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Review of "Atmospheric Carbon Dioxide Measurement from Aircraft and Comparison with OCO-2 and CarbonTracker Model Data" by Wang et al.

Anonymous Referee #1

Referee comment on "Atmospheric carbon dioxide measurement from aircraft and comparison with OCO-2 and CarbonTracker model data" by Qin Wang et al., Atmos. Meas. Tech. Discuss., https://doi.org/10.5194/amt-2021-92-RC1, 2021

Review of "Atmospheric Carbon Dioxide Measurement from Aircraft and Comparison with OCO-2 and CarbonTracker Model Data" by Wang et al.

The authors describe their approach on how to measure CO_2 mixing ratios and columns with an airborne LIDAR system. The study is motivated by addressing the limitations of fixed ground-based measurements and the limited spatio-temporal resolution of satellite measurements. Airborne measurements can have similar spatial resolution as ground-based measurements, and at the same time cover a larger area.

The study will be a valuable contribution to the community, and motivate others to use airborne LIDAR systems to infer CO_2 and probably other trace gases with high resolution on a regional scale. However, the manuscript needs a major revision because of some omissions that should be addressed in a scientific publication.

General comments and major points

1. The authors should give error ranges to all their average estimates, from the abstract to the conclusions, the values given in the text should have the form xxx.xx ± x.xx ppm, with an appropriate number of significant decimal places.
I'd suggest to round to 1 significant decimal place (xxx.x ± x.x) or at most 2 (xxx.xx ± x.xx), as too many can give a false impression of the precision.

2. The authors need to add units to all quantities, in particular the
ones used in the equations.

3. My major issue is the description of their "pulse integration method" with
a reference to an earlier paper using the same instrument. To my understanding,
what is described is not a pulse integration method, which uses the sum or average of
multiple pulses to increase the SNR.
Here the authors use "points on the pulse", which is something different.
Thus, the first paragraph in Sect. 3.2 needs to be re-written, it is not clear what the
authors did.
It would be helpful if the authors could provide an independent reference
that is not a self-citation.
Then, depending on the interpretation, Eqs. (8) and (9)
might have to be adjusted;
to my understanding in the case of un-weighted averaging,
the average variance is calculated by dividing by N, not by N^2.
As given, Eq. (8) resembles the standard error of the mean,
not the standard deviation as described in the text.
On the other hand, if the variance at each point is known,
then that is the variance of the signal, which gives the SNR.
Averaging points sounds as if the authors are binning in time.
But that has to be done for all points on the pulse, including the peak.
It does not make sense to average points before and after the peak,
and then to exclude the peak itself.
In addition, if the points before and after the pulse peak are averaged,
this average should be zero, as this amounts to averaging noise
as presented in Figs. 4--6.
If it is not zero, there might be additional terms from the variance
of the alpha values themselves.
In the case the authors use these points to get an estimate of the noise
in their signals to calculate the SNR in the first place, then this should
be described, and Eq. (8) should be replaced by the equation for the usual variance.
As a third option, the noise could be estimated from the residuals
after subtracting the matched filter signal.
Then, it is also not clear what quantities are averaged, the voltage?
How are alpha and sigma estimated?

Minor points and detailed comments

Abstract

- l 19: As mentioned in general comment 1, ± error ranges should be given.

- l 24: As mentioned in general comment 1, ± error ranges should be given.

- ll 26--27: Measurements can "indicate" but not "prove" something, which is a very strong statement.
  I'd suggest to remove "trend" and replace "which proved the existence of" by "showing".

Introduction

- Please re-introduce the acronyms again in the main text at their first appearance.

- l 42: Remove "the": "the methane" -> "methane"

- l 44: Change "vulnerable to the" to "affected by"

- l 80: Continue with "discussed in Sect. 3, and our conclusions are presented in Sect. 4."

Section 2

- Please add a few (1--3) sentences to motivate the measurements and data,
  i.e. why you need CarbonTracker when you have OCO-2 data?

Section 2.1

- l 84: "-1" should be a superscript in "h^-1"

- l 86: Please add the spectral resolution of the channels, also to table 1.

- l 87: Introduce "the": "the 532 and 1064 nm channels",
  remove "the": "detect the aerosols" -> "detect aerosols"

- l 90: Remove "our previous article": "described in (Zhu et al., 2020)."

- Table 1 should be on one page. Add a column with the spectral resolution.

Section 2.2

- Table 2 should be on one page.

Section 2.3

- l 126: typo: "UUGA" -> "UGGA"

- l 131: Insert "the": "the various types of surfaces."

- l 138: Remove "the": "at regional and global scales."

- l 139: Change "making coincident measurements" to "simultaneously measuring"

- l 142: Section 2.3.3 The authors should motivate their use of the CarbonTracker data, in particular since they also have OCO-2 data available.

Section 2.4

- As mentioned in general comment 2, all the quantities used in the equations should be given with proper units, SI or SI-derived.

- l 153: Replace "except" by "than"

- l 159: Use lower case "where" without a comma after it.

- l 162: Refer to Eq. (2) after "caused by CO2": "caused by CO2 (given by Eq. (2) below)"

- l 163: "detection signals" do you mean "monitor signals"?

- l 164: Insert "tau_CO2": "...of the CO2, tau_CO2, can..."

- l 167: Use lower case "where" without a comma after it.

- l 168: The sentence "R_G is the height ... aircraft platform." is the same as in line 160 and can be removed.

- l 169: Change "using" to "according to"

- l 172: Use lower case "where" without a comma after it.

- ll 172--173: What is R_v exactly? If I got it right, then it has the unit 1 / A, (A for Ampere), which does not look like a rate (~ 1 / s), and not like a power unit such as W or V·A (Volt·Ampere), as mentioned at the end of the sentence. Thus this is also related to my general comment 2 to add proper units to all quantities.

- l 173: Change "Therefore," to "Using Eq. (3),"

- l 175: Change to "detection signal voltages", or probably "monitor signal voltages", see comment on line 163.

- l 176: Change to "echo signal voltages".

- l 177: Change to "calculated using the following equations:"

- l 179, Eq. (6) upper and lower case "P" are used for pressure, please use the same consistently throughout the manuscript (see also the comment below)

- l 180: Use lower case "where" without a comma after it.

- l 180: Upper vs lower case "P" for pressure, in line 168 lower case "p" is used, please rectify to be consistent.

Section 3

Section 3.1

- l 194: Remove "Moreover": "No significant difference..."

- l 195: Change to: "over the residential and mountain areas."

Section 3.2

- The first paragraph "data processing" could be in the "methods" section.

- l 199: Refer to Eq. (2) after "DAOD".

- ll 199--211: As mentioned in general comment 3, this part needs to be rewritten and better explained what was done. As I read it, the authors bin the signal of a single pulse, but do so differently for the background noise ("before and after the peak") and the actual peak signal, where no averaging is indicated. In addition, Eqs. (8) and (9) might need to be adjusted.
  What quantities are alpha and sigma?
  What are N and k exactly, and what is denoted by the superscript l?

- ll 214, 216, 222--223: As mentioned in general comment 1, ± error ranges should be given.
  Please use the same order of ocean, residential, and mountainous areas for tau, IWF, and XCO2 consistently.
  If I use Eq. (5) with the values of tau and IWF as given, I get different results for XCO2, could the authors clarify?

Section 3.3

- l 226: The first sentence should be removed.

- l 229: Replace "because it produced errors and sudden spikes" by "because of sudden spikes"

- l 229: Insert "associated": "the associated sudden pressure changes."

- l 230: Consider replacing "concentration" by "volume mixing ratio",
concentration can be confused with the more typically used molar concentration
with units of mol / m3.
It is also possible to introduce the acronym "vmr" at the same place and use that
instead of "concentration" later on.

- l 230: Remove "the": "is largest".

- l 232: Remove "the": "in northeast China", and "Moreover, northeast China..."

- Table 3: Consider adding a column for the measured XCO2 values for an easier overview

- l 239: Remove "to be": "was likely caused by"

- l 243: What is shown in Fig. 16 exactly? Consider indicating the boundary layer height
as mentioned in the text.

- l 246: The reason needs to be strengthened, a similar variation or trend
alone does not imply a good agreement. There good be a large bias between the two.

- l 247: Consider replacing "concentration" by "volume mixing ratio", see comment on line 230.

- l 247: Remove "the": "is highest"

- ll 248--249: As mentioned in general comment 1, ± error ranges should be given.

- l 250: Remove "relatively"

- ll 251--252: This is a general statement, what exactly does it imply for the UGGA vs ACDL comparison?
  Is it feasible to compare them or not?

Section 3.4

- l 257: typo: "were removed."

- ll 257--258: As mentioned in general comment 1, ± error ranges should be given.

Section 3.5

- l 266: Replace "more" by "higher".

- ll 266--267: Be careful with the term "upper atmosphere", which usually refers to altitudes above 50 km, or sometimes 100 km.
  I suggest to use "atmosphere above" instead.

Conclusions

- l 274: Remove "relatively"

- ll 275--279: Related to general comment 3, this part should be improved to describe the method better. Please consider the following question:
  Is this part of the method essential to the results of the paper?
  In my opinion these details could be removed from the conclusions as they are very specific to the instrument used.

- ll 281--282: As mentioned in general comment 1, ± error ranges should be given.

- l 283: Remove "the": "was largest"

- ll 283--289: Consider replacing "concentration" by "volume mixing ratio", see comment on line 230.

- l 286: Is it variation or trend? As commented on line 246, neither a similar variation nor a similar trend imply a good agreement. The authors should discuss their definition of agreement, in particular with respect to a potential bias.

- l 288: Remove "relatively"

- ll 289--290: This is a general statement, is that a conclusion of the paper connected to the particular measurements? This sentence should be better connected to the method and the rest of the paper.

Figures

- Fig. 3: Add a label to the x-axis, probably "time".
"distance measured by the lidar", distance between what?
If it is the distance between the plane and ground, that should be described.
Last line: "dividing line for different".

- Figs. 7--9: Include axis labels with units for all panels (a).
The panels (b) need to be reconsidered after addressing general comment 3.
What units are used for SNR?

- Figs. 10--12: Replace "in" by "over": "XCO2 results over ocean..."
Add a label to the x-axis, probably "time".
By referring to Fig. 10, the last two sentences in the captions of Figs. 11 and 12 can be removed.

- Fig. 14: Legend: There is no need to list the values with 4 decimal places if the error range has only 2. Please round to 2 significant digits on both,

too many will give a false impression of the precision.

- Fig. 15: Designate the lines as "lines", i.e. "blue line", "black line", and "red line".

- Fig. 16: Add a label to the x-axis, probably "time".

- Fig. 17: Add a label to the x-axis, probably "time".
Use the same scaling for IPDA XCO2 and UGGA CO2 to make them better comparable in absolute terms.

- Fig. 18: Put (a), (b), and (c) on one page, include panel indicators (b) and (c) in the second row.

- Fig. 19: Consider replacing "concentration" by "volume mixing ratio", see comment to line 230.
Include the dates in the panels or as column headers to make it easier to find which panel shows the measurements from a certain date.
"Red and blue scatter" is better referred to as "red and blue errorbars".