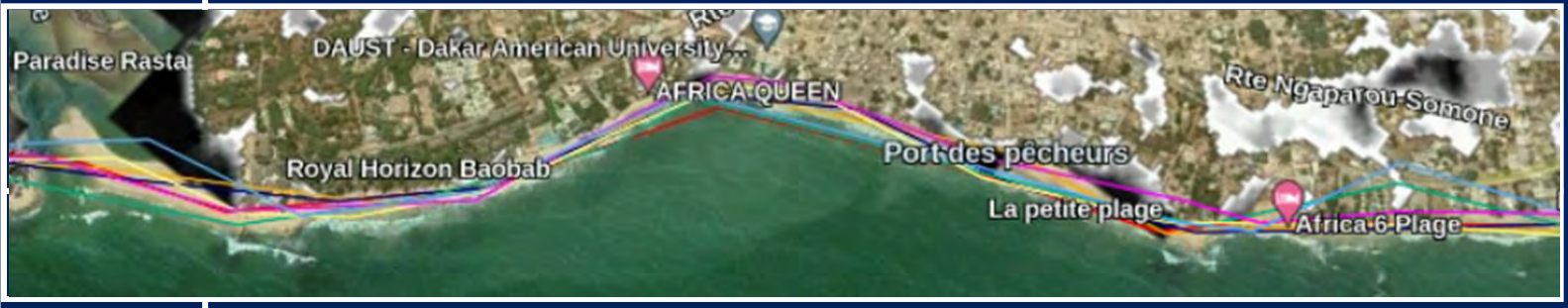

TRAINING KIT – COAS02

COASTAL EROSION MONITORING WITH SENTINEL-1 – July, 2015-2021 (Senegal)

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

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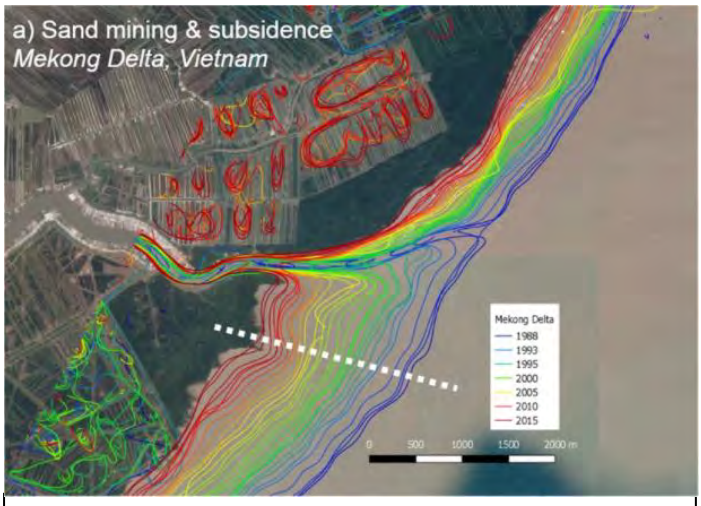
1 Introduction

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.



Luijendijk et al., 2018 - The State of the World's Beaches. - Mekong Delta in Vietnam. Erosion along the coast line, reaching -31 m/year DOI https://doi.org/10.1038/s41598-018-24630-6

Coastal erosion has been a major problem for many areas around the world. The coasts are economically important for many countries as a large part of the gross domestic product is derived from coastal activities, and they are being eroded too fast.

About 40% of the world's population live near coasts. Coastal erosion whether it is caused by natural or human activities, it has important effects on the populations who can no longer live close to the coastline, and the infrastructure.

There is an increasing trend of erosion along the world's coastlines, with twice as much land lost, than what was replaced over the last 30 years. It is estimated that this covers a surface area of about 28 000 km^2.

Monitoring of coastal environments and the tracking of their evolution provide fundamental information to policy and decision-makers on local, regional and national levels. More specifically, along the northwest coast of Africa, average rates of coastal retreat between one and two meters per year have been measured.

In this tutorial we will visit Senegal in Africa and we will check how the coastline has been changing in the last 7 years, using data from 2015 until 2021. Senegal is exposed to the Atlantic Ocean at its western part, so we will check how these coasts in different locations of the country are being affected. In order to be as consistent as possible to the weather conditions over the area, we used data taken on July for each year.

2 Training

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

The Training Code for this tutorial is COAS02. If you wish to practice the exercise described below within the RUS Virtual Environment, register on the RUS portal to request a Virtual Machine. Go to Your RUS Service → Your training activities and *Request a Webinar Training*.

2.1 Data used

- 7 Sentinel-1 GRD images have been selected over Senegal, for the month of July from 2015 to 2021 [downloadable at https://scihub.copernicus.eu/]

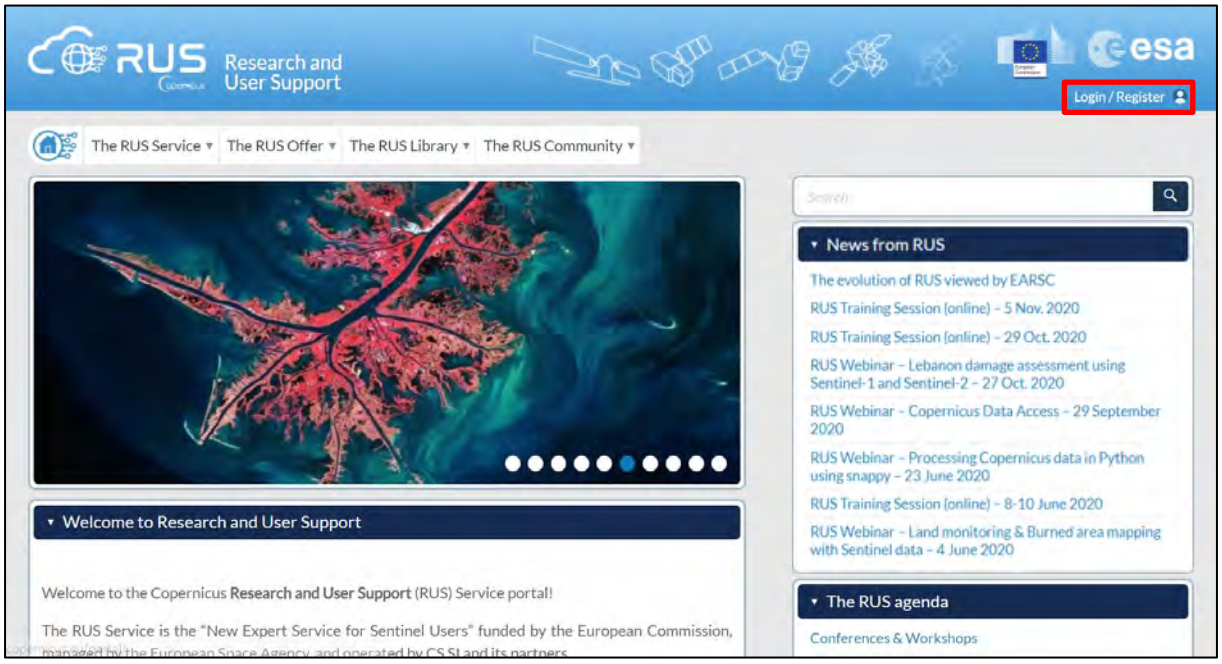
S1A_IW_GRDH_1SDV_20150717T191745_20150717T191810_006855_0093DD_E827
S1A_IW_GRDH_1SDV_20160711T191749_20160711T191814_012105_012BCD_7BF9
S1A_IW_GRDH_1SDV_20170706T191743_20170706T191808_017355_01CFB1_3168
S1A_IW_GRDH_1SDV_20180701T191750_20180701T191815_022605_0272F6_4D76
S1A_IW_GRDH_1SDV_20190708T191756_20190708T191821_028030_032A60_F0D4
S1A_IW_GRDH_1SDV_20200702T191802_20200702T191827_033280_03DB15_2AFB
S1A_IW_GRDH_1SDV_20210709T191809_20210709T191834_038705_04913C_4848

2.2 Software in RUS environment

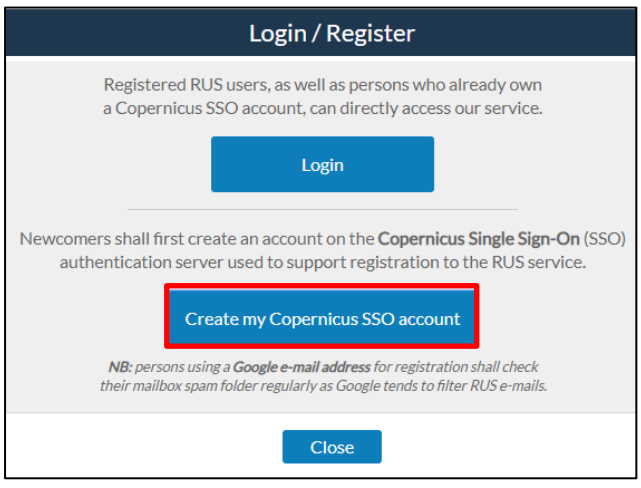
Internet browser, SNAP + Sentinel-1 Toolbox, QGIS, Google Earth.

3 Register to RUS Copernicus

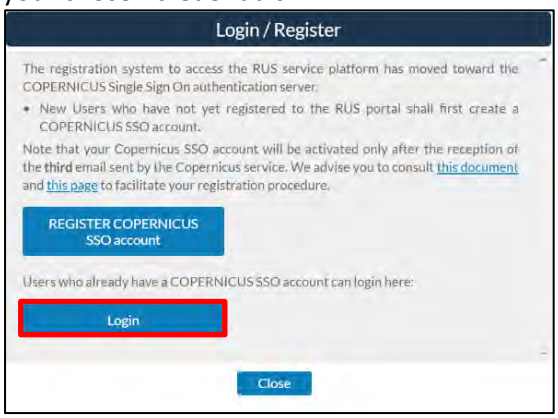
To repeat the exercise using a RUS Copernicus Virtual Machine (VM), you will first have to register as a RUS user. For that, go to the RUS Copernicus website (www.rus-copernicus.eu) and click on ***Login/Register*** in the upper right corner.

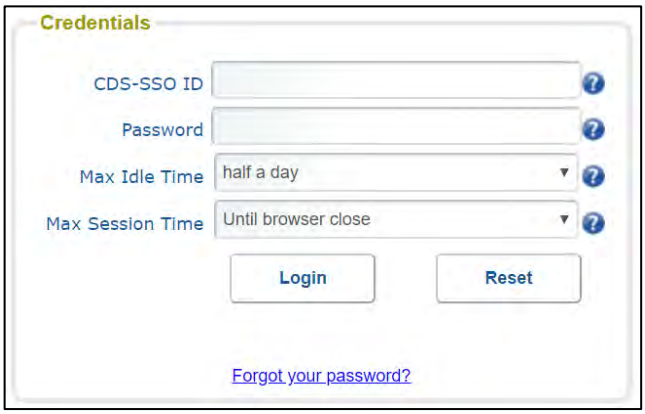


Select the option ***Create my Copernicus SSO account*** and then fill in ALL the fields on the **Copernicus Users' Single Sign On Registration**. Click ***Register***.

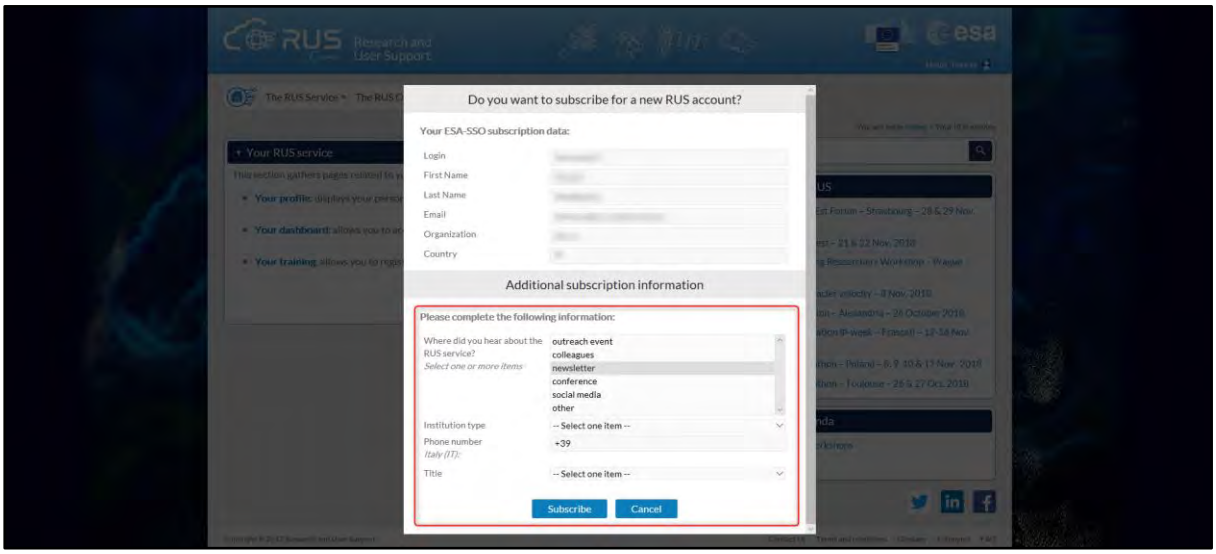


Within a few minutes you will receive an e-mail with activation link. Follow the instructions in the e-mail to activate your account.
You can now return to https://rus-copernicus.eu/, click on ***Login/Register***, choose ***Login*** and enter your chosen credentials.



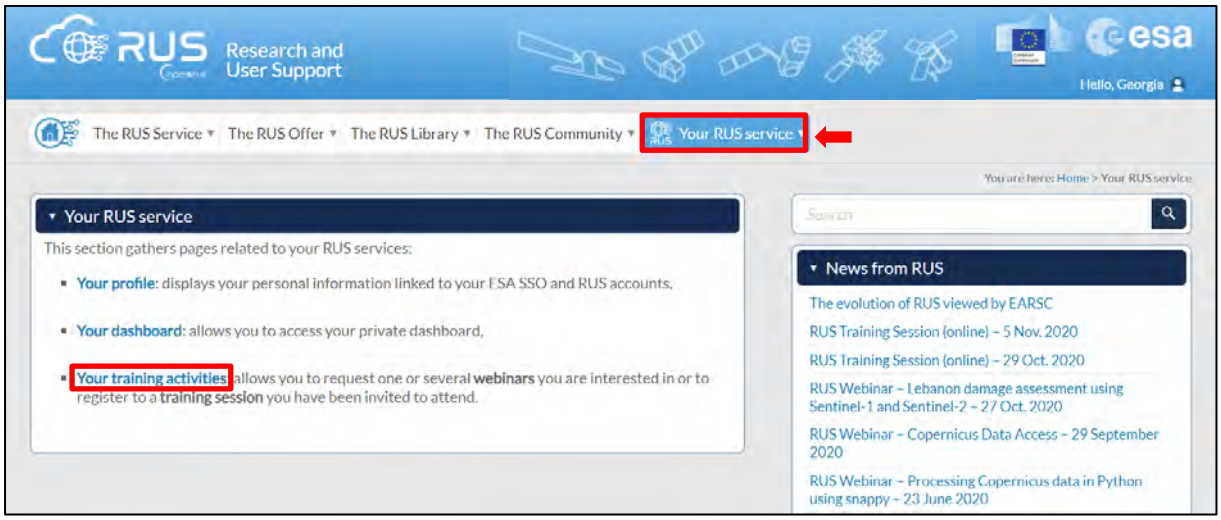


Upon your first login you will need to enter some details. You must fill all the fields.

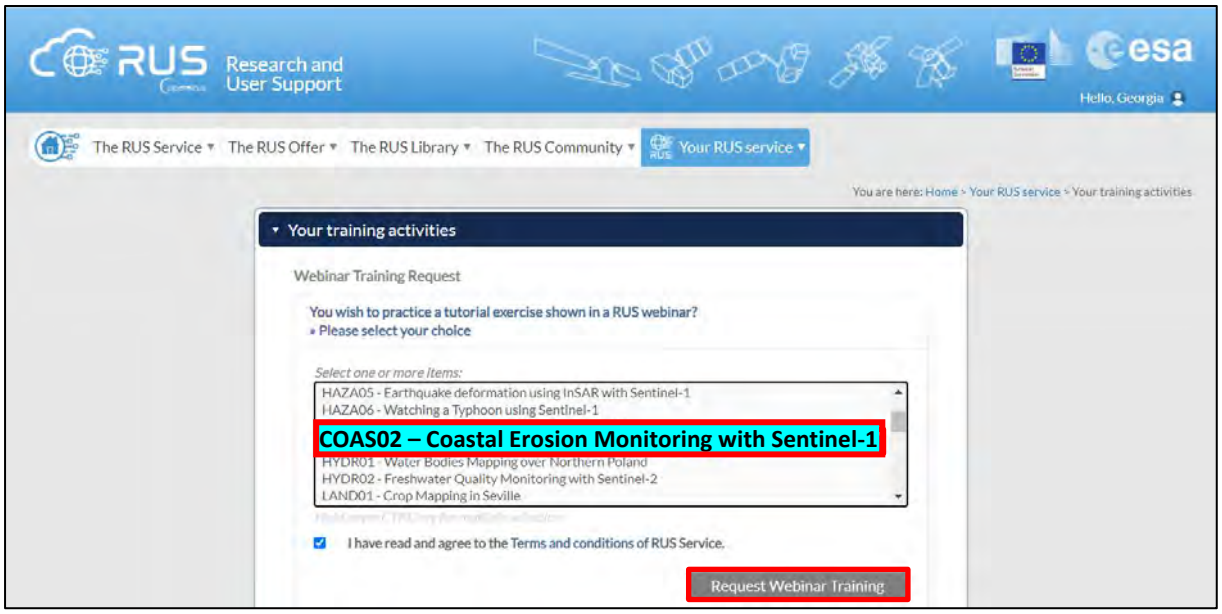


4 Request a RUS Copernicus Virtual Machine to repeat a Webinar

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 training activities***.



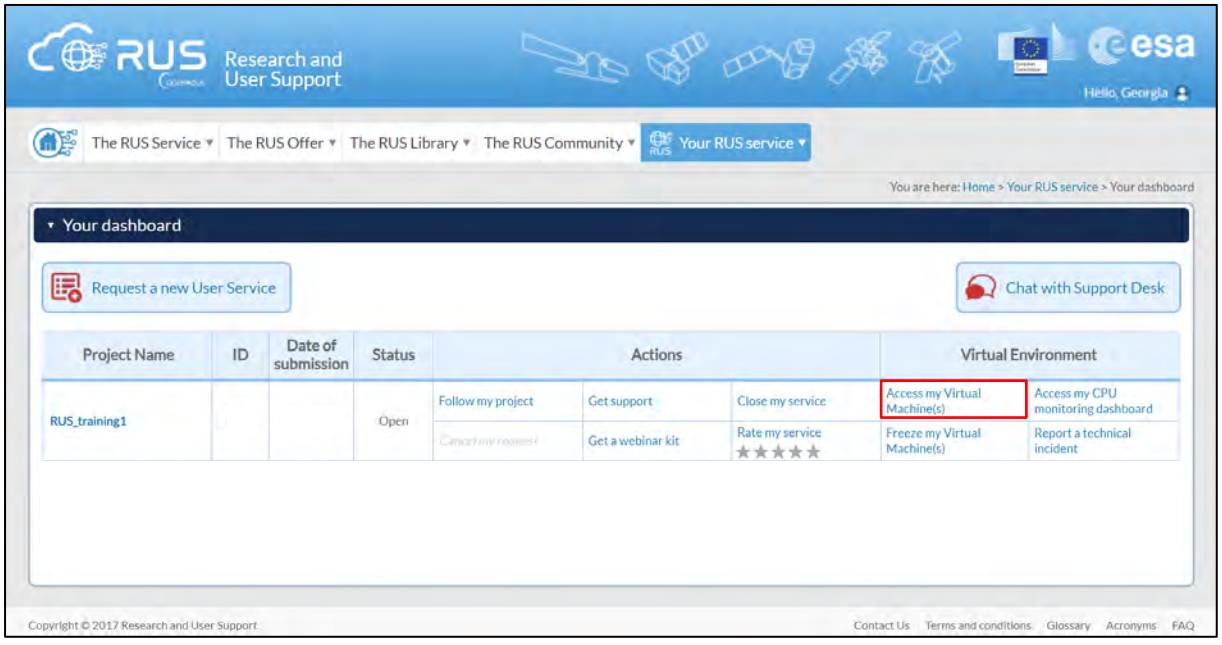
Select **COAS02 – Coastal Erosion Monitoring wirh Sentinel-1**, check the field *"I have read and agree to the Terms and conditions of RUS Service"* and then click on ***Request Webinar Training*** to request your RUS Virtual Machine.



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***.

NOTE: If the "***Access my Virtual Machine***" is greyed out, please access your VM from the direct link you have received at the email informing you about the creation of your VM.



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

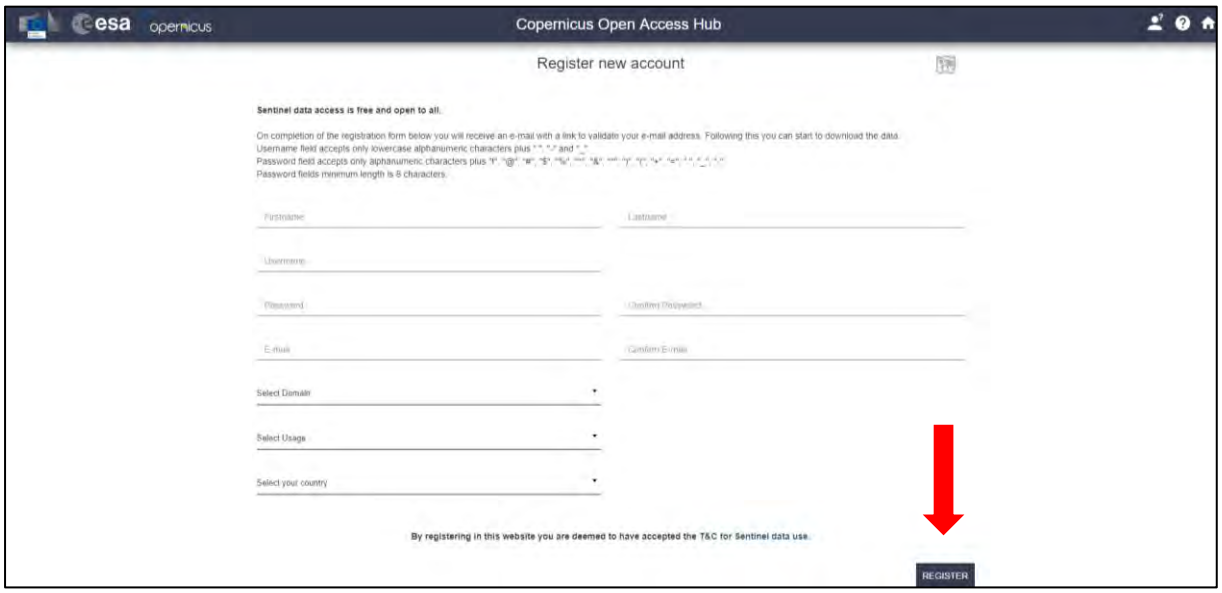
5.1 Data download – ESA SciHUB

In this step, we will download the Sentinel-2 scenes we will use for the exercise, 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 Senegal, in West Africa (**approximate area – green rectangle**).

We need to download 7 Sentinel-1 images over the area of interest, one for each year (2015 to 2021).

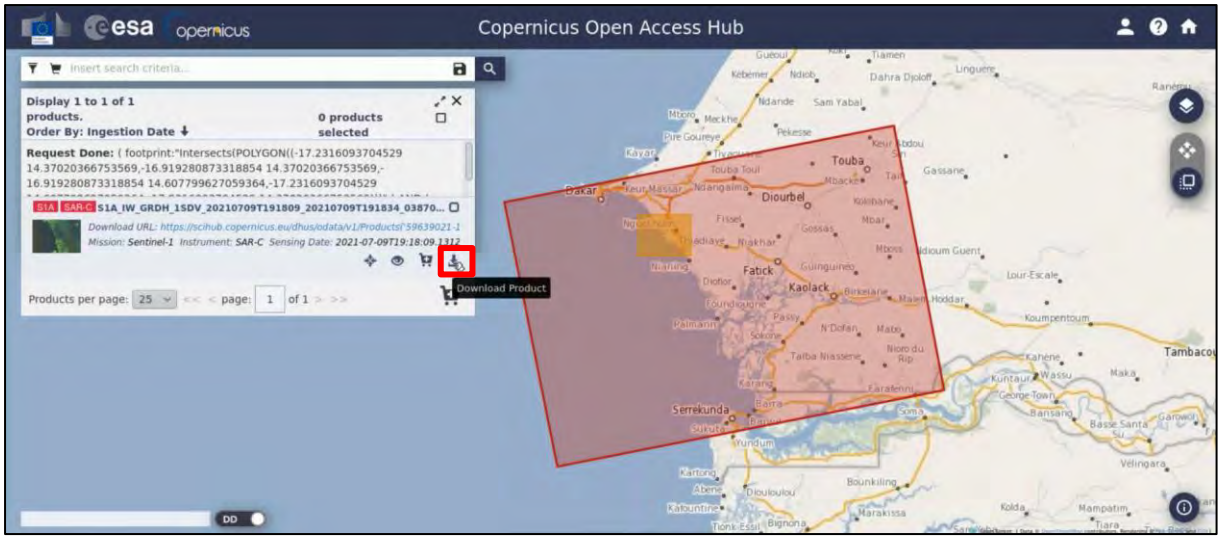
Zoom in a bit more, switch to "**drawing mode**" and draw a search rectangle approximately as indicated below. Open the search menu by clicking to the left part of the search bar. We will specify first the parameters for the 2021 product:

For Sentinel-1:

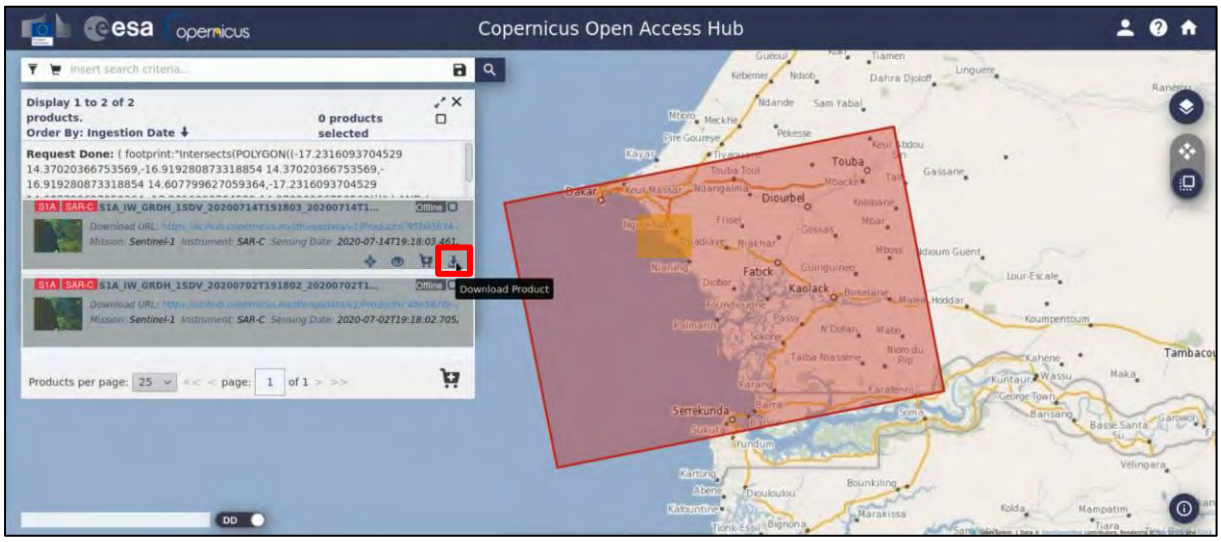
Sensing period: From 2021/07/01 to 2021/07/15
Select: Mission: Sentinel-1
Product Type: GRD
Sensor Mode: IW

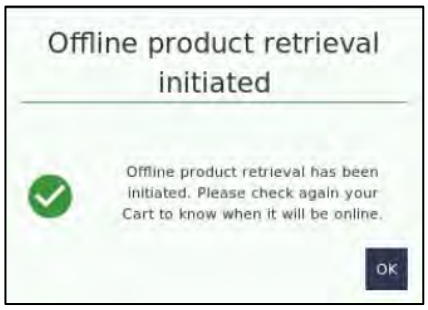
Then click on the "**Search**" icon. The search will return one results for the time period we set.

As next steps, you will set the sensing period for each year from 2015 to 2020 separately, from 1 July to 15 July each time.



As you can see, all the products acquired before 2021, appear to be "Offline". For those products, once we click on the download icon of the first one, the following message will appear. Click **OK**.





The product is automatically added in the "Cart". In case an error message appears, try again a bit later – you can request for one product per account per hour. (See NOTE 1 and NOTE 2):

The product will be online within few minutes.

By the time the product turns online, it remains like that for 4 days and then it goes back to offline again. You need to frequently check your cart for the product availability.

NOTE 1: Please keep in mind that you cannot download more than 2 products at the same time, per account from SciHub.

NOTE 2: You can find more information about the retrieval of offline/long term archive products here: https://scihub.copernicus.eu/twiki/do/view/SciHubUserGuide/LongTermArchive#Retrieval_of_offline_products_vi & https://scihub.copernicus.eu/userguide/LongTermArchive

You need to repeat the same process for all downloadable images mentioned in Chapter 2.1, the products will be downloaded at ***/home/rus*** as zip files. Move them to: ***/shared/Training/COAS02_CoastalErosion_Senegal/Original*** folder.

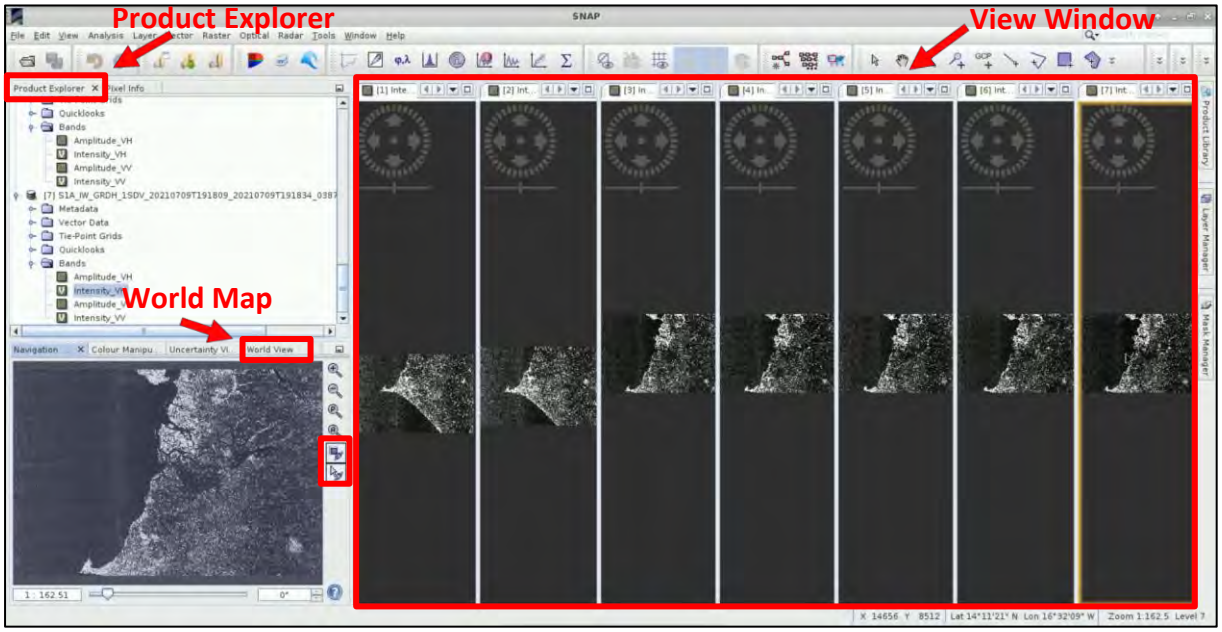
5.2 SNAP – open and explore data

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/COAS02_Coastal Erosion_Senegal/Original/*** folder and open all Sentinel-1 products (from oldest to the most recent).

Navigate to the path mentioned above and drag the products from the folder one by one and drop them to the **Product Explorer** Window.

Click **+** or to expand the contents of product from **17 July 2015** and see the information it includes. Double click on the ***Intensity_VH*** band and it will open at the **View Window**. Open the Intensity_VH band of all of each of the rest products too.

Go to **Window → Tile Horizontally** to see the 7 images created side by side. You can go to the **World Map** tab and zoom in to see the location of the opened product on the globe.



In the **Navigation** tab, click on the two icons shown within the red rectangular below, to synchronize the views and the cursor position between the views. You can open the ***Intensity_VV*** bands for visualization too, but according to literature, the **VH band** is more suitable for such applications.

5.3 Sentinel-1 Processing – Graph Builder

We need to create a Graph, where we will insert all the necessary operators, in order to prepare our data for the processing.

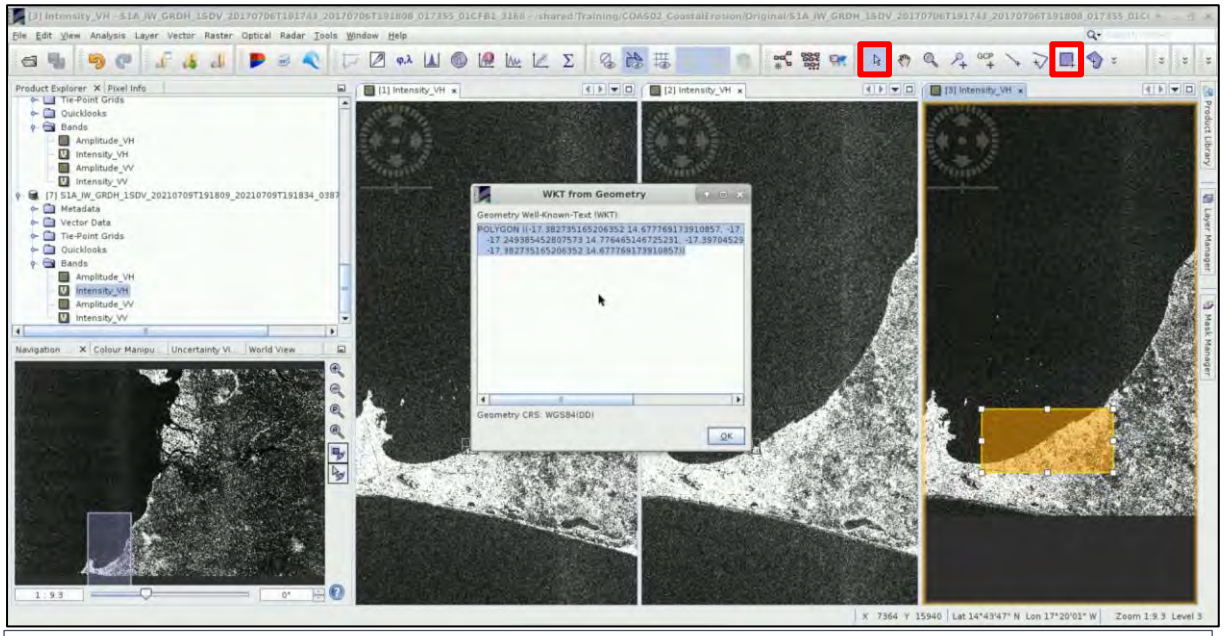
We will use the **GraphBuilder** tool, to create the chain with the processing steps we want to apply and at the end, only the final product will be physically saved (this way we will also save disk space since the products of the intermediate steps will not be stored).

5.3.1 Subset

Before we built the chain, we need to define the area over which we will focus. Zoom in a bit as shown at the picture below.

Click on the ***Rectangle drawing tool*** icon, and draw with your mouse a rectangle over the area as indicated in orange. Then click on the ***Selection Tool*** icon and select the rectangle you just drew.

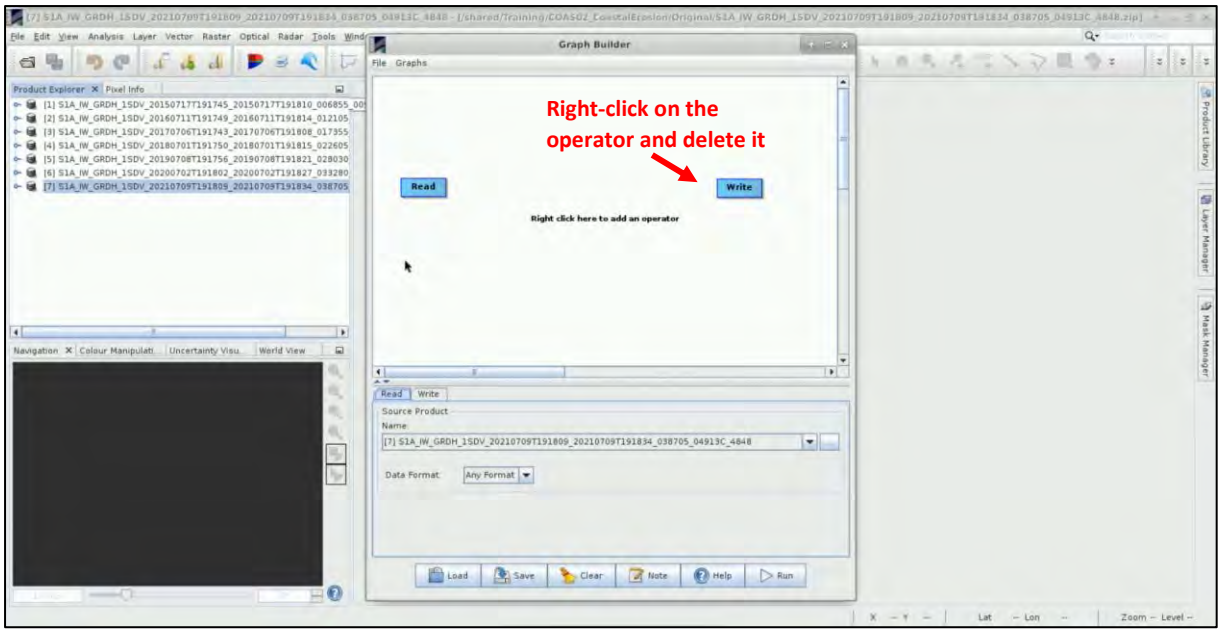
A **WKT from Geometry** window will pop up. Copy the context, click **OK** and then close it. Past it at a file for further use at the next steps. In this case in your VM you will find it at the ***/shared/Training/COAS02_CoastalErosion_Senegal/AuxData/*** folder, within the ***Expressions.txt*** file document (See NOTE 3).



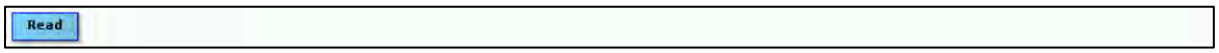
NOTE 3: The RADAR instrument onboard Sentinel-1 carries an antenna that is looking always to the right during its pass. These scenes were acquired during **ascending** pass (the satellite was moving in direction from south to north). That is why we see that the view of the image appears as if "mirrored" across the horizontal dimension because the view shows the pixels in the order of the data acquisition.

For now, we will not define any parameters in the tabs (they will be defined in the **Batch Processing** step where we will apply this processing for all images we have, at once), we will only create and save the graph.

Go to **Tools → GraphBuilder**. Right-click on the **Write** operator and **Delete** it.



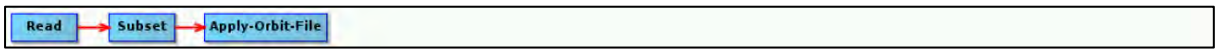
As mentioned, we will set the parameters at the **Batch Processing** step later on. We have only the **Read** operator in the graph for now.



To add the **Subset** operator, go to **Add → Raster → Geometric → Subset**. Connect the **Read** operator to it.

5.3.2 Apply Orbits

Next, we will apply the updated orbits to the products (See NOTE 4). Right-click and go to **Add → Radar → Apply-Orbit-File**. Connect the **Subset** operator to it.



> NOTE 4: 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**.

5.3.3 Thermal Noise Removal

Next we will remove the thermal noise of the image (See NOTE 5). Add the operator by right-clicking and going to **Add → Radar → Radiometric → ThermalNoiseRemoval**. Connect the **Apply-Orbit-File** operator to it.

> NOTE 5: 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*)

5.3.4 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 6). To add the operator, right-click and go to **Add → Radar → Radiometric → Calibration**. Connect the **ThermalNoiseRemoval** operator to it.

> NOTE 6: 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*)

5.3.5 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**

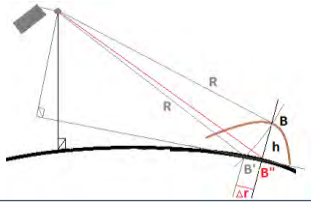
(See NOTE 7). To add the operator, right-click and go to **Add → Radar → Speckle Filtering → Speckle-Filter**. Connect the **Calibration** operator to it.

NOTE 7: 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*)

5.3.6 Geocoding – 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 8). To add the operator, right-click and go to **Add → Radar → Geometric → Terrain Correction → Terrain-Correction**. Connect the **Speckle-Filter** operator to it.

NOTE 8: 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)*



5.3.7 Sea Mask

To mask out the sea from yhr geocoded products and keep only the land areas, go to **Add → Raster → Masks → Land-Sea-Mask.** Connect the **Terrain-Correction** operator to it.

5.3.8 Write – Create the output

To create the output of this processing, we will add the **Write** operator. Right-click and go to **Add → Input-Output → Write**. Connect the **Land-Sea-Mask** operator to it.

Click on the 

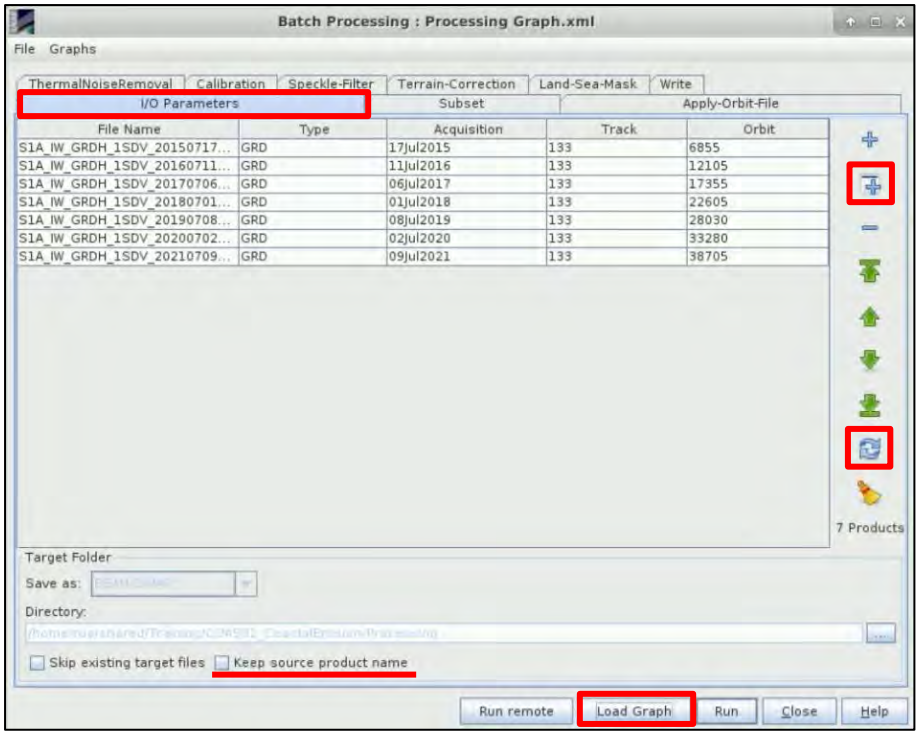
icon to save the graph. Go to the: ***/shared/Training/COAS02_CoastalErosion_Senegal/Processing*** folder and save it with the name: **Processing_Graph**.

5.4 Sentinel-1 Processing – Batch Processing

Batch Processing is used when we want to apply identical pre-processing steps at once, to multiple images. Open the **Batch Processing** tool by going to **Tools → Batch Processing**.

Deselect the "**Keep source product name**" option. In the **I/O Parameters** tab we will add all opened products from the **Product Explorer** window by clicking **Add Opened** at the right (second icon from the top of the column at the right) and then click **Refresh** (second icon from the bottom).

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

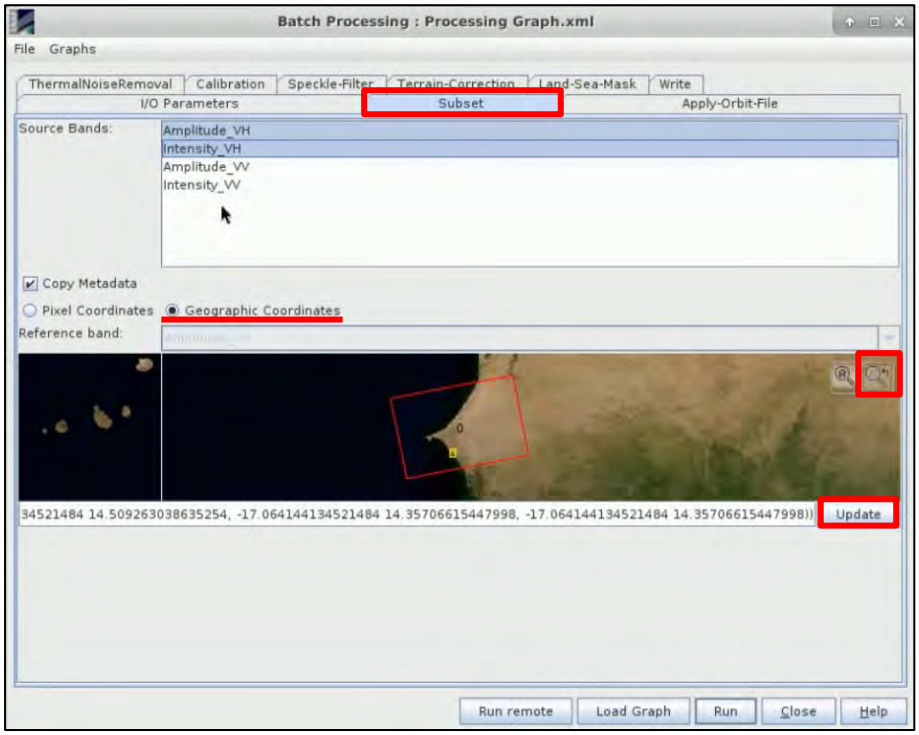


5.4.1 Subset

At the **Subset** tab, under the **Source Bands**, select only the **Amplitude_VH** and **Intensity_VH** bands, by having the Ctrl selected on your keyboard. Then select the **Geographic Coordinates** option and copy the WKT (well known text) from the ***Expressions*** file in the ***/shared/Training/COAS02_CoastalErosion_Senegal/AuxData*** folder and paste it to the text window below the map. WKT:

POLYGON ((-17.06414405322833 14.3570657208832, -16.94120142699375 14.380642844738034, -16.96706827615401 14.509263406182695, -17.090084604151496 14.485701700192015, -17.06414405322833 14.3570657208832))

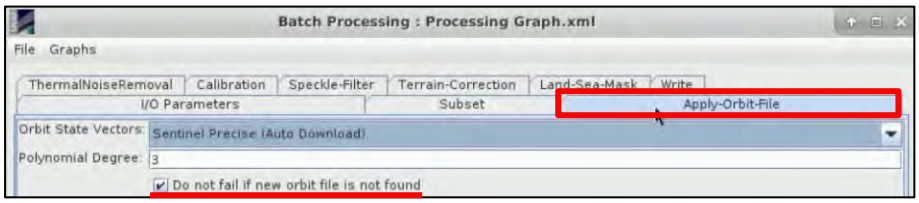
Click **Update** and then click the **Zoom-in** icon  to see your subset on the map.



Zoom in

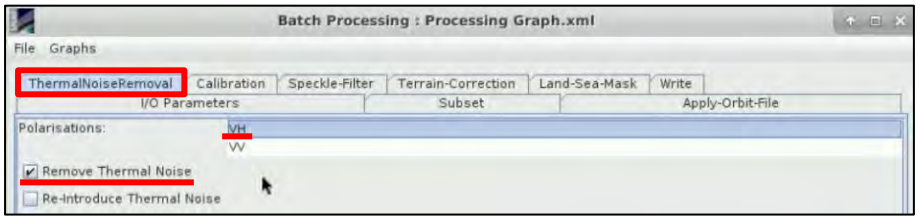
5.4.2 Apply Orbits

At the **Apply-Orbit-File** tab, make sure that the "***Do not fail if new orbit file is not found***" option is selected.



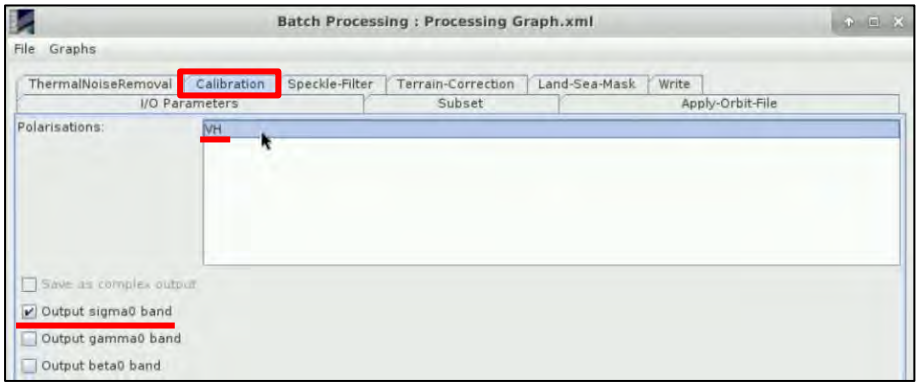
5.4.3 Thermal Noise Removal

At the **ThermalNoiseRemoval** tab select on the **VH** polarization, and make sure that the "***Remove Thermal Noise***" option is selected.



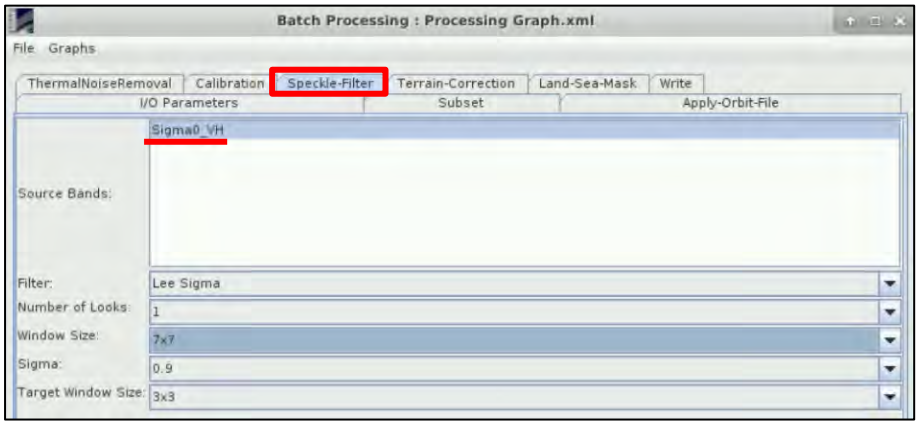
5.4.4 Calibration

At the **Calibration** tab, the **VH** polarization should already be selected, and make sure that the "***Output sigma0 band***" will be selected, as this will be the band we will be working with for our application. In case you want to proceed with other options too, e.g. with the "*beta0 band*", you can select that too.



5.4.5 Speckle Filtering

At the **Speckle-Filter** tab, only ***Sigma0_VH*** band should be present based on our previous selection, and for the rest parameters, keep the default ones as shown below for each one.

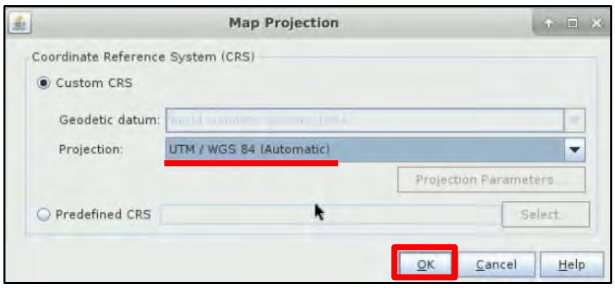


5.4.6 Geocoding – Terrain Correction

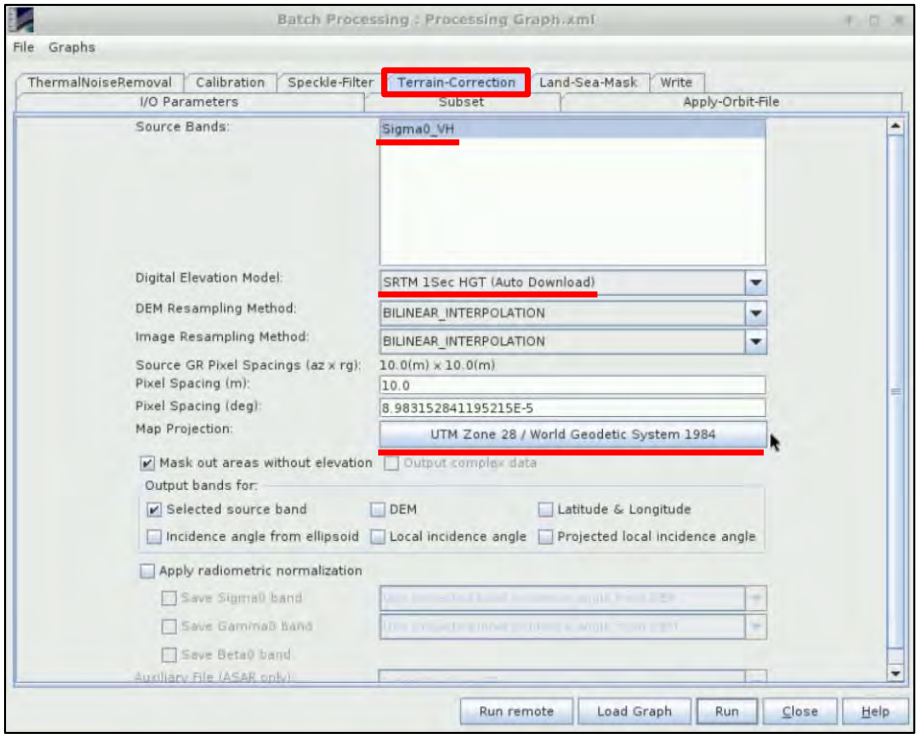
At the **Terrain-Correction** tab, the **Sigma0_VH** band should be selected as source band.

As **Digital Elevation Model** select the **SRTM 1Sec HGT (auto Download)** option.

Then go to **Map Projection**, click on it and at the window that will pop up, select the **UTM / WGS 84 (Automatic)** option.

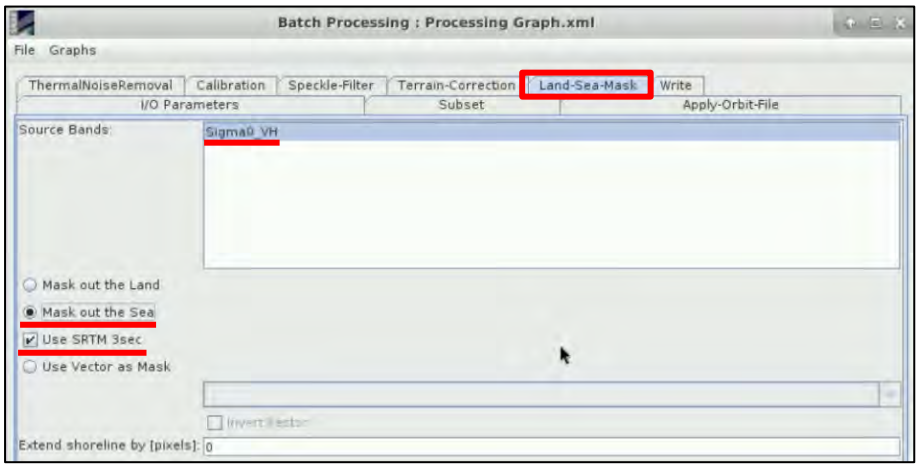


Click **OK**. The Map Projection will be automatically set to **UTM Zone 28 / World Geodetic System 1984**.



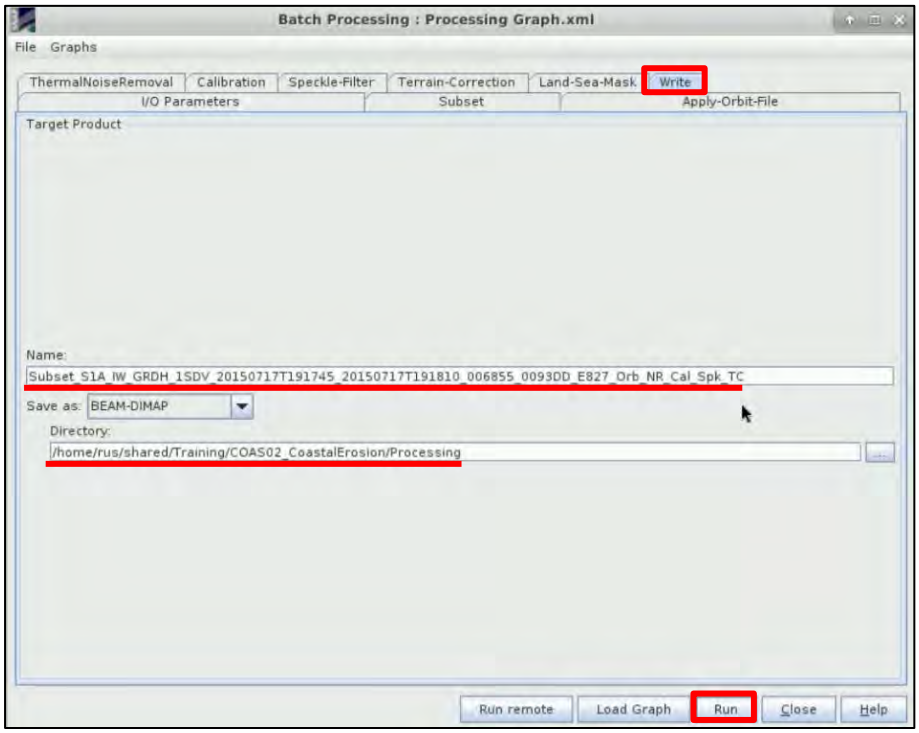
5.4.7 Sea Mask

At the **Land-Sea-Mask** tab, select the **Sigma0_VH** as source band, and select the "***Mask out the Sea***" and the "***Use SRTM 3sec***" options.

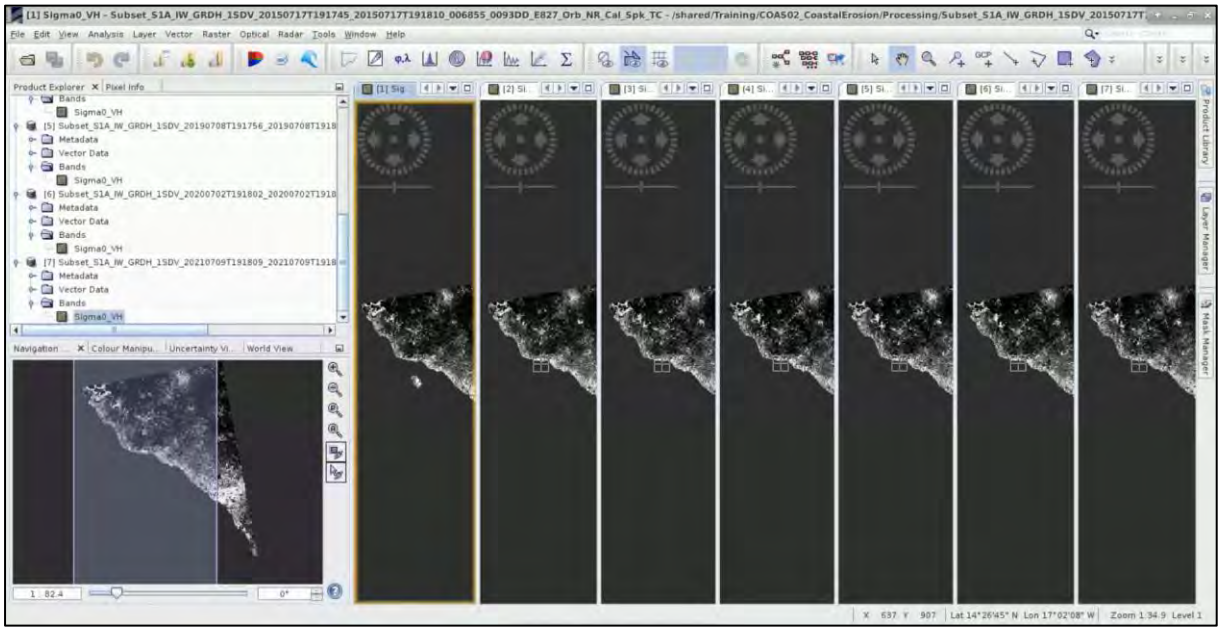


5.4.8 Write – Create the output

At the **Write** tab, under **Name** keep the default name (Subset and the rest suffixes will be added). At the Directory set the path to ***/shared/Training/COAS02_CoastalErosion_Senegal/Processing/*** and click **Run**.



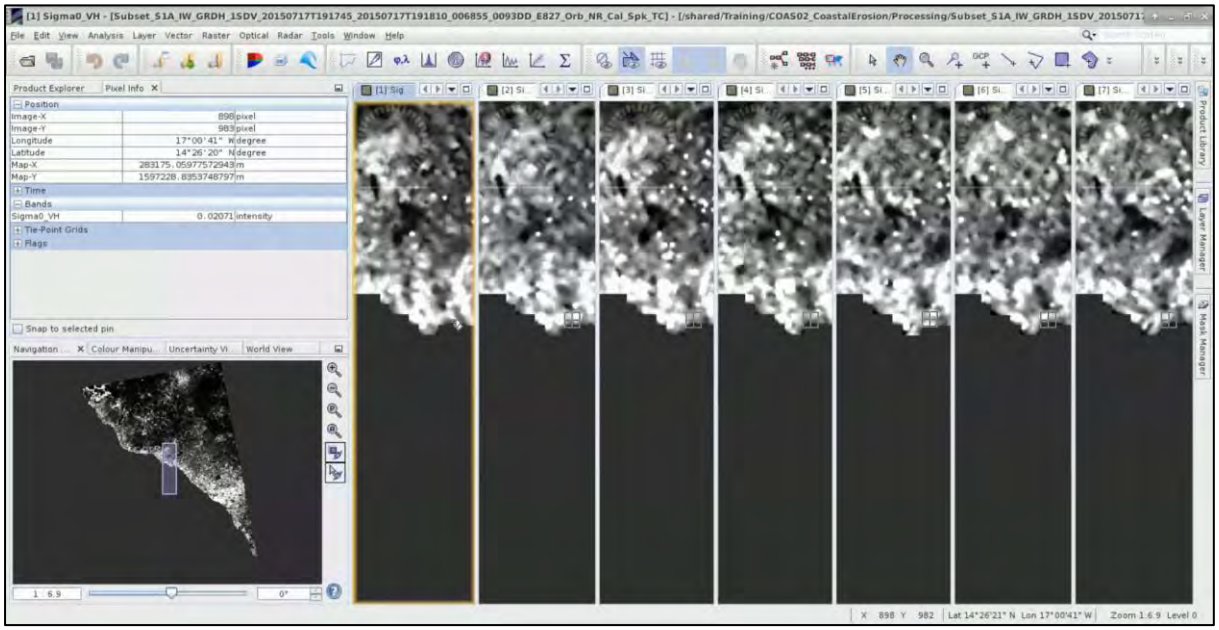
Once the processing is completed for all products, they will appear at the **Product Explorer** Window. Open the **Sigma0_VH** band of each product, and go to **Window → Tile Horizontally** to see all the 7 subset images created, side by side.



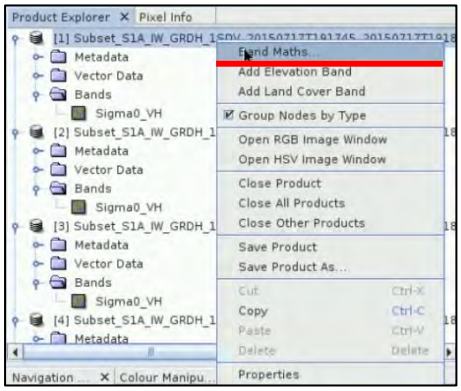
5.5 Masking – Band Maths

In order to further process the images we have and be able to distinguise the boundaries between land and sea so that we find the shoreline, we need to zoom in and find the value of the pixel that will

be the boundary one. We go to the **Pixel Info** Window and we navigate across the shoreline by moving the mouse over the pixels. There we can see the values on the window on the left, at the Sigma0_VH band. In our case, the value that we will use to separate land from sea will be the 0.02.



Let's go back to the **Product Explorer Window**, and let's create the mask band for each image. **Right click** on the image acquired on **17 July 2015** and click on **BandMaths**.

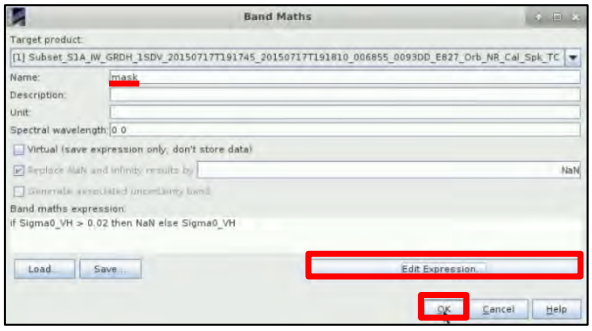


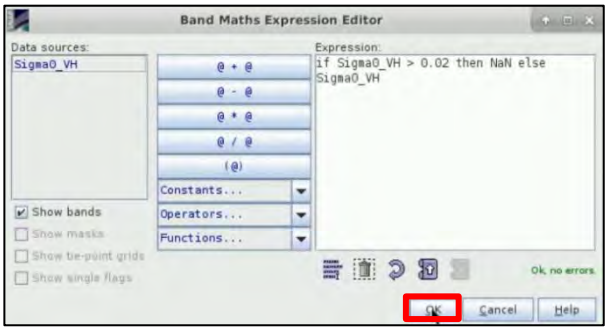
At the window that will open, at the **Name** write **mask**.

Make sure that you **deselect** the "***Virtual (save expression only, don't store data)***" option, as we want this band to be physically saved.

Then click on "***Edit Expression***" and at the Expression area write: if Sigma0_VH > 0.02 then NaN else Sigma0_VH

Then click **OK** on both windows and the mask band will have been created and opened at the **View Window**.

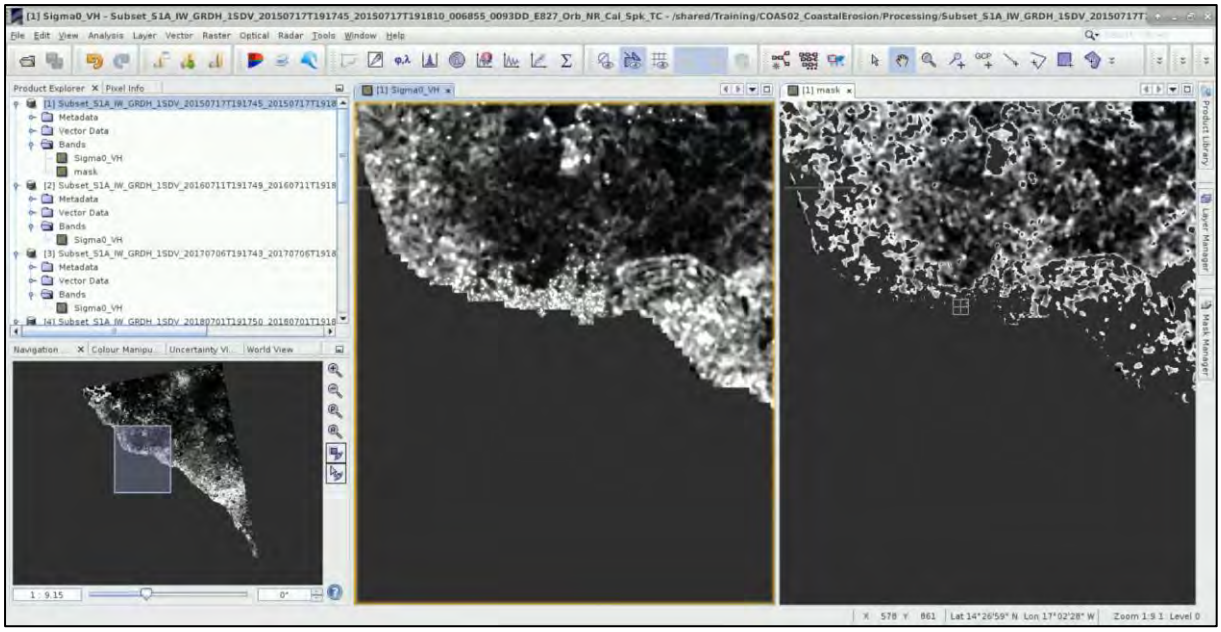




Repeat the same process for all the other products of the rest years as well.

If we now open the original **Sigma0_VH band** on the **17 July 2015** product and the band with the masked values, we will see that some pixels have been removed and we now can more clearly see the boundaries of the coastline.

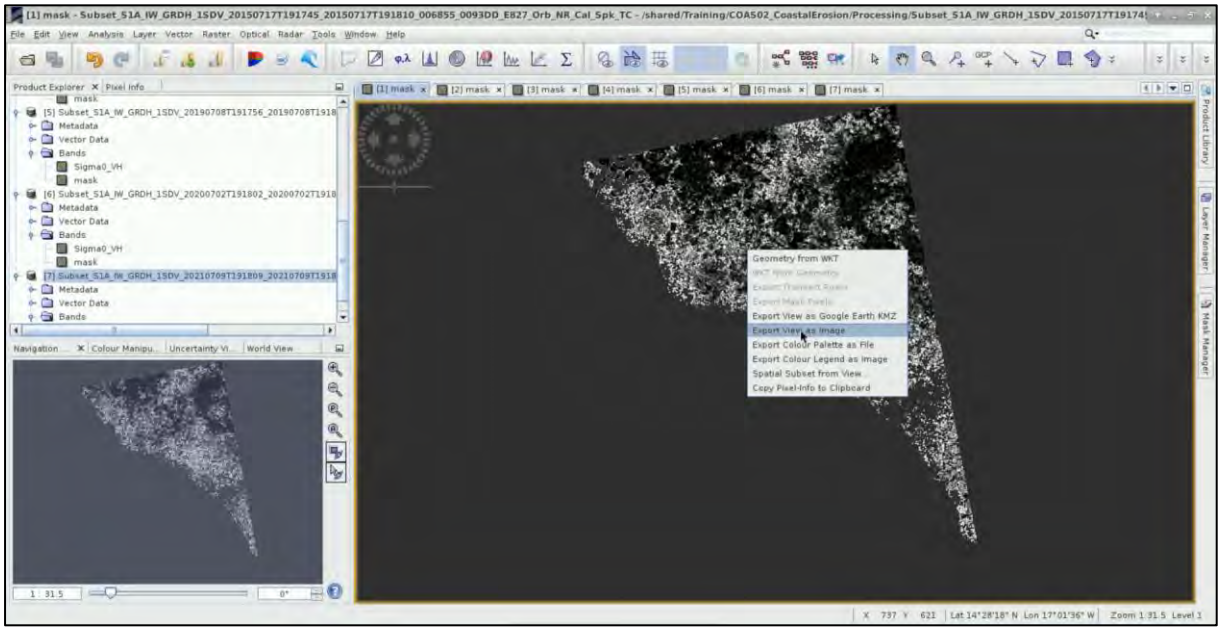
We can close the original band and we should now open all the masked bands of all products.



5.6 Export Products for GIS and Google Earth

For GIS processing:

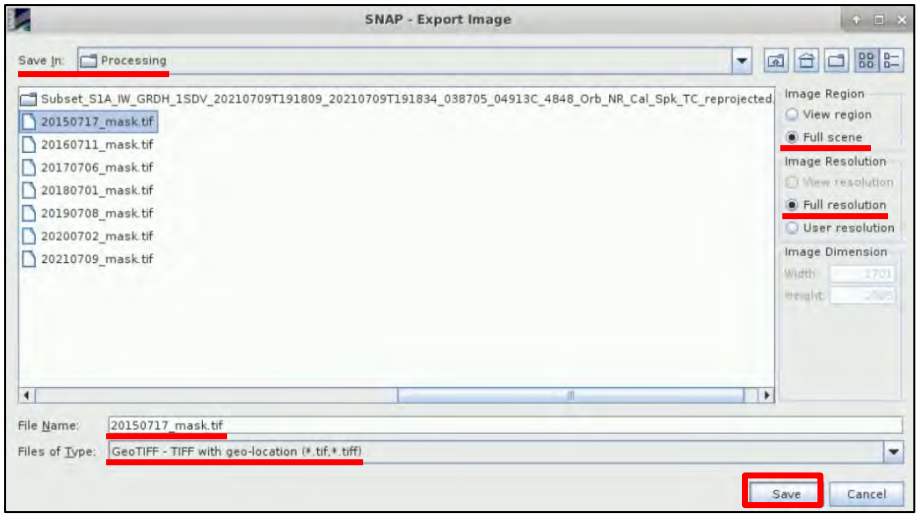
As you have all bands opened, just **right click** on the **View Window** and select "**Export as Image**". Alternatively if they are not already opened, select each product that is at the **Product Explorer** Window, one by one, and go to **File → Export → GeoTIFF.**



At the window that will appear, first select the path you want to store the geotiff file at, to: ***shared/Training/COAS02_CoastalErosion_Senegal/Processing***

At the **Images Region** on the right, select the option "***Full Scene***".
At the **Image Resolution**, select the option "***Full resolution***".
At the **Files of Type** select the "***GeoTIFF - TIFF with geolocation (* tif, * tiff)***".
Finally, at the **File Name**, set it to **20150717_mask.tif** for the **2015** product and click **Save**.

Repeat the same steps for the mask band of each of the rest products too.



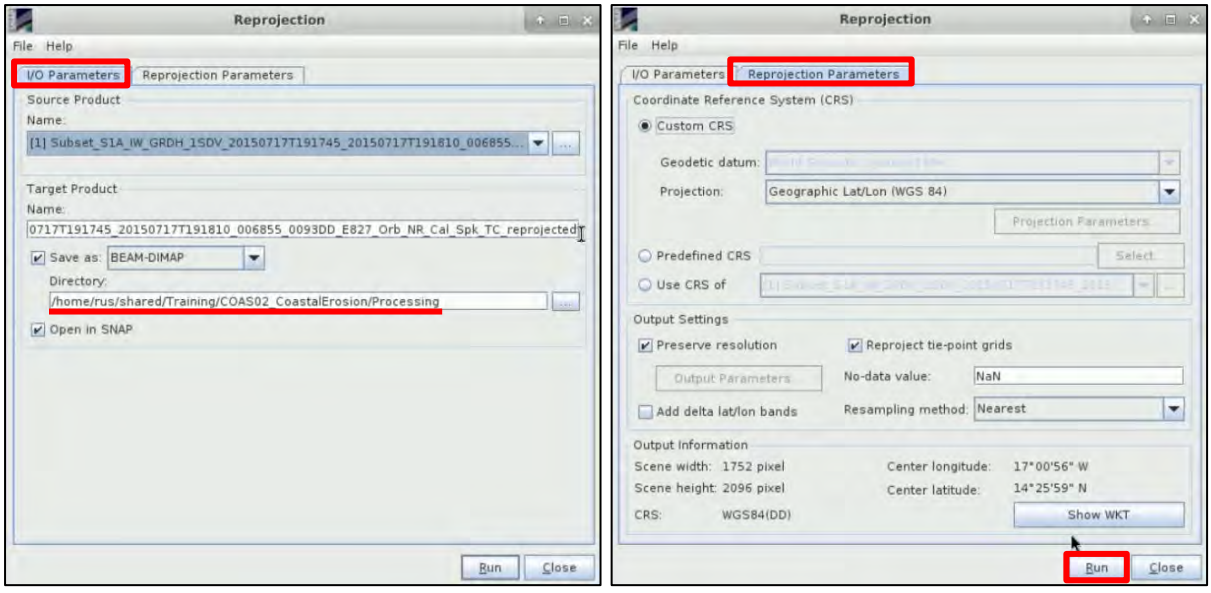
For Google Earth processing:

If you want to export the products for use is **Google Earth**, first you need to have them projected in "*Geographic Lat/Lon*". If you try to right click on the opened bands we have at the View Window, and right click and click to "*Export as Google Earth View*", you will receive an error message.

Go to **Raster → Geometric Operations → Reprojection** so that we reproject the products.

At the **I/O Parameters** tab, select the **2015** product at the **Source Product Name**, and keep the default **Target Product Name** that will be created.
Also, set the Directory to ***shared/Training/COAS02_CoastalErosion_Senegal/Processing***

At the **Reprojection Parameters** tab, keep the default options and click **Run**.



Once you have repeated this step for all 7 images and the products have been created and opened in the **Product Explorer** Window, select each one and go to **File → Export → Other → View as Google Earth KMZ**.

Alternatively, if you have the relative band of each image opened in the **View Window**, right-click on the image and select "**Export View as Google Earth KMZ"**.
Then set the path to which you want to save it: ***shared/Training/COAS02_CoastalErosion_Senegal/Processing*** and name each of them accordingly.

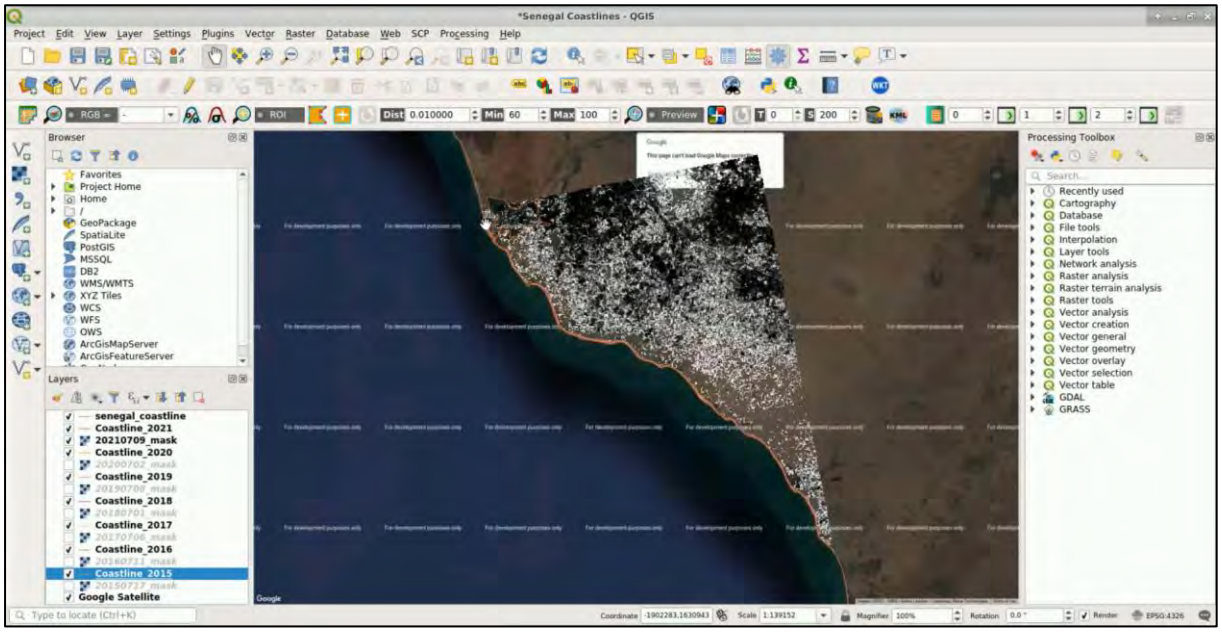
6 QGIS Visualization and Processing

Open **QGIS Desktop** and load all the tif files you created, at the **Layers** panel. You will find them under the path ***shared/Training/COAS02_CoastalErosion_Senegal/Processing***.

Also, add from the ***shared/Training/COAS02_CoastalErosion_Senegal/AuxData/*** folder the ***senegal_coastline.shp*** file, which contains the officially published shapefile for the

Finally, go to **Web → OpenLayers plugin → Bing Maps → Bing Aerial with labels** in order to add a basemap layer (See NOTE 9).

You can also add the shapefiles that correspond to the coastlines that were created in QGIS for each year, based on the Sentinel-1 processed images, and then set them in order from the older to the most recent, as shown below. You will also find them at the ***shared/Training/COAS02_CoastalErosion_Senegal/AuxData/*** folder.



> NOTE 9: 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. If you cannot find it, go to "Settings" and select the "Show also experimental plugins" option. Go back to the *"All"* tab, select the plugin on the list and click "Install Plugin". Restart QGIS to finalize the installation.

Let's see how you can create your own shapefile that will contain the coastline as you will define it. You should keep enabled the rasters one at a time, and create the corresponding coastline shapefile.

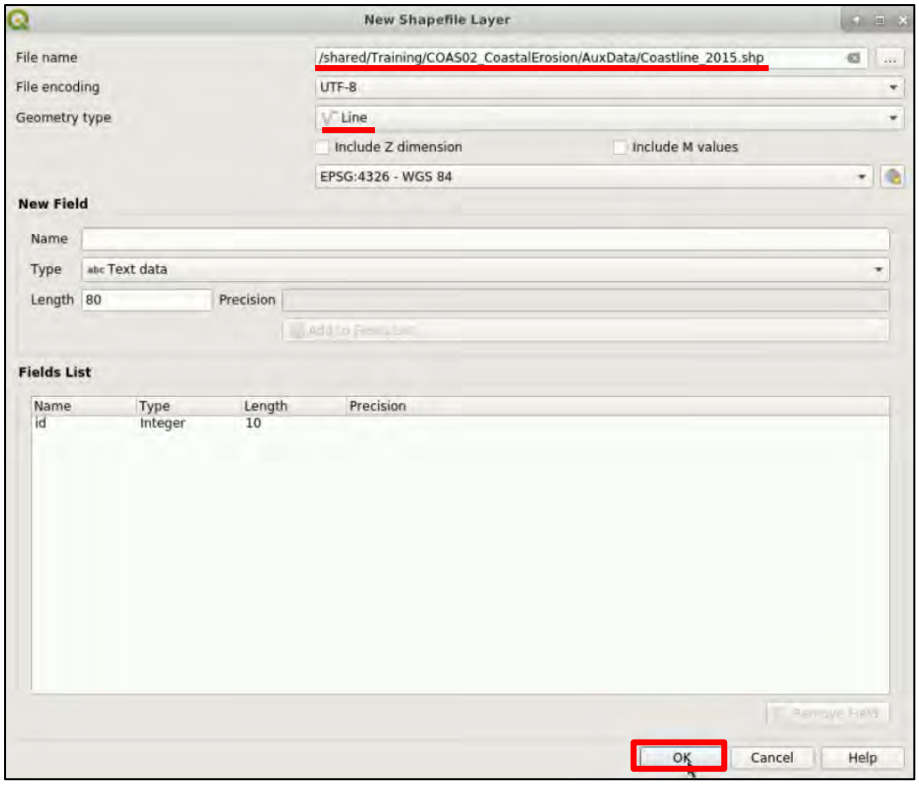
Go to **Layer → Create Layer → New Shapefile Layer**.

At the **File name**, , add the name **Coastline_2015**, for the **2015 image** and then click on the icon and set the path to ***shared/Training/COAS02_CoastalErosion_Senegal/AuxData/***. ThenYou can see how it will appear, on the next image.

At the **Geometry type**, select **Line** from the drop down menu.

Keep the rest fields as by default and click **OK**. The shapefile will appear on the Layers panel.

Repeat the same step for each of the 7 images you have.



Once you have selected the shapefile that corresponds to 2015, and also have enabled the *tif* for 2015, click on the **Toggle Editing** icon . Then click on the **Add Line Feature** icon , and start creating the coastline along the raster. Once you finish with the editing, click again on the **Toggle Editing** icon and **save** the edits.

Repeat the same process for the rest coastlines too.

7 Google Earth Visualization

It is time now to visualize our results to Google Earth, both from our satellite images and from the coastlines we have created in QGIS. The raster files from Sentinel-1, we had already exported them in the appropriate format, at SNAP.

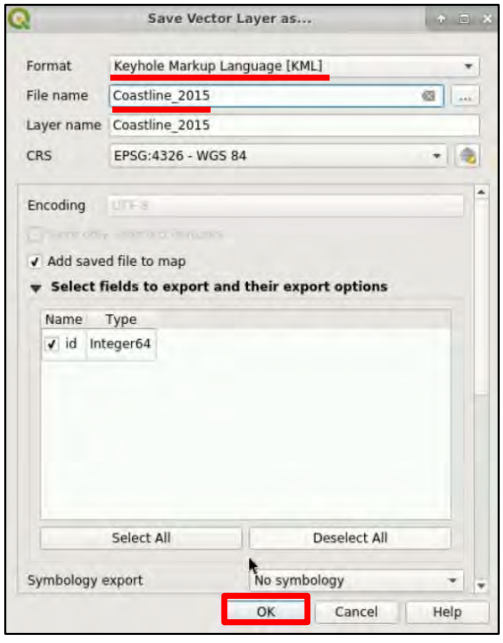
We now only need to save the coastlines shapefiles we created in QGIS, in a kml format, so that we can load them Google Earth too. We will apply the same steps for each one of the coastlines shapefile.

Right click on the first one, from **2015**, as it is opened on the Layers panel. Go to **Export → Save Features As…**

At the **Format**, select the **Keyhole Markup Language [KML]** option, from the drop down menu.

At the **File Name**, set as **Coastline_2015**, then click on the ... icon and set the path to save the output to ***shared/Training/COAS02_CoastalErosion_Senegal/AuxData/***

Click **OK**.



Launch **Google Earth** and load all the .kmz files of the coastlines and all the rasters from Sentinel-1. You will find them under the path ***shared/Training/COAS02_CoastalErosion_Senegal/AuxData*** (coastlines) and under the path ***shared/Training/COAS02_CoastalErosion_Senegal/Processing*** (Sentinel-1 images).

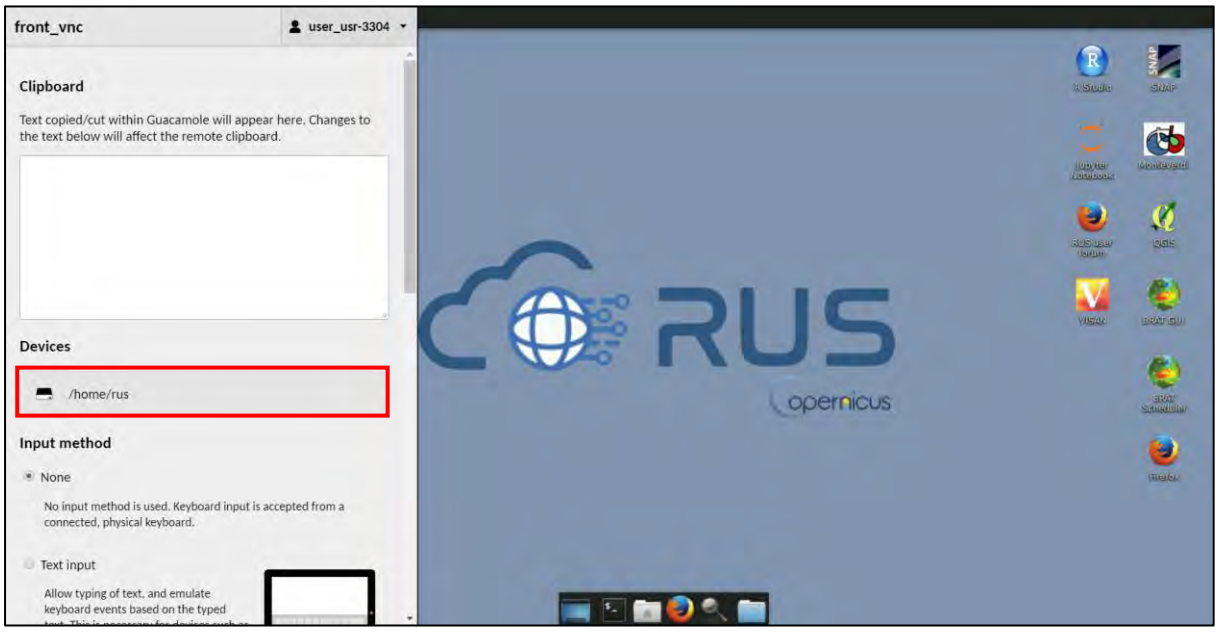
You can use the *History* option available at Google Earth, and see how the coastlines of Senegal have evolved all these years. You will notice that there are some areas eroding, while in some others we have sedimants deposition. This is of course highly correlated with action the authorities took, in order to prevent coastal erosion problems.

8 Extra Steps

8.1 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.



THANK YOU FOR FOLLOWING THE EXERCISE!

9 Further reading and resources

- Pelich, R., Chini, M., Hostache, R., Matgen, P., López-Martínez, C. *Coastline Detection Based on Sentinel-1 Time Series for Ship- and Flood-Monitoring Applications*, IEEE GEOSCIENCE AND REMOTE SENSING LETTERS
- Zollini, S., Alicandro, M., Cuevas-González, M., Baiocchi, V,. Dominici, D., Massimo Buscema, P. 2019. *Shoreline Extraction Based on an Active Connection Matrix (ACM) Image Enhancement Strategy*. J. Mar. Sci. Eng. 2020, 8(1), 9; Special Issue Remote Sensing in Coastline Detection https://doi.org/10.3390/jmse8010009
- Luijendijk, A.,Hagenaars, G., Ranasinghe, R., Baart, F., Donchyts, G., Aarninkhof, S., 2018. T*he State of the World's Beaches.* Scientific Reports **volume 8**, Article number: 6641 (2018) DOI https://doi.org/10.1038/s41598-018-24630-6
- Leatherman, S. P., Douglas, B. C., 2004. *Global Warming and Coastal Erosion,* Climatic Change 64(1):41-58 DOI: https://doi.org/10.1023/B:CLIM.0000024690.32682.48
- Standford Digital Repository - https://purl.stanford.edu/zn251qt9433
- Joint Research Center Data Catalogue - https://data.jrc.ec.europa.eu/dataset/18eb5f19-b916-454f-b2f5-88881931587e

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