Atmospheric Measurement Techniques Discussions

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# Comment on amt-2022-50

Anonymous Referee #1

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Referee comment on "Low-complexity methods to mitigate the impact of environmental variables on low-cost UAS-based atmospheric carbon dioxide measurements" by Gustavo Britto Hupsel de Azevedo et al., Atmos. Meas. Tech. Discuss., https://doi.org/10.5194/amt-2022-50-RC1, 2022

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Azevedo et al. aim to characterize two Senseair K30 NDIR $CO_2$ sensors for use in UAS-based atmospheric measurements. They try to isolate the impact of individual environmental parameters on $CO_2$ readings and investigate the sensors' time response to pressure. Overall, this topic is of great interest to readers of AMT, as the low cost and easy handling of NDIR sensors has made them widespread in the monitoring of atmospheric $CO_2$. While analyses of this nature are not novel, high-quality data and analyses - especially with regards to improving sensor accuracy beyond design specifications are of great interest.

The presentation quality of this paper is good, especially with regards to language. However, this paper falls short on the quality of its data and analysis. Regarding the influence of environmental parameters, the presented data is subject to external interferences which are left untreated and the analyses of said data lack the scientific rigor required to provide a significant contribution. The investigation of the time response to pressure is of interest, since these kinds of phenomena are difficult to treat in post-processing, however the quality of analysis is insufficient to be of practical use to readers. I therefore propose to reconsider the publication of this manuscript after major revisions.

General comments:

- It is difficult to review the scientific validity of the author's comments regarding the different sensors' dependences on environmental parameters, as the analyses are mostly of a qualitative nature. Increasing the level of quantification would also enable a comparison of their results with other analyses and would be of chief interest for readers of this paper, as they will potentially be looking to apply these corrections to their sensors.
  - Some examples (not complete):
    - L 148 "This hypothesis is supported by a stronger correlation between the test

and independent sensors."
    - L 156/157 "In this experiment, the absence of humidity dependence is evident."
    - L 174/175 "This experiment showed an extreme dependence between the $CO_2$ concentration values […] and pressure."
  - For reference on possible metrics and desired level of quantification and rigor, please consult publications in this journal like Arzoumanian (2019; doi:10.5194/amt-12-2665-2019)
- For all fits in this study, only r-values are provided and slope as well as intercept including respective errors are missing. Additionally, the factors found for the corrections (incl. time response correction) are not presented for any of the analyses, so neither the absolute dependence on environmental variables (or time response) nor the difference in dependence between the two sensors can be evaluated or compared to the scientific literature.
- Since not all environmental parameters are controlled in Benchtop experiments, showing the other environmental factors in the time-series and analysing them is important to ensure the isolation of relevant parameters which is a central goal of this paper.
- Some of the experiments were conducted months apart. Since NDIR sensors' optical properties (and thus dependences on environmental parameters) are known to change with time, I recommend against putting these experiments simply next to each other without some further justification or analysis.

Scientific comments

- L 60 "We also isolated the effects of pressure, temperature, and relative humidity on an NDIR sensor and analyzed their impact separately."
  - Did you consider also performing a linearity analysis?
- L 79 "[…] creating appropriate conditions to simulate UAS flights."
  - Is this the case for a pressure range from 1050 to 600 hPa (~4km height) as used in the Mesonet Pressure Dependence Experiment?
- L 87 "[…] this article considered only the $CO_2$ concentration values reported by each sensor unit."
  - How were the Senseair K30-FR units configured? Which kind of onboard compensations do they already have and which ones were active?
- Li-840A temperature independence
  - Please check your assumptions here, as the manual provides a total drift of the Licor of 0.4 ppm/°C. For the temperature range of 10 to 40C, this would equate to a drift of 12ppm, for 20 to 40C, a drift of 8ppm.
- Reference sensor deployment
  - Why did you choose to setup the 840A inside the chamber and the 820 outside? Was this an arbitrary choice?

- Mesonet Temperature Dependence Experiment
  - Why is the data range for $CO_2$ 160 to 320 ppm? These measurements don't seem to be realistic.
  - If you consider the independent sensors to be actually independent from environmental factors, why don't you use those to correct for external disturbances? Analysing the difference between the test sensors and the independent sensor for temperature dependencies would, then, yield more robust results.
  - As you performed the pressure experiment already 9 days before the temperature experiments, the high pressure dependence was already known. Did you perform any pressure measurements during the temperature experiment to disentangle the influence of the ambient pressure changes from the temperature changes? Or did you assess the possible effect the pressure dependence might have on the measurements?
  - Did you measure the temperature at the external independent sensor? Did you preclude any temperature interference here?
  - Quantification:
    - As one of the major sources of temperature dependence in NDIR spectrometers is a change in optics properties, did you consider time-lags in increasing sensor reading?
    - For which time periods did you calculate the correlation coefficients between sensor reading and temperature? If these were the actual transitions, this might be problematic because of time-lag, non-linearities or material effects.
    - After identifying an external interference in your measurements, it seems to me like you should not be able to draw conclusions about a sensor temperature dependence without EITHER: discarding the data and repeating the experiment without this source of interference (even Gaynullin, 2016 says that an "[a]bsolute elimination of contaminating leakages from ambient air" must be provided "to provide a reliable test environment") OR: treating the interference by e.g. analysing the difference in readings between the Licor and K30 sensors (under the assumption that the Licor readings are independent of temperature, which has to be proven given its design specifications – cf. above)

- Benchtop Temperature Dependence Experiment
  - $CO_2$ readings seem to decrease at the beginning of the experiment. Did you ensure the experiment was in a steady state with respect to $CO_2$?
  - L130/131 "Even though there is a slight 10 ppm increase […], it occurs a full minute after the temperature is brought back near its original state."
    - Again, might this be due to the temperature response time of optics/electronics, a large mixing volume or even some drift in timestamps of the recording PC (especially since this experiment was conducted 18 months after the other ones)? If this were the case, the increase in signal would fit very well with the expected one of the Licor due to temperature drift, which is 8ppm (cf. above).
    - Where was the temperature measured? Was the possibility of a time-lag between temperature measurement and sensor measurement of an air parcel excluded?
  - Since this experiment does not control RH, it is difficult to use this for a impact analysis isolating the environmental parameters, which is the stated aim of the paper. This would need some further justification leveraging measured RH values during the experiment.

- Mesonet Relative Humidity Dependence Experiment
  - The same comment regarding the external interference applies here (cf. Mesonet Temperature Dependence Experiment).
  - The same comment regarding the $CO_2$ data range (120-300 ppm) applies here (cf. Mesonet Temperature Dependence Experiment).
- Benchtop Relative Humidity Dependence Experiment
  - Details of the humid air source are missing – is it guaranteed that temperature stays constant and only RH increases?

- L 188/189 "the correction needs to be based on the variation magnitude from the initial state"
  - Can you provide some physical justification for this assertion? This is not discussed for temperature or humidity and to my knowledge, it is not common practice.
- L 202 "The results demonstrate four instances […]"
  - Where there further instances where this method was applied unsuccessfully?
  - Is this a robust method with respect to e.g. time and temperature?
- Fig 12: This dependence seems very linear, almost as if it were following the ideal gas law.
  - Again, please add some comments regarding pressure correction being enabled or disabled in the Senseair K30 units.
- Fig 13: There seems to be some kind of change of pressure dependence with time (similar to hysteresis effect)
  - Was this analysed further?
  - Could this be caused by the large pressure range?
- L 211 "Because the pressure chamber is completely isolated from the external environment […]":
  - In the experiment before, this chamber was not isolated which is why you had the outside reference sensor. In L 207/208 you write "the pressure correction experiment setup […] was used again" Is this not the same, non-isolated setup?

- L 222/223
  - Why did you use a different data source for estimating the exponential correction time constant and the time shift? Did you consider correcting the time shift first to then estimate the exponential correction time constant from this corrected data?
- L 225 "[…] an idealized signal was created […]"

    - How did you create this idealized signal? The experiments with this data are not shown in this paper. It would be important to at least add them to the supplement for the sake of documentation and repeatability.
    - Why did you opt for creating an idealized signal rather than applying the pressure correction to the exponential and time shift corrected data? Is the purpose of the exponential- and time shift correction not to improve the pressure correction?
- L 231 "Unfortunately, the attempted correction was not as effective on the gradual pressure changes"
    - Where do you see a difference in expected and real outcome? Did you quantify this?
- L 234 "we recommend repeating these experiments on a better quality chamber"
    - Why do you think the quality of the chamber is deficient? Why would smaller pressure changes help?

Technical comments

- L 48 None of the sensors available in the market was designed for UAS-based deployment.
    - None of the sensors available **on** the market **were** designed for UAS-based deployment.
- Fig 1:
    - Naming the sensor "CO2 Independent Sensor" is misleading as one might understand the sensor to be independent of $CO_2$ instead of temperature. I suggest amending the names.
- Fig 2:
    - Line colors:
        - Please consider choosing colors which have more contrast. Without zooming in, it is difficult to differentiate the lines.
        - Why do test sensor 1 and 2 have different levels of saturation? Visually, it seems like sensor 2 is less important.
    - Line types:
        - It is difficult to see the dashed and dash-dotted lines and doubly so to differentiate the two. Again, maybe rethink the figure layout.
- Figure 3:
    - For scatter plots between two $CO_2$ readings, always plot the 1:1 line, as the linear fit will be misinterpreted visually to be this 1:1 correlation. Alternatively, one can also restrict the line of the linear fit to the data and use the same x- as y-limits albeit for a larger span, ensuring the 1:1 line is at a 45 degree angle.
- Fig 3, 6, 8, 10:
    - Please consider using shared x- as well as shared y-axes. This makes such plots easier to read.
- Fig 16:
    - RMSEs by definition cannot be negative
    - Please add Pressure readings as one aim of this figure is to show the quality of the pressure correction.
- L 196 "All cases emulate a typical UAS-based $CO_2$ vertical profile"
    - Did you mean flight profile?
- L 196/197 "[…] there is a dwell period (in this case, 1.5 minutes) to ensure samples

from the previous altitude are discarded from the system after a change in altitude."
  - change altitude to pressure or use "simulated altitude"
- L 207 "No mention of such affect was found […]":
  - No mention of such **an effect** was found […]
- L 233 "For those who"
  - For those, **for whom**
- L 257
  - Please consider adding the statements with regards to long-term stability also to section 1.1 or 2.