Surface Soil Moisture Estimation by using Sentinel-1 and Sentinel-2 Data

Objective

The objective of this course is to show how to map the surface soil moisture over agricultural plots (summer and winter crops) and grasslands using the free and open source software QGIS, by coupling radar (Synthetic Aperture Radar "SAR") and optical images acquired at high spatial resolution (~10 m x 10 m).

Study site and satellite data

The study site located near Montpellier city, South of France (figure 1) is an agricultural area (15 km x 15 km). Figure 1 shows layout, made using QGIS, of a satellite image acquired over the study site by Sentinel-2A (S2A).

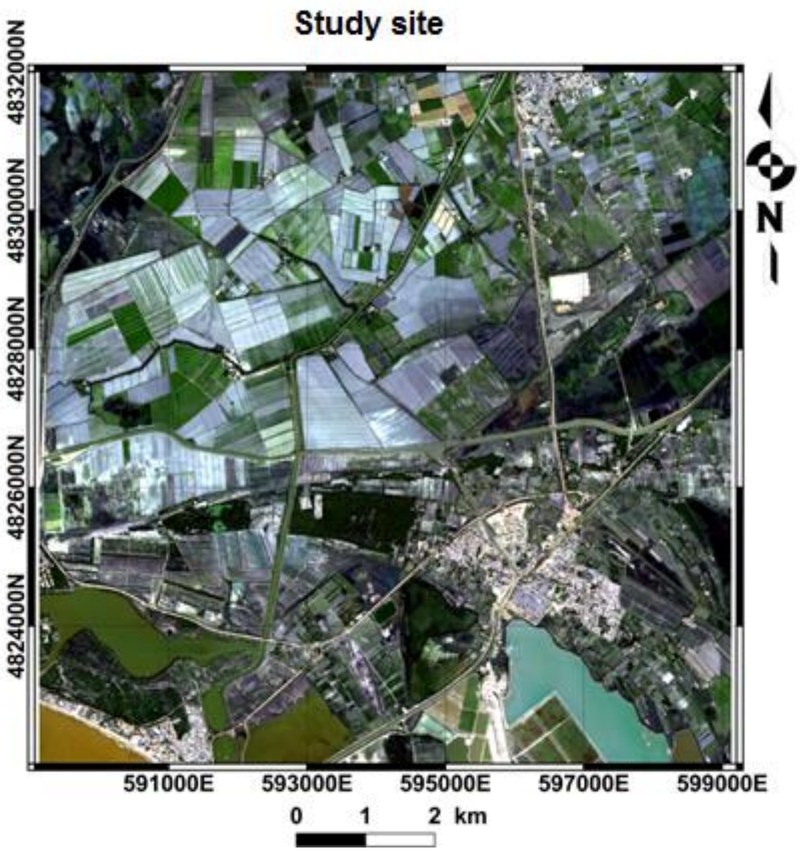


Figure 1: Study site located at 5 km east of Montpellier city, in the south of France. The background of the map is an optical image acquired by the satellite S2A. The geographical coordinates are in UTM (Universal Transverse Mercator), zone 31 N.

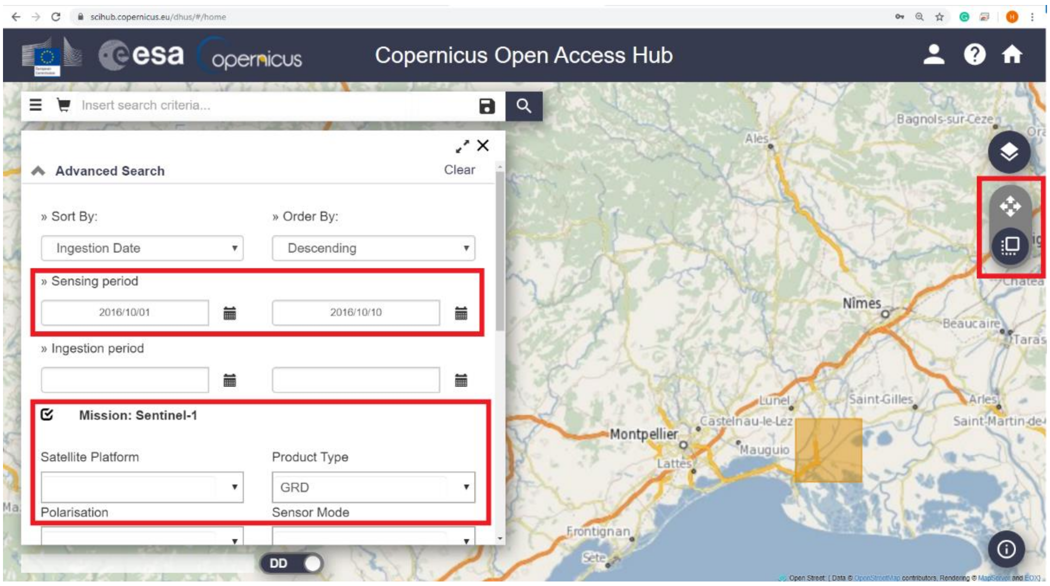
Satellite data used:

- One Sentinel-1 GRD image acquired on 10 October 2016
- One Sentinel-2 image acquired on 15 October 2016

1. Radar images

1.1 Download images

To download the radar images, create first an account on the ESA website[1]. The steps to create accounts are available on the web pages.

1- Download the radar image	➢ Go to ESA Open Hub website and site and click on « **Login** »  ➢ Draw a polygon that covers the study site with the tool « **Draw a shape** » located to the right of the screenshot below. This polygon represents the extent of the radar image to download. ➢ On the right side of the web page, select the Sensing period (date of the required image) ➢ To download the GRD Sentinel-1 image select the Sentinel-1 tab and select product type “GRD” ➢ Click on the search button to view all the available images ➢ Select the image needed and click on Download 

1 https://scihub.copernicus.eu/dhus/#/home

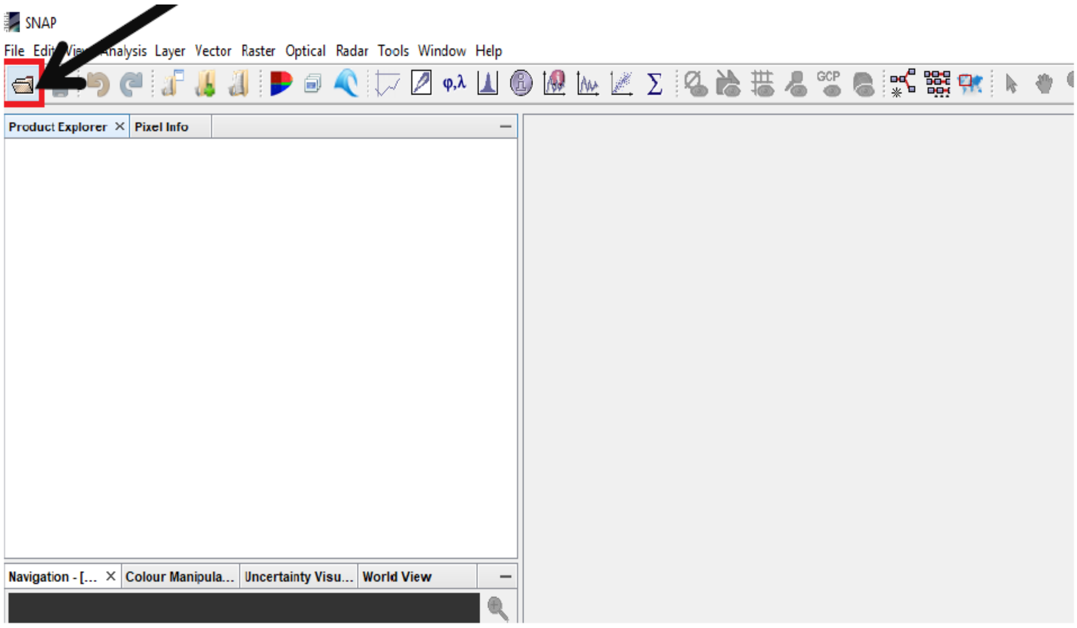
1.2 Calibration of Radar Image in SNAP

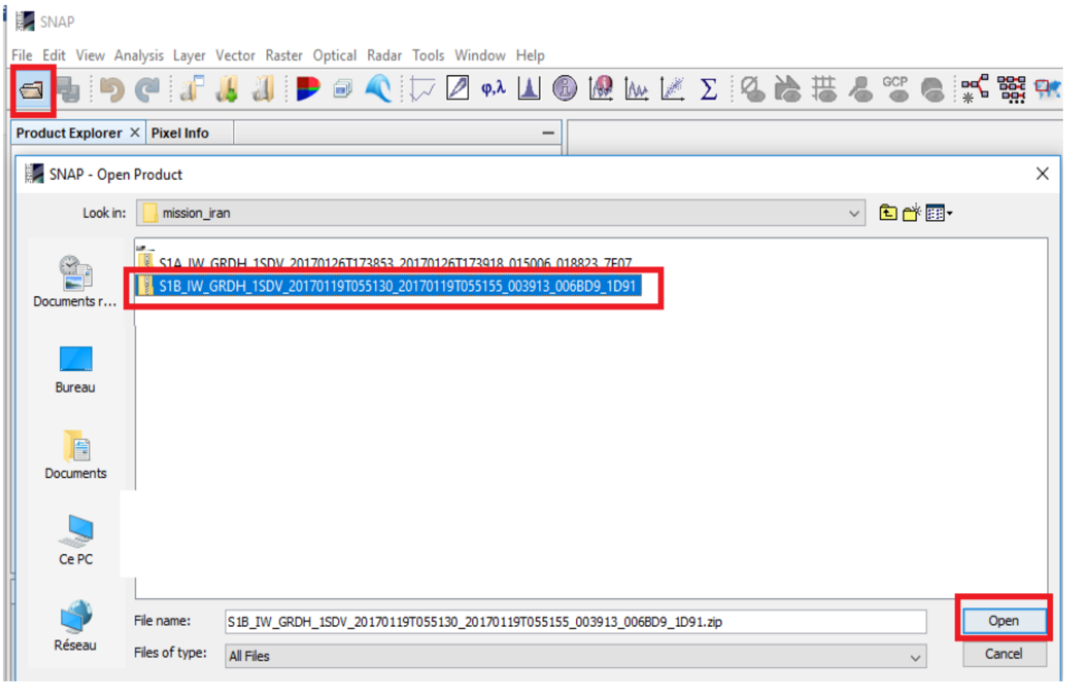
In order to calibrate the radar image, you should first install SNAP software[2] . Once the SNAP is downloaded, you can calibrate the radar image as follows:

<table>
<tr>
<td>1- Open Image in SNAP</td>
<td>

➢ Open the SNAP software

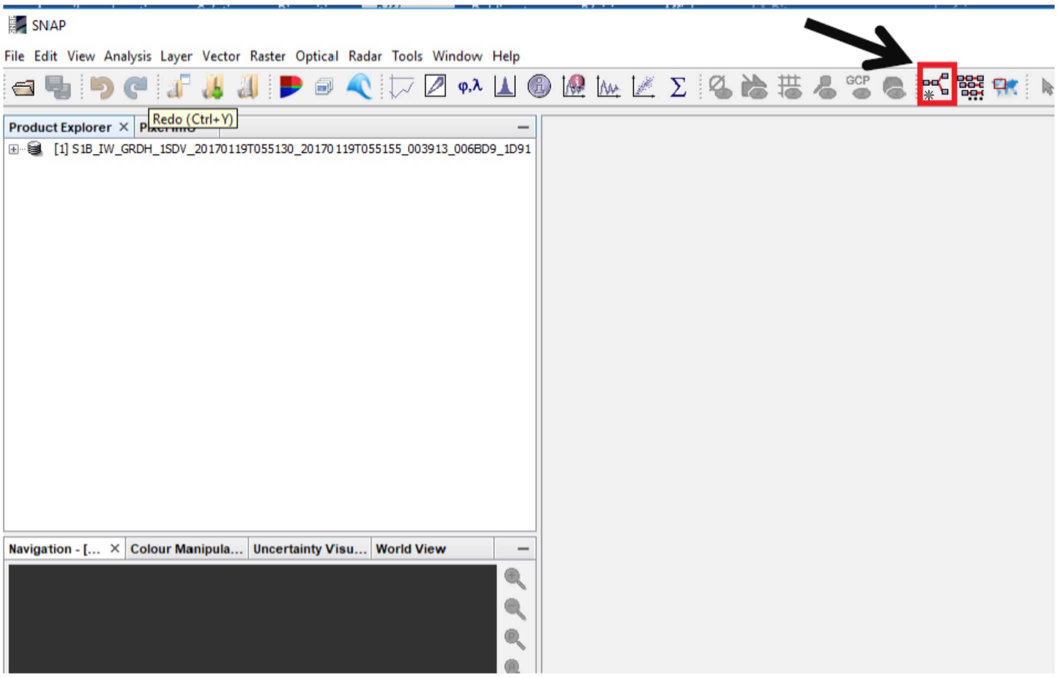
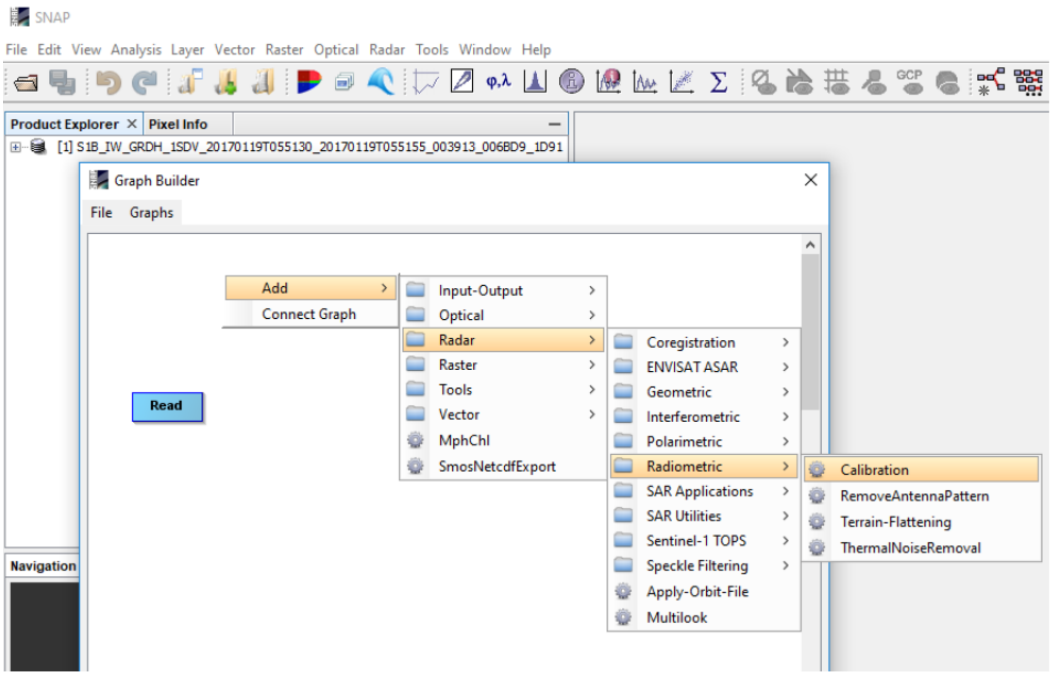
➢ Import the radar image into SNAP : « **Main Menu** » ➔ « **Open Product** » then select the S1 image



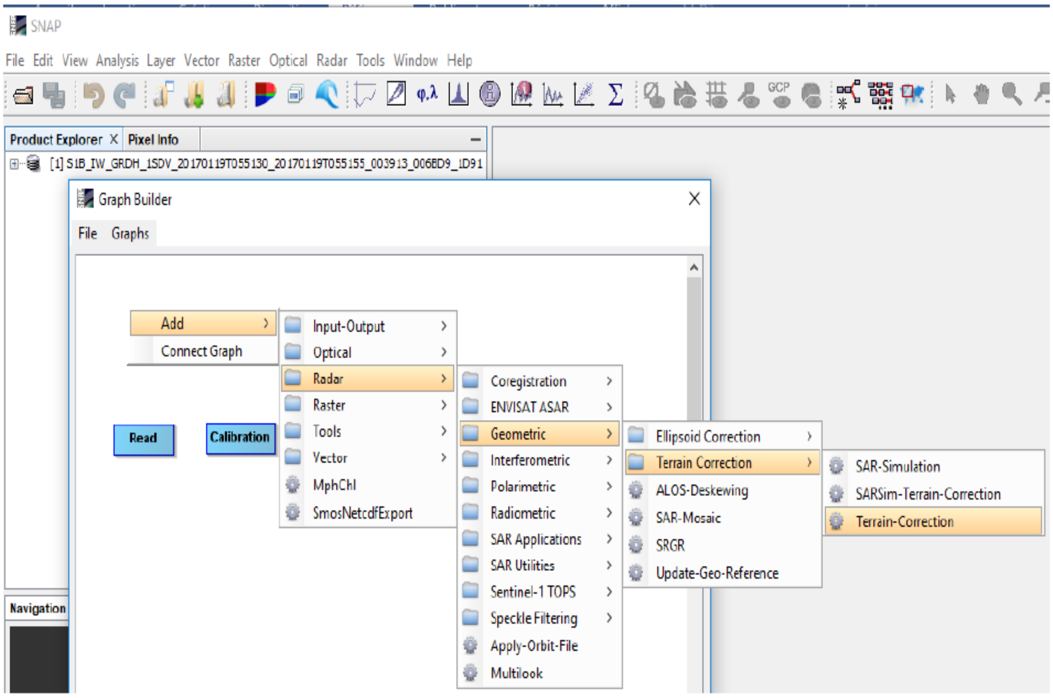


</td>
</tr>
</table>

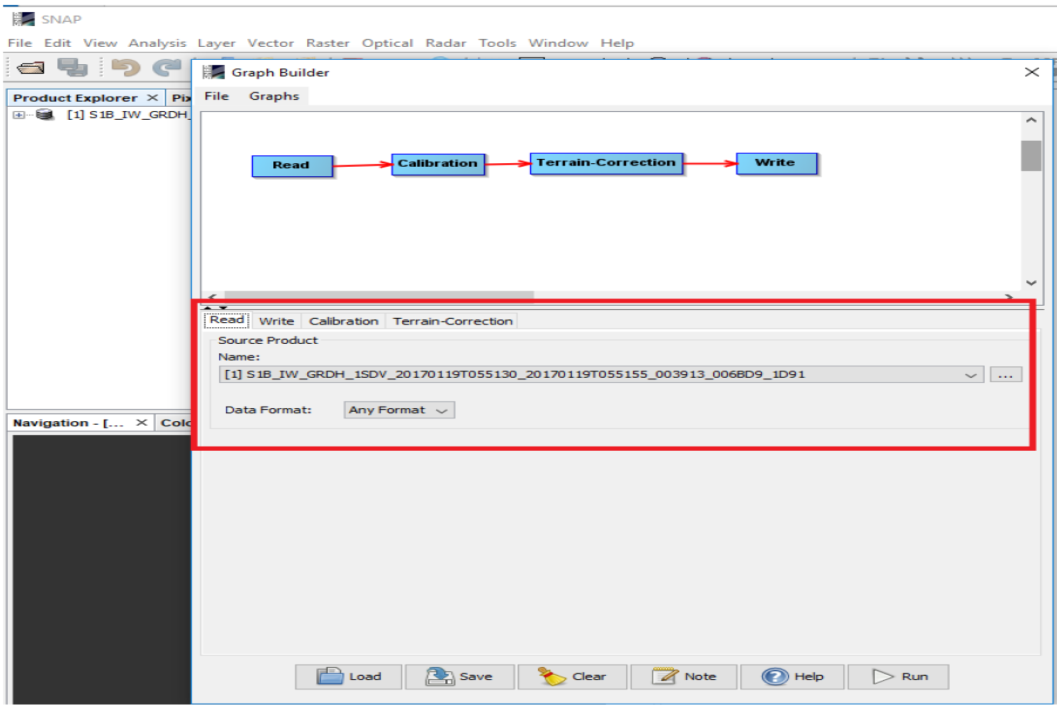
2 http://step.esa.int/main/download/snap-download/

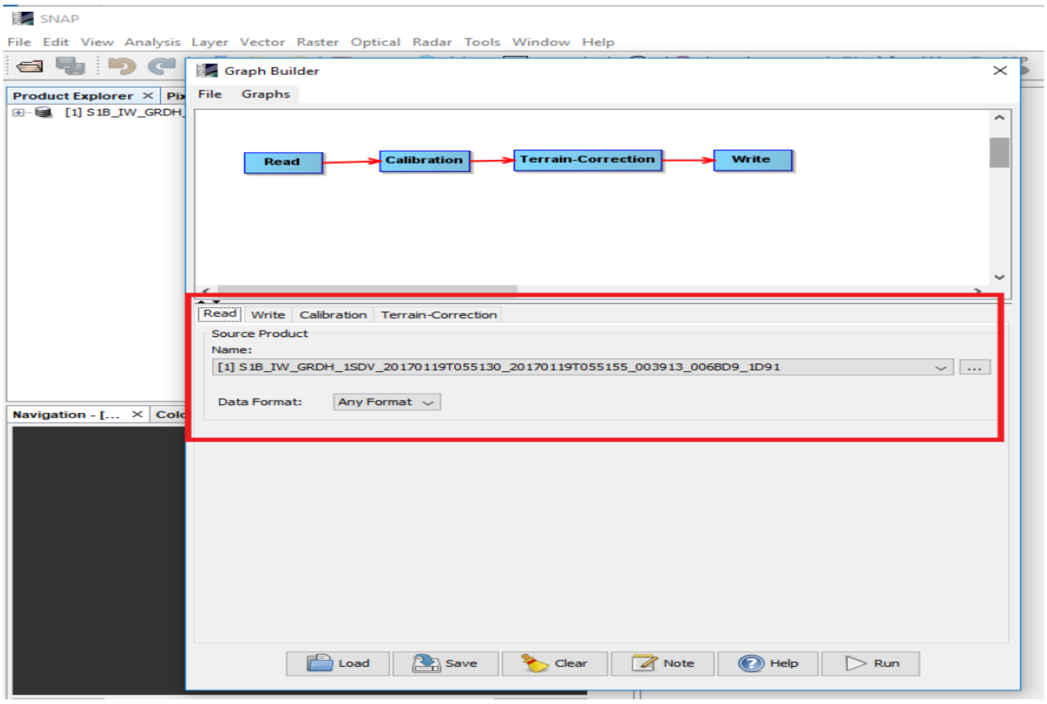
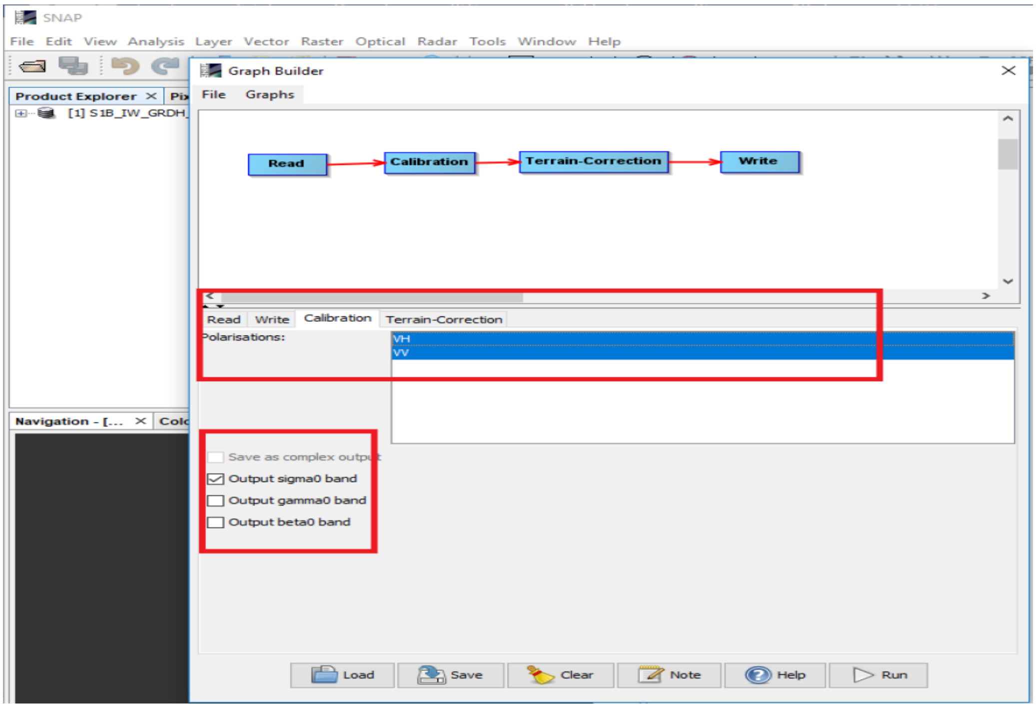
2- Create a graph of processing chain (Calibration and ortho-rectification):	➢ To create the graph builder: « **Main Menu** » ➔ « **Graph Builder** » then select the S1 image  ➢ Add the two calibration functions (calibration and ortho-rectification) in the graph builder: • Right Click ➔Radar➔ Radiometric ➔ Calibration 

- Right Click➔Radar➔Geometric➔ Terrain Correction➔ Terrain Correction

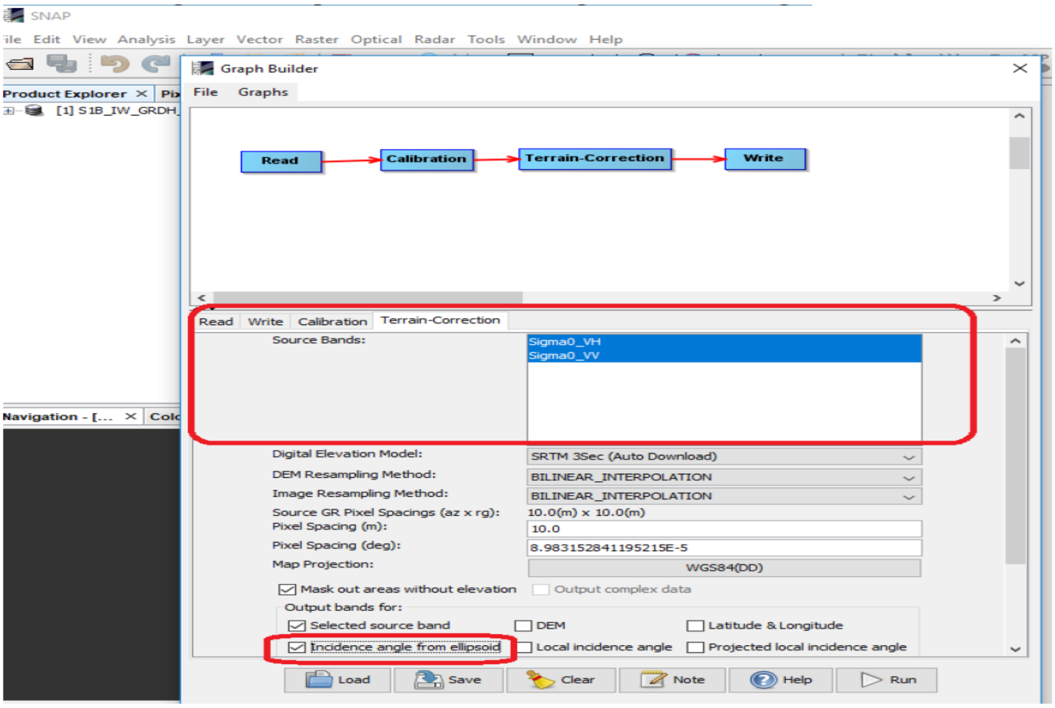


- Link between all the functions: Read, Calibration, Terrain Correction, Write

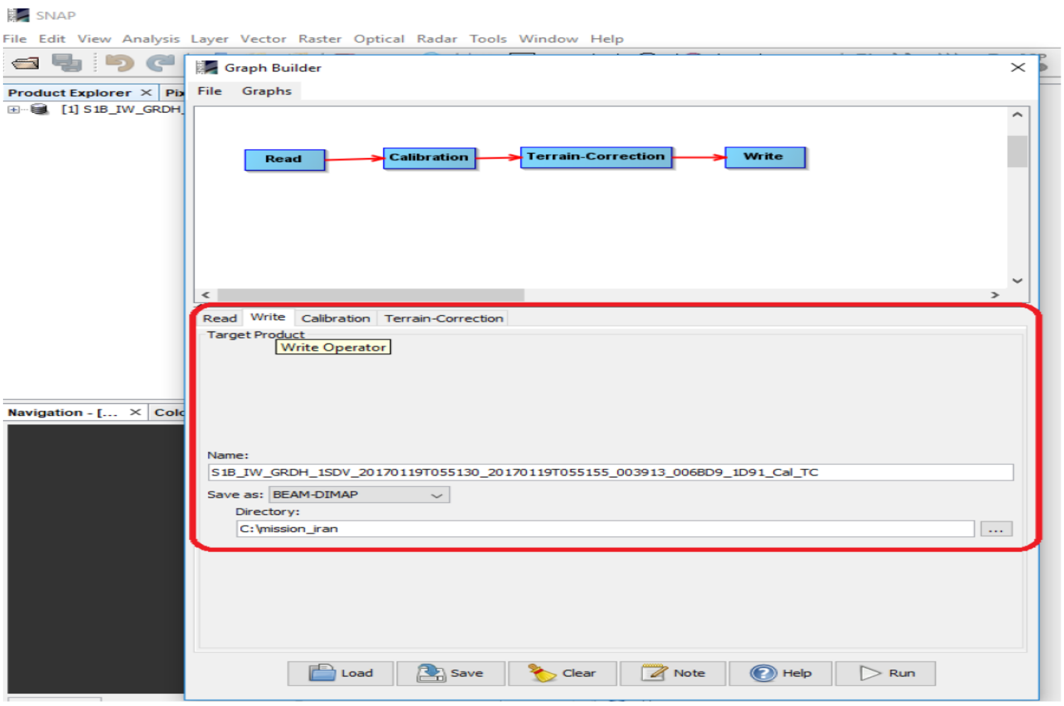


3- Select the input and give a name for the output image (calibrated and ortho-rectified image)	➤ In the read menu: select the input image  ➤ In the calibration menu select the bands (in the figure below it is VH and VV) to be calibrated. Activate the option “output sigma 0 band” to have an output image in linear unit. The image in linear unit should be used to calculate mean values of SAR backscattering signal (pixel values in linear image) 

➢ In the menu **Terrain-Correction,** select all polarizations. In addition, select « **incidence angle from ellipsoid** » to have the image of incidence angle



➢ In the menu Write give a name for the output image



➢ Finally Click on the **RUN** button

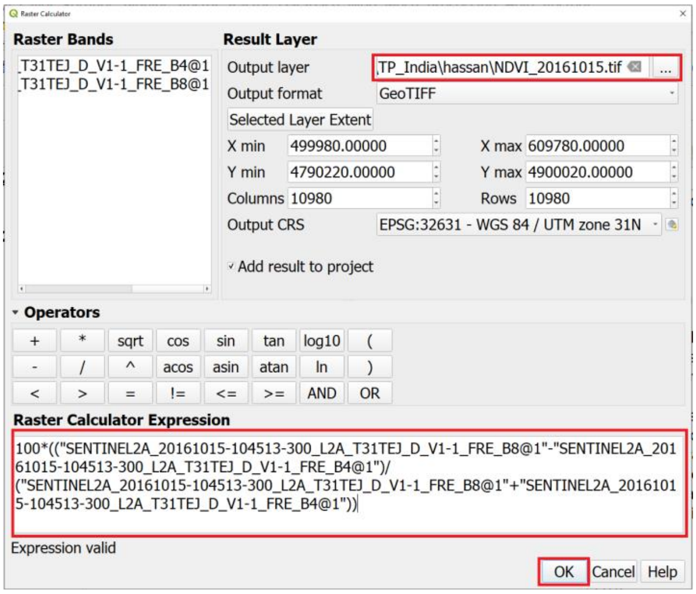
2. Optical image

2.1 Overview

In this tutorial, one optical image is downloaded from Theia website with a processing level 2A for the date 15/10/2016. However, optical images of Sentinel-2 mission could be also downloaded, as the radar image, from ESA website as explained in paragraph 1. Please make sure that the optical image is of level 2A. Otherwise, if the image is of level 1C, a calibration is required to obtain the 2A level image. This calibration is also performed by the SNAP software using the “sen2cor” module.

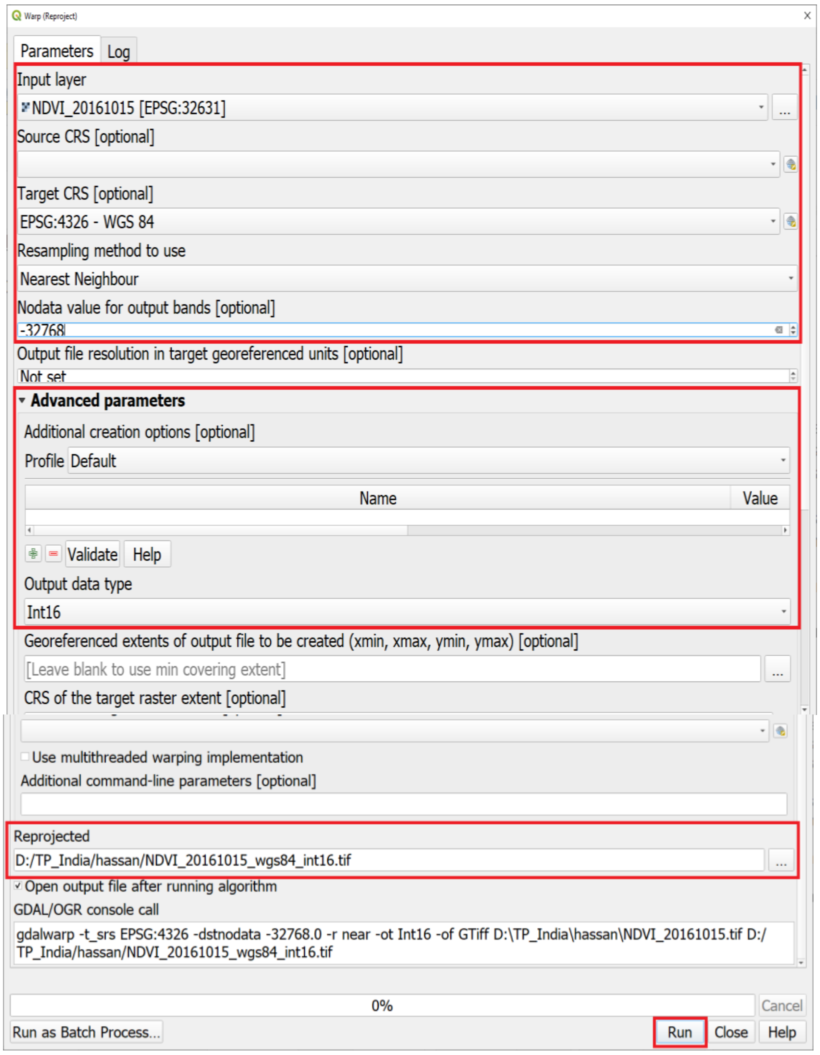
2.2 Calculation of NDVI

The optical image is downloadable as 13 separate spectral bands. To facilitate the use of the optical image, only the red (band 4), and near infrared (band 8) bands are used. The NDVI is first calculated from the red and infra-red band. The NDVI image is then clipped and re-projected to obtain the same projection of the radar image (WGS-84).

1- Calculation of the NDVI image	➢ To calculate the NDVI : • Import in QGIS the images found in folder “SENTINEL2A_20161015-104513-300_L2A_T31TEJ_D_V1-1” ✓ SENTINEL2A_20161015-104513-300_L2A_T31TEJ_D_V1-1_FRE_B4.tif (Red Band) ✓ SENTINEL2A_20161015-104513-300_L2A_T31TEJ_D_V1-1_FRE_B8.tif (Infrared Band) • In the menu bar, click on « Raster » ➔ « Raster Calculator » • In the window that appears, type the formula below. With this formula, the NDVI-values are multiplied by 100. This allows converting the encoding of the NDVI image into 16 bits without lose precision, and consequently accelerate the segmentation of the NDVI image. • 100*(("SENTINEL2A_20161015-104513-300_L2A_T31TEJ_D_V1-1_FRE_B8@1"-"SENTINEL2A_20161015-104513-300_L2A_T31TEJ_D_V1-1_FRE_B4@1")/("SENTINEL2A_20161015-104513-300_L2A_T31TEJ_D_V1-1_FRE_B8@1"+"SENTINEL2A_20161015-104513-300_L2A_T31TEJ_D_V1-1_FRE_B4@1")) • In « **Output Layer** », name the image as: « NDVI_20161015.tif ». • Finally, click on **« OK ».** Once processing is complete, the output image appears in the **« Layer »** and **« Display » part** of the QGIS interface. 

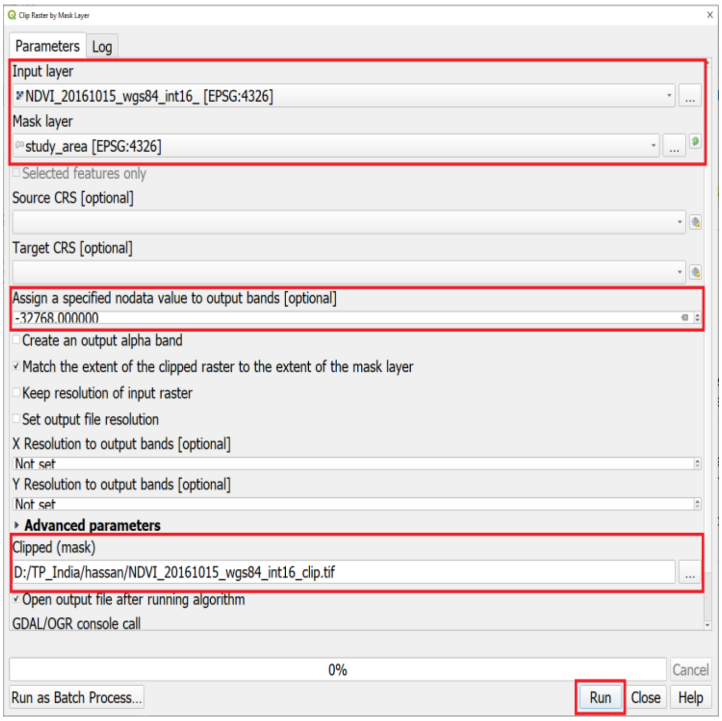
➢ Project the NDVI image (NDVI_20161015.tif) and convert into a 16-bit integer

- In the menu bar, click on « **Raster** » ➔ « **Projection** »➔ « **Warp (Reproject)** »
- In the window that appears, select in « **Input Layer** » the NDVI image (NDVI_20161015.tif)
- In the « **Target CRS** » choose EPSG:4326 –WGS84
- In the option « No data » enter -32768
- In the « **Advanced Parameters** » choose Output data type **“Int16”**
- In « **Reprojected** » enter NDVI_20161015_wgs84_int16.tif
- Finally, click on « **Run** ». Once processing is complete, the output image appears in the « **Layer** » and « **Display** » part of the QGIS interface.



- Clip the NDVI image “NDVI_20161015_wgs84_int16.tif

  - Add the shapefile of the study site extent to QGIS (study_area.shp) In the menu bar, click on **« Raster » ➔ « Extraction »➔ « Clip by Mask Layer »**
  - In the window that appears, select in **« Input Layer »** the NDVI_20161015_wgs84_int16.tif
  - In the **« Mask Layer »** choose “study_area”
  - In **« Clipped »** enter NDVI_20161015_wgs84_int16_clip.tif
  - Finally, click on **« Run ».** Once processing is complete, the output image appears in the **« Layer »** and **« Display »** part of the QGIS interface.



3. Segmentation of NDVI

3.1 Land Cover Map

To facilitate the manipulation of the land cover map, this map is first clipped, and then reprojected to WGS 84. Procedures for clip and re-project an image are explained earlier in section 2.2. The clipped and reprojected land cover map will be called ocsol_clip_wgs84.tif

3.2 Segmentation of crop's areas and grasslands

To delimit the spatial units, a mask is first generated from the land cover map to determine the crop and grasslands areas. Then, the NDVI image is used to segment crop and grasslands areas into homogeneous segments (spatial units).

1-Determination of crop's areas and grasslands, and segmentation

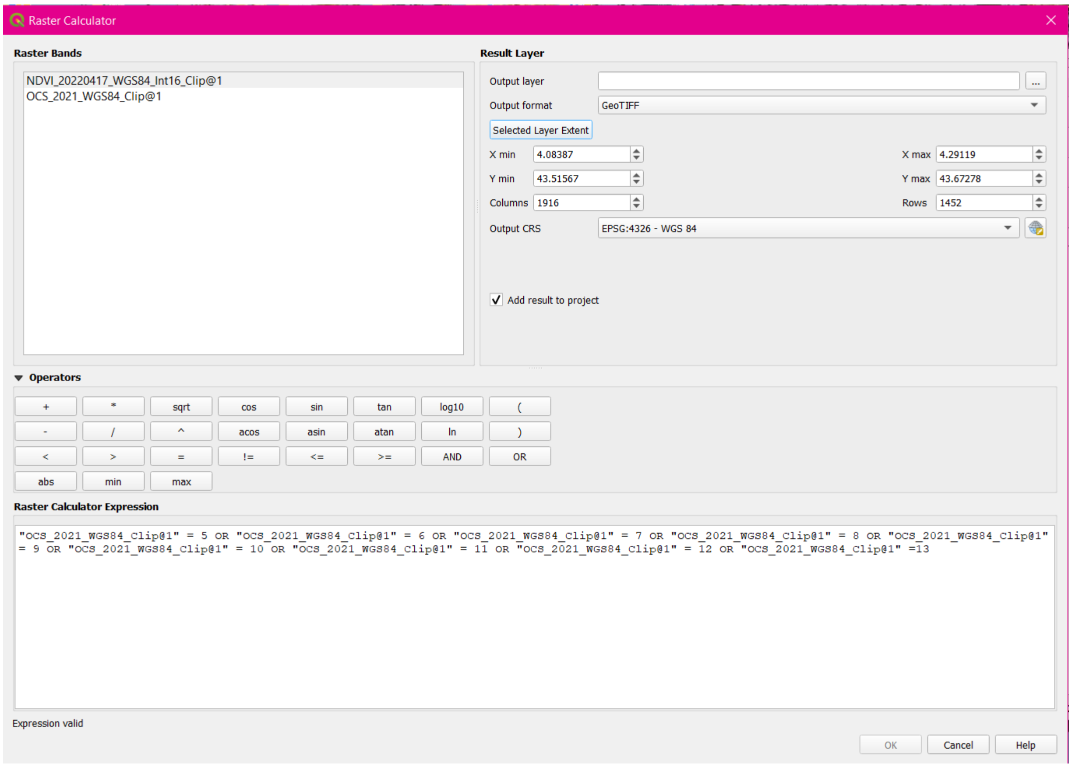
➢ To create the mask image, we will use the Raster Calculator

- Select the NDVI image clipped as the layer extent.
- In the « **Expression** » type the formula below:

"OCS_2021_WGS84_Clip" = 5 OR "OCS_2021_WGS84_Clip" = 6 OR "OCS_2021_WGS84_Clip" = 7 OR "OCS_2021_WGS84_Clip" = 8 OR "OCS_2021_WGS84_Clip" = 8 OR "OCS_2021_WGS84_Clip" = 10 OR "OCS_2021_WGS84_Clip" = 11 OR "OCS_2021_WGS84_Clip" = 12 OR "OCS_2021_WGS84_Clip" = 13

Using this formula, the pixels of the land cover map (OCS_2021_WGS84_Clip.tif) with values equal to 5 to 13 are set to 1 in the mask image (mask.tif), while the other pixels are set to 0.

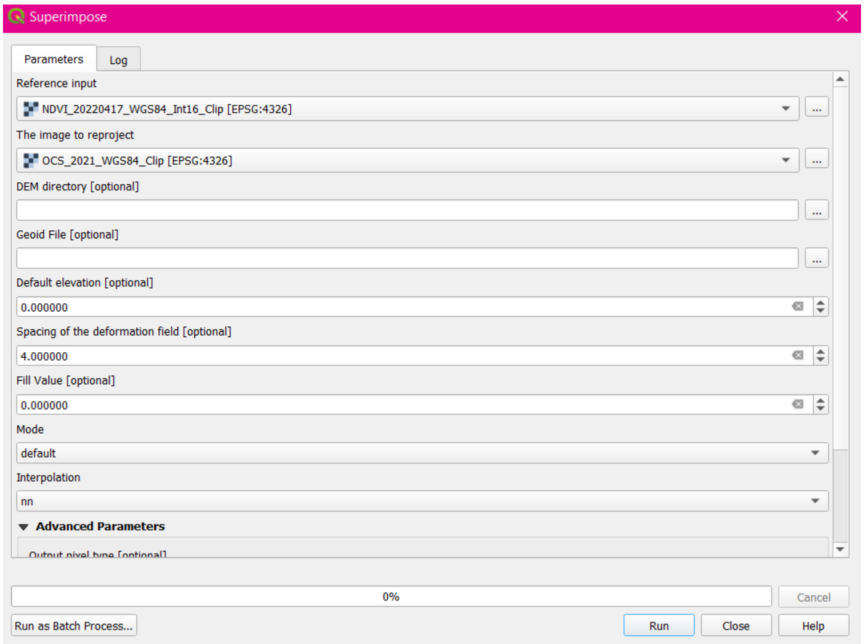
- Name the output image: mask.tif



➢ To set the same geographical origin and pixel size we will use the OTB tool "Superimpose" :

- Select the NDVI image as the Reference Input
- Select the Mask image as the image to reproject

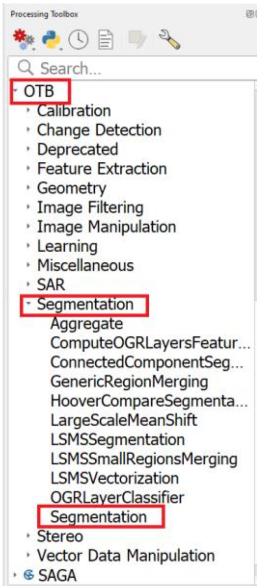
- Select the interpolation mode “nn”



➢ segment the areas of the NDVI image that correspond to crop plots and grasslands:

➢ To segment the areas of the NDVI image that correspond to crop plots and grasslands:

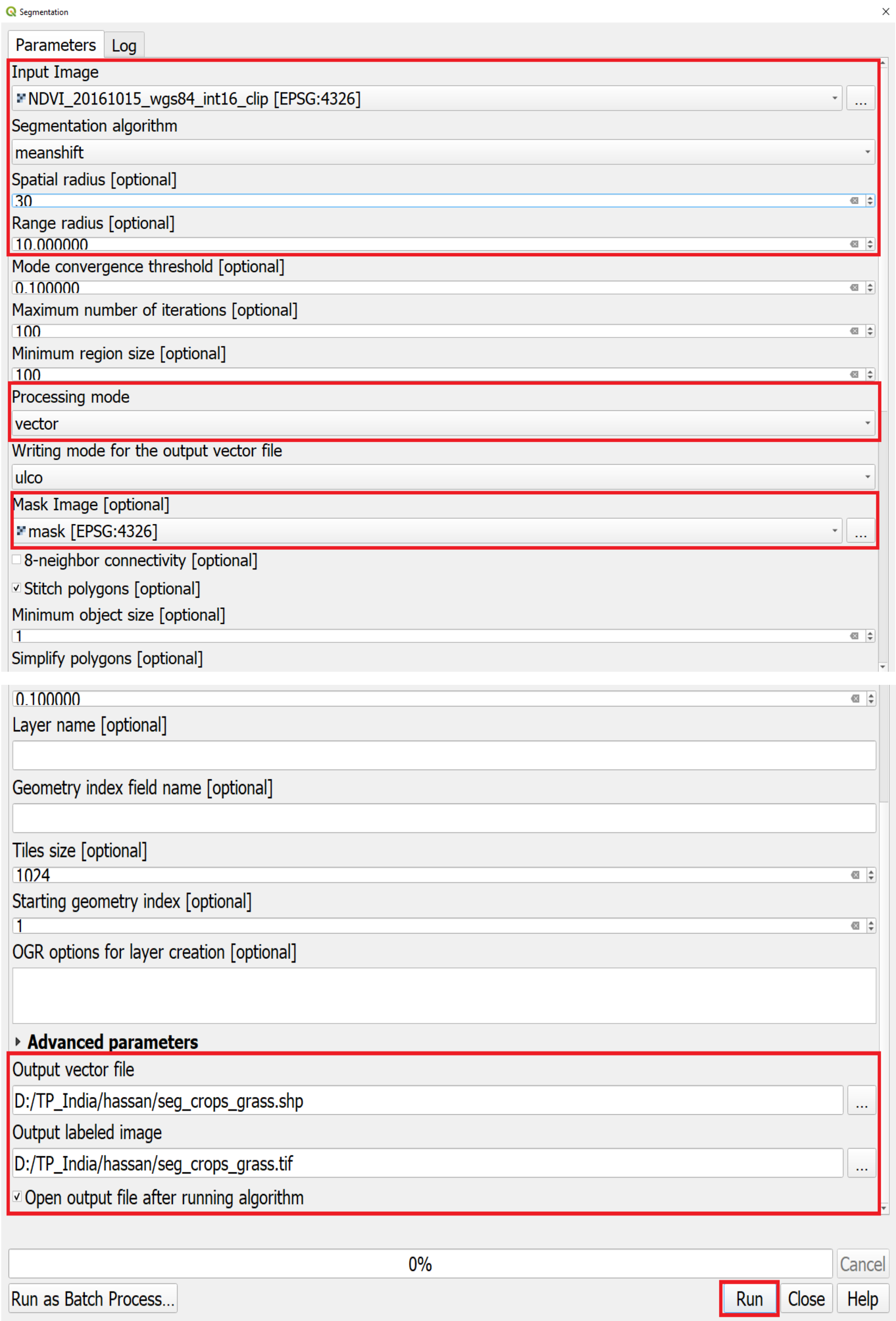
- Import the mask image and the NDVI image (NDVI_20161015_wgs84_int16_clip.tif)
- In the menu bar, click on « **Processing** » ➔ « **Toolbox** »
- In the window that appears to the right of the QGIS interface, click on « **OTB** » ➔ « **Segmentation** » ➔ « **Segmentation** »



- In the window that appears:
  - ✓ Select the input image « **input image** »: NDVI_20161015_wgs84_int16_clip.tif »
  - ✓ Segmentation algorithm « **segmentation algorithm** » meanshift
  - ✓ Spatial radius « **spatial radius** » = 30 pixels,
  - ✓ Range radius « **range radius** » : 10,

✓ Mask image « **mask image** » : « mask.tif »

- Name the vector layer of the output segmentation as follows: « **output vector file** » : « seg_crops_grass.shp » and the « **output labeled image** » as « seg_crops_grass.tif »
- Click on « **run** » to execute the segmentation function. Once processing is complete, the vector layer of the segmentation appears in the « **Layers** » and « **Display** » part of the QGIS interface.



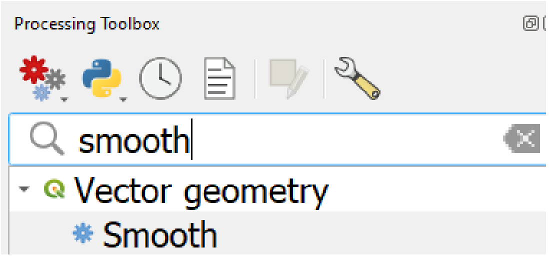
3.3 Elimination of small spatial units

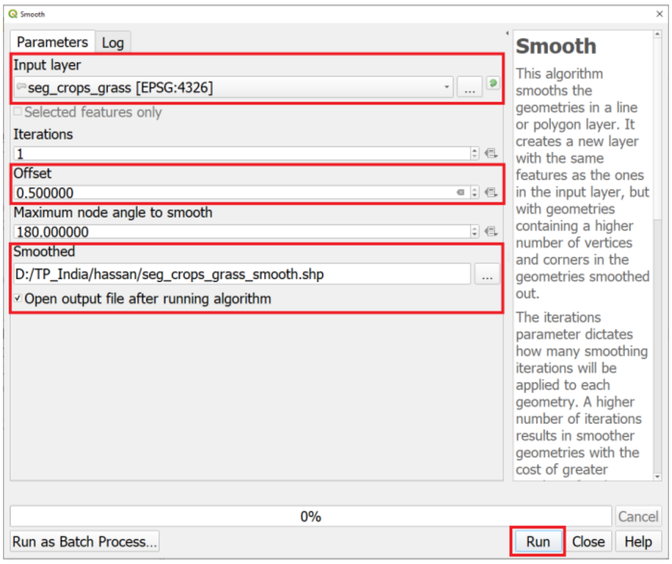
To eliminate the small spatial units present in the segmented image, a smoothing of polygon is first applied. A buffer zone of 10 m (0.0001°) inside each polygon is produced. Then, the number of pixels in each polygon is calculated. Finally, polygons with number of pixels less than 20 are deleted.

<table>
<tr>
<td>1- Elimination of small spatial units</td>
<td>

➢ To smooth polygons:

- In the main menu, click on « **Processing** » ➔ « **Toolbox** »
- In the window that appears, click on « **Vector geometry** » ➔ « **Smooth** »
- In « **Input Layer** » select the vector layer of the segmentation (seg_crops_grass.shp),
- In « **Offset** » enter the number 0.5 (unit = pixel)
- In « **Smoothed** » enter the output file name (seg_crops_grass_smooth.shp)
- Click on « **run** ». Once the processing is complete, the output file appears in the « **Layer** » and « **Display** » part of the QGIS interface.

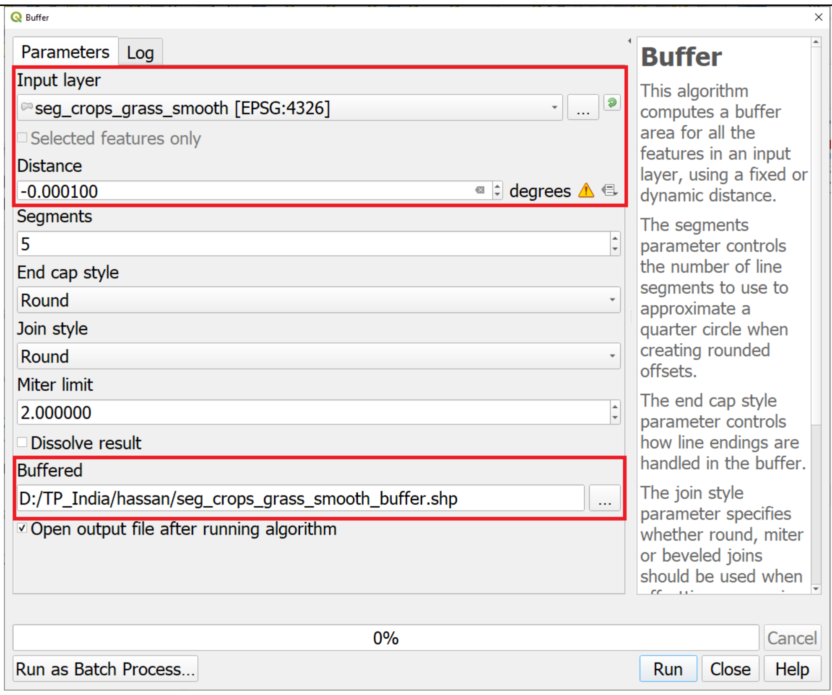




➢ To perform a buffer zone of 10 m :

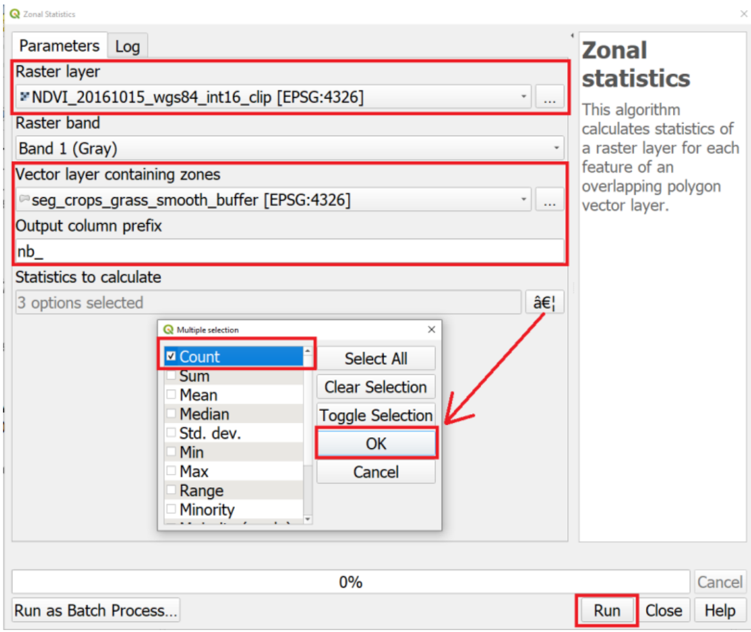
- In the menu bar, click on « **Processing** » ➔ « **Toolbox** »
- In the window that appears, click on « **Vector geometry** » ➔ « **Buffer** »
- In the window that appears, select the input layer (seg_crops_grass_smooth.shp)
- In « **Distance** » enter the number -0.0001° (-10 m)
- In « **Buffer** » enter the output file name (seg_crops_grass_smooth_buff.shp)
- Click on « **run** ». Once the processing is complete, the output file appears in the « **Layers** » and « **Display** » part of the QGIS interface.

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



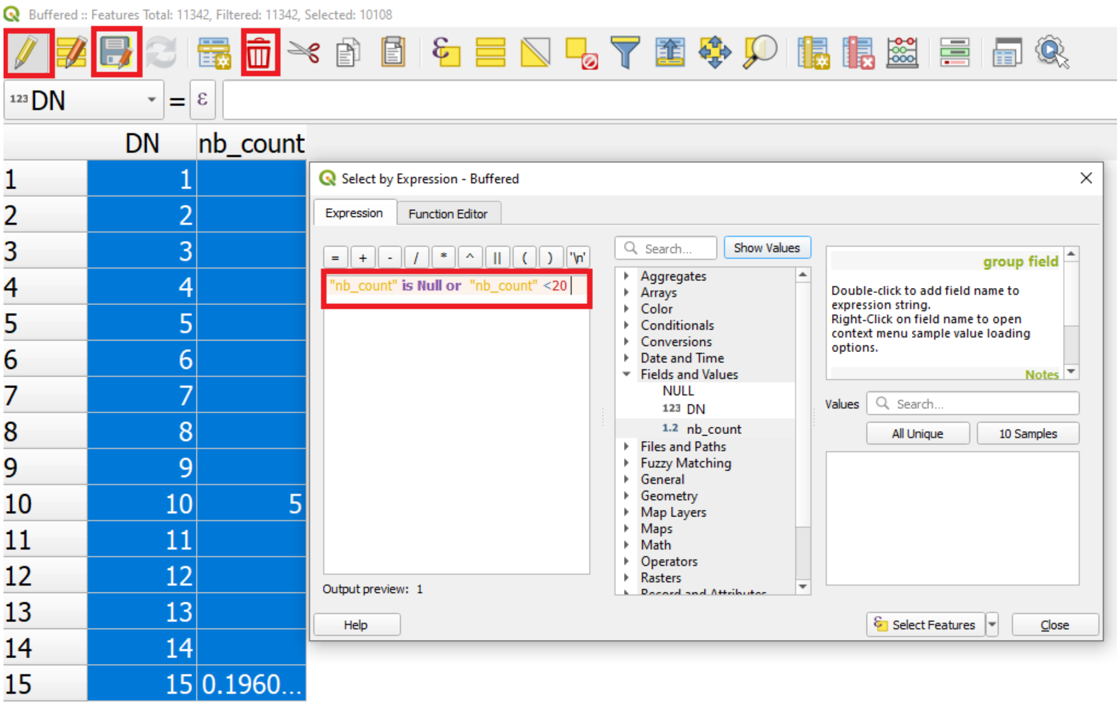
➢ To calculate the number of pixels in each polygon:

- In the menu bar, click on « **Processing** » ➔ « **Toolbox** »
- In the window that appears, click on « **Raster Analysis** » ➔ « **Zonal Statistics** »
- In « **Raster layer** » select the NDVI_20161015_wgs84_int16_clip.tif
- In « **Band** » select the band 1
- In « **Vector layer containing zones** » select the vector layer seg_crops_grass_smooth_buff.shp
- In « **Output column prefix** » type « *nb* »
- In « **Statistics to Calculate** » check only the option « **Count** »
- Click on « **ok** ». Once the processing is complete, statistics (number of pixels) are saved in the attribute table.



➢ To remove entities with a number of pixels less than 20:

- Open the attribute table of the vector layer seg_crops_grass_smooth_buff.shp :« **right click** » on the vector layer ➔ « **Open attribute table** »
- Activate the edit mode
- Click on « **Select features using an expression** » and type «"nb_count" is Null or "nb_count" <20 »
- Click on the icon « delete selected features »
- Disable the edit mode



4. Mapping soil moisture

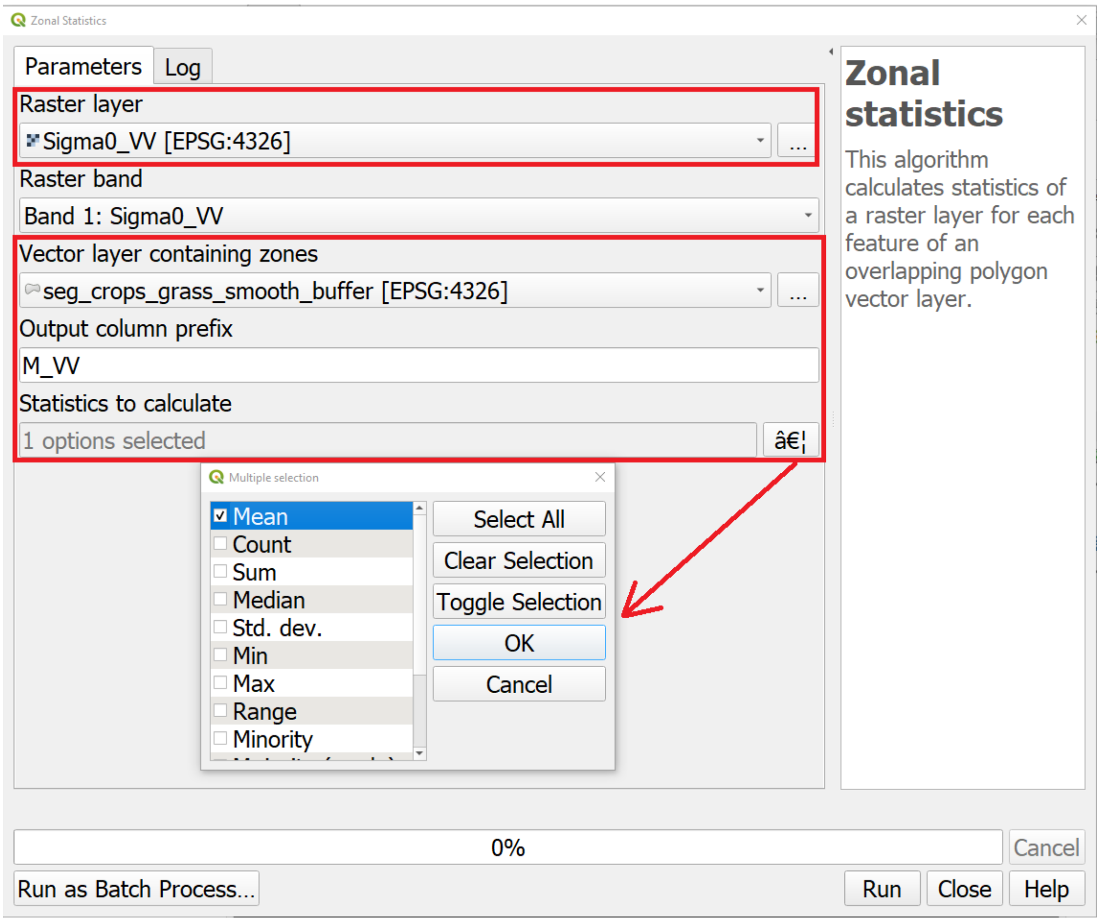
4.1. Calculation of mean backscattered signal, mean incidence angle, and mean NDVI

For each spatial unit (polygon), the mean of the backscattered radar signal (linear scale) in VVpolarization, of the local incidence angle, and of the NDVI were calculated. Then, the mean-values are exported to csv.

<table>
<tr>
<td>1- Calculation of mean backscattered radar signal, mean incidence angle, and mean NDVI for each spatial unit.</td>
<td>

➢ Calculate the mean backscattered radar signal (linear scale) using all pixels containing in each polygon (spatial unit) :

- Import the radar image (Sigma0_VV) and the incidence angle image (incidenceangle), and the segmentation vector layer segmentation seg_crops_grass_smooth_buff-10.shp.
- In the menu bar, click on « **Processing** » ➔ « **Toolbox** »
- In the window that appears, click on « **Raster Analysis** » ➔ « **Zonal Statistics** »
- In « **Raster layer** » select the Sigma0.img
- In « **Vector layer containing zones** » select the vector layer seg_crops_grass_smooth_buff.shp
- In « **Output column prefix** » type « M_VV » to denote that it is the mean (M) of the radar backscattering coefficient in VV
- Click on « **Statistics to calculate** » button â€¦ and check only the option « Mean »
- Click on « **ok** ». Once the processing is complete, the values of the mean are saved in the attribute table.



➢ Repeat the above step for the incidence angle image and the NDVI image using “M_Inc” and “M_NDVI” as column prefix respectively

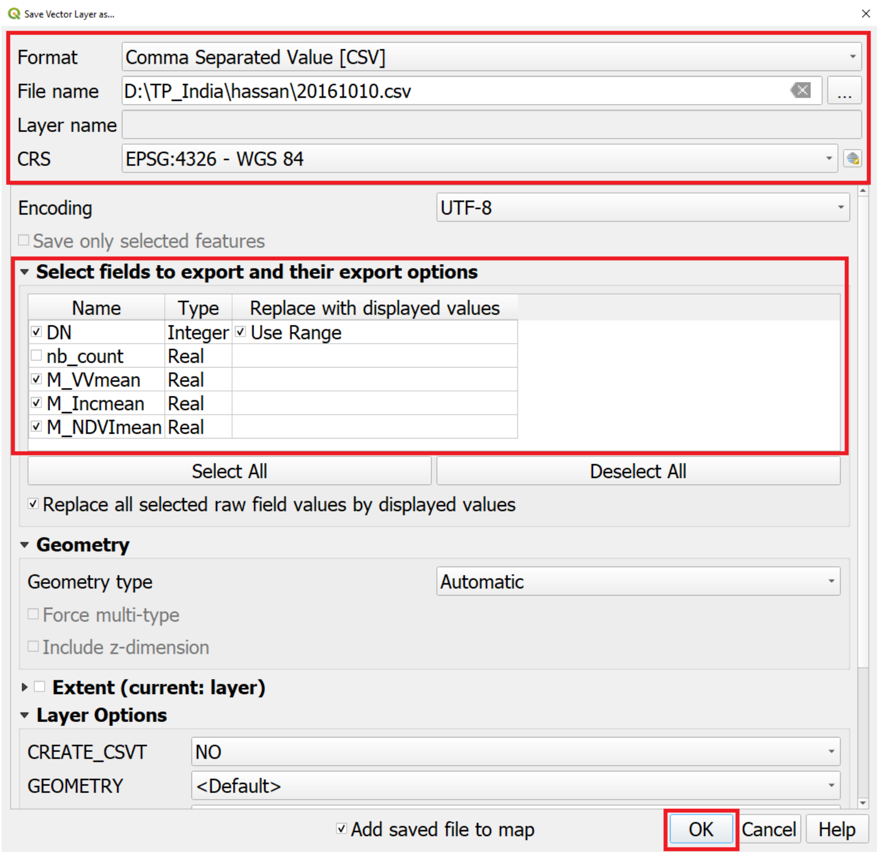
</td>
</tr>
</table>

- Open the attribute table to check the results

- To export the values from the vector layer to .csv file

  - Import the segmentation vector layer seg_crops_grass_smooth_buff.shp
  - Right click on the vector layer seg_crops_grass_smooth_buff.shp, and select « **Save As…** »
  - In « **Format** » select the option « **Comma Separated Values csv** »
  - In « **File name** », enter the following name 20161010.csv
  - Check the following fields only: DN, M_VVmean, M_Incmean and M_NDVImean
  - Click on « **ok** »

- Please note, in each file .csv, the first, second, third and fourth columns should be in the order : the identifier of each segment (DN), backscattered radar signal in VV (linear scale), backscattered radar signal in HV (linear scale), local incidence angle, and NDVI.



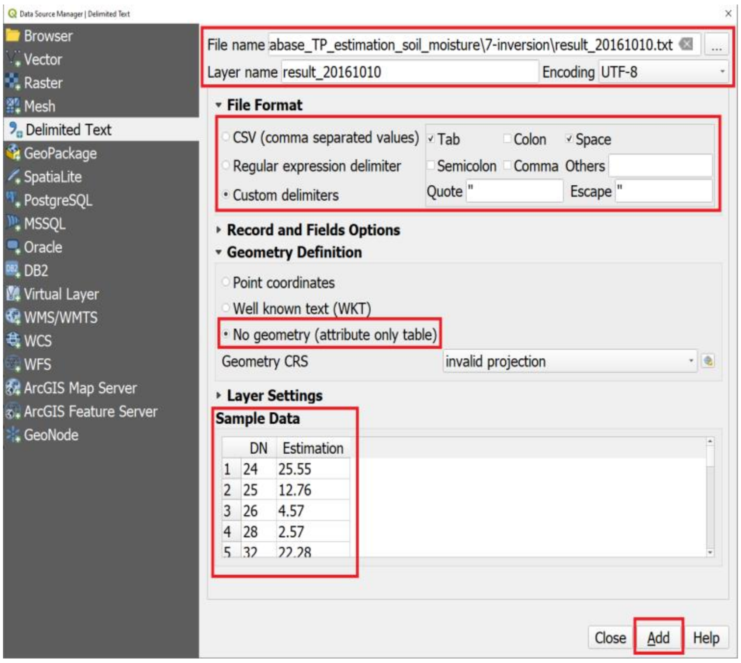
4.2 Application of the soil moisture estimation algorithm

To apply the soil moisture estimation algorithm, you should use the script consisting of programming codes written in Python language (apply_algo.py) to run the algorithm algo.sav (soil moisture estimation by neural network). The script use as input a file .csv that contains the statistics (mean of radar signal in VV and HV polarizations, incidence angle, and NDVI) and produces a text file that contains the identifier of each spatial unit and the associated estimated moisture.

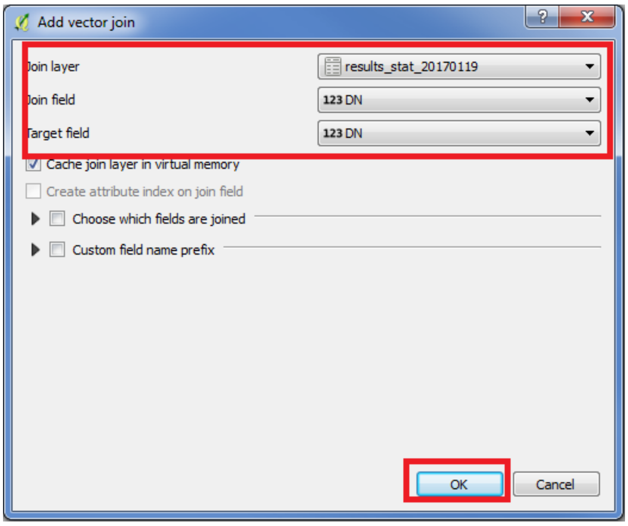
1- Execution of the algorithm to estimate the moisture on each polygon	➢ To apply the soil moisture estimation algorithm: • Move the csv files to the same directory as the script (apply_algo.py) • Open the script (apply_algo.py) : « **Right Click on the script** » ➔ « **Edit with IDLE** » • In the « zonal_stat » variable, put the name of the file .csv containing the statistics: zonal_stat = « 20161010.csv » • Click on « **F5** » on the keyboard to launch the algorithm • A text file is automatically generated (results_stat_20161010.txt). In this text file, the first column is the identifier (DN), and the second column is the estimated soil moisture.

4.3 Production of soil moisture maps

To produce soil moisture maps, joins are made according to the identifier (DN) between the text files that contain the estimated moisture values and the vector layer seg_cultures_prairie_liss_buf-10.shp. This allows adding in the attribute table of the vector layer seg_cultures_prairie_liss_buf.shp the estimated moisture values for the dates of the radar images (19/01/2017 and 26/01/2017). Then, visualization in the form of a map of the estimated moisture values is carried out.

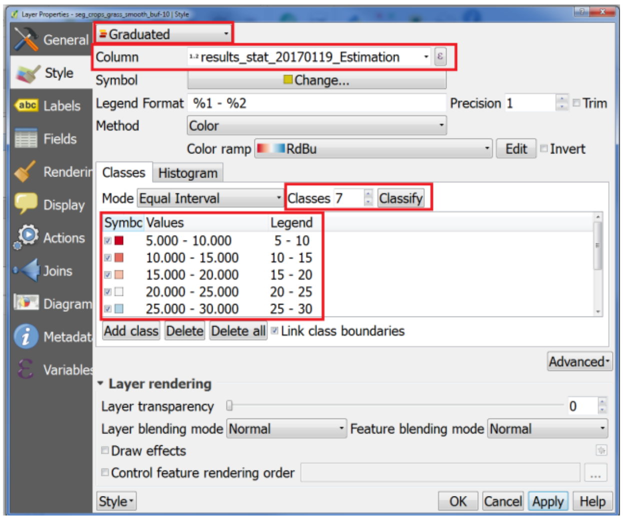
1- Join according to the identifier and viewing maps	➢ Add the estimated moisture values in the attribute table of the vector layer seg_crops_grass_smooth_buff.shp • Import the vector layer seg_crops_grass_smooth_buf.shp and the text file results_20161010.txt. To import the last file, click on « **Add Layer** » ➔ « **Add Delimited Text Layer** » in the menu bar. While importing the text file, make sure that you well specify the delimiter (space) and check the “No Geometry” button as shown in the figure below. 

- Right click on the vector layer seg_crops_grass_smooth_buf-10.shp ➔ « **Properties** » ➔ « **Joins** » ➔ « + »
- In the window that appears, select in « **Join Layer** » the text file results_stat_20160119.txt, choose « DN » in « **Join field** » and « **Target field** »
- Click on « **ok** »
- Open the attribute table of the vector layer to verify that the estimated moisture values are in the attribute table.



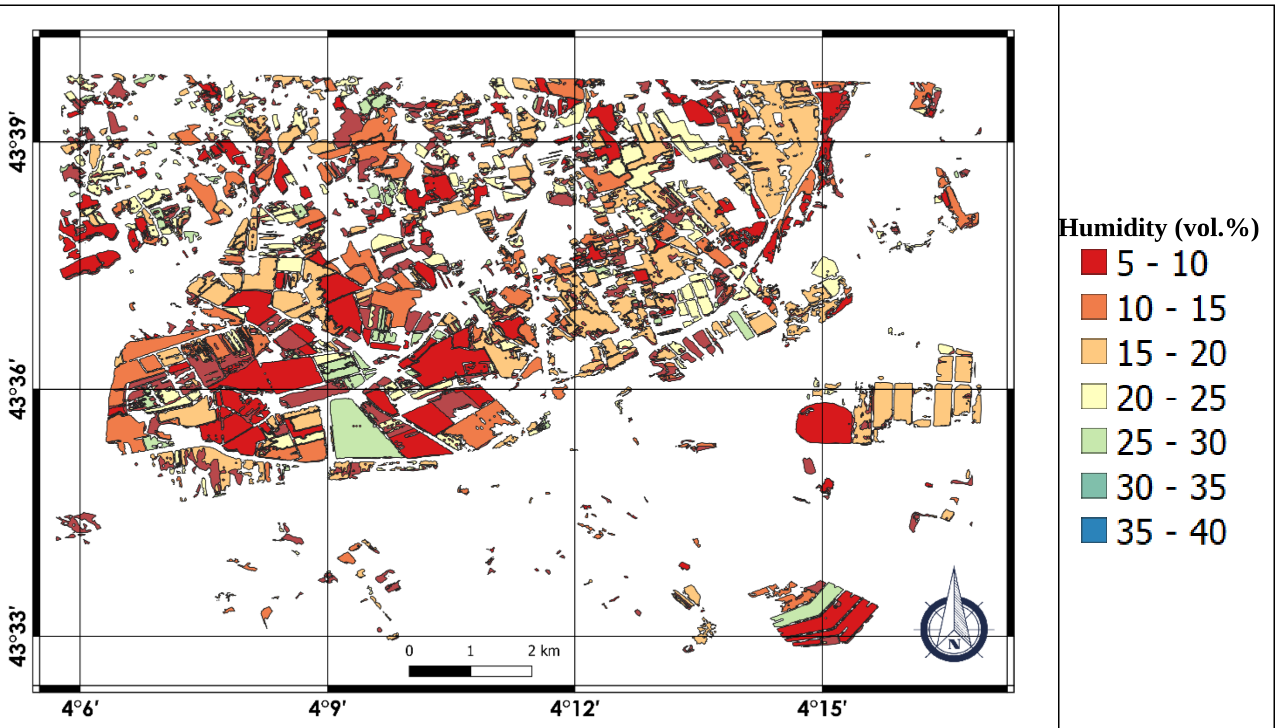
➢ To visualize as a map the soil moisture values estimated for the date 19/01/2017

- Right click on the vector layer seg_crops_grass_smooth_buf.shp ➔ « **Properties** »
- In the window that appears, go to the tab « **style** » and choose the option « **graduated** »
- In « **Column** », choose the column that contains the estimated moisture values for the date 10/10/2016
- In « **Color Ramp** » choose a Color degradation
- In « **Classes** » define 7 classes
- In « **Values** » define the lower and upper bounds of each class. In the figure below, the classes are [5-10], [10-15],…., [35-40] (vol.%)
- Click on « **Ok** »



4.4 Soil moisture maps

This section presents a spatial visualization of the estimated soil moisture values at each spatial unit (polygon). Figure below shows the soil moisture map of the date 10/10/2016. The map of shows that the soil of the study site is dry with moisture values between 5 and 20 vol.%.



(a)