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Atmospheric Measurement Techniques
Discussions
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Interactive comment on "Potential improvements in global carbon flux estimates from a network of laser heterodyne radiometer measurements of column carbon dioxide" *by* Paul I. Palmer et al.

Anonymous Referee #1

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This paper describes a potential low-cost network that leverages the AERONET infrastructure (and solar tracker) to measure total column dry-air mole fractions of CO_2 and CH_4. The authors explore the potential for "mini-LHR" spectrometers to provide an improved understanding of CO_2 fluxes using three sets of OSSEs: one using the mini-LHR network alone, one using the TCCON network alone, and one with the combined network. The results show that the mini-LHR network could significantly increase CO_2 flux a posteriori knowledge.

The idea of a low-cost network to help improve the density of high-quality ground-based measurements of XCO_2 is certainly an attractive one. Leveraging off of the

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Discussion paper

existing AERONET infrastructure is a great idea. The paper is generally well-written and is a suitable topic for AMT. I have several comments and requests listed below that, if addressed, would make this paper suitable for publication.

General Comments:

My main concern about this paper is the lack of consideration of site-to-site bias. This is a crucial problem in carbon cycle science, because spurious gradients in the measurements can cause us to infer large and spurious fluxes. The authors do mention a calibration of sorts using a 36-m long gas cell, but this does not seem representative of the atmosphere, changes in pressure, temperature, water vapor, and their vertical structures. Nor is there a discussion of instrument line shape (or instrument function) for these spectrometers and how much they might vary from instrument to instrument, what the airmass or solar zenith angle dependencies are likely to be, etc.

There is some discussion about ongoing side-by-side work with the Armstrong TCCON station, but there are no plots or concrete results from this work. I request that both a time series and a one-to-one plot (and any other relevant diagnostics) of the coincident measurements between the Armstrong TCCON station and the mini-LHR be presented in this paper. I also request plots of spectra and spectral fits from the coincident measurements to get a sense of the signal-to-noise ratio of the spectra and the quality of the retrievals, a priori profiles, and spectroscopy of the two retrieval algorithms.

Specific Comments:

Please provide more details of the retrieval algorithm: is it Optimal Estimation? Does the algorithm retrieve profiles of CO2 or does it perform a scaling retrieval (like TCCON)? Given equation (1), I would assume the former, but it's not clear. Does the mini-LHR measure oxygen to compute the dry-air mole fractions or does it rely on a precise surface pressure and water column measurement? Plots of example spectra would be helpful.

P2L9: Wunch et al. 2017 wasn't pointing out how poor the data are from OCO-2, it was pointing out how good it is when you account for some known (characterizable) biases!

Please add a table of the TCCON stations used for the OSSEs. There are missing and "mystery" TCCON stations on the map in Figure 4, bottom left panel. For example, missing sites include Eureka, East Trout Lake, Hefei (which has not yet delivered data to the TCCON archive, but has published a preliminary paper: Wang, W., Tian, Y., Liu, C., Sun, Y., Liu, W., Xie, P., Liu, J., Xu, J., Morino, I., Velazco, V. A., Griffith, D. W. T., Notholt, J., and Warneke, T.: Investigating the performance of a greenhouse gas observatory in Hefei, China, Atmos. Meas. Tech., 10, 2627-2643, https://doi.org/10.5194/amt-10-2627-2017, 2017). These stations may contribute to an increase in gamma over the northern latitudes.

There are markers north of Manaus (Paramaribo?), north of Reunion Island, central Australia, and Russia (Yekaterinburg?) that are not TCCON stations. You can guide your OSSEs by the map on the TCCON wiki (https://tccon-wiki.caltech.edu/) or on the TCCON archive (https://tccondata.org/). Including the correct TCCON station locations might impact your results.

As I understand it, the gamma parameter shows the improvement of integrating the measurements into the model over the pure model uncertainties. It is interesting to note that while both OSSEs (TCCON and mini-LHR) have similar numbers of stations in Australia/New Zealand, there is little to no improvement in the uncertainties in that region. Are we to interpret from this that the models perform extremely well in that region compared with the rest of the southern hemisphere land? Please expand on this. Why are the models so good there and not elsewhere over the SH land? Should we be putting any stations in Australia/NZ at all?

How many TCCON stations would need to be added to approach the gains from 50 mini-LHR stations, and where should those TCCON stations be placed? Should they be placed where you've placed the mini-LHRs? Would fewer TCCON stations do, if they were more strategically placed? For the same cost of the 50 mini-LHR stations, how many (if any) TCCON stations could be purchased (a TCCON station costs roughly $500,000 USD)?

In Figure 6, you show that the RMSE is more than double for the TCCON inversion than the LHR inversion over Europe? Why? There are about equal numbers of TCCON stations and LHR stations in Europe. What is it about the mini-LHR measurements in the region that provide this additional information?

In your OSSEs, what do you assume about the distribution of clouds and how they impact the density of measurements?

Technical Remarks

A 1 ppm precision after averaging over an hour ($\sim$30 measurements) is not particularly high precision these days, so please rephrase P1L16.

P1L27: Please revise the number 23 when you update your OSSEs to match the existing TCCON stations.

P2L7: GOSAT and OCO-2 measure sunlight reflected off the Earth's surface in the near-infrared, but they measure in nadir mode, glint mode, and target mode (not just nadir).

P2L11: I believe you mean to cite Wunch et al. 2011 and not 2017:

Wunch, D., G. C. Toon, J.-F. L. Blavier, R. A. Washenfelder, J. Notholt, B. J. Connor, D. W. T. Griffith, V. Sherlock, and P. O. Wennberg (2011), The Total Carbon Column Observing Network, Philos. Trans. R. Soc. A Math. Phys. Eng. Sci., 369(1943), 2087–2112, doi:10.1098/rsta.2010.0240.

P2L20: It is stated that the TCCON instruments report a precision of $\sim$1 ppm that is mitigated by comparing with aircraft profiles. This should be an *accuracy*, not a precision. The precision of TCCON is $\sim$0.4 ppm (1-sigma), according to Wunch et al.

2010.

P2L22: We technically cannot “calibrate” when measuring the atmosphere (as it cannot be controlled), so the phrase we use for this is to “tie” the TCCON measurements to the WMO scale.

P2L31: The TCCON can also measure in breaks between clouds and measure with a similar frequency as the mini-LHR.

P3L1: The higher latitudes are measured reasonably well by the satellites during summer, but it is correct to say that they are not well covered in winter.

P4L9: Why is the scattering package required for direct sun-viewing measurements?

P4L28: “PSG/API to *calculate* spectra” (remove “get”).

P5L19: Add “a”: “known to be *a* significant source”.

P5L26-27: Direct sun-viewing measurements should have very high signal-to-noise ratio (because the signal is so large). Please clarify.

P7L23: Why did you adopt a “uniform 50% a priori uncertainty and 1.5 ppm for individual measurement and model transport errors”?

P7L34: “using mini-LHR measurements collected *and* enhanced measurement configuration”

P8L3: Not including instrument biases is problematic for the carbon cycle (see General Comments).

P5L28: Wunch et al. 2011 is not the correct reference for the DC correction; please cite:

Keppel-Aleks, G., G. C. Toon, P. O. Wennberg, and N. M. Deutscher (2007), Reducing the impact of source brightness fluctuations on spectra obtained by Fourier-transform spectrometry., Appl. Opt., 46(21), 4774–4779, doi:10.1364/AO.46.004774.

Figure 3: Plotting column averaging kernels on a linear pressure grid is helpful for the total column, which is weighted by mass.

Table 2: Please organize this table by the Figure 6 sectors.

Figure 6: Could you please add an extra bar for the mini-LHR+TCCON inversions?

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