Detailed responses to Reviewer #2

The authors would like to thank the reviewer for their constructive comments and suggestions for improving the manuscript. Detailed responses are provided below in blue, and the manuscript has been revised accordingly.

Review of "Evaluating low-cost NDIR CO_2 for atmospheric observation in rural settings"

I read with great enthusiasm the work presented by the authors, who compare low-cost NDIR CO_2 sensors against a market-grade reference device for atmospheric carbon dioxide mixing ratio measurements in rural settings. The authors provide discussed improving sensor readings and identifying the root causes of deviations. However, I have a major concern regarding the overarching aim of the study, namely, the deployment of low-cost sensors (LCS) in rural environments and their operational reliability. In its current form, the manuscript is not yet suitable for publication.

General Comments

1. The results suggest that the tested LCS are not yet sufficiently reliable for deployment in rural environments, whereas they appear to perform more effectively in urban settings. The general average trend may be comparable but signal-to-signal observations between LCS and reference analyser is not well in the rural setting.

Re:

We would like to thank the reviewer for highlighting this concern. The authors acknowledge that the majority of the results presented in the manuscript demonstrate the performance of the LC devices in the urban setting, owing to data gaps during the long-term deployment of the LC AirGradient S8 at the rural site. We have now revised the manuscript to include results from periods when concurrent data were available from both the urban and rural sites, thereby demonstrating the reliability of the LC devices for measurements in rural settings (Fig. 6 is now Fig. 8 in the revised manuscript).

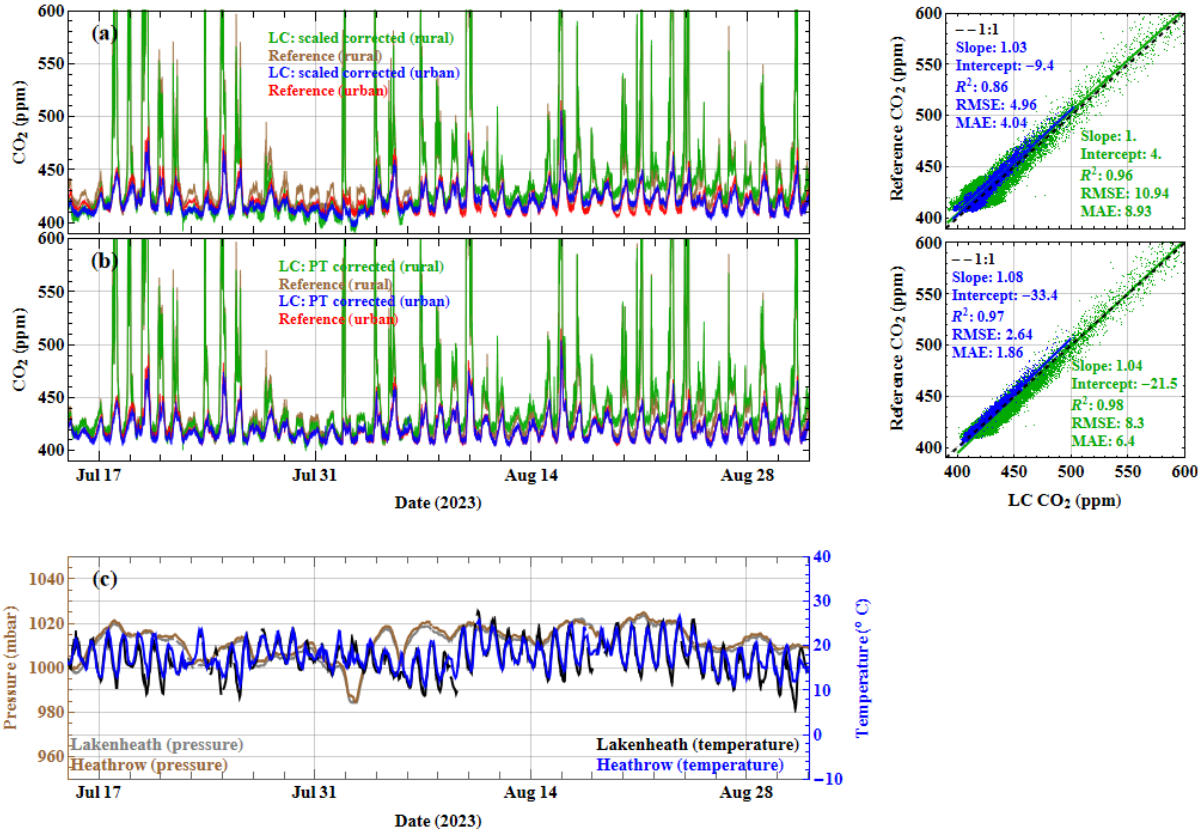

Figure 8: Comparison of two correction methodologies for the LC AirGradient S8 for the period 15 July to 31 August 2023 at the urban and rural locations. (a) simple linear scaling correction, (b) combined pressure-temperature corrected raw signal, (c) hourly pressure and temperature observation from London Heathrow and Lakenheath airport.

2. The manuscript requires some re-structuring required. The quality and presentation of the figures require improvement to enhance clarity and interpretability.

Re:

Thank you for the observation, we have updated the revised manuscript to reflect this.

Specific Comments

• **L28–29:** The authors recommend using the sensors as a reliable measurement source, but this assertion contradicts the findings presented in Figure 10, which demonstrate poor sensor performance in rural conditions. This discrepancy should be addressed.

Re:

We appreciate the reviewer's comment on this point. We suspect that the reviewer is referring to the rural deployment of the LC Magic K33 devices shown in Figure 11, rather than the earlier deployment of the same set of devices at the urban site shown in Figure 10.

The poorer performance at the rural site (Figure 11) is an artefact of the housing design of the LC Magic K33 devices, which made them more susceptible to higher local internal RH. We have revised this figure by combining it with Figure 10 and have moved it to the Supplementary Information (Fig S4) to avoid readers interpreting these results as representative of the general applicability of LC NDIR devices in rural settings. With this in mind, and considering the additional results from the rural deployment of the LC AirGradient S8 devices shown in Figure 6, we believe that the statement in L28-29 remains appropriate.

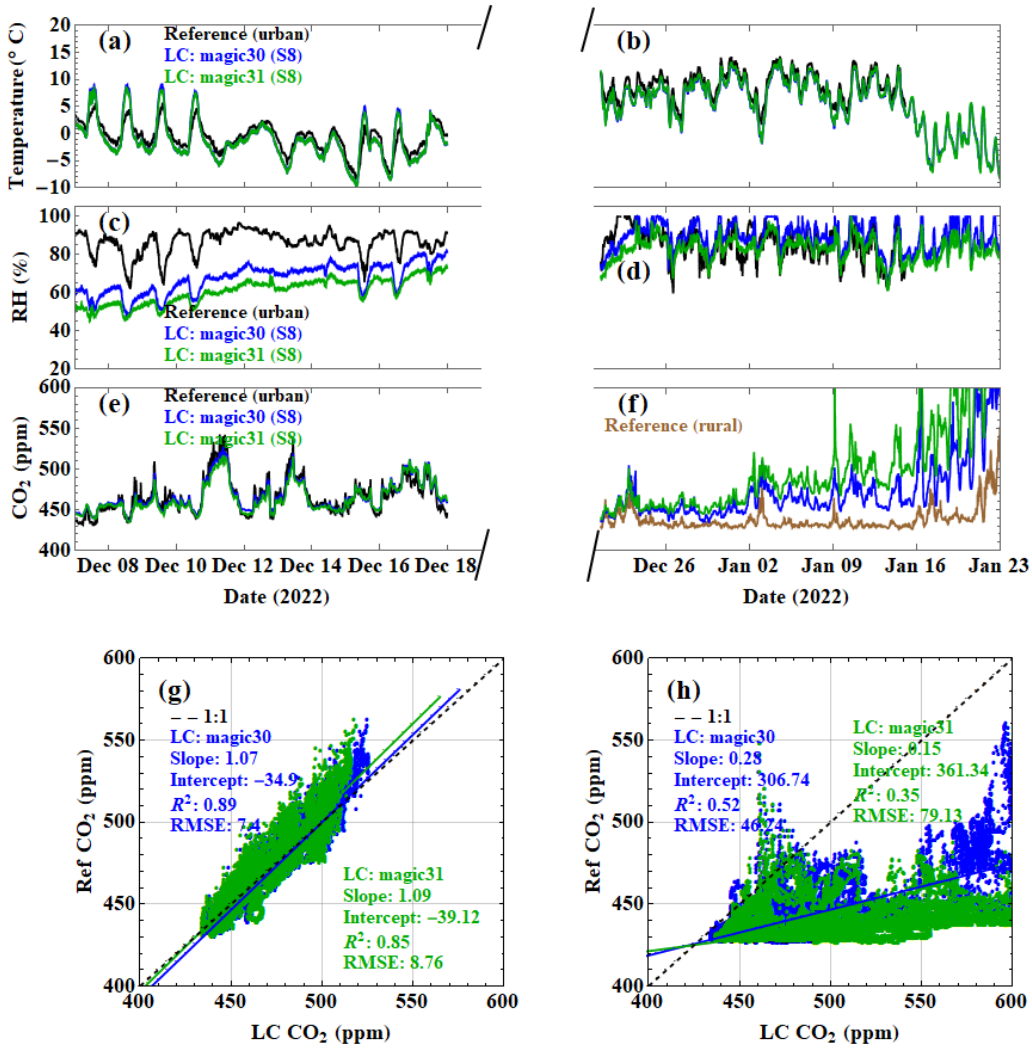

Figure S4. Comparison of paired LC Magic-K33 units with the reference instrument during urban and rural deployments. (a, b) temperature, (c, d), RH, (e, f) CO_2 and (g, h) CO_2 time series at the urban (7-18 December 2022) and rural (20 December 2022-22 January 2023) sites, respectively.

• **L64–67:** The cited reference does not adequately support the statement made here. The

authors should rephrase this section to more accurately reflect the use of low-cost sensors in the context of the referenced work. Specifically, it is not about the eddy covariance methods make expensive but the use of expensive analysers.

Re:

We have modified the statement to reflect the reviewers comment as follows

"Quantifying these fluxes at local scales typically relies on eddy covariance flux systems, which directly measure the net exchange of CO_2 between the land surface and the atmosphere but can be financially prohibitive due to the need for expensive high precision analyser typically operated at greater than 5Hz for many research or management applications (Wu et al., 2016)."

• **L360:** This content appears to belong in the Materials and Methods section and should be relocated accordingly.

Re:

We appreciate the reviewer's thought on this and we have moved this to the methodology section and retitled this section "**Assessment of the LC CO_2 data processing framework**"

• **L401:** Section 3.4 ("Suitability of LCS CO_2 in rural applications") appears to be the core of the rural evaluation. However, this section lacks statistical analysis. Furthermore, Figure 8 is not clearly explained and does not effectively support the narrative presented here.

Re:

Thank you for your comments. We have updated the description of this section as follows:

"To assess the potential deployment of LC Airgradient S8 CO_2 monitoring in rural environments, we compared measurements from corrected LC units with those obtained from reference-grade instruments at two locations, as outlined in Section 2. Although simple linear scaling produced similar trends to the reference data in both day-of-week diurnal and monthly plots, the LC measurements consistently underestimated CO_2 mixing ratios, particularly during the winter months approximately 10 ppm and 20 ppm at both urban and rural sites respectively. However, as illustrated in Figure 10 (b-d), the LC Airgradient S8 data corrected for pressure and temperature effects from the rural site show very good agreement with the reference measurements, both in terms of absolute values (see statistics in section 3.3) and temporal trends."

• **L467:** This important finding, central to the study's stated purpose of rural deployment, is not mentioned in either the abstract or the conclusion. It should be included in both.

Re:

The authors appreciate the reviewers comment on this. As addressed under the general comments the poor performance for the Magic sunrise CO_2 devices is not due to poor ventilation rather than intrinsic poor performance in rural settings as demonstrated by the good agreement of the AirGradient S8 and Sunrise devices results in our study. We have included the following paragraph in the conclusions.

"Episodes of extremely high RH can adversely affect the performance of NDIR CO_2 sensors, particularly when sensor housings are poorly ventilated, as observed for the Magic Sunrise CO_2 devices. This can result in anomalously high CO_2 measurements, especially at remote rural sites where high-RH conditions are more prevalent. In contrast, well-ventilated designs, such as the LC Airgradient S8 and Airgradient Sunrise CO_2 devices, demonstrate that NDIR sensors can reliably capture the large temporal variability in CO_2 concentrations characteristic of rural environments."

• **L484–488:** These lines are not informative and add little value to the discussion. The authors should either condense this section into a more concise statement or remove it entirely.

Re:

Thanks you for the suggestion. We have removed these lines from the revised manuscript.

Figures

The authors appear to use full-scale measurement ranges for CO_2 mixing ratios and environmental parameters throughout the main text. It would be beneficial to include zoom-in panels in relevant figures to highlight finer signal details. Additionally, the manuscript contains an excessive number of figures; several could be merged—for example, by combining figures for environmental parameters and mixing ratios for both urban and rural settings—and the remainder moved to the Supplementary Information.

Several figures suffer from poor readability due to overlapping lines (e.g., Fig. 3), excessively thin line weights (e.g., Fig. 5), illegible numerical labels, or overly lengthy captions (e.g., Fig. 9). These issues should be addressed to improve overall presentation.

Re:

We have modified the figures as recommended by the reviewer, including combining the environmental plots into a single panel, to improve their legibility. We have also revised and shortened the figure captions. In addition, some figures have been moved to the Supplement Information to reduce the number of figures in the main manuscript.

Editorial Corrections

• **L16 and throughout:** The term "mixing ratio" should be used in place of "concentration" for consistency with atmospheric measurement terminology.

Re:

The authors have effected this change in the manuscript.

• **L16** NDIR is not spelled-out.

Re:

We appreciate the reviewer's comment. We spelt out NDIR in the original manuscript (L46), but the definition was missing from the abstract. This has now been corrected accordingly.