**Simplified Level 2 Processor Implementation for CCRS Landsat Datacubes**

# Introduction

The Cumulative Effects Monitoring research project within Canada Centre for Remote Sensing is tasked with production of monthly vegetation biophysical parameter maps for fraction of canopy cover (FCOVER), leaf area index (LAI), and fraction of absorbed photosynthetically active radiation FAPAR) at better than 100m spatial resolution covering Canada for each growing season in a 10 year period. The purpose of these maps is to provide baseline information on vegetation status for trend and anomaly detection and for models. As an initial step, a single map representative of annual peak growth status during June, July, and August is required. The purpose of this report is to provide background regarding the input data and algorithm applied and details to apply accompanying computer code to produce the annual peak growing season maps.

# Algorithm

## Overview

The maps are produced by applying separate pixel based regression algorithms defined in the Simplified Level 2 Prototype Processor (SL2P, Weiss and Baret, 2016) adapted for Landsat 8 Operational Line Imager (OLI) data (SL2P-CCRS, Djamai et al., 2019) to predict each parameter and the standard error of the parameter estimate given clear sky OLI top of atmosphere (TOA) reflectance data as input, together with information on illumination and view geometry. An additional data quality sequence is also output for each pixel, coded using bit flags for a single integer.

The current algorithm is engineered to apply to OLI data formatted in a data cube produced by the CCRS OLI Processing System (Latifovic et al., 2015). The algorithm has been verified by comparing results of processing an OLI TOA image acquired from the United States Geological Survey using a MATLAB implementation of the SL2P (See Testing).

## Background

SL2P-CCRS is based on the European Space Agency (ESA) SL2P processor (Weiss and Baret, 2016). SL2P-CCRS calibrates separate non-linear regression models (shallow neural networks) to predict the expected value and standard error of each parameter given, in this case, TOA reflectance. The calibration database corresponds to 41742 paired simulations of TOA reflectance and target variables (FCOVER, LAI or fAPAR). The simulations are created using the PROSAIL radiative transfer model using input canopy, atmosphere and sensor parameters sampled from joint distributions of values representative of global land cover conditions and the Landsat 8 OLI. Orthogonal sampling is used to maximize the coverage of simulations over the sampled distribution. In addition to producing regression model coefficients, SL2P-CCRS also provides lists specifying the domain and range of the calibration data. These lists are used to flag retrievals that fall outside the domain or range of the calibration data.

SL2P-CCRS, including a detailed algorithm theoretic basis document (Fernandes and Djamai, 2020) is available at <https://github.com/rfernand387/SL2PD>. Validation of SL2P over croplands (essentially similar in performance to SL2P-CCRS) for top of canopy reflectance Landsat 8 OLI data is reported in Djamai et al. (2019). Validation over other land cover is ongoing. It is likely SL2P-CCRS will be revised after validation but this revision will impact the regression models rather than the application of the models to data.

# Implementation

The code is implemented in Windows under the platform of Visual Studio 2019 C++, the project template used is Console App. The codes will be migrated to Linux.

## Assumptions

The input data follows the CCRS Landsat Processing System data cube format (see Input Data File).

All pixels are processed. Users should only consider pixels corresponding to clear sky vegetated surfaces with zero data quality flags (good quality retrievals). This assumption should be enforced by post retrieval masking using associated OLI quality flags and land cover data.

Sensor azimuth and zenith angle is zero. This assumption is reasonable for OLI data over flat surfaces.

The surface is relatively flat and has homogenous (not highly clumped) vegetation cover. This assumption will be relaxed in upgrades.

## Input Data

The input data consists of an input data file and an input coefficient file.

### Input Data File

A binary file is required at the specified location on an accessible disk. The input image file name uses the naming convention of CCRS Landsat mosaic tile.

Table 1. **Input imagery files, index file, and look up table file**

|  |  |
| --- | --- |
| **File Name** | **File description** |
| Tile\*\_cch3.raw | mosaic channel 3 of Landsat 8, \* indicates the number of title; the data was multiplied by 10000, and the format is 16 bit short, the following input channels are the same. |
| Tile\*\_cch4.raw | mosaic channel 4 of Landsat 8, \* indicates the number of title |
| Tile\*\_cch5.raw | mosaic channel 5 of Landsat 8, \* indicates the number of title |
| Tile\*\_cch6.raw | mosaic channel 6 of Landsat 8, \* indicates the number of title |
| Tile\*\_cch7.raw | mosaic channel 7 of Landsat 8, \* indicates the number of title |
| Tile\*\_ind.raw | mosaic index of Landsat 8, \* indicates the number of title |
| lsit\*\_angl.txt | look up table associated with the above index file, \* indicates the year, like 2016 |

### Input Coefficient Files

The input coefficient files are a set of text files that specify the dates and names of Landsat scenes used to make the input data (Fileslist.txt), the regression models (\*netpara.txt) and a databases used to determine if outputs are valid (\*bar.txt) and inputs are valid (convex.txt).

Table 2**. Input coefficient files**

|  |  |
| --- | --- |
| **File name** | **File description** |
| Fileslist.txt | includes the full path of all coefficient file and quality control files |
| fapar\_netpara.txt | neural network coefficients for FAPAR |
| fcover\_netpara.txt | neural network coefficients for FCOVER |
| lai\_netpara.txt | neural network coefficients for LAI |
| lai\_cab\_netpara.txt | neural network coefficients for LAI.Cab |
| lai\_cw\_netpara.txt | neural network coefficients for LAI.Cw |
| fapar\_unnetpara.txt | uncertainty neural network coefficients for FAPAR |
| fcover\_unnetpara.txt | uncertainty neural network coefficients for FCOVER |
| lai\_unnetpara.txt | uncertainty neural network coefficients for LAI |
| lai\_cab\_unnetpara.txt | uncertainty neural network coefficients for LAI.Cab |
| lai\_cw\_unnetpara.txt | uncertainty neural network coefficients for LAI.Cw |
| fapar\_bar.txt | parameters for FAPAR in BIO\_VAR\_bounding\_box |
| fcover\_bar.txt | parameters for FCOVER in BIO\_VAR\_bounding\_box |
| lai\_bar.txt | parameters for LAI in BIO\_VAR\_bounding\_box |
| lai\_cab\_bar.txt | parameters for LAI.Cab in BIO\_VAR\_bounding\_box |
| lai\_cw\_bar.txt | parameters for LAI.Cw in BIO\_VAR\_bounding\_box |
| convex.txt | parameters for convex hull |

## Output Files

The output consists of single band image binary files the same spatial extent and resolution as the input data files for biophysical parameter estimates, uncertainty estimates and quality mask.

### Biophysical parameter files

**Table 3. Output of Biophysical parameter files.**

|  |  |
| --- | --- |
| **File name** | **File description** |
| Tile\*\_FAPAR.raw | output of biophysical parameter FAPAR, \* indicates the tile number, the output is 32 bit float, all other outputs are the same. |
| Tile\*\_FCOVER.raw | output of biophysical parameter FCOVER |
| Tile\*\_LAI.raw | output of biophysical parameter LAI |
| Tile\*\_LAI\_Cab.raw | output of biophysical parameter LAI.Cab |
| Tile\*\_LAI\_Cw.raw | output of biophysical parameter LAI.Cw |

### Uncertainty files

**Table 4. Output of uncertainty biophysical parameter files.**

|  |  |
| --- | --- |
| **File name** | **File description** |
| Tile\*\_unFAPAR.raw | output of uncertainty biophysical parameter FAPAR, \* indicates the tile number, the output is 32 bit float, all other outputs are the same. |
| Tile\*\_unFCOVER.raw | output of uncertainty biophysical parameter FCOVER |
| Tile\*\_unLAI.raw | output of uncertainty biophysical parameter LAI |
| Tile\*\_unLAI\_Cab.raw | output of uncertainty biophysical parameter LAI.Cab |
| Tile\*\_unLAI\_Cw.raw | output of uncertainty biophysical parameter LAI.Cw |

### Flag files

**Table 5. Output of flag file of biophysical parameters.**

|  |  |
| --- | --- |
| **File name** | **File description** |
| Tile\*\_flag\_FAPAR.raw | output of quality flag of biophysical parameter FAPAR |
| Tile\*\_flag\_FCOVER.raw | output of quality flag of biophysical parameter FCOVER |
| Tile\*\_flag\_LAI.raw | output of quality flag of biophysical parameter LAI |
| Tile\*\_flag\_LAI\_Cab.raw | output of quality flag of biophysical parameter LAI.Cab |
| Tile\*\_flag\_LAI\_Cw.raw | output of quality flag of biophysical parameter LAI.Cw |

### Log file

Tile\*\_log.txt- a log file created to record path, the input files name, the output file names and time.

## Classes and functions in the code

SL2P.cpp is the main function with the following functions:

* calculateAngles - function to calculate solar and sensor angles based on tile index
* CalBioPhy - function to calculate BioPhysical parameters based on input imagery cubes
* CalNeuralNetFlagOutput - function to calculate biophysical parameters and flag based on the input pixels
* CalunNeuralNetOutput - function to calculate uncertainty biophysical parameters based on the input pixels
* outputToFile - function to save the result to file

Class BioPhy is a biophysical wrapper class to access the parameters in Class Network, class Convexhull, class BioVARboundingbox.

Class Network is the kernel part in the implementation, which include parsing the coefficients of neural network, and computation of the output of neural network.

Class Convexhull is to parse the parameters from the convex.txt and has the regular functions of setter and getter.

Class BioVARboundingbox is to parse the parameters from the input text file and has the regular functions of setter and getter.

# Installation

## Windows/Linux

The codes were developed in Windows under the platform of Visual Studio 2019 C++, the project template used is Console App, which is easily migrated to Linux.

## Testing

There are two testing methods:

One is used the executable file BioPhy.exe located at BioPhy -Tileprocessing - \x64\Release with the following data setting.

Copy the sample data (5000 by 50000) under C directory, the coefficient files are also include in the sample data with a subdirectory of \coefficients.

The second is to change the code at the beginning of SL2P.cpp to reflect the input data path and data size; at the same time, change the content of Filelist.txt located at Tile43\coefficients with the full path name of those coefficients.

A sample of this testing result is provided at Google Drive (https://drive.google.com/open?id=1Wsht8GRtpo5Sg96ExFrRs2g\_cBRB1149).

# Conclusions

This document described an implementation of the SL2P-CCRS system for mapping vegetation biophysical variables applied to Landsat 8 OLI image cubes produced by the CCRS Landsat Processing System.

Details regarding the algorithm, implementation, installation and testing were provided.

The system will be upgraded in the near future to include additional regression networks as required follow validation of outputs.

# References

Fernandes, R.A. and Djamai, N., 2020. Algorithm Theoretical Basis Document Version 1.0: Simplified Level 2 Vegetation Processor – Distributed (SL2P-D) for Estimating Biophysical Variables using Sentinel-2 Multispectral Imager Data. *Geomatics Canada*, Open File, in press, available at “https://github.com/cmacdou/SL2PD-flight/blob/master/Reports/sl2p-d.docx”.

Djamai N., Fernandes, R., Weiss, M., McNairn, H., and Goita, K., 2019. Validation of the Sentinel Simplified Level 2 Product Prototype Processor (SL2P) for mapping cropland biophysical variables using Sentinel-2/MSI and Landsat-8/OLI data. *Remote Sensing of Environment*, 225, 416-430.

Latifovic, R, Pouliot, D, Sun, L, Schwarz, J, Parkinson, W., 2015. Moderate resolution time series data management and analysis: automated large area mosaicking and quality control; *Geomatics Canada*, Open File 6, 2015, 25 pages, https://doi.org/10.4095/296204 (Open Access).

Weiss, M. and Baret, F., 2016. S2ToolBox level 2 products. Version 1.1. Available online step.esa.int/docs/extra/ATBD\_S2ToolBox\_L2B\_V1.1.pdf, last accessed: 28-03-2020.