TP3: Calculate Vegetation indices using QGIS, OTB and SNAP

Nicolas Baghdadi and Hassan Bazzi

Objective :

In this TP, we will calculate a few vegetation indices, using the spectral bands of the optical Sentinel-2 images.

The vegetation indices to calculate are :

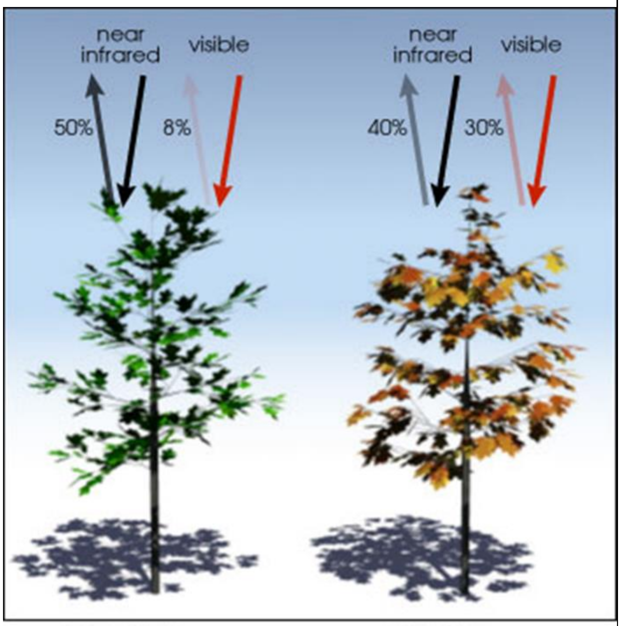
- Normalized Differential Vegetation Index (NDVI)
- Normalized Differential Water Index (NDWI)
- Enhanced Vegetation Index (EVI)
- Soil Adjusted Vegetation Index (SAVI)
- Green Chlorophyll index CI_Green
- CI_Rededge Chlorophyll index
- Leaf Area Index (LAI)
- Canopy Water Content (CWC)
- Canopy Chlorophyll Content (CAB)

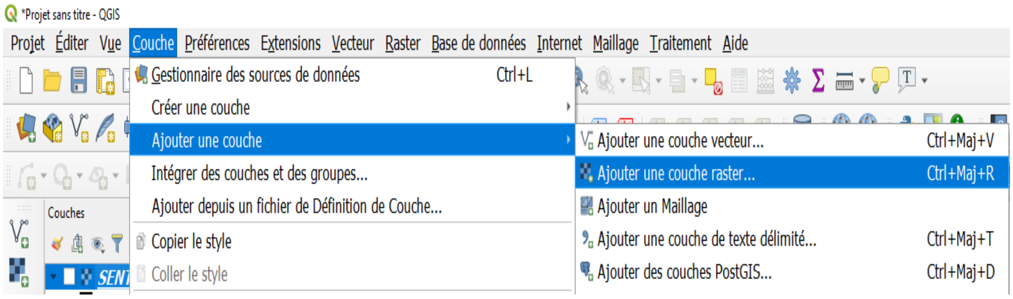
Prerequisite for this TP:

1. Installation of QGIS (3.20)
2. Installation of OTB (OrfeoToolbox)
3. Installation of (SNAP 7.0)

1. Normalized Differential Vegetation Index NDVI:

Objective: Calculate the vegetation index NDVI

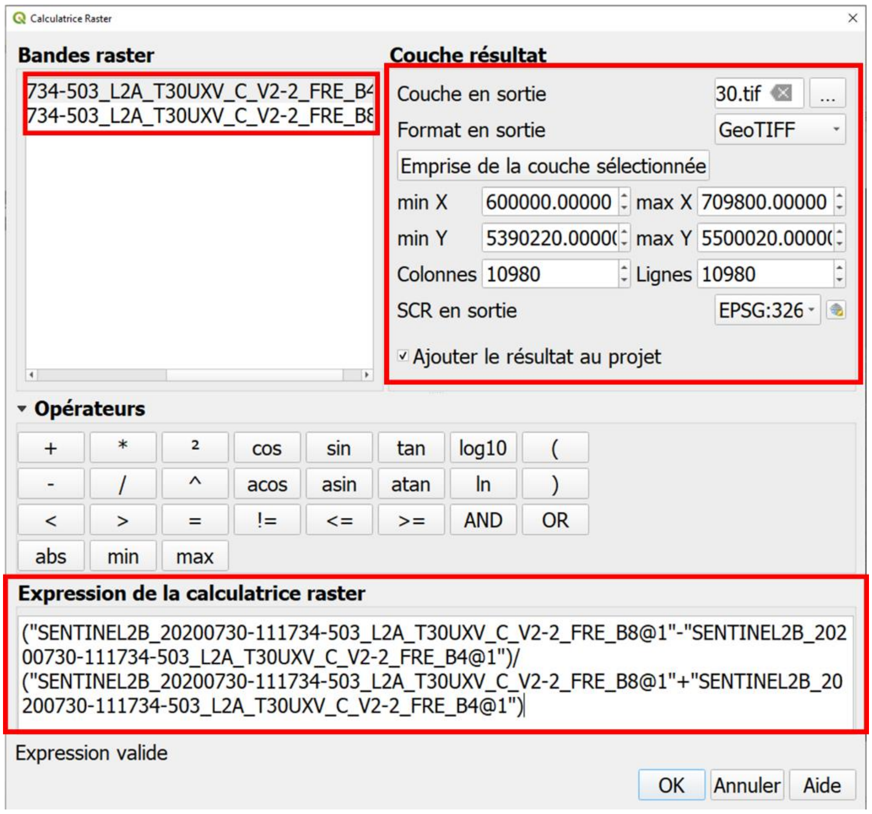
Steps	Manipulation sous QGIS
1. Definition and formula	Green plants absorb the solar radiation from the visible spectrum range of the radiation (red, green et blue), and uses this radiation as source of energy to accomplish photosynthesis. The cells in the leaves reflect the solar radiation that in near to infrared, because the energy of these photons that a wavelength superior to around 700 nanometer (infrared) and is too weak to be used for the synthesis of molecules by the plant. The index that is used the most in the remote sensing of vegetation is the NDVI NDVI " Normalized Differential Vegetation Index ". It is in fact the normalized ratio of the difference between the infrared reflectance and the red reflectance. $$\textbf{NDVI} = \frac{Near\ Infrared - Rouge}{Near\ Infrared + Rouge}$$ The range of NDVI values are between -1 et +1. Negative values correspond to surfaces other than vegetation cover, like snow, water surfaces and clouds, for these surfaces the reflectance of red radiation is bigger than the reflectance of near infrared radiation. For bare soil, the reflectance of red and infrared is almost the same, thus the NDVI will be close to 0. Whereas, vegetation cover will have positive NDVI values, generally varying between 0.1 and 0.9. The higher the value, the denser the vegetation.  $\frac{(0.50 - 0.08)}{(0.50 + 0.08)} = 0.72$ $\frac{(0.4 - 0.30)}{(0.4 + 0.30)} = 0.14$
2. Formula of NDVI for Sentinel-2	For Sentinel-2, the infrared band corresponds to the band B8 whereas the red band corresponds to B4. Using Sentinel-2 data, NDVI is calculated as such : $$\textbf{NDVI} = \frac{B8 - B4}{B8 + B4}$$
3. Calculating NDVI on QGIS	➢ Launch QGIS ➢ In the menu, click on « Layers» « Add layer» « Add raster layer »



- In the new window click on  and navigate to the folder with the S2 images (..TP3\SENTINEL-2)
- Select these two images

  « **SENTINEL2B_20200730-111734-503_L2A_T30UXV_C_V2-2_FRE_B4.tif** » and « **SENTINEL2B_20200730-111734-503_L2A_T30UXV_C_V2-2_FRE_B8.tif** ». These two bands correspond to the bands "Red" and "Near infrared".
- In the **menu bar,** click on **« Raster »▯ « Raster calculator»**
- **« Raster bands »** contains all the raster layers that are loaded and exploitable. To add a raster to the equation, double-click on its name in the list. You could either use the operator buttons available or type it in the expression box directly.
- Type the following formula:

("SENTINEL2B_20200730-111734-503_L2A_T30UXV_C_V2-2_FRE_B8@1"-"SENTINEL2B_20200730-111734-503_L2A_T30UXV_C_V2-2_FRE_B4@1")/("SENTINEL2B_20200730-111734-503_L2A_T30UXV_C_V2-2_FRE_B8@1"+"SENTINEL2B_20200730-111734-503_L2A_T30UXV_C_V2-2_FRE_B4@1")



- Save the result as « ndvi_20200730.tif »
- Click on « selected layer extent » to calculate the index for the extent of the input bands.

<table>
<tr><td></td><td>➢ check « Add result to project »</td></tr>
</table>

2. Normalized Differential Water Index NDWI:

Objective: Calculating the vegetation index NDWI

<table>
<tr><th>Steps</th><th>Manipulation sous QGIS</th></tr>
<tr><td>1. Definition and formula</td><td>

The Normalized Differential Water Index (NDWI) (Gao, 1996) is an index derived from satellite data from Near-Infrared (NIR) and Short Wave Infrared (SWIR).

The reflectance of SWIR reflects the changes in the magnitude of water in the vegetation, whereas the reflectance of NIR is affected by the internal structure of the leaves and the magnitude of dry material in the leaves, but not water content.

The combination of NIR and SWIR negates the variations caused by the internal structure of the leaves and by the dry matter content inside the leaves, this increases the precision of capturing the total water content of the vegetation (Ceccato et al. 2001).

The quantity of water available in the internal structure of the leaves controls to a great extent the spectral reflectance in the SWIR zone of the electromagnetic spectrum. Thus, the reflectance of SWIR negatively correlated with the quantity of water inside the leaves. (Tucker 1980).

The NDWI is useful for monitoring drought and as an early alarm to drought. Since it is calculated using the reflectance in the Near infrared (NIR) and Short Wave Infrared (SWIR) which makes it sensitive to changes in the water content of the vegetation cover.

This index varies in function of water content of the leaves. It decreases when the plants are in a water stress state, and so it is useful for following vegetation in dry areas.

The NDWI is complimentary to NDVI

The formula for NDWI is:

$$\mathbf{NDWI} = \frac{NIR - SWIR}{NIR + SWIR}$$

The values of NDWI are between -1 and +1.

</td></tr>
<tr><td>2. Formula for Sentinel-2</td><td>

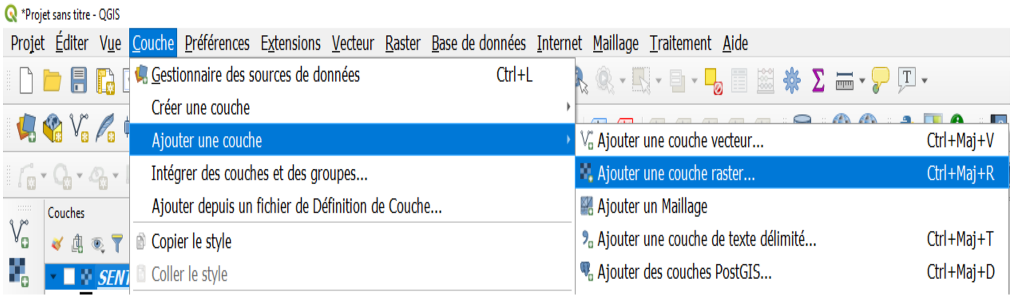
For Sentinel-2, the infrared band corresponds to the band B8 whereas the band SWIR corresponds to B12. Using Sentinel-2 data, the NDWI is calculated as such:

$$\mathbf{NDWI} = \frac{B8 - B12}{B8 + B12}$$

</td></tr>
<tr><td>3. Calculating the NDWI index in QGIS</td><td>

➢ Launch QGIS

➢ In the menu, click on « Layers» « Add layer» « Add raster layer »



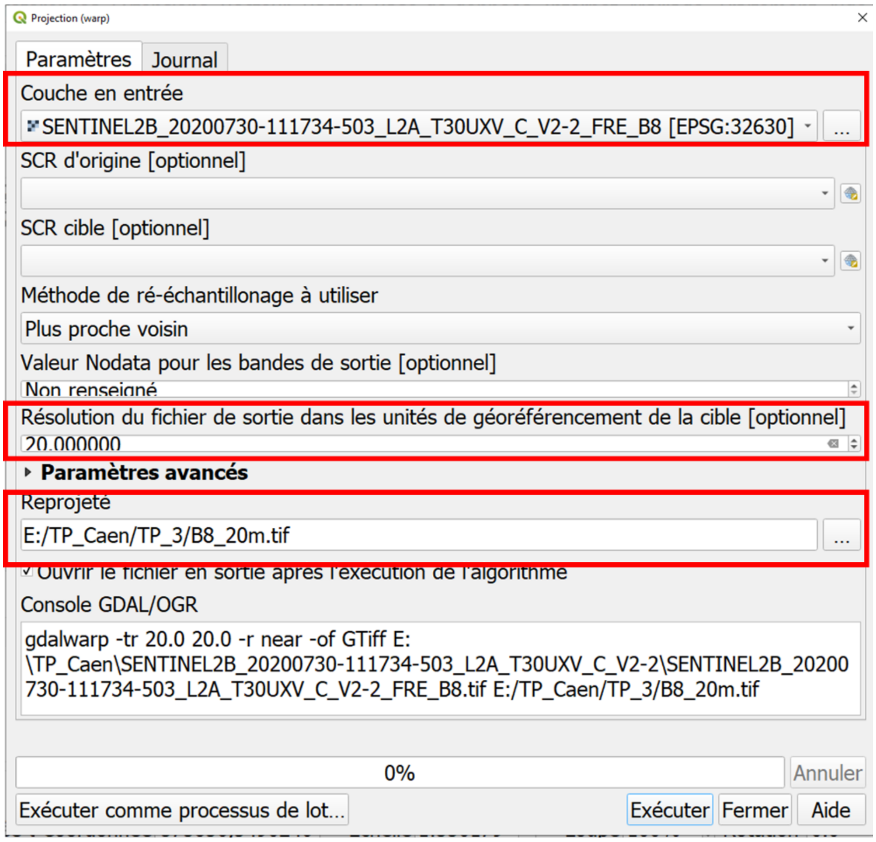
</td></tr>
</table>

- In the new window click on  and navigate to the folder with the S2 images (..TP3\SENTINEL-2)
- Select these two images :

  « **SENTINEL2B_20200730-111734-503_L2A_T30UXV_C_V2-2_FRE_B8.tif** »
  « **SENTINEL2B_20200730-111734-503_L2A_T30UXV_C_V2-2_FRE_B12.tif** »

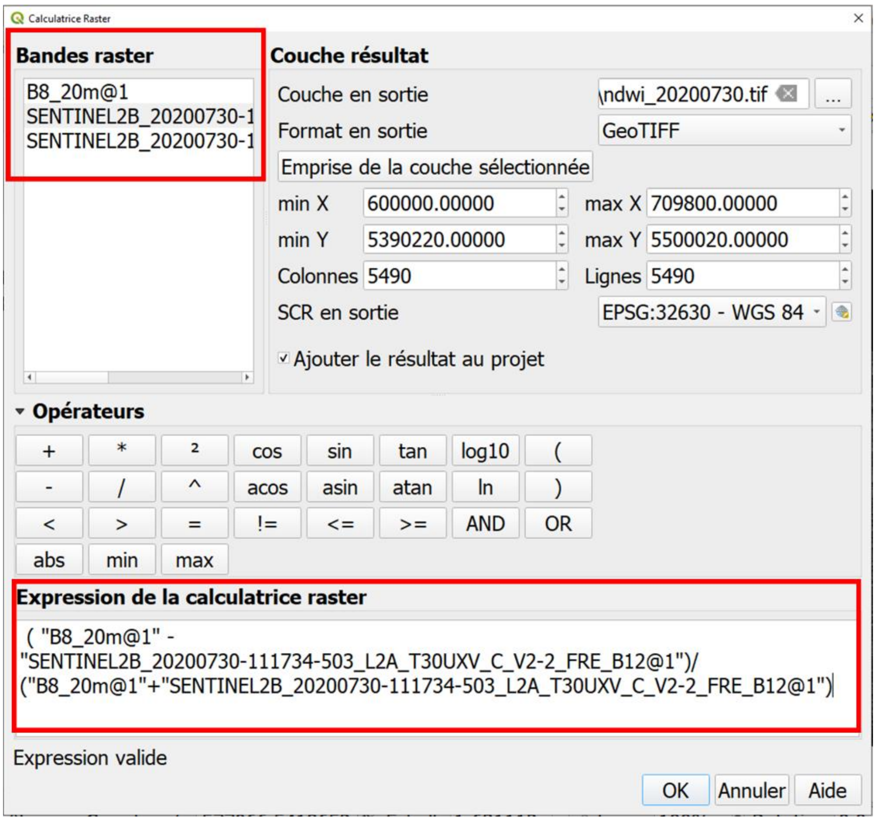
  These images correspond to bands " NIR " et "SWIR".

- The band B12 of Sentinel-2 has a resolution of 20 m whereas the infrared band has a resolution of 10m. The equation cannot be applied for images with different resolutions, and so we need to do a resampling of the B8 image to make it at a 20m resolution in the aim of calculating NDWI.
- Open the tab « Projection (warp) » : Raster Projection Projection (warp)
- In the window of « Projection », set the following parameters:
  - Input layer : **SENTINEL2B_20200730-111734-503_L2A_T30UXV_C_V2-2_FRE_B8.tif**
  - Output file resolution in target georeferenced units: « 20 »
  - in « Output Image » : click and save the image as **« B8_20m.tif »**
  - check « Open output file after running algorithm »
  - click on **« Run »**



- The images B8 et B12 are now at the same spatial resolution (20 m) and we can calculate the NDWI at a resolution of de 20 m
- In the **Menu bar,** click on **« Raster »** **« Raster calculator »**
- Type the following expression:

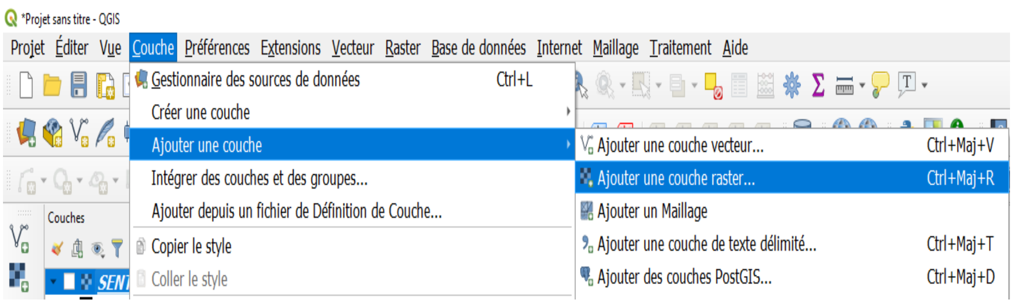
("B8_20m@1" - "SENTINEL2B_20200730-111734-503_L2A_T30UXV_C_V2-2_FRE_B12@1")/("B8_20m@1"+"SENTINEL2B_20200730-111734-503_L2A_T30UXV_C_V2-2_FRE_B12@1")



- Save the output as « ndwi_20200730.tif »
- Click on « selected layer extent » to calculate the index for the extent of the input bands.
- check « Add result to project »

3. Soil Adjusted Vegetation Index SAVI:

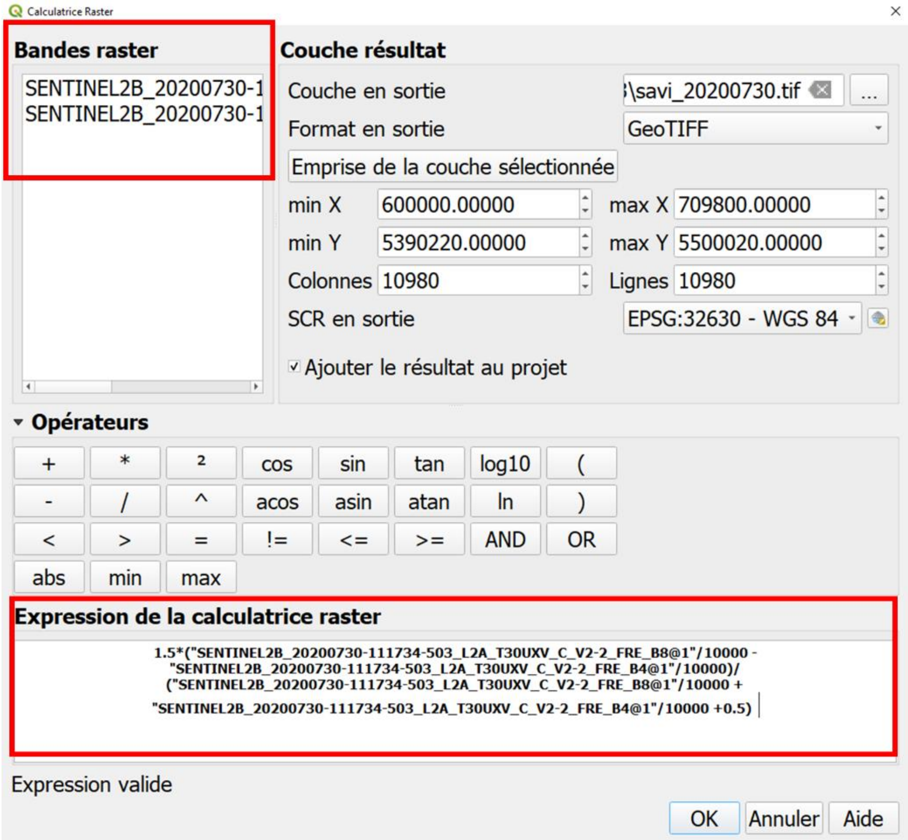
Objective: Calculating the vegetation index SAVI

Steps	Manipulation sous QGIS
1. Definition and formula	The SAVI « Soil adjusted vegetation index » is an index similar to NDVI, but it removes the effect of the ground pixel. The index SAVI minimizes the influence of the ground's luminosity using the spectral indices of vegetation and wavelengths from red to near infrared (NIR). It uses the adjustment factor of canopy « L », which is in function of the vegetation's density. Therefore, it requires preexisting knowledge of the vegetation quantity. Huete (1988) suggested an optimal value of L=0,5 in order take into account the variation of the ground. This index is used in zones where vegetation is more or less dispersed and where the ground is visible through the vegetation cover. The formula for SAVI is: $$\textbf{SAVI} = (1 + L) \times \frac{NIR - Red}{NIR + Red + L}$$ **with L = 0,5:** $$\textbf{SAVI} = \textbf{1,5 x } \frac{NIR - Red}{NIR + Red + 0{,}5}$$
2. Formula for Sentinel-2	For Sentinel-2, the infrared band corresponds to B8 and the red band corresponds to B4. SAVI is calculated a such : $$\textbf{SAVI} = 1.5 \times \frac{B8 - B12}{B8 + B12 + 0.5}$$ Sentinel-2 bands are multiplied by 10000 since they are saved in the 16 bit format. This is why we have to divide the bands by 10000 when we are doing an addition or subtraction with other numbers
3. Calculating SAVI in QGIS	➢ Launch QGIS ➢ In the menu, click on « Layers» « Add layer» « Add raster layer »  ➢ In the new window click on  and navigate to the folder with the S2 images (..TP3\SENTINEL-2) ➢ Select these two images : « **SENTINEL2B_20200730-111734-503_L2A_T30UXV_C_V2-2_FRE_B4.tif** » « **SENTINEL2B_20200730-111734-503_L2A_T30UXV_C_V2-2_FRE_B8.tif** »

These images correspond to "Red" et "NIR".

- In the **Menu bar,** click on **« Raster » « Raster calculator »**
- Type the following expression:

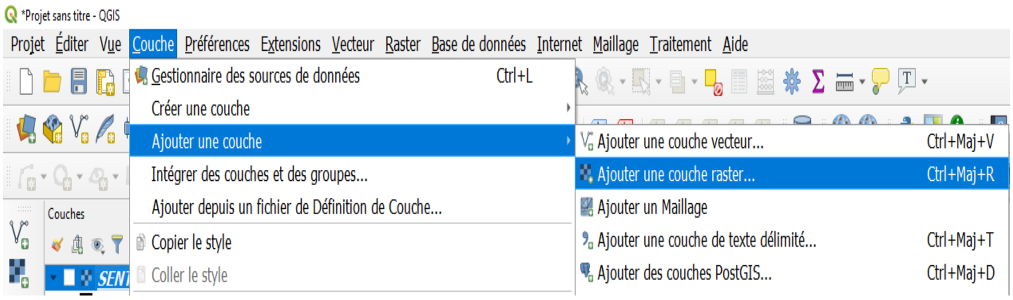
1.5*("SENTINEL2B_20200730-111734-503_L2A_T30UXV_C_V2-2_FRE_B8@1"/10000 - "SENTINEL2B_20200730-111734-503_L2A_T30UXV_C_V2-2_FRE_B4@1"/10000)/("SENTINEL2B_20200730-111734-503_L2A_T30UXV_C_V2-2_FRE_B8@1"/10000 + "SENTINEL2B_20200730-111734-503_L2A_T30UXV_C_V2-2_FRE_B4@1"/10000 +0.5)



- Save the output as « savi_20200730.tif »
- Click on « selected layer extent » to calculate the index for the extent of the input bands.
- check « Add result to project »

4. Enhanced Vegetation Index EVI:

Objective: Calculating the vegetation index EVI

Steps	Manipulation sous QGIS
1. Definition and formula	The index EVI « Enhanced Vegetation Index » is an 'optimized' vegetation index, created to better capture the signal of vegetation, with a high sensitivity in region that have a very high vegetation biomass. It allows for an ameliorated monitoring of vegetation. While NDVI is sensitive to chlorophyll, EVI is more sensitive to the structural variations in the vegetation cover, including the Leaf Area Index (LAI), it depends on the type and architecture if the vegetation. NDVI et EVI are complementary indices when studying vegetation, they enhance the ability to detect changes in the vegetation, and allow for the extraction of the biophysical parameters of the canopy. This index was initially developed to be used alongside MODIS data, as an enhancement compared to NDVI, by optimizing the signal of the vegetation in the zones with a high Leaf Area Index (LAI). It is useful in zones with a high LAI, where NDVI becomes saturated. It used the NIR reflectance as well as the red reflectance. It also uses the reflectance in the blue wavelength to correct for the ground effect and to limit atmospheric interference, such as diffusion from particulates. EVI values should be between 0 and 1 for vegetation. Reflective elements such as clouds and white buildings, as well as darker areas like water, might give abnormal values in an EVI image: $$\mathbf{EVI = 2{,}5\ x}\ \frac{NIR - Red}{NIR + 6 \times Red - 7{,}5 \times Blue + 1}$$
2. Formula for Sentinel-2	For Sentinel-2, infrared corresponds to B8, Red corresponds to B4 et and blue corresponds to B2. EVI is calculated as such : $$\mathbf{EVI = 2{,}5\ x}\ \frac{B8 - B4}{B8 + 6 \times B4 - 7{,}5 \times B2 + 1}$$ As previously mentioned, Sentinel-2 bands are multiplied by 10000 since they are saved in the 16 bit format. This is why we have to divide the bands by 10000 when we are doing an addition or subtraction with other numbers
3. Calculer l'indice EVI avec QGIS et OTB	➢ Launch QGIS ➢ In the menu, click on « Layers» ▯ « Add layer» ▯ « Add raster layer »  ➢ In the new window click on  and navigate to the folder with the S2 images (..TP3\SENTINEL-2) ➢ Select these three images : « **SENTINEL2B_20200730-111734-503_L2A_T30UXV_C_V2-2_FRE_B4.tif** » « **SENTINEL2B_20200730-111734-503_L2A_T30UXV_C_V2-2_FRE_B8.tif** »

« **SENTINEL2B_20200730-111734-503_L2A_T30UXV_C_V2-2_FRE_B2.tif** ».

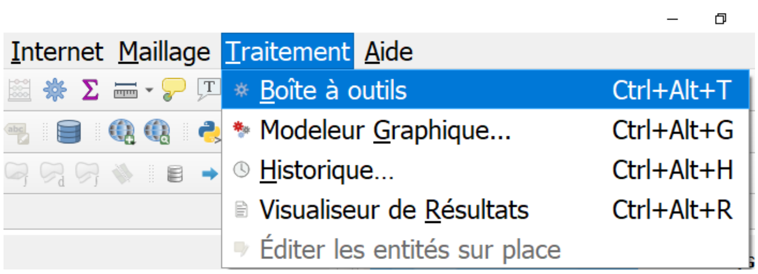
- We will now use a new tool called "matrix calculator". OTB, which is integrated in QGIS, also has a tool for calculating images pixel by pixel. The matrix calculator in OTB is called "BandMath".
- In "BandMath", the variables entered (pixels in images) are accessible by image and by channel using the following syntax: imXbY where X is the image number and Y the canal number. Here's a few examples illustrating the principle of identification of images and bands (channels) :
  - im1b1 : Image 1, band 1
  - im1b2 : Image 1, band 2
  - im4b3 : Image 4, band 3

Attention, the order of images is the same that appears in the list of images when entered.

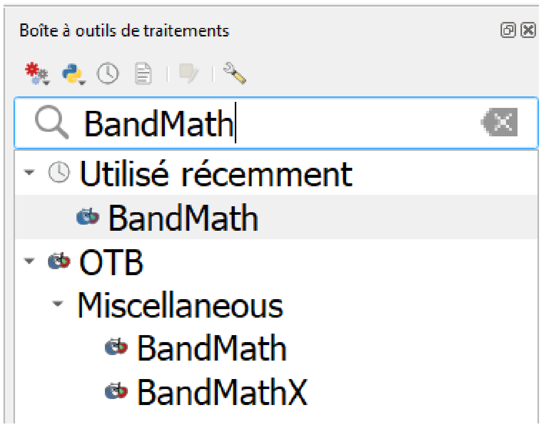
- This table shows a few mathematical operation available in BandMath:

Name	Description
Sin	Sinus
Cos	Cosinus
Tan	Tangent
Ln	Logarithmique base e
Log10	Logarithmique base 10
Sqrt	Racine
….	…..

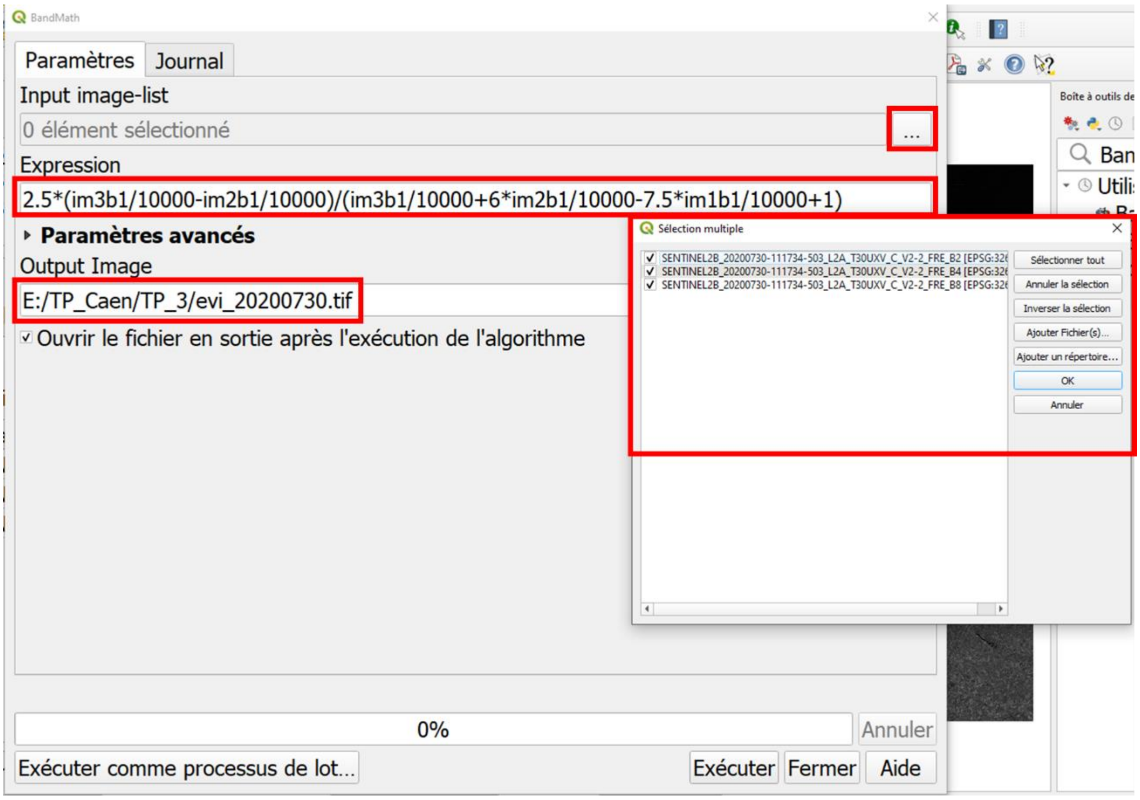
- In the Menu Bar of QGIS, click on : Processing Toolboxes :



- In the toolbox of QGIS, look for the « BandMath » tool under OTB and double-click it to pên « BandMath »



- In the BandMath window, do the following:



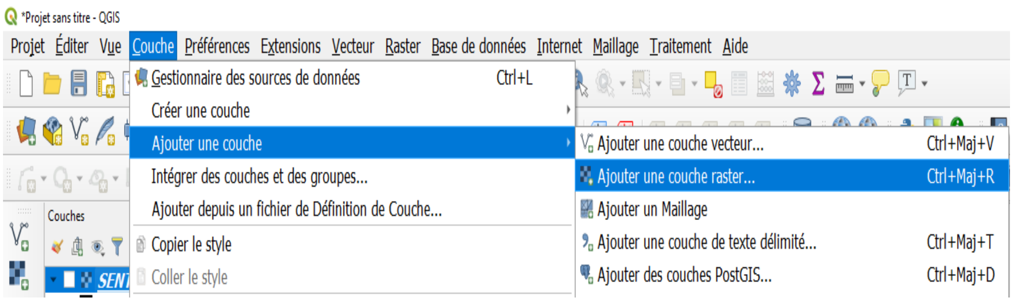
- In « Input image-list » click on  and select the three bands « B2, B4 et B8)
- In the « Expression » section, type:

  2.5*(im3b1/10000-im2b1/10000)/(im3b1/10000+6*im2b1/10000-7.5*im1b1/10000+1)

- In « Output Image » save the output as « evi_20200730.tif »
- Check « Open output file after running algorithm»
- Click Run

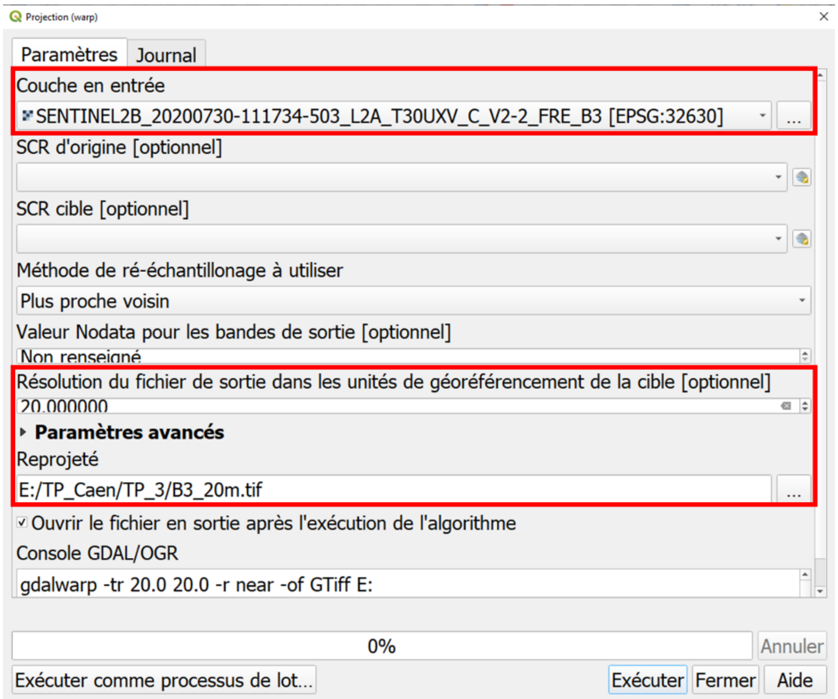
5. Red-Edge and Green Chlorophyll Index (CI_green et CI_rededge):

Objective: Calculating the vegetation index CI_green et CI_rededge

Steps	Manipulation sous QGIS
1. Definition and formula	Chlorophyll is a green pigment present in the leaves, it plays an important role important in photosynthesis, the conversion of luminous energy to chemical energy. Therefore, it is a direct indicator of the primary production of the plant and of its photosynthetic potential. It is also used for understanding the nutritional status of the plant, its water stress, disease, etc. Many indices were developed to estimate the chlorophyll content of the leaves. These chlorophyll indices are used for calculating the total chlorophyll content of the leaves. The reflectance values in the green band and the red-edge band sensitive to small variation in the chlorophyll content. The « red-edge » is an intermediary band between the red and the NIR band. For this reason, there are two main indices for chlorophyll content estimation Green Chlorophyll index « CI_Green » and red-edge Chlorophyll index (CI_Rededge) The formula of CI_Green is: $$\textbf{CI\_Green} = \frac{Red_{Edge}(730\,nm)}{Green} - 1$$ The formula de CI_Rededge is: $$\textbf{CI\_Rededge} = \frac{Red_{Edge}(850\,nm)}{Red_{edge}(730\,nm)}$$
2. Formula for Sentinel-2	For Sentinel-2, Red-edge at 730nm corresponds to band B5, green band is band B3. Rededge band at 850nm is band B6. CI_green et CI_rededge is calculated as such : $$\textbf{CI\_Green} = \frac{B5}{B3} - 1$$ $$\textbf{CI\_Rededge} = \frac{B6}{B5} - 1$$
3. Calculate lCI_Green on QGIS	➢ Launch QGIS ➢ In the menu, click on « Layers» « Add layer» « Add raster layer »  ➢ In the new window click on  and navigate to the folder with the S2 images (..TP3\SENTINEL-2) ➢ Select these two images : « **SENTINEL2B_20200730-111734-503_L2A_T30UXV_C_V2-2_FRE_B3.tif** » « **SENTINEL2B_20200730-111734-503_L2A_T30UXV_C_V2-2_FRE_B5.tif** »

- The band B12 of Sentinel-2 is at a resolution of 20 m whereas the infrared has a resolution of 10 m. thus we will resample B3 from 10 m to 20 m before calculating the index.

- Use the "Projection (warp)" like in part 2.3 to resample the B3 band to a resolution of 20 m

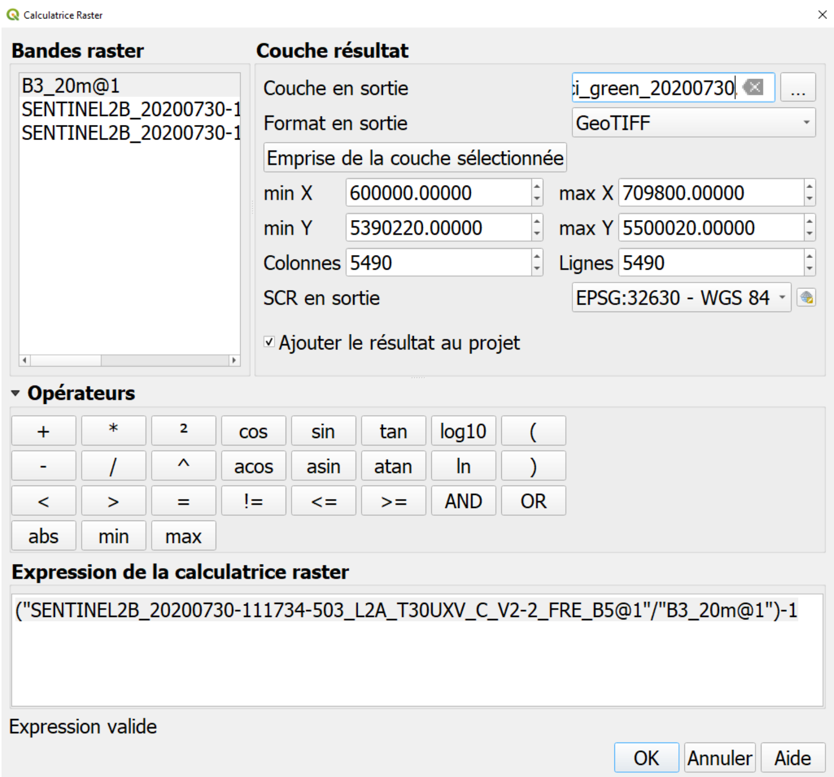


- In the **Menu** bar, click on **« Raster »** **« Raster caculator »**

- Type the following formula:

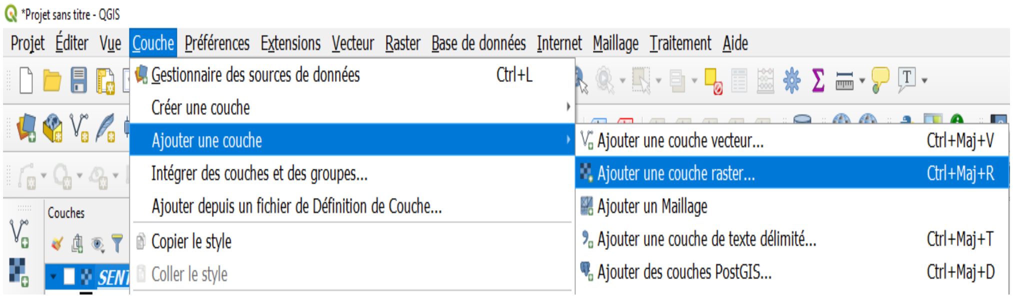
("SENTINEL2B_20200730-111734-503_L2A_T30UXV_C_V2-2_FRE_B5@1"/"B3_20m@1")-1

- Save the output image as « ci_green_20200703.tif »



<table>
<tr>
<td>Calculate CI_rededge on QGIS</td>
<td>

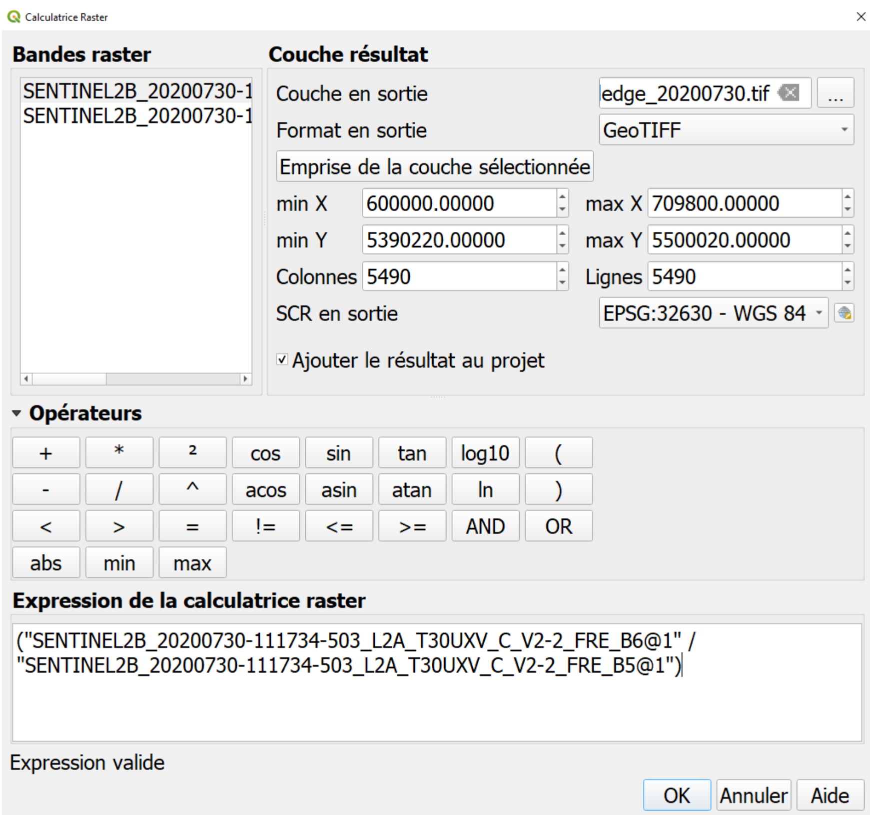
- « CI_rededge » uses bands B5 and B6, both are at a resolution of 20 m. Therefore, we don't need to do any resampling
- In the menu, click on« Layer» «Add layer» « Add raster layer»



- In the new window click on  and navigate to the folder with the S2 images (..TP3\SENTINEL-2)
- In the directory ….\SENTINEL2B_20200730-111734-503_L2A_T30UXV_C_V2-2:
- Select the two images:
« **SENTINEL2B_20200730-111734-503_L2A_T30UXV_C_V2-2_FRE_B5.tif** »,« **SENTINEL2B_20200730-111734-503_L2A_T30UXV_C_V2-2_FRE_B6.tif** »
- In the **Menu bar,** click on **« Raster » « Raster calculator»**
- Type the following formula:

("SENTINEL2B_20200730-111734-503_L2A_T30UXV_C_V2-2_FRE_B6@1"/"SENTINEL2B_20200730-111734-503_L2A_T30UXV_C_V2-2_FRE_B5@1") - 1

- Save the output image as « ci_redege_20200703.tif »



</td>
</tr>
</table>

6. Calculate the biophysical parameters of the canopy using SNAP

Objective: Calculate the biophysical parameters such as the Leaf Area Index (LAI), The Canopy Water Content (CWC) and the leaf Chlorophyll content (Cab) using the program SNAP from ESA.

<table>
<tr><th>Steps</th><th>Manipulation sous SNAP</th></tr>
<tr><td>1. Definition</td><td>

LAI : Leaf Area Index

LAI is a measure of the total surface of leaves per unite of ground surface. It is directly related to the amount of light that is intercepted by the plant. It is an important valuable when estimating the potential of photosynthetic production, the evapotranspiration and when measuring crop growth.(LAI = surface of leaves / surface of ground, m^2 / m^2)

LAI determines the total interaction area of the plant (including with radiation) between the canopy and the atmosphere. LAI is not linearly correlated with reflectance.

The LAI can be determined directly by measuring the leafy area of a sample plot then dividing by the total area of the parcel, but this method requires a lot of time and resources, especially for larger areas.

CAB: Canopy Chlorophyll Content:

The amount of chlorophyll is a very good indicator of stress, including Nitrogen deficiency. because is directly linked to the amount of Nitrogen in the cell (Houlès et al. 2001).

We can calculate the amount chlorophyll by multiplying the amount of chlorophyll in the leaves by the area of the leaves.

Some studies have shown that this product could be of great interest for the models that estimate primary production because it estimates the efficiency of photosynthesis. (Green et al. 2003).

Canopy Water Content CWC:

Since NIR and Medium infrared radiation is absorbed significantly by water, Sentiel-2 allows us to access this variable because water is responsible for 60% to 80% of the total weight of plants.

The closest variable to the remote sensing signal is the weight of water per unit of ground ($g.m^{-2}$).

Since an issue of detecting water from remote sensing is the water moisture of the ground, The CWC index is used as a candidate to fix this in the Sentinel-2 product line-up.

</td></tr>
<tr><td>2. Formula in SNAP</td><td>

ESA developed a tool “Biophysical Processor” for estimating the biophysical parameters of vegetation using Sentinel-2 data.

Acronym	Central (nm)	Width (nm)	Spatial resolution (m)
B3	560	35	10
B4	665	30	10
B5	705	15	20
B6	740	15	20
B7	783	20	20
B8a	865	20	20
B11	1610	90	20
B12	2190	180	20

This tool is based on a neural network that utilizes the surface reflectance of Sentinel-2 bands (level 2A) for estimating the biophysical parameters of vegetation: LAI, CWC et Cab.

</td></tr>
</table>

It also uses the acquisition proprieties and the geometry of the image, like the solar zenith, the observation zenith and the relative azimuthal angle.

The output will be generated for each pixel. Including LAI, Cab and CWC values derived from a neural network. Moreover, a quality flag is also generated.

Product	Unit	Minimum	Maximum	resolution
LAI	$mP^{2P}.mP^{-}$ 2P	0	8.0	0.01
CCC	g/cm²	0	600	1
CWC	µg/cm²	0	0.55	0.0025

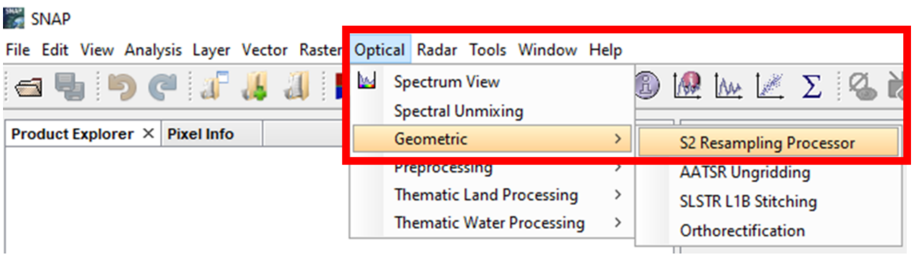
3. Calculating the biophysical variables with SNAP

- Launch SNAP by double-clicking the icon
- In the main Menu, add the recently calibrated S2 image at level2A using Sen2cor, in the section 3 of TP1.

  Click on File Open Product Go the file directory .SAFE the result of the calibration of the S2 image(…\TP3\ESA_SENTINEL-2) select the file « MTD_MSIL2A.xml »
- Calculating the biophysical variables in SNAP requires that all the S2 band have the same resolution. Since we have images that have a spatial resolution of 10 m and other at 20 m, we need to resample all the images to 20 m.
- Thus, we will do two steps :
  1. Resampling of all the bands to the same resolution (20m)
  2. Calculating biophysical variables

1. Resampling of all the bands to the same resolution:

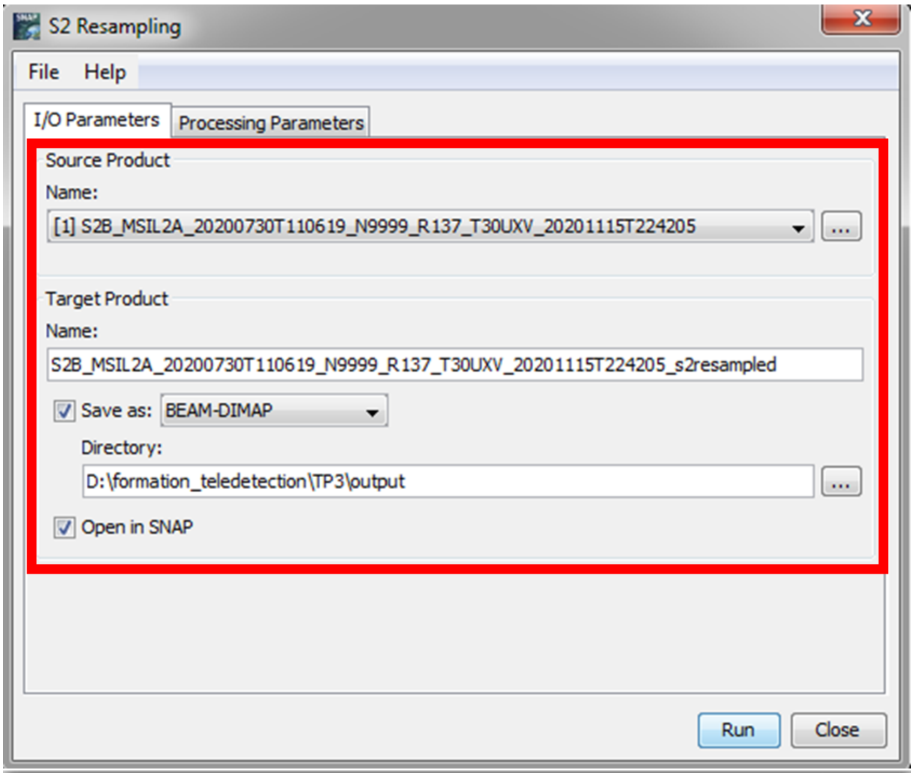
✓ Open « S2Resample Processor » : click on Optical Geomteric S2Resampling Processor

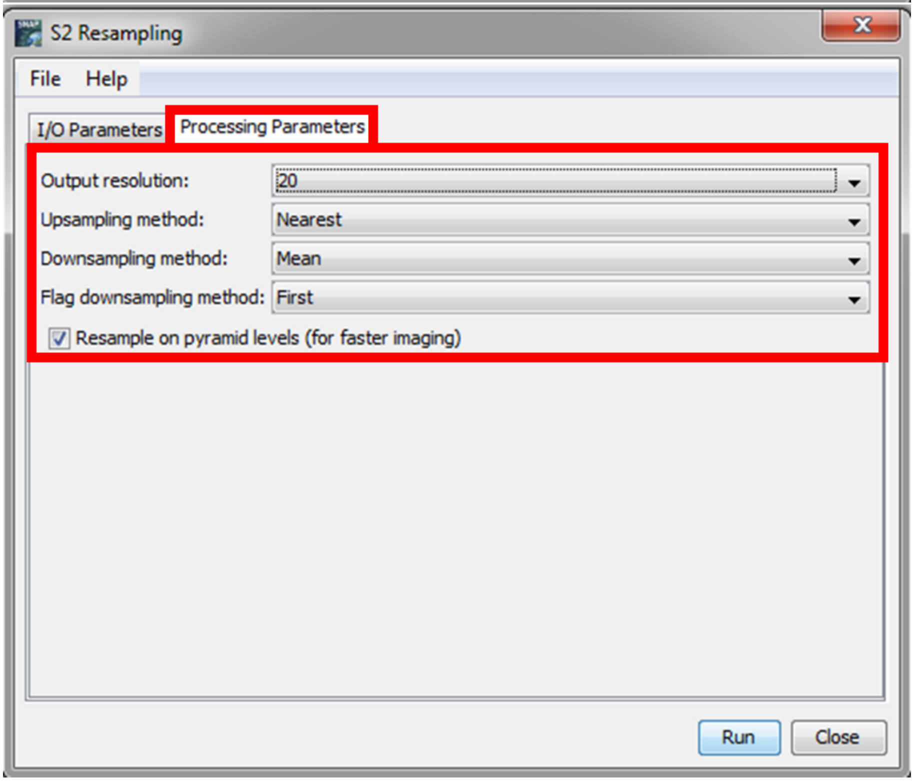


✓ Select the entry image (image added in the previous part) and specify the output folder

✓ In « Processing Parameters »:

- Output resolution : 20
- Upsampling Method : Nearest
- Downsampling Method : Mean
- Flag downsampling Method: First

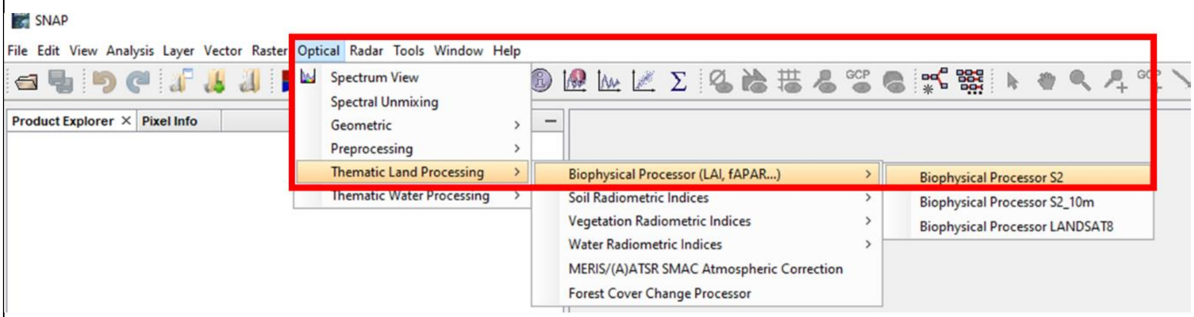




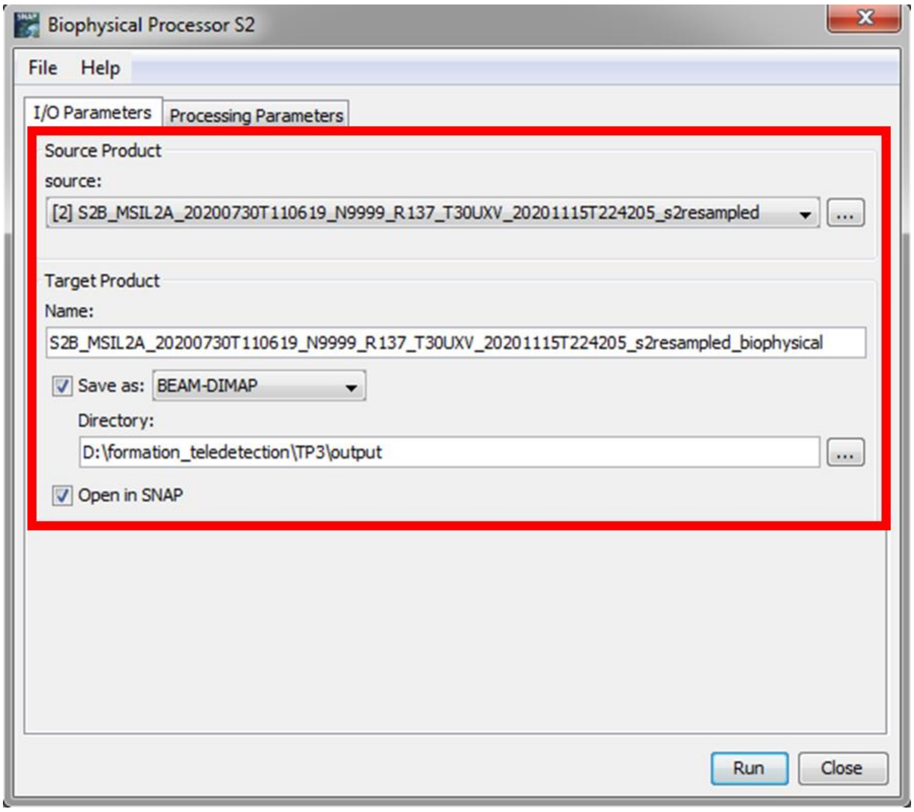
- ✓ Cliquer sur « Run »
- ✓ The processing needs some time (environ 20 min) for each image

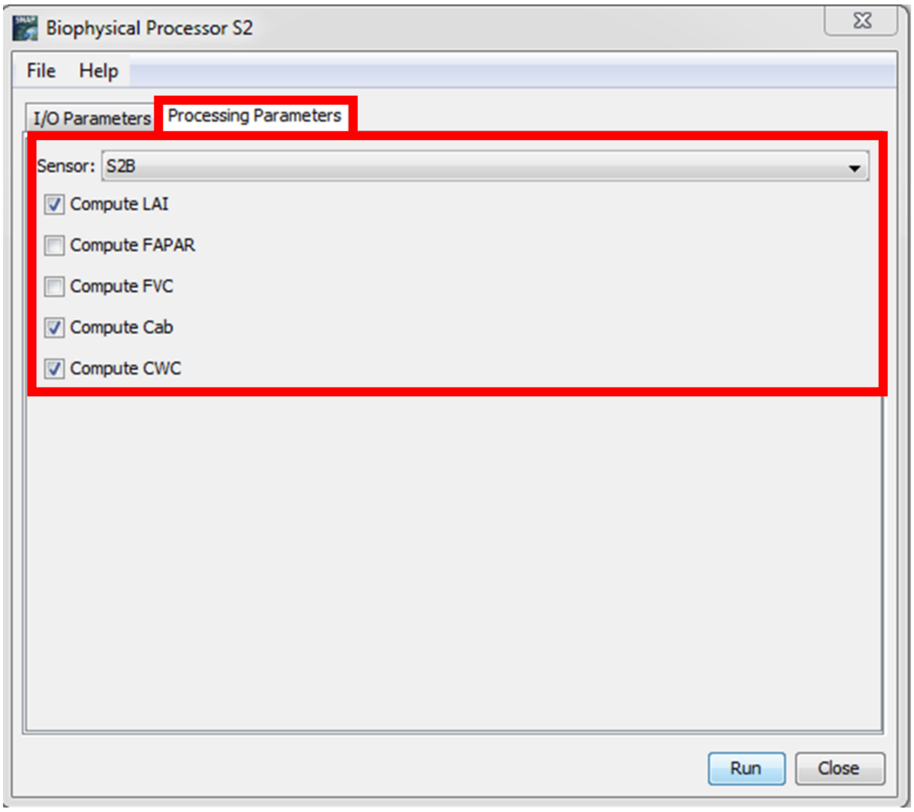
2. Calculating the biophysical variables:

- ✓ Open « S2Resample Processor » : Click on Optical Thematic Land Processing Biophysical ProcessorBiophysical Processor S2

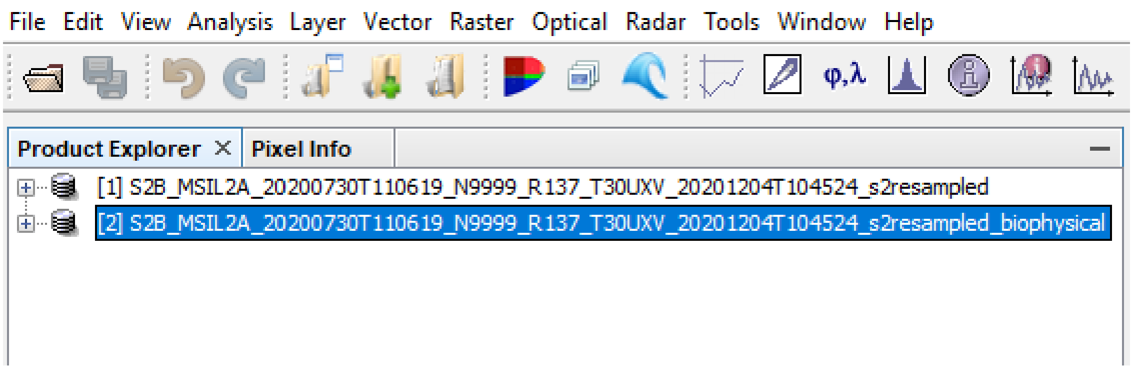


- ✓ In « I/O Parameters » :
  - Source Product: the result of « S2Resample »
  - Target Product : the name is generated automatically
  - Directory: select a directory to save the output in
- ✓ In « Processing Parameters » :
  - Sensor : select « S2B »
  - check : Compute LAI, Compute Cab, Compute CWC



<table>
<tr>
<td></td>
<td>


✓ Click « Run »
</td>
</tr>
<tr>
<td>Visualization of the three indices in SNAP</td>
<td>
➢ When « Biophysical Processor S2 » is done and (LAI, CAB et CWC) are calculated, the result will be added to the table of contents (Product Explorer, on the right) in SNAP



➢ In « Product Explorer » double click the product « S2B_MSIL2A_20200730T110619_N9999_R137_T30UXV_20201115T224205_s2resampled _biophysical.data

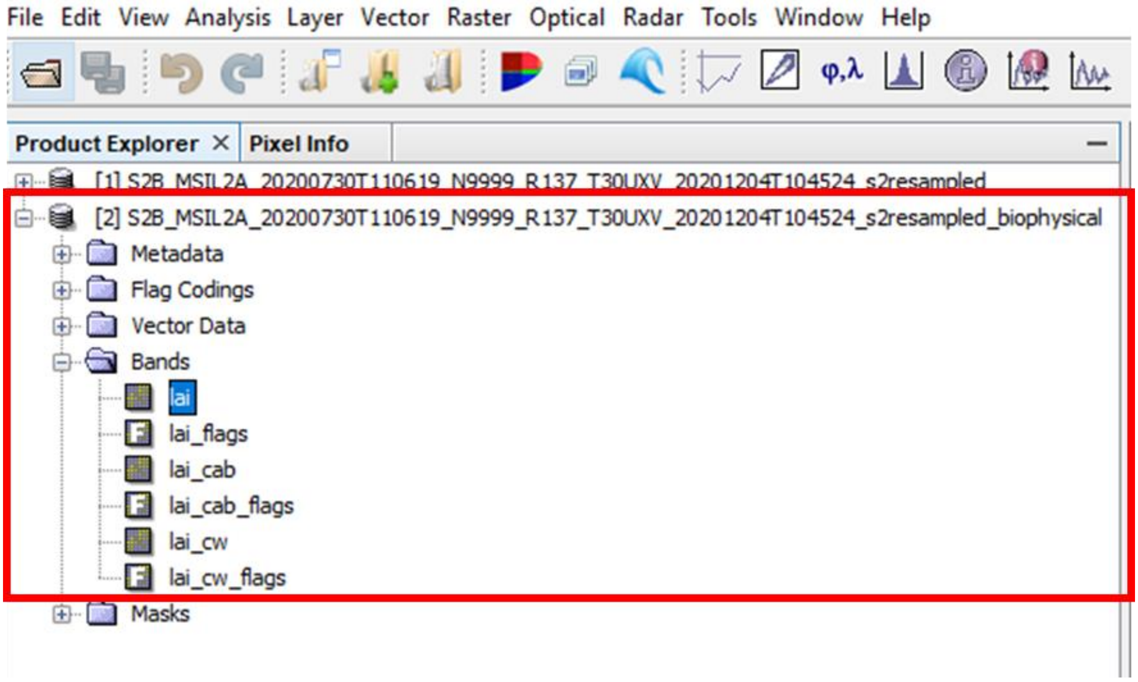
➢ Next, double click on « Bands »

➢ In this folder, you will find the three outputs

✓ Lai : LAI estimation image

✓ lai_cab : CAB estimation image

✓ lai_cw : CWC estimation image
</td>
</tr>
</table>



- Double click each image to visualize in SNAP