# THE USE OF SENTINEL-3 SYNERGY PRODUCTS FOR PHYSICALLY BASED AUTOMATIC ATMOSPHERIC CORRECTION OF SENTINEL-2 IMAGERY

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## ABSTRACT

The objective of atmospheric correction is to retrieve the surface reflectance from remotely sensed imagery by removing the atmospheric effects. The present study describes the development, the implementation and the automation of a physically-based atmospheric correction method for ESA's high resolution mission Sentinel-2, by exploiting atmospheric products of the Sentinel-3 synergy product. The 6s (Second Simulation of Satellite Signal in the Solar Spectrum) radiative transfer model is used for simulating the interaction between land and atmosphere, which enables accurate simulations of satellite and plane observation. Since neither Sentinel-2, nor Sentinel-3 data/products are available at the moment, alternative data are used in this study. To cope with large computation time, a fitting method is employed between measured radiance and surface reflectance. The results are similar to the case without using fitting and the coefficient of determination ($R^2$) in all cases was found greater than 0.98.

## 1. INTRODUCTION

The magnitude of the signal received from a satellite sensor is dependent on several factors, particularly: reflectance of the target; nature and magnitude of the atmospheric interactions; slope and aspect of the ground target area relative to the solar azimuth; and angle of view of the sensor and solar elevation angles. The role of atmospheric correction is to decompose the above signal and to extract the component that originates from the target, in order to estimate the target reflectance. The fundamental philosophy of atmospheric correction is to determine the optical characteristics of the atmosphere and then to apply this in order to correct the atmospheric effects of satellite images [1].

Two main categories of atmospheric correction methods can be identified, the ones that rely on radiative transfer modelling and the imaged-based. The later rely only on the information of the image in question and they are mainly using statistical analysis of the primary pixels. Some examples of image-based atmospheric correction methods are the Darkest Object Subtraction (DOS) method [2], the Dense Dark Vegetation (DVV) method [3] and its modified version (MDDV) [4], the Covariance Matrix method [5] and methods based on regression analysis [6] and regression intersection [6].

On the other hand, the atmospheric correction methods that rely on radiative transfer modelling, require independent data for atmospheric optical characteristics at the time of image acquisition. These models simulate the distribution of radiation in atmosphere. A number of radiative transfer codes on radiative transfer theory have been developed for this purpose, i.e. LOWTRAN and MODTRAN [7], the SMAC [8], the SBDART [9] and ATCOR [10]. Past studies have shown that these radiative transfer codes can accurately convert satellite measurements to surface reflectance [11].

In this study the 6s (Second Simulation of Satellite Signal in the Solar Spectrum) radiative transfer model [12] is used for simulating the interaction between land and atmosphere and retrieve surface reflectance for Sentinel-2 imagery. The 6s models has been used in the past for atmospheric correction of fine resolution Earth Observation (EO) data. Zelazowski et al. [13] developed a Matlab interface called LandCor to facilitate the use of 6s code for atmospheric correction of Landsat data, while Wilson [14] developed a Python interface for atmospheric correction with 6s.

This paper describes the development, the implementation and the automation of a physically-based atmospheric correction method for ESA's high resolution mission Sentinel-2, by exploiting atmospheric products of the Sentinel-3 synergy. It is investigated to what extent atmospheric properties from Sentinel-3 products can be considered with fine-resolution land imagery, in order to improve the estimates of surface reflectance through physically based atmospheric correction. Accurate calculations of surface spectral reflectance are useful for object recognition, segmentation and material classification.

The 6s (Second Simulation of Satellite Signal in the Solar Spectrum vector code) radiative transfer model is used for simulating the interaction between land and atmosphere. It enables accurate simulations of satellite and plane observation, accounting for elevated targets, use of anisotropic and Lambertian surfaces and calculation of gaseous absorption. The 6s is chosen among others, as in some independent publications [15] provides more accurate than other models for atmospheric correction of high resolution optical imagery.

## 2. TEST AREA AND DATASETS

Since neither Sentinel-2, nor Sentinel-3 data/products are available at the moment. Sentinel-2 is launching late June 2015, while Sentinl-3 is scheduled for launch in October 2015. In this study, alternative data are used. Simulated data from the Sentinel-2 APEX campaign are used, acquired on a cloud-free day over Zurich, Switzerland [16]. This is the most realistic simulation of a Sentinel-2 scene available at the moment. It includes all spectral and spatial characteristics of all 13 Sentinel-2 bands and contains top-of-atmosphere radiance data, corresponding to a Sentinel-2 level 1c product [17]. The scene covers an extent of 16 x 22 km$^2$ over the area of Zurich and its surroundings (Fig. 1), and includes a wide range of land covers and land uses: buildings, urban parks, airport, lakes, rivers, forests, and crop fields at various phenological stages.

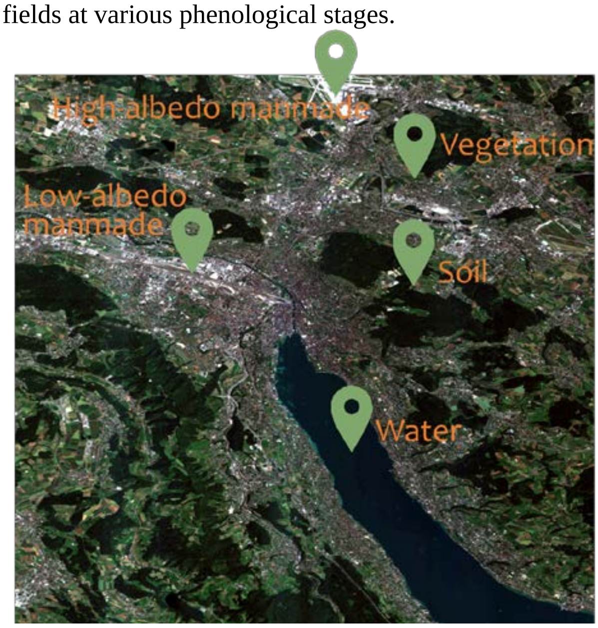


*Figure 1. True-color composition of the Sentinel-2 simulated image of the study area, the broader area of Zurich, Switzerland (26.06.2011). The location of example spectra shown in Fig. 5 is presented.*

Aerosol optical thickness at 550 m from the MODIS (Moderate Resolution Imaging Spectroradiometer) Aerosol Product (MOD02_L2) is used [18] in this study, instead of the Sentinel-3 Level-2 SYN product (SY_2_SYN) [19] for the atmospheric correction of Sentinel-2 simulated data. A Digital Elevation Model (DEM) of 30 m spatial resolution produced within the EU-DEM project was also used. Finally, information on the Sentinel-2 Multispectral Instrument (MSI) spectral response function (Fig. 2) was available from ESA [20].

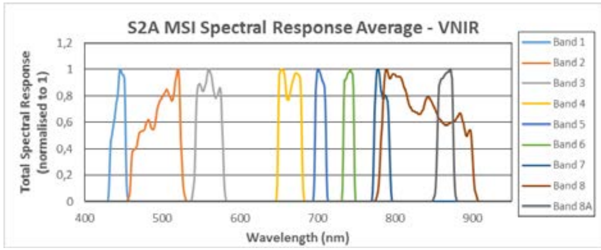


*Figure 2. The spectral response function of the Sentinel-2 MSI.*

## 3. METHODOLOGY

In this section the theory behind the radiative transfer code is shortly presented, followed by the fitting approach used in the study to atmospherically correct the Sentinel-2 simulated imaged. A technical description of the methodology and is also shortly presented.

### 3.1. The 6s radiative transfer code theory

The 6s model simulates the land-atmosphere interaction and for a given radiance measured by the sensor, it computes the surface reflectance [12]. More specifically, it computes the surface reflectance ρ* as:

$$\rho^* = \frac{Y}{1.0 + (x_c \cdot Y)} \quad (1)$$

where $Y = x_a \cdot L_{sat}(\lambda) - x_b$

$x_a$ is the inverse of transmittance, $x_b$ is the scattering term of the atmosphere, and $x_c$ is the reflectance of the atmosphere for isotropic light [15].

### 3.2. The fitting approach

The 6s code simulates the land-atmosphere interaction for given measured radiance and atmospheric information. Thus, it corrects for one pixel at a time, which means that for one Sentinel image (large swath of 290 km), the 6s code will need to run more than 60 billion times to correct for all bands. Given that in a conventional computer the 6s takes about 1/10 second to run, that would mean years to correct for a single image.

For this reason, an approach based on linear fitting was developed to accelerate the atmospheric correction procedure with 6s. A set of 1000 pixels were randomly selected and the respective surface reflectance was calculated using 6s. Then the calibration coefficients were estimated assuming linear relationship between the calculated reflectance and the observed radiance for the above set of pixels. Surface reflectance for all the image is estimated by applying the linear relationship each pixel for the whole Sentinel-2 image in a few minutes.

### 3.3. Technical implementation

The methodology described above was implemented using a combination of Fortran and Matlab codes, to make the atmospheric correction procedure easy to apply for any Sentinel-2 image given the atmospheric information from the Sentinel-3 product.

For implementing this method, the following input data are necessary:

- the Sentinel-2 image to correct
- AOD info from Sentinel-3
- terrain info from DEM
- the solar/satellite zenith and azimuth angles corresponding to the Sentinel-2 image

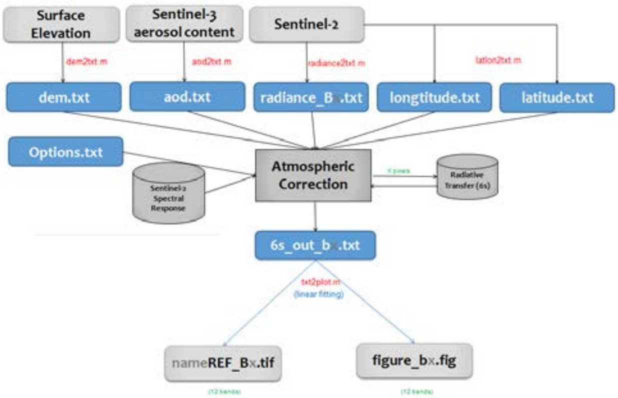

*Figure 3. Methodology flowchart*

The spatial resolution of Sentinel-2 bands is 10, 20 and 60 m. The spatial resolution of Sentinel-3 AOD product is 1 km. By assuming homogeneous distribution of aerosols in each 1 km pixel, AOD values are assigned to each Sentinel-2 pixel using nearest neighbour interpolation. To match the terrain information to Sentinel-2, the DEM was spatially interpolated as well to the spatial resolution of each Sentinel-2 band using the nearest neighbour method.

The 6s model is coded in Fortran. To handle image data, Matlab scripts were developed to convert the image files to simple text files to be used as input for 6s. Information on the solar/satellite zenith and azimuth angle are included in the 6s options text file (options.txt). The options file includes all the necessary parameterization for the atmospheric correction (i.e. the aerosol model to be used, the atmospheric model, the number of random pixels to use for fitting calibration etc). The spectral response function of Sentinel-2 was adjusted and imported to 6s, using 2.5 μm spectral intervals.

The Atmospheric Correction mode reads and keeps all the inputs, it randomly selects a set of pixels and then calls 6s for each random pixel to estimate the surface reflectance. The results are stored in a text file.

A Matlab script reads the 6s results for the random pixels and performs the linear fitting between surface reflectance and measured radiance. The coefficients (slope and intercept) are then used to estimate the surface reflectance for the whole Sentinel-2 image.

## 4. RESULTS

The 6s radiative transfer model was run as described in Section 3 using the input data described in Section 2. Fig. 4 shows a pseudo-color composition of the atmospherically corrected Sentinel-2 simulated image (Bands: 8-3-2). Fig. 5 shows an example of some characteristic surface covers, before (Fig. 5a) and after (Fig. 5b) the atmospheric correction.

Figure. 6 presents examples of the points used for the fitting model calibration and the respective fitting lines. Table 1. shows slope, intercept and the coefficient of determination ($R^2$) for the linear relationship between surface reflectance and measured radiance, $\rho^* = a \cdot L_{sat} + b$, for each band.

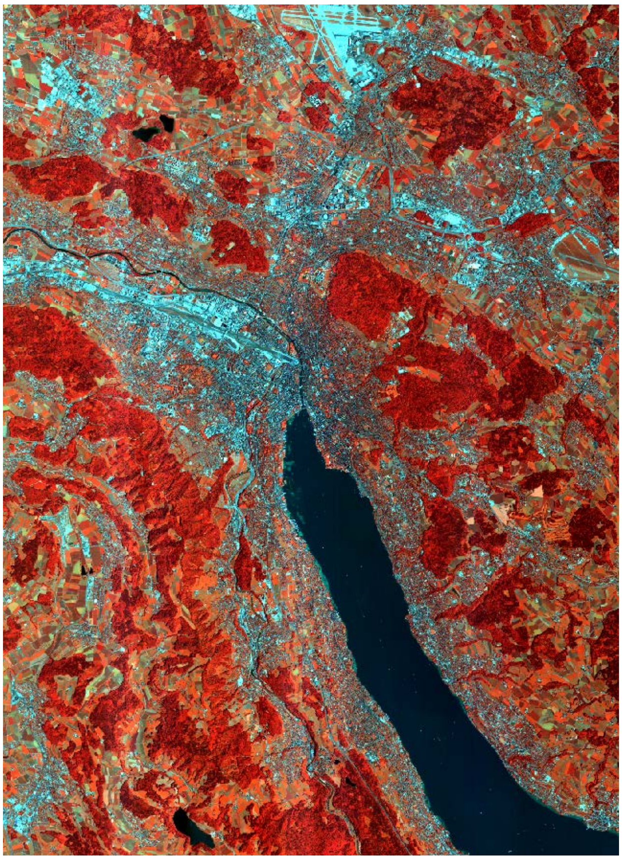
*Figure 4. Pseudo-color composition of the atmospherically corrected Sentinel-2 simulated image (Bands: 8-3-2).*

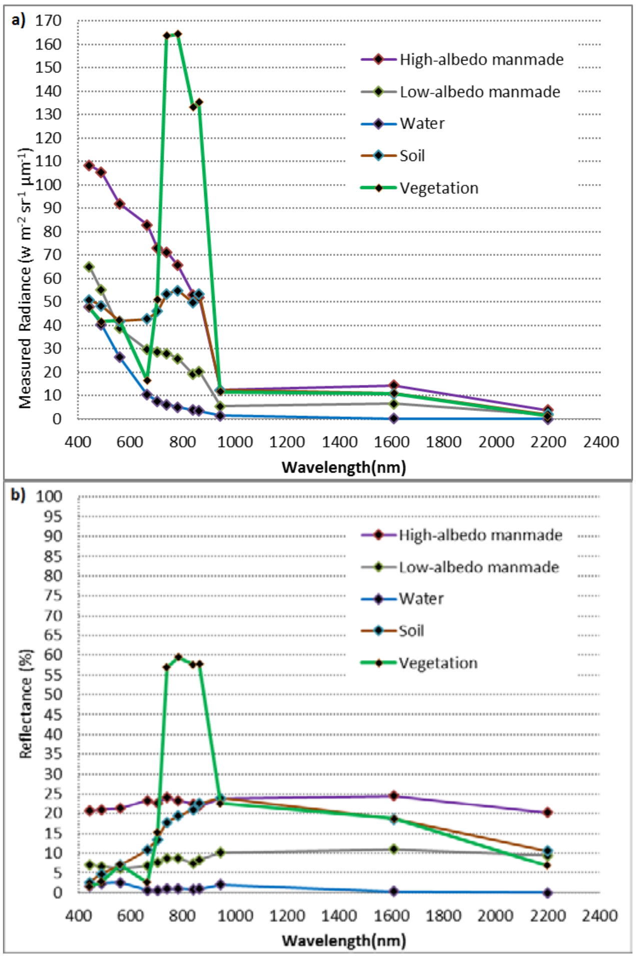


*Figure 5. a) The radiance of some characteristic surface covers and b) their respective reflectance values after the atmospheric correction*

*Table 1. Slope, intercept and the coefficient of determination ($R^2$) for the linear relationship between surface reflectance and measured radiance.*

| Band | Slope | Intercept | $R^2$ |
|---|---|---|---|
| 1 | 0.327 | -13.779 | 0.9926 |
| 2 (Blue) | 0.293 | -9.231 | 0.9967 |
| 3 (Green) | 0.292 | -4.966 | 0.9982 |
| 4 (Red) | 0.319 | -2.540 | 0.9989 |
| 5 | 0.348 | -2.078 | 0.9974 |
| 6 | 0.365 | -1.278 | 0.9951 |
| 7 | 0.377 | -0.909 | 0.9959 |
| 8 (Nir) | 0.450 | -0.824 | 0.9958 |
| 8a | 0.442 | -0.567 | 0.9967 |
| 9 | 2.082 | -1.029 | 0.9825 |
| 11 | 1.760 | -0.158 | 0.9996 |
| 12 | 5.543 | -0.086 | 0.9999 |

A comparison of the fitting procedure described in Section 3.2. was performed by running 6s for every pixel of the Sentinel-2 simulate image and comparing the results to the respective atmospheric correction using the fitting approach. Fig. 6a shows the scatterplot of the reflectance (%) estimated using the proposed fitting approach and the one estimated by running 6s for the whole image.

The respective histogram of the difference in reflectance estimated using the two approaches is shown in Fig. 6b. It doesn't look like Gaussian, as expected, because AOD, DEM, latitude and longitude variables, were not used in the reflectance/radiance fitting. The most important of these parameters is AOD. Since the spatial resolution of AOD is 1 km, a few AOD product cells, with discrete AOD values used in this study. Therefore, since the fitting error is expected to be minimum for the mean AOD, Fig.7b would be more closely to Gaussian, if mean AOD values were included in the used AOD product cells.

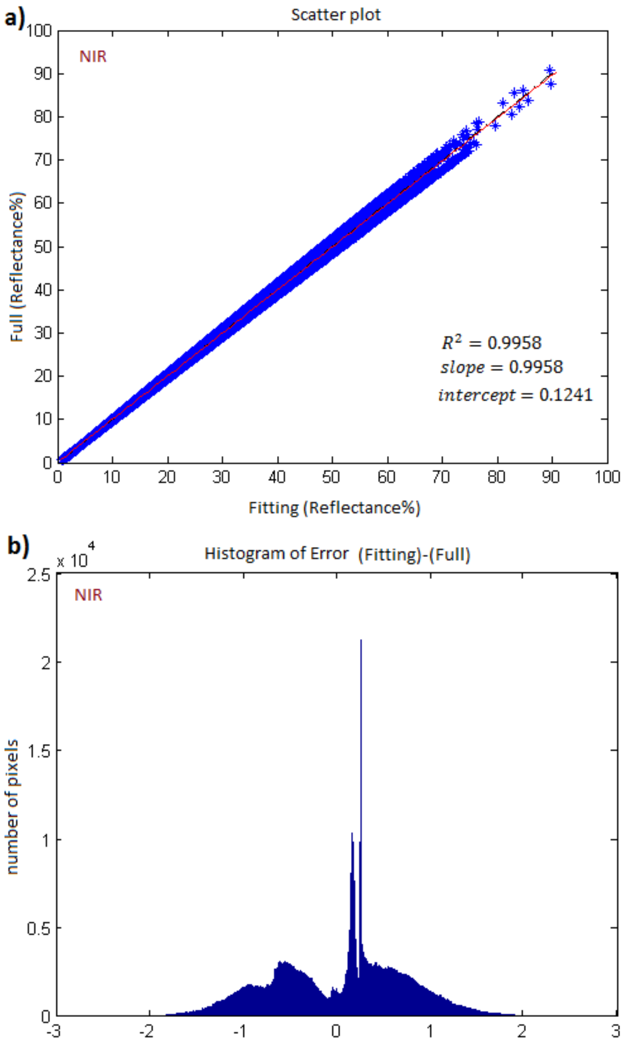


*Figure 6. a) Scatterplot of the reflectance (%) estimated using the proposed fitting approach and the one estimated running 6s for the whole image and b) the respective histogram of the difference.*

## 5. CONCLUSIONS

In this study, an atmospheric correction procedure based on radiative transfer is described for Sentinel-2 data with the use of atmospheric information from Sentinel-3 products. The 6s radiative transfer model was adjusted for use with the Sentinel-2 data and Sentinel-3 products. A fitting procedure ensures fast results with randomly selected pixels atmospherically corrected with 6s using a friendly interface developed for this purpose.

Since, the Sentinel-2 mission will provide global coverage of the Earth's land surface every 5 days with 2 satellites, its data will be of great use in several studies, for the majority of which, accurate atmospherically corrected products are essential. The Sentinels constellation is designed to support synergistic use, therefore this study highlights the use of Sentinel-3 atmospheric products for improving the accuracy of Sentinel-2 derived surface reflectance.

## 6. REFERENCES


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