vertical resolution" refers to the thin layer that can be sampled using the FME.

Line 196: Replace "saw" with "observe"

Response: We changed it in the text.

Line 205: Optical observation seems to be critical, but not described in the method section. What means "wavy conditions"? Presence of capillary waves?

Response: Thank you for pointing this out. Optical observation ("watching") the FME played a crucial role in the design process and testing. We will add it to the methods section of the manuscript.

Line 210: I believe that the chamber technique quantifies the water-air flux, not the surface concentration. Please verify and correct if necessary

Response: The floating chambers can be installed without continuous air-flow. After a long equilibration time, the chambers gas volume is equilibrated with the surface microlayer. One can then sample the gas in the chamber. However, this method is very slow.

Line 221: The authors compare FME at 2cm with CO2 probe at 25 cm in terms of signals from the rain events. That is inappropriate because the impact on rain is highest at the surface – for obvious reason – and decrease with depth. I would not expect rain effects at 25 cm, but for a full assessment data on wind speed would be helpful.

Response: We agree that effects observed in 25 cm are expected to be low. However, throughout our manuscript we establish that 25 cm (or even deeper) is a common depth to measure CO_2 concentrations, from which fluxes are calculated. Installing conventional probes close to the surface would come with both the risk of contamination with atmospheric air and a larger diameter, limiting vertical resolution. The point in showing this result is to demonstrate a practical use-case in a field deployment, not to compare the two probes.

Line 228: See previous comment. Comparison between FME and standard CO2 probe should be done only at the same depth.

Response: Please see our response to the previous comment, where this point is addressed.

Line 231: How fast? This should be given with a quantity.

Response: Thank you for pointing this out. We will add this information to the results section (line 170).

Line 251; Have water traps being used in this study? If not, why? I also feel that deployments only at very calm conditions is a strong limitations, as CO2 gradients will change with increased wind-driven turbulence.

Response: We have not used water traps, because we tried to make the air-flow as smooth as possible. The air pump installed in the CO_2 analyzer (EGM-5, PP-systems) is very small. We were afraid of causing unnecessary wear to it. Further, our deployments were usually between 1 and 3 days, and we observed water in the tubes with a lot of care to avoid instrument damage.

We deployed the FME in calm conditions, because we found concentration differences of CO_2 only in such conditions in our previous publication (Aurich et al. 2025). As a consequence of this study we designed and built the FME. The FME is specifically built to study CO_2 concentrations at the water surface, when measurements in the underlying water are very likely to be different (such as in calm conditions). The point of the paper now, is to present a proof of concept under lab conditions and field conditions. Further, since the FME is designed for calm conditions, there is only little need to make it work in conditions of higher turbulence, because conventional probes are suitable for that already.