

***Interactive comment on* “Technical Note: Cost-efficient approaches to measure carbon dioxide (CO₂) fluxes and concentrations in terrestrial and aquatic environments using mini loggers” by D. Bastviken et al.**

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Review of the technical note “Cost-efficient approaches to measure carbon dioxide (CO₂) fluxes and concentrations in terrestrial and aquatic environments using mini loggers” by David Bastviken et al.

This paper reports some tests of methods for in situ measurements of CO₂ fluxes (FCO₂, fig. 3) from lakes and soils, and CO₂ partial pressure (pCO₂) in lake and stream waters (figs. 4-6). Such technical note is potentially of great interest for the

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scientific community, because few reliable data are available in order to adequately integrated CO₂ fluxes from continental waters (and some coastal waters as well), where spatial and temporal variability is very important. Consequently, new and cheap methods are potentially welcome. In the title and abstract, the authors stress that the originality of their approach is the use of small and cheap CO₂ “mini-loggers”, which cost 1-20% of classical research gas analysers. Indeed, the low cost has the great advantage to allow multiple in situ deployments and, thus, to investigate spatial and temporal variability of FCO₂ and pCO₂. However, major originality of the paper is not only in the use of these mini-loggers, but in their coupling with what can be called a “chamber-equilibrator” or “in situ headspace” to measure water pCO₂. The real significant technical advance I see here consists in installing these cheap mini-loggers inside floating chambers that are deployed for a long time and at various locations in aquatic systems, so the air in the chamber fully equilibrates in CO₂ with the underlying water, and thus the sensor records continuously the surface water pCO₂. This technique has great advantage compared to what has been done previously for measuring water pCO₂: (1) the sensor provides accurate pCO₂ values in a range commonly found in freshwaters (although some additional tests could be necessary at very low pCO₂ in some aquatic systems); (2) a low cost, so one can obtain concomitant pCO₂ data at different locations; and (3) low energy consumption (no need for an air pump and/or a water pump as in classical equilibrators) which allows long term deployments. I believe that if this pCO₂ method can be fully validated (and it is not totally the case here, see comments below), it would constitute a real great technical advance.

Although I am enthusiastic with the pCO₂ method, which I find promising, I consider that the FCO₂ methods, as tested and presented here, have little interest for a technical note, even considering the low cost of the sensors. Indeed, as far as the reliability of the mini-logger has been checked by comparing with research gas analyser (Fig.2), the fact that it gives consistent results with GC-CO₂ derived fluxes in soil chambers (Fig 3C) is trivial because these measurements are short. Under outdoor conditions, drift of the sensors might be different from that under indoor conditions. In fact, what

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would be more important to test are the long-term (weeks, months) stability of the CO₂ mini-logger signal inside a soil chamber, and how these cheap soil chambers compare with commercial soil chambers on the long term. (Energy is not necessarily a crucial criteria in terrestrial systems). Automated soil chamber systems (LiCOR[®] for instance http://www.licor.com/env/products/soil_flux/multiplexed.html that allows connecting up to 16 chambers to a single gas analyser) are indeed expensive. However, they are automated, and the majority of their cost is not due to the gas analyser itself, but to the system that lifts the different bells, that commands the valves and the pump circulating the air, etc. An objective comparison of soil FCO₂ measurements would consist in placing the mini-loggers inside each bell of such soil CO₂ chamber system during a long period. It is not sure that on the long term, 16 cheap mini-loggers would beat one very stable research IRGA connected to 16 chambers, even including the criterion of the cost. To that respect, the authors statement in their abstract "Results from all these examples indicate that this approach can provide a cost- and labor efficient alternative for direct measurements and monitoring of CO₂ flux and pCO_{2aq} in terrestrial and aquatic environments" is not based on sufficient objective experimental facts, at least for terrestrial environments.

Concerning FCO₂ from aquatic systems, the problem is that, whatever the sensor used for CO₂ detection, chamber fluxes are potentially biased under some environmental and experimental conditions. Indeed, chambers may greatly alter the turbulence at the aquatic boundary layer and modify the CO₂ flux, either increasing or decreasing the k value. There is now an abundant literature that reports FCO₂ values derived from chambers and that discuss the validity of the method. Today there is no real consensus on how and where floating chambers can provide reasonable CO₂ fluxes data. There is little comparison with non-intrusive techniques and, depending on the environmental conditions (wind, current, heat, rain, and even phytoplankton biomass whose activity might be affected by the chamber's shadow, etc., etc.) and the experimental conditions (for instance drifting or not) comparisons reach different conclusions. I will not review

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here all the potential bias of floating chambers, which are multiple. However, in their MS, the authors have not even mentioned the occurrence of these biases, which might be problematic for a technical note: with this MS, inexperienced readers might consider the floating chamber as a reference method for CO₂ flux measurements. This is definitively not the case, whatever the CO₂ sensor used and its cost. Because chamber FCO₂ is affected by a large panel of drivers, and is potentially affected by biases, which also depend on these drivers, it is probably more relevant to put efforts in constructing a large database of water pCO₂, rather than a large database of chamber FCO₂ with little or no possibility of quality check. Water pCO₂ can then be used to compute the flux using calculated k and if some new insights rise on k parameterization, fluxes can still be corrected based on high quality pCO₂ data. In addition, as the authors state, floating chambers must be deployed during short periods (30 minutes in their case), otherwise the air becomes saturated in CO₂ and the signal becomes an equilibration time-course (Fig. 3B). Chambers cannot provide FCO₂ temporal variations in an autonomous way, except if, as the case for the soil chambers, they are equipped with a system that regularly lifts them automatically. The maximum number of CO₂ flux obtained here was two per day with each chamber, one in the morning and one in the evening. This limits the interest in multiplying the number of floating chambers for FCO₂, as a manual operation still remains necessary after 30 minutes. It was not tested in the study how many chambers can be deployed in a lake of a given size (thanks to the cheap sensors) and how many additional data they provide compared to a single chamber deployed manually during 30 minutes at different places one after the other.

As I said in my introduction, the equilibration chamber has a real potential of application for continuous pCO₂ measurements in aquatic systems. Data presented in Figs4-6 are indeed quiet encouraging. However, the method has not been fully validated here and some additional tests are necessary. First, the paper does not provide a comparison of absolute pCO₂ values obtained with this method with those obtained with classical methods (headspace, syringes, equilibrator. . .). Some qualitative statements are given

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P2371-L3-5 but do not rely on experimental data. Second, more information is needed on the equilibration time of the system, in relation with the rapid temporal changes of pCO₂ in the studied ecosystems. As mentioned in the paper, equilibration is faster when turbulence at the water surface inside the chamber is high, thus it is faster in streams than in lakes. In the wetland pond (Fig5), as well as in the lake (Fig4) some diurnal variations appear, however, the authors mention that at this time scale, the equilibration is probably incomplete. Again, the discussion on equilibration time (P2369 L8_15) is only verbal and not based on quantitative experimental data. One would expect more precision from a technical note, assessing for instance the equilibration time in a lake as a function of wind speed. A statement like “Thus the pCO_{2aq} values should be seen as a moving average” must be supported by objective facts (comparing for instance with daily average using a reference technique). If for instance, wind speed follows a significant diurnal trend, as the case for example in the tropics with stronger wind at daytime, equilibration might be more delayed at nighttime than at daytime, and daily average pCO₂ might be underestimated. Such bias is probably significant in some conditions but not in others. This deserves a precise investigation.

The statement “Over time moisture seemed to accumulate in the sensor protection box and consequently unrealistic high peaks caused by water condensation inside the measurement cell, often reaching the maximum value (10 000 ppm; Fig. 5a), were noted more frequently with time.” seems contradictory with that one “The combined influence of temperature and humidity was found to be small, causing an error < 7.6 % (see Supplement)”. The authors also mention respiration of insects or frogs inside the bells: can these animals release such quantity of CO₂ so fast?

As a final comment, I think a more exhaustive survey of the literature can inspire the authors on how to improve this technical note. For instance very precise protocols for measuring response time of equilibrators systems are described in : Frankignoulle, M., Borges, A. & Biondo, R. A new design of equilibrator to monitor carbon dioxide in highly dynamic and turbid environments. *Water Res.* 35, 1344–1347 (2001) and in :

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Santos, I. R., Maher, D. T. & Eyre, B. D. Coupling automated radon and carbon dioxide measurements in coastal waters. *Environ. Sci. Technol.* 46, 7685–7691 (2012).

High resolution automated pCO₂ measurements in rivers, streams and riparian ground water (including diurnal variations) using new promising approaches are shown in : Lynch, J.K., Beatty, C.M., Seidel, M.P., Jungst, L.J. and M.D. DeGrandpre. (2010). Controls of riverine CO₂ over an annual cycle determined using direct, high temporal resolution pCO₂ measurements, *J. Geophys. Res.- Biogeosciences*, 115, G03016, doi:10.1029/2009JG001132 and in : H Peter, GA Singer, C Preiler, P Chiffard, G Steniczka, TJ Battin Scales and drivers of temporal pCO₂ dynamics in an Alpine stream *Journal of Geophysical Research: Biogeosciences* 119 (6), 1078-1091 These studies report some troubleshooting during their measurements and discuss their origin. This information is useful for comparison with the technique proposed here.

End of review

Interactive comment on *Biogeosciences Discuss.*, 12, 2357, 2015.

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