SENTINEL-2 LEVEL 2A PROTOTYPE PROCESSOR: ARCHITECTURE, ALGORITHMS AND FIRST RESULTS

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ABSTRACT

Sen2Core is a prototype processor for Sentinel-2 Level 2A product processing and formatting. The processor is developed for and with ESA and performs the tasks of ***Atmospheric Correction*** and ***Scene Classification*** of Level 1C input data. Level 2A outputs are: Bottom-Of-Atmosphere (BOA) corrected reflectance images, Aerosol Optical Thickness-, Water Vapour-, Scene Classification maps and Quality indicators, including cloud and snow probabilities. The Level 2A Product Formatting performed by the processor follows the specification of the Level 1C User Product.

1. INTRODUCTION

The prototype implementation for the Level 2A processing of Sentinel-2 imagery over land is a combination of state-of-the-art techniques for performing Atmospheric Corrections (AC, including Cirrus clouds correction) [1], tailored to the Sentinel-2 environment and a Scene Classification (SC) module, as described in [2].

Level 2A processing is applied to Top-Of-Atmosphere (TOA) Level 1C ortho-image reflectance products. Level 2A main output are ortho-image Bottom-Of-Atmosphere (BOA) corrected reflectance products. Additional outputs are an Aerosol Optical Thickness (AOT) map, a Water Vapor (WV) map and a Scene Classification (SC) map together with Quality Indicators for cloud and snow probabilities at 60 m resolution.

A large database of look-up tables (LUTs) has been compiled using an atmospheric radiative transfer model based on libRadtran[1]. The LUTs are generated for a wide variety of atmospheric conditions, solar geometries, and ground elevations and are calculated with a high spectral resolution of 0.6 nm. This database has been subsequently resampled with the Sentinel-2 spectral responses, in order to obtain the sensor-specific functions needed for the atmospheric correction.

2. FEATURES AND PLATFORMS

Sen2Cor is written in the python language 2.7. The Atmospheric Correction module based on the ATCOR program was ported from IDL and is attached to the software in form of a binary library. Sen2Cor is equipped with its own python distribution based on *Anaconda*, using the additional third party software *pyTables* and *GDAL*.

Due to its implementation in python, the software shows a high degree of portability, as was a user requirement. The Software will run on Linux®, Mac OS X® and Windows® 64 bit platforms. Sufficient memory (16 GB) is recommended, due to the huge image sizes (10.000 x 10.000 pixel for a single band JPEG-2000 image at 10 m resolution) to be processed. The software acts as a command line tool which can be operated in a batch mode, compatible to the Sentinel-2 Toolbox. A development environment based on *Eclipse* and *PyDev* is provided for future evolutionary upgrade of the software.

3. PRODUCT FORMAT

The Level 2A Product format is closely related to the Level 1C Top-of-Atmosphere (TOA) reflectance product which serves as an input to the processor. It consists of 13 JPEG-2000 images, associated to the 13 Sentinel-2 spectral bands at three different spatial resolutions with a ground sampling distance of 10, 20, and 60m.

The generated Level 2A BOA reflectance output images are resampled and generated with an equal spatial resolution for all bands, based on three user selectable resolutions of 10, 20 and / or 60m.

The tile level contains different components, based on the user selected resolution:

- a 10 m resolution product contains spectral bands 2,

[1] https://www.libradtran.org

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3, 4 and 8 and an AOT map resampled from 20m

- a 20 m product contains band 2 – 7, the bands 8a, 11 and 12 and an AOT and WV map
- a 60m product contains all components of the 20m product and additionally the 60m bands 1 and 9

The Cirrus band 10 will be omitted in the Level 2A output, as it does not contain surface information. Fig. 2 shows the Level 2A user product on tile level.

4. ALGORITHM

The basic framework of the processor consists of five different modules:

L2A Process: this module coordinates the interaction between the other modules.

L2A SceneClass: this module performs the classification of the input images into the different contents like clouds, snow, water, soil etc., provides statistical analysis.

L2A AtmCorr: this module transforms the input from TOA to BOA and performs the atmospheric correction.

L2A Config: this is a helper class providing the configuration parameter handling for the other modules.

L2A Tables: this module converts JPEG-2000 based input data to an internal format (pyTables) and vice versa and provides a high performance access to the data for the other four modules. Fig. 3 shows the relationships between the different modules.

Fig. 1 shows the main processing workflow. After reading and processing the input parameter and data the main processing module triggers the creation of an internal temporary database, which is then used by the Scene Classificaton and the Atmospheric Correction module to retrieve and to store the data and intermediate products. The processing can act in a loop, dependent on the number of different product resolutions to be generated.

The Scene Classification algorithm allows to detect clouds, snow and cloud shadows and to generate a classification map, which consists of 4 different classes for clouds (including cirrus), together with six different classifications for shadows, cloud shadows, vegetation, soils / deserts, water and snow. The algorithm is based on a series of threshold tests that use as input top-of-atmosphere reflectance from the Sentinel-2 spectral bands. In addition, thresholds are applied on band ratios and indexes like the Normalized Difference Vegetation - and Snow Index (NDVI, NDSI [3]). For each of these thresholds tests, a level of confidence is associated. At the end of the processing chain a probabilistic cloud mask quality map and a snow mask quality map is produced. The algorithm uses the reflective properties of scene features to establish the presence or absence of clouds in a scene. Cloud screening is applied to the data in order to retrieve accurate atmospheric and surface parameters, either as input for the further processing

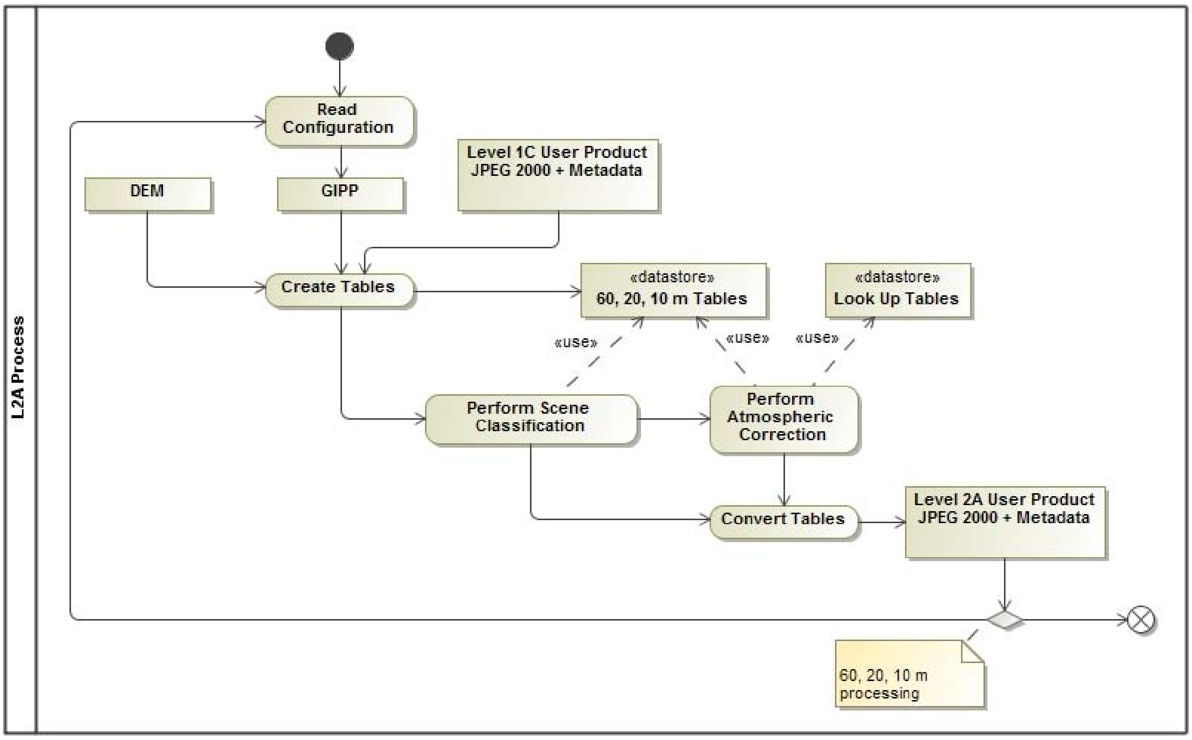

Figure 1. Processing Flow, Overview

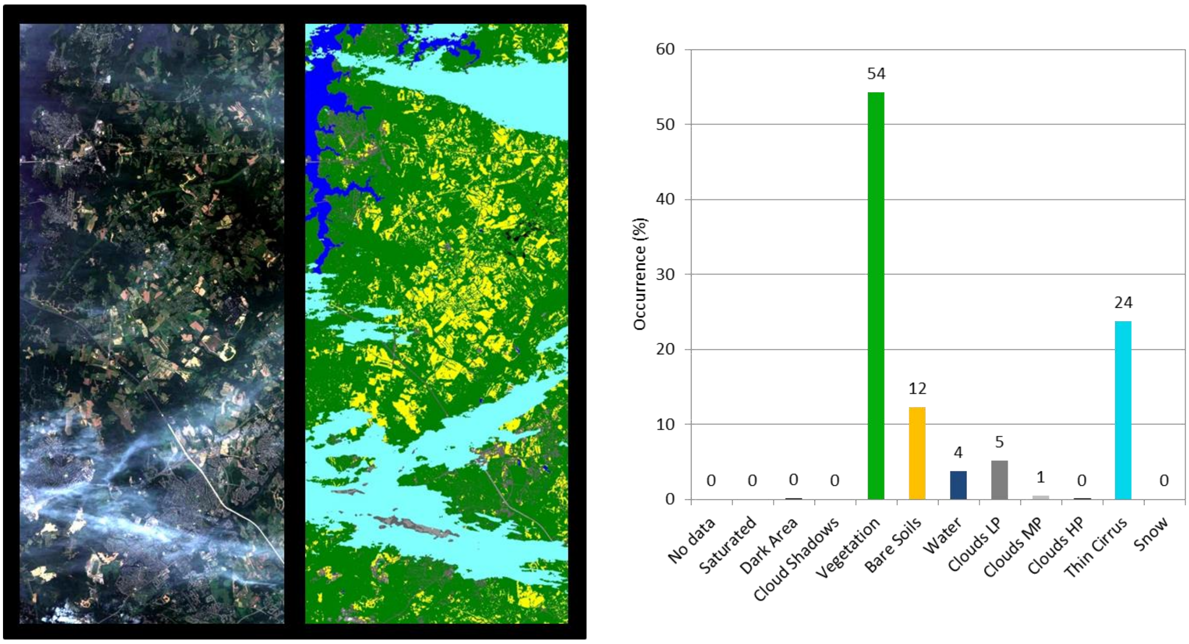

Figure 2. Scene Classification

steps below or for being valuable input for processing steps of higher levels.

Fig. 2 above shows the results of a scene classification (right side) based on modified AVIRIS testdata (left side). Twelve different classifications are provided.

The Algorithm for the Atmospheric correction consists of a set of four different subtasks, having three different user products as output. The correction is performed using a set of Look-up tables generated via libRadtran. Baseline processing is the rural/continental aerosol type. Other Look-Up tables can also be used according to the scene geographic location and climatology. The Atmospheric correction module is a porting and adaptation of the ATCOR software into python. Regression tests between Sen2Cor and the original implementation have been performed on a set of test data, acquired by AVIRIS [4], spectrally resampled with the Sentinel-2 response curves for all channels and products. Data labelled with “Control” in the subsequent drawings show always the original ATCOR results for comparison.

Aerosol Optical Thickness (AOT) retrieval provides a measure for the visual transparency of the atmosphere. It is derived using the DDV (Dense Dark Vegetation) algorithm [5], using the (SWIR) band 12 and correlates its reflectance with bands 4 (red) and 2 (blue). The algorithm requires that the scene contains reference areas of known reflectance behaviour, preferably Dark Dense Vegetation (DDV) and/or dark soil and water bodies.

The algorithm starts with a user-defined visibility (default: 20 km) as input. If the scene contains no dark vegetation or soil pixels, the surface reflectance threshold of band 12 will be successively iterated in order to include medium brightness reference pixels in the sample. If the scene contains no reference and no water pixels the scene is processed with the start visibility instead. The algorithm delivers an AOT map as shown in Fig. 3 below.

Water Vapour retrieval over land is performed with the Atmospheric Pre-corrected Differential Absorption algorithm (APDA, [6]) which is applied to the two Sentinel-2 bands B8a, and B9 (Fig. 4). Band 8a is the reference channel in an atmospheric window region. Band B9 is the measurement channel in the absorption region. The absorption depth is evaluated by calculating the radiance for an atmosphere with no water vapour, assuming that the surface reflectance for the measurement channel is the same as for the reference channel. The absorption depth is then a measure of the water vapour column content.

The **Cirrus Correction** algorithm uses the sentinel (cirrus) channel 10. Thin cirrus clouds affect the visible, near- and shortwave infrared spectral regions. They are partially transparent and thus difficult to detect with broad-band multispectral sensors, especially over spatially inhomogeneous land areas.

Water vapour, in contrast, dominates in the lower troposphere of 0-5 km. A narrow spectral band in a spectral region of very strong water vapour absorption (Band 10) will thus absorb the ground reflected signal, but will receive the scattered cirrus signal.

Cirrus reflectance of band 10 can therefore be correlated with other bands in the VNIR and SWIR region and the cirrus contribution can thus be removed from the radiance signal to obtain a cirrus-corrected scene. This is qualitatively shown in Fig. 5 below.

Surface Reflectance retrieval has been performed for each sequential Band B1 – B12 and compared to the original ATCOR algorithm. Only band 2 is shown here, but the results for the other bands are at the same level of exactness.

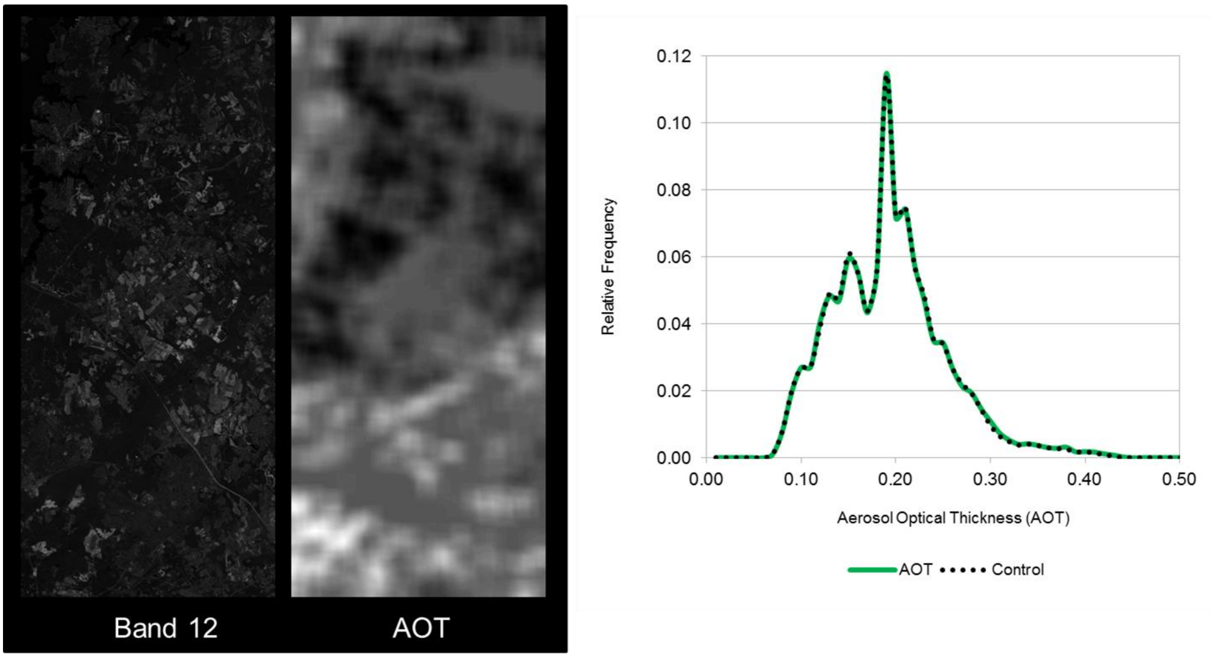

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Figure 3. AOT Retieval using Band 12

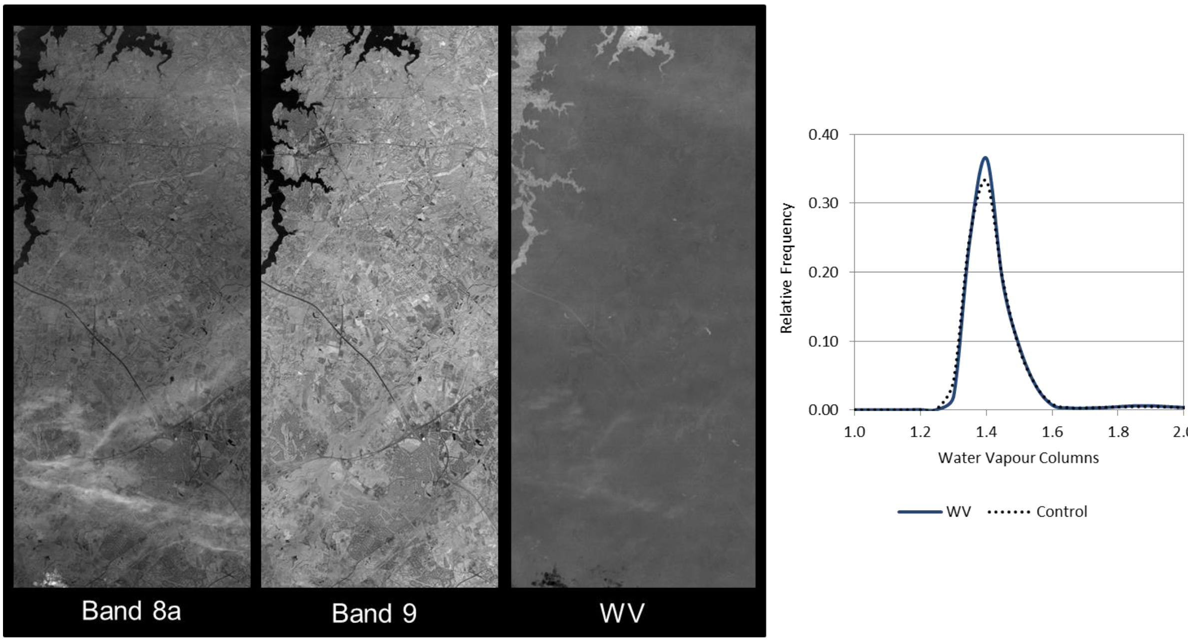

Figure 4. WV Retrieval using Bands 8a and 9

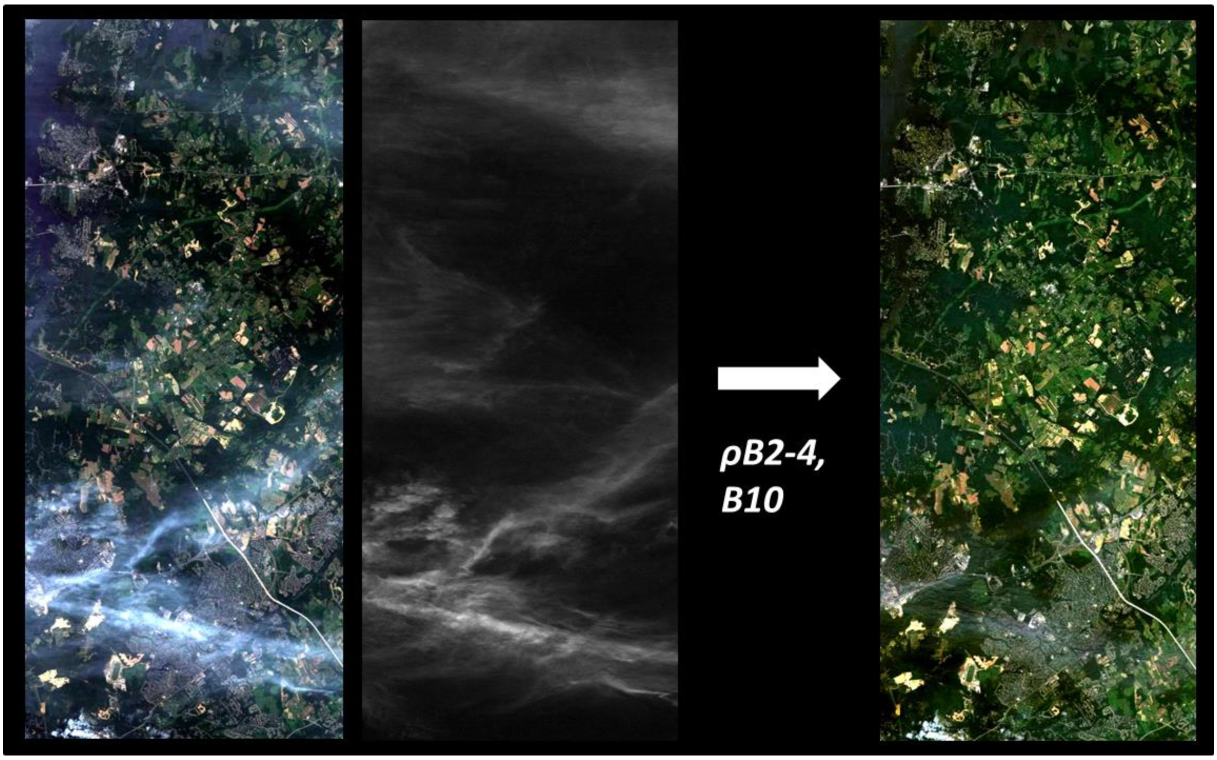

Figure 5. Cirrus Correction, Bands 2-4 with Band 10

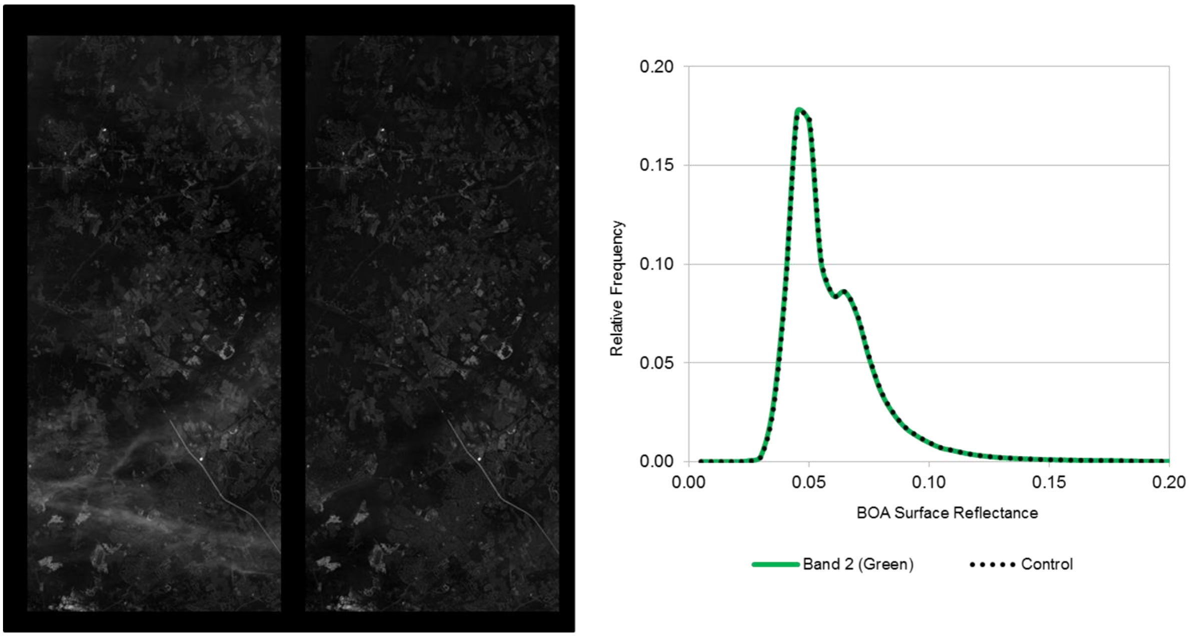

Figure 6. Reflectance Retrieval, Band 2

5. RESULTS

Twenty-one simulated Sentinel-2 Level 1C test datasets, derived from Hyperion hyper spectral instrument flown on board of EO-1 have been generated up to now and used for subsequent testing of Sen2Cor. The computational performance and output product format validity was assessed in order to demonstrate the capabilities of the processor.

Figs. 7-10 show exemplary data of a L2A conversion for aSentinel-2 modified Hyperion swath, collected at the region of Buenos Aires, Argentinia in 2003. Three qualitative different regions (soil, vegetation and an urban area) from one swath had been selected for a subsequent analysis. The three next Figs. 8-10 show a comparison of the reflectance histograms for the three visible channels 2 (blue), 3 (green) and red (4) before (Level 1C, upper left figure, dashed line in histograms) and after Level 2A processing (lower left figure and solid lines in histograms).

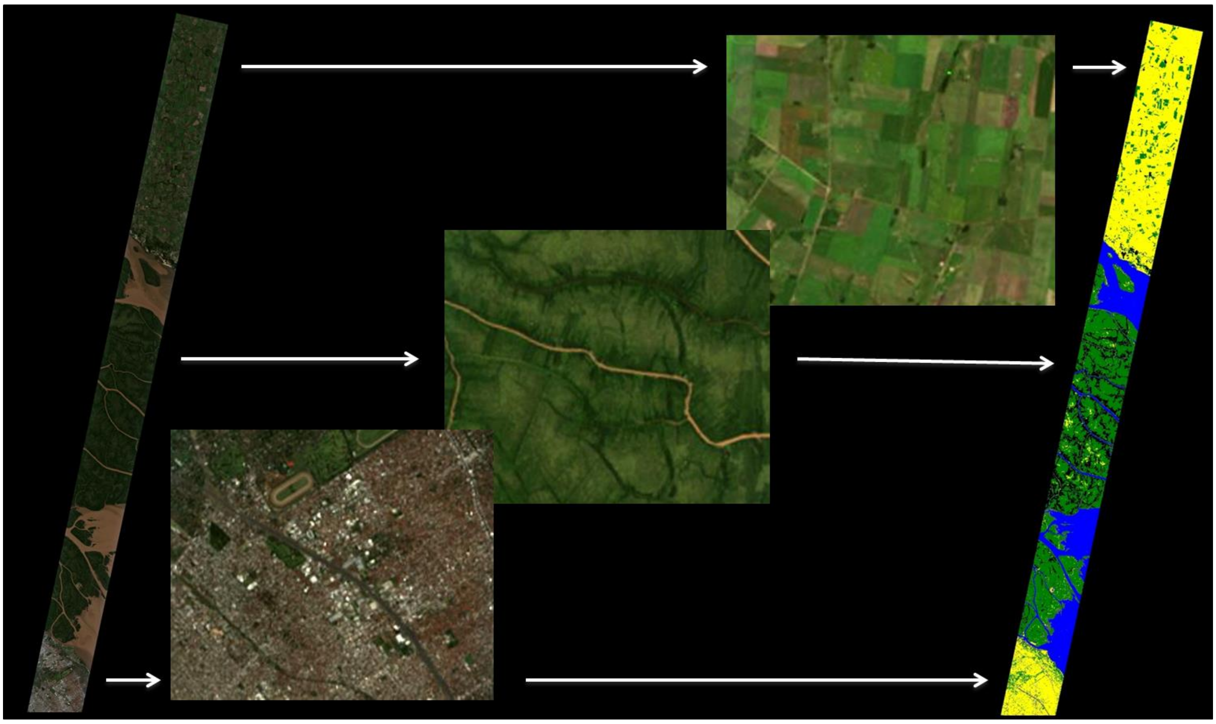

Figure 7. Scenario Selection from Hyperion Swath

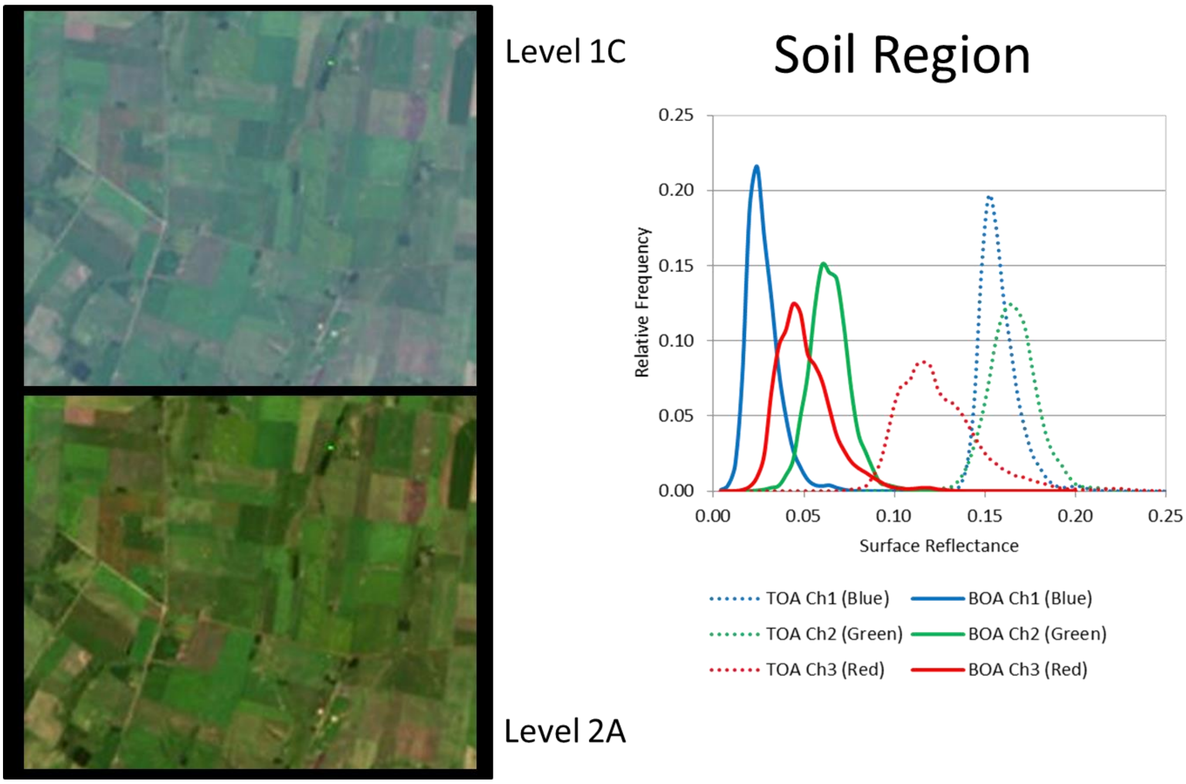

Figure 8. Reflectance Analysis of Soil Area

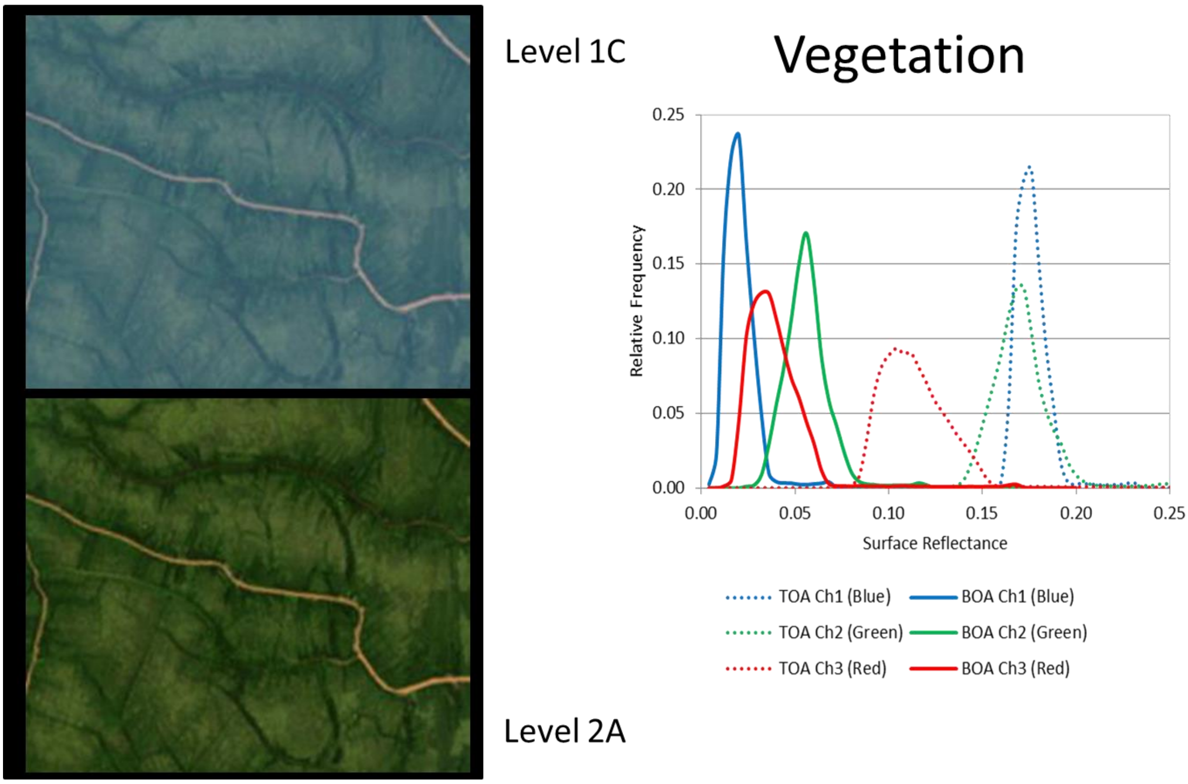

Figure 9. Reflectance Analysis of Vegetation Area

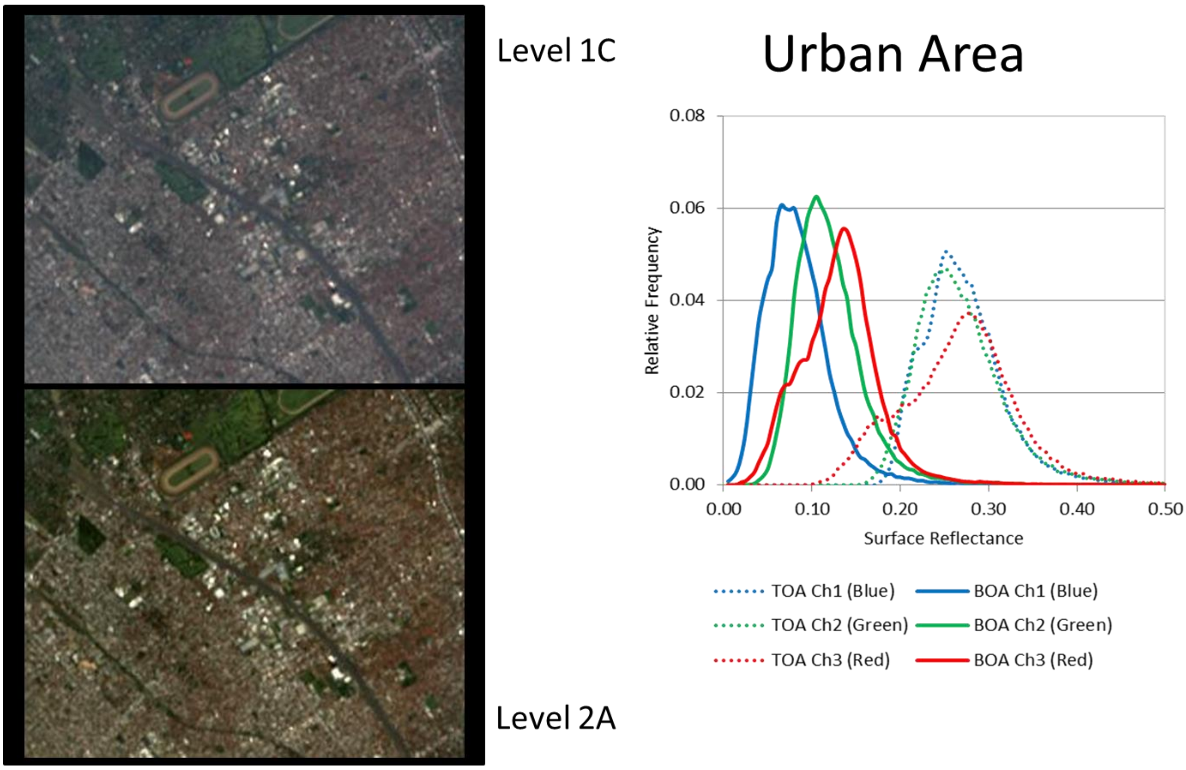

Figure 10. Reflectance Analysis of Urban Area

6. SUMMARY

The implementation of the Sen2Cor software is to date mostly completed, and the initial performance assessment results are quite promising.

The verification of the implementation of the AC algorithm is based on comparison of the test results with the original ATCOR software. Data formatting and resampling of the Level 1C input data has been implemented and a representative set of input test data have been generated and used to support the initial performance assessment.

Future work includes improvement of the processor with respect to performance time and capacity as well as a full validation with improved test data sets, which will take place during the upcoming validation campaign. The Processor will be deployed as integral part of the Sentinel-2 toolbox, currently under development.

7. REFERENCES

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