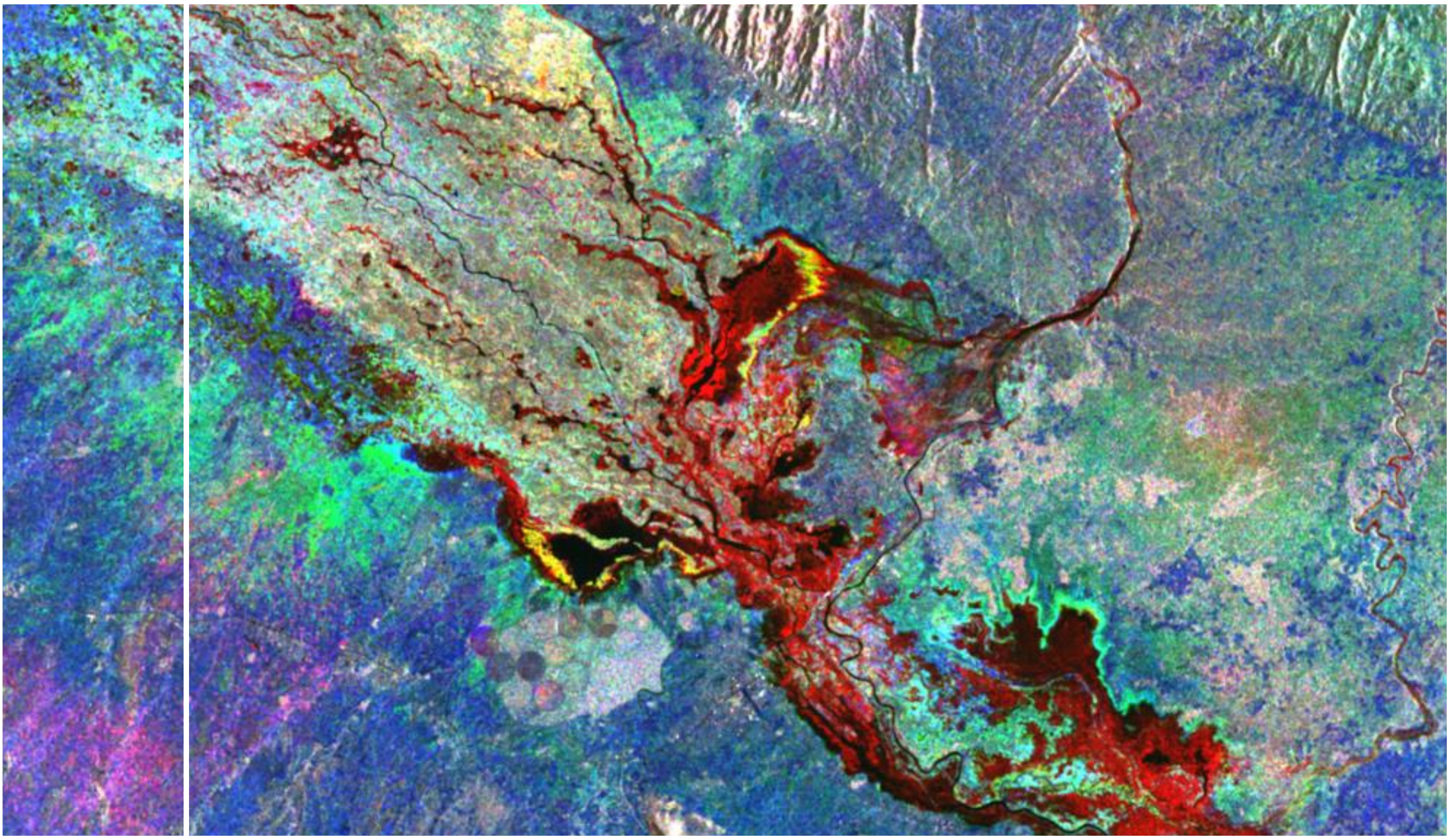
RUS

Copernicus



TRAINING KIT – HAZA01

FLOOD MONITORING WITH SENTINEL-1 USING S-1 TOOLBOX - JANUARY 2015, MALAWI

Research and User Support for Sentinel Core Products

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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

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1 Introduction to RUS

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.

Malawi floods January 2015 Credits: www.theguardian.com [February 10, 2015]

The Republic of Malawi declared a State of Disaster on 13 January 2015 in the 15 affected districts (out of a total of 28 districts). The southern districts of Nsanje, Chikwawa, Phalombe and Zomba were the most affected.

The area experienced heavy rains, more than 150% of normal rainfall, throughout December and January, partially related to Cyclone Bansi and Tropical Storm Chedza, which led to severe flooding. The flood left 276 people dead and estimated 230 000 displaced with some areas completely inaccessible. It also caused extensive damage to crops, livestock and infrastructure with estimated 64 000 hectares of land damaged, further deepening the humanitarian disaster.

2 Training

Approximate duration of this training session is one hour.

The Training Code for this tutorial is HAZA01. 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

- Four Sentinel-1A IW GRDH images with VV polarization acquired before the flood event on 29 December 2014 and during the flood event on 22 January, 27 February and 23 March 2015 [downloadable @ https://scihub.copernicus.eu/]

  S1A_IW_GRDH_1SSV_20150323T030724_20150323T030752_005153_0067F3_832F.zip
  S1A_IW_GRDH_1SSV_20150227T030723_20150227T030752_004803_005F89_DB68.zip
  S1A_IW_GRDH_1SSV_20150122T030723_20150122T030752_004278_005347_8809.zip
  S1A_IW_GRDH_1SSV_20141229T030724_20141229T030753_003928_004B86_DA25.zip

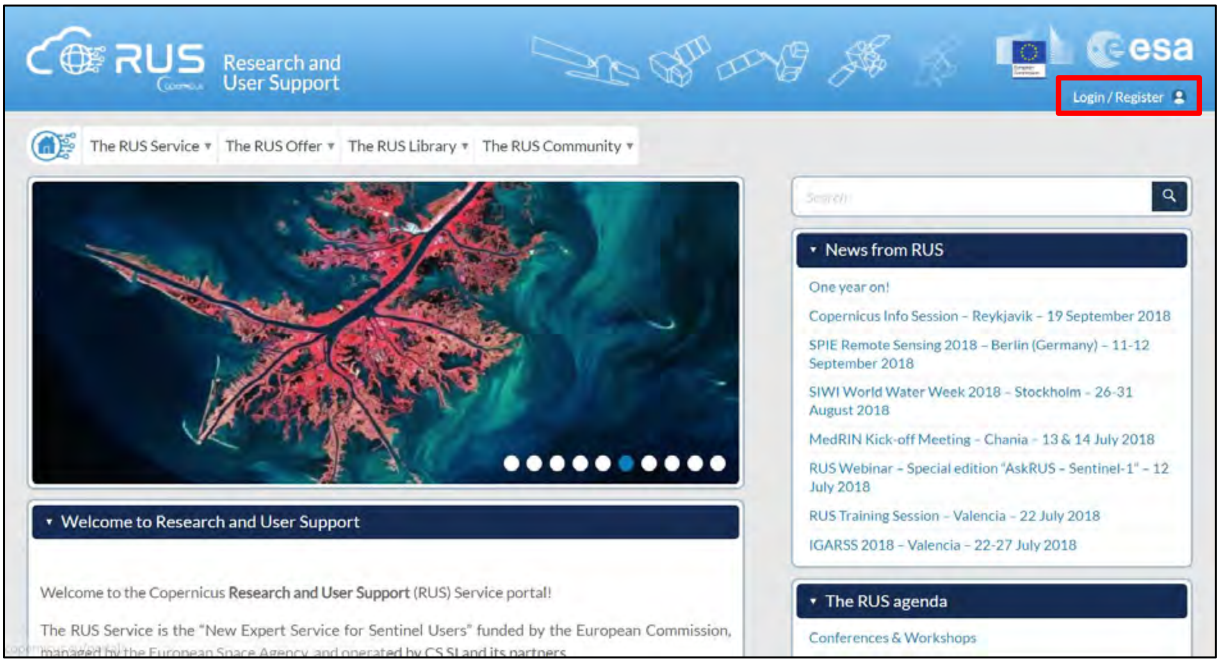
- Sentinel-1 Precise Orbits (PODs) for the corresponding dates (auxiliary data) automatically downloaded [downloadable @ https://qc.sentinel1.eo.esa.int]

2.2 Software in RUS environment

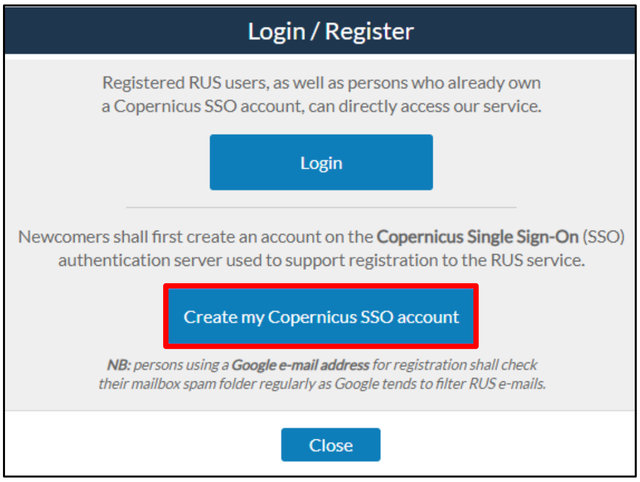
Internet browser, SNAP + Sentinel-1 Toolbox, QGIS

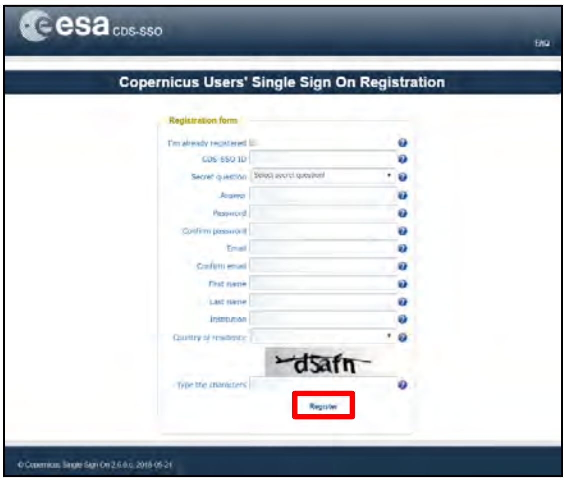
3 Register to RUS Copernicus

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.



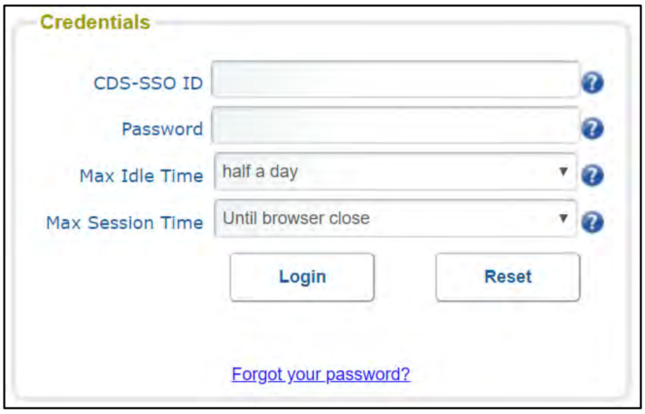
Select the option ***Create my Copernicus SSO account*** and then fill in ALL the fields on the **Copernicus Users' Single Sign On Registration**. Click ***Register***.



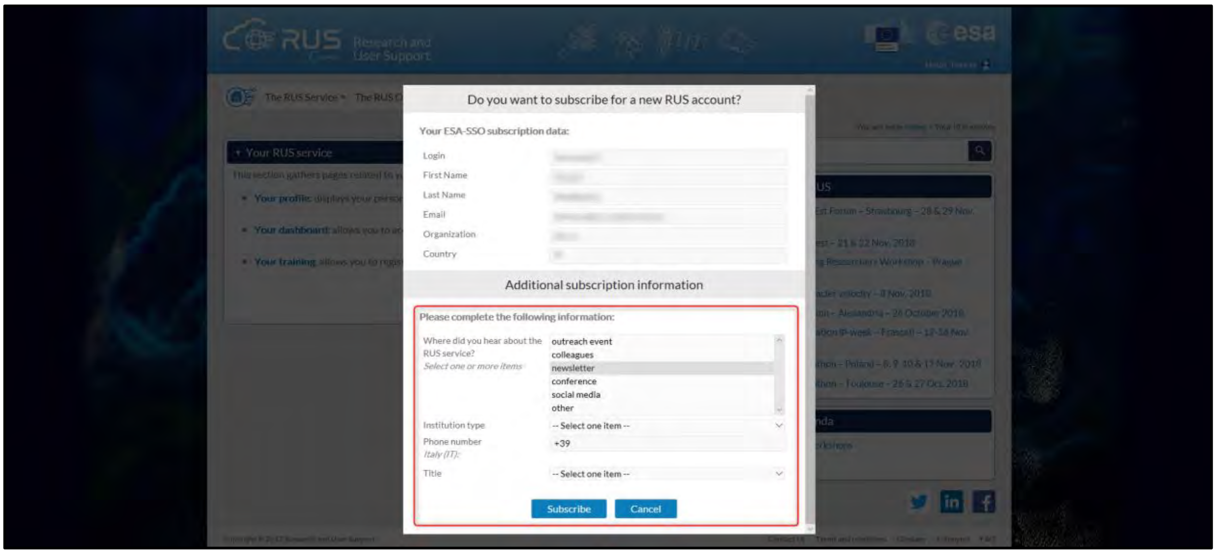


Within a few minutes you will receive an e-mail with activation link. Follow the instructions in the e-mail to activate your account.

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

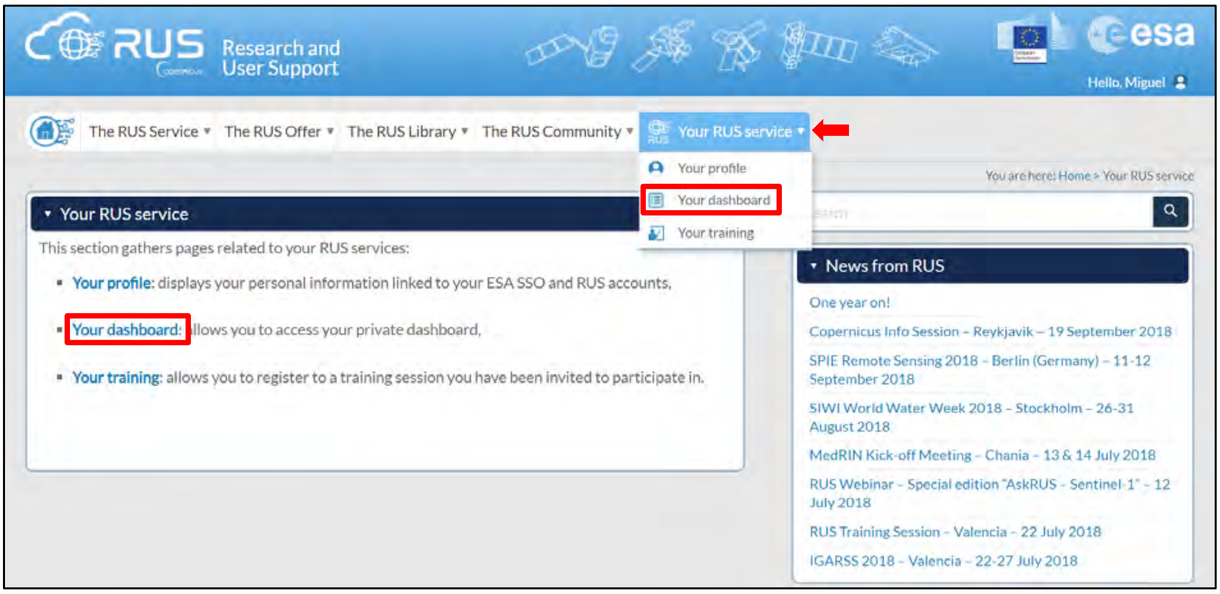


Upon your first login you will need to enter some details. You must fill all the fields.

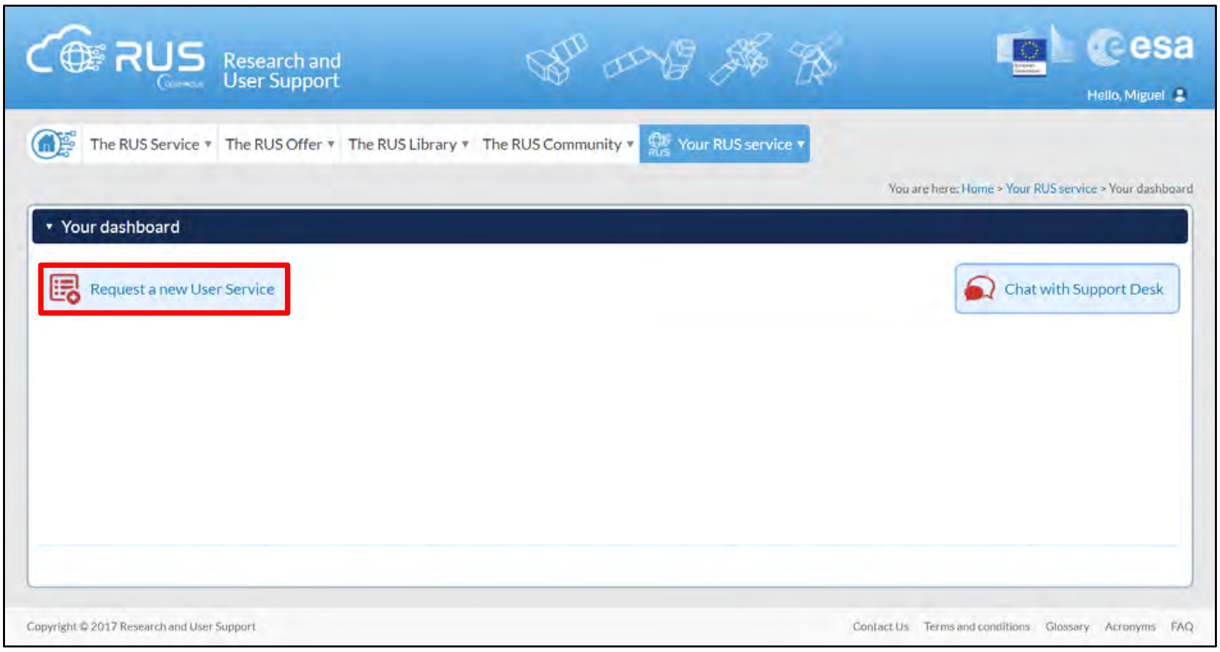


4 Request a RUS Copernicus Virtual Machine

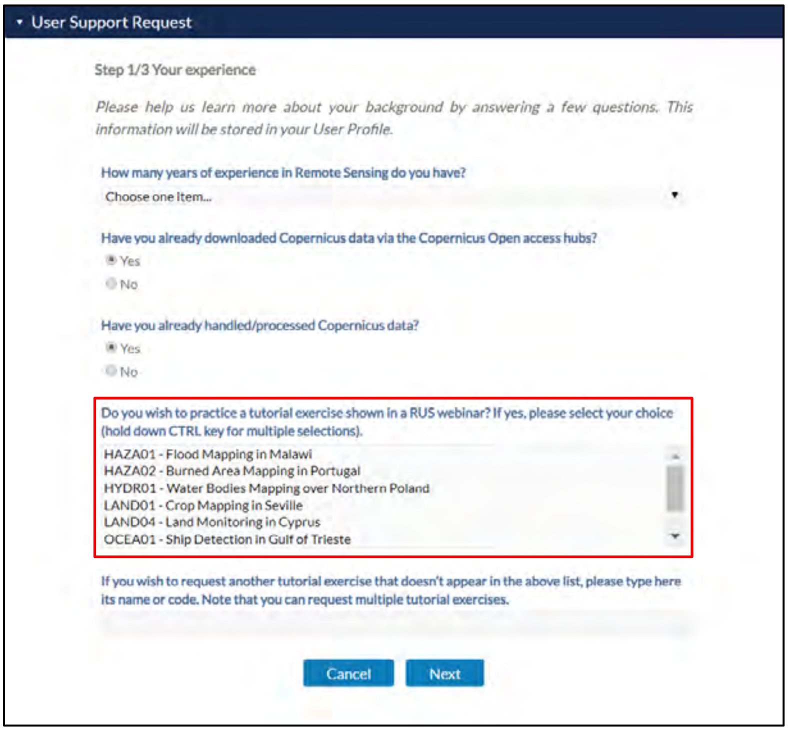
Once you are registered as a RUS user, you can request a RUS Virtual Machine to repeat this exercise or work on your own projects using Copernicus data. For that, log in and click on ***Your RUS Service → Your Dashboard***.



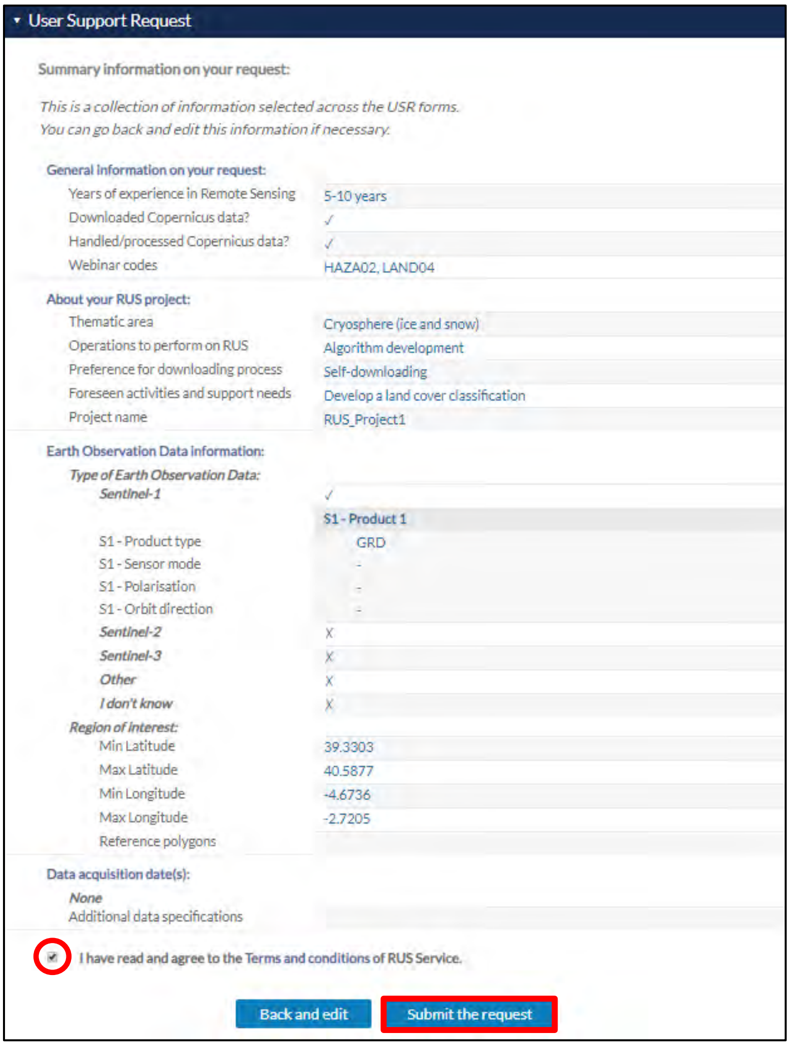
Click on ***Request a new User Service*** to request your RUS Virtual Machine. Complete the form so that the appropriate cloud environment can be assigned according to your needs.



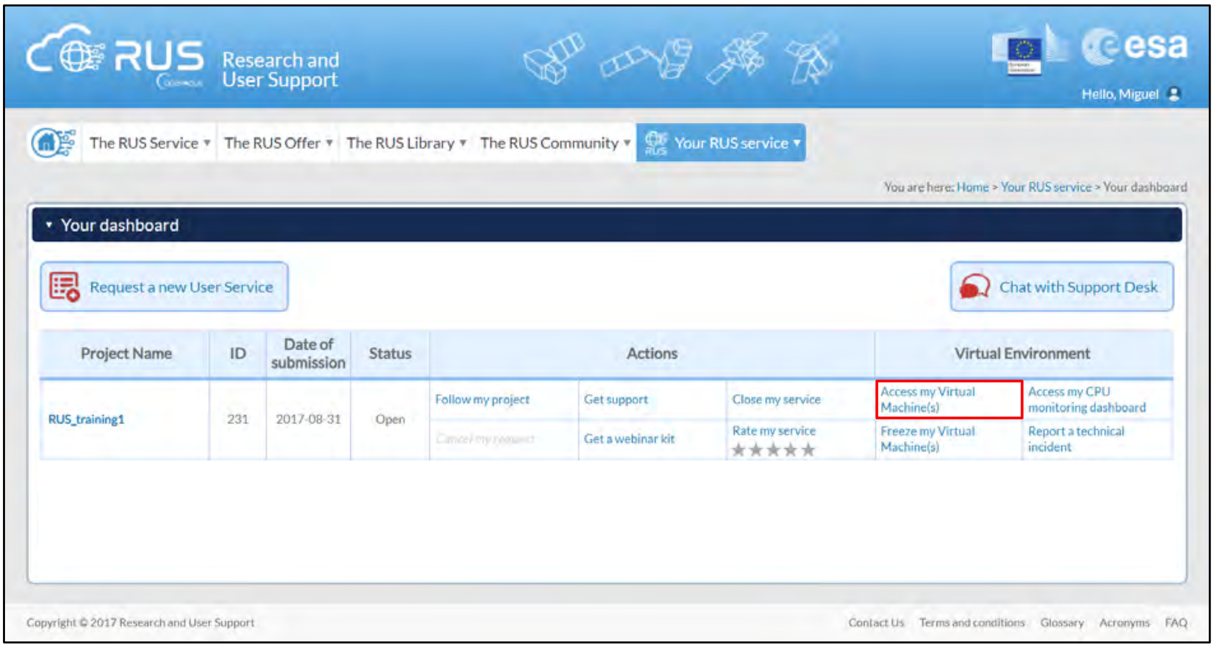
If you want to repeat this tutorial (or any previous one) select the one(s) of your interest in the appropriate field.



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.

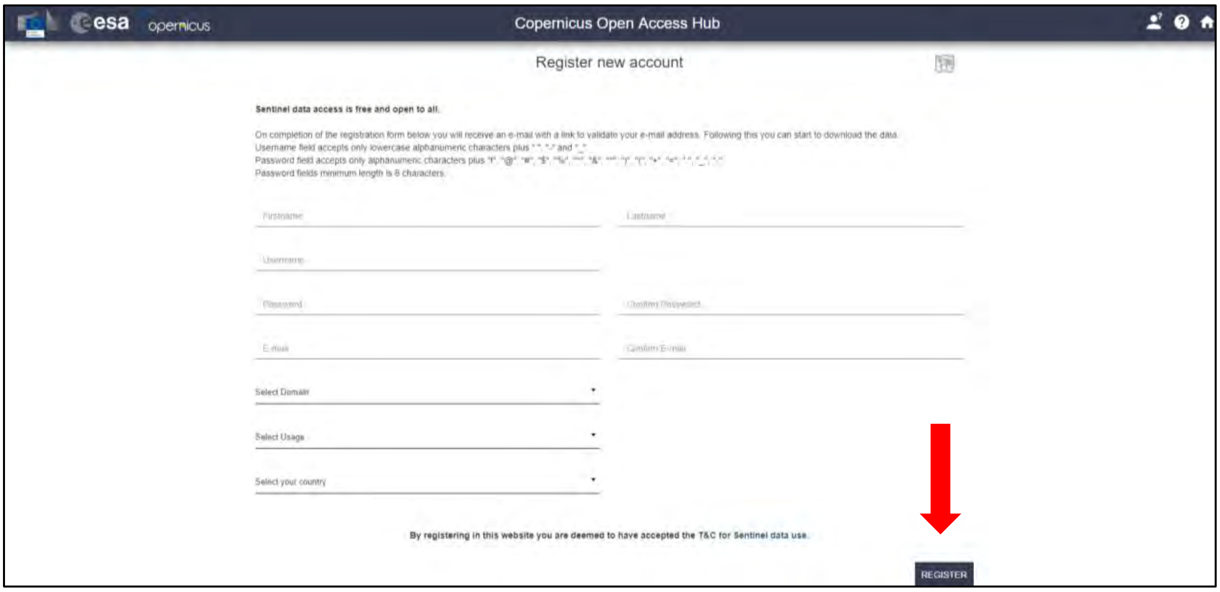
5 Step by step

5.1 Data download – ESA SciHUB

In this step, we will download Sentinel-1 scenes from the Copernicus Open Access Hub using the online interface (**Applications → Network → Firefox Web Browser** or click the link below).

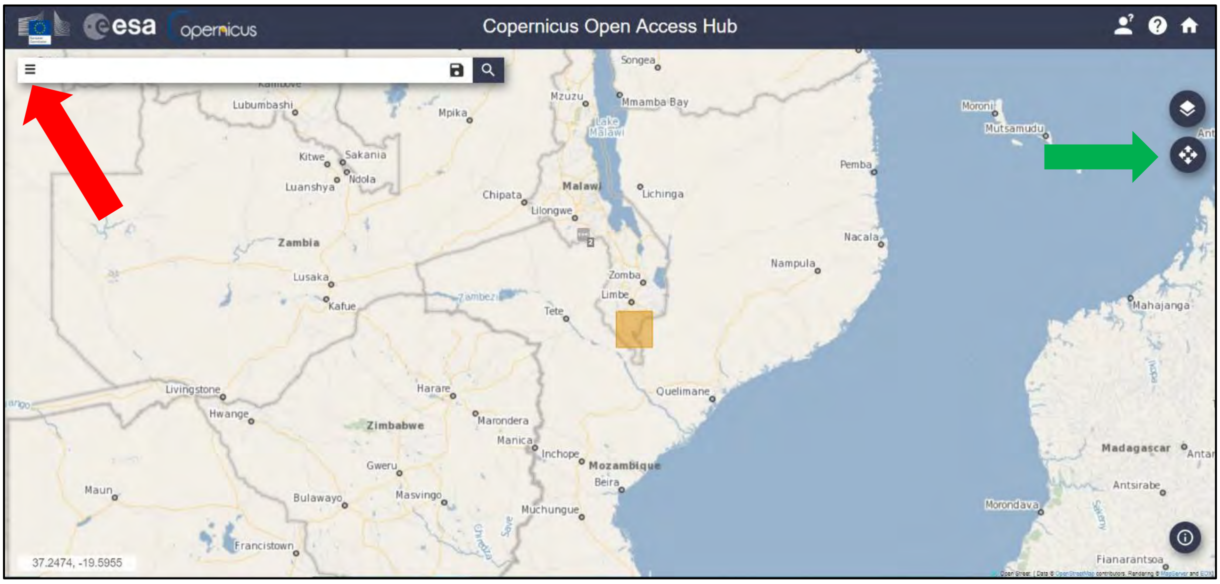
Go to https://scihub.copernicus.eu/

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**”.

Then click on the map and Navigate to the approximate location of south Malawi. Switch to drawing mode (green arrow) and draw search rectangle approximately as indicated below.



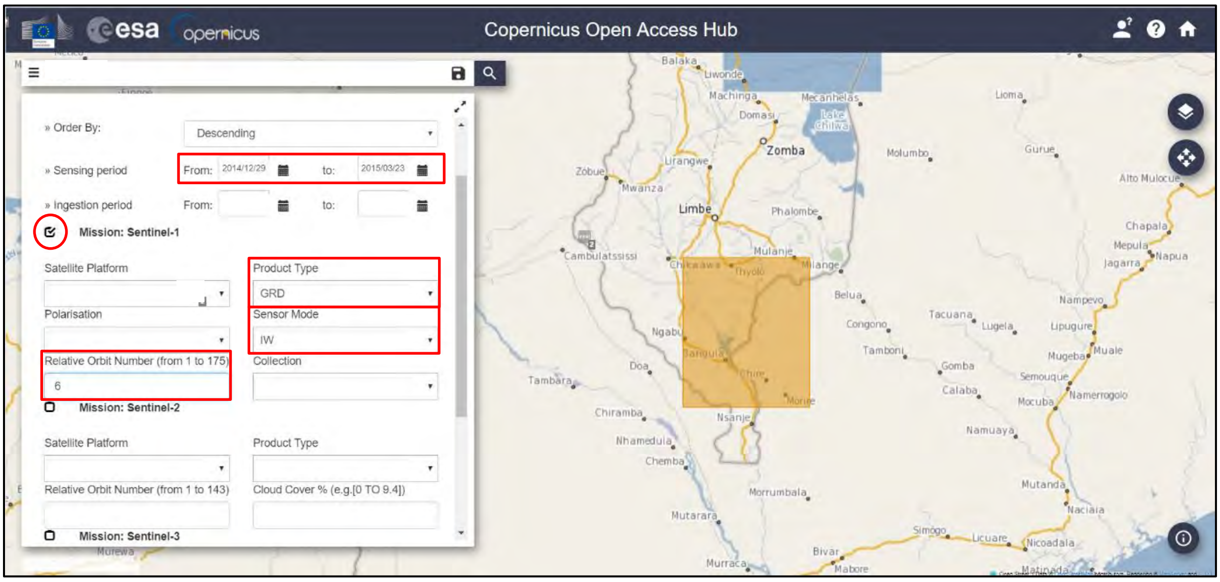
Open the search menu by clicking to the left part of the search bar and specify the following parameters:

Sensing period: From 2014/12/29 to 2015/03/23

Check Mission: Sentinel-1

Product Type: GRD (Ground-range-detected product)

Relative Orbit number: 6 (to ensure identical acquisition geometry for all scenes)

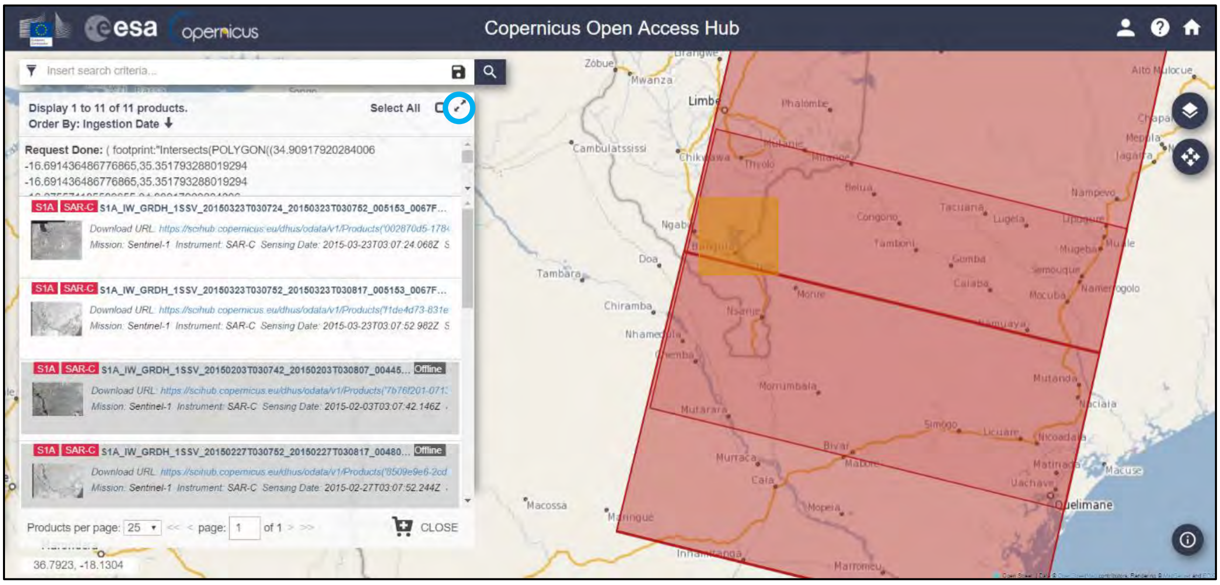


In our case, the search returns only 11 results but this will depend on the exact search area defined. Download the following scenes:

S1A_IW_GRDH_1SSV_20150323T030724_20150323T030752_005153_0067F3_832F
S1A_IW_GRDH_1SSV_20150227T030723_20150227T030752_004803_005F89_DB68
S1A_IW_GRDH_1SSV_20150122T030723_20150122T030752_004278_005347_8809
S1A_IW_GRDH_1SSV_20141229T030724_20141229T030753_003928_004B86_DA25

Note that you can only download 2 scenes in parallel. To see the full name of the scene you can click the full screen view (indicated by blue circle below).

You can find instructions how to download larger numbers of products in the Copernicus Open Access Hub User Guide (https://scihub.copernicus.eu/userguide/GraphicalUserInterface)

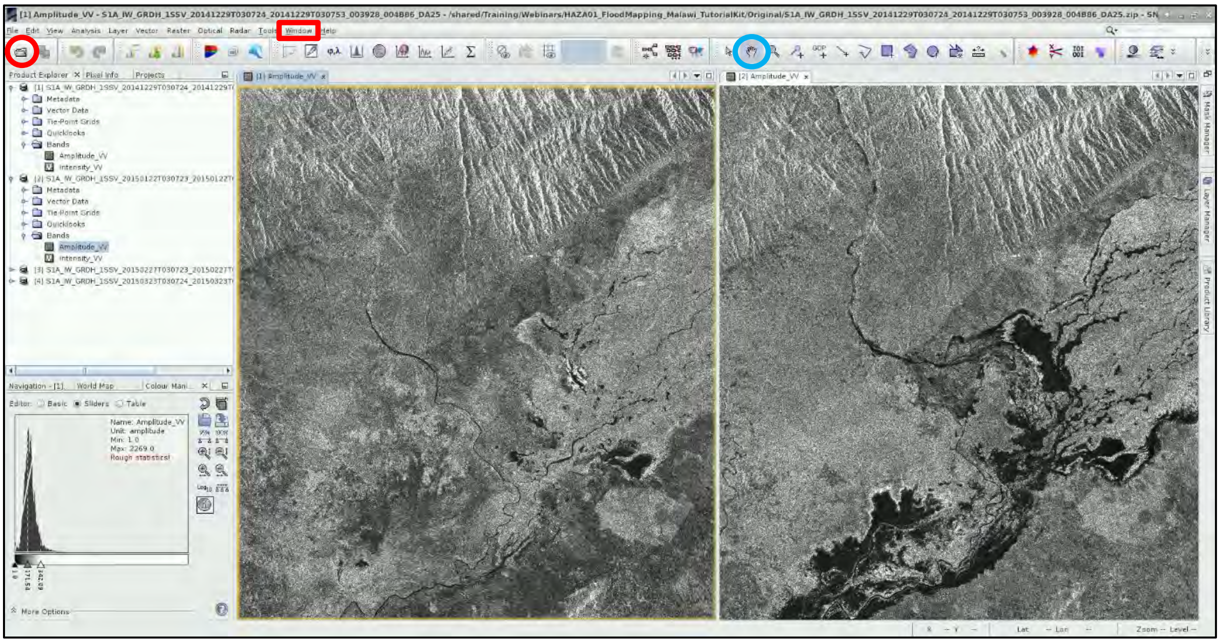


Move the downloaded scenes from the *Downloads* folder (*/home/rus/Downloads)* to: ***/shared/Training/HAZA01_FloodMapping_Malawi_TutorialKit/Original***

5.2 SNAP – open and explore data

Open **SNAP Desktop** (icon located on the desktop); click Open product , navigate to: ***/shared/Training/HAZA01_FloodMapping_Malawi_TutorialKit/Original*** and open all the downloaded files.

The opened products will appear in **Product Explorer**. Click **+** or the to expand the contents of the file from December 2014, then expand Bands and double click ***Amplitude_VV*** to visualize the band. Then do the same for the image from 22 January 2015. To compare both images, go to **Window → Tile Horizontally** and zoom-in to the lower right corner of the image.

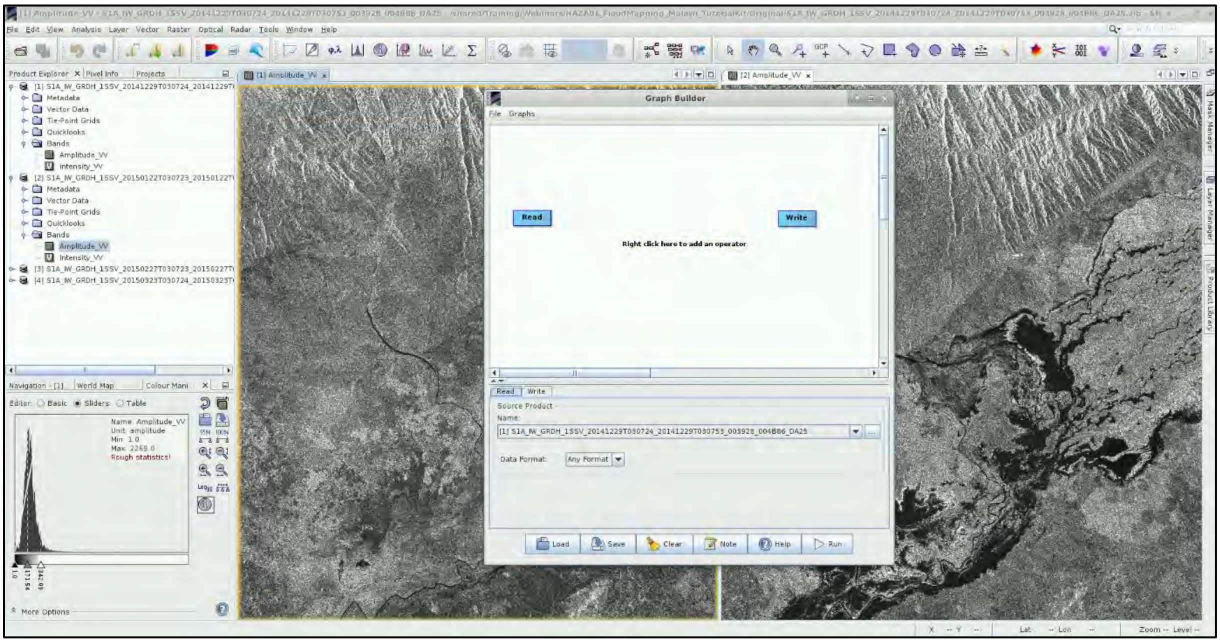


5.3 *Pre-processing*

We need to apply identical pre-processing steps to all our scenes. However, processing the data step by step and product by product would be time consuming and inconvenient. Luckily, we can use the **Batch Processing** tool available in SNAP to apply all steps to both images in one go (this also saves disk space as only the final products are physically saved).

5.3.1 Build the Graph

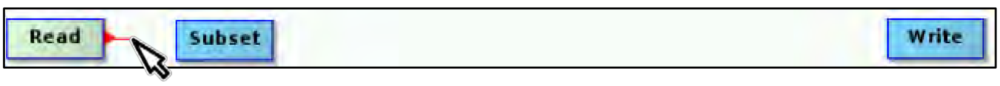
To use the tool, we first need to define the process we want to apply and all its steps. We can do this using the **GraphBuilder**. To build our graph, go to **Tools → GraphBuilder**.



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

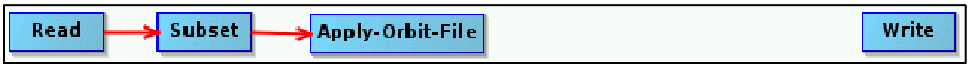
Since our Area of Interest (AOI) is quite small and there is no need to process the whole image, we start by adding a **Subset** operator. To add the operator right-click the white space in the graph builder and go to **Add → Raster → Geometric → Subset.**

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 and going to **Add → Radar → Radiometric → ThermalNoiseRemoval.** Connect the **ThermalNoiseRemoval** operator with the **Apply-Orbit-File** operator.

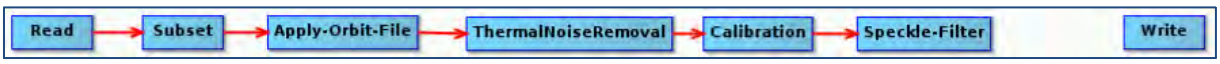
> NOTE 2: Thermal noise in SAR imagery is the background energy that is generated by the receiver itself. (*SNAP Help*) It skews the radar reflectivity to towards higher values and hampers the precision of radar reflectivity estimates. Level-1 products provide a noise LUT for each measurement dataset,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

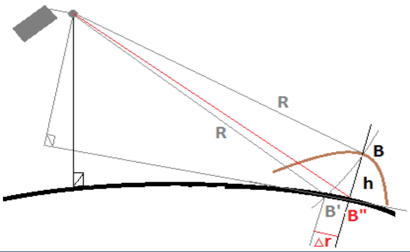
SAR images have inherent salt and pepper like texturing called speckles which degrade the quality of the image and make interpretation of features more difficult (See NOTE 4). To reduce the speckle effect and smooth the image we apply speckle filter. To add the operator, go to **Radar → Speckle Filtering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

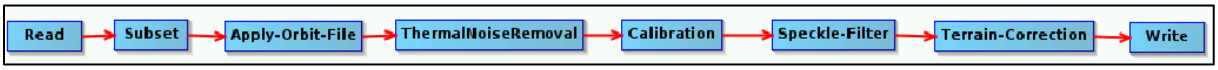
> NOTE 4: Speckle is caused by random constructive and destructive interference of the de-phased but coherent return waves scattered by the elementary scatters within each resolution cell. Speckle noise reduction can be applied either by spatial filtering or multilook processing. (*SNAP Help*)



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 preprocessing, 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** and then connect the **Speckle-Filter** operator to it. Finally, connect the **Terrain Correction** operator to the **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)*





For the moment, do not change anything in the parameter tabs and save the graph as ***Graph_preprocess.xml*** to: ***/shared/Training/HAZA01_FloodMapping_Malawi_TutorialKit/Processing*** by clicking **Save** at the bottom of the window. After you save the graph, close the **GraphBuilder** window.

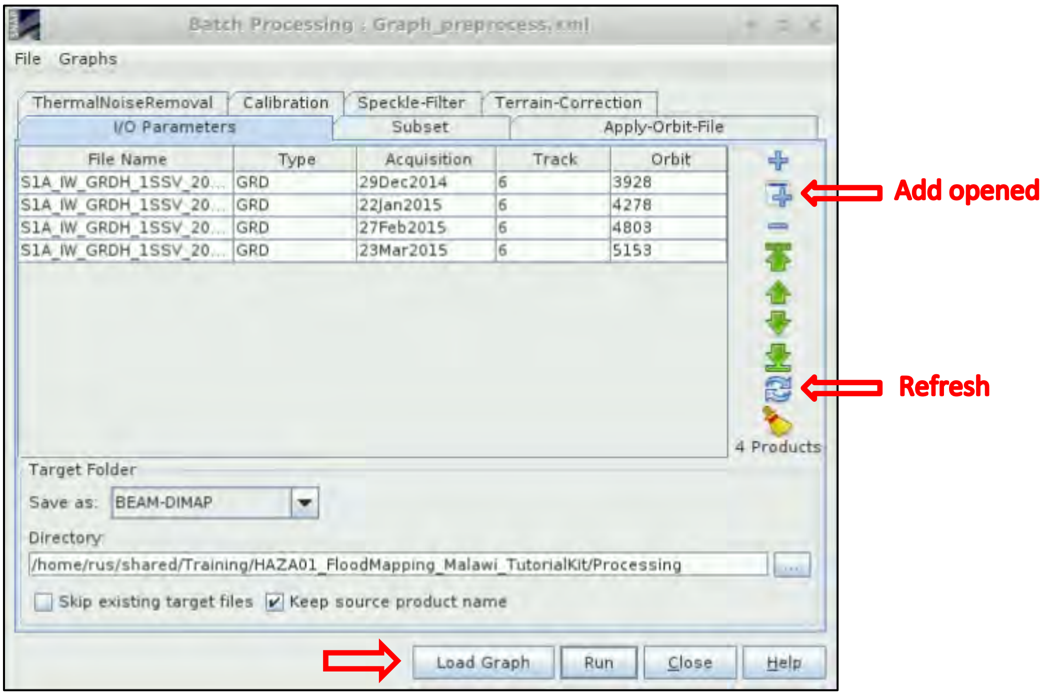
5.3.2 Batch processing

In the **Product Explorer**, we select (highlight) the product [1] (29 December 2014). Now we can open the **Batch Processing** tool at **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 click **Load Graph** at the bottom of the window and navigate to our saved graph and open it. We see that new tabs have appeared at the top of window corresponding to our operators except for **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/HAZA01_FloodMapping_Malawi_TutorialKit/Processing*** and make sure the "**Keep source product name**" option is selected (See NOTE 6).

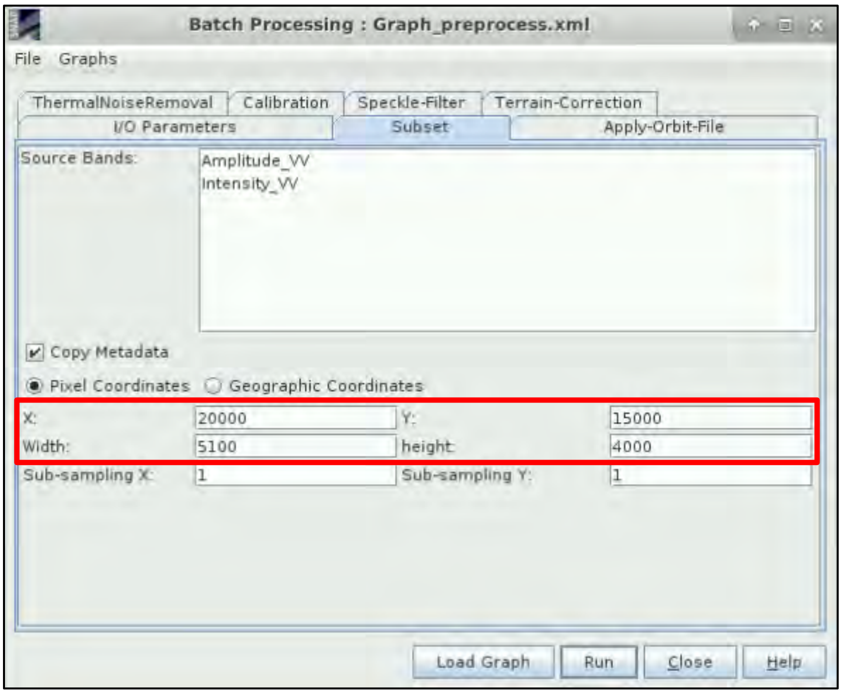
NOTE 6: The product file names will be identical to the input file names. If you set your output directory to the folder that contains your input data, the input data will be overwritten!



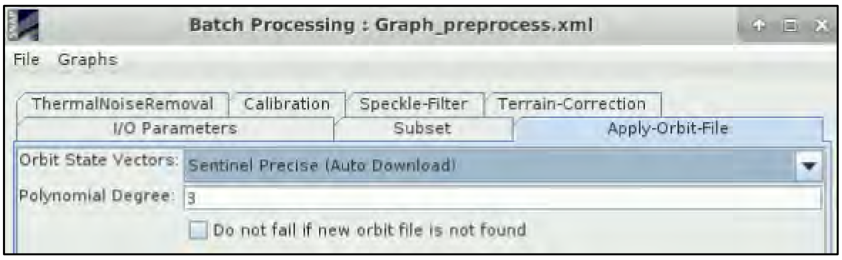
Now let's set the parameters.

In the **Subset** tab, set the extent of the AOI in pixel coordinates to:

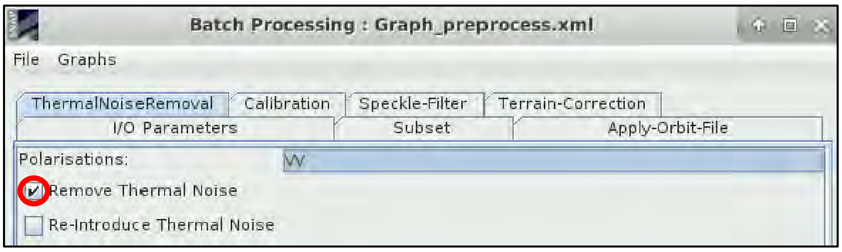
X: **20000** Y: **15500** Width: **5100** Height: **4000**



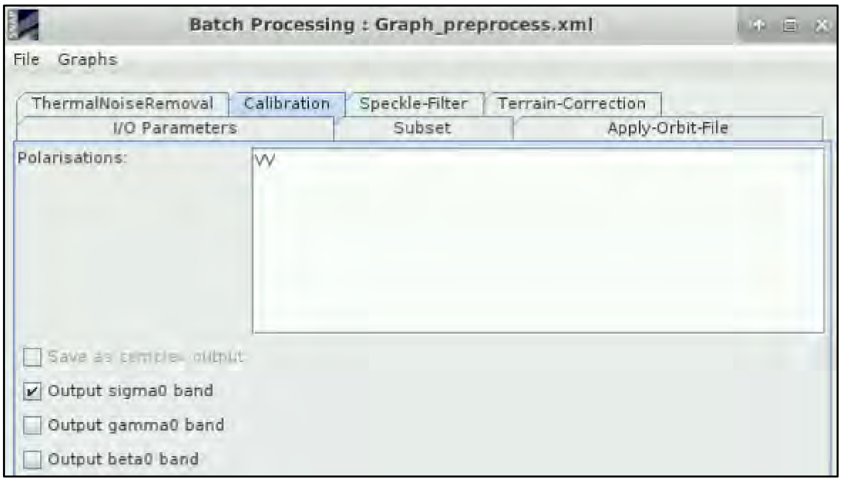
In the **Apply-Orbit-File** tab we well keep the default settings.



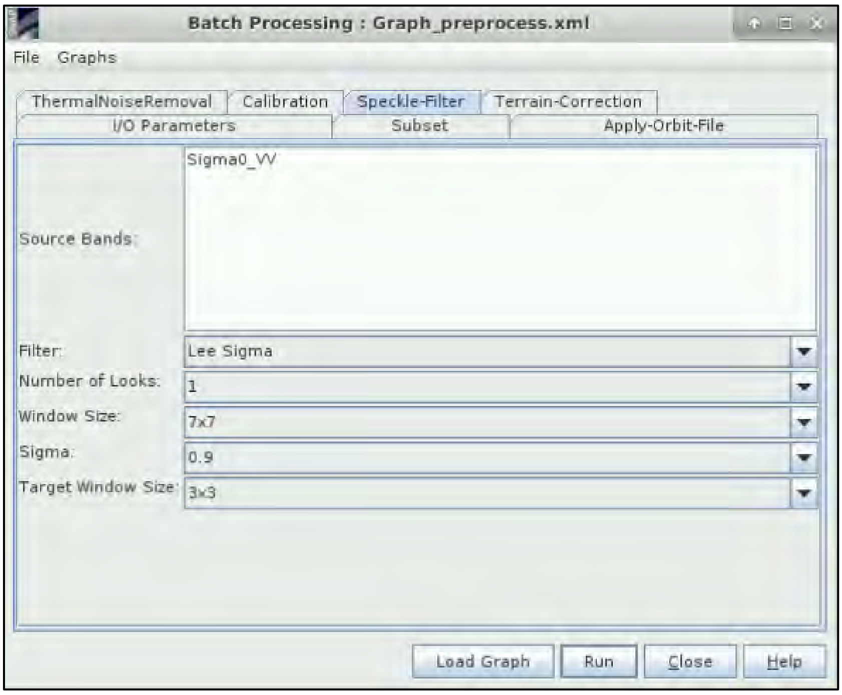
In the **ThermalNoiseRemoval** tab, select VV polarization and make sure that the "**Remove Thermal Noise**" option is selected.



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



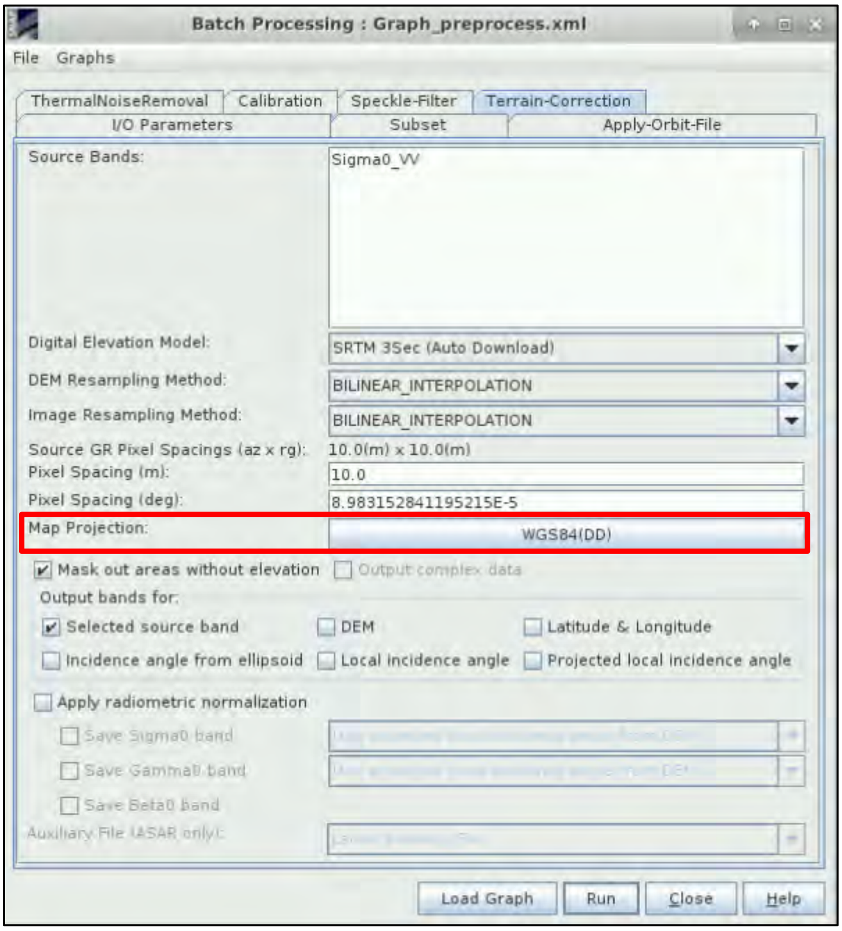
Now we go to the **Speckle-Filter** tab. For this exercise we choose the simple Lee filter with **Window Size** of **7x7** pixels (See NOTE 7).

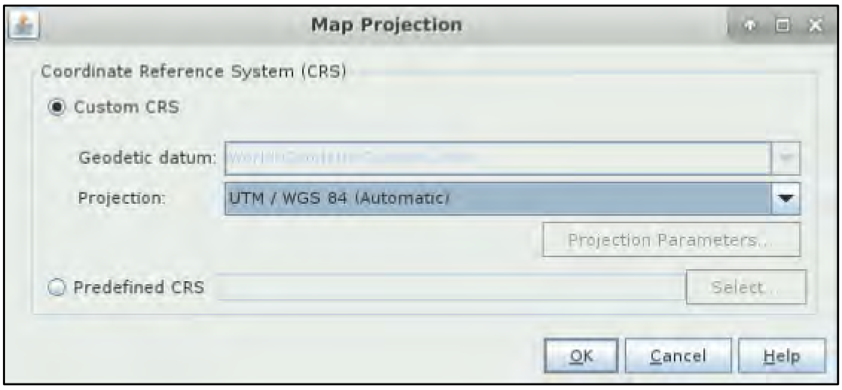


NOTE 7: Lee Filter, introduced by Jong-Sen Lee in 1980, is a widely used local statistics filter for speckle noise reduction. It is a pointwise linear filter minimizing the mean square error using measurements of the sample mean and sample variance of the noisy image and knowledge of the type of detection and number of looks.

Last, we go in the **Terrain-Correction** tab, click on the **Map Projection** and set as Projection**: UTM / WGS84 (Automatic)**.

Click **OK**. At the "Map Projection" you will see: UTM Zone 36, South / World Geodetic System 1984.





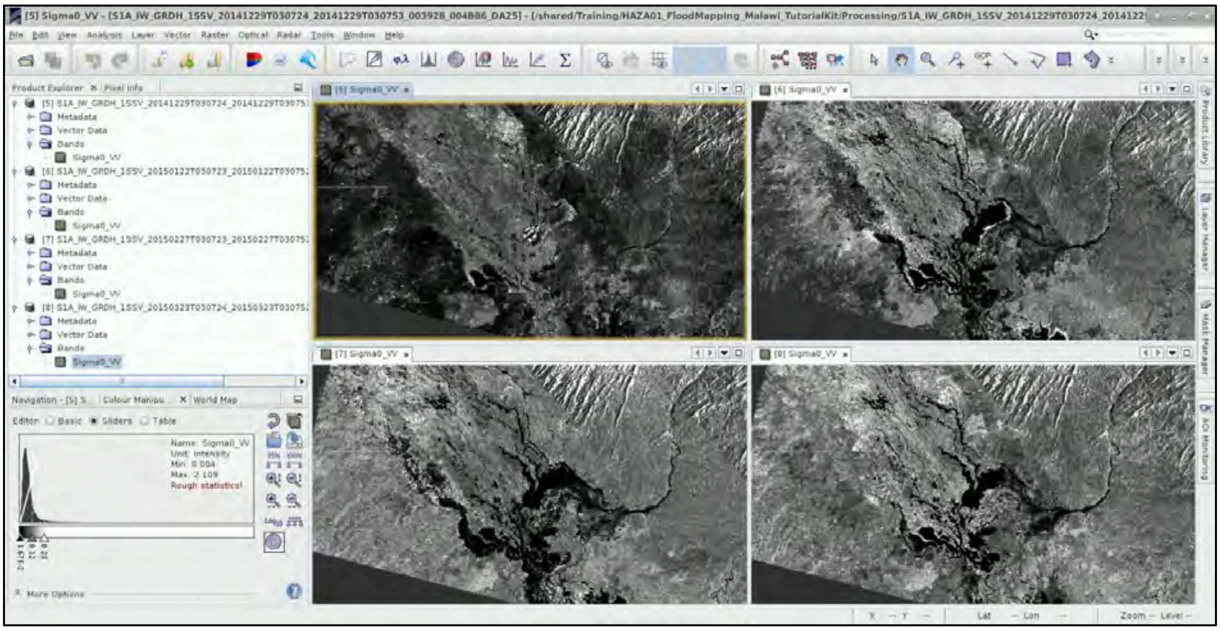
Leave all the other default settings and click **Run** to pre-process our images. *Approximate processing time: 5 minutes*

Now you should have four new products in the **Product Explorer**. Select the original products [1-4], right-click and click **Close 4 Products** (Click **No** if asked to save).

5.4 Binarization

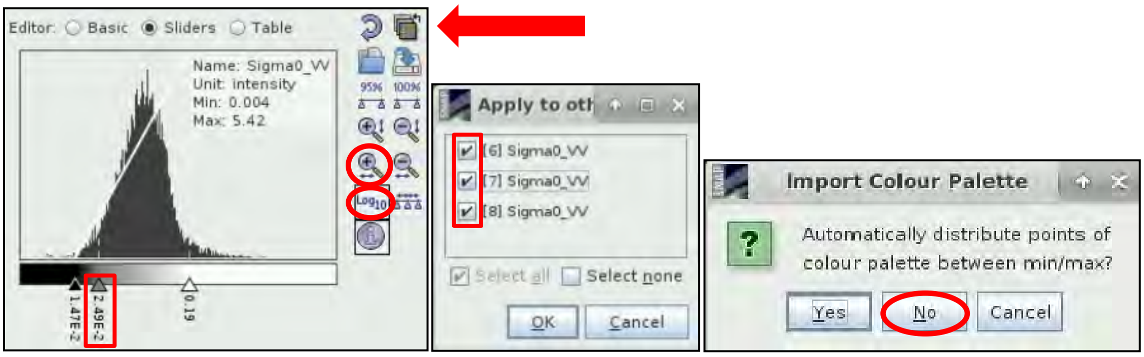
To separate water from non-water a threshold can be selected for each image. For this, we will analyze the histogram of the filtered backscatter coefficient. Low values of the backscatter will correspond to the water, and high values will correspond to the non-water class.

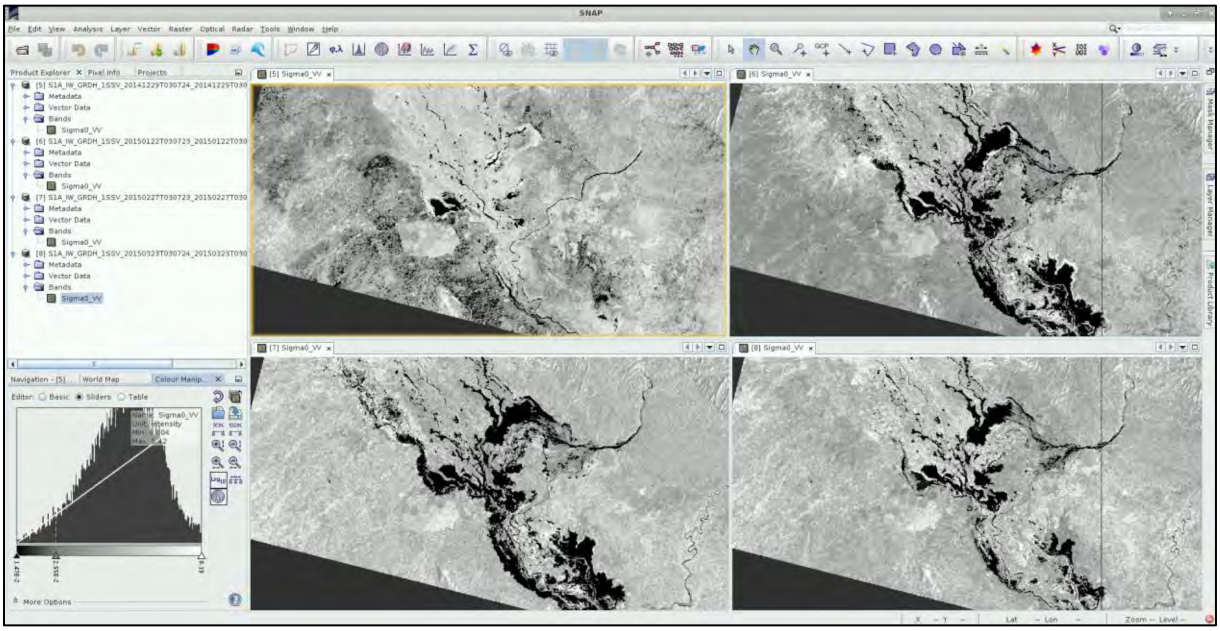
Open the **Sigma0_VV** band from all four created products [5-8] in the View and then go to **Window → Tile Evenly**. Click on the view [5] Sigma0_VV to activate it (a yellow boundary appears around it).



Then go to the left side panel, select the **Color Manipulation** tab and click once at the (Stretch the histogram horizontally) on the left side of the tab.

Then move the middle slider below on the histogram to approx. ~0.025 and click on Log_{10}. Now we can see the water bodies better. Let's apply the same histogram stretch to other three images. To do this click on and select all three bands and click **OK**. In next dialog click **No** (for each band).





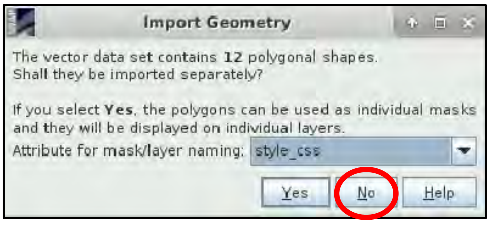
To create a binary mask of water and non-water pixels we create a new band and apply a conditional expression based on our threshold. To obtain our threshold value we will check the values occurring over the open water.

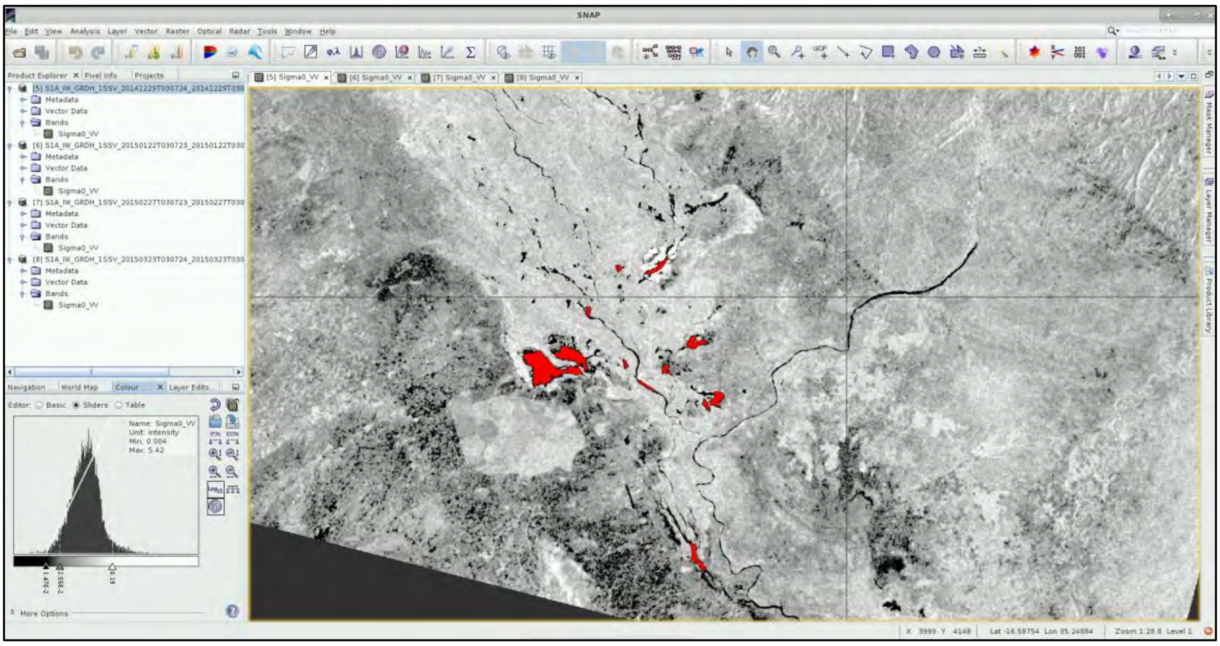
Go to **Window → Tile Single**. Go to View [5] Sigma0_VV.

You can create your own water body mask, but for this tutorial we will use one that has been prepared in advance and saved in the *Auxdata folder*. We can import it by clicking on the Product [5] in **Product Explorer** and then going to **Vector → Import → ESRI Shapefile.**

Navigate to ***/shared/Training/HAZA01_FloodMapping_Malawi_TutorialKit/Auxdata*** and open the shapefile ***Water_ROI_Polygon.shp***.

Click **No** in the **Import Geometry** dialog (import all features into single mask).

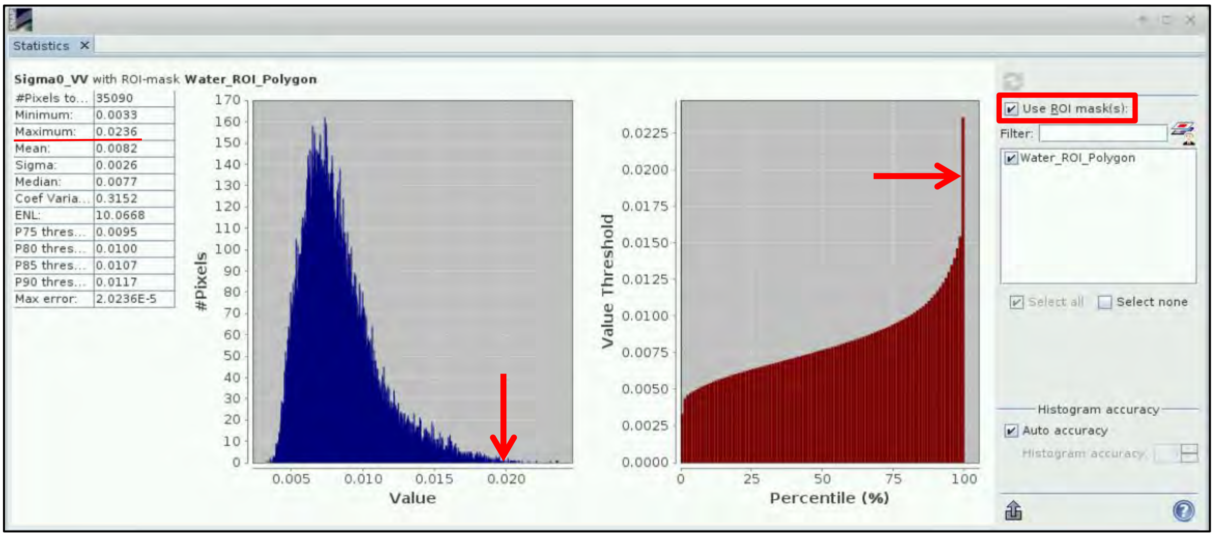




Now let's have a look at the statistics.

In the **Product Explorer** window, expand the bands folder in product [5] and click on band ***Sigma0_VV*** so it is highlighted.
Then go to **Analysis → Statistics.**
A new window will appear. On the right side select ✓ the "**Use ROI Mask(s)**", select the ***Water_ROI_Polygon*** (See TIP 1) and click **Refresh**.

TIP 1: If the ROI/geometry does not appear in the window go to **Product Explorer**, expand the ***Vector Data*** folder in product [5] and click on ***Water_ROI_Polygon***. Now it should appear in the statistics window as well and you can select it.



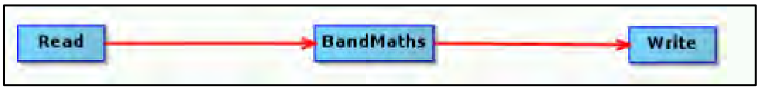
Now we can investigate the statistics. We can see that the maximum value in our Water polygons is 0.0236, the statistics also produces 90% percentile which gives a value of 0.0117. For our purposes we will adopt a value close to the 99% percentile which is not provided but can be estimated from the histograms. Let's choose 0.020 as our threshold (the statistics is of course always dependent on the ROI you choose and therefore can vary significantly). Now that we have the value of our threshold, we can close this window.

Here we assume that our polygons cover only pure water pixels and are not contaminated by any mixed coastal pixels or objects in the water (ships), therefore, we conclude that all the values smaller than our maximum value will correspond to water as well. We are still considering 1% of potentially contaminated pixels when choosing the 99% percentile. We could be more conservative to avoid misclassification (choose lower value), but threshold selection always requires some testing.

Now let's apply the threshold. We will apply the same threshold to all our images, therefore we can use the **Batch processing** again.

Firstly, let's build a very simple graph. Go to **Tools → Graph Builder**.

Add the **Band Math** operator (right-click on the white space and go to **Raster → BandMaths**) and connect the operators as shown below. At the bottom of the window **Save** the graph to the ***/shared/Training/HAZA01_FloodMapping_Malawi_TutorialKit/Processing/Bin*** folder with the name: ***Graph_binary.xml***.

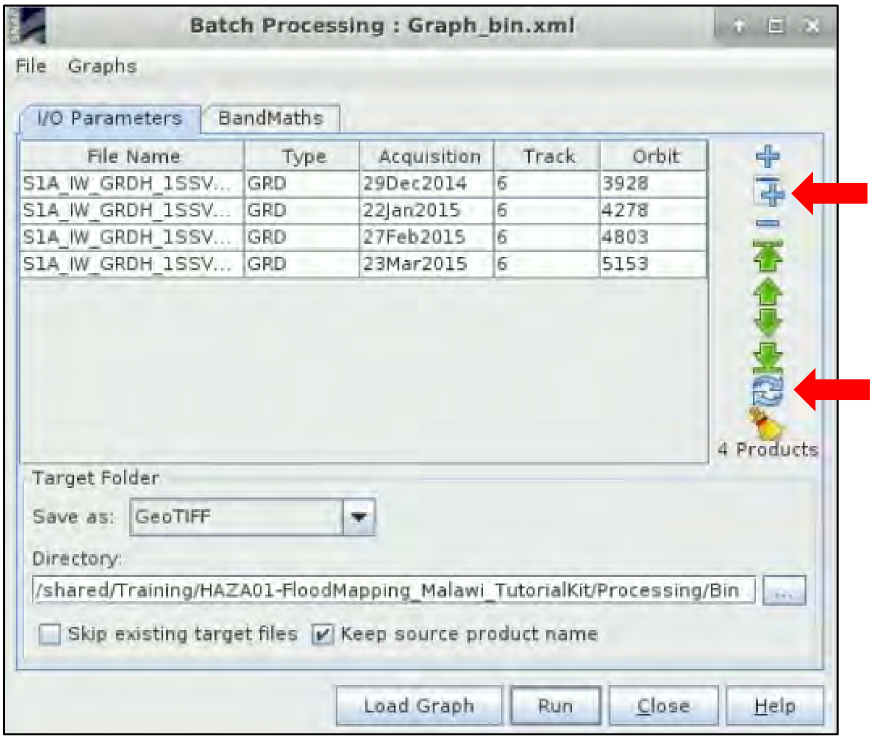


Close the **Graph Builder**.

Then go to **Tools → Batch Processing** and click **Add Opened** on the upper right (second icon from the top) and click **Refresh**. Click on the **Load Graph** button, navigate to our saved graph and open it. We can now see that the **BandMaths** tab has appeared at the top of window.

In the **I/O Parameters** tab, under the *Target Folder*, make sure that:

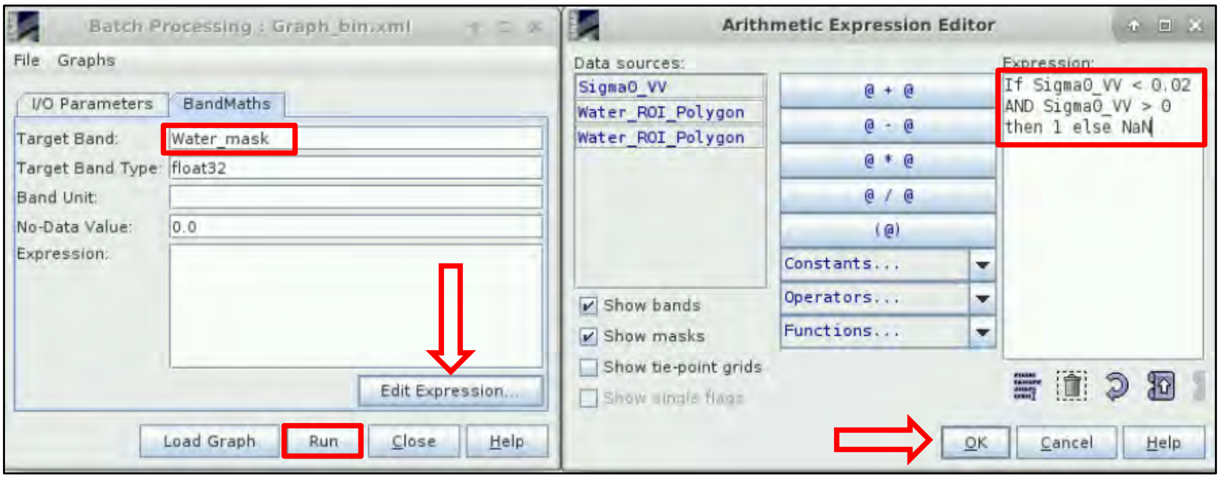
a) the format (Save as) is set to **GeoTIFF**,
b) the directory is: ***/shared/Training/HAZA01_FloodMapping_Malawi_TutorialKit/Processing/Bin***
c) and the "**Keep source product name**" option is selected (See NOTE 6 - Page 14).



In the **BandMaths** tab, rename the new band to *Water_mask,* open the "**Edit Expression…**" and enter the following expression:

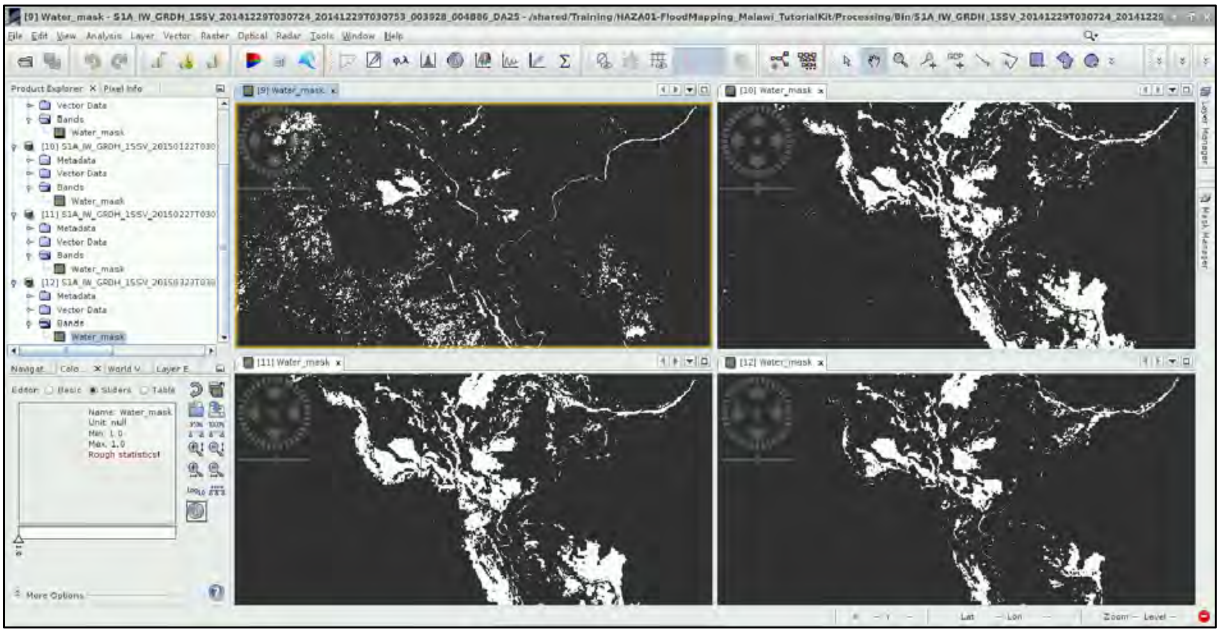
```
If Sigma0_VV < 0.02 AND Sigma0_VV > 0 then 1 else NaN
```

If no errors are found, click **OK** to close the Arithmetic Expression Editor and then click **Run**. After the processing is completed, close the Batch Processing window.

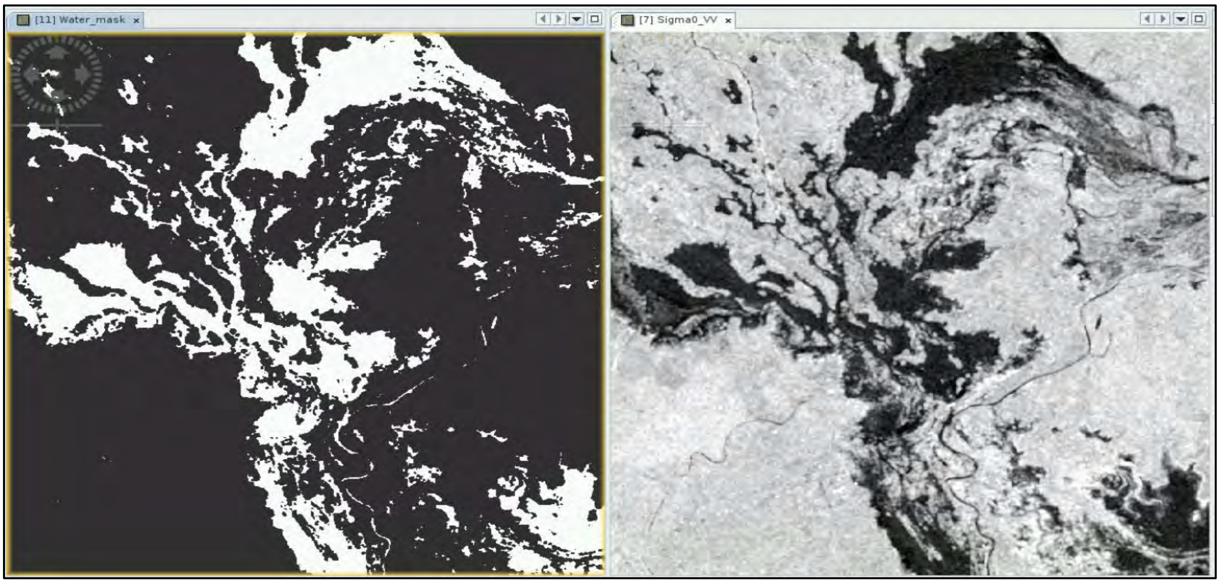


Four new products [9-12] have appeared in the **Product Explorer**. Close all opened view windows and open the **Water_mask** band for all the new products.

Go to **Window → Tile Evenly** in order to see all products at the same time.



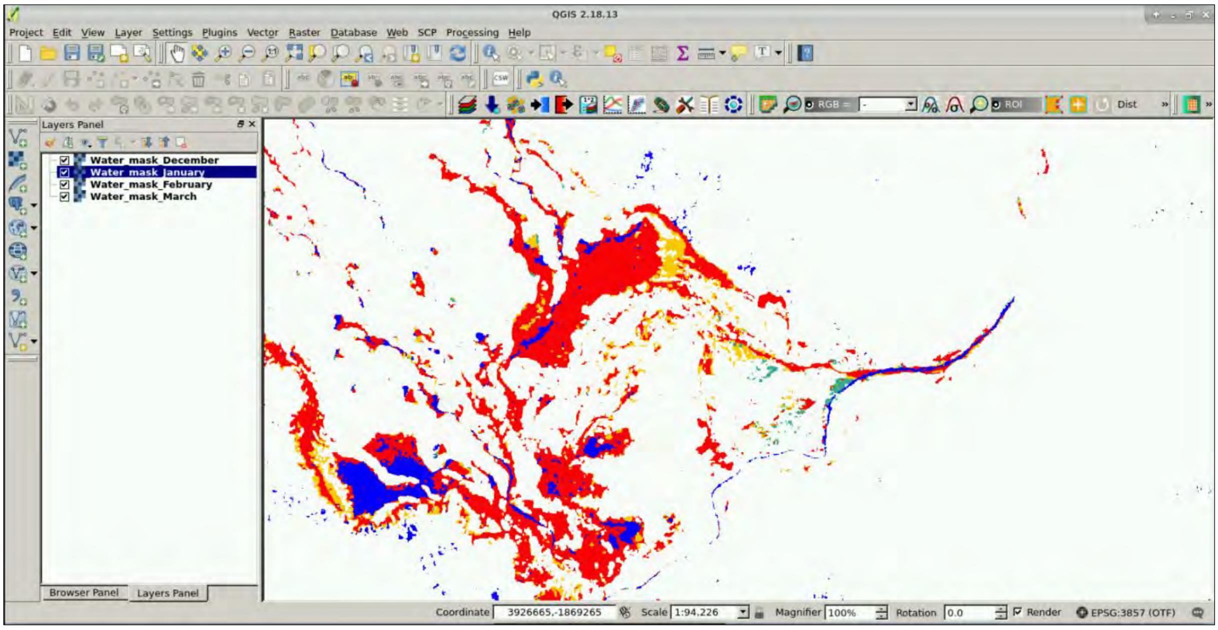
You can also compare the ***Sigma0_VV*** band to the ***Water_mask*** band of every product (29 December 2014).



Now we can close SNAP. To better visualize the output of our multi-temporal flood analysis, we will open the saved masks (GeoTIFF) in QGIS.

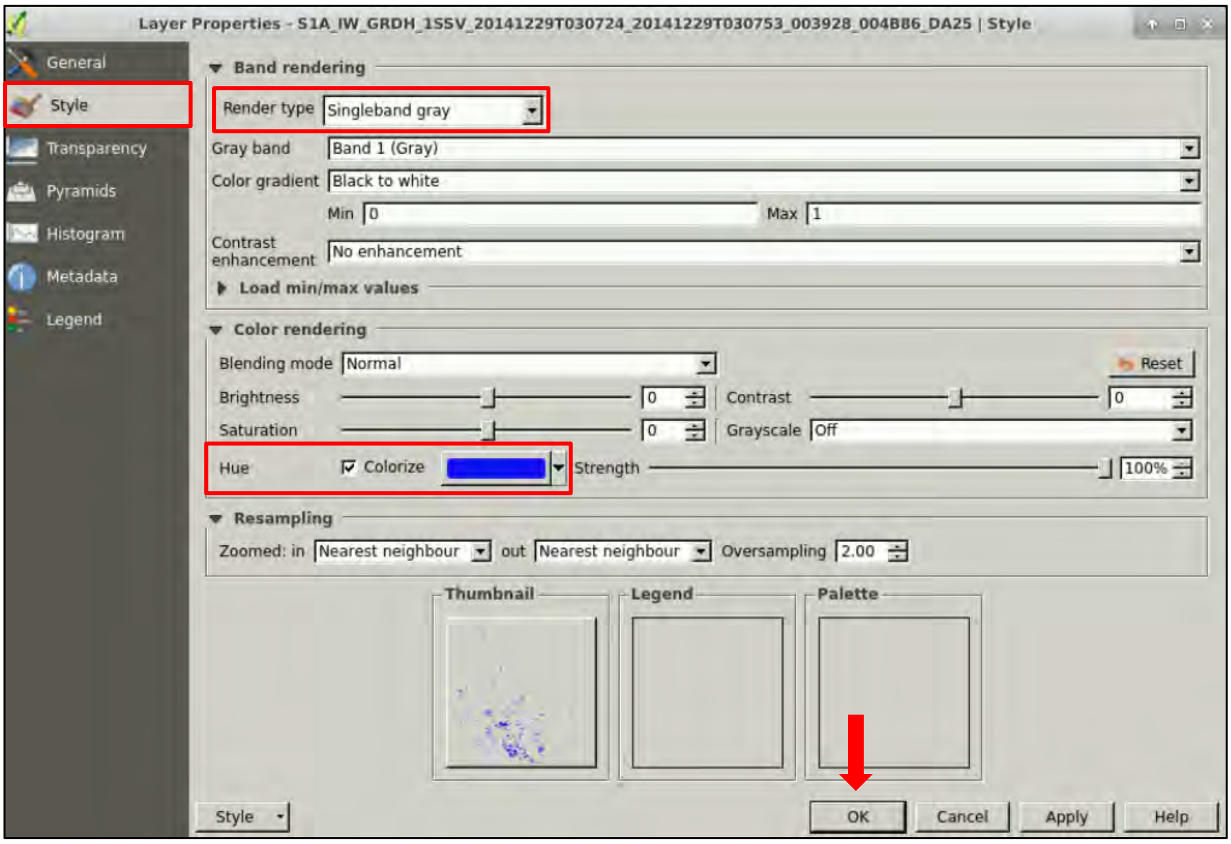
5.5 Visualization (QGIS)

Open QGIS from the desktop shortcut or go to **Application → Processing → QGIS Desktop**. Click on the **Add Raster Layer** button located in the left panel ( ), navigate to: ***/shared/Training/HAZA01_FloodMapping_Malawi_TutorialKit/Processing/Bin*** select the four water masks and click **Open**.



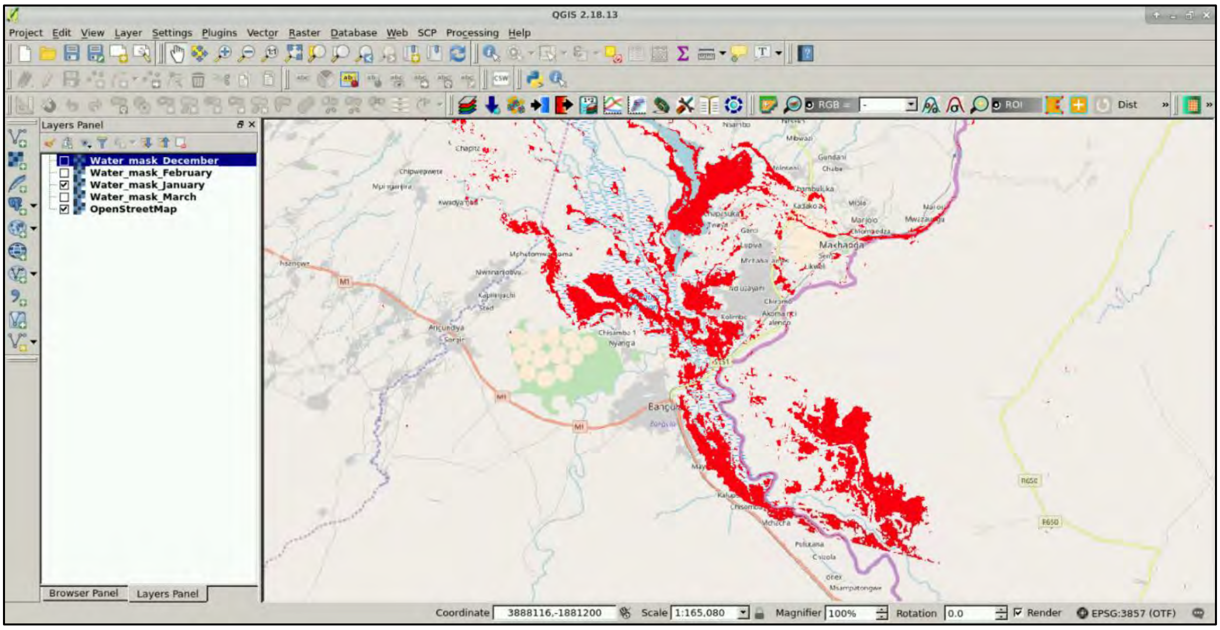
You can change the style of each layer in the **Properties** menu. Right-click on the product you want to change and select **Properties**.

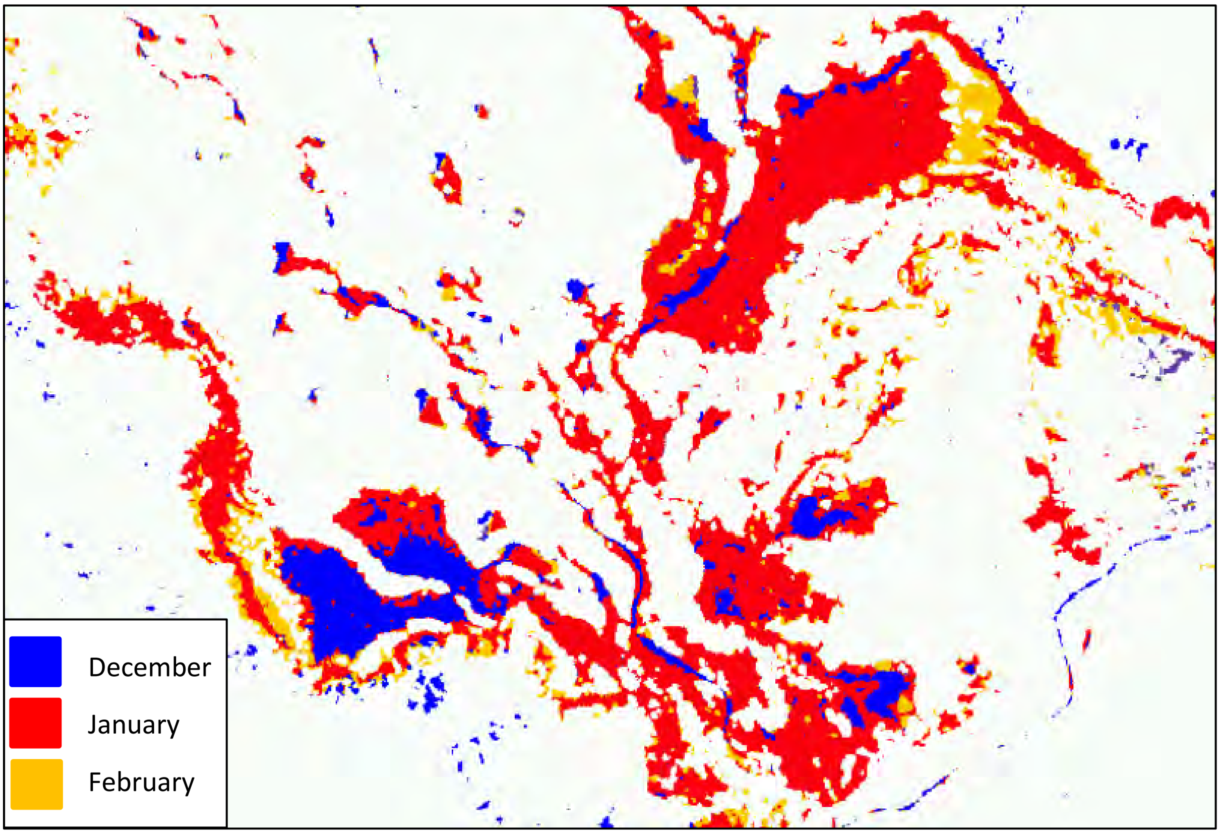
In the **Style** tab, under Band Rendering select "**Singleband gray**" as **Render type**.
In the **Color Rendering** section, activate the **Colorize** option, select a color and click **OK**.



Finally, we can add a base-map to link our water masks to GIS data. Click on **Web → OpenLayers plugin → OpenStreetMap → OpenStreetMap** (See NOTE 8).

NOTE 8: 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.





THANK YOU FOR FOLLOWING THE EXERCISE!

6 Further reading and resources

Irimescu, A., Gh Stancalie, V. Craciunescu, C. Flueraru, and E. Anderson. “The Use of Remote Sensing and Gis Techniques in Flood Monitoring and Damage Assessment: A Study Case in Romania.” In *Threats to Global Water Security*, 167–77. NATO Science for Peace and Security Series C: Environmental Security. Springer, Dordrecht, 2009. doi:10.1007/978-90-481-2344-5_18.

Fayne, J., Bolten, J., Lakshmi, V., & Ahamed, A. (2017). Optical and Physical Methods for Mapping Flooding with Satellite Imagery. In *Remote Sensing of Hydrological Extremes* (pp. 83–103). Springer, Cham. https://doi.org/10.1007/978-3-319-43744-6_5

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