

Measurement of Atmospheric CO₂ Column Concentrations to Cloud Tops with a Pulsed Multi-wavelength Airborne Lidar

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General Comments:

The authors describe use of a pulsed integrated-path, differential absorption lidar to measure CO₂ column abundances between an aircraft and various cloud decks and the ground. Measurements are compared with in situ measurements taken aboard the same aircraft. The “cloud slicing” technique provides advantages relative to passive measurements of CO₂ in that CO₂ column amounts can be measured in the presence of cloud fields, which is currently not possible with passive instruments. The manuscript is clear, concise, and well-written. I recommend publication with only minor changes and clarifications as described below.

Specific Comments:

P. 3, L. 22: In the text discussing figure 2, there is no description of the line shape calculation. From what altitude were the met parameters obtained for use in calculating the line shapes? Were these parameters obtained in an aircraft spiral (which is implied later in the manuscript, but not in this section)? If they were obtained via aircraft spiral maneuver, what is the spatial and temporal separation between this CO₂ line retrieval and the sampling spiral?

P. 7, Line 39: I found this paragraph and Figure 12 difficult to follow, and it may need clarification for readers not familiar with the measurement. I suggest clarification in this section that the lidar measurements are column integral measurements, and that the in situ measurements plotted in figure 12 are point measurements at each altitude. For clarification, can the plot include the integral value of the in situ measurement at each altitude that the lidar is being compared with for a more direct comparison? Otherwise, the reader needs to do a mental integral to verify that indeed, the lidar and in situ columns agree at the top of the cumulus clouds (~1.7 km) even though the lidar column value of 393 ppm is very different than the in situ point value of ~385 ppm at that altitude.

P. 19, Figure 6: Why are there no ground returns below the lowest cloud deck on this figure?

P. 22, Figure 9: the CO₂ sounder instrument measurements show a steady trend of decreasing CO₂ with decreasing altitude, in agreement with in situ measurements, but the CO₂ sounder measurements clearly show an end to the drawdown trend in the lowest altitude bin, with the in situ data clearly showing a continuing drawdown. Is there an explanation for the ~4 ppm high bias of the remote measurement relative to the in situ measurement at this altitude?

Technical corrections:

P. 1, L. 13: multiple wavelengths should be multi-wavelength

P. 1, L. 34: present should be presence

P. 2, L 3: recommending adding citation for NRC report in references list

P. 2, L 8: suggest adding “and other targets” after cloud tops since ranging applies to the ground measurements as well.

P. 2, L 33: Should “after passing through” be replaced with “pass through” to be clear that the NB filter is after the receiver telescope and not before it?

P. 3, L. 15: need to add “being” after “before”

P. 4, L. 6: need “the” before “field-of-view”

P. 4, L. 29: by “quality” do the authors mean high precision or high accuracy? What is the definition of quality?

P. 5, L. 5: what is the definition of “sufficient backscatter”? Is there some metric relative to the noise floor that is used as a discriminator?

P. 5, L. 33: Reinecker et al., 2008 is cited in the text but the reference list only includes Reinecker, et al., 2015.

P. 5, L. 36: Should “weighed” be “weighted”?

P. 5. L. 45: please define TCCON.

P. 6, L. 4: recommend adding citation for Jucks, et al., in references list

P. 6, L. 12: suggest changing west side of continents to west side of the United States for clearer context.

P. 6, L. 22: the standard deviations of the two high-altitude and one low-altitude data points appear to be larger than 2-3 ppm as stated, perhaps 2-5 ppm. Can the authors verify this stated range?

P. 6, L. 23: please define AVOCET

P. 6, L. 23: should be “are” after signals

P. 6, L. 40: as stated for line 22 above, the standard deviations of the one low-altitude data point appears to be larger than 3-6 ppm as stated, perhaps 3-10 ppm. Can the authors verify this stated range?

P. 7, L. 1: need “with” after “results”

P. 8, L. 30: I recommend adding some quantitative results to this section such as accuracy and precision values relative to correlated in situ measurements. The conclusion section is mostly a restatement of the introduction without quantitative results.

P. 8, L. 37: that statement about which cases are excluded due to proximity to cloud tops and aircraft tilt would be useful at the beginning of the manuscript, perhaps in section 2.0.

P. 11, L. 23: Ramanathan, et al., 2013 does not appear to be cited in the manuscript text.

Pgs. 16-17: Figures 3 and 4: are there nadir camera images from the flights that could be added to these figures to provide a visual description of the cloud fields? The pictures on figures 6 and 8 are very helpful for describing the cloud field and should be included with figures 3 and 4 if possible.

P. 20, Figure 7: Is the range value in meters here? Suggest adding the unit. What is the definition of the red dotted line (not defined in the legend)? I suggest using thicker lines in the plot for increased readability, and adding the word “dense” before “cloud top” in the caption.

P. 21, Figure 8: AVOCET should be all caps in the legend. In line 2 of the caption, do the authors mean “altitude intervals” instead of “attitudes”?

P. 25, Figure 12: suggest adding “(shown as red dashed line)” at the end of the caption to define the red dashed altitude line in the plot.