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S2 MPC

L1C Data Quality Report

Ref. S2-PDGS-MPC-DQR

Authors Table

	Name	Company	Responsibility	Date	Signature
Written by	S. Clerc & MPC Team	ARGANS	Technical Manager	05/03/2019	
Verified by	O. Devignot	CS	Quality Manager	05/03/2019	
Approved by	L. Pessiot	CS	Service Manager	05/03/2019	

Table of contents

1. Introduction

1.1 Scope of the document

This document provides the data quality status of Copernicus Sentinel-2 mission L1C products.

It documents:

- ✓ the measured product performance vs. specifications (Section 2),
- ✓ processing chain improvements associated to each Processing Baseline (Section 3),
- ✓ an overview on L1C product evolution (Section 3.3),
- ✓ observed anomalies and known issues (Section 4),
- ✓ the list of defective pixels (Section 5).

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

- ✓ Minor evolution of the processing chain on 21/02/2019 (section 3.3.2)
- ✓ New anomaly (#49): misregistration of some S2A products (section 4.39)

2. Measured Product Performances

2.1 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 S2A and S2B, except for the geolocation performance which is not yet stabilized for S2B.

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

Requirement	Description	Measured performance
Absolute geolocation (without ground control points)	The geo-location uncertainty shall be better than 20 m at 2σ confidence level (without Ground Control Points).	< 11 m at 95.5% confidence (baseline 02.04)
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
Absolute radiometric uncertainty	The absolute radiometric uncertainty shall be better than 5 % (goal 3%).	B1 to B12, excl. B10: < 5%±2%
SNR	The Signal-to-Noise Ratio (SNR) shall be higher than specified values (see Table 2-5 in this document)	All bands compliant with > 27% margin

Measured performances are detailed in the following sections.

2.2 Geometric Performance

2.2.1 Geometric Calibration Status

2.2.1.1 S2A

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 10/01/2019.

Another update of the geometric calibration is planned in the coming weeks to avoid reoccurrence of anomaly #18 on S2A. The latter anomaly originated by an imperfect alignment of the back-up Star Tracker (STR3).

2.2.1.2 S2B

Due to an on-board anomaly (#48) the geolocation performance was degraded for orbit 8366.

The geometric calibration of S2B has been updated on 30/01/2019.

2.2.2 Geometric Refinement and Global Reference Image (GRI)

The L1C processing chain implements a geometric refinement step which aims at improving the repetitiveness of the image geolocation, in order to reach the multi-temporal geolocation requirement (< 0.3 pixel at 95%). The refinement step will be activated upon completion of the GRI and the final validation of the refining algorithm.

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. The GRI is an internal database used only for processing and not for dissemination. In particular, the GRI is not meant to be a cloud-free mosaic of the globe. Once the geometric refinement is activated, all images will have essentially the same geolocation accuracy.

The elaboration of the GRI is currently on-going. Continental sub-blocks are first built, processed and validated individually. In a second step, the sub-blocks (Europe, Africa and Asia on one hand, North and South America on the other hand) will be consolidated to improve the consistency at the boundary of the sub-blocks. The elaboration status is presented in the table below:

GRI sub-block	Status
Europe	Ready and Validated
North-Africa/Middle-East	Ready and Validated
Australia	Ready and Validated
South-Africa	Ready and Validated
North-America	Ready and Validated
South-America	Ready and Validated
Asia	Ready and Validated
Islands	In progress
Canada – Greenland	In progress

2.2.3 Absolute Geolocation

Absolute geolocation is constantly monitored for S2A and S2B. The long-term performance is close to 11 m at 95% for both satellites.

At the end of December 2018, a degradation of the geolocation performance was observed for both S2A and S2B. This has in particular impacted the geometric consistency between S2A and S2B images. After updates of the geometric calibration for both S2A and S2B in January 2019, the geometric performance is nominal again.

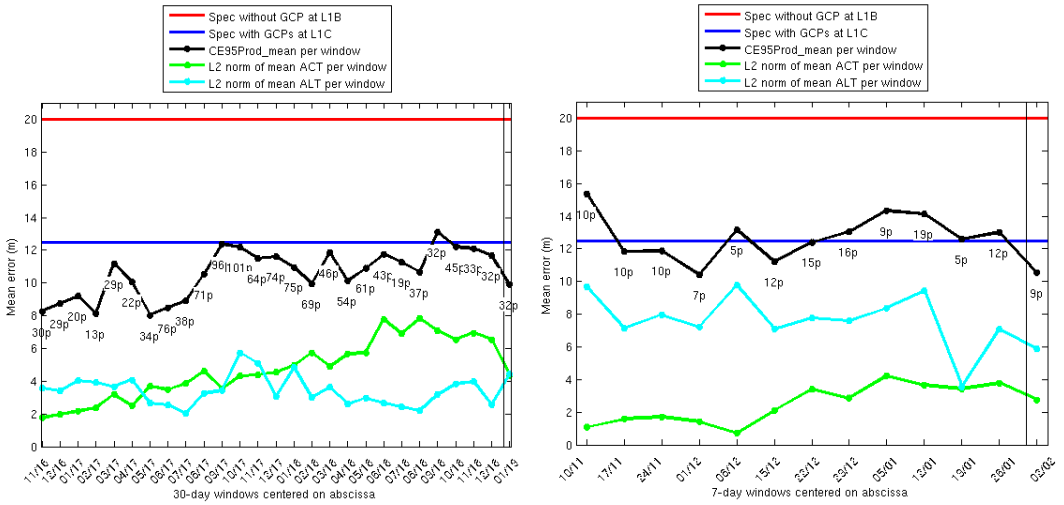

Figure 1: Geolocation performance for S2A (left) and S2B (right). The performance is computed over a sliding window of 30 days (S2A, left) or 7 days (S2B, right). Number of products used in the sliding window indicated for each point. (ACT= across track, ALT= along track). A vertical line indicates a geometric calibration event.

Note that the geolocation performance has a latitude-dependent component. This effect is particularly visible on the along-track component, and more pronounced for S2B than S2A. Images are shifted of 5 m Southward (approximately) in the Northern latitudes, to 5 m Northward in the Southern latitudes. This will be corrected with the introduction of the geometric refinement.

2.2.4 Multi-Spectral Registration

The co-registration requirement (< 0.3 pixel at 99.7% confidence) is met for all measured band couples. The performance for S2B has been improved with respect to S2A thanks to a better control of on-board vibrations.

S2A			
Bsec/Bref	**B04**	**B05**	**B11**
B02	0.168		
B03	0.209		
B06		0.139	
B07		0.152	
B08	0.165		
B8A		0.157	
B11		0.185	
B12		0.166	0.203

S2B			
Bsec/Bref	**B04**	**B05**	**B11**
B02	0.130		
B03	0.115		
B06		0.071	
B07		0.097	
B08	0.181		
B8A		0.176	
B09			
B11		0.163	
B12		0.149	0.150

Table 2-2: Multi-Spectral co-registration performance (per band couple and detector number) for S2A (top) and S2B (bottom). Requirement is 0.3 pixel.

2.2.5 Multi-Temporal Registration

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 value for all tiles measured on the reference band (B04). According to this methodology, the current performance is around 12 m. Figure 2 shows the histogram of the distribution of multi-temporal registration errors for S2A and S2B respectively. Table 3 present the observed statistical distribution of the observed multi-temporal registration performance for S2A and S2B products (separately and with respect to each other).

It is recalled that the objective is to meet the required 3 m performance (95.5% confidence level) with the activation of the geometric refinement using the GRI.

After the geometric calibration operations of January 2019, the S2A vs S2B multi-temporal registration is back to nominal values after a significant degradation in December 2018.

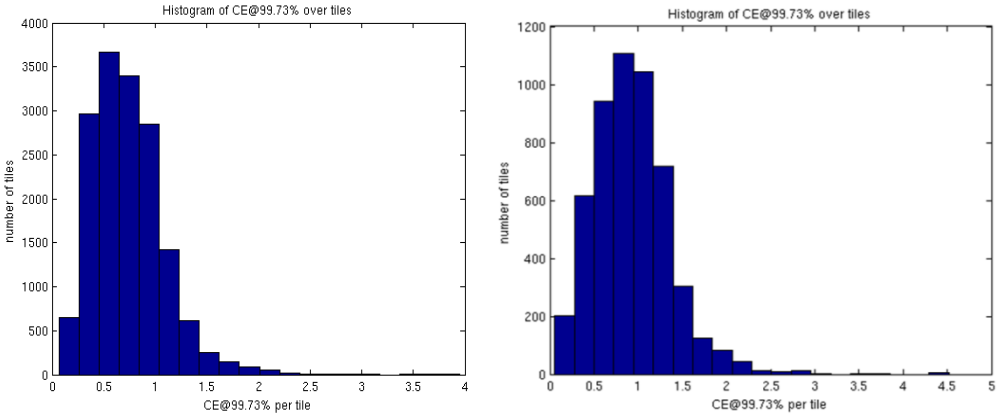

**Figure 2: Histogram of the multi-temporal performance for S2A (left) and S2B (right, different scale). The 3 m requirement will be applicable only after activation of the geometrical refinement.
The current performance is 11 m (S2A) and 13 m (S2B) at 95% confidence.**

Co-registration error	0<X<0.5 pixels	0.5<X<1 pixels	1<X<1.5 pixels	>1.5 pixels
S2A % of products	60%	32%	7%	1%
S2B % of products	42%	44%	13%	1%
S2A/A2B % of products*	58%	22%	18%	2%

Table 2-3: Multi-temporal performance statistics for Sentinel 2 constellation. *The performance for the S2A versus S2B is computed on a small sample.

2.3 Radiometric Performance

2.3.1 Radiometric Calibration Status

2.3.1.1 Sun-diffuser model improvement

Product baseline 02.06 has been deployed on 23/10/2017. With this new baseline, the Sun-diffuser model used for calibration has been improved to reduce seasonal effects. The update did not result in a discrepancy in the time series of the radiometry (impact on calibration lower than 0.2% at this time of year, see DQR issue 22 for details).

2.3.1.2 S2A

Radiometric calibrations are performed routinely at the beginning of each month. Decontamination operations are scheduled every 6 months (January and July).

S2A underwent decontamination on 17/09/2018. The radiometric calibration has been subsequently updated on 20/09/2018. In the interval, a modification of the radiometric response can be expected (1% typically on SWIR bands).

2.3.1.3 S2B

Radiometric calibration is currently performed once per month.

The S2B MSI underwent decontamination on November 12th, 2018. The calibration gains were subsequently adjusted on November 15th. In the interval, the radiometric accuracy of SWIR bands may be affected.

2.3.2 Radiometric Uncertainty

Radiometric validation has been 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 (Landsat-8 OLI (Collection-1 over Libya-4) and S2A for S2B case).

The results are presented in the figures below for S2A and S2B for all methods. Results are provided for all bands except B09 & B10. All results are compatible with the 5% (3%) radiometric accuracy requirement (Goal) respectively.

A small systematic difference in radiometry is observed between S2A and S2B:

S2A is brighter (measured reflectance higher) than S2B by about 1%. This difference is currently under study.

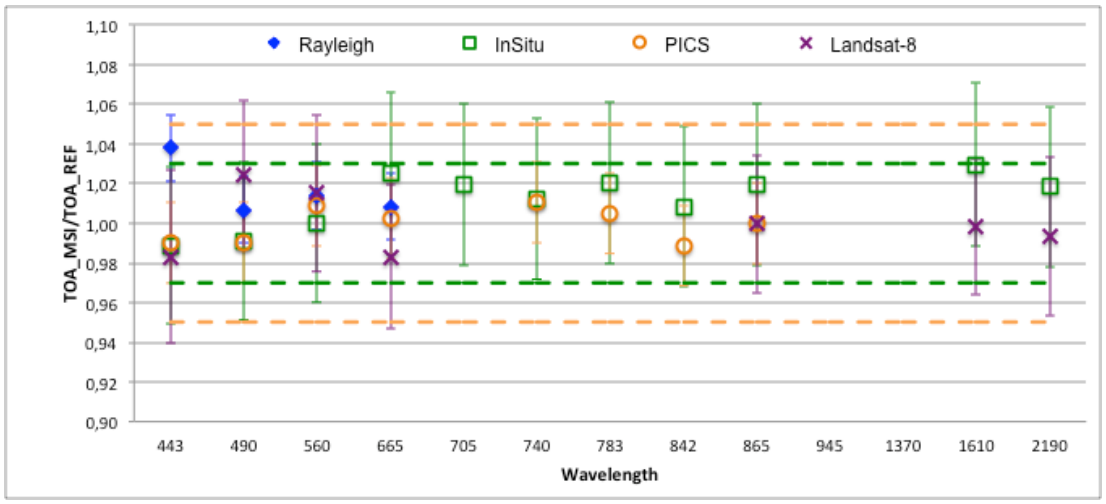

Figure 3: Comparison of radiometric accuracy for all spectral bands (except B10 and B09): ratio of S2A measurement on reference. Error bars indicate the method uncertainty.

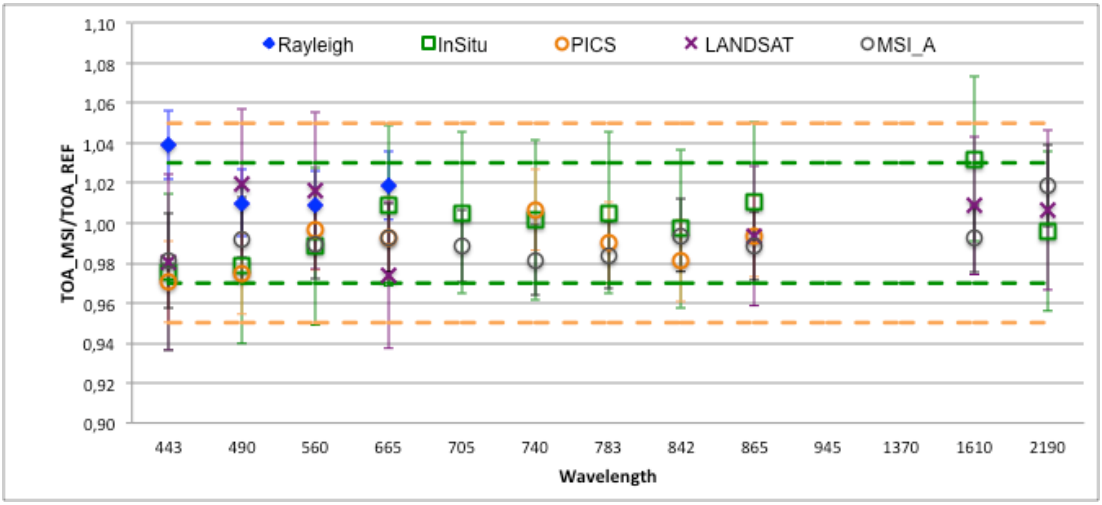

Figure 4: Comparison of radiometric accuracy for all spectral bands (except B09 & B10): ratio of S2B measurement on reference. Error bars indicate the method uncertainty.

Tabulated results for bands B01 to B12 (B09 & B10 excluded) presented below indicate the effectiveness and reliability of the on-board calibration method for both sensors S2A/MSI and S2B/MSI.

Table 2-4: Best estimate of S2A and S2B calibration gains from validation

Sensor		S2A		S2B	
	Wavelength (nm)	Gain Coefficient	Standard Deviation	Gain Coefficient	Standard Deviation
B01	443	1.000	0.026	0.989	0.028
B02	490	1.003	0.016	0.995	0.020
B03	560	1.010	0.007	1.000	0.012
B04	665	1.005	0.017	0.997	0.017
B05	705	1.020	N/A	0.997	0.012
B06	740	1.011	0.001	0.997	0.013
B07	783	1.013	0.011	0.993	0.011
B08	842	0.999	0.014	0.991	0.008
B8A	865	1.006	0.011	0.997	0.009
B11	1610	1.014	0.022	1.011	0.020
B12	2190	1.006	0.018	1.007	0.011

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), and no-trend is detectable yet for S2B.

2.3.3 Noise

The SNR for both S2A and S2B is exceeding requirements (worst-case >160 for band B8A). The table below provides the most recent estimates (August 2017 for S2A and September 2017 for S2B).

Table 2-5: Estimated SNR performance for S2A and S2Bat reference radiance.

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	1347	211	239	222	246	215	224	216	157	222	391	159	167
S2B	1371	213	242	230	248	223	232	230	169	239	396	166	172
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.

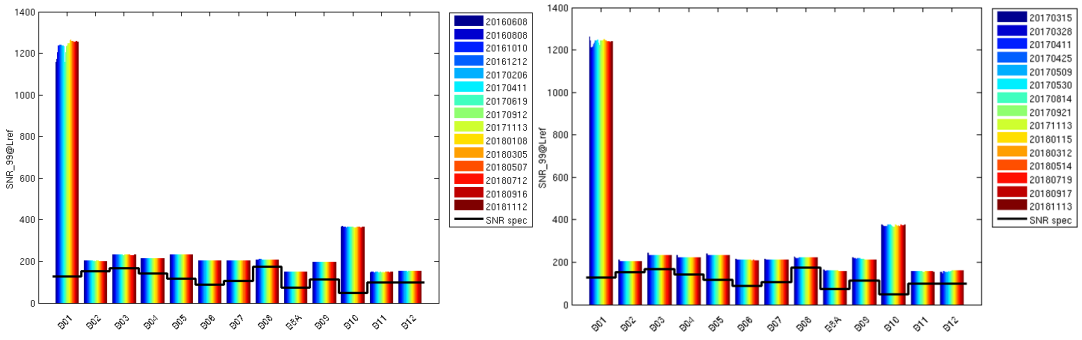

Figure 5: Evolution of the SNR performance or S2A since 08/06/2016 (left) and S2B since 15/03/2017 (right)

Another aspect of the image noise is the so-called Fixed Pattern Noise: this is the residual pixel radiometric error after equalization. The performance is better than the specification for all bands except for a few pixels on Bands B11 and B10.

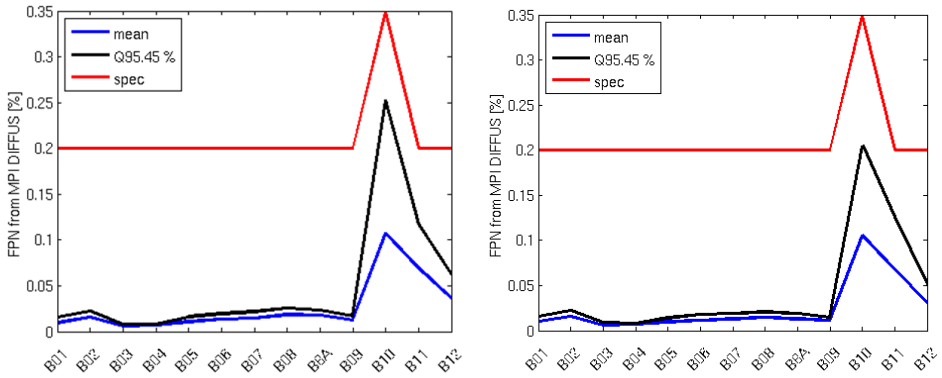

Figure 6: Fixed Pattern Noise (residual error after equalization) measured on diffuser images for S2A (left) and S2B (right). Blue curve: mean FPN, black: 95 percentile, red: specified value.

2.3.4 Modulation Transfer Function

The Modulation Transfer Function (MTF) has been estimated by analysing images with sharp edges for all bands (except B10 for which in-orbit assessment is difficult).

Globally the across track values measured in flight are lower than those expected from ground measurements. The MTF is above the maximum value requirement for B5, B6, B7 and B8A for the across track direction. For the along track direction, the requirement is generally met (marginally in some cases). Note that only the minimum value requirement has a direct impact on image quality. This requirement is satisfied for all bands.

Table 2-6: S2A MTF performance assessment.

Spectral Band	Measured ACT	Measured ALT	Requirement
B01	0.34±0.03	0.28±0.03	0.15 < MTF
B02	0.25±0.06	0.27±0.06	0.15 < MTF
B03	0.27±0.03	0.28±0.04	0.15 < MTF
B04	0.25±0.04	0.23±0.03	0.15 < MTF
B05	0.42±0.03	0.34±0.05	0.15 < MTF
B06	0.35±0.12	0.33±0.05	0.15 < MTF
B07	0.35±0.07	0.34±0.03	0.15 < MTF
B08	0.26±0.11	0.25±0.06	0.15 < MTF
B8A	0.36±0.06	0.31±0.04	0.15 < MTF
B09	0.25±0.10	0.27±0.03	0.15 < MTF
B11	0.20±0.04	0.24±0.04	0.15 < MTF
B12	0.24±0.07	0.22±0.06	0.15 < MTF

Table 2-7: S2B MTF performance assessment.

Spectral Band	Measured ACT	Measured ALT	Requirement
B01	0.35±0.02	0.30±0.02	0.15 < MTF
B02	0.31±0.13	0.27±0.06	0.15 < MTF
B03	0.33±0.11	0.23±0.06	0.15 < MTF
B04	0.31±0.10	0.22±0.05	0.15 < MTF
B05	0.39±0.03	0.31±0.02	0.15 < MTF
B06	0.36±0.03	0.29±0.00	0.15 < MTF
B07	0.36±0.03	0.30±0.01	0.15 < MTF
B08	0.24±0.06	0.22±0.04	0.15 < MTF
B8A	0.33±0.03	0.29±0.01	0.15 < MTF
B09	0.36±0.02	0.30±0.02	0.15 < MTF
B11	0.21±0.02	0.17±0.00	0.15 < MTF
B12	0.25±0.01	0.23±0.01	0.15 < MTF

3. Processing Chain Status

3.1 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.

3.2 Status of Processing Baselines and Known Processing Anomalies

The table below summarizes recent evolutions of the evolutions of the processing baseline and the known processing anomalies affecting the production. The dates mentioned in the table refer to the product creation date.

Note that anomaly #37, which was duplicating #11, has been deleted.

Table 3-1: Summary of identified processing anomalies and associated processing baselines. Red: systematic anomaly. Orange: random anomaly affecting only a few products

Anomaly ID	Baseline number	02.01		02.02	02.03	02.04			02.05	02.06	02.07
	Deployment date	15/12/2015	31/03/2016	03/05/2016	09/06/2016	15/06/2016	03/08/2016	26/01/2017	27/04/2017	23/10/2017	06/11/2018
	Anomaly title										
4	Instrument Measurement Time metadata										
5	Pixels with 0 value										
7	Missing Physical Gains metadata										
12	Anomalous Pixels	At end of datastrips									
15	Strong Misregistration										
16	Stretched 60 m bands		Orbit S2A 4427								
19	Wrong footprint on antemeridiem										
23	Degraded AUX files										
24	Imprecise technical quality mask										
25	Geolocation error on orbit 7174						Orbit S2A 7174				
26	Incomplete manifest		Until 18/05/2017								

Anomaly ID	Baseline number	02.01		02.02	02.03	02.04			02.05	02.06	02.07
	Deployment date	15/12/2015	31/03/2016	03/05/2016	09/06/2016	15/06/2016	03/08/2016	26/01/2017	27/04/2017	23/10/2017	06/11/2018
	Anomaly title										
27	Incorrect footprint and missing metadata										
29	Incorrect cloud MTD							A few products			
30	Corrupted metadata							Orbit S2A 9095 Tile 50SQA 20/03/2017			
32	Missing viewing angles at ante-meridiem										
33	Missing files								A few products		
34	Missing ECMWF files								Sensing time near 9AM or 9PM		
35	Wrong quantification value								Orbit S2A 10724 to 10729		
36	Misregistration B09 and B10								Orbit S2A 11799		
37	Missing viewing angles	Some products									
38	'Null' Folder					A few products					
39	Incorrect S2A spectral response	Until January 15th 2018									
40	Incorrect file name									A few products	
41	Incorrect instrument temperature metadata										
42	Incorrect NODATA mask format									A few products	
44	Incorrect Cloud Cover percentage	Partially acquired tiles only									

Anomaly ID	Baseline number	02.01		02.02	02.03	02.04			02.05	02.06	02.07
	Deployment date	15/12/2015	31/03/2016	03/05/2016	09/06/2016	15/06/2016	03/08/2016	26/01/2017	27/04/2017	23/10/2017	06/11/2018
	Anomaly title										
45	Incorrect equalization									18/07/18 to 18/07/30	
46	Missing Corners									18/07/18 to 18/08/06	
47	S2A product processed as S2B									Orbit 10722	
49	Misregistration of some S2A products										A few products

3.3 Processing baseline status

3.3.1 Baseline 02.07

On 06/11/2018, a new Production Baseline (02.07) has been deployed. This version introduces several improvements and evolutions:

- ✓ **Accurate tile sensing date**. The L1C granule metadata "tile sensing time" is now computed accurately at tile level
- ✓ **Straightening of image boundaries**. Staircase patterns on image boundaries have been smoothed out.

Figure 7: Swath boundary with the current processing baseline 02.06 (Left) and new processing baseline 02.07 (Right). The coarse staircase-like boundary has been refined. More valid pixels are provided.

- ✓ **Accurate detector footprint mask**. The overlap area between detectors has been removed, which provides the exact location of the interface.

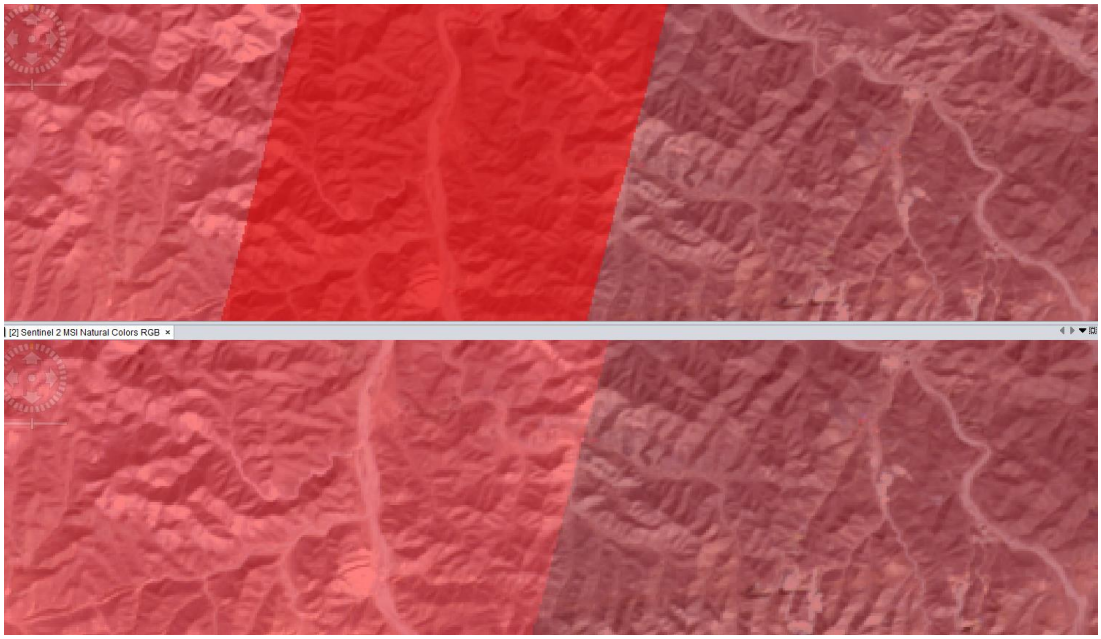

Figure 8: Detector footprints for the current processing baseline 02.06 (top) and new processing baseline 02.07 (bottom). The detector footprint do no longer include the overlap area.

- ✓ **Improved dark current processing**. This evolution removes the across-track noise that can be observed on some dark images (see paragraph 6.3 and figure below).

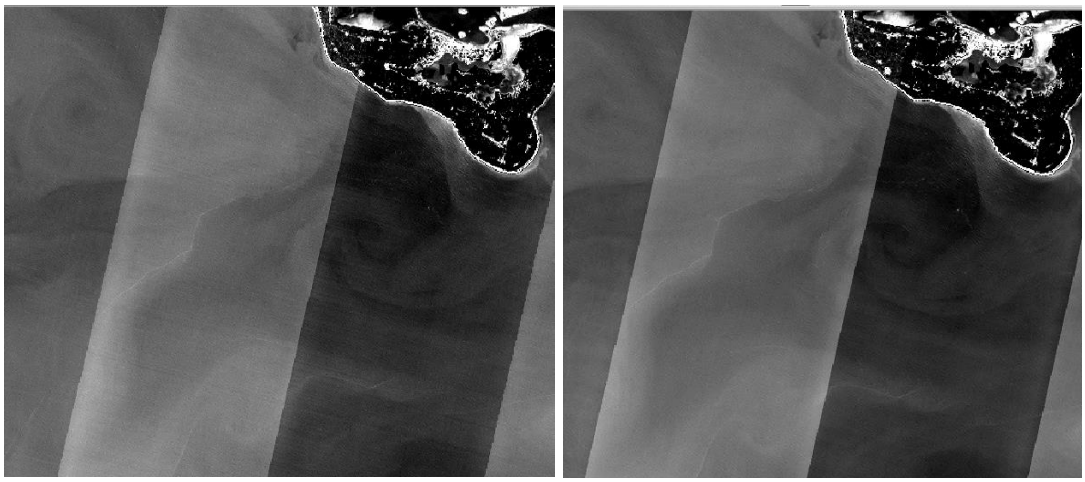

Figure 9: B01 image over sea with the current processing baseline 02.06 (Left) and the new processing baseline 02.07 (Right). Across-track lines due to correlated dark signal noise have been filtered.

Note that this evolution does not affect the product format. Products are still compliant with PSD v14.5.

Baseline 02.07 also corrects anomaly #44 affecting the cloud coverage percentage metadata.

3.3.2 Minor update of the processing chain

On 21/02/2019 a minor evolution of the processing chain has been implemented. It does not affect the format or quality of the L1C products and is not leading to a change of processing baseline.

4. Product Anomalies

4.1 Introduction

This section describes all known product anomalies. Each anomaly is tagged with a code "#N" allowing linking it to a given Processing Baseline through Table 3-1.

The table below provides the status of anomalies which are not related to processing and can therefore not be corrected through reprocessing. It complements Table 3-1 above.

On 26/03/2018, a large data loss occurred during downlink of orbit S2B 5499. Several products from this orbit over South America were strongly affected and it was decided to remove these products from the archive. Note all affected products are correctly flagged by quality masks and metadata.

Anomalies affecting obsolete products (baseline 02.00) are no longer described in this report.

Table 4-1: On-board Anomalies.

Anomaly ID	Anomaly title	Criticality	Unit	Affected products	Product status
9	Striping of SWIR bands	Minor	S2A	A few orbits, not systematic	Available
10	Striping of Visible bands	Major	S2A	A few orbits, not systematic	Removed from archive
13	B10 saturation	Minor	S2A	Products with high reflectances	Available
14	Geolocation error	Major	S2A	Orbits 3218, 4080 and 4081	Removed from archive
17	Misaligned detectors on band 1	Minor	S2A	A few orbits impacted (beginning of the datastrip)	Available
18	Geolocation Error	Major	S2A	Orbits 6003 to 6011 Orbits 16381 to 16392	Removed from archive
43	Geolocation error	Major	S2A	Orbits 1296 to 1304	Removed from archive
48	Geolocation error following orbit control manoeuvre	Minor	S2AB	Orbit 8366	Available

4.2 Instrument Measurement Time metadata (#4)

Within the satellite ancillary metadata, the value of Instrument Measurement Time (IMT) is not represented correctly due to a formatting error. This anomaly is corrected with product baseline 02.05.

4.3 Missing Physical Gains metadata (#7)

Band 12 is missing in the "physical gains" metadata of the user product. However the full list of physical gains is present in the metadata at granule level. This error was corrected early August 2016 and recent products are not anymore affected.

4.4 Striping of SWIR Bands (#9)

This anomaly is characterized by along-track stripes on some detectors of SWIR band images (see image below). Other detectors are also misaligned (along-track shift).

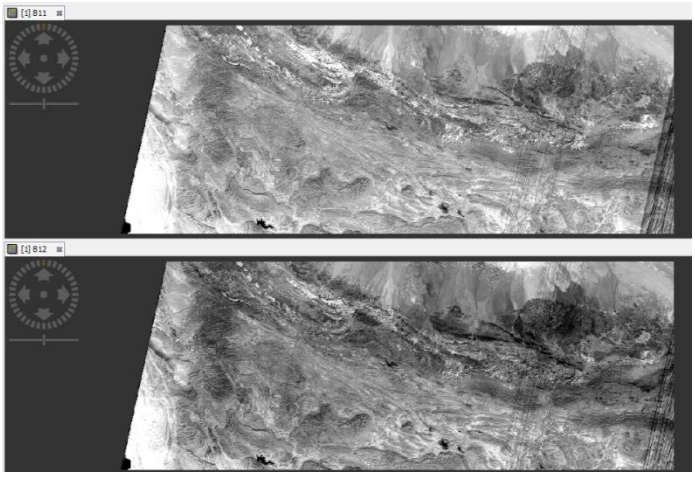

Figure 10: Striping of SWIR bands (anomaly #9). Top: B11, Bottom, B12.

This anomaly occurred during commissioning as a result of an incorrect instrument configuration. Users are advised to use only VISNIR bands for the corresponding orbits.

Table 4-2: List of orbits affected by anomaly #9.

1118	1205	1302	1404
1143	1218	1308	
1146	1227	1314	
1151	1234	1319	
1156	1244	1326	
1159	1246	1329	
1171	1251	1337	
1175	1256	1342	

1186	1261	1343	
	1272	1348	
	1274	1391	
	1298	1394	

4.5 Striping due to lost source packets (#10)

Data downlink issue sometimes lead to missing instrument source packets. This results in missing or corrupted pixels in L1C image, typically affecting only odd or even detectors and some spectral bands. The figure below presents an example of product affected by missing packets.

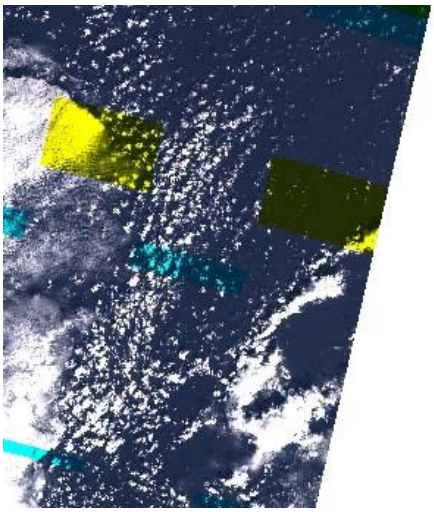

Figure 11: L1C product affected by a large number of missing packets. This type of feature is not considered as an anomaly and will not lead to removal of affected products.

Under the current quality control policy, this effect is not considered as an anomaly. Products affected by missing packets will remain in the archive.

This type of behaviour is expected and traced in the product:

- ✓ a technical quality check is performed at datastrip level and reported in the End User product metadata in case of failure;
- ✓ the number of missing packets is reported in the datastrip metadata;
- ✓ the affected area is described in the technical quality masks (TECQA gml files).

4.6 Missing viewing angles (#11)

This anomaly affected a few products of baseline 02.01: the viewing angles (part of the granule Metadata) are missing for some spectral bands. It has been corrected on 31/03/2016.

4.7 Anomalous Pixels (#12)

This anomaly is characterized by anomalous pixel values at the boundary of a datastrip. This anomaly has been corrected with baseline 02.02.

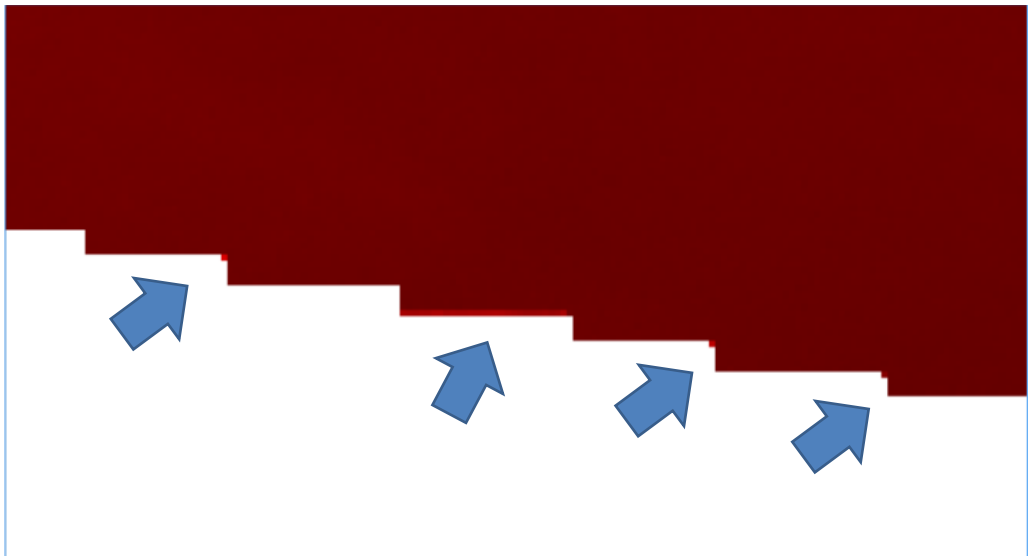

Figure 12: Anomalous pixels on band B4 (anomaly #12).

4.8 Saturation noise on Band 10 Images (#13)

This feature is characterized by noise patterns on bright images. It has now been identified as generated by saturation of the detector. This effect is not an anomaly in itself, however the saturation is currently not correctly reported in the image quality masks. A modification of the processor is in progress to solve this issue.

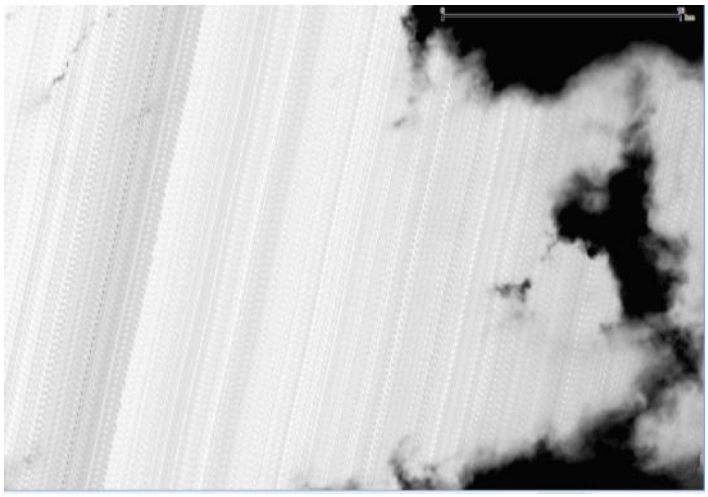

Figure 13: Along-track noise pattern on B10 images over bright clouds (#13).

4.9 Geolocation and Co-registration Error (#14)

A major anomaly has led to a strong and temporary geolocation and spectral registration errors. The anomaly occurred on February 3rd (orbit 3218) and 3rd of April 2016 (orbits 4080, 4081 and 4082). This anomaly has been correctly identified by the automatic on-line quality control and the degraded geometric performance is reported in the product metadata (geometric quality check status is "FAILED"). After identification of the anomaly, the defective products have been removed from the public archive.

The root cause of this anomaly has been identified. Missing data from attitude control telemetry is at the origin of the anomaly. An optimization of the management of the on-board telemetry has been implemented since and should avoid any re-occurrence.

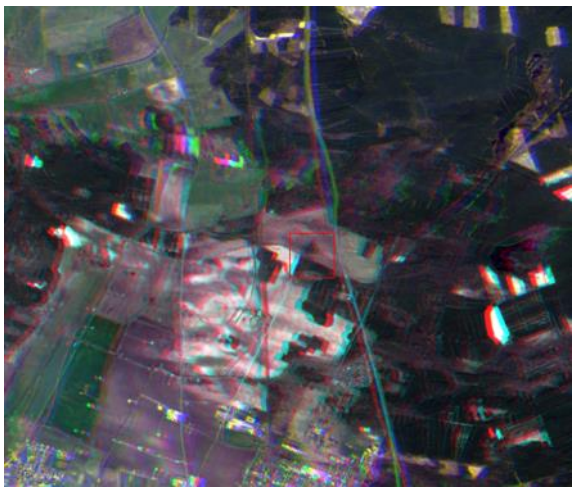

Figure 14: Spectral co-registration error (anomaly #14).

4.10 Strong Misregistration (#15)

Processing Baseline 02.03 deployed on 09/06/2016 was affected by an anomaly due to an incorrect configuration of the processing centres. This anomaly results in a strong spectral misregistration. This issue was rapidly identified, defective products have removed from the archive and subsequently reprocessed with baseline 02.02. After correction of the configuration error, baseline 02.04 was deployed on 15/06/2016.

4.11 Stretching of 60 m Bands (#16)

This anomaly is characterized by an incorrect appearance of the 60 m bands: images are stretched across-track and discontinuities are visible between detector boundaries. A few occurrences have been observed, and none since 27/04/2016.

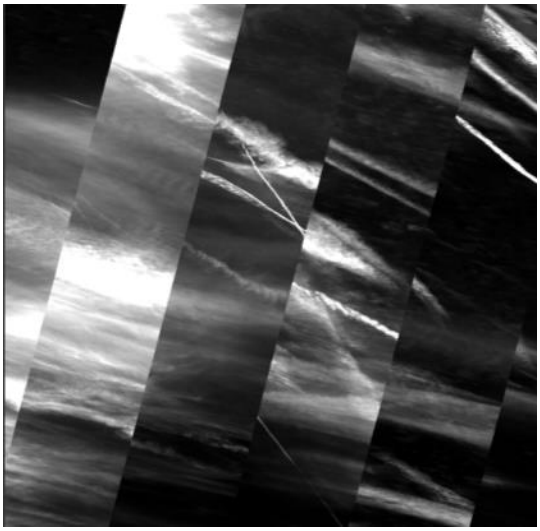

Figure 15: Stretching of 60 m bands (anomaly #16).

4.12 Misaligned detectors on band 1 (#17)

An anomaly on the receiving ground station occurred on 12th of July 2016 and led to corrupted products for a few orbits (5509 to 5525). The anomaly affects only band 1 and is limited the first products for the datastrips (Northern part). It is characterized by a misalignment of the odd and even detectors, as illustrated in the figure below.

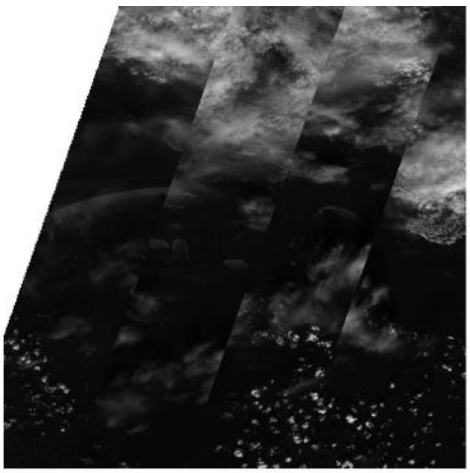

Figure 16: Detector misalignment on band B1 (anomaly #17).

A possible correction of this anomaly by an ad-hoc reprocessing is under study.

4.13 Geolocation Error (#18)

This anomaly occurred while the satellite was performing a collision avoidance manoeuvre on 16th August 2016. One Star Tracker was temporarily blinded by the Sun, which led to a degradation of the attitude estimation. As a result, the geolocation of the products acquired during this period (orbits 6003 to 6011) is affected by a variable geolocation error of up to 100 meters.

Another occurrence of the same anomaly was detected on 12/08/2018 and affects S2A orbits 16 381 to 16 392.

The anomaly is related to the handling of the redundant Star Tracker in the attitude estimation system.

A correction of the alignment of the redundant Star Tracker is planned to avoid another re-occurrence of this anomaly.

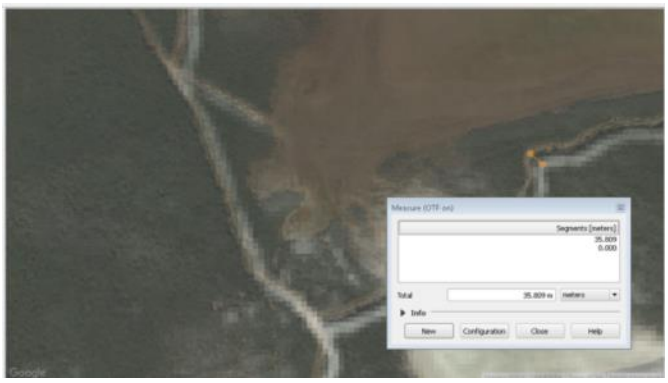

Figure 17: S2 image superimposed with reference map, showing a geolocation error of 35 m (anomaly #18).

4.14 Product footprint on the ante-meridiem (#19)

With the introduction of single tile products in October 2016, an issue has been identified in the product footprint for tiles crossing the ante-meridiem (180° longitude). The footprint should be composed of two polygons (above -180° and below +180°). Instead, only the second polygon is present.

This anomaly has been fixed on 26/01/2017. All points are now present but in a single polygon.

4.15 Degraded AUX files (#23)

This anomaly affects the ECMWF auxiliary files, for some specific tiles. The files are truncated and contain aberrant values. This anomaly is fixed with production baseline 02.05.

4.16 Imprecise technical quality mask (#24)

Since October 2016, technical quality masks (TECQA) are reporting instance of lost data packets (see anomaly #10). However it has been found that the masks are not perfectly accurate (see figure below). This anomaly is essentially corrected with production baseline 02.05. Some residual errors have been observed, which led to a further improvement deployed the 07/06/2018.

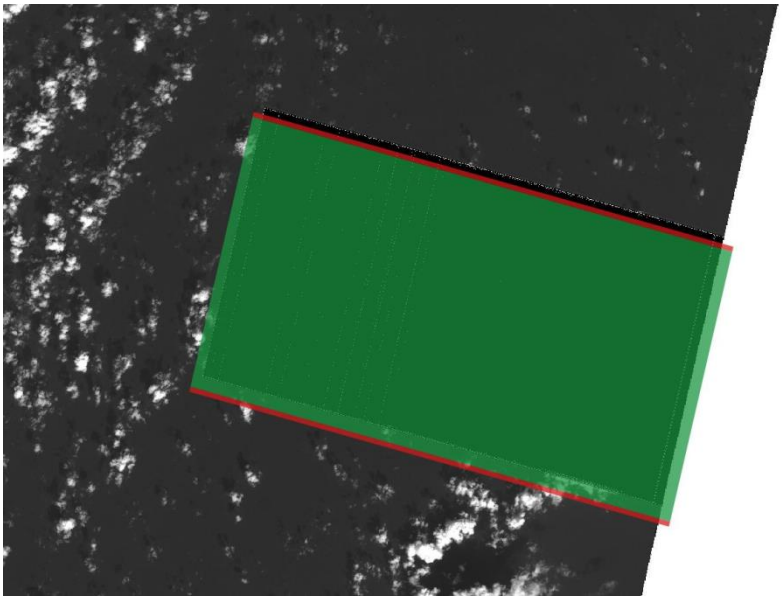

Figure 18: Technical Quality masks (green: lost packets, red: degraded packets) overlayed over an affected imaged. A small gap exists between the mask and the affected area (anomaly #21).

4.17 Geolocation error on orbit 7174 (#25)

A geolocation error of more than 100 m has been observed on the first datastrip of orbit 7174 (acquired 05/11/2016). A reprocessing is planned for this datastrip to correct this anomaly.

4.18 Incomplete manifest (#26)

In products generated before 18/05/2017, the meteorology Auxiliary files are missing from the file listing in the manifest.safe.

4.19 Inaccurate footprint and incomplete metadata (#27)

This anomaly occurred on January 20th 2017 following a change in the user product generation chain, and was solved on January 26th 2017. The anomaly affected the diffusion of products on the SciHub, and as a result few products affected by this anomaly have been disseminated. The characteristics of this anomaly are:

- ✓ Coarse precision of product footprint (1/3°)
- ✓ Missing Datastrip Identifier and granule Identifier attributes.

4.20 Incorrect cloud coverage metadata (#29)

Two products have been found affected by this anomaly. The products have very small data coverage and are completely cloudy. The cloud mask is accurate but the cloud coverage metadata is reported as zero. The affected products are 30UXB on 11/02/2017 and 50KQL on 12/04/2017.

The issue has been fixed the 07/06/2018.

4.21 Corrupted metadata (#30)

The product for tile 50SQA generated on 20/03/2017 has several metadata with an incorrect "0" value (quantification value, spectral irradiances). No other product has been found with this anomaly so far.

4.22 Missing viewing angles metadata (#32)

Viewing angles metadata (part of L1C granule metadata) are systematically missing for tiles of UTM zone 01 crossing the ante-meridiem. This anomaly is fixed with baseline 02.06.

4.23 Missing files (#33)

Some recent products have been found with one or several files missing (spectral bands or metadata files). This anomaly is now corrected for real time processing and the archive is progressively cleaned.

4.24 Missing ECMWF auxiliary files (#34)

In some products from baseline 02.06, the meteorology auxiliary files (ECMWF data) are missing in the products. The issue has been solved in February 2018.

4.25 Wrong quantification value (#35)

An incorrect calibration file has been deployed by error for S2A on 12/06/2017 and affected orbits 10724 to 10729. The quantification value is 1,000 instead of 10,000. The affected products have been reprocessed and the archive will be updated.

4.26 Misregistration on bands 9 and 10 (#36)

On 25/09/2017, an anomaly at the reception station led to a severe loss of instrument source packets. As a side effect, a mis-registration of bands B09 and B10 has been observed downstream of the area affected by missing packets. In view of this strong degradation, the affected orbit (S2A orbit 11 799) will be removed from the archive.

4.27 "Null" folder (#38)

A few products of baseline 02.04 have been generated with an additional empty Granule folder with a name ending with "null". As a side effect, this generates a failure with Sen2cor. This very minor anomaly can be corrected by deleting the empty folder.

4.28 Incorrect S2A Spectral Response Function (#39)

The spectral response functions provided in the metadata of the S2A products are affected by errors affecting mostly bands B01, B02 and B08. The anomaly has been corrected on January 15th 2018 (cf. https://cophub.copernicus.eu/news/News00138).

Note that this issue has negligible impact on the radiometry of the L1C reflectance products. On the other hand the conversion to radiance values and the computation of downstream products relying on the spectral response function can be impacted (such as L2A products).

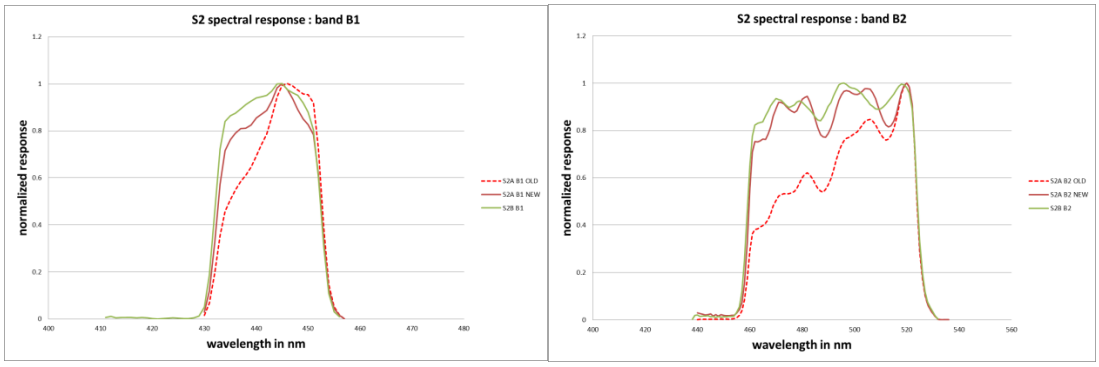

Figure 19: Spectral Response Functions for bands B01 and B02. Red – dashed: S2A before correction. Red – solid: S2A after correction. Green: S2B.

4.29 Incorrect Product Name (#40)

A few S2B products have been found with an additional number (0 or 1) at the end of the product discriminator field. This minor anomaly has been understood and correction actions are in progress to prevent re-occurrence. In the meantime the products will be removed and replaced with new ones with the correct naming.

4.30 Incorrect Instrument Temperature metadata (#41)

This anomaly affects the Instrument temperature data reported in the "expertise" section of the Datastrip metadata. The temperatures are not converted to degrees Celsius as they should be. In addition the GPS time is not correctly reported. This minor anomaly affects all products of baseline 02.06 and earlier. Remediation is in progress.

4.31 Incorrect NODATA mask format (#42)

A few products from baseline 02.06 have been generated which use a comma ',' instead of a decimal point '.' in the description of the mask polygon (NODATA and DEFECT masks). This minor error is due to an incorrect language setting which has been corrected. It does not prevent the handling of the products by such tools as SNAP, QGIS or Sen2cor. The issue has been finally solved on 24/05/2018.

4.32 Geolocation error due to GPS anomaly (#43)

Due to an anomaly on the GPS receiver of S2A in September 2015, orbits 1296 to 1304 (inclusive) were affected with a large geolocation error (up to 1000 m). Affected products have been removed from the archive.

4.33 Incorrect cloud coverage percentage (#44)

This anomaly affects the "Cloud_Coverage_Assessment" parameter reported in the user product metadata as well as the "CLOUDY_PIXEL_PERCENTAGE" of the tile metadata for products with a partial acquisition. The percentage is not correctly computed and can lead to over- or under-estimation of the percentage.

Since the Sentinel Data Hub uses this metadata to record catalogue entries, requests using filtering on cloud percentage can be affected.

On the other hand the cloud mask itself is correct.

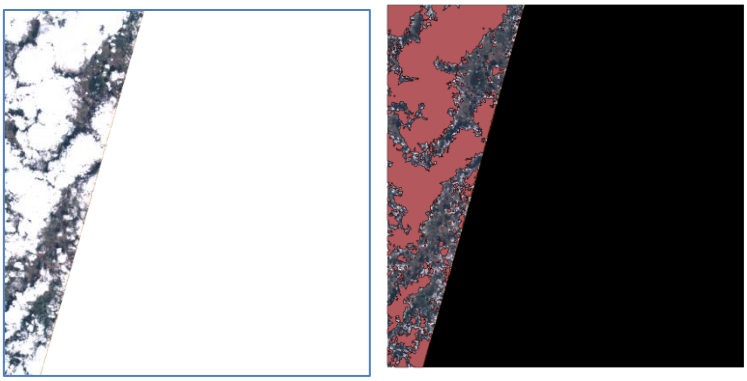

Figure 20: Tile 40UGE acquired on 12/06/2018 by S2B. Left: RGB composite, Right: cloud mask (in red). The cloud coverage percentage is incorrectly reported as 19.3% (anomaly #44).

Anomaly #44 is corrected with baseline 02.07.

4.34 Pixels with 0 value (#5)

Until product baseline 02.01, several products had valid pixels with a reflectance value of 0 (No Data) instead of 1 (minimal reflectance). This anomaly was essentially fixed with baseline 02.01. However errors induced by compression noise can still be found on very dark areas (e.g. over topographic shadows or water on SWIR bands).

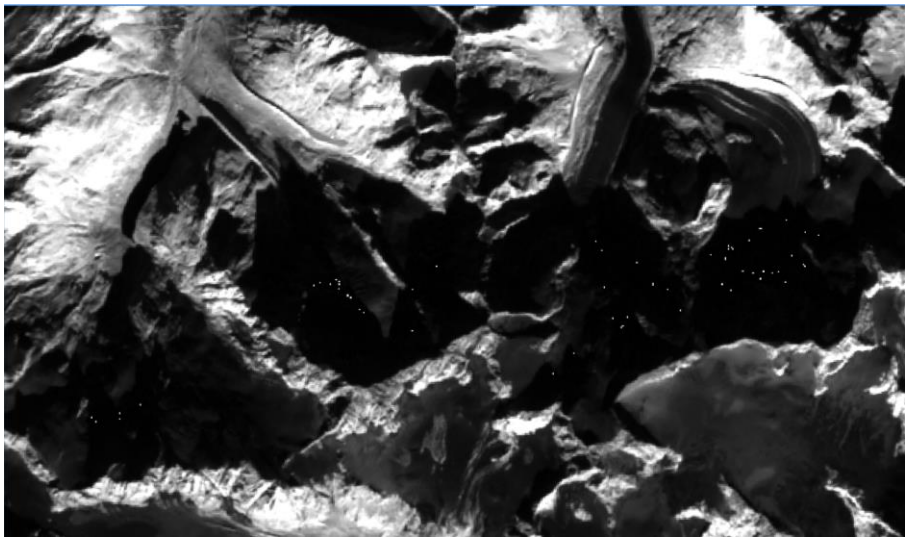

Figure 21: Pixels with 0 value (No Data) shown here as transparent, in a dark area of a B12 image (Anomaly #5).

4.35 Incorrect equalization (#45)

Since 18/07/2018, equalization issues have been observed on S2A products. The issue is especially visible on Band 10 if the contrast is enhanced. This issue also affects the cirrus cloud mask which may exhibit discrepancies between detectors. Note that the impact on the radiometry is limited to a few percent. The anomaly has been corrected on 30/07/2018.

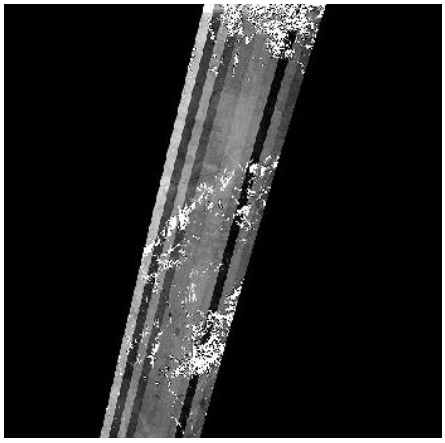

Figure 22: Incorrect equalization of B10 for S2A (anomaly #45).

4.36 Missing corners (#46)

Since 22/06/2018 an anomaly affects all L1C products. A triangular area of 50 to 100 pixels is systematically missing on the top-right and bottom-left corners of each tile. The affected area can be larger at high latitudes.

These pixels are flagged by the "No-Data" mask so no impact on downstream processing is expected.

Figure 23: Top-right corner of the image of the same L1C tile from orbit 7053 (unaffected, left) and orbit 7196 (affected, right). (Anomaly #46)

This anomaly has been fixed on 08/09/2018. Affected products are still present on the archive.

4.37 S2A products processed as S2B (#47)

On 25/09/2018, 132 products from S2A orbit 17022 have been incorrectly processed as S2B products. This induces large discrepancies on radiometric and geometric performances. This anomaly was corrected on 02/10/2018 (affected products removed and reprocessed as S2A products).

4.38 Geolocation Error after orbit control manoeuvre (#48)

On 12/10/2018 (orbit 8366) a geolocation error of up to 40 m has been observed. This error is caused by a collision avoidance manoeuvre performed during observation time. The products are available from the archive but should be used with caution. The manoeuvre planning procedures have been updated in order to avoid a repetition of this anomaly.

4.39 Misregistration of some S2A products (#49)

This anomaly occurred during 05/02/2019 and 12/02/2019. Some S2A products were affected by a variable spectral mis-registration (up to 2 pixels). This anomaly has been fixed and the affected products have been reprocessed.

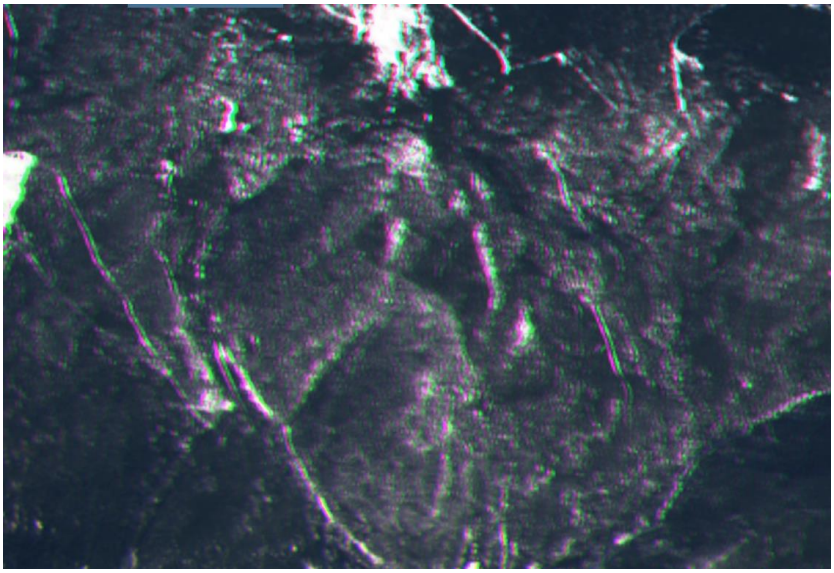

Figure 24: Spectral mis-registration (anomaly #49). Affected S2A products (between 04/02/2019 and 14/02/2019) have been removed from the archive and reprocessed.

5. Pixels Status

5.1 Defective pixels

5.1.1.1 S2A

In the following tables are listed all the identified defective pixels which are currently replaced by an interpolation of neighbouring pixels.

On 04/06/2018, a SWIR reselection operation has been performed. This operation has allowed reverting some defective status to nominal as indicated in the table below.

Table 5-1: Defective pixels on S2A

Band B10			Current status & R2DEPI defective pixels	
Band	**Detector**	**Pixel number (from 0)**	**Current status**	**Last updated**
B10	4	1104	Nominal	18/07/2018
B10	10	879	Defective	23/06/2015
B10	10	1174	Defective	23/06/2015
B11	11	24	Defective	26/08/2015
B12	1	440	Defective	26/08/2015
B12	1	703	Nominal	18/07/2018
B12	5	174	Nominal	18/07/2018

In addition to the defective pixels listed above, a group of pixels (570 to 600) of Band 11 D11 are affected by a non-linear radiometric response. This effect generates a darker along-track area in dark B11 images (e.g. on snow, see figure below).

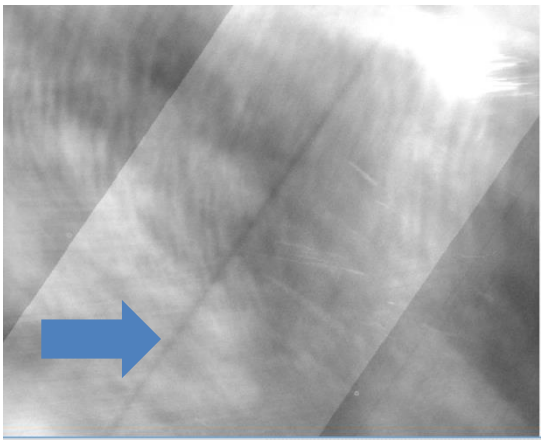

Figure 25: Along-track stripe on B11 image due to a non-linear response on D11 (contrast strongly enhanced).

5.1.1.2 S2B

Table 5-2: Defective pixels on S2B band 12.

Band B12			Current status & R2DEPI defective pixels	
Band	**Detector**	**Pixel number (from 0)**	**Current status**	**Last updated**
B12	D3	1132	Defective	30/05/2017
B12	D11	760	Defective	30/06/2018

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 cross-talk during detector read-out. This results in errors which can reach a few digital counts, depending on the observed scene.

The following tables provide the list of affected pixels.

Table 5-3: S2A Pixel affected by reset spike noise.

Band	pixel number		Current status
	Odd detector number	**Even detector number**	
B02, B03, B04	35	2556	Pixel Reset Noise
	489	2102	Pixel Reset Noise
	781	1810	Pixel Reset Noise
	961	1630	Pixel Reset Noise
	1036	1555	Pixel Reset Noise
	1177	1414	Pixel Reset Noise
	1252	1339	Pixel Reset Noise
	1724	867	Pixel Reset Noise
	1822	769	Pixel Reset Noise
B08	35	2556	Pixel Reset Noise

Table 5-4: S2B Pixel affected by reset spike noise.

Band	Pixel number		Current status
	Odd detector number	Even detector number	
B2	618	1973	Pixel Reset Noise
	619	1972	Pixel Reset Noise
	715	1876	Pixel Reset Noise
	895	1696	Pixel Reset Noise
	1047	1544	Pixel Reset Noise
	1539	1052	Pixel Reset Noise
	1596	995	Pixel Reset Noise
	1612	979	Pixel Reset Noise
	1669	922	Pixel Reset Noise
B3,B4	187	2404	Pixel Reset Noise
	619	1972	Pixel Reset Noise
	715	1876	Pixel Reset Noise
	895	1696	Pixel Reset Noise
	1047	1544	Pixel Reset Noise
	1539	1052	Pixel Reset Noise
	1596	995	Pixel Reset Noise
	1612	979	Pixel Reset Noise
	1669	922	Pixel Reset Noise
B5	1243	52	Pixel Reset Noise
B7	1273	22	Pixel Reset Noise
B8	87	2504	Pixel Reset Noise

6. Product Features

6.1 Spectral Response Non-uniformity

In this section we report on a known feature of Sentinel 2 products created by the spectral response non-uniformity. This feature has been anticipated since the design phase and is compliant with mission specification.

This feature is characterized by along-track soft-edged darker or brighter stripes near the detector boundaries, as shown on the figure below. Indeed, the spectral response is slightly different at the edges of the detectors, especially for bands B03 and B05. When the spectrum of the scene has strong gradient over the spectral bandwidth of the detector, a difference in the measured radiometry can be observed (up to 2% in worst-cases).

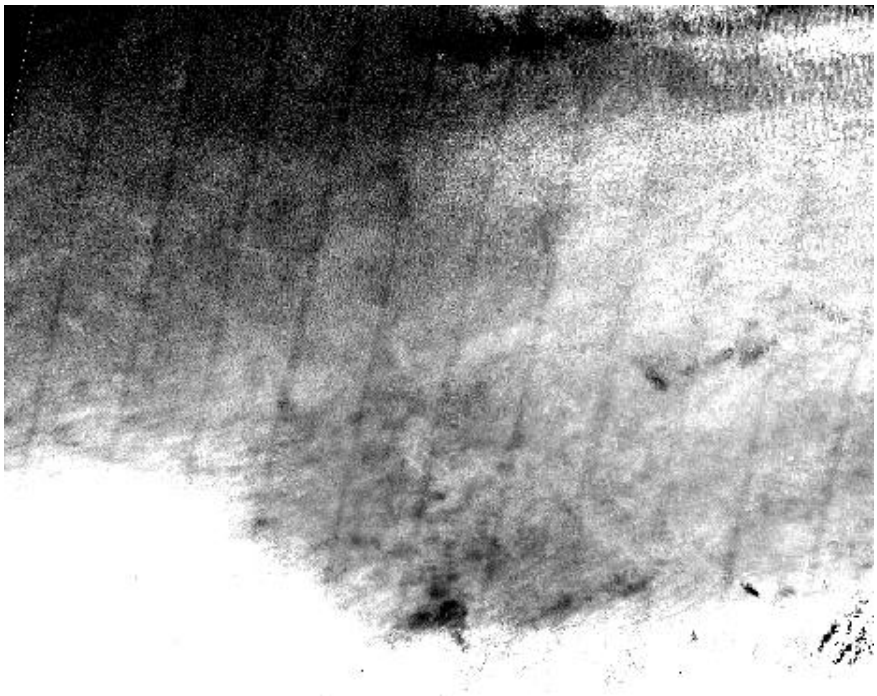

Figure 26: Along-track stripes resulting from spectral response non-uniformity (band B03).

6.2 Parallax effects

In this section we report on parallax effects created by the staggered configuration of the focal plane. Indeed the instrument swath is covered by 12 individual detectors assembled in a staggered manner. Because of this configuration, odd and even detectors do not see the ground under the same viewing angles. This can create visible effects on some images, as detailed in the next subsections.

6.2.1 Surface reflectance effects

Because the viewing angles are not the same for even and odd detectors, differences in measured radiometry can be observed on non-Lambertian surfaces. This is especially visible on Sun glint over sea surfaces (see Figure below).

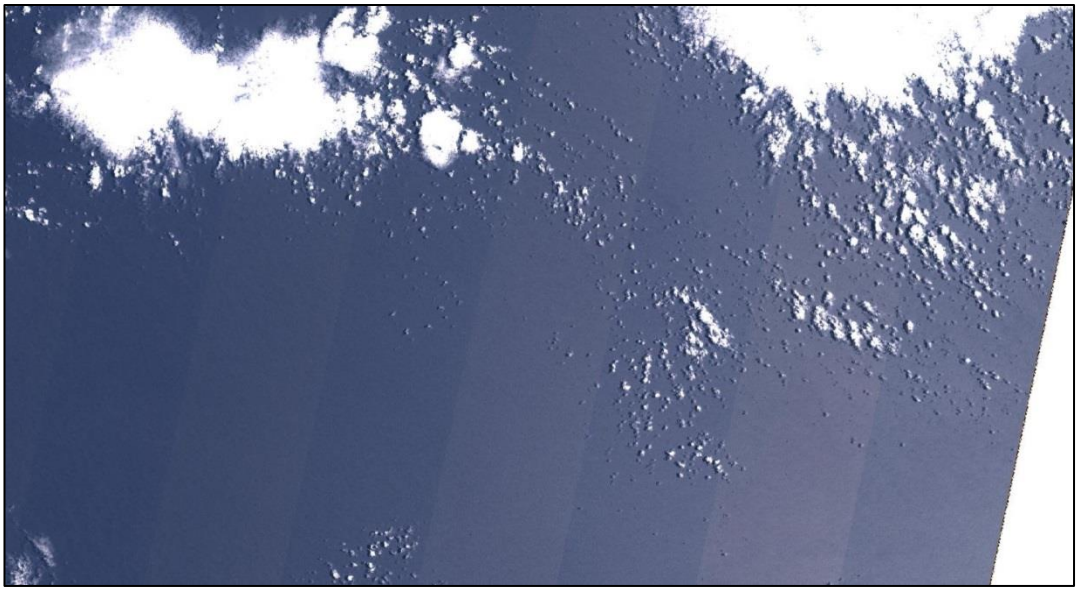

Figure 27: Stripe pattern over sea surface, due to the observation parallax effect between odd and even detectors.

6.2.2 Misregistration of High Altitude Objects

The processing algorithm ensures the co-registration of images acquired by all spectral bands and the detectors for features at ground level. Objects at a higher altitude like planes and clouds cannot be properly co-registered. As already reported in the first issue of the Data Quality Report, this effect leads to spectral misregistration ("rainbow" effect) and discontinuities between detectors.

Both effects can be seen in Figure 28 below.

Figure 28: Spectral misregistration and detector misalignment for object at high altitude (plane and contrail). This feature is not an anomaly.

6.3 Gradient cross-talk

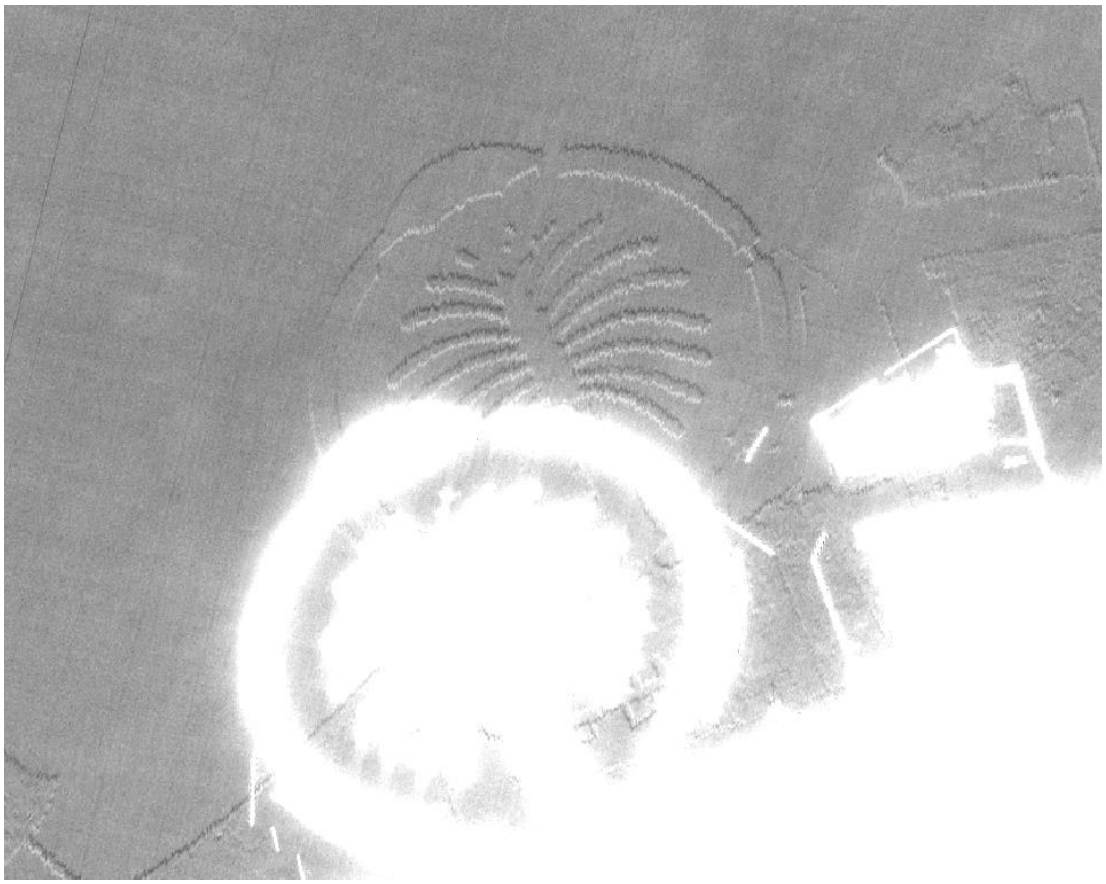

Figure 29: Gradient cross-talk on band B12 (highly enhanced contrast).

This feature can be seen on contrasted images on band B12 (typically near the coast). It can be explained by a cross-talk signal coming from the along-track gradient of the B11 image. The typical amplitude of the effect is 10 digital counts.

6.4 Data-strip overlap

Sentinel-2 products are generated by a network of several ground stations around the globe. Data acquired by the satellites are split into processing units called "data-strips" which are processed independently, and subsequently transferred to the Sentinel Data Hub. A given continuous acquisition sequence (or "data-take") can be split into several data-strips. In that case, two different products will be generated for level 1C tiles located at the interface between the data-strips. Images from the two products can be merged seamlessly.

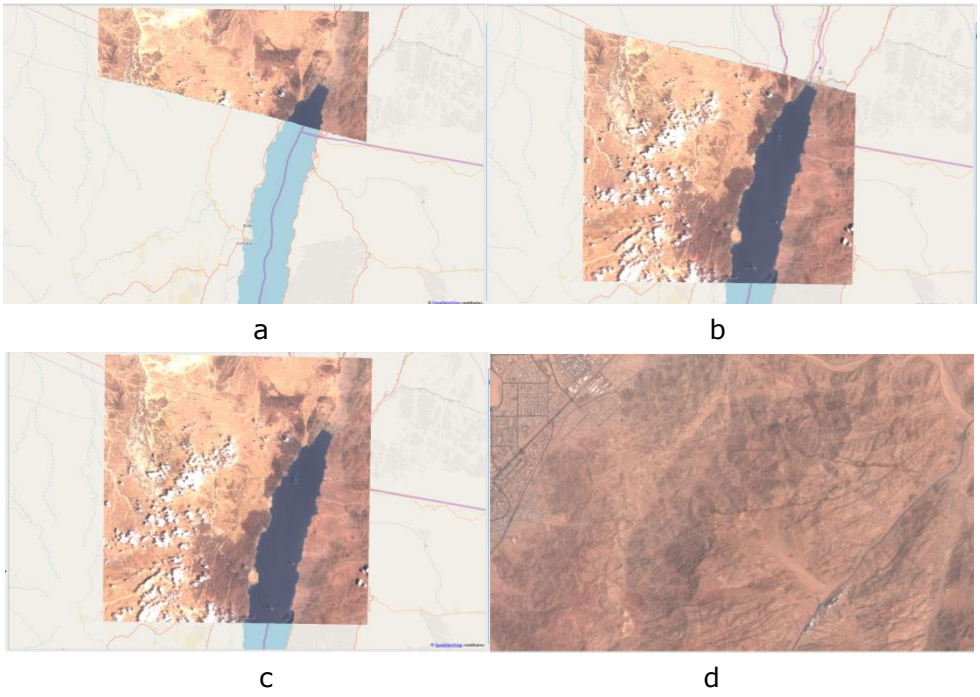

Figure 30: Example of a pair of products at the overlap between two data-strips. a: product from the first data-strip, processed at Svalbard (SGS) b: product from the second data-strip, processed at Matera (MTI). c: the two products overlap seamlessly to reconstruct the complete acquisition. d: close-up near the transition line.

End of document