COPERNICUS SPACE COMPONENT SENTINEL OPTICAL IMAGING

MISSION PERFORMANCE CLUSTER SERVICE

Data Quality Report

Sentinel-2 MSI L2A

March 2024

Ref.: OMPC.CS.DQR.002.02-2024
Issue: 71.0
Date: 11/03/2024
Contract: 4000136252/21/I-BG

Customer:	ESA	**Document Ref.:**	OMPC.CS.DQR.002.02-2024
Contract No.:	4000136252/21/I-BG	**Date:**	11/03/2024
		Issue:	71.0

Project:	COPERNICUS SPACE COMPONENT SENTINEL OPTICAL IMAGING MISSION PERFORMANCE CLUSTER SERVICE		
Title:	Data Quality Report - MSI L2A		
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Distribution:	ESA, published in Sentinel Online		
Accepted by ESA	V. Boccia, ESA Deputy TO		S. Dransfeld, ESA TO
Filename	OMPC.CS.DQR.002.02-2024 - i71r0 - MSI L2A DQR March 2024.docx		

Changes Log

Version	Date	Changes
71.0	11/03/2024	First version

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Version	Section	Answers to RID	Changes

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1. Introduction

1.1 Scope of the Document

This document provides the status of Sentinel-2 mission Level-2A (L2A) products data quality. It refers to systematic production from processing baselines 02.07 and higher and complements the Data Quality Report for Level-1C (L1C) products.

Please note that the data quality status before the beginning of 2023 is covered by the Annual Performance Report of 2022. Please refer to this document as well as former Data Quality Reports (DQR) if needed.

It documents the measured product performances, the status of L2A processing chain, and the list of known anomalies on the production.

Additional performance metrics (in particular geometry) are reported in the companion L1C Data Quality Report. Similarly, anomalies affecting L1C products documented in that report also impact L2A products.

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 and performance have generally improved since then. Detailed inter-comparison of cloud masking of Sen2Cor with other processors is published in S. Skakun et al., "Cloud Mask Intercomparison eXercise (CMIX): An evaluation of cloud masking algorithms for Landsat 8 and Sentinel-2", Remote Sensing of Environment, Volume 274, 2022, 112990, ISSN 0034-4257[1].

1.2 Main points for this month

- Updated assessment of the classification accuracy over no snow/snow covered products (see section 3.2.4),
- Revised statistics for the monitoring of the Aerosol Optical Depth (CAMS) and the Total Column of Water (ECMWF) auxiliary data embedded in L1C and L2A products (see section 4),
- Please be aware that there is an inconsistency in the L_{ref} value for the B12 noted in certain Sentinel-2 documents: 1.5 [W/m²/sr/µm] instead of 1.7 [W/m²/sr/µm]. To obtain information on the band parameters for each spectral band, kindly refer to the L_{ref} values directly extracted from the MRD (Mission Requirements Document, Table 4),
- Deployment of Copernicus DEM at 30m resolution for Sentinel-2 products (see more details in the section 2.1),
- Availability of the Copernicus Sentinel-2 Collection-1 data (see section 7.1),
- New organization of the Sentinel Online website: please visit the SentiWiki webpages,
- Sentinel-2 products (including Collection-1) are available on the Copernicus Data Space Ecosystem.

[1] https://doi.org/10.1016/j.rse.2022.112990

2. Processing Baseline Status

2.1 Processing baseline description

On December 13th, 2023, the **processing baseline 05.10** was deployed. The format of the L1C and L2A products within this new PB remains the same as outlined in the current Product Specification Document (version 14.9).

The operational processor for this processing baseline remains the same as the one operated to generate the Copernicus Sentinel-2 Collection-1 (for more details please refer to the section 7.1), combined with the use in operation of the **Copernicus DEM at 30 meters ground spatial resolution**. As a reminder, the previous processing baseline 05.09 was using the same operational processor but with the Copernicus DEM at 90 meters. Then, the Copernicus DEM at 30 meters being already used for the historical archive reprocessing, the new processing baseline 05.10 ensures continuity with the Copernicus Sentinel-2 Collection-1 tagged with the processing baseline identifier 05.00.

In addition, we remind here that a **radiometric offset** on reflectance digital numbers has been introduced with processing baseline 04.00 deployed on January 25th, 2022, and that it is still present in the more recent processing baselines. Then, the dynamic range is shifted by a band-dependent constant: BOA_ADD_OFFSET. This offset allows encoding negative surface reflectances that may occur over very dark surfaces. **From the user's point of view, the L2A Surface Reflectance (L2A_SR) shall be retrieved from the output radiometry as follows**:

- Digital Number DN=0 remains the "NO_DATA" value
- For a given DN in [1; 1;2^15-1], the L2A BOA reflectance value is:

L2A_SRi = (L2A_DNi + BOA_ADD_OFFSETi) / QUANTIFICATION_VALUEi

The radiometric offset value is reported in the field:

General_Info/Product_Image_Characteristics/BOA_ADD_OFFSET_VALUES_LIST/BOA_ADD_OFFSET

of the User Product Metadata, as well as in the field:

Image_Data_Info/Radiometric_Info/BOA_ADD_OFFSET_VALUES_LIST/BOA_ADD_OFFSET

of the Datastrip Metadata. It is set to -1000 Digital counts for all spectral bands.

For further information on the former processing baselines, please refer to https://sentiwiki.copernicus.eu/web/s2-processing#S2Processing-L2AProcessingBaseline.

2.2 Configuration and differences with Sen2cor 'User' version

The Level-2A operational processor generates, using algorithms of scene classification and atmospheric correction included in Sen2Cor processor, Level-2A (Surface Reflectance) products from Level-1C products. Level-2A can also be generated by the User from the Level-1C product using the standalone version of the Sen2Cor processor: https://step.esa.int/main/snap-supported-plugins/sen2cor/.

Sen2cor configuration applied for the Level-2A operational products:

- has Terrain correction activated,
- uses CCI AUX data to support scene classification.

Since Baseline 02.11, individual configuration parameters are set as follows and are the same default parameters provided with Sen2cor standalone version:

Log_Level	INFO
DEM	Copernicus DEM at 30 m since baseline 05.10 Copernicus DEM at 90 m since baseline 03.00 Planet-DEM 90 m for previous baselines
Generate_DEM_Output	FALSE
Generate_TCI_Output	TRUE
Generate_DDV_Output	FALSE
Downsample_20_to_60	TRUE
Aerosol_Type	RURAL
Mid_Latitude	SUMMER
Ozone_Content	get the best approximation from metadata
WV_Correction	1: only 940 nm bands
VIS_Update_Mode	1: variable visibility
WV_Watermask	1: land-average
Cirrus_Correction	FALSE
DEM_Terrain_Correction	TRUE
BRDF_Correction	0: no BRDF correction
Adj_Km	1.000
Visibility km	40.0
Smooth_WV_Map	100.0
WV_Threshold_Cirrus	0.25

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

- If the Digital Elevation Model (DEM) is different, this can impact terrain correction results. Users have access to SRTM-DEM and Copernicus DEM at 90 m and 30 m whereas L2A operational products uses:
  - Planet-DEM for processing baselines >=02.11,
  - Copernicus DEM at 90 m for processing baselines >= 03.00,
  - Copernicus DEM at 30 m for processing baselines >= 05.10.
- The JP2000 compression library is different, which leads to a slightly different size of the products and a different compression noise.

3. Measured Product Performances

3.1 Performances Overview

The following overview table provides a summary of the Level 2A products data quality performances. Note that the cloud masking performance and performances for water vapour and aerosol optical thickness reported in this issue of the L2A Data Quality Report have been assessed with Sen2cor versions 2.10 (operational processing, PBL 4.00), and may thus slightly differ from the performance of the current processing baseline. Surface reflectance performance is based on Sen2Cor 2.8.

Table 3-1: Summary of Sentinel-2 L2A products measured performances for mission key requirements.

Requirement on	Description	Measured performance
Surface reflectance	Uncertainty goal of Bottom-of-Atmosphere reflectance retrieval: $U(\rho) \leq 0.05\rho_{reference} + 0.005$	79% of retrieved SR values are within uncertainty goal
Water Vapour	Uncertainty goal of WV retrieval: $U(WV) \leq (0.1{*}WV_{ref}{+}0.2)$ g/cm2	96% of retrieved Water vapour values are within uncertainty goal
Aerosol Optical Thickness at 550 nm	Uncertainty goal of AOT550 retrieval: U(AOT) ≤ 0.1*AOTref+0.03	48% (57%) of Aerosol optical thickness values at 550 nm retrieved with DDV algorithm (with CAMS data as fallback solution) are within uncertainty goal
Classification / Cloud masking	No requirement defined.	Commission of clear pixels ranges from 0% to 8% depending on test site with the higher values mostly due to confusion with transparent clouds. It is 30% for snow covered winter-season products. Balanced overall accuracies of clear vs cloud pixels range between 84 – 100% and is 81% for snow covered winter-season products

Measured performances are detailed in the following sections.

Starting with Processing Baseline 04.00, Sentinel-2 L2A products are compliant with the CEOS-ARD requirements at the threshold level (see https://ceos.org/ard/).

3.2 Performances

3.2.1 Surface reflectance radiometry

New quantitative assessment of surface reflectance radiometric retrieval for Sen2Cor 2.8 was done relative to a limited number of surface reflectance reference measurements (B. Pflug *et al.*, "Evaluation of Sen2Cor Surface Reflectance products over land surface with reference measurements on ground", IGARSS 2022 - 2022 IEEE International Geoscience and Remote Sensing Symposium, Kuala Lumpur, Malaysia, 2022, pp. 4308-4311, doi: 10.1109/IGARSS46834.2022.9883369). Measurements at RadCalNet sites LaCrau and Gobabeb were provided by CNES and RadCalNet-teams and measurements over test sites in Germany were provided by DLR.

The data set used contains 40 sample days from October 2017 to May 2018 for RadCalNet site Gobabeb, 21 sample days from January to September 2018 for RadCalNet site LaCrau, and 4 sample days from May 2018 to October 2021 for different locations in North-Eastern Germany. Reference measurements from RadCalNet sites Gobabeb and LaCrau are reused from Atmospheric Correction Intercomparison eXercise ACIX-2 (G. Doxani *et al.*, "Atmospheric Correction Inter-Comparison Exercise", Remote Sensing, 10 (352), pp 1-18. DOI: doi:10.3390/rs10020352 ISSN 2072-4292). They were provided by CNES for Sentinel-2 bands B02 to B11 in the same angular conditions as Sentinel-2A & 2B observations over the sites.
The site Gobabeb is located in Namibia in a desert environment without vegetation. The site LaCrau is located in the South of France and has sparse vegetation cover. The test areas in Germany represent flat terrain containing meadows and soil in a vegetated environment. Note that this data set is still too small for providing statistically reliable information. It will be extended with availability of new reference measurements.

The quantitative assessment of surface reflectance radiometric performance is provided for Sen2Cor version 2.80 'user' processing with CAMS fall back.

The correlation plot of SR retrieval by Sen2Cor over reference measurements on ground (Figure 1) shows good performance of Sen2Cor SR retrieval for the investigated data set. Results look similar to equivalent plots in the literature. The total uncertainty of SR retrieval with Sen2Cor over all sites is about 0.02 respectively 9% and nearly 80% of SR retrievals are compliant with uncertainty goal $\Delta SR \leq 0.05 * SR_{ref}$ +0.005. Systematic uncertainty $U_{sys}(SR)$= (0.02 ±0.007) ∗SR + (0.0 ±0.002) is well within the uncertainty goal. Figure 2 gives deeper insight into SR retrieval performance by looking to average systematic uncertainties per band. Whereas random uncertainty is little increasing with band number respectively with SR values, we can observe much higher systematic uncertainty for B05 and B11. The origin for that is still not cleared. Current interpretation is that it may be caused by WV absorption which is present in both bands.

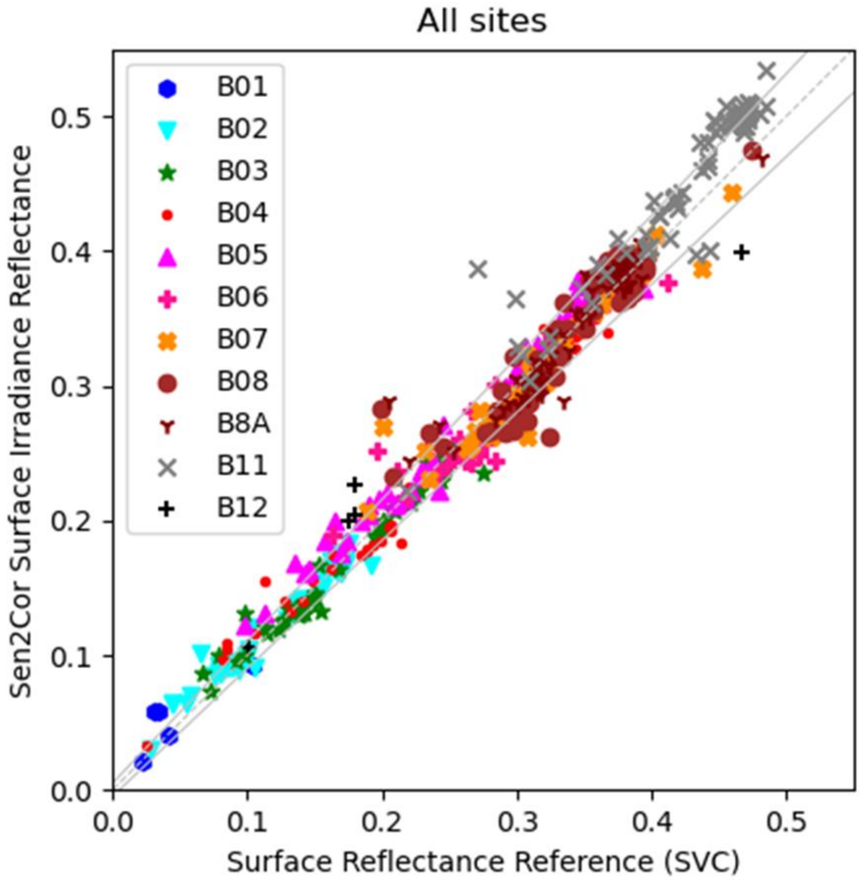


Figure 1: Correlation plot of SR retrieval by Sen2Cor over reference measurements on ground.

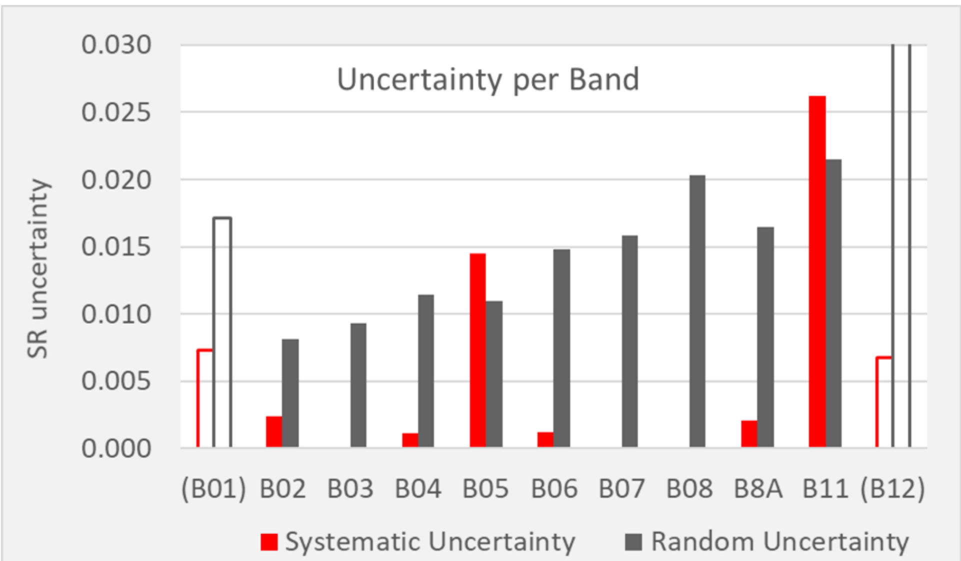


Figure 2: Average SR retrieval performance per band estimated by comparison with ground measurements. B01 and B12 are shown with empty bars because they result from 4 campaign sample days only. There are no measurements from LaCrau and Gobabeb for B01 and B12.

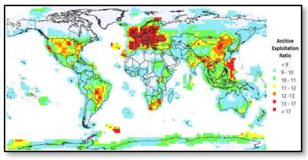
3.2.2 Water Vapour accuracy

Quantitative assessment of water vapour retrieval uncertainty is determined by direct comparison of Sen2Cor output averaged over 9 km x 9 km region of interest around Sun photometer location with ±15 min time average reference value from AERONET Sun photometer.

The analysis is based on a large dataset of 1989 match-ups in year 2022 at 76 AERONET locations distributed over all continents and all climate zones.

Table 3-2 : Test data selection: AERONET data (level ≥ 1.5) available within ±15 min to overpass time. Number of tiles used for analysis per continent. Data selection oriented on data use (1/3 weight) and area of continent (2/3 weight).

climate zone	N-America	S- America	Europe	Africa	Asia	Australia	No. of Sites	No. of Tiles
Polar	72		154				**7**	226
Temperate	159		242				**14**	401
Midlatitude N	248		191	45	213		**21**	697
Subtropical N	85			101	116		**13**	302
Tropical		78		78	39	19	**13**	214
Subtropical S		9		61		11	**5**	81
Midlatitude S		23		0		34	**4**	57
Aural		11					**1**	11
number of Tiles	**564**	**121**	**587**	**285**	**368**	**64**	**76**	**1989**
percentage of Tiles	**28%**	**6%**	**30%**	**14%**	**19%**	**3%**		
⅔ area +⅓ access	18%	9%	30%	15%	23%	5%		
data access	17%	0.4%	76%	0.1%	4%	3%		
area fraction	18%	13%	8%	22%	33%	6%		



The correlation plots of WV retrieval by Sen2Cor 2.10 (PBL 4.00) over AERONET reference are shown in Figure 3.

Water vapour retrieval is very accurate up to really high WV content with 96% of retrievals within the uncertainty goal. Average WV retrieval uncertainty is 0.23 g/cm^2. Validation shows a trend for little underestimation of WV by Sen2Cor confirmed by systematic part of the uncertainty:

$U_{sys}(WV) = (-0.08 \pm 0.003) * WV + (0.01 \pm 0.006)$

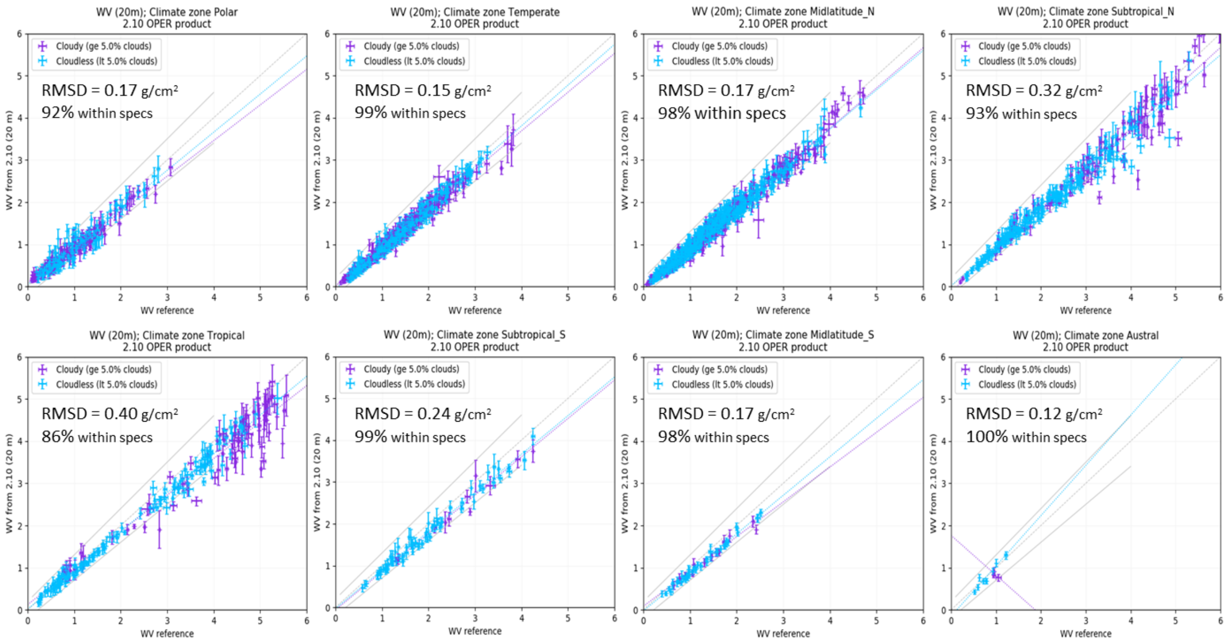


Figure 3: Correlation plots of Sen2Cor 2.10 (PBL 4.00) WV retrieval at 20 m resolution over WV reference from AERONET per climate zone on basis of a data set at 76 AERONET sites. *The dashed line indicates x=y and the solid lines show the limits of uncertainty goal* $U(WV) \leq (0.1 \cdot WV_{ref}+0.2)\ g/cm^2$*)*

3.2.3 Aerosol Optical Thickness

Quantitative assessment of aerosol optical thickness retrieval uncertainty is determined by direct comparison of Sen2Cor output averaged over 9 km x 9 km region of interest around Sun photometer with ±15 min time average reference value from AERONET Sun photometer. The analysis is based on a large dataset of 1989 match-ups in year 2022 at 76 AERONET locations distributed over all continents (see Figure 3 for more details).

The correlation plots of AOT retrieval by Sen2Cor 2.10 (PBL 4.00) over AERONET reference are shown in Figure 4. The data were processed with DDV algorithm respectively using AOT from the Copernicus Atmosphere Monitoring Service (CAMS) as fall back-solution for AOT-retrieval when there are less than 2% Dense Dark Vegetation (DDV) pixels in the image.

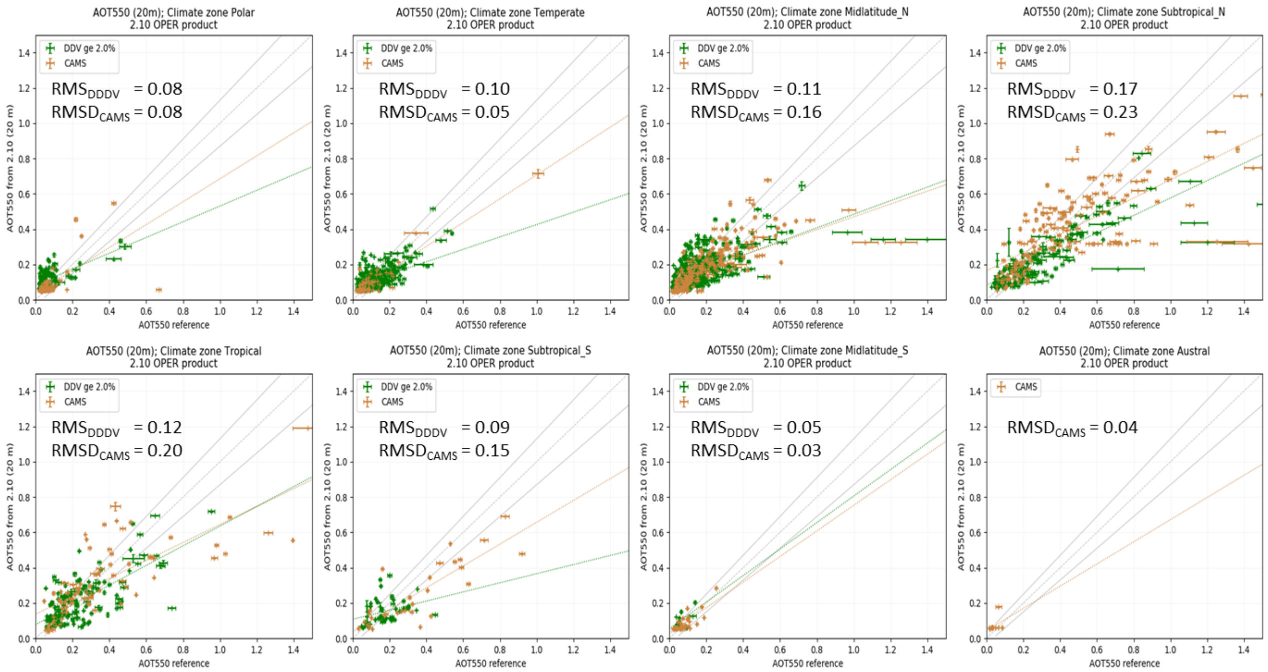


Figure 4: Correlation plot of Sen2Cor AOT$_{550}$ retrieval at 20 m resolution over AOT$_{550}$ reference from AERONET per climate zone on basis of a data set at 76 AERONET sites. *Green triangles are AOT$_{550}$ retrieved with the DDV-algorithm and orange triangles are AOT$_{550}$ resulting from using CAMS data as fall-back solution. The dashed grey line indicates x=y and the solid grey lines show the limits of uncertainty goal U(AOT$_{550}$) ≤ 0.1*AOT$_{550ref}$+0.03.*

The AOT-retrieval algorithm implemented in Sen2Cor requires DDV-pixels in the image. If there are not enough DDV-pixels present, then the auxiliary CAMS files embedded in the L2A products are used as fall-back solution. Therefore, aerosol optical thickness retrieval results are analysed separately for the DDV algorithm and the CAMS-fall-back solution. The DDV algorithm gives 25% to 63% of values within uncertainty goal dependent on climate zone (average 48%) with average total uncertainty of 0.11. Validation shows a trend for underestimation of higher AOT by DDV algorithm implemented in Sen2Cor confirmed by systematic part of the uncertainty U_{sys}^{DDV}(AOT) = (-0.54 ±0.01) ∗AOT + (0.08 ±0.003). CAMS fall-back solution mostly is activated in arid, non-vegetated regions or during winter time. It gives 34% to 80% of values within uncertainty goal dependent on climate zone (average 57%), however with larger average uncertainty of 0.16. This larger uncertainty results at least partly from the higher AOT-values present in situations when CAMS data are used. Systematic uncertainty U_{sys}^{CAMS}(AOT) = (-0.42 ±0.01) ∗AOT + (0.08 ±0.005) again shows a trend for AOT underestimation relative to AERONET at higher AOT values.

3.2.4 Classification accuracy

Classification performance is evaluated by comparison of the Sen2Cor outputs with reference samples. The reference samples were labelled visually based on the RGB and false-RGB composites, cirrus band layer, and the spectral profiles.

Current analysis of classification accuracy for Sen2Cor 2.11 SCL products were evaluated on a set of 19 Sentinel-2 L2A scenes of PB 05.09 at 5 test sites (Table 3-3) for non-snow-covered products and on a set of 2 Sentinel-2 L2A scenes for test site Yakutsk with snow coverage. These 5 test sites were selected as they are distributed over different continents, covering different climate zones, and including various seasons, and environments. The scene selection is rotated on a monthly basis for each site with cloud cover closest to 20% and no data pixels of less than 33%. Scenes with snow cover of less than 50% are considered non-snow-covered, whereas scenes with snow cover of more than 50% are considered snow-covered. The validation results for snow-covered products are reported separately from non-snow-covered products. 9 scenes are from 2022 under PB 04.00 and 12 scenes are from 2023 under PB 05.09.

Table 3-3: Selected test sites for Sen2Cor 2.11 validation

Site	Tile	Date	Cloud cover (%)	No data pixels (%)	Processing Baseline (PB)	Snow cover >50%
Potsdam (Germany)	T33UUU	22 March 2022	6.07	0	04.00	No
		4 August 2022	18.58	0	04.00	No
		3 January 2023	21.28	32.58	05.09	No
		12 June 2023	19.12	32.32	05.09	No
		7 November 2023	27.44	0	05.09	No
Rimrock (USA)	T11TMM	24 April 2022	7.27	1.79	04.00	No
		16 September 2022	28.12	2.00	04.00	No
		8 February 2023	21.44	1.88	05.09	No
		25 July 2023	25.66	27.98	05.09	No
		25 December 2023	40.18	1.80	05.09	No
Murcia (Spain)	T30SXH	15 May 2022	24.01	0	04.00	No
		7 October 2022	11.00	0	04.00	No
		11 March 2023	29.42	0	05.09	No
		8 August 2023	10.94	0	05.09	No
Bandung (Indonesia)	T48MZT	10 June 2022	26.48	6.48	04.00	No
		22 November 2022	96	0.86	04.00	No
		6 April 2023	48.40	0.75	05.09	No
		18 September 2023	30.40	0.62	05.09	No
Yakutsk (Russia)	T52VEP	28 July 2022	12.84	0	04.00	No
		1 May 2023	15.48	0	05.09	Yes
		28 October 2023	27.16	0	05.09	Yes

Table 3-4: Summary of the cloud masking validation results for 4 study areas with no snow cover. True values are in columns and predicted values are in rows.

Potsdam (T33UUU)

	Clear	Cloud	Sum	UA	CE	OA
Clear	**63%**	3%	66%	96%	4%	92%
Cloud	5%	**29%**	34%	86%	14%	
Sum	68%	32%	100%			
PA	93%	91%				Balanced OA
OE	7.0%	8.6%				**94%**

Rimrock (T11TMM)

	Clear	Cloud	Sum	UA	CE	OA
Clear	**52%**	3%	55%	95%	5%	94%
Cloud	3%	**42%**	45%	93%	7%	
Sum	55%	45%	100%			
PA	95%	94%				Balanced OA
OE	5.3%	5.9%				**95%**

Murcia (T30SXH)

	Clear	Cloud	Sum	UA	CE	OA
Clear	**51%**	3%	55%	94%	6%	92%
Cloud	5%	**41%**	45%	90%	10%	
Sum	56%	44%	100%			
PA	92%	92%				Balanced OA
OE	8.2%	7.7%				**93%**

Bandung (T48MZT)

	Clear	Cloud	Sum	UA	CE	OA
Clear	**38%**	3%	41%	92%	8%	84%
Cloud	12%	**47%**	59%	79%	21%	
Sum	50%	50%	100%			
PA	76%	93%				Balanced OA
OE	24.5%	6.9%				**84%**

Yakutsk

	Clear	Cloud	Sum	UA	CE	OA
Clear	75%	**0%**	75%	100%	0%	100%
Cloud	0%	**25%**	25%	99%	1%	
Sum	75%	25%	100%			
PA	100%	99%				Balanced OA
OE	0.2%	0.7%				**100%**

The accuracy assessment for cloud masking per test site is presented in Table 3-4 for products without snow cover. Sen2Cor classes cloud medium probability, cloud high probability and thin cirrus are aggregated to clouds, whereas Sen2Cor classes water, vegetated, non-vegetated and snow are aggregated to clear pixels. Commission and omission errors correspond to user's (UA) and producer's (PA) accuracies respectively. Balanced overall accuracy (OA) is the average of omission (OE) and commission (CE) errors. Results show good cloud masking performance with balanced overall accuracies of clear vs cloud pixels ranging between 90-98%. In terms of commission errors of the clear pixel the range is between 0-13% with the lower values in Murcia and Potsdam and higher in Rimrock and Bandung.

Table 3-5: Summary of the cloud masking validation results for snow covered products. True values are in columns and predicted values are in rows.

Yakutsk (T52VEP, winter – with snow cover)

	Clear	Cloud	Sum	UA	CE	OA
Clear	31%	13%	**44%**	70%	30%	84%
Cloud	3%	54%	**56%**	95%	5%	
Sum	**33%**	**67%**	**100%**			
PA	92%	80%				Balanced OA
OE	7.8%	19.6%				**81%**

The accuracy assessment for cloud masking on snow covered products (so far only test site Yakutsk) is presented in Table 3-5. Results show worse cloud masking performance compared to products without snow cover, with balanced overall accuracy of clear vs cloud pixels of 81%. Commission errors of the clear pixel is 30%. It is important to consider that labelling the snow-covered product is more challenging than products without snow cover, which leads to higher uncertainties in the labelled masking references. There are more (longer) shadows in winter due to the low sun elevation, which are difficult to recognize over bright snow surface.

Figure 5Figure 5 to Figure 7 Figure 7 show the misclassification of the clear, thin cirrus, and cloud high probability pixels in more details in the form of spider plots. Figure 5 shows the misclassification of omitted clear pixels and the real classes of the committed clear pixels. There are 3% clear pixels misclassified as thin cirrus in Bandung, 1% in Murcia, 1% in Potsdam, and 2% in Yakutsk winter scenes. In Yakutsk winter scene, there are 12% of cloud shadow pixels misclassified as clear pixels. Figure 6 Figure 6shows the misclassification of omitted thin cirrus pixels and the real classes of the committed thin cirrus pixels. These graphs show mostly confusion between different types of clouds (thin cirrus, high probability, and medium probability). In Rimrock scene, there are 5% thin cirrus pixels misclassified as non-vegetated. Figure 7 shows the misclassification of omitted cloud high probability pixels and the real classes of the committed cloud high probability pixels. These graphs also show mostly confusion between different types of clouds. In conclusion, cloud pixel identification on top of land surface by Sen2cor on these 7 PB 05.09 scenes are relatively good. However, in snow covered scenes, cloud shadow pixels on snow are often misclassified as clear pixels due to their brighter reflectance compared to cloud shadow on land without snow cover.

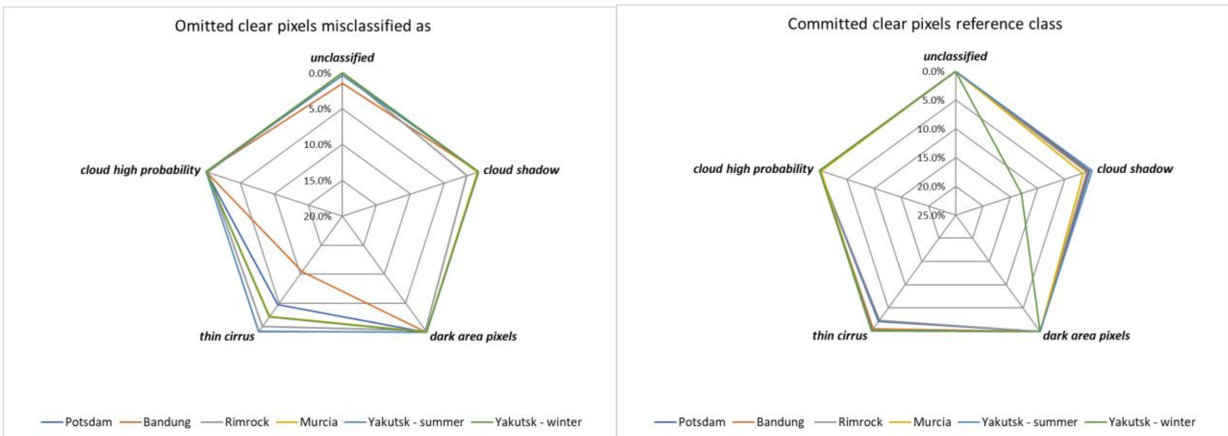


Figure 5: Spider plots of the omission and commission errors of clear pixels

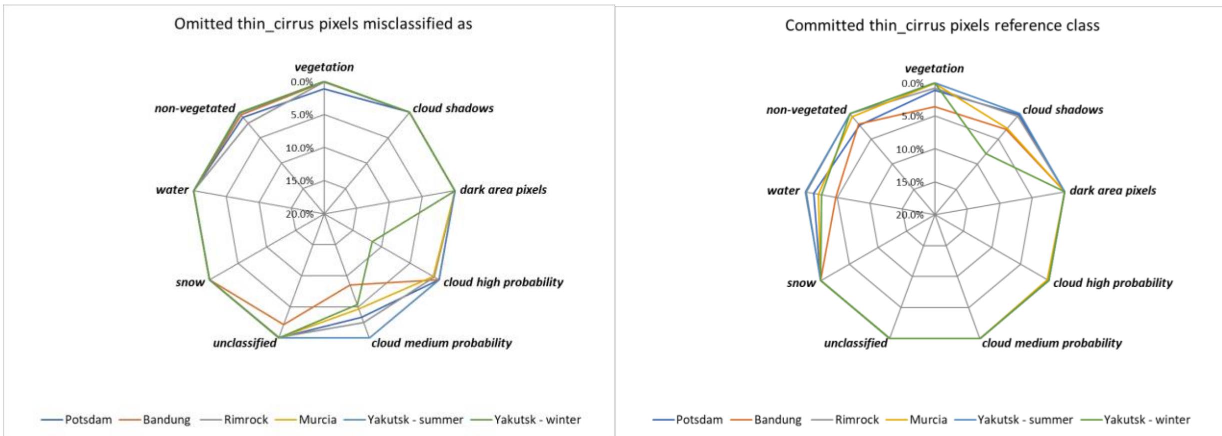


Figure 6: Spider plots of the omission and commission errors of thin cirrus pixels

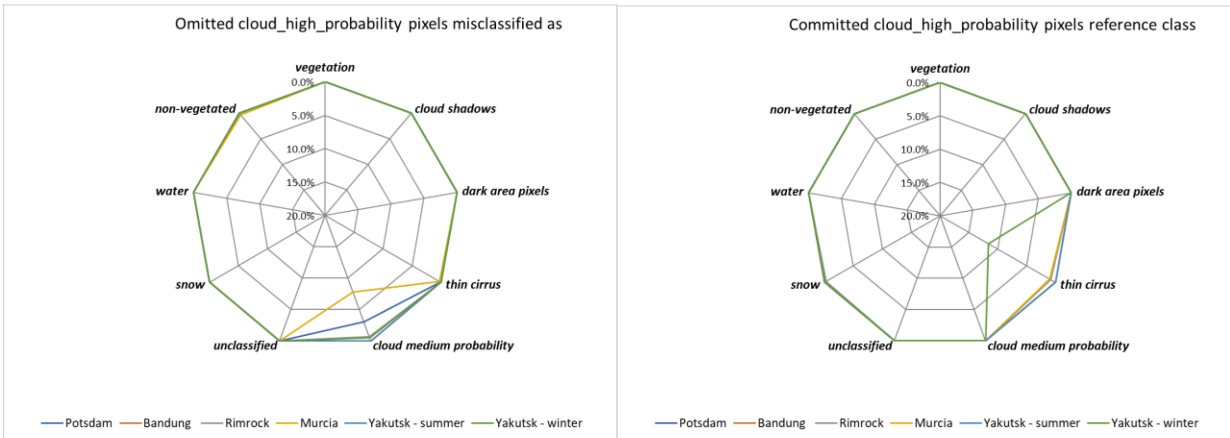


Figure 7: Spider plots of the omission and commission errors of cloud high probability pixels

4. Auxiliary Data Monitoring

This section reports on the monitoring of two auxiliary data parameters provided in L1C and L2A products in the granule AUX_DATA folder, respectively in the files AUX_CAMS_FO and AUX_ECMWFT:

- Aerosol Optical Depth at 550 nm (in AUX_CAMS_FO),
- Total Column of Water (in AUX_ECMWFT).

The parameters in AUX_CAMS_FO originate from ECMWF through the Copernicus Atmosphere Monitoring Service (CAMS) that generates every day, five-day forecasts of aerosols, atmospheric pollutants, greenhouse gases, stratospheric ozone, and the UV-Index.

The Aerosol Optical Depth at 550 nm from AUX_CAMS_FO can be used as atmospheric information fallback in the L2A processor when performing the atmospheric correction for certain Sentinel-2 tiles when not enough dark dense vegetation pixels are present to perform an independent aerosol retrieval (see 3.2.3).

The parameters in AUX_ECMWFT originate from ECMWF that generates every day global meteorological forecasts.

The Total Column of Water from AUX_ECMWFT is not used in the L2A processor when performing the atmospheric correction. However, it is interesting to check how its performance compares with the L2A processor outputs (see 3.2.2).

4.1 Material and methods

The monitoring is performed on 24 different locations distributed over all continents and all climate zones using 24 AERONET stations.

We would like to express our gratitude to the Principle Investigator(s) and Co-Investigator(s) as well as all the persons involved for establishing and maintaining the 24 sites used in this analysis: 'Lille', 'Kyiv', 'Kangerlussuaq', 'NEON_UNDE', 'Toravere', 'MetObs_Lindenberg', 'NEON_CVALLA', 'Medenine-IRA', 'Valladolid', 'XiangHe', 'OHP_OBSERVATOIRE', 'Gangneung_WNU', 'NEON-Disney', 'Tamanrasset_INM', 'Kanpur', 'Dhaka_University', 'Ilorin', 'Silpakorn_Univ', 'Huancayo-IGP', 'Jambi', 'Rio_Branco', 'Mongu_Inn', 'Fowlers_Gap', 'CEILAP-RG'.

The data period covers about 25 months of data, between 25/01/2022 to 23/02/2024, starting with Sentinel-2 PB 04.00, since the AUX_CAMS_FO files are embedded in the L1C and L2A products.

The values of AUX_CAMS_FO and AUX_ECMWFT are extracted at the AERONET site location using its geographic coordinates.

The Aerosol Optical Depth at 550 nm AERONET values are spectrally and temporally interpolated to the Sentinel-2 acquisition time. The Precipitable Water AERONET values are temporally interpolated to the Sentinel-2 acquisition time.

4.2 Aerosol Optical Depth at 550 nm

Figure 8 presents a temporal plot of all the concomitant Sentinel-2 auxiliary CAMS data (in red) with the AERONET data (in light red), for one AERONET site: Lille, France.

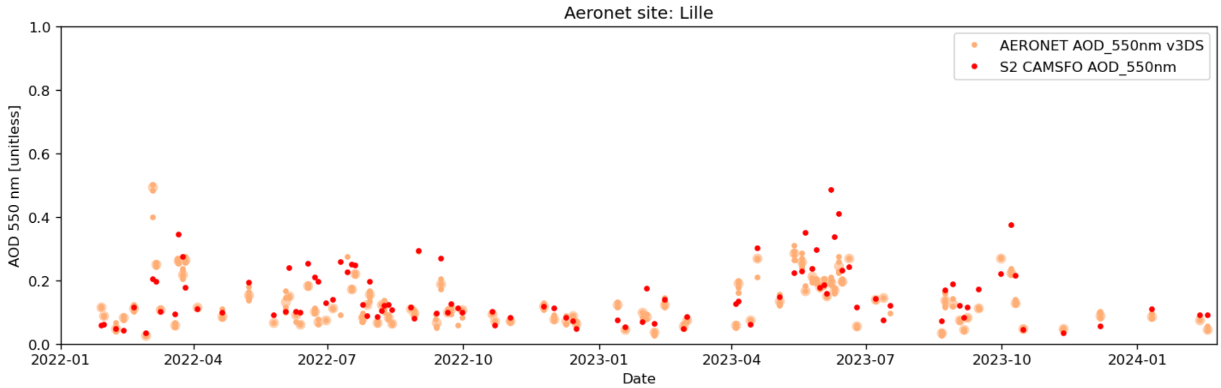


Figure 8: Aerosol Optical Depth at 550 nm; AERONET data (light red) and S2 CAMS data (red)
Lille: Tile 31UES Sentinel-2 products between 25/01/2022 and 23/02/2024

Figure 9 presents a scatter plot of all the concomitant Sentinel-2 auxiliary CAMS data with respect to the AERONET data for all the 24 AERONET test sites.

These consolidated statistics on all test sites show that 54% of CAMS data is within the uncertainty goal with an overall uncertainty of 0.17 without significant bias. It should be noted however that depending on the test site this value can range from 23% for the lowest agreement (Ilorin) up to 84% for the best agreement (Kangerlussuaq). In general, the agreement is better for test sites with lower aerosol load.

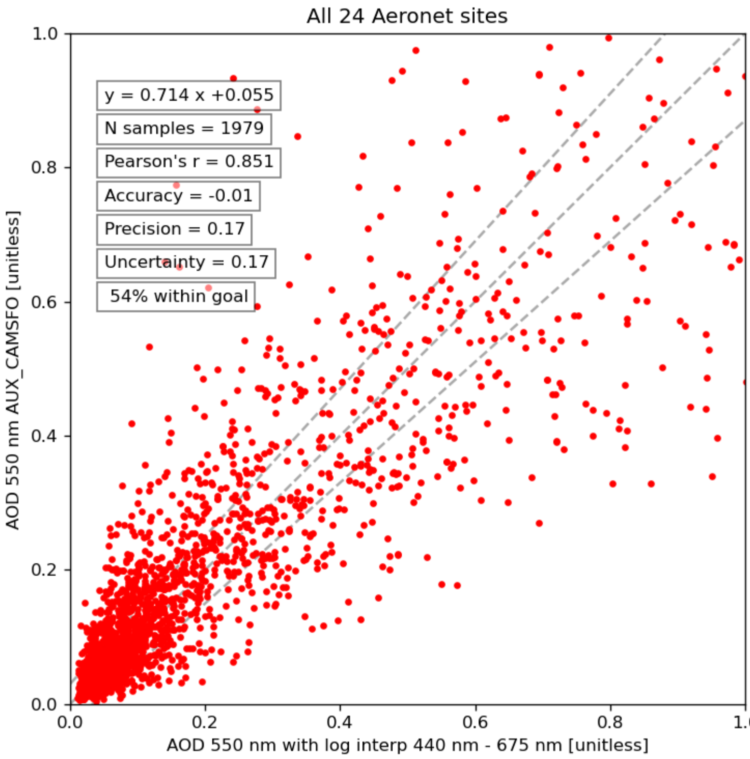


Figure 9: Aerosol Optical Depth at 550 nm; scatter plot S2 CAMS data vs AERONET data
24 test sites: Sentinel-2 products between 25/01/2022 and 23/02/2024

4.3 Total Column of Water

Figure 10 presents a temporal plot of all the concomitant Sentinel-2 auxiliary ECMWF data (in blue) with the AERONET data (in light blue), for one AERONET site: Lille, France. A seasonality can be observed with an atmosphere wetter in summer and dryer in winter.

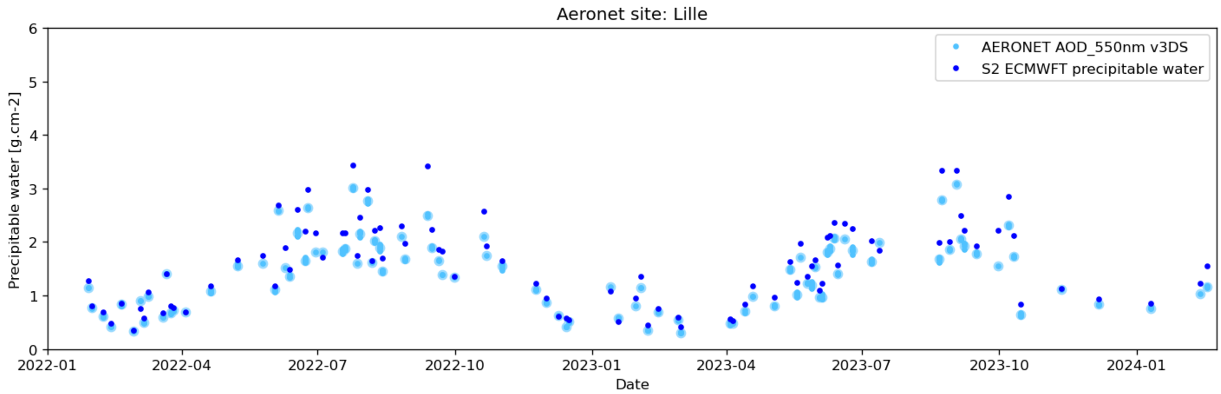


Figure 10: Total Water Column [g.cm-2]; AERONET data (light blue) and S2 ECMWFT data (blue) Lille: Tile 31UES Sentinel-2 products between 25/01/2022 and 23/02/2024

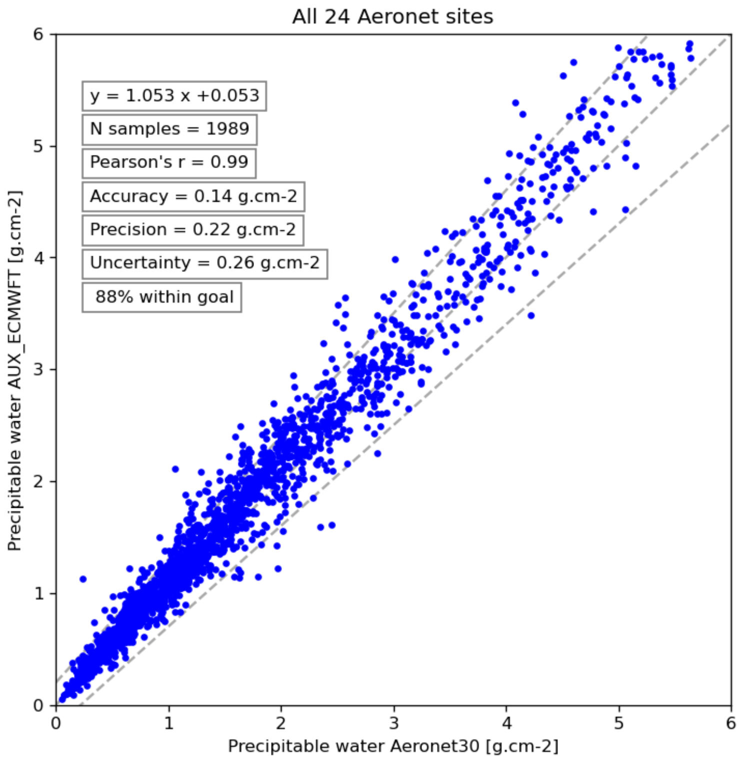


Figure 11: Total Water Column [g.cm-2]; scatter plot S2 ECMWFT data vs AERONET data 24 test sites: Sentinel-2 products between 25/01/2022 and 23/02/2024

Figure 11 presents a scatter plot of all the concomitant Sentinel-2 auxiliary ECMWF data with respect to the AERONET data for all the 24 AERONET test sites.

These consolidated statistics on all test sites show that 88% of ECMWF data is within the uncertainty goal with an overall uncertainty of 0.26 $g.cm^{-2}$ with a slight positive bias of 0.14 $g.cm^{-2}$. It should be noted however that depending on the test site, this value can range from 75% for the lowest agreement (OHP_OBSERVATOIRE) up to 98% for the best agreement (Kangerlussuaq). In general, the agreement is better for test sites with dryer atmosphere.

5. Product features

Some known product features are visible on Sentinel 2 Level-2A products.

These features are generated by:

- the current scene classification algorithm which has some known limitations,
- the overlap area between adjacent tiles,
- terrain over-correction on shaded areas due to inaccuracies of the Digital Elevation Model,
- products with a Sun-Zenith Angle (SZA) higher than 70°,
- corrupted pixels affected by missing or degraded instrument source packets,
- discontinuities visible in Terrain Correction on very flat areas,
- artefacts at the edge of the swath due to L2A NoData mask.

Please refer to https://sentiwiki.copernicus.eu/web/s2-products#S2Products-L2AproductsFeatures for more details and examples of the known Sentinel 2 product features, as well as to the Sentinel 2 Annual Performance Report covering the year 2022.

6. Product anomalies

6.1 Introduction

This section describes the L2A product anomalies that occurred in 2023. Please refer to the Sentinel 2 Annual Performance Report covering the year 2022 or to the on-line Sentinel-2 anomaly database https://s2anomalies.acri.fr/anomalies to have the full list of anomalies.

Note that some L1C anomalies affect also the quality of L2A products. Whenever this is the case, any reprocessing to correct an anomaly will include level 2 products.

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

The following table provides the status of known L2A processing anomalies. Note that some L1C anomalies directly affect the quality of the L2A products.

Table 6-1: Anomaly and processing baseline summary.

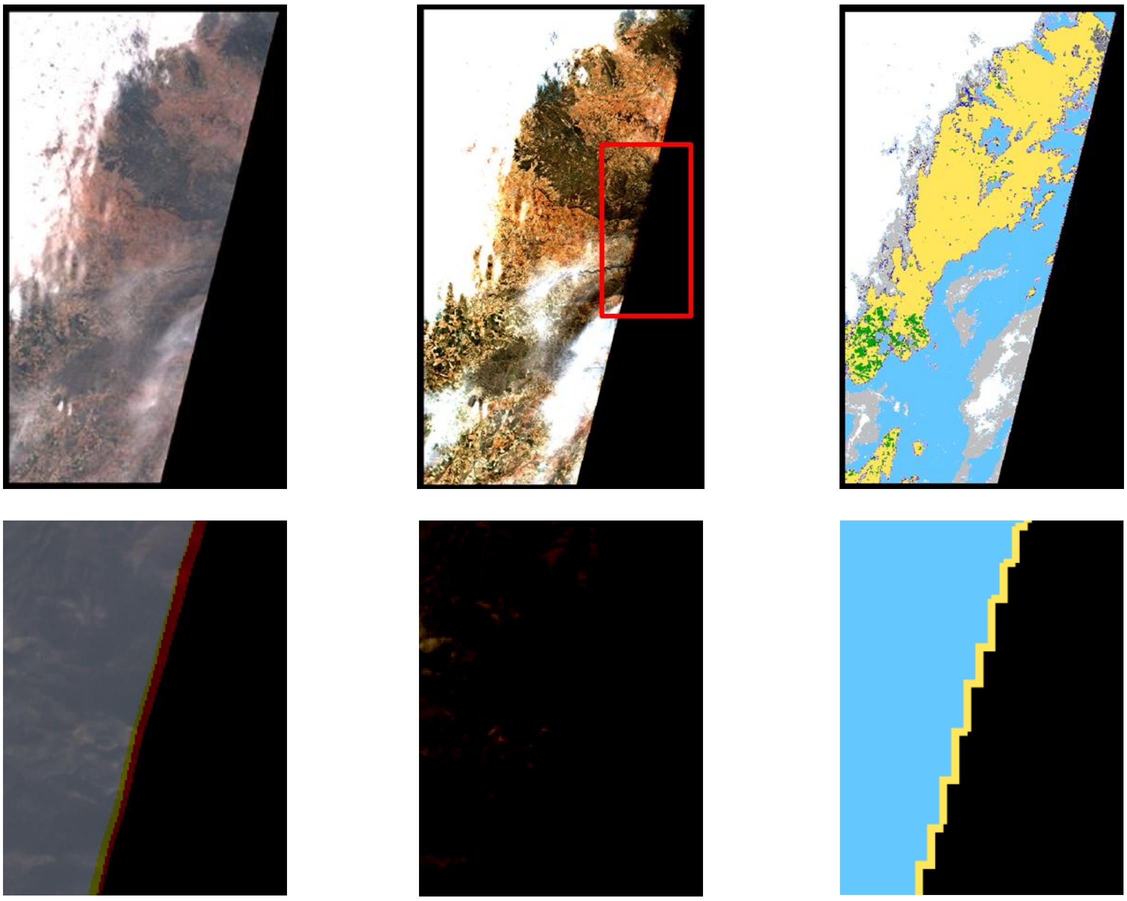
Anomaly ID	Baseline number	05.09	05.10
	Deployment date	06/12/2022	13/12/2023
	Anomaly title		
81	Very low negative reflectances near the edge of the swath	Some products	

6.2 Very low negative reflectances near the edge of the swath (#81)

A new anomaly consisting in a dark area with very low negative reflectances near the edge of the swath was observed by the S2GM team on the product:

S2B_MSIL2A_20220329T105629_N0400_R094_T30SXJ_20220329T134242.

This anomaly is particularly visible on the B02 band. This radiometry "distortion" defect is not present in the L1C image. This defect is the result of an overcorrection of the adjacency correction algorithm for the case when the radiometry of the pixels near the swath border is noticeably different from the average radiometry of the scene. The blue bands are the spectral bands which are affected the most. An evolution is in preparation to improve the quality of the adjacency correction for the pixels near the swath border. Users are advised to pay particular attention to the swath border area for the cases mentioned above (very heterogeneous radiometry of the scene). The effect can be visible up to 1 km from the swath border. An evolution is in preparation to improve the quality of the adjacency correction for the pixels near the swath border for these particular cases.



L1C TCI **L2A TCI** **L2A SCL**

Figure 12 : Illustration of the very low negative reflectances near the edge of the swath observed on the L2A product: S2B_MSIL2A_20220329T105629_N0400_R094_T30SXJ_20220329T134242.
An illustration of the corresponding L1C product (first column) is also shown

7. General information on products

7.1 Insights into the Copernicus Collection-1

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

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

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

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

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

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

Collection-1 products are distributed on CDSE (Collection-1 flag).

Collection-1 production has started with December 2021 products and goes in reverse chronological order of sensing time. In February 2024, Collection-1 products from September 2018 to December 2021 are available. Please note that the period reported is considered available for the most part, while gradually densifying in particular on the side of the earlier months of the period.

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

7.2 Product Format

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

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.

7.3 Reprocessed products

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

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

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

End of document