

Response to interactive comment (Anonymous Referee #1) on 'Gas chromatography vs. quantum cascade laser-based N₂O flux measurements using a novel chamber design'

[R#1.1] Brümmer et al. present a study analyzing linear and non-linear flux calculation methods under high and low flux rates of nitrous oxide and different scenarios of closure time. They use both traditional gas chromatography (GC) (low sampling number during closure time) and high-resolution quantum cascade laser (QCL) sampling. They find that non linear concentration changes are more clearly detectable during high emission scenarios and long chamber closure. Shortening of closure time results in a reasonable agreement between linear (3min) and non-linear (60min) flux estimates, but can only be applied when using the QCL set up. While under low flux conditions, GC measurements result in more scattered flux estimates, in both campaigns mean flux estimates of GC and QCL agreed well. Rare negative fluxes detected by GC measurements seem to be arbitrary and not caused by actual N₂O uptake. The paper is well written and a good fit for the journal.

However, I could not help thinking that most of the results were as to be expected from literature and not 'radically' new.

[AC#1.1] We highly appreciate the comments and suggestions given by Anonymous Referee #1. We agree that some results like higher non-linearity in concentration changes under higher emission regimes and longer closure times have been hypothesized and reported earlier. The basic idea of this study is to give a concise overview by showing a side-by-side comparison of QCL vs. GC characteristics, low and high exchange regimes, linear and non-linear flux calculation methods alongside a presentation of our custom-built chamber design. Many other papers, however, usually deal with only a few of the above mentioned components, i.e. either low vs. high fluxes, or only with a GC vs. QCL comparison, or purely with different calculation methods. Therefore, we aimed at integrating the characterization of the measurement system, the exchange regime, and the flux calculation by means of two short campaigns without going into too extensive analyses.

Changes to the manuscript:

None specifically for this comment, but responses to comments R#2.4 and R#2.12 from Reviewer #2 deal with similar topics. See AC#2.4 and AC#2.12.

[R#1.2] Ultimately, the high temporal resolution of measurements possible with QCL (which do provide more sophisticated ways of flux data processing) and the fact that the concentration measurements are instantaneous, make these measurements desirable for exactly the long-term applications, the authors are suggesting.

[AC#1.2] The novel QCL application combines multiple advantages over traditional manual sampling systems. These are (amongst others)

- higher temporal resolution of concentration data leading to a higher number of flux rates per day,
- the possibility for robust application of flux calculation procedures,
- easy determination of system malfunction, e.g. caused by insufficiently closed chambers,
- low maintenance for laser operation,

- low uncertainty in flux estimates providing the opportunity for ecological process studies and calculating robust trace gas budgets

For those cases where QCL methodology cannot be applied, e.g. due to high initial investment costs, GC-based measurements may still be useful when investigating longer periods when the focus is not on short-term variability of gas exchange dynamics.

Changes to the manuscript:

None.

[R#1.3] It is not clear to me, what the accessibility of the described instrumentation is. Is there a plan to make it available for other users, i.e. to 'rent' it out or to make it available within the ICOS project? If that is the case, it should be pointed out more clearly.

[AC#1.3] We thank the reviewer for this comment. It is a good idea to promote the presented chamber design more clearly as it meets the anticipated standards listed in the ICOS protocol for chamber measurements. That protocol, which will be made publicly available soon by the Ecosystem Thematic Center of ICOS, does not explicitly state precise mandatory dimensions for chamber volume and design, but rather provides size ranges depending on ecosystem type. Information about our chamber system including the construction plan is open to the scientific community and can be requested from the authors. We add the respective information at the end of Chapter 2.1.

Changes to the manuscript:

Sentence added at the end of Chapter 2.1: 'Information about our chamber system including the construction plan is open to the scientific community and can be requested from the authors.'

[R#1.4] Overall, the most interesting aspect to me is the possibility to study ecological processes in a new way, as shown for the possible net N₂O uptake and diurnal variability in emission rates. Interestingly, the study they compare their results to (Shurpali et al. 2016) is mostly an eddy covariance study. It would be interesting if the authors could comment on possible advantages of this automatic chamber against eddy covariance and whether other gases can be sampled in parallel to N₂O (I am thinking mostly of CO₂, considering the possible coupling of plant activity and N₂O emission rates).

[AC#1.4] One advantage of chamber measurements in comparison with an eddy-covariance approach is the possibility to study small-scale spatial variability of greenhouse gas exchange. This can either be done in natural homogeneous environments or in specific trials at plot scale, e.g. when different types and amount of fertilizers are applied on relatively small plots of a few square meters where the eddy-covariance approach would fail as it requires a homogeneous fetch of up to a few hectares around the tower. Secondly, continuous automated measurements using QCL spectrometry for trace gas analysis like in our study do provide robust estimates of exchange fluxes in situations where assumptions of the eddy-covariance theory are violated. These situations are for example low atmospheric turbulence conditions that frequently occur during nighttime or when measurements are conducted in hilly terrain and advective flows cause significant bias in EC-based fluxes.

As many laser spectrometers that are currently available on the market allow for parallel detection of selected other trace gases – usually CH₄ and CO₂ – in one analyzer cell, our sampling setup can simultaneously provide concentrations and flux estimates of the chosen greenhouse gases to study coupled environmental processes such as effects of water table, soil moisture and temperature on the respective gases of interest.

We will add the information that parallel detection of different trace gases is possible with most common analyzers in combination with our chamber system.

Changes to the manuscript:

Sentence modified at the end of Chapter 3.4: 'Our study highlights that through its high time resolution QCL-based measurements will not only help enhance process understanding of N₂O exchange by disentangling the strength of different drivers of N₂O production like temperature, soil moisture, nitrogen availability, and microbial activity, but has also the potential to provide new insight into bidirectional exchange characteristics of other trace gases such as CH₄, which can be sampled simultaneously with our chamber system depending on analyzer type used.'