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Interactive comment on "Automatic high-frequency measurements of full soil greenhouse gas fluxes in a tropical forest" *by* Elodie Alice Courtois et al.

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The authors measured in situ soil fluxes of CO2, CH4 and N2O continuously with a commercially available automated chamber system coupled with a CRDS analyser in a tropical forest for four months. The manuscript is focused entirely on the methodological aspect of these measurements, stressing the importance of adjusting chamber closure times for the different gases for reliable flux calculations. The effect of closure times on flux calculation results were studied by trying different chamber closure times in the field and by adjusting the number of data points used for the actual flux calculation. This is a well-designed study, and overall, the manuscript is well written and

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Discussion paper

structured. Also choosing appropriate chamber closure times and the operation of automated chamber systems are important topics for the soil flux community. However, I recommend publication of this manuscript after major revision because I have some general concerns with this manuscript.

Response: We express our deep thanks to reviewer for his positive comments about our manuscript and constructive remarks. We have addressed, see below, our answers to each comment / remark.

1. Soil Flux Pro provides for each chamber measurement linear and non-linear flux calculations. Why did you choose to use only the linear flux calculation results?

Response: We firstly decided to use linear flux calculations only because we thought that the saturation effects characterised by a plateau after a certain time would be low. However, following your comment and comment from other reviewers, we changed flux calculations in the new version of the manuscript to use exponential estimations.

The underestimation of fluxes with linear regression due to saturation effects is well-known. That's why numerous non-linear calculation schemes have been developed. Could you have significantly reduced the chamber closure time for the N2O flux calculation if you had used non-linear flux calculation?

Response: See previous comment.

The selection of the flux calculation scheme can change the MDF at least for chamber measurements with only few gas samples over time. Does this effect disappear with high-frequency analysers, i.e. selection of the flux calculation scheme becomes less crucial in that regard? Would there still be a significant difference between the SHORT and LONG flux calculation for the different gases when using non-linear flux estimates?

Response: The standard error approach that we used (Nickerson, 2016) is a first order approximation for the MDF from high-frequency measurements and the "true" MDF is a function of the chamber time-series fit type as well (i.e. Linear, exponential, quadratic).

Nonetheless, while the use of linear regression resulted in systematically smaller fluxes as compared to exponential regression. It is therefore recommended to initially calculate fluxes with linear regression to determine the threshold for “low” fluxes and to recalculate them using exponential regression (Korkiakoski et al., 2017).

Korkiakoski, M., Tuovinen, J.-P., Aurela, M., Koskinen, M., Minkkinen, K., Ojanen, P., Penttilä, T., Rainne, J., Laurila, T. and Lohila, A.: Methane exchange at the peatland forest floor–automatic chamber system exposes the dynamics of small fluxes, 2017. Nickerson, N.: Evaluating gas emission measurements using Minimum Detectable Flux (MDF), Eosense Inc Dartm. N. S. Can., 2016. 2. You write about high-frequency measurements only as sampling measurement plots more frequently over time. However, you could also address the high-frequency sampling during a chamber closure since you use high-frequency gas analysers and work with MDF in your data analysis. There are several automated chamber systems which do not employ high frequency analysers, but still collect discrete gas samples which have to be analysed with a GC. Especially for N2O it is very interesting to see what fluxes we can capture with CRDS in comparison to GC analysis.

Response: In a previous study in the same environment (Courtois et al., 2018), we estimated that the minimum detectable fluxes using Gas Chromatography analysis of four discrete gas samples over 30 minutes for N2O was $\pm$ 8.3 μg N m$-$2 h$-$1. MDF estimated in the present study using high frequency measurement was 0.002 nmol m-2 s-1 or 0.2 μg N m-2 h-1 for N2O which is therefore $\sim$ 40 times lower. We added a sentence in the manuscript to highlight this interesting fact.

Courtois, E. A., Stahl, C., Van den Berge, J., Bréchet, L., Van Langenhove, L., Richter, A., Urbina, I., Soong, J. L., Peñuelas, J. and Janssens, I. A.: Spatial Variation of Soil CO2, CH4 and N2O Fluxes Across Topographical Positions in Tropical Forests of the Guiana Shield, Ecosystems, 1–14, 2018. 3. You only write how the SHORT and LONG measurements affected the flux estimates. But how did they affect the uncertainty of the single flux estimates? How large/small were the error bars for the flux estimates?

Response: Comparison of standard error of single flux estimates using 2 minutes or 25 minutes estimations for two weeks (from August 2nd for August 9th and from August 16th for August 25th) shows that standard errors are always higher for 2 minutes than for 25 minutes estimation for all three gases (Figure 2 below). Nonetheless, we decided not to integrate this figure in the manuscript because it does not add much to the study.

4. Could you have just used one, namely the LONG, closure time for all chambers and only choose for the flux calculation between SHORT and LONG calculation times? This would be more practical than rotating closure times between chambers.

Response: Setting all chambers as LONG measurements would have led to a maximum of $\sim$ 3 measurements only per chamber and per day. Mixing LONG and SHORT measurements allows to maximise the number of measurements per chamber and per days while ensuring a reliable estimation of the low N2O fluxes and to capture transient peaks of CH4 and N2O.

5. In section 3, the results are clearly presented, but the discussion part is very limited.

Response: The main aim of our study was not to identify controls and mechanisms of the soil GHG fluxes but rather to test novel soil GHG systems for continuous high-frequency measurements. We think that this manuscript could be used as technical support to set up new soil systems and contribute to record comparable soil GHG data in other regions around the world. Nonetheless, the discussion has been revised in the new version of the manuscript to integrate discussion on spatio-temporal variability of fluxes based on our study.

Specific comments: Page 2, line 26: numbers instead of author names for references

Response: This has been corrected.

You are not always consisted in how you write company names (capital versus small letters). Also often you write ‘minute’ when you could just use ‘min’.

Response: We corrected this in the new version of the manuscript.

Page 3, line 23: What are the pump specifications? Was it the pump supplied by Picarro with the instrument or did you use another pump?

Response: We have included more information in the manuscript about the external pump provided by PICARRO: recirculation pump A0702

Page 4, lines 9.: The soil temperature and soil moisture probes, were those the ones which can be directly attached to the chambers?

Response: The soil temperature and soil moisture probes were those provided by Li-COR, which are directly attached to the chambers. The probes measured soil temperature and soil moisture around the PVC collars. We have added more details in the text.

Page 5, line 5.: Did you use the analytical accuracy specified on the technical data sheets of the analysers or did you perform measurements yourself?

Response: We used the analytical accuracy specified on the technical data sheets of the analysers. This is now specified in the new version of the manuscript.

Where there significant air pressure and ambient temperature changes at your site over the four months? If yes, did you test how different temperature and pressure values could change the MDF estimate? Is nincl. or excl. the deadband?

Response: Please, see our response to reviewer 1 above (2.). In our study site, because all the systems were operating under dense understory vegetation and canopy cover, air temperature remained relatively constant over the year (i.e. at daily and seasonally time scale) near the soil surface. This is also true for air pressure.

Page 6, line 6: What CO2 concentrations were reached during LONG closure times (and forCH4)?

Response: CO2 concentration can reach 2000 ppm and CH4 concentration 4 ppm.

Page 6, line 7: I find that confusing in comparison to section 2.5. So considering the

deadband, the chambers were closed for 3 and 26 minutes, respectively?

Response: No, the chamber stayed close for 2 minutes and 25 minutes and the first minute was not used for the flux estimation. As we have a sampling frequency of 1 second, it still represents 60 points for curve fitting. Nonetheless, we agree that this could be considered as a too short period for CH4 and CO2 estimation using the SHORT (2 minutes) closure time. We therefore compared the CO2 and CH4 estimations with a deadband of 60 seconds (fluxes estimation with 60 seconds) with a deadband of 30 seconds (fluxes estimation with 90 seconds) for the week from August 16th to August 25th. These two estimations were very well correlated (see figure 3 below) so we decided to keep our 60 s deadband results.

Page 6, line 20: Why did you consider these fluxes as unreliable when the chamber quality check using the R^2 for CO2 was passed? Are you not unnecessarily filtering out fluxes which are not significantly different from zero, and thus introducing a bias in your data? Because this often happens when using R^2 as a filter criterion for low fluxes.

Response: Because of the high soil respiration activity, low soil CO2 fluxes do not really occur in this tropical rainforest, not even during the dry season. When the R2 criterion for CO2 was not passed, it always corresponded to situations of imperfect closure of the chamber, due to leaves or small branches lying on the soil collars (381 measurements over 17796, i.e. 2.1%). In these cases, it was therefore necessary to remove flux data for the three gases.

Page 6, first paragraph of section 3: You had no problems with humidity and the automated chamber system at your site?

Response: Please, see our response to reviewer 1 above (1.); at the given flow rate and the small diel cooling, we had no problems with water condensation inside the tubing lines of our system.

Page 7, line 3: The conclusion about the 2 min sampling time sounds absolute, but

it is only valid for your small chambers. Except for the necessary descriptions in the method section, you completely disregard the role of chamber volume for choosing the right chamber closure time.

Response: We added a sentence to precise that our result is valid for small chambers only.

Page 7, lines 20/21: That sentence does not make any sense to me. 85.6 % of the fluxes were above or below?

Response: This sentence has been considerably modified.

Page 8, line 4: You didn't show the diurnal variation in your data. This is more a point for the discussion than a conclusion from your presented data.

Response: We agree with the reviewer; however, ecological interpretation of our data will require more long-term data and will be published in a future paper. Here, we wanted to provide a technical report with information on how to get robust results on GHG flux estimations rather than on how these fluxes are produced and vary.

The references are not well formatted.

Response: References were reformatted

Table 1: Use superscript for the units.

Response: This has been corrected

Table 2: Include n for each chamber.

Response: This information has been added.

Check how the units are written on the y-axis of the figures.

Response: This has been checked..

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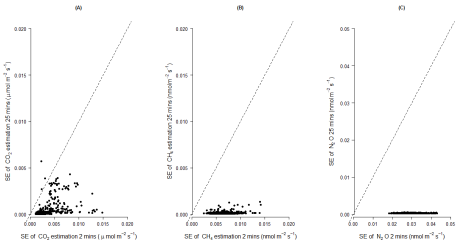

Figure 2: Comparison of standard error of single flux estimates using 2 minutes or 25 minutes estimations for two weeks (from August 2nd for August 9th and from August 16th for August 25th)

Fig. 1.

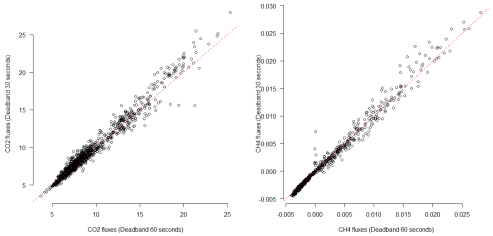

Figure 3: Comparison of CO2 and CH4 fluxes with a 30 seconds and a 60 seconds deadband for the week from August 16th to August 25th. The red dotted lines represents the 1:1 line.

Fig. 2.