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S2 MPC

Level 2A Data Quality Report

Ref. S2-PDGS-MPC-L2ADQR

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Table of contents

1. SCOPE OF THE DOCUMENT 4
1.1 Introduction 4
1.2 Main points for this month 4
2. MEASURED PRODUCT PERFORMANCES 5
2.1 Performances Overview 5
2.2 Performances 6
2.2.1 Surface reflectance radiometry accuracy 6
2.2.2 Water Vapour accuracy 7
2.2.3 Aerosol Optical Depth accuracy 10
2.2.4 Classification accuracy 13
3. PROCESSING CHAIN STATUS 16
3.1 Processing baseline 16
3.1.1 Evolution 16
3.1.2 Configuration and differences with Sen2cor Toolbox version 17
3.2 Status of Processing Baselines and Known Processing Anomalies 18
4. PRODUCT ANOMALIES 19
4.1 Introduction 19
4.2 Incorrect Tile ID metadata (#1) 19
4.3 Incorrect No Data mask (#2) 19
4.4 Encoding of Quality Bands (#3) 19
4.5 Terrain correction over clouds (#4) 20
4.6 Naming of quality masks files (#5) 20
4.7 Incorrect cloud probability near the boundary of the swath (#6) 20
5. PRODUCT FEATURES 22
5.1 Scene classification 22
5.2 Overlap between tiles 23
5.3 Terrain over-correction on shaded areas 23
5.4 Maximal Sun-Zenith Angle 23

1. Scope of the Document

1.1 Introduction

This document provides the status of Sentinel-2 mission Level 2A products data quality. It refers to systematic production from processing baselines 02.07 and higher and complements the Data Quality Report for L1C products.

It documents the measured product performances, the status of Level 2A processing chain, and the list of known anomalies on the production.

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). More information about L2A performance validation can be found in G. Doxani et al., "Atmospheric Correction Inter-Comparison Exercise", Remote Sensing, 10 (352), pp 1-18. DOI: doi:10.3390/rs10020352 ISSN 2072-4292. Please note that a former version of Sen2Cor was used during this inter-comparison exercise (not 02.07) and performance have generally improved since then.

1.2 Main points for this month

- Illustration of expected improvements with forthcoming PB 02.12 (section 3.1.1)

2. Measured Product Performances

2.1 Performances Overview

The following overview table provides a summary of the Level 2A products data quality performances. Note that the performances reported in this issue of the L2A Data Quality Report have been measured with Sen2cor versions 2.5 (toolbox version), and may thus slightly differ from the performance of the current processing baseline.

Table 2-1: Summary of Sentinel-2 L2A products measured performances for mission key requirements.

Requirement	Description	Measured performance
Surface reflectance accuracy	Uncertainty of Bottom-of-Atmosphere reflectance ρ shall be less than $0.05\rho_{reference} + 0.005$	Accuracy: B5 and B12 outside specification, all other bands within Uncertainty: all bands outside specification
Water Vapour accuracy	The difference ΔWV of retrieved Water vapour to reference from AERONET WV_{ref} shall be within $\|\Delta WV\| \leq 0.1*WV_{ref}+0.2$	92% of retrieved Water vapour values are within requirement
Aerosol Optical Depth accuracy	The difference ΔAOT of retrieved Aerosol optical thickness at 550 nm to reference from AERONET AOT_{ref} shall be within $\|\Delta AOT\| \leq 0.1*AOT_{ref}+0.03$	41% of retrieved Aerosol optical thickness values at 550 nm are within requirement
Classification accuracy	No requirement defined.	omission and commission classification errors are 15% and 16% for recognition of clear pixels over land and water

Measured performances are detailed in the following sections.

2.2 Performances

2.2.1 Surface reflectance radiometry accuracy

Quantitative assessment of surface reflectance radiometric performance is provided for Sen2Cor version 2.5 toolbox version. AERONET-corrected surface reflectance data serve as a reference for this analysis. They are computed from the Sentinel-2 L1C data (TOA) using the aerosol properties obtained from AERONET in-situ measurements as input to the 6S radiation transport processor.

The analysis is based on the dataset defined for the Atmospheric Correction Inter-comparison Exercise (ACIX) (G. Doxani *et al.*, "Atmospheric Correction Inter-Comparison Exercise", Remote Sensing, 10 (352), pp 1-18. DOI: doi:10.3390/rs10020352 ISSN 2072-4292). Plots were generated for all Sentinel-2 bands showing the average accuracy, precision and uncertainty values (APU) over all images within the validation data set per surface reflectance bin. Accuracy value is equivalent to the mean bias, precision value is equivalent to the repeatability or variation around the mean bias and uncertainty is quadratic sum of Accuracy and Precision.

Average APU per band is shown in Figure 1, while Figure 2 shows the average APU per band relative to the average surface reflectance of the band. Accuracy is outside specification in band 5 and band 12 and within specification for all other bands. Both accuracy value and uncertainty show an increasing trend with wavelength (band number). Precision value increases up to band 5 and then stays constant. Thus, best performance is achieved for VIS bands with lowest accuracy and precision values and lowest uncertainty. Average accuracy value relative to average surface reflectance reference is below or near to 5% except for bands 5 and 12 (Figure 2).

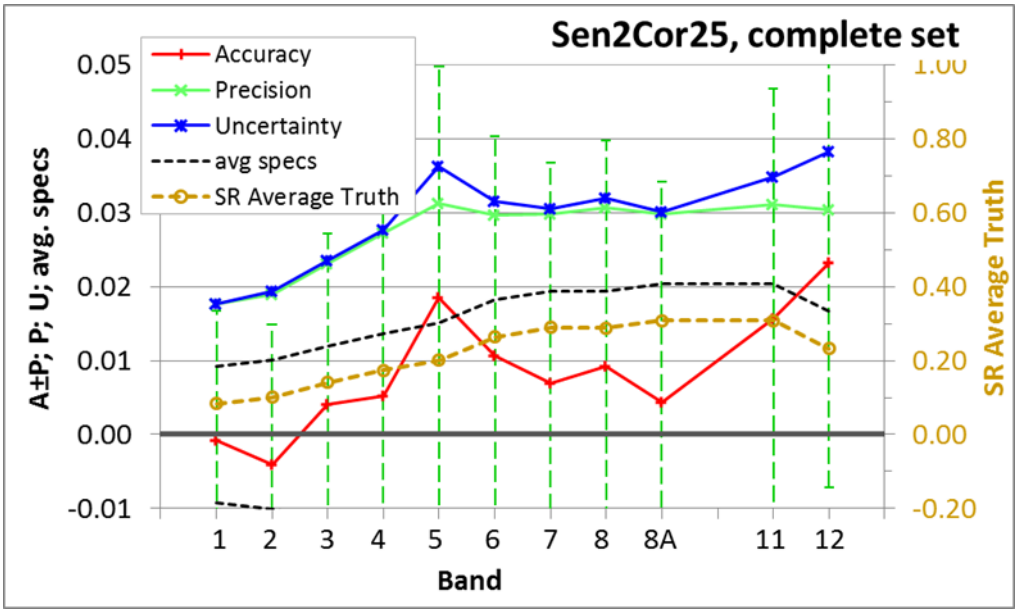

Figure 1: Average accuracy, precision, uncertainty (solid lines, left hand side scale) and surface reflectance reference (dashed line, right hand side scale) per band for Sen2Cor version 2.5 based on the ACIX-dataset.

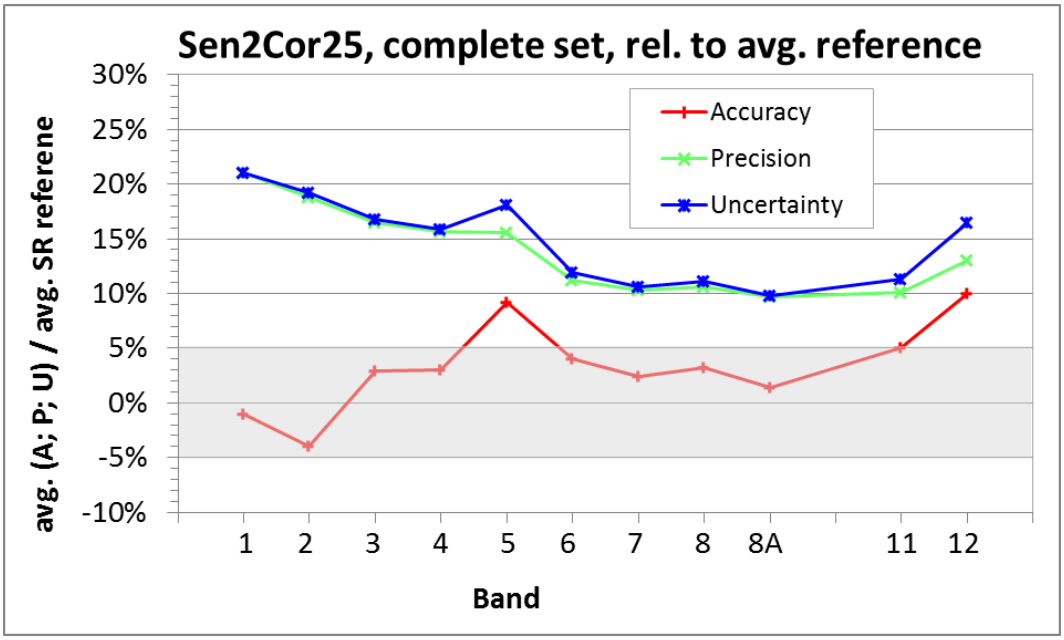

Figure 2: Average accuracy, precision and uncertainty relative to average surface reflectance reference per band for Sen2Cor version 2.5 based on the ACIX-dataset.

2.2.2 Water Vapour accuracy

Quantitative assessment of water vapour retrieval accuracy is determined by direct comparison of Sen2Cor output averaged over 9 km x 9 km region of interest around Sun photometer with reference value from AERONET Sun photometer.

The analysis is based on a large dataset of 559 match-ups at 25 AERONET locations distributed over all continents and all climate zones except Midlatitude S.

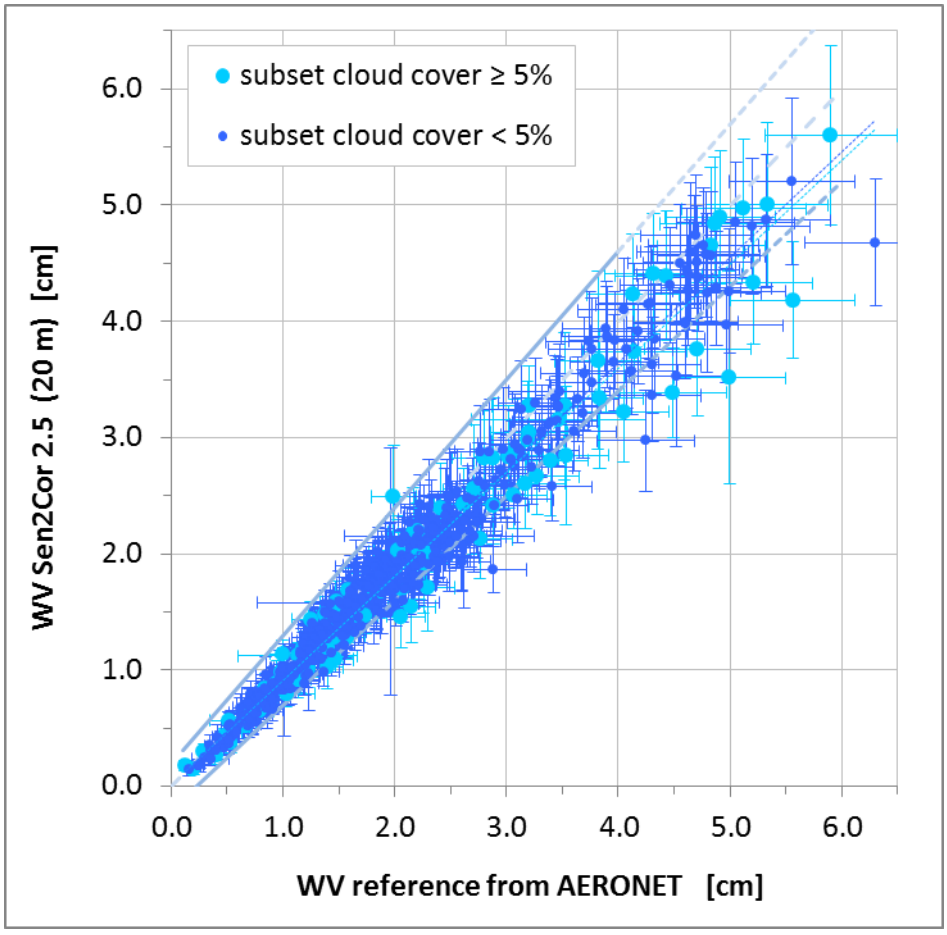

Figure 3: Correlation plot of Sen2Cor WV retrieval at 20 m resolution over WV reference from AERONET on basis of a data set at 25 AERONET sites. The dashed line indicates x=y and the solid lines show the limits of accuracy requirement $|\Delta WV| \leq 0.1 * WV_{ref} + 0.2$.

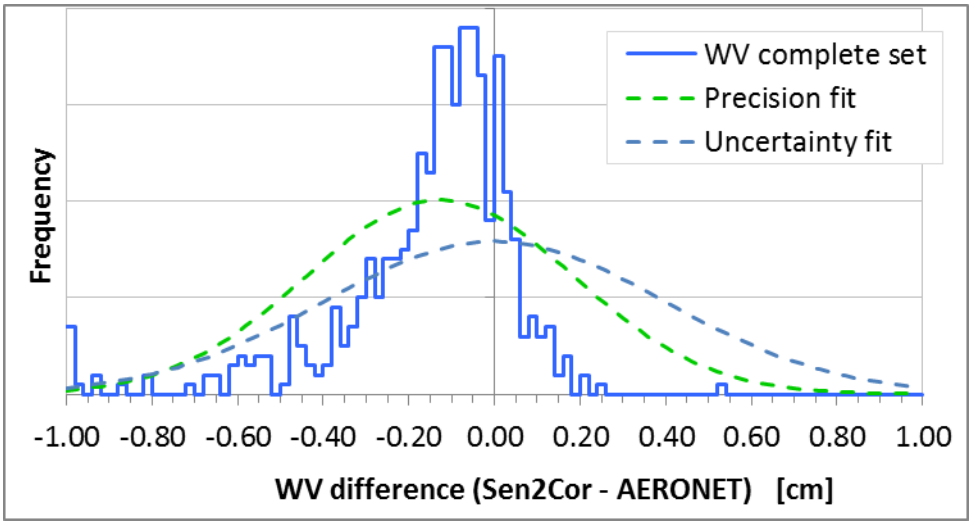

Figure 4: Histogram plot of WV (at 20 m resolution) retrieval difference to the reference value from AERONET. The green dashed curve gives a normal distribution computed with accuracy as mean value and precision as standard deviation. The blue dashed curve represents a normal distribution around zero with uncertainty as standard deviation.

Table 2-2: Statistical numbers reporting on WV-validation for Sen2Cor 2.5 on basis a data set at 25 AERONET sites.

WV statistics	
Total no. of granules	559
WV retrievals within requirement	92%
R^2 (Coefficient of variation)	0.97
r (Pearson's corr. coeff.)	0.98
MA (Median Accuracy value)	-0.13 cm
MP (Median Precision value)	0.22 cm
Uncertainty (U)	0.28 cm
Max WV difference	1.63 cm

Water vapour retrieval is very accurate with correlations over 0.98 and with 92% of retrievals within the requirement. Validation shows a trend for little underestimation of WV by Sen2Cor. The large maximum difference of WV retrieval occurs at WV reference value above 6 cm, which is an extreme value even for the tropics.

2.2.3 Aerosol Optical Depth accuracy

Quantitative assessment of aerosol optical depth retrieval accuracy is determined by direct comparison of Sen2Cor output averaged over 9kmx9km region of interest around Sun photometer with reference value from AERONET Sun photometer. The analysis is based on a large dataset of 559 match-ups at 25 AERONET locations distributed over all continents and all climate zones except Midlatitude S.

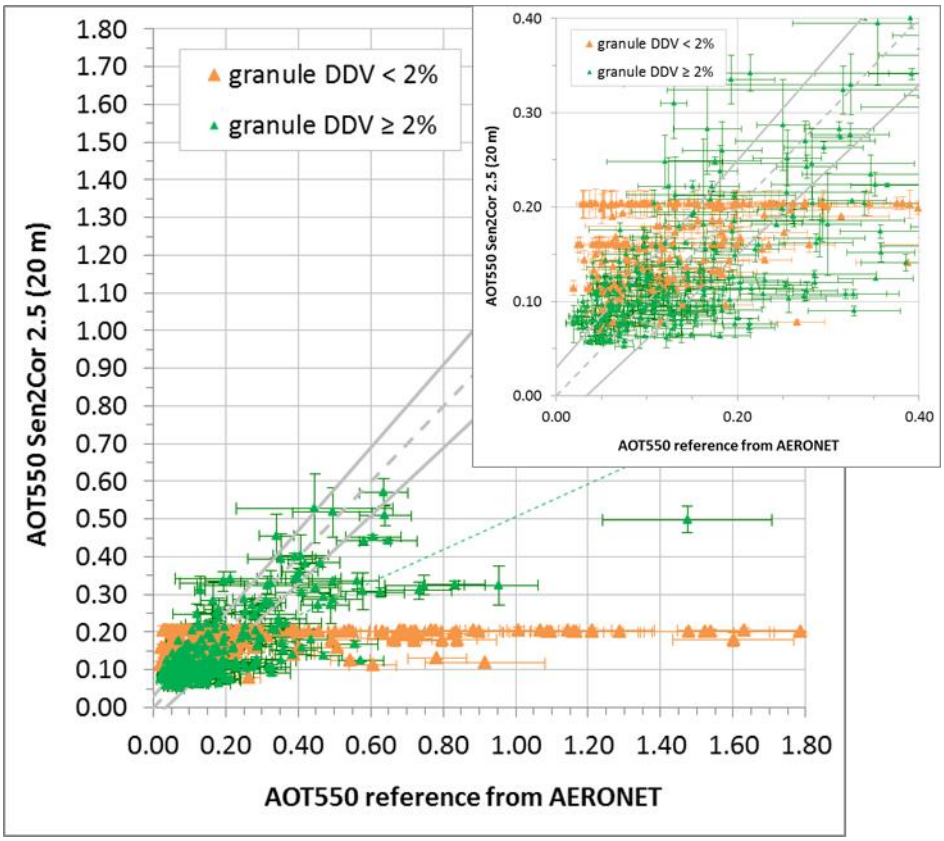

Figure 5: Correlation plot of Sen2Cor AOT_{550} retrieval at 20 m resolution over AOT_{550} reference from AERONET on basis of a data set at 25 AERONET sites. Green triangles are AOT_{550} retrieved with the DDV-algorithm and orange triangles are AOT_{550} resulting from the present fall-back solution (process with configured start VIS of 40 km). The dashed grey line indicates x=y and the solid grey lines show the limits of accuracy requirement $|\Delta AOT_{550}| \leq 0.1 * AOT_{550ref} + 0.03$. (Inset: zoom on low AOT values).

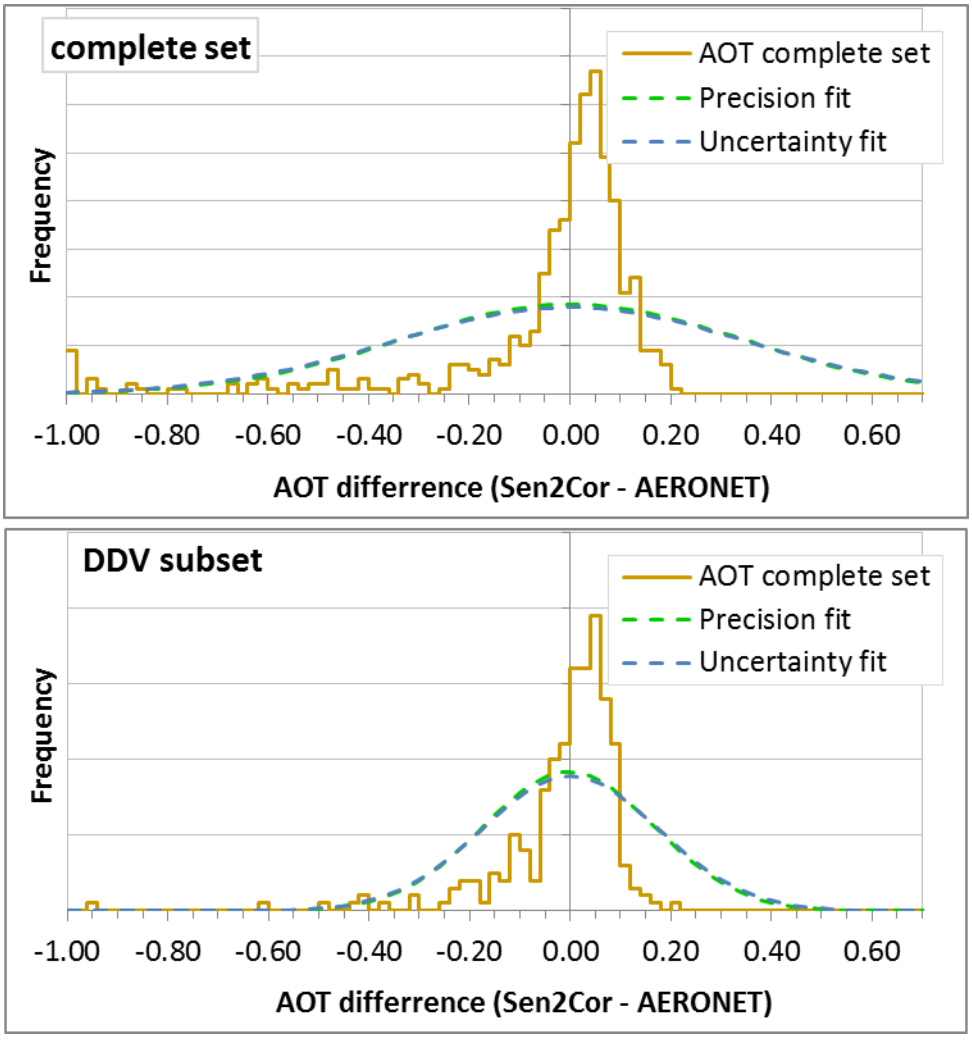

Figure 6: Histogram plots of AOT_{550} (at 20 m resolution) retrieval difference to the reference value from AERONET. The blue dashed curves give normal distributions around zero with uncertainty as standard deviation. The upper plot shows results for the complete data set and the lower plot for the subset of images containing more than 2% DDV-pixels.

Table 2-3: Statistical numbers reporting on AOT_{550}-validation for Sen2Cor 2.5 on basis of the ACIX data set excluding water sites. The DDV set is a subset of the complete data set limited to images which contain more than 2% DDV-pixels.

AOT statistics	Complete set	DDV set
Total no. of granules	559	277
Retrievals within requirement	41%	48%
R^2 (Coefficient of variation)	0.21	0.57
r (Pearson's correlation coeff.)	0.46	0.76
MA (Median Accuracy value)	0.003	-0.003
MP (Median Precision value)	0.24	0.12
U (Uncertainty)	0.25	0.12
Max AOT_{550} difference	1.59	0.98

Aerosol optical depth retrieval results are very different between the complete data set and the dataset limited to images with at least 2% of dense dark vegetation (DDV) pixels. The AOT-retrieval algorithm implemented in Sen2Cor requires DDV-pixels in the image. If there are not enough DDV-pixels present, then the processing is done with a fixed AOT leading to large AOT errors (Figure 5, Figure 6, Table 2-3).
Accuracy ± precision and uncertainty values are 0.00±0.12 and 0.12 for the DDV subset (Table 2-3), which is a very good performance increase since Sen2Cor version 2.4. Correlations are significant higher for the DDV-subset and it contains more retrievals within requirement. Nevertheless there are only about 50% of retrievals within requirement.

A processor evolution is in development to improve the results for arid regions where no DDV-pixels are present in the image.

2.2.4 Classification accuracy

Classification accuracy is evaluated by comparison of the Sen2Cor outputs with reference samples. The reference samples are generated by visual inspection and labelling of a validation data set, which was determined by stratified random sampling.

Current analysis of classification accuracy for Sen2Cor 2.5 using CCI data as auxiliary information is based on 14 Sentinel-2 L2A images over 13 test sites (Table 2-4).

Table 2-4: Selected test sites for Sen2Cor 2.5 validation

Site	Tile	Date (MM/DD/YYYY)	L1C Cloud cover
Antarctic	21EVK	2/4/2016	9.9
Barrax (Spain) 1	30SWH	5/9/2017	17.7
Barrax (Spain) 2	30SWH	5/19/2017	1.6
Berlin (Germany)	33UUU	5/4/2018	0.9
Casleo (Argentina)	19HDE	8/12/2016	21.7
Dunhuang (China)	46TFK	1/22/2018	29.4
Manila (Phillipines)	51PTS	3/19/2018	1.4
Rimrock (USA)	11TMM	5/12/2018	0.7
Yakutsk (Russia)	52VEP	3/8/2016	61.5
Etna Volcano (Italy)	33SVB	3/9/2017	6.9
Kilauea Volcano (USA - Hawaii)	05QKB	4/23/2018	28.4
Lagos (Portugal)	29SNB	8/8/2018	0.0
Buenos Aires (Argentina)	21HUC	8/27/2018	0.0
Tallin (Estonia)	35VLG	7/14/2018	2.1

Beside the Copernicus Sentinel-2 L2A images over core-test sites (defined in Calibration and Validation Plan ROCVP) for the regular validation of scene classification, 6 additional sites – Antarctic, two volcano sites and three coastal sites – were selected. Validation data set represents different atmospheric conditions (e.g. cloud cover), latitudes (various solar angles and seasons), topography (flat, rough and mountainous terrain), and land cover types (agricultural area, forests, water bodies, arid area, urban area, deserts, permanent ice, and active volcanos).

The accuracy assessment per test site is presented in Table 2-5. OA of clear pixels over land and water aggregate results for the Sen2Cor classes vegetation, non-vegetated and water. OA of clouds aggregates results for Sen2Cor classes cloud_medium_probability, cloud_high_probability and thin cirrus. The average

overall accuracy for 14 classification products reached 81.1±14.1%. The recognition of clear pixels over land and water reached OA of 91.5% and a consolidated OA for clouds recognition is 94.8% (Table 2-5).

Table 2-5: Accuracy assessment per test site for SCL product with 11 classes, and for clear land and water pixels, and clouds separation.

Site		OA	OA clear pixels	OA clouds	Pixel validated
Antarctic		94.7	96.8	98.8	527803
Barrax (Spain) -1		64.6	96.9	98.7	141546
Barrax (Spain) -2		90.5	98.7	99.5	104799
Berlin (Germany)		93.4	96.5	no clouds	51964
Casleo (Argentina)		63.8	86.1	98.1	186238
Dunhuang (China)		57.3	66.2	no clouds	105454
Manila (Phillipines)		82.1	90.0	91.6	106263
Rimrock (USA)		90.2	98.2	99.2	103394
Yakutsk (Russia)		69.9	93.8	92.9	177983
Etna Volcano (Italy)		95.8	97.9	99.4	132340
Kilauea Volcano (USA - Hawaii)		60.4	75.4	74.2	118357
Lagos (Portugal)		96.8	97.3	no clouds	69753
Buenos Aires (Argentina)		91.8	97.3	no clouds	31841
Tallin (Estonia)		84.3	90.4	95.6	71773
	Average	81.1	91.5	94.8	137822
	Stdev	14.1	9.4	7.4	

Commission and omission errors (corresponding to user's and producer's accuracies respectively) are presented in Table 2-6. Commission for recognition of clear pixels over land and water reached about 16% and omission error was 15%. Commission for recognition of clouds reached 25% while omission error was 11%. In total 1,929,508 pixels were validated.

Table 2-6: Summarized results of omission and commission classification errors for clear pixels and clouds detection for 14 Sentinel-2 images.

Clear pixels over land and water				
	Clear pixels Land-Water	Others	Sum	**Commission**
Clear pixels Land-Water	733113	78587	811700	16.136
Others	72526	1045282	1117808	26.874
Sum	805639	1123869	1929508	
Omission	15.011	18.818		
All clouds				
	Clouds	Others	Sum	**Commission**
Clouds	491769	30212	521981	25.013
Others	54967	1352560	1407527	5.082
Sum	546736	1382772	1929508	
Omission	10.788	2.642		

3. Processing Chain Status

3.1 Processing baseline

3.1.1 Evolution

Since 26/03/2018, Level 2A products are produced systematically over Europe and distributed in the Sentinel Data Hub (product type "MSIL2A").

On 23rd May 2018 processing baseline 02.08 was introduced. This baseline corrected a minor bug in the product metadata: the field:

<n1:L2A_Quality_Indicators_Info>

was renamed as:

<n1:Quality_Indicators_Info>,

in line with PSD 14.4.

On 06/11/2018 processing baseline 02.10 was introduced to reflect an evolution of upstream Level 1C products (L1C baseline 02.07, see the L1C Data Quality Report for details). The main evolutions of the product will be:

- Accurate tile sensing time
- Improved detector footprint masks
- Improved image boundary
- Reduction of Across-Track correlated noise

Processing baseline 02.11 was deployed on 21/11/2018. This baseline corrects anomaly #4 (terrain correction over cloudy pixels).

In the coming days, a new processing baseline (02.12) will be deployed. This version will be aligned with the public (toolbox) version of the Sen2cor 2.8.0 which will be released simultaneously. It will rely on OpenJPEG 2.3 for faster reading of L1C bands.

Baseline 02.12 will also introduce an optimization of the terrain correction to improve image quality over terrain with low relief, see figure below.

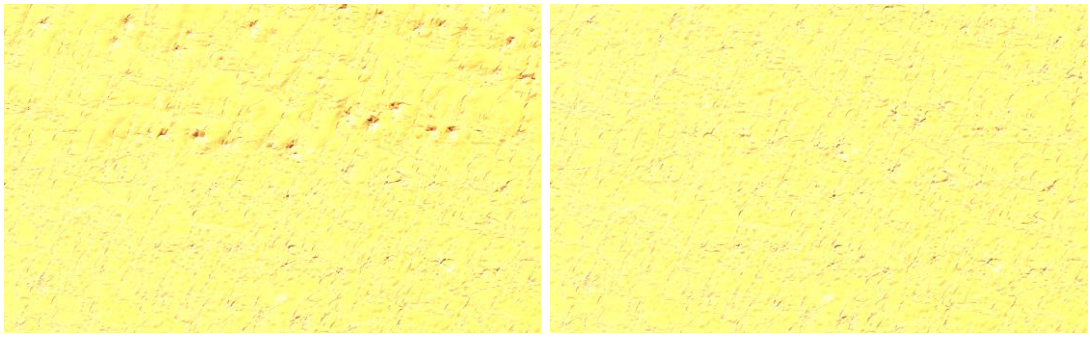

Figure 7: 10 m True Color Images of tiles 32RLV and 32LRU acquired on 14/04/2019. Left: processing baseline 02.11 – terrain correction is not applied on tile 32RLV which leads to a visual discontinuity in the image. Right: processing baseline 02.12 – terrain correction is applied on both tiles and no discontinuity can be seen.

3.1.2 Configuration and differences with Sen2cor Toolbox version

Baseline 02.11 uses Sen2cor defaults configuration parameters except:

- Terrain correction is activated,
- CCI AUX data is used to support scene classification.

Some differences can be found between L2A products generated by users with current Sen2cor Toolbox version and the products from the 02.11 baseline:

- The Digital Elevation Model (DEM) is different, which can impact terrain correction results,
- The JP2000 compression library is different, which leads to a slightly different size of the products and a different compression noise,
- Anomaly #4 is corrected in baseline 02.11, while this anomaly will be corrected in a future version of the toolbox version.

3.2 Status of Processing Baselines and Known Processing Anomalies

The following table provides the status of known L2A processing anomalies. Note that some L1C anomalies directly affect the quality of the L2A products. Users are invited to refer to the L1C Data Quality Report for a complete status.

Table 3-1: Anomaly and processing baseline summary.

Anomaly ID	Baseline number	02.07	02.08	02.09	02.10	02.11
	Deployment date	26/03/2018	23/05/2018	08/09/2018	06/11/2018	21/112018
	Anomaly title					
1	Wrong tile ID metadata	All products until 05/04/2018				
2	Incorrect No Data mask	Limited occurrences for pixels near the edge of the swath (Until 19/09/2018)				
3	Encoding of Quality Bands	Until 19/09/2018				
4	Terrain Correction over clouds	A few products				
5	Naming of quality mask files			A few products		
6	Cloud Probability mask	Some products				

4. Product Anomalies

4.1 Introduction

This chapter describes anomalies observed on the L2A production.

4.2 Incorrect Tile ID metadata (#1)

This minor anomaly affects the L1C_TILE_ID field of the tile metadata. The processing baseline of the source L1C product is incorrectly reported as 02.07 instead of 02.06. The issue has been corrected on 05/04/2018.

4.3 Incorrect No Data mask (#2)

In the Scene Classification mask (SCL) some pixels near the edge of the swath may be incorrectly flagged as "water" instead of "No Data". The issue has been fixed and has been deployed on 19/09/2018.

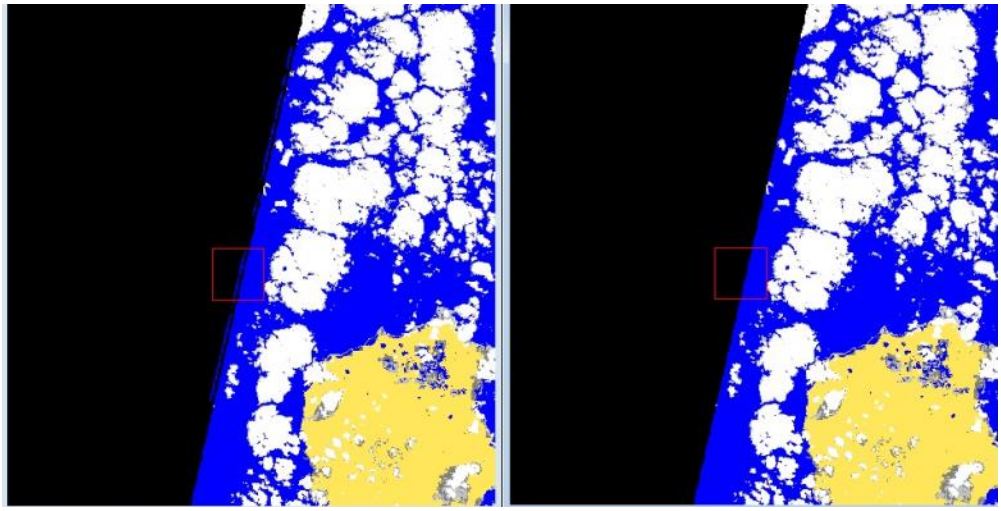

Figure 8: Incorrect No Data Mask (anomaly #2). Left: pixels incorrectly flagged as water (blue) near the swath edge. Right: same image after correction.

4.4 Encoding of Quality Bands (#3)

In products from processing baselines 02.07 and 02.08, the quality bands are coded over 16 bits instead of 8 bits as specified in the Product Definition Document (PDD). This minor anomaly affects the following bands: SCL, CLD, SNW, PVI, TCI. The correction has been deployed on 19/09/2018.

4.5 Terrain correction over clouds (#4)

This anomaly creates spurious topographic correction over cloudy pixels. Please note the impact of this anomaly is limited to the visual appearance of the images. Cloudy pixels are flagged in the scene classification mask and shall not be used for quantitative remote sensing.

Terrain correction has been de-activated for cloudy pixels with processing baseline 02.10.

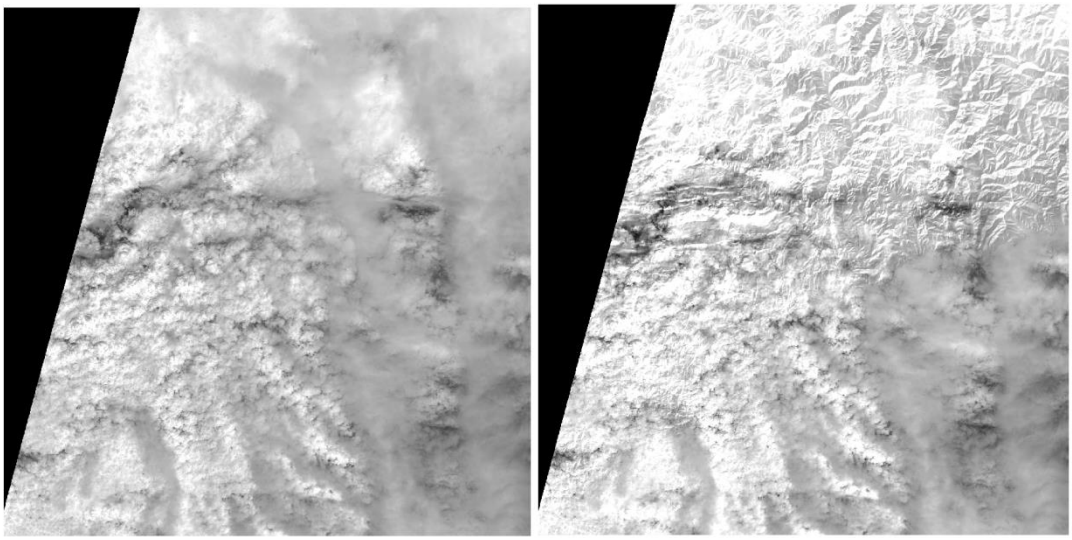

Figure 9: Band B04, Tile 32TLP from orbit S2B 7098. Left: L1C image; Right: L2A image. The topography seems to be visible through the opaque clouds. (Anomaly #4)

4.6 Naming of quality masks files (#5)

This anomaly affects the naming of the quality mask files in the QI_DATA folder. The "long name" convention (e.g. S2A_OPER_MSK…) is used instead of the "short name" convention (MSK_DEFECT…). This anomaly has been found on L2A products of orbit S2B 8458. It is currently under investigation.

4.7 Incorrect cloud probability near the boundary of the swath (#6)

This issue affects the computation of the cloud probability (CLDPRB mask) near the boundary of the swath. The mask extends outside the area of valid data. Users are advised to disregard the cloud probability values for pixels which are flagged as No Data in the spectral band images.

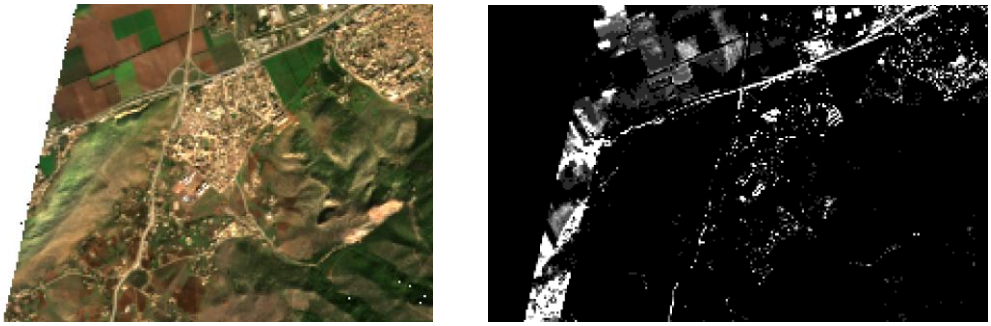

Figure 10: incorrect values of the cloud probability mask (CLDPRB) near the boundary of the swath. Left: L2A true colour image, Right: CLDPRB mask.

5. Product features

5.1 Scene classification

The current scene classification algorithm has some known limitations:

- Over-detection of clouds over bright targets,
- Under-detection of semi-transparent clouds or cloud edges,
- Cloud pixels miss-classified as snow (shaded parts of the clouds),
- Dark areas miss-classified as cloud shadows. This can occur in particular when bright objects are incorrectly classified as clouds,
- Topographic shadows may be miss-classified as water,
- Open fires can be miss-classified as cirrus.

As mentioned in section 3.1, these problems have been significantly reduced starting with baseline 02.09.

Starting with baseline 02.10, terrain correction is no longer applied for pixels identified as cloudy. This can lead to visual artefacts at the edges of semi-transparent clouds, see figure below.

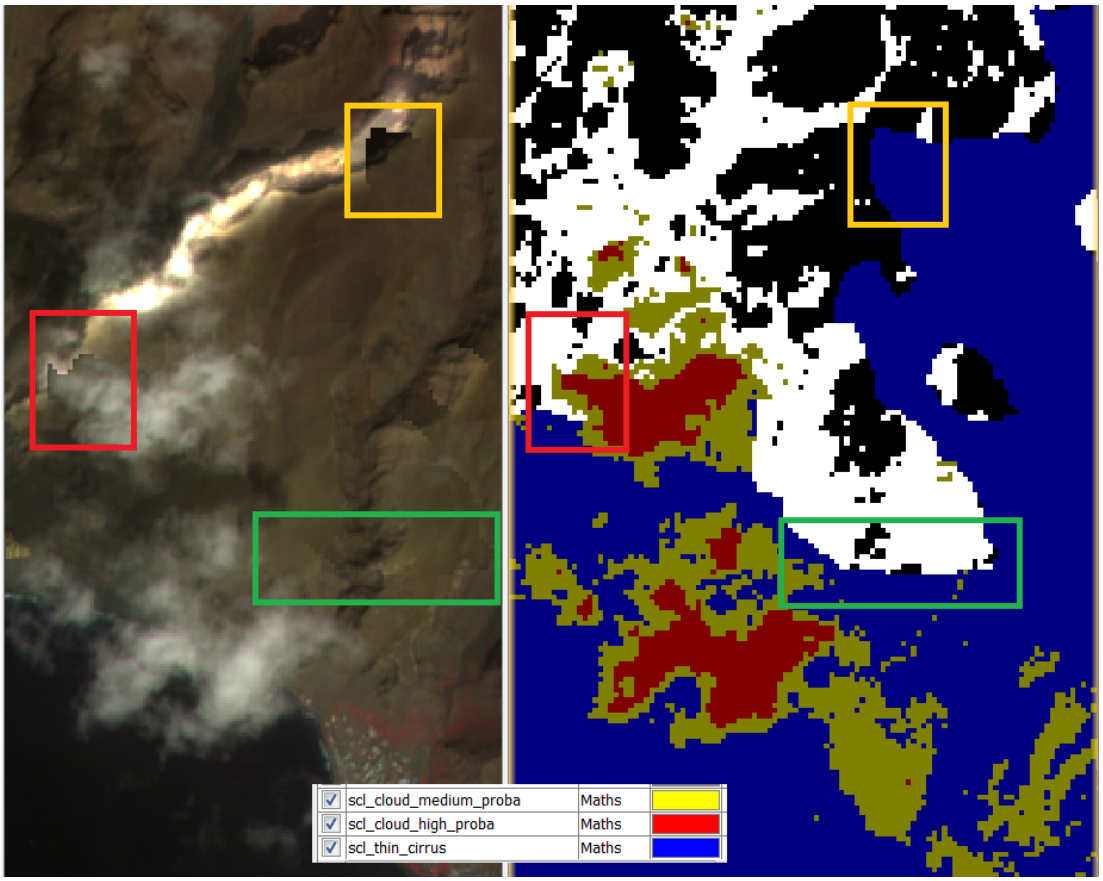

Figure 11: Visual artefacts at the edges of semi-transparent clouds.

Another known issue concerns the occurrence of blocky patterns on the Scene Classification mask, as illustrated in the figure below. This issue is due to the coarser resolution of the CCI auxiliary data used to improve the scene

classification. In some cases (as on Figure 12 – Left) it can lead to a local over-detection of clouds.

Figure 12: Blocky patterns on the scene classification layer (SCL). Left: near the coastline. Right: near city boundaries.

5.2 Overlap between tiles

The L2A products are processed at tile level and some differences can occur in the overlap area between adjacent tiles:

- The scene classification may be different for a few pixels
- The AOD and surface reflectances are generally different, although the difference should be small.

5.3 Terrain over-correction on shaded areas

Due to inaccuracies of the Digital Elevation Model, a strong terrain correction may be applied in totally or partially shaded areas. This results in a bluish colour in colour composite and inaccuracy in the surface reflectance.

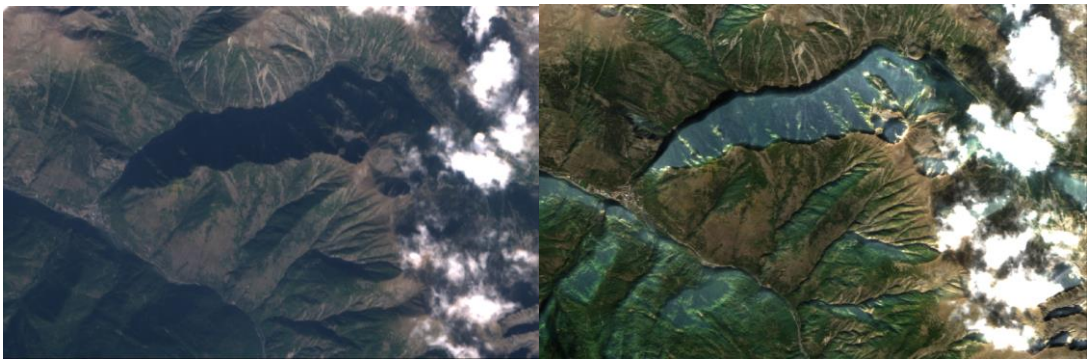

Figure 13: Terrain over-correction on shaded areas. Left: Level 1C true colour image, right: L2A true colour image.

5.4 Maximal Sun-Zenith Angle

Users are advised that products with a Sun-Zenith Angle (SZA) higher than 70° are processed with a clipped SZA value of 70°. This results in an under-correction of the atmospheric signal, which results in a bluish colour on the L2A

products. The surface reflectance of products with SZA > 70° should not be used for qualitative analysis. The value of the SZA can be obtained from the GRANULE metadata (MTD_TL.xml, field Mean_Sun_Angle/ZENITH_ANGLE).

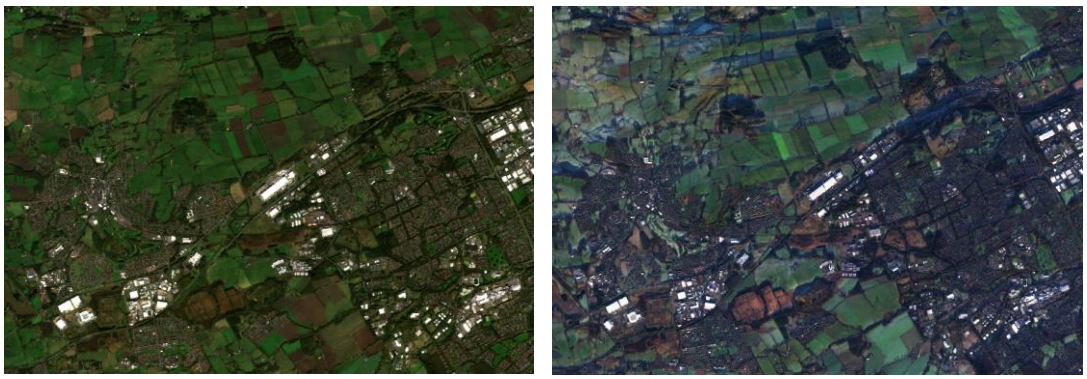

Figure 14: L2A True Colour Image of tile 30VVH; left: 10/10/2018, SZA = 62°; right: 24/12/208, SZA = 80°. The radiometric quality for surface reflectance is not ensured for SZA > 70°.

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