EVALUATION OF SEN2COR SURFACE REFLECTANCE PRODUCTS OVER LAND SURFACE WITH REFERENCE MEASUREMENTS ON GROUND

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ABSTRACT

Sen2Cor is the atmospheric correction processor selected by ESA for operational, systematic processing of Copernicus Sentinel-2 mission data. It is used for generating the Level-2A products distributed to users by the Copernicus SciHub. Accurate atmospheric correction of Sentinel-2 data and knowledge of its uncertainties are preconditions for high quality downstream applications.

In this work we present the comparison of Sentinel-2 Bottom-of-Atmosphere products with measurements of surface reflectance on ground. Source of reference measurements are both surface reflectance data from RadCalNet and from dedicated field campaigns. The analysis shows, that the uncertainty of SR-retrieval with Sen2Cor is better than about 7% for bright surfaces and about 17% for darker. In addition to this performance evaluation, the data are also applied to compare the use of reference data coming from permanent operating bright RadCalNet sites and from ad-hoc field campaigns at darker sites.

Index Terms**—** Copernicus Sentinel-2, Atmospheric correction, Sen2Cor, Surface Reflectance, Validation

1. INTRODUCTION

Copernicus Sentinel-2 is an optical remote sensing mission [1] providing global data in 13 spectral bands at different spatial resolution of 10m, 20m and 60m. It is dedicated for a wide field of applications on land surface related to agriculture, forestry and land-cover change and it is also used to monitor coastal and inland water. These applications rely on Bottom-of-Atmosphere (BOA)-data. Those data are provided by Sen2Cor processor [2] which is used by ESA for systematic global Level-2A processing of Sentinel-2 acquisitions. In addition, it can be downloaded from ESA website [3] as standalone tool for individual processing by the users.

Evaluation of surface reflectance (SR) products is difficult due to lack of reference measurements. Therefore, reference measurements at RadCalNet (Radiometric Calibration Network) [4] sites are frequently used. Reference measurements from RadCalNet sites LaCrau and Gobabeb had been used for Atmospheric Correction Intercomparison eXercise ACIX-2 [5]. These reference measurements are reused in this study. However, primary objective of RadCalNet is to serve for vicarious calibration of TOA data. RadCalNet sites have surfaces which are much brighter than the surfaces observed by most downstream applications. Therefore, own field measurements over meadows and dark soil are additionally used to answer the question of how representative evaluation of SR retrieval with reference data from RadCalNet sites is for darker surfaces.

There are only few investigations in the literature for evaluation of SR retrieval with Sen2Cor based on reference measurements. Pancorbo et.al. [6] and Origo et.al. [7] used reference measurements in Spain over wheat and alfalfa for comparing with SR retrieval of Sen2Cor. However, Pancorbo et.al. performed only a statistical single-sample t-test to determine whether the values observed from S2 sensor are significantly different from measured field spectra. The aim of Origo et.al. was a practical demonstration of a surface reflectance validation based on fiducial reference measurements (FRM), which utilizes metrological practices for uncertainty characterization. The important step forward with this work is to provide a quantification of the uncertainty of SR-retrieval with

Sen2Cor on a larger number of overpasses and variability of surface cover.

2. MATERIALS AND METHODS

2.1. Surface Reflectance Reference Measurements

2.1.1. Data provided from RadCalNet sites

SR reference measurements at RadCalNet sites LaCrau and Gobabeb had been used in ACIX-2. These data will be reused in this study. 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 [5].

The site LaCrau is located in the south of France [8]. The site area has a pebbly soil with sparse vegetation cover. The surface reflectance variability across site (uniformity) over area of 100m x 100m is 3%.

The site Gobabeb is located in Namibia [9]. The site area is characterized as gravel plains in a desert environment (without vegetation). Surface reflectance variability across site (uniformity) over area of 100m x 100m is 3-5% and better than 3% for larger area from 500-1000m extent.

The ROSAS system (RObotics Station for Atmosphere and Surface) used for SR measurements at both sites is equipped with filters at wavelengths near to the position of Sentinel-2 bands in the spectrum. A spectrum based on hyperspectral measurements on the ground is fitted to the observed surface reflectance to allow a better matching of spectral bands. The uncertainties on the surface reflectances vary from 3.5 to 5% depending on the spectral band [8].

2.1.2. Data provided from field campaigns

Surface reflectance measurements on ground in parallel to cloudless Sentinel-2 overpasses were performed once per year since 2018 at different sites in North-East Germany (Figure 1). Measurements were performed more following recommended best practices from year to year.

The test areas represent flat terrain containing meadows in 2018, 2019 and 2021 and soil (harvested corn field) in 2020. They are located in a vegetated environment. Variability of surface reflectance across site (uniformity of selected test area) on meadows range from 1% to 6% over 5x5 Sentinel-2 pixels (100m x 100m). Variability across site is below 2% on the harvested corn field.

A SVC spectrometer HR-1024i [10] was used for SR measurements. The SVC was mounted on a tripod with a distance lens-ground of 1 m in 2018-2020 and 1.5 m in 2021. This results in a 7cm respectively 10cm diameter footprint on ground for the instrument set up with a 4° FOV fore-optic. The spectrometer was placed over different points on test area measuring surface reflectance relative to the reflectance of a white disk. Raw data were corrected for the real reflectance of the white disk and convolved with spectral response function of the Sentinel-2 bands [11] before comparing with Sentinel-2 SR retrievals. Average of more than 50 spectra recorded at locations distributed over the test area was computed for upscaling from the small SVC-footprints to Sentinel-2 pixels. The uncertainty of the resulting surface reflectance measured on ground is about 20%. Its dominating contribution comes from the variability of spectra recorded for the small spectrometer footprints.

Aerosol optical thickness (AOT) spectra, vertical ozone column content and integrated water vapor (WV) were measured with Microtops sunphotometers [12] additional to SR measurements. Sunphotometer measurements were averaged over ±15 min to satellite overpass time to give reference values.

Figure 1: Location of the field campaigns in Germany

2.2. Sentinel-2 data

The used data set contains 21 sample days from January to September 2018 for LaCrau, 40 sample days from October 2017 to May 2018 for Gobabeb and 4 sample days from May 2018 to October 2021 for Germany.

Table 1: Characteristics of used Sentinel-2 data
(RO stand for relative orbit, VZA for view zenith angle and RAA for relative azimuth angle between sun and view direction)

Site	Granule	RO	VZA	RAA
Gobabeb	T33KWP	107	8°	190°-260°
La Crau	T31TFJ	8	9°	110°
La Crau	T31TFJ	108	7°	51°
Germany $^{2018-2019}$	T32UQE	22	11°	49°
Germany $^{2020-2021}$	T33UUU	22	9.1°	59°

Sen2Cor was applied to correct mono-temporal Copernicus Sentinel-2 Level 1C products from the effects of the atmosphere in order to deliver radiometrically corrected surface reflectance images [2]. Sen2Cor 2.8 toolbox version [3] was used to process all Sentinel-2 images used in this study uniformly. Spatial averages over 100m x 100m are computed from Sentinel-2 images for comparison with reference measurements. Only exception is the campaign in 2018 in Germany where Sentinel-2 data of a single pixel are extracted for comparison.

3. RESULTS AND DISCUSSION

Correlation plots of SR retrieval by Sen2Cor over reference measurements on ground (Figure 2) show good performance of Sen2Cor SR retrieval for the investigated data set. Results look similar to equivalent plots in [7]. The uncertainty of SR retrieval over all sites is 8% and 80% of SR retrievals is compliant with specification $\Delta SR \leq 0.05*SRref + 0.005$.

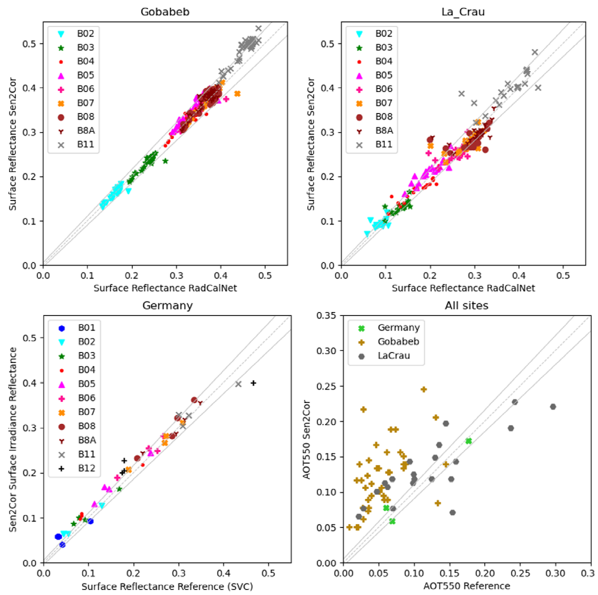

Figure 2: Correlation plots of SR and AOT retrieval by Sen2Cor over reference measurements on ground for test sites Gobabeb, LaCrau, Germany and for all test sites. Gray lines mark the uncertainty specification. Note, that B01 and B12 are not plotted for Gobabeb and LaCrau due to missing reference data.

Absolute differences between retrieval and reference are comparable for all three sites at the low average value of 0.005±0.02. This shows, that performance assessment of SR retrieval based on reference data from RadCalNet sites can give results representative also for darker surfaces types.

However, common metrics for performance reporting is uncertainty. Total uncertainty is the root of squared sum of random and systematic uncertainty. It is computed as RMS of the relative differences and systematic uncertainty is computed as their mean value. The relative total uncertainty at the darker sites in Germany is much higher than at the brighter RadCalNet sites. Band average relative total uncertainty of SR retrieval with Sen2Cor was estimated as 7% over the bright RadCalNet sites and as 17% over the limited number of darker sites in Germany. The larger numbers for Germany are at least partly caused by the relative assessment and the lower surface reflectance values. Total uncertainties per band are shown in Figure 3. The results for Germany are consistent with [7] which found uncertainties between 29% for B02 and 8% for band 08A over dark surface.

Lowest relative total uncertainty was found for site Gobabeb (Figure 3) despite this site shows the worst AOT-retrieval (Figure 2). This can be explained by the less importance of AOT for bright sites compared to dark because the direct radiation dominates the signal received at satellite instead of the diffuse. Gobabeb performs better than LaCrau, possibly because surface optical properties in LaCrau have larger annual variation. The different error propagation from AOT retrieval to SR is a critical aspect in transferring performance assessment of SR retrieval based on reference data from RadCalNet sites to darker surfaces types. It needs very careful interpretation.

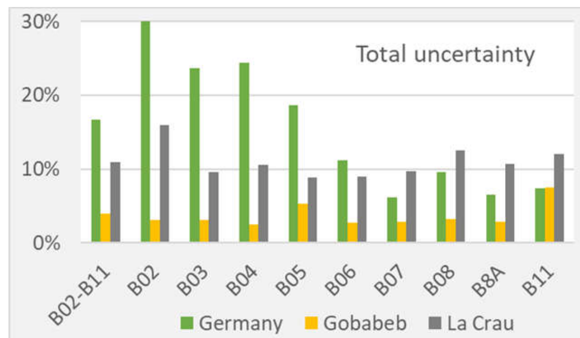

Figure 3: Total uncertainty of SR retrieval per band and site.

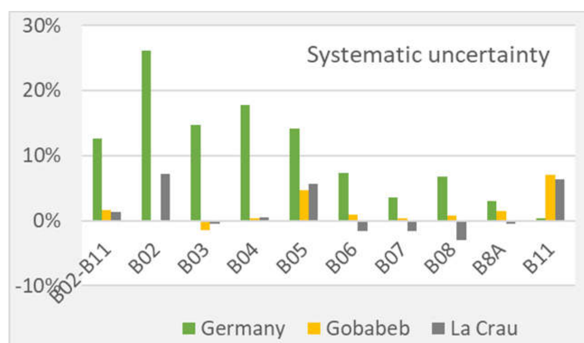

Figure 4: Systematic uncertainty of SR retrieval per band and site.

Systematic uncertainty shows a tendency for SR overestimation. Average systematic uncertainty over B02 to B11 is 1.5% for bright sites and 13% over the darker sites in Germany. Again, values are much larger for test sites in Germany because of the darker surfaces except B11. RadCalNet test sites show a significant larger systematic uncertainty for B05 and B11 than for other bands. This is not observed for the darker test sites. Current interpretation is that it may be caused by WV absorption which is present in both bands. Opposite to Gobabeb and sites in Germany, LaCrau shows some underestimation of SR for the NIR bands.

The current analysis has some limitations. There are only 4 samples for Germany which gives not a statistical reliable information. Additionally (even if the expected influence is small relative to observed uncertainties), there was no correction for BRDF-effects respectively observation geometry for Germany as was done for the reference measurements at RadCalNet sites. Sentinel-2 observations over all sites were acquired with a similar viewing zenith angle of about 10°, but different view azimuths (Table 1). Last, analysis was limited to differences per band only and did not considered spectral correctness of individual SR retrievals.

4. CONCLUSION

Sentinel-2 downstream applications require an accurate atmospheric correction together with an up-to-date, reliable information on the uncertainties in the provided products. Total uncertainty of SR retrieval with Sen2Cor was estimated as 7% with a systematic contribution of 1.5% over the bright RadCalNet sites and as 17% with a systematic contribution of 13% over the limited number of darker sites in Germany.

Performance assessment of Sen2Cor SR retrieval at permanent operating (RadCalNet) sites has the advantage, that many match-ups with satellite overpasses are achieved. The sites can be characterized much better and more extensive than changing campaign locations and the data processing can more easily follow established, standardized guidelines, best practice protocols and traceable procedures. On the other hand, permanent operating sites are currently limited to bright target surfaces except single sites in Australia. The results showed, that transferring performance assessment of SR retrieval based on reference data from bright sites to darker surfaces types can be critical. Hence, there is a clear need for establishing permanent operating sites on dark surfaces around the globe dedicated for validation of SR retrieval. Additional field campaigns offer the advantage to have more variability of target surfaces.

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