COPERNICUS SENTINEL-2 COLLECTION-1: A CONSISTENT DATASET OF MULTI-SPECTRAL IMAGERY WITH ENHANCED QUALITY

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ABSTRACT

The Copernicus Sentinel-2 satellite mission, with its Sentinel-2A and Sentinel-2B units, offers since several years now a massive quantitative and qualitative resource for the Earth Observation community. Since the launch of Sentinel-2A in 2015, and Sentinel-2B in 2017, many lessons have been learnt leading to continuous improvements of the radiometric and the geometric performances. However, the current archive is composed of heterogenous processing baselines with inconsistent product formats and uneven data quality, which limits its use for multi-temporal monitoring applications.

To overcome this limitation, the Copernicus program has undertaken a complete reprocessing with the latest processing baseline (05.00). It concerns the L1C (Top-Of-Atmosphere reflectance) and L2A (Surface Reflectance) products. This paper recalls the features of Collection-1 products and gives an overview of the first validation results.

***Index Terms*—** Sentinel-2, Copernicus, Collection-1, OPT-MPC

1. INTRODUCTION

The Copernicus Sentinel-2 constellation has been providing since 2015 multi-spectral imagery of the Earth with a spatial resolution of 10, 20 or 60 m, depending on the spectral band [1]. The launch of Sentinel-2B in 2017 has improved the revisit time from 10 to 5 days. The existing archive comprises a mix of diverse processing baselines (PB) ranging from PB 02.00, which was the initial product baseline, to PB 05.09 currently. This results in irregular product formats and inconsistent data quality limiting its use for multi-temporal monitoring applications. In order to overcome this limitation, the Copernicus program has initiated a comprehensive reprocessing of the L1C (Top-Of-Atmosphere reflectance) and L2A (Surface Reflectance) products using the latest processing baseline (05.00).

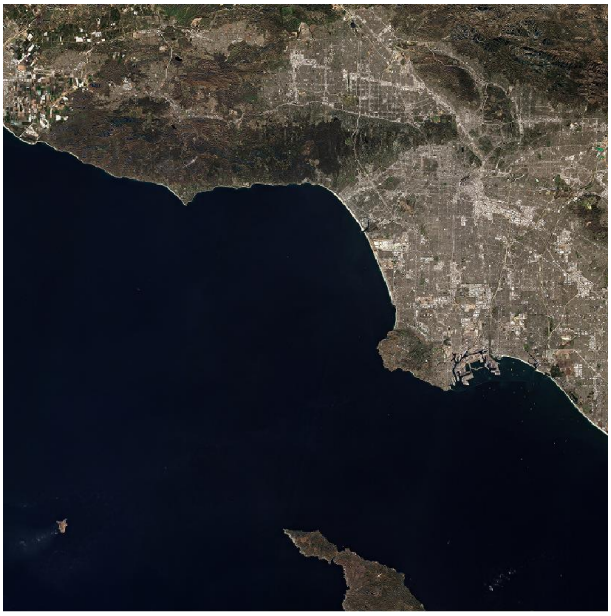


Figure 1. Sentinel-2B Level-2A True Color Image over Pasadena, California (T11SLT, 19.12.2022)

With a total data volume of 26 pebibytes (PiB), the Sentinel-2 Collection-1 reprocessing represents the largest effort in

the history of Earth Observation. The reprocessing started with data from December 2021 and will proceed in reverse chronological order. Reprocessed products are progressively made available on the Copernicus Data and Information Access Services (DIAS) and will be released via the Copernicus Data Space Environment shortly.

2. FEATURES OF COLLECTION-1 PRODUCTS

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

One of the main benefits of Collection-1 regards the improved geometry thanks to the systematic use of the geometric refining based on the Sentinel-2 Global Reference Image (GRI) and the Copernicus Digital Elevation Model (DEM) at 30 m resolution. This brings the geometric uncertainty of Collection-1 products below 8 m (CE95) and the multi-temporal uncertainty below 5 m (CE95).

In terms of radiometry, Collection-1 encloses the correction of 1.1% on VNIR bands of Sentinel-2B images in order to harmonize their TOA reflectance with Sentinel-2A images [2]. The radiometric calibration has also been improved thanks to an upgraded model of the on-board Sun diffuser (deployed in operation in June 2017), and optimization of the applicability dates of calibration files.

The Level-1C quality masks use the latest raster format, and track accurately missing packets, radiometric saturation as well as partially corrected crosstalk effects at pixel level. Moreover, the Collection-1 also includes a coarse snow mask.

The introduction of a radiometric offset in both Level-1C and Level-2A products allows to avoid truncation of negative reflectances to zero values in the uncertainty domain of low signal (e.g., noise range).

Level-2A products benefit from the successive improvements introduced since the first deployment in 2018 and brings Collection-1 Surface Reflectance products in compliance with the Committee on Earth Observation Satellites (CEOS) Analysis Ready Data (ARD) standard with a traceable Digital Object Identifier (DOI). Surface reflectance images benefit from the use of auxiliary atmospheric data from the Copernicus Atmospheric Monitoring Service (CAMS) as fallback solution for the aerosol load (AOT) value estimation to be used in the atmospheric correction for vegetation-free areas. The Scene Classification Layer (SCL) has been significantly upgraded with respect to the first implementation. Expected improvements include reduction of cloud commission errors due to bright surface objects, reduction of snow commission errors thanks to a new algorithm based on MSI parallax properties and to an improved probability climatology, and an accurate tracking of cast topographic shadows. Information about missing source packets identified in L1C products is also propagated to the L2A scene classification.

3. VALIDATION RESULTS

To ensure that the Collection-1 products are well reprocessed and that are in agreement with the PB 05.00, the Optical Mission Performance Cluster (OPT-MPC) team performed various validation activities.

Besides regular quality checks on randomly reprocessed products, specific assessments performed by the Experts from the OPT-MPC team are showed in the following sections.

3.1. Radiometric validation from vicarious methods

The radiometric verification of the reprocessed products consists mainly in the check of the alignment of Sentinel-2B with Sentinel-2A radiometry. Indeed, among the evolutions of the baseline 04.00 on 25th January 2022 the mitigation of the radiometric differences between both satellites was set by applying a radiometric bias correction of 1.1 % to Sentinel-2B VNIR bands B01 to B09. This radiometric correction was applied to the entire Sentinel-2B Collection-1 database.

About 135 Sentinel-2A and 152 Sentinel-2B acquisitions are reprocessed and collected over desert-PICS test sites over 2021, then are ingested to the Database for Imaging Multi-spectral Instruments and Tools for Radiometric Intercomparison (DIMITRI). The Desert-PICS methodology is applied, and the outputs are compared to the same operational acquisition's outputs.

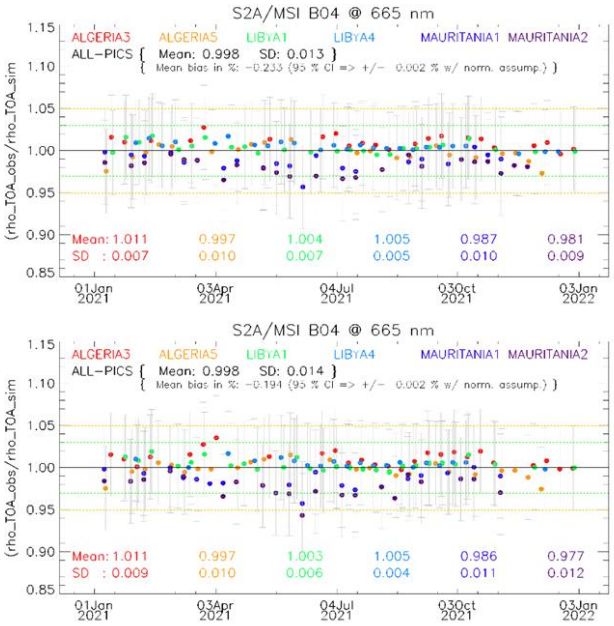


Figure 2: Time series of the ratio of observed TOA reflectance to simulated one for S2A/MSI operational products (top) and Collection-1 (bottom) products for B04 over the 6 PICS sites between Jan-Dec 2021. Error bars indicate the desert methodology uncertainty.

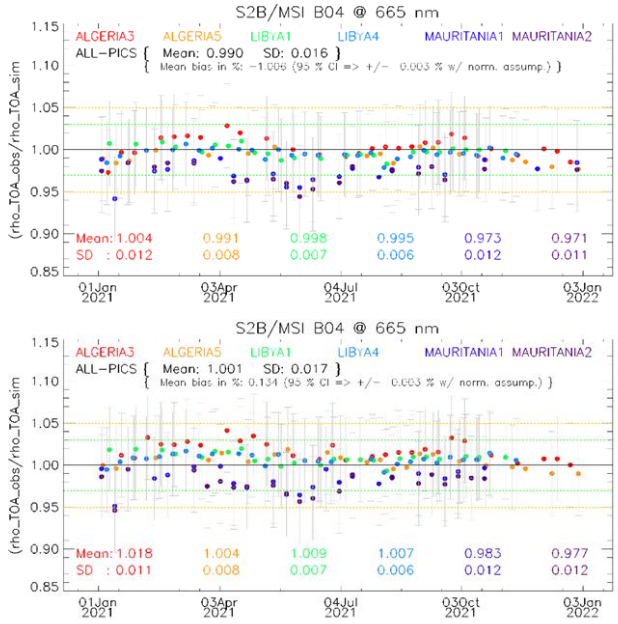


Figure 3: Time series of the ratio of observed TOA reflectance to simulated one for S2B/MSI operational products (top) and Collection-1 (bottom) products for B04 over the 6 PICS sites between Jan-Dec 2021. Error bars indicate the desert methodology uncertainty.

Figure 2 and Figure 3 show similar results as for the operational Sentinel-2A ones (ratios of TOA difference < 0.005), while the reprocessed results of S2B show higher gain of about 1% (ratios of TOA difference = 0.011).

These results illustrate the successful reprocessing and confirm that the bias correction is considered for Sentinel-2B radiometry alignment.

3.2. Temporal geometric co-registration

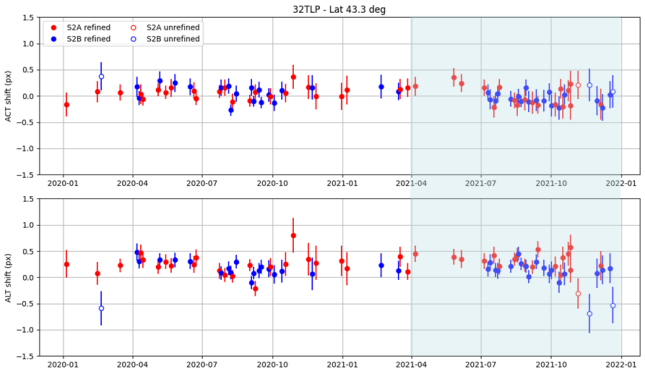
Collection-1 introduces several improvements in terms of geometry. First, the geometric refinement based on the GRI and applied to the full time series improves the temporal co-registration for products originally processed with baselines earlier than 03.00 which did not benefit from geometric refinement.

The use of the Copernicus DEM at 30 m resolution improves the local co-registration between products acquired from different repeat orbits (and thus with different viewing angles). The improvement is especially noticeable at the extremity of the swath over mountainous areas but it does not significantly affect the mean co-registration over the L1C tile. This improvement will be implemented soon in the near real time (NRT) production (PB 05.09), making Collection-1 and NRT products perfectly aligned.

Finally, the static geometric calibration has been partially optimized for the whole mission. This improvement concerns only non-refined products, either on areas not covered by the Sentinel-2 GRI (e.g. Antarctica) or in cases where the refinement is not applicable (e.g. very cloudy data).

The geometric performance has been assessed using GRI images projected to L1C tiles (see [3]). A set of tiles around the globe have been selected and the co-registration of all products with a cloud coverage lower than 10% has been measured. During the validation activities, a processing anomaly was detected on some products. After correction of this anomaly, the performance of Collection-1 products is in-line or better than those of PB 03.00 or subsequent (see Figure 4). Figure 4 highlights the temporal overlap between the datasets (shaded background). Refined products (closed symbols) are essentially aligned while unrefined products (open symbols) show a reduced across-track error.

a) Collection-1



b) Processing Baseline 03.00 and subsequent

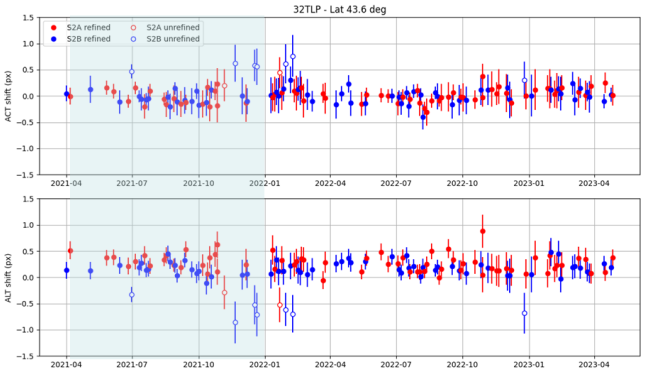


Figure 4: Time series of co-registration of L1C products with Sentinel-2 GRI, for tile 32TPL (Nice, France). Across-track (top) and along-track (bottom) shifts in pixel. a) Collection 1 products; b) Processing baselines with geometric refinement applied (03.00 and subsequent). The green background shows the overlap period.

3.3. Quality assessment of Scene Classification

The verification of the Scene Classification in the reprocessed products was performed based on several products over Potsdam/Berlin (Germany), Rimrock (US), Barrax/Murcia (Spain) and Yakutsk (Russia) test sites. No

artifacts resulting from the reprocessing chain were observed through visual examination of 24 products spanning January to March 2019 and October to December 2021.

Besides visual inspection, differences of class percentage between the Collection-1 and operational products were computed. Figure 5 shows typical results.

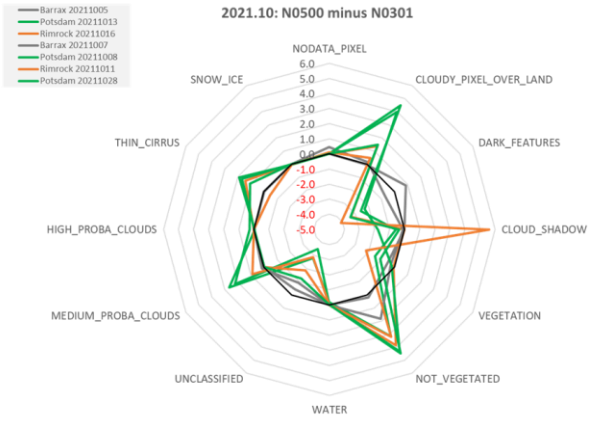


Figure 5: Difference of class percentage in reprocessed products (PB 05.00) minus class percentage in earlier products with PB 03.01 resulting from Sen2Cor 2.80. Analysed data are from October 2021 and test sites Barrax, Rimrock and Potsdam/Berlin. The black line marks the line indicating no change.

In terms of unclassified pixels, a remarkable decrease is observed. The transition from dark features to either vegetated or non-vegetated classes is linked to a redefinition of those categories in the latest PB. Indeed, in the previous PB, the class dark features could contain any dark area like dark water or land area, burned area or topographic shadows. In PB 05.00 this class is changed to contain only topographic or cast shadows while any other dark area is now attributed to the class it belongs to. Differences of scene classification in reprocessed products to older PB increase significantly for low sun elevation and can reach 25%.

A slight increase of the number of "noData" pixels is also observed in the reprocessed products due to an evolution solving reported issues at the swath border. Reprocessed products generally report more clouds than previous products, which could be expected due to introduction of a dilation of clouds. A general improvement is also observed in the cloud shadows classification. Figure 5 shows a strong increase of cloud shadows at test site Rimrock. This appears when the images are acquired with low sun elevation in the presence of both cirrus clouds and lower-altitude clouds resulting in extreme long cloud shadows. This behavior is related to the Sen2Cor classification algorithms and doesn't come from an error in the reprocessing chain.

Figure 6 gives similar results for images with remarkable snow cover. Again, there are less unclassified and dark features pixels and more not vegetated. We observe also changes between cloud and snow detection in both directions – either more clouds classified and less snow or opposite.

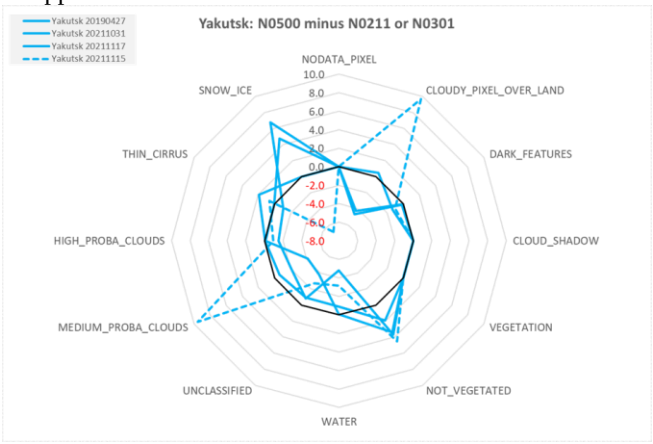


Figure 6: Difference of class percentage in reprocessed products (PB 05.00) minus class percentage in earlier products with PB 03.01 resulting from Sen2Cor 2.80. Analysed images are from test site Yakutsk (Russia) in April 2019 and October/November 2021. The black line marks the line indicating no change.

Please note that the changes observed in the scene classification are reasonable and are related to improvements in the processing algorithm. However, the performed analysis is no quantitative justification, which requires comparison with labelled reference data.

6. CONCLUSIONS

Copernicus Collection-1 products provide consistent Sentinel-2A and Sentinel-2B time series with a uniform processing baseline and optimized calibration. There are several enhancements and changes between the current archive and the Collection-1 products - which improves interoperability of the Sentinel-2 archive through time. The preliminary validation results presented in this paper highlight the improvements in terms of radiometric and geometric consistency, as well as in the surface classification.

11. REFERENCES

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[2] B. Alhammoud, C. Quang, V. Boccia, and R.Q. Iannone, "Assessment of Copernicus Sentinel-2 Constellation After Five Years In-Orbit: Level-1C User-Products", IEEE-IGARSS2021, DOI: 10.1109/IGARSS47720.2021.9554851

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