Reference: S2-PDGS-MPC-DQR
Issue: 08
Date: 05/10/2016

S2 MPC

Data Quality Report

Ref. S2-PDGS-MPC-DQR

Authors Table

	Name	Company	Responsibility	Date	Signature
Written by	S. Clerc & MPC Team	CS	*Technical Manager*	05/10/2016	Digitally signed by Clerc DN: cn=Clerc, c=FR, o=ACRI-ST, ou=Operational Systems, email=sebastien.clerc@acri-st.fr Date: 2016.10.06 10:18:01 +0200'
Verified by	O. Devignot	CS	*Quality Manager*	05/10/2016	
Approved by	L. Pessiot	CS	Service Manager	05/10/2016	

Table of contents

1. Scope of the Document

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

It documents measured product performance vs. specifications, observed anomalies and known issues, the list of defective pixels, processing chain improvements associated to each Processing Baseline, and an outlook on product evolution.

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.

Table 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).	< 9.2 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.	< 0.29 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 5 in this document)	All bands compliant with > 27% margin

Measured performances are detailed in the following sections.

2.2 Geometric Performance

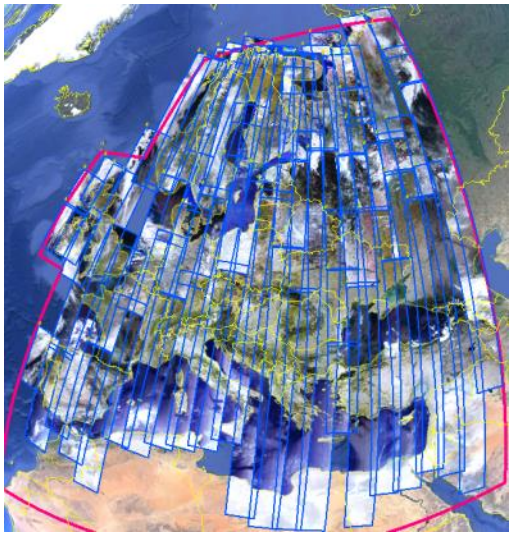
2.2.1 Geometric Calibration Status

As reported in the previous issues of the Data Quality Report, the improvement of the yaw bias correction has led to a significant improvement of the geolocation accuracy, see section 2.2.2. Monitoring of the performance revealed a small roll bias which will be corrected in the coming months.

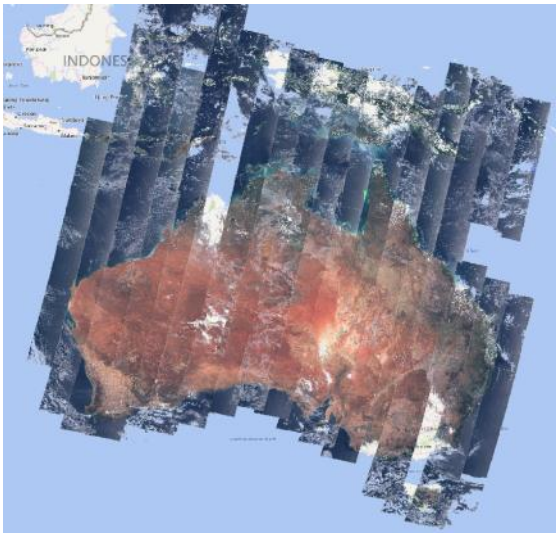
The European subset of the Global Reference Image (GRI), illustrated in Figure 1: Quicklook mosaics of the subsets of Ground Reference Image (GRI) over: Europe, availability for internal assessment Dec 2015 (a); Australia, Apr 2016 (b); North-Africa and Middle-East, Sep 2016 (c); South-Africa, Nov 2016 (e); North-America, Dec 2016 (d); South-America, Jan 2017 (f); Asia, Feb 2017 (g); and isolated island, Mar 2017, illustrated here with the Fiji Islands (h) and New Caledonia (i). (a), has been completed and its accuracy has been assessed. The Australian subset has been also processed and its validation is in progress. The processing of the North-African/Middle-Eastern subset has been completed, and the South-African subset is in progress.

In parallel, the software for refining images is under validation. The deployment and the first internal production tests are expected for beginning of November.

The future deployment of the GRI within the processing chain will improve the geolocation accuracy in a product all through the swath and between products acquired at different dates, whatever relative orbit (same or adjacent).



(a)



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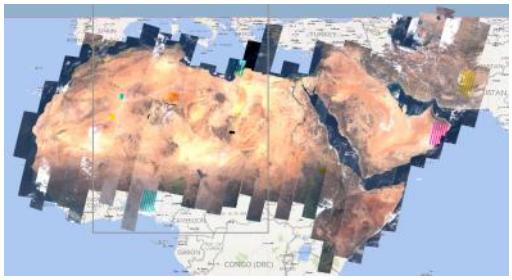

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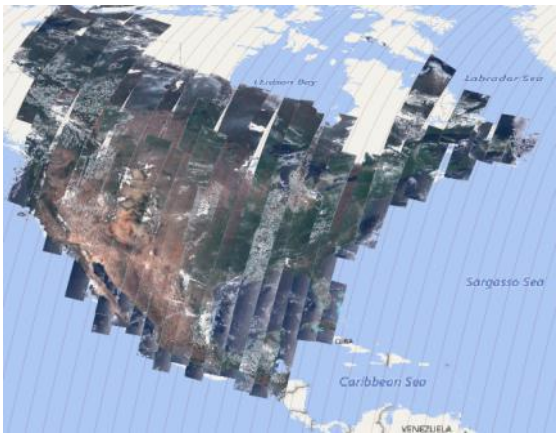

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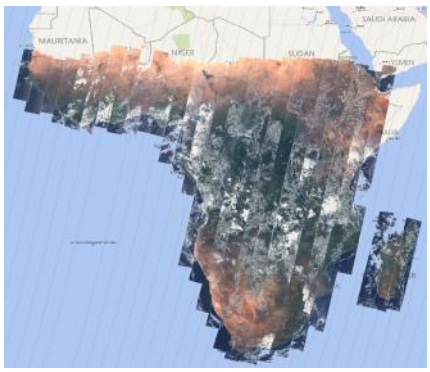
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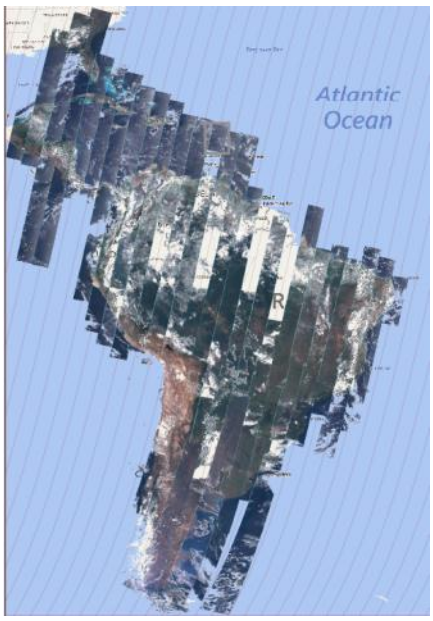
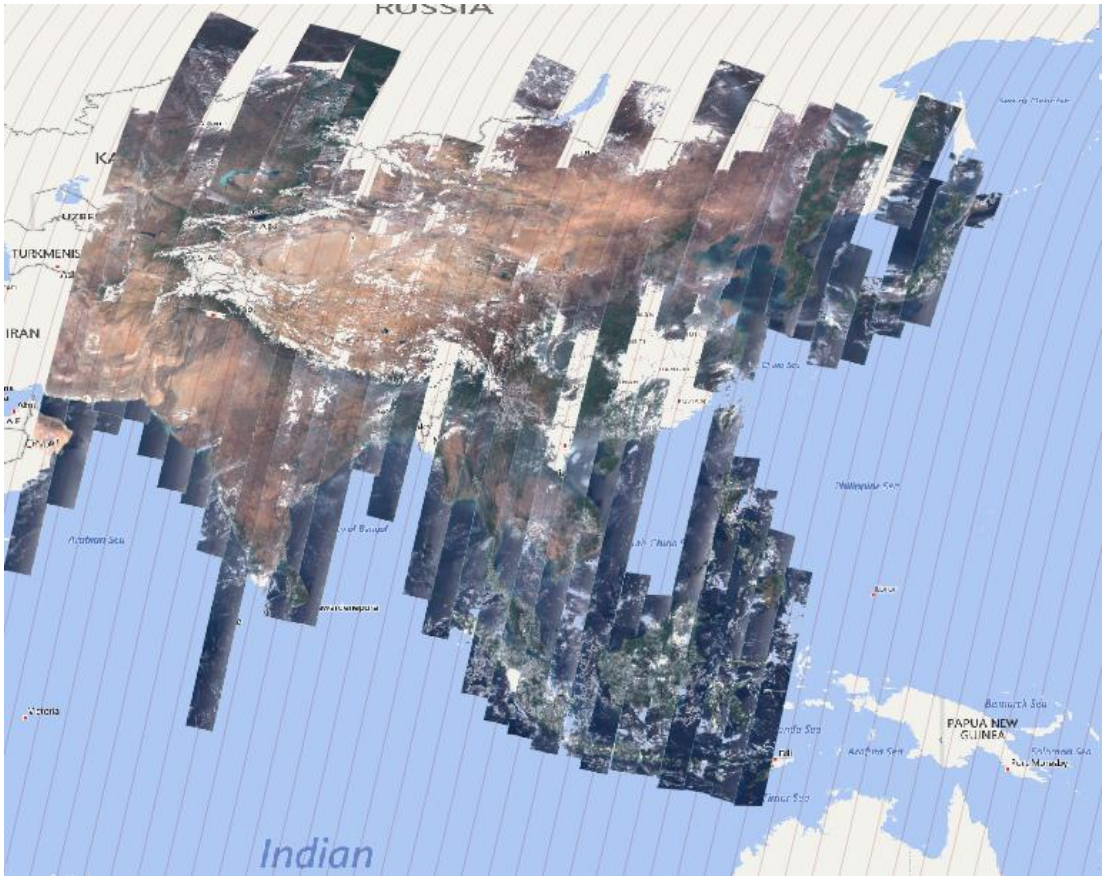
NIGER
SUDAN
SAUDI ARABIA

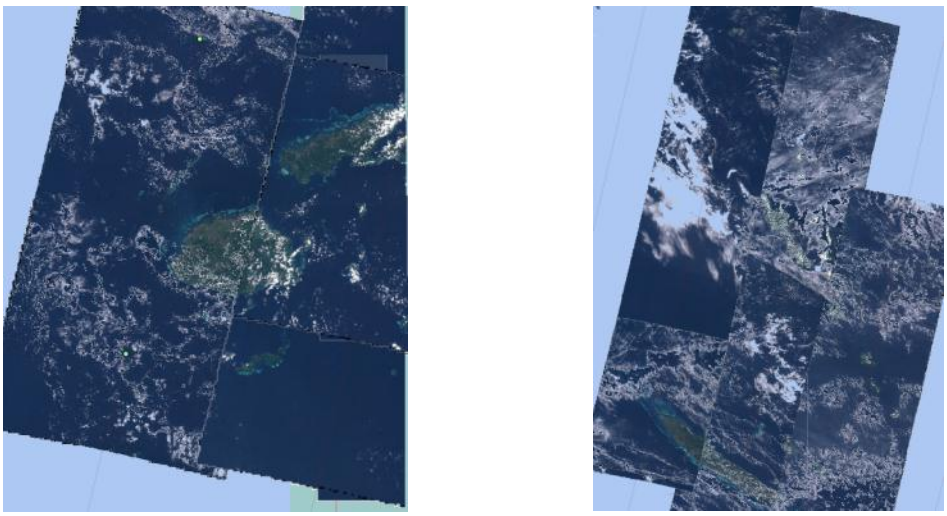
(e)


Atlantic
Ocean

(f)


RUSSIA
UZBE
TURKMENIS
IRAN
PAPUA NEW
GUINEA
Indian

(g)



(h) (i)

Figure 1: Quicklook mosaics of the subsets of Ground Reference Image (GRI) over: Europe, availability for internal assessment Dec 2015 (a); Australia, Apr 2016 (b); North-Africa and Middle-East, Sep 2016 (c); South-Africa, Nov 2016 (e); North-America, Dec 2016 (d); South-America, Jan 2017 (f); Asia, Feb 2017 (g); and isolated island, Mar 2017, illustrated here with the Fiji Islands (h) and New Caledonia (i).

2.2.2 Absolute Geolocation

The geolocation performance has been assessed by measuring the error on a set of ground control points (GCPs) for 160 products since November 2015.

The latest performance estimation for processing baseline 02.04 is 9.2 m at 95.5% (vs. requirement of 20 m for unrefined products).

Figure 2 (left) presents the point cloud of measured errors for all products analysed (baseline 02.04). The figure shows a small negative across-track bias, which has been linked to a small drift of the roll viewing angle of the instrument. This effect will be corrected by calibration in the next period.

Figure 2 (left) also reveals the presence of two outlier measurements with an error exceeding 12.5 m (blue circle) but still within the applicable requirement (20 m, red circle). These outliers are also clearly visible on the timeline (Figure 2, right) and correspond to acquisitions on orbit 5601 (18/07/2016). Further investigations showed that the reduced performance is linked to a temporary outage of the Star Tracker. It has been decided to add an automatic quality check to track such events and report them in the product quality metadata.

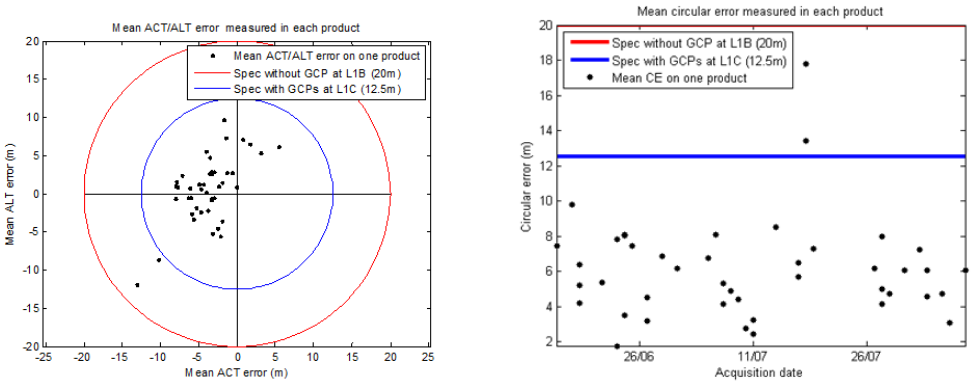


Figure 2: Geolocation performance assessment with processing baseline 02.04. Left: Point cloud of measured errors in Across-Track (ACT)/Along-Track (ALT) frame. Right: Timeline of measured circular errors.

2.2.3 Multi-Spectral Registration

New results obtained using a product over Australia indicate that the co-registration requirement (< 0.3 pixel at 99.7% confidence) is met with margins better than 10% for B11/B12 correlations, and better than 20% for other bands.

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

Bref/Bsec - Det	CE@99.73%	Bref/Bsec - Det	CE@99.73%
B04/B03-D01	0.237	B05/B11-D01	0.189
B04/B03-D02	0.214	B05/B11-D02	0.222
B04/B03-D03	0.202	B05/B11-D03	0.181
B04/B03-D04	0.165	B05/B11-D04	0.15
B04/B03-D05	0.182	B05/B11-D05	0.16
B04/B03-D06	0.168	B05/B11-D06	0.147
B04/B03-D07	0.203	B05/B11-D07	0.151
B04/B03-D08	0.162	B05/B11-D08	0.143
B04/B03-D09	0.146	B05/B11-D09	0.127
B04/B03-D10	0.145	B05/B11-D10	0.111
B04/B03-D11	0.135	B05/B11-D11	0.125
B04/B03-D12	0.122	B05/B11-D12	0.113
B11/B12-D01	0.259	B05/B12-D01	0.212
B11/B12-D02	0.292	B05/B12-D02	0.221
B11/B12-D03	0.218	B05/B12-D03	0.178
B11/B12-D04	0.155	B05/B12-D04	0.151
B11/B12-D05	0.182	B05/B12-D05	0.141
B11/B12-D06	0.133	B05/B12-D06	0.121
B11/B12-D07	0.109	B05/B12-D07	0.115

Bref/Bsec - Det	CE@99.73%	Bref/Bsec - Det	CE@99.73%
B11/B12-D08	0.121	B05/B12-D08	0.117
B11/B12-D09	0.107	B05/B12-D09	0.113
B11/B12-D10	0.084	B05/B12-D10	0.107
B11/B12-D11	0.114	B05/B12-D11	0.114
B11/B12-D12	0.091	B05/B12-D12	0.096

2.2.4 Multi-Temporal Registration

While the progress on the GRI continues, the methodology to assess multi-temporal performance has been consolidated and preliminary estimation of the performance before refinement has been obtained. The multi-temporal registration error for one tile is estimated as a worst-case (99.73% percentile) of the 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. According to this methodology, the current performance is 1.12 pixel. Figure 3 shows the histogram of the distribution of multi-temporal registration errors, showing a peak at 0.3 pixels.

It is recalled that the objective is to meet the required 0.3 pixel performance (95.5% confidence level) with the activation of the geometric refinement using the GRI.

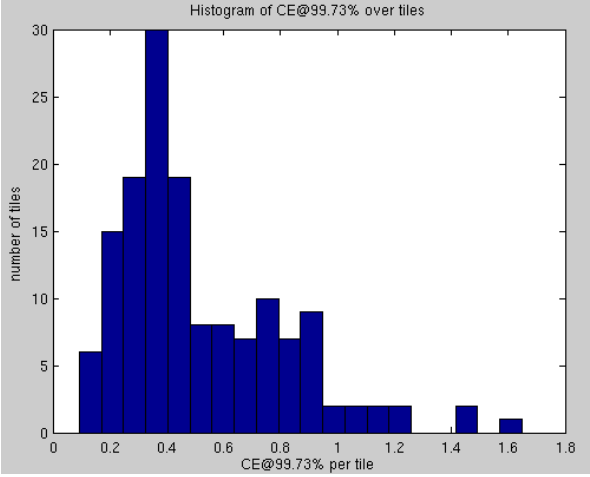


Figure 3: Histogram of the measured circular error (in pixels).

2.3 Radiometric Performance

2.3.1 Radiometric Calibration Status

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

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.
- Comparison with other sensors (Landsat OLI).

The first two methods indicate a radiometry slightly above the reference (typically 2.5%) for visible bands but still within requirements.

Table 3: Best estimate of the absolute vicarious calibration coefficients and the standard deviation for S2A/MSI from Rayleigh methodology application over four ocean-sites.

S2A/MSI	Wavelength (nm)	Vic. Calib. Coefficient (Best estimate)	Standard Deviation
B01	443	1.028	0.025
B02	490	1.024	0.018
B03	560	1.023	0.023
B04	665	1.021	0.019

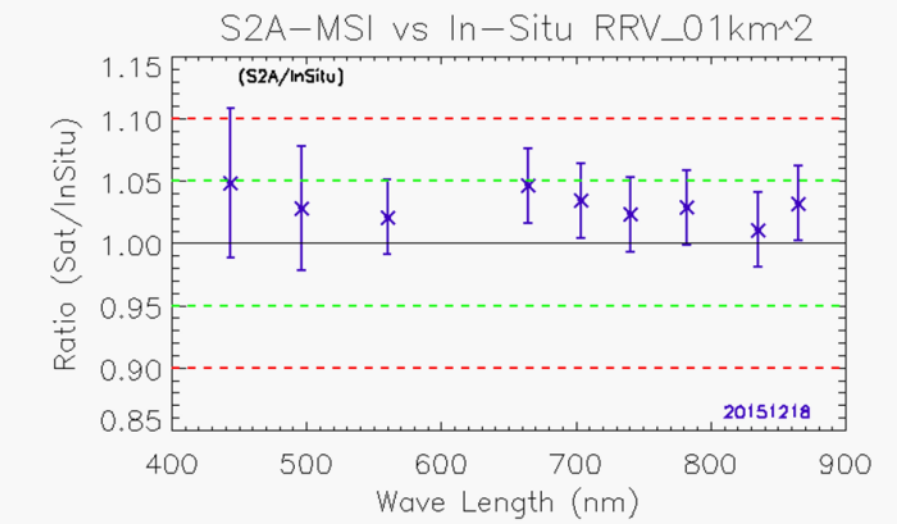


Figure 4: Comparison with in-situ measurements over Railroad Valley, USA, on 18th December 2015. In-situ measurements courtesy of USGS.

Comparison with reference models over 6 desert sites indicates a radiometric accuracy within 2%, with the exception of band B05, see Table 4. As illustrated in Figure 5, the trends observed with the VNIR bands show the good sensor stability. All the statistics are compliant to the mission requirements.

Table 4: Best estimations of the gain coefficients and the standard deviation from S2A-MSI over the six PICS sites over the period July 2015 to June 2016.

S2A/MSI	Wavelength (nm)	Gain Coefficient	Standard Deviation
B01	443	0.996	0.039
B02	490	0.989	0.035
B03	560	1.012	0.031
B04	665	1.002	0.022
B05	705	1.048	0.033
B06	740	1.016	0.025
B07	783	1.006	0.017
B08	842	0.994	0.033
B8A	865	0.994	0.019

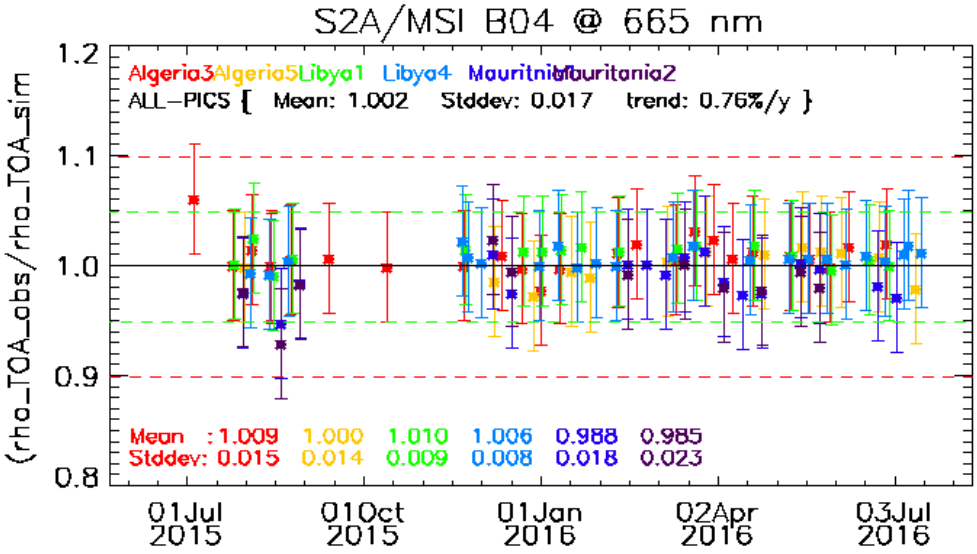


Figure 5: Time series of the ratio as observed reflectance over simulated from S2A/MSI for band B04: 665 nm over the 6 PICS Cal/Val-sites. Error bars indicate the method uncertainty.

Direct comparison of measurements acquired in similar viewing conditions by Sentinel 2 / MSI and Landsat 8 / OLI also confirm the good agreement previously observed for all spectral bands.

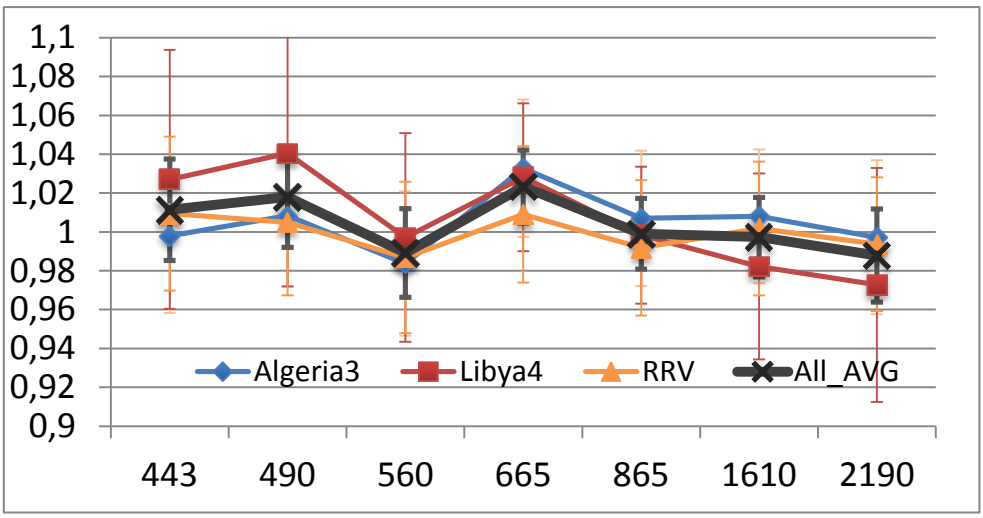


Figure 6: Ratio of S2 MSI to LANDSAT OLI TOA reflectances acquired in similar viewing conditions. Sites Algeria3, Lybia4, Railroad Valley and average value. Error bars indicate the uncertainty of the methodology.

2.3.3 Noise

The Signal-to-Noise Ratio (SNR) performances estimates have been slightly revised for 60 m bands to better take into account the effect of spatial binning. The performances remain excellent. The SNR is higher than 160 (worst-case for band B8A).

Table 5: Estimated SNR performance at 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
Measured	1362	214	249	230	253	220	227	221	161	227	387	159	217
Requirement	129	154	168	142	117	89	105	174	72	114	50	100	100
Margin (%)	956	39	48	62	116	147	116	27	124	99	674	59	117

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

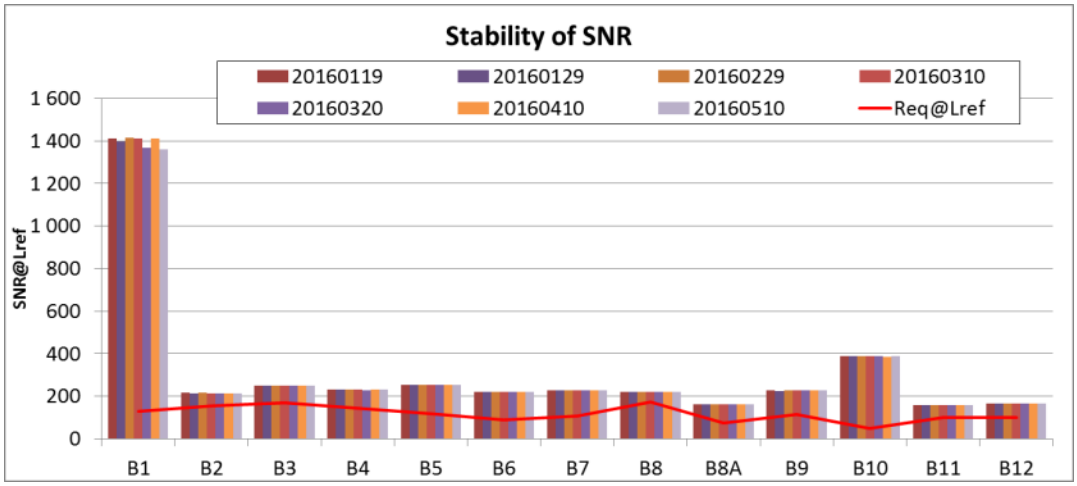


Figure 7: Evolution of the SNR performance since 19/01/2016.

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-flight assessment is difficult).

Globally, see Table 6, 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 6: Preliminary MTF performance assessment.

Spectral Band	Measured ACT	Measured ALT	Requirement
B01	0.34±0.03	0.28±0.03	0.15 < MTF < 0.45
B02	0.25±0.06	0.27±0.06	0.15 < MTF < 0.30
B03	0.27±0.03	0.28±0.04	0.15 < MTF < 0.30
B04	0.25±0.04	0.23±0.03	0.15 < MTF < 0.30
B05	0.42±0.03	0.34±0.05	0.15 < MTF < 0.30
B06	0.35±0.12	0.33±0.05	0.15 < MTF < 0.30
B07	0.35±0.07	0.34±0.03	0.15 < MTF < 0.30
B08	0.26±0.11	0.25±0.06	0.15 < MTF < 0.30
B8A	0.36±0.06	0.31±0.04	0.15 < MTF < 0.30
B09	0.25±0.10	0.27±0.03	0.15 < MTF < 0.45
B11	0.20±0.04	0.24±0.04	0.15 < MTF < 0.30
B12	0.24±0.07	0.22±0.06	0.15 < MTF < 0.30

3. Processing Chain Status

3.1 Status of Processing Baselines and Known Processing Anomalies

Since October 27, Sentinel-2 products are disseminated through the SciHub and collaborative ground segments in a "single tile" package, compared to a package of 6 or more L1c tiles previously. This evolution answers requests from users for smaller products easier to transfer and manipulate. Note that the format and processing characteristics are otherwise unchanged.

A simplification of the product format is scheduled for end of October, see next section.

The table below summarizes 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.

Table 7: Summary of identified processing anomalies and associated processing baselines.

Anomaly ID	Baseline number	02.01		02.02	02.03	02.04	
	Deployment date	27/01/2016	31/03/2016	03/05/2016	09/06/2016	15/06/2016	03/08/2016
	Anomaly title						
4	Instrument Measurement Time MTD		yes				
5	Minimum Reflectance "0"	yes					
6	Detector Footprint at Equator	yes					
7	Missing Physical Gains MTD	yes					
11	Missing Viewing Angles MTD	yes, not systematic					
12	Anomalous Pixels	yes, few products impacted					
15	Strong Misregistration				yes		
16	Stretched 60 m bands	A few orbits impacted					

3.2 Archive Reprocessing

A reprocessing campaign of images acquired during the commissioning period (from launch till 30/11/2015) is in progress.

Due to a major anomaly in the L0 archive of the reprocessing centre, many L1 products generated for the period between 04 July and 03 September 2015 with baseline 02.01 and 02.02 are anomalous. This period is being reprocessed with processing baseline 02.04 and users are advised to only use products generated with this baseline.

3.3 Outlook

In the coming months some improvements are foreseen on the products. In particular the naming convention will be modified in order to reduce the length of product filename tree. Further details can be found at the following webpage:

https://sentinels.copernicus.eu/web/sentinel/news/-/article/forthcoming-sentinel-2-l1c-product-evolution-in-autumn-2016

4. Product Anomalies

4.1 Introduction

This section describes all known product anomalies. Each anomaly is tagged with a code #N" allowing to link it to a given Processing Baseline through Table 7.

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 7 above.

Table 8: Anomalies not related to processing.

Anomaly ID	Anomaly title	Classification	Affected products	Product status
9	Striping of SWIR bands	Minor	A few orbits, not systematic	Not released
10	Striping of Visible bands	Major	A few orbits, not systematic	Removed from archive
13	B10 noise	Minor	Products with high reflectances	Available
14	Geolocation error	Major	Orbits 3218, 4080 and 4081	Removed from archive
17	Misaligned detectors on band 1	Minor	A few orbits impacted (beginning of the datastrip)	Available
18	Geolocation Error	Minor	Orbits 6003 to 6011	Available

4.2 Instrument Measurement Time MTD (#4)

Within the satellite ancillary metadata, the value of Instrument Measurement Time (IMT) is not represented correctly due to a formatting error.

4.3 Minimum Reflectance "0" (#5)

Valid pixels with zero reflectance could not be distinguished from "no data" pixels (coded with value 0). Zero reflectance pixels could be observed on the water vapour absorption band B10 or on SWIR band B12 over water surfaces.

It has been decided to truncate reflectance values to digital number 1 (i.e. reflectance 0.0001) to solve this issue, only "no data" pixels will be marked with value 0.

4.4 Detector Footprint at Equator (#6)

An error was found in the detector footprint gml file for tiles immediately North of the equator (systematic error). This error is corrected with baseline 02.01 after end of March 2016.

4.5 Missing Physical Gains MTD (#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 and recent products are not anymore affected.

4.6 Striping of Visible Bands (#10)

A major anomaly affecting VIS band images occurred on 21/02/2016 after a restart of the Sentinel-2A mass memory unit (MMFU).

The data of even detectors of visible bands were missing from products acquired at the beginning of a datastrip. This results in discoloured stripes along-track in RGB images. Anomalous products have been rapidly removed from the catalogue. The anomaly can be corrected by reprocessing the instrument source packets after filtering. Therefore, the missing products for the corresponding period should be available in the future.

The anomaly was traced back an incorrect handling of instrument source packets by the MMFU after the reboot of the unit. A procedure to handle this problem in case of a potential re-occurrence has been established.

4.7 Missing Viewing Angles MTD (#11)

For some products, the mean viewing angles in the tile metadata were missing for some bands in some products (not systematic). This anomaly is solved with baseline 02.01 after end of March 2016.

4.8 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.

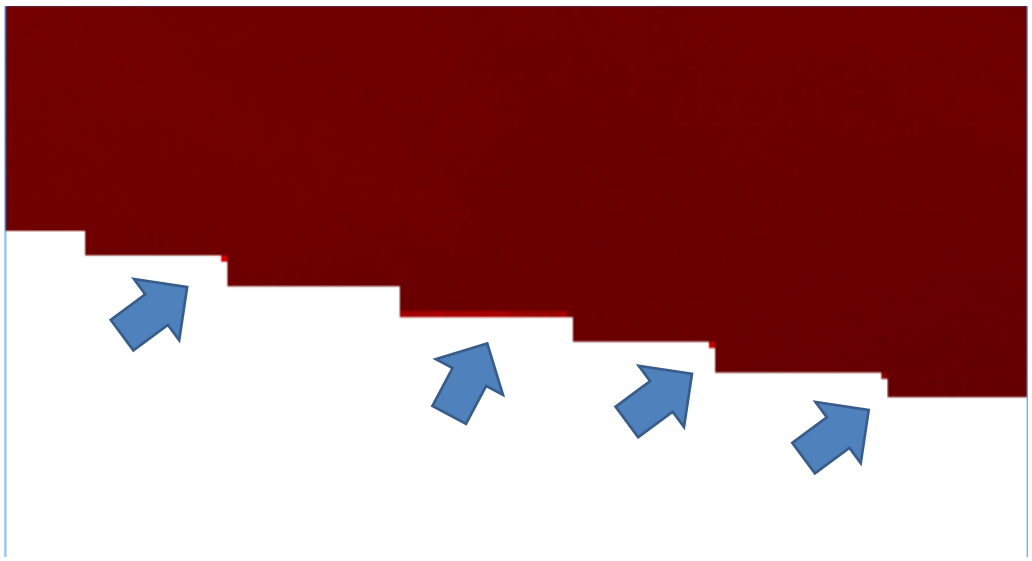


Figure 8: Anomalous pixels on band B4 (anomaly #12).

4.9 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.

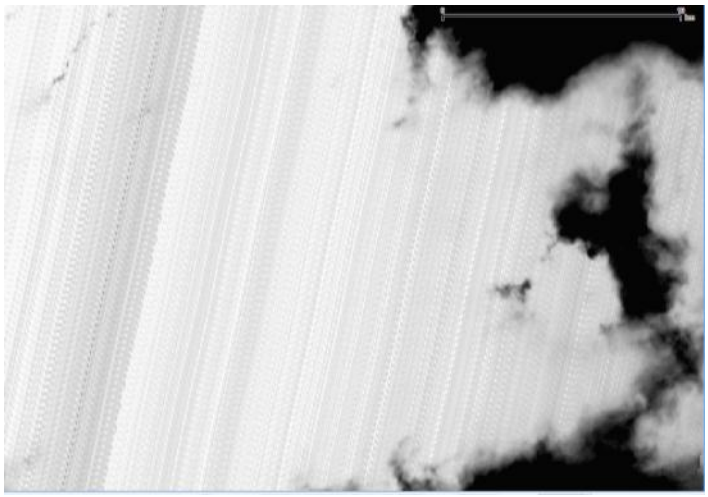


Figure 9: Along-track noise pattern on B10 images over bright clouds (#13).

4.10 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 April 3rd (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.

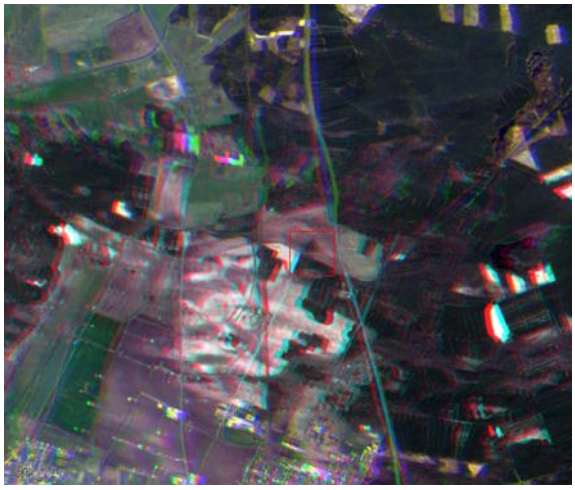


Figure 10: Spectral co-registration error (anomaly #14).

4.11 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.

4.12 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. This anomaly is currently under investigation.

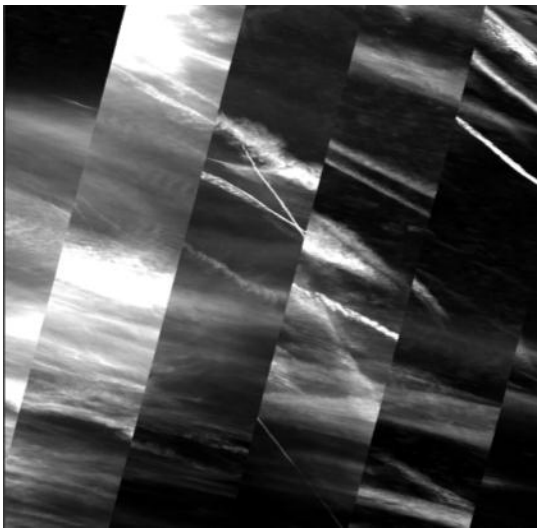


Figure 11: Stretching of 60 m bands (anomaly #16).

4.13 Misaligned detectors on band 1 (#17)

An anomaly on the receiving ground station occurred on 12th of July 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.

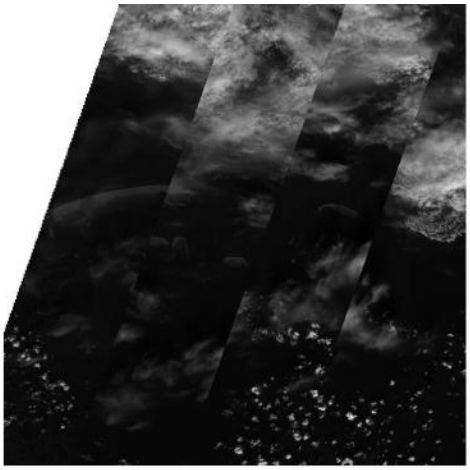


Figure 12: Detector misalignment on band B1 (anomaly #17).

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

4.14 Geolocation Error (#18)

This anomaly occurred while the satellite was performing a collision avoidance manoeuvre. 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.

The anomaly seems related to the handling of the redundant Star Tracker in the attitude estimation system. Further analysis is on-going and possible remediation is investigated.

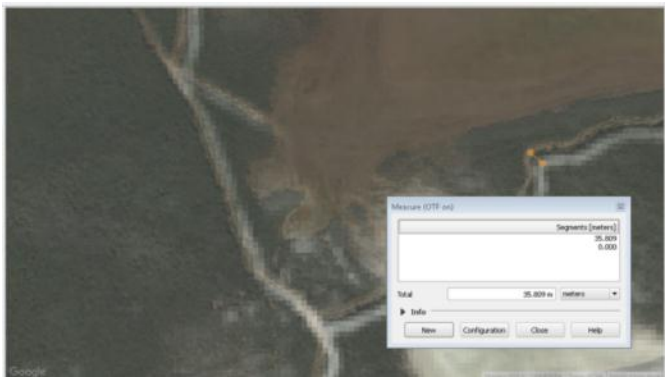


Figure 13: S2 image superimposed with reference map, showing a geolocation error of 35 m (anomaly #18).

5. Pixels Status

In the following tables are listed all the identified defective and noisy pixels:

- Defective pixels which currently replaced by an interpolation of neighbouring pixels. Defective pixels are interpolated.
- Noisy pixels: pixels operational but with a high noise level. These pixels are being monitored and could be declared defective in the future.

Following the decontamination operation in July, the health status is being reassessed.

Table 9: Defective pixels on Band 10.

Band B10			Current status & R2DEPI defective pixels	
Band	Detector	Pixel number (from 0)	Current status	Last updated
B10	4	1104	Defective	16/11/2015
B10	10	879	Defective	23/06/2015
B10	10	1174	Defective	23/06/2015

Table 10: Defective pixels on Band 11.

Band B11			Current status & R2DEPI defective pixels	
Band	Detector	Pixel number (from 0)	Current status	Last updated
B11	2	471	Noisy	
B11	8	61	Noisy	
B11	8	999	Noisy	
B11	11	1271	Noisy	

Table 11: Defective pixels on band 12.

Band B12			Current status & R2DEPI defective pixels	
Band	Detector	Pixel number (from 0)	Current status	Last updated
B12	1	185	Noisy	
B12	1	213	Noisy	

B12	1	440	Defective	26/08/2015
B12	1	488	Noisy	
B12	1	592	Noisy	
B12	1	603	Noisy	
B12	1	703	Defective	06/11/2015
B12	1	727	Noisy	
B12	1	855	Noisy	
B12	1	1045	Noisy	
B12	3	1089	Noisy	
B12	4	25	Noisy	
B12	4	32	Noisy	
B12	4	73	Noisy	
B12	4	126	Noisy	
B12	4	444	Noisy	
B12	4	682	Noisy	
B12	4	716	Noisy	
B12	4	726	Noisy	
B12	4	799	Noisy	
B12	4	803	Noisy	
B12	4	806	Noisy	
B12	4	880	Noisy	
B12	4	1075	Noisy	
B12	4	1110	Noisy	
B12	4	1245	Noisy	
B12	5	303	Noisy	
B12	5	661	Noisy	
B12	5	1121	Noisy	
B12	5	1122	Noisy	
B12	6	90	Noisy	
B12	6	773	Noisy	
B12	8	805	Noisy	
B12	8	965	Noisy	
B12	9	176	Noisy	

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).

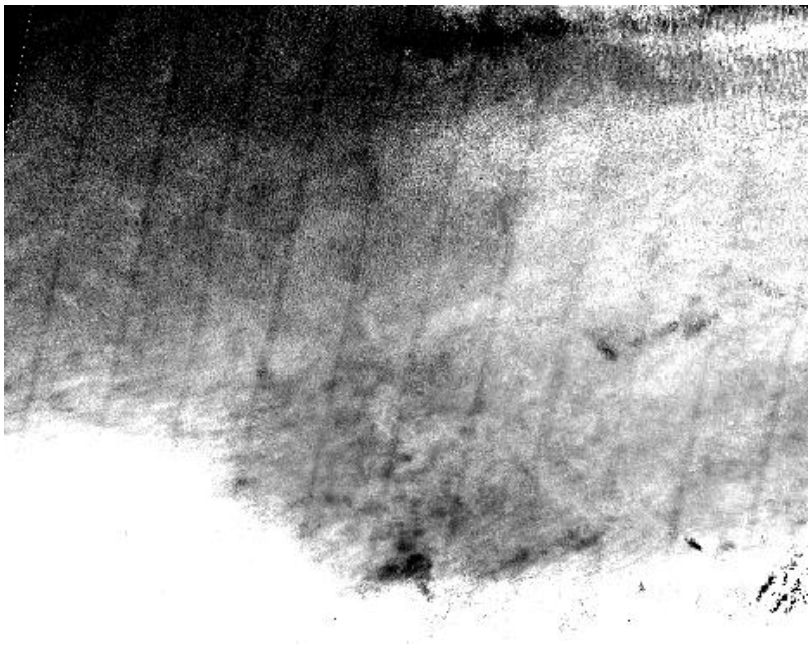


Figure 14: Along-track stripes resulting from spectral response non-uniformity (band B03).

6.2 Misregistration of High Altitude Objects

The processing algorithm ensures the coregistration 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 coregistered. 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 15 below.

Figure 15: Spectral misregistration and detector misalignment for object at high altitude (plane and contrail). This feature is not an anomaly.

6.3 Across-Track noise

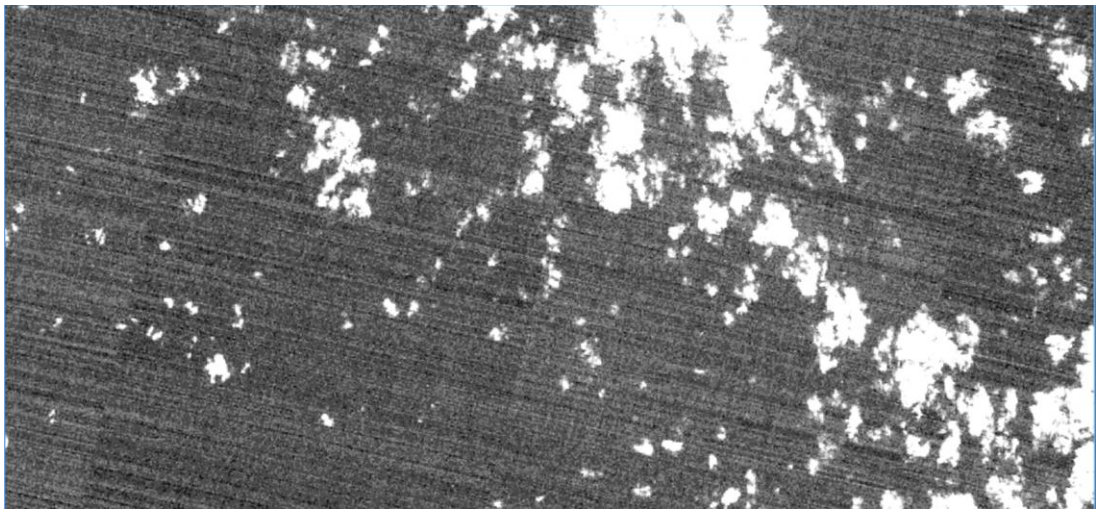


Figure 16: Across-Track intra-detector noise pattern

This feature can be observed in very dark images (typically on B10 or B12 over the sea). It is characterized by across-track lines covering a whole detector. The typical range of this noise pattern is a few digital counts, and therefore within the requirements of the mission.

This phenomenon is induced by the compression noise on "blind" pixels used for dark signal correction. A solution to filter out this noise has been identified and its operational implementation is currently under study.

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