Reply to Community Comment #1

Dear Kai Qin,

Thank you for reviewing our manuscript and providing constructive comments. Below, the comments are reproduced in black and our point-by-point answers are in blue. Each substantive response is followed by the corresponding revised text and/or figures and tables. Revised passages and figure captions are quoted from the revised manuscript and Supplement. Page and line numbers refer to the revised manuscript; S-numbered figures and tables refer to the revised Supplement.

Sincerely,
Yike Wang
On behalf of all co-authors
Wuhan University

General comment

This study presents a systematic comparison of DQ-1 ACDL XCO_2 with passive satellite products from OCO-2, OCO-3, GOSAT, and GOSAT-2. Wang et al. develop a unified comparison framework that combines CAMS-based assessment of background-field spatiotemporal coherence, multi-satellite sampling availability, daily 2° spatial aggregation, spatiotemporal collocation, and correction for differences in XCO_2 column definitions among the satellite products.

The study further investigates the remaining inter-product differences through surface-reflectance analysis, validation against TCCON observations, nighttime comparisons with an external model reference, and regional sampling analyses.

The datasets used in this study are comprehensive, and the proposed framework provides a useful basis for assessing the comparability and potential joint use of active and passive satellite XCO_2 observations. The manuscript is generally well structured and relevant to the scope of Atmospheric Chemistry and Physics. However, several methodological details and some of the principal conclusions require further clarification and quantitative support.

I recommend publication after the following comments have been adequately addressed.

ANSWER: We thank Dr. Qin for the careful and constructive assessment. We have revised the manuscript and Supplement substantially to clarify the active/passive observation operators and novelty, add an overall workflow, quantify the effect of the CAMS-based column-definition harmonization, apply the official GOSAT-2 empirical correction, strengthen TCCON uncertainty/sampling information, and address the technical and presentation issues listed below.

Main comments

Comment Main 1

Although both DQ-1 ACDL and passive satellite products provide XCO_2 retrievals, the two approaches differ in their retrieval formulations and effective vertical weighting. Please add a brief comparison in Sects. 2.1.1–2.1.2, noting that passive XCO_2 retrievals depend on prior CO_2 profiles and are characterized by column averaging kernels, whereas ACDL derives a weighted column from differential absorption measurements and its weighting functions.

This clarification would help readers understand that the original active and passive XCO_2 products should not be interpreted as directly equivalent without accounting for differences in their effective column definitions, and would provide the necessary context for the column-definition correction in Sect. 2.2.3.

ANSWER: We have clarified that the reported active and passive XCO_2 quantities have different effective vertical sensitivities. Passive retrievals use product-specific prior profiles, pressure weights, and column averaging kernels. DQ-1 ACDL instead derives a path-integrated weighted column from online/offline differential absorption, with vertical sensitivity represented by its weighting function and effective pressure layers.

The revised instrument descriptions introduce this distinction, and Sect. 2.2.3 expresses it through the corresponding observation operators. A common CAMS profile is passed through each operator to estimate the column-definition difference, which is then used for harmonization. This treatment addresses the modeled difference in column definitions.

Changes in the manuscript:

Sect. 2.1.2, pp. 5–6, lines 145–147.

> **Revised text:** "Although all products report XCO_2, their effective column definitions are not identical because the passive products use product-specific prior profiles, pressure weights, and column averaging kernels, whereas DQ-1 ACDL uses its weighting function and effective pressure layers. These differences are accounted for in Sect. 2.2.3."

Sect. 2.2.3, p. 12, lines 307–312.

> **Revised text:** "The active and passive satellite XCO_2 products do not necessarily share the same effective column definition because they differ in prior profiles, pressure weighting functions, column averaging kernels, and vertical sensitivities. If the retrieved XCO_2 values are compared directly, part of the difference may arise from differences in the observation operators, rather than from real atmospheric CO_2 differences. To reduce this effect, we use CAMS 3-hourly CO_2 profiles as a common external reference profile and apply the observation operator of each satellite to these profiles to estimate the theoretical difference caused by XCO_2 column-definition differences."

Sect. 2.2.3, p. 12, lines 334–336.

> **Revised text:** "This correction only accounts for the theoretical difference produced when the same CO_2 profile is represented under different satellite column definitions. CAMS is used only to estimate column-definition differences and is not treated as a truth reference for correcting satellite biases."

Comment Main 2

The novelty of the manuscript could be stated more clearly relative to previous DQ-1 validation studies and intercomparisons among passive satellite products.

Please clarify in the final part of the Introduction, and briefly reinforce in the Conclusions, that the principal contribution of this study is the systematic comparison of DQ-1 with OCO-2, OCO-3, GOSAT, and GOSAT-2 within a common framework that jointly accounts for background-field coherence, multi-sensor sampling availability, daily gridded collocation, observation-time differences, and differences in XCO_2 column definitions among the satellite products.

The authors should also explain briefly how this framework extends beyond previous validation of individual DQ-1 products and conventional intercomparisons among passive satellite products.

ANSWER: We have revised the final part of the Introduction and the Conclusions to identify the contribution more precisely. The contribution is the coordinated comparison of DQ-1 with OCO-2, OCO-3, GOSAT, and GOSAT-2 while jointly addressing background-field coherence, sampling availability, daily aggregation, observation-time differences, and effective column definitions.

Earlier DQ-1 studies established retrieval performance and validation, and earlier passive-satellite intercomparisons established important product-consistency methods. Our extension is to bring the distinct active and passive observation operators and sampling characteristics into the same comparison sequence. We therefore changed the title from "First comparison" to "Assessing the consistency of XCO_2 products from DQ-1 ACDL and passive satellites using a unified comparison framework". We also state that the resulting consistency applies primarily to the selected coherent and well-sampled regions, rather than presenting it as a global absolute-accuracy claim.

Changes in the manuscript:

Introduction, p. 3, lines 87–91.

> **Revised text:** "To our knowledge, no previous study has systematically compared DQ-1 ACDL with OCO-2, OCO-3, GOSAT, and GOSAT-2 within a unified active–passive framework that jointly accounts for background-field coherence, multi-satellite sampling availability, spatiotemporal collocation, and XCO_2 column-definition differences. This unified framework provides a consistent basis for

interpreting inter-product differences between active and passive satellite XCO_2 observations."

Comment Main 3

The study contains several interconnected processing steps, including comparison-region selection, satellite-data aggregation and collocation, column-definition correction, inter-satellite comparisons, TCCON validation, nighttime DQ-1 assessment, surface-reflectance analysis, and regional sampling evaluation. However, the overall methodological structure is difficult to follow from the text alone.

I suggest adding a workflow figure showing the input datasets, principal processing steps, and relationships among the different analyses. In particular, the different roles of CAMS in comparison-region selection, column-definition correction, and nighttime DQ-1 assessment should be clearly distinguished.

ANSWER: We have added a workflow diagram as Fig. 1 showing the input datasets, product-specific quality control, comparison-region selection, daily aggregation and collocation, column-definition harmonization, TCCON validation, inter-satellite comparisons, regional surface diagnostics, nighttime DQ-1 assessment, and regional sampling analysis. The figure explicitly separates the reference roles of TCCON and CAMS. The workflow figure is intended to clarify the logical sequence and relationships among the analyses rather than only summarize data-processing steps.

We also revised Sect. 2.1.3 to distinguish the three uses of CAMS: (1) CAMS column XCO2 supports the background-field coherence assessment; (2) CAMS profiles provide a common atmospheric input to the satellite-specific observation operators for column-definition harmonization; and (3) CAMS-derived XCO2 serves as an external model reference for diagnostic comparisons, including nighttime DQ-1. TCCON is identified separately as the ground-based observational reference for daytime validation. This avoids interpreting the different CAMS uses as independent validations or as observational truth.

Changes in the manuscript:

Introduction, p. 3, lines 92–99.

Revised text: "In this study, we compare DQ-1 ACDL with OCO-2, OCO-3, GOSAT, and GOSAT-2 XCO_2 products from June 2022 to December 2024 within a unified active–passive framework. We first identify coherent and well-sampled comparison regions, evaluate the satellite products against TCCON, and quantify inter-satellite consistency after daily 2° aggregation, collocation, and correction for XCO_2 column-definition differences. We then diagnose the remaining regional differences, assess nighttime DQ-1 against CAMS-derived XCO_2, and examine regional monthly variability and sampling continuity. The overall workflow is summarized in Fig. 1. Our objective is to evaluate the comparability and complementarity of DQ-1 active IPDA XCO_2 observations relative to passive NIR/SWIR products and to support future active–passive joint XCO_2 analyses, flux inversions, and emission monitoring."

Sect. 2.1.3, p. 6, lines 154–160.

Revised text: "CAMS is used in three main ways in this study. First, CAMS column-averaged XCO_2 is used to evaluate the spatial homogeneity and short-term temporal coherence within each 2° candidate grid cell, thereby identifying background regions that are more suitable for inter-satellite comparison. Second, CAMS model-level CO_2 profiles are used as a common external profile and are passed through the observation operators of different satellites to construct CAMS-derived XCO_2 values consistent with each satellite's column definition. This allows us to estimate the theoretical differences caused by differences in vertical sensitivity and effective column definition. Third, for nighttime DQ-1 observations, CAMS-derived XCO_2 is used as an external model reference to evaluate the consistency between nighttime DQ-1 XCO_2 and the model reference field."

Sect. 2.1.3, p. 6, lines 161–164.

Revised text: "Throughout this study, TCCON is used as the ground-based observational reference for daytime validation, whereas CAMS is used as a model-based common reference for comparison-region selection, column-definition harmonization, and diagnostic analyses. CAMS is not treated as observational truth. The specific uses of CAMS are described in Sects. 2.2.1, 2.2.3, and 2.2.7."

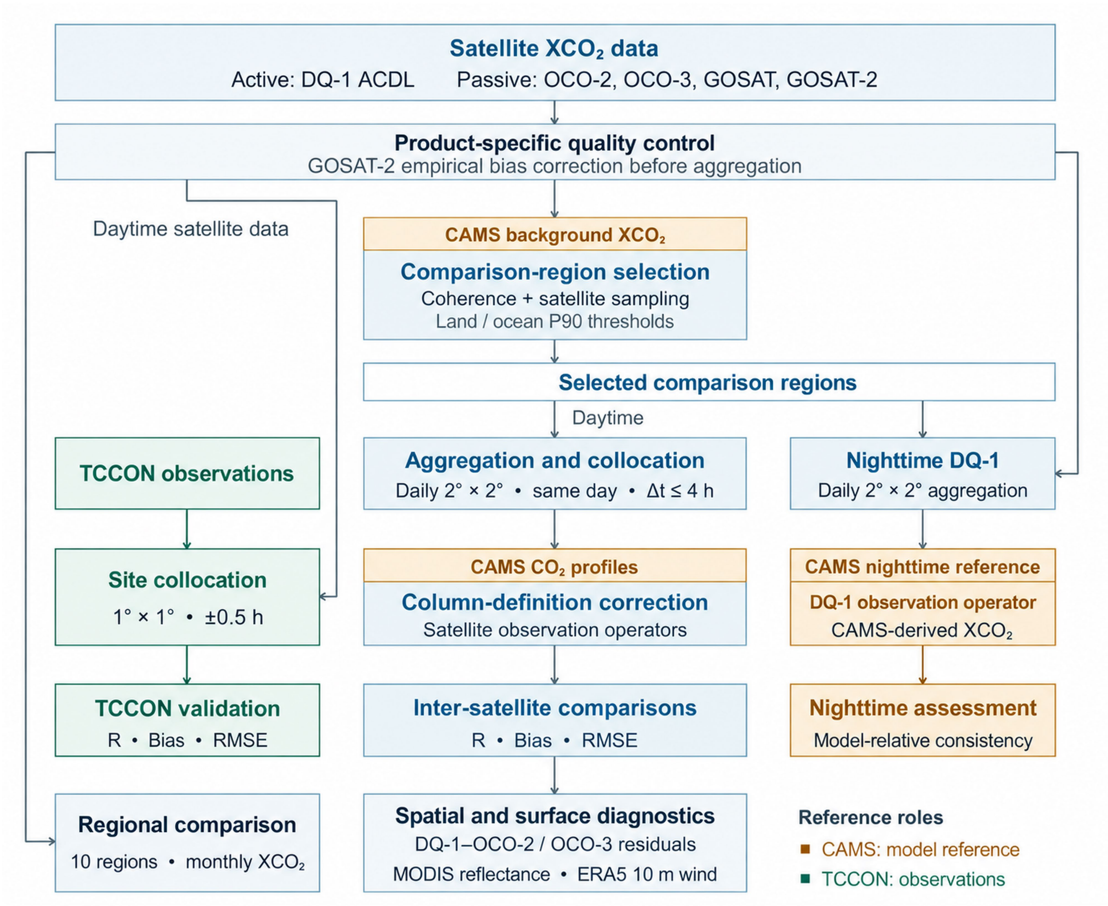

Figure 1. Workflow of the unified active–passive XCO_2 comparison framework.

Comment Main 4

The CAMS-based treatment of XCO_2 column-definition differences is a central component of the proposed framework, but its magnitude and influence on the final results are not sufficiently demonstrated. The authors should present the spatial distributions of the column-definition differences between DQ-1 and OCO-2, OCO-3, GOSAT, and GOSAT-2 for the collocated samples or selected comparison regions, and briefly discuss where these differences are relatively pronounced.

In addition, the correlation coefficient, mean difference, and RMSE should be reported before and after column-definition correction for each satellite pair. This comparison would quantify the actual influence of the correction and show whether and to what extent the correction affects the inter-product statistics and conclusions.

ANSWER: We have added Fig. S1 to show the spatial distributions of the CAMS-derived DQ-1-minus-passive column-definition differences for the collocated samples, and Table S3 to report R, bias, and RMSE before and after harmonization for every satellite pair, separately over land and ocean.

The pair-mean differences in Fig. S1 are +0.44 ppm for OCO-2, +0.44 ppm for OCO-3, +1.30 ppm for GOSAT, and +0.49 ppm for GOSAT-2. The largest pair-mean term is therefore for GOSAT, with pronounced positive values among its comparatively sparse collocations, including sampled land and ocean locations. The OCO and GOSAT-2 maps contain mostly smaller positive differences, with local variation across the sampled regions. These maps describe the collocations and are not continuous global correction fields.

For DQ-1–OCO-2, bias changes from 0.92 to 0.45 ppm over land and from 0.91 to 0.49 ppm over ocean; RMSE decreases from 1.54 to 1.27 ppm and from 1.79 to 1.59 ppm, respectively. For DQ-1–GOSAT, land RMSE decreases from 2.30 to 1.47 ppm, whereas ocean RMSE increases from 1.86 to 2.30 ppm. Thus, the correction has a material effect on some absolute offsets and does not uniformly improve agreement. R changes by no more than 0.01 in most comparisons.

The conclusions now describe consistency after model-assisted harmonization. We distinguish this operator correction from empirical bias correction and retain uncertainties associated with the CAMS profiles, retrievals, and sampling.

Changes in the manuscript:

Sect. 3.3, p. 17, lines 457–463.

> Revised text: "Following the independent TCCON evaluation, we next examine the relative consistency among satellite XCO_2 products over the coherent and well-sampled comparison regions. Figure 4 summarizes the pairwise consistency statistics for the five satellite XCO_2 products over the selected comparison regions. Figure S1 shows the spatial distributions of the CAMS-derived column-definition differences, and Table S3 reports the pairwise statistics before and after the column-definition correction. The mean DQ-1-minus-OCO-2, OCO-3, GOSAT, and GOSAT-2 column-definition differences are 0.44, 0.44, 1.30, and 0.49 ppm,

respectively. The correction changes the correlation coefficients by no more than 0.01 in most comparisons, while the bias and RMSE can change more noticeably."

Sect. 2.2.3, p. 12, lines 334–336.

Revised text: "This correction only accounts for the theoretical difference produced when the same CO_2 profile is represented under different satellite column definitions. CAMS is used only to estimate column-definition differences and is not treated as a truth reference for correcting satellite biases."

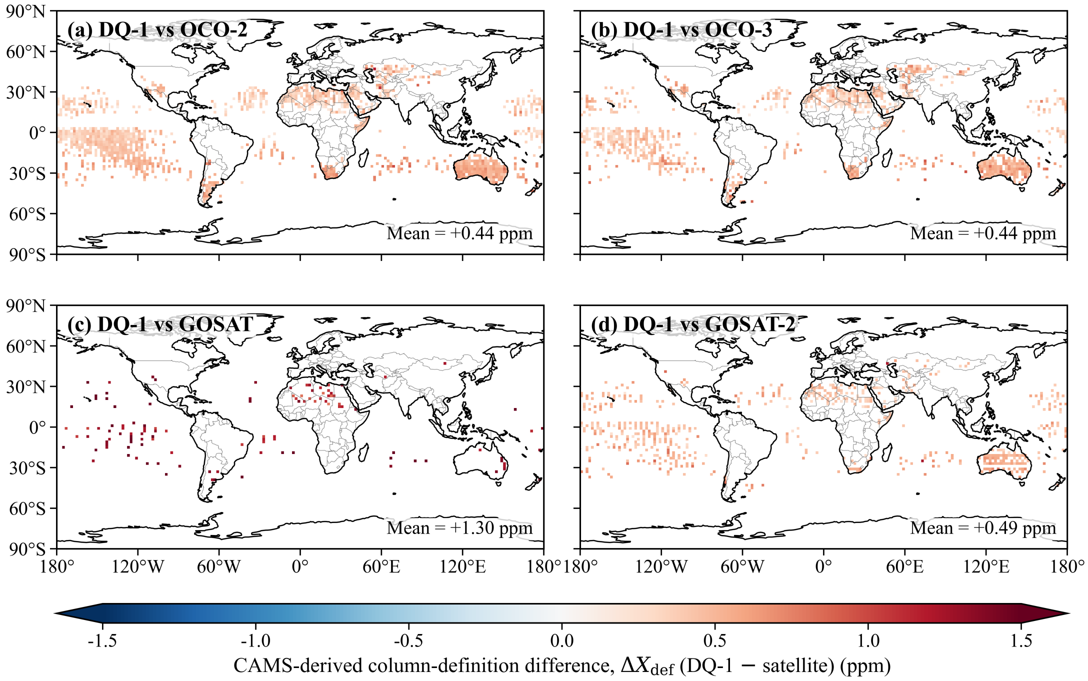

Figure S1. Spatial distributions of the CAMS-derived XCO_2 column-definition differences between DQ-1 and (a) OCO-2, (b) OCO-3, (c) GOSAT, and (d) GOSAT-2 for the collocated samples. The column-definition difference is defined as XCO_2 (DQ-1 definition) − XCO_2 (satellite definition), and the mean value for each satellite pair is shown in the lower-right corner of each panel.

Table S3. Pairwise consistency statistics for satellite XCO_2 products before and after CAMS-based column-definition correction over the selected comparison regions. Bias is defined as the y-axis product minus the x-axis product.

Y-axis product	X-axis product	Surface type	N	Before correction			After correction		
				R	Bias (ppm)	RMSE (ppm)	R	Bias (ppm)	RMSE (ppm)
DQ-1	OCO-2	Land	1559	0.93	0.92	1.54	0.93	0.45	1.27
		Ocean	1922	0.89	0.91	1.79	0.89	0.49	1.59
DQ-1	OCO-3	Land	1099	0.92	0.51	1.38	0.92	0.06	1.26
		Ocean	628	0.87	0.81	1.87	0.86	0.38	1.71
DQ-1	GOSAT	Land	80	0.91	1.97	2.30	0.90	0.76	1.47
		Ocean	79	0.77	0.01	1.86	0.76	-1.39	2.30
DQ-1	GOSAT-2 (original)	Land	569	0.87	-2.18	2.80	0.87	-2.66	3.19
		Ocean	479	0.83	-2.87	3.41	0.82	-3.36	3.84
DQ-1	GOSAT-2 (corrected)	Land	569	0.85	1.54	2.31	0.86	1.06	2.02
		Ocean	479	0.83	0.24	1.80	0.83	-0.25	1.80
OCO-2	OCO-3	Land	1435	0.97	-0.32	0.82	0.97	-0.30	0.81
		Ocean	1203	0.99	-0.09	0.45	0.99	-0.08	0.45
OCO-2	GOSAT	Land	86	0.94	0.58	1.14	0.94	0.08	1.03
		Ocean	96	0.93	-0.69	1.23	0.94	-1.34	1.66
OCO-2	GOSAT-2 (original)	Land	754	0.91	-3.42	3.78	0.91	-3.48	3.82
		Ocean	667	0.94	-3.69	3.92	0.94	-3.75	3.97
OCO-2	GOSAT-2 (corrected)	Land	754	0.91	0.23	1.45	0.91	0.17	1.45
		Ocean	667	0.95	-0.57	1.24	0.95	-0.63	1.24
OCO-3	GOSAT	Land	63	0.92	1.29	1.72	0.91	0.76	1.38
		Ocean	49	0.92	-0.62	1.27	0.93	-1.27	1.64
OCO-3	GOSAT-2 (original)	Land	534	0.93	-2.85	3.24	0.93	-2.90	3.29
		Ocean	307	0.91	-3.63	3.91	0.92	-3.70	3.97
OCO-3		Land	534	0.92	0.77	1.58	0.92	0.72	1.57

Y-axis product	X-axis product	Surface type	N	Before correction			After correction		
				R	Bias (ppm)	RMSE (ppm)	R	Bias (ppm)	RMSE (ppm)
	GOSAT-2 (corrected)	Ocean	307	0.94	-0.42	1.18	0.94	-0.49	1.20
GOSAT-2 (original)	GOSAT	Land	122	0.89	5.09	5.32	0.88	4.68	4.94
		Ocean	61	0.95	3.28	3.45	0.95	2.79	2.99
GOSAT-2 (corrected)	GOSAT	Land	122	0.90	1.04	1.74	0.89	0.63	1.54
		Ocean	61	0.91	0.02	1.26	0.91	-0.46	1.32

Comment Main 5

The manuscript reports that GOSAT-2 is systematically higher than the other satellite products and TCCON and attributes this mainly to the absence of empirical bias correction. However, differences in the bias-correction status of the products may confound differences related to sensors and retrieval algorithms with those caused by product post-processing.

The official NIES release notes for the GOSAT-2 SWIR L2 Full-Physics V02.20 product provide land- and ocean-specific empirical bias-correction formulas and coefficients based on TCCON GGG2020 data. The authors should apply the corresponding correction to the pixel-level GOSAT-2 XCO_2 retrievals and update the inter-satellite and TCCON comparisons. At minimum, results before and after empirical correction should be presented as a sensitivity analysis.

The product version used during the study period and the order in which empirical bias correction and column-definition correction are applied should also be stated explicitly.

ANSWER: We have applied the official NIES empirical bias correction to the individual quality-controlled GOSAT-2 retrievals and updated both the inter-satellite and TCCON comparisons. GOSAT-2 V02.20 is used through February 2024 and V02.21 from March 2024 onward. The version-specific land/ocean empirical correction is applied before daily 2° aggregation and collocation, and the CAMS-based column-definition correction is applied afterward to the collocated samples. Table 1 and Sect. 2.1.2 now specify both the versions and this processing order.

For the same 880 GOSAT-2–TCCON collocations, empirical correction changes R from 0.91 to 0.92, mean bias from +3.56 to +0.01 ppm, and RMSE from 3.98 to 1.54 ppm. Corrected GOSAT-2 is used in the principal comparisons, while Fig. 3d and Tables S2–S3 retain original and corrected results. We also state explicitly that the official correction coefficients were derived using TCCON GGG2020 as the reference. Consequently, the corrected GOSAT-2–TCCON comparison is not fully independent of TCCON; this limitation is now stated in Sect. 4.2. This qualification avoids conflating the value of TCCON as a common validation reference with statistical independence for the corrected GOSAT-2 product.

Changes in the manuscript:

Sect. 2.1.2, p. 5, lines 132–147.

> Revised text: "OCO-2 and OCO-3 are NASA Orbiting Carbon Observatory missions designed to retrieve XCO2 from reflected solar spectra using three-channel high-resolution grating spectrometers and full-physics retrieval algorithms (Crisp et al., 2017; Eldering et al., 2017; O'Dell et al., 2018; Taylor et al., 2023). GOSAT and GOSAT-2 carry the Thermal And Near-infrared Sensor for carbon Observation Fourier Transform Spectrometer (TANSO-FTS) and its successor TANSO-FTS-2, respectively. Their instrument characteristics, retrieval algorithms, and XCO2 products have been described in previous studies (Kuze et al., 2009, 2016; Noël et al., 2021, 2022; Suto et al., 2021; Yoshida et al., 2023). For GOSAT-2, the official land- and ocean-specific empirical bias corrections were applied to the individual XCO2 retrievals following the V02.20 and V02.21 release notes (NIES GOSAT-2 Project, 2026a, b). The official correction coefficients were derived using TCCON GGG2020 as the reference. GOSAT-2 V02.20 was used through February 2024 and V02.21 from March 2024 onward. The empirical bias correction was applied to each quality-controlled individual retrieval before daily 2° aggregation and collocation, whereas the CAMS-based column-definition correction was subsequently applied to the collocated samples. The passive satellite products are provided as individual soundings and provide the XCO2 observations for comparison with DQ-1. The corresponding quality-control criteria are summarized in Table 2, and the spatiotemporal collocation and column-definition correction are described in Sects. 2.2.2 and 2.2.3. Although all products report XCO2, their effective column definitions are not identical because the passive products use product-specific prior profiles,

pressure weights, and column averaging kernels, whereas DQ-1 ACDL uses its weighting function and effective pressure layers. These differences are accounted for in Sect. 2.2.3."

Sect. 3.2, pp. 16, lines 422–428.

Revised text: "For GOSAT-2, the uncorrected XCO_2 product shows a pronounced positive bias relative to TCCON, with R = 0.91, a mean bias of 3.56 ppm, and an RMSE of 3.98 ppm (gray symbols in Fig. 3d). Similar positive biases of GOSAT-2 XCO_2 relative to TCCON have also been reported in previous studies (Ji et al., 2024; Yang et al., 2025). After applying the official empirical bias correction to the pixel-level GOSAT-2 XCO_2 data, the mean bias decreases to 0.01 ppm and the RMSE to 1.54 ppm, while R changes only slightly to 0.92 (colored symbols in Fig. 3d). The substantial reductions in bias and RMSE indicate that the pronounced overestimation in the uncorrected product is largely associated with systematic biases addressed by the empirical correction. After correction, GOSAT-2 shows good agreement with TCCON."

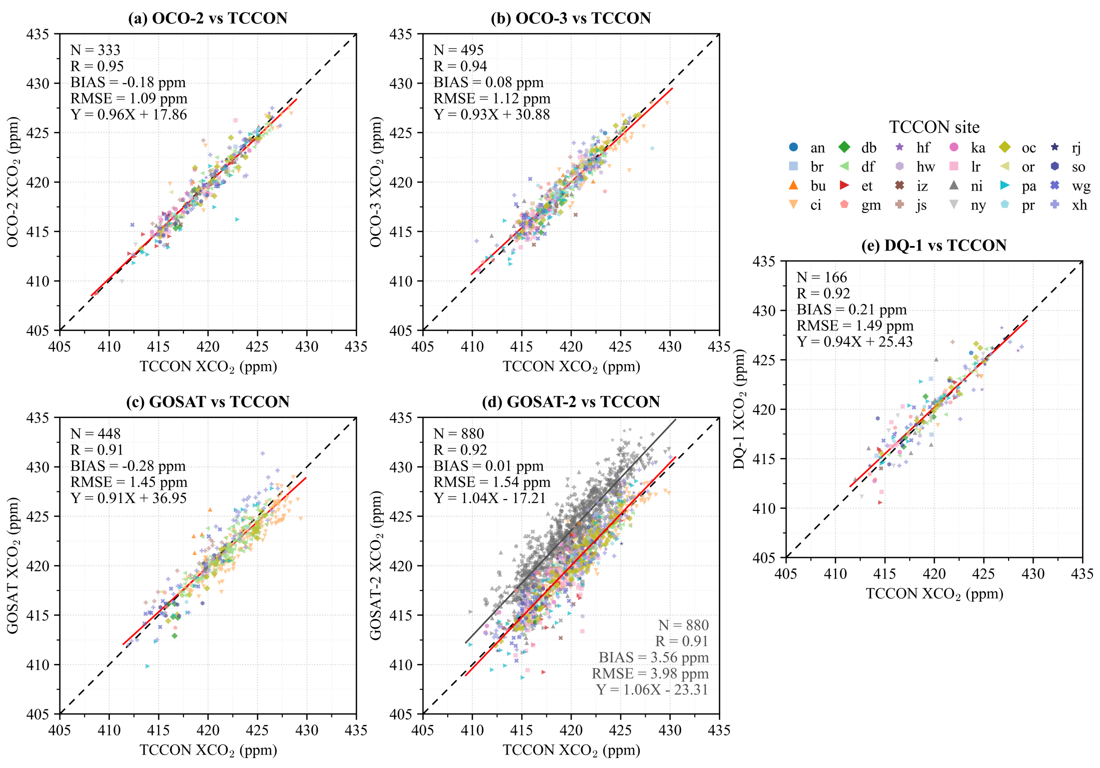

Figure 3. Comparison of satellite XCO_2 products with TCCON observations. (a–e) OCO-2, OCO-3, GOSAT, GOSAT-2, and DQ-1 XCO_2 compared with collocated TCCON XCO_2, respectively. Different colors and symbols denote individual TCCON sites. In panel (d), colored and gray symbols denote empirically bias-corrected and uncorrected GOSAT-2 XCO_2, respectively, with the corresponding linear least-squares fits shown by the red and

gray solid lines. Red solid lines in panels (a–c, e) indicate linear least-squares fits, and black dashed lines indicate the 1:1 relationship. The TCCON site abbreviations are defined in Table A2

Table S2. Satellite–TCCON validation statistics, site-level variability, and 95 % confidence intervals. The 95 % confidence intervals (CIs) of the pooled bias and RMSE are defined by the 2.5th and 97.5th percentiles of 20 000 TCCON-site cluster-bootstrap realizations. Interstation bias is the standard deviation of the site-specific mean biases, and site-mean RMSE is the arithmetic mean of the site-specific RMSE values, with equal weight assigned to each contributing site.

Product	N	Bias (95 % CI) (ppm)	Interstation bias (ppm)	RMSE (95 % CI) (ppm)	Site-mean RMSE (ppm)
OCO-2	333	−0.18 [−0.35, 0.00]	0.60	1.09 [0.89, 1.31]	1.04
OCO-3	495	0.08 [−0.10, 0.28]	0.56	1.12 [0.98, 1.27]	1.12
GOSAT	448	−0.28 [−0.72, 0.60]	1.40	1.45 [1.21, 1.85]	1.60
GOSAT-2 original	880	3.56 [3.24, 3.88]	1.19	3.98 [3.75, 4.27]	4.03
GOSAT-2 corrected	880	0.01 [−0.20, 0.26]	0.97	1.54 [1.33, 1.81]	1.70
DQ-1	166	0.21 [−0.08, 0.48]	0.73	1.49 [1.25, 1.74]	1.40

Minor comments

Comment Minor 1

Notation throughout the manuscript: Please check the entire manuscript, including the title, Abstract, main text, equations, tables, figure captions, and axis labels, and consistently replace "CO_2" and "XCO_2" containing the Unicode subscript character "$_2$" with "CO_2" and "XCO_2" produced using standard subscript formatting.

ANSWER: Revised. CO_2 and XCO_2 have been standardized using subscript formatting in the manuscript text and equations.

Comment Minor 2

P3, L66: The word “characteristics” is repeated in the phrase “global XCO_2 observation characteristics characteristics”. Please remove the duplicated word.

ANSWER: Revised. The duplicated “characteristics” has been removed.

Comment Minor 3

Table 1: The column heading “Native resolution/scale” combines temporal resolution, spatial resolution, and sampling mode, which are not directly comparable across the listed datasets. Please either separate this information into “Temporal resolution” and “Spatial resolution/sampling” columns or revise the heading and entries so that the dataset characteristics are described consistently.

ANSWER: Revised. Table 1 now separates “Temporal resolution” from “Spatial resolution/sampling”, and the entries have been revised accordingly.

Comment Minor 4

(1)–(16): Please format all displayed equations consistently following the ACP/Copernicus manuscript template. The equations should be left-aligned, with the equation numbers aligned on the right and numbered consecutively in order of appearance.

ANSWER: Revised. The displayed equations have been reformatted with left-aligned expressions, right-aligned equation numbers, and consecutive numbering.

Comment Minor 5

P7, L180 and L189: “Where” should be changed to lowercase “where”, as the text following the equation continues the preceding sentence. In addition, please remove the extra space before the comma after “d” on L180.

ANSWER: Revised. “Where” has been changed to “where”, and the extra space before the comma has been removed.

Comment Minor 6

P8, Eq. (6): The text following the equation states that represents “the overall sampling sufficiency of grid cell ”. The latter expression should be replaced by “grid cell ”.

ANSWER: Revised. The text following Eq. (6) now consistently refers to grid cell g.

Comment Minor 7

The colorbar in Figure 1 needs to be adjusted. The present colorbar cannot clearly distinguish regions with no valid observations from those where the number of valid observations is lower than 20. The color corresponding to zero valid observations could be changed to white or another color clearly distinct from dark blue.

ANSWER: Revised. The original Fig. 1 is now Fig. A1. Its color scheme uses white for zero observations and colored shading for positive counts, improving the distinction between absent and sparse observations.

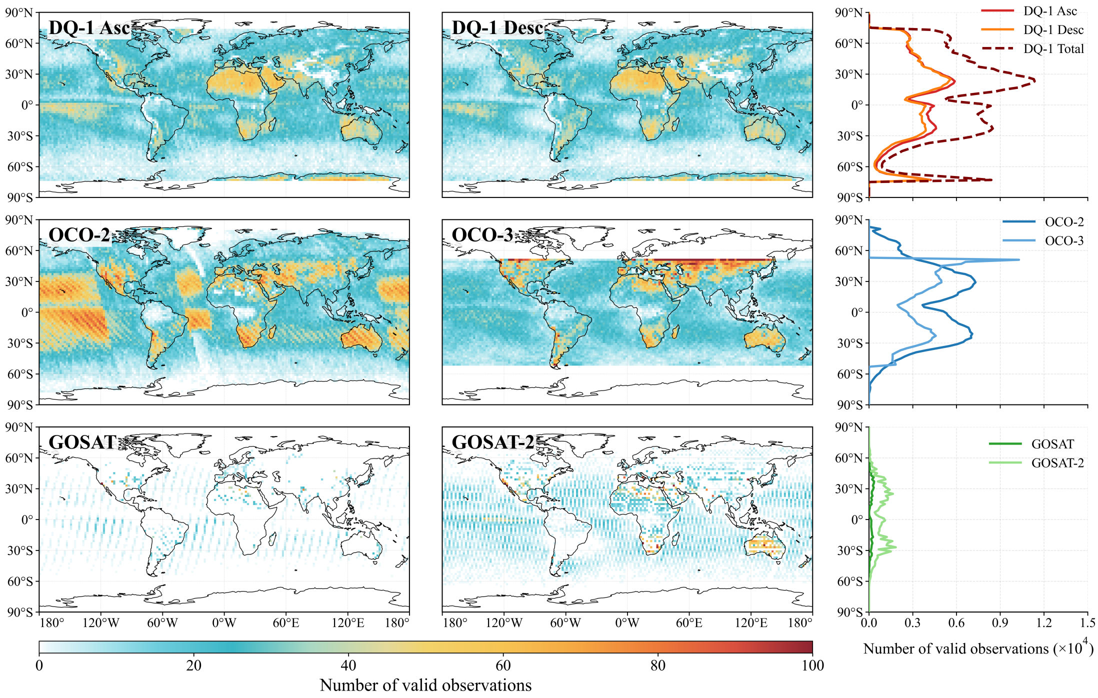

Figure A1. Spatial distributions and zonal totals of cumulative number of valid observations for the satellite XCO_2 products at 2° × 2° resolution.

Comment Minor 8

Figure 2 and the associated text: The term "valid-observation cell-days" does not accurately describe the reported quantity and should be replaced with "number of valid observations". Please define the counting unit explicitly at its first occurrence and revise the terminology consistently throughout the relevant methods, results, figure captions, and axis labels.

The manuscript should also state explicitly that DQ-1 Asc+Desc is calculated as the direct sum of the ascending and descending observation counts.

ANSWER: Revised. We use "number of valid observations" and define the counting unit in Sect. 2.2.1: one sensor, one day, and one 2° grid cell count as one valid observation when the accumulated along-track sampling length reaches at least half of the local grid-cell diagonal. It is therefore a gridded availability count, not the number of raw soundings. DQ-1 Asc and Desc are counted separately, and Total (Asc+Desc) is their direct sum. The terminology has been updated in the sampling figures and related text.

Changes in the manuscript :

Sect. 2.2.1, p. 9, lines 240–250.

Revised text: “To ensure stable multi-satellite observational coverage in the candidate 2° grid cells, we construct a satellite sampling availability score. For each satellite, daily XCO_2 observations after quality control are first assigned to the same 2° grid according to the latitude and longitude of the observation center. Following the grid-based spatial-coverage method of Han et al. (2024) and the path-length-based definition of valid gridded observations described by Han et al. (2025), we do not use the raw number of observations as the only criterion for determining valid gridded observations. Instead, for each sensor, day, and grid cell, we calculate the along-track sampling length by accumulating the great-circle distances between adjacent valid observation centers along the same orbit track. For each sensor and day, only grid cells with an accumulated sampling length greater than or equal to half of the diagonal length of the local 2° grid cell are counted as one valid observation. DQ-1 Asc and Desc are counted separately, and DQ-1 Total (Asc+Desc) is calculated as the direct sum of the two counts. The number of valid observations is then accumulated over the study period and normalized to the range 0–1 using the 95th percentile among grid cells with positive values, yielding the satellite sampling availability score.”

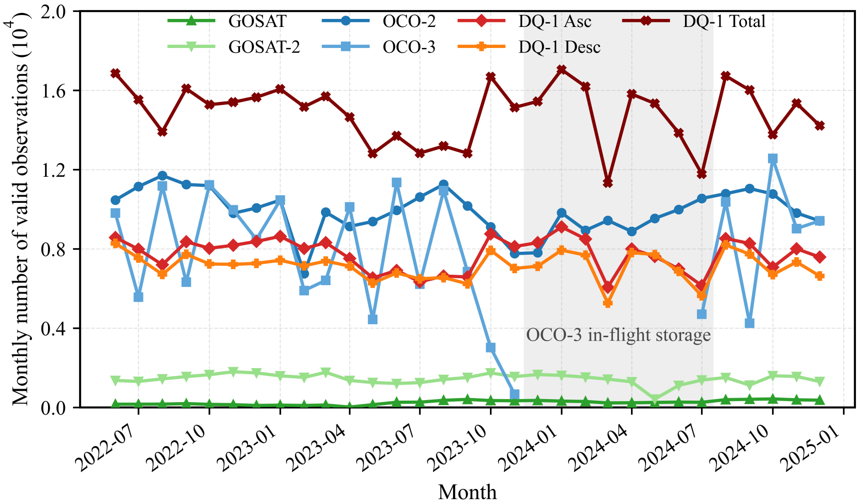

Figure A2. Monthly variations in the number of valid observations for the satellite XCO_2 products. The gray-shaded region indicates the OCO-3 data gap associated with its temporary storage on the ISS.

Comment Minor 9

P14, L366: "Final score" appears within a sentence and should be changed to lowercase "final score" for consistency with sentence-style capitalization.

ANSWER: Revised. "Final score" within the sentence has been changed to "final score".

Comment Minor 10

Figure 4 and Table A2: Please clearly specify the sign convention used for the mean bias or mean difference, for example, "the product shown on the y axis minus the product shown on the x axis". The regression method used to derive the slope and intercept should also be specified in the figure caption or table note.

ANSWER: Revised. Bias is explicitly defined as the y-axis product minus the x-axis product in Sect. 2.2.2, the caption of Fig. 4, and Table S3. The revised Fig. 4 and Table S3 report R, N, bias, and RMSE rather than regression slopes and intercepts, so the former inter-satellite regression-parameter table is no longer retained. The fits displayed in the TCCON comparison, now Fig. 3, are identified in its caption as linear least-squares fits.

Comment Minor 11

Table A1: The caption refers to the "valid observation periods" of the TCCON sites, but the table does not appear to include a corresponding observation-period column. Please add this information or revise the caption accordingly. The column headings could also be standardized as "Latitude (°N)", "Longitude (°E)", and "Altitude (m)".

ANSWER: Revised. The site-information table is now Table A2 and includes a "Valid observation period" column. Its note defines the period as the overlap of site data availability with 1 June 2022–31 December 2024. The coordinate and altitude headings are "Latitude (°N)", "Longitude (°E)", and "Altitude (m)".

Table A2. Abbreviated names, geographic information, and valid observation periods of the TCCON sites used for validation. The valid observation period denotes the overlap between data availability at each site and the study period (1 June 2022–31 December 2024).

Abbreviated name	TCCON site	Latitude (°N)	Longitude (°E)	Altitude (m)	Valid observation period
an	Anmyeondo [anmeyondo01]	36.54	126.33	20	2023-02-09–2024-03-03
br	Bremen [bremen01]	53.10	8.85	30	2022-06-01–2024-12-31
bu	Burgos [burgos01]	18.53	120.65	40	2022-06-01–2024-12-31
ci	Caltech [pasadena01]	34.14	−118.13	240	2022-06-01–2024-12-31
db	Darwin [darwin01]	-12.46	130.93	40	2022-06-01–2024-12-31
df	Edwards [edwards01]	34.96	−117.88	700	2022-06-01–2024-12-31
et	East Trout Lake [easttroutlake01]	54.35	−104.99	502	2022-06-01–2024-12-31
gm	Garmisch [garmisch01]	47.48	11.06	743	2022-06-01–2024-01-16
hf	Hefei [hefei01]	31.91	117.17	40	2022-06-01–2024-12-31
hw	Harwell [harwell01]	51.57	−1.32	142	2022-06-01–2024-12-31
iz	Izana [izana01]	28.31	−16.50	2370	2022-06-01–2023-08-30
js	Saga [saga01]	33.24	130.29	9	2022-06-01–2023-12-13
ka	Karlsruhe [karlsruhe01]	49.10	8.44	110	2022-06-01–2024-12-27
lr	Lauder [lauder03]	-45.04	169.68	370	2022-06-01–2024-12-31
ni	Nicosia [nicosia01]	35.14	33.38	185	2022-06-01–2024-12-31
ny	Ny-Ålesund [nyalesund01]	78.92	11.92	20	2022-06-01–2024-12-31
oc	Lamont [lamont01]	36.60	−97.49	320	2022-06-01–2024-12-31
or	Orléans [orleans01]	47.96	2.11	130	2022-06-01–2024-12-31
pa	Park Falls [parkfalls01]	45.94	−90.27	476	2022-06-01–2024-12-31
pr	Paris [paris01]	48.85	2.36	60	2022-06-01–2024-12-31
rj	Rikubetsu [rikubetsu01]	43.46	143.77	380	2022-06-01–2024-12-31
so	Sodankylä [sodankyla01]	67.37	26.63	188	2022-06-01–2024-12-31
wg	Wollongong [wollongong01]	-34.41	150.88	30	2022-06-01–2024-12-31

Abbreviated name	TCCON site	Latitude (°N)	Longitude (°E)	Altitude (m)	Valid observation period
xh	Xianghe [xianghe01]	39.80	116.96	40	2022-06-01–2024-12-31

Comment Minor 12

The manuscript uses TCCON data, but the corresponding data providers are not acknowledged. Please add an appropriate acknowledgement and include the relevant dataset citations or DOIs for the TCCON sites listed in Table A1.

ANSWER: Revised. We have acknowledged the TCCON investigators and data providers, added a site-to-reference mapping beneath Table A2, and included the corresponding GGG2020 dataset citations and DOIs in the reference list.

Comment Minor 13

Author contributions: “Author contributions.” appears twice at the beginning of this section. Please remove the duplicated text.

ANSWER: Revised. The duplicated “Author contributions” text has been removed.

Comment Minor 14

References: The bibliographic information for Han et al. (2017, 2018) appears incomplete. Please provide the journal name, volume, page range or article number, and DOI, following the same format used for the other references.

ANSWER: Revised. The bibliographic entries for Han et al. (2017, 2018) have been completed and standardized to include the journal information, volume, page/article information, and DOI in the same reference style as the rest of the manuscript.