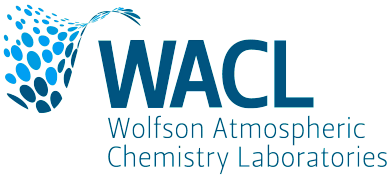

QUANT Wider Participation Study

Low Cost Sensor Evaluation
First Calibration Period: July 2021 to January 2022

Clarity

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1 QUANT Wider Participation Study

This report contains an evaluation of the low-cost sensor (LCS) units from Clarity that were monitored as part of the Wider Participation extension of the QUANT study. The study aims to perform a transparent long-term evaluation of a subset of commercially available LCS technologies for outdoor air pollution monitoring in background UK urban environments and is focused on key pollutants of interest: nitrogen dioxide (NO2), ozone (O3), and particulate matter (PM). Nine commercial sensor device companies elected to participate, all of them contributing duplicate or triplicate units with the ability to run continuously and report high time resolution data in near real-time via API. All the devices were deployed in Manchester in June 2021 and were installed as per manufacturer recommendations. The chosen site provides extensive reference measurements in a chemical range representative of UK urban environments. To ensure data integrity, given that all the assessed brands provide and store the data through their own data servers, a daily scrape was performed to transfer the measurement data to a secure server at the University of York. To ensure impartiality and consistency, device calibrations were performed by the manufacturers without any intervention from our team, and all reference data was embargoed until it was released to all manufacturers simultaneously. All data from this study will be made publicly available, along with the wider QUANT data, before February 2023.

If you have any questions please contact Sebastian Diez (`sebastian.diez@york.ac.uk`) or Pete Edwards (`pete.edwards@york.ac.uk`).

1.1 Study period

Following installation at the site on 17th June 2021, the LCS systems were running in "out-of-the-box" mode initially until co-located reference data until the 16th July was provided on 23rd July, allowing for calibration adjustments to be made. Only measurements from the period after calibrations were applied will be assessed in this report, starting on 18 Aug 2021 and ending on 25th January 2022 at the end of the first blind period. These dates are based on communications with LCS suppliers, but please contact the QUANT team if the dates used in this report are incorect.

1.2 Manchester Supersite

The Manchester Air Quality Supersite (MAQS) (located at 53° 26′ 39.2″N, 2° 12′ 51.9″W) was chosen because it is one of the largest air quality research facilities in the UK, and also because it is located in the south of the city of Manchester (one of the biggest metropolitan areas in the UK, with approximately 3.3 million inhabitants) in an urban background environment (average winter-time temperature of around 4-5 °C and ~87% RH; average summer-time temperature of around 16-17 °C and ~88% RH). The research-grade instrumentation at the MAQS used for this analysis are:

- NO2: a Cavity Attenuated Phase Shift Spectroscopy (CAPS) NO2 analyzer (Teledyne, T500. Limit of detection <40 ppt, root mean square "zero" noise <20 ppt)
- O3: a UV photometric O3 analyzer (Thermo Scientific, 49i. Limit of detection <1.0 ppb, root mean square "zero" noise <0.25 ppb)
- PM: an optical aerosol spectrometer (Palas, FIDAS200. Mass range 0-10000 ţg/m3, particle size range 0.18-18 ţm)

1.3 Evaluation methodology

No post-processing (for example no outlier removal or corrections) has been applied to the measurement data beyond averaging at an hourly rate to facilitate comparison with the co-located reference data. The species under evaluation are whichever are available out of NO2, O3, and PM2.5 and will be assessed for their accuracy by comparison to reference data by means of 4 methods:

- A time-series plot allowing for visual inspection of any overall longitudinal trends

- A scatter plot assessing the linearity of the sensor system, along with the R^2 and Root Mean Square Error (RMSE) summary metrics
- A Bland-Altman plot to ascertain the nature of the errors and whether they follow a homoscedastic relationship with respect to the quantity being measured
- A plot of the Relative Expanded Uncertainty (REU) along with the relevant Data Quality Objectives (DQO) and Limit Values (LV)

It is important to note that the results displayed in this summary only reflect the performance at the study location and in the study time window, and may be affected by factors external to the LCS system, for example the distance the system is installed from the inlet. Furthermore, the reference data has not been fully ratified during this time-frame. **As such, these results cannot be extrapolated to either future time-periods, alternative field locations, or both.**

1.4 Relative Expanded Uncertainty Parameters

The Relative Expanded Uncertainty (REU) that forms one of the assessment pillars in this report is particularly appealing for its ability to explicitly account for uncertainty in the comparison reference data, rather than treating it as entirely error-free. An additional benefit of the REU is the fact that it is being used by regulatory bodies to provide guidelines for permissible uncertainty (Data Quality Objectives (DQO)) at the designated limit values, which are displayed in Table 1. The figures used for the uncertainty inherent in the reference instruments are also displayed in Table 1.

Table 1: REU Parameters for O3, NO2, and PM2.5. Units are ppb for NO2 and O3 and ug/m3 for PM2.5

Species	Limit Value	DQO	Uncertainty
O3	60	30	0.55
NO2	105	25	0.26
PM2.5	30	50	0.48

2 Field Results

2.1 Data availability

Table 2 summarises the data availability from the deployed low cost sensors throughout the duration of this project.

Table 2: Data availabilty from the low-cost devices. The columns show the number of hours with at least one valid measurement out of a maximum possible 3864

	Number of hours of data available	
Device	NO2	PM2.5
A50LXXPZ	3840 (99.4%)	3840 (99.4%)
ACG0QLMP	3840 (99.4%)	3840 (99.4%)
ADBJW6TG	3840 (99.4%)	3840 (99.4%)

2.2 NO2

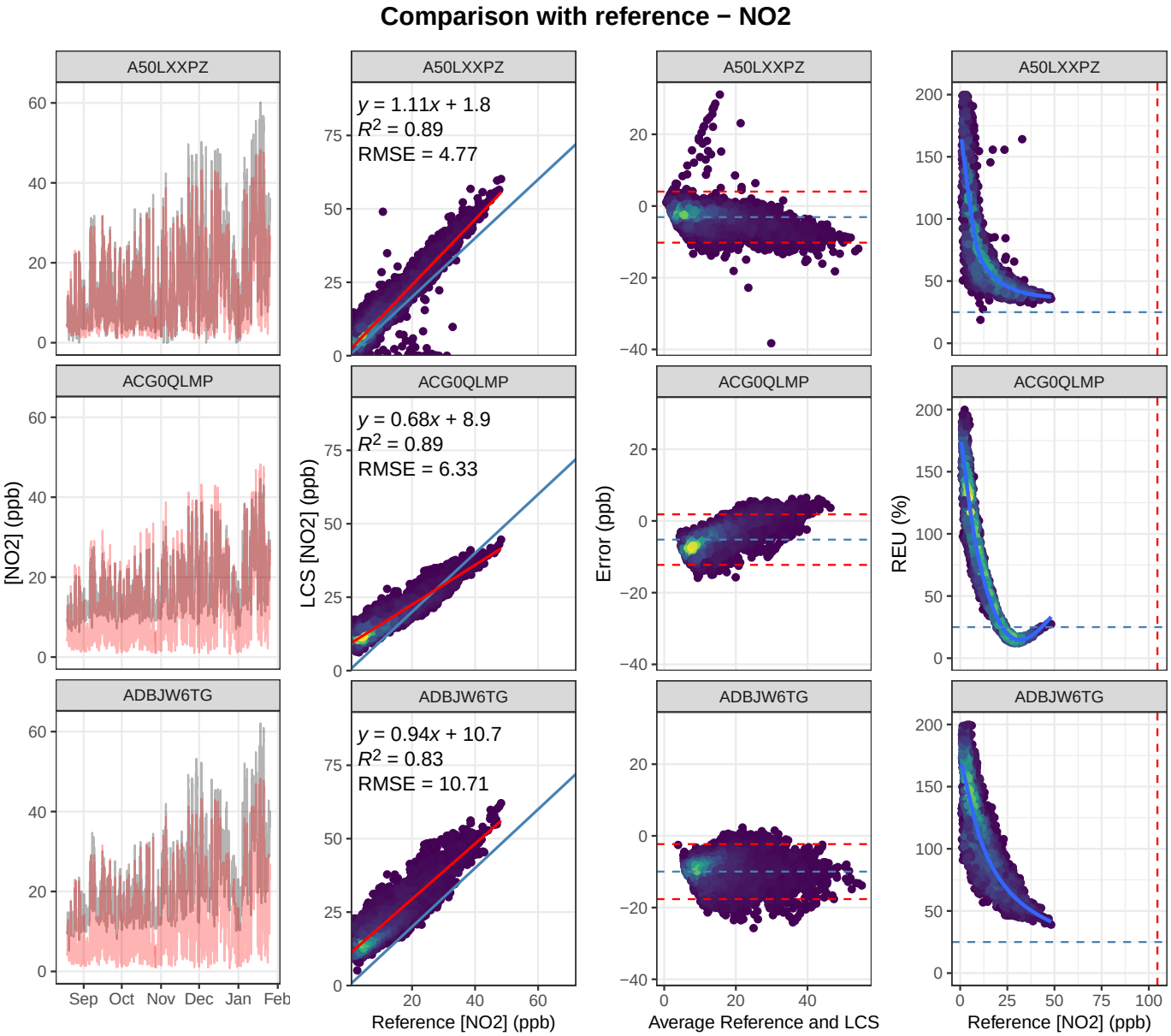

Figure 1: NO2 quantiative evaluation. Column 1: time-series plot of the LCS measurements (black) alongside reference (red). Column 2: Regression plot against reference data (blue and red lines are 1:1 and linear regression fit respectively). Column 3: Bland-Altman plot (blue line indicates mean error and the red lines represent 2 standard deviations). Column 4: Relative Expanded Uncertainty (REU) with the Limit Value and Data Quality Objectives shown by the dashed red and blue lines respectively. The blue solid line shows a non-linear line of best fit. The axes are restricted to REU values between 0 and 200% for clarity.

2.3 O3

No data available for this pollutant

2.4 PM2.5

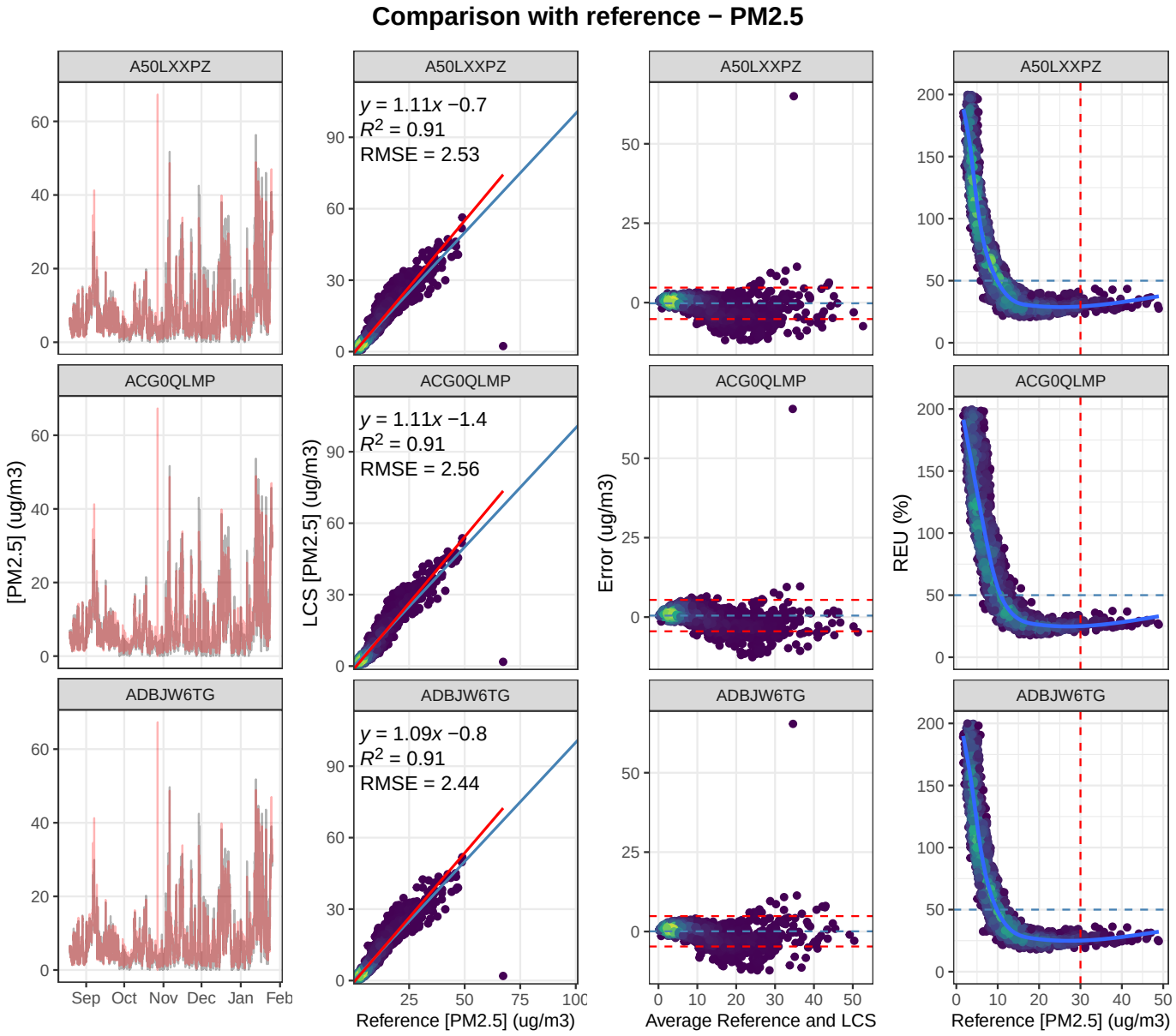

Figure 2: PM2.5 quantiative evaluation. Column 1: time-series plot of the LCS measurements (black) alongside reference (red). Column 2: Regression plot against reference data (blue and red lines are 1:1 and linear regression fit respectively). Column 3: Bland-Altman plot (blue line indicates mean error and the red lines represent 2 standard deviations). Column 4: Relative Expanded Uncertainty (REU) with the Limit Value and Data Quality Objectives shown by the dashed red and blue lines respectively. The blue solid line shows a non-linear line of best fit. The axes are restricted to REU values between 0 and 200% for clarity.

3 Results from all study participants

This section places the above results into the context of the full Wider Participation study by showing the performance metrics of all deployed low-cost sensor systems from the 19th August 2021 until 25th January 2022 (Figure 4). However, this comparison is provided solely as an illustrative figure and is **not** intended to be used as an exhaustive comparison, nor is it suitable for this purpose owing to the fact that this timeframe comprises non-overlapping recording periods and discrepencies regarding which calibrations have been applied. **Morever, Figure 4 should be reproduced or redistributed**.

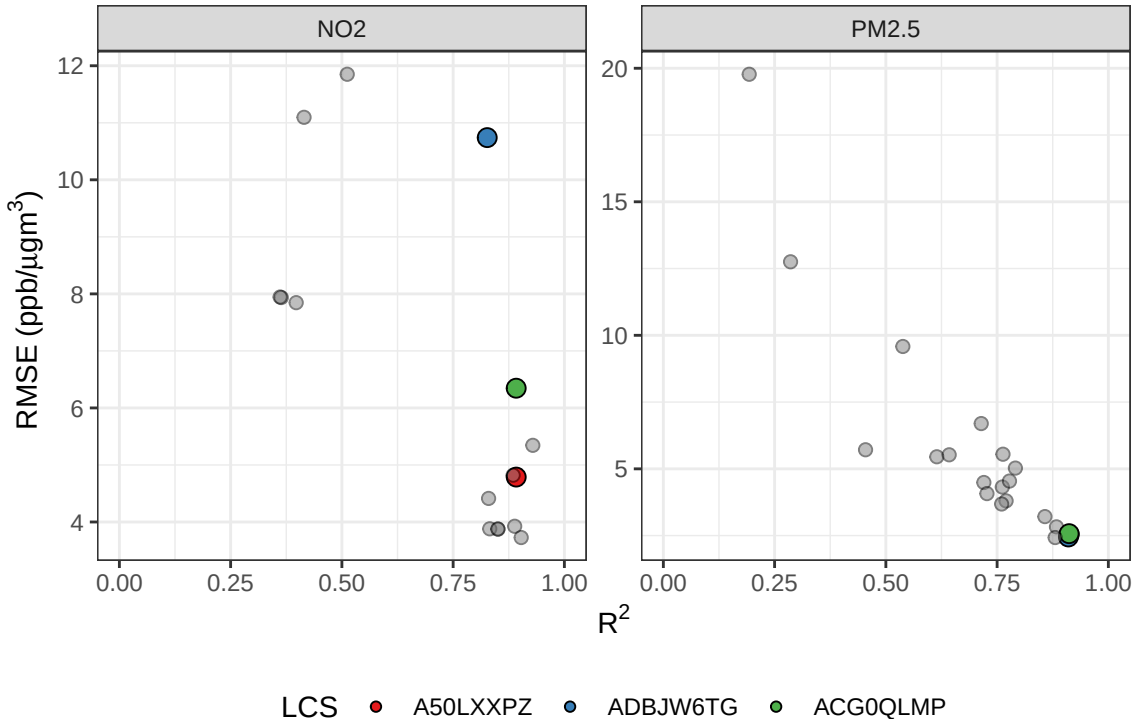

Figure 3: RMSE and R2 of all devices in the wider participation study. Clarity's devices are highlighed in colour