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Python version of Simplified Level 2 Prototype Processor for Retrieving Canopy Biophysical Variables from Sentinel 2 Multispectral Instrument Data

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Abstract

The Copernicus Sentinel-2 mission is designed to provide data that can be used to globally map widely used vegetation biophysical variables. Currently, estimates of vegetation biophysical variables are not produced operationally by the Sentinel-2 ground segment. Instead, a retrieval algorithm called Simplified Level 2 Prototype Processor (SL2P) has been defined by the European Space Agency. SL2P uses backpropagation neural networks, one to estimate vegetation variables and one to quantify the uncertainty of the estimate, using a database of globally representative canopy conditions populated using canopy radiative transfer model simulations. SL2P had been implemented within the Canada Centre for Remote Sensing LEAF-Toolbox that relies on Google Earth Engine. This document describes a PYTHON implementation of SL2P (SL2P-PYTHON) that provides identical outputs as the LEFA-Toolbox implementation given the same input Sentiel-2 image.

1   Introduction

The Global Climate Observing System (GCOS) has defined requirements for global mapping of essential climate variables (ECVs; WMO, 2023). A subset of these ECVs, leaf area index (LAI), fraction of canopy cover (fCOVER), fraction of absorbed photosynthetically active radiation (fAPAR) and surface albedo, can be derived using Sentinel-2 multispectral satellite imagery in a manner than meets GCOS spatial resolution requirements and has the potential for satisfying GCOS thematic uncertainty requirements. Sentinel-2 is a constellation of two satellites (Sentinel-2A and Sentinel-2B) carrying virtually identical decametric resolution multi-spectral imagers (MSI) with four bands at 10 m, six bands at 20 m, and three bands at 60 m spatial resolution. Currently, estimates of vegetation biophysical variables are not produced operationally by the Sentinel-2 ground segment. Instead, a retrieval algorithm called Simplified Level 2 Prototype Processor (SL2P, *Weiss and Baret, 2016*) has been defined that s capable of estimating LAI, fAPAR, fCOVER, canopy chlorophyll concentration (CCC), canopy water content (CWC) and surface albedo.

SL2P is a collection of backpropagation artificial neural networks (ANN) trained using a globally representative set of simulations from the PROSAILH (*Jacquemoud and Baret, 1990, Verhoef, 1984)* canopy radiative transfer model. Simulations were sampled from a single joint probability density

function of canopy variables, based on heuristics considered representative of cropland and natural vegetation, and a regular sampling of local flat earth view and illumination geometry for the global coverage of the sensor under consideration. Two neural networks were trained for each biophysical variable. The first neural network was trained to predict the expected value of the biophysical variable. The second neural network was trained to predict the expected value of the residual of the estimated biophysical variable by the first neural network. The thematic performance of SL2P estimates of LAI, fAPAR and fCOVER has been extensively quantified over a range of land cover in temperate, boreal and sub-tropical biomes (*Djamai et al., 2019; Brown et al., 2021; Fernandes et al. 2023*).

SL2P has been implemented in both the European Space Agency Sentinel Application Platform (SNAP) and the Canada Centre for Remote Sensing LEAF-Toolbox (https://github.com/rfernand387/LEAF-Toolbox, Fernandes et al., 2021). These implementations show slight differences in predictions due to an error in the European Space Agency SNAP implementation not present in LEAF-Toolbox (Fernandes et al. (2023). This document describes a PYTHON implementation (SL2P-PYTHON) that provides identical predictions as the LEAF-Toolbox version of SL2P both because the latter matches the original SL2P ATDB and because it has been extensively validated (Brown et al., 2021, Fernandes et al., 2023).

2   Methodology

SL2P-PYTHON corresponds to python modules that ingests a ESA Sentinel-2 Level 2A product and applies required neural networks and quality flag algorithms to produce an output Level 2B Biophysical product (https://github.com/djamainajib/SL2P_python). For convenience, a Jupiter Notebook is provided to demonstrate the required sequence of operations.

2.1   Required Inputs

SL2P-PYTHON requires as input an ESA SAFE format Sentinel-2 Level 2A product (https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-2/data-products). However, the code can be easily adapted to reformatted versions of these products by modifying the first processing step described below.

2.2   Process Flow

The user should specify the location of Sentinel-2 image to be processed, the needed vegetation variable, and the needed spatial resolution.

SL2P-PYTHON processing chain contains the following steps:

i. Read the ESA SAFE Sentinel-2 Level 2A product in the needed spatial resolution. This step should be replaced by a used defined function if Sentinel-2 Level 2A products in different formats are to be processed.

ii. Prepare SL2P inputs: this step includes (1) resample view/sun zenith an azimuth angles, (2) compute the relative azimuth angle, (3) compute the cosine of angles, and build a 3D (K*N*M) dataset to be SL2P inputs. K is the number of used bands which depends on the needed spatial resolution (Tables 1 and 2), and N/M are the number of raw/columns of the used image.

iii. Run SL2P: SL2P-PYTHON uses the original SL2P ANN's coefficients from LEAF-Toolbox to estimate the needed vegetation variable and the corresponding uncertainty. In addition, it outputs two QA maps: SL2P_input_flags (inputs out of the domain of the calibration dataset) and SL2P_output_flag (estimates out of the nominal variation range) maps.

iv. Export outputs in a 4-layers GeoTIFF format.

Table 1: Order and variation range of SL2P-PYTHON input data used for 20m spatial resolution option.

Order	Sentinel-2 data	Variation range
1	cosVZA	0 - 1
2	cosSZA	0 - 1
3	cosRAA	-1 - 1
4	B03	0 - 1
5	B04	0 - 1
6	B05	0 - 1
7	B06	0 - 1
8	B07	0 - 1
9	B8A	0 - 1
10	B11	0 - 1
11	B12	0 - 1

Table 2: Order and variation range of SL2P-PYTHON input data used for 10m spatial resolution option.

Order	Sentinel-2 data	Variation range
1	cosVZA	0 - 1
2	cosSZA	0 - 1
3	cosRAA	-1 - 1
4	B02	0 - 1

5	B03	0 - 1
6	B04	0 - 1
7	B08	0 - 1

2.3 Output

SL2P-PYTHON outputs a 4-layers (Table 3) GeoTIFF map for each selected vegetation variable (Table 4)

Table 3: SL2P-PYTHON output layers for one selected vegetation variable

Layer	Description
Vegetation variable estimate	Map of vegetation variable
Uncertainty of vegetation variable estimates	Map of the uncertainty of vegetation variable
SL2P input flag (Quality Code)	0: Valid, 1: SL2P input out of SL2P calibration domain
SL2P output flag (Quality Code)	0: Valid, 1: estimates out of the nominal variation range (Table 2.2)

Table 4: Vegetation variables could be estimated using SL2P-PYTHON

Vegetation variable	Description	Unit	Valid range
LAI	Half the total green foliage area per horizontal ground area.	m2 foliage /m2 ground	0 - 8
fCOVER	Fraction of nadir canopy cover	ratio	0 – 1
fAPAR	Fraction of absorbed clear sky PAR at 10:30am local time	ratio	0 – 1
CCC	Canopy chlorophyll A+B content	g/m2	0 - 600
CWC	Canopy water content	g/m2	0 – 1
Albedo	Black sky shortwave albedo at 10:30am local time	ratio	0 – 0.2

2.4 Code Verification

SL2P-PYTHON was tested using one Sentinel-2 image acquired over Ottawa (ON) on August 31, 2023 (S2B_MSIL2A_20230831T155829_N0509_R097_T18TVR_20230831T203613.SAFE). Products are compared to the corresponding products obtained using the LEAF-Toolbox and SNAP implementation of SL2P.

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3   Results

Figure 1 presents the true-color composite image of the Sentinel-2 image used for testing SL2P-Python.

Figure 1: Sentinel-2 MSI L2A image used for testing SL2P-PYTHON

3.1   Comparison of SL2P-PYTHON vs. LEAF-Toolbox

Figure 2 shows scatter plots comparing vegetations variables estimates obtained using SL2P-PYTHON with the corresponding estimates obtained using SL2P- LEAF-Toolbox. Figure 3 shows scatter plots comparing the uncertainty of vegetations variables estimates obtained using SL2P-PYTHON with the uncertainty of corresponding estimates obtained using SL2P- LEAF-Toolbox. We notice that products from SL2P-PYTHON and SL2P- LEAF-Toolbox are exactly the same.
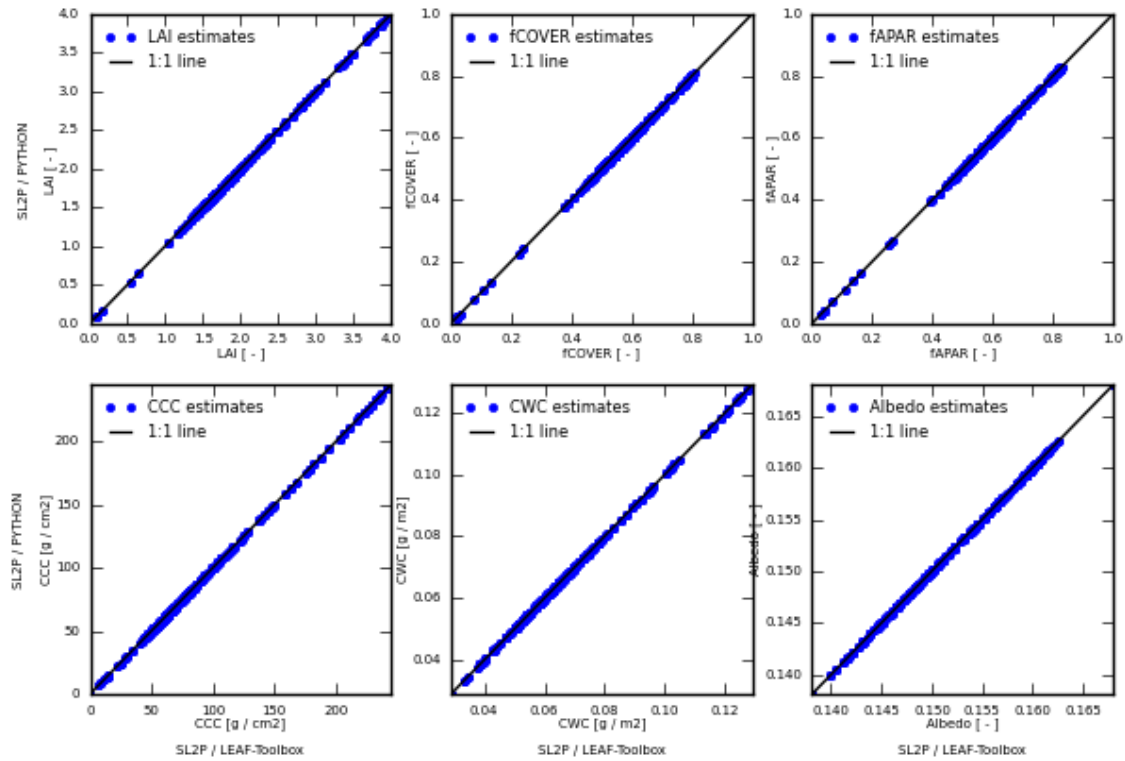
Figure 2: Scatter plots of vegetations variables estimates obtained using SL2P-PYTHON compared to the corresponding estimates obtained using SL2P- LEAF-Toolbox
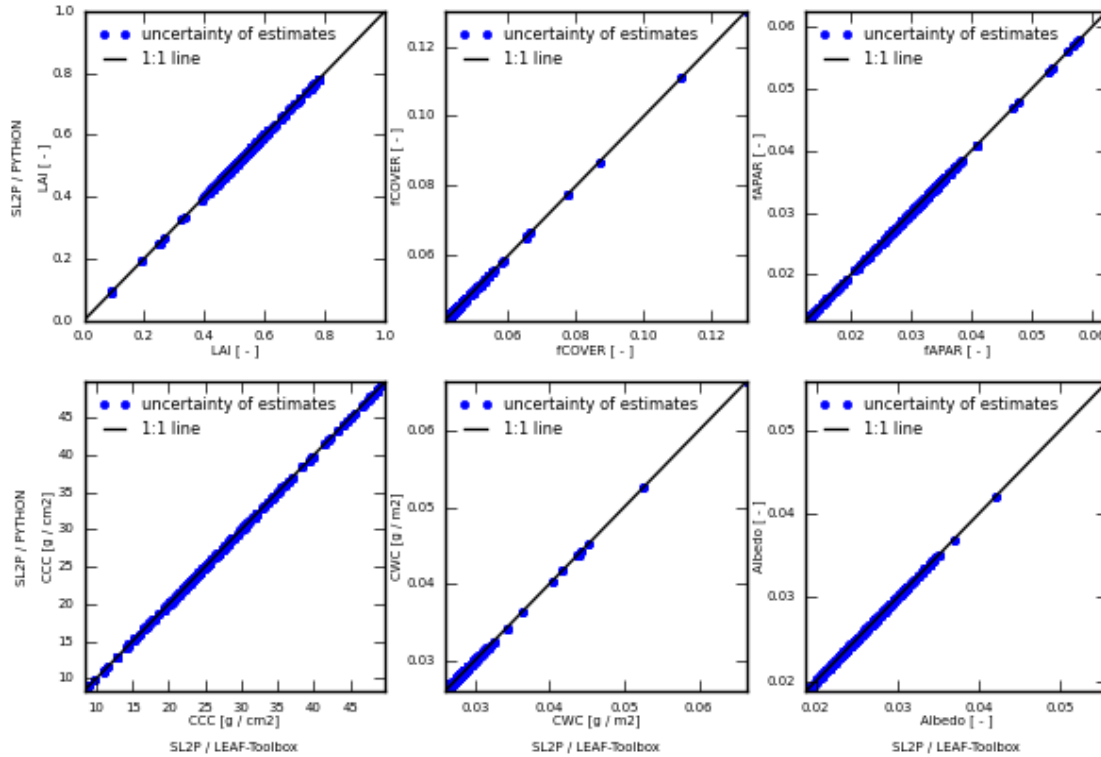

Figure 3: Scatter plots of uncertainties of vegetations variables estimates obtained using SL2P-PYTHON compared to the uncertainty of corresponding estimates obtained using SL2P- LEAF-Toolbox

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3.2   Comparaison SL2P-PYTHON vs SNAP implementation of SL2P

Figure 4 shows density scatter plots (isolines) comparing vegetation variables estimates obtained using SL2P-PYTHON compared to the corresponding estimates obtained using SNAP implementation of SL2P. Slightly different estimates are obtained using SL2P-PYTHON due to an error in the SNAP implementation (Fernandes et al. (2023).
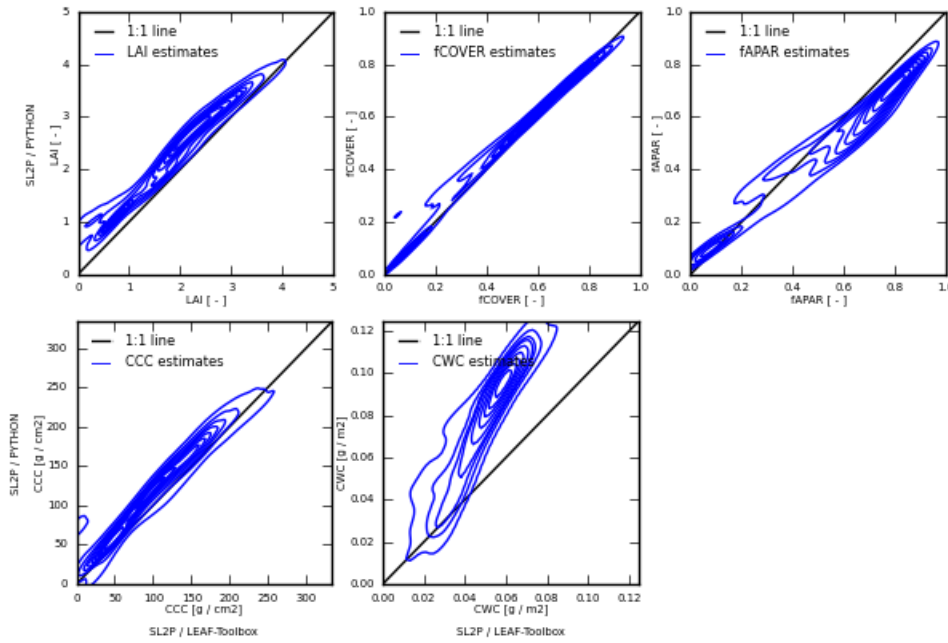

Figure 4: Density scatter plots (isolines) of vegetations variables estimates obtained using SL2P-PYTHON compared to the corresponding estimates obtained using SL2P- SNAP implementation.

4   Conclusions

A python implementation of SL2P (SL2P-PYTHON) that does not rely on the Google Earth Engine API is described. SL2P-PYTHON maps leaf area index, fraction of canopy cover, fraction of absorbed photosynthetically active radiation, canopy chlorophyll concentration, canopy water content, and albedo at 10 or 20 m spatial resolution using ESA Sentinel-2 MSI L2A products in SAFE format. An additional uncertainty layer and quality index layer is provided to satisfy the Committee of Earth Observing Systems requirements for Analysis Ready Data. SL2P-PYTHON provides identical results as the CCRS implementation of SL2P within the LEAF-Toolbox that follows the algorithm theoretical basis document of Weiss and Baret (2016). However, SL2P-PYTHON differs from the ESA-SNAP

implementation due to differences in calibration of neural networks documented in Fernandes et al. (2023). SL2P-PYTHON is available to use under the Government of Canada's Open Science policy and can be accessed at https://github.com/djamainajib/SL2P-PYTHON.

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