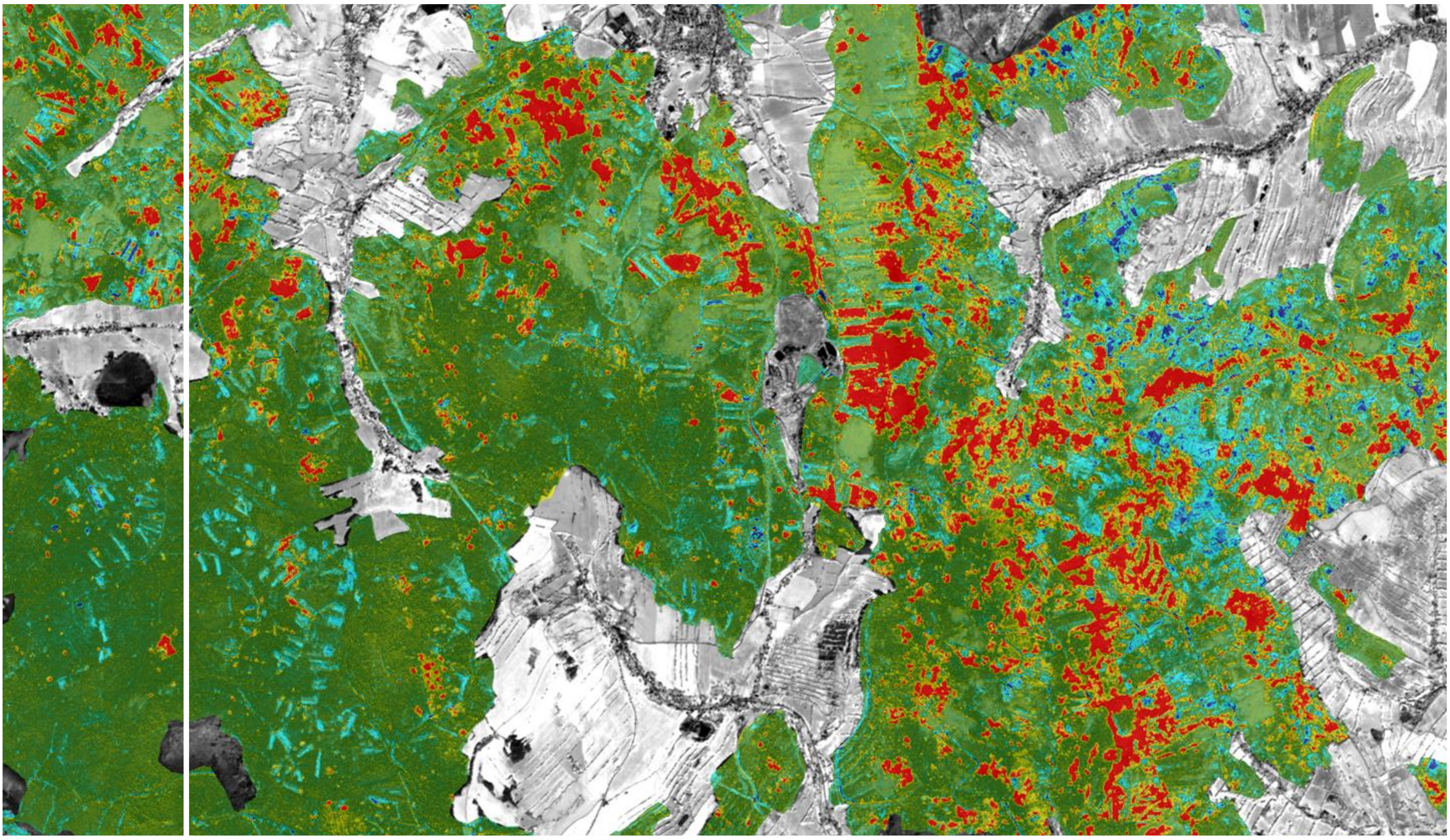

TRAINING KIT – TAT0618

FOREST MONITORING WITH SENTINEL-1, -2, -3
JESENÍKY, CZECH REPUBLIC, 2016-2018

Did you find this material useful?

Authors would be glad to receive your feedback or suggestions and to know how this material was used. Please, contact us on training@rus-coperenicus.eu

Enjoy RUS!

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1 Introduction

The Research and User Support for Sentinel core products (RUS) service provides a free and open scalable platform in a powerful computing environment, hosting a suite of open source toolboxes pre-installed on virtual machines, to handle and process data derived from the Copernicus Sentinel satellites constellation.

Forests destroyed by bark beetle infestation, Credits: silvarium.cz

The health of the forests around the world is declining due to climate change, air pollution and increase in human activities. Remote sensing has been considered an important tool for wide coverage monitoring of forested areas.

Some of the most commonly used techniques include calculation of various Vegetation Indices (VIs) from optical data (such as Sentinel-2 or -3). The VIs are generally calculated as a combination of surface reflectance at two or more wavelengths; they are designed to highlight certain property of the vegetation (Tuominen et al. 2009).

In many areas of the world, the use of the optical data is limited due to persistent cloud cover and SAR sensors are employed to monitor the changes in vegetation or increase the frequency of the observations. The characteristics of optical and SAR sensors are very different and require different processing steps. In this exercise, we will look at both and see how they can help us assess the damage caused by a bark beetle infestation in Jeseníky foothills in the northeast of Czech Republic.

2 Training

Approximate duration of this training session is two hours.

2.1 Data used

- Three Sentinel-1A IW GRDH products acquired in May 2016, 2017 and 2018 [downloadable @ https://scihub.copernicus.eu/]

  S1A_IW_GRDH_1SDV_20180514T050109_20180514T050134_021896_025D35_E395
  S1A_IW_GRDH_1SDV_20170519T050103_20170519T050128_016646_01BA02_07F0
  S1A_IW_GRDH_1SDV_20160524T050046_20160524T050111_011396_01152F_FED2

- One cloud-free Sentinel-2A Level-1C product acquired on 24 May 2016 [downloadable @ https://scihub.copernicus.eu/]

  S2A_OPER_PRD_MSIL1C_PDMC_20160523T143616_R079_V20160523T095404_20160523T095404

- One cloud-free Sentinel-2A Level-2A tile (Tile ID: T33UXR) acquired on 13 May 2018 [downloadable @ https://scihub.copernicus.eu/]

  S2A_MSIL2A_20180513T095031_N0207_R079_T33UXR_20180513T115612

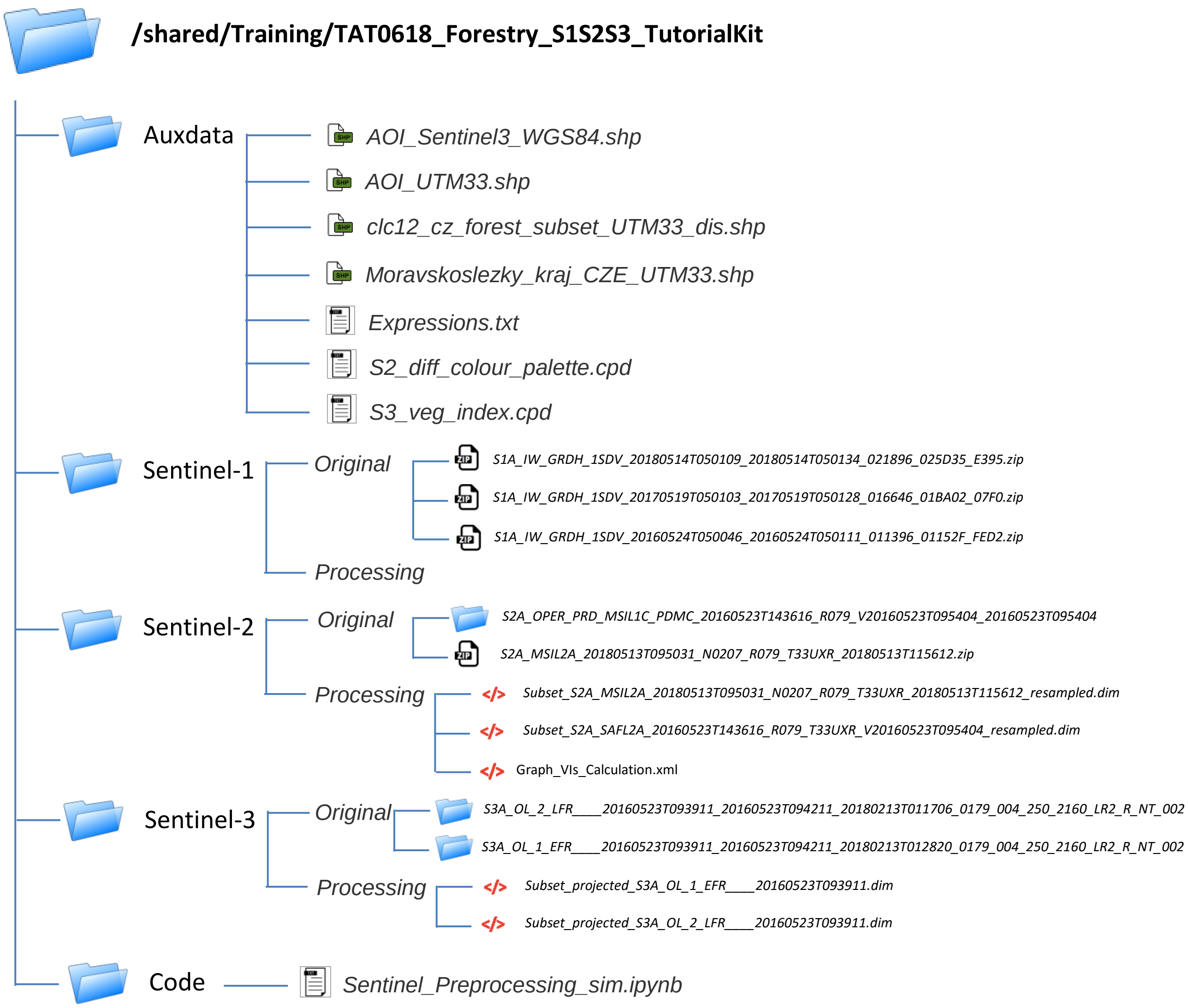
- Two partly cloud-free Sentinel-3A OLCI products (Level-1 EFR and Level-2 LFR) acquired on 13 May 2018 [downloadable @ https://scihub.copernicus.eu/s3]

  S3A_OL_2_LFR____20160523T093911_20160523T094211_20180213T011706_0179_004_250_2160_LR2_R_NT_002
  S3A_OL_1_EFR____20160523T093911_20160523T094211_20180213T012820_0179_004_250_2160_LR2_R_NT_002

2.2 Software in RUS environment

Internet browser, SNAP + Sentinel-1 and -2 Toolbox, QGIS (Extra steps: Sen2Cor, Google Earth)

2.3 Contents of the Exercise folder

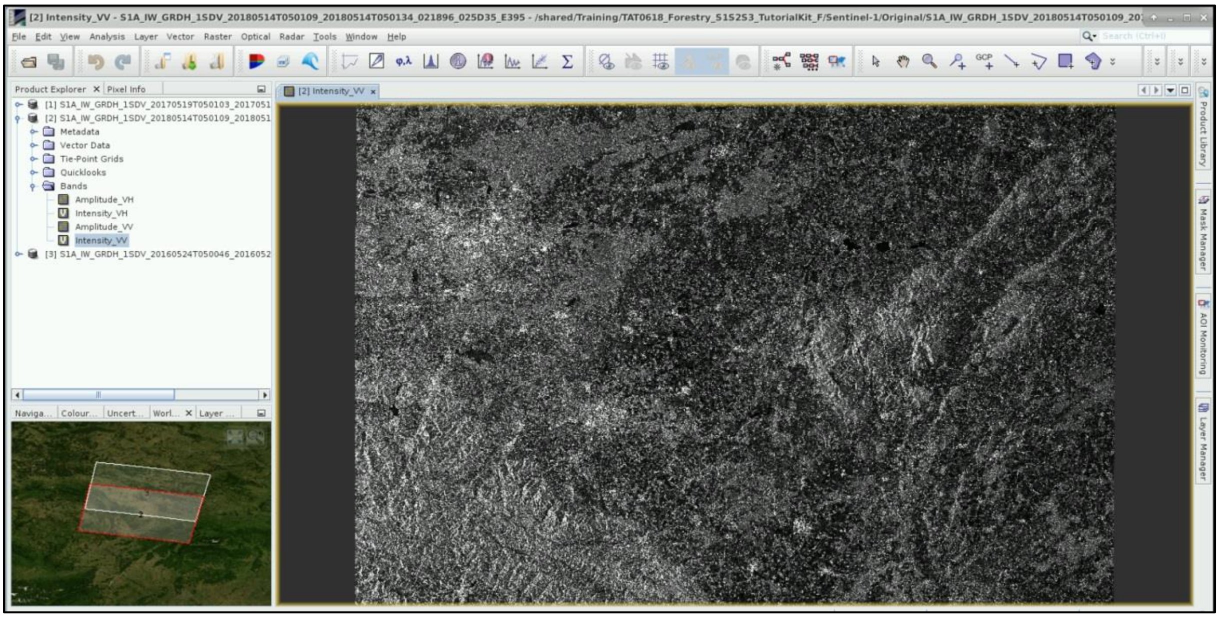


3 Step by step

3.1 *SAR data – Sentinel-1*

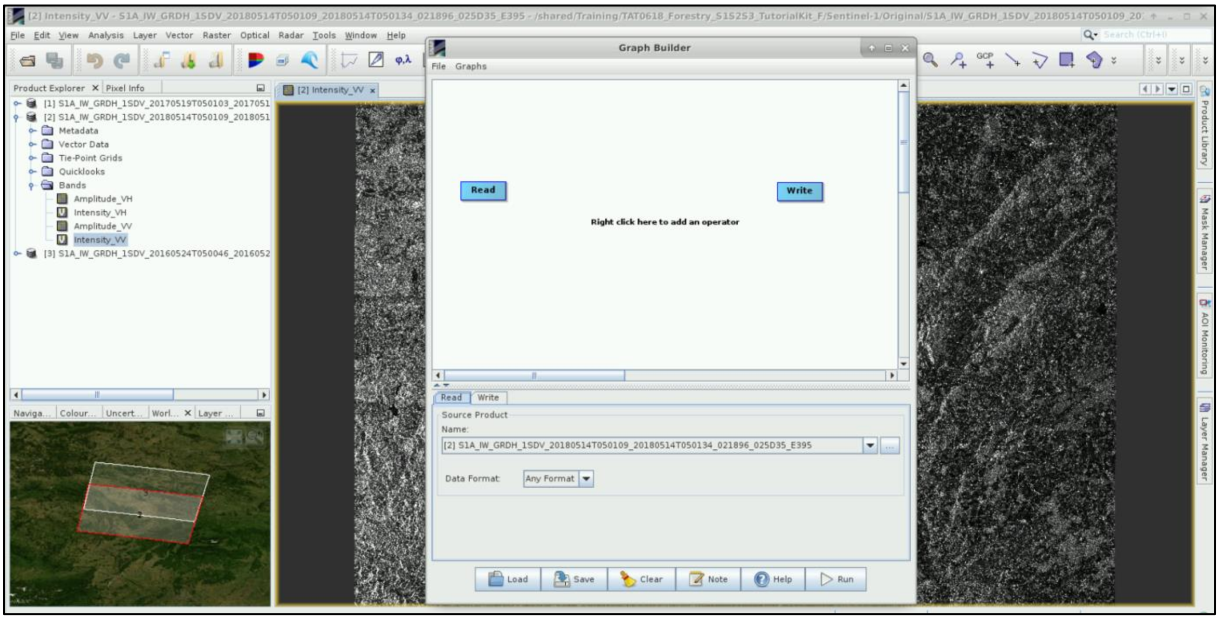
3.1.1 SNAP – open and explore data

Launch SNAP (icon on desktop). When the SNAP window opens click Open product, navigate to */shared/Training/TAT0618_Forestry_S1S2S3_TutorialKit/Sentinel-1/Original* and open the three S1 products. Right-click the product from 2018 and expand the Bands folder. Then, double click the *Intensity_VV* band (for data download, see section **4.1 Data download**).



3.1.2 Build step-by step processing chain

We will now need to pre-process all three images but doing this one-by-one would be quite time consuming. Luckily, we can use the **Batch Processing** tool available in SNAP to process all three images at the same time.

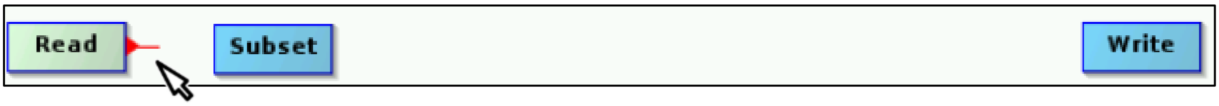


To use the tool, we first need to define the process we want to apply and all its steps. We can do this using the **GraphBuilder** tool. The advantage of the **GraphBuilder** is that no intermediate product will be physically saved, only the end product, which saves valuable disk space.

Go to **Tools -> GraphBuilder**. At the moment, the graph only has two operators: **Read** (to read the input) and **Write** (to write the output).

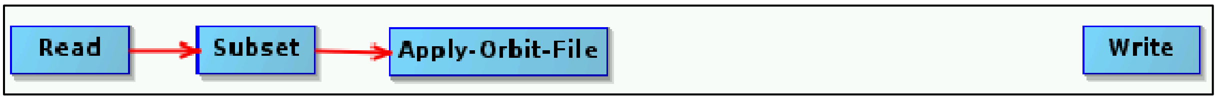
Since our Area of Interest (AOI) is quite small and there is no need to process the whole image, we start by adding a **Subset** operator. To add the operator right-click the white space in the graph builder and go to **Add -> Raster -> Geometric -> Subset.**

A new operator rectangle appears in our graph and a new tab appears below. Now, connect the new **Subset** operator to the **Read** operator by clicking to the right side of the **Read** operator and dragging the red arrow towards the **Subset.**



In the next step, we will update the orbit metadata (See NOTE 1). To add the operator, right-click the white space between existing operators and go to **Add -> Radar -> Apply-Orbit-File.** Connect the new **Apply-Orbit-File** operator with the **Subset** operator.

> NOTE 1: The orbit state vectors provided in the metadata of a SAR product are generally not accurate and can be refined with the precise orbit files, which are available days-to-weeks after the generation of the product. The orbit file provides accurate satellite position and velocity information. Based on this information, the orbit state vectors in the abstract metadata of the product are updated. (*SNAP Help*)



The next step will remove the thermal noise (See NOTE 2). We do this by right-clicking the white space somewhere left of the resample operator and going to **Add -> Radar -> Radiometric -> ThermalNoiseRemoval.** Connect the **ThermalNoiseRemoval** operator with the **Apply-Orbit-File** operator.

> NOTE 2: Thermal noise in SAR imagery is the background energy that is generated by the receiver itself. (*SNAP Help*) It skews the radar reflectivity to towards higher values and hampers the precision of radar reflectivity estimates. Level-1 products provide a noise LUT for each measurement dataset, provided in linear power, which can be used to remove the noise from the product.

Now, we can add the **Calibration** operator. The objective of SAR calibration is to provide imagery in which the pixel values can be directly related to the radar backscatter. Though uncalibrated SAR imagery is sufficient for qualitative use, calibrated SAR images are essential to quantitative use of SAR data (See NOTE 3). To add the operator go to **Add -> Radar -> Radiometric -> Calibration.** Connect the **ThermalNoiseRemoval** operator to the **Calibration** operator.

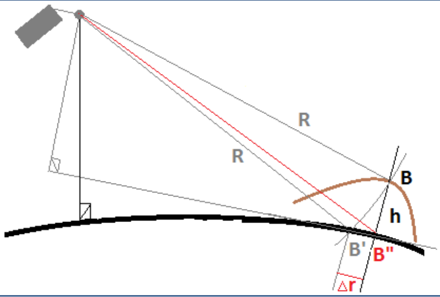
NOTE 3: Typical SAR data processing, which produces level-1 images, does not include radiometric corrections and significant radiometric bias remains. The radiometric correction is necessary for the pixel values to truly represent the radar backscatter of the reflecting surface and therefore for comparison of SAR images acquired with different sensors, or acquired from the same sensor but at different times, in different modes, or processed by different processors. (*SNAP Help*)

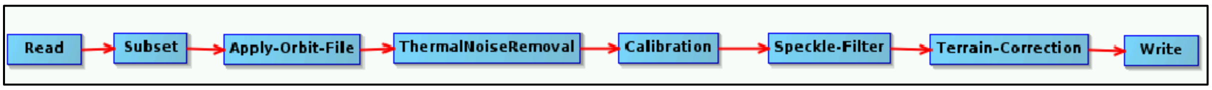
SAR images have inherent salt and pepper like texturing called speckle, which degrade the quality of the image and make interpretation of features more difficult (See NOTE 4). To reduce the speckle effect and smooth the image we apply speckle filter. To add the operator, go to **Radar -> Speckle Filtering -> Speckle-Filter** then connect the **Calibration** operator to it.

NOTE 4: Speckle is caused by random constructive and destructive interference of the de-phased but coherent return waves scattered by the elementary scatters within each resolution cell. Speckle noise reduction can be applied by either spatial filtering or multilook processing. (*SNAP Help*)

Our data are still in radar geometry, moreover due to topographical variations of a scene and the tilt of the satellite sensor, the distances can be distorted in the SAR images. Therefore, as the last step of our pre-processing, we will apply terrain correction to compensate for the distortions and reproject the scene to geographic projection (See NOTE 5). To add the operator, go to **Radar -> Geometric -> Terrain Correction -> Terrain-Correction** then connect the **Calibration** operator to it. At last, connect the **Terrain-Correction** to **Write** operator.

NOTE 5: The geometry of topographical distortions in SAR imagery is shown on the right. Here we can see that point **B** with elevation **h** above the ellipsoid is imaged at position **B'** in SAR image, though its real position is **B"**. The offset **Δr** between **B'** and **B"** exhibits the effect of topographic distortions. *(SNAP Help)*





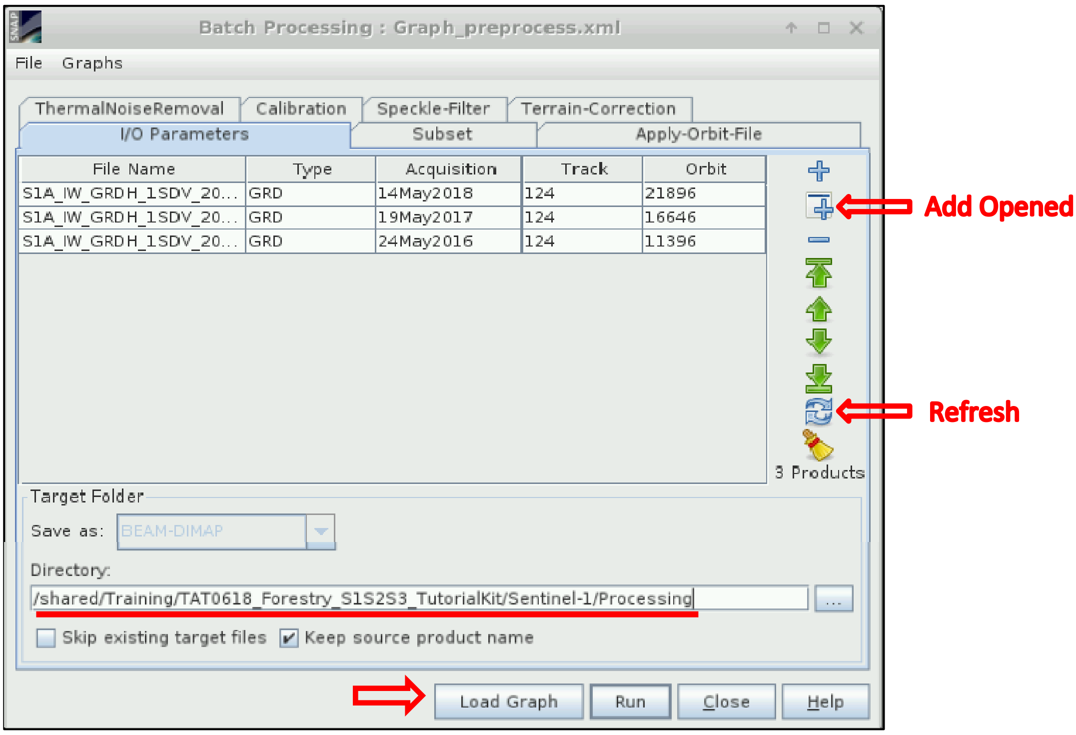
At the moment, do not change anything in the parameter tabs and save the graph as *Graph_preprocess.xml* to: */shared/Training/TAT0618_Forestry_S1S2S3_TutorialKit/Sentinel-1/Processing* by clicking **Save** at the bottom of the window.

3.1.3 OPTION 1 - Batch processing in GUI

In the Product Explorer, we select (highlight) the product with index [1]. Now, we can close the **GraphBuilder** window and open the Batch Processing tool (**Tools -> Batch Processing**).

We will add the opened products by clicking **Add Opened** on the upper right (second icon from the top) and click refresh. Then, we click **Load Graph** at the bottom of the window, navigate to our saved graph, and open it. We see that new tabs have appeared at the top of window corresponding to our operators with the exception of **Write**; this is correct, as these parameters will be set in the **I/O Parameters** tab.

In the **I/O Parameters** tab set directory to:
/shared/Training/TAT0618_Forestry_S1S2S3_TutorialKit/Sentinel-1/Processing.

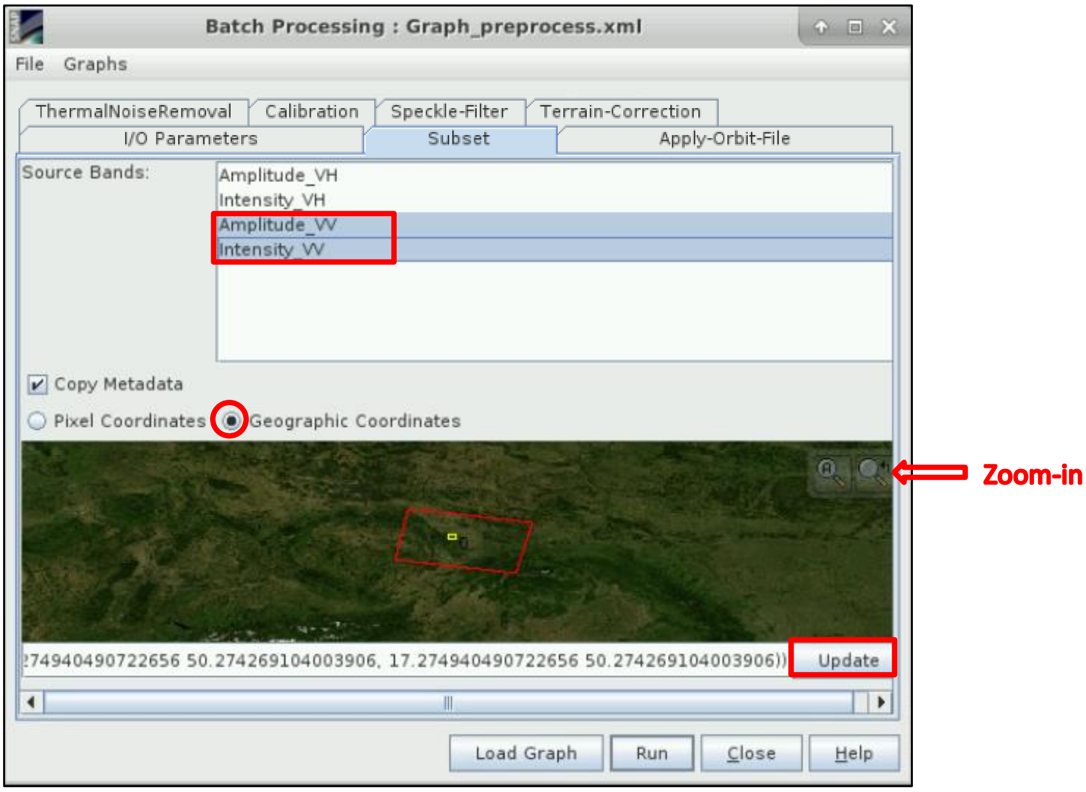


Now, let's set the parameters. In the **Subset** tab, press **Shift** and select bands *Amplitude_VV* and *Intensity_VV* then click to select the **Geographic Coordinates** option and paste the area of interest definition in WKT (well know text) format to the text window below the map.

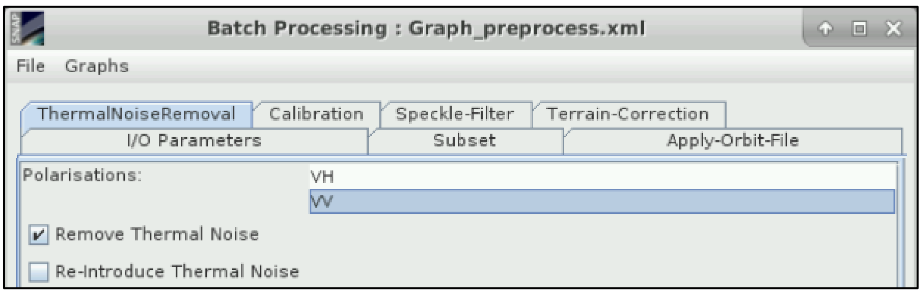
```
POLYGON ((17.27494 50.27427, 17.52966 50.26901, 17.52134 50.11134, 17.26746 50.11658, 17.27494 50.27427))
```

TIP: All expressions you will be using during this tutorial are available to copy-paste from the ***Expressions.txt*** file in */shared/Training/TAT0618_Forestry_S1S2S3_TutorialKit/Auxdata*

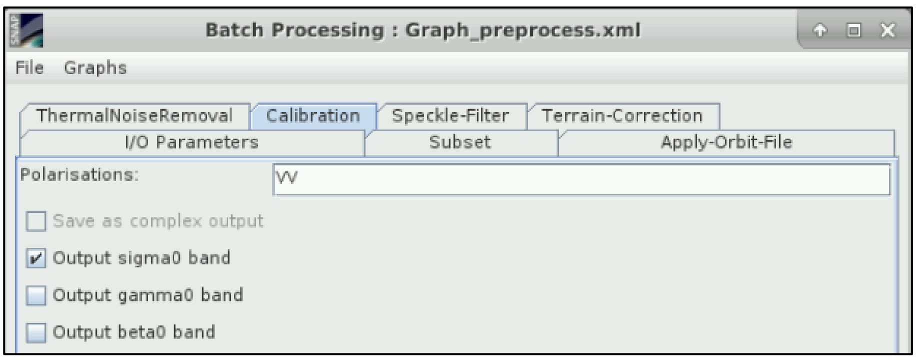
Click **Update** and then click the **Zoom-in** icon to see your subset on the map.



In **Apply-Orbit-File** tab, we can accept the default settings. In the **ThermalNoiseRemoval** tab select VH polarization and make sure that “Remove Thermal Noise” option is selected.

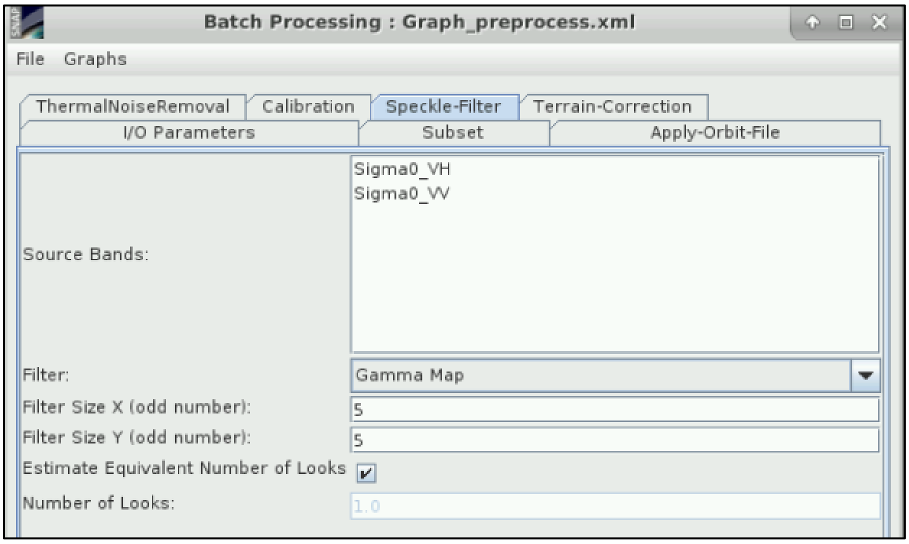


In the **Calibration** tab we will also accept all default settings.



In the **Speckle Filter** tab, set:

Filter: Gamma Map
Filter size X: 5
Filter Size Y: 5

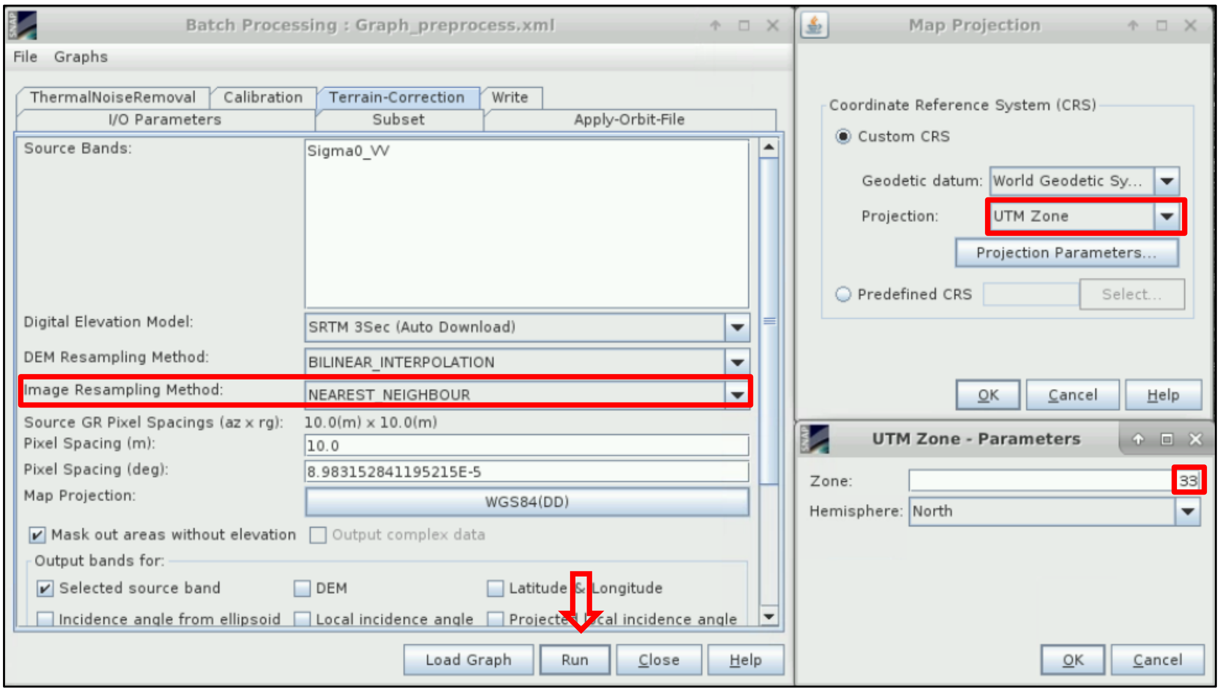


In the **Terrain-Correction** tab set:

Image Resampling Method -> **Nearest Neighbour**.

Map Projection -> Custom CRS: UTM Zone -> Click on **Projection Parameters…** Set **Zone** to **33**.

Leave all the other default settings.



Finally, click **Run** to pre-process our images.

Approximate processing time: 3 minutes depending on machine

Now, you should have three new products in the **Product Explorer**. Select the original products [1-3], right-click and click **Close 3 Products**.

3.1.4 OPTION 2 - Batch processing in using GPT and Python (Jupyter Notebook)

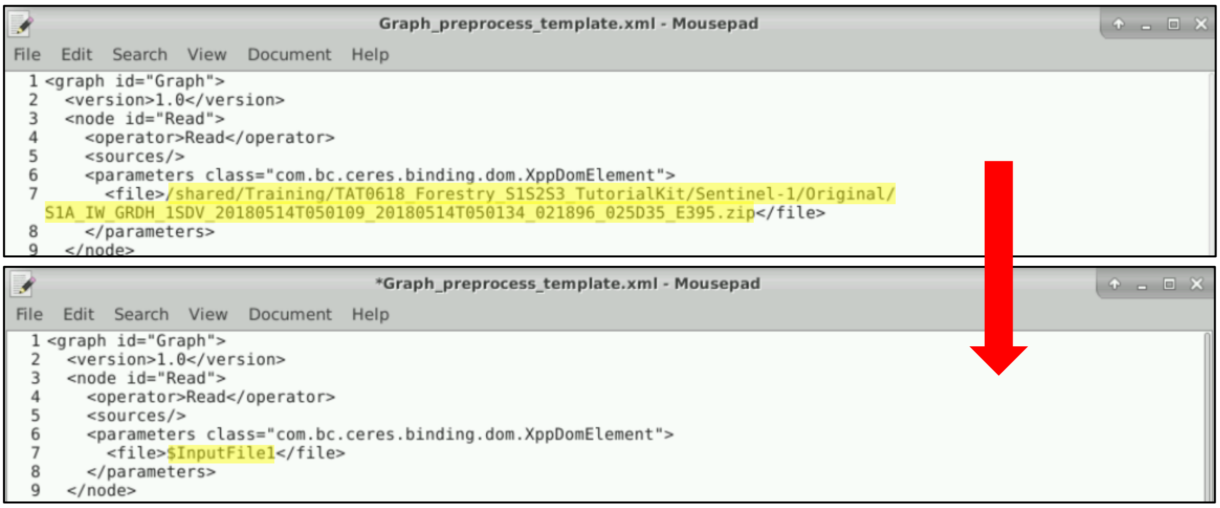
To use this method we must first prepare graph template file, where all parameters will be pre-set except the input and output file path and name. The Graph Builder window should still be open or we can reopen it and load the Graph_preprocess.xml file we have saved in the previous step. Now, we will set all the processing parameters in the tabs below the graph. For the parameters - Subset, Apply Orbit File, ThermalNoiseRemoval, Calibration and Terrain Correction - see the section above. Leave the Read and Write tabs unchanged.

Save the graph (**Save** button at the bottom of the window) with filled in parameters as *Graph_preprocess_template.xml* to: */shared/Training/TAT0618_Forestry_S1S2S3_TutorialKit/Sentinel-1/Processing*

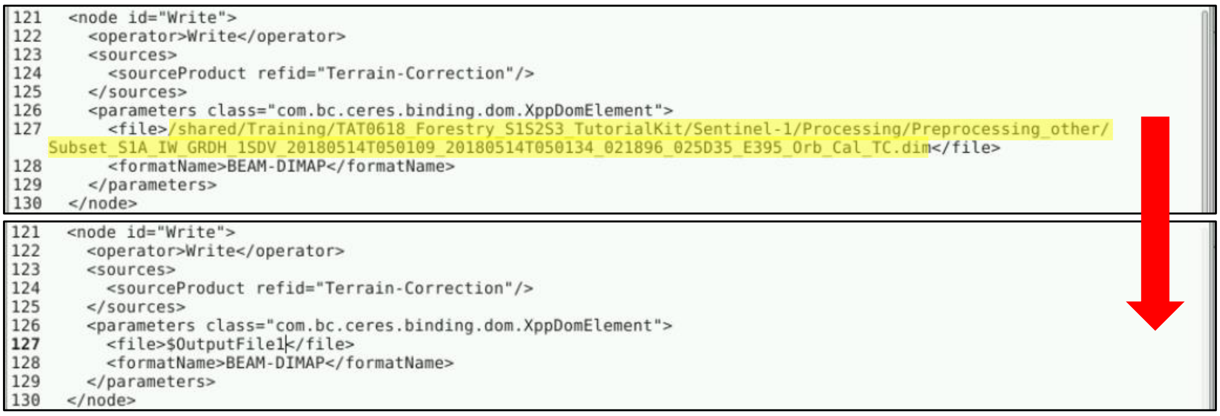
Then, in the file explorer, (outside SNAP) navigate to the folder and right-click on the saved file. Select **Open with** -> **Open with "Mousepad".** When the file is open, go to **View -> Line Numbers** for easier navigation.

Now, we need to replace the input and output file path with a pattern that will allow the python code to recognize and replace it within the template file before processing.

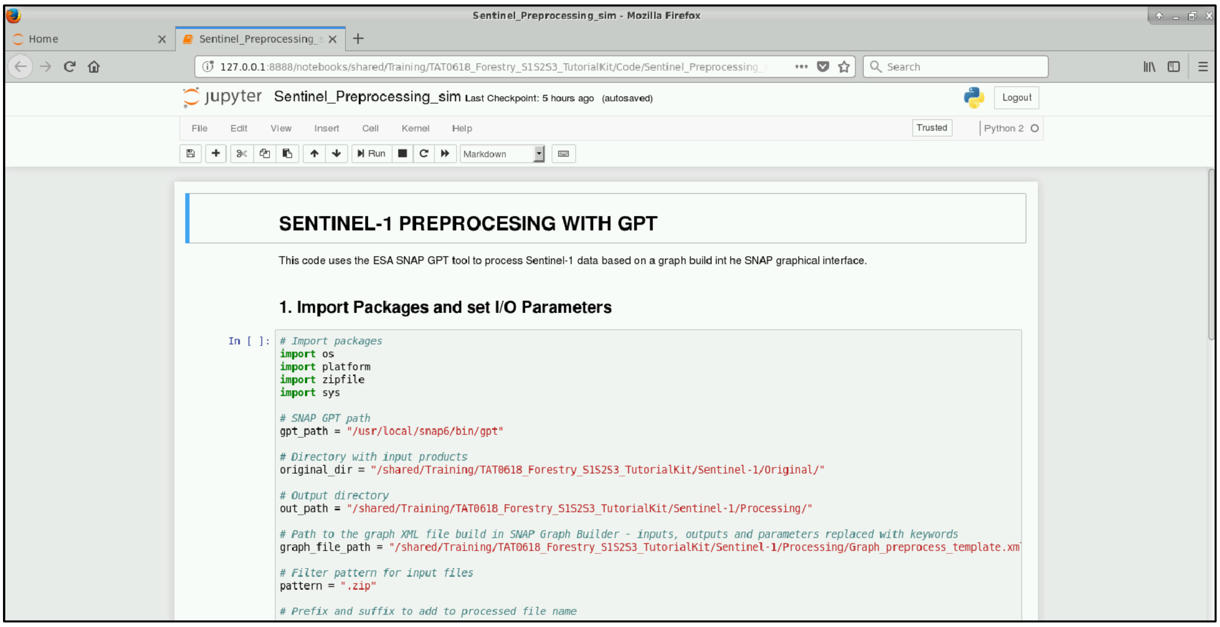
In line 7 (in the node with id='Read') replace the path to input file with (between <file> and </file>): $InputFile



In line 127 (in the node with id='Write') replace the path to output file with (between <file> and </file>): $OutputFile



Save the file and close it. Then go to the Desktop and open the Jupyter Notebook application. A command line terminal will open and then a Firefox browser window will open with a home folder directory. In the browser, navigate to */shared/Training/TAT0618_Forestry_S1S2S3_TutorialKit/Code* and double click the *Sentinel_Preprocessing_sim.ipynb* to open it.



In section **1. Import Packages and set I/O Parameters** (first cell), all the necessary inputs are defined. The parameters have been predefined for you but you should check them again to make sure and to understand them better.

SNAP GPT path – do not change this parameter it provides the code with the path to the GPT installation.

```
gpt_path = "/usr/local/snap6/bin/gpt"
```

Directory with input products - path to the directory where the downloaded Sentinel-1 products are placed.

```
original_dir = "/shared/Training/TAT0618_Forestry_S1S2S3_TutorialKit/Sentinel-1/Processing"
```

Path to the graph template XML file we have edited

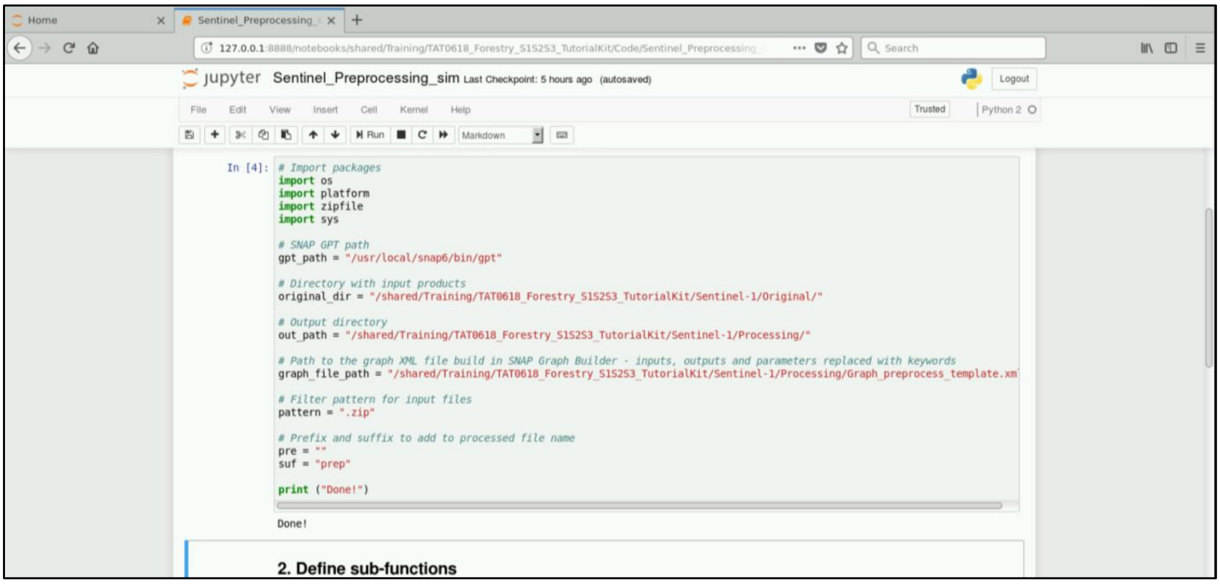
```
graph_file_path = "/shared/Training/TAT0618_Forestry_S1S2S3_TutorialKit/Sentinel-1/Processing/Graph preprocess template.xml"
```

Our input folder only contains zipped S1 products; therefore, the filter pattern is not strictly necessary. It is used to filer files, which should be processed. We can also define the prefix and/or suffix to add to the original file name.

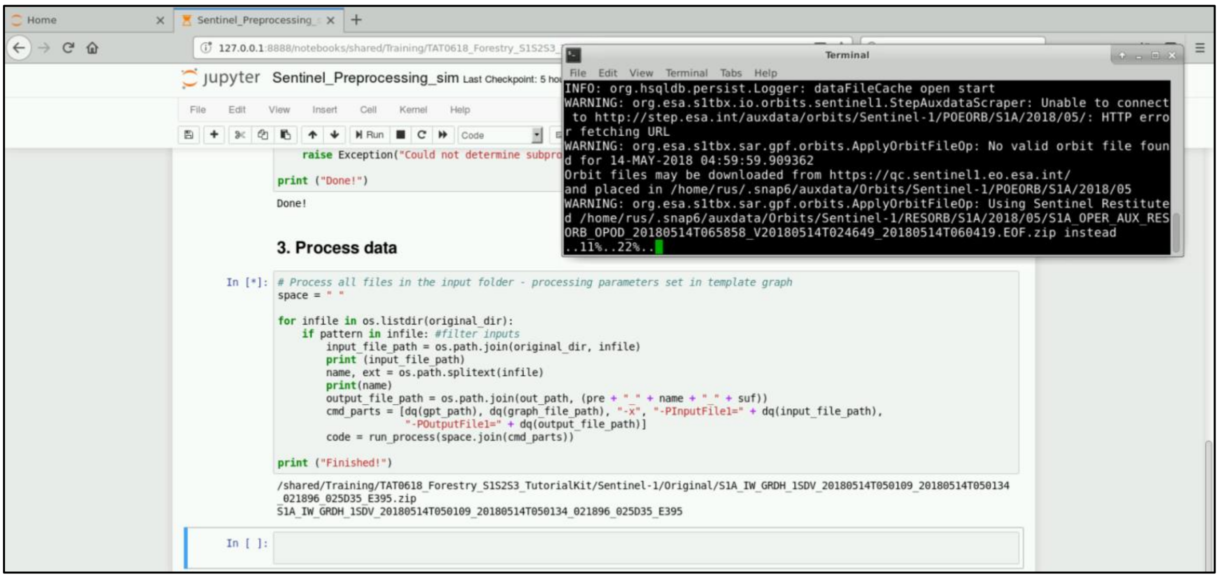
Now we can run the process. Click on the **In [1]** (or around it but not inside the cell), a blue line will appear next to the cell then click **Shift+Enter** to execute the cell (See TIP).

TIP: Check the available keyboard shortcuts. You can find them in **Help -> Keyboard Shortcuts**.

If the cell was executed successfully a “Done!” will be printed below it and the next cell will be highlighted.



Press the **Shift+Enter** again to move to the next code cell. The second code cell (**2. Define Sub-functions**) contains sub-functions necessary to run the process. Do not change anything and press **Shift+Enter** to execute the cell and again to move the highlight to the last code cell. The last cell (**3. Process data**) is responsible for processing the data. Again, do not change anything and press **Shift+Enter.**



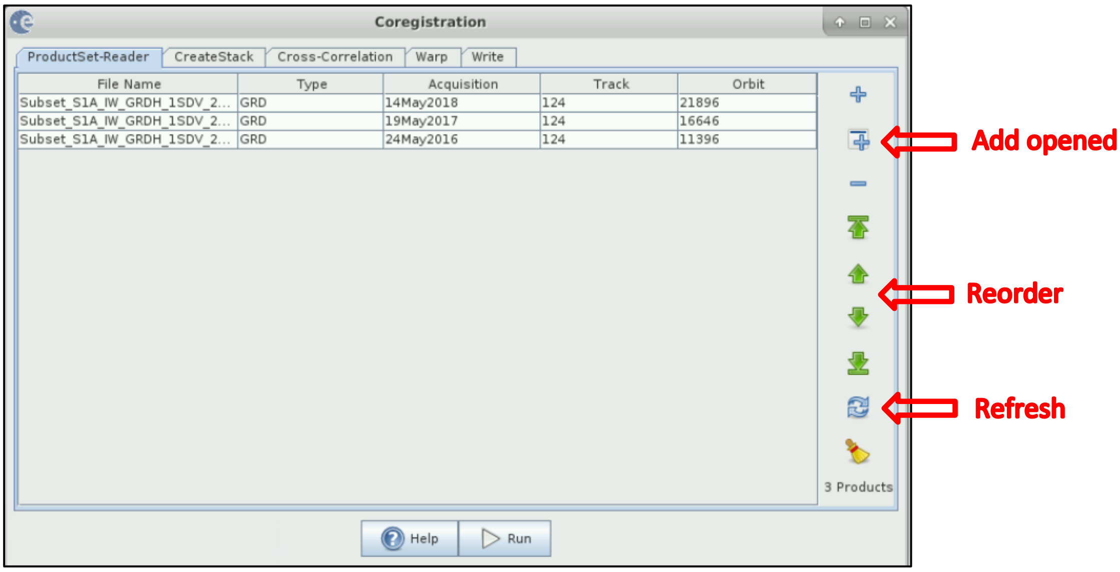
All the files in the *Original* folder will be processed one-by-one. You can monitor the process in the Terminal. When all the input files are processed, "Finished!" will be printed below the cell.

Go back to the SNAP window and open the processed products. Select the original products [1-3], right-click and click **Close 3 Products**.

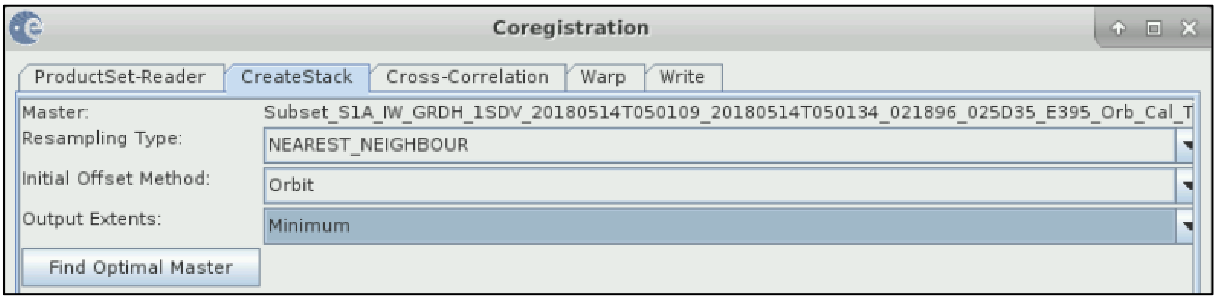
3.1.5 Coregistration

Now, we need to add all our pre-processed products to a single coregistered stack so we can visualize the changes in backscatter. Unfortunately, coregistration is rather heavy and time consuming, so be patient.

Go to **Radar -> Coregistration**. We will add the opened products by clicking **Add Opened** on the upper right (second icon from the top) and click **Refresh**. Use the arrows to order products by date from 2018 to 2016.

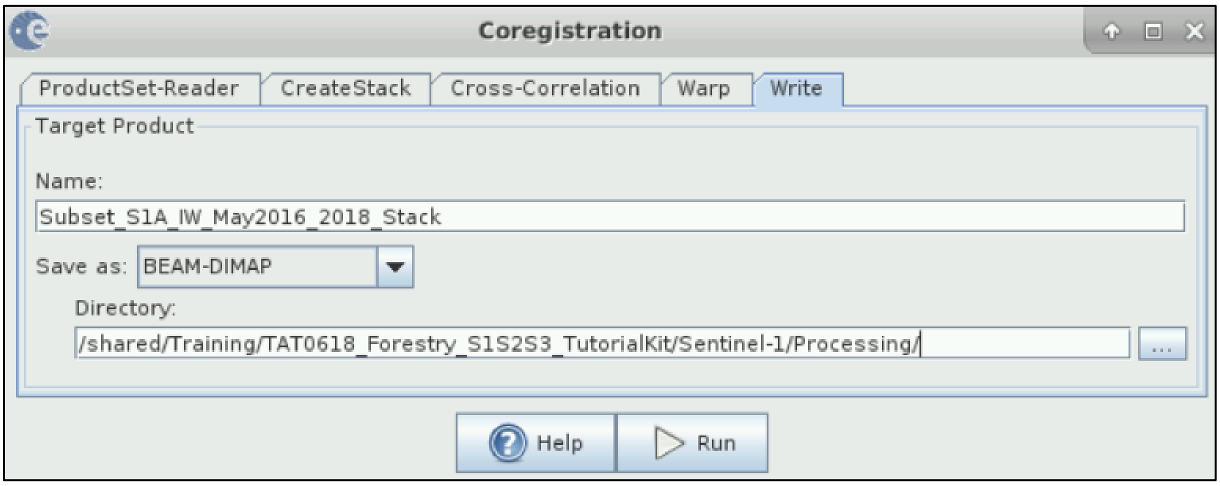


In the **CreateStack** tab, set **Resampling Type** as **Nearest Neighbour** and set **Output Extents** to **Minimum.**



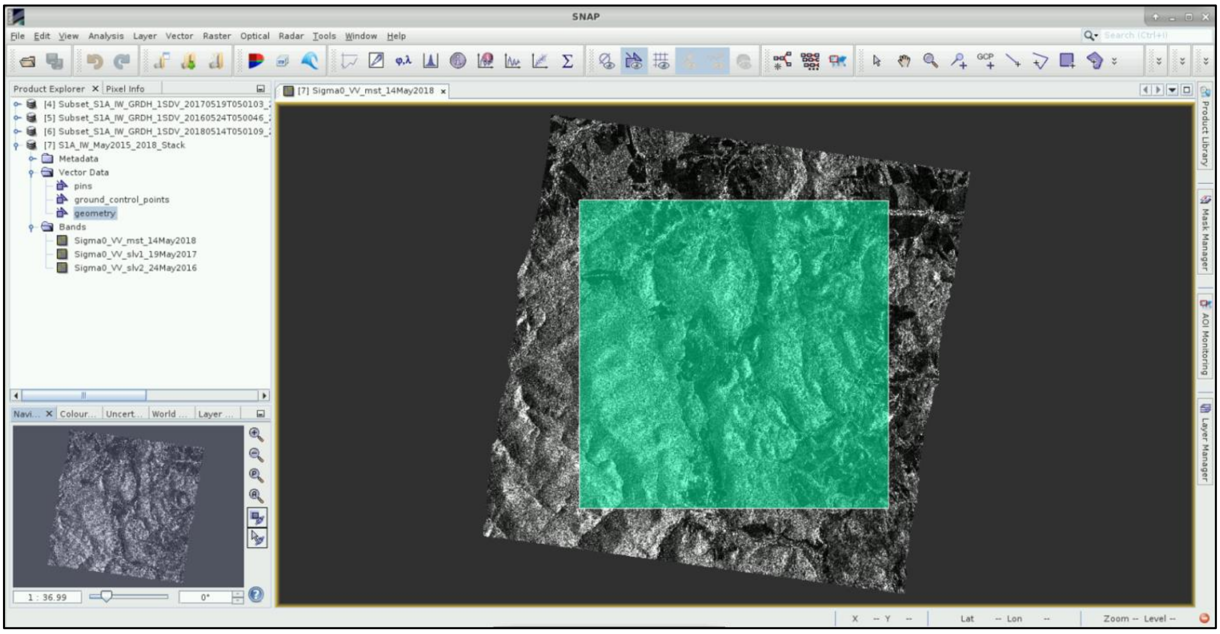
In the **Cross-Correlation** and **Warp** tabs, leave the defaults.

In Write tab, change the name to S1A_IW_May2016_2018_Stack and make sure that the output directory is: */shared/Training/TAT0618_Forestry_S1S2S3_TutorialKit/Sentinel-1/Processing*



Click **Run**. *Approximate processing time: 3.5 minutes depending on machine*

A new product [7] has appeared in the Product Explorer. Expand it and have look at the contents of the *Bands* folder. It contains three bands each corresponding to one acquisition date. Double click the first band to open it in View.

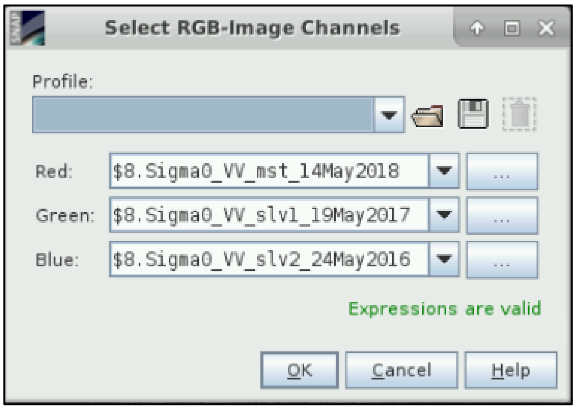


We have selected the first subset larger than our final subset (marked in green above) because we have applied it before the terrain correction in order to minimize processing time. However, to ensure the exact extent that we want, we should only perform the subset after the terrain correction when the data are converted from the SAR geometry to a geographic projection. Above you can see the final AOI indicated in green. We will use a simple subset again to acquire or final AOI. Go to **Raster -> Subset**.

In the **Spatial Subset** tab click on the **Geo Coordinates** and set:

North latitude bound: 50.26272
West longitude bound: 17.29581
South latitude bound: 50.12339
East longitude bound: 17.49995

Click **OK**. New product [8] has appeared in the product explorer. Right-click the product and go to **Open RGB Image Window**.

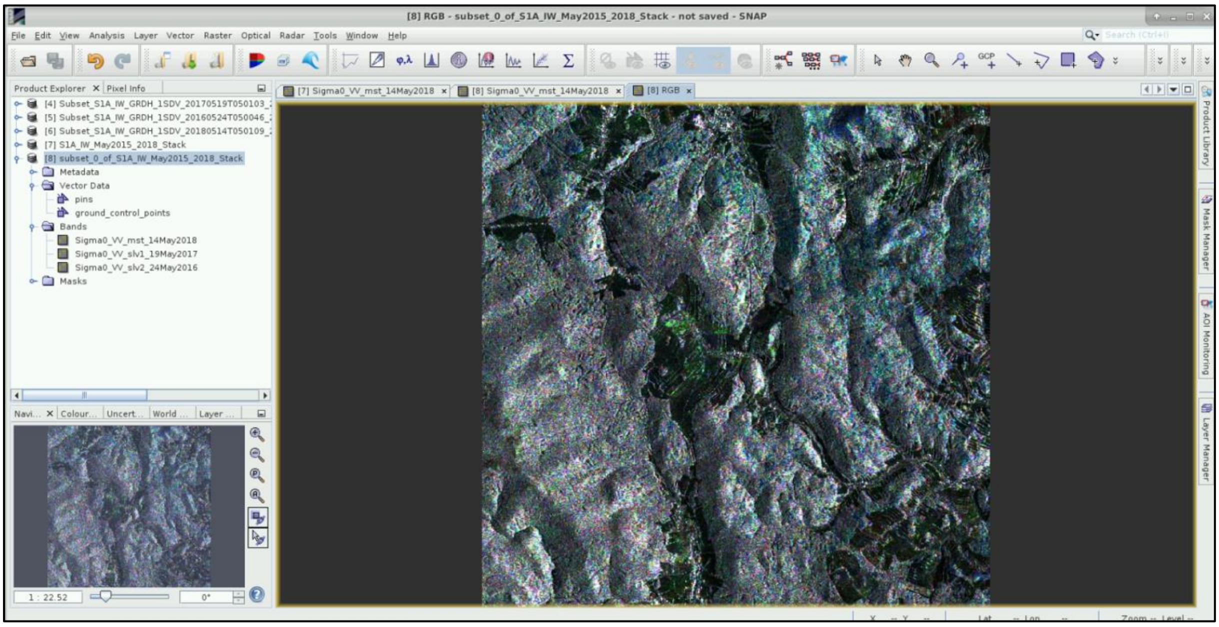


Set:

Red: $8.Sigma0_VV_mst_14May2018

Green: $8.Sigma0_VV_slv1_19May2017

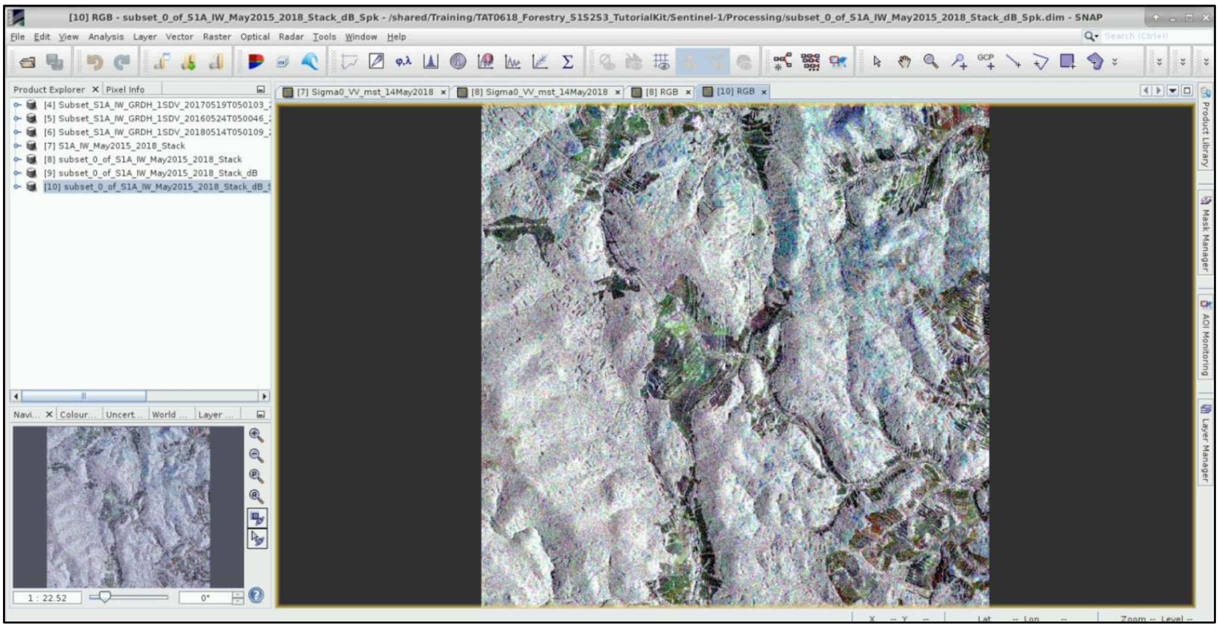
Blue: $8.Sigma0_VV_slv2_24May2016



3.1.6 Conversion to dB and mask

To enhance the contrast, let us convert the data to decibel. Go to **Raster -> Data Conversion -> Convert bands to/from dB**. Set the source to the subset product with index number [8] and output Directory: */shared/Training/TAT0618_Forestry_S1S2S3_TutorialKit/Sentinel-1/Processing*

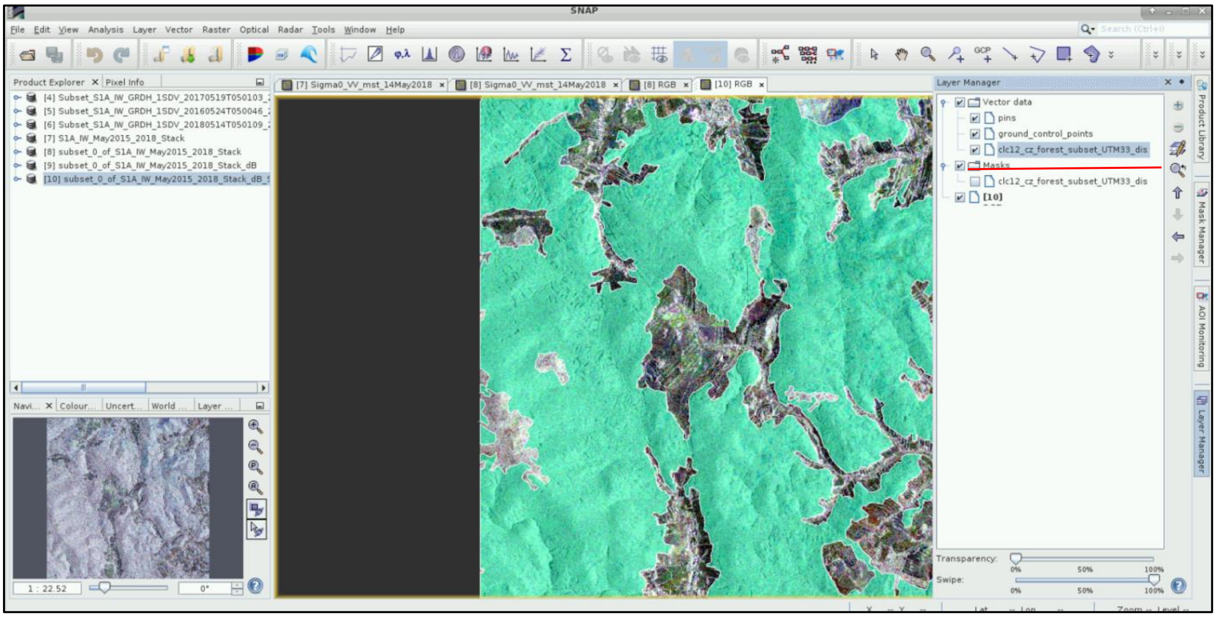
Leave the other default parameters and click **Run**. A new product [9] was created. Open RGB view of the newly created product.



Next, we need to assign the NoData value. Go to **Raster -> Data Conversion -> Set No-Data Value**. Select ☑ **No Data Value Used**, and set **No Data Value** to 0.0. Click yes to **Overwrite the existing file**.

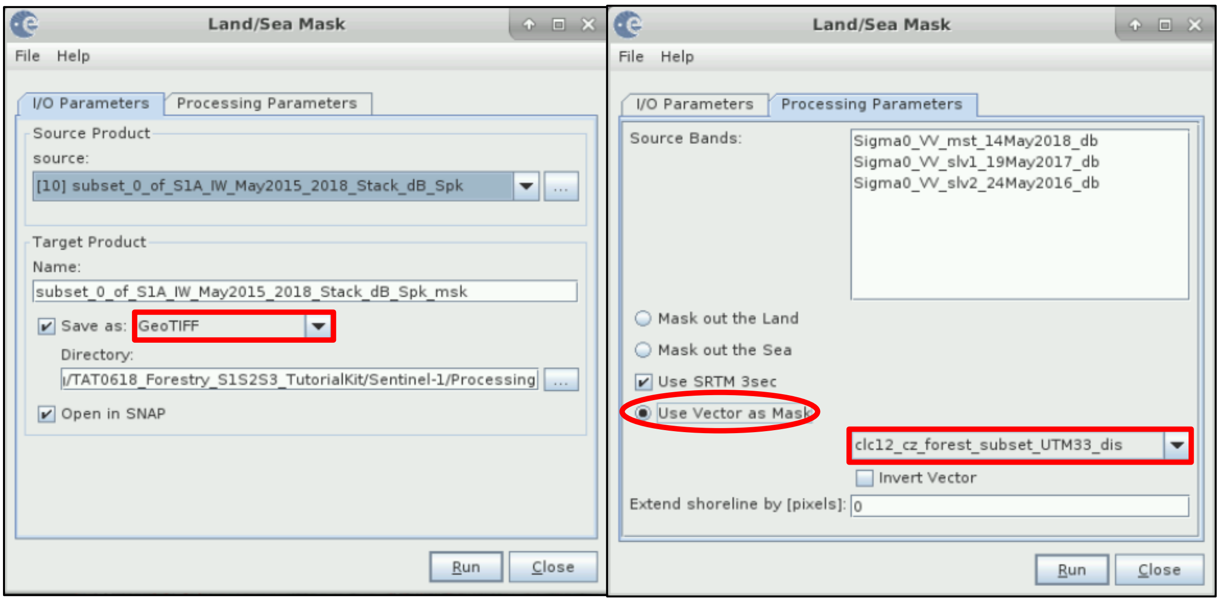
In Product Explorer, click on the last product [9] to highlight it, then go to **Vector -> Import -> ESRI Shapefile**. Navigate to */shared/Training/TAT0618_Forestry_S1S2S3_TutorialKit/Auxdata* and open the *clc12_cz_forest_subset_UTM33_dis.shp.*

A vector overlay appeared over the view; we could edit the appearance by going to **Layer Manager** (on the left side panel or in **View -> Tool Windows**). In the **Layer Manager,** expand the **Vector data** folder and select *clc12_cz_forest_subset_UTM33_*dis and click on **Layer Editor**.



The vector layer presents forest areas. It was derived from the Corine Land Cover 2012 for Czech Republic (provided by the CENIA - Czech Environmental Information Agency) by aggregating classes 311 to 313. The RGB composite is a good indicator of forest damage – change in backscatter. Let us mask the out the non-forest areas and save the layer as GeoTIFF so we can inspect it in QGIS over aerial orthophoto. Go to **Raster -> Masks -> Land/Water Mask**.

In the **I/O Parameters,** set: **Save as:** GeoTIFF.
In the **Processing Parameters,** tab set: **Use Vector as Mask**. Then click **Run.**

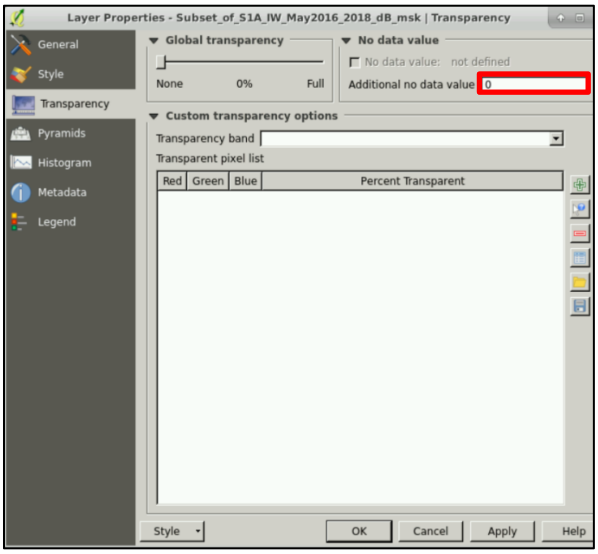


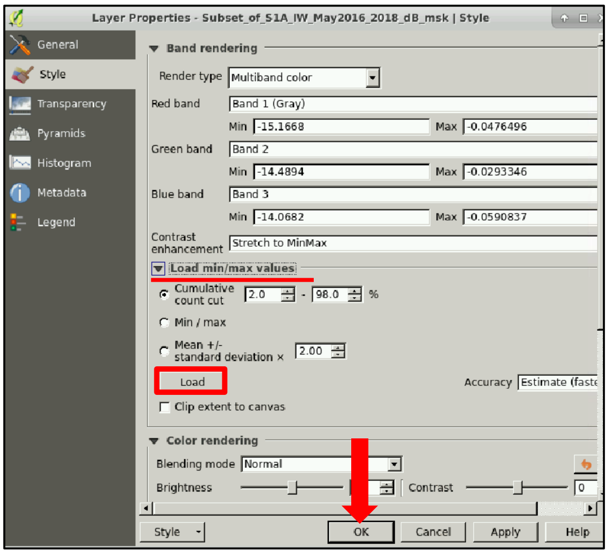
3.1.7 Visualization (QGIS) and comparison

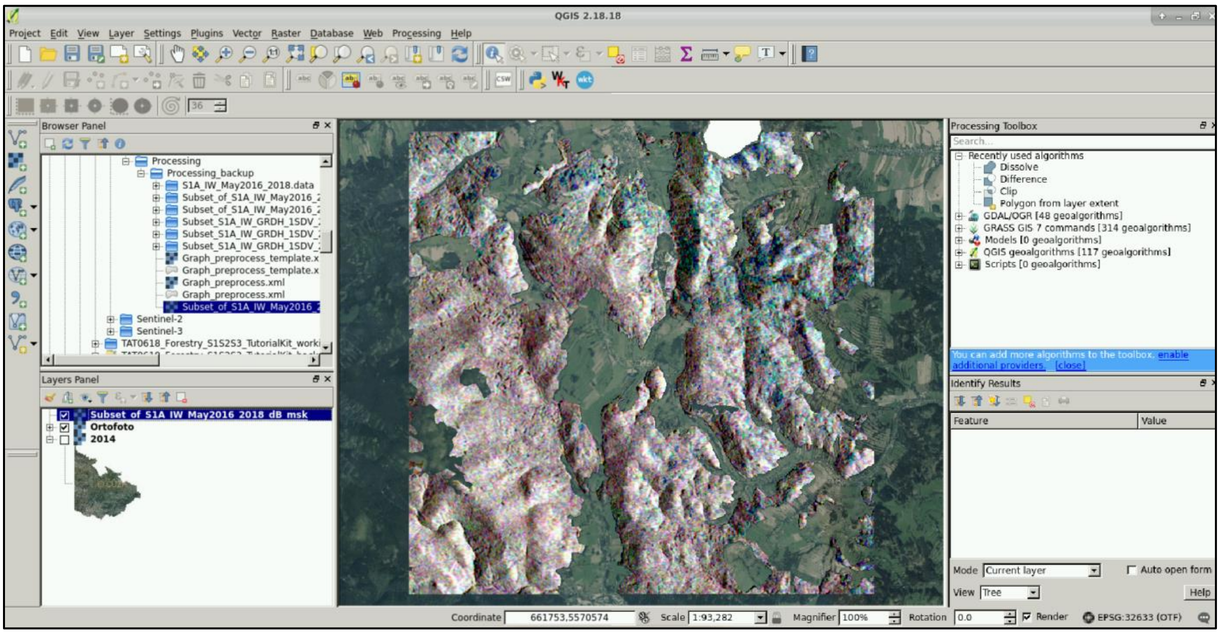
Let's inspect the product in QGIS. Go to *Application -> Processing -> QGIS Desktop*. Click on the **Add Raster Layer** button located in the left panel ( ), navigate to:

/shared/Training/TAT0618_Forestry_S1S2S3_TutorialKit/Sentinel-1/Processing select the saved *Subset_S1A_IW_May2016_2018_Stack_dB_msk.tif* and click **Open**.

Right-click the *Subset_S1A_IW_May2016_2018_Stack_dB_msk* in the **Layers Panel** and then go to Properties - in the **Transparency** tab set: **Additional no data value:** 0







Disturbed areas appear in bluish colours. In this case, the method cannot be confidently used to delineate the structurally damaged areas but can serve as an indicator of the locations (See TIP).

TIP: The orthophoto can be added to your QGIS project as WMS service provided by the Czech National Geoportal INSPIRE. In the **Browser Panel**, scroll down and right-click at the **WMS**. Go to **New Connection…** In the Connection details set:

Name: Orthophoto_2016

URL: http://geoportal.cuzk.cz/WMS_ORTOFOTO_PUB/WMService.aspx

Click OK. Then add another WMS with

Name: Archive_orthophoto

URL: http://geoportal.cuzk.cz/WMS_ORTOFOTO_ARCHIV/WMService.asp?

3.2 *Optical data – Sentinel-2 MSI*

3.2.1 SNAP – open and explore data

Launch SNAP (icon on desktop). When the SNAP window opens click Open product, navigate to: */shared/Training/TAT0618_Forestry_S1S2S3_TutorialKit/Sentinel-2/Original*

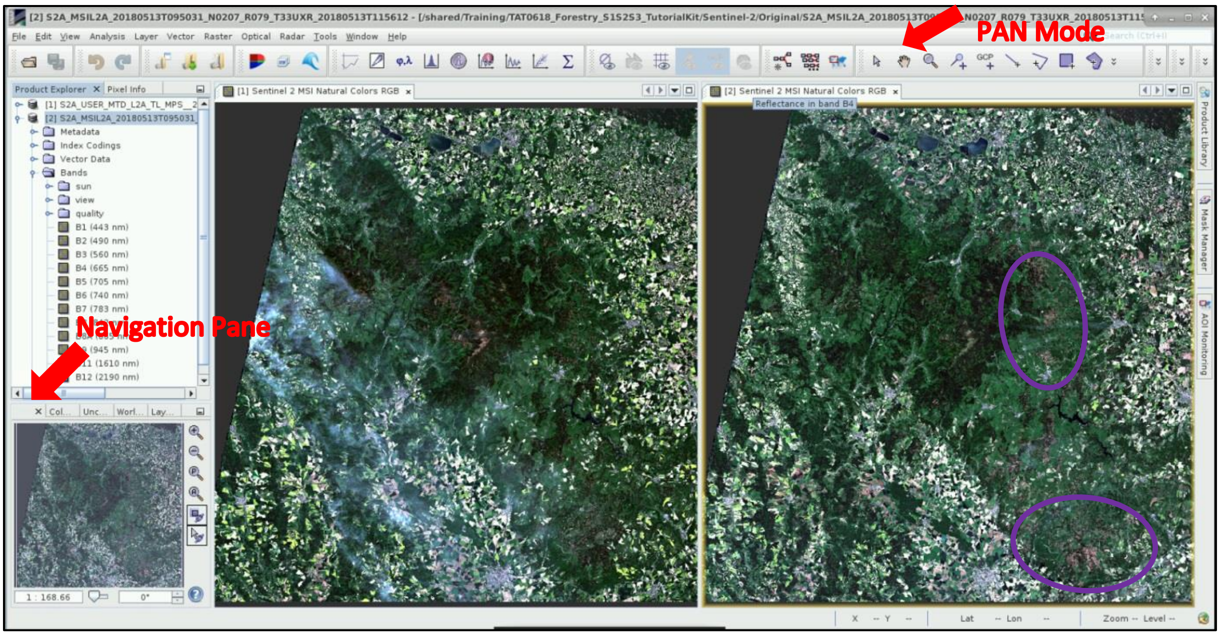
Open the S2 product from 2018. Then open the Level-2A product from 2016 by navigating inside the folder to *GRANULE/S2A_USER_MSI_L2A_TL_MPS__20160523T133345_A004795_T33UXR_N02.00* and selecting the .xml file (see NOTE 6).

> NOTE 6: The product from 2016 we have downloaded is a Level-1C product - not atmospherically corrected (for data download, see section **4.1 Data download**). Before opening the product in SNAP we will run the atmospheric correction using the Sen2Cor algorithm. The steps are described in section **4.2 Atmospheric correction for S2**.

Right-click the product and click **Open RGB image window,** a new window will open. From the drop down menu select:

Profile: Sentinel 2 MSI Natural Colors

Investigate the change visually in areas indicated by purple ellipses below.

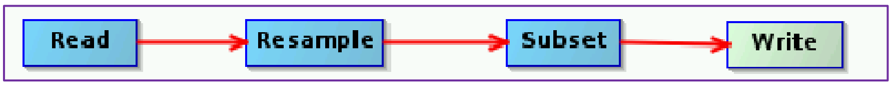


3.2.2 Resample & subset

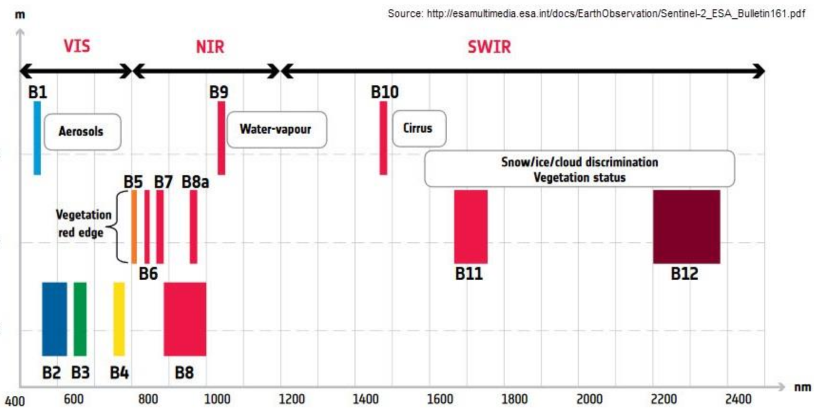
To avoid processing the datasets one by one we will use the **Batch processing** and **Graph Builder again**. Go to **Tools -> GraphBuilder**. At the moment, the graph only has two operators: **Read** (to read the input) and **Write** (to write the output).

The 13 bands in Sentinel-2 products do not all have the same resolution (= size, see NOTE 7). Many operators in SNAP toolbox do not support products with bands of different sizes, so first we need to resample the bands to equal resolution. Right-click on the white space between the operators and go to **Add -> Raster -> Geometric -> Resample** (See NOTE 8).

Then, we need to subset our data to our area of interest (AOI). Go to **Add -> Raster -> Geometric -> Subset.** Then right-click again and go to **Connect Graph.**



NOTE 7: The input product contains 13 spectral bands in three different spatial resolutions (The surface area measured on the ground and represented by an individual pixel). When we open the RGB view all our input bands have 20 m resolution, however, the view is displayed in the full 10 m resolution.

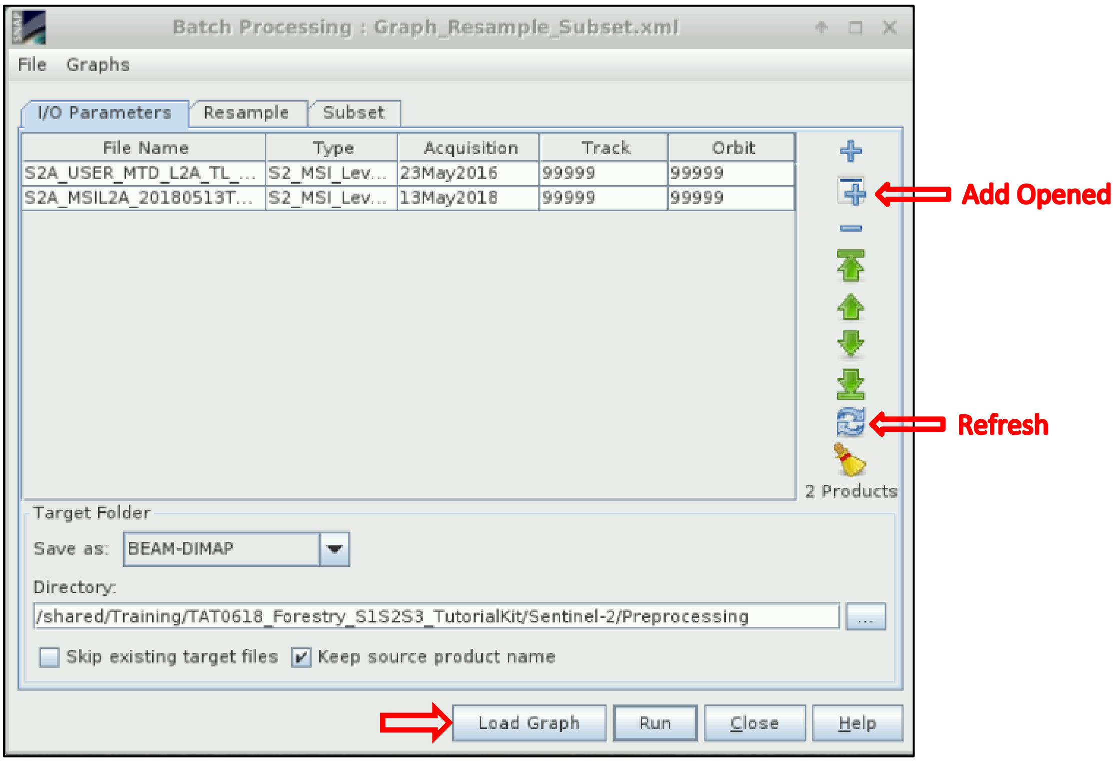


Credits: ESA 2015

NOTE 8: The resampling product appears in the Product explorer but it is not physically saved. Therefore, it will be lost if you close it or if you close the source product.

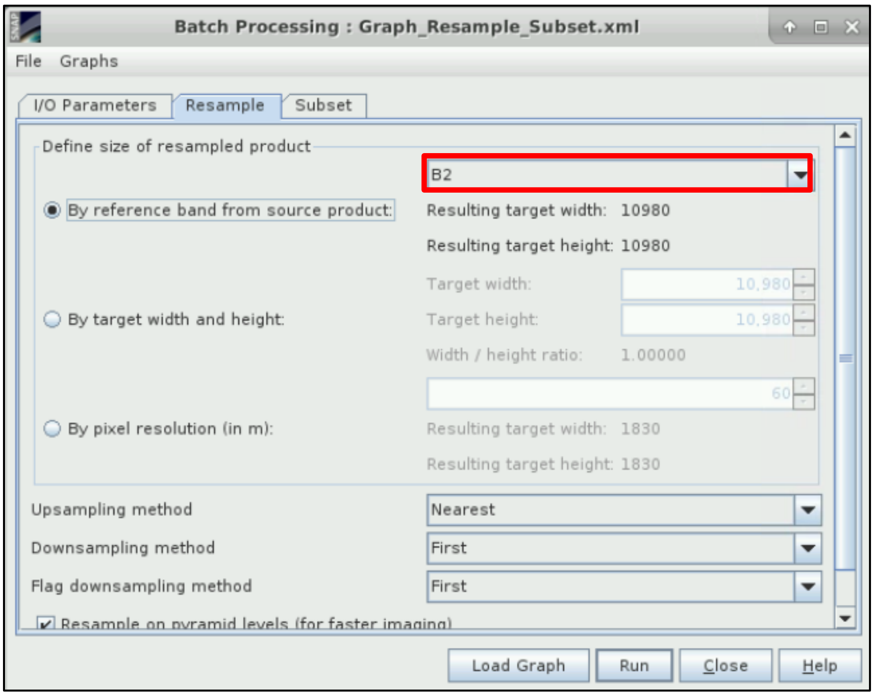
Save the graph to */shared/Training/TAT0618_Forestry_S1S2S3_TutorialKit/Sentinel-2/Processing*

Go to **Tools -> Batch Processing**. We will add the opened products by clicking **Add Opened** on the upper right (second icon from the top) and click refresh. Then, we click **Load Graph** at the bottom of the window, navigate to our saved graph, and open it. We see that new tabs have appeared at the top of window corresponding to our operators with the exception of **Write**; this is correct, as these parameters will be set in the **I/O Parameters** tab.



Se the target **Directory** to:
/shared/Training/TAT0618_Forestry_S1S2S3_TutorialKit/Sentinel-2/Processing

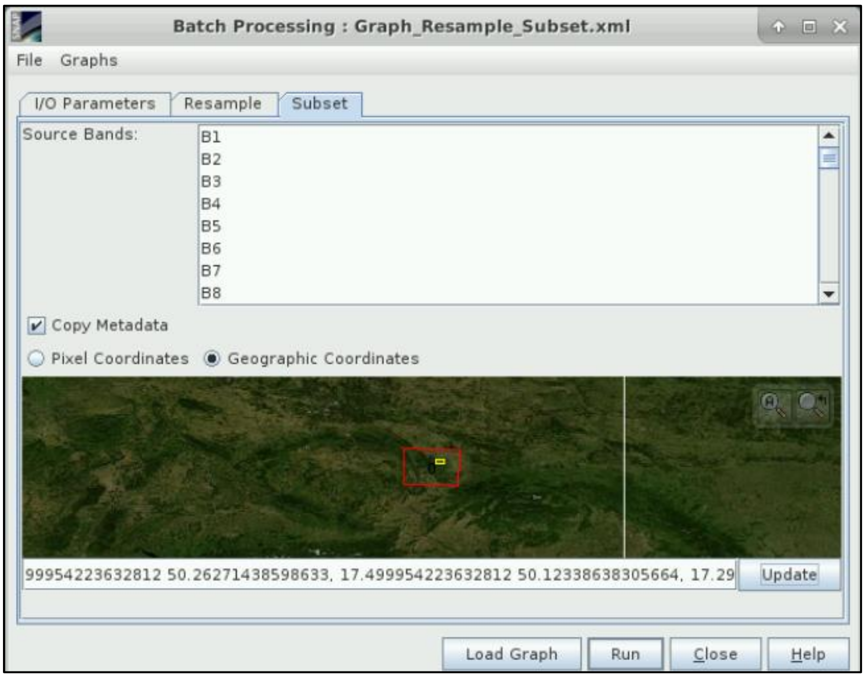
In the **Resample** tab, set: **Define size of resampled product:**
By reference band from source product: B2



In the **Subset** tab, click to select the **Geographic Coordinates** option and paste the area of interest definition in WKT (well know text) format to the text window below the map.

```
POLYGON ((17.29581 50.26272, 17.50702 50.25835, 17.49995 50.12339, 17.28933 50.12773, 17.29581 50.26272))
```

Click **Update** and then click the **Zoom-in** icon  to see your subset on the map.

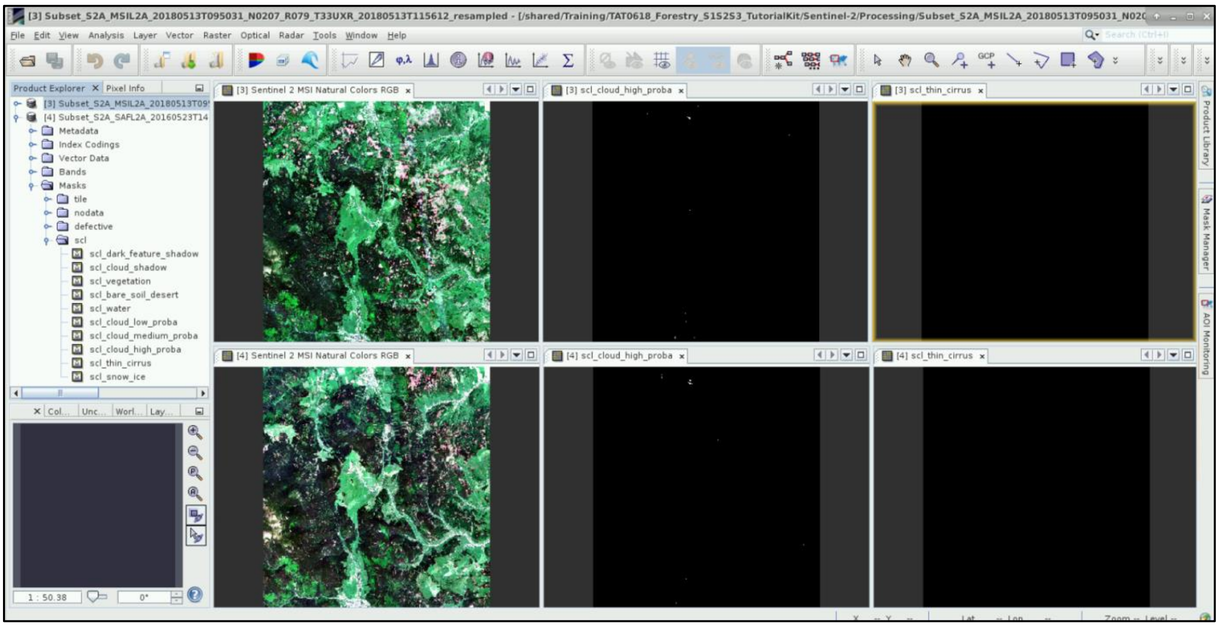


Click **Run**. Two new products will appear in your **Products Explorer** tab. Now close the two original products [1] and [2].

3.2.3 Cloud cover

First, let's investigate the cloud cover bands that are generated as a by-product of atmospheric correction applied to the Level-2A products. Expand the product in the **Product Explorer** and go to **Masks -> scl**. Open masks *scl_cloud_high_proba* (pixels with high cloud probability) and *scl_thin_cirrus* (thin cirrus clouds).

Now you should have four bands open. Go to **Window -> Tile Evenly** and then go to the **Navigation** tab, click **Zoom All**. We can see that as expected our image is cloudless.



3.2.4 Vegetation indices (VIs)

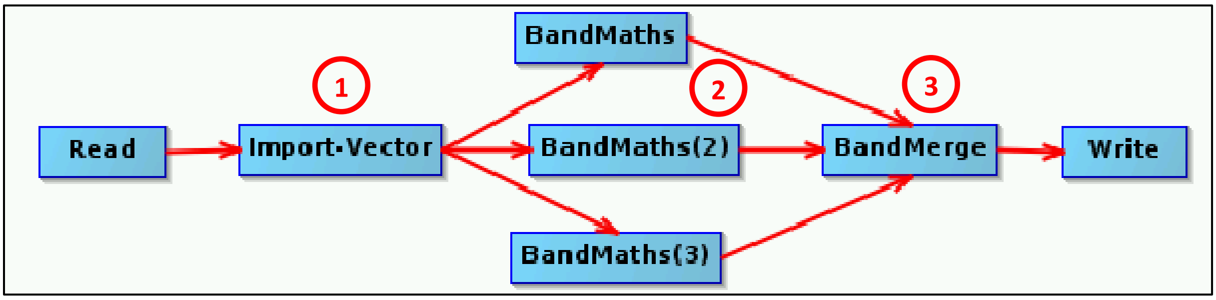
Vegetation indices are usually an arithmetic combination of surface reflectance at two or more wavelengths, designed to highlight a particular property of the vegetation. Below you will find a list of selected VIs. Select two VIs that you find most interesting/relevant plus NDVI.

S-2 Band	1	2	3	4	5	6	7	8	8A	9	10	11	12
Central wavelength (nm)	443	490	560	665	705	740	783	842	865	945	1375	1610	2190
Bandwidth (nm)	20	65	35	30	15	15	20	115	20	20	30	90	180
Spatial res. (m)	60	10	10	10	20	20	20	10	20	60	60	20	20

Name	Equation (Sentinel-2 bands)	Notes
NDVI (Rouse 1974)	$\frac{NIR_{842} - Red_{665}}{NIR_{78842} + Red_{665}} = \frac{B8 - B4}{B8 + B4}$	The **N**ormalized **D**ifference **V**egetation **I**ndex algorithms exploit the strength and the vitality of the vegetation on the earth's surface. Indicates amount of vegetation, distinguishes veg from soil and minimizes topographic effects. Range: -1 to 1 Values: A zero means no vegetation and close to +1 (0.8 - 0.9) indicates the highest possible density of green leaves.

RVI (Blackburn 1998)	$\frac{NIR_{842}}{Red_{665}} = \frac{B8}{B4}$	The **R**atio **V**egetation **I**ndex algorithm is the simplest ratio-based one. The simplest ratio-based index is also called the Simple Ratio (SR or PSSR). Indicates amount of vegetation and reduces the effects of atmosphere and topography. Values: high values for vegetation, low for soil, ice, water, etc.
TNDVI (Baret and Guyot 1991)	$\sqrt{\frac{NIR_{842} - Red_{665}}{NIR_{842} + Red_{665}} + 0.5} = \sqrt{\frac{B8 - B4}{B8 + B4} + 0.5}$	The **T**ransformed **N**ormalized **D**ifference **V**egetation **I**ndex algorithm indicates the amount of green biomass that is found in a pixel. TNDVI is the square root of the NDVI. It has higher coefficient of determination for the same variable. The formula of TNDVI has always-positive values and the variances of the ratio are proportional to mean values.
NDVI45 (Delegido et al. 2011)	$\frac{Red_{705} - Red_{665}}{Red_{705} + Red_{665}} = \frac{B5 - B4}{B5 + B4}$	The **N**ormalized **D**ifference **I**ndex **45** algorithm is linear, with less saturation at higher values than the NDVI. Specifically designed for Sentinel-2 data. Range: -1 to 1
MTCI (Dash and Curran 2004)	$\frac{NIR_{740} - Red_{705}}{Red_{705} - Red_{665}} = \frac{B6 - B5}{B5 - B4}$	The **M**eris **T**errestrial **C**hlorophyll **I**ndex algorithm was developed for estimating chlorophyll content from MERIS (Medium Resolution Imaging Spectrometer) data. The MTCI aims at estimating the Red Edge Position (REP) - the maximum slant point in the red and NIR region of the vegetation spectral reflectance. It is useful for observing the chlorophyll contents, vegetation senescence, and stress for water and nutritional deficiencies, but it is less suitable for land classification.
IRECI (Clevers 1988)	$\frac{NIR_{783} - Red_{665}}{Red_{705}/\ NIR_{740}} = \frac{B7 - B4}{B5/B6}$	The **I**nverted **R**ed-**E**dge **C**hlorophyll **I**ndex algorithm incorporates the reflectance in four bands to estimate canopy chlorophyll content.
MCARI (Daughtry et al. 2000)	$[(Red_{705} - Red_{665}) - 0.2 * (Red_{705} - G_{560})] * (Red_{705} - Red_{665}) = [(B5 - B4) - 0.2 * (B5 - B3)] * (B5 - B4)$	The **M**odified **C**hlorophyll **A**bsorption **R**atio **I**ndex algorithm was developed to be responsive to chlorophyll variation. This algorithm is responsive to both leaf chlorophyll concentrations and ground reflectance.
GNDVI (Gitelson, Kaufman, and Merzlyak 1996)	$\frac{Red_{783} - G_{560}}{Red_{783} + G_{560}} = \frac{B7 - B3}{B7 + B3}$	The **G**reen **N**ormalized **D**ifference **V**egetation **I**ndex algorithm was developed to be more sensitive than NDVI to identify chlorophyll concentration, which is highly correlated with nitrogen. The use of green spectral band was more efficient than the red spectral band to discriminate nitrogen. Range: -1 to 1
S2REP (Frampton et al. 2013)	$705 + 35 * \left(\frac{\left(\frac{NIR_{783} + Red_{665}}{2}\right) - Red_{705}}{NIR_{740} - Red_{705}}\right) = 705 + 35 * \left(\frac{\left(\frac{B7 + B4}{2}\right) - B5}{B6 - B5}\right)$	The **S**entinel-**2** **R**ed-**E**dge **P**osition **I**ndex algorithm is based on linear interpolation. Red edge, as the inflection point of the strong red absorption to near infrared reflectance, includes the information of both chlorophyll content (Nitrogen) and growth status.

Now we will use a graph that has been provided for you in the *Processing* folder - *Graph_Vis_Calculation.xml.*



In **Step 1**, we import vector forest mask to mask out all non-forest areas. The vector layer has been created based on the Corine Land Cover 2012 for Czech Republic (provided by the CENIA - Czech Environmental Information Agency) by aggregating classes 311 to 313.

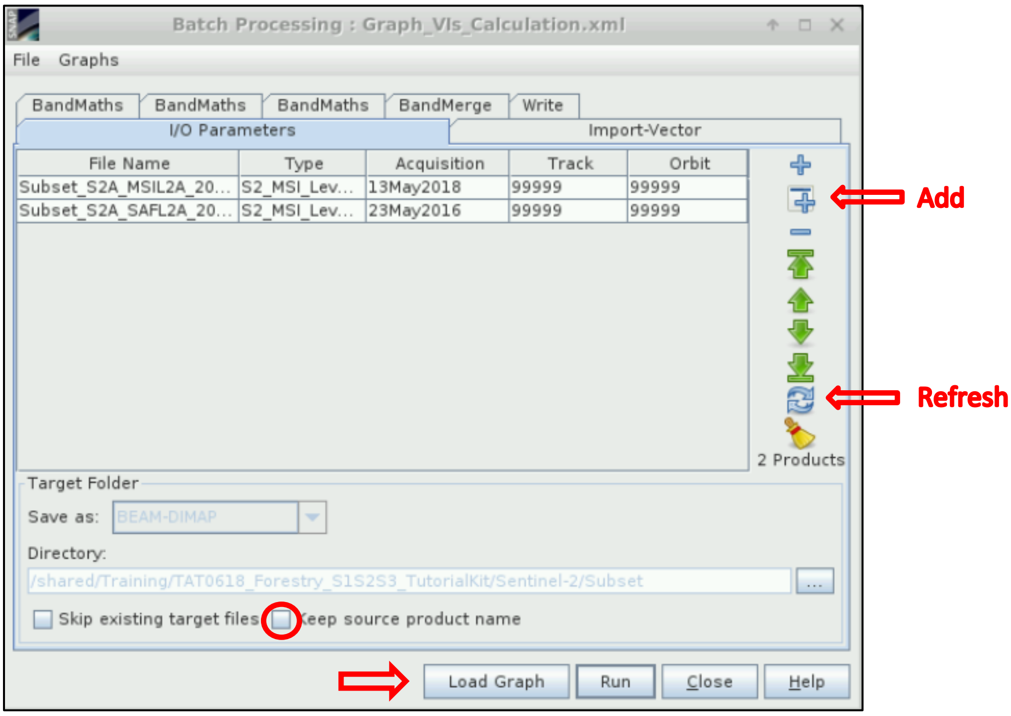
In **Step 2**, we use the **BandMaths** to calculate three VIs (NDVI + two selected VIs).

Then in **Step 3**, we use the **BandMerge** to merge the calculated VI bands to single output product.

To use the graph, go to **Tools -> Batch Processing**. We will add the opened products by clicking **Add Opened** on the upper right (second icon from the top) and click refresh.

Then, deselect the ☐ **Keep source product name**!

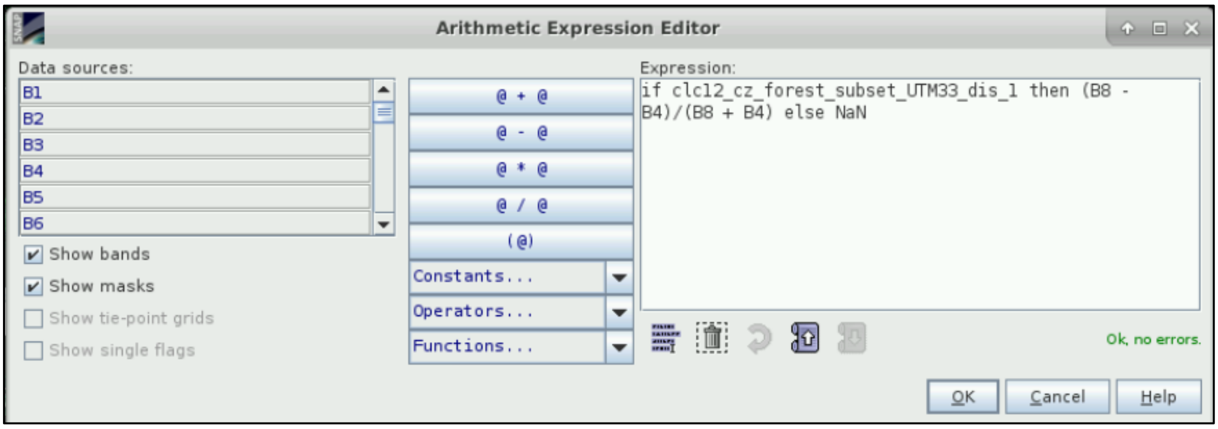
Next, click **Load Graph** at the bottom of the window; navigate to */shared/Training/TAT0618_Forestry_S1S2S3_TutorialKit/Sentinel-2/Processing/* and open *Graph_VIs_Calculation.xml*. We see that new tabs have appeared at the top of the window corresponding to our operators.



In the **Import-Vector** tab, go to */shared/Training/TAT0618_Forestry_S1S2S3_TutorialKit/Auxdata* and open *clc12_cz_forest_subset_UTM33_dis.shp*. In the first **BandMaths** tab, set following parameters:

Target Band: NDVI
No-Data Value: NaN

Expression: `if clc12_cz_forest_subset_UTM33_dis_1 then (B8 - B4)/(B8 + B4) else NaN`

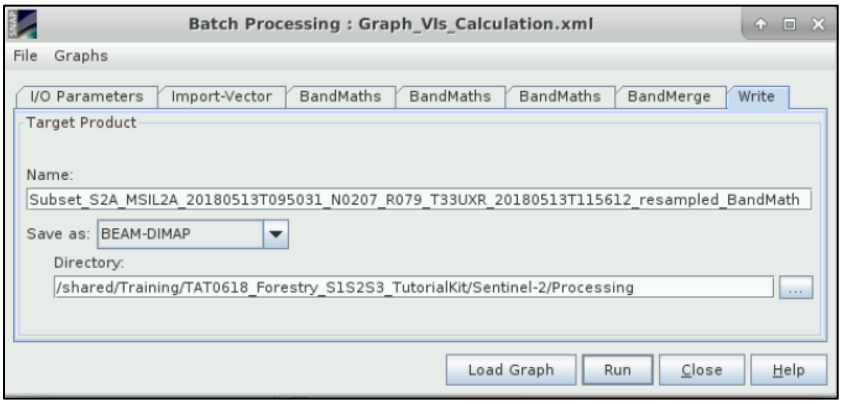


Repeat the same for the next two BandMaths tabs with your selected VIs.

Target Band: <name>
No-Data Value: NaN
Expression: `if clc12_cz_forest_subset_UTM33_dis_1 then <equation> else NaN`

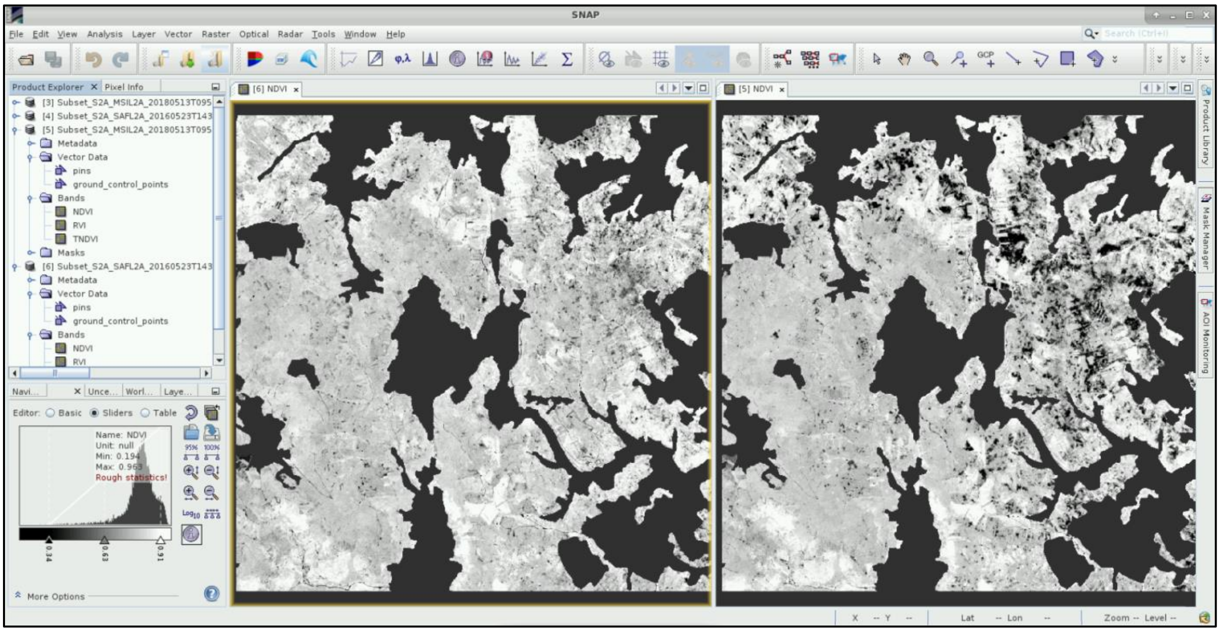
TIP: All expressions you will be using during this tutorial are available to copy-paste from the ***Expressions.txt*** file in */shared/Training/TAT0618_Forestry_S1S2S3_TutorialKit/Auxdata.*

In the **Write** tab, set the target **Directory** to:
/shared/Training/TAT0618_Forestry_S1S2S3_TutorialKit/Sentinel-2/Processing



Click **Run**. Two products will be created and added in the **Product Explorer**. Now, click on the + sign to expand the product in the **Product Explorer**, go to the **Vector Data** and delete the *clc12_cz_forest_subset_UTM33_dis_1.* Do the same for the second product.

Open the **Bands** folder and explore the calculated VI bands.



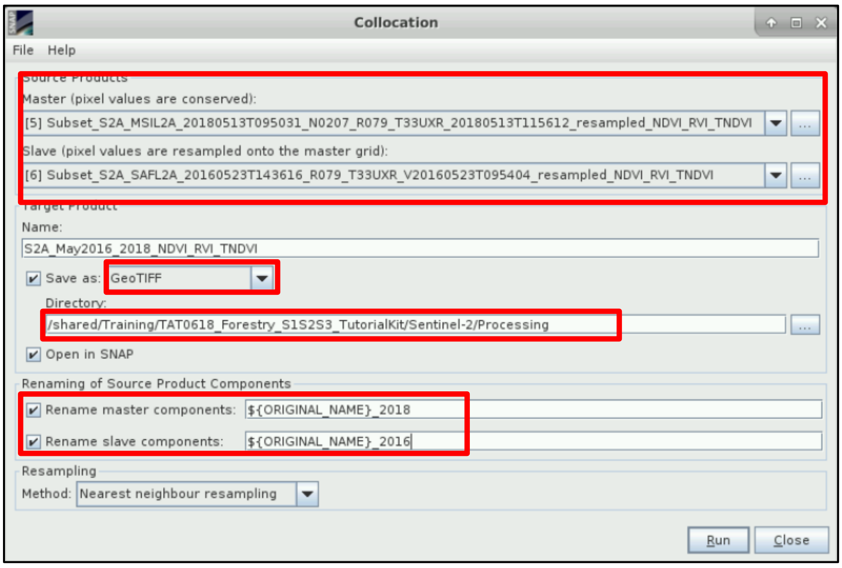
3.2.5 Collocation

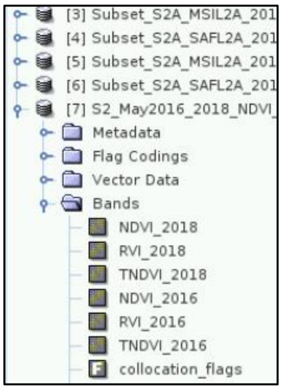
Now, we will use the collocation tool to add both products to a single one in order to calculate the change in the NDVI (and other VIs). Go to **Raster -> Geometric Operations -> Collocation**. In the menu that appears, in the **Source Products** set the VI product from 2018 as **Master** and the product from 2016 as a **Slave**. In the **Target Products:**

Name: *S2A_May2016_2018_<names of the VIs>*
Format: GeoTIFF
Directory: */shared/Training/TAT0618_Forestry_S1S2S3_TutorialKit/Sentinel-2/Processing*

In the **Renaming of Source Product Components** section:

Rename master components: replace “M” with “2018”
Rename slave components: replace “S” with “2016”





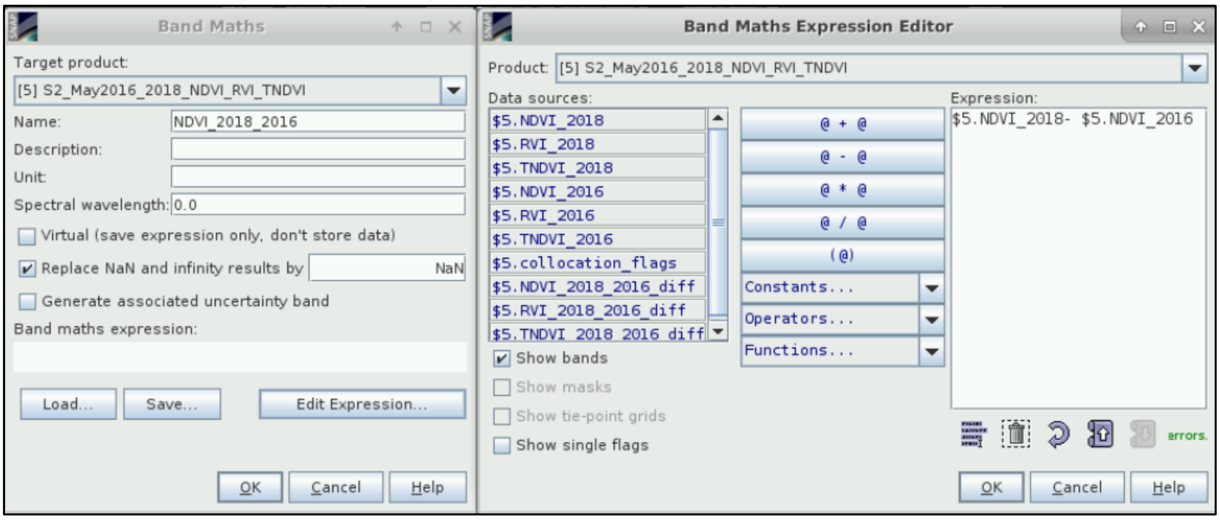
Click **Run**.

3.2.6 Calculate change between 2016 and 2018 and visualize

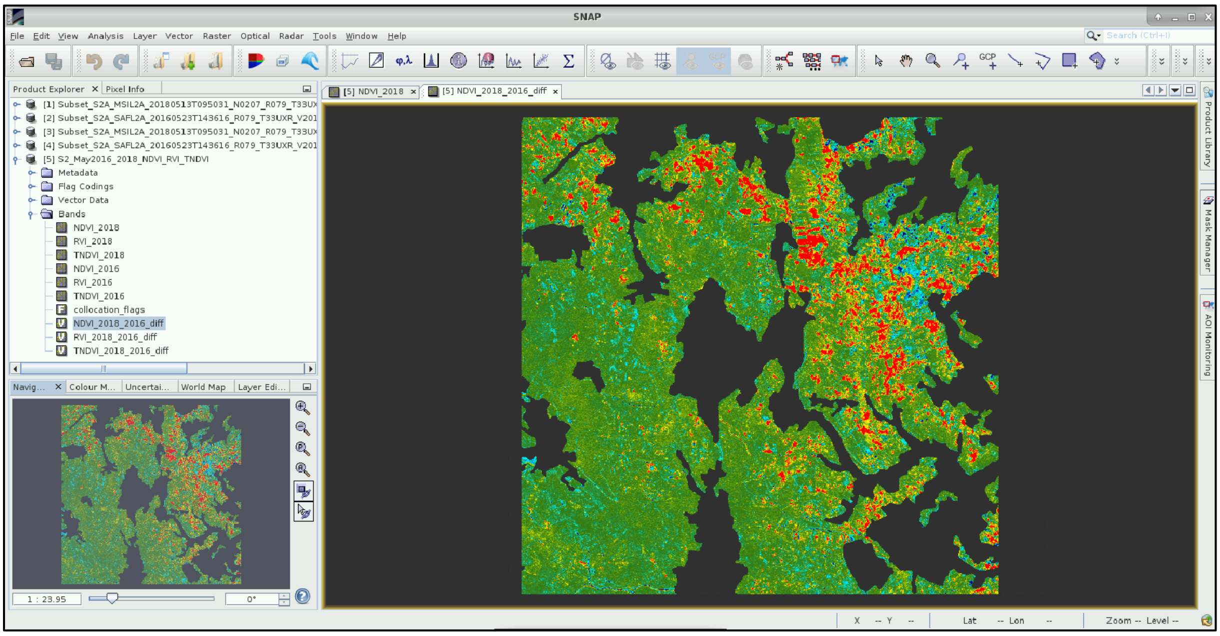
A new product with index number [5] was added to the **Product Explorer** containing all the calculated VIs for 2016 and 2018. Now we can use the **BandMath** operator to calculate the change. Right-click the product and select **Band Math …** and for each VI calculate the difference between 2018 and 2016. Set:

Name: *<VI name>_2018_2016*

Deselect **Virtual** as we want our calculated bands to be physically saved.



Investigate the difference bands. In the **Colour Manipulation** tab, click **Import colour pallete from text file**. Navigate to: */shared/Training/TAT0618_Forestry_S1S2S3_TutorialKit/Auxdata* and open *S2_diff_colour_palette.cpd*. In the next dialogue click **No** (**Do not distribute from min to max**) for NDVI (select **Yes** for other VIs).



Compare your results from the three VIs. Do you see differences? What are they? Can you explain them based on what you know about the indices? Right-click on the product and click **Save Product** to save our changes and calculated bands.

3.3 *Optical data – Sentinel-3 OLCI*

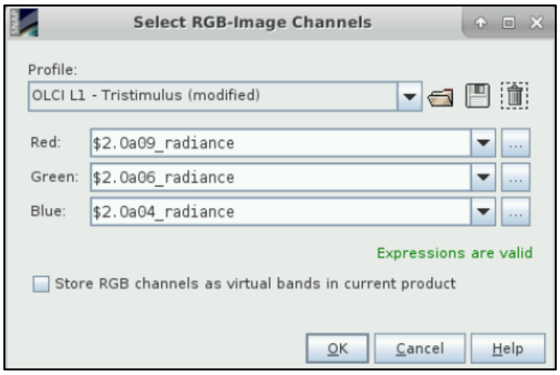
3.3.1 SNAP – open and explore data

Re-Launch SNAP (icon on desktop). When the SNAP window opens, click Open product, navigate to: */shared/Training/TAT0618_Forestry_S1S2S3_TutorialKit/Sentinel-3/Processing*

Open both .dim files. We have two products, Level-1 and Level-2 from 23 May 2016 (See NOTE 9). Both have already been reprojected and subset to the area of the administrative region Moravskoslezký Kraj (for details see section **4.3 Sentinel-3 OLCI pre-processing steps**). Unfortunately, it was not possible to find a cloudless image for 2018 (before May 15, 2018) and therefore, we will only have a look at the situation in 2016.

> NOTE 9: Level-1 products include Top-Of-Atmosphere (TOA) radiometric measurements, radiometrically corrected, calibrated and spectrally characterised. It is quality controlled, ortho-geolocated (latitude and longitude coordinates, altitude) and annotated with satellite position and pointing, landmarks and preliminary pixel classification (e.g. land/water/cloud masks). Products are generated in FR (300 m) and in RR (1.2 km) for the whole globe with the same coverage (ESA, 2018).
>
> Level-2 products consist of geophysical quantities derived from the processing of measurement data provided in the Level-1 product. Level-2 products specifically for marine and land application domains are generated separately by the SENTINEL-3 PDGS, with each containing the parameter relevant for the specific field of application (Land/Water). Level-2 atmospheric information relevant for both application domains, such as water vapour, is reported in both types (ESA, 2018).

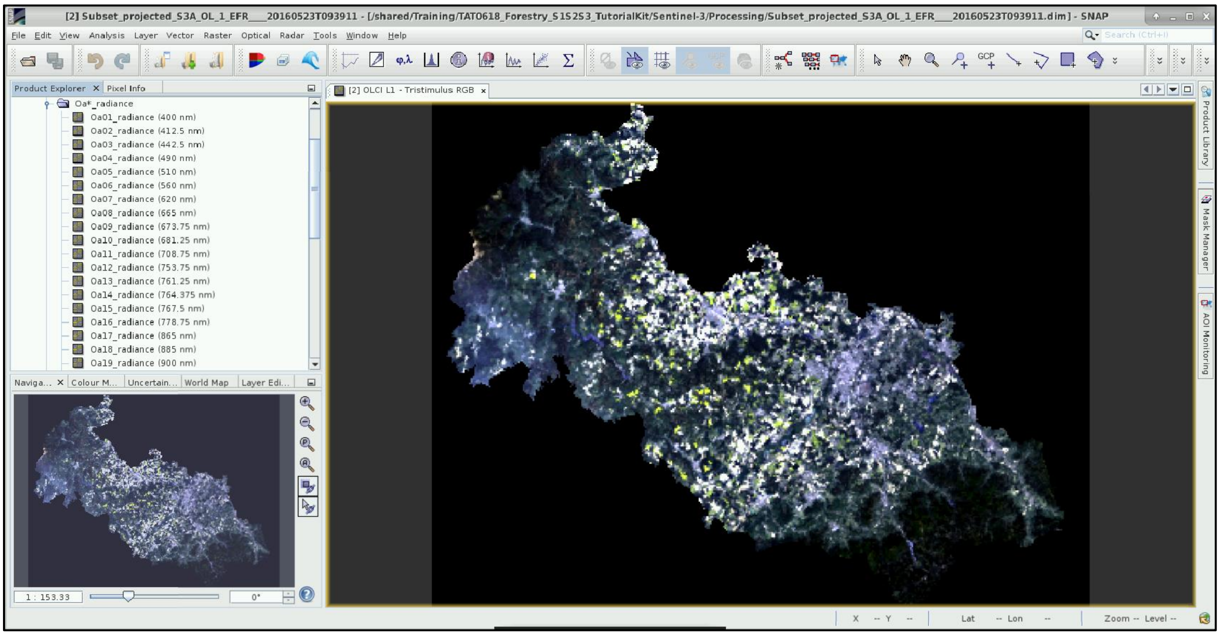
First, let's open the RGB View of the Level-1 product. Right-click the product and select Open RGB Image Window and set:



Red: Oa09_radiance (673.75 nm)

Green: Oa06_radiance (560 nm)

Blue: Oa04_radiance (490 nm)



The Level-1 data are not atmospherically corrected and at this moment, no atmospheric correction for S3 data is available in SNAP. We can see cirrus contamination in our scene, which can severely distort the calculation of VI indices for our location. Luckily, the Level-2 Land processing product (LFR) is available (for general Level-2 product description see NOTE 9).

In the LFR, product includes following parameters calculated from the radiometrically, geometrically and atmospherically corrected data:

- OLCI Global Vegetation Index – OGVI (See NOTE 10)
- Rectified reflectances at 681 and 685 nm - RC681, RC865
- OLCI Terrestrial Chlorophyll Index - OTCI (See NOTE 11)

NOTE 10: **OGVI** - Before computing the OLCI Global Vegetation Index (OGVI), a spectral test is performed on every land pixel to flag any pixels that are not vegetated. On vegetated pixels, the OGVI is estimated in two steps. The information contained in the blue band at 443 nm is combined with the information in the bands at 681 and 865 nm, traditionally used to monitor vegetation, to generate "rectified channels" at these latter two wavelengths. The OGVI has been optimised to assess the presence on the ground of healthy, live, green vegetation. The optimisation procedure has been constrained to provide an estimate of the Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) in the plant canopy, although the index is expected to be used in a wide range of applications - (ESA, 2018).

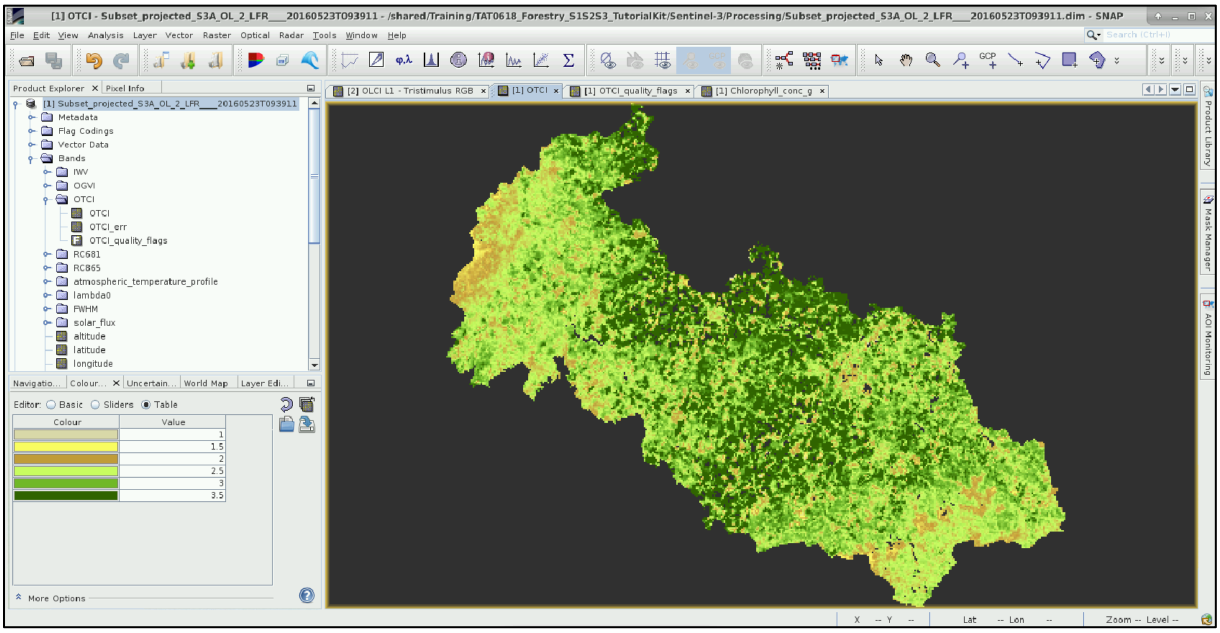
NOTE 11: **OTCI** - The OLCI Terrestrial Chlorophyll Index (OTCI) is produced globally at 300 m spatial resolution for land from OLCI data on the SENTINEL-3 mission and is designed to be a continuation of the MERIS Terrestrial Chlorophyll Index derived from MERIS data. The ENVISAT MERIS Terrestrial Chlorophyll Index (MTCI) was designed to monitor vegetation condition through an estimation of chlorophyll content using reflectance in the red edge region of the reflectance spectra. The use of red shift allows the MTCI product to remain responsive to high chlorophyll content, which would saturate conventional vegetation indices. The OTCI is a chlorophyll index similar to the MTCI (ESA, 2018).

$$\frac{NIR_{753} - Red_{709}}{Red_{709} - Red_{681}} = \frac{B12 - B11}{B11 - B10}$$

Expand the Level-2 product in **Product Explorer** and go to **Bands -> OTCI** to open the view. We can enhance the view by going to the **Colour Manipulation** tab and loading a colour palette (**Import colour pallete from text file)** *S3_veg_index.cpd* from:

/shared/Training/TAT0618_Forestry_S1S2S3_TutorialKit/Auxdata

We can use the **Colour Manipulation -> Table** menu to adapt the values to better represent our data. For example, stretch the values from 1 to 3.5 by 0.5 steps as seen below.



We could do many more things with these data. For example, we could create time series to see how the index values in the area changed over the last years (since the availability of S3 OLCI LFR data) but we could also look at previous MERIS Level-2 data, which would extend our time series to 2001.

THANK YOU FOR FOLLOWING THE EXERCISE!

4 Extra steps

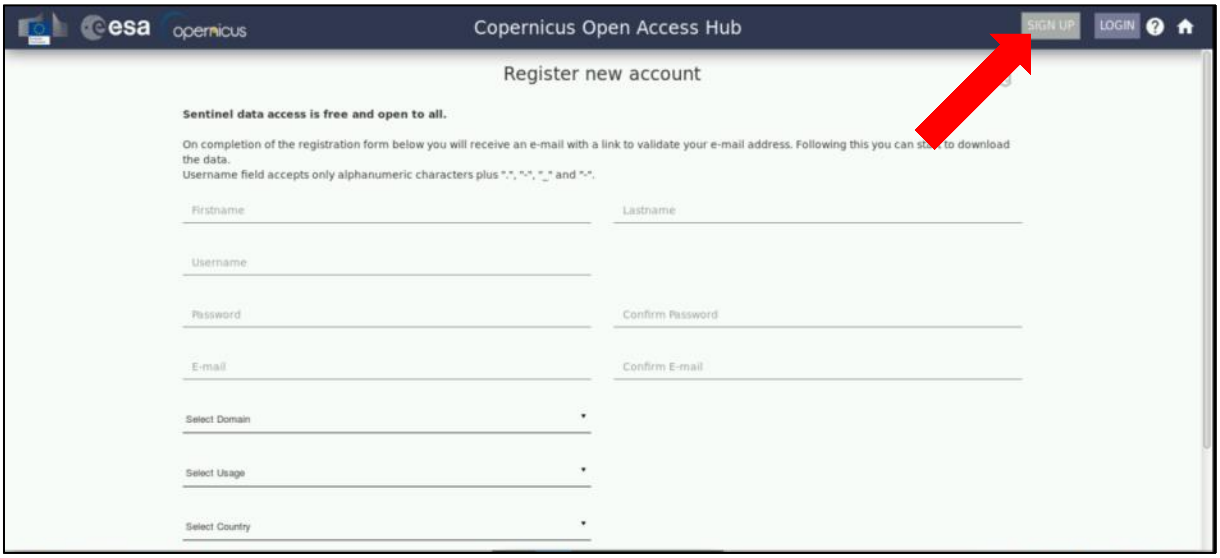
4.1 *Data download*

4.1.1 ESA SciHUB – Sentinel-1 and -2

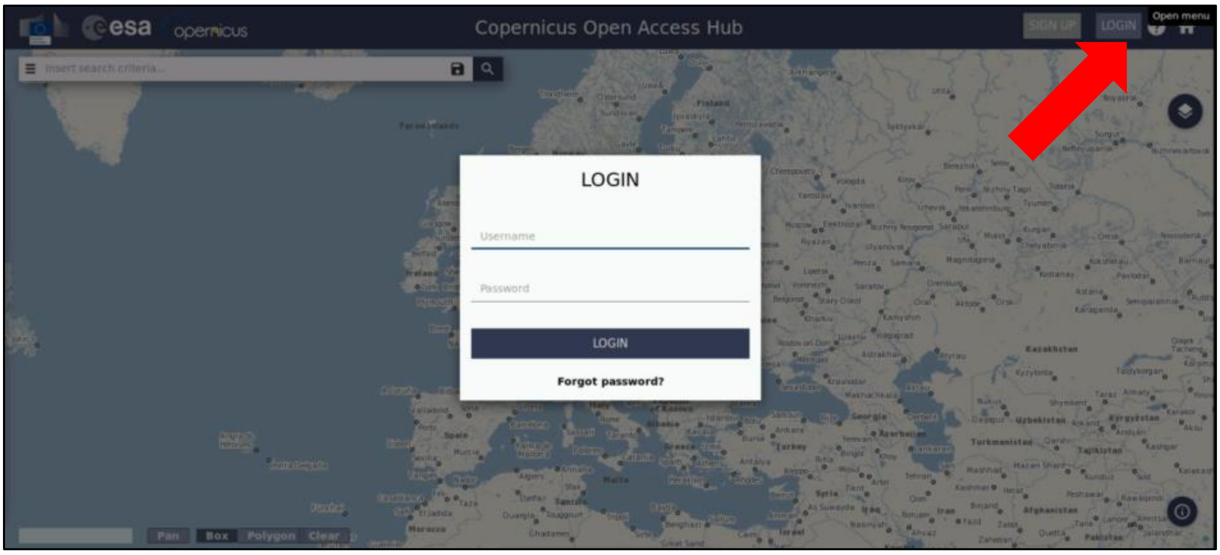
In this step, we will download a Sentinel-2 scene from the Copernicus Open Access Hub using the online interface (**Applications -> Network -> Web Browser,** or click the link below).

Go to https://scihub.copernicus.eu/

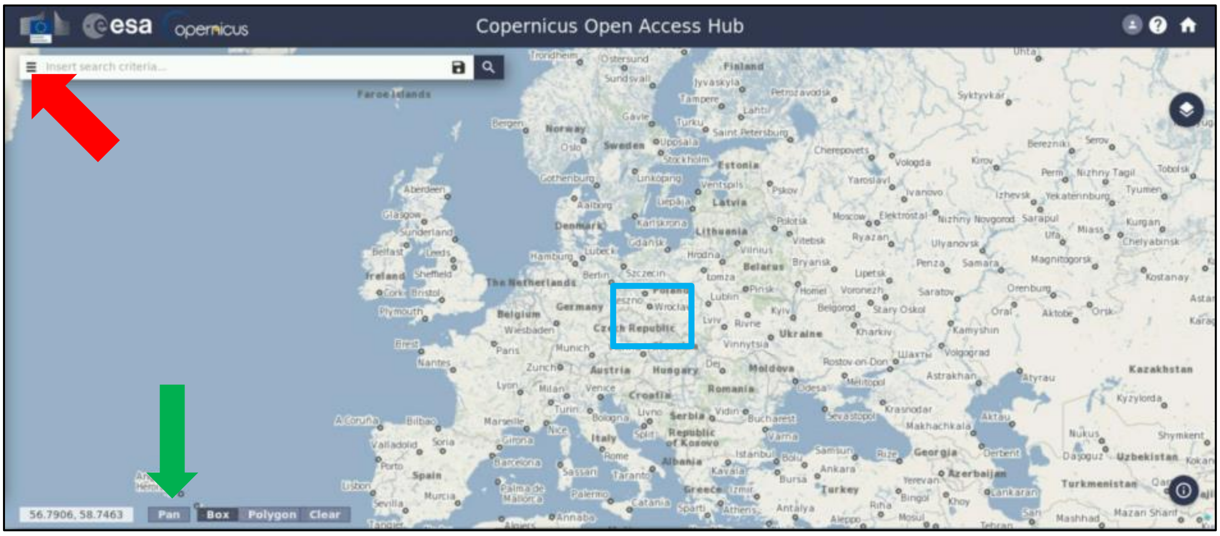
Go to Open HUB, if you do not have an account please register in upper right corner.



After you've filled in the registration form, you will receive an activation link by e-mail. Once your account is activated or if you already have an account, log in.

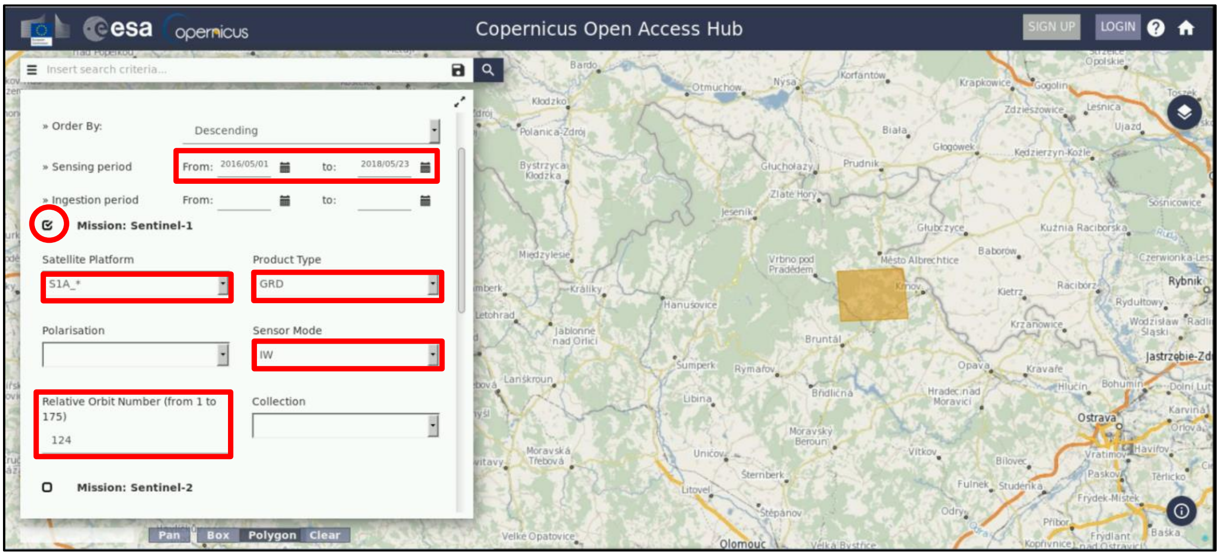


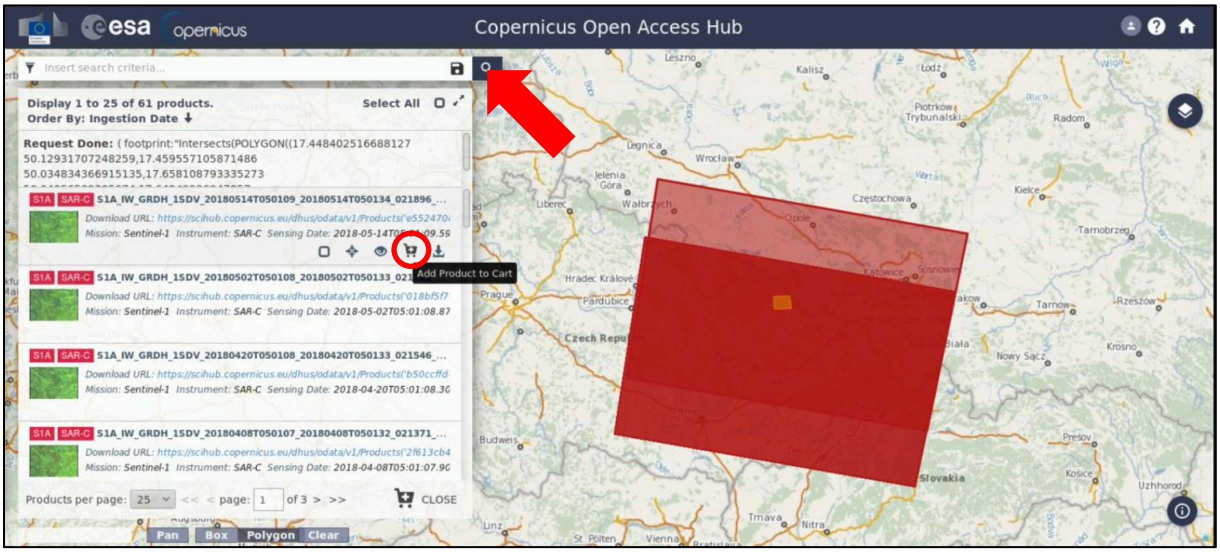
Switch the rectangle-drawing mode to pan mode by clicking on the ‘Pan’ icon in the lower left corner of the map (**Green arrow**) and navigate over Portugal (**approximate area – blue rectangle**).



Switch to drawing mode and draw a search rectangle approximately as indicated below north of the town of Bruntál. Open the search menu (red arrow) and specify the following parameters:

Sensing period:	From 2016/05/24 to 2018/05/14
Check Mission:	Sentinel-1
Satellite Platform:	S1A*
Product Type:	GRD
Sensor Mode:	IW
Relative Orbit:	124





In our case, the search returns 61 results depending on the exact search area defined. Search through the results for datasets from following dates (14 May 2018, 19 May 2017 and 24 May 2016):

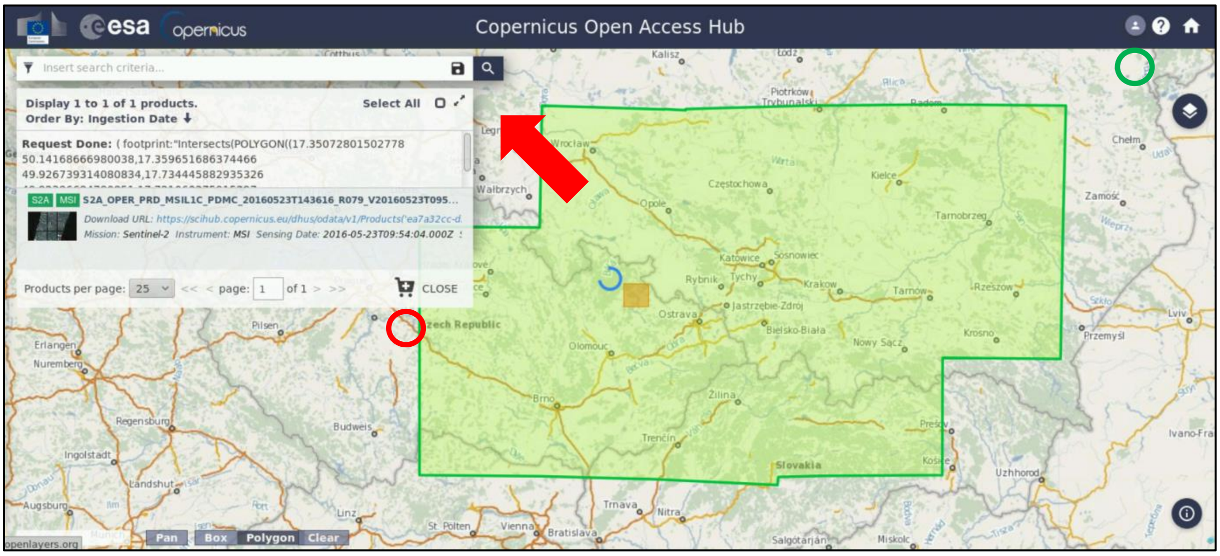
*S1A_IW_GRDH_1SDV_**20180514**T050109_20180514T050134_021896_025D35_**E395***
*S1A_IW_GRDH_1SDV_**20170519**T050103_20170519T050128_016646_01BA02_**07F0***
*S1A_IW_GRDH_1SDV_**20160524**T050046_20160524T050111_011396_01152F_**FED2***

You can also identify them by the unique product code – above in blue.

Then open the search menu again and reset the parameters as defined below, do not forget to deselect Mission: Sentinel-1 as this time we will search for Sentinel-2 data (See TIP):

Sensing period: From 2016/05/23 to 2016/05/23
Check Mission: Sentinel-2

TIP: For 2016, only Level-1C products are available and we will have to perform atmospheric correction – pre-processing of Level-1C product to a Level-2A is described in section **4.1**. For 2018, the Level-2A products are available and the atmospheric correction has already been applied. Since April 2017, the Level-2A products have been operationally generated and are available to download for acquisitions over Europe.



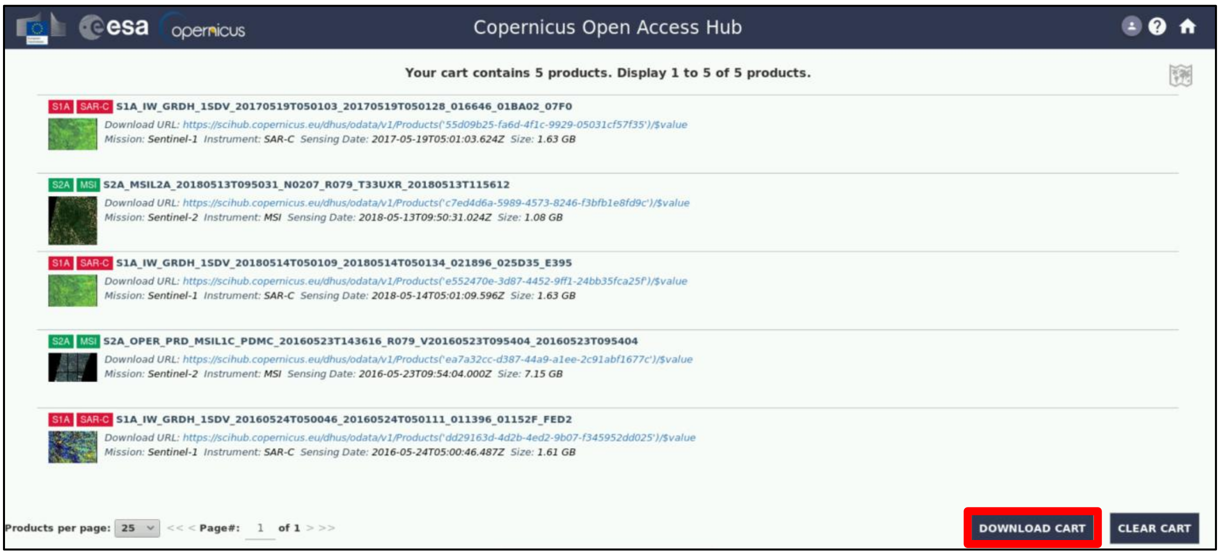
In our case, the search returns single result. Using the icon, import the following product to Cart: *S2A_OPER_PRD_MSIL1C_PDMC_**20160523**T143616_R079_V20160523T095404_20160523T095404*

Go back to the search and set following parameters find the S2 product from May 2018:

Sensing period: From 2018/05/13 to 2018/05/13
Check Mission: Sentinel-2
Satellite Platform: S2A_*
Product Type: S2MSI2A

Again a single product was found for our criteria, using the icon, import the following product to Cart: S2A_MSIL2A_**20180513**T095031_N0207_R079_T33UXR_20180513T115612

Once all our S1 and S2 data are in the cart, click on the Profile icon in the upper left corner (marked with **green circle** above) and go to **Cart**. You should now have five products in your cart. Click **Download Cart**.

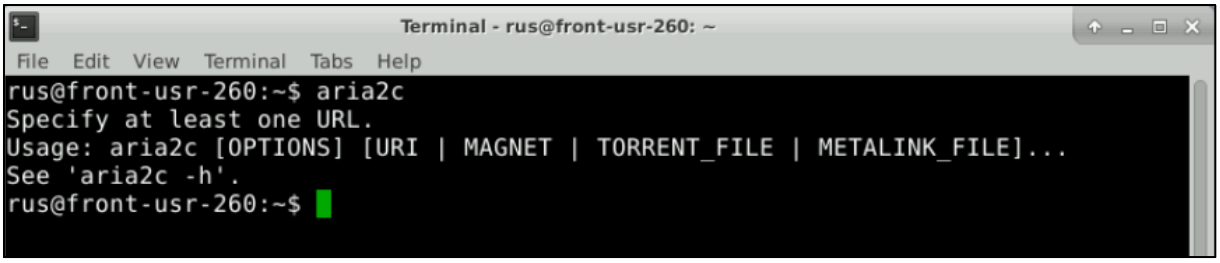


A *products.meta4* file will be downloaded to your */home/rus* folder. To download our data we will use **aria2** tool. To use the tool, we first need to place the products.meta4 file to the folder where we wish our data to be downloaded to: */shared/ TAT0618_Forestry_S1S2S3_TutorialKit/*

First, let's test our aria2 installation. To do this we open the Command Line (in the bottom of your desktop window) and type:

```
aria2c
```

The correct response should be as follows:



If the response is "-bash aria2c: command not found" (see NOTE E1).

> NOTE E1: If (**and only if**) the response is "-bash aria2c: command not found". Then we have to install the tool, to do this in command line type: `sudo apt-get install aria2`
> When requested type: `Y`
> Then you can test you installation again.

If you have received the correct response then we can run the tool by typing following commands in the command line (replace <username> and <password> with your login credentials for Copernicus Open Access Hub):

```
cd /shared/Training/TAT0618_Forestry_S1S2S3_TutorialKit/

aria2c      --http-user='<username>'      --http-passwd='<password>'      --check-
certificate=false --max-concurrent-downloads=2 -M products.meta4
```

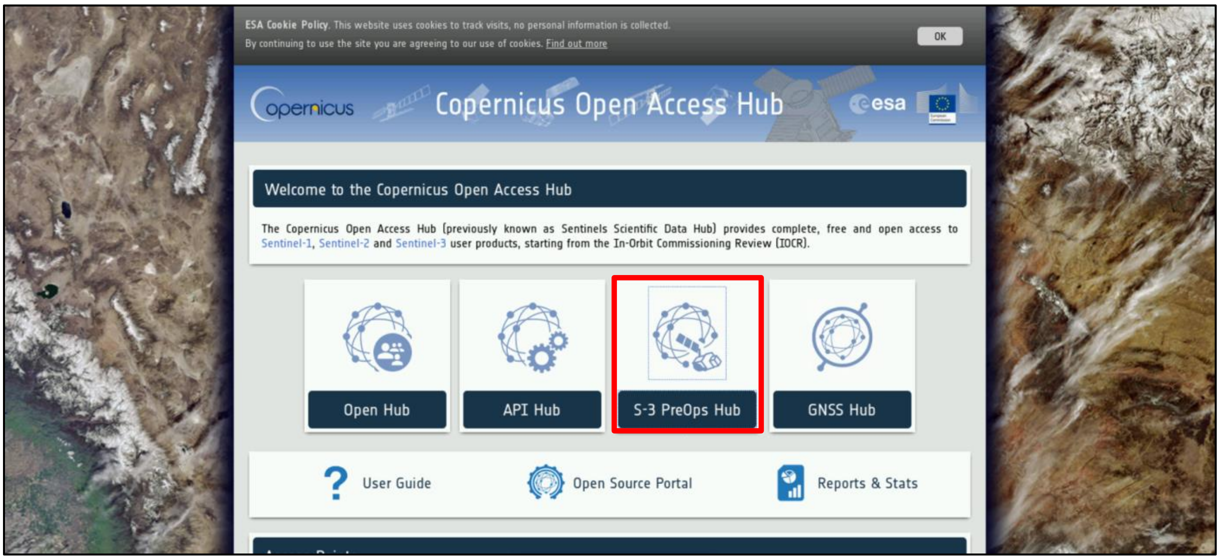
The first line changes our directory to the target directory. The second line runs the download tool (Type the red text all in single line). All six products will be downloaded to the *Original* folder two products in parallel automatically (Note that the constraint of maximum two parallel downloads at a time is imposed by the Copernicus Access Hub, if you increase the number the download will fail). This might take some time.

Once they are downloaded, move the products to the appropriate folder. The three Sentinel-1 products should be moved to:
/shared/TAT0618_Forestry_S1S2S3_TutorialKit/Sentinel-1/Original

The two Sentinel-2 products should be moved to:
/shared/TAT0618_Forestry_S1S2S3_TutorialKit/Sentinel-2/Original

4.1.2 ESA Sentinel-3 Pre-Operations Data Hub

The Sentinel-3 OLCI data cannot be downloaded from the Copernicus Open Access Hub now of preparation of this tutorial, they are available only from the Sentinel-3 Pre-Operations Data Hub. It can be navigated the same way as the Copernicus Open Access Hub. You can login using the credentials provided on top of the login window (username: s3guest; password: s3guest).

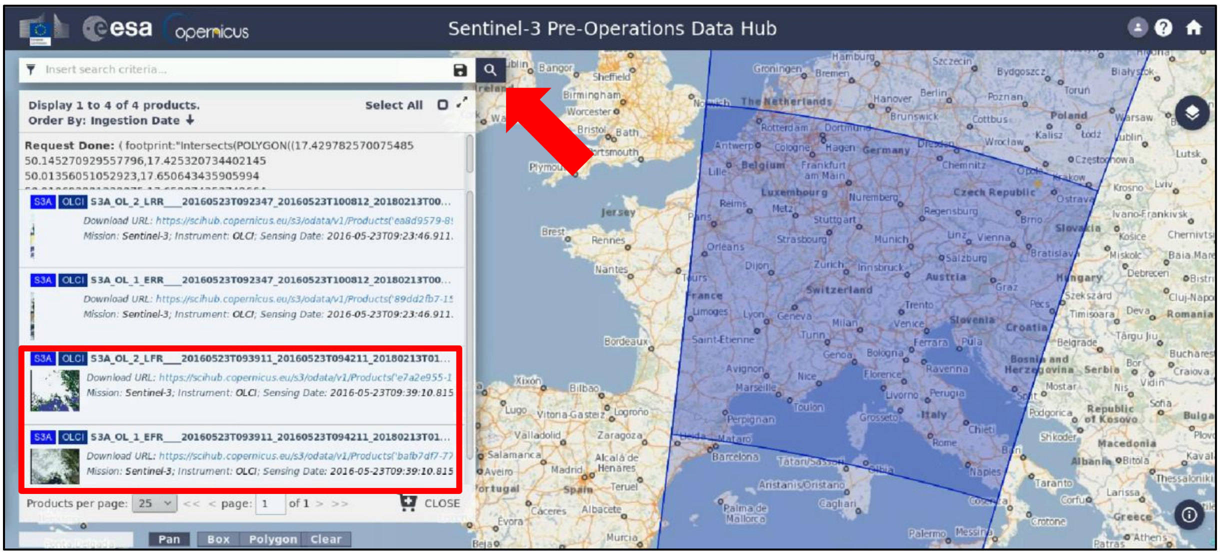


Go back to the search and set following parameters:

Sensing period: From 2016/05/23 to 2016/05/23

Check Mission: Sentinel-3

Instrument: OLCI



No cart is available in the Pre-Operations hub so we have to download the products manually.

S3A_OL_2_**LFR**____20160523T093911_20160523T094211_20180213T011706_0179_004_250_2160_LR2_R_NT_002
S3A_OL_1_**EFR**____20160523T093911_20160523T094211_20180213T012820_0179_004_250_2160_LR2_R_NT_002

When downloaded move the products from */home/rus* to: */shared/TAT0618_Forestry_S1S2S3_TutorialKit/Sentinel-3/Original*

4.2 Atmospheric correction for S2

Solar radiation reflected by the Earth's surface to satellite sensors is affected by its interaction with the atmosphere. The objective of applying an atmospheric correction is to determine true surface (Bottom-Of-Atmosphere, BOA) reflectance values from the Top-Of-Atmosphere (TOA) reflectance values, by removing atmospheric effects. (See NOTE E2) Atmospheric correction is especially important in cases where multi-temporal images are compared and analysed as it is in our case (pre-fire and post-fire images).(Mousivand et al. 2015)

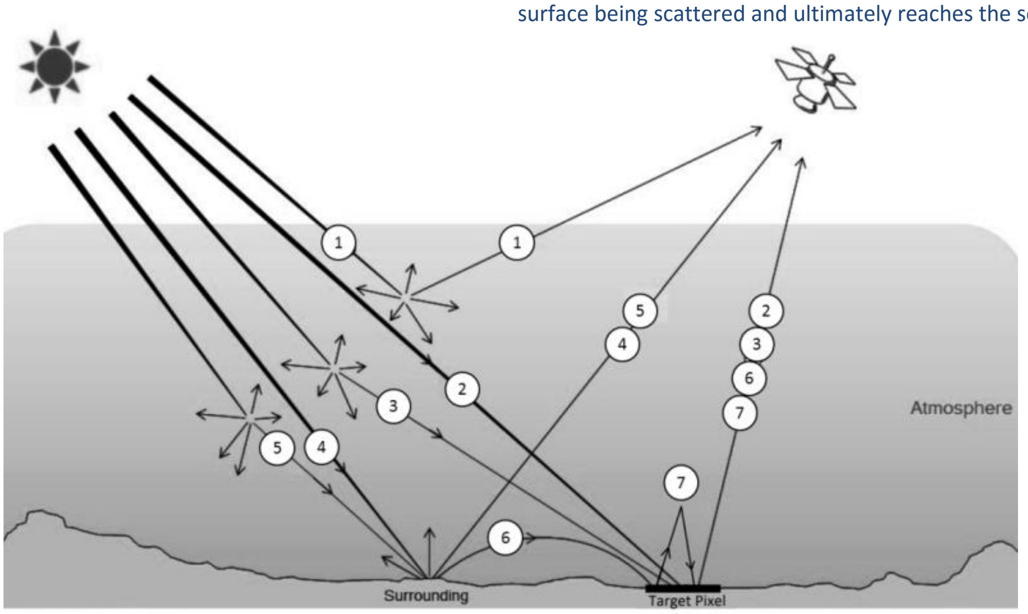
NOTE E2: The radiance reaching the sensor is a result of following components:

1. Radiation from the sun and, scattered into the field of view of the sensor by the atmosphere without reaching the surface.
2. Direct radiation that goes through the atmosphere without being absorbed or scattered, reaches the sensor after being reflected by the target pixel.
3. Radiation scattered by the atmosphere into the target pixel and reflected back towards the sensor.

4. & 5. Direct or diffuse radiation reflected or scattered by the surrounding areas into the field of view of the sensor. This effect is so called "adjacency effect" or "blurring effect".

6. Diffuse radiation coming from the adjacent features into the field of view of the sensor.

7. So-called trapping effect and it is a part of the radiation reflected from the surface into the air column above the surface being scattered and ultimately reaches the sensor.



Credits: Mousivand et al.. 2015[1]

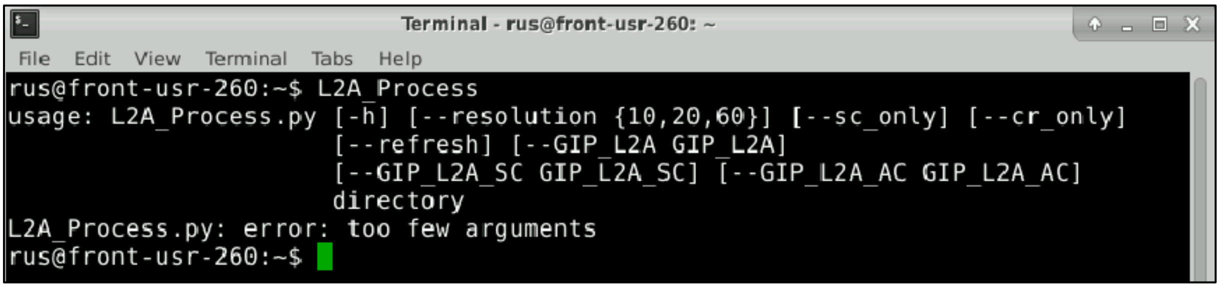
In this tutorial, we will use the Sen2Cor processor. Sen2Cor is a processor for Sentinel-2 Level-2A product generation and formatting; it performs the atmospheric, terrain and cirrus correction of Top-Of-Atmosphere Level-1C input data. Sen2Cor creates Bottom-Of-Atmosphere, optionally terrain and cirrus corrected reflectance images; additional, Aerosol Optical Thickness, Water Vapour, Scene Classification Maps and Quality Indicators for cloud and snow probabilities.

We can run the algorithm in two ways: in the SNAP GUI or in the command line. In this tutorial, we will use the command line. You can also run the process on a single tile or on the whole product (if the product is not cut to tiles). We will run the process on full product.

First, we need to unzip the Level-1C product in the *Original* folder. Then we test our Sen2Cor installation, to do this we open the Command Line (in the bottom of your desktop window) and type:

```
L2A_Process
```

The correct response should be as follows:



If you have received the correct response, then we can run the tool by typing following commands in the command line:

```
cd /shared/TAT0618_Forestry_S1S2S3_TutorialKit/Sentinel-2/Original

L2A_Process
S2A_OPER_PRD_MSIL1C_PDMC_20160523T143616_R079_V20160523T095404_20160523T095404.SA
FE
```

The first line changes our directory to the input directory. The second line runs the tool on the defined product in the input directory (Type the red text all in single line).

The process creates new Level-2A product in the .SAFE format in the input directory:
/shared/ TAT0618_Forestry_S1S2S3_TutorialKit/Sentinel-2/Original

The process can be very time consuming – several hours if run on full product. You can also run the product on a single tile by navigating to the *GRANULE* folder inside the input product directory.

We are using the tile **T33UXR** therefore; the command would then be as follows:

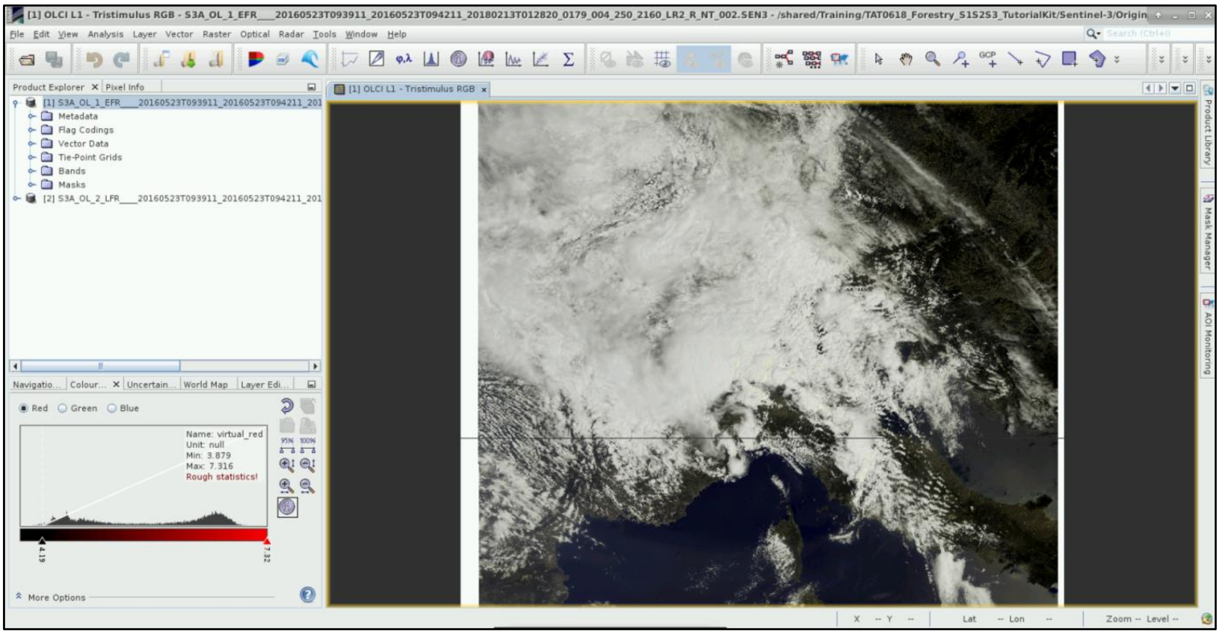
```
cd               /shared/TAT0618_Forestry_S1S2S3_TutorialKit/Sentinel-2/Original/
S2A_OPER_PRD_MSIL1C_PDMC_20160523T143616_R079_V20160523T095404_20160523T095404.SA
FE/GRANULE/

L2A_Process S2A_USER_MSI_L2A_TL_MPS__20160523T133345_A004795_T33UXR_N02.00
```

The process creates new Level-2A product in the SAFE format in the input *GRANULE* directory inside the original product. It is recommended to move the created folder out of the original product directory to the main input folder.

4.3 Sentinel-3 OLCI pre-processing steps

First, we need to unzip the two products we have downloaded. Then we launch SNAP (icon on desktop). When the SNAP window opens, click Open product, navigate to: */shared/Training/TAT0618_Forestry_S1S2S3_TutorialKit/Sentinel-3/Original.*

Open the S3 OLCI products one by one by going inside the unzipped folder and opening the *xfdumanifest.xml* file. Both products are derived from the same acquisition; therefore they have the same extent and geometry. Go to **Product Explorer**, right click the Level-1 product, and open RGB view. We can accept the default **Profile:** OLCI L1 – Tristimulus

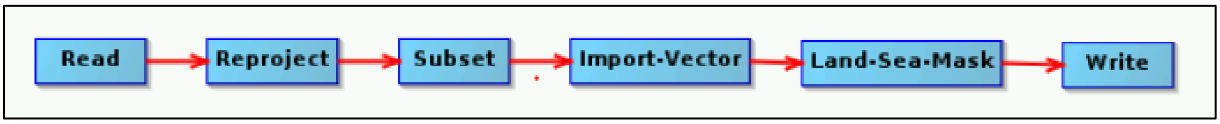


The swath width of the product is 1270 km, which makes the OLCI the ideal tool for monitoring regional to global scale. For our purposes, we will subset the data to the administrative region in the east of Czech Republic. We will also reproject the data to WGS84 UTM Zone 33 projection.

To avoid processing the datasets one by one, we will use the **Batch processing** and **Graph Builder again**. Go to **Tools -> GraphBuilder**. At the moment, the graph only has two operators: **Read** (to read the input) and **Write** (to write the output).

First, we will reproject the data. Right-click on the white space between the operators and go to **Add -> Raster -> Geometric -> Reproject.** Then we need to subset our data to our area of interest (AOI). Go to **Add -> Raster -> Geometric -> Subset.**

Our area of interest is within the boundaries of the region, the subset produces a rectangular output. For this reason, we will also use a vector mask to mask out areas outside the region boundaries. First, we need to import the vector layer (**Add -> Vector -> Import Vector**) and then, use the **Land-Sea-Mask** operator. Finally, right-click again and go to **Connect Graph.**

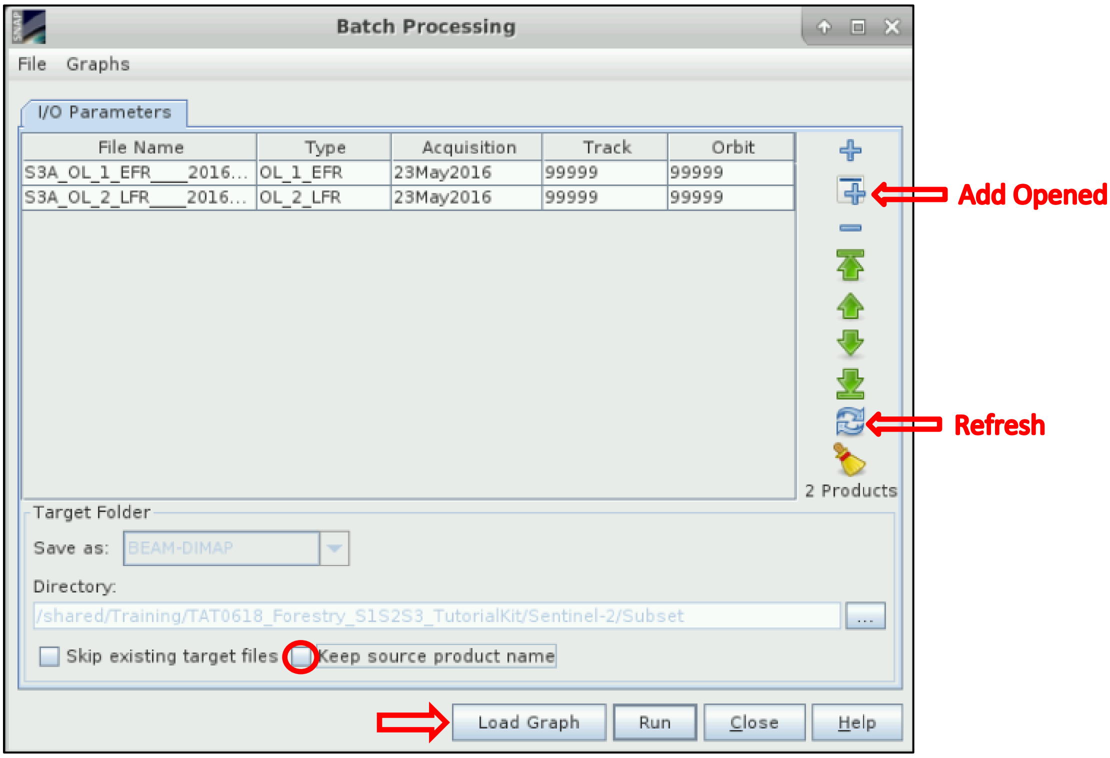


Save the graph to */shared/Training/TAT0618_Forestry_S1S2S3_TutorialKit/Sentinel-3/Processing*

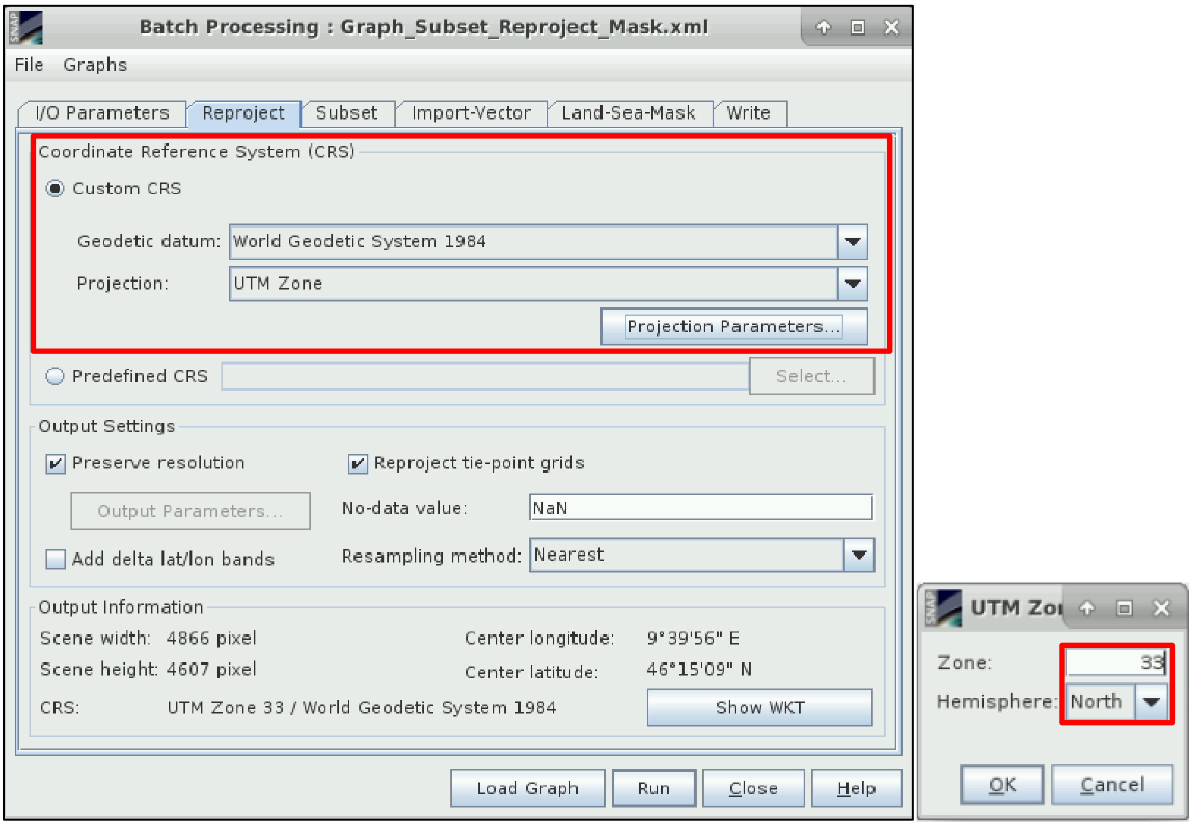
Go to **Tools -> Batch Processing**. We will add the opened products by clicking **Add Opened** on the upper right (second icon from the top) and click refresh.

Then, deselect the ☐ **Keep source product name**!

Click **Load Graph** at the bottom of the window, navigate to our saved graph, and open it. We see that new tabs have appeared at the top of window corresponding to our operators.



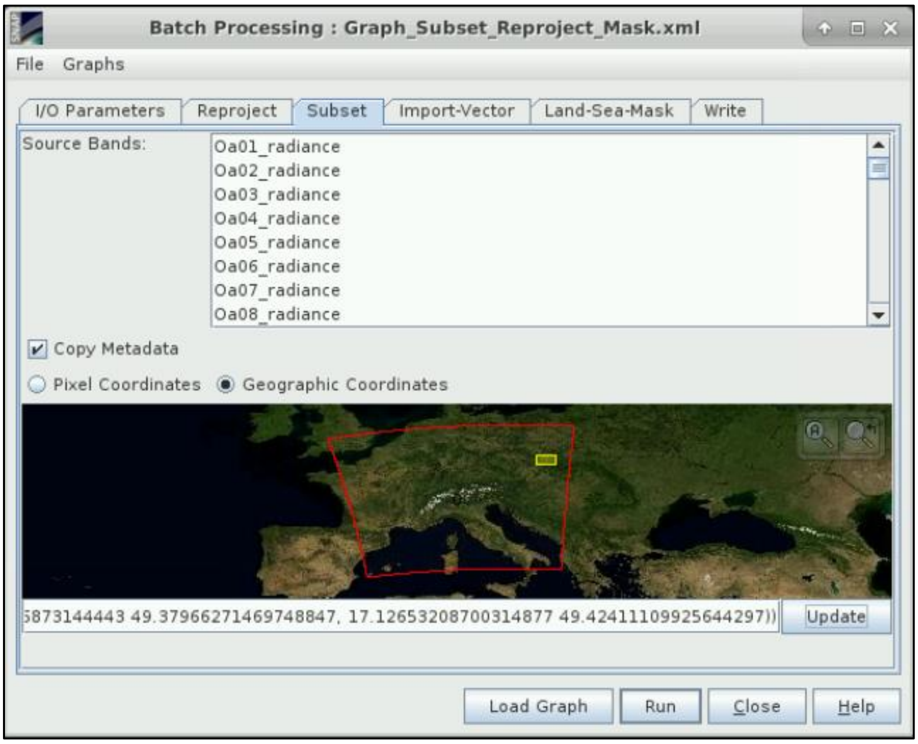
In the **Reproject** tab, set **Coordinate Reference System (CSR) -> Custom CRS -> Projection** to UTM Zone. In **Projection Parameters** set Zone 33 North.



In the **Subset** tab, click to select the **Geographic Coordinates** option and paste the area of interest definition in WKT (well know text) format to the text window below the map (you can copy the WKT from *Expressions.txt* in the *Auxdata* folder).

```
POLYGON ((17.12653 49.42411, 17.16711 50.33883, 18.91914 50.29293, 18.84590 49.37966, 17.12653 49.42411))
```

Click **Update** and then click the **Zoom-in** icon to see your subset on the map.



In the Import-Vector tab, go to */shared/Training/TAT0618_Forestry_S1S2S3_TutorialKit/Auxdata* and the *Moravskoslezky_kraj_CZE_UTM33.shp.*

In the **Land-Sea-Mask** tab, set **Use Vector as Mask**, the imported vector will automatically be selected as the mask.

Lastly, in the **Write** tab, set the **Directory** to:
/shared/Training/TAT0618_Forestry_S1S2S3_TutorialKit/Sentinel-3/Processing

Click **Run**. Two new products will appear in your **Products Explorer** tab. Now close the two original products [1] and [2].

4.4 Downloading the outputs from VM

On your keyboard, press **Ctrl+Alt+Shift.** A pop-up window will appear on the left side of the screen. Click on the bar below **Devices**, the folder structure of your VM will appear. Navigate to your Processing folder and **double click any file you want to download.**

5 References

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Blackburn, George Alan. 1998. “Quantifying Chlorophylls and Caroteniods at Leaf and Canopy Scales: An Evaluation of Some Hyperspectral Approaches.” Remote Sensing of Environment 66 (3): 273–85. https://doi.org/10.1016/S0034-4257(98)00059-5.

Clevers, J. G. P. W. 1988. “The Derivation of a Simplified Reflectance Model for the Estimation of Leaf Area Index.” Remote Sensing of Environment 25 (1): 53–69. https://doi.org/10.1016/0034-4257(88)90041-7.

Dash, J., and P. J. Curran. 2004. “The MERIS Terrestrial Chlorophyll Index.” *International Journal of Remote Sensing* 25 (23): 5403–13. https://doi.org/10.1080/0143116042000274015.

Daughtry, C. S. T, C. L Walthall, M. S Kim, E. Brown de Colstoun, and J. E McMurtrey. 2000. “Estimating Corn Leaf Chlorophyll Concentration from Leaf and Canopy Reflectance.” *Remote Sensing of Environment* 74 (2): 229–39. https://doi.org/10.1016/S0034-4257(00)00113-9.

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Mousivand, Alijafar, Wout Verhoef, Massimo Menenti, and Ben Gorte. 2015. “Modeling Top of Atmosphere Radiance over Heterogeneous Non-Lambertian Rugged Terrain.” Remote Sensing 7 (6): 8019–44. https://doi.org/10.3390/rs70608019.

Rouse, J. W. 1974. “Monitoring Vegetation Systems in the Great Plains with ERTS.” In . https://ntrs.nasa.gov/search.jsp?R=19740022614.

Tuominen, J., T. Lipping, V. Kuosmanen, and R. Haapanen. 2009. “Remote Sensing of Forest Health | IntechOpen.” In Geoscience and Remote Sensing. London: IntechOpen Limited. /books/geoscience-and-remote-sensing/remote-sensing-of-forest-health.