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Atmospheric Measurement Techniques Discussions

Interactive comment on "Evaluation and enhancement of a low-cost NDIR CO_2 sensor" *by* Cory R. Martin et al.

Anonymous Referee #2

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General comments

This study characterizes the performance (accuracy, precision, drift) of one type of low-cost CO2 sensor for ambient air measurements. The paper describes an experiment where duplicate sensors are used to make continuous ambient measurements in an environment with conditions that change slowly over time. Ambient pressure, temperature, and humidity are monitored simultaneously and used to derive empirical corrections for individual sensors, which significantly improve the accuracy of the final datasets. The overall experiment is well-designed and the analysis of the resulting data is sound.

The paper topic is highly relevant and potentially useful to the broader atmospheric measurement community, but currently falls short of that potential. There are several

additional experiments and analyses one could imagine that would fit in the same paper and would improve the scope and significance, such as: (i) test whether a unique correction is needed for each unit and what the uncertainty would be if a generalized correction were applied, (ii) demonstrate an experiment which would allow correction factors to be rapidly derived in the lab, (iii) test the K30 in a real-world environment, (iv) test the K30 for long-term drift. At a minimum, it appears that the authors can use the existing dataset to address point (i).

Specific comments

Los Gatos Instrument

You use the LGR dataset as a control, but I am concerned that there could be large uncertainty associated with the LGR water correction. Do you know the accuracy of the LGR water correction? I have never seen an assessment of it.

You calibrate the instrument with two points by assuming a linear fit. How do you know the true instrument response is linear?

How did you decide to measure the tank at 23 and 47 hour intervals? How do you know that significant drift did not occur over shorter intervals?

Why do you need to measure the tank for such long time periods (10-60 minutes)? Does it take that long for the measurement to equilibrate? If you are using the proper materials in your plumbing, the measurement should equilibrate in a matter of seconds to minutes. If it is taking a long time for the CO2 signal to equilibrate, that suggests that CO2 may be absorbing/desorbing onto the walls in your plumbing.

What is the purpose of the Dasibi calibrator? Did you have to dilute the tank air to get ambient values?

Figure 3: If you take the linear trend out, are the remaining variations related to a physical parameter such as temperature (ambient or cell)?

Your drift correction technique of fitting a line to each subsequent pair of calibration points will introduce discontinuities into the corrected dataset that do not represent the real-world. It would be better to fit a smoothed curve (captures short-term drift) or a single linear fit (captures the long term drift).

When describing the differences between the K30 and LGR, you say that the LGR cavity temperature and pressure are relatively well controlled. Please give some numbers to give us a sense of how well controlled they are.

You average the datasets into 1-minute bins based partially on the Allan variance results for the K30. Did you also do an Allan variance for the LGR?

K30 Sensor Performance and Evaluation

Sect 2.1 – Did you compute an Allan variance for more than one sensor? Do they all perform similarly?

Figure 4 – CO2 traces show periods of higher noise on some sensors (e.g. K30-3 during the second half of the time period shown). In particular, I am wondering about the smattering of points that appear as outliers. In these cases, are the sensors still meeting the manufacturer's specification of +/- 30 ppm? Is there evidence that a sensor's precision can diminish over time?

At the beginning of section 5, you state that CO2 measurement differences are correlated with environmental variables, but you have not demonstrated the correlation. Can you show some scatter plots?

Before doing an empirical fit to the environmental parameters, it would seem sensible to account for the dilution of the CO2 mixing ratio in humid air. See section 2 of Shusterman et al. 2016 for an example.

Table 1 – Are all of the regression coefficients significant? Which parameter leads to the biggest improvement and which leads to the smallest improvement?

Section 6.1 – Do you find that the K30 sensors that were closer to the LGR inlet have shorter lag times relative to the LGR response? You should try computing cross-correlation functions for each K30 against the LGR to improve the time-matching of the different time series.

Significant figures - Most of the performance metrics stated for the K30 sensors in units of ppm CO2 are given with two decimal places, yet you state the K30 measurement resolution is only 1 ppm.

Figures 5,6,7,8,10 are all shown for K30 #1, which, from Figure 4, appears to be one of the best performing sensors. I would be curious to see a residual plot for sensor #3, 5 or 6.

You state that one goal of this work is to understand how correction coefficients can be derived quickly. Wouldn't it be more efficient to design a controlled experiment where controlling variables are deliberately varied across the full range of operating conditions?

Section 7 – In future work, you aspire to characterize the sensors' maximum performance in a controlled environment. Yet, if the big-picture goal is to use these sensors is to generate science quality ambient air measurements, I believe a more worthy goal would be to characterize their minimum performance in an uncontrolled environment.

Technical comments

Title – I don't think "enhancement" is the right word. How about something like "Evaluation and correction of CO2 measurement in ambient air from a low-cost sensor"

Abstract – The quantities reported have different numbers of significant figures. These should be uniform and reflect the precision of the measurement.

Pg 1, Ln 25 – "dry air" is used twice in this sentence.

Pg 1, Ln 28 – The WMO compatibility goal is a goal, but is not always achieved, and

certainly not for historical measurements.

Pg 1, Ln 29 – Suggest: '. . .to collect samples, which are subsequently transported'

Pg 1, Ln 30 – You mention two expensive types of measurements – flasks and Picarros, but you do not mention moderately-priced analyzers from LiCor and Los Gatos, which are used at many research-grade monitoring sites.

Pg 2, Ln 1 – Be consistent about whether you spell out carbon dioxide or use the abbreviation.

Pg 2, Ln 2 – Suggest paragraph break at "Recent research"

Pg 2, Ln 8 – Is 8-12 sites typical? There are $\sim$5 sites in Boston, SLC, and Paris.

Pg 2, Ln 9 – You say that more dense observations, even with larger uncertainties, yield better inversion constraints, but this is all relative and depends on the inversion setup/goals. See Turner et al., 2016, ACP for an exploration of the tradeoffs.

Pg 2, Ln 14 – Suggest deleting "however"

Pg 2, Ln 16 – Suggest changing the phrasing to: "Recent evaluations and implementations of new low-cost sensors demonstrate their promise for ambient air monitoring."

Pg 2, Ln 26 – Can you give some numbers to scope what you mean by "reasonably accurate"?

Pg 3, Ln 7 – Suggest: "The K30 sensor moduel from SenseAir (Sweden) is the loc-cost NDIR CO2 sensor that was tested for this study".

Pg 3, Ln 10 – Suggest deleting "given as"

Pg 3, Ln 13 – Suggest: "The K30 was chosen not only because it has the highest manufacturer-specified accuracy, but also because initial testing showed reliability and consistency with higher-quality observations."

Pg 3, Ln 17 – You should give the units (relative humidity) for the 3% and 0.008%

quantities.

Pg 3, Ln 24 – "less than one percent" "< 1%"

Pg 4, Ln 5 – Another difference between the two analyzers could be their sensitivity to the isotopes of CO2.

Pg 4, Ln 29 – Can you briefly describe what you mean by "various complications"?

Pg 5, Ln 1 – My understanding is that you merged datasets by their timestamps. Did you have to do something to keep the clocks synchronized?

Pg 5, Ln 13 – "longer averaging times do not reduce the noise"

Pg 7, Ln 21 – Suggest deleting "However".

Pg 7, Ln 22 – Is the statement about each K30 meeting the manufacturer's uncertainty specification in regards to the raw (2-second) data or 1-minute averages? Please clarify in the text.

Pg 10, Ln 21 – suggest: ". . . and 1.48 ppm, for 1-minute, 10-minute, and hourly averages, respectively.

Pg 10, Ln 26 – suggest: "One goal of this work is to develop a methodology to evaluate individual sensors quickly. . ."

Pg 11, Ln 32 – "less than five parts per million" "< 5 ppm"

Figure 1 – A ballpoint pen is included in the picture for size reference. A ruler instead of a pen would be more useful.

Figure 2 – What was the CO2 concentration of the tank used?

Figure 4 – State the time interval of the data shown. I can't tell if this is raw 2-second data or 1-minute averages.

Figure 8 – I don't understand the difference between the red and blue points.

Figure 9 – Can you put error bars on each point for the y-variable?

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