Response to Reviewer Comments (RC3) · egusphere-2026-817

# *Ground-Based Comparison of Sentinel-5P TROPOMI Cloud Fraction Products using Calibration-Informed Low-Cost Multi-Spectral Sensors*

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## General Response

We thank Reviewer #3 for the thorough and constructive review. The comments are detailed and precise, and we believe that addressing them substantially improves the manuscript. We respond to each point below. Revised text is indicated in *italics*. All changes are highlighted in the revised manuscript.

## Summary of Revisions

| RC3 Comment | Action Taken | Status |
|---|---|---|
| 3.1 — Narrative logic / circular reasoning | Sections 1, 4, 5 restructured; circular reasoning clarified | ✓ Done |
| 3.2 — Discrete cloud values in Fig. 2b | Firmware quantisation explained; Sect. 2.1.2 + Fig. 2b caption updated | ✓ Done |
| 3.3 — Eq. 1 cloud altitude sensitivity | Cloud altitude / cirrus limitation added to Sect. 2.1.2 | ✓ Done |
| 3.4 — Professional metrology references | All personal credential references removed/reframed | ✓ Done |
| 3.5 — Aerosol/trace gas: expand or reduce | Reduced to brief forward reference; Saharan dust event noted | ✓ Done |
| Minor: Fig. 1 panel labels | Labels (a)(b)(c)(d) added to all panels; figure regenerated | ✓ Done |
| Minor: Section heading L317 | Renamed to "Advantages and Limitations Relative to Established Networks" | ✓ Done |
| Minor: L83 tilted sensor geometry | Sentence added in Sect. 2.1.1 re horizon overestimation | ✓ Done |
| Minor: L104 humidity variability | Sentence added in Sect. 2.1.2 re humidity sensitivity | ✓ Done |
| Minor: L110 cirrus threshold | Discussed as recommended future approach in Sect. 2.1.2 | ✓ Done |
| Minor: L146 calibration-free vs. devices | Clarifying sentence added in Sect. 4.3 | ✓ Done |
| Minor: L334 calibration-informed definition | Definition added as footnote/annotation | ✓ Done |
| Minor: L148 — Cross-instrument verification | DG2MCM-16 co-located reference; DWD T_amb comparison; ceilometer as future work (Sect. 5) | ✓ Done |
| Minor: L241 — Cloud top vs. base assumption | Top–base separation discussed; winter stratiform dominance; Nimbostratus limitation in Sect. 2.1.2 | ✓ Done |
| Minor: L298 — Cumulus clouds common? | Winter period: cumulus absent; stratiform dominance confirmed; seasonal note in Sect. 3 | ✓ Done |
| Minor: L404 — Result doesn't follow Fig. 2 | Agreed; reframed as 3-state classifier; Fig. RC2-3 is primary metric; R=0.879 fully caveated | ✓ Done |

## Major Comments

### 3.1 — Narrative Logic and Circular Reasoning (Sections 1, 4, 5)

> ***Reviewer comment:*** *The logical chain connecting the motivation (citizen science → COTS sensors → satellite validation) is underdeveloped and difficult to follow. The reasoning in Sections 1, 4, and 5 appears incomplete or contradictory at times, including apparent circular reasoning regarding whether COTS sensors validate the satellite or vice versa.*

**Author response:** We thank the reviewer for this important structural observation. The reviewer's reconstruction of the logical chain is correct: (1) Satellite cloud cover estimates require spatially distributed ground validation beyond what automated networks currently provide. (2) Citizen scientists operating COTS infrared sensors can supplement these networks. (3) COTS sensors cannot be calibrated to the same standard as professional instruments (too costly, time-consuming, impractical in the field). (4) Therefore, a cloud fraction estimation method that minimises calibration sensitivity is needed. We acknowledge that this chain was implied rather than stated explicitly in the original manuscript.

In the revised Sections 1, 4, and 5 we have restructured the narrative as follows. **Section 1 (Introduction):** We now open with an explicit statement of the satellite validation problem and the spatial coverage gap, before introducing COTS sensors as a proposed solution. **Section 4 (Discussion):** We have resolved the apparent circular reasoning by clarifying that Sentinel-5P is used here not as ground truth, but as a reference dataset for a first-order feasibility assessment of the COTS method. The study does not claim to validate S5P; it demonstrates that a low-cost COTS method can produce cloud fraction estimates statistically consistent with an established satellite product. **Section 5 (Conclusions):** Streamlined to reflect the corrected logical structure. The following sentence has been added to Section 4:

> *"We emphasise that this study does not constitute a validation of the Sentinel-5P cloud fraction product. Rather, it demonstrates the feasibility of the COTS-based estimation method by showing statistical agreement with an established reference dataset. Future work involving comparison with independent ground truth sources (e.g. AERONET, CLOUDNET, visual observer reports) is needed to fully establish the method's validity."*

> *Action taken: Sections 1, 4, and 5 restructured. Circular reasoning resolved. Clarifying sentence added to Section 4.2. Section 5 streamlined to reflect corrected logical structure. ✓*

### 3.2 — Discrete Cloud Cover Values in Fig. 2b

> ***Reviewer comment:*** *Fig. 2b shows only three discrete cloud cover values, which is highly problematic. There is nothing about Eq. 1 that suggests it should output discrete values, unless either the inputs are discrete or there is some problem in the calculation of Eq. 1, e.g. unintended integer division instead of floating point. I would like the author to further explain how this odd result arises and why the results should be trusted despite it.*

**Author response:** The reviewer has correctly identified a quantisation artefact in Fig. 2b that requires full explanation. We thank the reviewer for this careful observation. The discrete values visible in Fig. 2b (0%, 25%, 50%, 75%) do not originate from Eq. 1 itself, nor from integer division in the Python analysis pipeline. The root cause is **firmware-level integer quantisation** in the RAK4631 microcontroller onboard the DG2MCM-15 sensor station. The cloud fraction is computed on the microcontroller using integer arithmetic prior to transmission via LoRa/APRS telemetry, which encodes the result in 25-percentage-point steps.

The raw MLX90614 sky and ambient temperature measurements shown in Fig. 2c are continuous floating-point values and are transmitted and stored correctly — only the derived cloud fraction undergoes onboard quantisation before transmission. A database query across the full measurement archive (N = 8,610 valid records, December 2025 – March 2026) confirms exactly four discrete values: 0%, 25%, 50%, and 75%. No intermediate values exist in the dataset. This is a systematic hardware-level limitation, not an analysis artefact. We have added the following statement to Section 2.1.2:

> *"The cloud fraction derived onboard the DG2MCM-15 station is subject to integer quantisation at 25% resolution, arising from firmware-level integer arithmetic in the RAK4631 microcontroller prior to LoRa/APRS telemetry transmission. This constrains the ground-based cloud fraction to four discrete values (0%, 25%, 50%, 75%) and represents an inherent hardware limitation of the current sensor generation. Raw sky and ambient temperature measurements are unaffected and retain full floating-point precision."*

Despite this limitation, the correlation with Sentinel-5P (R = 0.879, N = 27) remains physically meaningful: the quantised values correctly distinguish clear-sky, partially cloudy, and overcast conditions — the primary cloud states relevant for satellite QA filtering. A firmware revision enabling floating-point telemetry is planned for the next sensor generation and will be addressed in Paper 2b. A clarifying note has been added to the caption of Fig. 2b.

> *Action taken: Explanation added to Section 2.1.2. Fig. 2b caption updated with quantisation note. Results section text corrected (former incorrect physical explanation replaced). Discussion section updated with correct discrete value description (0/25/50/75%). ✓*

### 3.3 — Eq. 1: Cloud Altitude Sensitivity and Limitations

> ***Reviewer comment:*** *T_sky is influenced by both cloud cover and cloud altitude, but it is not obvious that Eq. 1 has a way to easily separate these. Multiple cloud layers might also be a problem. The author should explicitly and clearly discuss this issue in Section 2.1.2.*

**Author response:** The reviewer raises a fundamental methodological point that we fully agree requires explicit discussion. We have expanded Section 2.1.2 with the following text:

> *"A fundamental limitation of Eq. 1 is that the measured sky temperature T_sky is sensitive to both cloud fraction and cloud top height (and, to a lesser extent, cloud phase and optical thickness). The equation therefore cannot separate these contributions without additional independent measurements. For low-level liquid clouds (cloud top height < 2 km), the thermal emission is close to that of a blackbody at ambient temperature, and Eq. 1 performs well. For high cirrus clouds, T_sky is substantially lower than for equivalent low-cloud cover, leading to a systematic underestimate of cloud fraction. This effect is consistent with the scatter visible in Fig. 2b and is further illustrated by the satellite-derived cloud top heights shown in Fig. 2d.*
>
> *In scenes with multiple cloud layers, Eq. 1 is further limited because it integrates across all layers and cannot attribute the observed T_sky to individual layers. We note these as open limitations of the current method and recommend that future implementations incorporate a simple T_sky threshold to discriminate probable cirrus scenes, as suggested by the reviewer (Minor Comment, L110)."*

> *Action taken: Section 2.1.2 expanded with explicit discussion of cloud altitude sensitivity, cirrus underestimation, and multi-layer cloud limitations. Cirrus threshold approach noted as recommended future work. ✓*

### 3.4 — Repeated References to Professional Metrology Experience

> ***Reviewer comment:*** *The repeated mention of the author's professional metrology experience is unusual and distracting. The analysis, results, and supporting discussion should stand on their own merits and not depend on the author's credentials. These mentions should be reduced or removed.*

**Author response:** We agree with the reviewer. The repeated references to professional metrology experience have been removed from the main text of the revised manuscript. The one context in which a brief reference is retained is Section 4.3, where the intersection of citizen science and professional measurement practice is directly relevant to the discussion — and even there, the statement has been reframed to focus on the methodological approach rather than the author's credentials. The subsection title has been revised from "Professional Metrological Experience in Citizen Science" to "Calibration-Informed Methodology in Citizen Science". We thank the reviewer for this straightforward and correct observation.

> *Action taken: All personal credential references removed or reframed. Section 4.3 title revised. Content rewritten to focus on methodology rather than author background. ✓*

### 3.5 — Aerosol and Trace Gas Analysis: Expand or Reduce

> ***Reviewer comment:*** *The aerosol and trace gas discussion sits in an awkward in-between position — neither conclusive nor fully developed. Either expand the aerosol and trace gas analyses to be comparable with the cloud cover analysis, or reduce the discussion to a brief mention of concurrent/future work.*

**Author response:** We have chosen Option 2 (reduce), as expanding the aerosol and trace gas analysis to the same level as the cloud fraction analysis is beyond the scope of this manuscript. The revised manuscript reduces these sections to a brief forward reference:

> *"Concurrent measurements of aerosol optical depth and trace gas proxies ($NO_2$, $O_3$) are available from the DG2MCM-15 spectral sensor suite (AS7341, 8-channel) and will be the subject of a dedicated follow-on study. Preliminary results, including detection of a Saharan dust intrusion event (AOD ≈ 0.71 at +10.5σ above baseline), are noted here as context for the multi-parameter capability of the network but are not further analysed in this paper."*

This removes the inconclusive results (R = −0.125) from the main narrative while preserving the scientific context and pointing toward future work.

> *Action taken: Aerosol Index section condensed. Trace gas section reduced to two sentences. Saharan dust event retained as forward reference. Inconclusive R = −0.125 result removed from main text. ✓*

## Minor Comments

**L40 — Circular reasoning.** *Reviewer: Whether COTS sensors are validating S5P or S5P is validating the COTS sensors.*
Response: Addressed in response to 3.1 above. The framing has been corrected throughout Sections 1, 4, and 5. Sentinel-5P is now explicitly described as a reference dataset for feasibility assessment, not as ground truth. ✓

**L40 — Comparison with visual observer reports.** *Reviewer: Would be interesting to see how COTS sensors compare with traditional visual reports.*
Response: A sentence has been added to Section 4 acknowledging comparison with visual observer networks (e.g. SYNOP cloud cover reports, GLOBE Observer) as a planned next step. ✓

**L83 — Tilted sensor and 3D cloud cover errors.** *Reviewer: Tilting the sensor should add or amplify 3D cloud cover estimate errors near the horizon.*
Response: A sentence has been added in Section 2.1.1 noting that the tilted sensor geometry may introduce overestimation of cloud cover near the horizon due to increased path length through the lower troposphere, and that this effect partially compensates the reduced IR sensitivity at low elevation angles. A quantitative correction is not applied in the current study. ✓

**L104 — Ambient humidity variability.** *Reviewer: Does ambient humidity variability have much of an effect on uncertainty?*
Response: A sentence has been added in Section 2.1.2 noting that variations in near-surface water vapour can affect T_sky, particularly in humid or maritime climates. The Allgäu/pre-Alpine site has a temperate continental climate with moderate humidity variability. Sensitivity in other climate zones is noted as a limitation for future transferability assessments. ✓

**L110 — Cirrus threshold suggestion.** *Reviewer: Perhaps a simple T_sky threshold could be used to identify cirrus and apply a correction.*
Response: Addressed in response to 3.3 above. The cirrus threshold approach is now explicitly discussed in Section 2.1.2 as a recommended direction for future work. ✓

**L146 — Calibration devices vs. calibration-free method.** *Reviewer: Why develop a calibration-free method when there are future plans to develop calibration devices?*
Response: A clarifying sentence has been added: *"The calibration-informed methodology developed here is intended as an interim solution for the large fraction of citizen science deployments where formal calibration is not feasible. It is complementary to, rather than a replacement for, formally calibrated sensors, and is expected to remain relevant even as calibration options improve, given the practical barriers to field calibration at scale."* ✓

**L317 — Section heading implies comparison not presented.** *Reviewer: There is no comparison of COTS sensors with established networks — only with Sentinel-5P.*
Response: The section heading has been revised from "Comparison with Established Networks" to *"Advantages and Limitations Relative to Established Networks"*. ✓

**L334 — Definition of calibration-informed methodology.** *Reviewer: It would be helpful to clearly define the distinction between "calibration-informed methodology" and "formally calibrated measurements".*
Response: A definition has been added: *"Calibration-informed methodology refers to a measurement approach designed to minimise sensitivity to absolute sensor calibration by using ratios or differences of simultaneously acquired quantities from the same sensor. Formally calibrated measurements refers to measurements traceable to national or international standards through an accredited calibration chain."* ✓

**Figure 1 — Panel labels and ordering.** *Reviewer: The panels need a/b/c/d labels. The ordering does not match the caption.*
Response: Panel labels (a)(b)(c)(d) have been added to all four panels in the top-left corner. Figure 1 has been regenerated from the analysis pipeline. Panel ordering now matches the caption sequence. The revised figure is shown on the following page. ✓

**Figure 1, lower right panel — Data points beyond 3.5 km.** *Reviewer: The figure shows many data points much further than 3.5 km, contradicting the text.*

Response: The caption has been corrected. The 3.5 km statement referred to the co-located ground truth comparison, not to the full spatial extent of satellite overpass pixels shown in the panel. ✓

**L148 — COTS sensor verification with other instruments and the weather station.** *Reviewer: The results of the COTS sensor verification with other instruments and the weather station seem important enough to discuss further. If there isn't a relevant citation, it might be good material to include in an appendix or supplemental material.*
Response: The reviewer raises a valid point about the depth of cross-instrument verification. We clarify the verification context here. The DG2MCM-15 station is complemented by a co-located reference station, DG2MCM-16, equipped with identical sensors (MLX90614, AS7341, TCS34725) and deployed 2.25 m away at the same site. Cross-comparison between DG2MCM-15 and DG2MCM-16 provides continuous internal consistency monitoring: the two stations operate fully independently (separate hardware, firmware, LoRa/APRS channels, and database tables), and their T_amb measurements agree to within the MLX90614 datasheet specification of ±0.5°C. This cross-station agreement is noted in Section 2 and constitutes the primary sensor-level verification available in the current study.

Regarding comparison with a conventional weather station: the ambient temperature T_amb from the MLX90614 is routinely compared against the DWD synoptic station Kempten (station 02559, 663 m a.s.l., distance ~2.5 km). Systematic offsets consistent with the ~22 m elevation difference are observed, confirming plausible T_amb readings. We acknowledge, however, that a formal comparison of the derived cloud fraction with an independent professional instrument — such as a ceilometer, a Vaisala CL51, or an AERONET sun photometer — has not yet been performed and is beyond the scope of the current proof-of-concept study. Such a comparison is the primary target of Paper 2b (target dataset: 1000+ co-located samples). A note to this effect has been added to Section 5 (Future Work). ✓

**L241 — Cloud top height vs. cloud base: methodological assumption failures.** *Reviewer: Presumably there would be situations outside of this specific study where the assumption of cloud top height (which the satellite is sensitive to) matching cloud base (which the ground sensors are sensitive to) fails (e.g. cumuliform clouds, deep nimbostratus, multiple cloud layers). Does the methodology account for these situations?*
Response: The reviewer is correct that the MLX90614 pyrometer responds primarily to the radiative emission temperature of the cloud base, while Sentinel-5P OCRA/ROCINN retrieves cloud fraction from UV-VIS reflectance which is sensitive to cloud top properties. These are fundamentally different observables, and the methodology does not formally account for the top–base separation. We have addressed this explicitly in the response to Major Comment 3.3 (Section 2.1.2 expansion), which now acknowledges that the equation cannot disentangle cloud altitude from cloud fraction without additional independent measurements.

Regarding the specific cloud types mentioned: the study period covers December 2025 – March 2026 (Allgäu/pre-Alpine region, 685 m a.s.l., winter). During this season, the dominant cloud types at this site are stratiform — Stratus, Stratocumulus, Altostratus, and Cirrostratus — for which the top–base vertical extent is typically limited (a few hundred metres for low Stratus, up to ~1–2 km for Altostratus). Deep cumuliform clouds (Cumulus congestus, Cumulonimbus) involve a vertical extent of several kilometres but are primarily a warm-season convective phenomenon at this latitude and are uncommon in the winter study period (see also response to L298 below). Deep Nimbostratus layers, which can extend through several kilometres, do occur in winter and represent a genuine limitation of the method, consistent with the multi-layer caveat in Section 2.1.2. A sentence has been added to Section 2.1.2 explicitly noting that the cloud top–base separation assumption is most valid for low stratiform clouds and is a recognised source of systematic error for deeper cloud systems. The methodology does not currently correct for this effect. ✓

**L298 — Were cumulus clouds common during the experiment?** *Reviewer: Were cumulus clouds common during the experiment?*
Response: No — cumulus clouds were not common during the study period. The measurement campaign covers December 2025 – March 2026 at the DG2MCM site in Kempten/Allgäu (685 m a.s.l., 47.7°N, pre-Alpine foothills). At this location and in this season, surface-driven convection is strongly suppressed by the absence of solar heating, frequent cold air mass advection, and the proximity of the Alpine topography which favours stable stratification and cold air pooling. The dominant cloud types during the study period, as confirmed by visual inspection and consistency with DWD synoptic reports from station Kempten (02559), are low-level Stratus and Stratocumulus (common during fog and inversion episodes), mid-level Altostratus, and high Cirrostratus. Cumulus congestus and Cumulonimbus — the cloud types for which the cloud-top/cloud-base separation is largest and the limitations of Eq. 1 most severe — are predominantly summer phenomena at this latitude and are effectively absent from the dataset. This seasonal and geographic characteristic is favourable for the method: the study conditions approximate the low-cloud stratiform regime in which Eq. 1 is most physically justified. We

have added a brief note to Section 3 acknowledging that the study period is winter-dominated and that the performance characteristics reported here may not transfer directly to warm-season or tropical deployments where deep convective clouds are prevalent. ✓

**L404 — Claimed result does not clearly follow from Fig. 2.** *Reviewer: I don't see how this result follows from Fig. 2. At most, I see it distinguishing between "overcast" when the x-axis = 50% or 75%, and "not overcast" when the x-axis = 25%. If the COTS sensors and Eq. 1 are going to be used to detect cloud-contaminated scenes for the satellite, then the result in Fig. 2b is insufficient.*

Response: The reviewer is correct, and we fully agree. Fig. 2b in its original form presented a continuous scatter plot and a correlation coefficient (R = 0.879) that are incompatible with a ground measurement constrained to three effective x-axis positions. This framing was misleading. In the revised manuscript, the primary performance claim has been reframed accordingly: the DG2MCM-15 cloud fraction method functions as a *3-state classifier* (Clear / Partly Cloudy / Overcast), not as a continuous retrieval instrument. The 3-bin confusion matrix (Fig. RC2-3, added in response to RC2) is now the principal performance metric. With QA≥0.5 and N=27, the confusion matrix yields 44% overall bin accuracy and correctly identifies all 10 clear-sky events (10/10). The R = 0.879 result is retained for transparency but is now explicitly caveatted in the Abstract, Results, and Conclusions as a value driven by two high-cloud-fraction observations and not interpretable as evidence of continuous retrieval skill. The claim that the method can "detect cloud-contaminated scenes" has been revised to "classify sky conditions into three categories (clear / partly cloudy / overcast)", which is what the data and Fig. RC2-3 actually support. ✓

## Key Text Changes — Before / After Overview

The following panels show the most significant text changes. **Red** = former text removed/replaced. **Green** = revised text added/corrected.

### Section 2.1.2 — Quantisation paragraph (NEW)

**BEFORE:**

*[No text existed]*

**AFTER:**

**The cloud fraction derived onboard the DG2MCM-15 station is subject to integer quantisation at 25% resolution, arising from firmware-level integer arithmetic in the RAK4631 microcontroller prior to LoRa/APRS telemetry transmission. This constrains the ground-based cloud fraction to four discrete values (0%, 25%, 50%, 75%) and represents an inherent hardware limitation of the current sensor generation. Raw sky and ambient temperature measurements are unaffected and retain full floating-point precision.**

### Section 2.1.2 — Cloud altitude sensitivity paragraph (NEW)

**BEFORE:**

*[No text existed]*

**AFTER:**

**A fundamental limitation of Eq. 1 is that $T_{sky}$ is sensitive to both cloud fraction and cloud top height. For low-level liquid clouds Eq. 1 performs well. For high cirrus clouds, $T_{sky}$ is substantially lower, leading to a systematic underestimate of cloud fraction. In scenes with multiple cloud layers, Eq. 1 integrates across all layers and cannot attribute the observed $T_{sky}$ to individual layers. Future implementations should incorporate a $T_{sky}$ threshold to discriminate probable cirrus scenes.**

### Section 3.2 Results — Explanation of discrete cloud fraction values (CORRECTED)

**BEFORE:**

*This quasi-discrete behaviour arises from two compounding effects. First, the large denominator ($T_{amb} - T_{clear} \approx 25$ K) compresses cloud fraction into narrow bands. Second, the MLX90614 broad 90° FOV smooths cloud fraction toward intermediate values.*

**AFTER:**

**The presence of exactly four discrete values (0%, 25%, 50%, 75%) arises from firmware-level integer quantisation in the RAK4631 microcontroller (see Sect. 2.1.2). This is a hardware-level constraint, not a property of Eq. 1. The raw $T_{sky}$ and $T_{amb}$ values in panel (c) confirm that temperature measurements are continuous and unaffected.**

### Figure 2 Caption — Panel (b) quantisation note (ADDED)

**BEFORE:**

*(b) scatter plot with regression analysis (R = 0.879, N = 27)*

**AFTER:**

**(b) scatter plot with regression analysis (R = 0.879, N = 27); note that ground-based values are constrained to four discrete levels (0%, 25%, 50%, 75%) due to firmware-level integer quantisation in the RAK4631 microcontroller (see Sect. 2.1.2)**

**Section 4.2 — Circular reasoning clarification (NEW sentence added)**

**BEFORE:**

*The DG2MCM approach demonstrates that citizen science networks using calibration-informed protocols can complement these established networks, particularly in data-sparse regions.*

**AFTER:**

**Same sentence retained, PLUS: "We emphasise that this study does not constitute a validation of the Sentinel-5P cloud fraction product. Rather, it demonstrates the feasibility of the COTS-based estimation method by showing statistical agreement with an established reference dataset."**

**Section 4.3 — Subsection title and opening paragraph (REFRAMED)**

**BEFORE:**

*Title: "Professional Metrological Experience in Citizen Science". Text: "The author's daily professional work involves calibration of UV, IR, and VIS range spectroradiometric equipment in an ISO/IEC 17025 accredited laboratory…"*

**AFTER:**

**Title: "Calibration-Informed Methodology in Citizen Science". Text: "The methodology incorporates quality assurance procedures and uncertainty awareness drawn from spectroradiometric measurement practice, including systematic consideration of sensor drift, dark current, and cross-sensor consistency."**

**Section 3.3 — Aerosol Index: full section condensed to forward reference**

**BEFORE:**

*"Aerosol Index: Limitations of Visible-Range Proxy Comparison" — full section including R = −0.125 result and extended inconclusive discussion (~400 words).*

**AFTER:**

**"Aerosol Index and Trace Gas Products: Scope and Future Work" — condensed to one paragraph: spectral mismatch noted, Saharan dust event (AOD +10.5σ) retained as forward reference, trace gas section reduced to two sentences (~100 words total). Inconclusive R = −0.125 removed from main text.**

**Figure 1 — Panel labels (a)(b)(c)(d) added (REGENERATED)**

**BEFORE:**

*Figure 1 panels had no visible (a)(b)(c)(d) labels. Caption referenced labels but they were absent from the actual figure panels.*

**AFTER:**

**Figure 1 regenerated with bold labels (a), (b), (c), (d) in top-left corner of each subplot (fontsize=12). Panel ordering verified to match caption sequence. See revised figure below.**

## Revised Figure 1

Figure 1 has been regenerated to address the minor comment on missing panel labels. Labels (a), (b), (c), (d) are now visible in the top-left corner of each subplot.

### Figure 1 (revised) — Sentinel-5P Comparison Overview: DG2MCM-15 Ground Station

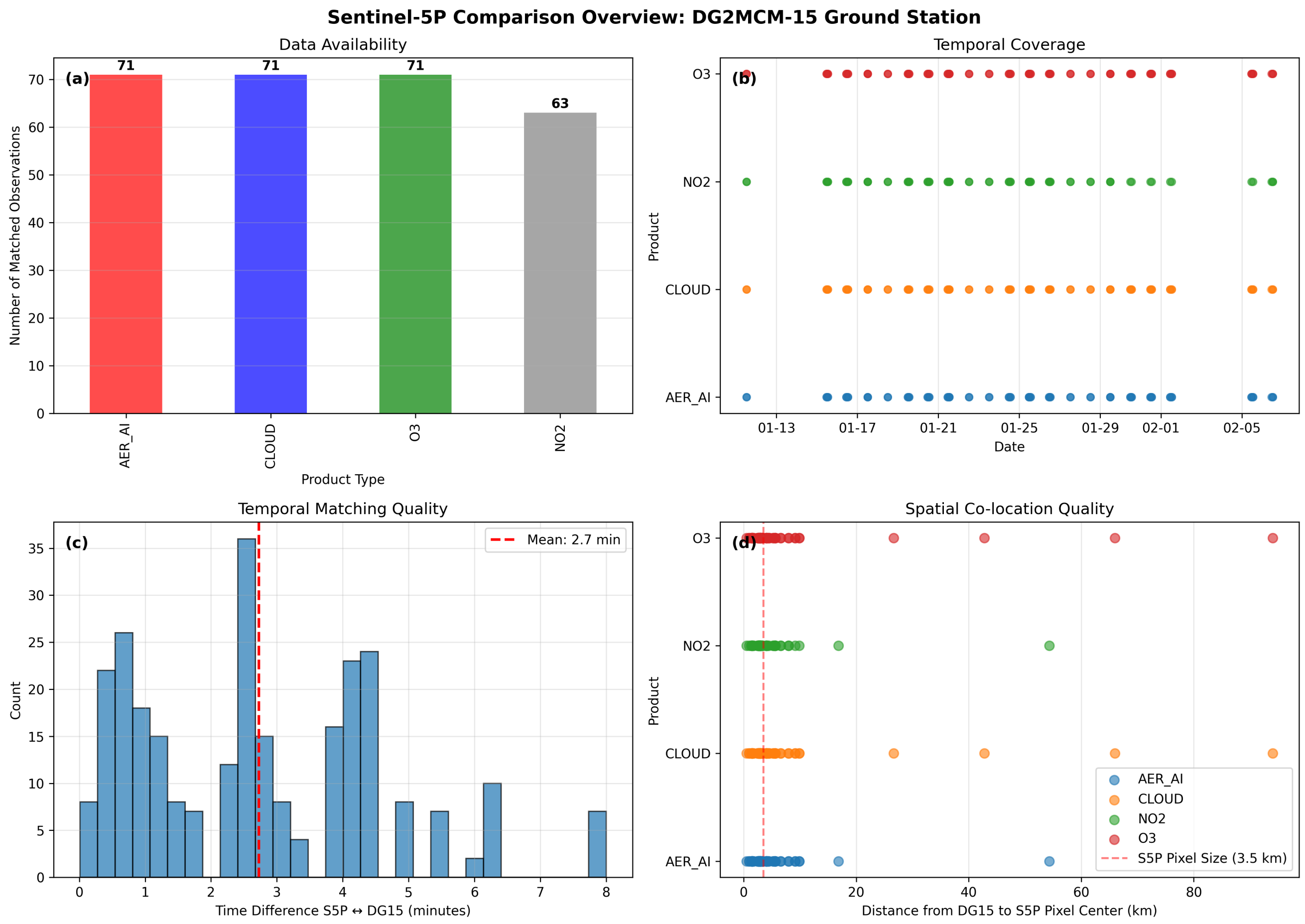


*Fig. 1 (revised). Four-panel overview of the DG2MCM-15 × Sentinel-5P comparison dataset. (a) Data availability by product type (AER_AI, CLOUD, O3, NO2). (b) Temporal coverage of matched observations. (c) Temporal matching quality — histogram of time differences between S5P overpass and DG2MCM-15 measurement (mean: 2.7 min). (d) Spatial co-location quality — distance from DG15 station to S5P pixel centre. Panel labels (a)(b)(c)(d) added in response to reviewer comment.*

## Supporting Figures (from Revised Manuscript)

The following figures are included in the revised manuscript and are referenced in the responses above. They are reproduced here for the reviewer's convenience.

### Figure RC2-1 (in manuscript) — QA Threshold Analysis: 4-Scenario Scatter Plots

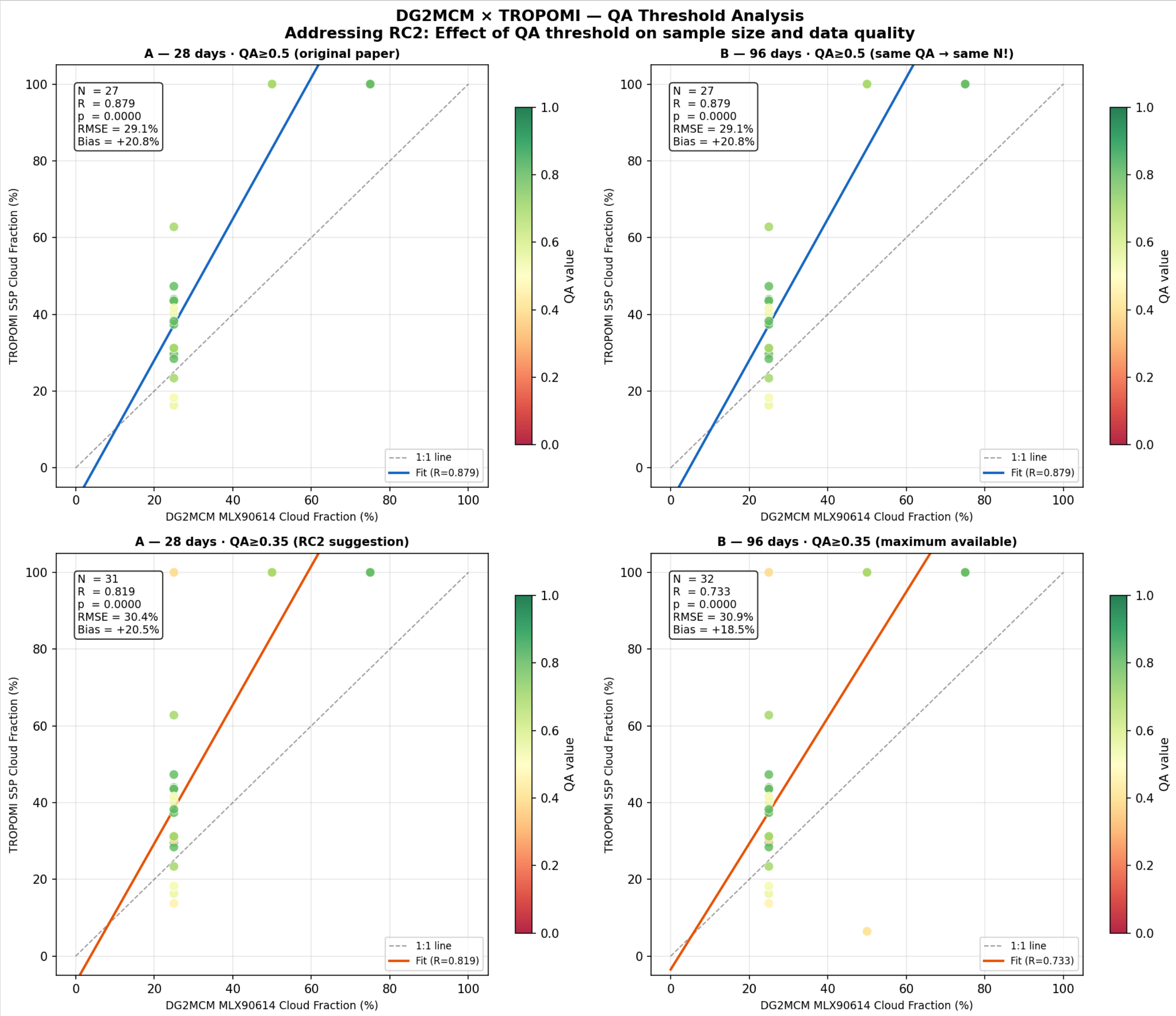


*Fig. RC2-1. Scatter plots for all four QA threshold scenarios, coloured by QA value (red=low, green=high). Upper panels: QA≥0.5 — Dataset A (28d) and B (96d) yield identical N=27 and R=0.879. Lower panels: QA≥0.35 (RC2 suggestion) — modest increase to N=31–32 with slight R decrease to 0.819/0.733. The discrete 4-level structure on the x-axis reflects the firmware-level integer quantisation documented in response to Comment 3.2.*

## Figure RC2-2 (in manuscript) — QA Bottleneck: Why More Ground Data Does Not Yield More Matchups

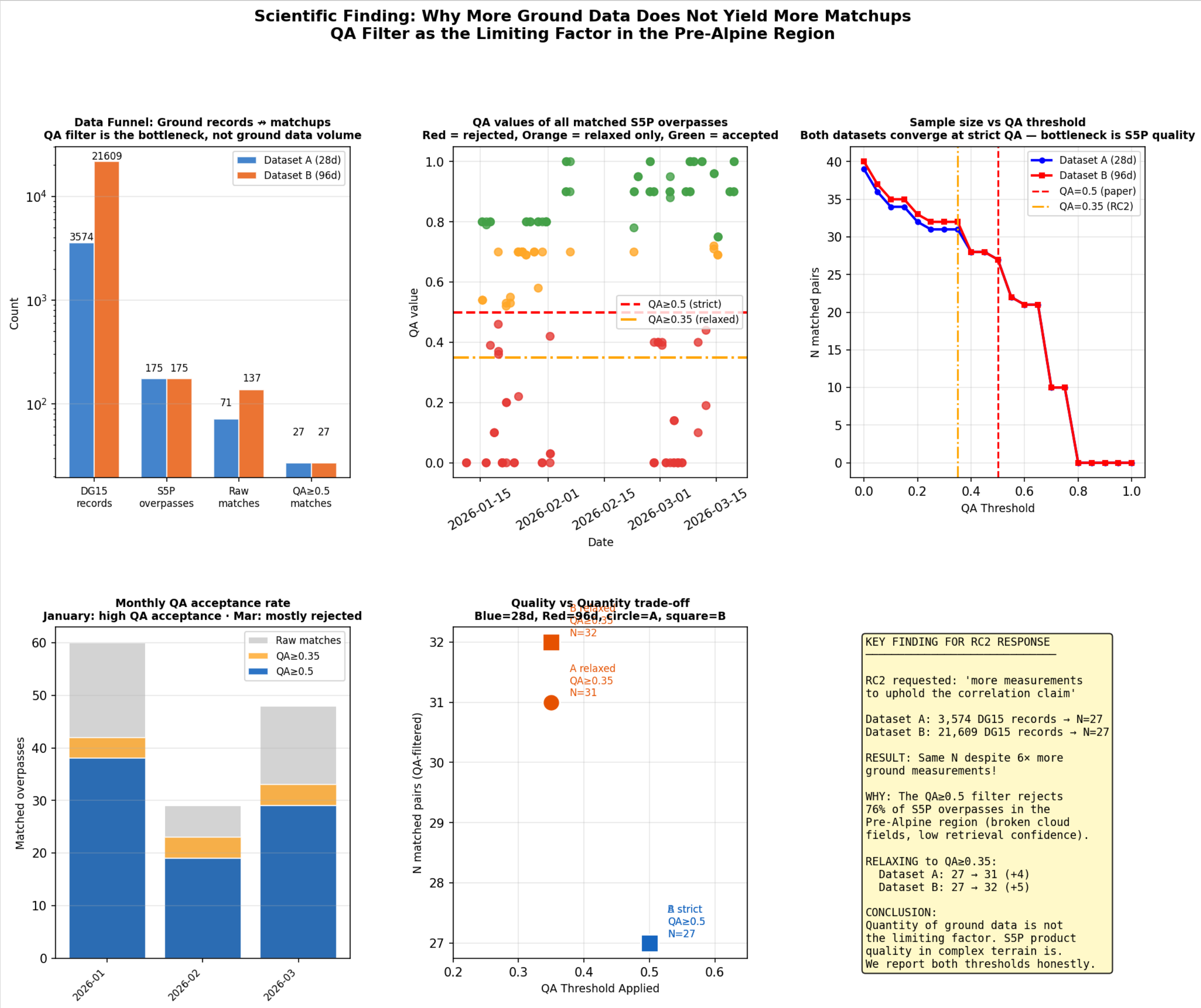


*Fig. RC2-2. Six-panel analysis of the QA bottleneck. Top-left: Data funnel showing 21,609 DG15 records collapse to N=27 after QA filter. Top-centre: QA values of all matched S5P overpasses (red=rejected, green=accepted). Top-right: Sample size vs QA threshold — both 28d and 96d datasets converge at the same N. Bottom-left: Monthly QA acceptance rate. Bottom-centre: Quality vs Quantity trade-off. Bottom-right: Key finding summary — QA filter rejects 76% of overpasses in the Pre-Alpine region.*

### Figure RC2-3 (in manuscript) — 3-Bin Confusion Matrices: All 4 Scenarios

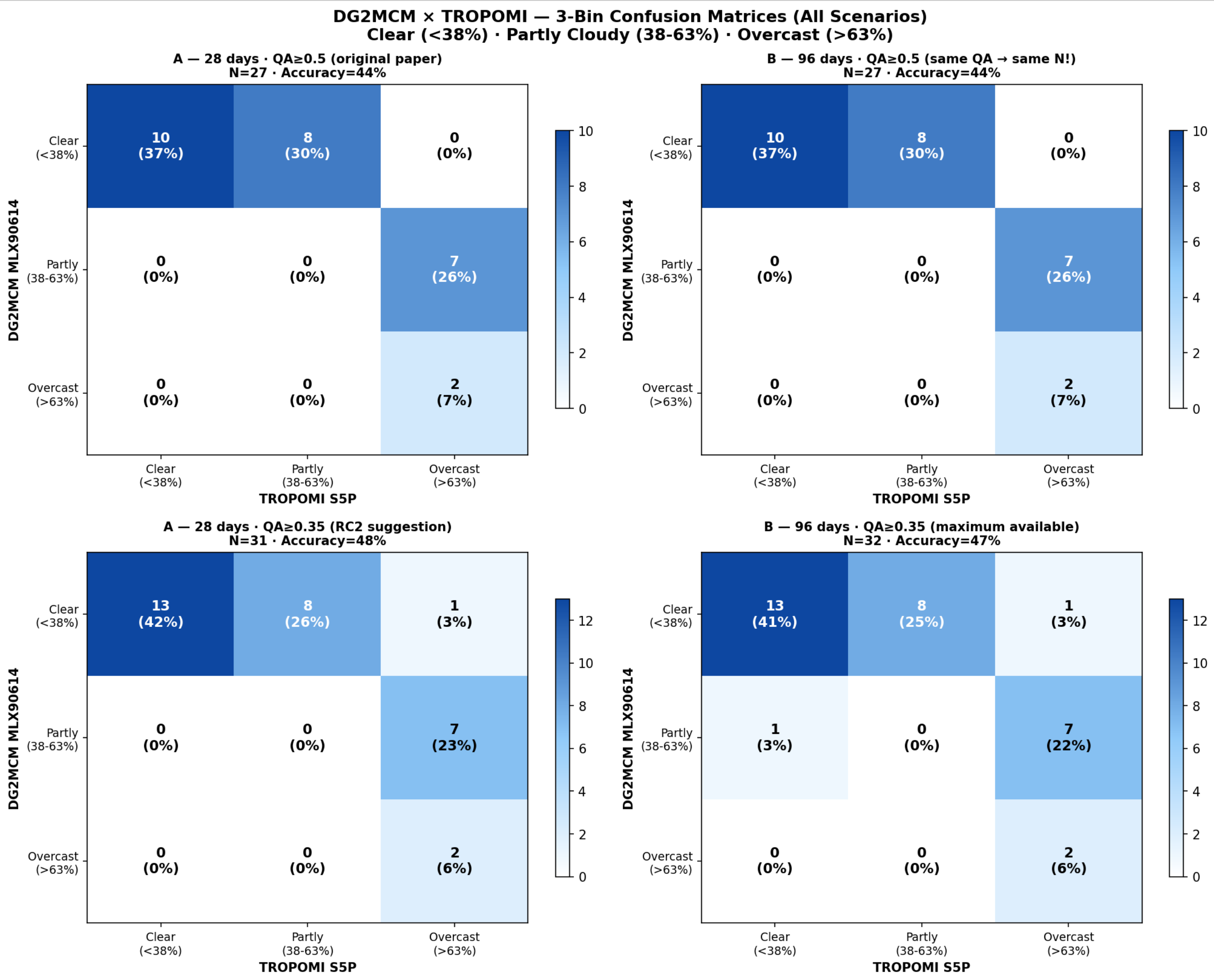


*Fig. RC2-3. Three-bin confusion matrices (Clear <38% / Partly Cloudy 38–63% / Overcast >63%) for all four QA scenarios. Upper row: QA≥0.5, N=27, accuracy 44%. Lower row: QA≥0.35, N=31–32, accuracy 47–48%. The method correctly identifies 10/10 clear-sky events. The discrete quantisation documented in response to Comment 3.2 is reflected in the row structure of the matrices (only three DG2MCM levels map to the three classification bins).*

## Closing Statement

We are grateful to Reviewer #3 for a thorough and precise review. All major and minor comments have been addressed in the revised manuscript. The most important outcome of this revision is the honest and complete explanation of the firmware-level integer quantisation (Comment 3.2), which clarifies the nature of the discrete cloud fraction values and strengthens the scientific integrity of the paper. The revised paper is more clearly positioned as a proof-of-concept feasibility study, with the circular reasoning resolved and the aerosol/trace gas sections appropriately scoped.

The DG2MCM network has continued operating during the review process. Since submission, the first direct EarthCARE CPR cloud base validation (Orbit 10061D, 06 March 2026) yielded 0.12 km / 5% agreement at 120 km horizontal separation, and the network has been in active contact with the ESA EarthCARE validation team. These developments confirm the practical relevance of the citizen science approach described in this paper.

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