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Atmospheric Measurement Techniques Discussions

Interactive comment on "An airborne amplitude-modulated 1.57 µm differential laser absorption spectrometry: simultaneous measurement of partial column-averaged dry air mixing ratio of CO_2 and target range" *by* D. Sakaizawa et al.

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Dear Dr. C. Frankenberg,

We thank the referee for fruitful suggestions, especially for suggesting the better terms and sentences. We have revised the manuscript on the basis of the Referee's

comments.

We look forward to a publication of our manuscript in AMT.

Sincerely,
Daisuke Sakaizawa

‡ **Bold fonts** means review's comment.

Specific comments:
Nomenclature:
I find the symbol q (with a bar) somewhat misleading, why not use XCO_2 as column averaged mixing ratio (as is done in most of the column average remote sensing and ground-based community)? This would help avoid some misunderstandings (even though you only plot partial columns but you could indicate this by a superscript indicating the actual height up to which is integrated)

Answer:
According to the reviewer's comment, $\bar{q}$ (representing "weighted" column averaged mixing ratio) has been changed from $\bar{q}$ to XCO_2.

Page 4852:
Line 7:
The high correlation is mainly caused by variations in topography, not CO_2. Depending on the kind of terrain you are flying over, it is very easy to get good correlations but is not necessarily a proof that you can measure XCO_2 well (see later comments)

Answer:
In accordance with reviewer's comment, we rewrote Fig. 8 and changed the following text on p. 4852 line 7:
"Simultaneous measurements of the partial column-averaged dry air mixing ratio of CO_2 (XCO_2) and target range were demonstrated using airborne amplitude-modulated 1.57 μm differential laser absorption spectrometer (LAS). The LAS system is useful for discriminating between ground and cloud return signals and has a demonstrated ability to suppress the impact of integrated aerosol signals on atmospheric CO_2 measurements. A high correlation coefficient (R) of 0.987 between XCO_2 observed by LAS and XCO_2 calculated from in-situ measurements of CO_2 was obtained."

Line 13:
"highly distributed": do you mean "enhanced"?

Answer:
We have changed "highly distributed" to "enhanced".

Line 17:
Please provide a reference for this statement, it seems rather vague and not fully justified.

Answer:
We agree with the relevance of this comment, and have added references.
"A global carbon cycle study using higher spatial resolution than an $8^\circ \times 10^\circ$ grid is currently required to improve the knowledge of the carbon cycle (Rayner and O'Brien, 2001; Baker et al. 2011). Transport models and observational data sets improve evaluations of regional carbon fluxes (Maksyutov et al. 2008)".

Page 4853:
line 5: There are more original references to GOSAT (e.g. Kuze et al and Hamazaki et al; you have GOSAT scientists on the team, please consult with them

Answer:
We agree with the relevance of this reviewer's comment, and made additions to the discussion and references.
Original:
The Greenhouse gases Observing SATellite (GOSAT) is the first step in dealing with the above-mentioned issue (Yoshida et al., 2011; Palmer et al., 2011). The sensors on board the GOSAT, GOSAT-2, the Orbiting Carbon Observatory (OCO), and OCO-2 are based on a passive remote sensing technique (Kuze et al., 2009; Crisp et al., 2012; Eldering et al.2012).
Modified:
The Greenhouse gases Observing SATellite (GOSAT) is the first step in dealing with the above-mentioned issue (Kuze et al., 2009; Yoshida et al., 2011; Palmer et al., 2011). The sensor on board the GOSAT is based on a passive remote sensing technique.

line 9:
precision or accuracy?

Answer:
We mean precision. As noted in a recent paper (Morino et al., 2011) published by the NIES-GOSAT validation group, we use both the precision and accuracy. The uncertainty that is the quadratic summation of precision and accuracy.

line 17:
Please rephrase, it sounds as if NIR spectrometers are essentially useless (which is not the case).

Answer:
In accordance with the reviewer's comment, we have changed following the text on line 17.

Before:
"In contrast, active optical remote sensors are valuable for near-future trace gas mea-

surements from space."

Modified:
"In contrast, active optical remote sensors as a differential absorption spectrometer are less impact by the above factors on atmospheric CO_2 measurements."

line 25: "at a specific position *to* less than..."

Answer:
We mean "at a specific position with a precision of less than 100 kHz"
We have modified the line as follows:
"Although in a pulsed system aerosol or cirrus clouds have less impact on total column measurements, the pulsed-laser wavelength must be stabilized at a seeding laser wavelength with a precision of less than 100 kHz to reduce error due to wavelength stability, which requires large resources."

line 20:
iwf is a somewhat unfortunate symbol I think.

Answer:
We have removed "iwf", and combined equation (4) with equation (3). We have changed the symbol of the weighting function "wf(r)" to "w(r)".

Page 4856
Line 2:
Water vapor may be highly variable. What is you estimated error induced by this uncertainty (same holds for changes in surface pressure)?

Answer:
We describe the error due to water vapor, temperature, and pressure on p.4856 line 10. The error is 0.16% (described on p.4856 line 14). Of the total error, the breakdown is as follows: 0.1% atmospheric temperature (uncertainty of 1 K), 0.12% atmospheric pressure (uncertainty of 1 hPa), and 0.06% relative humidity (uncertainty of 20%). We

have also evaluated the bias error due to surface pressure as 0.035% for measurement accuracy of 5 m.

Page 4861:
line 24:
spectroscopy error of "0.13%"! How do you know this error to two digits? It seems very low. How would a deviation from a Voigt line-shape (speed dependent line-shape, line-mixing, etc) play into your retrieved column?

Answer:
As pointed out by the reviewer, the error of the line parameters itself is larger than 0.13%. We mean that the value is the uncertainty of the integrated weighting function "w(f)" using the spectroscopic parameters (line-intensity, air-broadening coefficient, pressure shift coefficient, and temperature dependence of air-broadening coefficient) published in recent studies. We have changed the following text on lines 23 – 24,
"The bias error due to the spectroscopic data for the CO_2 R(12) line was estimated to be 0.13%; the spectroscopic data were taken from recent studies (Devi et al., 2007; Rothman et al., 2009; Predoi-Cross et al., 2009)."

The difference between forward transmittances without and with the line-mixing effect was less than 0.05% from the ground to the aircraft height. Accounting for the differential absorption, the influence of line-mixing and other effects in the 1.6 μm region was also less than 0.05%. We considered quantification of the error due to Voigt-shape to be necessary to evaluate the atmospheric CO_2 remote sensing performance. The contribution to the effect was less than other deviations for the atmospheric parameters, wavelength fluctuation, and signal SNR. This result was for the 1.6 μm wavelength region as denoted in a recent paper (J-M Hartmann, et al. Atmos. Chem. Phys. 9 7303 – 7312, 2009).

Page 4862
line 8:

Did you plot sub-columns in Figure 9? I.e. did you also integrate the profile for the in-situ data (up to the respective height of the LAS system)?

Answer:
Yes, we plotted XCO_2 (both LAS and in-situ) from the ground to the aircraft height. We integrated XCO_2 from in-situ data points shown in Fig. 9 from the ground to the airplane height.

line 17-18:
"return from nearby airplanes": don't understand what you mean return from nearest overlapping area between transmitting and receiving optics.

Answer:
We agree that this point requires clarification, and have changed the following text on lines 17-18: "return from nearby airplanes" $\rightarrow$ "nearest area less than 500 m from the aircraft (the overlapping function between the field of view of receiving optics and transmitting laser beam becomes unity after 500 m)".

Page 4864
line 3:
"significant similarity": You didn't really show this yet though I think you should be able to easily do this. First of all, it is somewhat unclear what you mean by q profile (as all of those are sub-column just with a different integration ceiling). Looking at your figure 9 and table 3, you should be able to create a correlation plot of XCO_{2LAS} and XCO_{2VAL} using data points for different days and flight altitude (ideally, days and heights are somehow visible in such a scatter plot, e.g. by using different symbols per day and height indicated by color-scaling). If you can show how well these correlate (maybe exclude the 2009 flight as it has so much less CO_2), you can really strengthen the manuscript and corroborate your claims (with the naked eye, it looks like they should but it is not easily obvious from your plots).

Answer:
According to the reviewer's comment, we rewrote Fig. 8 by using XCO_2 instead of $\Delta\tau$. Please refer to amt-2012-100-supplement.pdf (page 1) for revised Fig. 8.

Figure 5 (and 6): Is the lowest panel really the difference between the two curves in the second lowest panel? differences of only about 20m seem very low and judging by eye, the scatter looks larger. Also: How many XCO_2 measurements did you get per day? Judging from Fig 5, you should be able to record quite a lot per day but you don't seem to show them. Why can't you show a plot like Fig 5 and 6 and also plot the retrieved XCO_2 along the track? This would make it much more convincing, otherwise it looks like some data points are "hidden". This is a crucial point I think! If noise is an issue, you can smooth the XCO_2 time-series.

Answer:
Previous Figs. 5 and 6 had indicated uncorrected flight data including the case when the aircraft was tilted (displayed tilted data are not corrected by the pitch-yaw-roll angle). We corrected Figs 5 and 6. The revised Figs. 5 and 6 display all data points after correction, but the correction is imperfect due to a timing mismatch between the flight data and observed LAS data.

We missed to indicate that XCO_2 is retrieved from the averaged $\Delta\tau$ among nadir or near-nadir viewing data, and does not include off-nadir viewing or imperfect viewing corrected data. In order to reduce the deviation of $\Delta\tau$, we averaged all measured $\Delta\tau$ during each level flight. The nadir viewing data were collected from decent spiral measurements taken only on a level flight during when the aircraft was circling. We also indicated XCO_2 at specific altitude during the spiral flight measurements over the Moshiri, Tsukuba, and Koganei-sites; this does not represent the averaged value per day. The reason was to compare XCO_2 from LAS with XCO_2 from in-situ with reliable atmospheric parameters by radiosonde measurements.

However, we agree that additional information on XCO_2 along the track as suggested

by the reviewer would be quite valuable. We are now investigating this consideration and intend to report our result in a later paper.

Please refer to amt-2012-100-supplement.pdf (pages 2 and 3) for revised Figs. 5 and 6.

Please also note the supplement to this comment:
http://www.atmos-meas-tech-discuss.net/5/C2981/2012/amtd-5-C2981-2012-supplement.pdf

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Interactive comment on Atmos. Meas. Tech. Discuss., 5, 4851, 2012.