Measurement Methods and Applications of Atmospheric Refractivity Based on Raman Lidar

General comment

The manuscript presents a Raman lidar system for retrieving atmospheric refractivity profiles and evaluates its performance through comparison with meteorological tower observations. The introduction would benefit from a clearer explanation of the measurement needed motivating this development and its contribution beyond existing methods. Although the relevance of refractivity to electromagnetic wave propagation and the limitations of existing techniques are discussed, their connection to the specific objective of the study could be more clearly established.

A stronger quantitative assessment of the results would be particularly valuable. Several statements regarding measurement accuracy and agreement between instruments remain qualitative; supporting these statements with numerical values and references to the relevant figure panels would strengthen the interpretation. Further details on the calibration procedures and the justification of the retrieval assumptions, as outlined in the specific comments, would also improve methodological clarity and reproducibility.

Major comments

M1 | Introduction, Lines 11–84

The connection between the background and the specific motivation for this study could be strengthened. The introduction discusses the relevance of atmospheric refractivity and several limitations of existing measurement techniques, but the extent to which the proposed system addresses these limitations is not sufficiently clear. In particular, the discussion in Lines 58–75 shifts towards the general importance of temperature, humidity and lidar observations, making the motivation for refractivity measurements less apparent. A more focused discussion linking these limitations to the development and evaluation of the proposed system would help clarify the measurement need and the intended contribution of the study.

M2 | Section 2, especially Lines 85–128 and 155–206

Reorganize the methods and standardize the notation. Several concepts and processing steps are introduced abruptly, without sufficient explanation of their purpose or their connection to the preceding section. Please present the retrieval chain in a logical sequence, explain the input and output of each step, and explicitly link the processing description to the corresponding equations. Section 2.3 particularly needs clearer transitions and methodological detail.

The distinction between abbreviations and mathematical symbols should also be made clear. For example, temperature is referred to as both AT and T, and pressure as AP and P, while P is subsequently used for photon counts in the explanation of Eq. (8). Use consistent notation and avoid assigning the same symbol to unrelated quantities.

M3 | Section 2.1.2, Lines 116–121; Eq. 5

The calibration procedure would benefit from further clarification. The statement that calibration yields $\kappa = 9$ does not provide sufficient information to assess or reproduce its determination. Relevant details include the reference measurements, the calibration procedure, and the units and uncertainty associated with κ. It would also be useful to specify the averaging interval of the measurements used for calibration and whether κ remains constant throughout the experiment or is updated over time, including the update frequency where applicable.

A reference supporting the water-vapour mixing-ratio retrieval equation (Eq. 5) would also be helpful, for example Whiteman et al. (1992). For clarity and consistency with commonly used notation, I suggest using r(z) or w(z) for the water-vapour mixing ratio instead of D(z), with its units explicitly stated.

Equation (5) does not explicitly include the differential atmospheric transmission term between the water-vapour and molecular-reference wavelengths. Clarification is therefore needed as to whether this term is neglected, incorporated elsewhere, or approximated during calibration. Its magnitude depends on the wavelength separation and aerosol loading as discussed by Whiteman et al. (1992), Whiteman (2003) and Díaz-Zurita et al. (2025).

I recommend including at least the molecular contribution to this term, which can be estimated from atmospheric density, and assessing the uncertainty associated with the aerosol contribution if aerosol extinction measurements are unavailable. This assessment should consider the actual detection wavelengths (386.7 and 407.5 nm) and the measurement range investigated here (2.4–120 m), since estimates reported for longer propagation paths may not be directly applicable. If the differential atmospheric transmission term is considered negligible over this range, a quantitative estimate of its effect on the retrieved water-vapour mixing ratio, relative to the reported measurement accuracy, would support this assumption.

M4 | Sections 2.1–2.2, Lines 88–153; Eqs. 5; Fig. 3

Discuss the temperature dependence and spectral response of the channels. Please describe the effective spectral passbands of the detection system, including the gratings, fibre selection and any filters, and explain how their temperature-dependent response is accounted for in the retrievals. For water-vapour measurements, the relative temperature dependence of the water-vapour and molecular-reference signals can introduce a retrieval bias and should be assessed for the selected passbands.

For the pure rotational Raman temperature retrieval, temperature sensitivity is the intended measurement principle. The issue is therefore how this sensitivity is represented in the calibration and how the chosen spectral response affects the result, rather than how to eliminate temperature sensitivity altogether. Please distinguish these two issues and quantify any residual effect over the temperature range of the experiment.

The treatment of temperature dependence in the water vapour retrieval would benefit from further clarification. It is not clear why this effect is neglected in Eq. (5), or whether the spectral characteristics of the interference filters justify considering the ratio of the water-vapour and molecular-reference signals practically independent of temperature.

It would be useful to provide the central wavelengths and full widths at half maximum (FWHM) of both filters and explain whether the resulting

Spectral selection justifies approximating the ratio of the temperature dependent factors of the two channels to unity. An assessment of this approximation over the temperature range encountered during the experiment would support the omission of this term (Whiteman, 2003).

- Whiteman et al. (1992): https://doi.org/10.1364/AO.31.003068
- Whiteman (2003): https://doi.org/10.1364/AO.42.002571
- Díaz-Zurita et al. (2025): https://doi.org/10.3390/rs17203444

M5 | Section 3, Lines 224–315; Figs. 7–10; Table 2

One of the main concerns regarding the manuscript is that several conclusions about the system's performance are not sufficiently supported by the analysis presented. The discussion frequently uses expressions such as "high accuracy", "excellent agreement", "small deviations" or "negligible effects" without providing numerical values that would allow these statements to be assessed. This issue therefore extends beyond the presentation of the results and concerns the evidence supporting the conclusions drawn from them.

Furthermore, the descriptions of the figures are often too general and do not identify the specific panels, time intervals or heights where the reported behaviour can be observed. This makes the interpretations difficult to verify and leaves the reader to infer the evidence supporting each statement. Linking each specific finding to the relevant numerical results and figure panel or table entry, rather than citing the figure only at the beginning of a paragraph, would substantially improve the discussion.

Although Table 2 presents quantitative results by height for the 60 min integration period, it does not cover all the comparisons discussed. I suggest adding a table summarising the numerical results supporting these comparisons, including bias, RMSE, MAE, correlation and the number of paired observations for the different integration periods and, where relevant, the heights or time intervals analysed. This would allow the statements about noise reduction, systematic deviations, height dependence and temporal agreement to be assessed. Conclusions for which sufficient evidence is unavailable would benefit from qualification or reconsideration. Specific examples are detailed below.

- Line 227: The statement that "AT shows the best consistency and accuracy" and that "RH fluctuates more at lower ATs" remains qualitative. Reporting the statistics supporting both observations, including the temperature ranges considered, would help establish their validity. The basis for comparing accuracy across variables with different units would also benefit from clarification.
- Lines 229–230: The statement that the accuracy of N is closely related to that of AT and RH, while "the overall performance trend is good", would benefit from a more precise explanation and quantitative support. An assessment of how uncertainties in AT and RH propagate into N would help substantiate this relationship. The meaning of "good" performance could also be clarified using the relevant error statistics.
- Lines 230–231: The statement that "there is no obvious impact on the inversion accuracy due to height changes" would benefit from a quantitative assessment of how the retrieval errors vary with height. The relevant statistics and corresponding figure panels or table entries would help establish whether the observed differences are negligible.
- Lines 231–232: The claim that "Raman lidar demonstrates high accuracy" would be more informative if accompanied by the corresponding error statistics and the conditions under which this performance is obtained.
- Lines 235–236: The statement that the trends of AT, RH and N are consistent at a 5 min integration time, while their correlation is low, requires clarification. Reporting the correlation coefficients for each variable and identifying the relevant panels would help distinguish agreement in the general temporal evolution from agreement between individual measurements.

- Lines 236–237: The “significant systematic deviations in AT, RH and N” are not quantified. Specifying their magnitude and direction for each variable, together with the affected time intervals, heights and figure panels, would make this interpretation verifiable. The meaning of “significant” would also benefit from clarification.
- Lines 237–239: It is unclear how the conclusions regarding the 10 min integration time were established: agreement in the vertical behaviour, weakening of high-frequency random noise, suppression of fluctuations in the medium- and low-temperature regions, and reduced error. These statements would benefit from a clearer description of the comparison being made and numerical estimates of the changes in variability and error. The meaning of “medium and low AT areas” and the relevant figure panels could also be specified.
- Lines 242–243: The statement that RMSE and MAE decrease as integration time increases would benefit from the corresponding values for each variable at each integration time. Including these results in the suggested table would allow the magnitude and consistency of the improvement to be assessed.
- Line 246: The statement that integration time has little impact on correlation would benefit from the correlation coefficients for the different integration periods and the corresponding figure-panel references. This would provide a quantitative basis for describing the effect as small.
- Line 256: The interpretation of the warming as “the passage of a warm air mass” would benefit from supporting meteorological evidence. A temperature increase alone does not establish the passage of a distinct air mass. If additional evidence is unavailable, describing the observed warming without attributing it to a specific mechanism would be more appropriate.
- Lines 256–257: The description of a uniform warm layer between 5 and 10 °C extending from near the surface to 120 m would be easier to assess if linked directly to the relevant temperature panels and time interval. While a temperature range is provided, the assertion that both instruments captured this structure “accurately” would also benefit from a quantitative comparison between their measurements.
- Lines 259–261: The claim that the vertical temperature gradients are “perfectly synchronized” and demonstrate comparable accuracy in resolving thermal stratification is not sufficiently established by the accompanying description. Identifying the specific gradients, heights and time intervals, and quantifying their agreement, would help support this conclusion. Otherwise, more measured wording would reflect the evidence presented.
- Line 262: The statement that the lidar retrievals show “excellent agreement” with the tower observations and “faithfully” reconstruct the actual water-vapour structure would benefit from numerical support and a direct reference to the relevant panels. Since the comparison concerns RH, describing the observed feature as a relative- humidity structure would also be more precise than referring to it as the actual water-vapour structure.
- Line 263: The statement that both systems “precisely resolved a strong humid structure” during Time = 15–18 days is difficult to assess without references to the relevant figure panels. Specifying the heights, RH values and differences between the instruments during this episode would help substantiate the claimed agreement.

- Line 265: The description of a “hyper-arid period” during Time = 22–30 days would benefit from explicit figure-panel references and the corresponding RH values. Clarification of the time coordinate is also needed to reconcile this interval with the stated observation period of 10–26 January. “Low-relative-humidity period” may be more appropriate than “hyper-arid period” for a short episode identified from RH measurements.
- Line 271: The assertion that Raman lidar “successfully and faithfully captures the pronounced negative gradient structure” would benefit from identifying the relevant N panels, heights and time intervals. Quantifying the vertical gradients and their agreement with the tower- derived gradients would provide support for this interpretation.
- Line 273: The discussion of the structure observed during Time = 11– 18 days would be clearer with a direct reference to the relevant figure panels and a specification of its vertical extent and N values. A quantitative comparison between the two instruments would help establish how well the lidar reproduces this feature.
- Line 275: The description of a “slight, systematic positive bias in N” would benefit from reporting the magnitude of the bias, the affected heights and time intervals, and the relevant figure panels. This would provide a basis for characterising the bias as slight and systematic.
- Lines 276–277: The conclusion that this discrepancy “does not materially affect” the determination of the spatial distribution or temporal evolution of N is not sufficiently supported by the qualitative description. A quantitative assessment of its influence on the identified structures, gradients or temporal variations would help justify this statement. Otherwise, the conclusion would benefit from qualifications.
- Line 282: The statement that there is “no observable lag or distortion” relative to the tower measurements would benefit from an assessment of temporal alignment and differences in the observed variations, taking the measurement time resolution into account. Visual similarity alone provides limited support for excluding such effects.
- Line 283: The description of a “localized, slight overestimation at low altitudes” would benefit from specifying the altitude range, time interval and magnitude of the overestimation, together with the corresponding figure panels. These details would allow the extent of the discrepancy and its relevance to the reported retrieval accuracy to be assessed.

M6 | Figs. 3–4 and 6–10; Section 3, especially Lines 250–284

Improve the figures and explain what they demonstrate. Labels in Figs. 3 and 4 are difficult to read, and Figs. 6–10 do not allow the reader to assess many of the features discussed in the text easily. Please increase label and tick sizes, improve the layout and visual separation of the series or panels, and revise the captions to explain the plotted quantities and comparisons clearly. Apply these readability improvements consistently across the figures. For Fig. 10, consider a clearer time–height presentation and difference plots so that the claimed structures and discrepancies can be assessed directly.

M7 | Lines 1–2, 17–25 and 279; terminology throughout

The distinction between atmospheric refractivity and refractive index would benefit from consistent terminology. N is introduced as atmospheric refractivity in Lines 1–2, and its relationship with the refractive index n is defined in Lines 17–25. However, Line 279 refers to N

as “the dielectric refractive index”. These quantities are not interchangeable: $N = (n - 1) \times 10^6$, where n is the refractive index. Replacing this expression with “atmospheric refractivity (N)” and checking terminology throughout the manuscript would improve clarity.

Similarly, Line 279 refers to RH as “the water vapor spatial field”. Relative humidity depends on both temperature and water-vapour abundance and is not a direct measure of water-vapour content. “Relative-humidity distribution” would therefore be more appropriate when discussing RH. If the interpretation concerns changes in atmospheric water-vapour content, supporting evidence based on water-vapour mixing ratio would be needed.

M8| Independence of calibration and validation, Lines 108–120, 193–201 and 208–223

Beyond documenting calibration, it would be important to establish whether the tower measurements used for the reported validation statistics were also used to derive calibration coefficients, height-dependent adjustments, or filter settings and initialisation values. The current description does not establish this independence; it does not demonstrate that data reuse occurred. If the same observations contributed to both stages, evaluation on separate time blocks or an independent period, with the processing parameters fixed beforehand, would provide a stronger test of performance. Separating adjacent samples randomly may not adequately account for their temporal dependence.

M9| Near-surface capability and differential overlap, Lines 76–78, 130–150, 199–201 and 211–223; Figs. 2–4

The reported output range begins at 2.4 m, whereas the lowest tower comparison is at 8 m. Distinguishing the lowest output range from the lowest independently validated height would clarify the demonstrated near-surface capability. This distinction is also relevant to the abstract.

The explanation of the detection-range-factor correction in Lines 199–201 identifies a height-dependent effect but does not describe the function applied or its determination. The transmitter–receiver geometry, instrument height and range-zero definition, complete-overlap distance and channel-dependent overlap behaviour would help assess the lowest measurement bins. It would be useful to provide the height-dependent adjustment and its uncertainty and explain whether differential overlap cancels in the signal ratios or is explicitly accounted for. If no independent measurements exist below 8 m, the validated performance could be stated as applying to 8–120 m.

M10| Construction and statistical treatment of averaged products, Lines 221–249, 288–295 and 340–342; Figs. 8–9; Table 2

How are the 10, 15 and 60 min products generated: by accumulating signals before retrieval, averaging the retrieved quantities, or using overlapping running windows? These operations are not equivalent to nonlinear retrievals. Fig. 8 appears to retain a similar sample-index extent for each integration period. Clarification of the output cadence, window overlap and edge treatment would help explain this presentation and the number of valid comparisons.

The definition of the “Total” row in Table 2 would also be useful: does it pool all paired observations or combine statistics calculated separately at each height? Likewise, the meaning of “mean R” in Lines 341–342 could be specified. Any uncertainty intervals should account for temporal dependence and dependence between heights, rather than treating all 32,008 paired comparisons as independent. A breakdown by daytime and night-time, including data availability

after screening, would further clarify the operating conditions represented by the reported performance.

Minor comments

The scientific clarifications below complement the major comments. They should not all be treated as purely grammatical corrections.

C01 | Lines 1–10, Abstract

Please revise the abstract to improve its clarity and flow. It should state the measurement problem, the specific contribution of the instrument, the validation approach and the principal findings more directly. Clarify how temperature, humidity and pressure are used to obtain N and ensure that the reported performance is linked to the measurement conditions and averaging period.

C02 | Lines 3–5 and 76–78

The wording suggests that the hypsometric formula directly provides N. It would be clearer to state that pressure is estimated using the barometric relation and that N is subsequently calculated using Eq. (1).

C03 | Lines 6–9

"Conducted in 10 to 26 January 2024 LT" could be revised to "conducted from 10 to 26 January 2024". "The overall RMSE values … were" would also improve the grammar. Where RH errors are absolute differences between values expressed in percent, reporting them in percentage points would distinguish them from relative percentage errors.

C04 | Lines 26–27

For clarity, "on the basis of formulas" could be replaced with an explicit reference to Eq. (1), if this is the expression intended here.

C05 | Line 41

Please define M at its first occurrence.

C06 | Lines 54–57

"Numerical weather prediction models" or "numerical weather prediction methods" may be more appropriate than "NWP technology" here, depending on the intended meaning.

C07 | Introduction

However is used repeatedly throughout the introduction. Please revise the transitions and sentence structure to improve the flow, retaining this connector only where a contrast is needed.

C08 | Lines 58–59

Consider replacing detecting meteorological elements with measuring atmospheric variables or retrieving meteorological parameters. The latter terms describe the quantities measured by lidar more precisely.

C09 |Lines 61–68 and 74–77

The phrases “RH an calculated of AP”, “its a rapidly changing humidity field”, “water vapor vibration Raman lidar” and “a AT and RH profile of the Raman lidar system” would benefit from grammatical revision. “Water-vapour vibrational Raman lidar” is clearer for the third expression. The statement that a temperature inversion is “the core cause of haze formation” would also benefit from qualification.

C10 | Lines 63–65

Please provide appropriate references for the statements about thermodynamic regulation and energy transfer through phase changes, and about the influence of the vertical temperature distribution on atmospheric stability and pollutant dispersion.

C11 | Lines 65–66

Replace the semicolon before The boundary layer with a full stop and revise the following sentence so that it is grammatically complete.

C12 | Lines 72–74

Capitalize Lidars at the beginning of the two sentences. Also revise the consecutive wording “spectral-resolution lidar. lidars used ...” to avoid repetition and improve the connection between the temperature and water-vapour measurement descriptions.

C13 | Lines 88–94; Eq. 2

The explanation initially refers to nitrogen, whereas Eq. (2) includes contributions from both N_2 and O_2. Are these contributions separated spectrally, or are both included in each integrated detection channel? Please explain how the instrument and retrieval account for the contribution of each species.

C14 | Lines 92–93; Fig. 1

The temperature dependence described in Lines 92–93 appears to be reversed relative to Fig. 1. In the figure, the intensities of the low-J lines (J = 4 and 6) decrease with increasing temperature, whereas those of the high-J lines (J = 12 and 15) increase. Revising the wording to reflect these trends would ensure consistency between the text and the figure.

C15 | Lines 94–95

Please clarify the term echo signal. If this refers to the detected Raman backscatter, Raman return signal or Raman backscatter signal would be more explicit.

C16 | Lines 100–102

Please clarify that it is the atmospheric transmittances at the selected wavelengths that are being approximated as equal. Quantify the effect of this approximation on the retrieved temperature for the actual channel passbands and atmospheric conditions and provide references supporting its use. This assessment should be distinguished from the evaluation of the differential atmospheric transmission term in Eq. (5).

C17 | Lines 108–111; Eq. 3

The parameter q in Eq. (3) is not explicitly defined. A brief definition would help clarify its meaning.

C18 | Lines 112–114; Eq. 4

It would be helpful to explain how the calibration constants α, β and γ are determined, including the reference data and fitting procedure used.

C19 | Section 2.1.2, Lines 116–118; Eq. 5

Please cite the theoretical basis of the water-vapour retrieval, for example Whiteman et al. (1992, 2006). Clarify that N_2 is the molecular reference selected for this instrument. Other configurations use a pure rotational molecular-reference signal containing contributions from N_2 and O_2; distinguish this option from the vibrational–rotational N_2 reference used here and cite an appropriate source such as (Whiteman et al., 1992, 2006).

Whiteman et al., 2006: https://doi.org/10.1175/JTECH1838.1

C20 | Eq. 5 and its use in Eq. 6

Consider using r(z), or another conventional and clearly defined symbol, for the water-vapour mixing ratio instead of D(z). This is a notation preference rather than an error; whichever symbol is chosen should be used consistently and accompanied by its definition and units.

C21 | Line 125

In "The AP P(z) at height …", AP and P(z) appear consecutively, which may be confusing. "The atmospheric pressure P(z) at height z …" would be clearer.

C22 | Fig. 3, p. 7; Lines 140–150

Please enlarge the labels and expand the discussion of the figure. Explain the selected spectral regions, their connection to the low- and high-J channels, and what the additional channels contribute to the measurement.

C23 | Line 154

Remove the full stop between Table and its number: write "Table 1", not "Table. 1".

C24 | Section 2.3, Lines 155–206

Please revise this section as a connected explanation of the processing workflow. Introduce the purpose of each correction before describing its application, explain the transition between steps, and provide the equations, parameters or references required to understand the method. See major comment M2.

C25 | Fig. 4, p. 8; figures throughout

The labels are too small to read comfortably. Increase their size and ensure that all panel labels and optical-path annotations remain legible at the final publication size. Check the remaining figures for the same problem.

C26 | Lines 164–178

The description "multialkali cathodes (BIALKALA)" appears internally inconsistent and would benefit from checking against the detector specification. "PTM" in Line 177 should read "PMT". Using a different symbol for the number of accumulated laser pulses would avoid reusing Q, which already denotes the Raman signal ratio.

C27 | Lines 161–169

How are the PMT temperature-dependent sensitivity corrections determined and applied? Please describe the characterization procedure,

the temperature measurement used and the correction equation, rather than only listing the coefficients. Replace the ambiguous wording temperature constants ... revised with a description of the actual correction.

C28 | Lines 185–187

Visibility greater than 10 km does not by itself establish cloud-free conditions. Distinguishing the visibility criterion from any separate cloud screening would make the definition of normal operating conditions more precise

C29 | Lines 185–187

Please support the interpretation of low signal as an indication of cloud/fog or instrument malfunction with an appropriate reference or diagnostic evidence. Explain how these possibilities are distinguished in practice.

C30 | Lines 188–190

Please justify the rules that determine whether valid output extends to 360 or 120 m. Cite the source if these thresholds follow an established method; otherwise explain how the thresholds were established and validated for this instrument.

C31 | Lines 191–192

The phrase “Following the principles of Raman lidar measurement” is too general. Please identify the equations used to calculate temperature and RH at this stage and specify which corrected signals are their inputs.

C32 | Lines 194–198

Please provide references for the filtering methods and describe their implementation and parameter selection. Naming Butterworth, EMD and Kalman filtering without these details is insufficient to explain how the results were obtained.

C33 | Lines 202–203; Eq. 8

The notation in Eq. (8), which describes the photon-counting correction, may cause confusion because N is also used for atmospheric refractivity. I suggest using a different symbol for the photon counts and explicitly referring to Eq. (1) when describing the calculation of atmospheric refractivity in Lines 202–203.

C34 | Lines 208, 224–225 and 239

“As show in in Fig. 5” should read “as shown in Fig. 5”. “Full time series data of accumulated over 5 minutes” would benefit from grammatical revision to describe the actual accumulation or averaging procedure. “AR” in Line 239 appears to be a typographical error for “AT”.

C35 | Fig. 6 caption, p. 12

Please revise the caption to identify the panels and variables unambiguously. Suggested wording: “Time series of air temperature (AT),

relative humidity (RH), and atmospheric refractivity (N) at the eight comparison heights, obtained from (a) the meteorological tower and (b) the Raman lidar. Colours identify the measurement heights." Also state the averaging interval and clarify that tower N is calculated from the reference meteorological data.

C36 | Lines 217–219

The stated "allowable measurement error range" would benefit from a numerical definition and a supporting source. The absence of visually apparent distortion alone does not establish measurement reliability.

C37 |Lines 294–299; Table 2

The minimum temperature RMSE in Table 2 is 0.40 °C at 80 m, rather than 0.42 °C. The reported range is therefore 0.40–0.63 °C. The maximum also conflicts with the statement that discrepancies remain "strictly within 0.6 °C". In addition, RMSE is not an upper bound on individual measurement differences.

C38 | Line 269

Insert a space between the sentences: "fidelity. In terms ...".

C39 | Lines 295–298

Please provide references for the proposed effects of tower structures, radiative interference and local turbulence on the comparison. To attribute the observed vertical error pattern specifically to these mechanisms or to lidar SNR, supporting evidence from this experiment is also needed. Without such evidence, present them as possible explanations rather than established causes.

C40 | Lines 304–308; Table 2

The low-level N correlation values include 0.89 at 8 m, so the stated range of 0.86–0.88 omits this level. Correlation does not increase steadily to 120 m: it decreases from 0.93 at 102 m to 0.91 at 120 m. Revising the description to match Table 2 would improve accuracy. A space is also missing in "80 m.These".

C41 | Table 2, p. 18

"MEA" should be "MAE" in all three variable groups. Consistent numerical precision, including 0.40 rather than 0.4, would improve presentation. Defining R and specifying the 60 min integration period in the caption would make the table self-contained. A rounded R = 1.00 should not be interpreted as perfect agreement.

C42 | Figs. 1 and 3, pp. 4 and 7

The scattering quantity in Fig. 1 is labelled in $cm^3\ sr^{-1}$, whereas Fig. 3 uses $cm^2\ sr^{-1}$ and a different numerical scale. Clarifying the physical quantity, normalisation and units in each figure would help establish their consistency. The abbreviations ST and AST could also be defined in the captions.

C43 | Fig. 2, p. 6; Fig. 4, p. 8

"Acquisittion" in Fig. 2 should read "Acquisition". Visible panel labels (a), (b) and (c) in Fig. 4 would help match its components to the caption.

C44 | Table 1, p. 9

Definitions of NA, T and R would make the table more self-contained. The wavelength ranges “350 360 nm” and “380 410 nm” need separators. It would also be useful to state whether the 1 mrad field of view is a full angle or a half angle.

C45 | Figs. 8–10, pp. 14–17; Lines 255–264

The temperature unit “°c” in Fig. 8 should be “°C”. The dashed line in Fig. 9 needs identification, and “63m” in its caption should be “63 m”. The repeated wording “Comparative analysis of correlation analysis” could be simplified. References to “deep red” regions in the discussion do not match the blue-to-yellow scale in Fig. 10. Describing numerical ranges would avoid this mismatch. The Fig. 10 caption could use “Panel (a) shows …; panel (b) shows …”. The vertical interpolation used to display the eight tower levels would also benefit from explanation.

C46 | Conclusions, Lines 317–334

The opening paragraphs of the conclusions largely repeat background information and measurement principles already discussed in the introduction and methods sections. Shortening this passage, while retaining a brief summary of the system developed, would give greater prominence to the main findings, their limitations and their implications.

C47 | Lines 320–321:

The sentence is repetitive, particularly the wording “between meteorological parameters and N to calculate and obtain the N”. Rephrasing it would improve clarity and readability.

C48 | Lines 329–330:

The sentence “at varying heights without physical contact with the target gas, achieving long-range remote sensing while simultaneously retrieving AT, RH, and N data” is lengthy and awkwardly structured. Rephrasing it would improve clarity and readability.

C49 | References, Lines 376–430

Several journal entries, including Doyle et al. (2025), Ji et al. (2025) and Yang et al. (2024), lack volume and page or article-number information in the submitted list. Checking the publication status and completing these details where available, together with available DOIs and consistent journal capitalisation, would improve the bibliography.