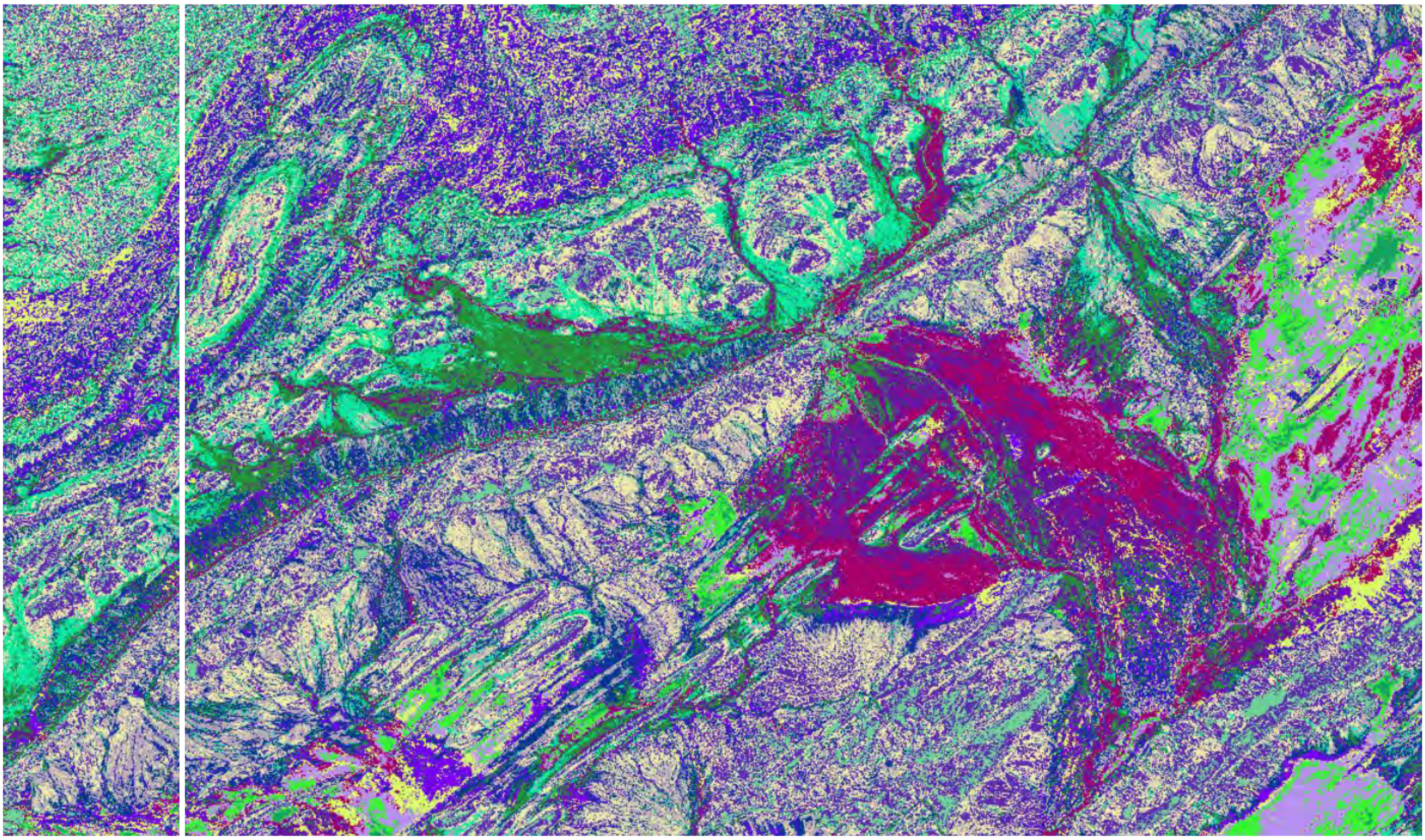

TRAINING KIT – GEOL01

LITHOLOGICAL CLASSIFICATION WITH SENTINEL-1 & SENTINEL-2 – SEPTEMBER 2019 (MOROCCO)

Research and User Support for Sentinel Core Products

The RUS Service is funded by the European Commission, managed by the European Space Agency and operated by CSSI and its partners.

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

Cover image produced by RUS Copernicus

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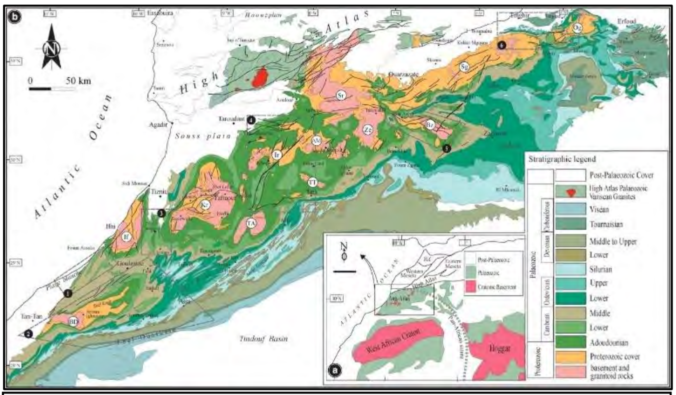
1 Introduction

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 acquired by the Copernicus Sentinel satellites constellation.

Geologists can employ both SAR and optical remote sensing data in order to extract geological information, depending on the geological setting of area of interest. The use of SAR images is playing an important role in recent years by providing a wealth of information in this field, such as geological structure and lithological mapping. The fusion of radar and optical images can simplify the interpretation and improve the accuracy of recognizing and detecting lithological units.



Stratigraphy of Anti-Atlas Mountains (Source: Soulaimani A. & Burkhard M. Geological Society, London, Special Publications, 297, 433-452, 1 January 2008 https://doi.org/10.1144/SP297.20

Morocco consists of very fascinating landforms and landscapes and it is an attractive field for studying geology. It is located at the node of Africa (continent), the Atlantic Ocean and an active plate collision zone - the Alpide belt system. This composition results in a rough topography with terrains spanning from Archean to Cenozoic Era, with diverse tectonic systems.

The Anti-Atlas Mountains formed in the Paleozoic Era as a result of continental collisions and are part of the Atlas Mountains, with a SW-NE direction. Most of the land is dry and barren with annual precipitation less than 200 mm, thus, the rocky outcrops and lunar landscapes of extreme contrasts are dominant.

2 Training

Approximate duration of this training session is **two** hours.

The Training Code for this tutorial is GEOL01. If you wish to practice the exercise described below within the RUS Virtual Environment, register on the RUS portal and open a User Service request from Your RUS service → Your dashboard.

2.1 Data used

- One Sentinel-1A IW GRD image acquired on 8 September 2019 [downloadable at https://scihub.copernicus.eu/]

  S1A_IW_GRDH_1SDV_20190908T062923_20190908T062948_028926_03478B_AE88

- One cloud-free Sentinel-2B Level 2A image (Tile ID: T29RNN) acquired on 14 September 2019 [downloadable at https://scihub.copernicus.eu/]

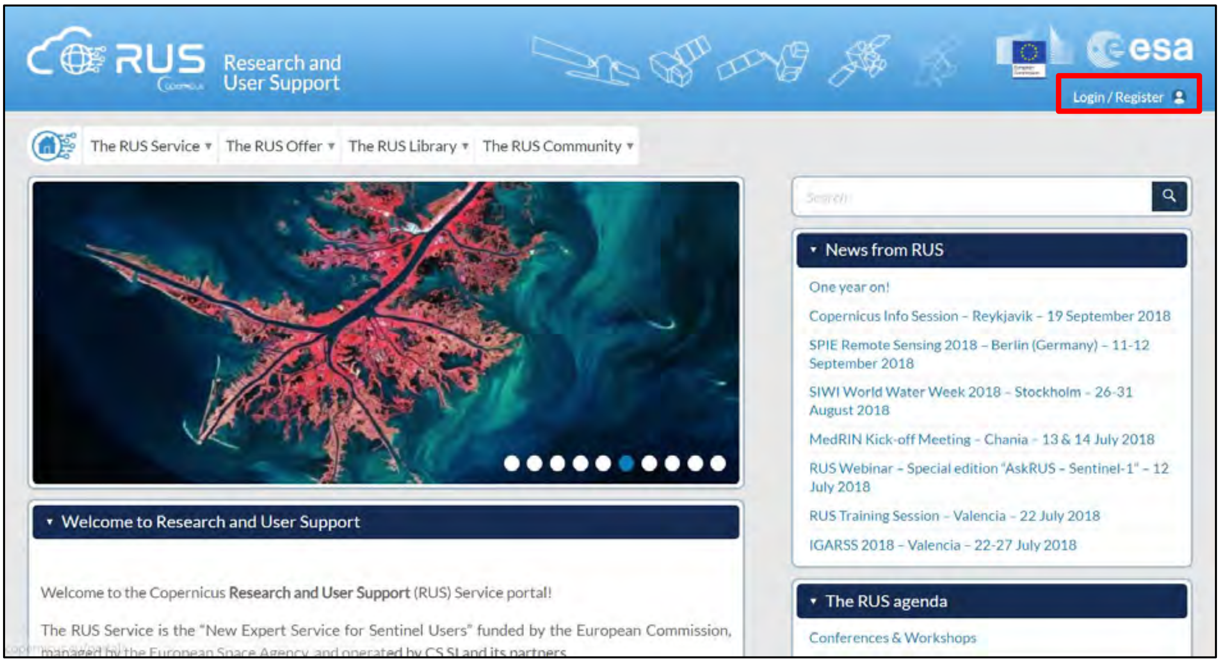
  S2B_MSIL2A_20190914T110649_N0213_R137_T29RNN_20190914T142009

2.2 Software in RUS environment

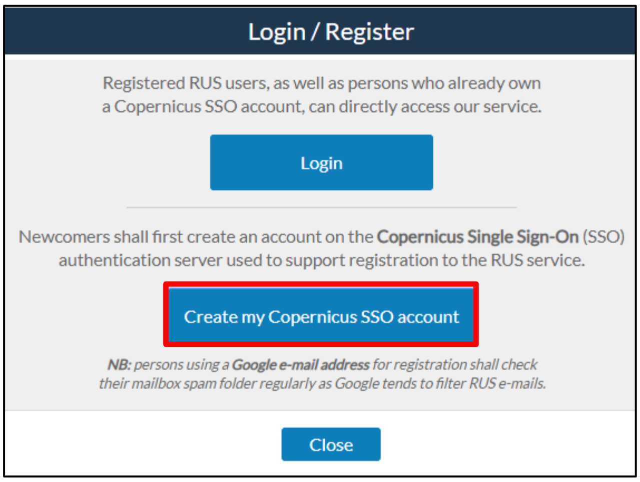
Internet browser, SNAP + Sentinel-1 & Sentinel-2 Toolboxes, QGIS, (Extra steps: Google Earth)

3 Register to RUS Copernicus

To repeat the exercise using a RUS Copernicus Virtual Machine (VM), you will first have to register as a RUS user. For that, go to the RUS Copernicus website (www.rus-copernicus.eu) and click on ***Login/Register*** in the upper right corner.

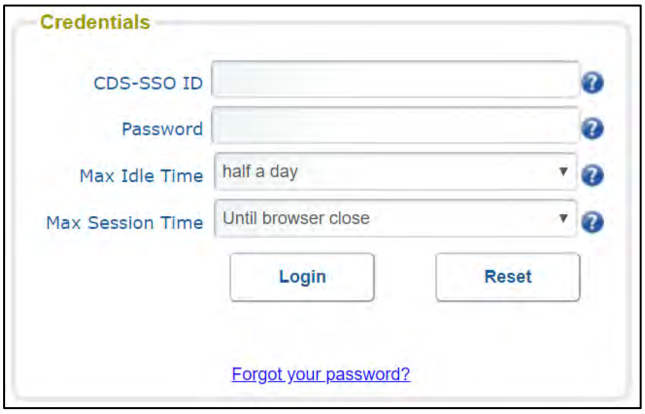


Select the option ***Create my Copernicus SSO account*** and then fill in ALL the fields on the **Copernicus Users' Single Sign On Registration**. Click ***Register***.

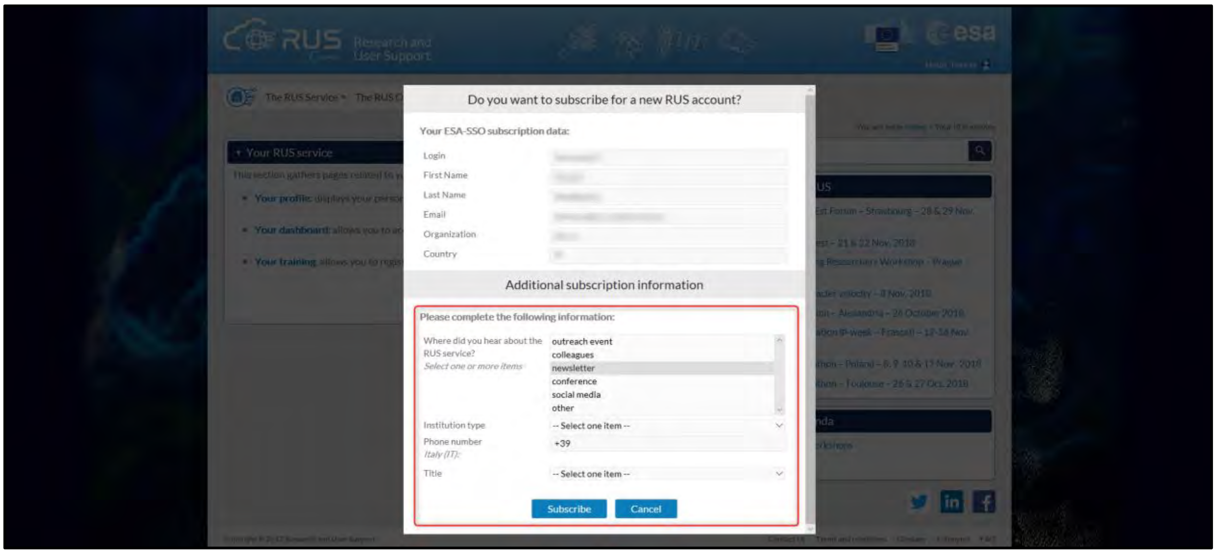


Within a few minutes you will receive an e-mail with activation link. Follow the instructions in the e-mail to activate your account.

You can now return to https://rus-copernicus.eu/, click on ***Login/Register***, choose ***Login*** and enter your chosen credentials.

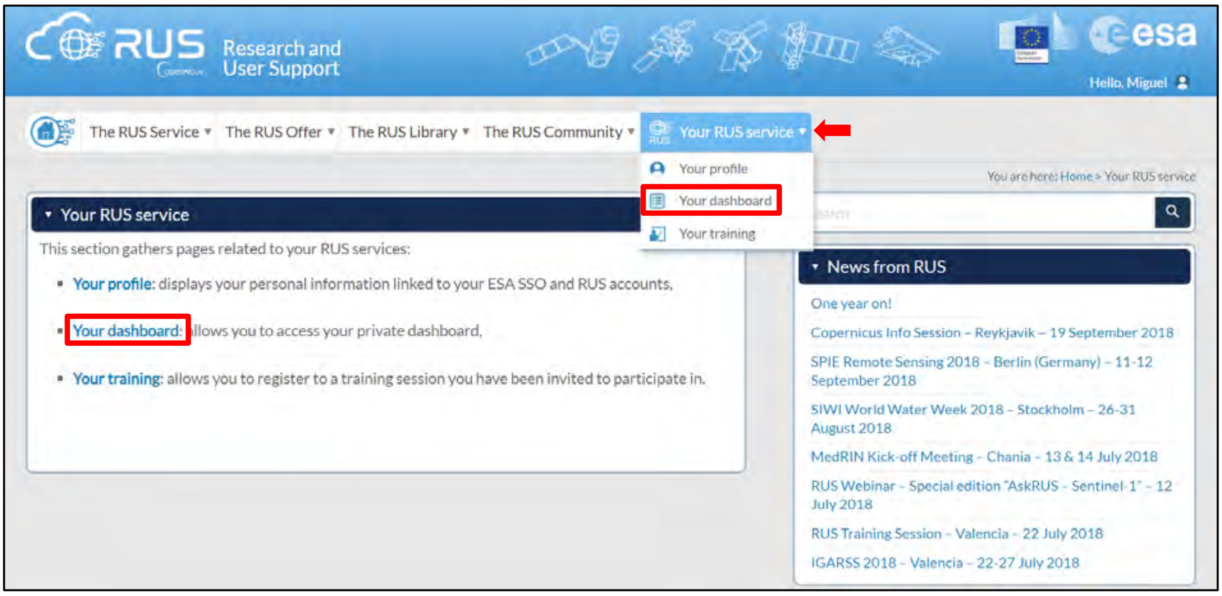


Upon your first login you will need to enter some details. You must fill all the fields.

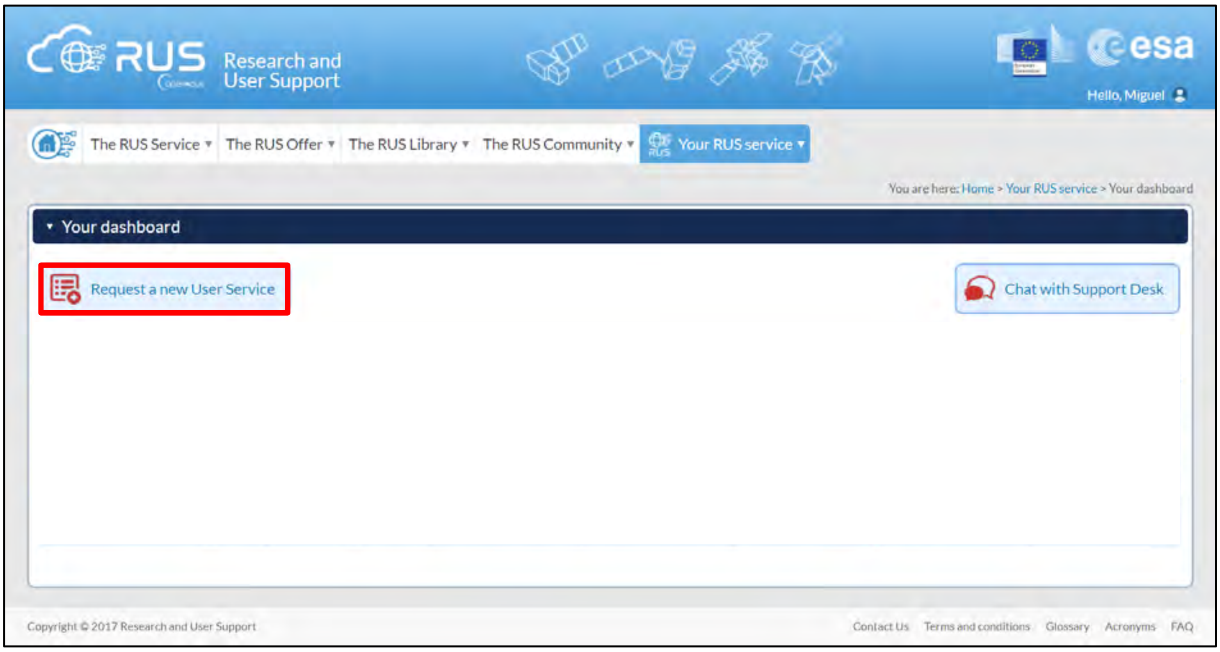


4 Request a RUS Copernicus Virtual Machine

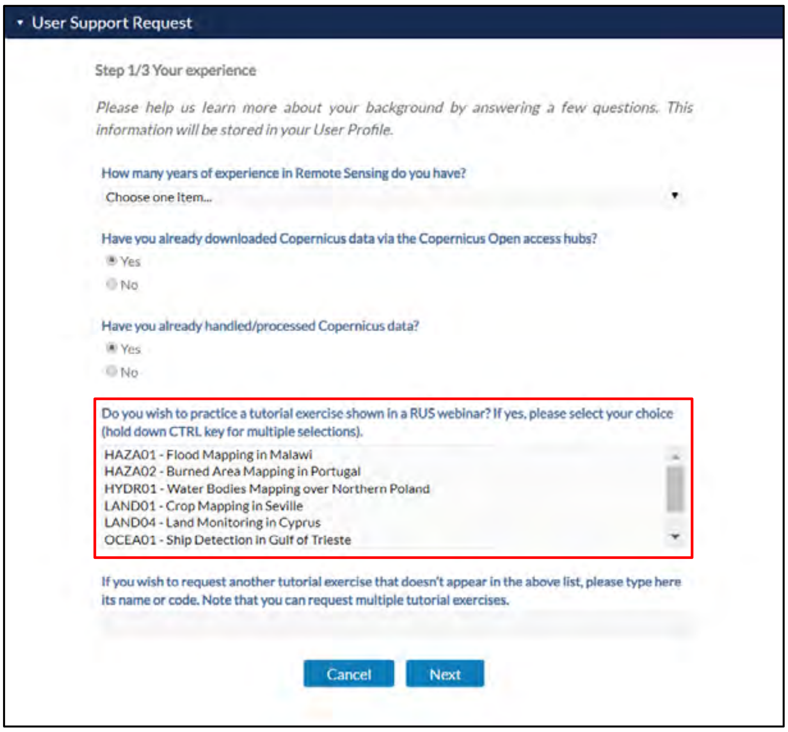
Once you are registered as a RUS user, you can request a RUS Virtual Machine to repeat this exercise or work on your own projects using Copernicus data. For that, log in and click on ***Your RUS Service → Your Dashboard***.



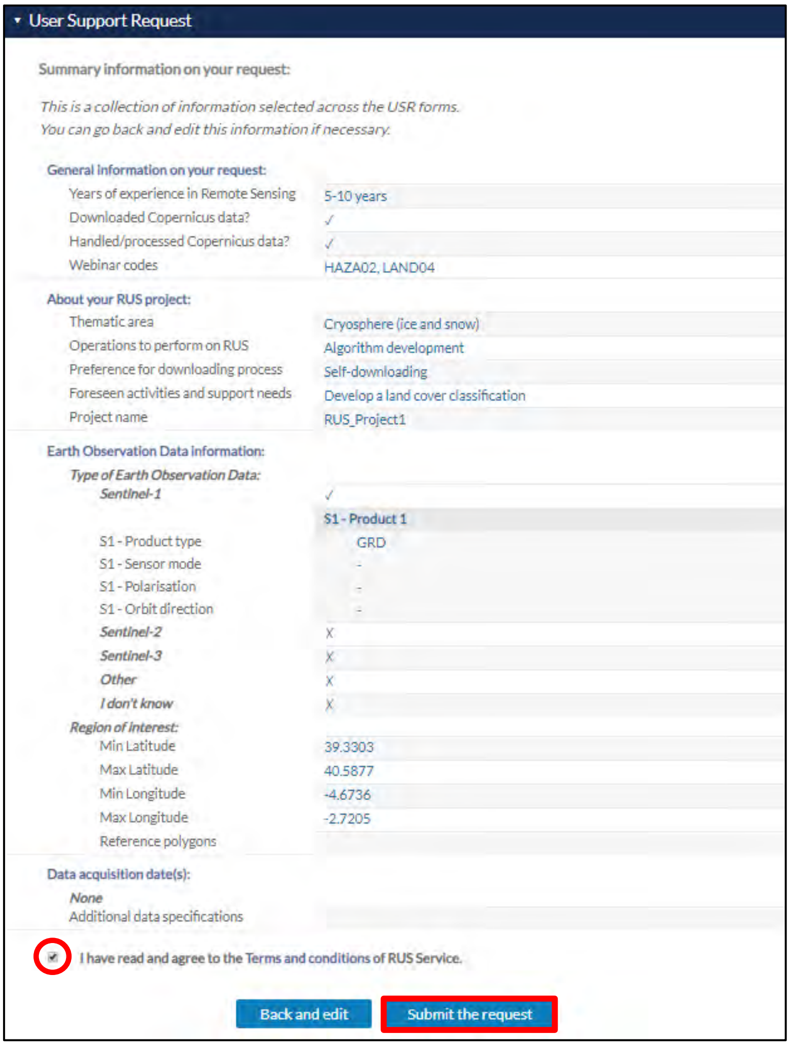
Click on ***Request a new User Service*** to request your RUS Virtual Machine. Complete the form so that the appropriate cloud environment can be assigned according to your needs.



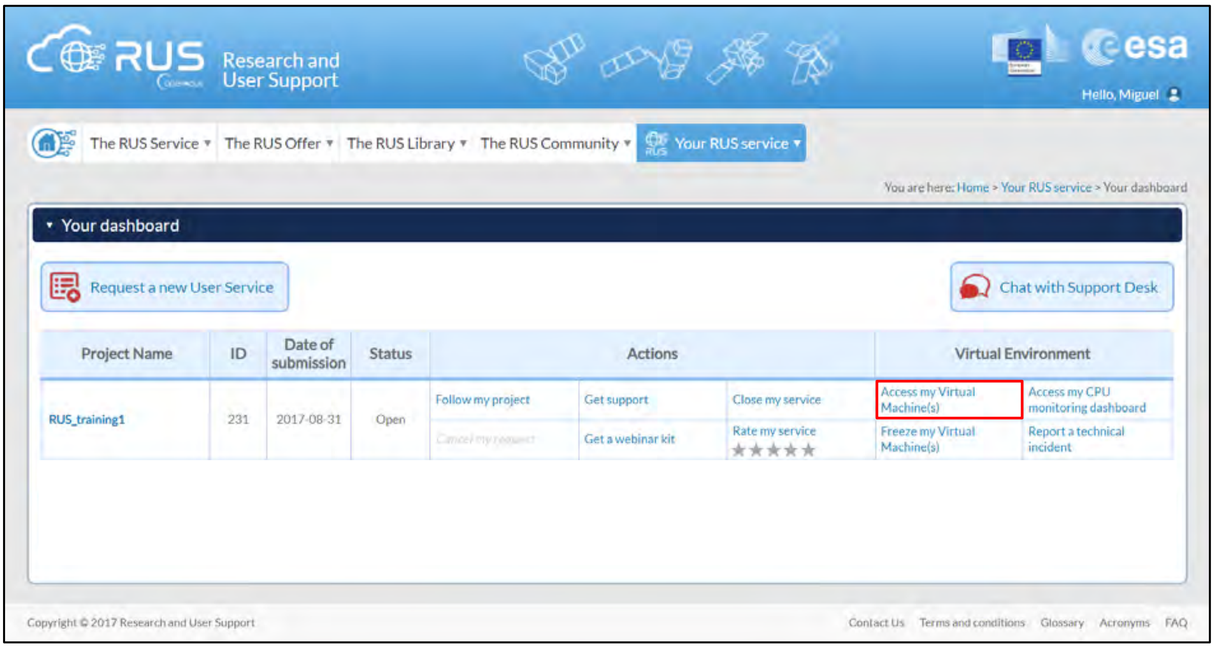
If you want to repeat this tutorial (or any previous one) select the one(s) of your interest in the appropriate field.



Complete the remaining steps, check the terms and conditions of the RUS Service and submit your request once you are finished.



Further to the acceptance of your request by the RUS Helpdesk, you will receive a notification email with all the details about your Virtual Machine. To access it, go to ***Your RUS Service → Your Dashboard*** and click on ***Access my Virtual Machine***.



Fill in the login credentials that have been provided to you by the RUS Helpdesk via email to access your RUS Copernicus Virtual Machine.

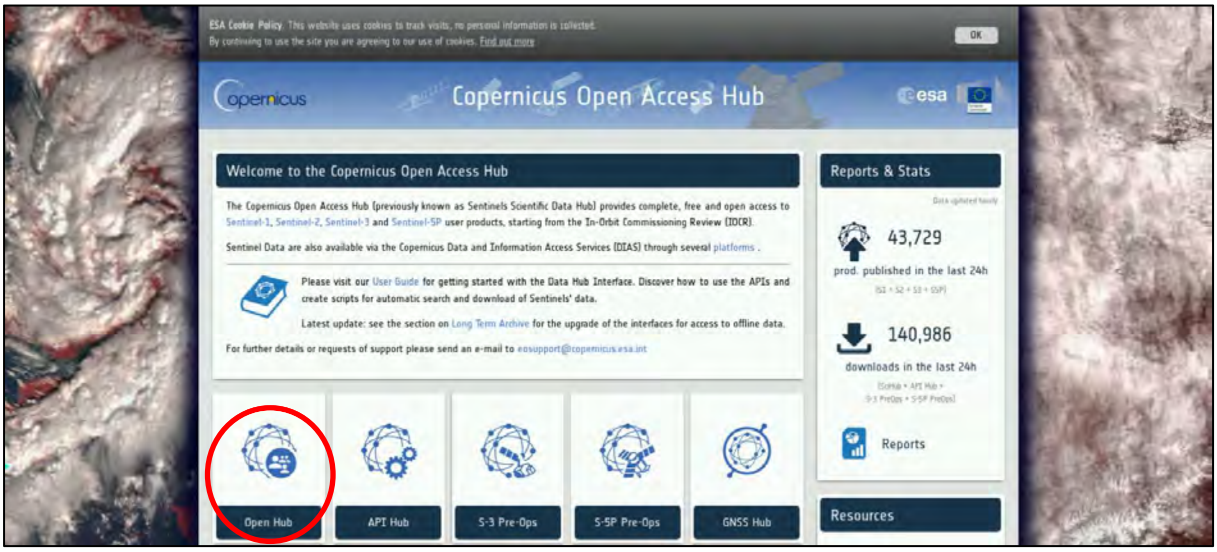
This is the remote desktop of your Virtual Machine.

5 Step by step

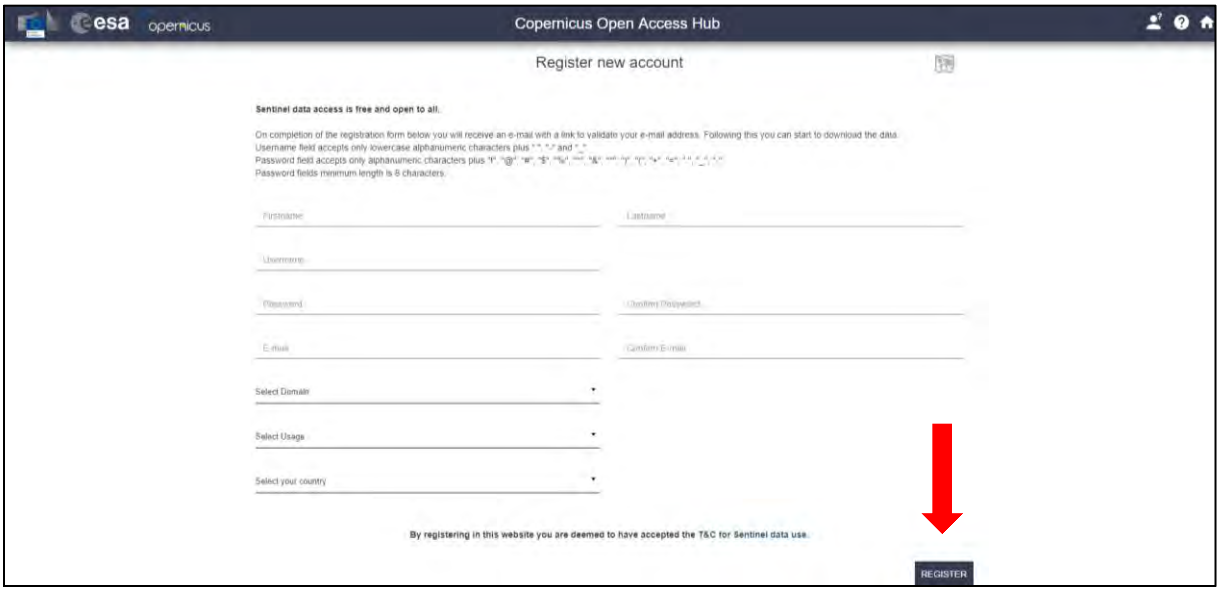
5.1 Data download – ESA SciHUB

In this step, we will download the Sentinel-1 scenes from the Copernicus Open Access Hub using the online interface. Go to **Applications → Network → Firefox 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 by going to "**Sign-up**" in the LOGIN menu in the upper right corner.



After you have 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, “**LOGIN**”.

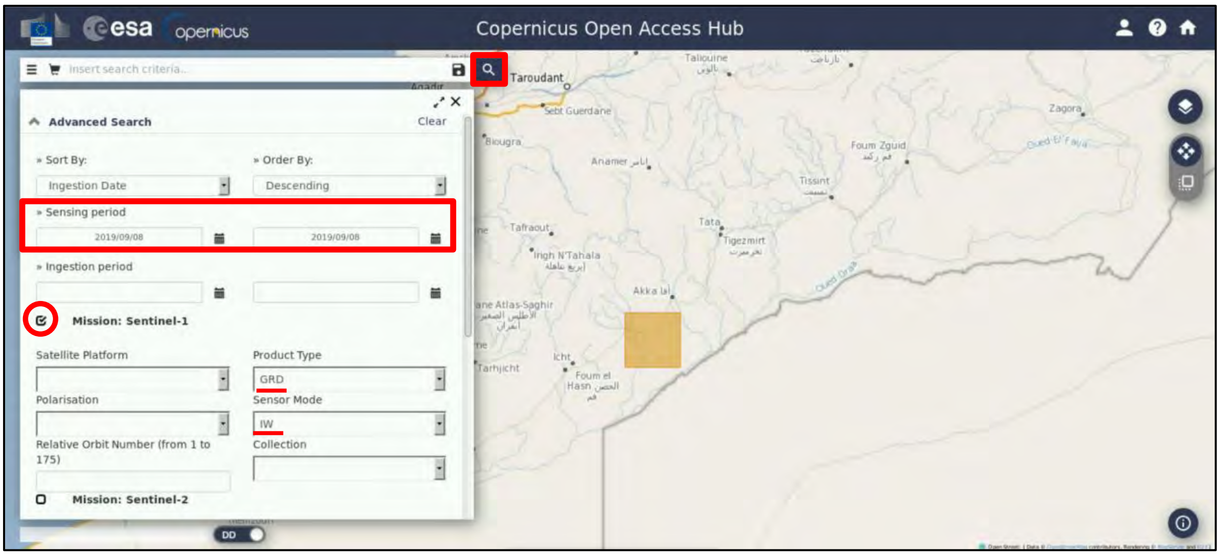
Navigate over Morocco (**approximate area – green rectangle**).

We need to download images over the area of interest for the same date if possible. For Sentinel-1 we will select one on 8 September 2019 and for Sentinel-2 one on 14 September 2019. There is not a Sentinel-2 image available for the 8th of September, so looking for the closest available which would be the most cloudless, we selected the one on September 14 and not on 9th. Depending on the subset you want to create, you might be able to use the cloud free parts of the image acquired on 9th.

Zoom in to the south-east area of Anti-Atlas Mountains, switch to “**drawing mode**” and draw a search rectangle approximately as indicated below. Open the search menu by clicking to the left part of the search bar. We will first specify the parameters for Sentinel-1 and then for Sentinel-2.

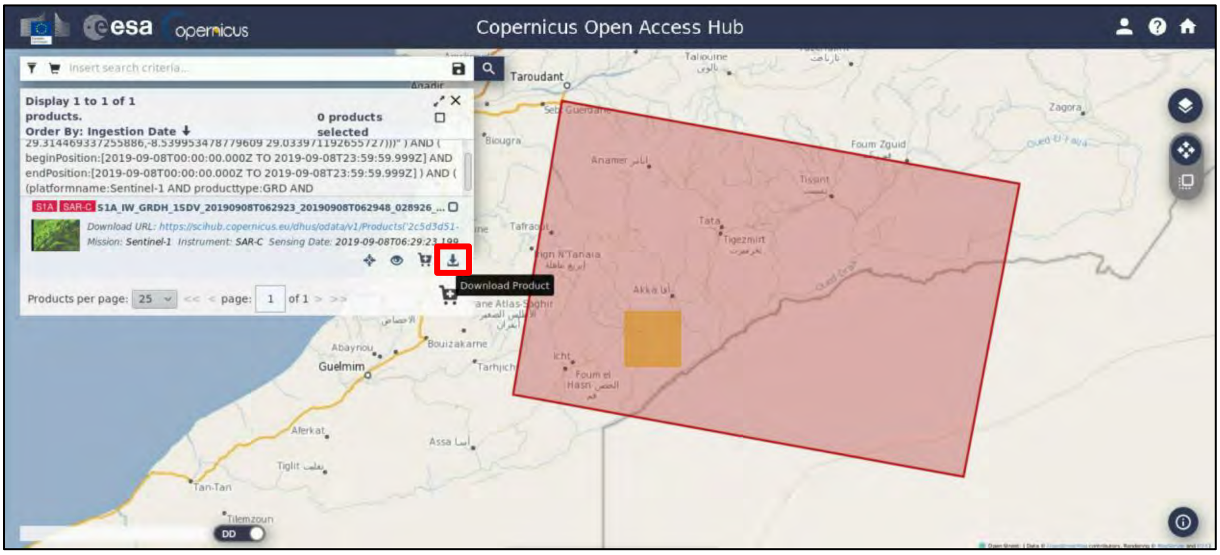
For Sentinel-1:

Sensing period: From 2019/09/08 to 2019/09/08
Select: Mission: Sentinel-1
Product Type: GRD
Sensor Mode: IW



Then click on the “**Search**” icon. The search returns 1 result for the time period we set. Download the image by clicking on the “**Download Product**” icon:

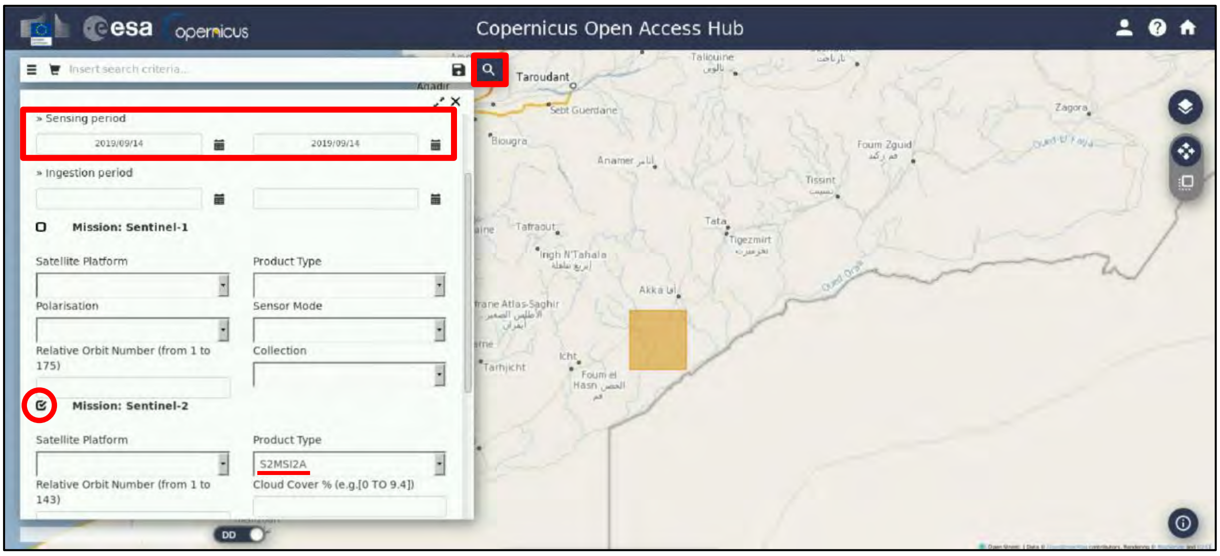
S1A_IW_GRDH_1SDV_20190908T062923_20190908T062948_028926_03478B_AE88



Return to the search menu, deselect Sentinel-1 mission, and apply the following steps.

<u>For Sentinel-2:</u>

Sensing period: From 2019/09/14 to 2019/09/14
Select: Mission: Sentinel-2
Product Type: S2MSI2A



Then click on the “**Search**” icon. The search returns 1 result for the time period we set. Download the image by clicking on the “**Download Product**” icon:

S2B_MSIL2A_20190914T110649_N0213_R137_T29RNN_20190914T142009

The products will be downloaded at ***/home/rus*** as zip files*.* Move them to: ***/shared/Training/GEOL01_LithologicalClassification_Morocco_TutorialKit/Original*** folder.

5.2 SNAP – open and explore data

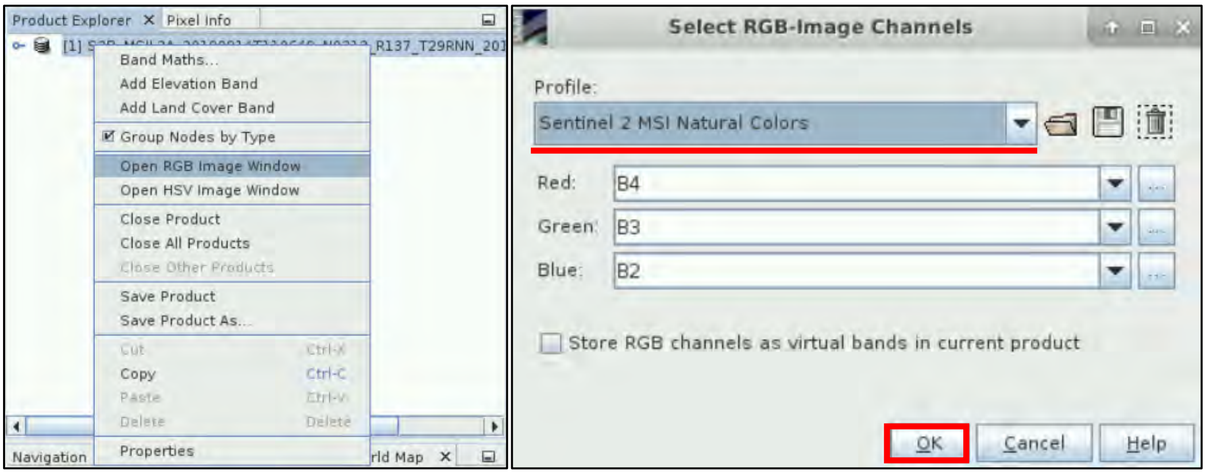
Open **SNAP** software from the icon located on the desktop or go to **Applications → Processing → SNAP Desktop**. Click the **Open Product** icon , navigate to: ***/shared/Training/GEOL01_Lithological Classification_Morocco_TutorialKit/Original*** folder and open the Sentinel-2 product:

S2B_MSIL2A_20190914T110649_N0213_R137_T29RNN_20190914T142009.zip

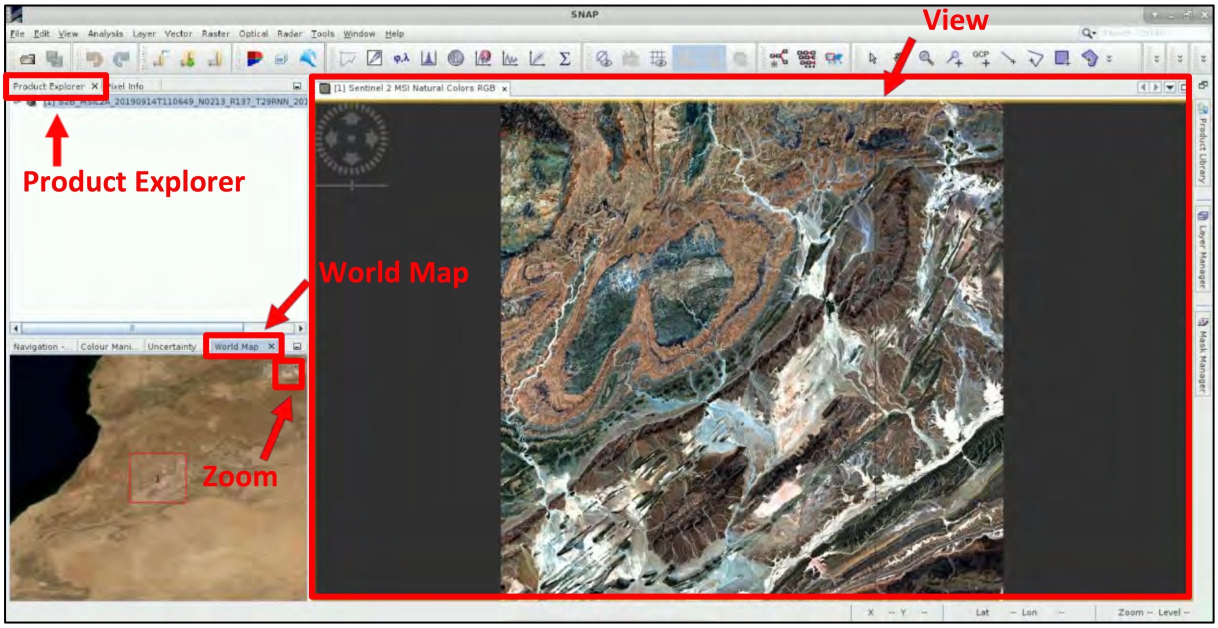
or just open a folder in your VM, navigate to the path mentioned above and then drag the product from the folder and drop it to the **Product Explorer** Window.

5.2.1 Create RGB Image

Go to the opened product in the **Product Explorer** window, right click on it, and select from the menu "**Open RGB Image Window**". Select at **Profile: Sentinel 2 MSI Natural Colors** and at the bands keep on Red: B4, Green: B3, Blue: B2. Then click **OK** and the new RGB image of natural colors will appear at the **View Window.**

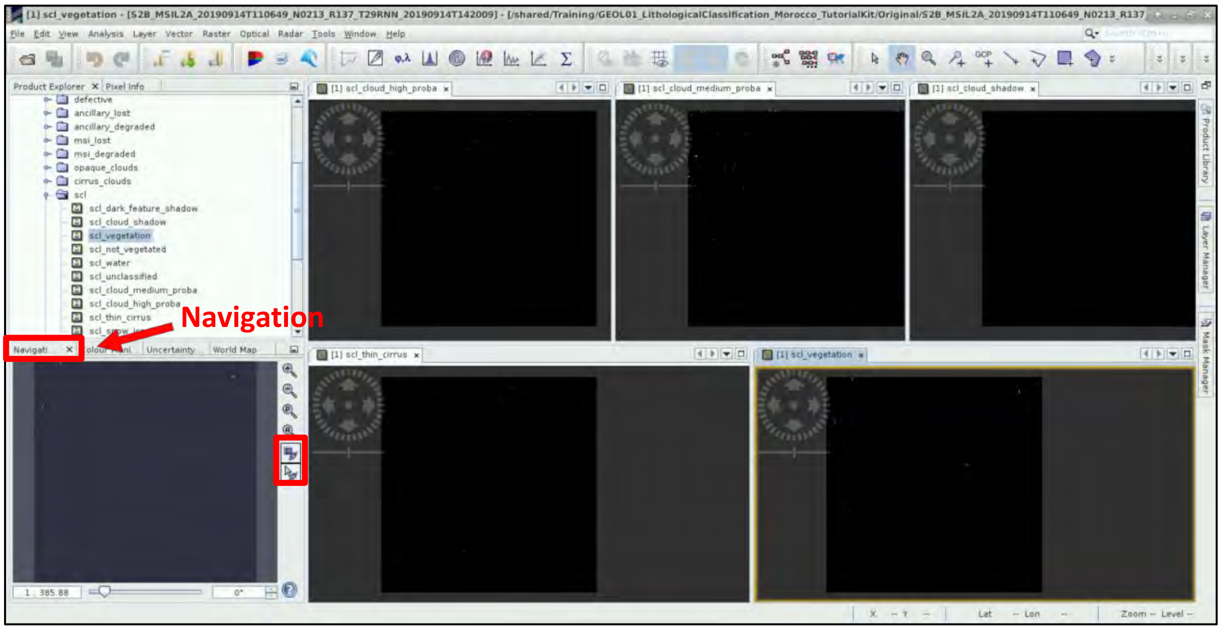


You can go to the **World Map** tab and zoom in to see the location of the opened product on the globe.



Click on the expand icon or **+** to expand the contents of product **[1]**, then expand **Bands** folder, then expand the **scl** folder (See NOTE 1) and double click on the following bands to visualize them in the **View** window: **scl_cloud_shadow**, **scl_cloud_medium_proba**, **scl_cloud_high_proba** and **scl_thin_cirrus** in order to see if there are any clouds at the image and the **scl_vegetation** band to check how much of the area is vegetated. The areas with clouds and vegetation will be visualized with white pixels.

Go to **Window → Tile Evenly** so that you can see all the opened bands at the same time. Go to the **Navigation** tab and click on the two icons shown within the red rectangular below to synchronize the views and the cursor position between the views.



If we zoom in, we will see that there are very few white pixels in all of them: very little clouds and vegetation, meaning that they will not affect our processing. Then you can close all opened views.

NOTE 1: You can find more information about the **S**cene **Cl**assification map (**scl** folder context) here: https://sentinel.esa.int/web/sentinel/user-guides/sentinel-2-msi/processing-levels/level-2

5.3 *Sentinel-2 Processing*

Let's start with the Sentinel-2 processing steps. The operators that will be used are the following, and we will explain each one of them more analytically:

5.3.1 Resample

First, we need to resample all the 13 spectral bands of the product in order to have them in the same spatial resolution (See NOTE 2).

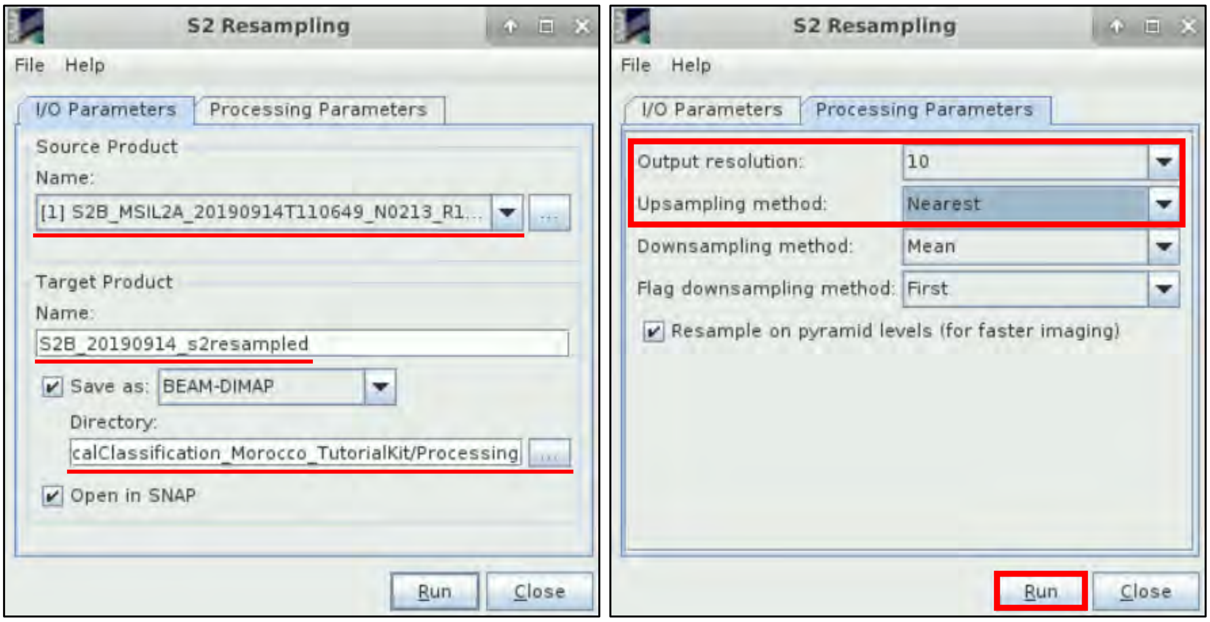
Go to **Optical → Geometric → S2 Resampling Processor**.

In the **I/O Parameters** tab set as:

Source Product Name: S2B_MSIL2A_20190914T110649_N0213_R137_T29RNN_20190914T142009
Target Product Name: S2B_20190914_s2resampled
Directory: */shared/Training/GEOL01_LithologicalClassification_Morocco_TutorialKit/Processing*

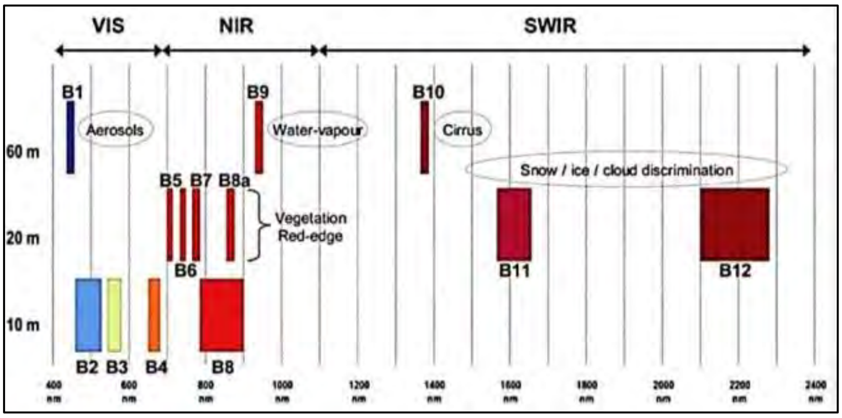
In the **Processing Parameters** tab set as:

Output resolution: 10
Upsampling method: Nearest
Keep **the Downsampling method** and the **flag downsampling method** as by default, and make sure that the "**Resample on pyramid levels (for faster imaging)**" option, is selected.



Click **Run**. The new product will appear at the **Product Explorer** window.

TIP 1: The S2 Resampling processing is quite heavy and time demanding. If you want to complete it faster, select as **Output resolution:** 20 or create a smaller subset.



Source: ESA 2015

NOTE 2: 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).

This option allows to resample Sentinel-2 products having into account the particularities of the angle bands. This operator uses not only the angles bands but also the detector footprints. By using the footprints, it is possible to "isolate" the angles of each detector and interpolate them without using the angle information of the adjacent detectors (which causes the blurring). (SNAP Help)

5.3.2 Subset

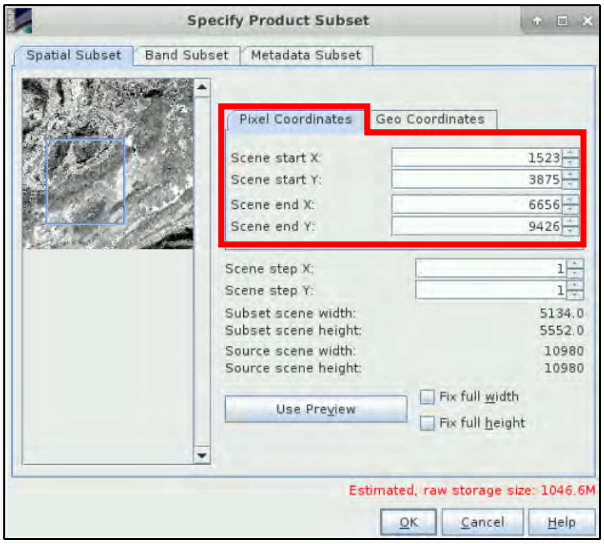
Since we do not need to process the whole image, we will create a subset of it over our area of interest.

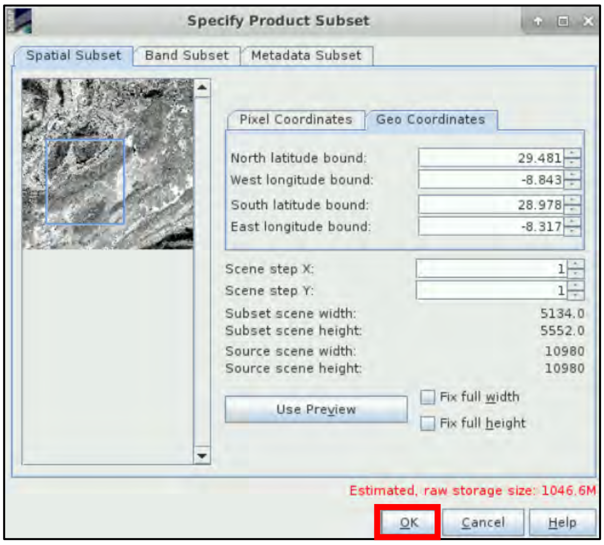
Go to **Raster → Subset**.

In the **Spatial Subset** tab, go to **Pixel Coordinates** tab and set the following parameters:

Scene start X: 1523 **Scene start Y:** 3875 **Scene end X:** 6656 **Scene end Y:** 9426

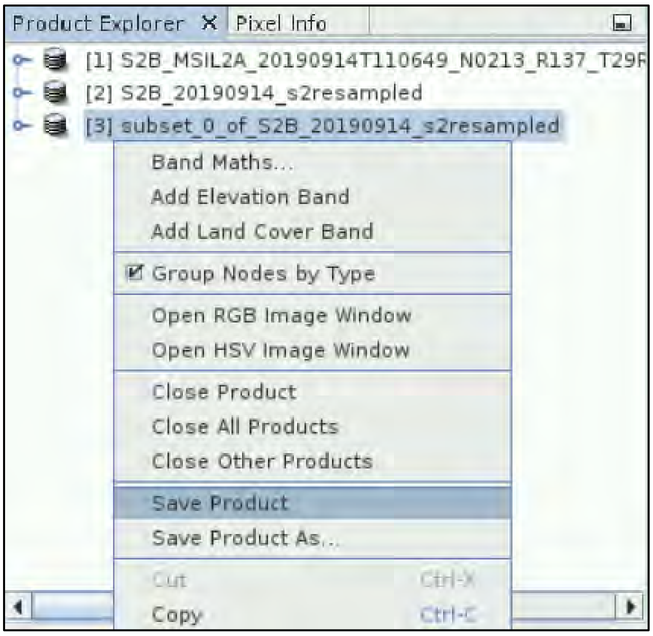
TIP 2: Go to the **Geo Coordinates** tab, and write down the values for the **North latitude bound**, **West longitude bound**, **South latitude bound** and **East longitude bound**, because we will need them for the second subset part of the Sentinel-1 processing, at ***5.4.9 Subset*** chapter.

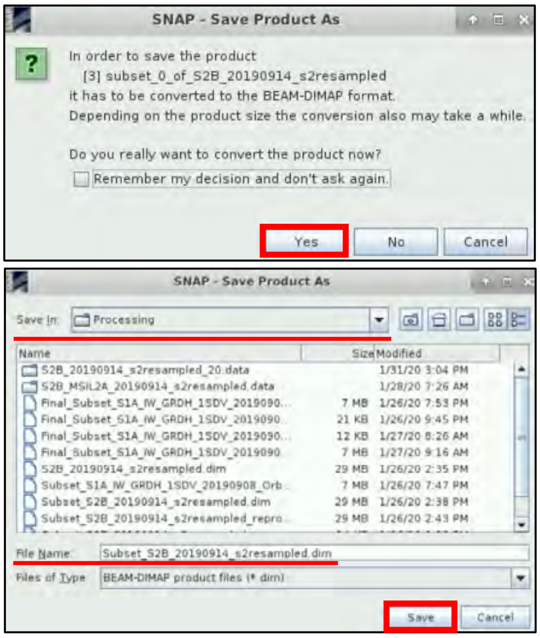




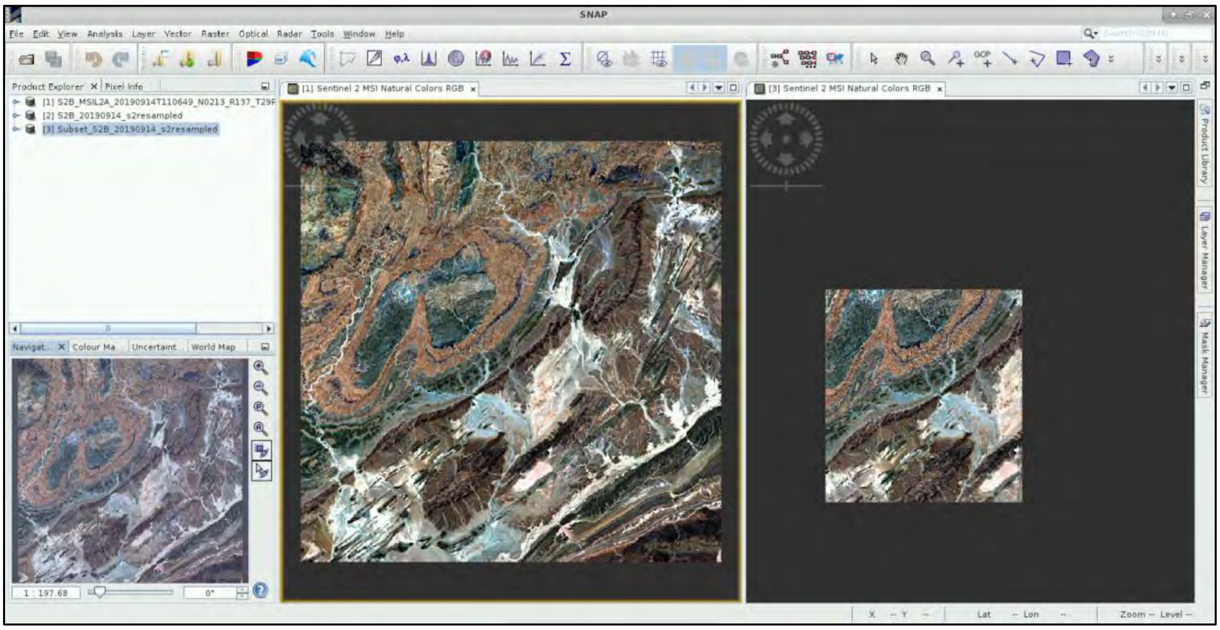
Click **OK**. The **subset_0_of_S2b_20190914_s2resampled** product, will appear at the **Product Explorer** window. Right click on it, select **Save Product**, then click **Yes** on the window that appears.

Navigate to ***/shared/Training/GEOL01_LithologicalClassification_Morocco_TutorialKit/Processing*** path and **Save** it with the **File Name:** Subset_S2B_20190914_s2resampled.





Then go to the subset at the **Product Explorer** window, right click on it, select **Close Product** and then load in SNAP the lately saved subset. Create RGB images for both the original and the subset products, go to **Window → Tile Horizontally** and view/compare the two images.



5.3.3 Reproject

We need to convert the coordinate reference system of our product from UTM to **Geographic Lat/Lon WGS84**, otherwise we currently cannot continue to the Classification steps.

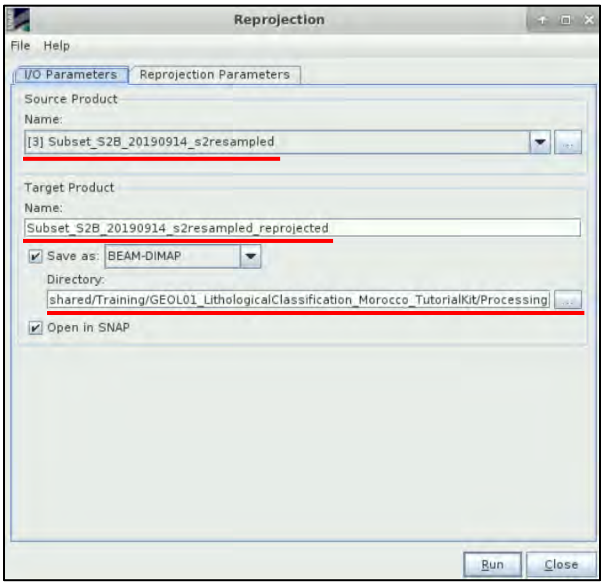
Go to **Raster → Geometric Operations → Reprojection**.

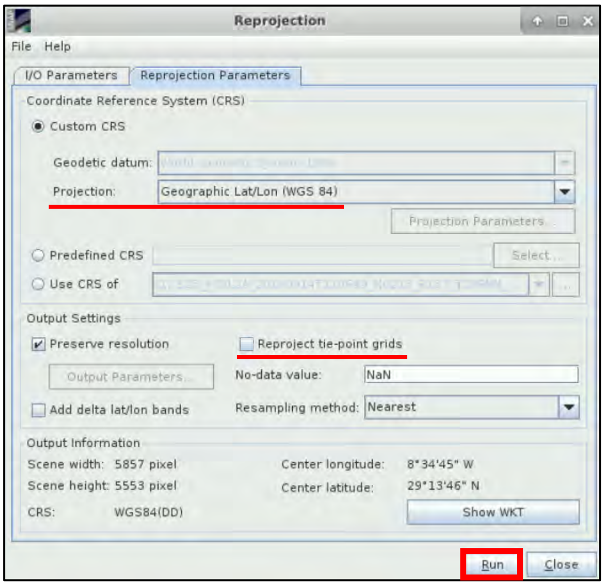
In the **I/O Parameters** tab set as:

Source Product Name: S2B_20190914_s2resampled
Target Product Name: Subset_S2B_20190914_s2resampled_reprojected
Directory: */shared/Training/GEOL01_LithologicalClassification_Morocco_TutorialKit/Processing*

In the **Reprojection Parameters** tab set:

At Coordinate Reference System (CRS), under **Custom CRS**, **Projection**: Geographic Lat/Lon (WGS84)
Deselect the "Reproject tie-point grids" option.





Click **Run**. The new product will appear at the **Product Explorer** window. Now we can continue with the classification steps. Close all the previously opened view windows in SNAP.

5.3.4 Unsupervised Classification

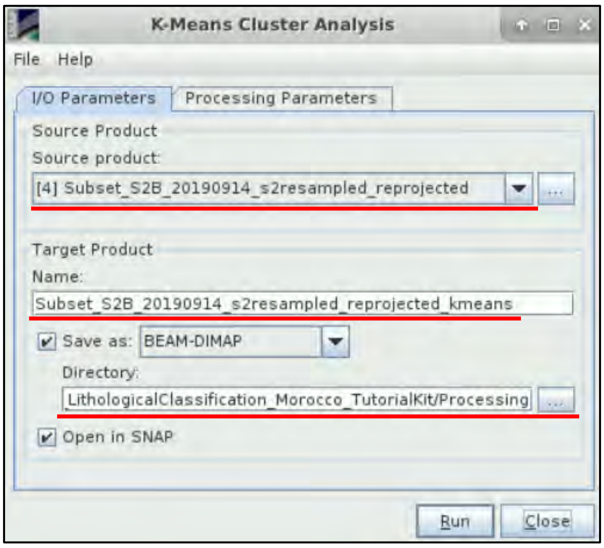
First, we will apply an unsupervised classification by using the K-Means Cluster Analysis. This way, all pixels of our product will be classified in the most appropriate cluster (See NOTE 3).

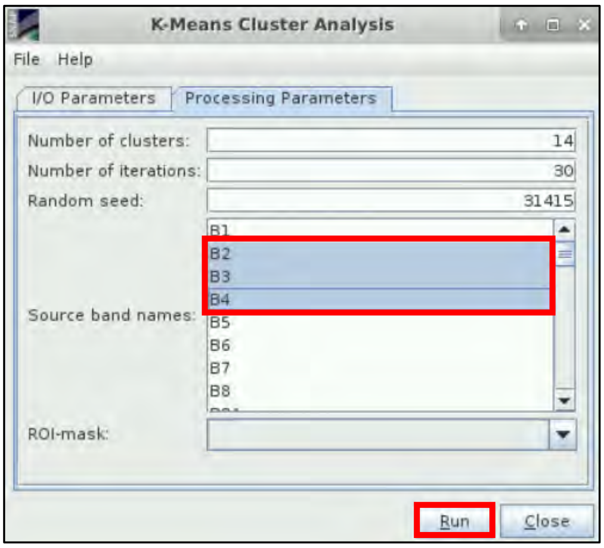
Go to **Raster → Classification → Unsupervised Classification → K-Means Cluster Analysis.**

In the **I/O Parameters** tab set as:

Source Product: Subset_S2B_20190914_s2resampled_reprojected
Target Product Name: Subset_S2B_20190914_s2resampled_reprojected_kmeans
Directory: */shared/Training/GEOL01_LithologicalClassification_Morocco_TutorialKit/Processing*

In the **Processing Parameters** tab, keep the **Number of clusters**, **Number of iterations** and **Random seed** as by default, and at the **Source bands names**, press Ctrl and select only the B2, B3 and B4.





Click **Run**. The new product will appear at the **Product Explorer** window.

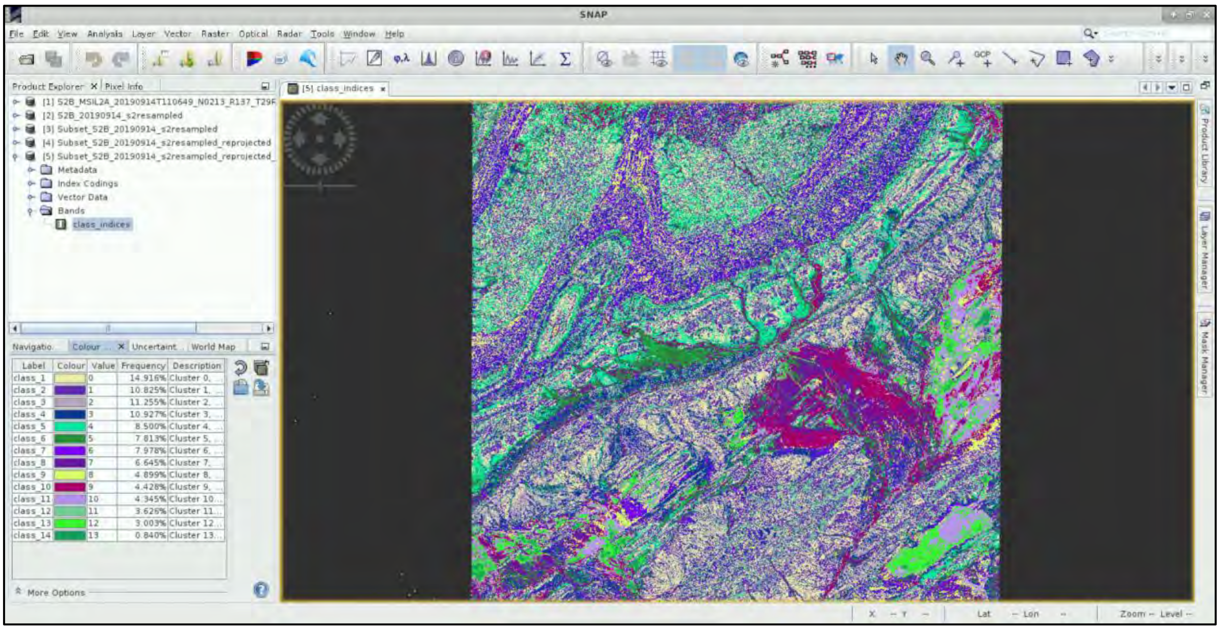
NOTE 3: Cluster analysis is the classification of objects into different groups, so that the data in each subset **share** some **common trait**. The **k-means** clustering tool, **randomly chooses k pixels** whose samples define the initial cluster centers, **assign each pixel to the nearest cluster center** as defined by the Euclidean distance and recalculate the cluster centers as the arithmetic means of all samples from all pixels in a cluster (the last two are being repeated until the convergence criterion is met). Finally, the convergence criterion is met when the maximum number of iterations specified by the user is exceeded or when the cluster centers did not change between two iterations. (SNAP Help)

Now go to the **Subset_S2B_20190914_s2resampled_reprojected_kmeans** product at the **Product Explorer** window, expand it, then expand the **Bands** folder and double click on the **class_indices** band to visualize it.

You can also go at the **Colour Manipulation** tab and get information about each class, like the frequency.

We can see how all pixels have been classified and export the view in .tif and/or .kmz format for further steps.

Label	Colour	Value	Frequency	Description
class_1		0	14.916%	Cluster 0, ...
class_2		1	10.825%	Cluster 1, ...
class_3		2	11.255%	Cluster 2, ...
class_4		3	10.927%	Cluster 3, ...
class_5		4	8.500%	Cluster 4, ...
class_6		5	7.813%	Cluster 5, ...
class_7		6	7.978%	Cluster 6, ...
class_8		7	6.645%	Cluster 7, ...
class_9		8	4.899%	Cluster 8, ...
class_10		9	4.428%	Cluster 9, ...
class_11		10	4.345%	Cluster 10...
class_12		11	3.626%	Cluster 11...
class_13		12	3.003%	Cluster 12...
class_14		13	0.840%	Cluster 13...

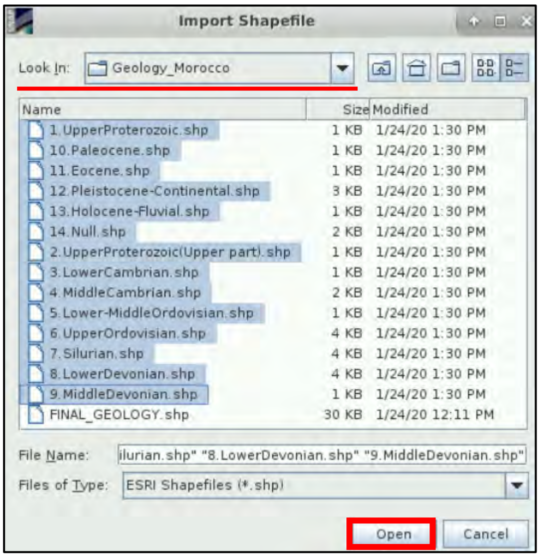


5.3.5 Supervised Classification

In order to continue to the supervised classification, we need to import the shapefiles with the geology of the area and then create training data for each different lithology. In this case the training data have already been created and will be loaded on the **Subset_S2B_20190914_s2resampled_reprojected** product. The classifier we will use is **Random Forest Classifier**.

Select the **Subset_S2B_20190914_s2resampled_reprojected** product at the **Product Explorer** window and go to **Vector → Import → ESRI Shapefile**.

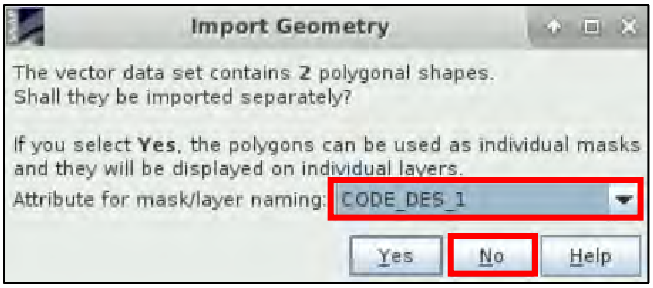
Navigate to ***/shared/Training/GEOL01_LithologicalClassification_Morocco_TutorialKit/AuxData*** folder, open the **Geology_Morocco** folder and select all shapefiles with numbering from 1 to 14 (apart from the FINAL_GEOLOGY.shp) and click **Open**.



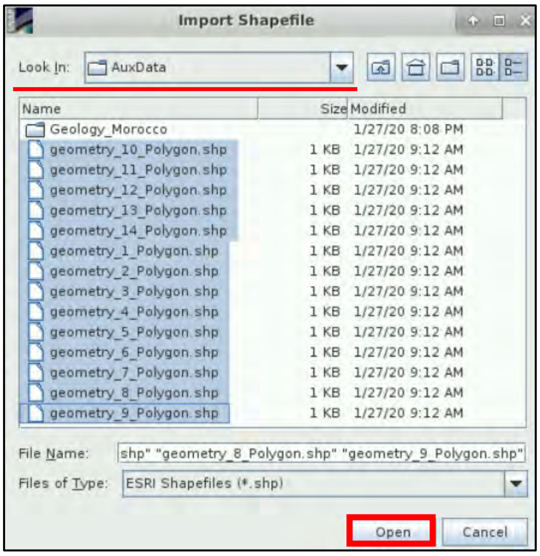
In the **Import Geometry** window that will appear, select for each shapefile:

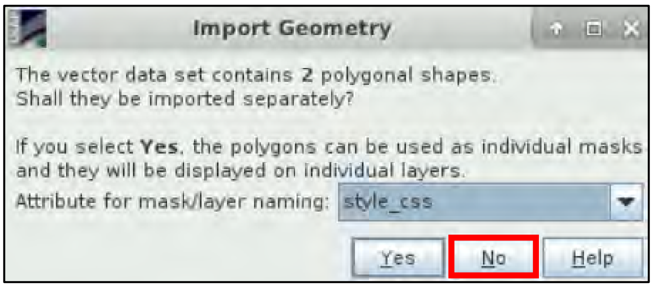
Attribute for mask/layer naming: CODE_DES_1
Click **No** so that all the polygons that correspond to the same lithology, will be displayed on one layer.

Repeat for all shapefiles until they are all imported.



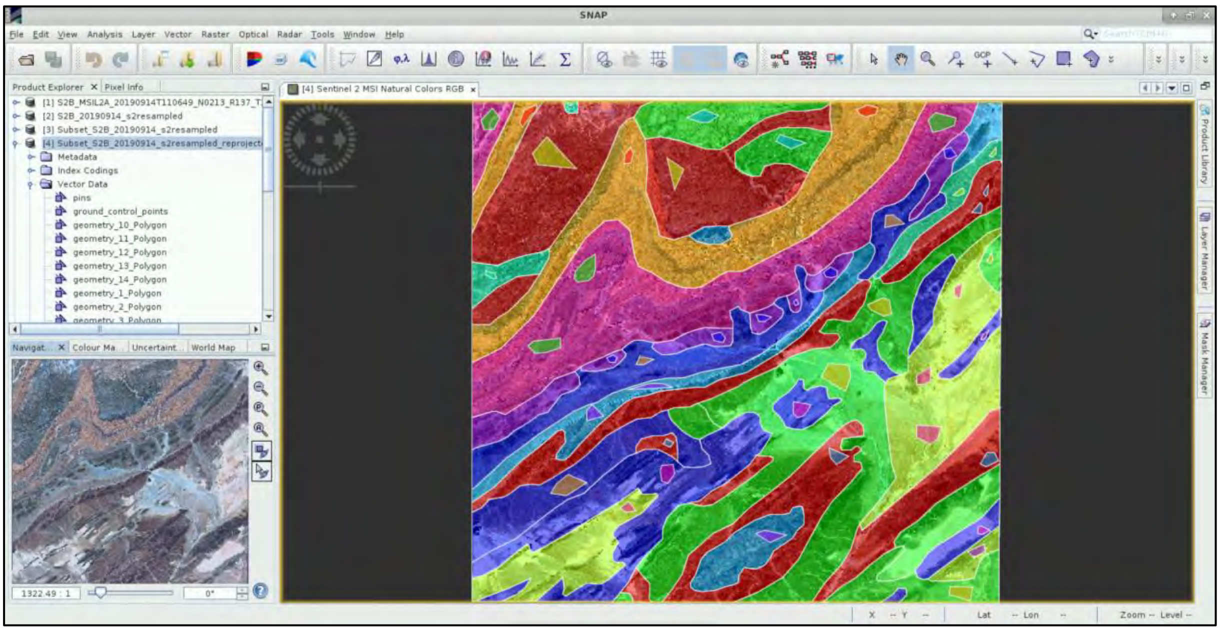
Now also import the training data. Go again to **Vector → Import → ESRI Shapefile**, and from the **AuxData** folder, select and open all **geometry_xx_Polygon.** Click **No** to the **Import Geometry** window.





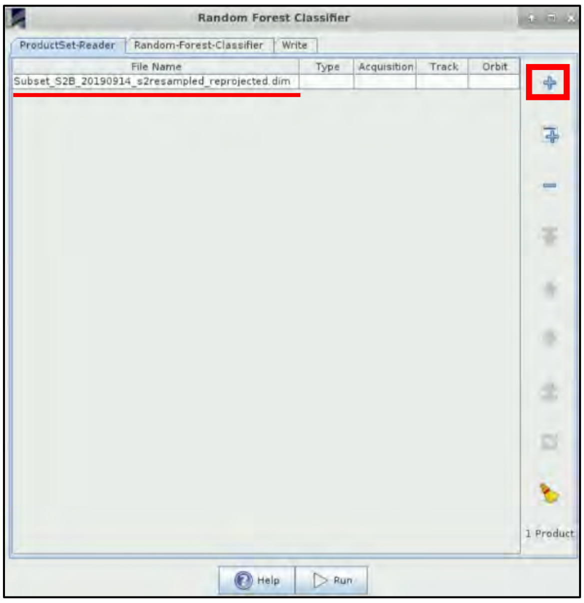
Go to the **Subset_S2B_20190914_s2resampled_reprojected** product and expand the **Vector Data** folder. You will see that all the shapefiles we have imported are now in that folder as in the following image.

Right click on the product and select **Save Product**, to save the imported data.



Go to **Raster → Classification → Supervised Classification → Random Forest Classifier**.

In the **ProductSet-Reader** tab, click on ➕, navigate to ***/shared/Training/GEOL01_LithologicalClassification_Morocco_TutorialKit/Processing*** and add this product: **Subset_S2B_20190914_s2resampled_reprojected**



In the **Random-Forest-Classifier** tab set as:

Select **Train and apply classifier**: newClassifier_S2
Keep **Train on Vectors** and **Evaluate classifier** selected
Keep **Number of training samples** and **Number of trees** as by default

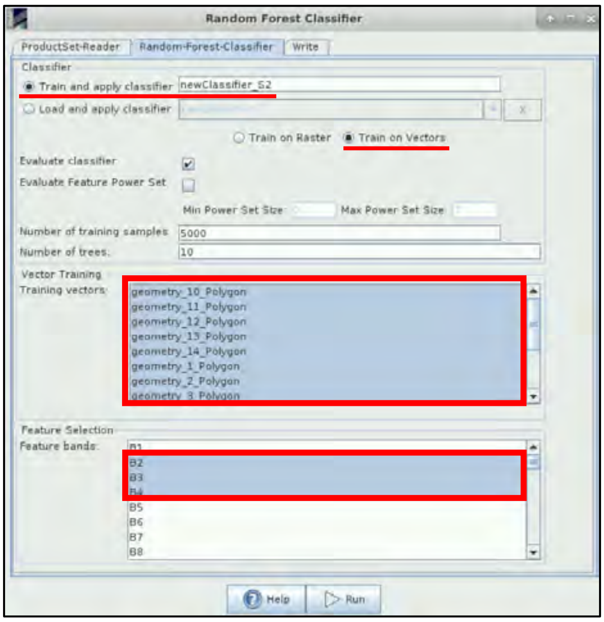
In the **Training vectors** select all "geometry_xx_Polygon"

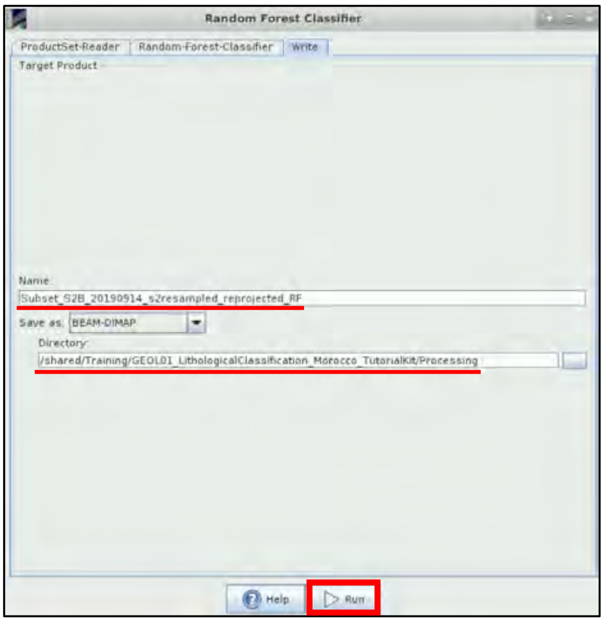
In the **Feature bands** select only B2, B3 and B4.

In the **Write** tab set as:

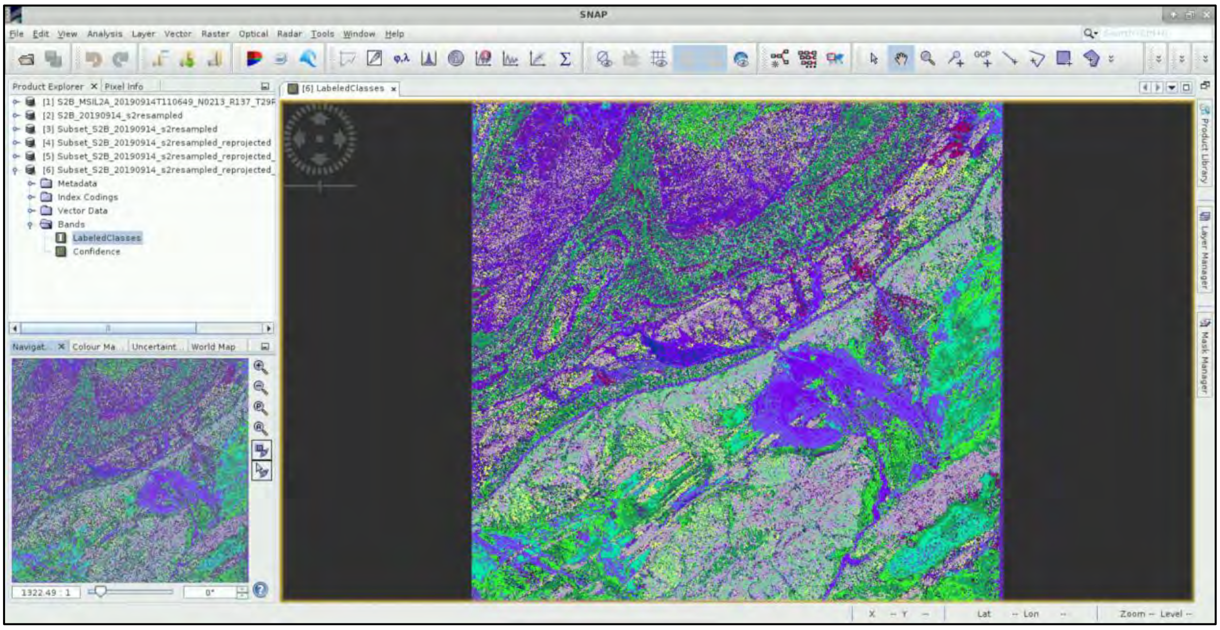
Name: Subset_S2B_20190914_s2resampled_reprojected_RF
Directory: */shared/Training/GEOL01_LithologicalClassification_Morocco_TutorialKit/Processing*

Click **Run**. The new product will appear at the **Product Explorer** window (See NOTE 4).

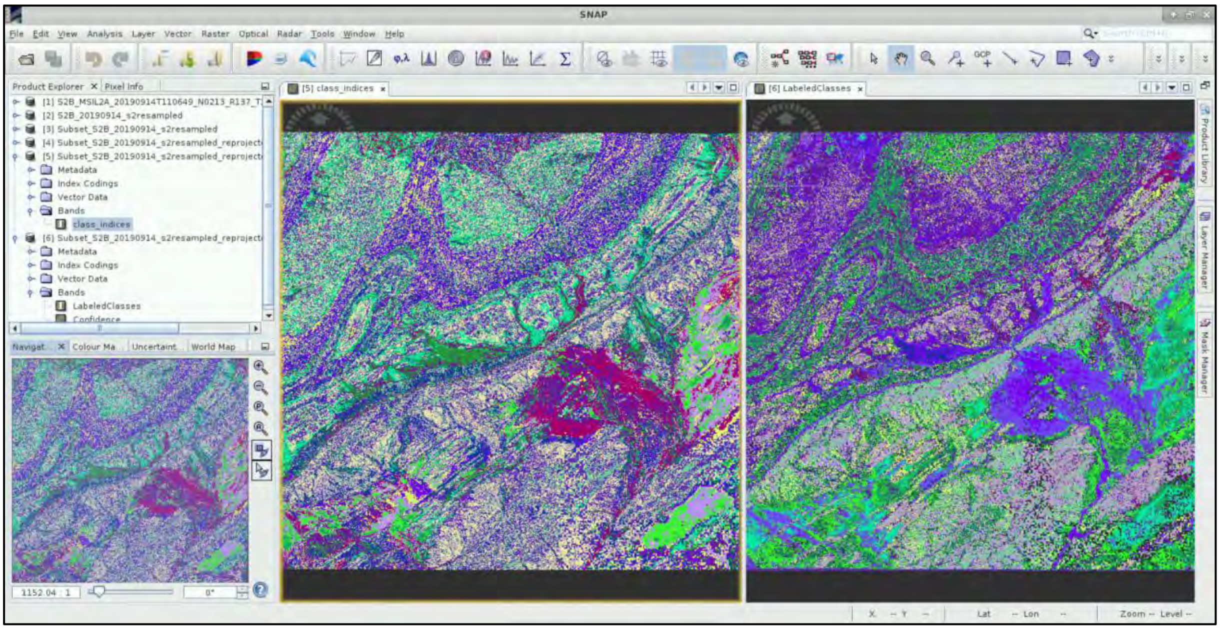


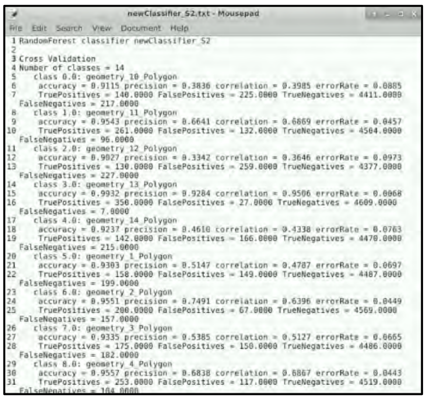


Now go to the **Subset_S2B_20190914_s2resampled_reprojected_RF** product at the **Product Explorer** window, expand it, then expand the **Bands** folder and double click on the **LabelledClasses** band to visualize it (See NOTE 5). In case you see the shapefiles imported initially, go to *Vector Data* folder, select them, right-click and **Delete** them.



Open the **class_indices** band from **Subset_S2B_20190914_s2resampled_reprojected_kmeans** product as well, go to **Window → Tile Horizontally** and compare the results of the two different classifications. We can see that the results from both Unsupervised and Supervised Classification are quite good, and by creating appropriate training data, the Supervised Classification is more accurate.

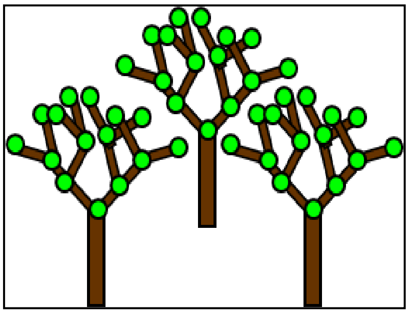




NOTE 4: When running Fandom Forest Classification, a *.txt* file is being created.

It contains information about the classes, like accuracy, precision and correlation of each class/polygon we have created with our training data.

Go to **File → Save as**. Save the file with name: **newClassifier_S2** at this folder: ***/shared/Training/GEOL01_LithologicalClassification_Morocco_TutorialKit/Processing***



NOTE 5: The **Random Forest** algorithm is a **machine learning technique** that can be used for classification or regression. In opposition to parametric classifiers (e.g. Maximum Likelihood), a machine learning approach does not start with a data model but instead learns the relationship between the training and the response dataset. The **Random Forest classifier** is an aggregated model, which means it **uses the output from different models** (trees) **to calculate the response variable**.

Decision trees are predictive models that recursively split a dataset into regions by using a set of binary rules to calculate a target value for classification or regression purposes. Given a training set with n number of samples and m number of variables, a random subset of samples n is selected with replacement (bagging approach) and used to construct a tree. At each node of the tree, a random selection of variables m is used and, out of these variables, only the one providing the best split is used to create two sub-nodes.

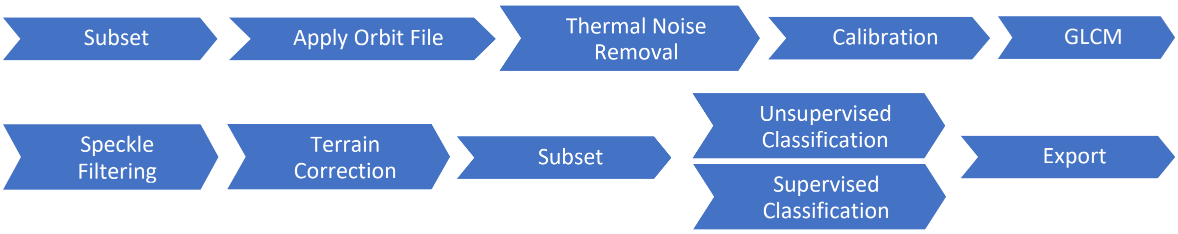
By combining trees, the forest is created. Each pixel of a satellite image is classified by all the trees of the forest, producing as many classifications as number of trees. Each tree votes for a class membership and then, the class with the maximum number of votes is selected as the final class. (SNAP Help)

More information about Random Forest can be found in Breiman, 2001.

You will find information on how to export Sentinel-2 and Sentinel-1 products with the classification outputs at the ***5.5 Export Products*** chapter.

5.4 Sentinel-1 Processing

Now we will continue with the Sentinel-1 processing steps. The operators that will be used are the following, and we will explain each one of them more analytically:



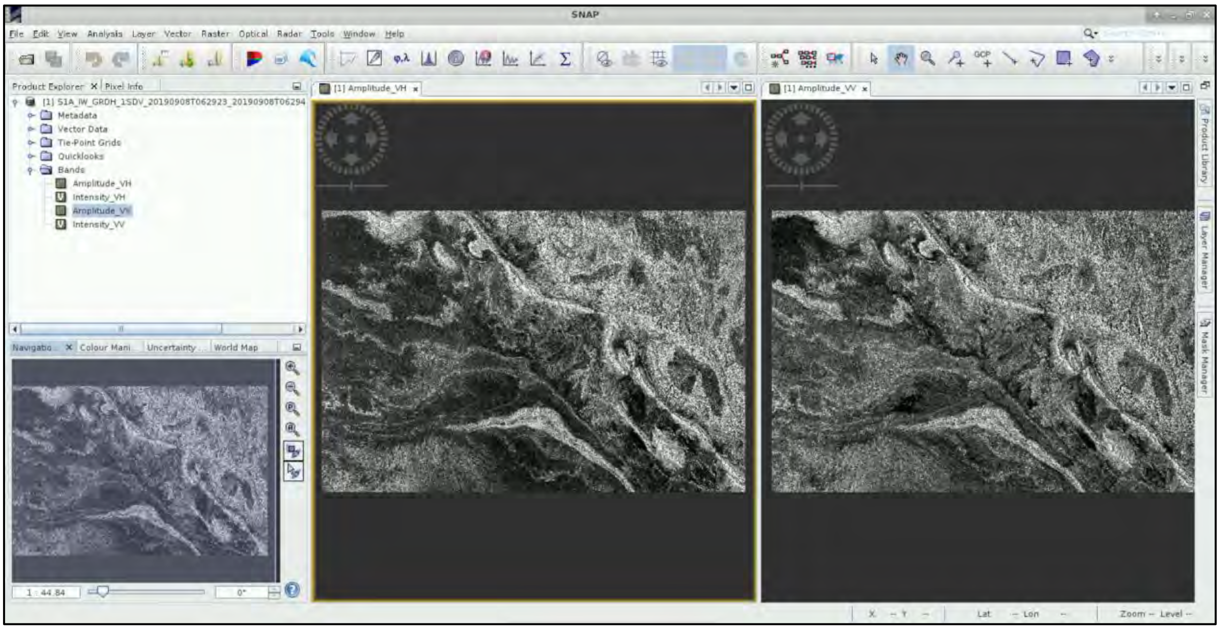
First, close SNAP to empty the cache from all Sentinel-2 processing and open it again. If any window pops up, select **No**.

Navigate to: ***/shared/Training/GEOL01_LithologicalClassification_Morocco_TutorialKit/Original*** folder and open the Sentinel-1 product:

S1A_IW_GRDH_1SDV_20190908T062923_20190908T062948_028926_03478B_AE88.zip

Go to the opened product in the **Product Explorer** window, click **+** or to expand the contents of the product, then expand **Bands** folder and double click on ***Amplitude_VH*** and ***Amplitude_VV*** bands to visualize them in the **View** window. Go to **Window → Tile Horizontally** (See NOTE 6).

NOTE 6: The RADAR instrument onboard Sentinel-1 carries an antenna that is looking always to the right during its pass. This scene was acquired during **descending** pass (the satellite was moving in direction from north to south) and in this case while looking to the right it was actually looking towards the west. That is why we see that the view of the image appears as if "mirrored", because the view shows the pixels in order of the data acquisition.



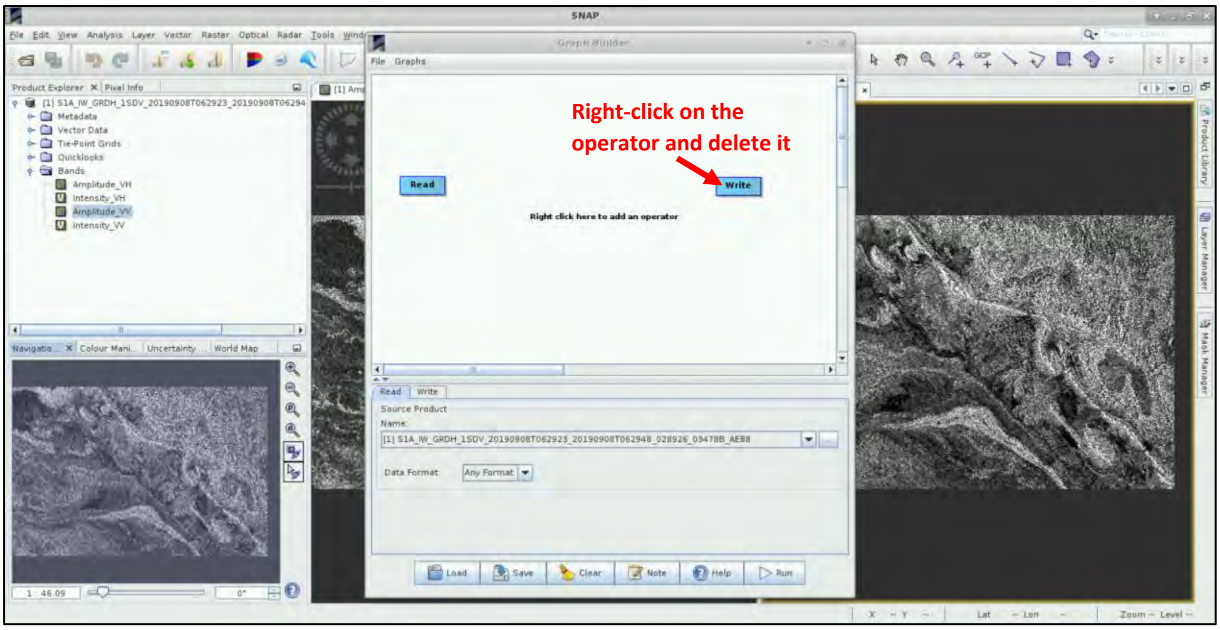
5.4.1 Graph Builder

By using the **GraphBuilder** tool, we can define the steps of the process we want to apply and at the end only the final product will be physically saved (this way we will also save disk space since the products of the intermediate steps will not be stored).

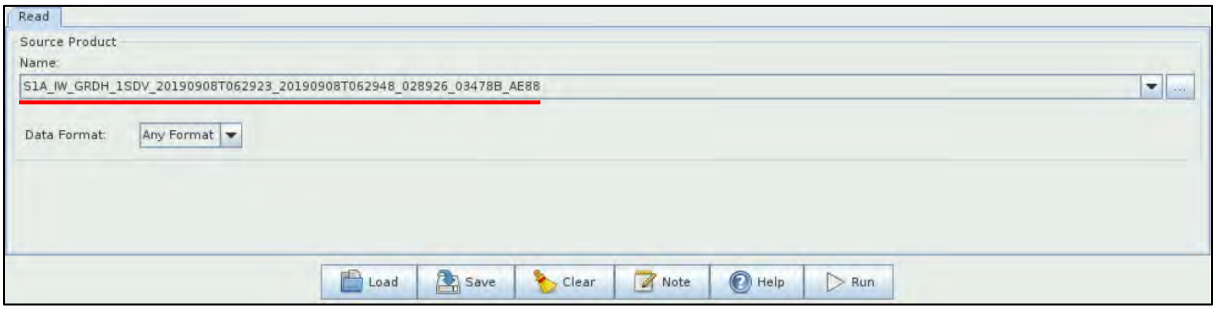
Go to **Tools → GraphBuilder** to build our graph.

We can see that the graph has only two operators: **Read** (to read the input) and **Write** (to write the output). Below there also are the corresponding to the operators' tabs.

First, right-click on the **Write** operator and **Delete** it. The corresponding tab will be removed as well. This is to avoid confusion to the sequence of the graph. The **Write** operator will be added again at the end. Every time an operator is added, we will also define the parameters in the tab.



In the **Read** tab choose the opened in the **Product Explorer** window Sentinel-1 product:
S1A_IW_GRDH_1SDV_20190908T062923_20190908T062948_028926_03478B_AE88



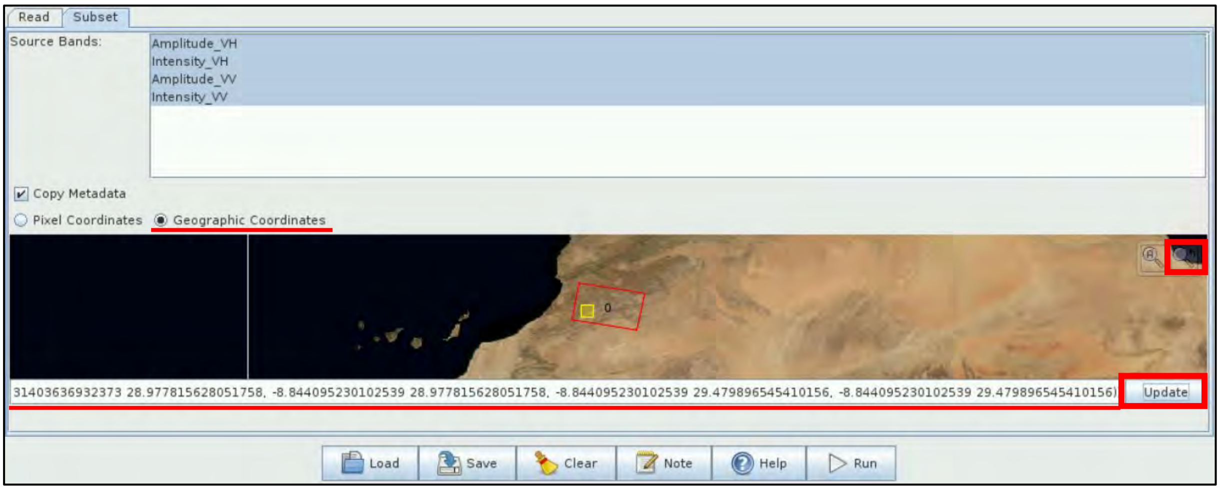
5.4.2 Subset

In the next step, we will subset the image by using the same extent as of the Sentinel-2 product. To add the operator right-click on the white area to the right of **Read** and go to **Add → Raster → Geometric → Subset**. Connect the **Read** operator to it by dragging the red arrow from the right side of **Read** operator towards the **Subset** operator.

In the **Subset** tab press **Ctrl** select all bands and then click to select the **Geographic Coordinates** option. Paste the area of interest definition in WKT (well know text) format to the text window below the map.

```
POLYGON ((-8.844095230102539 29.479896545410156, -8.31403636932373 29.479896545410156, -8.31403636932373 28.977815628051758, -8.844095230102539 28.977815628051758, -8.844095230102539 29.479896545410156, -8.844095230102539 29.479896545410156))
```

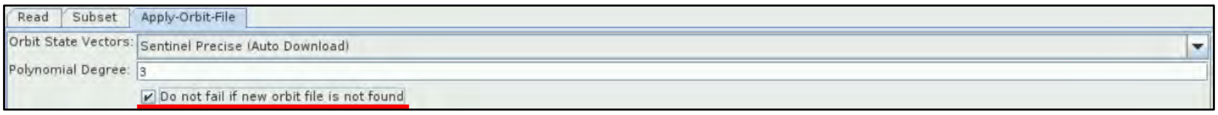
Click **Update** and then click the **Zoom-in** icon to see your subset on the map.



5.4.3 Apply Orbit File

Now we will add the **Apply-Orbit-File** operator by right-clicking and going to **Add → Radar → Apply-Orbit-File** (See NOTE 7). Connect the **Subset** operator to it.

In the **Apply-Orbit-File** tab we will keep the default settings and make sure that you will **select** the "**Do not fail if new orbit file is not found**" option.



NOTE 7: 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**. In case precise orbits are not found, restituted orbit files will be used. (SNAP Help)

5.4.4 Thermal Noise Removal

Next we will remove the thermal noise of the image (See NOTE 8). Add the operator by right-clicking and going to **Add → Radar → Radiometric → ThermalNoiseRemoval**. Connect the **Apply-Orbit-File** operator to it.

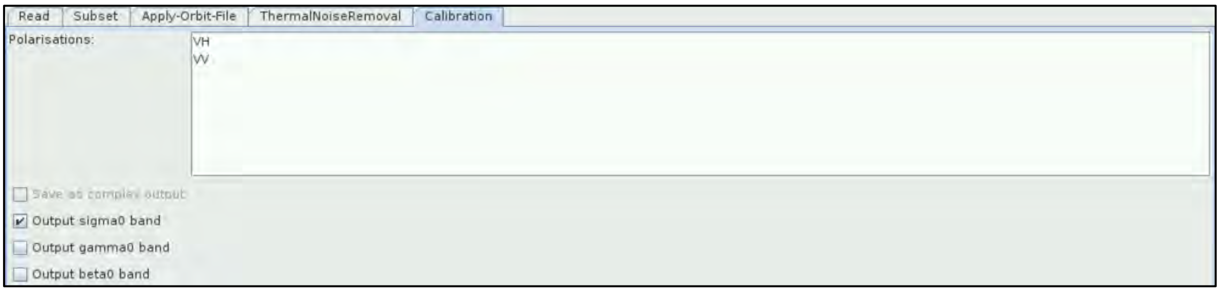
In the **ThermalNoiseRemoval** tab, keep the default parameters.

NOTE 8: Thermal noise in SAR imagery is the background energy that is generated by the receiver itself. It skews the radar reflectivity to towards higher values and hampers the precision of radar reflectivity estimates. Level-1 products provide a noise LUT (Look-Up-Table) for each measurement dataset, provided in linear power, which can be used to remove the noise from the product. (*SNAP Help*)

5.4.5 Calibration

The objective of SAR calibration is to provide imagery in which the pixel values can be directly related to the RADAR backscatter (See NOTE 9). To add the operator, right-click and go to **Add → Radar → Radiometric → Calibration**. Connect the **ThermalNoiseRemoval** operator to it.

In the **Calibration** tab, keep the default parameters.



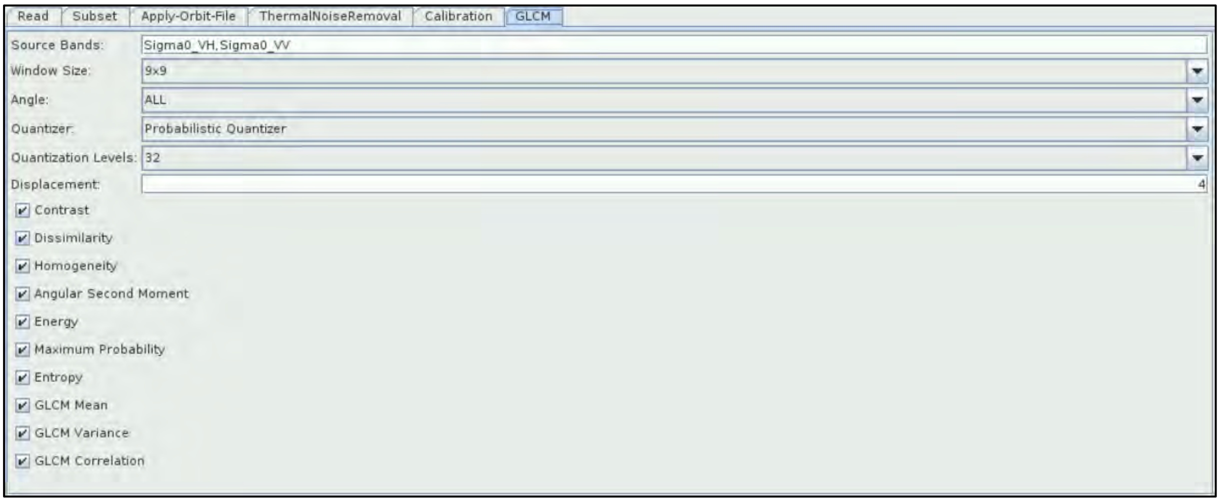
NOTE 9: The radiometric correction is necessary for the pixel values to truly represent the radar backscatter of the reflecting surface and therefore for comparison of SAR images acquired with different sensors or acquired from the same sensor but at different times, in different modes, or processed by different processors. Typical SAR data processing, which produces level-1 images, does not include radiometric corrections and significant radiometric bias remains. (*SNAP Help*)

5.4.6 GLCM

GLCM (Gray Level Co-occurrence Matrix) is a measure of the probability of occurrence of two grey levels separated by a given distance in a given direction. It provides spatial information in the form of texture features that are useful for image classification (See NOTE 10). To add the operator, right-click and go to **Add → Raster → Image Analysis → Texture Analysis → GLCM**. Connect the **Calibration** operator to it.

In the **GLCM** tab, keep all the default parameters.

TIP 3: If you want the processing to be completed faster, select **Window Size: 11 x 11**. For lithological classification we will only use the **Contrast**, **Homogeneity** and **GLCM Mean** features. In case you do not know which features you need, select them all and once you have the results, use the most appropriate.



NOTE 10: Texture measures can produce new images by making use of spatial information inherent in the image. It involves the information from neighbouring pixels which is important to characterize the identified objects or regions of interest in an image. The GLCM proposed by Haralik, 1973 is one of the most widely used methods to compute second order texture measures. Each feature models different properties of the statistical relation of pixels co-occurrence, estimated within a given moving window and along predefined directions and inter-pixel distances. (*SNAP Help)*

5.4.7 Speckle Filtering

SAR images have inherent salt and pepper like textures called speckles which degrade the quality of the image and make interpretation of features more difficult. To remove that, we apply **Speckle Filter** (See NOTE 11). To add the operator, right-click and go to **Add → Radar → Speckle Filtering → Speckle-Filter**. Connect the **GLCM** operator to it.

In the **Speckle-Filter** tab, keep all default parameters.

TIP 4: You can also decrease the Window Size or even select a different filter than Lee Sigma if it meets better the criteria for classifying your area of study. In that case, you will need to adjust accordingly the rest parameters of the filter you will use.

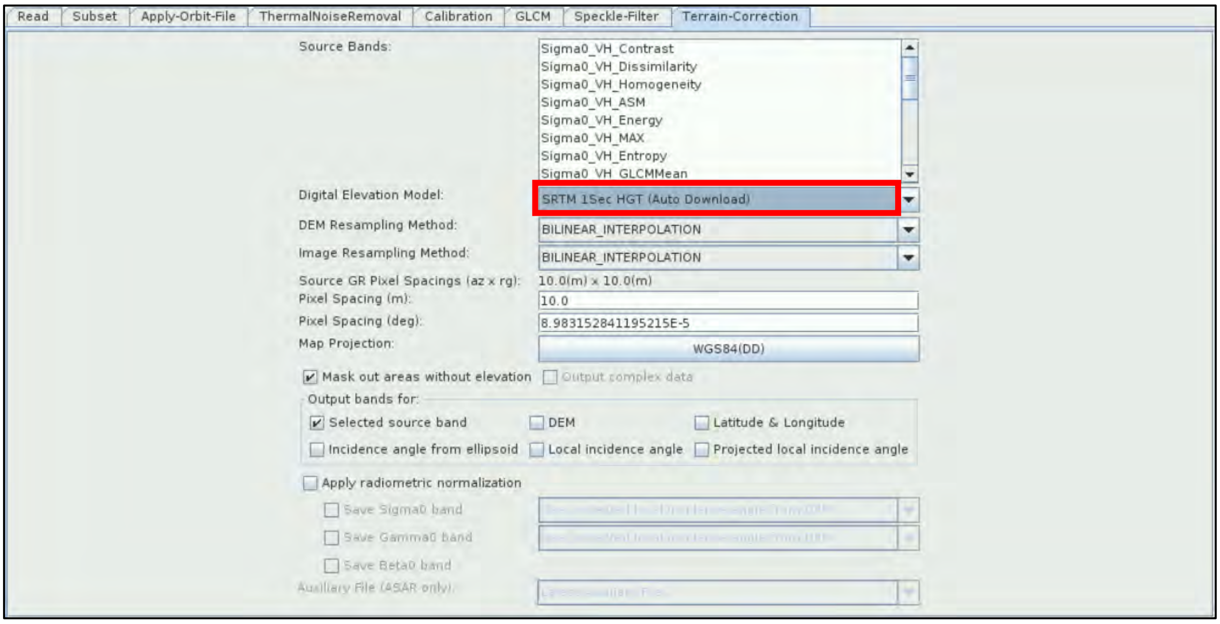
NOTE 11: Speckles are caused by random constructive and destructive interference of the de-phased but coherent return waves scattered by the elementary scatters within each resolution cell. Speckle noise reduction can be applied either by spatial filtering or multilook processing. (*SNAP Help*)

5.4.8 Terrain Correction

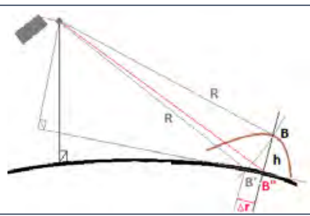
We need to convert the data that are still in radar geometry, into geographic coordinates. Moreover, this is necessary because the distances can be distorted in the SAR images, due to topographical variations of a scene and the tilt of the satellite sensor (See NOTE 12). To add the operator, right-click and go to **Add → Radar → Geometric → Terrain Correction → Terrain-Correction**. Connect the **Speckle-Filter** operator to it.

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

Digital Elevation Model: SRTM 1Sec HGT (Auto Download)
Keep the rest parameters as by default.



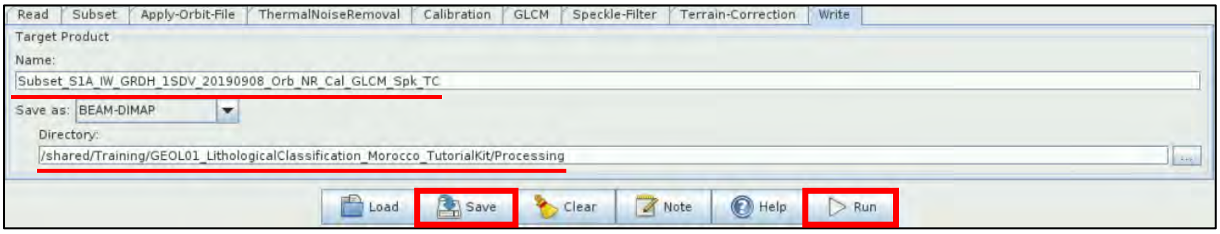
NOTE 12: The geometry of topographical distortions in SAR imagery is shown on the right. Here we can see that point **B** with elevation **h** above the ellipsoid is imaged at position **B'** in SAR image, though its real position is **B''**. The offset **Δr** between **B'** and **B''** exhibits the effect of topographic distortions. *(SNAP Help)*

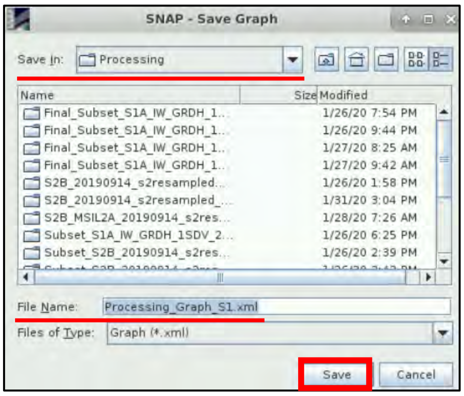


Finally, we need to add the **Write** operator to save the output of our processing graph. Right-click and go to **Add → Input-Output → Write**. Connect the **Terrain-Correction** operator to it.

In the **Write** tab, set as:

Target Product Name: Subset_S1A_IW_GRDH_1SDV_20190908_Orb_NR_Cal_GLCM_Spk_TC (we see that all suffixes from the operators added at the processing chain, have been added but we will shorten the name a bit).
Directory: */shared/Training/GEOL01_LithologicalClassification_Morocco_TutorialKit/Processing*





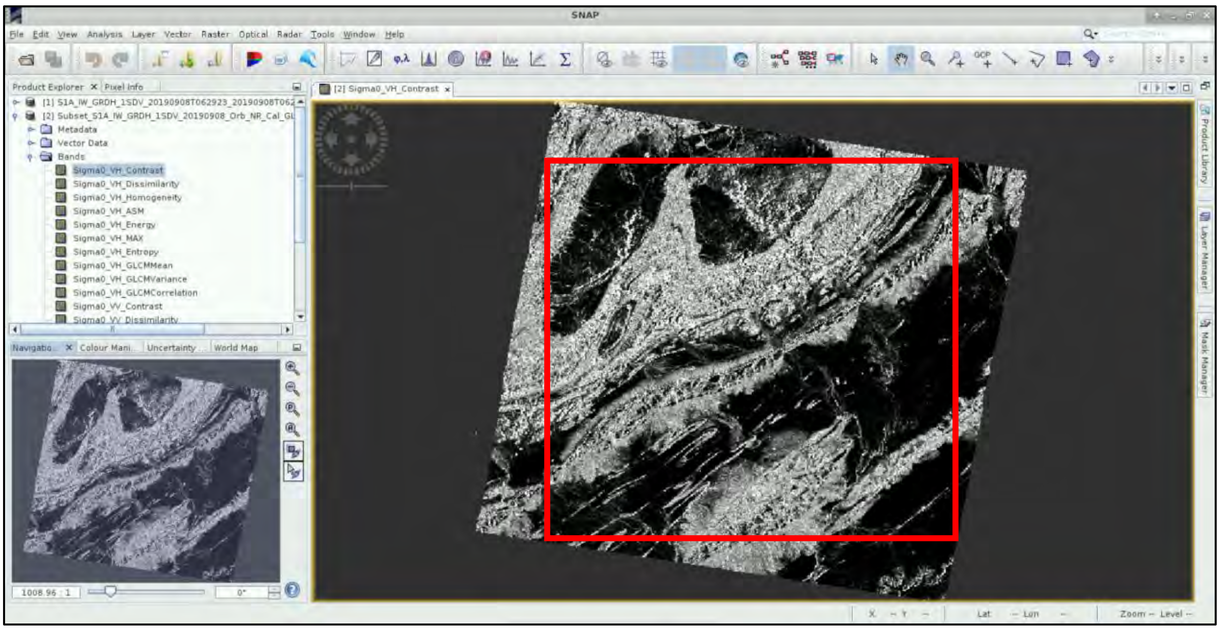
Once the graph is completed, go to **Save**.

Navigate to ***/shared/Training/GEOL01_LithologicalClassification_Morocco_TutorialKit/Processing*** folder
Save the graph with the **File Name:**
Processing_Graph_S1.

Then click **Run.**

The new product will appear at the **Product Explorer** window.

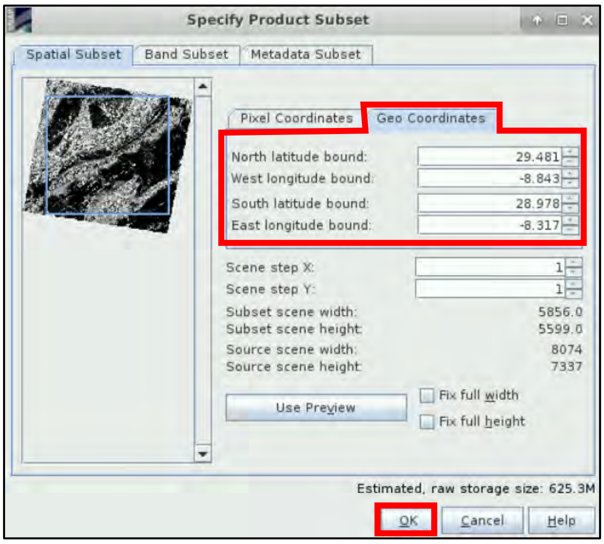
Go to the new product in the **Product Explorer** window, click **+** or to expand the contents of the product, then expand **Bands** folder. We can see that the folder contains 20 bands, that refer to the 10 GLCM features for both VH and VV polarizations. Double click on a band, e.g. ***Sigma0_VH_Contrast*** to visualize it in the **View** window. You can explore the other bands as well.



5.4.9 Subset

We can see that the extent of the image is larger than the one of the Sentinel-2 subset (marked in red in the previous image) although we have used the exact coordinates. This is because we have performed the Subset before we have projected (assigned coordinate system) the product. We will now correct this by using a Subset again.

> TIP 5: For this Subset we will use the **Geo Coordinates** mentioned at ***5.3.2 Subset*** chapter for the Sentinel-2 product, and we will save the product following the same steps.



Select the **Subset_S1A_IW_GRDH_1SDV_20190908_Orb_NR_Cal_GLCM_Spk_TC** product and go to **Raster → Subset**.

In the **Spatial Subset** tab, go to **Geo Coordinates** tab and set the following parameters:

North latitude bound: **29.481**

West longitude bound: **-8.843**

South latitude bound: **28.978**

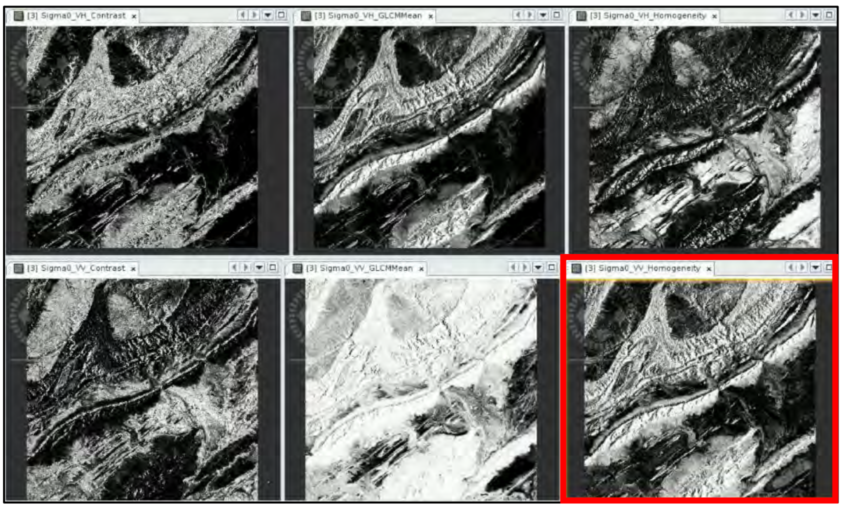
East longitude bound: **-8.317**

Click **OK**.

The **subset_0_of_Subset_S1A_IW_GRDH_1SDV_20190908_Orb_NR_Cal_GLCM_Spk_TC** product, will appear at the **Product Explorer** window. Right click on it, select **Save Product**, then click **Yes** on the window that appears.

Navigate to ***/shared/Training/GEOL01_LithologicalClassification_Morocco_TutorialKit/Processing*** path and **Save** it with the **File Name:**
Final_Subset_S1A_IW_GRDH_1SDV_20190908_Orb_NR_Cal_GLCM_Spk_TC

Then go to the subset at the **Product Explorer** window, right click on it, select **Close Product**, click no if a window pops up and then load in SNAP the Final saved subset. Open the following bands:



Sigma0_VH_Contrast
Sigma0_VH_Homogeneity
Sigma0_VH_GLCMMean
Sigma0_VV_Contrast
Sigma0_VV_Homogeneity
Sigma0_VV_GLCMMean

Go to **Window → Tile Evenly**

These are the bands that will initially be used for the Unsupervised lithological Classification based on their results.

Additionally, **Sigma0_VV_Homogeneity** band has been chosen to be used for a second Unsupervised Classification to see if the results will be improved. This band will also be the one that will be used for the Supervised Classification. Explore more bands and select any that you consider more appropriate.

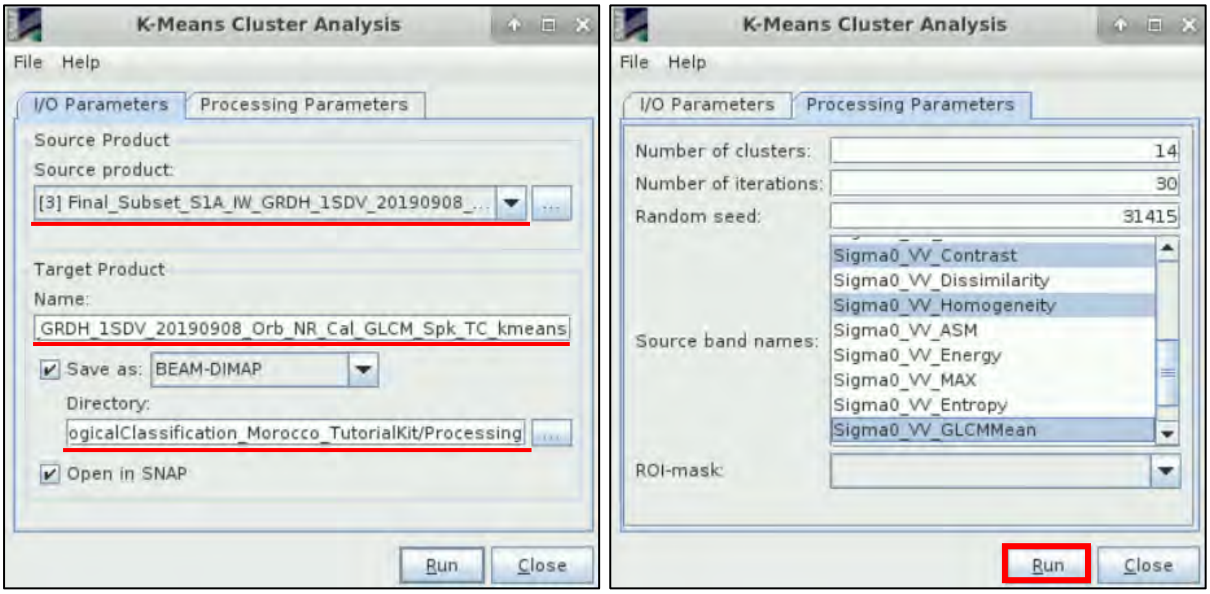
5.4.10 Unsupervised Classification

Go to **Raster → Classification → Unsupervised Classification → K-Means Cluster Analysis.**

In the **I/O Parameters** tab set as:

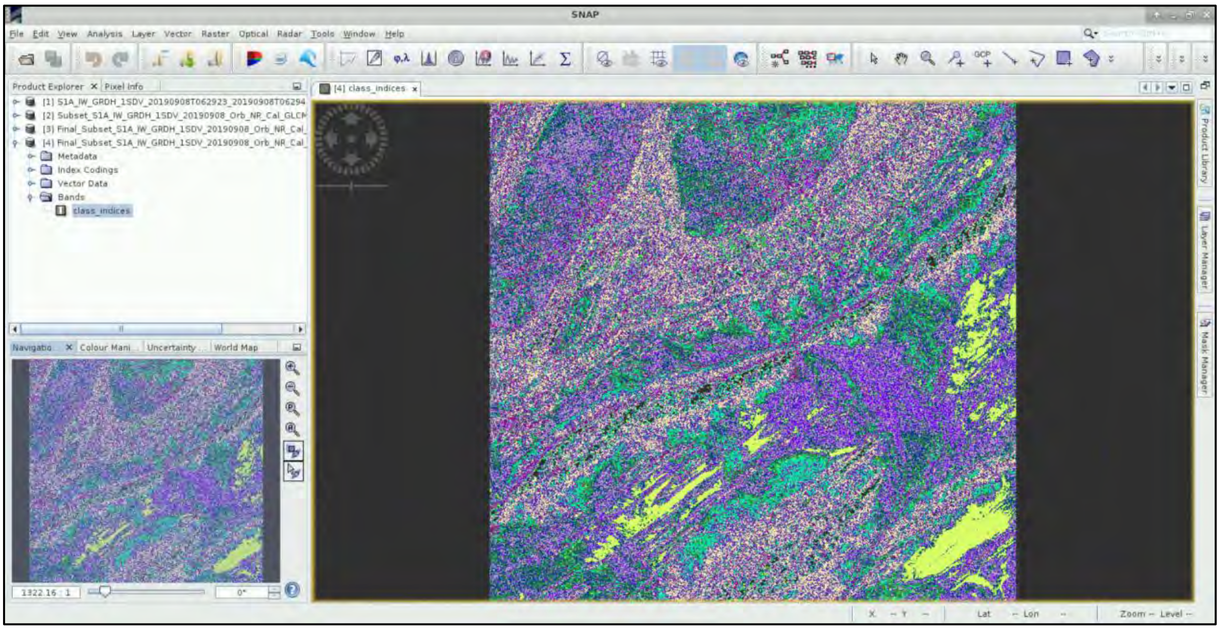
Source Product: Final_Subset_S1A_IW_GRDH_1SDV_20190908_Orb_NR_Cal_GLCM_Spk_TC
Target Product Name: Final_Subset_S1A_IW_GRDH_1SDV_20190908_Orb_NR_Cal_GLCM_Spk_TC_kmeans
Directory: */shared/Training/GEOL01_LithologicalClassification_Morocco_TutorialKit/Processing*

In the **Processing Parameters** tab, keep the **Number of clusters**, **Number of iterations** and **Random seed** as by default, and at the **Source bands names**, press Ctrl and select only the Sigma0_VH_Contrast, Sigma0_VH_Homogeneity, Sigma0_VH_GLCMMean , Sigma0_VV_Contrast, Sigma0_VV_Homogeneity and Sigma0_VV_GLCMMean bands, that have been mentioned before.



Click **Run**. The new product will appear at the **Product Explorer** window. Close the previous views.

Now go to the **Final_Subset_S1A_IW_GRDH_1SDV_20190908_Orb_NR_Cal_GLCM_Spk_TC_kmeans** product at the **Product Explorer** window, expand it, then expand the **Bands** folder and double click on the **class_indices** band to visualize it.

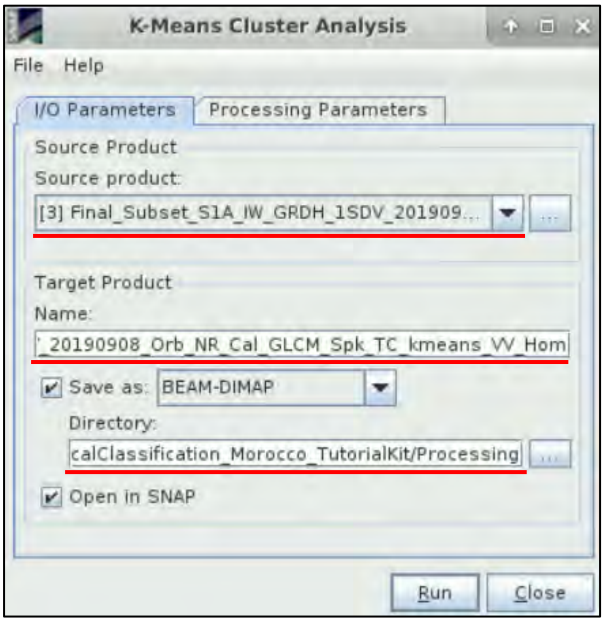


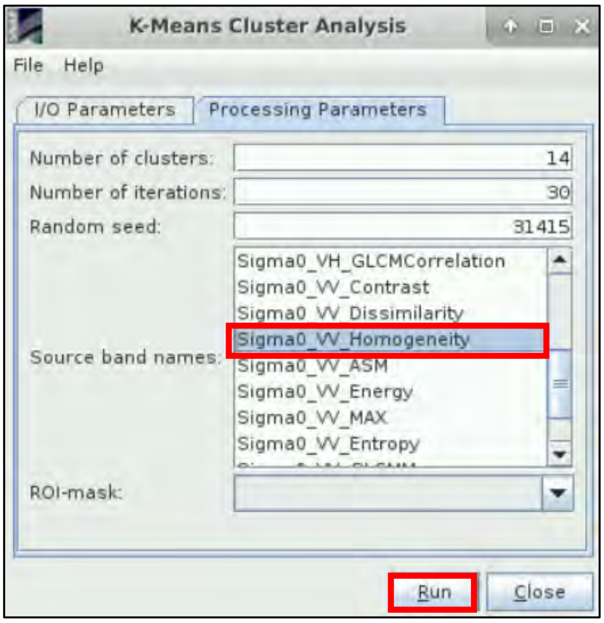
Repeat the **K-Means Cluster Analysis Unsupervised Classification**. Keep ALL parameters the same as previously, apart from the following:

In the **I/O Parameters** tab change only the **Target Product Name** to:

Final_Subset_S1A_IW_GRDH_1SDV_20190908_Orb_NR_Cal_GLCM_Spk_TC_kmeans**_VV_Hom**

In the **Processing Parameters** tab select only the **Sigma0_VV_Homogeneity** band.

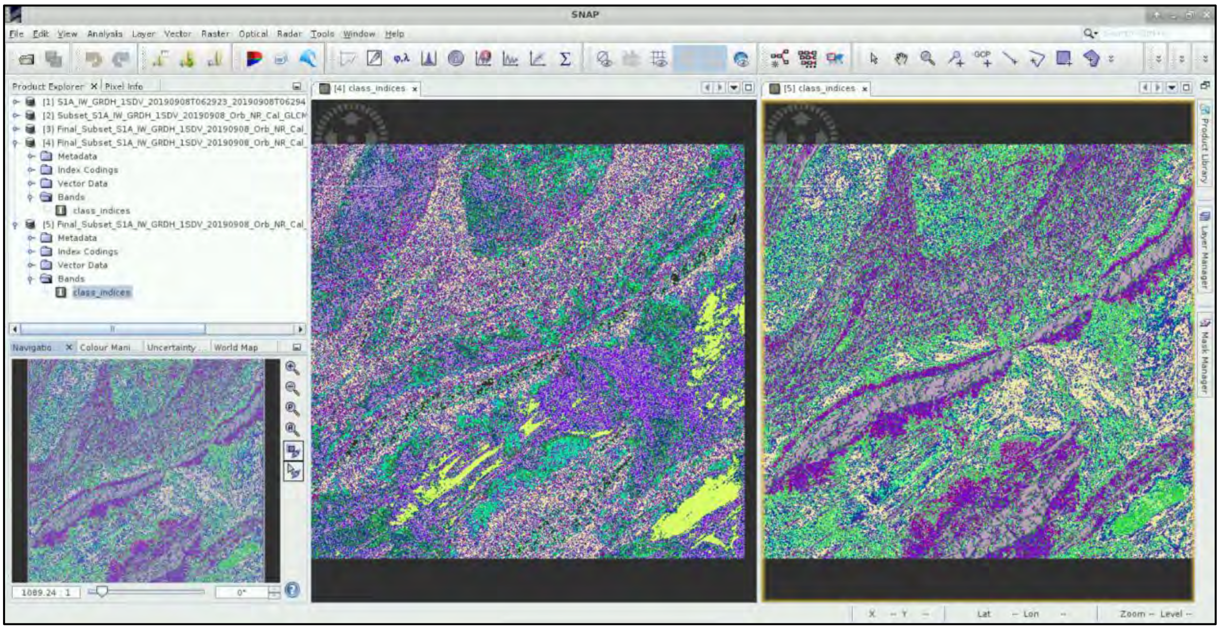




Click **Run**. The new product will appear at the **Product Explorer** window.

Go to the new classified product **Final_Subset_S1A_IW_GRDH_1SDV_20190908_Orb_NR_Cal_GLCM_Spk_TC_kmeans_VV_Hom** product at the **Product Explorer** window, expand it, then expand the **Bands** folder and double click on the **class_indices** band to visualize it.

Go to **Window → Tile Horizontally** and compare the results of the two classifications. We can see that when we classify our product based only on **Sigma0_VV_Homogeneity** band, the results look better and more precise, for this reason we use only this band for the supervised classification that follows.

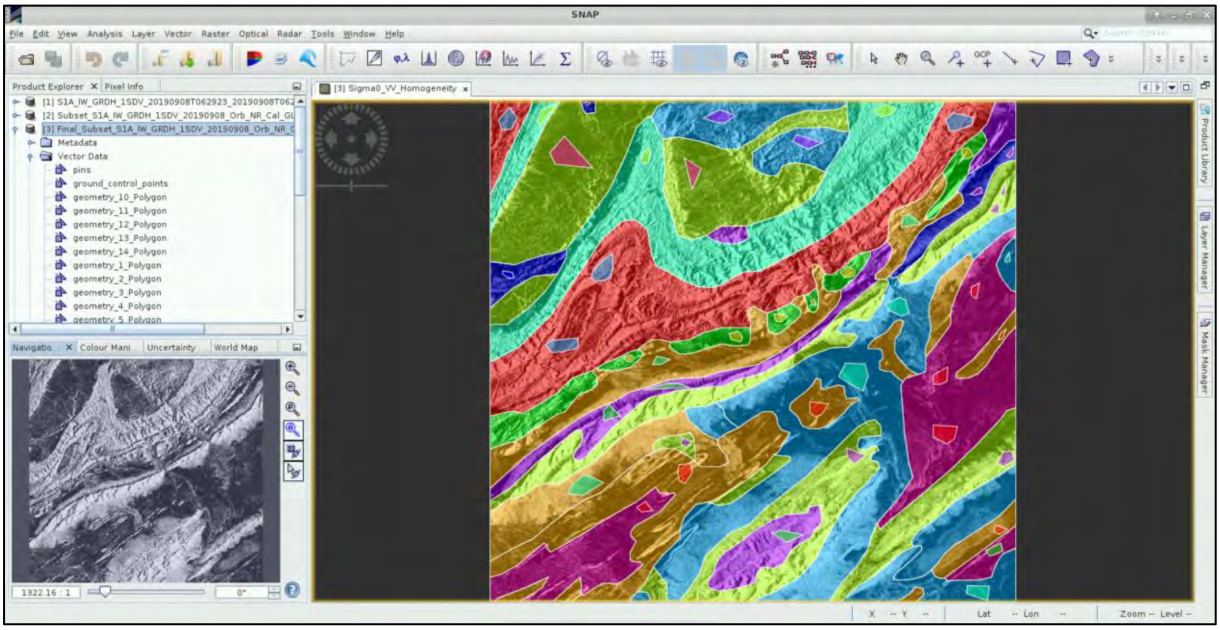


5.4.11 Supervised Classification

Let’s continue now to the supervised classification by importing the shapefiles with the geology of the area and the training data for each different lithology, as mentioned in ***5.3.5 Supervised Classification*** chapter. The shapefiles will be loaded on the **Final_Subset_S1A_IW_GRDH_1SDV_20190908_Orb_NR_Cal_GLCM_Spk_TC** product. Close the previously opened views.

Select the **Final_Subset_S1A_IW_GRDH_1SDV_20190908_Orb_NR_Cal_GLCM_Spk_TC** product at the **Product Explorer** window and import the shapefiles and the training data from ***/shared/Training/GEOL01_LithologicalClassification_Morocco_TutorialKit/AuxData*** folder, as mentioned before in the ***5.3.5 Supervised Classification*** chapter.

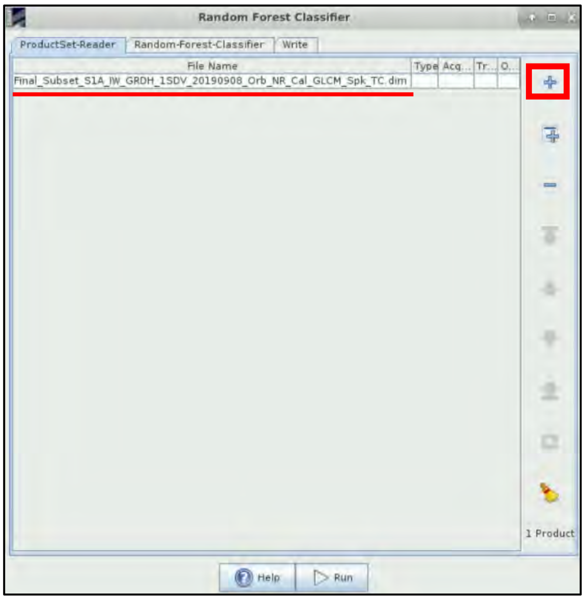
Go to the **Final_Subset_S1A_IW_GRDH_1SDV_20190908_Orb_NR_Cal_GLCM_Spk_TC** product and expand the **Vector Data** folder. You will see that all the shapefiles we have imported are now in that folder as in the following image. **Right click** on the product and select **Save Product**, to save the imported data. Double-click on **Sigma0_VV_Homogeneity** band to open it in a View window.



The classifier we will use is again **Random Forest Classifier**.

Go to **Raster → Classification → Supervised Classification → Random Forest Classifier**.

In the **ProductSet-Reader** tab, click on , navigate to ***/shared/Training/GEOL01_LithologicalClassification_Morocco_TutorialKit/Processing*** and add this product: **Final_Subset_S1A_IW_GRDH_1SDV_20190908_Orb_NR_Cal_GLCM_Spk_TC**



In the **Random-Forest-Classifier** tab set as:

Select **Train and apply classifier**: newClassifier_S1
Keep **Train on Vectors** and **Evaluate classifier** selected

Keep **Number of training samples** and **Number of trees** as by default

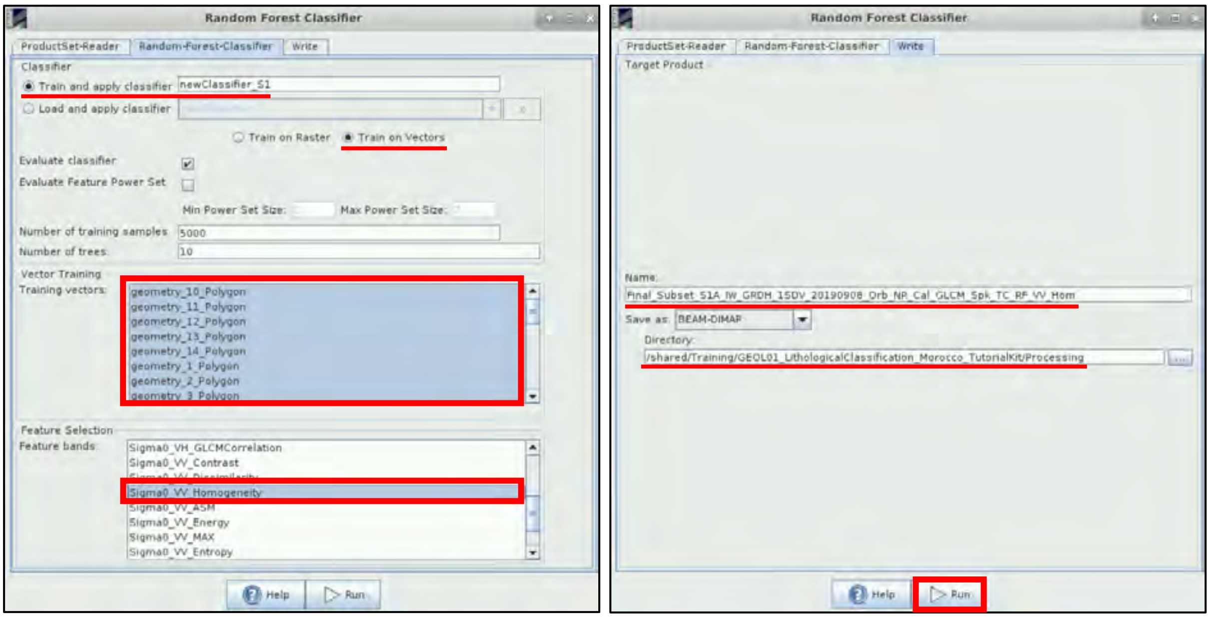
In the **Training vectors** select all “geometry_xx_Polygon”

In the **Feature bands** select only Sigma0_VV_Homogeneity band.

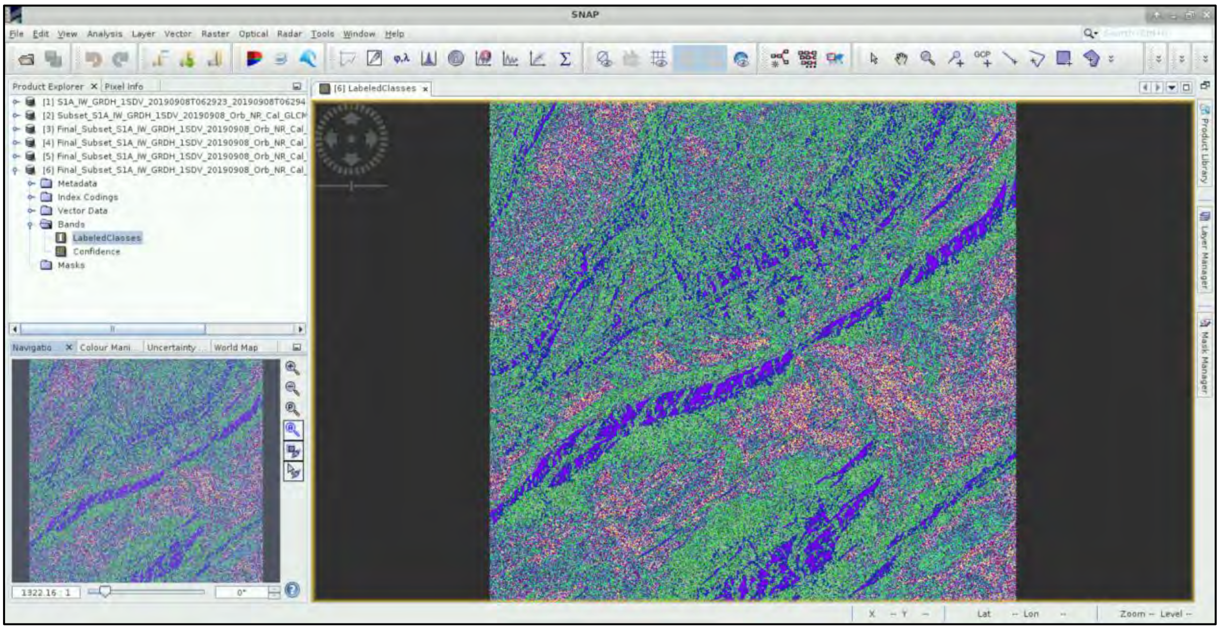
In the **Write** tab set as:

Name: Final_Subset_S1A_IW_GRDH_1SDV_20190908_Orb_NR_Cal_GLCM_Spk_TC_RF_VV_Hom
Directory: */shared/Training/GEOL01_LithologicalClassification_Morocco_TutorialKit/Processing*

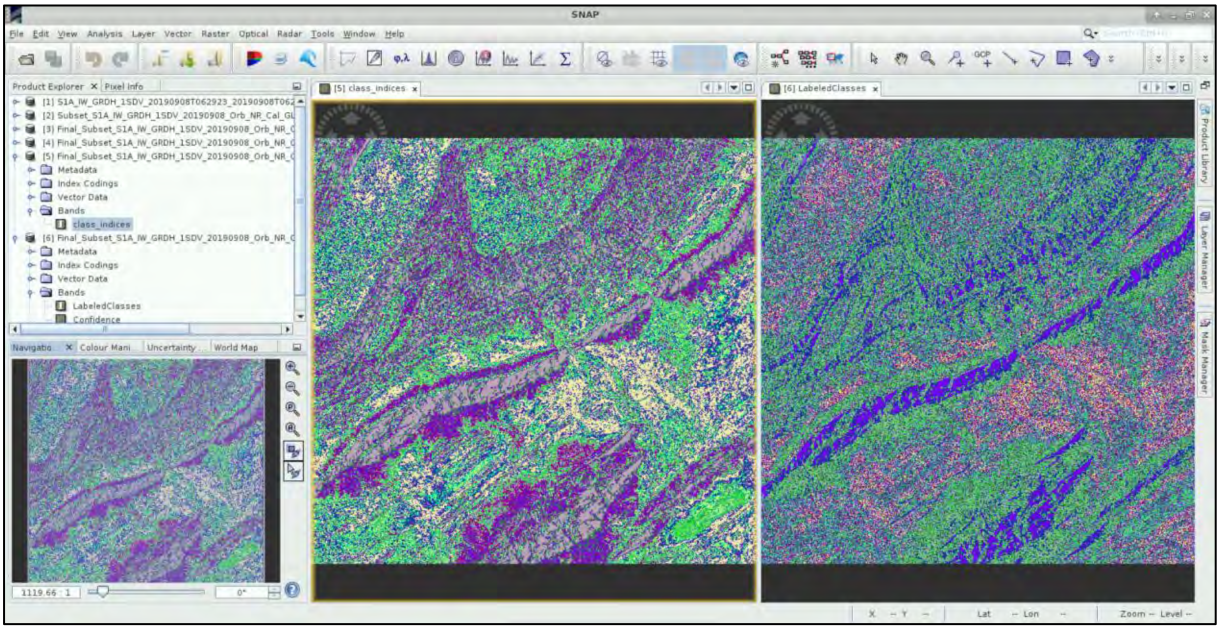
Click **Run**. The new product will appear at the **Product Explorer** window.



Go to the **Final_Subset_S1A_IW_GRDH_1SDV_20190908_Orb_NR_Cal_GLCM_Spk_TC_RF_VV_Hom** product at the **Product Explorer** window, expand it, then expand the **Bands** folder and double click on the **LabelledClasses** band to visualize it. In case you see the shapefiles imported initially, go to *Vector Data* folder, select them, right-click and **Delete** them.



Open the **class_indices** band from **Final_Subset_S1A_IW_GRDH_1SDV_20190908_Orb_NR_Cal_ GLCM_Spk_TC_kmeans_VV_Hom** product as well, go to **Window → Tile Horizontally** and compare the results of the two different classifications. You can zoom in to selected areas and see differences between the two outputs.



We see that the results from the Unsupervised Classification based on the *Sigma0_VV_Homogeneity* band, look better than those from the Supervised Classification. This happens because the training data we used, were the same as in the optical image. Since in this case the *Sigma0_VV_Homogeneity* band is more appropriate for lithological classification, we can create new training data based on this band and apply again the Random Forest Classification. The results will be much more accurate. The same can be done for Sentinel-2 products as well, if there are not auxiliary geological data of the area.

Now load in SNAP the following products, so that you can make comparisons for the classification results between Sentinel-1 and Sentinel-2 data and have them ready for exporting those you want to *.tif* and *.kmz* formats:

Subset_S2B_20190914_s2resampled_reprojected_kmeans
Subset_S2B_20190914_s2resampled_reprojected_RF
Subset_S2B_20190914_s2resampled_reprojected

5.5 Export products

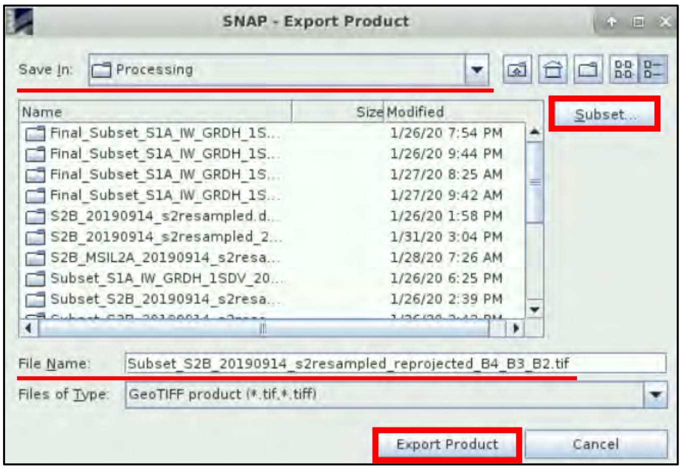
Let's export the bands we want to visualise in **QGIS**. Select the appropriate band from the products at the **Product Explorer** window. Go to **File → Export → GeoTIFF.**

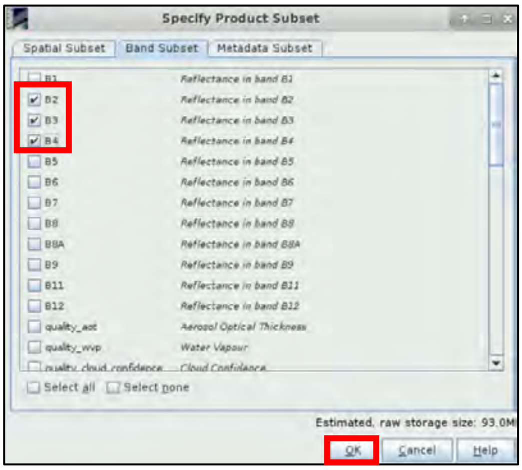
To all of them set in **Save In:** ***/shared/Training/GEOL01_LithologicalClassification_Morocco_Tutorial Kit/Processing*** path. For the classified products, write at the **File Name** the full name of the product:

Subset_S2B_20190914_s2resampled_reprojected_kmeans
Subset_S2B_20190914_s2resampled_reprojected_RF
Final_Subset_S1A_IW_GRDH_1SDV_20190908_Orb_NR_Cal_GLCM_Spk_TC_kmeans
Final_Subset_S1A_IW_GRDH_1SDV_20190908_Orb_NR_Cal_GLCM_Spk_TC_kmeans_VV_Hom
Final_Subset_S1A_IW_GRDH_1SDV_20190908_Orb_NR_Cal_GLCM_Spk_TC_RF_VV_Hom

Then click **Export Product**.

For the **Subset_S2B_20190914_s2resampled_Reprojected** product, we only need to export the bands B4, B3 and B2 to have an RGB image in Natural Colours. For this, go to **File → Export → GeoTIFF**, click on **Subset**, go to **Band Subset** and select only B2, B3 and B4. Click **OK**, set the name of the output as **Subset_S2B_20190914_s2resampled_reprojected_B4_B3_B2** and click **Export Product**.





In order to export the views you need for visualization in Google Earth, just **right click** on the opened View window in SNAP and select **Export View as Google Earth KMZ**. Define the name and the path as mentioned above.

Then close SNAP. If a window appears asking to save the changes, click **No**.

6 Visualization in QGIS

Open **QGIS Desktop** application. First go to **Web → OpenLayers plugin → Bing Maps → Bing Aerial** to add a basemap (See NOTE 13).

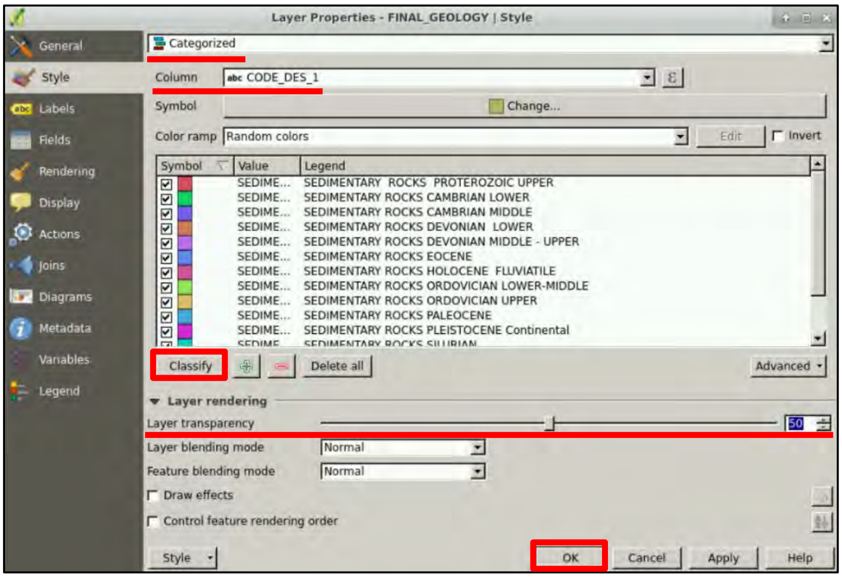
Then navigate to ***/shared/Training/GEOL01_LithologicalClassification_Morocco_TutorialKit/Processing*** folder by opening a folder window, and drag and drop one by one the following *.tif* files you have exported before:

Subset_S2B_20190914_s2resampled_reprojected_B4_B3_B2.tif
Subset_S2B_20190914_s2resampled_reprojected_kmeans.tif
Subset_S2B_20190914_s2resampled_reprojected_RF.tif
Final_Subset_S1A_IW_GRDH_1SDV_20190908_Orb_NR_Cal_GLCM_Spk_TC_kmeans.tif
Final_Subset_S1A_IW_GRDH_1SDV_20190908_Orb_NR_Cal_GLCM_Spk_TC_kmeans_VV_Hom.tif
Final_Subset_S1A_IW_GRDH_1SDV_20190908_Orb_NR_Cal_GLCM_Spk_TC_RF_VV_Hom.tif

> NOTE 13: In case the **OpenLayers** plugin is not installed, click on **Plugins → Manage and Install Plugins.** Select the *"All"* tab on the left-side panel and write "**OpenLayers plugin**" on the search box. Select the plugin on the list and click "Install Plugin". Restart QGIS to finalize the installation.

Deselect them all, apart from the **Subset_S2B_20190914_s2resampled_reprojected_B4_B3_B2.tif** and the **Bing Aerial**. Right-click on the selected product and click on **Zoom to Layer**.

Navigate to ***/shared/Training/GEOL01_LithologicalClassification_Morocco_TutorialKit/Auxdata/Geology_Morocco*** folder and load in QGIS the **FINAL_GEOLOGY.shp**. Move it on the top of all layers.



Right-click on the selected Sentinel-2 product and go to **Properties**.

At the **Style** tab select **Categorized**

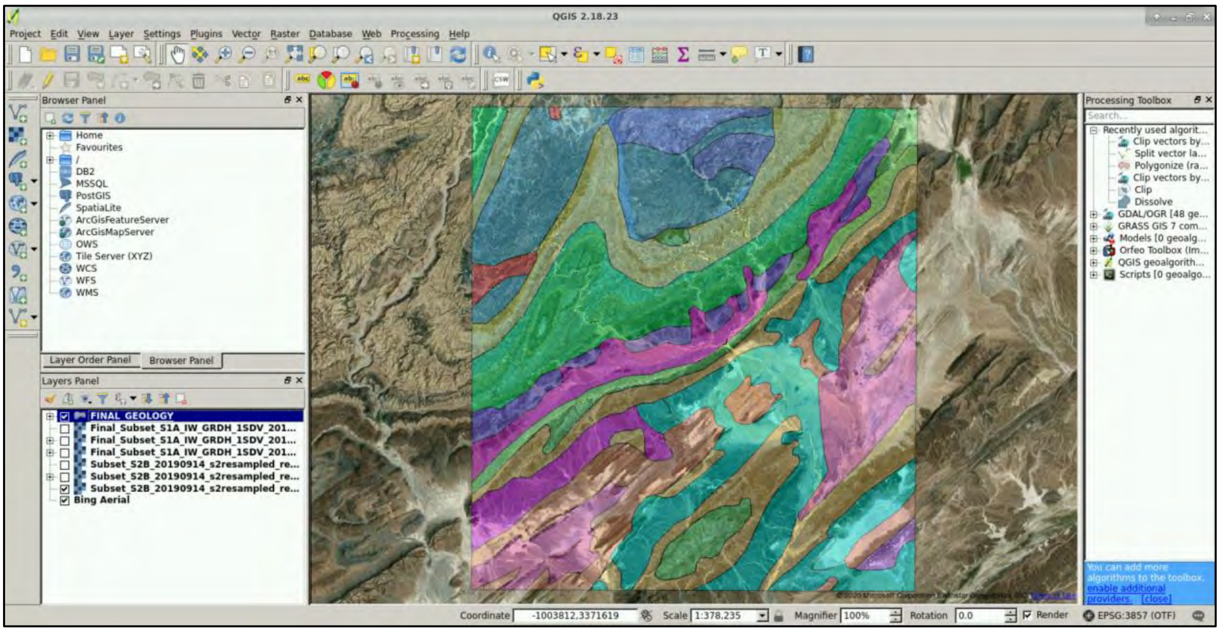
At the **Column: CODE_DES_1**

Click on **Classify**.

Set the **Layer transparency** to **50**

Finally click **OK**.

You can select and deselect the layers, set them under certain Transparency, see the classification results and compare it with the geological maps or other auxiliary data.

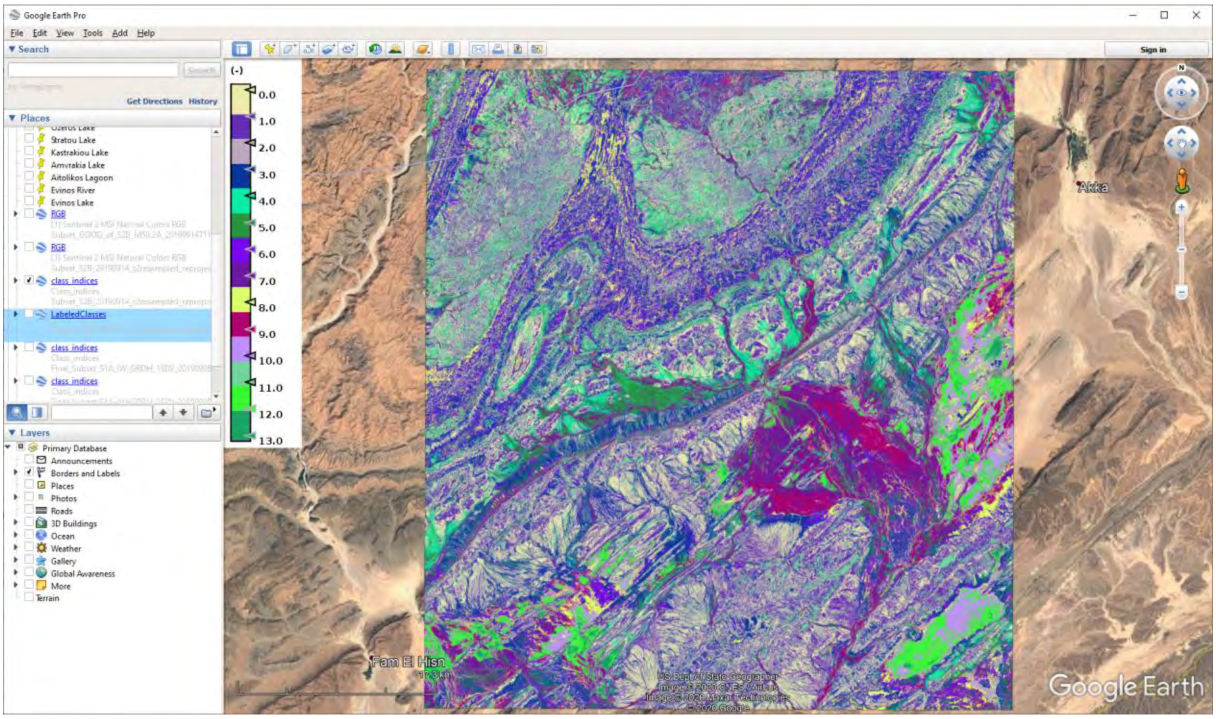


7 Extra Steps

7.1 Visualization in Google Earth

Google Earth is not pre-installed in RUS VMs and if you want to visualise the results, you need to download them to your local computer. We have already exported the results to **KMZ** format. Download the following products and then load them in Google Earth:

Subset_S2B_20190914_s2resampled_reprojected_B4_B3_B2.kmz
Subset_S2B_20190914_s2resampled_reprojected_kmeans.kmz
Subset_S2B_20190914_s2resampled_reprojected_RF.kmz
Final_Subset_S1A_IW_GRDH_1SDV_20190908_Orb_NR_Cal_GLCM_Spk_TC_kmeans.kmz
Final_Subset_S1A_IW_GRDH_1SDV_20190908_Orb_NR_Cal_GLCM_Spk_TC_kmeans_VV_Hom.kmz
Final_Subset_S1A_IW_GRDH_1SDV_20190908_Orb_NR_Cal_GLCM_Spk_TC_RF_VV_Hom.kmz



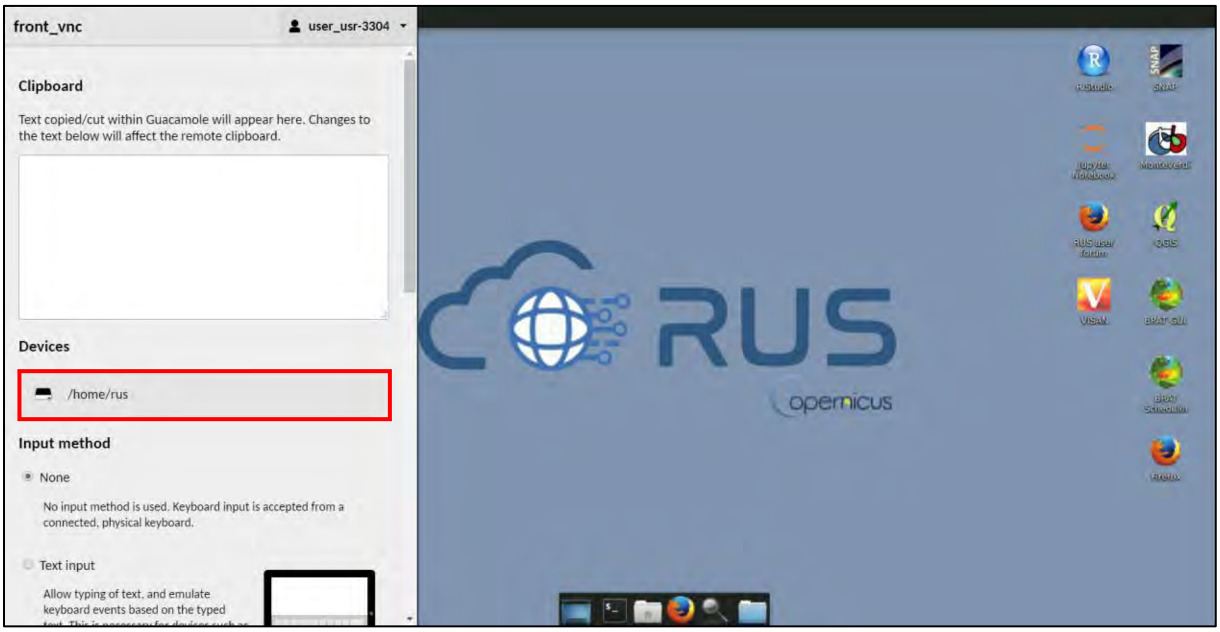
Example of **Subset_S2B_20190914_s2resampled_reprojected_kmeans.kmz** image in Google Earth.

7.2 Download files from VM

In your VM, press **Ctrl+Alt+Shift.**

A pop-up window will appear on the left side of the screen. Click on the bar below **Devices**, navigate to the folders you have saved the files you want to download and **double click** on them. The downloading process to your local computer will start automatically.

Once the KMZ files have been downloaded, you can load and visualize them in **Google Earth**.



THANK YOU FOR FOLLOWING THE EXERCISE!

8 Further reading and resources

- Breiman, L. 2001. Random forests. Machine Learning 45: 5-32.
- Haralick, R.M., Shanmugam, K., Denstien, I., 1973. “Textural features for image classification,” IEEE Trans Syst Man Cybern, vol. 3, no. 6, pp.610-621, 1973.
- FAL, S., MAANAN, M., BAIDDER, L., Rhinane, H., 2019. “The contribution of Sentinel-2 satellite images for geological mapping in the south of Tafilalet basin (Eastern Anti-Atlas, Morocco)” The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLII-4/W12, 2019 https://doi.org/10.5194/isprs-archives-XLII-4-W12-75-2019
- Soulaimani A. & Burkhard M. 2008. Geological Society, London, Special Publications, 297, 433-452, 1 January 2008 https://doi.org/10.1144/SP297.20
- https://sentinel.esa.int/web/sentinel/missions/sentinel-1 - Sentinel-1 Mission
- https://sentinel.esa.int/web/sentinel/missions/sentinel-2 - Sentinel-2 Mission
- http://antimonyworld.com/index/documents - Geological Map of Morocco

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