Atmos. Meas. Tech. Discuss.,
doi:10.5194/amt-2020-466-RC2, 2021
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Atmospheric Measurement Techniques Discussions

Interactive comment on “Retrieval Algorithm for the Column CO_2 Mixing Ratio from Pulsed Multi-Wavelength Lidar Measurements” *by* Xiaoli Sun et al.

Anonymous Referee #2

Received and published: 29 January 2021

The paper by Sun et al. discusses measurements of an airborne CO2 lidar that operates at multiple wavelengths, thus sampling the atmospheric transmission spectra of a single CO2 line. The paper puts much weight on the description of the least-squares retrieval algorithm for the (below-aircraft) column-average dry-air mole fraction of CO2 (XCO2) and the retrieval diagnostics. The topic is suitable for AMT and the demonstrator results in section 6 show excellent performance. The paper is a bit heavy on the algorithm description (which actually is a standard technique) but this might be justified since the paper aims at making a link from the lidar community to the community that works on passive remote sensing of CO2. Overall, I recommend publication after considering my mostly minor comments below.

Comments

1. The least-squares fit of an atmospheric transmission spectrum is not new. Its detailed description in section 2 through 5 might be justified in the present context where a new experimental technique is further developed. I would see one purpose in connecting the CO2 lidar community to the passive remote sensing community. But, then, the notation chosen by Sun et al. does not really correspond to standard notation e.g. defined in Rodgers, 2000, https://doi.org/10.1142/3171. I find it particularly twisting to use various “overhead” symbols for discriminating between true, a priori and estimated states. While it is not a mandatory request, I would recommend considering to go closer to standard notation.

2. I was particularly puzzled by the section on averaging kernels. It is a well-known problem that total-column/profile-scaling retrievals complicate the averaging kernel calculation. The most straight-forward work-around is to implement a formal profile retrieval (Philipps-Tikhonov 1st order) and to regularize ad infinitum. Then, the algebra just delivers the averaging kernel at the expense of enhanced computational cost since one needs to calculate the layer-wise Jacobians. If computational cost is an issue, one can follow the recipe in section 2.3 of Borsdorff et al., 2014, https://doi.org/10.5194/amt-7-523-2014. Isn’t that about the same as what section 5 proposes? Please put your work in relation to the above paper (and consider using their standard notation).

In equ. 21, I cannot follow the last identity. Given that K=dF1(S)/dS (equ 14), why is this equivalent to a derivative involving Delta-y1? Delta-y1 contains F0 i.e. the forward model at the initial state while the Jacobian K needs to be calculated at the iterated state. If the averaging kernel is calculated for the initial state, there might be residual non-linearity errors since for the initial state, it is less likely to be in the “linear neighbourhood” of the true state than for the iterated/final state. These effects are probably small as long as a reasonable prior is chosen and the scaling factor is just about unity. So it is merely a matter of precise understanding, I guess.

3. In the conclusions, Sun et al. highlight that the spectral sampling of the absorption line is superior to simple on/offline lidar setups. Would it be possible to demonstrate/quantify that statement e.g. by mimicking an on/offline measurement by picking two spectral samples?

Technical comments:

L40: uses -> used

L57: for the CO2 is measured -> check sentence structure

L60: seeder -> seed

L80: mereological -> meteorological

L97: check sentence structure

Section 3.3: It would be good to highlight that the scaling factor applies to the below-aircraft CO2 profile, not to the CO2 profile up to top-of-the-atmosphere (as it would for passive solar backscatter techniques since the downward lightpath always travels the entire column). Therefore, the quantity XCO2 is actually the below-aircraft column mole fraction.

L125: into account of the effects -> into account the effects

L144: I wonder whether it would be more straightforward to first define OD via an equation and then define the transmission (equ. 4) via OD.

L161: “as in conventional trace gas sounding” - Does “conventional” refer to passive solar backscatter remote sensing? The passive techniques only formally retrieve profiles that consist of several layers but they effectively regularize the inverse problem such that they end up with $\sim$1 DFS which is equivalent to the total column. The benefit of a formal profile retrieval is that one gains flexibility and the algebra delivers all the diagnostics.

L184: slop -> slope

L186 and following: Is it common (compliant with AMT rules?) to write vectors in capital letters and their elements in regular letters?

L202: Is the measurement error strictly diagonal or is there correlations possible e.g. considering the drift in laser energy?

L204: parameters set -> parameters set \vec{S}

L218: Preconditioning the least-squares with 1/f0 can end up in numerical issues if the transmission approaches zero i.e. if the absorption becomes opaque. While the absorption line used here is not opaque, there might be a word of caution warranted for the reader to consider this aspect in general.

L269: “second row” It should be made clear that it is the second row because the state vector chooses the scaling factor to be the second element. Of course, any ordering is possible in general.

Section 7.3: There is more to inverse estimation than least-squares and (truncated) SVD, for example optimal estimation and Philipps-Tikhonov. As noted above, going to a formal profile retrieval has the benefit, that the algebra delivers the averaging kernels and that one becomes flexible to empirically tune the regularization strength instead of retrieving exactly 1 DFS (total column).

Figure 5: Do I understand correctly that the units for the vertical axis are fractions or is it differences as the caption says? Maybe, one could change the axis label to “measured/modelled” or “measured-modelled”, whatever applicable.

Figure 5: Do you think the fit could be improved by using a refined line-shape model e.g. including finer collisional effects or line-mixing or by using a dedicated cross-section database of the narrow wavelength band? I recommend adding a word on these spectroscopic effects in the manuscript.

Figure 7: The surface reflectance of 0.3 looks quite favorable for the experiment. Could you say a word on whether the conditions you encountered are representative of the performance for more extended sets of measurements e.g. over vegetation surfaces.

Figure 7: Could you add a horizontal axis for (approximate) travel distance?

Figure 8: It might be a bit misleading to plot the figure as a height profile since the individual data are representative for the "columns below aircraft" (if I understand correctly). If one wanted to derive the vertical profile, one would need to peel it out from the differences between consecutive data points, right? Maybe, you could guide the reader by putting a caveat into the caption?

Interactive comment on Atmos. Meas. Tech. Discuss., doi:10.5194/amt-2020-466, 2020.