

We thank anonymous referee #1 for evaluating our manuscript and for the very useful comments, which we treat in the following item-by-item. In this author's comment, the points as raised by the reviewer are replicated in **blue text**, along with the corresponding reply from the authors in black text.

General comments

Manuscript continues series of papers devoted to the development of the COCCON network which is based on EM27/SUN FTSs (Fourier transform spectrometer) observations. This type of FTS designed by KIT in close collaboration with Bruker Optics has a number of unique characteristics including portability, robustness, and ease of use. The combination of EM27/SUN FTS together with the state-of-the-art open-source codes (PREPROCESS and FROFFAST) designed at KIT for processing of interferograms and spectra allows provision the highest accuracy/precision values of atmospheric XCO₂, XCH₄, XH₂O and XCO. Since 2014, EM27/SUN spectrometers have been successfully tested in various kinds of environments including a number of intensive field campaigns. The COCCON community is growing rapidly, therefore one of most important tasks is to develop tools to ensure rigorous QA/QC throughout the network. Namely, the manuscript focuses on the improved procedure of EM27/SUN calibration including the analysis of ILS (Instrumental Line Shape) by means of newly designed cell filled with C₂H₂-air mixture in comparison with standard procedure based on open path measurements of H₂O spectral signatures.

The manuscript is well written nevertheless the current version mostly resembles a technical report. In conclusion, it would be useful to give a brief recommendation on how the COCCON community could (or should) implement the findings presented in paper in practice.

We agree that the paper, which reports our recent progress on network calibration work for COCCON shares some resemblance with a technical report. We nevertheless believe that it contains significant new methodological improvements justifying a publication in AMT. Especially, we refine the open-path procedures, introduce an improved H₂O line list for the analysis of open path measurements and the design and commissioning of a C₂H₂ reference cell.

We hope the paper will provide a useful reference for both the COCCON community in a narrower sense (instrument operators) as well as for the wider range of COCCON data users. For the first group, the new H₂O line list we created for the analysis and other details of the refined procedure are made available for achieving network-wide improved open-path ILS results (suggestion to use the most accurate pressure reference available, use of the revised internal path length, to check also the CO channel ILS). For the second group, the provided estimate of the performance of all individual spectrometers will be of relevance (then read as a report on the achieved network performance). In the summary, we have added the statement (**red**):

“We recommend the application of this new refined procedure for characterizing the ILS parameters of the EM27/SUN FTIR spectrometer from open path measurements.”

We plan to circulate calibrated C₂H₂ cells as an additional handle for recognizing instrumental drifts in the network, this further step is under preparation and will involve all interested COCCON partners. In the current paper, our aim was to demonstrate the feasibility of the new C₂H₂ cell method and the quality of results achievable with such a cell. In the summary, we added the statement (**red**):

“Based on these encouraging results, we plan to circulate C₂H₂ cells for demonstrating the level of temporal stability of individual spectrometers and the level of instrument-to-instrument consistency across the network.”

We also added further information on the retrieved C₂H₂ cell column values from measurements taken with different spectrometers to inform the reader which level of consistency is achieved across different spectrometers (see updated Fig. 16).

Specific comments

Thanks for the list of specific comments, which we handle in the following. Please note that we meanwhile discovered that our revised results for spectrometers SN29, SN32, SN50, SN52 and SN53 were suspicious outliers in the resulting instrument specific gas calibration factors when compared to the previous results by Frey et al. (2019). We identified the reason of this problem (we used outdated and not the latest sets of laboratory spectra available for those spectrometers as used by Frey et al. (2019)). We repeated the analysis for these spectrometers and updated accordingly all dependent figures and tables in the paper.

Abstract, lines 19-20: It is worth mentioning that new calibration cell is filled with air-C₂H₂ mixture.

Correct, we use the assumption of some air contamination of the cell (pressure values in table 2), but we did not add deliberately air to the cell content. As the partial pressure of C₂H₂ follows from the measured line strengths, this is not a free adjustable parameter if we maintain the assumption that the reported band intensity in HITRAN is correct. For reproducing the line widths measured with the IFS125HR spectrometer, we decided to use the total pressure as tuning parameter. The values (total pressure about 15% higher than partial pressure) might indicate that (1) the reported self-broadening parameters are underestimated (2) the reported band intensity is overestimated (3) the cell actually contains some air contamination – or a combination of all three impacting factors. Following this procedure and line of reasoning, our only reference point is the IFS125HR instrumental line shape, which we assume to equal that of a nominal spectrometer.

We agree to the referee that depending on cell length and band intensity as determined by the chosen target gas, it might indeed be required to work with a significantly diluted target gas (and then this fact should be mentioned), but with the cell, gas, and spectral band used here, “pure” C₂H₂ does a reasonable job.

Line 119: The distance "about 4 m" is mentioned, while Figure 1 caption says about "distanse of 4.20 m". How critical is the precise knowledge of the distance between lamp and the first mirror of EM27/SUN solar tracker?

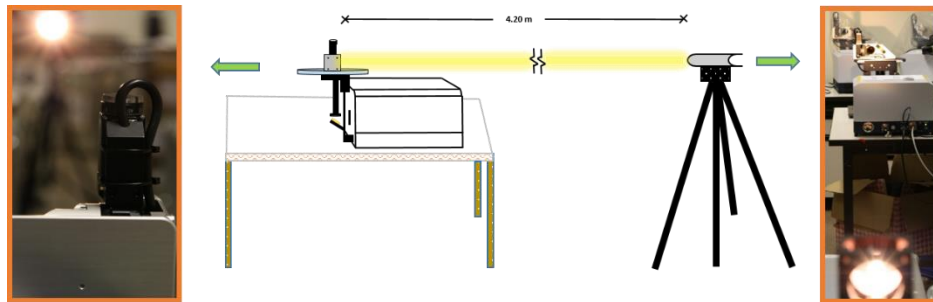
Thank for this observation! Before January 2020 this distance was fixed to 4.0 m, after that and because we implemented the cell-measurements together with the open path, we changed that value to 4.20 m. The initial idea of increasing the distance was to preserve the 4 m distance with the cell in the beam and to derive both the cell (20 cm cell length) and open path results from the same measured spectrum. But it turned out that the cell observations require less scans than the open path measurements, so we decided to keep both measurements separated (for excluding any possible residual disturbances on the open path spectra due to the presence of the cell) and as a result continued the measurements with 4.2 m distance. Certainly, this change is reflected in the data analysis of the open path measurements. In the previous calibration paper (Frey et al, 2015) a sensitivity study of retrieved modulation efficiency as function of open path length was carried out and found that the residual variation of the M.E by changing this distance between 3 and 6 meters is only ~ 0.11%, so we do not expect a significant impact of this modification. This residual change detected by Frey et al. (2015) is probably due to spectroscopic issues. Because we revised the H₂O line list, we hoped for a further reduction of this effect and redid the exercise, but the sensitivity remains about the same. We decided to omit these results in the (already lengthy) paper, as the findings by Frey et al. (2015) remain valid.

We have added the following sentence to the manuscript (in red):

“The spectrometer resides on a table, while the lamp is mounted on a tripod at about 4.20 m (4.0 m for instruments calibrated before January 2020) distance from the first mirror of the solar tracker attached to the spectrometer.”

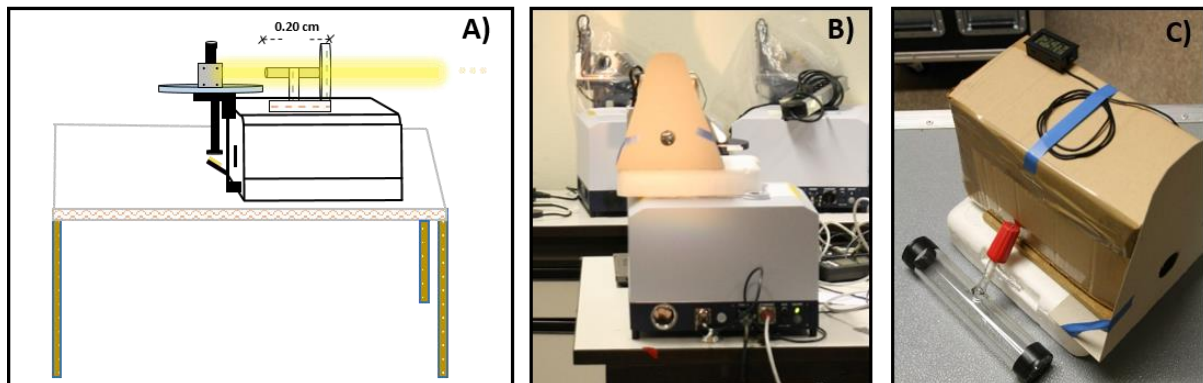
Figure 1: In addition to the existing panels it would be helpful providing an extra panel with the side view on the set-up for open-path measurements.

Thanks for the suggestion, we have added the following figure:



Lines 131-132: “The spectrometer is now oriented in such a way that the cell can be conveniently located in the infrared beam on top of the spectrometer housing (see Figure 1 and Figure 4 A).”: This is not clear from the photos in Fig.1 and Fig.4A where/how the cell is placed.

Figure 4 was updated with the side-view of the set-up, based on Figure 1, to better show the way how the cell is mounted on the cover of the spectrometer.



Line 138-139: The term "instrument entrance" is not mentioned/presented in the list in Figure 2, so it is unclear which path (inaccessible) is being measured.

The figure has been replaced by the figure below. The instrument’s entrance window (we assume that this location is defined by the long-pass filter integrated in the cover of the spectrometer) and the position of the aperture stop inside the spectrometer are now clearly marked to avoid confusion.

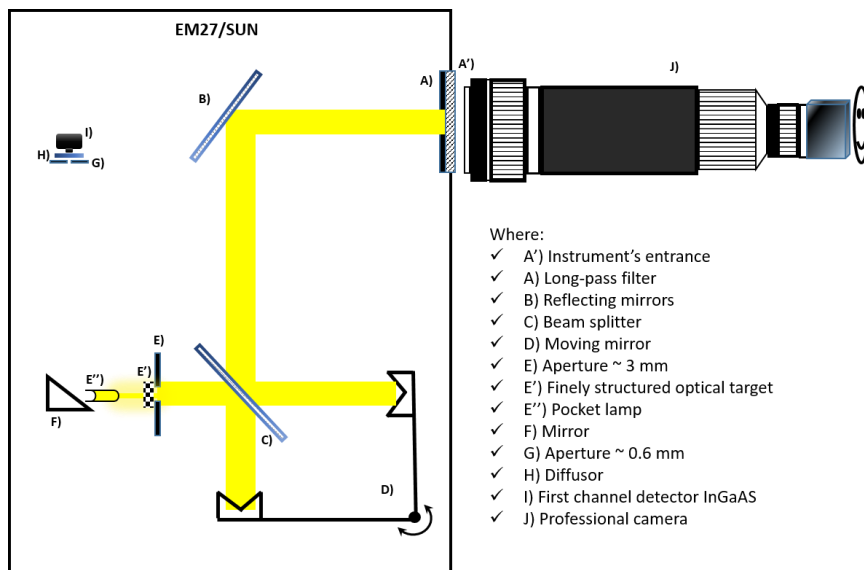


Fig.2: It would be helpful to indicate the position of an fine optical target in Fig.2.

The figure has been updated in this respect also and now contains the position of the illuminated target (which coincides with the aperture stop of the interferometer).

Lines 193-195: “The latter window resides in the spectral overlap region covered by both detectors, allowing a check for a degraded ILS of the CO channel with respect to the primary channel, because in this spectral window the retrieval of ILS parameters can be performed from both main channel and CO channel spectra.” Could authors explain why ILS of the CO channel is degraded?

The ILS of the CO channel is not necessarily degraded. If the alignment of the spectrometer is nominal, then no ILS degradation occurs. In practice, however, the field stop of the primary detector is used as the reference for the interferometric alignment, while the CO detector field stop is adjusted to optically coincide with the field stop of the primary detector (using an additional mirror which decouples some radiation from the primary beam). As a consequence of this procedure, some misalignment between the two detectors might remain and checking the ILS of both detectors is a more stringent procedure for quality assurance than checking only the ILS of the primary detector.

We have added the following statement in the manuscript (in red):

“A dedicated check of the CO channel seems advisable, because the primary channel is used as the reference for the interferometric alignment, while the CO channel is only adjusted to match the alignment of the primary channel.”

Line 264: “2.4 Error budget of the cell measurement for measuring ILS parameters of the EM27/SUN spectrometer” More detailed discussion of error budget is expected in section 2.4.

Thanks for the hint, we agree. We have extended the discussion and have included a table for specifically showing the error contribution from spectral noise, cell temperature, and from a correlated disturbance of the reference cell parameters: total pressure (P_{tot}) and partial pressure (P_{part}). By changing these values by 0.5%. The calibration of the cell parameters turns out to be a critical task (as it contributes a systematic uncertainty to all cell results); we added this information to the text.

Error source	uncertainty	Propagation on MEA
Spectral signal-to-noise ratio	2000	$1.5 \cdot 10^{-4}$
Temperature	1 K	$2.5 \cdot 10^{-3}$
Empirical cell pressure parameters (systematic error contribution)	0.5%	$3.6 \cdot 10^{-3}$

Fig.7: The blue dotted line in right panel does not correspond to $y=x$.

Many thanks for this observation! The Figure legend has been update with the correct equation!

Technical corrections

Line 128: An excess colon.

The colon was deleted

Line 129: “In” should be written with a capital letter.

Changed accordingly.

Line 132: An excess parenthesis after “ Figure 4 A)”.

The Figure 4 is split in A) and B). In that sentence by coincidence, we must have two parenthesis at the end: the referenced Figure part and the closing one.

Line 186: Please clarify the "ca." abbreviation.

We have changed “ca” which is an abbreviation of “circa” for “approximately”, which is more conventional than the other one.

Line 505: “Figure 19: ... (derived from high-resolution IFS125-LR spectra using GGG2014, red)...”. Is “IFS125-LR” correct here?

Many thanks for pointing this out. In that sentence is not correct, therefore we have changed the ending “LR” by “HR”.