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Atmospheric Measurement Techniques Discussions

Interactive comment on "The arctic seasonal cycle of total column CO_2 and CH_4 from ground-based solar and lunar FTIR absorption spectrometry" *by* Matthias Buschmann et al.

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We would like to thank Debra Wunch for the feedback and suggestions. Point-by-point responses to the individual issues raised are listed below.

Comment:
The language needs tightening - some technical concepts that are specific to TCCON or Bruker 125HR instruments that may not be familiar to the wide AMT audience are glossed over and should be written in a clearer, more general way.

Response:
The final manuscript will be revised with emphasis on readability. We have tried to define TCCON and instrumental specific references to be more approachable by a general AMT audience.

Comment:
Night time validation with aircraft or AirCore profiles would be best, but appear to be unavailable (at least, they are not mentioned in the manuscript). Perhaps this should be mentioned in the discussion or conclusions section.
Response:
Correct, so far no aircraft campaigns above Ny-Ålesund are available. Aircore measurements are difficult. Ny-Ålesund is a coastal town surrounded by mountains and glaciers and the retrieval of the probe has to be ensured. One obvious solution to this is to deploy a guided descent, but as far as we know a secure retrieval glider is still under development. This will be mentioned in the Conclusions of the revised manuscript.

Comment:
In Figure 14, you compare the XCH4 seasonal cycle from your lunar and solar measurements to the MACC model. It shows significant disagreement in summer, but not in winter, showing that the model isn't able to properly reproduce the Arctic methane seasonal cycle amplitude. Do you have any idea why? This, to me, is one of the most interesting figures/results of the paper.
Response:
This is indeed very interesting, and something we hope to examine further. It appears that there is a general bias between the model and the solar FTS measurements with

specific events in spring, where the FTS measurements show sudden decreases of the xCH4. Our current understanding is, that the model is not capable of addressing vertical transport very well. Specifically stratospheric intrusions during the breakdown of the polar vortex in spring lead to large, short-term decreases in xCH4. This is currently being investigated by using a stratospheric species as a tracer to seperate the xCH4 column in a tropospheric and stratospheric part but exceeds the scope of this paper, however we will add the above explanation to Section 5 of the final manuscript.

Comment:
P1L4: The moon isn't a light source - it's reflected sunlight off the moon.
Response:
Yes, in the NIR, reflected sunlight is the main component of the lunar irradiance. This will be reworded for clarity.

Comment:
P1L5: I don't think you mean "parallel".
Response:
Yes, the measurements are not actually 'parallel', but happen on consecutive days and nights. Wording has been adjusted.

Comment:
P1L23: You don't need extended InGaAs detectors to measure above 5000 cm-1.
Response:
Correct, reworded for clarity.

Comment:
P2L18: Do you use the solar brightness fluctuation corrections for high cirrus typically employed by TCCON (embedded in I2S for DC-recorded interferograms)?
Response:
Yes, however the effect of the correction is minimal, because in case of lunar spectra there is not enough signal with strong cirrus present. Additionally, due to the low resolution of the spectra, thin cirrus clouds typically lead to brightness fluctuations between consecutive scans and less to fluctuations within one interferogram record. This will be added to the description of the postprocessing of the spectra in Section 3.1.

Comment:
P2L22: 0.04 what units? mrad?
Response:
Here: 0.04 radians. The units have been added.

Comment:
P2L22: This sentence may be too technical for this audience. Explain that this ME and phase error are consistent with a well aligned instrument.
Response:
The fact that these values are indicative of a well-aligned instrument has been included in the revised manuscript.

Comment:
L25-35: This is too technical - please explain further.

Response:
Assuming this comment refers to section 2.2, this will be reworded, see also the answer to the comments in review #1.

Comment:
P4L11: Rework sentence beginning with "Generally speaking, . . ."
Response:
The sentence has been reworded to: Decreasing the resolution leads to a shorter measurement time and therefore allows for integration of more interferograms in the same time frame. Increasing the entrance aperture allows for more incident light on the detector which increases the signal-to-noise-ratio.

Comment:
P4L14: The entrance aperture wasn't always 3.15 mm? Please explain.
Response:
At full moon, the entrance aperture could be set to 3.15 mm. If the moon is not full, its image on the aperture wheel requires a smaller aperture to still ensure that the aperture is uniformely lit. Additionally, the four-quadrant diode used in the tracking system, sometimes has difficulties centering the non-full lunar image, using a smaller aperture in this case, again ensures full illumination of the entrance aperture. The respective paragraph in Section 3.1 has been reworded to clarify this.

Comment:
P7L1: Please note that the large deviations are at very high SZA that would be filtered out in a typical TCCON filter. Could you make this plot for days with lower SZAs? Does

it look the same?
Response:
This has been only done for the Ny-Ålesund site, here lower SZAs are only possible in summer and due to the midnight sun conditions, the differences between the day and night atmospheric models are smaller. However this approach can easily be adapted to other TCCON sites. It will be noted in Section 3.3 of the revised manuscript that higher SZA are generally filtered out in standard TCCON.

Comment:
P7L11: This worry no longer holds, given that Bruker has provided two solutions to the ghost problem (the laser sampling board potentiometer and the new M16 controllers with the XSM option), and TCCON provides a ghost removal procedure with I2S, as long as you measure simultaneously on another detector with a spectral range that is entirely within a single alias. In fact, I believe Bruker recommends 20kHz as their preferred scanner speed.
Response:
Yes, the paragraph will be adjusted. See also the answer to review #1 regarding this issue.

Comment:
Fig 5: I see what you're trying to do with this figure, but I find it very difficult to read and interpret quantitatively. Perhaps you also need to show example slices through the 3D figures showing XCH4 vs resolution and XCH4 vs SNR.
Response:
Figure 5 was intended to present the qualitative behaviour of different SNRs as a function of resolution. The quantitative information, e.g. xCH4 vs. resolution - for two

extrem cases of SNR - is shown in Fig. 6. An additional plot will be added as described in the answer to review #1 showing the improvement of the S/N with decreasing resolution.

Comment:
Fig 6: Would the x-axis scale work better as a log10 scale? Also, with the low SNR error bars as large as they are, it's difficult to see what the mean value is as a function of resolution. Perhaps you need to reduce the y-axis limits and show a representative error bar.
Response:
The errorbars have been removed and representative errors added to the caption.

Comment:
P10L10: The averaging kernel also depends on the retrieval methodology.
Response:
Yes, this detail has been included.

Comment:
P12L1: Can you assume that the total columns do not change significantly during the 24-hour period? What about drawdown from the terrestrial biosphere throughout the day and respiration at night? Is night time respiration a feature of the carbon cycle you can hope to measure with your lunar measurements given the precision of your measurements? The y-axis scale is too large in Figure 9 to see whether there is any diurnal cycle in your data and models. Ditto for Figure 10.
Response:

The standard deviation of all models are in the order of 0.2 - 0.3 ppm for xCO2 and 1.0 - 1.6 ppb for xCH4, which is an argument for the stability of the columns during the validation time period. Unfortunately the errors are too large to investigate night-time to day-time differences, e.g. due to respiration and carbon uptake, with the lunar observation presented here. The y-axis scales cannot easily be adjusted without loosing information on the lunar data points. However corresponding values for mean and standard deviation are given in Table 2.

Comment:
P14L25: Remove the comma after "both".
Response:
Done.

Comment:
P14L25: The models don't capture the secular trends in XCO2 and XCH4? Why not?
Response:
This is a misunderstanding. The models do capture the secular trends. In order to directly compare one year with another, the time series has to be detrended. This will be rephrased in the final version.

Comment:
Fig 13, 14: I don't see any green dots.
Response:
The color reference will be updated.
