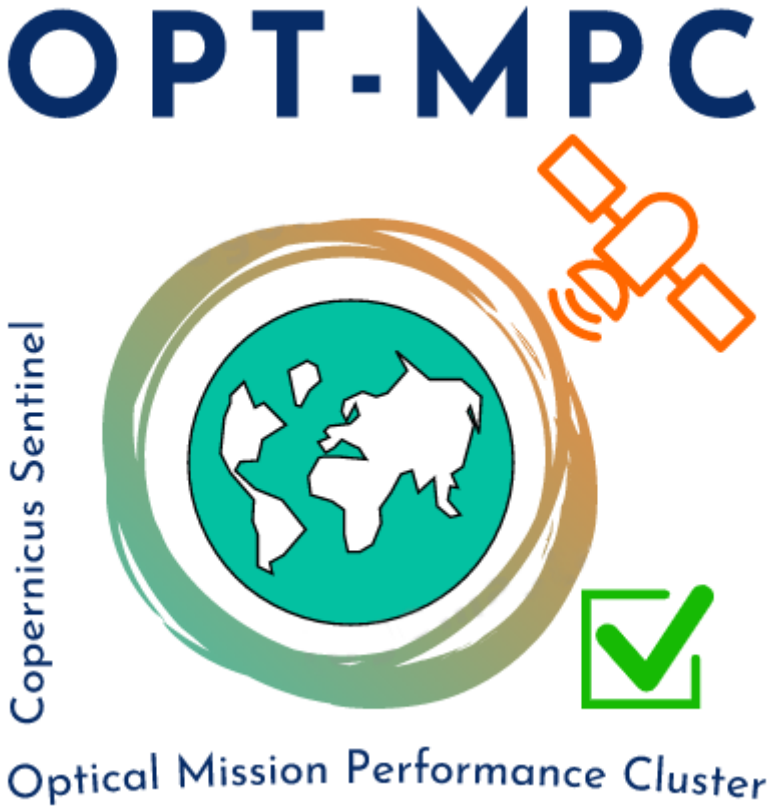
COPERNICUS SPACE COMPONENT SENTINEL OPTICAL IMAGING

MISSION PERFORMANCE CLUSTER SERVICE

Data Quality Report

Sentinel-2 L1C MSI

May 2023



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Changes Log

Version	Date	Changes
87.0	11/05/2023	First version

List of Changes

Version	Section	Answers to RID	Changes

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1 Introduction

1.1 Scope of the document

This document provides the data quality status of Copernicus Sentinel-2 mission L1C products. Please note that the data quality status before the beginning of 2023 is covered by the Annual Performance Report of 2022. Please refer to this document as well as former Data Quality Reports (DQR) if needed.

The DQR documents:

- processing chain improvements associated to each Processing Baseline (Section 2),
- the calibration description and status (Section 3),
- the measured product performance vs. specifications (Section 4),
- observed anomalies and known issues (Section 7),
- general information on products (Section 8).

Note that a reference article provides an in-depth presentation of Sentinel-2 Calibration and Validation methods and results after one year in operation (F. Gascon *et al.*, "Copernicus Sentinel-2 Calibration and Products Validation Status", RSE, 2017).

Since May 2018, a Data Quality Report for Level 2A products is also available from the Sentinel-2 Document Library.

1.2 Main points for the Reporting Period

- A new calibration file has been released to improve the multispectral registration for S2B on May 4th (see section 3.3.3),
- Several occurrences of lost packets have been observed on Sentinel-2B data. The problem has been resolved and no new occurrences have been observed since 04/05/2023,
- A new pixel has been added as defective in the configuration file for S2A: band B11, detector 11, pixel 24. This pixel is situated in the inter-detector area. Therefore, the L1C users are not impacted (see section 5.1),
- Availability of the Copernicus Sentinel-2 Collection-1 data (see section 8.1).

2 Processing Baseline Status

On December 6th, 2022, the **processing baseline 05.09** was deployed. The format of the L1C and L2A products within this new PB remains the same as outlined in the current Product Specification Document (version 14.9).

The operational processor deployed for this processing baseline (version 6.1) is the same used to generate the Copernicus Sentinel-2 Collection-1 (for more details please refer to the section 8.1). The particularity of the current processor is that it can operate with both the Copernicus DEM at 90 meters ground spatial resolution, and/or with its finer defined version at 30 meters resolution. Currently, the 90 m version of the DEM will continue being used for the nominal productions while the 30 m version of the DEM is being used for the historical archive reprocessing.

The Processing Baseline identifier 05.09 tags the operational products generated with the 90 m version of the Copernicus DEM. The Processing Baseline identifier 05.00 tags the Copernicus Sentinel-2 Collection-1 products.

The following evolutions are included:

- Update of the radiometric saturation threshold to allow saturation mask computation. This is the final fix for anomaly #13 and ensures that the saturation mask (QUALIT mask layer 8) is now fully operational. Users are advised that radiometric accuracy requirements are not applicable to saturated pixels.

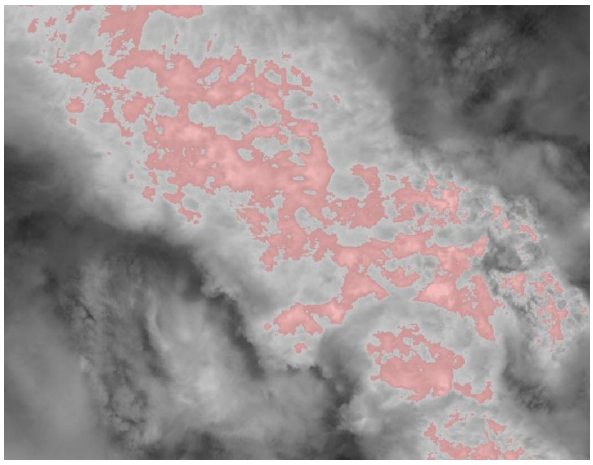


Figure 1. B08 image with saturation mask overlayed (semi-transparent red).

- Partially corrected mask: flag pixels where there is a crosstalk between one band and another one which is saturated. With processing baseline 05.XX, the partially corrected quality mask (QUALIT mask layer 7) becomes operational. The radiometric accuracy of partially corrected pixels may be slightly degraded.

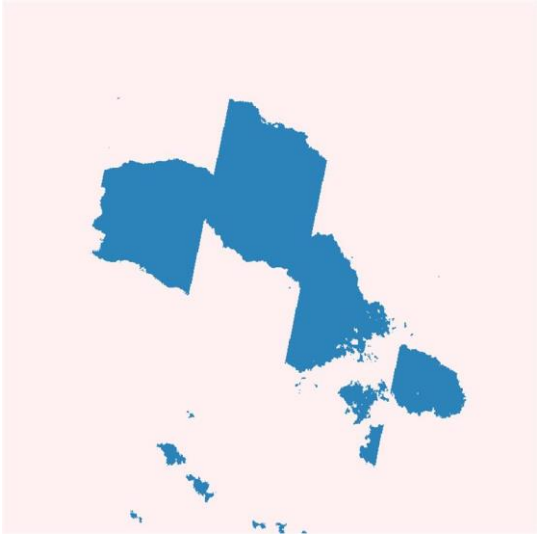


Figure 2. Partially corrected pixel mask for B12.
The mask correctly reflects the impact of crosstalk from B10.

In addition to the evolutions included in the processing baseline 05.09, we remind here that a **radiometric offset** on reflectance digital numbers has been introduced with processing baseline 04.00 deployed on January 25th, 2022. Then, the dynamic range is shifted by a band-dependent constant: RADIO_ADD_OFFSET. This offset allows encoding negative surface reflectances that may occur over very dark surfaces. **From the user's point of view, the L1C Top of Atmosphere (TOA) reflectance (L1C_TOA) shall be retrieved from the output radiometry as follows**:

- Digital Number DN=0 remains the "NO_DATA" value
- For a given DN in [1; 1;2^15-1], the L1C TOA reflectance value is:

L1C_TOAi = (L1C_DNi + RADIO_ADD_OFFSETi) / QUANTIFICATION_VALUEi

The radiometric offset value is reported in the field General_Info/Product_Image_Characteristics/Radiometric_Offset_List/RADIO_ADD_OFFSET of the User Product Metadata, as well as in the field Image_Data_Info/Radiometric_Info/Radiometric_Offset_List/RADIO_ADD_OFFSET of the Datastrip Metadata. It is set to -1000 Digital counts for all spectral bands.

For further information on the former processing baselines, please refer to https://sentinels.copernicus.eu/web/sentinel/technical-guides/sentinel-2-msi/processing-baseline.

3 Calibration status

3.1 Instrument settings

There has been no change in the Sentinel-2A or Sentinel-2B instrument settings since the beginning of the year 2023.

3.2 Radiometric Calibration Status

3.2.1 Overview

Radiometric calibration is performed routinely at the beginning of each month. It includes a dark signal calibration as well as an absolute and relative gain calibration, and results in the update of the R2EQOG and R2ABCA calibration files used by the processor to generate Level-1C products:

- R2EQOG calibration file contains information to perform the equalisation on ground, in correcting the measured signal from the non-linearity of the pixel response and the non-uniformity behaviour of each pixel with the others. The objective is to get a uniform image when the observed landscape is uniform.
- R2ABCA calibration file contains the absolute calibration coefficient for each spectral band to convert the equalized signal into equivalent radiance at the entrance of the MSI sensor.

The table below provides the start validity dates of R2ABCA and R2EQOG calibration files (a couple of days after the monthly calibration itself) released since the beginning of 2023.

Table 3-1 : Start validity date of R2ABCA and R2EQOG calibration files released in 2023

Month	S2A	S2B
January	12/01/2023	24/01/2023
February	09/02/2023	21/02/2023
March	09/03/2023	23/03/2023
April	18/04/2023	20/04/2023

Decontamination operations are scheduled once a year.

3.2.2 Sentinel-2A

A decontamination of the instrument was performed on the 7th – 8th of November 2022. The calibration coefficients were updated on the 15th of November.

Dark signal stability:

The dark signal is quite stable. Its variations are:

- lower than 0.5 LSB for most of pixels in VNIR bands
- lower 1.0 LSB for most of pixels in SWIR bands

while the mean value of the dark signal is between 440 and 520 LSB, depending on the spectral band.

Absolute calibration:

The absolute gain coefficients for MSI-A are stable in a range of ±0.2% over the year 2022. The B10 and B11 SWIR bands show a loss of sensitivity with time which is compensated by the annual decontamination in November 2022.

3.2.3 Sentinel-2B

A decontamination was performed on 12th – 13th December 2022. The post-decontamination radiometric calibration was implemented on 19th of December.

Dark signal stability:

The high stability of the dark signal is similar for both MSI-A and B.

Absolute calibration:

The absolute gain coefficients for MSI-B are stable in a range of ±0.2% over the year 2022. The B10 and B11 SWIR bands show a loss of sensitivity with time which is compensated by the annual decontamination in December 2022.

With the introduction of the baseline 04.00 on 25th January 2022, a radiometric harmonization between Sentinel-2A and Sentinel-2B (keeping Sentinel-2A as reference) was introduced. Indeed, among the evolution of this baseline the mitigation of the radiometric differences between both satellites was set by applying a radiometric bias correction of 1.1 % to Sentinel-2B VNIR bands B01 to B09.

The harmonization was effective from 09:00 UTC. The first Sentinel-2B sensing using the updated R2ABCA calibration file was: 20220125T073939. The time series below (Figure 3) shows this change in the radiometry for Sentinel-2B since the introduction of this radiometric correction factor (January 2022) and highlights the current alignment between Sentinel-2A and Sentinel-2B for Libya4 PICS Cal/Val site.

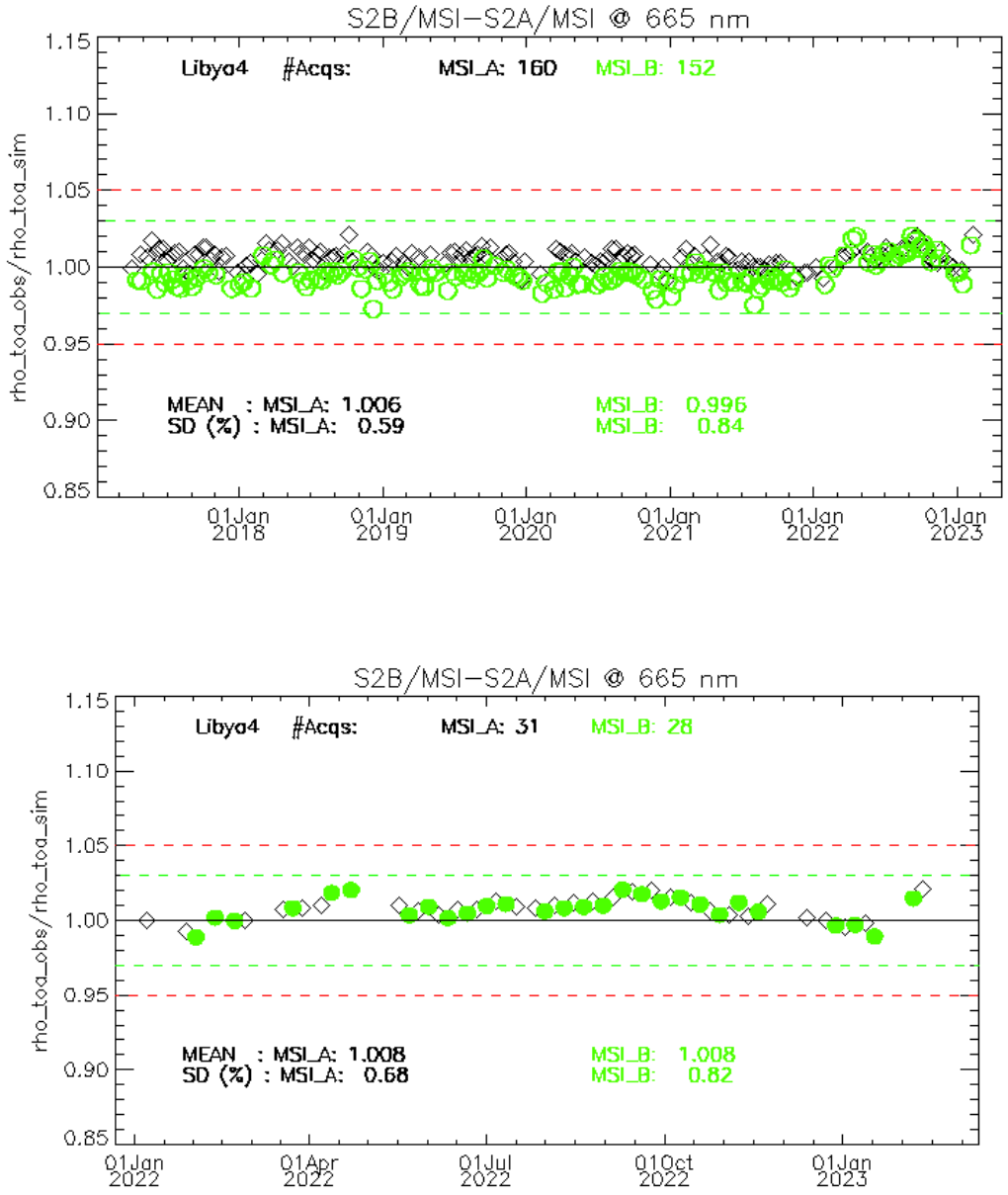


Figure 3 : Time-series of the elementary ratios (observed/simulated) signal from MSI-A (black diamonds) and MSI-B (green dots) over the period (top) up to July 2022 and (bottom) January 2022 - February 2023 for band B04 from Libya4 PICS Cal/Val site. Dashed-green and orange lines indicate the 3% and 5% error respectively.

3.3 Geometric Calibration Status

3.3.1 Overview

Geometric calibration is performed to ensure the maintenance of the best geometry in the images by estimating the parameters of the Sentinel-2 MSI geometric model (orientation of the viewing frames and lines of sight of the detectors of the different focal planes). It results in updated SPAMOD calibration files, that contains the bias values for each angle (roll, pitch, yaw) in MSI geometric model viewing frame.

The table below provides the start validity dates of the last SPAMOD calibration file released for both S2A and S2B.

Table 3-2 : Start validity date of the SPAMOD calibration files used in operation

S2A	S2B
21/04/2021	04/05/2023

Since 30 March 2021 (PB 03.00), the geometric refinement for Sentinel-2 products was deployed over the Euro-Africa region and then in August worldwide (except Antarctica, some isolated islands and some high latitude areas), improving the multi-temporal co-registration and the relative geolocation accuracy of the products (see section 4.2 for more details).

The geometric refinement relies on the Sentinel-2 Global Reference Image (GRI). The GRI is a set of Level-1B images (in sensor frame) covering the whole globe with highly accurate geolocation information obtained through a spatio-triangulation algorithm using reference Ground Control Points. The images use the reference band (B04) and are mostly (but not entirely) cloud-free. In particular, the GRI is not meant to be a cloud-free mosaic of the globe. Thanks to the geometric refinement, all refined products inherit the same absolute geolocation performance.

With PB 03.00, a new Digital Elevation Model (DEM), the Copernicus DEM, is used to orthorectify the L1C products. This improves the local geolocation for all products in mountainous areas. This applies also to unrefined products, although the improvement is more effective for refined products.

3.3.2 Sentinel-2A

An improvement of the yaw angle bias correction was performed on May 30th, 2016. Before this date, a relatively large along-track bias can be observed between different repeat orbits in the overlap region at the edges of the swath. The multi-temporal co-registration performance reported in this document is computed for products acquired after this date.

The geometric calibration of S2A has been updated on April 21st, 2021.

3.3.3 Sentinel-2B

An updated geometric calibration has been deployed on February 24th, 2022 to improve the geolocation of non-refined products. Refined products (PB 03.00 and higher) have reduced geolocation bias compared to non-refined product. In addition, the refinement corrects any biases between S2A and S2B refined products.

A new geometric calibration has been deployed on May 4th, 2023 to improve the multispectral registration. Before that date, the latest multispectral registration results have highlighted that the SWIR/VNIR pairs are above mission specifications due to an offset of -0.2 pixels in the along-track component.

4 Measured Product Performances

4.1 Performances Overview

The following overview table provides a summary of the Level-1C products data quality performances measured on products in Processing Baselines 02.01 and higher, for a set of key mission requirements.

Similar performances are observed for both S2A and S2B satellites.

Table 4-1: Summary of Sentinel-2 L1C products measured performances for mission key requirements.

Requirement	Description	Measured performance
Absolute geolocation	The geo-location uncertainty shall be better than 20 m at 2σ confidence level (unrefined products)	< 11 m at 95.5% confidence (unrefined products)
Multi-temporal registration	The spatial co-registration accuracy of Level 1c data acquired at different dates over the same geographical area shall be better than or equal to 0.3 SSD at 2 σ confidence level.	< 5 m at 95.5% confidence (refined products)
Multi-spectral registration	The inter-channel spatial co-registration of any two spectral bands shall be better than 0.30 of the coarser achieved spatial sampling distance of these two bands at 3σ confidence level.	< 0.3 pixel at 99.7% confidence All bands couples are within or close to the specifications except the couples B02/B04, B02/B08, B01/B09 and B08/B09 for S2B.
Absolute radiometric uncertainty	The absolute radiometric uncertainty shall be better than 5 % (goal 3%). (see Table 4-3 in this document)	B1 to B12, excl. B10: < 3%±2%
SNR	The Signal-to-Noise Ratio (SNR) shall be higher than specified values (see Table 4-4 in this document)	All bands compliant with > 27% margin

Measured performances are detailed in the following sections.

4.2 Geometric Performance

4.2.1 Geometric Refinement and Global Reference Image (GRI)

Since March 2021 (processing Baseline 03.00) a geometric refinement step is used to improve the multi-temporal geolocation performance. Thanks to this processing, the performance of refined products is notably improved compared with the performance of the unrefined ones.

Validation results indicate the following performances for the refined products:

- Absolute geolocation: better than 6 m
- Multi-temporal co-registration (same or different satellites), same repeat orbit: better than 5 m at 95% confidence
- Multi-temporal co-registration, different repeat orbits: better than 5 m.

4.2.2 Refinement coverage and fallback analysis

In order to avoid any case of badly refined products, refining is disabled if some quality criteria are not met ("fallback" case). Another instance of non-refined products is when there is no product in the GRI covering the current datastrip ("unrefined" case). This happens for instance over Antarctica.

Figure 4 provides the rate of unrefined products for S2A and S2B. The number of unrefined datastrips is higher for S2B than S2A, especially during the Austral Summer. This reflects the fact that Antarctica is mostly covered by S2B. The number of refined datastrips increases during the Northern Summer as more land masses are acquired with a lower cloud coverage. The number of fallback datastrips is slightly larger for S2B than S2A.

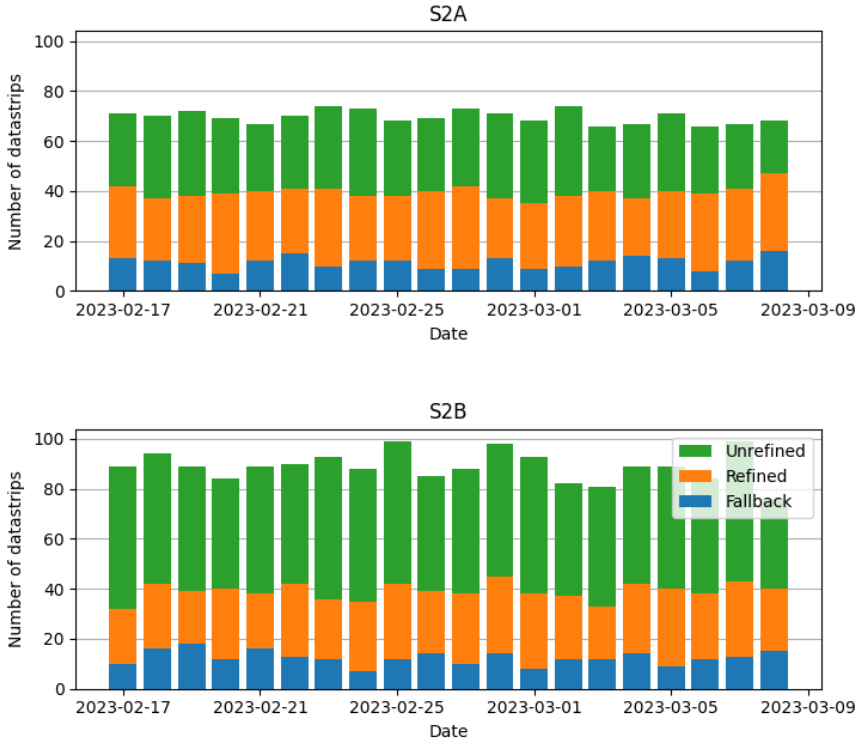


Figure 4: Number of refined and unrefined datastrips per five days period.

The following maps provide the location of the datastrips in fallback based on different criteria and unrefined for a cycle period during February 2023. The cloud cover criteria is active mainly for high latitude products in the Northern hemisphere (winter season). The criteria on the number of valid zones also rejects some cloudy products as well as products with a large part over the Ocean. The criteria on the number of GCPs rejects a few products over very small, isolated islands. The criteria on the maximum distance at the corners of the datastrip and the one on the standard deviation of shifts mostly affect long datastrips on continents. Finally, unrefined datastrips (without a GRI product for refinement) are located at high latitudes and Antarctica, on very small islands or on open Ocean.

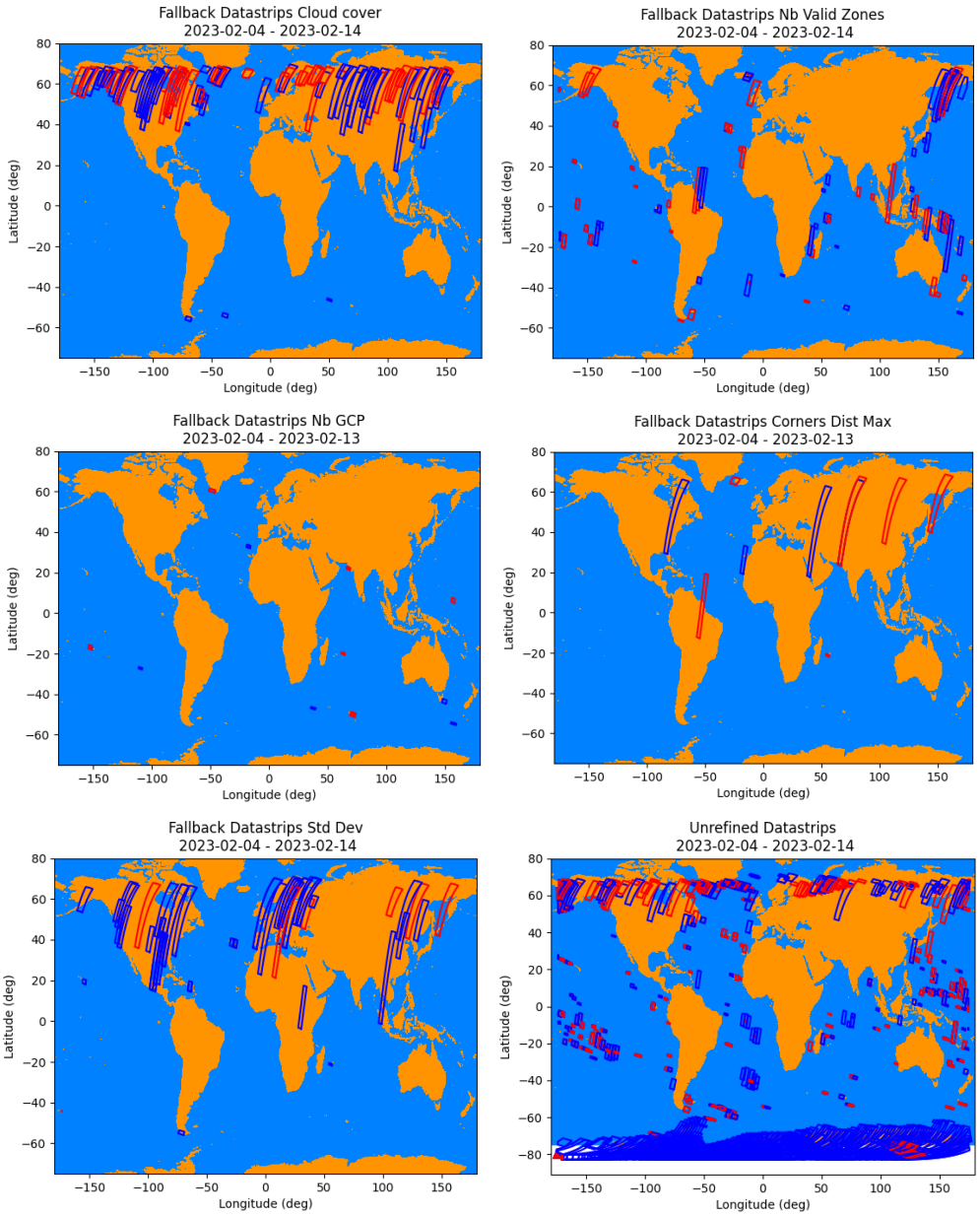


Figure 5 : Location of datastrips in fall-back and unrefined over a cycle period in February 2023 for S2A (red datastrips) and S2B (blue datastrips)

4.2.3 Relative Geolocation

4.2.3.1 Unrefined products

The long-term performance for unrefined products is around 1.1 pixels for S2A and around 1.3 pixels for S2B (at 95% confidence). Since the activation of the global refinement in August 2021, the performance is estimated on a limited set of unrefined products.

Figure 6 shows the geolocation performance for the unrefined products relative to the Sentinel-2 GRI. The real absolute performance is expected to be a little worse due to the GRI absolute geolocation uncertainty (0.6 pixels). Stable results are observed for both S2A and S2B in the last months.

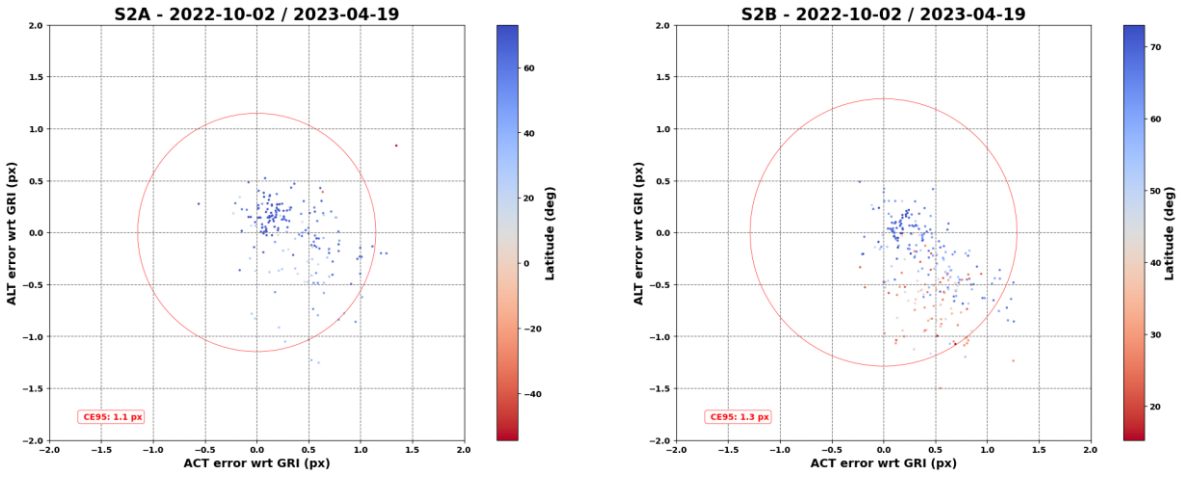


Figure 6: Relative geolocation performance for unrefined products. Left: S2A, Right: S2B (02.10.2022 – 19.04.2023)

4.2.3.2 Refined products

Geolocation estimations for refined products relative to the Sentinel-2 GRI show a stable performance for both S2A and S2B with a relative geolocation error better than 0.53 pixels for S2A and 0.43 pixels for S2B (at 95% confidence). The bias with respect to the GRI is around 0.2 pixels along-track for S2A and below 0.1 pixels for S2B. The across-track bias is negligible for both satellites. Please note that, as for the unrefined products, the real absolute performance is expected to be a little worse due to the GRI absolute geolocation uncertainty (6 m).

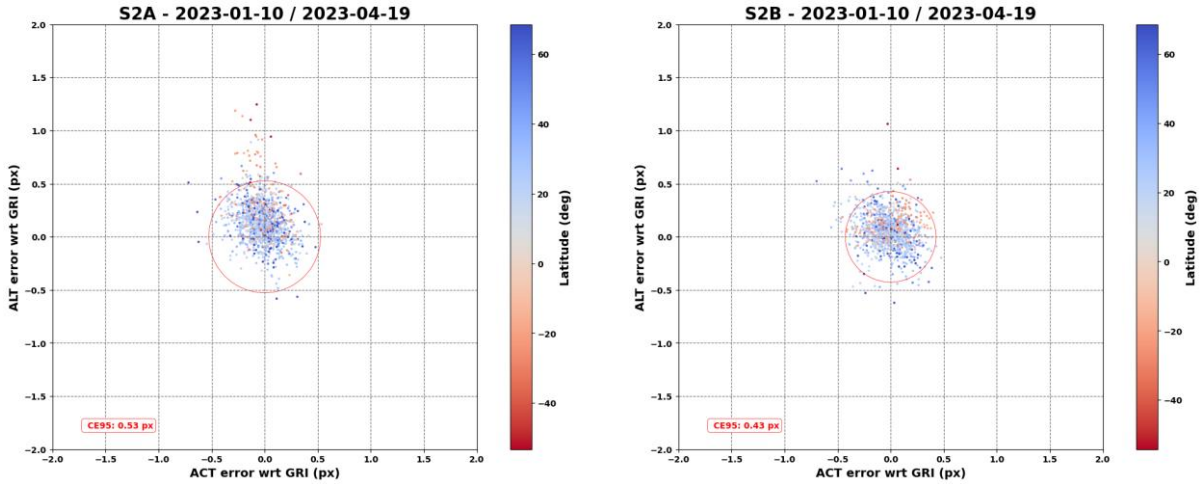


Figure 7: Relative geolocation performance for refined products.
Left: S2A, Right: S2B (10.01.2023 – 19.04.2023)

4.2.4 Absolute Geolocation

Absolute geolocation is assessed independently of the GRI. This absolute performance is computed on Level-1C products compared with reference images. The algorithm used for geometrical calibration with Level-1B products has been adapted to Level-1C products. Only the B4 spectral band is chosen for validation because it gives the best correlation with reference data.

Around fifty reference sites are used. Indeed, the range of scenes needs to cover a variety of geographic sites all over the world with a good distribution in latitude to ensure the non-dependency of weather conditions and the visibility of a potential dependency on latitude, date or other criteria.

The performances are given below in terms of median circular error, mean circular error probable at 95%, mean ACT and ALT errors.

4.2.4.1 Unrefined products

Absolute geolocation estimations for S2A and S2B unrefined products exhibits variability during the analyzed period of January 2022 to the end of March 2023. Performances on unrefined products are not significant because statistics are calculated on few products.

For S2A, the mean circular error probable at 95% is 13.11m, while the mean ACT and ALT error is 7.57m and 7.26m, respectively. Similarly, for S2B, the mean circular error probable at 95% is 14.75m, while the mean ACT and ALT error are 6.49m and 9.28m, respectively.

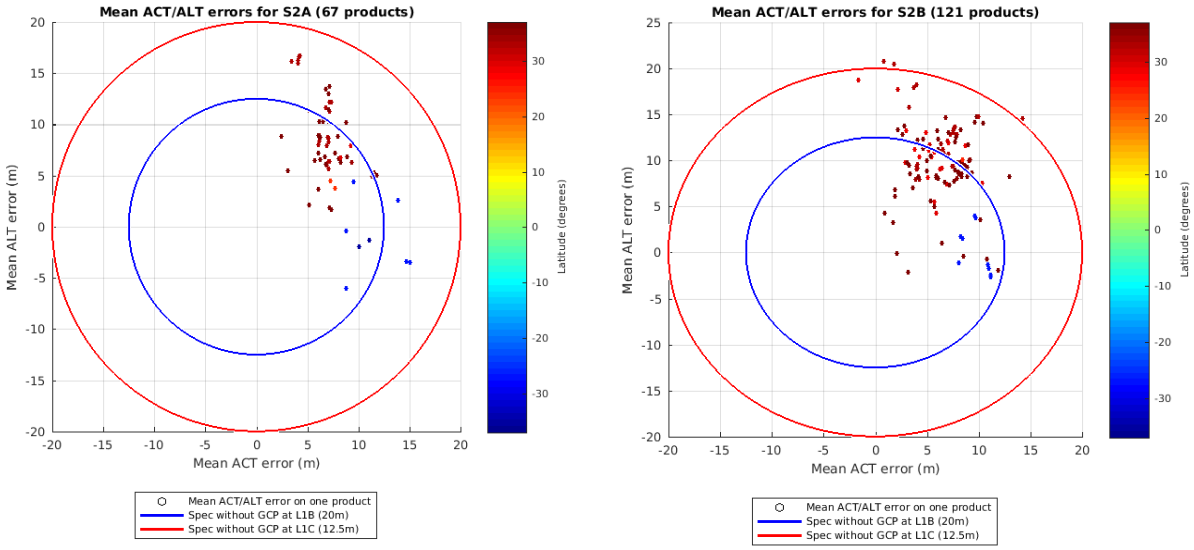


Figure 8: Absolute geolocation performance for unrefined products. Left: S2A, Right: S2B (01.2022 – 03.2023)

4.2.4.2 Refined products

Absolute geolocation performances are compliant to requirements for refined products.

Absolute geolocation estimations for both S2A and S2B refined products show a stable performance over the analysed period from January 2022 to the end of March 2023, with a mean circular error probable at 95% equal to 9.15m for S2A and 8.67m for S2B. For S2A, the mean ACT error is equal to 3.69m and the mean ALT error is equal to 0.68m while for S2B the mean ACT error is equal to 3.61m and the mean ALT error is equal to 1.28m.

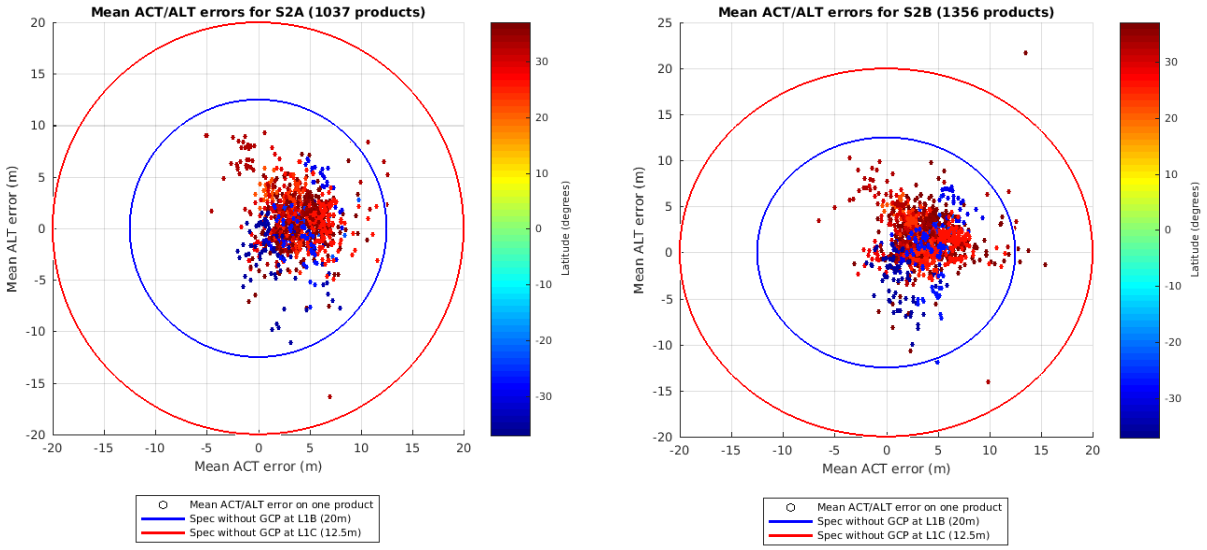


Figure 9: Absolute geolocation performance for refined products. Left: S2A, Right: S2B (01.2022 – 03.2023)

4.2.5 Multi-Spectral Registration

The multi-spectral evaluation is performed over refined and unrefined Level-1C products acquired over suitable validation sites (flat terrain with good appropriate texture and spectral characteristics). Of all possible sites identified in the Cal/Val plan, the Karakum desert (tile 40TGK) meets the criteria and provides the opportunity to monitor the multi-spectral registration throughout the year (Figure 10). The co-registration requirement (< 0.3 pixel at 99.7% confidence) for both S2A and S2B are within or close to specifications for almost all measured band couples. For S2B, some exceptions are encountered: the bands couples B02/B04, B02/B08, B01/B09 and B08/B09 which are above 0.3px (under investigation).

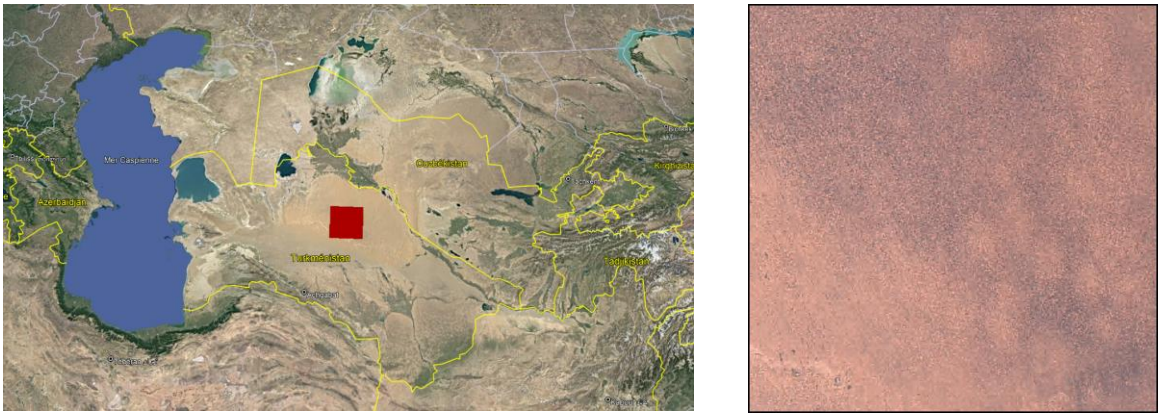


Figure 10: Location and illustration of the Karakum desert site (Tile 40TGK) used to perform the inter-band co-registration measurements

Table 4-2: Multi-Spectral co-registration performance (per band couple and detector number) for S2A on 2023/02/22 (top) and S2B on 2023/04/08 (bottom).

Sentinel-2A

	B01	B03	B04	B06	B07	B08	B8A	B09	B11	B12
B02		0,24	0,35			0,35				
B05				0,12	0,14		0,19		0,27	0,26
B01,B08	0,29							0,25		

Sentinel-2B

	B01	B03	B04	B06	B07	B08	B8A	B09	B11	B12
B02		0,37	0,53			0,65				
B05				0,14	0,17		0,22		0,39	0,39
B01,B08	0,26							0,99		

4.2.6 Multi-Temporal Registration

4.2.6.1 Methodology

The multi-temporal registration error for one tile is estimated as the mean measured error for all control points of the tile. Then the global performance is taken as the 95.5% percentile of the mean shift for all tiles. The performance is measured on the reference band (B04).

4.2.6.2 Refined products

Figure 11 below shows the histograms of the co-registration for pairs of S2A, S2B and any S2A/S2B products. The performance for all cases is around 0.5 pixels at 95.45%.

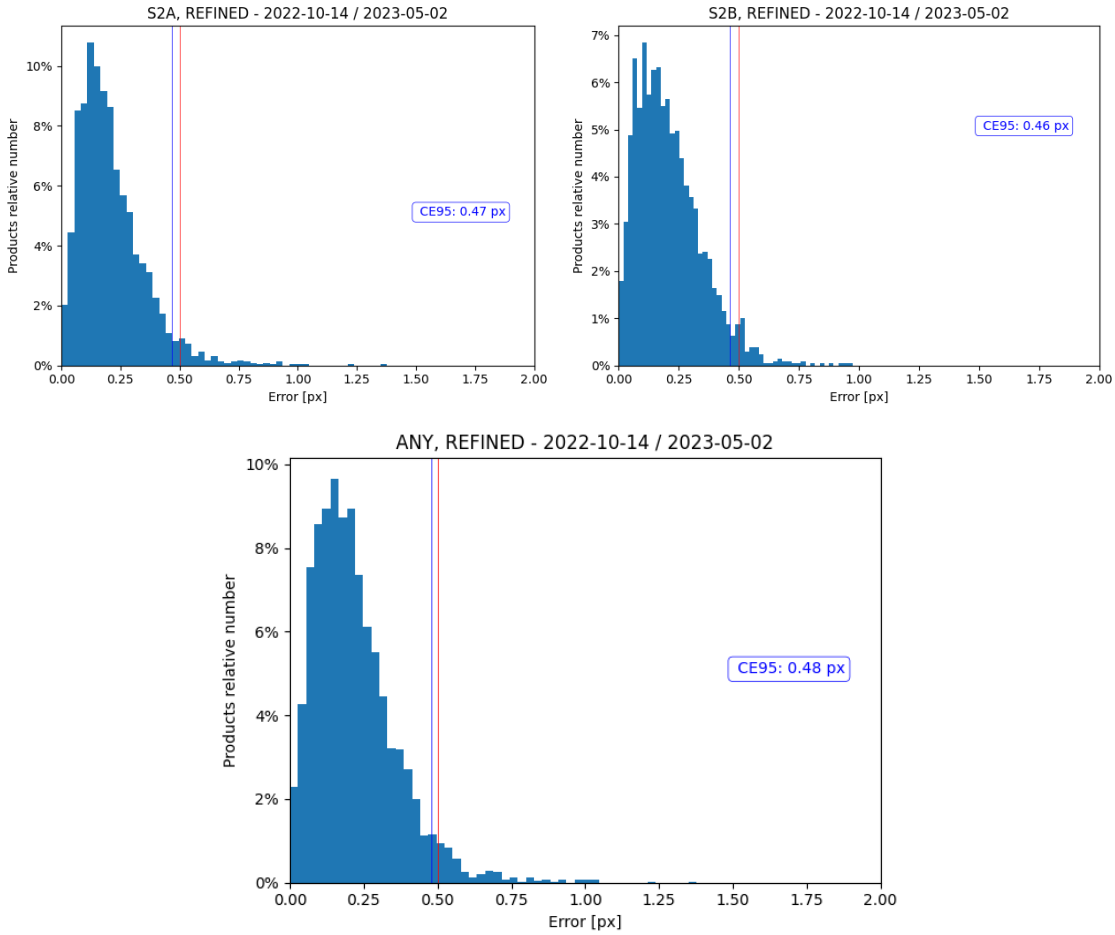


Figure 11: Multi-temporal 2D co-registration errors for refined S2A (left) and S2B pairs (right), and all pairs (bottom) (14.10.2022 to 02.05.2023). The 95.45% performance is around 5 m.

4.2.6.3 All products

The following figure provides the multi-temporal performance for all products, whether refined or unrefined. The performance drops to 0.73 pixels.

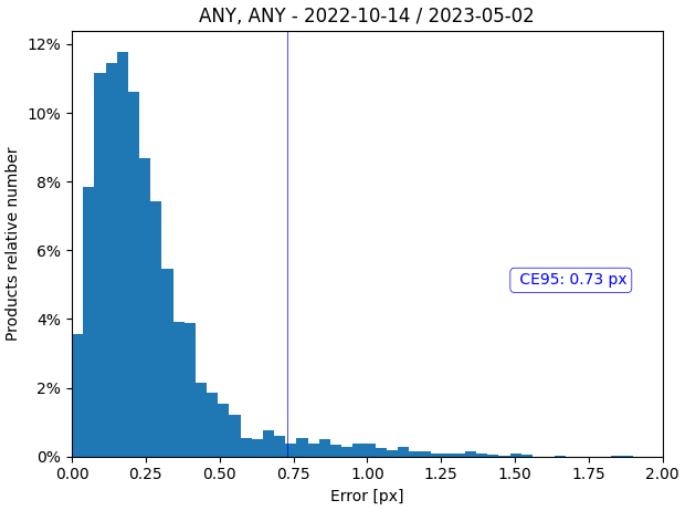


Figure 12: Histogram of the multi-temporal performance for all products (refined and unrefined) (14.10.2022 to 02.05.2023).

4.3 Radiometric Performance

4.3.1 Radiometric Uncertainty

Radiometric validation is performed using several methods:

- "Rayleigh" method: measurement of the Rayleigh atmospheric backscattering over deep ocean sites.
- Comparison with in-situ data.
- Measurement over well characterized, temporally stable desert areas (Pseudo-Invariant Calibration Sites or PICS).
- Comparison with other sensors such as Landsat-8 OLI (Collection-1 over Libya-4) and cross-comparison S2A vs S2B.
- The DCC method for relative radiometric assessments. Because DCC are high-altitude targets, they are less dependent on an estimation of the radiative transfer through the atmosphere.

The radiometric validation results based on different methods are presented in the figures below. Results are provided for S2A and S2B and for all bands except B09 & B10.

On 25th January 2022, a radiometric harmonization factor between Sentinel-2A and Sentinel-2B (keeping Sentinel-2A as reference) was introduced in operation. Figure 13 and Figure 14 here below shows the radiometric accuracy before the introduction in operation of this radiometric harmonization factor (January 2022) (top figures) and after the introduction in operation on the radiometric harmonization

factor (bottom figures). Please note that the in-situ analysis for the data acquired after January 2022 is ongoing.

All results are within the 5% (3%) radiometric accuracy requirement (Goal) respectively.

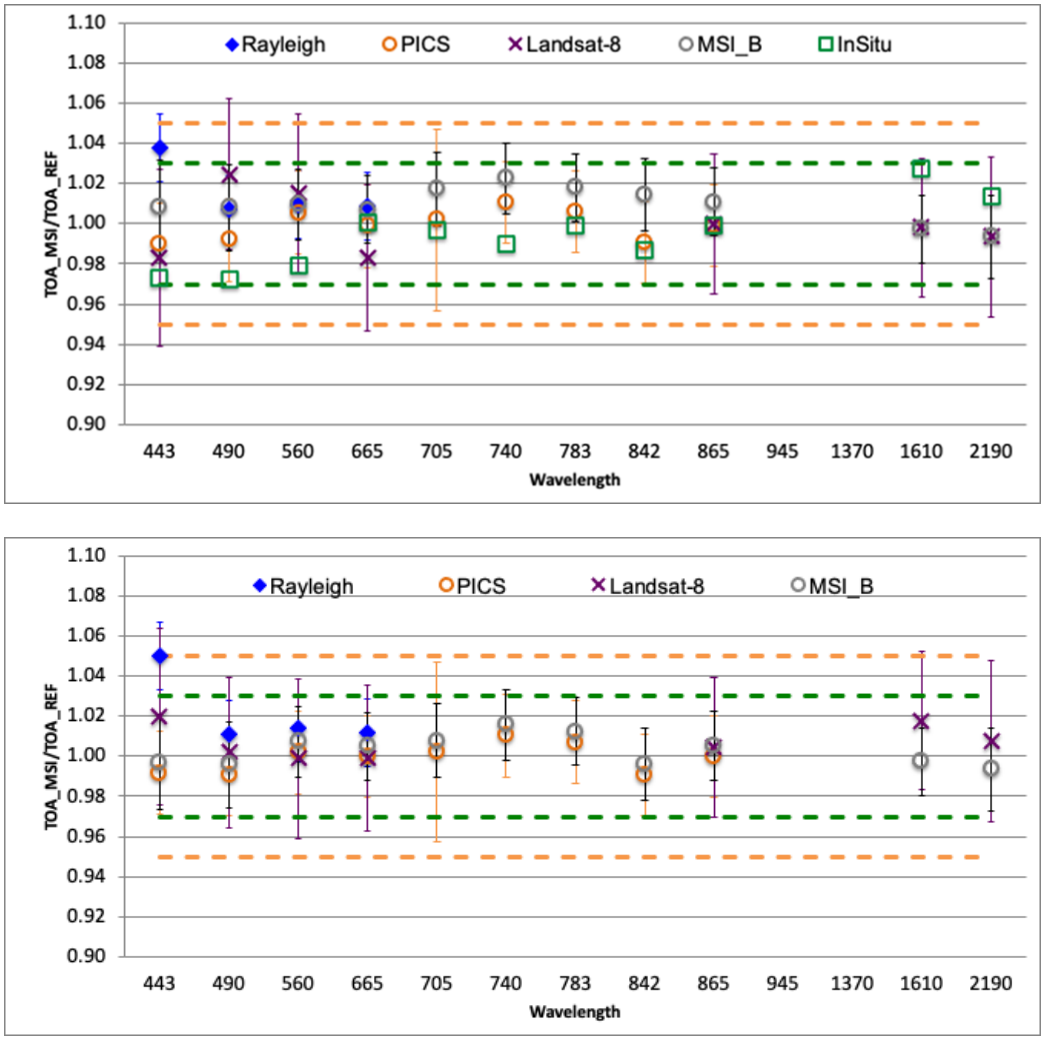


Figure 13: Comparison of radiometric accuracy for all spectral bands (except B09 and B10): ratio of S2A measurement on reference (top) pre-radiometric harmonization between Sentinel-2A and Sentinel-2B in January 2022, (bottom) post-radiometric harmonization up to 03/2023.
Error bars indicate the method uncertainty.

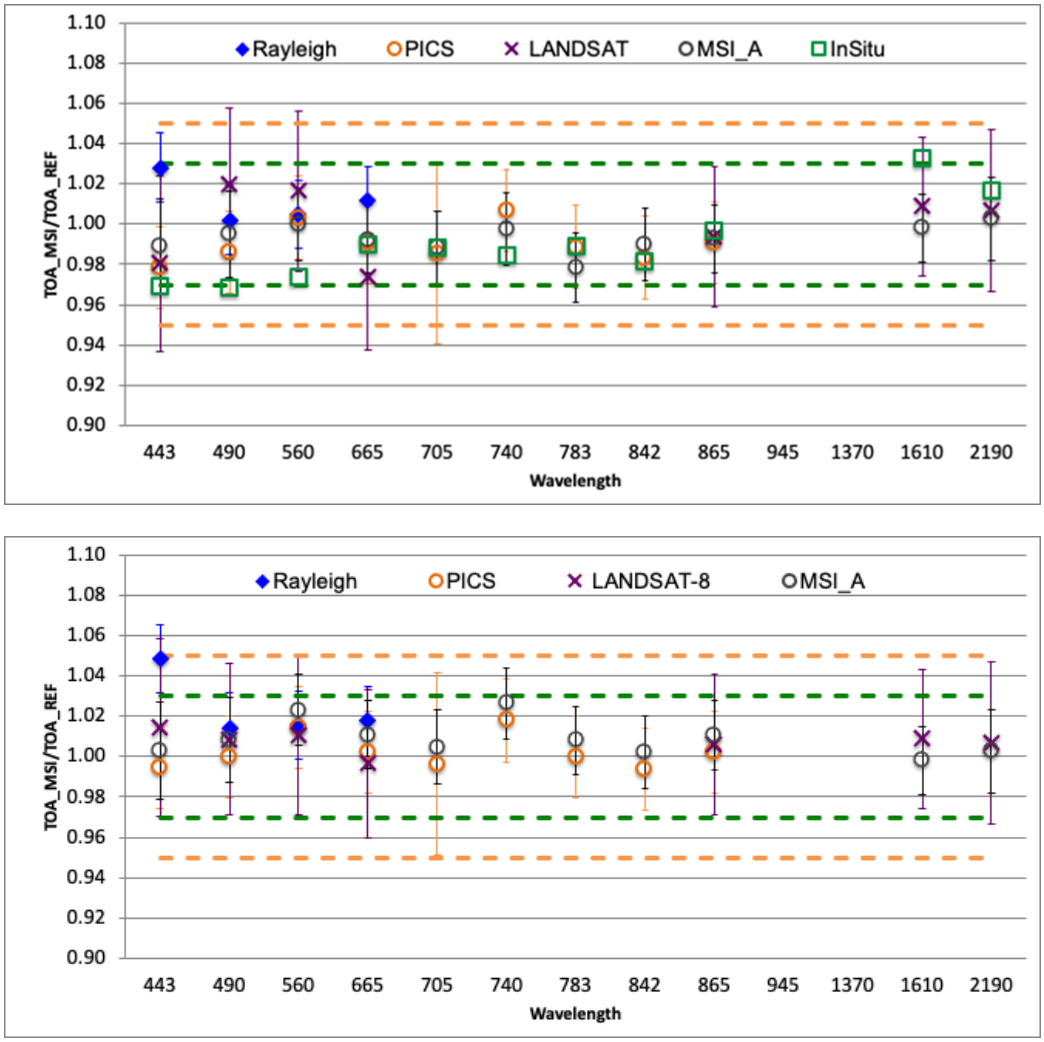


Figure 14: Comparison of radiometric accuracy for all spectral bands (except B09 & B10): ratio of S2B measurement on reference (top) pre-radiometric harmonization between Sentinel-2A and Sentinel-2B in January 2022, (bottom) post-radiometric harmonization up to 03/2023. Error bars indicate the method uncertainty.

Table 4-3 presents the best estimate of the ratio (gain coefficient) and standard deviations retrieved over the period January 2022 up to March 2023 over the six CEOS-PICS and six Ocean sites. We observe that the gains are within ±3% over all the VNIR bands (B05 excluded due to gas absorption), and compliant with the mission requirements of 5%. The standard deviation of the gain coefficients is found to be of <3%, which illustrates the consistency intra-sites in term of TOA-reflectance.

Table 4-3: Best estimate of S2A and S2B calibration gains coefficient and the standard deviation over the six CEOS-PICS and 6 Ocean sites over the January 2022- February 2023

Sensor		S2A		S2B	
	Wavelength (nm)	Gain Coefficient	Standard Deviation	Gain Coefficient	Standard Deviation
B01	443	1.015	0.027	1.015	0.024
B02	490	1.000	0.009	1.008	0.006
B03	560	1.005	0.007	1.016	0.005
B04	665	1.004	0.006	1.007	0.009
B05	705	N/A	N/A	N/A	N/A
B06	740	1.013	0.004	1.022	0.006
B07	783	1.010	0.004	1.004	0.006
B08	842	0.994	0.004	0.998	0.006
B8A	865	1.003	0.003	1.006	0.004

Time series of measurements are also produced to monitor the evolution in time of the radiometric response, in particular to detect a possible degradation of the diffuser. The current assessment is compatible with the specified stability requirement for all visible and NIR bands (< 1% per year).

The validation of the inter-satellite relative radiometric uncertainty is performed using Deep Convective Cloud (DCC) images. The method is based on statistics of DCC reflectances: a reflectance indicator is computed from DCC pixels reflectances for each band and detector. The reflectances are corrected from atmospheric transmissions between top-of-DCC and top-of-atmosphere using a transmission spectrum obtained from radiative transfer simulations. Previously limited to the VNIR range, the transmission spectrum has been extended to the SWIR and commissioned early October 2022.

A slight increase of the bias, comparable with the one noted in March, is observed for the VNIR spectral bands for the month of April.

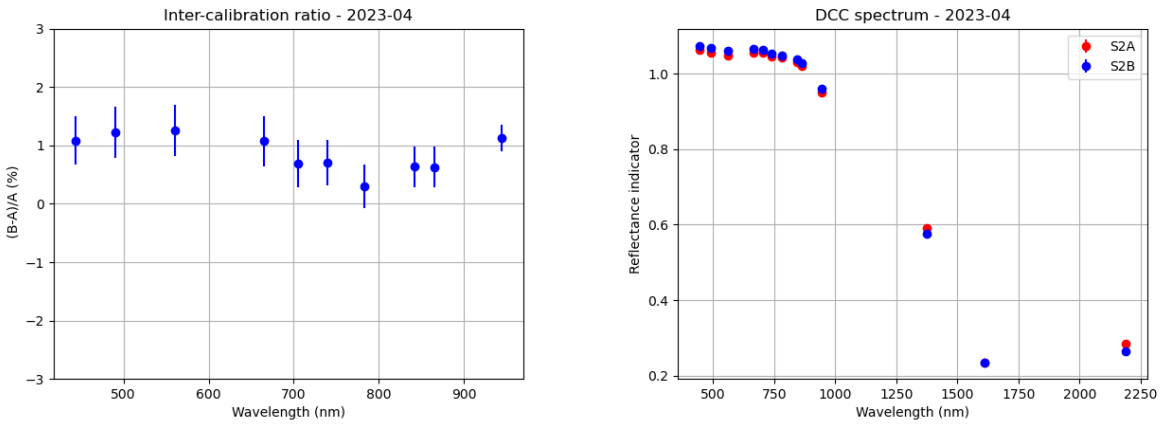


Figure 15 : Inter-calibration ratio between S2A and S2B as a function of the wavelength (left) assessed based on acquisitions from April 2023. Reflectance indicator for all wavebands in the VNIR shows an alignment of S2A compared to S2B following the introduction of the radiometric harmonization factor on 01/2022.

4.3.2 Noise

4.3.2.1 Signal-to-Noise Ratio

The SNR is computed based on:

- diffuser acquisitions for short-term performance monitoring,
- homogeneous ground images for long-term performance assessment.

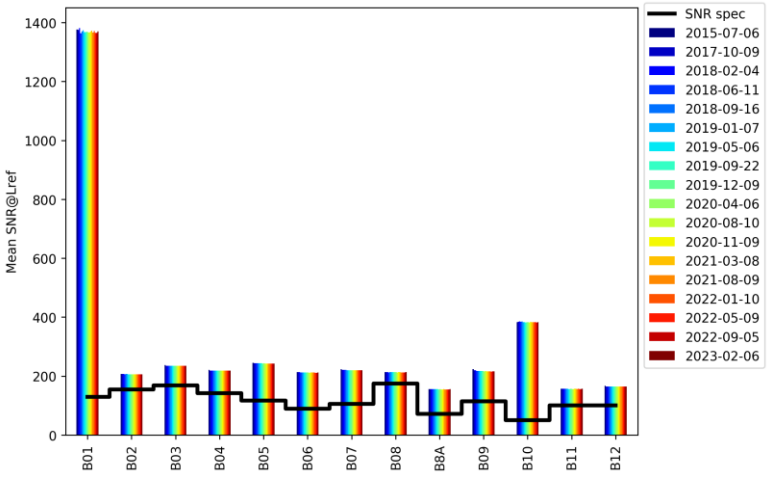
The SNR for both S2A and S2B is exceeding requirements (worst-case >155 for band B8A). The table below provides the mean estimates over 2022.

Table 4-4: Estimated SNR performance for S2A and S2B at reference radiance based on diffuser acquisitions. Average value over the year 2022 of the mean SNR@Lref per month (mean value over all the valid pixels for the monthly sun diffuser acquisition) and maximum difference over the months.

Spectral Band	B1	B2	B3	B4	B5	B6	B7	B8	B8A	B9	B10	B11	B12
Ref. radiance [W/m²/sr/µm]	129	128	128	108	74.5	68	67	103	52.5	9	6	4	1.5
S2A Mean SNR@Lref	1367	206	235	218	243	212	220	213	155	215	383	156	165
Max deviation	0,7%	0,3%	0,2%	0,2%	0,2%	0,3%	0,4%	0,4%	0,2%	0,6%	0,8%	0,7%	0,5%
S2B Mean SNR@Lref	1330	208	236	224	242	217	226	224	165	231	394	164	169
Max deviation	1,4%	0,6%	0,6%	0,5%	0,6%	0,6%	0,7%	0,7%	0,6%	1,3%	1,1%	1,2%	0,9%
Requirement	129	154	168	142	117	89	105	174	72	114	50	100	100

As seen in the figure below, the noise characteristics are very stable over time.

S2A



S2B

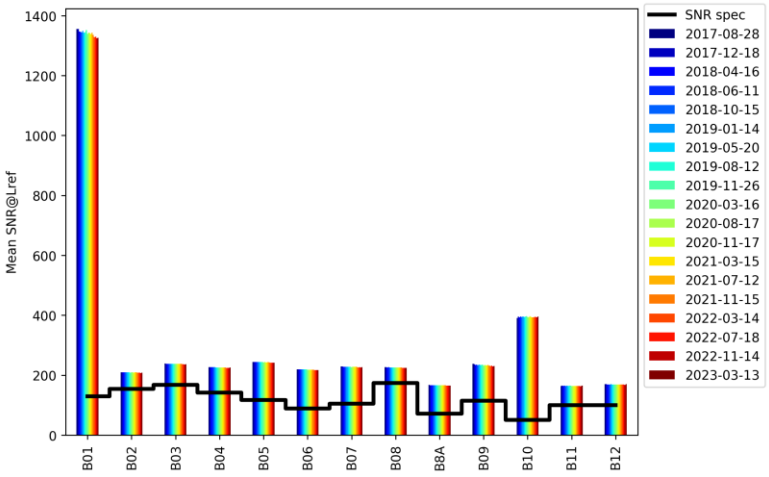


Figure 16: Evolution of the SNR performances based on diffuser acquisitions for S2A from 06/07/2015 to 06/02/2023 (top) and S2B from 28/08/2017 to 13/03/2023 (bottom)

The SNR is also computed over cloudless homogeneous landscapes. For this purpose, a number of pseudo-invariant calibration sites (PICS) are used, including sites in Libya, Mali, Saudi Arabia and Mauritania. Small homogeneous regions are identified from these landscapes and the SNR is estimated from a Fourier Transformation of these regions. The results are consistent with the ones issued from the diffuser. The calculated SNRs in both sensors are stable over time in every band and consistently exceed the requirements.

S2A

S2B

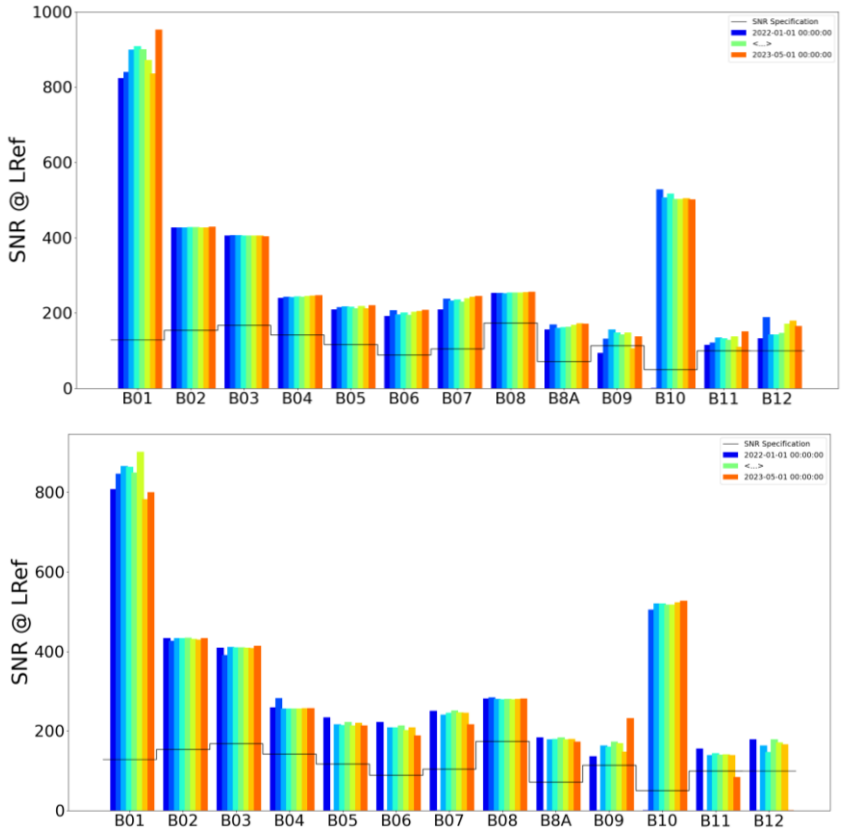


Figure 17 : Evolution of the SNR performances based on homogeneous natural acquisitions for S2A (top) and S2B (bottom) from 01/01/2022 to 01/05/2023

4.3.2.2 Fixed Pattern Noise

Another aspect of the image noise is the so-called Fixed Pattern Noise (FPN): this is the residual pixel radiometric error after equalization. The performance computed on sun diffuser acquisitions is estimated with operational equalization coefficients resulting from the sun calibration of the previous month. Therefore, it is an estimate for the highest changes of the sensor response till the previous calibration. However, the FPN is better than the specification for all bands except for a few pixels on bands B10 and B11. The monthly update of the calibration coefficients resolves the few pixels with an equalization fault.

Figure 18 shows typical estimates of the FPN, for the different spectral bands.

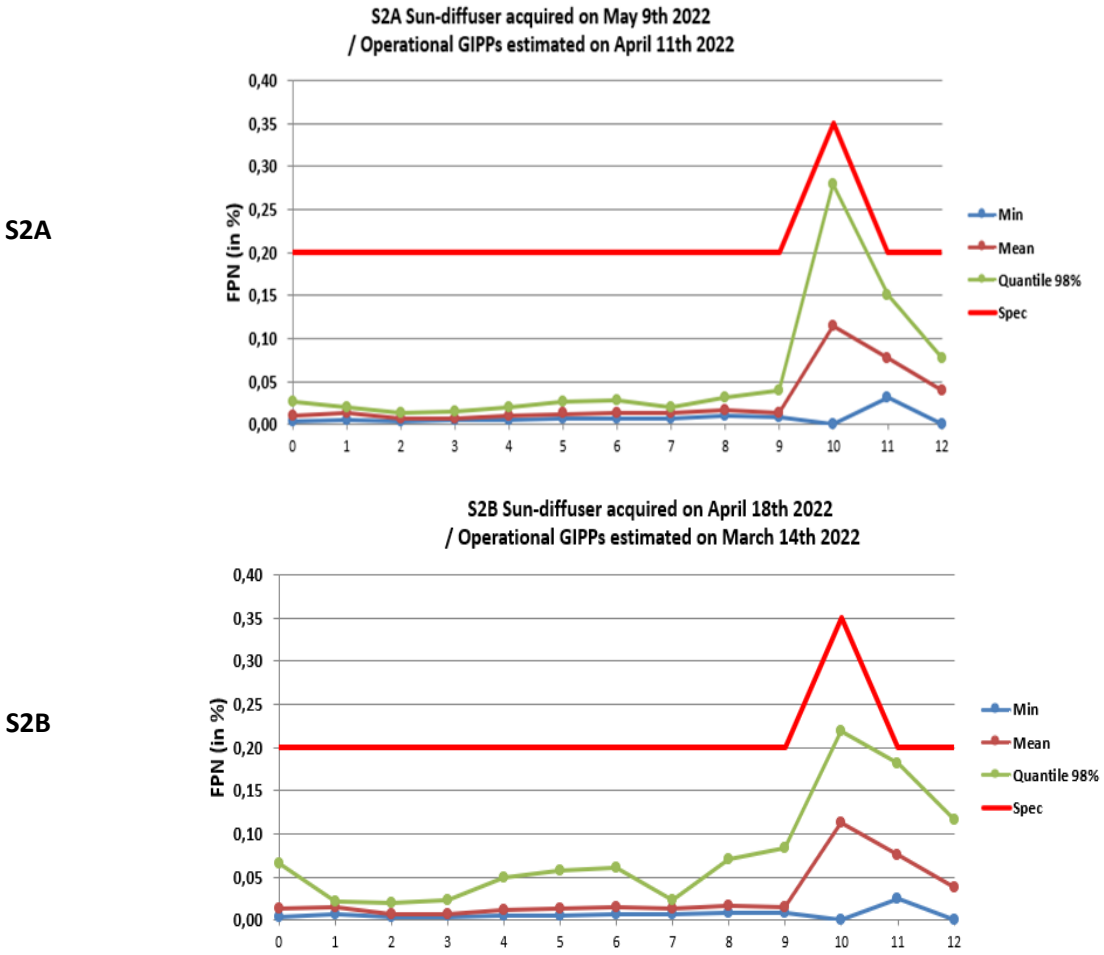
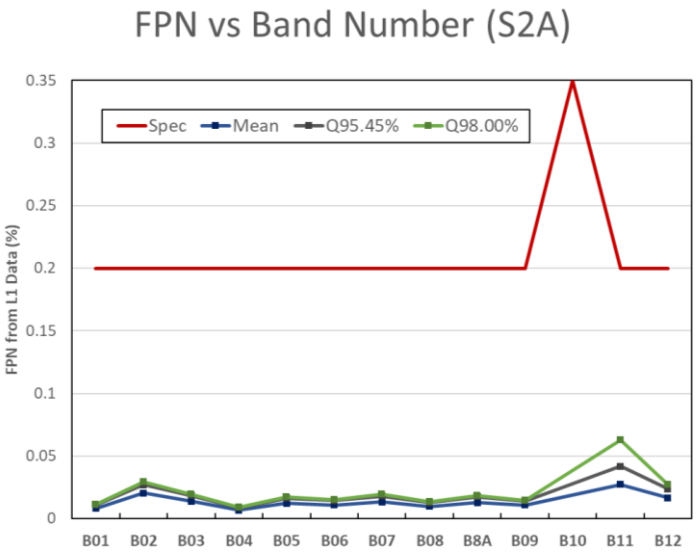


Figure 18: Fixed Pattern Noise (residual error after equalization) measured on diffuser images for S2A (top) and S2B (bottom). Blue curve: min FPN, marron: mean, green: 98 percentile, red: specified value.

The FPN is also computed on images over radiometrically uniform natural targets like deserts or snow. A selection based on the cloud cover is performed.

As for the assessment performed over diffuser acquisitions, the performance computed is better than the specification for all bands. For the band B10 the method is not applicable as the ground is not visible. Figure 19 shows the average values obtained using products acquired in March 2023 for the different spectral bands.

S2A



S2B

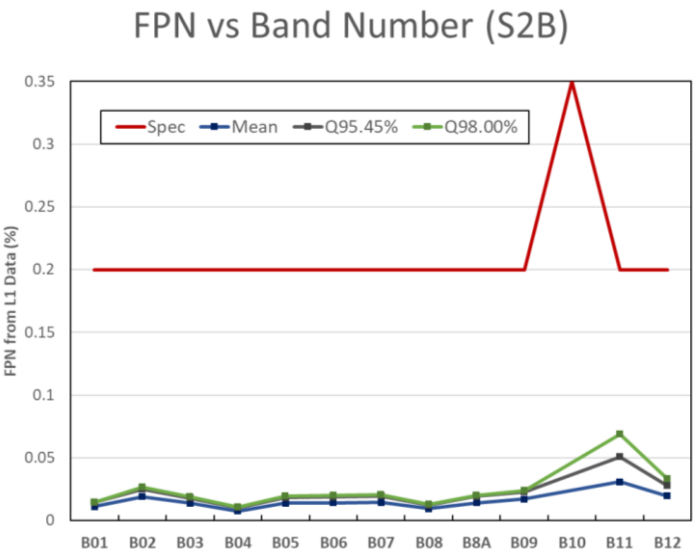


Figure 19 : Fixed Pattern Noise (residual error after equalization) measured on homogeneous natural images for S2A (left) and S2B (right) for March 2023.
Blue curve: mean FPN, grey curve: Q95.45%, green curve: Q98.00% and red curve: specified value.

4.3.3 Modulation Transfer Function

The Modulation Transfer Function (MTF) has been estimated by analysing images with sharp edges or lines for all bands (except B10 for which in-orbit assessment is difficult and for B1 and B9 in ACT: no suitable areas have been found).

Globally, the values measured in flight are consistent with In Orbit Tests (IOT) measurements and are stable in time except for 2021. Indeed, the 2021 measurements appear to be biased compared to the other measurements. No evolution in the MTF assessment is observed when the 2021 measurements are not considered.

The MTF requirements are satisfied for all bands (minimum specified to 0.15 for all bands). The MTF is above the maximum value requirement for B5, B6, B7 and B8A for the across and along track directions.

Note that only the minimum value requirement has a direct impact on image quality; this requirement is satisfied for all bands.

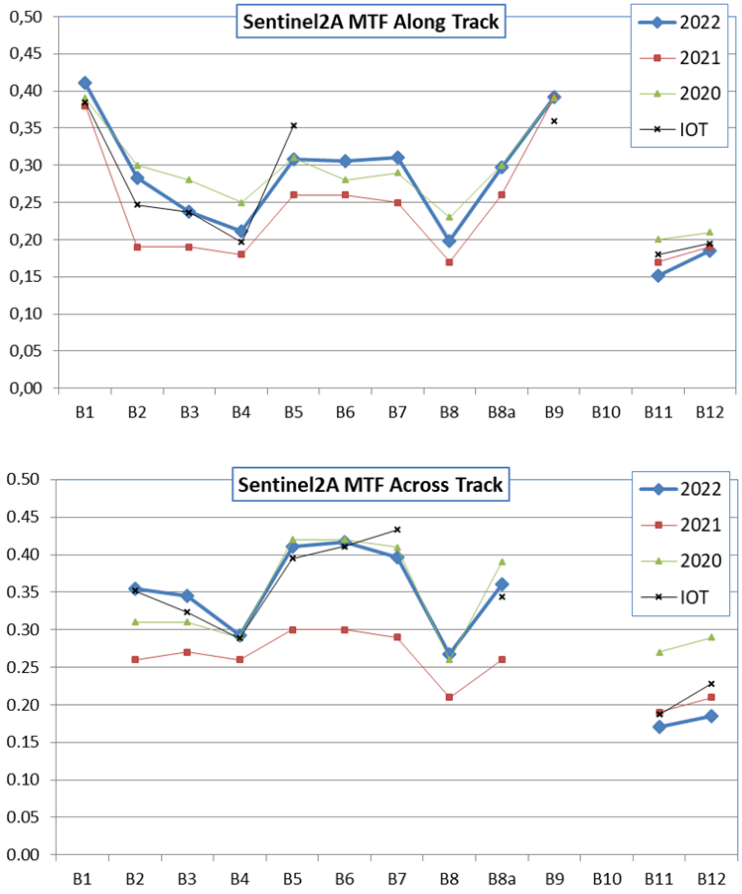
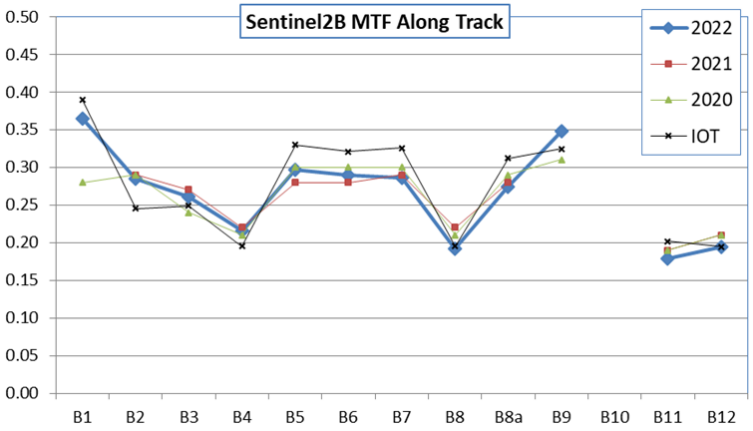


Figure 20 : MTF performance assessments for S2A (along and across track) performed using products from last 3 years and compared to IOT measurements.



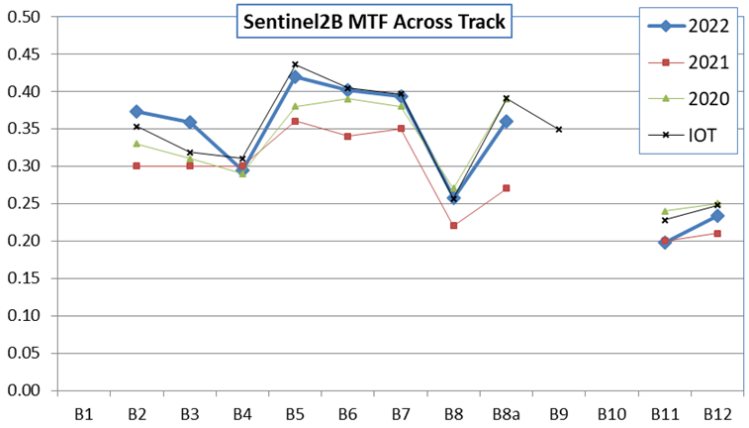


Figure 21 : MTF performance assessments for S2B (along and across track) performed using products from last 3 years and compared to IOT measurements.

The following table gives the measured values.

Table 4-5: S2A and S2B performances assessments using products from 2022.

2022 MTF	B1	B2	B3	B4	B5	B6	B7	B8	B8a	B9	B10	B11	B12
S2A ALT	0.41	0.28	0.24	0.21	0.31	0.31	0.31	0.20	0.30	0.39		0.15	0.19
S2A ACT		0.35	0.35	0.29	0.41	0.42	0.40	0.27	0.36			0.17	0.18
S2B ALT	0.36	0.28	0.26	0.22	0.30	0.29	0.29	0.19	0.27	0.35		0.18	0.19
S2B ACT		0.37	0.36	0.29	0.42	0.40	0.39	0.26	0.36			0.20	0.23

5 Pixels Status

5.1 Defective pixels

In the following tables are listed the identified defective pixels **since the beginning of year 2023**. The radiometry of these pixels is then replaced by an interpolation of neighboring pixels.

Table 5-1 : Defective pixels on S2A

Band	Detector	Pixel number (from 0)	Last update	Observations
B11	11	24	24/04/2023	Pixel in the inter-detector area. Not used for the resampling from L1B to L1C products. The update of the R2DEPI configuration file aims to be consistent for L1B images only. This pixel has been considered defective for radiometric calibrations since 2019.

Table 5-2 : Defective pixels on S2B

Band	Detector	Pixel number (from 0)	Last update
B12	4	1121	11/04/2023

Please refer to the Sentinel 2 Annual Performance Report covering the year 2022 to retrieve the list of older defective pixels for both S2A and S2B.

5.2 Reset Spike pixels

During the MSI design phase, it has been identified that a few pixels of the 10 m bands are affected by an electronic crosstalk during detector read-out. This results in errors which can reach a few digital counts, depending on the observed scene.

The list of affected pixels can be retrieved in the Sentinel 2 Annual Performance Report covering the year 2022.

6 Product Features

Some known product features are visible on Sentinel 2 products.

These features are generated by:

- the spectral response non-uniformity,
- parallax effects created by the staggered configuration of the focal plane,
- surface reflectance effects,
- misregistration of High-Altitude Objects,
- gradient crosstalk on band B12,
- data-strip overlap.

Please refer to https://sentinels.copernicus.eu/web/sentinel/technical-guides/sentinel-2-msi/data-quality-reports/product-features for more details and examples of the known Sentinel 2 product features, as well as to the Sentinel 2 Annual Performance Report covering the year 2022.

7 Product anomalies

This section describes the L1C product anomalies that occurred in 2023. Please refer to the APR 2022 or to the on-line Sentinel-2 anomaly database https://s2anomalies.acri.fr/anomalies to have the full list of anomalies.

Each anomaly is tagged with a code "#N" allowing linking it to a given processing baseline through the three tables provided in the sub-sections below.

7.1 Level-1C processing anomalies

7.1.1 Introduction

The table below summarizes the known processing anomalies affecting the current L1C production.

Table 7-1: L1C processing anomalies

Anom. ID	Baseline number	05.09
	Deployment date	06/12/2022
	Anomaly title	
73	Inconsistent data loss report	Some products
83	QUALIT_MSK not detecting all missing packets	A few products

7.1.2 Inconsistent data loss report (#73)

This anomaly concerns products affected with missing packets (data loss). The reports in the Datastrip Metadata and the Granule metadata are inconsistent. Known occurrences are listed below:

- S2A_MSIL1C_20220110T155631_N0301_R054_T18UXE_20220110T175004.SAFE has missing packets on bands 1,7,8A,9, and 12 but reports 0 lost packet at datastrip level
- S2B_MSIL1C_20211215T234509_N0301_R044_T54DVM_20211216T003204.SAFE has missing packets on band 3 but reports 0 lost packet at datastrip level
- S2B_MSIL2A_20220131T161509_N0400_R140_T17RLN_20220131T185140.SAFE has missing packets reported in the datastrip metadata but missing from the tile metadata.

7.1.3 QUALIT_MSK not detecting all missing packets (#83)

All the lost packets are not flagged in the quality masks of some products. Investigation to solve this issue is ongoing.

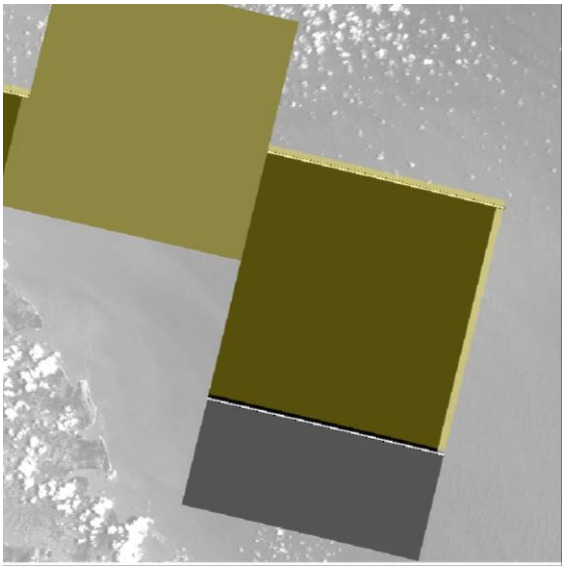


Figure 22: B02 of S2B_MSIL1C_20230110T073159_N0509_R049_T36KYC_20230110T092744 in background with band 3 (dedicated to lost packets) of the corresponding MSK_QUALIT superimposed in yellow. All the black pixels, due to data loss, in B02 are not flagged in the quality mask.

7.2 Instrument anomalies

7.2.1 Introduction

The table below provides the status of anomalies which are not related to processing and can therefore not be corrected through reprocessing. It complements the table provided in the sub-section above.

Table 7-2: On-board Anomalies.

Anomaly ID	Anomaly title	Criticality	Unit	Affected products	Product status
77	Geolocation error after collision avoidance manoeuvre	Minor	S2A	Orbit 39313	Available

7.2.2 Geolocation error after collision avoidance manoeuvre (#77)

Some products acquired shortly after a collision avoidance manoeuvre (S2A orbit 39313 on 01/01/2023) are affected with a geolocation error of about 35 m. As the products are mainly cloudy and on the ocean, they have been kept into the archive.

8 General information on products

8.1 Insights into the Copernicus Collection-1

The Collection-1 reprocessing will provide consistent Sentinel 2A and Sentinel 2B time series with a uniform processing baseline (PB 05.00) and optimized calibration.

The L2A surface reflectance product will be compliant with the CEOS Analysis Ready Data for Land (CARD4L) standard from 2015 to the present.

The improvements introduced in recent baselines will be generalized to the whole time series:

- Geometric refining using the high-quality Copernicus Digital Elevation Model (introduced in PB 03.00),
- Harmonized radiometry after alignment of S2B on S2A (introduced with PB 04.00),
- Most recent product format for L1C and L2A with radiometric offset, quality masks in raster format, L2A quality indicators, DOI (introduced in PB 04.00),
- Improved L2A processing algorithms for scene classification and surface reflectance (aligned with PB 04.00).

In addition, the PB 05.00 will provide some specific improvements over the current 04.00 baseline:

- Optimization of the applicability of successive radiometric and geometric calibrations,
- Reliable quality mask for radiometric saturation,
- Identification of defective pixels from missing instrument source packets in L2A Scene Classification layer,
- Use of the Copernicus Digital Elevation Model at 30 m resolution.

Collection-1 products are distributed via three different platforms:

- https://creodias.eu.: the data catalogue is accessible at https://finder.creodias.eu/. To query only Collection-1 products, a filter on the sensing date (i.e. before January 2022 for Collection-1 products) and on the publication date can be used, as the dissemination of these products started in January 2023.
- https://www.onda-dias.eu: the data catalogue is accessible at https://catalogue.onda-dias.eu/catalogue/. To query only Collection-1 products (PB 05.00), you can write "*_N0500_*" in the research bar of the catalogue.
- https://mundiwebservices.com: L1C Collection-1 products can be found at https://mundiwebservices.com/geodata/S2R_MSI_L1C, and L2A Collection-1 products at https://mundiwebservices.com/geodata/S2R_MSI_L2A.

Collection-1 production has started with December 2021 products and goes in reverse chronological order of sensing time. In April 2023, Collection-1 products from April to December 2021 are available. Please note that the period reported is considered available for the most part, while gradually densifying in particular on the side of the earlier months of the period.

Additional information regarding the status and accessibility of Collection 1 reprocessed data can be found on: https://sentinels.copernicus.eu/web/sentinel/technical-guides/sentinel-2-msi/copernicus-sentinel-2-collection-1-availability-status.

8.2 Product Format

On December 6th 2016, a new naming convention has been introduced (Product Specification Document version 14). The new convention leads to shorter product paths with less redundancy of information. The product name now includes the acquisition date and a "product discriminator" which is related to the acquisition date but can be different in some instances.

A reformatting of the Data Hub product archive to the single-tile, short name format is currently in progress. The JP2000 images are not affected by the reformatting.

Note that the product footprint for all products generated before July 20th 2016 include areas of No Data, while for the later product the footprint outlines valid pixels only.

8.3 Off-line products

Beginning 23rd September 2019, Sentinel-2 products older than one year will not be available on-line in the Copernicus data hubs. Instead, they will be retrieved on demand from the Long-Term Archive (LTA). Products retrieved from the LTA will be different from the original ones delivered in Near Real Time production:

- The product discriminator (the second date in the product) will be different. However, the zip file provided with the delivery will keep the name of the original product.
- The product will be restored using the latest applicable format (currently compact, single tile format, PSD v14.2).
- The GENERATION_TIME field in the User Product metadata will also reflect the date of the retrieval from the LTA.

See https://scihub.copernicus.eu/userguide/LongTermArchive for more details.

8.4 Reprocessed products

Two situations can lead to a recovery reprocessing and update of the SciHub archive:

- Products affected by major anomalies tracked in the Sentinel-2 anomaly database
- Datastrips with missing L1C tiles. In this case the products are not tracked in the anomaly database.

In both cases, the original products are removed and replaced by products with a more recent generation time. However, in the latter case, the original products can still be considered as valid.

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