

COPERNICUS SPACE COMPONENT SENTINEL OPTICAL IMAGING
MISSION PERFORMANCE CLUSTER SERVICE

Data Quality Report

Sentinel-2 L1C MSI

March 2024

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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

- ❖ Assessment of the current geometric and radiometric performances (see sections 4.2 and 4.3),
- ❖ Please be aware that there is an inconsistency in the L_{ref} value for the B12 noted in certain Sentinel-2 documents: 1.5 [W/m²/sr/μm] instead of 1.7 [W/m²/sr/μm]. To obtain information on the band parameters for each spectral band, kindly refer to the L_{ref} values directly extracted from the MRD ([Mission Requirements Document](#), Table 4),
- ❖ Deployment of Copernicus DEM at 30m resolution for Sentinel-2 products (see more details in the section 2),
- ❖ Distribution to all users of the Sentinel-2 Global Reference Image (GRI) database and the derived products (see section 4.2.2),
- ❖ Availability of the Copernicus Sentinel-2 Collection-1 data (see section 8.1),
- ❖ New organization of the Sentinel Online website: please visit the [SentiWiki](#) webpages,
- ❖ Sentinel-2 products (including Collection-1) are available on the [Copernicus Data Space Ecosystem](#).

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2 Processing Baseline Status

On December 13th, 2023, the **processing baseline 05.10** 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 for this processing baseline remains the same as the one operated to generate the Copernicus Sentinel-2 Collection-1 (for more details please refer to the section 8.1), combined with the use in operation of the **Copernicus DEM at 30 meters ground spatial resolution**. As a reminder, the previous processing baseline 05.09 was using the same operational processor but with the Copernicus DEM at 90 meters. Then, the Copernicus DEM at 30 meters being already used for the historical archive reprocessing, the new processing baseline 05.10 ensures continuity with the Copernicus Sentinel-2 Collection-1 tagged with the processing baseline identifier 05.00.

In addition, we remind here that a **radiometric offset** on reflectance digital numbers has been introduced with processing baseline 04.00 deployed on January 25th, 2022, and that it is still present in the more recent processing baselines. 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; 2¹⁵-1], the L1C TOA reflectance value is:

$$L1C_TOA_i = (L1C_DNI + RADIO_ADD_OFFSET_i) / QUANTIFICATION_VALUE_i$$

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://sentwiki.copernicus.eu/web/s2-processing#S2Processing-ProcessingBaseline>.

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 2024.

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 2024.

Table 3-1 : Start validity date of R2ABCA and R2EQOG calibration files released in 2024

Month	S2A	S2B
January	10/01/2024	-
February	20/02/2024	21/02/2024

Decontamination operations are scheduled once a year.

3.2.2 Sentinel-2A

A decontamination of the instrument was performed on the 6th – 7th of November 2023. The calibration coefficients were updated on the 9th of November 2023.

Dark signal stability:

The dark signal is quite stable. Its variations remains:

- ❖ lower than 0.5 LSB for most of pixels in VNIR bands,
- ❖ lower than 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 gain calibration:

A trend of increase of the absolute gain coefficients has been observed since January 2022 for VNIR bands. The highest increase is for the B09 band, with a change of around 0.7% between January 2022 and November 2023. The increase is around 0.6% from band B06 to band B8A, and around 0.5% from band B03 to B05. The lowest changes are for the B02 band (no more than 0.3%) and the B01 band (no significant change). Figure 1 shows the time variation of these absolute gain coefficients.

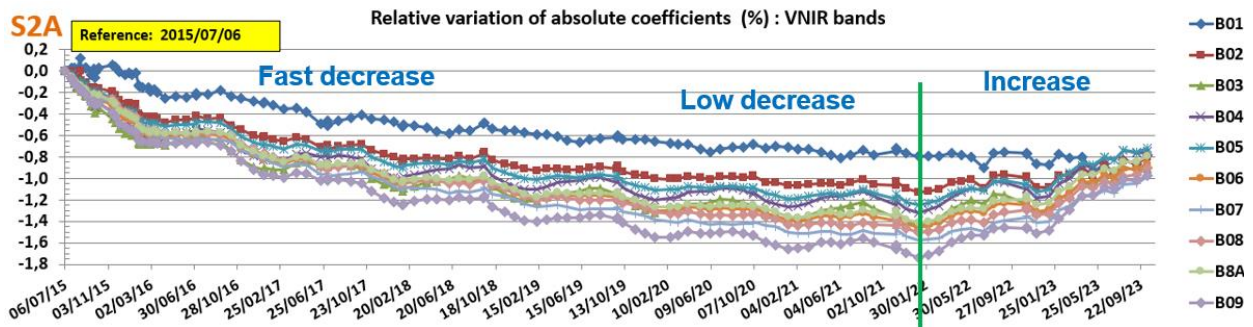


Figure 1: Relative variation of the absolute gain coefficients for VNIR bands of MSI-A, with respect to the first Sun acquisition on 6th of July 2015.

Regarding the SWIR bands, it is not possible to have a similar estimate because they have a loss of sensitivity with time between successive decontaminations (for B10 and B11), which can hide a trend of slight increase.

This behaviour is unexpected and investigations on possible causes are on-going. Note that so far, the radiometric performance measured through vicarious methods is still excellent.

3.2.3 Sentinel-2B

A decontamination was performed on 4th – 5th December 2023. The post-decontamination radiometric calibration was implemented on 11th of December.

Dark signal stability:

The high stability of the dark signal of MSI-B is similar to that of MSI-A.

Absolute gain calibration:

As for MSI-A, a similar trend of increase of the absolute gain coefficients has been observed since January 2022 for the VNIR bands. Figure 2 shows the variation of the MSI-B absolute gains throughout its lifetime in space. The order of magnitude is similar to the changes estimated for MSI-A, with the same dependence of the spectral band.

As for MSI-A, this behaviour is unexpected and investigations on possible causes are on-going.

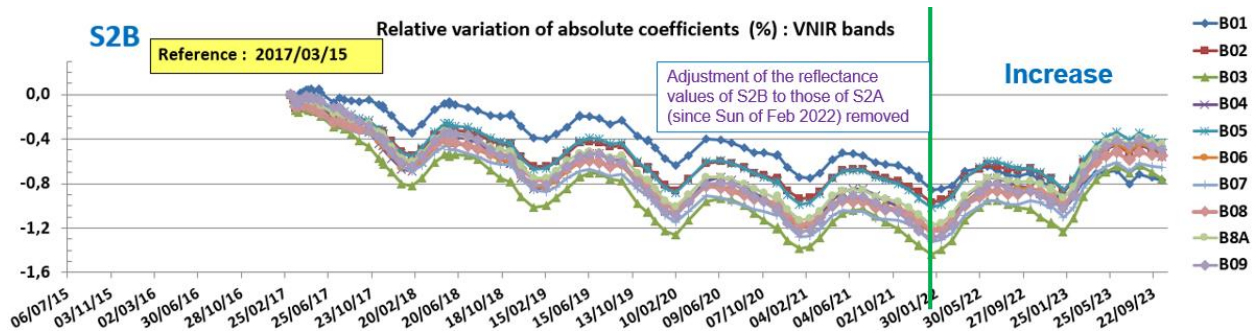


Figure 2: Relative variation of the absolute gain coefficients for VNIR bands of MSI-B, with respect to the first Sun acquisition on 15th of March 2017. The radiometric harmonization (applied since 25th January 2022) has been removed from this time series to make clearly noticeable the time variation of absolute gains.

As a reminder, with the introduction of the baseline 04.00 on 25th January 2022, a **radiometric harmonization coefficient 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.

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
23/11/2023	23/11/2023

The geometric refinement relies on the Sentinel-2 **Global Reference Image** (see section 4.2.2). Introduced in operation since 30 March 2021 (PB 03.00) over the Euro-Africa region and then in August worldwide (except Antarctica, some isolated islands and some high latitude areas), it has improved the multi-temporal co-registration and the relative geolocation accuracy of the Sentinel-2 products (see section 4.2 for more details).

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Since the deployment of PB 05.09 in December 2023, the orthorectification is performed with the Copernicus Digital Elevation Model (DEM) at 30 m spatial resolution. 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

The latest geometric calibration was deployed on November 23rd, 2023 to improve the geolocation of unrefined products. The correction concerned mostly the roll and yaw angles.

3.3.3 Sentinel-2B

As for Sentinel-2A, the latest geometric calibration was deployed on November 23rd, 2023 to improve the geolocation of unrefined products. The correction concerned mostly the roll and yaw angles.

On May 4th, 2023 a geometric calibration has been deployed 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 2 σ confidence level (unrefined products)	< 15 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) for S2B and slightly above the specifications for S2A (5.5 m at 95.5% confidence)
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 3 σ confidence level.	< 0.3 pixel at 99.7% confidence All bands couples are within or close to the specifications except the couples B05/B11 for S2B and B05/B12 for both S2A and 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% \pm 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.

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4.2 Geometric Performance

4.2.1 Geometric Refinement

Since March 2021 (processing Baseline 03.00) a geometric refinement step based on the GRI (see section 4.2.2) 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: around 5 m for both S2A and S2B.

4.2.2 Global Reference Image (GRI)

The Global Reference Image (GRI) is a layer of reference composed of Sentinel-2 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, acquired between 2015 to 2018, use the reference band (B04) and are mostly (but not entirely) cloud-free. The GRI covers most emerged land masses except Antarctica and has a global geolocation uncertainty better than 6 m.

The Level-1B GRI, along with new products derived from the Sentinel-2 GRI in a more accessible format are now freely available.

The list includes:

- ❖ L1B/ L1C GCPs Database: database of GCPs in L1B/ L1C geometry,
- ❖ Multi-layer L1C GRI set of L1C images (orthorectified in UTM projection),
- ❖ Multi-layer L1B GRI – set of overlapping Level-1B images (in sensor geometry) – used currently in the geometric refinement of the Copernicus Sentinel-2 imagery.

For more information on the generation of these GRI databases, download access, and corresponding documentation, please refer to the [Sentinel Online webpages](#).

4.2.3 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 3 provides the rate of unrefined products for S2A and S2B. Since Antarctica is observed mainly by S2B during the Austral summer, there is a higher number of unrefined products for this satellite.

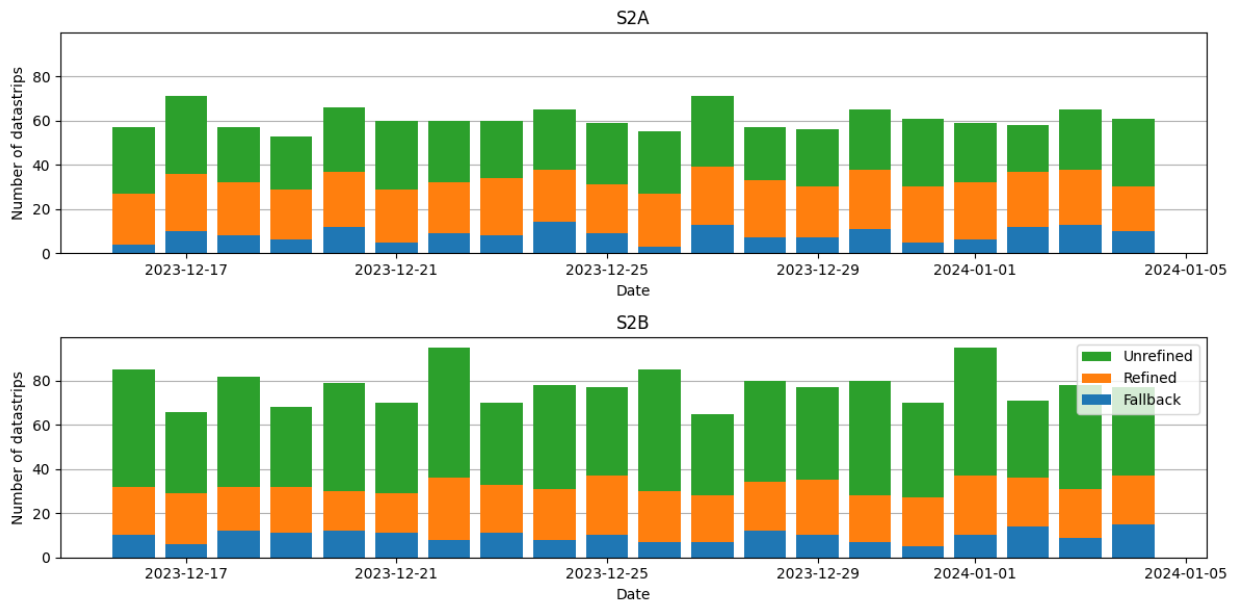
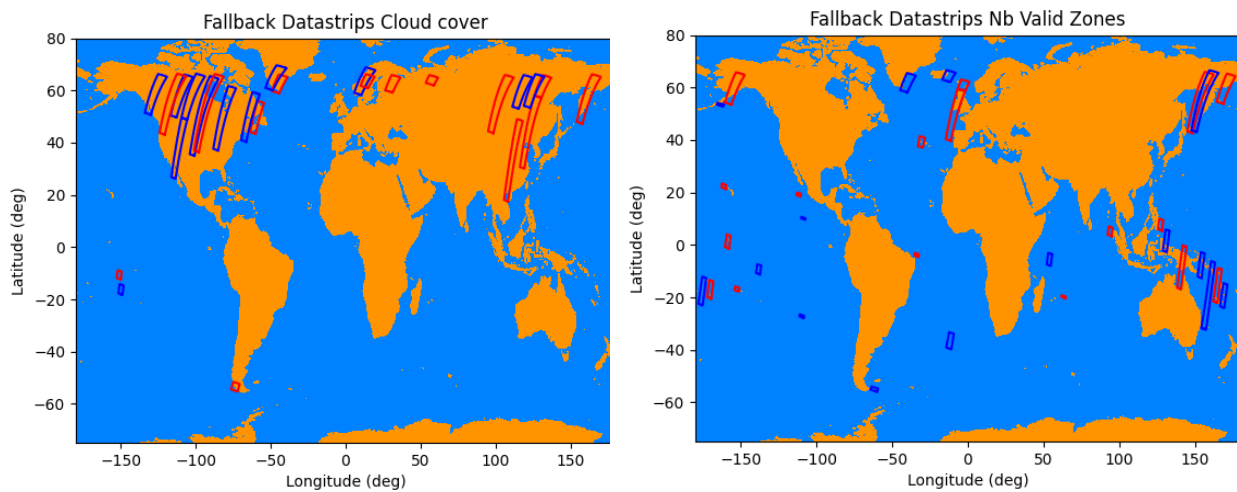


Figure 3: Number of refined (orange), unrefined (products without GRI, green) and fallback (blue) datastrips per day.

The following maps provide the location of the datastrips in fallback based on different criteria and unrefined for a cycle period during February 2024. 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.



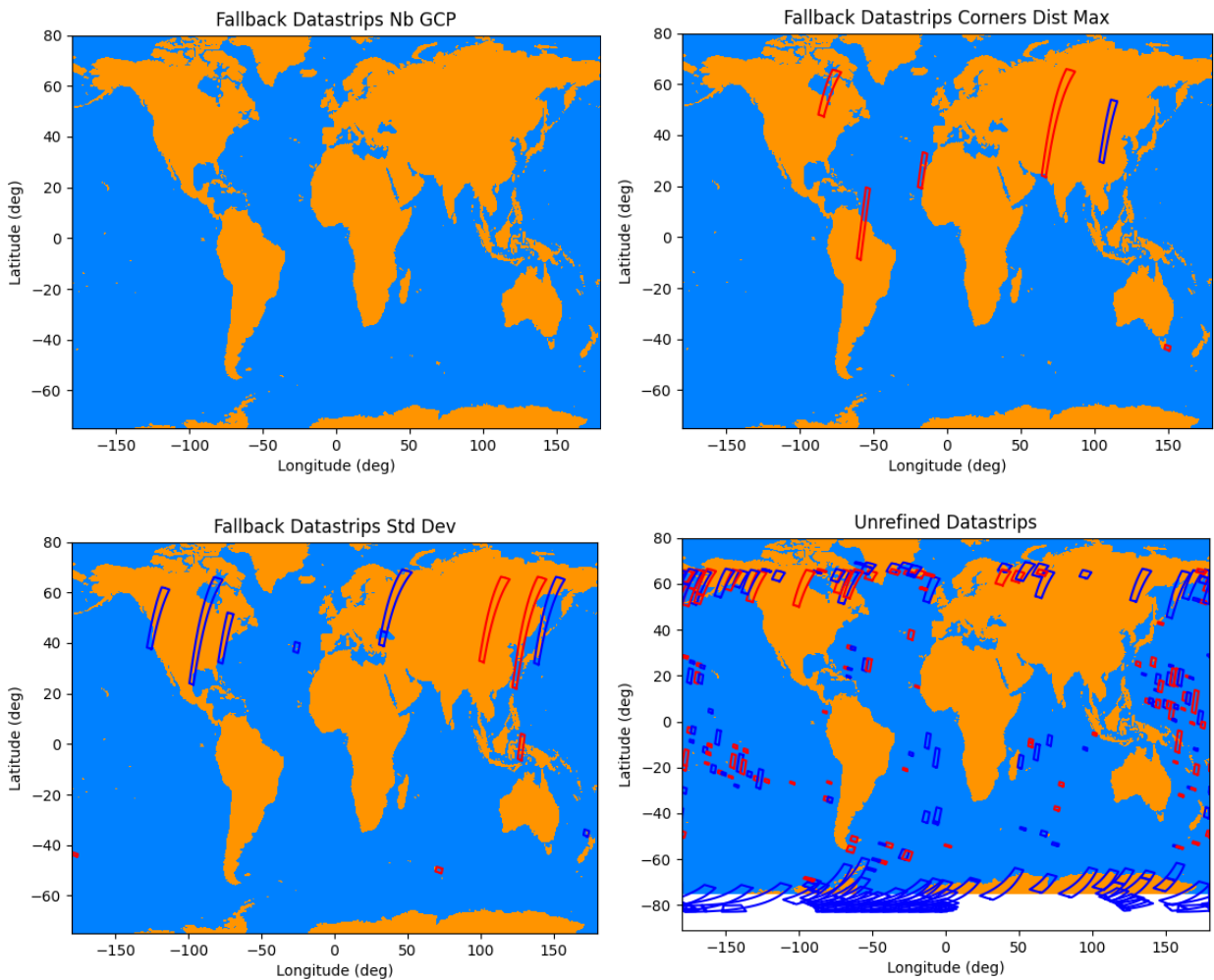


Figure 4 : Location of datastrips in fall-back and unrefined over a cycle period in February 2024 for S2A (red datastrips) and S2B (blue datastrips)

4.2.4 Relative Geolocation

4.2.4.1 Unrefined products

Since the activation of the global refinement in August 2021, the performance is estimated on a limited set of unrefined products. Figure 5 shows the geolocation performance for the unrefined products relative to the Sentinel-2 GRI. Please note that the real absolute performance is expected to be a little worse due to the GRI absolute geolocation uncertainty (6 m).

On November 23, 2023, the geometric calibration has been updated (see section 3.3) leading to an improvement of the geolocation performance of unrefined products (see Figure 5). In particular, the across-track (ACT) bias has been reduced for both satellites. After calibration, the point clouds for S2A and S2B look very similar, with a CE95 performance less than 11 m.

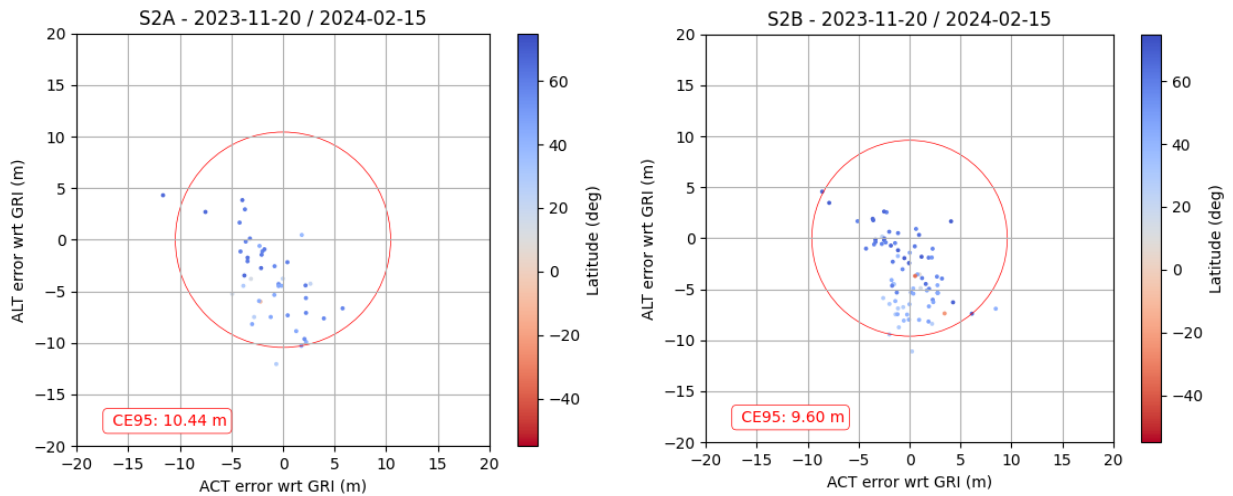


Figure 5: Relative geolocation performance for unrefined products.
Left: S2A, Right: S2B.

4.2.4.2 Refined products

The geometric refinement performance is measured on a set of sample tiles around the globe. In May 2023, new tiles have been introduced over Southern America. This change of sampling explains the apparent evolution of the relative geolocation results but the actual performance has remained stable over the recent period for both satellites at comparable latitudes.

During the last reporting period, the performance of S2A has significantly improved due to a reduction of the number of outliers with high along-track error in the Southern latitudes. Some outliers possibly linked to shadow effects are present in the Northern hemisphere. Both satellites show a similar performance around 5 m at 95% confidence.

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).

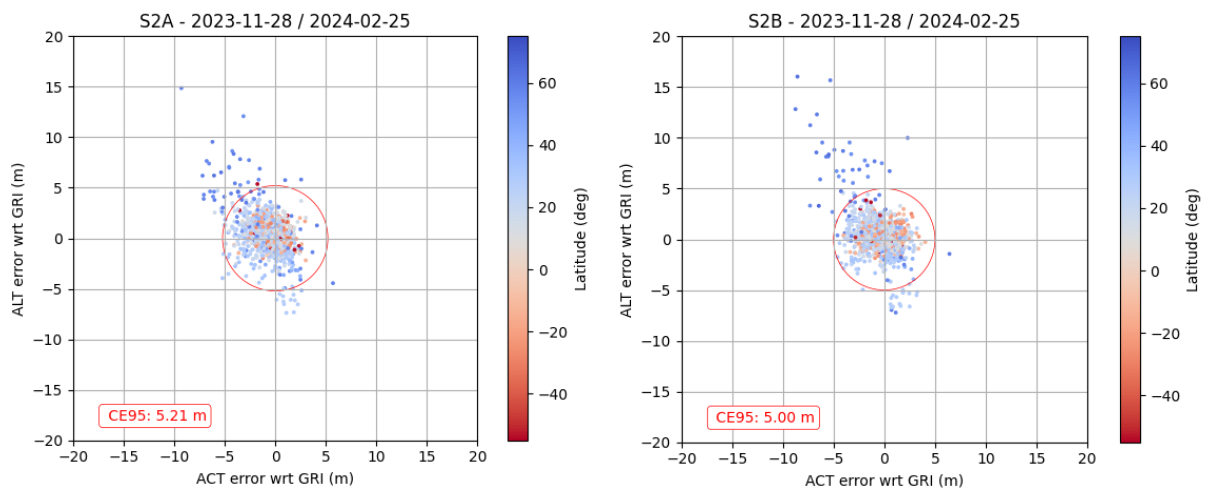


Figure 6: Relative geolocation performance for refined products.
Left: S2A, Right: S2B

4.2.5 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.

4.2.5.1 Unrefined products

Absolute geolocation estimations for S2A and S2B unrefined products exhibits variability during the analysed period of January 2022 to the end of December 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 13.72 m, while the mean ACT and ALT error is 8.79 m and 4.18 m, respectively. Similarly, for S2B, the mean circular error probable at 95% is 15.35 m, while the mean ACT and ALT error are 8.65 m and 7.55 m, respectively.

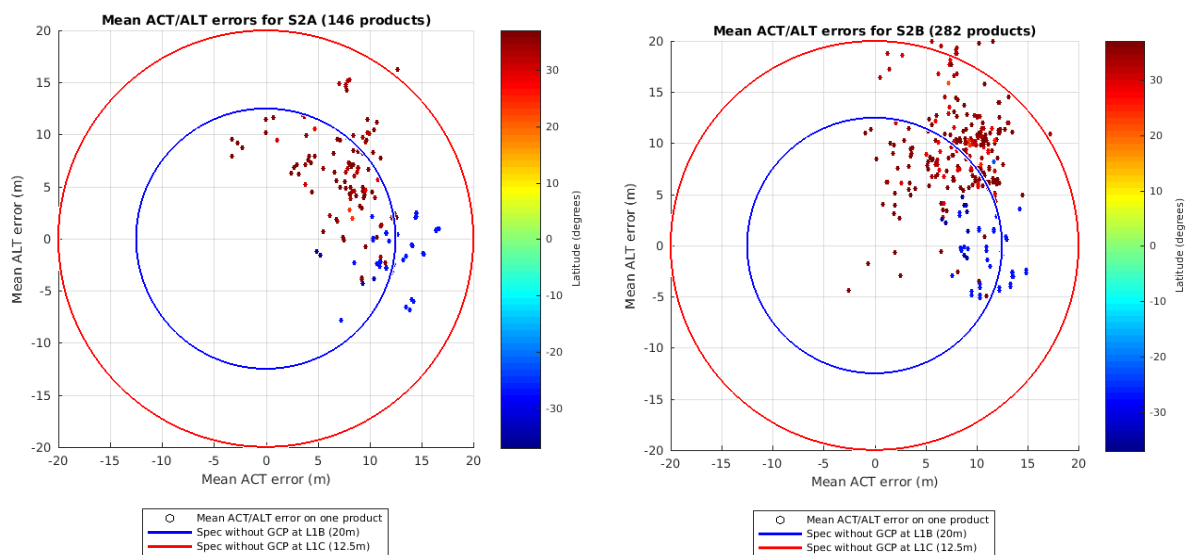


Figure 7: Absolute geolocation performance for unrefined products.
Left: S2A, Right: S2B (01.2022 – 12.2023)

4.2.5.2 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 December 2023, with a mean circular error at 95% equal to 8.78

m for S2A and 8.29 m for S2B. For S2A, the mean ACT error is equal to 3.59 m and the mean ALT error is equal to -0.35 m while for S2B the mean ACT error is equal to 3.64 m and the mean ALT error is equal to 0.48 m.

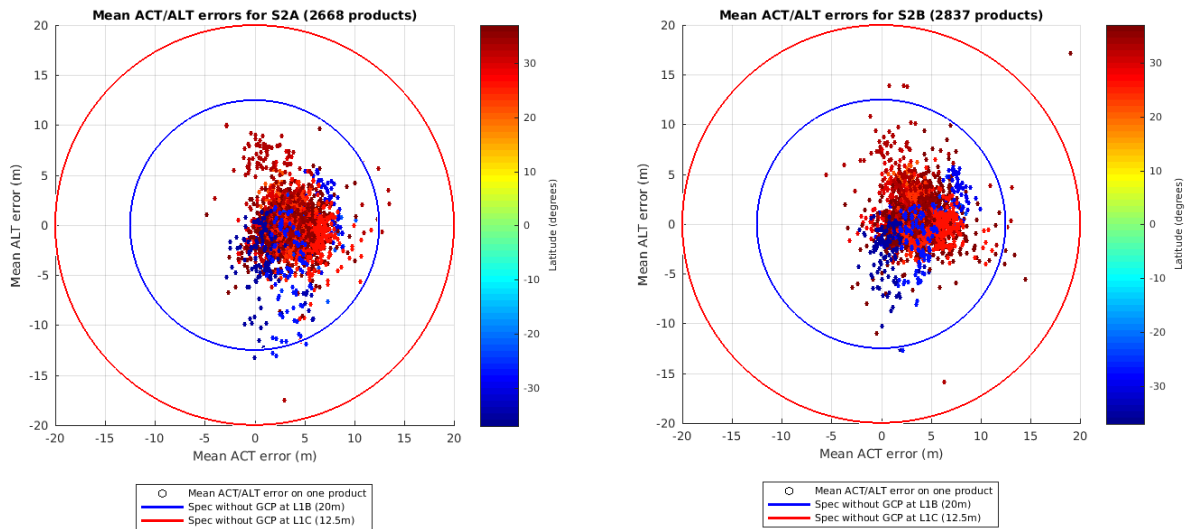


Figure 8: Absolute geolocation performance for refined products.
Left: S2A, Right: S2B (01.2022 – 12.2023)

4.2.6 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). A site in Kazakhstan near Kyzylorda (tile 41TNK) meets the criteria and provides the opportunity to monitor the multi-spectral registration throughout the year (Figure 9). 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. The band couples B05/B11 and B05/B12 are more critical because the spectral bands are on different focal planes (VNIR and SWIR). For S2B, a recalibration of the alignment has been performed in May 2023. For both satellites, a small residual alignment of less than 0.1 pixel in the along-track direction can be observed but is not considered critical.



Figure 9: Location and illustration of the Kyzylorda site (Tile 41TNK) 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 20/10/2023 (top) and S2B on 01/11/2023 (bottom).

Sentinel-2A

	B01	B03	B04	B06	B07	B08	B8A	B09	B11	B12
B02		0.17	0.18			0.25				
B05				0.08	0.11		0.13		0.29	0.31
B02, B08	0.10							0.11		

Sentinel-2B

	B01	B03	B04	B06	B07	B08	B8A	B09	B11	B12
B02		0.12	0.18			0.28				
B05				0.07	0.08		0.12		0.30	0.33
B02, B08	0.10							0.09		

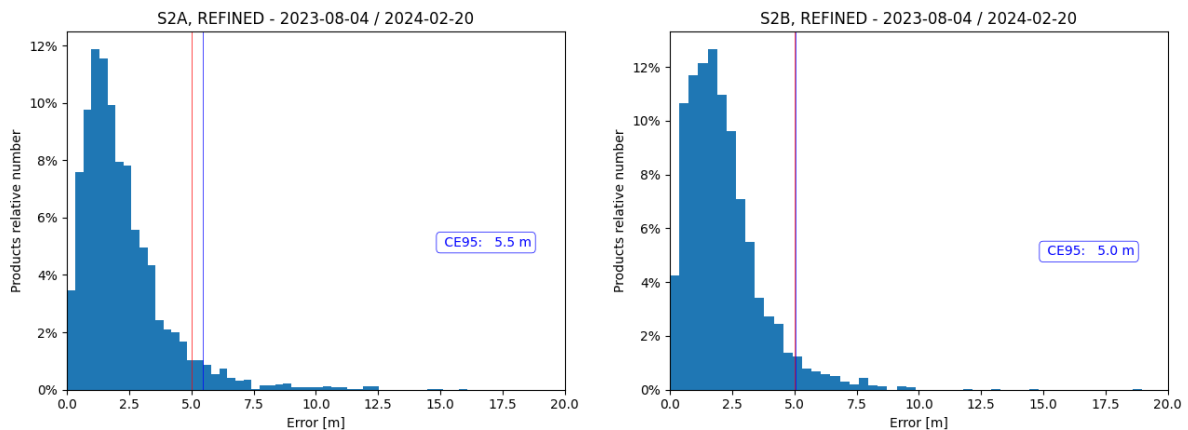
4.2.7 Multi-Temporal Registration

4.2.7.1 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).

4.2.7.2 Refined products

Figure 10 below shows the histograms of the co-registration for pairs of S2A and S2B products. The performance meets the requirements for both S2A and S2B with a mean circular error around 5 m at 95%.



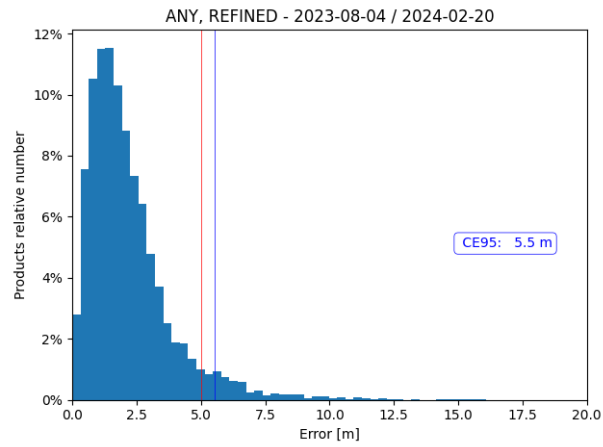


Figure 10: Multi-temporal 2D co-registration errors for refined S2A (upper left) and S2B pairs (upper right), and all pairs (bottom). The 95.45% performance is around 5 m.

4.2.7.3 All products

The multi-temporal performance for all products, whether refined or unrefined, is presented in the following figure, indicating a performance level of 7.9 m.

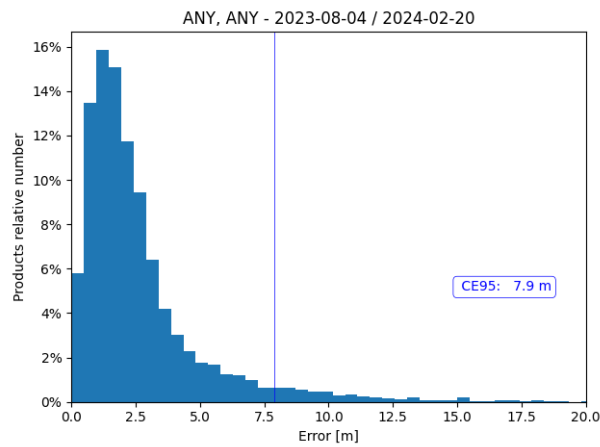


Figure 11: Histogram of the multi-temporal performance for all products (refined and unrefined).

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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 12 and Figure 13 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).

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

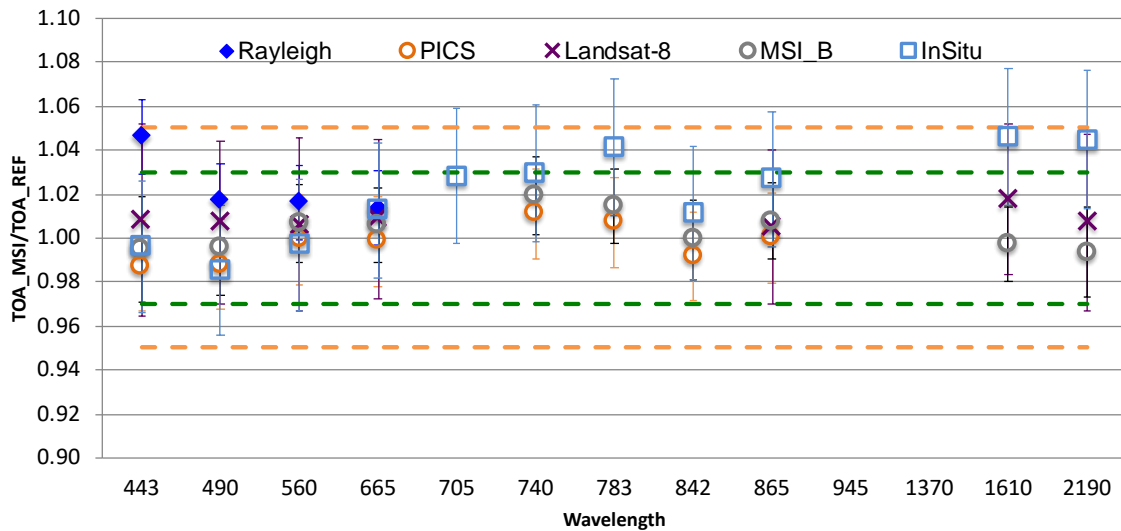
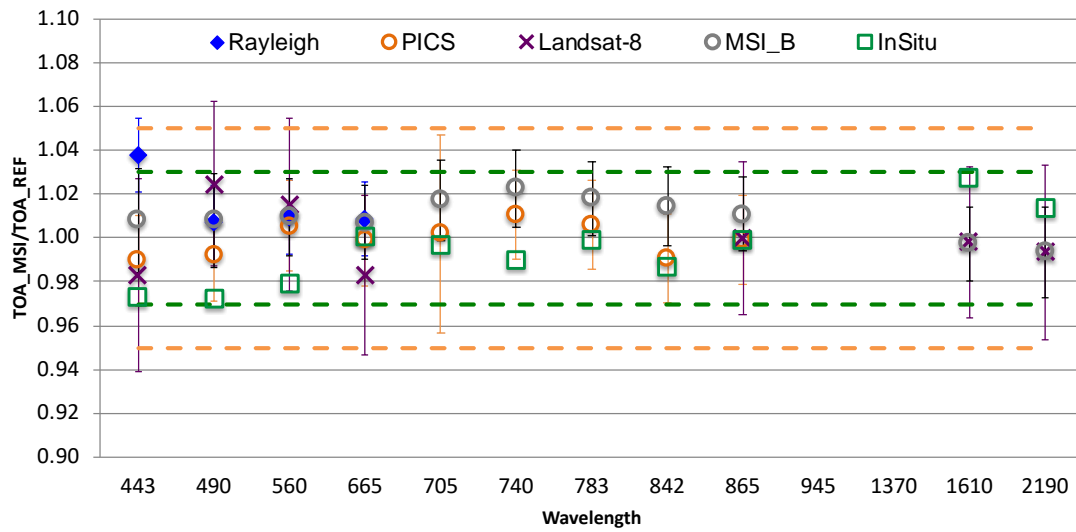


Figure 12: Comparison of radiometric accuracy for all spectral bands (except B09 and B10): ratio of S2A measurement on reference (top) pre-radiometric harmonization between Sentinel-2A and Sentinel-2B in January 2022, (bottom) post-radiometric harmonization up to 12/2023. Error bars indicate the method uncertainty.

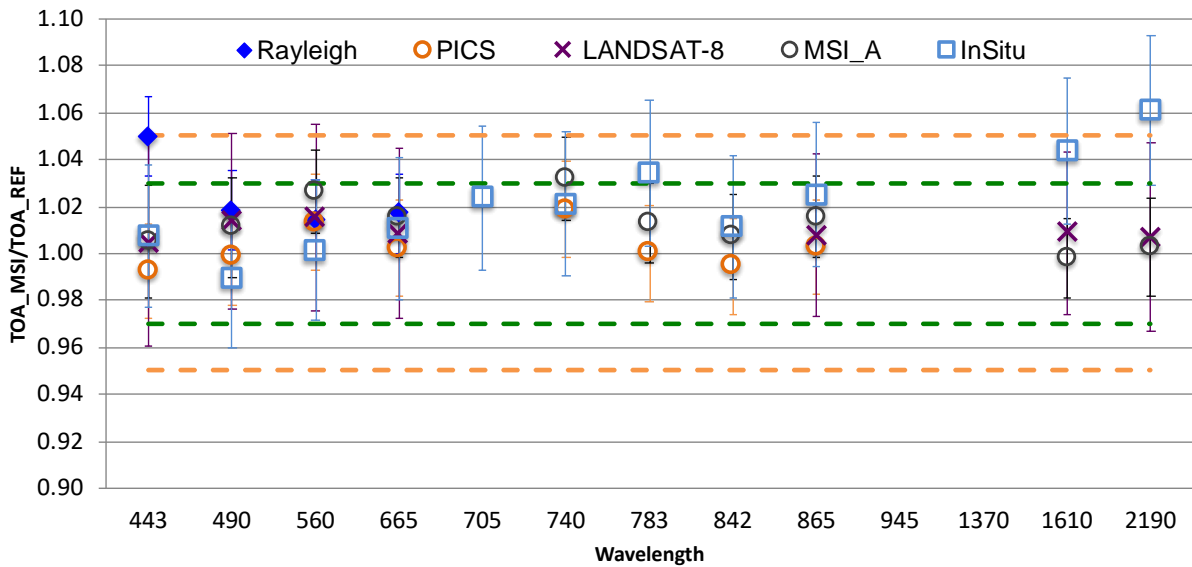
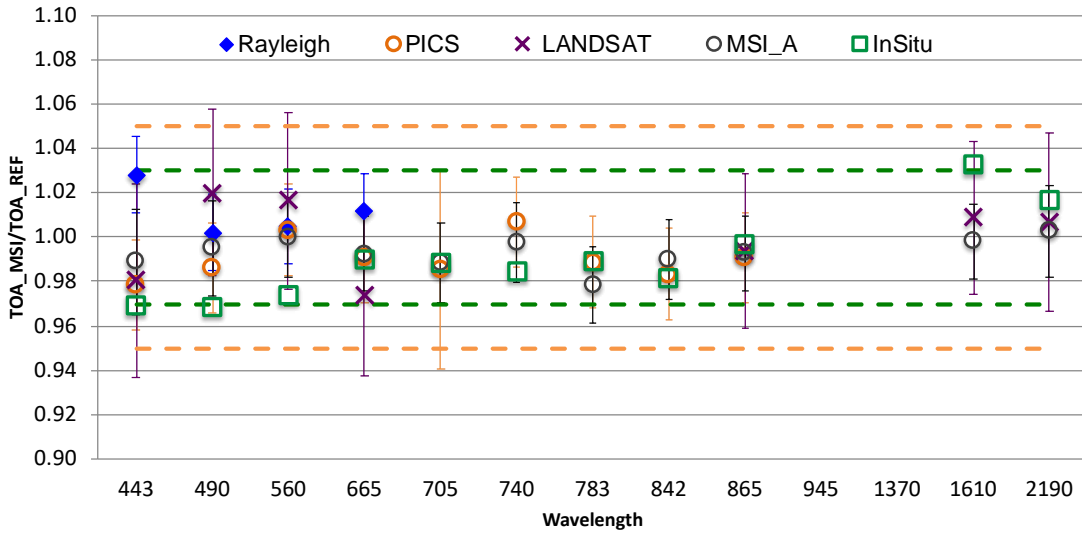


Figure 13: Comparison of radiometric accuracy for all spectral bands (except B09 & B10): ratio of S2B measurement on reference (top) pre-radiometric harmonization between Sentinel-2A and Sentinel-2B in January 2022, (bottom) post-radiometric harmonization up to 12/2023. Error bars indicate the method uncertainty.

Table 4-3 presents the best estimate of the ratio (gain coefficient) and standard deviations retrieved over the period January 2022 up to December 2023 over the six CEOS-PICS sites, four RadCalNet sites and six Ocean sites. We observe that the gains are within $\pm 3\%$ 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 - December 2023

Sensor	Wavelength (nm)	S2A		S2B	
		Gain Coefficient	Standard Deviation	Gain Coefficient	Standard Deviation
B01	443	1.007	0.023	1.012	0.022
B02	490	0.999	0.013	1.006	0.012
B03	560	1.005	0.007	1.014	0.009
B04	665	1.008	0.006	1.011	0.006
B05	705	N/A	N/A	N/A	N/A
B06	740	1.020	0.009	1.024	0.007
B07	783	1.021	0.018	1.016	0.017
B08	842	1.001	0.010	1.004	0.009
B8A	865	1.010	0.012	1.013	0.010

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.

The results for the month of February 2024 (Figure 14) are within the 1% range and stable compared to the last analysed months for the VNIR bands.

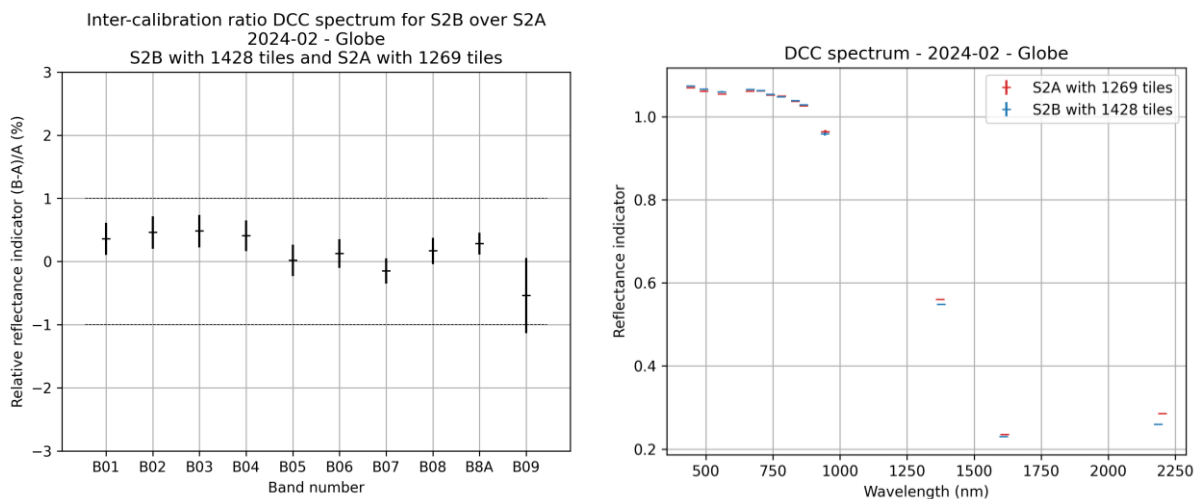


Figure 14 : DCC inter-calibration ratio between S2A and S2B as a function of the band number (left) ;

DCC reflectance indicator for S2A and S2B as a function of the wavelength (right) assessed based on acquisitions from February 2024, on the globe. 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 2023.

Table 4-4: Estimated SNR performance for S2A and S2B at reference radiance based on diffuser acquisitions. Average value over the year 2023 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/m ² /sr/μm]	129	128	128	108	74.5	68	67	103	52.5	9	6	4	1.7
S2A													
Mean SNR@Lref	1366	206	235	219	243	212	220	213	155	216	383	156	165
Max deviation	0.8%	0.3%	0.4%	0.3%	0.3%	0.3%	0.6%	0.5%	0.4%	0.6%	0.7%	0.6%	0.4%
S2B													
Mean SNR@Lref	1326	208	236	225	242	217	226	225	166	231	394	164	169
Max deviation	1.5%	0.4%	0.3%	0.3%	0.4%	0.5%	0.7%	0.2%	0.4%	1.6%	0.9%	1.4%	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.

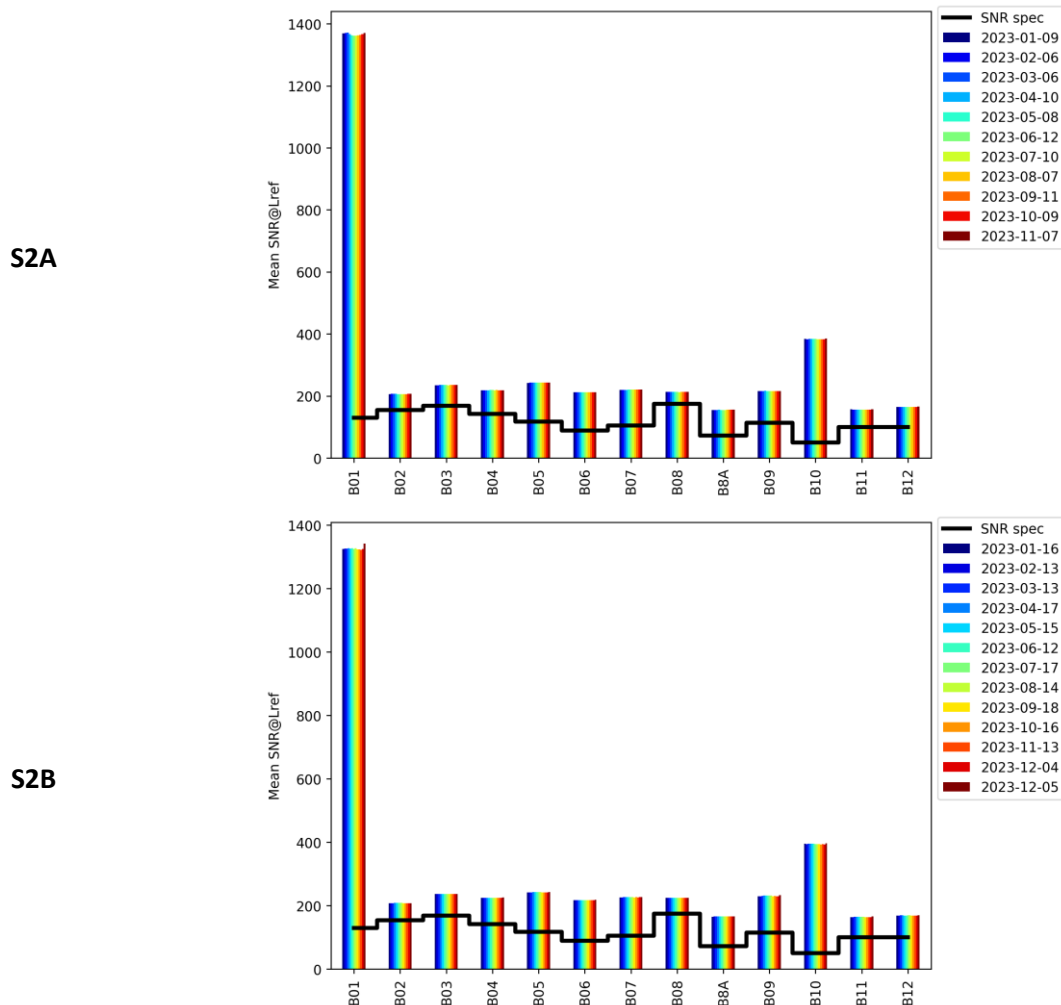
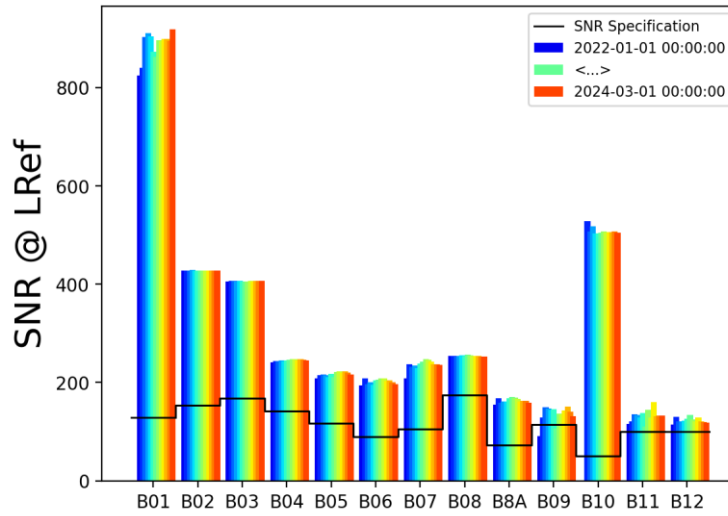


Figure 15: Evolution of the SNR performances based on diffuser acquisitions for S2A from 08/05/2023 to 09/10/2023 (top) and S2B from 15/05/2023 to 16/10/2023 (bottom)

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 Algeria, 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

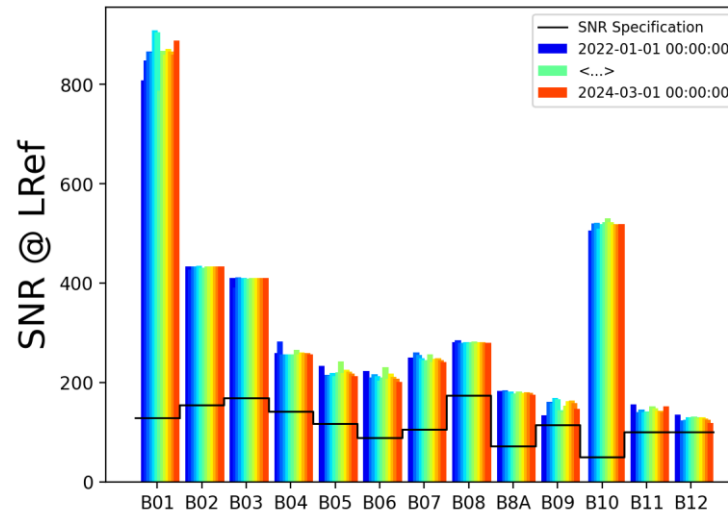


Figure 16 : Evolution of the SNR performances based on homogeneous natural acquisitions for S2A (top) and S2B (bottom) from 01/02/2022 to 31/02/2024

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

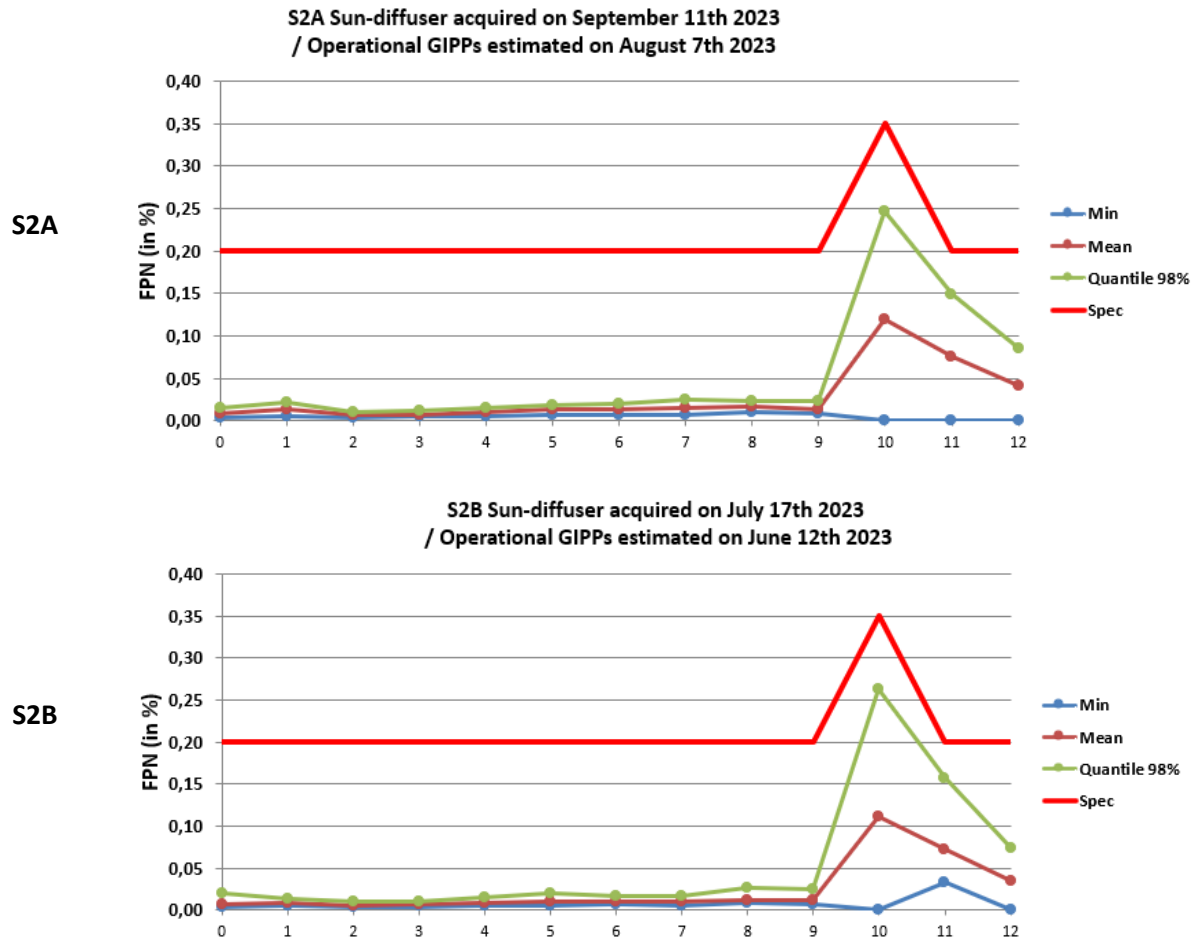


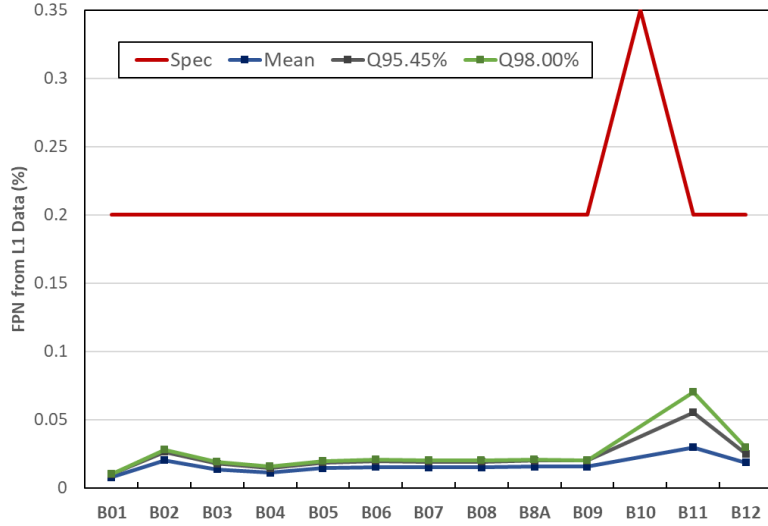
Figure 17: Fixed Pattern Noise (residual error after equalization) measured on diffuser images for S2A (top) and S2B (bottom). Blue curve: min FPN, marron: mean, green: 98 percentile, red: specified value.

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 18 shows the average values obtained using products acquired in January 2024 for the different spectral bands.

S2A

FPN vs Band Number (S2A)



S2B

FPN vs Band Number (S2B)

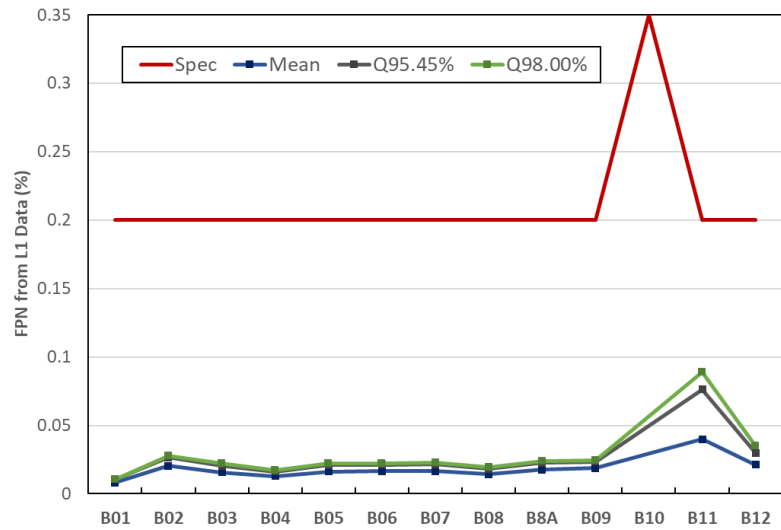


Figure 18 : Fixed Pattern Noise (residual error after equalization) measured on homogeneous natural images for S2A (left) and S2B (right) for January 2024.

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 in ACT for S2A: 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.

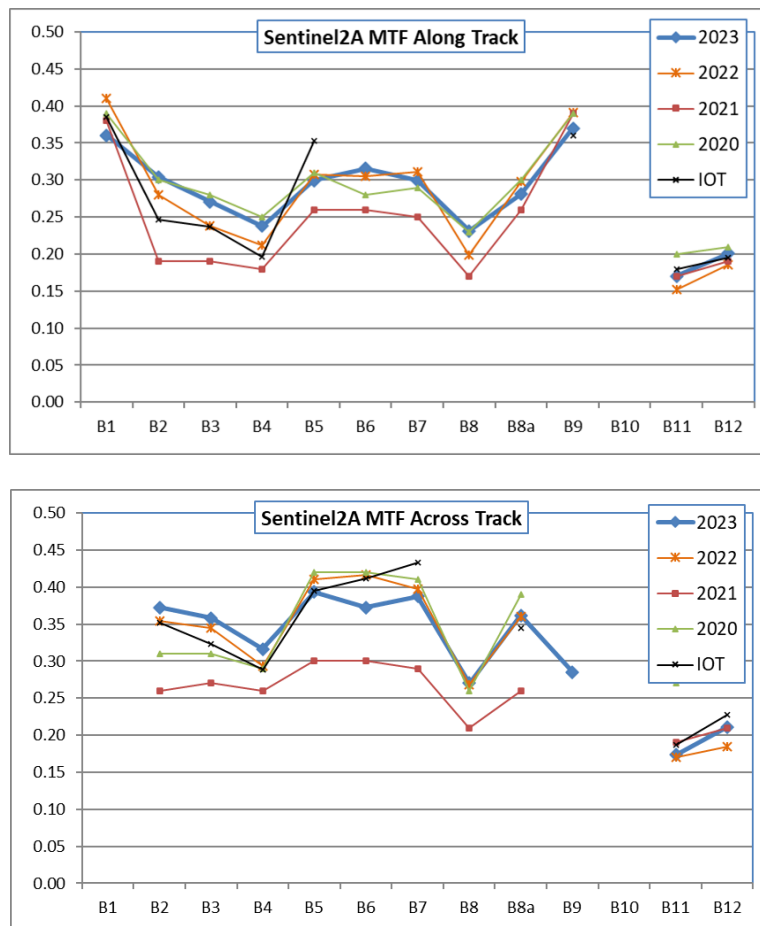


Figure 19 : MTF performance assessments for S2A (along and across track) performed using products from last 4 years and compared to IOT measurements.

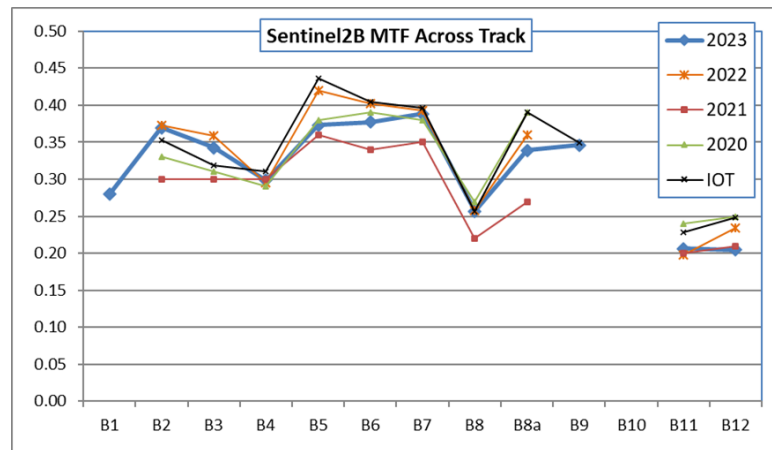
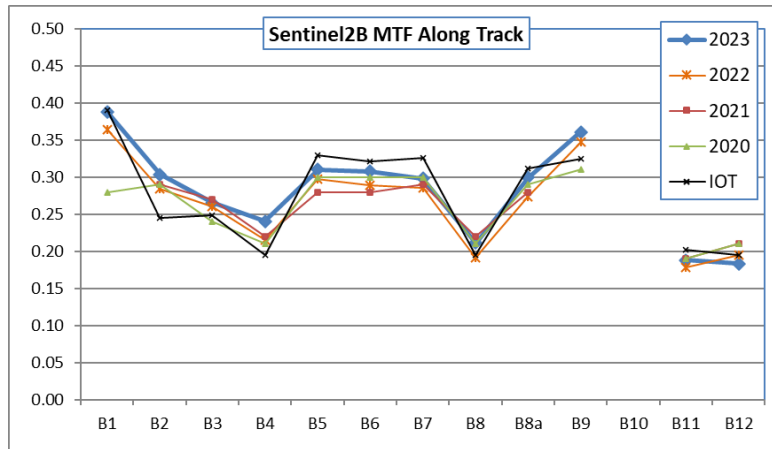


Figure 20 : MTF performance assessments for S2B (along and across track) performed using products from last 4 years and compared to IOT measurements.

The following table gives the measured values.

Table 4-5: S2A and S2B performances assessments using products from 2023.

2023 MTF	B1	B2	B3	B4	B5	B6	B7	B8	B8a	B9	B10	B11	B12
S2A ALT	0.36	0.30	0.27	0.24	0.30	0.32	0.30	0.23	0.28	0.37		0.17	0.20
S2A ACT		0.37	0.36	0.32	0.39	0.37	0.39	0.27	0.36	0.29		0.17	0.21
S2B ALT	0.39	0.3	0.27	0.24	0.31	0.31	0.3	0.21	0.3	0.36		0.19	0.18
S2B ACT	0.28	0.37	0.34	0.30	0.37	0.38	0.39	0.26	0.34	0.35		0.21	0.20

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	Observations
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 Dust deposit

Following the Sentinel-2B radiometric calibration from the Sun acquisition on October 16th, an unusual increase of the equalization coefficients by about 1.1%, for pixels number 459 to 491, of the band B05, detector 7 was observed.

A wide strip is clearly noticeable (see Figure 21) on a desert image acquired on October 16th at 06:31 UTC. Previous experience has enabled to link this phenomenon to a dust deposit on the detector. The updated equalisation coefficients correct this phenomenon.

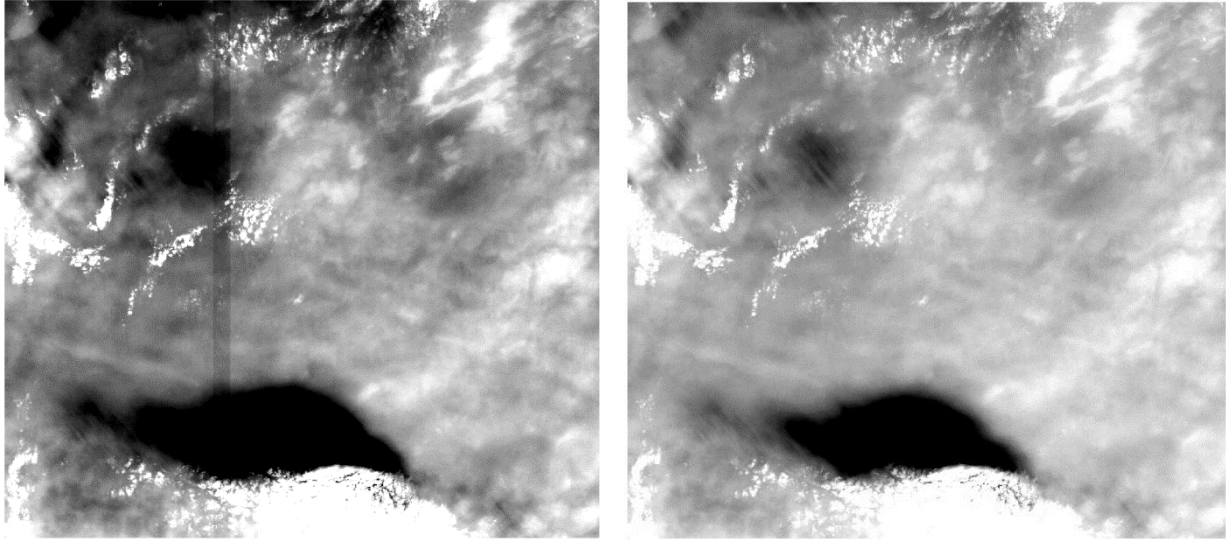


Figure 21: Sentinel-2B Level-1B acquisition on 2023-10-16 at T06:31:37 for detector D07 and band B05. On the left, the image is equalized with the R2EQOG calibration files from September while on the right side, the image is equalized with the updated R2EQOG calibration files from October.

The update of the R2EQOG calibration files has been active in operation since 2023-10-20T00:30:00, from the orbit 34577. Analysis of older images highlighted that the wide strip on B05 D07 might be visible on products acquired between October 6th and October 20th 2023 at 00:30 UTC.

5.3 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.

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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://sentiwiki.copernicus.eu/web/s2-products#S2Products-L1CproductFeatures> 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 [Sentinel 2 Annual Performance Report](#) covering the year 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, or which have affected the 2023 production, or which have been spotted in 2023.

Table 7-1: L1C processing anomalies

	Baseline number	Previous PB	05.09	05.10
Anom. ID	Deployment date	-	06/12/2022	13/12/2023
	Anomaly title			
73	Inconsistent data loss report		Some products	
83	QUALIT_MSK not detecting all missing packets	A few products		
86	Footprint anomaly at antemeridian		Some products	
90	Corrupted detector footprint	A few products		
91	Empty preview image	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.

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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. The cause of this problem has been found by the processing chain maintainers, and a fix will be implemented.

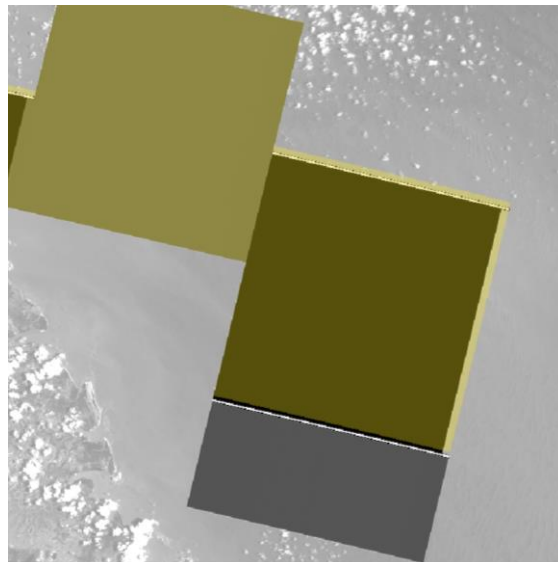


Figure 22: B02 of S2B_MSIL1C_20230110T073159_N0509_R049_T36KYC_20230110T092744 in background with band 3 (dedicated to lost packets) of the corresponding MSK_QUALIT superimposed in yellow. All the black pixels, due to data loss, in B02 are not flagged in the quality mask.

7.1.4 Footprint anomaly at antemeridian (#86)

The footprint of S2A and S2B products generated from datastrips crossing the antemeridian and acquired between 19/10/2023 and 31/10/2023 is not displayed correctly on [Copernicus Data Space Ecosystem](https://cdse.copernicus.eu) (CDSE). The issue has been solved and the impacted products are now displayed correctly.

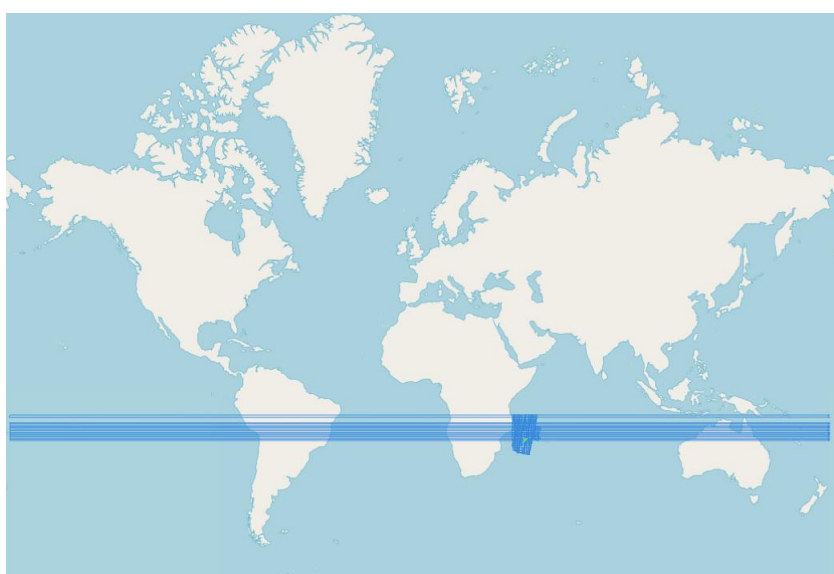


Figure 23 : Footprint of S2 tiles crossing the antemeridian were not displayed correctly

7.1.5 Corrupted detector footprint (#90)

Due to a processing issue, some tiles of two datastrips

- ❖ S2B_OPER_MSI_L1C_DS_SGS__20170910T170015_S20170910T113505_N02.05, and
- ❖ S2A_OPER_MSI_L1C_DS_MPS__20170420T194923_S20170403T104019_N02.04

have a corrupted detector footprint mask. The impacted products are still in the archive and will not be reprocessed as the corresponding Copernicus Sentinel-2 Collection-1 products are fine and will be disseminated to the users soon.

7.1.6 Empty preview image (#91)

Due to a processing issue, some tiles of the datastrip S2A_OPER_MSI_L1C_DS_MPS__20161101T124351_S20161101T085223_N02.04 have an empty preview image. The impacted products are still in the archive and will not be reprocessed as the corresponding Copernicus Sentinel-2 Collection-1 products are fine and will be disseminated to the users soon.

7.2 Instrument anomalies

7.2.1 Introduction

The table below provides the status of anomalies since the beginning of 2023, and 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
85	Geolocation error after collision avoidance manoeuvre	Major	S2A	Orbit 42831	Removed
87	Geolocation error after collision avoidance manoeuvre	Major	S2A	One datatake from orbit 43812	Removed
88	Missing L0 granules causing bad processing	Major	S2B	One datastrip from orbit 34954	Removed
89	Missing L0 granules causing bad processing	Major	S2A	Three datastrips from orbits 9043, 15049 and 16735	Removed

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Anomaly ID	Anomaly title	Criticality	Unit	Affected products	Product status
92	Geolocation error after collision avoidance manoeuvre	Major	S2A	One datatake from orbit 45364	Removed

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 over the ocean, they have been kept into the archive.

7.2.3 Geolocation error after collision avoidance manoeuvre (#85)

Products from datastrips DS_2APS_20230904T082658_S20230904T062632, DS_2APS_20230904T083522_S20230904T063121 and DS_2APS_20230904T090309_S20230904T063906, acquired shortly after a collision avoidance manoeuvre on 04/09/2023 are impacted by a geolocation error higher than 30 m. L1C and L2A products have been removed from the archive.

7.2.4 Geolocation error after collision avoidance manoeuvre (#87)

Following a collision avoidance manoeuvre on 2023-11-11, one datatake (GS2A_20231111T210921_043812_N05.09) suffers from a high geolocation error. Corresponding L1C and L2A products have been removed from the archive.

7.2.5 Missing L0 granules causing bad processing (#88)

Because of snow on radome at Svalbard station, several L0 granules were lost, causing an issue in the processing of one datastrip. The impacted L1C and L2A products have been removed from the archive.

7.2.6 Missing L0 granules causing bad processing (#89)

Missing L0 granules have caused an issue in the processing of three datastrips:

- ❖ S2A_OPER_MSI_L1C_DS_MPS__20170316T132839_S20170316T112104_N02.04
- ❖ S2A_OPER_MSI_L1C_DS_MPS__20180510T133456_S20180510T112250_N02.06
- ❖ S2A_OPER_MSI_L1C_DS_SGS__20180905T111600_S20180905T085814_N02.06

The impacted L1C and L2A products have been removed from the archive.

7.2.7 Geolocation error after collision avoidance manoeuvre (#92)

Following a collision avoidance manoeuvre on 2024-02-28, two datastrips suffer from a high geolocation error. Corresponding products have been removed from the archive.

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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 on [CDSE](#) (Collection-1 flag).

Collection-1 production has started with December 2021 products and goes in reverse chronological order of sensing time. In February 2024, Collection-1 products from September 2018 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.

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

8.3 Reprocessed products

Two situations can lead to a recovery reprocessing and update of the CDSE 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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