Interactive Comment on **"Ground-based integrated path coherent differential absorption lidar measurement of CO_2: hard target return", by S. Ishii, M. Koyama, P. Baron, H. Iwai, T. Itabe, A. Sato, and K. Asai**

This manuscript describes an investigation that is relevant to Atmospheric Measurement Techniques Discussions. The authors describe experimental measurements of atmospheric CO_2 mixing ratio using a differential absorption lidar in two modes: IPDA and range-gated DIAL. This is an interesting and useful measurement technique. The scientific community encourages the development of high-precision CO_2 measurement techniques that are used in a remote sensing mode, complementing *in situ* methods. The authors discuss their results in terms of measurement precision achieved using each of the two modes. The results indicate that the two modes yield mean values of CO_2 mixing ratio that agree to well within the measurement random error, which is encouraging. Correlative measurements using an *in situ* CO_2 sensor are also described briefly.

The paper does have some issues that need clarification. I'll begin with a couple of high level comments. First, the Title is not fully representative of the work described. As stated above, the measurements reported here include range-gated DIAL using the atmospheric aerosol to provide the backscatter. These measurements receive as much attention as the topographic (hard target) IPDA measurements. Second, the Conclusions are unfinished, leaving the reader with questions that the authors should clarify in their paper. What are the near-term and/or longer-term future applications that the authors have in mind that are consistent with their concluding statements regarding Q-switched lasers and simultaneous hard target and atmospheric return measurements? IPDA as a space-based global-scale measurement technique is emphasized in the Introduction. However there is no further discussion of the requirements relating to this application. On the other hand, future applications of the ground-based measurements using scanning capability may be in the authors' minds, but this is not clear either.

Below are several specific comments that hopefully will stimulate clarification and refinement of the presentation and the assumptions underlying the data comparison.

Specific Comments:

Abstract:

(1) Why do your results indicate that a Q-switched laser is important? What unique properties of a Q-switched laser are essential? Also, in what measurement context are you assuming that "it is better to simultaneously conduct both hard target and atmospheric return measurements…"? I assume that you're thinking of ground-based local/regional measurements in urban areas, not global measurements from Earth orbit. Please clarify.

(2) The statement is made both here and in the Conclusions that a lidar with high prf laser (few tens of kHz) is (or "may be") necessary for 1-2 ppm precision. Why?

Do you consider it important or essential to obtain CO_2 measurements on time scale of a few seconds rather than ~5-10 minutes?

1. Introduction:
(1) lines 27,28: referring to the passive sensor: "…..therefore, it tends to overestimate the optical depth of aerosols and to underestimate that of thin clouds.? This is not correct as written. Please clarify.
(2) "A differential absorption lidar is not affected by the presence of aerosols and clouds….." This is not true as stated. Aerosols and clouds provide backscattered signals to a DIAL system. This should be re-worded or removed. You must be referring to an IPDA system here.

2. Coherent 2-micron differential absorption and wind lidar:
(1) The 1 MHz absolute frequency stability of the injected pulsed laser is very good, certainly sufficient for high-precision CO_2 measurements.
(2) "The interferences due to the presence of other atmospheric gases are almost negligible." This is ambiguous. Please be quantitative, maybe by providing a statement that they contribute less than a particular equivalent CO_2 DAOD. Water vapor is likely the most probable. Since your weather station provides Relative Humidity, do you account for water vapor in your analysis?

3. Estimation of CO2 and Error Analysis:
(1) Equation (2): Another factor $ct_p/2$, where t_p is pulse duration, is needed in this equation to account for the fact that the distributed aerosol backscatter is coming from an integrated column at any given time. Although not stated, this reviewer assumes the usual units for beta, $\beta(R)$, i.e. $m^{-1}sr^{-1}$.
(2) Equation (5): Define N_{air}.
(3) Equation (5): "The CO_2 volume mixing ratio…" Is this the dry air CO_2 volume mixing ratio?
(4) State explicitly that sigma, σ, depends on p, T.

4. Ground-based in situ measurements
(1) "…which leads to a total error of 0.1% in the CO_2 volume mixing ratio…." Cite your equation (10). This applies to the atmosphere near the NICT building; however variability in these atmospheric parameters along the measurement path may result in additional uncertainty.

5. Experimental hard target measurement:
(1) "We used the range resolution of 150m to avoid speckle-induced intensity fluctuation for determining a correct range." Please clarify this with some additional text.
(2) Page 8590, line 3: I believe this would be improved by stating "…..for the three shot pair cases."

(3) lines 7-10, beginning with "The relative error of the DAOD…" Please explain/clarify. …two times lower than the minimum..??
(4) line 19: "Therefore the N_C for the hard target return is limited to improving the SNR." Please clarify the intending meaning of this statement.
(5) lines 25-28: Please clarify. I assume you believe that increasing the number of shot pairs in the measurement will continue to decrease the relative random error, with a laser having a prf of a few tens of kHz being necessary in order to attain the goal of 1-2 ppm relative error within a convenient measurement duration
(6) Page 8591, line 14: Here you state that you used the slope method. What alternate algorithm would be practical for detecting/identifying localized plumes at locations along your path? What is your estimate of the minimum detectable localized rise in CO_2 due to an emission plume?
(7) Page 8592, lines 16-21: I assume that your "..fluctuation of the DAOD due to the decrease in the CNR" refers to the variable atmospheric aerosol backscatter coefficient, the value of which depends on the variable aerosol sources and the atmospheric conditions. Please clarify.

6. Conclusions:

As stated in my general comments, the conclusions should be strengthened, made more meaningful, by tying your results to some high-level objectives of an application (e.g. precision, measurement time scale, spatial resolution), whether it's ground-based urban studies, global-scale measurements from Earth orbiting platform, or some other application.

Last sentence: "….has a great advantage in terms of discussing uncertainty due to the presence of aerosols and clouds." ?? Do you mean to say "reducing uncertainty"?