Atmospheric Measurement Techniques Discussions

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Comment on amt-2022-118

Grant Allen (Referee)

Referee comment on "Improvements of a low-cost CO_2 commercial nondispersive near-infrared (NDIR) sensor for unmanned aerial vehicle (UAV) atmospheric mapping applications" by Yunsong Liu et al., Atmos. Meas. Tech. Discuss., https://doi.org/10.5194/amt-2022-118-RC1, 2022

General Comments:

This paper presents a characterisation of two SenseAir NDIR CO_2 sensors. It consists of a report on rigorous lab tests against calibrated and certified reference gas cylinders on a 3-point scale, Allan variance tests, and a demonstration of flight tests on board an aircraft and a UAV, which represents the context of applications of the sensor as proposed in the title of the paper. The study also evaluates pressure and temperature responses of the NDIR sensor and offers a useful blueprint for readers and future users on approaches to sensor characterisation and operational use on UAVs (and other platforms). The case is well made in the paper that CO_2 measurements from a lightweight, relatively accurate (after calibration), cheap and lightweight sensor could further open up important scientific and industrial applications for GHG accounting and pollution studies, building on much welcome momentum in the UAV and GHG measurement field. The approach to sensor assessment in the paper is thorough and rigorous and demonstrates the utility of these sensors in providing UAV measurements with a precision of ~+/- 2 ppm (1 s.d. @ 1 Hz) after (important and critical) calibration and characaterisation. Such a precision is useful for pollution monitoring applications such as those described in the paper. I have no doubt that the results of the paper will be of interest to a large community following this field and the paper offers a blueprint for getting the best quality data of these specific sensors, as well as similar sensors. Other higher precision UAV CO_2 instruments do exist (see Shaw et al., 2021 - https://royalsocietypublishing.org/doi/10.1098/rsta.2020.0450 for a review about CH_4 on UAVs, which also discusses some CO_2 sensors). But these very high precision instruments are (at present) heavier and significantly more expensive, so this study demonstrates a useful measurement alternative for applications where ~2 ppm CO_2 precision can offer meaningful scientific investigation. Perhaps the most important aspect of the paper is the focus on how to properly characterise and calibrate individual NDIR sensors, such that future users do not use otherwise very inaccurate data from them as “plug and play”, offering the information and methods needed for others to follow. The paper culminates in a real-world UAV field trial with some encouraging results that demonstrate their use for GHG plume measurements and interpretation.

The paper is highly suited to AMT, applies excellent standards of academic rigour and presentation quality, and I recommend publication with only minor corrections after consideration of the comments below.

Specific comments and Questions:

1/ Figure 4 and section 3.1 – the mean bias with respect to the calibration cylinders is large (but clearly measurable and correctable). As the two sensors tested in this work have significant (and different) positive and negative mean biases, this demonstrates that any individual sensor will always need a robust calibration (like the approach in the paper) to obtain meaningful data. This is an important statement to make clear in the paper to guide future users – i.e. that no SenseAir NDIR CO2 system should considered plug-and-play without conducting calibrations and bias correction prior to any measurement campaign and that data would suffer from extreme unknown biases without that important step. It may be worthwhile discussing that operational calibrations against any high precision instrument (e.g. Picarro or LGR or similar) may still be suitable for this task so long as those reference sensors are calibrated to NOAA/WMO gas cylinders themselves, i.e. a transferrable standard. This might avoid the step of future users needing to obtain expensive gas cylinders if they have access to other high precision reference instruments for example. It might be worth adding this to the discussion.

2/ Section 3.2. This is a very robust and rigorous calibration of the two specific sensors in this study and their (correctable) response to T and P, which look linear and encouraging. But, as rightly said in the paper, the equations derived are only applicable to these two specific sensors (and different for each sensor). A P and T calibration would need to be produced for any new unit, as suggested. This should be made extremely clear in the paper so that future users do not use the P and T relationships given in Equations 1 and 2, which only apply to these two specific units. Any information that could be given to help readers on this might be useful, e.g. might SenseAir provide those P and T calibrations with any new instrument or would those tests be something that users would always need to perform with a new sensor themselves? I see that it is recommended that users perform a T and P characterisation (line 208), so this mostly addresses the comment above, but it isn't clear if the guidance is to always perform this characterisation prior to any new measurement project, or it just needs to be done once for each unit (and therefore repeatable), or if this could this change over time, needing repeated characterisation?

3/ Line 53 - In the introduction section, it is claimed that "until now very few calibrated CO_2 measurements have been reported in the literature" from aircraft. This is not accurate. Many papers from groups in the US, EU, and UK have reported calibrated CO_2 measurements from instruments onboard manned aircraft over the past 10-15 years. For example, here is just a small sample of papers from a UK team, which describe the use of calibrated CO_2 instrumentation (and their calibration procedures): Barker et al., 2020 - https://acp.copernicus.org/articles/20/15443/2020/ ; Pitt et al., 2018 - https://acp.copernicus.org/preprints/acp-2018-1033/acp-2018-1033.pdf; O'Shea et al, 204 - doi:10.5194/acp-14-13159-2014, 2014. I would recommend rephrasing this sentence to state that there are actually many high-precision calibrated aircraft CO_2 instruments (citing a couple of papers like the ones above, or others), but that those instruments are typically very heavy and expensive and not suitable for UAV use.

4/ Introduction – this is mostly a very thorough description of the state of the UAV CO_2 field but it is missing some description of other current very high precision UAV CO_2 sensors, e.g. the LGR Hoverguard system and AERIS sensors, which are a few kg in mass and now flown on UAVs – e.g. Shah et al., 2020 - https://amt.copernicus.org/articles/13/1467/2020/. But again, while those instruments are higher precision, I believe they may also be very expensive compared to the NDIR here, and also somewhat heavier. So much like comment #3 above, a short summary of higher-precision CO2 instruments (<0.1 ppm 1.s.d @ 1 HZ) and their pros and cons for UAV use compared with the NDIR, would be a very valuable addition to the introductory discussion.

Technical Corrections:

1/ Remove space between number and percentage (there are no spaces between number and "%", only SI units)

2/ Line 95 – add "law" to "Beer Lambert…."

3/ Line 277 – "Embarked" may be better replaced with "UAV-integrated", or "installed".