Sentinel-2-A/B & Chinese Data Agriculture monitoring & retrievals [D5OTP2]

November 22, 2019

1 Introduction

This document outlines the steps that will be taken in the practical of "*Agriculture monitoring & retrievals*" of the ESA land training course 2019 (D5OTP2). The objectives of this session are to familiarize students with the SNAP v7.0 optical thematic Land processing tools mainly in the context of analyzing spatialized scientific Sentinel 2 datasets used in agriculture monitoring and retrievals for precision farming.

2 Packages

1. SNAP v7.0: Download and install it from the ESA website: http://step.esa.int/main/download/snap-download/)

3 Data set

3.1 The Sentinel-2 data set on Maccarese (Italy)

The Maccarese Area Of Interest (41.833◦ lat. N, 12.217◦ long. E, alt. 8 m a.s.l.) is located in the west coast of Central Italy, near Rome. It is a private farm of 3,200 ha in a flat area with large agricultural fields. Field campaigns were carried out to measure biophysical variables on the durum wheat (*Triticum durum Desf.*) crop from January 2018 to April 2018 to monitor its growing season. Field campaigns dates are close to Sentinel-2 acquisitions.

The Sentinel-2 images acquired on the Maccarese farm are available in the repository as:

~\Maccarese Test Site IT\Maccarese S2 2018 data

The images were downloaded as L2A product (i.e. reflectances) and resized according to the AOI (i.e. Maccarese experimental fields). The provided products consist of bottom-of-atmosphere reflectance data. It is in UTM 32 projection, GCS WGS-84 date/spheroid. The data includes 12 spectral bands at 443 nm, 490 nm, 560 nm, 665 nm, 705 nm, 740 nm, 783 nm, 842 nm, 865nm, 945 nm, 1610 nm, 2190 nm. Pixel size is 10 m for all bands, after aggregating them to the 10 m red band. Data is stored in the SNAP *.dim* format.

The crop biophysical variables were sampled according to an elementary sampling unit (ESU) scheme, to capture the variability within and among different fields. Each ESU consisted of a quadrat of 20m by 20m size, to easily accommodate the Sentinel-2 10-m pixel resolution. A total of 15 ESUs, placed at different locations were employed at different sampling dates. Each ESU contains nine points, where LAI, FVC and

Chlorophyll measurements were collected. Leaf area index was measured using the LAI-2000 or the LAI-2200C Plant Canopy Analyzer (LI-COR, Lincoln, NE, USA). Chlorophyll measurements were obtained using the Force-A Dualex leaf clip reader on the top-most leaves. The 2018 growing season ground validation dataset is composed of 45 samples for Maccarese (i.e. by averaging each ESU).

Ground Measurements data as well as the shape file of the fields of interest for this experiment are provided on the repository in *ASCII* format in the folder:

~\Maccarese_Test_Site_IT\Maccarese GM

3.2 The Sentinel-2 data set on Shunyi (China)

Shunyi Area of Interest is located in the Shunyi district (40.130 lat. N, 116.654 long. E), Beijing, China. Ground campaigns were carried out in the period between April and May 2016 to collect measurements on winter wheat (*Triticum aestivum L.)* crop. LAI was measured using the Licor LAI 2000/2200C instrument and leaf chlorophyll was measured using the Force-A Dualex readings calibrated using laboratory analysis. From April to May 2016, at four different dates, with 24 observations per date, LAI and LCC measurements were collected.

Two Sentinel-2A images on the Shunyi farm are available in the repository as:

~\Shunyi_Test_Site_CH\Shunyi S2 2016 data

The images were downloaded as L1C product (i.e. radiance) and preprocessed using Sen2Cor in SNAP and resized according to the AOI (i.e. Shunyi Experimental Fields). The provided product consists of bottom-of-atmosphere reflectance data. It is in a 10 m raster WGS-84. The data includes 12 spectral bands at 443 nm, 490 nm, 560 nm, 665 nm, 705 nm, 740 nm, 783 nm, 842 nm, 865nm, 945 nm, 1610 nm, 2190 nm. Pixel size is 10 m for all bands, after aggregating them to the 10 m red band. Data is stored in the SNAP *.dim* format.

The ground validation dataset is composed of 96 samples.

Ground Measurements data of the fields of interest for this experiment are provided on the repository in *ASCII* format in the folder:

~\Shunyi\Shunyi GM

3.3 The GF-1 data set on Shunyi (China)

Three GF-1 images on the Shunyi farm are available in the repository as:

~\Shunyi\Shunyi GF1 2016 data

The images were provided by RADI/CAS (Beijing, China) in radiance and preprocessed using the FLAASH tool implemented in the ENVI 5.4 software. The provided product consists of reflectance data in UTM 50N, WGS-84. The data includes 4 spectral bands at 485 nm, 555 nm, 675 nm, 789 nm. Data is stored in the ENVI format and can be opened in SNAP by using the **File/Import/Generic Formats/ENVI**.

The ground validation dataset is composed of 23 samples. Ground Measurements data are provided on the repository in *ASCII* format in the folder:

~\Shunyi\Shunyi GM

4 Practical exercises

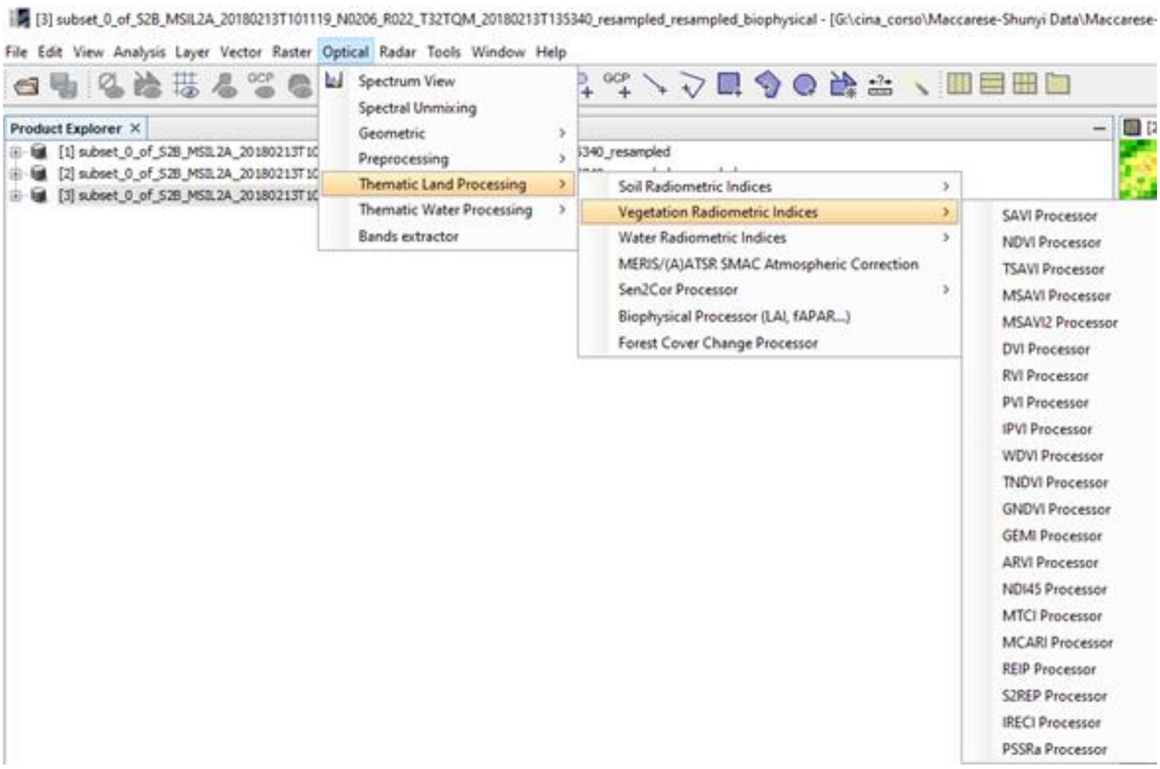
4.1 Objective: estimation of crop related vegetation indices and biophysical variables from a subset of a Sentinel-2 L2A product

The exercise is realized by using the SNAP software tool.

- Start the SNAP and to visualize Sentinel-2 data of Maccarese (Italy): select **File > Open Product**
    - folder: *Maccarese Test Site IT\Maccarese S2 2018 data\S2B_MSIL2A_20180213T101119_N0206_R022_T32TQM_20180213T135340.SAFE*
    - image name: *subset_5_of_S2B_MSIL2A_20180213T101119_N0206_R022_T32TQM_20180213T135340_resampled.dim*
- Click right button on the file name in the **Product Explorer** window and select ***Open RGB Image Window***

4.1.1 VI retrieval using SNAP tool

From the Optical menu, select **Thematic Land processing > vegetation radiometric indices**



Calculate on the menu the following vegetation indices:

	Biomass (structural)	Pigments (Chl)
Group A	NDVI	PSSRa
Group B	MSAVI	REIP
Group C	TSAVI	IRECI
Group D	TNDVI	MCARI

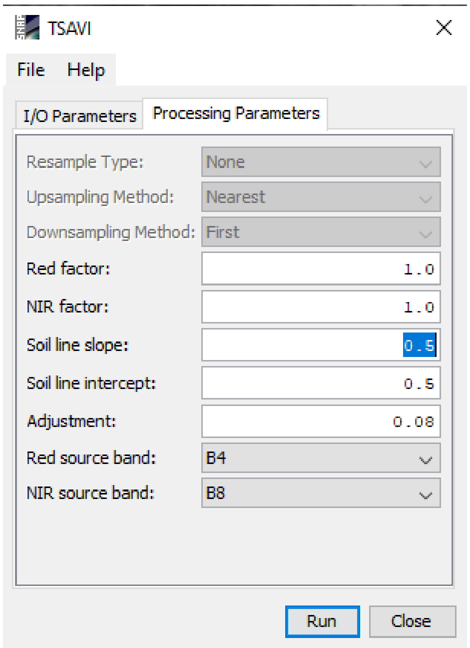
Refer to the SNAP Help for the description of the VIs algorithms.

Each index includes a Processing Parameter Window that could be used to tune the index input parameters. For example:

NDVI = $(\text{IR\_factor} * \text{near\_IR} - \text{red\_factor} * \text{red}) / (\text{IR\_factor} * \text{near\_IR} + \text{red\_factor} * \text{red})$

TSAVI = $s * (\text{IR\_factor} * \text{near\_IR} - s * \text{red\_factor} * \text{red} - a) / (s * \text{IR\_factor} * \text{near\_IR} + \text{red\_factor} * \text{red} - a * s + X * (1 + s * s))$

where: ***a*** is the soil line intercept; ***s*** is the soil line slope; **X** is the adjustment factor to minimize soil noise. TSAVI calculated using the SNAP standard parameter for ***a*** and ***s***.



REIP = $705 + 35 * ((B4 + B7)/2 - B5) / (B6 - B5)$

Where, the Central wavelength/Bandwidth are B7 = 783 nm, B6 = 740 nm, B5 = 705 nm, B4 = 665 nm

IRECI = $(\text{IR\_factor} * \text{near\_IR} - \text{red1\_factor} * \text{red1}) / (\text{red2\_factor} * \text{red2} / \text{red3\_factor} * \text{red3})$

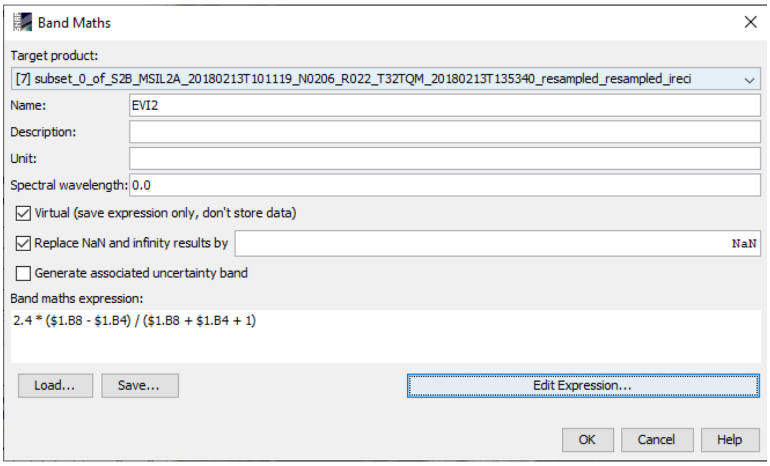
For Sentinel-2 is (B7 - B4) / (B5 / B6), where: B7 = 783 nm, B6 = 740 nm, B5 = 705 nm, B4 = 665 nm

4.1.2 VI retrieval not included in SNAP tool

From the **Raster menu > Band Maths**

EVI2 assessment: **EVI2** = *2.4 * (NIR - RED) / (NIR + RED + 1); i.e. for* Sentinel-2 (B08 - B04) / (B08 + B04 + 1.0)

EVI2 performed according to Jiang et al., 2008 and Stevens, 2009.



LAI assessment is performed according to Delegido et al. 2011

$\boldsymbol{LAI_{BM}} = 8.452\left(\frac{R_{705} - R_{665}}{R_{705} + R_{665}}\right)$; i.e. Sentinel-2 bands B4 and B5.

OSAVI index calculated from Xu, M., et al. 2019,

OSAVI = $(1 + 0.16)(R_{865} - R_{665})/(R_{865} + R_{665} + 0.16)$; i.e. Sentinel-2 bands B8A and B4.

The TSAVI was calculated according to Baret et al. (1989)

TSAVI$_{BM}$ = *s * (IR_factor * near_IR - s * red_factor * red - a) / (s * IR_factor * near_IR + red_factor * red - a * s + X * (1 + s * s))*

where: ***a*** is the soil line intercept; ***s*** is the soil line slope; **X** is the adjustment factor to minimize soil noise.

In order to apply VI that reduce the influence of the soil, it is necessary to calculate the soil line that corresponds to the linear regression line between values in red and in the NIR of the soil. For this aim, we use first the SNAP scatterplot (**Analysis > Scatter plot menu)** selecting the Sentinel-2 image (i.e. *subset_5_of_S2B_MSIL2A_20180213T101119_N0206_R022_T32TQM_20180213T135340_resampled.dim*). In the pop up window select Band 4 of the first product opened for X-Axis and Band 8 for Y-Axis. Use the refresh  button to view the scatter plot. The graph shows the red and NIR values of all the pixels in the image, but we would like to use only those in which the bare soil is present, therefore a mask of soil fields is required.

Open a RGB image selecting the most appropriated bands to visualize bare soil (e.g. bands 8-4-2).

Use the Drawing tools  to create a series of polygons to select areas where the bare soil is clearly visible from the image.

Open the Mask manager menu and rename the newly created "**geometry**" mask by clicking on the name and typing "Soil" in the text box.

On the Scatter Plot window click on the right button and copy to clipboard; paste on an excel worksheet and determine the linear regression line. The estimated slope (***a***) and intercept (***b***) corresponds to the values to be used as input in the TSAVI processing parameter window in SNAP (see the above figure for TSAVI configuration window).

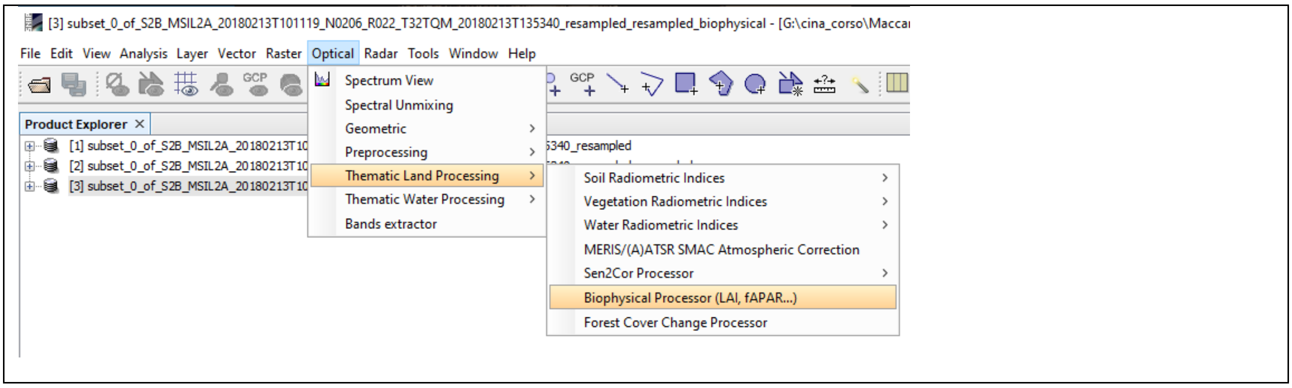
4.1.3 Estimation of biophysical variables (LAI, LAI_Cab, LAI_cw, FAPAR, FCOVER) from a subset of a Sentinel-2 L2A product

The biophysical variables are retrieved using the SNAP biophysical processor which algorithm derives from top-of-canopy normalized reflectance data a set of biophysical variables:

- LAI: Leaf Area Index
- FAPAR: Fraction of Absorbed Photosynthetically Active Radiation
- FCOVER: Fraction of vegetation cover
- Cab: Chlorophyll content in the leaf
- CW: Canopy Water Content

The Sentinel-2 SNAP algorithm for the biophysical variable retrieval is based on a NNs algorithm (https://step.esa. int/docs/extra/ATBD_S2ToolBox_L2B_V1.1.pdf).

From the **Optical menu > Thematic land processing > Biophysical Processor,** select the input reflectance imagery (L2A) to obtain the raster images of the variables of interest.



5 Comparison and Validation

5.1 Import ground measurements

Open the VI indexes and the Biophysical parameters as derived from SNAP toolbox.

Import the ground measurements relative to each image (same dates) as follows:

- **Import > vector from csv**
  - open file “DDMMYY *DurumWheat_Maccarese_GTSurvey.txt”*
    - Custom CRS /Geographic Lat/Lon(WGS 84)
    - Track points

Check the data integrity by double click on **Product Explore / Vector Data /** “DDMMYY *DurumWheat_Maccarese_GTSurvey.txt”*

5.2 Validation of VI and Biophysical parameters vs Ground Measurements

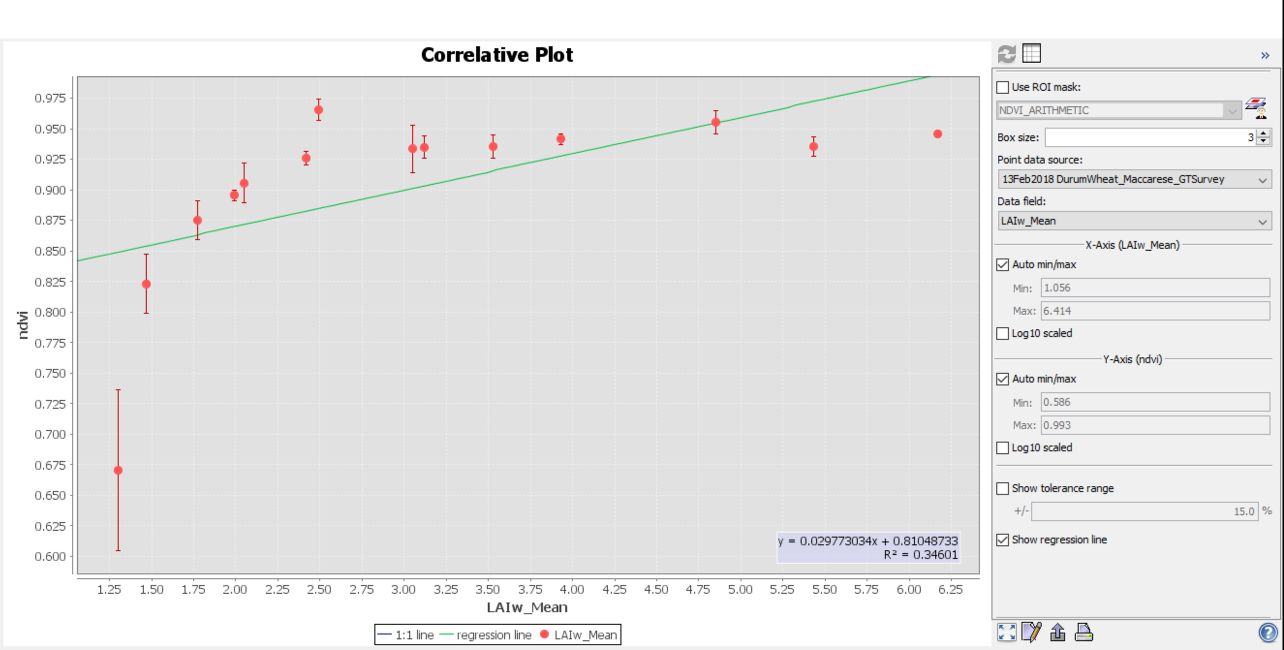
In this section the ground validation of the retrieved parameters and indexes is performed by using the collected ground measurements for the two test sites.

Open Analysis > Correlative plot 

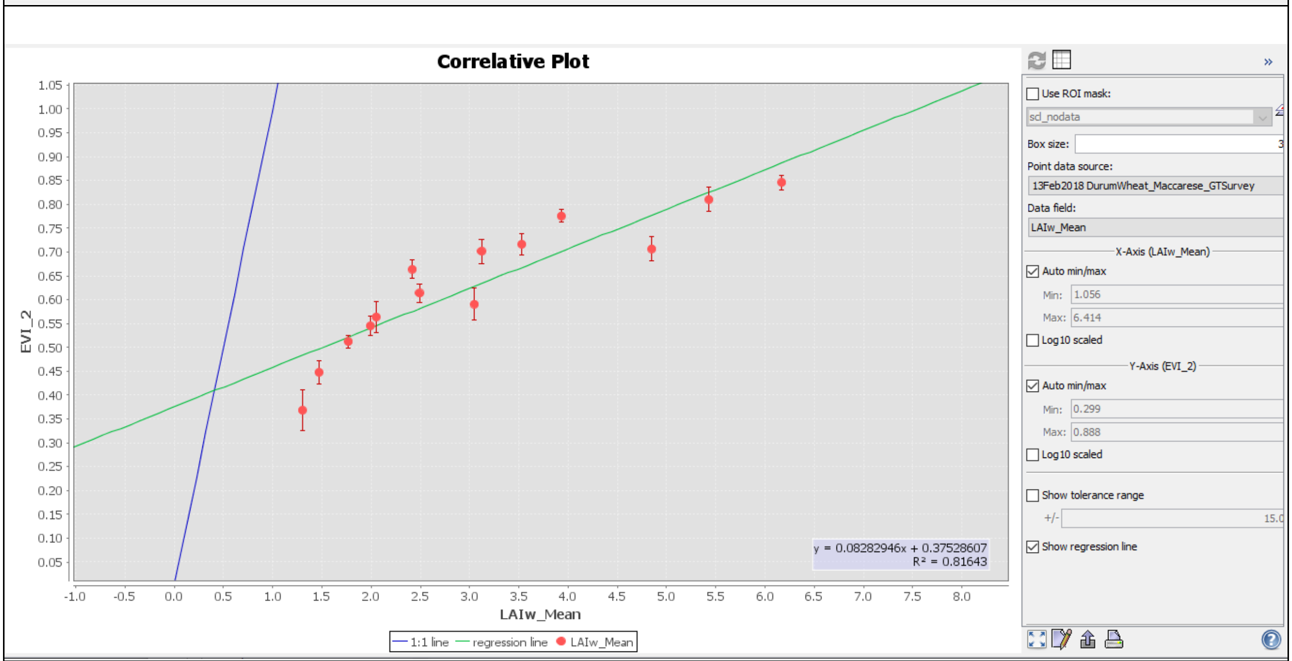
Select in the:

- **Product Explorer** window the VI or biophysical parameter to be plotted in the Correlative Plot
- **Correlative Plot** window the **Point data source,** drop down menu, and choose the ground measurements file previously imported;
- **Data field,** drop down menu, the variable of interest to be plotted (i.e. LAI)

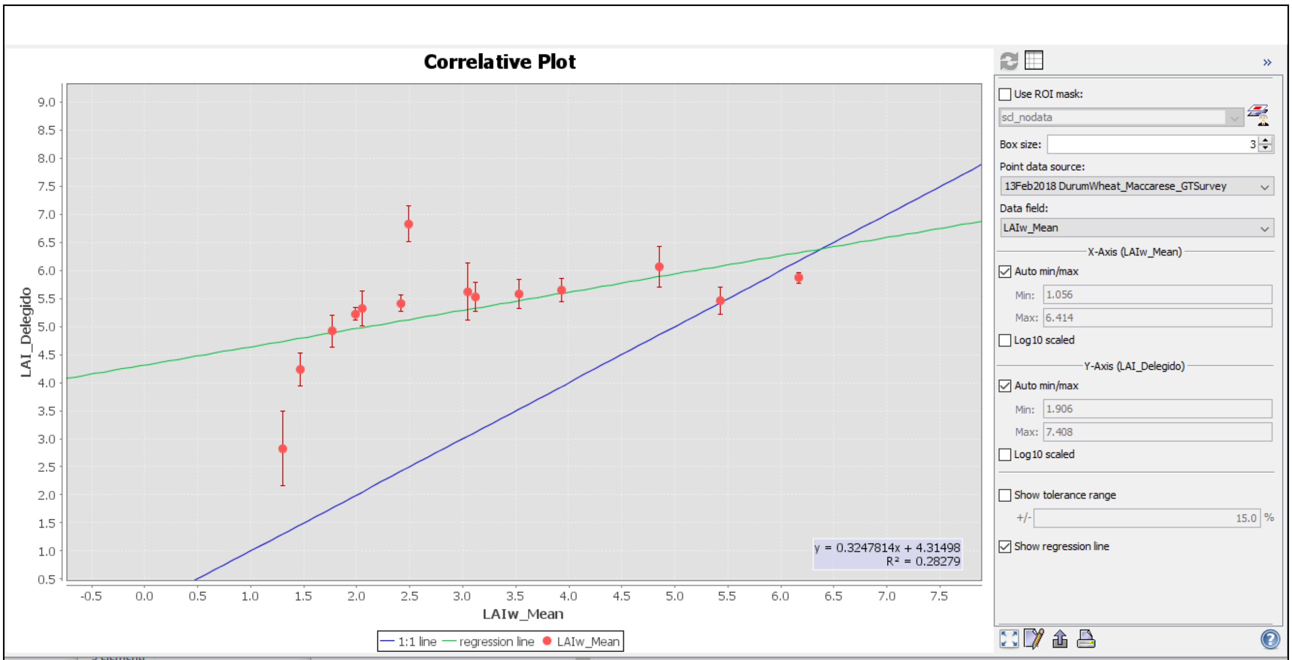
In the Correlative Plot window click on the right button and select the ***Copy data to Clipboard***, then paste it on a *.xls* worksheet to plot the LAI ground measurements vs the retrieved parameter.

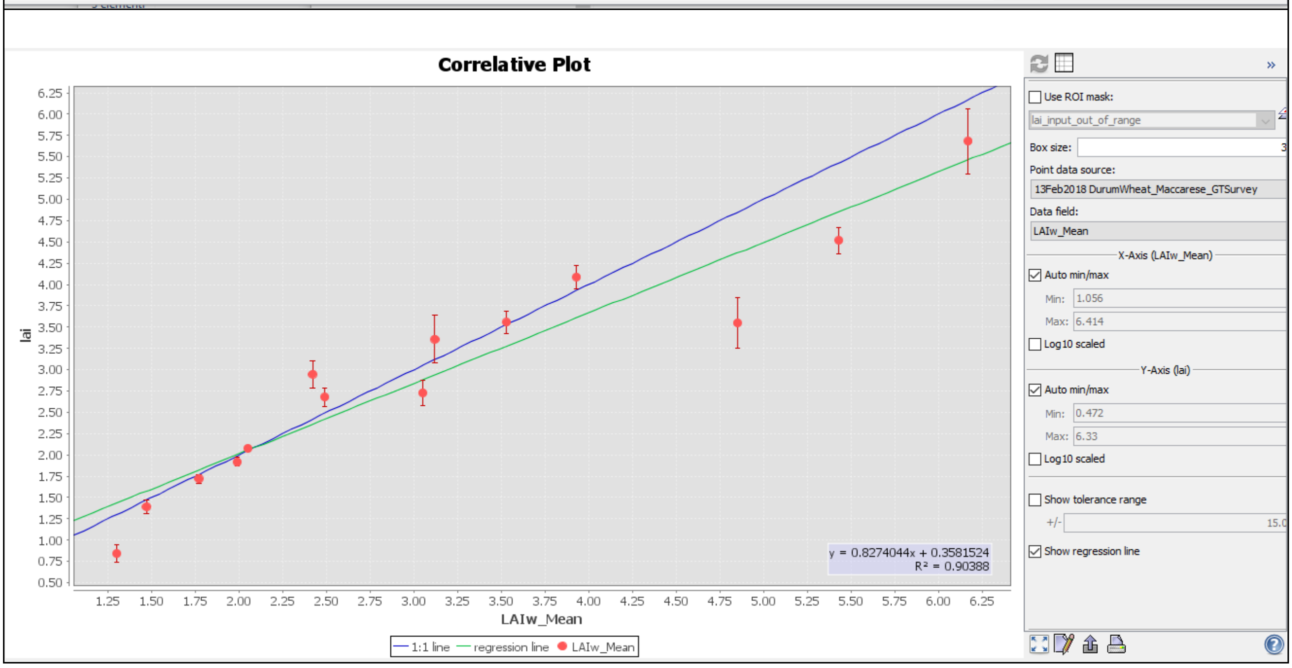


Correlative Plot
ndvi
LAIw_Mean
y = 0.029773034x + 0.81048733
R² = 0.34601
1:1 line
regression line
LAIw_Mean
Use ROI mask:
NDVI_ARITHMETIC
Box size:
3
Point data source:
13Feb2018 DurumWheat_Maccarese_GTSurvey
Data field:
LAIw_Mean
X-Axis (LAIw_Mean)
Auto min/max
Min: 1.056
Max: 6.414
Log10 scaled
Y-Axis (ndvi)
Auto min/max
Min: 0.586
Max: 0.993
Log10 scaled
Show tolerance range
+/- 15.0 %
Show regression line



Correlative Plot
EVI_2
LAIw_Mean
y = 0.08282946x + 0.37528607
R² = 0.81643
1:1 line
regression line
LAIw_Mean
Use ROI mask:
scl_nodata
Box size:
Point data source:
13Feb2018 DurumWheat_Maccarese_GTSurvey
Data field:
LAIw_Mean
X-Axis (LAIw_Mean)
Auto min/max
Min: 1.056
Max: 6.414
Log10 scaled
Y-Axis (EVI_2)
Auto min/max
Min: 0.299
Max: 0.888
Log10 scaled
Show tolerance range
Show regression line





Repeat the 5.1 and 5.2 instructions for all Sentinel-2 images provided in the Repository for the Maccarese test site.

Apply the retrieved regression coefficients to derive a LAI map from one of the selected Vis. Compare it with respect to the LAI map retrieved by inverting the RTM model using SNAP.

5.3 Discussion

- Present your statistical accuracy assessment to the group for the different biomass and pigments related VIs.
- Why do different groups have differing results?
- How do you judge the quality of the retrieved LAI maps derived from point 5.2?

- Where do you see problems?
- How do you judge the quality of the Sentinel-2 data set for this exercise?

6 Time series analysis

Open the LAI time series over Maccarese in the folder *Maccarese Test Site IT\Maccarese Sentinel-2 2018 data\TEMPORAL_SERIES_BIOPHYSICAL-VARIABLES_Maccarese_S2_2018*.

Activate in the **Analysis menu the Time Series** button and include all the images by using the icon opened in the Product Explorer window. Use the icon to select the parameter to be shown in the graph. Select some fields and identify it with a pin so to view their different LAI behavior along the time series (different crops).

7 Summary of Achievements

During the present course you have learned how to apply Sentinel-2 data in the framework of agricultural monitoring and crop related variables retrievals. SNAP tools have been used for visualization, band maths, retrieval of crop biophysical parameters (NN procedure applied to PROSAIL RTM). You have analyzed and processed Sentinel-2 data acquired on agricultural test sites of Maccarese (Italy) and Shunyi (China) and GF-1 imagery acquired on Shunyi.

You have got insights into the Sentinel-2 and GF-1 capabilities to monitor crop biophysical parameters and how to validate them using ground measurements.

On the basis of the discussion you have learned about the relevance of crop monitoring in agricultural areas so to derive proxy agronomical variables in view of a sustainable agriculture.

References

Upreti, D., Huang, W., Kong, W., Pascucci, S., Pignatti, S., Zhou, X., ... & Casa, R. (2019). A Comparison of Hybrid Machine Learning Algorithms for the Retrieval of Wheat Biophysical Variables from Sentinel-2. Remote Sensing, 11(5), 481.

Zhou, X., Huang, W., Zhang, J., Kong, W., Casa, R., & Huang, Y. (2019). A novel combined spectral index for estimating the ratio of carotenoid to chlorophyll content to monitor crop physiological and phenological status. International Journal of Applied Earth Observation and Geoinformation, 76, 128-142.

Xu, M., Liu, R., Chen, J. M., Liu, Y., Shang, R., Ju, W., ... & Huang, W. (2019). Retrieving leaf chlorophyll content using a matrix-based vegetation index combination approach. Remote Sensing of Environment, 224, 60-73.

Xie, Q., Dash, J., Huete, A., Jiang, A., Yin, G., Ding, Y., ... & Ye, H. (2019). Retrieval of crop biophysical parameters from Sentinel-2 remote sensing imagery. International Journal of Applied Earth Observation and Geoinformation, 80, 187-195.

8 For fast people

Repeat the exercise proposed for Maccarese on Shunyi using the Sentinel-2 (April 03 and May 03 2016) and GF-1 (April 10, April 21 and May 8, 2016) imagery present in the repository.

Ground measurements are provided in the Repository as:

- 2016 April 07 Shunyi_GT new.txt
- 2016 April 21 Shunyi GT new.txt
- 2016 May 03 Shunyi_GT new.txt

Generate the VI you prefer and retrieve the biophysical variables using the SNAP tool and plot them against the collected ground measurements (LAI and Chl).

Compare and discuss *Measured vs. Estimated* plots derived for Maccarese and Shunyi winter wheat fields.