

amt-2018-376 Submitted on 23 Oct 2018

Development of a balloon-borne instrument for CO₂ vertical profile observations in the troposphere

Reply to the comments by Editor and Referees

Comment by Editor

I congratulate you to the fact that both referee reports indicate that your paper is well suited for publication after some technical corrections. Please take their comments into account and update the document accordingly. I would also like to point out two issues that might or might not relate to the observed discrepancy between the NDIR instrument and the airplane profiles.

(reply)

I appreciate the editor for the valuable comments. We have considered the comments carefully and revised the manuscript.

First, the abstract is misleading since it compares laboratory calibrations between 1010 and 250 hPa and aircraft data up to altitudes up to 7 km (500 hPa). It emphasises on the agreement in that range even though data from higher altitudes exist, albeit with discrepancies on the claimed accuracy level. This should be clearly stated in the abstract and in the main text, as pointed out by one of the referees.

(reply)

The comparison with in-situ aircraft data was conducted for the altitude range up to 7 km because the JAXA/NIES chartered aircraft data were available up to approximately 7 km. We have added the following sentences in the abstract and main text.

(page 2, lines 31-37)

Two CO₂ vertical profile data obtained using the CO₂ sondes, which were launched on January 31st and February 3rd, 2011 at Moriya, were compared with the chartered aircraft data on the same days and the commercial aircraft data obtained by the Comprehensive Observation Network for TRace gases by Airliner (COTRAIL) program on the same day (January 31rd) and one day before (February 2nd). The difference between the CO₂ sonde data and these four sets of *in-situ* aircraft data (over the range of each balloon altitude \pm 100 m) up to the altitude of 7 km was 0.6 ± 1.2 ppm (average $\pm 1\sigma$).

(page 20, lines 471-474)

“It is noted that, although error estimation was conducted for the data up to an altitude of 7 km due to the availability of the chartered aircraft data, the CO₂ sonde data above 7 km up to about 10 km. The measurement errors for the data above 7 km are expected to be larger than the above estimation.”

Second, eq. (1) is strictly valid only for high resolution spectra at individual wavelengths. From this, the NDIR signal can be obtained by spectral integration, but this certainly will lead to a deviation from the law, taking into consideration that the strongest transitions will be saturated. Also, if one applies the series expansion in eq (2), one expects a relative error on the order of about 1 to 2% (4 to 8 ppm at 400 ppm). This is quite large compared to the intended measurement accuracy. It would be important to point out these inherent methodological drawbacks and explain why they dont matter in the current application.

(reply)

Thank you for the comments. Although saturation of the total signal intensity due to strong transitions potentially occur, the effect is not critical for the certain concentration range as can be seen in Figure 4. We have added the following sentence in the revised manuscript.

(page 8, lines 179-182)

“Although the NDIR analyzer potentially exhibits non-linear absorption due to the saturation of strong absorption lines, the NDIR analyzer is known to have a good linearity within a certain concentration range [Galais et al. 1985]. In our analyses of the balloon data, eq. (1) was used only for the interpolation between the low and high mole fractions of the in-flight calibration gases to obtain the ambient CO₂ mole fractions.”

As pointed out by one of the referees, the English could be improved at instances. Dont hesitate to ask a native speaker for checking the manuscript once again.

(reply)

We have checked and corrected the English throughout the manuscript. We already got commercial scientific English proofreading for our manuscript and spent about 600 US dollars.

Technical comments

Has the acronym NDIR been defined ?

(reply)

It is defined in line 51 in the introduction of the revised manuscript.

Abstract/ please follow the recommendation of the second referee concerning the abstract and include the instrument performance in the document.

(reply)

The following sentences have been added in the abstract.

(page 2, lines 31-37)

“Two CO₂ vertical profile data obtained using the CO₂ sondes, which were launched on January 31st and February 3rd, 2011 at Moriya, were compared with the chartered aircraft data on the same days and the commercial aircraft data obtained by the Comprehensive Observation Network for TRace gases by Airliner (COTRAIL) program on the same day (January 31rd) and one day before (February 2nd). The difference between the CO₂ sonde data and these four sets of *in-situ* aircraft data (over the range of each balloon altitude \pm 100 m) up to the altitude of 7 km was 0.6 ± 1.2 ppm (average $\pm 1\sigma$).”

L 27 - 29. The phrase is difficult to understand. Maybe you should regroup : Vertical profiles of atmospheric CO2 can be measured with a 240-400 m altitude resolution through regular onboard calibrations using two different CO2 standard gases.

(reply)

We have revised the sentence following the comment.

L 31 - 32. This sentence is not clear. Please revise.

(reply)

This sentence has been revised as follows.

“The difference between the CO₂ sonde and *in-situ* aircraft data up to the altitude of 7 km was 0.6 ± 1.2 ppm and within the precision of the CO₂ sonde.”

L 180 proportional constant -> proportionality constant

L 530 frequently -> frequent

(reply)

We have replaced these words according to the comments.

L 531 any parts of the world. This is probably too optimistic considering safety regulations. You should replace "any" by "many"

(reply)

We have replaced this word according to the comment.

L 534 will help improve -> could help improve. Depending on the satellite program, a bias on the order of 1 ppm or larger might be too large for validation.

(reply)

We have replaced this word according to the comment.

Comment by Anonymous Referee #1

The authors reply to the question "Why was the dehumidifier not placed in front of the pump to avoid a wet pump that may be a contamination source of CO₂?" explains how the dehumidifier vessel is used as a buffer to reduce pressure variations; however, this can be replaced by any type of buffer. The main concern is that a wet pump may be a contamination source, which has not been addressed.

(reply)

I appreciate the reviewer for the positive comments. Temperatures in the CO₂ sonde are higher than those outside due to the heat produced by the NDIR lamp, pump and solenoid valves as described in lines 251-255 (in the revised manuscript), and the RH in the pump is lower than those outside. Therefore, we do not need to concern about the contamination due to the condensation of water vapor in the pump.

Anonymous Referee #2

This work describes an atmospheric measurement technique, specifically the measurement of CO₂ mole fraction using a balloon-borne sensor, enabling CO₂

measurements through the troposphere. There are not a lot of ways to accomplish this measurement using a sensor light-weight enough to be able to be flown without specific FAA approval or waiver. These measurements would be valuable to the CO₂ measurement community. I believe it should be published in AMT because for me it satisfies the requirements there: 1) it is a new technique 2) it is described adequately 3) the paper includes estimates of uncertainties.

One reviewer previously objected to the paper because the instrument may not give measurements of sufficient accuracy as to be useful for certain studies (carbon cycle). I do not think it is more suitable as a technical note, and believe it should be published in AMT so it is in the open literature, as have been other papers using low-accuracy / low-precision CO₂ measurement systems (e.g. Shusterman et al., 2018; Martin et al., 2017). I would argue that a user would need to decide whether this instrument would have the accuracy to meet their science requirements.

(reply)

I appreciate the editor for the valuable comments. We have considered the comments carefully and revised the manuscript.

I do agree with the reviewer; however, that the authors must be honest about statements that are made in the manuscript regarding the accuracy and applicability of the measurement to different science questions, and that the uncertainties must be expressed honestly and not misrepresented (which I believe has been done here). I would also recommend the authors insert the uncertainty metrics below 7 km in the abstract itself, so that the reader quickly knows the final result, and that the manuscript includes the cost of the parts for the disposable sonde.

Overall, I believe the authors addressed the original reviewer comments sufficiently to warrant publication. I believe they have represented the accuracy of the system properly, and would only want the cost estimate to be included, because that is another very important piece for these measurements, as they are being offered as an alternative to aircraft flights that have been shown to have higher accuracy.

(reply)

Thank you for the valuable comments. We have added the information on the uncertainty metrics in the abstract and cost in the main text as follows.

(page 2, lines 31-37)

“Two CO₂ vertical profile data obtained using the CO₂ sondes, which were launched on

January 31st and February 3rd, 2011 at Moriya, were compared with the chartered aircraft data on the same days and the commercial aircraft data obtained by the Comprehensive Observation Network for TRace gases by Airliner (COTRAIL) program on the same day (January 31rd) and one day before (February 2nd). The difference between the CO₂ sonde data and these four sets of *in-situ* aircraft data (over the range of each balloon altitude \pm 100 m) up to the altitude of 7 km was 0.6 ± 1.2 ppm (average $\pm 1\sigma$)."

(page 13, lines 297)

"A prototype of the CO₂ sonde is available from Meisei Co. Ltd. (Isesaki, Japan) with about \$4,500."

Notes:

The English is still a bit awkward in several places. Through the text (e.g. L449, Table 2) sometimes "concentration" is used instead of "mole fraction", this should be checked throughout.

(reply)

We have checked and corrected the English throughout the manuscript. We already got commercial scientific English proofreading for our manuscript and spent about 600 US dollars.

Re L34-35, I agree with the authors response that they can claim the measur ements are "useful". There are certainly applications where they would be useful, the accuracy does not need to be better than that of global models to be considered useful (one might be interested in much smaller-scale variability of CO2 than such a model can achieve, such as within boundary layer variability).

(reply)

Thank you for agreeing with our suggestion.

L47 Winderlich is misspelled I believe

(reply)

We have corrected the typo.

L 84-85: The NOAA aircraft program (Sweeney et al) is neither short-term nor limited to

near large airports, so this sentence should be modified. (12 flasks are sampled from 0-8 km every two weeks at sites across the US).

(reply)

We have revised the sentence following the comments.

(lines 89-91)

“Although these aircraft measurements provided the vertical profiles of CO₂ concentrations, vertical profile measurements using the commercial airlines are limited around the large airports and frequency of the measurements using chartered airplane is often limited by their relatively high cost.”

L 118: I agree with a previous reviewer that more discussion of cost and recoverability should be made here. If a user must spend \$4000 per flight, that is pretty significant. This cost estimate should be in the manuscript (not just in the reviewer response), even if it is a crude estimate of the cost of parts only. I am not sure it can compete with hiring a charter pilot to do the profile and getting permission from the FAA to fly a small airplane is trivial (for a pilot). (L121).

(reply)

We have added the following sentence in the revised manuscript.

(page 13, lines 297)

“A prototype of the CO₂ sonde is available from Meisei Co. Ltd. (Isesaki, Japan) with about \$4,500.”