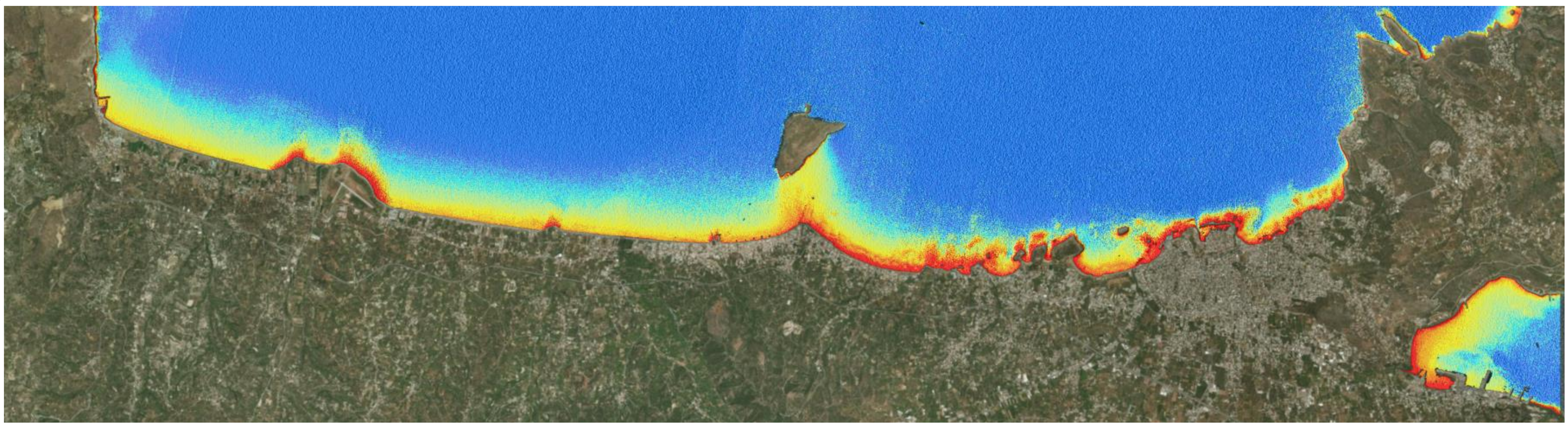
TRAINING KIT – COAS01

NEARSHORE BATHYMETRY DERIVATION with SENTINEL-2

Case Study: Gulf of Chania, Crete - Greece, August 2018



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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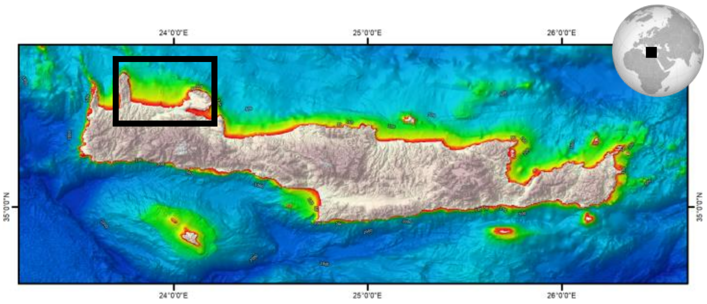
1 Introduction

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.



Gulf of Chania, NW Crete, Greece. Mean Depth by EMODnet.

We will employ RUS to derive the nearshore bathymetry in the Gulf of Chania (Crete, Greece) using Sentinel-2 data.

Recent advances in satellite technology in terms of higher spatial resolution, multi-spectral bands, open data access, etc. have enhanced the ability for the monitoring and management of coastal areas. Satellite images are to be one of the most potential alternatives to water depth estimation due to the wide area coverage, repeatability, and low cost. Depth retrieval using the Empirical Bathymetry method can follow the approach of: a) Lyzenga et al. (1978, 2006) proposing log-linear correlation between multiband and water depth values, and focusing mainly on removing all other reflected parameters attenuating water bottom signals, and b) Stumpf et al. (2003) using a ratio of bands and the difference in attenuation of different bands in water.

Sentinel-2 is a wide-swath, high-resolution, multi-spectral imaging mission, also supporting water cover monitoring. The acquired data, mission coverage and high revisit frequency are particularly effective for Satellite Derived Bathymetry (SDB) application.

This exercise is focused on SDB using the ratio transform algorithm developed by Stumpf et al. (2003) and Sentinel-2 imagery for depth derivation.

2 Training

Approximate duration of this training session is three hours.

2.1 Data used

- One Sentinel-2 image Level 2A acquired on August 24, 2018.
  [downloadable @ https://scihub.copernicus.eu/]

  S2B_MSIL2A_20180824T090549_N0208_R050_T34SGE_20180824T151929

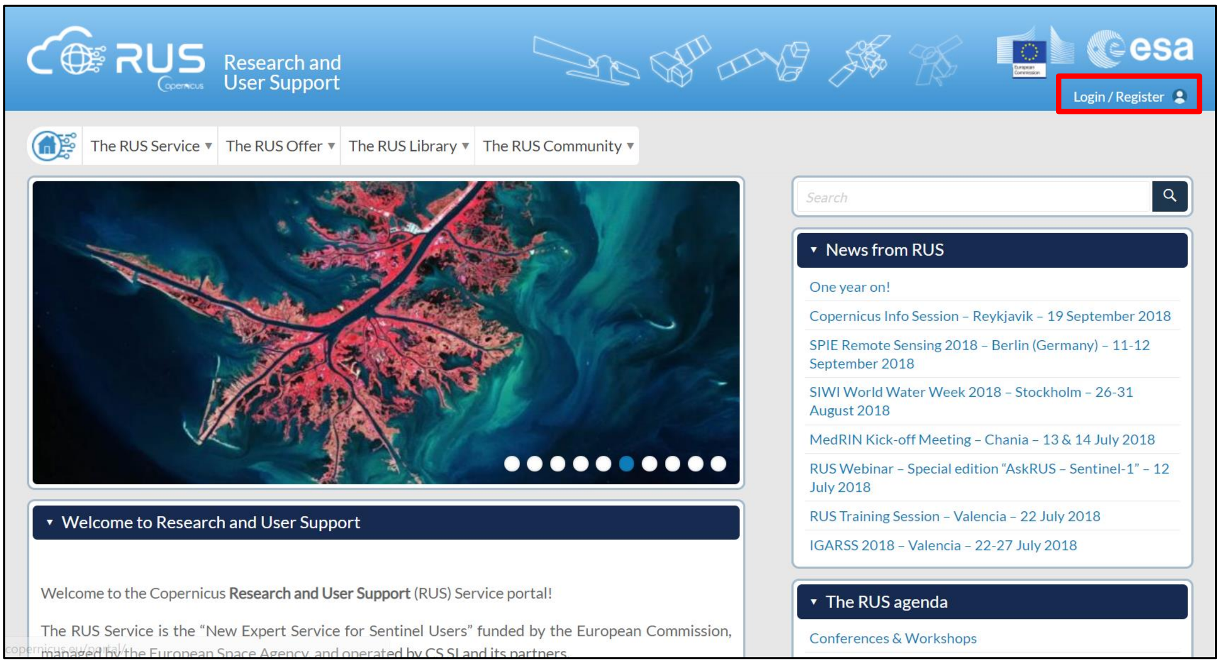
- Auxiliary data stored locally at:
  /shared/Training/COAS01_BathymetryDerivation_Greece/AuxData

2.2 Software in RUS environment

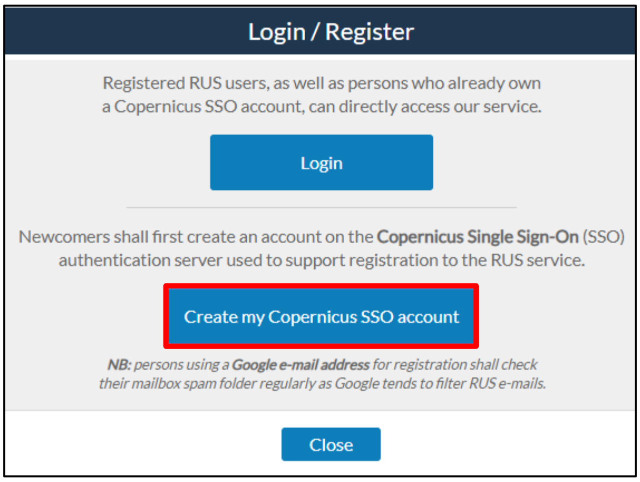
Internet browser, SNAP + Sentinel-2 Toolbox

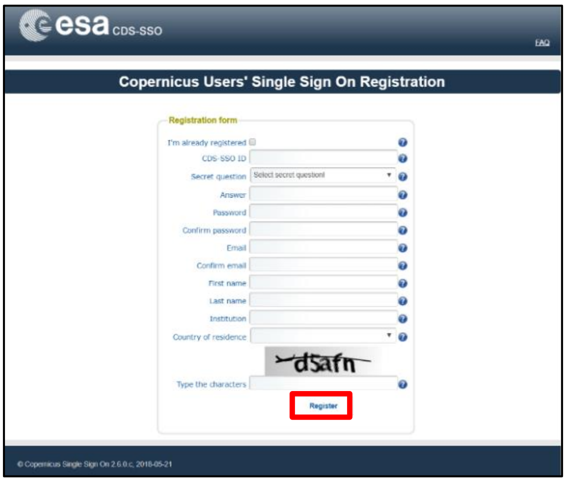
3 Register to RUS Copernicus

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.



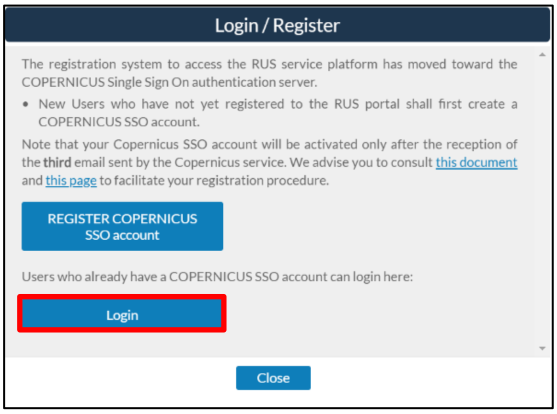
Select the option ***Create my Copernicus SSO account*** and then fill in ALL the fields on the **Copernicus Users' Single Sign On Registration**. Click ***Register***.

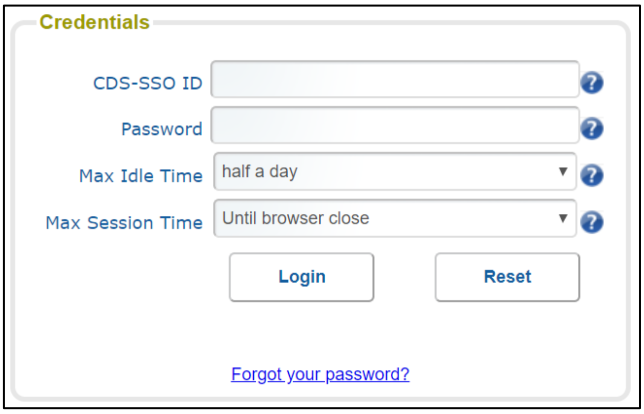




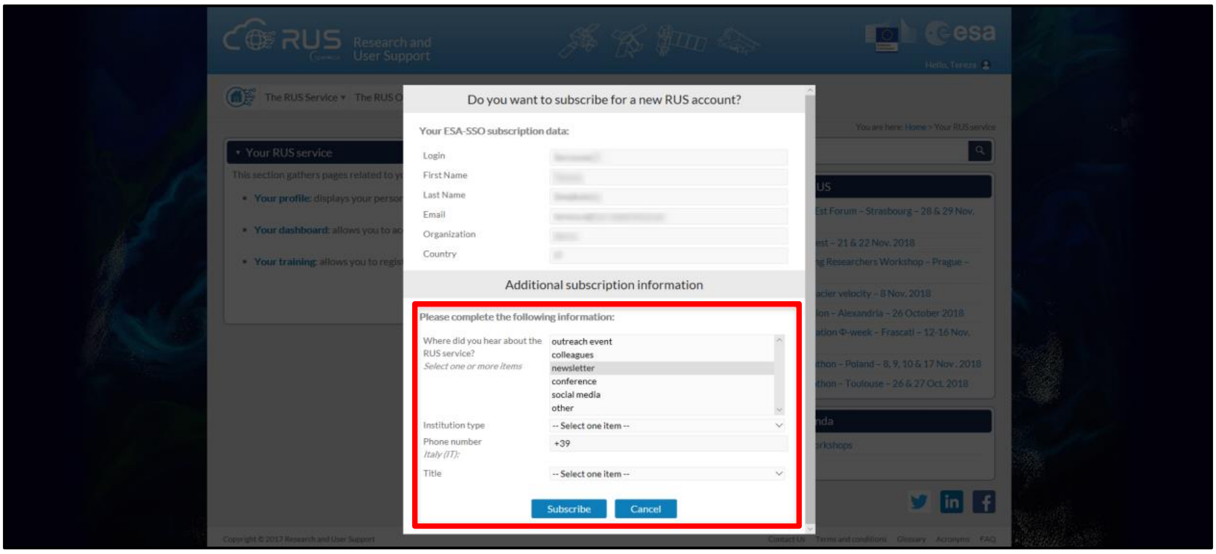
Within a few minutes you will receive an e-mail with activation link. Follow the instructions in the e-mail to activate your account.

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



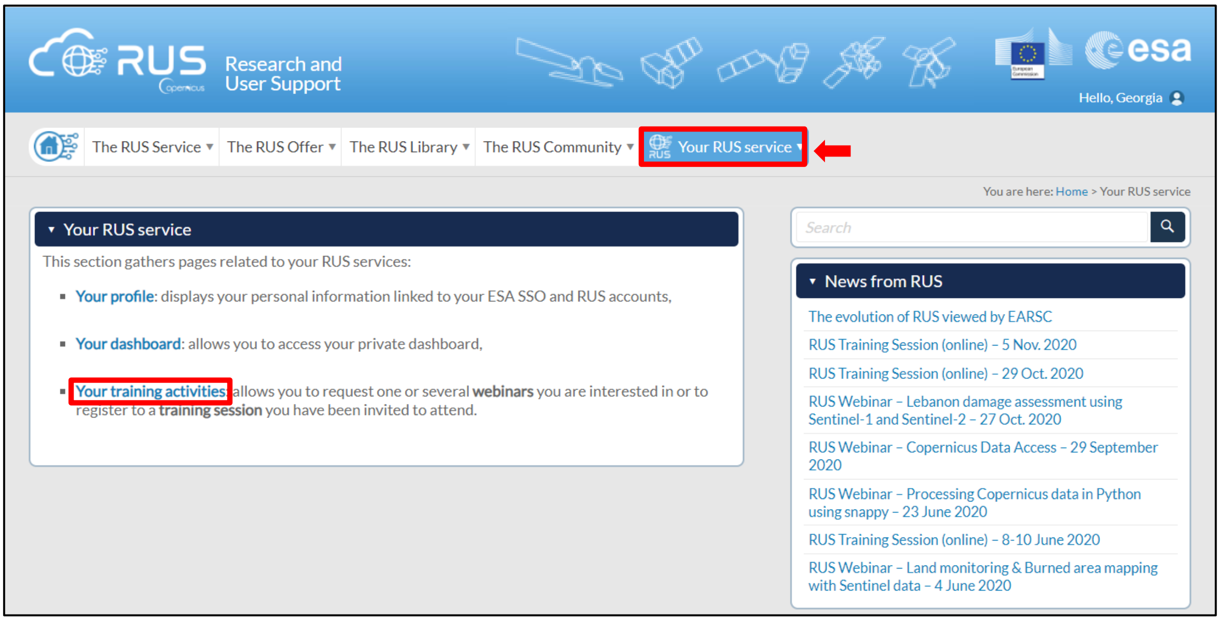


Upon your first login you will need to enter some details. You must fill all the fields.

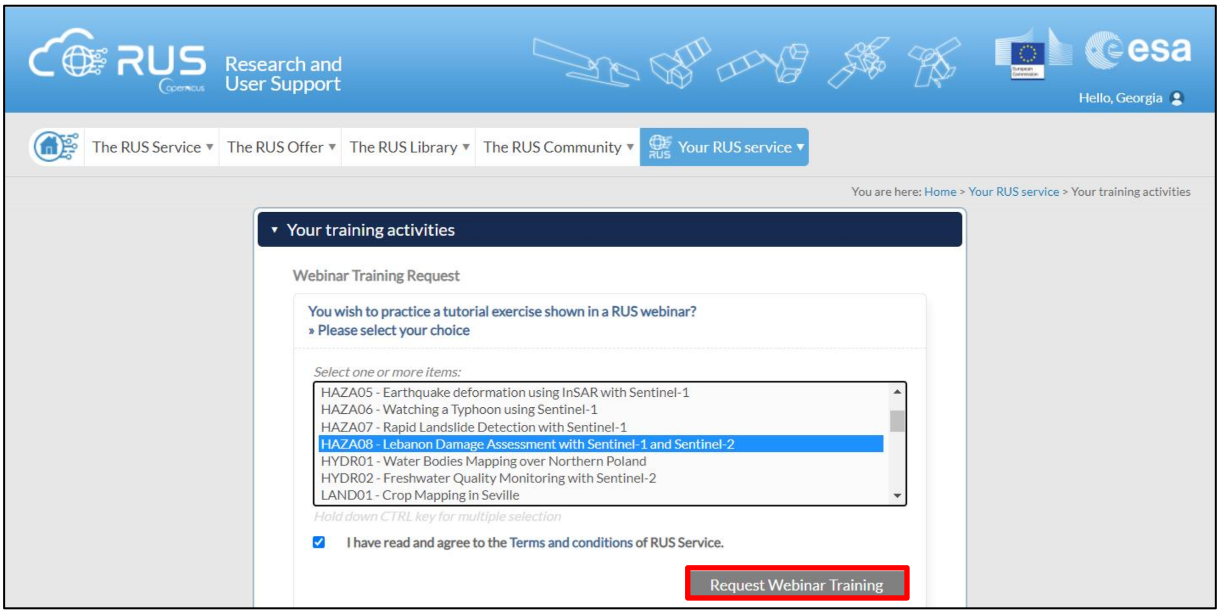


4 Request a RUS Copernicus Virtual Machine to repeat a Webinar

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***.

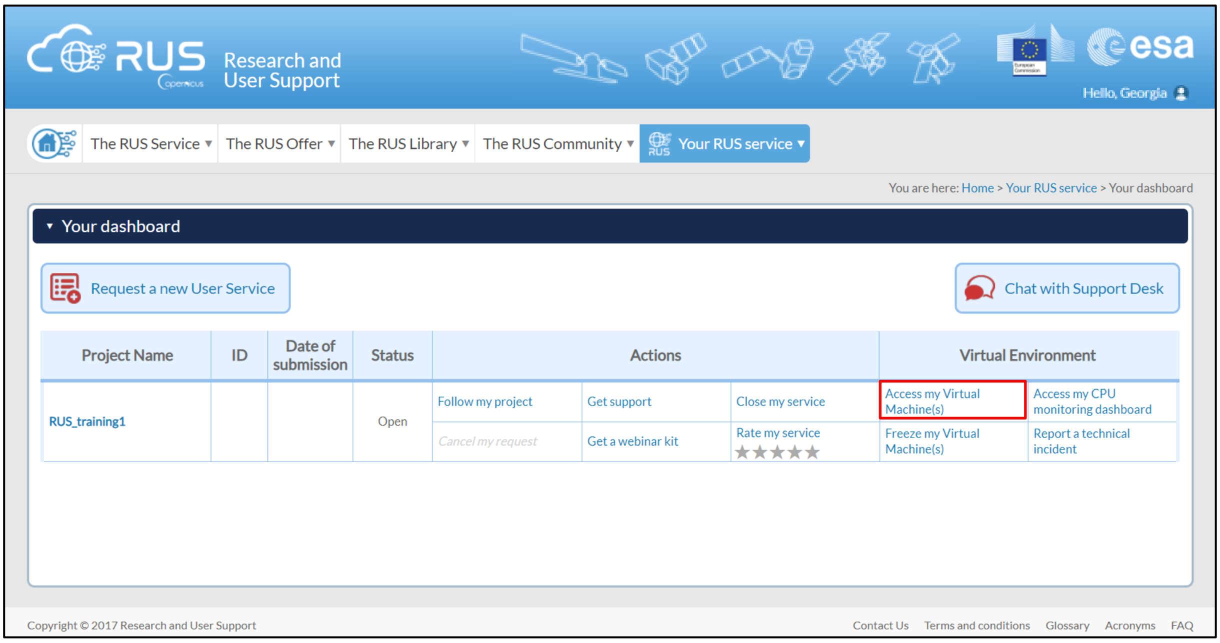


Select one or more webinars check the field *"I have read and agree to the Terms and conditions of RUS Service"* and then click on ***Request Webinar Training*** to request your RUS Virtual Machine.



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***.



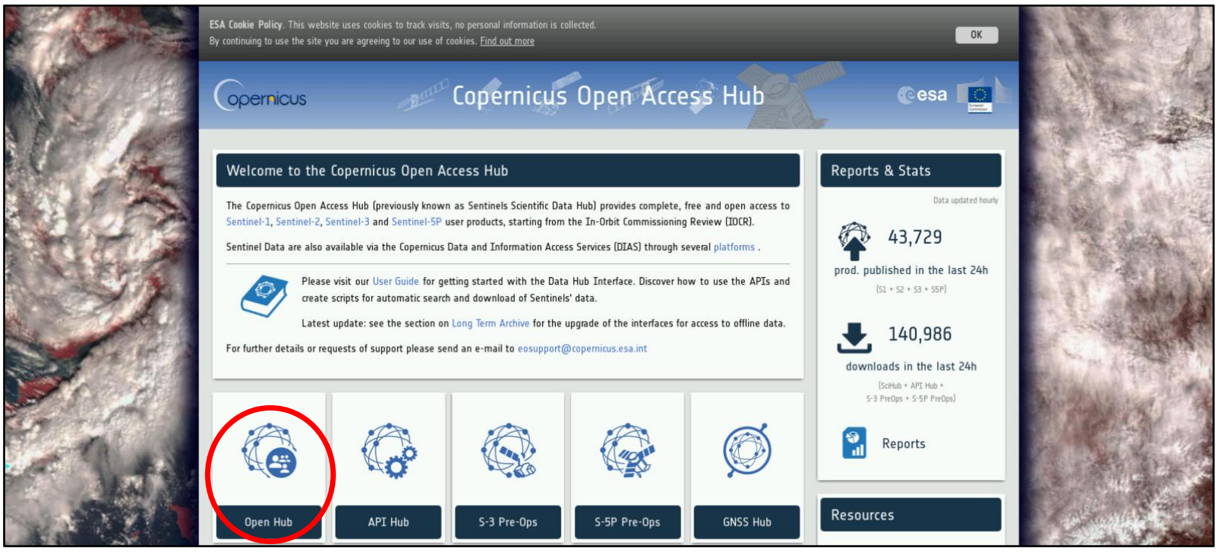
Fill in the login credentials that have been provided to you by the RUS Helpdesk via email to access your RUS Copernicus Virtual Machine.

This is the remote desktop of your Virtual Machine.

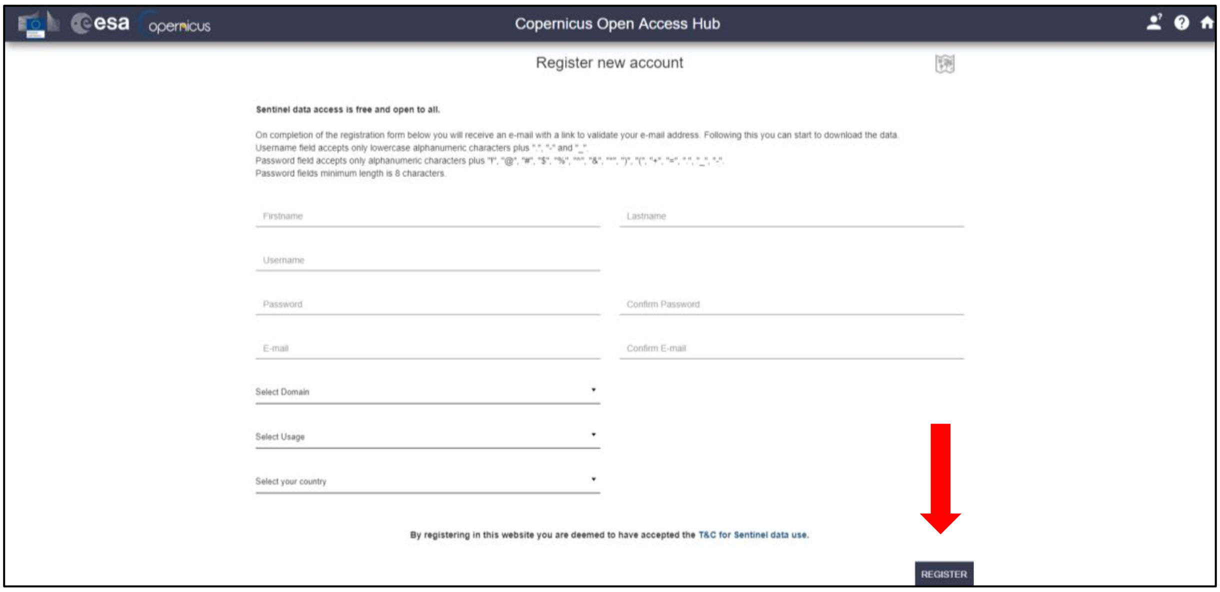
5 Step by step

5.1 Data download – ESA SciHUB

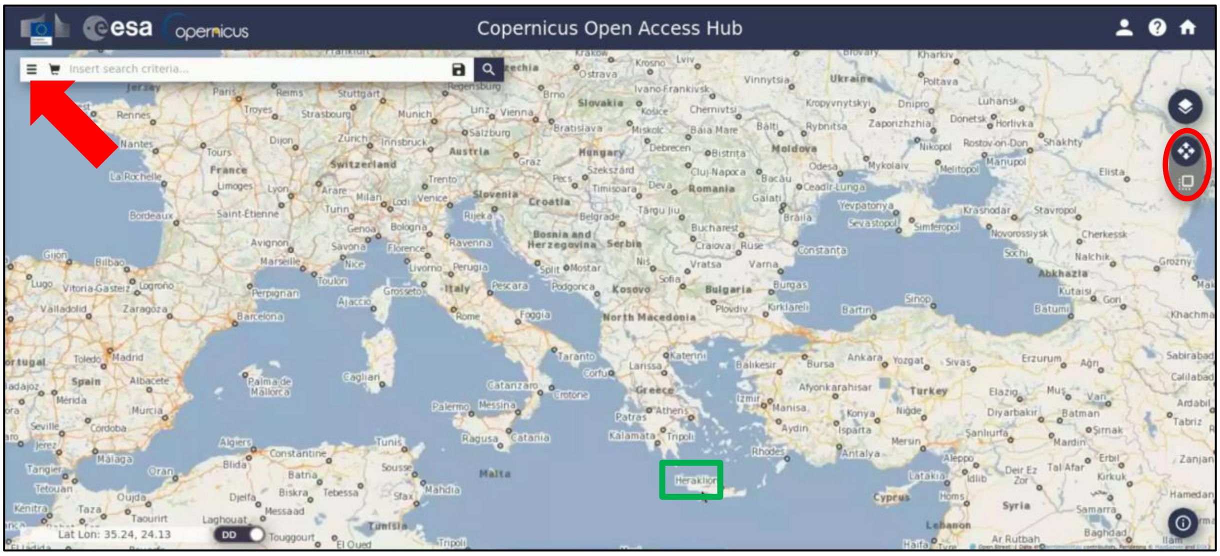
In this step we will download one Sentinel-2 scene from the Copernicus Open Access Hub using the online interface (**Applications → Network → Web Browser** or click the link below). Go to https://scihub.copernicus.eu/



Go to “**Open HUB**”, if you do not have an account please register by going to “**Sign-up**” in the LOGIN menu in the upper right corner.

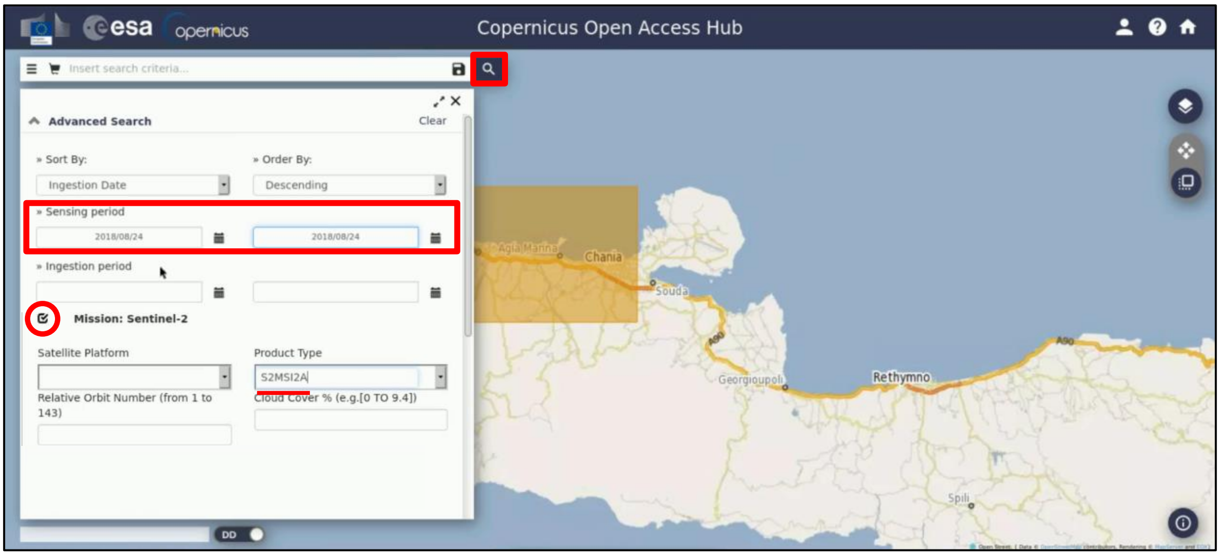


Navigate to Greece (**approximate area – green rectangle**).



Zoom in over Crete island, 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 and specify the following parameters:

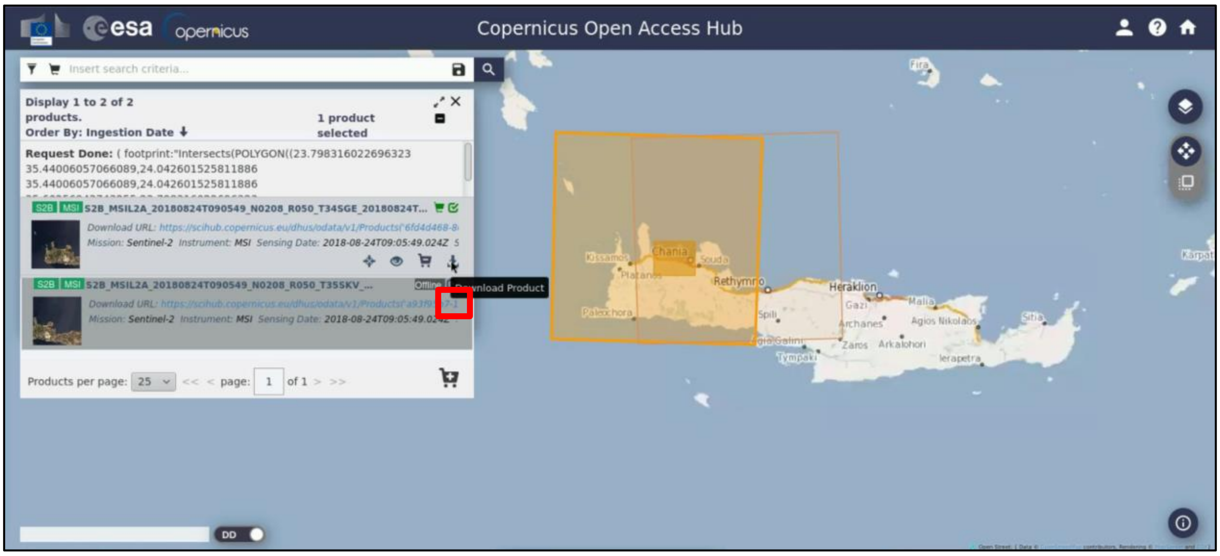
Sensing period: From 2018/08/24 to 2018/08/24
Select: Mission: Sentinel-2
Product Type: S2MSI2A



Then click on the "**Search**" icon .

In our case, the search returns 2 results for the time period we set over our area of study. Select the westward one, the: S2B_MSIL2A_20180824T090549_N0208_R050_T34SGE_20180824T151929 and then click on the download icon below.

The product will be downloaded to ***/home/rus*** as zip archive. Move it to the following folder: ***/shared/Training/COAS01_BathymetryDerivation_Greece/Original***

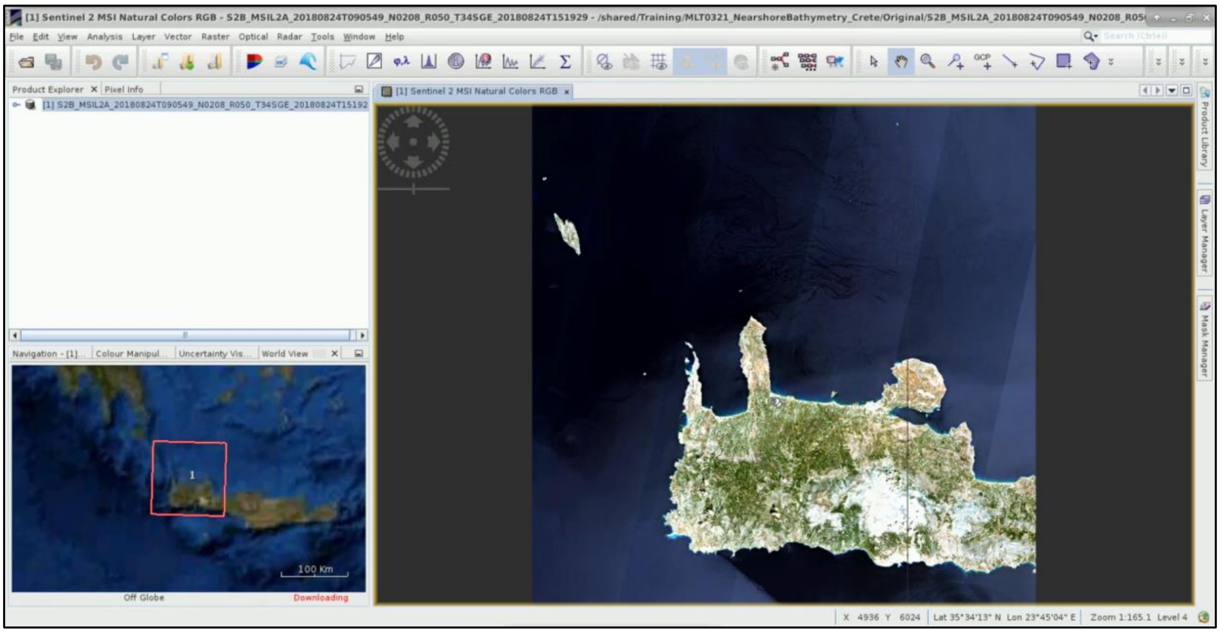


For the case that you want to use a Level-1C product as mentioned in the Chapter 6.1, download the S2B_MSIL1C_20180824T090549_N0206_R050_T34SGE_20180824T132333 product.

5.2 SNAP – open and explore data

Launch SNAP (icon on desktop). When SNAP opens, click **Open Product** , navigate to the folder in ***/shared/Training/COAS01_BathymetryDerivation_Greece/Original*** and open the Sentinel-2 zipped image. To visualize the product, right click and select **Open RGB Image Window**.

In the new window set the following parameters:
Profile: Sentinel-2 MSI Natural Colors
Red: B4
Green: B3
Blue: B2



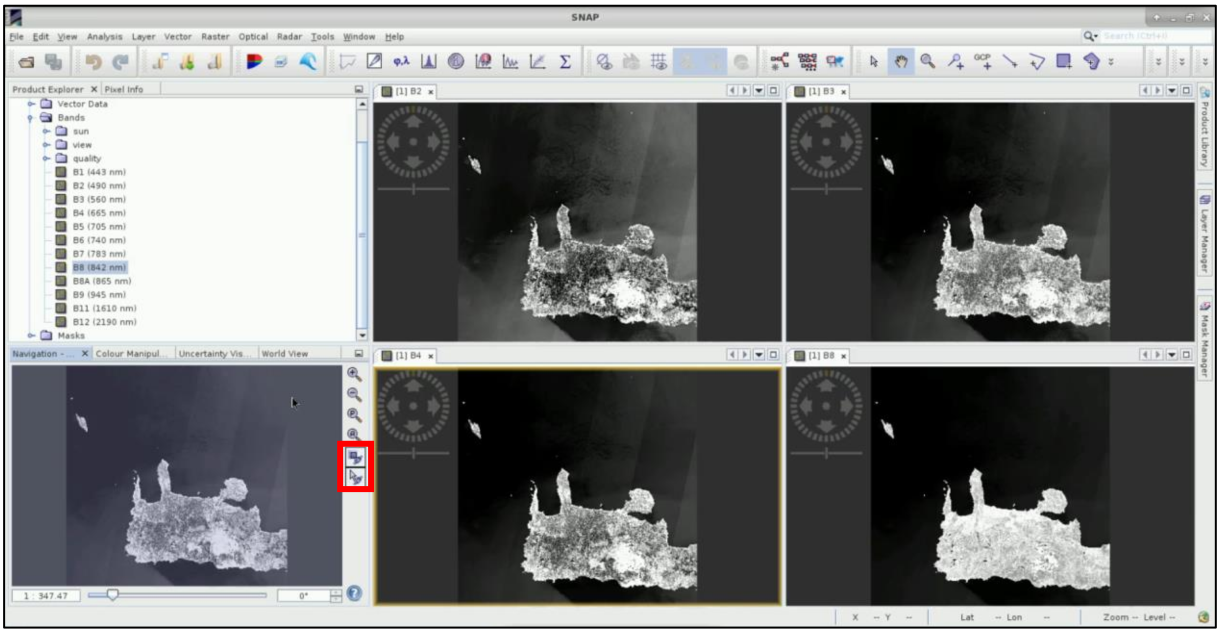
The Sentinel-2 MSI scene has 0% cloud cover and was acquired in Level-1C i.e. orthorectified (in cartographic projection), TOA (top-of-atmosphere) reflectance with spatial registration on a global reference system with sub-pixel accuracy.

In the context of this exercise, only bands with 10 meter spatial resolution will be used (See  NOTE 1), the visible (VIS) Blue (band 2), Green (band 3), Red (band 4) and Near Infrared (NIR) band (band 8).

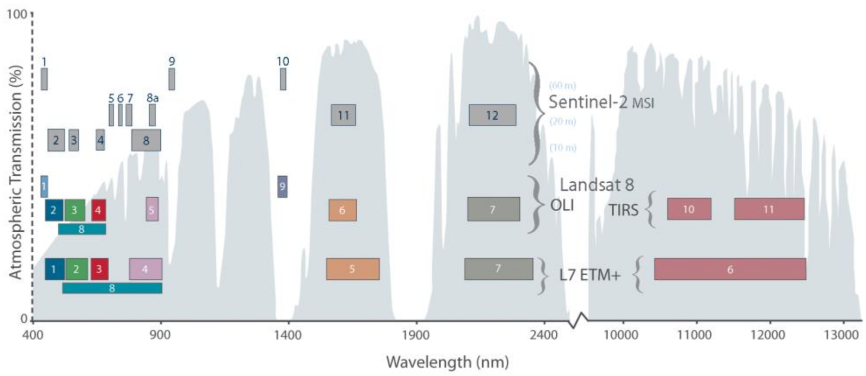
The selection of bands was based on literature review (Stumpf et al., 2003; Drakopoulou et al., 2018), as the use of blue and green bands seems to be most common in SDB application with a strong linear correlation with depth. The NIR band is used for masking land.

To display the different bands in the View Window, expand the **Bands** folder of the image and double click in on them (B2, B3, B4, B8).

To synchronize the views, go to **Navigation** tab in the lower left (red arrow) and make sure the cursor  and the views  are linked.



 NOTE 1: The Sentinel-2 Multispectral Instrument (MSI) samples 13 spectral bands: four bands at 10 metres, six bands at 20 metres and three bands at 60 metres spatial resolution (https://sentinel.esa.int/web/sentinel/missions/sentinel-2/instrument-payload/resolution-and-swath). The Level-1C product is composed of 100x100 km^2 tiles (ortho-images in UTM/WGS84 projection). The Level-1C product results from using a Digital Elevation Model (DEM) to project the image in cartographic geometry. Per-pixel radiometric measurements are provided in Top Of Atmosphere (TOA) reflectances along with the parameters to transform them into radiances.



SENTINEL-2 and LANDSAT spectral bands - Source: USGS

5.3 *Resample*

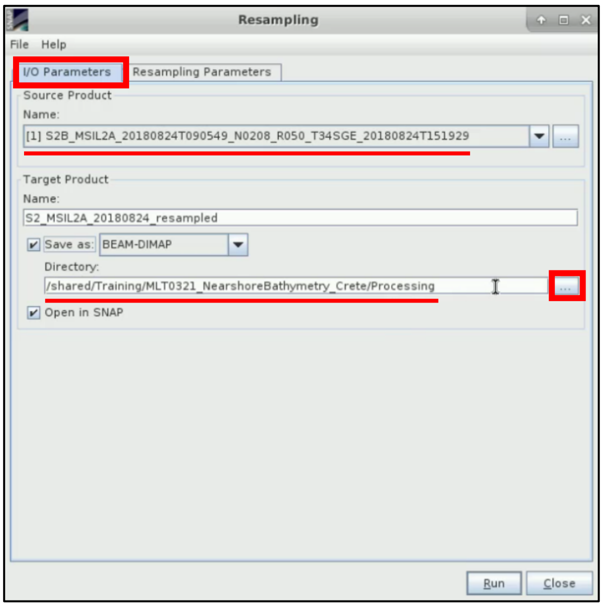
The 13 bands in Sentinel-2 products do not all have same resolution (therefore size, see NOTE 2). Many operators in SNAP toolbox do not support products with bands of different sizes so first we need to resample the bands to equal resolution.

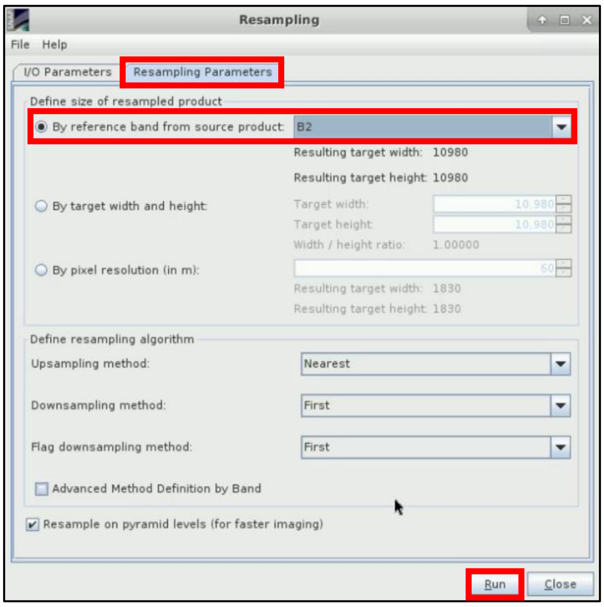
Go to **Raster → Geometric Operations → Resampling.**

In the **I/O Parameters** tab keep as "Source Product" the loaded on SNAP product, and under the "Target Product", set as **Name: S2_MSIL2A_20180824_resampled**.

Select "**Save as**" and under **Directory**: click on the [...], navigate to the folders and select the appropriate path as: ***/shared/Training/COAS01_BathymetryDerivation_Greece/Processing***

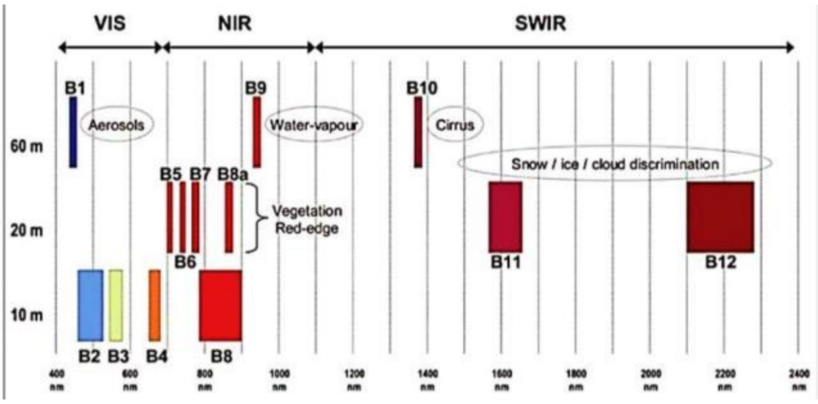
In the **Resampling Parameters** tab under "Define size of resampled product", select: **By reference band from source product: B2**





Click **Run**. After the process is completed, if a window appears, click **OK**. Close the Resampling Window.

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). When we open the RGB view all our input bands have 20 m resolution, however, the view is displayed in the full 10 m resolution.



Credits: ESA 2015

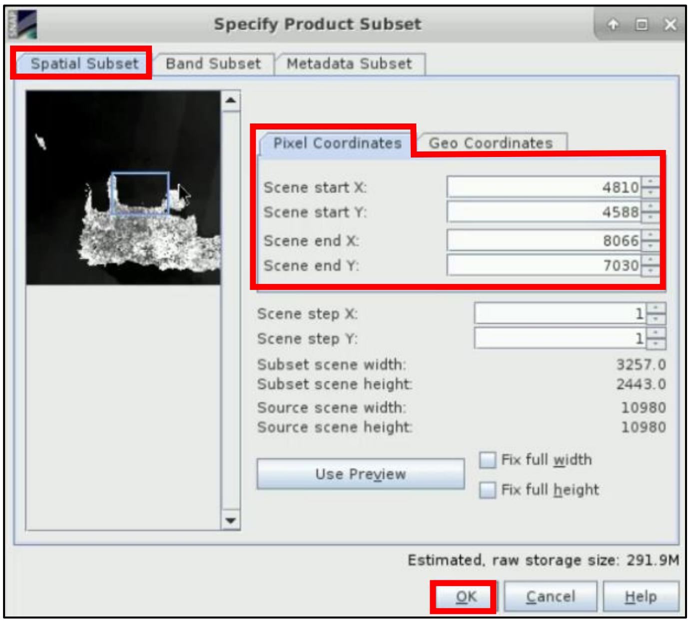
A new product [2], named **S2_MSIL2A_20180824_resampled** appeared in the **Product Explorer** Window.

5.4 Subset

Sentinel-2 Level-2A images cover an area of about 100x100 km^2. To simplify our analysis and focus on the region of interest (ROI) that is of primary interest we can create a subset of the larger scene.

Keep the resampled product selected and go to **Raster → Subset.**

In the **Spatial Subset** tab select the **Pixel Coordinates** tab and set the following parameters:



Scene start X: 4810

Scene start Y: 4588

Scene end X: 8066

Scene end Y: 7030

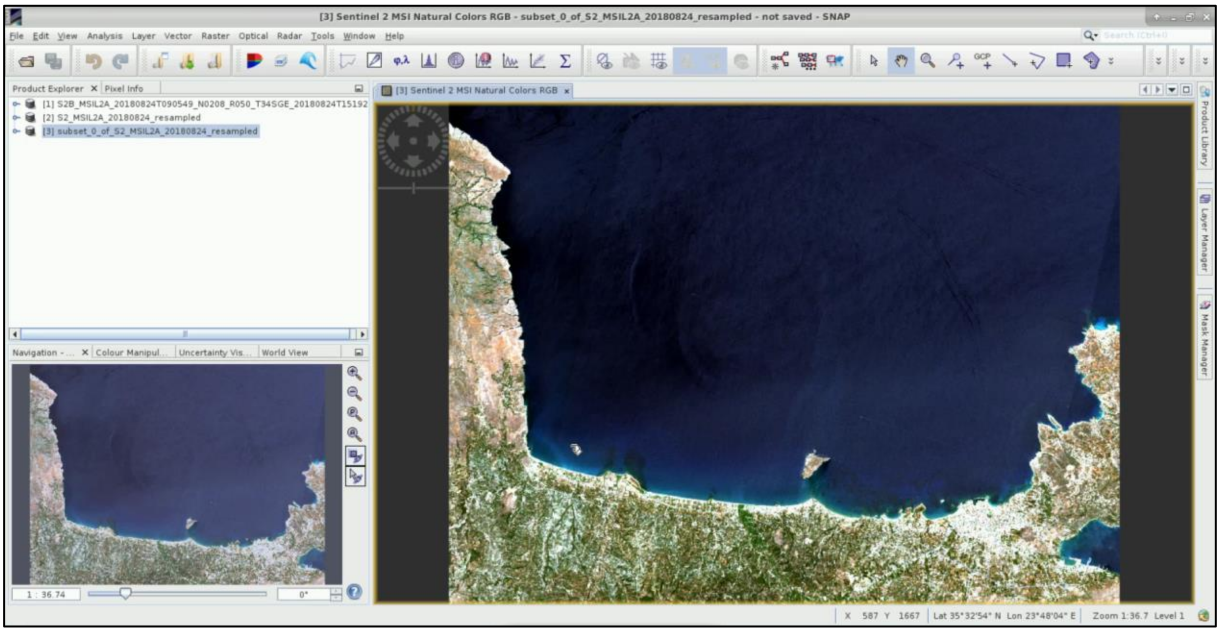
Click **OK**.

Right click on the subset product that will appear at the Product Explorer Window and click on **Save as**. Navigate to ***/shared/Training/COAS01_BathymetryDerivation_Greece/Processing*** folder and save the product as **Subset_S2_MSIL2A_20180824_resampled**. When a dialogue window appears click **YES**.

Right-click the product [3] and click **Open RGB image window** and from the dropdown menu select:

Profile: Sentinel 2 MSI Natural Colors

Click **OK**. We can see that it contains only the area we selected to subset.



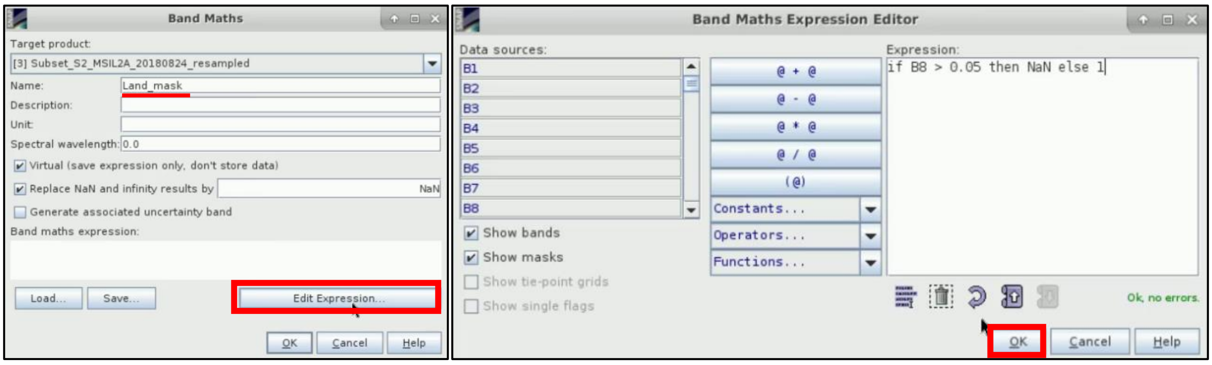
Right click on it, close it, and load from the ***Processing*** folder the saved **Subset_S2_MSIL2A_20180824_resampled** product to continue with our processing steps.

5.5 Land Mask

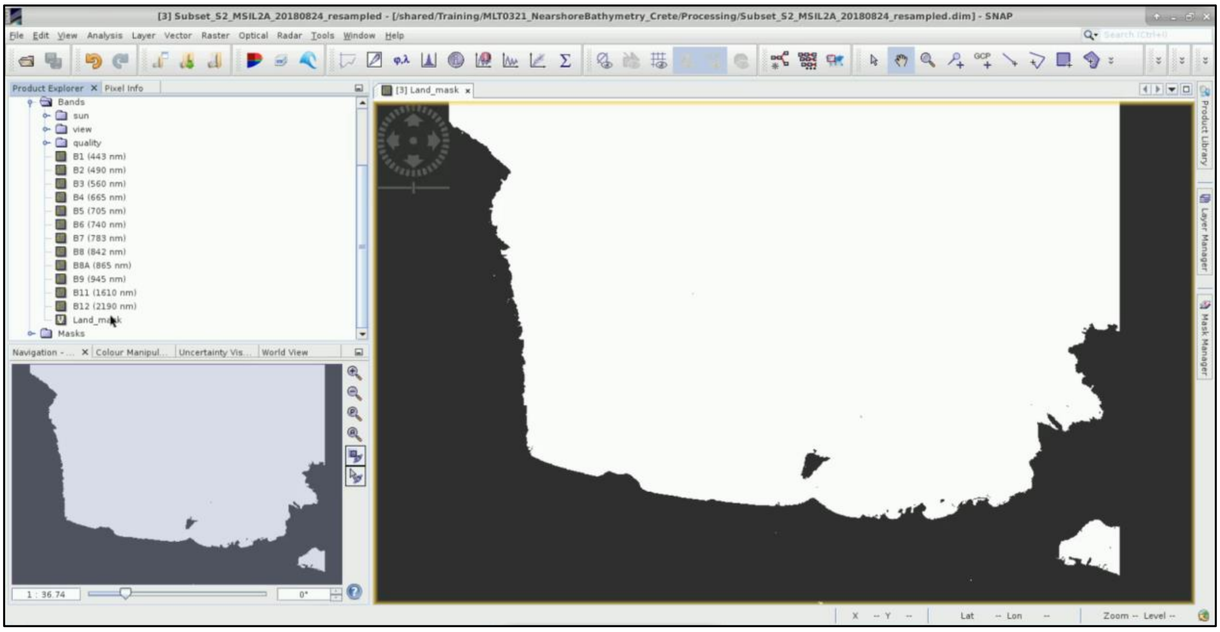
To proceed with the next steps we have first to mask the land cover in all four bands (B2, B3, B4, B8). Therefore, we have to create a land mask with values consisting of 0 and 1 for land and sea, respectively. NIR band will be used to mask land from the image, since the water appears dark and facilitates to discriminate water from land, which looks much brighter. The mask can be created either with the use of a threshold value of the NIR band that separates land from sea, or a polygon which describes the land. Finally, by applying the land mask in each band we will create a masked image that contains only the aquatic elements.

Right- click on **Subset_S2_MSIL2A_20180824_resampled** go to **Band Maths** and set **Name**: Land_mask

Then click on **Edit Expression** and set at the **Band maths expression**: if B8 > 0.05 then NaN else 1



Click **OK**. In the **Product Explorer Window**, the new band has been added, double click on it to visualize the land mask.

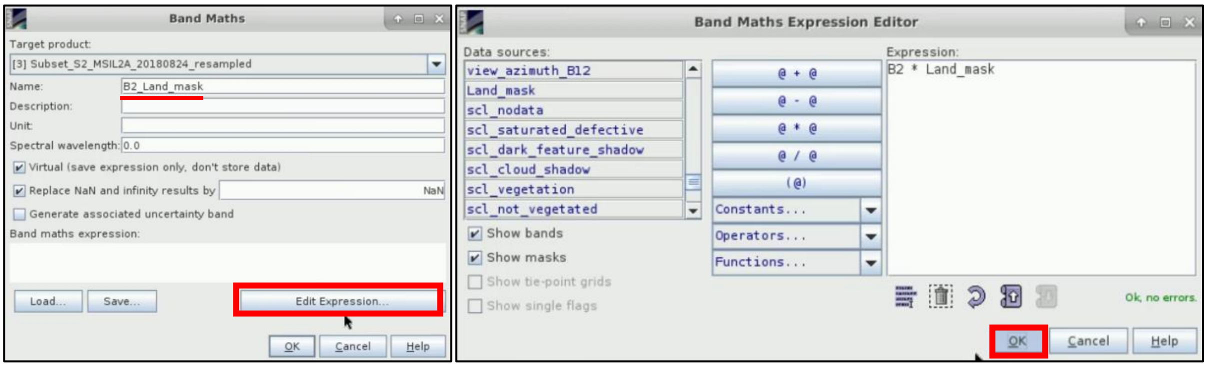


Keep in mind that from now on we will use Band Maths a lot.

To apply the land mask in each of the rest 3 bands we need to work with, right-click on this product **Subset_S2_MSIL2A_20180824_resampled** go to **Band Maths** and set the parameters for band B2:

Name: B2_Land_mask

Band maths expression: B2 * Land_mask



Click **OK**. The new band has been added in Product Explorer Window.

Repeat the process for bands B3, B4, B8, giving them the relative name each time:

Name: B3_Land_mask
Band maths expression: B3 * Land_mask

Name: B4_Land_mask
Band maths expression: B4 * Land_mask

Name: B8_Land_mask
Band maths expression: B8 * Land_mask

They will all appear at the product on the left, and they will also open in the **View Window**. Once you check that all of them have been created successfully, you can close the Views. Right click on the product and click **Save**, to store the new bands created.

5.6 Sun Glint Correction

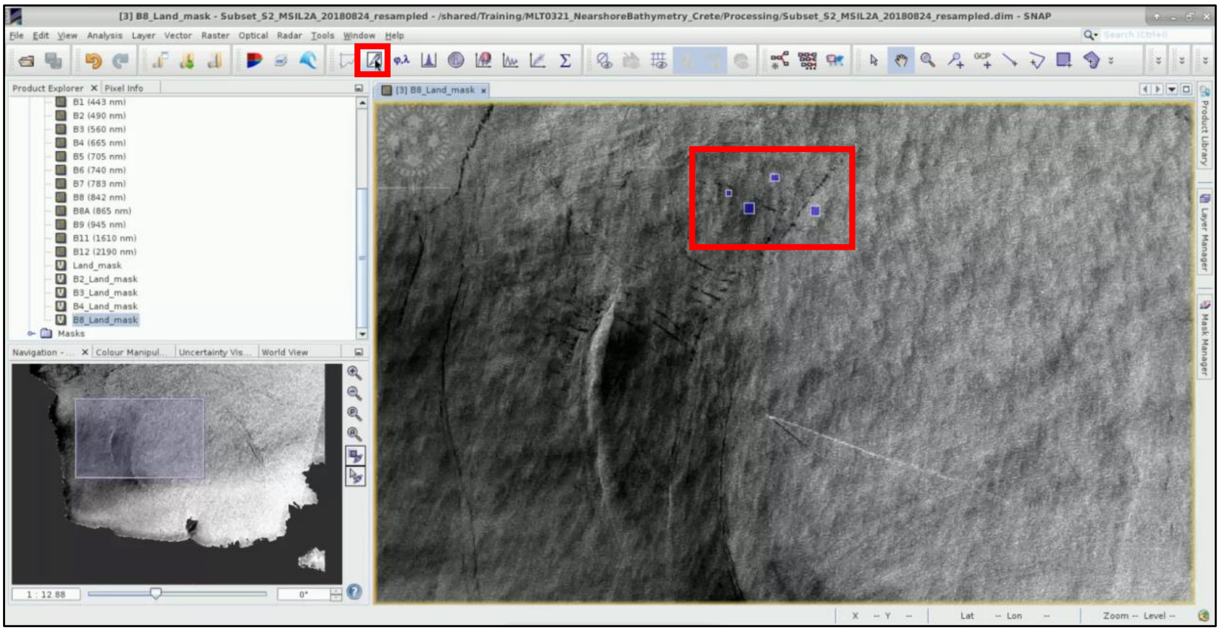
Sun glint is a common phenomenon in satellite images and it essentially refers to the specular reflection of the sun on water surfaces. The water-leaving reflectance can be difficult to observe due to the reflection of direct sunlight on the air-water interface (sunglint) in the direction of the satellite. The viewing geometry of Sentinel-2 satellite makes it vulnerable to sunglint contamination. Sun glint removal is a pre-processing step of multispectral images which is necessary when the amount of sun glint prevents the visibility of the sea bottom, usually in cases of marine habitat mapping.

There are several available sun glint removal methods for high resolution images and coastal applications. In this exercise we will apply the deglint methodology proposed by Hedley et al. (2005) that describes the linear relationships between NIR and visible bands using linear regression based on a sample of the image pixels.

To apply the correction we have to use one or more image samples of sun glinted regions to scale the relationship between the NIR signal and sun glint. These regions are chosen to include a range of pixel glint levels, but an assumed consistent underlying brightness and very low water-leaving reflectance in the NIR, typically deep water areas (Kay et al., 2009). To establish the relationship a linear regression between the two bands is performed over a deep water area, where the contribution from below the water surface is assumed homogenous, and so the derived relationship is only based on the surface reflectance.

Double click on band **B8_Land_mask** and then go to **Vector → Import → ESRI Shapefile** to open the image samples **geometry_Polygon** shown below. You can find this file, if you navigate to the following path: ***/shared/Training/COAS01_BathymetryDerivation_Greece/AuxData.*** Once you select it, at the dialogue window that will appear, click **No**.

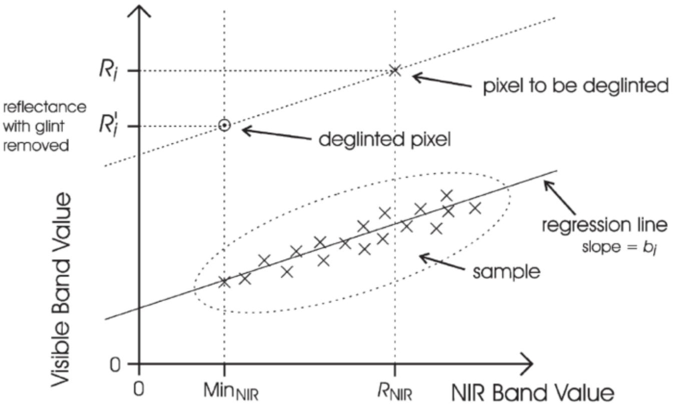
Then go to the SNAP toolbar and select the **Scatter Plot** to plot the NIR band against the VIS bands.



NOTE 3: The equation (1) described by Hedley et al. (2005) for the deglinting of a multispectral image is:

$$R'_i = R_i - b_i\,(R_{NIR} - Min_{NIR})$$

where R'_i is the deglinted pixel in band i, R_i is the reflectance from visible band i, b_i is the regression slope, R_{NIR} is the NIR band value and the Min_{NIR} the minimum NIR value of the sample.



To deglint a visible wavelength band, a regression is performed between the NIR brightness and the brightness in the visible band using a sample set of pixels, which would be homogeneous if not for the presence of sun glint (e.g. deep water). For other pixels, the slope of the regression is then used to predict the brightness in the visible band that would be expected if those pixels had a NIR value of Min_{NIR} (equation (1)). Min_{NIR} is the NIR value expected from a pixel with no sun glint, which can be estimated by the minimum NIR value found in the sample.

In the Scatter Plot set the following parameters, (**Subset_S2_MSIL2A_20180824_resampled** selected):

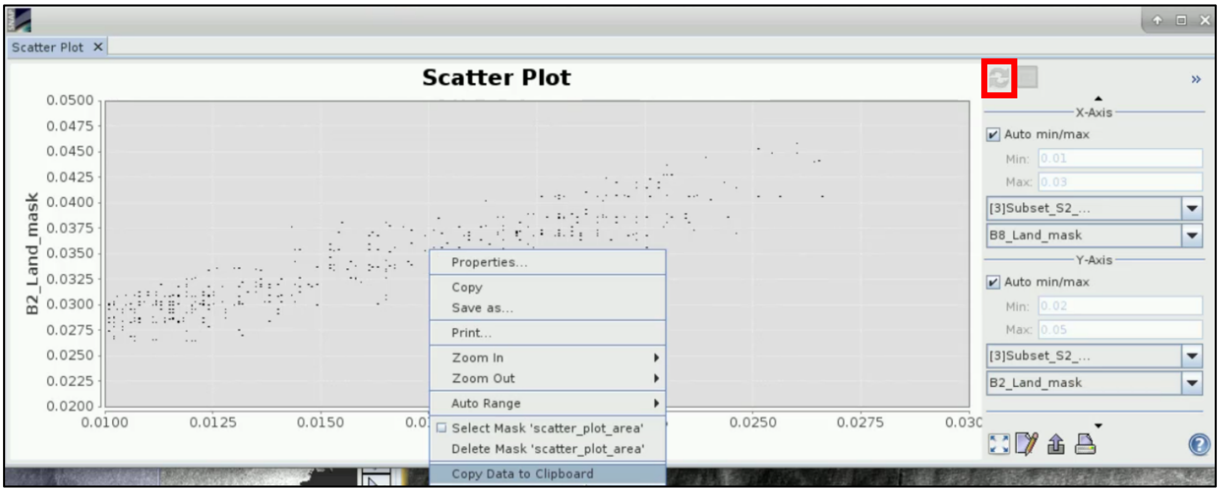
Use ROI mask: geometry_Polygon

X-Axis: B8_Land_mask

Y-Axis: B2_Land_mask

Then click the **Refresh View** .

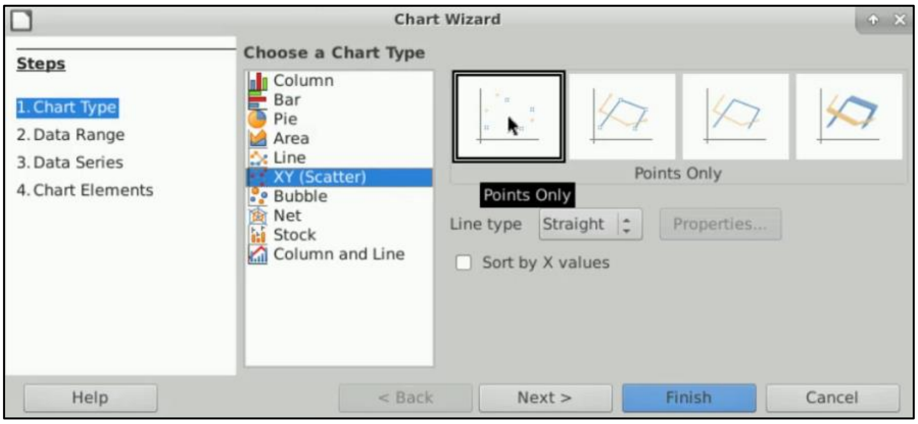
The plot will be created. Right-click on the plot and select **Copy Data to Clipboard**.



Go on the top left corner of the screen, go to **Applications → Office → LibreOffice Calc** open a new sheet and paste the data. Click **OK** to the window that will appear.

Select all cells and go to **Edit → Cell Protection** (make sure the lock is removed, otherwise it will not allow you to perform any analysis on the data). Stretch a bit the columns of the cells if you want, for better visualization.

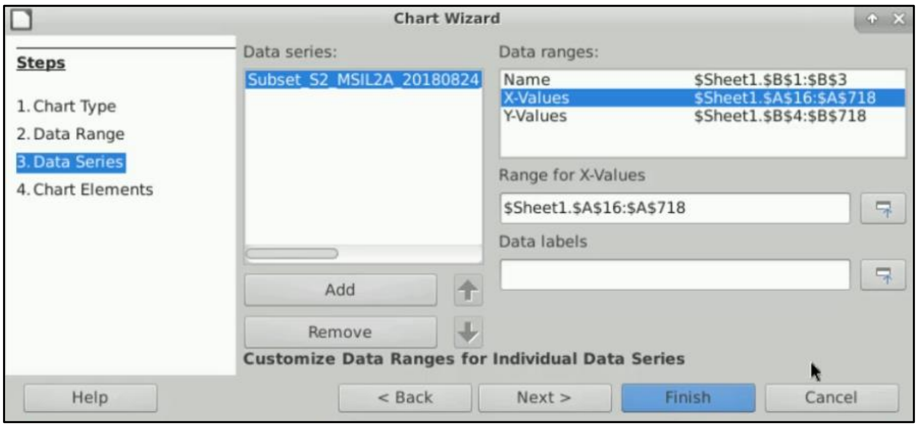
Select **Columns A and B**. Those are the ones that contain the values we will work with. Go to **Insert → Chart** and select as **Chart Type** the XY (Scatter) of **Points Only**.



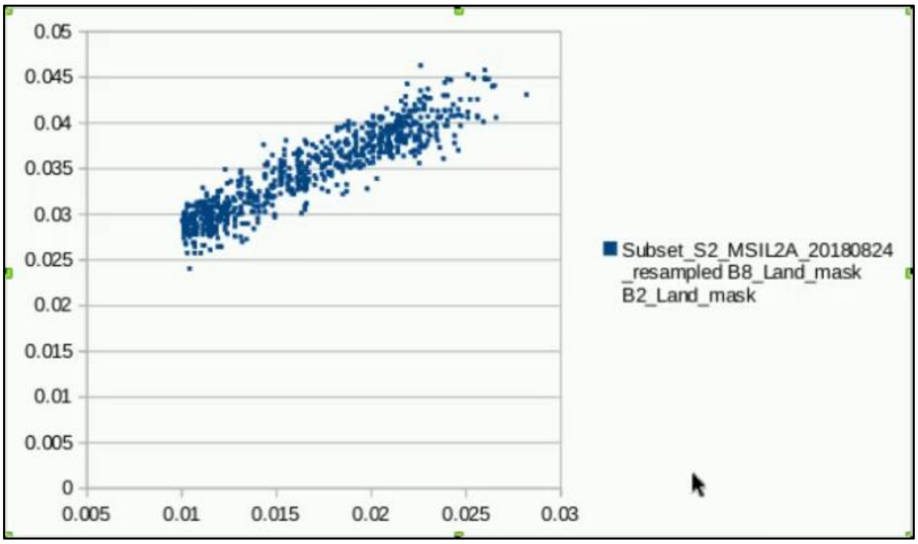
Click **Next** until you reach the **Data Series.** Choose the **Data Series** having the NIR band (B8) values on X-axis and the VIS band (B2, then B3 and then B4) values on Y-axis.

Set for **X-axis**: $Sheet1.$A$16:$A$718 and for **Y-axis**: $Sheet1.$B$16:$B$718. Then, click **Finish**.

Remember that what we need to set for **X-axis**, are the values on column A, when you will apply this in your case, you might have a different range than the A16-A718. The same logic applies for **Y-axis.** <u>KEEP THIS IN MIND FOR ALL THE REST SHEETS YOU WILL WORK WITH, FOR EACH OCCASION.</u>



This is the initial chart. You can double click on the blue points and modify their colour or width for better visualization.



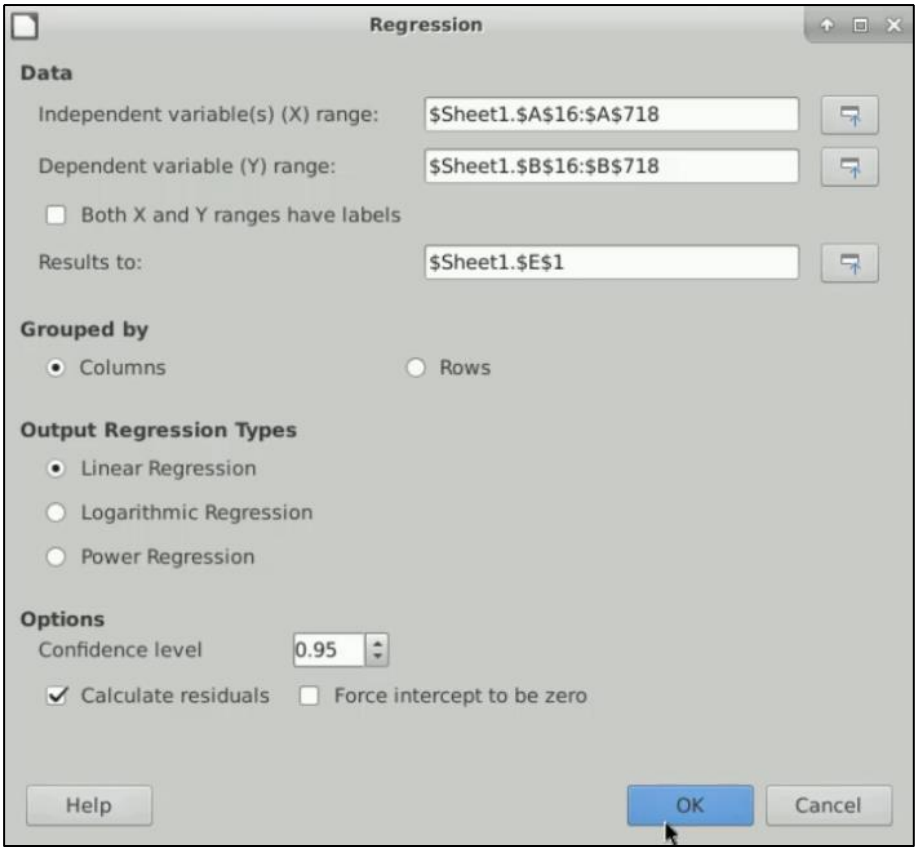
We now need to perform the **Regression Analysis** to retrieve the slope of the regression and use the values from the **R^2 equation**. Go to **Data → Statistics → Regression…** Under **Data**, set as before:

For **Independent variable(s) (X) range**: $Sheet1.$A$16:$A$718

For **Independent variable(s) (Y) range**: $Sheet1.$B$16:$B$718

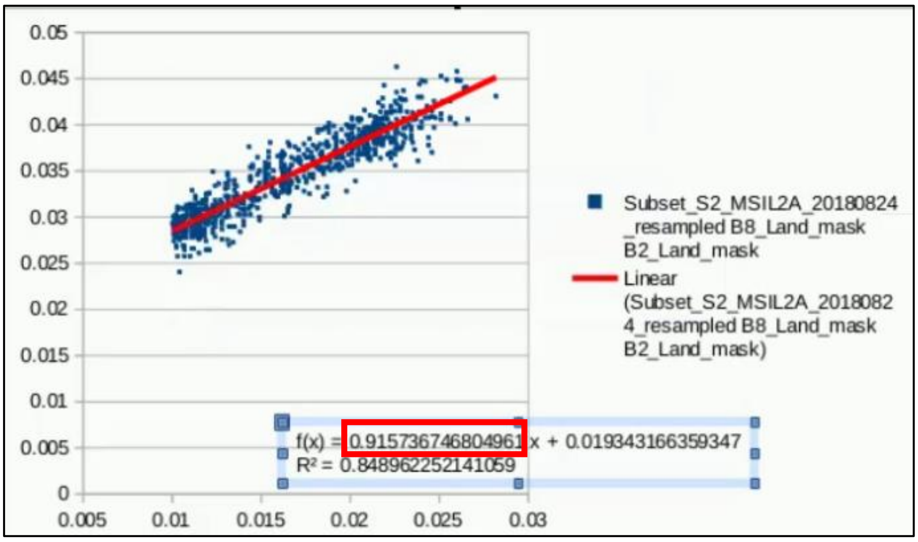
For **Results to**: $Sheet1.$E$1

Make sure that as **Output Regression Type**, the **Linear Regression** is selected. Click **OK**.



The Regression results will appear on the Sheet.

Click on the Data Points within the chart, once. Then right-click on them and select **Insert Trend Line**. You can also modify its colour and width if you double click on it. Then right click again and select **Insert R^2 and Trend Line Equation.** The number in the red rectangle below, is the number we need for B2.



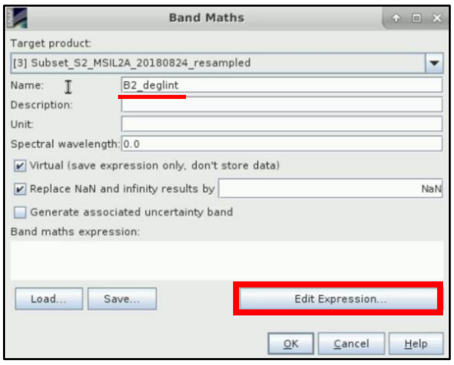
When you have reached that step, you can **Save** the Sheet with the name **B2_Land_mask** under the ***/shared/Training/COAS01_BathymetryDerivation_Greece/Processing*** folder.

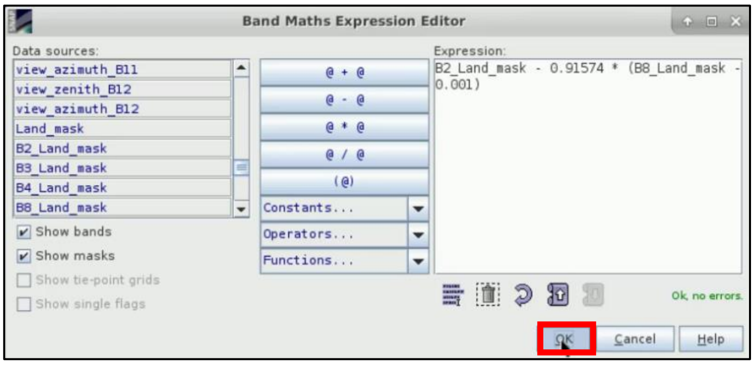
Repeat the process from 5.6 chapter so far, for bands B3 and B4 as well.

Now let's continue with the deglint steps in SNAP. Right-click again at the product we are working on, go to **Band Maths** and set the following parameters for deglinting band B2:

Name: B2_deglint

Band maths expression: B2_Land_mask - 0.91574 * (B8_Land_mask - 0.001)





Accordingly, set the following parameters for deglinting band B3 and band B4:

Name: B3_deglint

Band maths expression: B3_Land_mask - 1.00116 * (B8_Land_mask - 0.001)

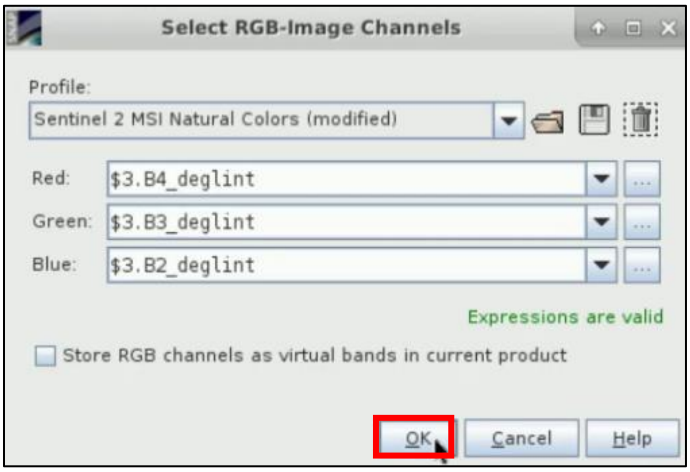
Name: B4_deglint

Band maths expression: B4_Land_mask - 1.0223 * (B8_Land_mask - 0.001)

Right click and **Save** the product.

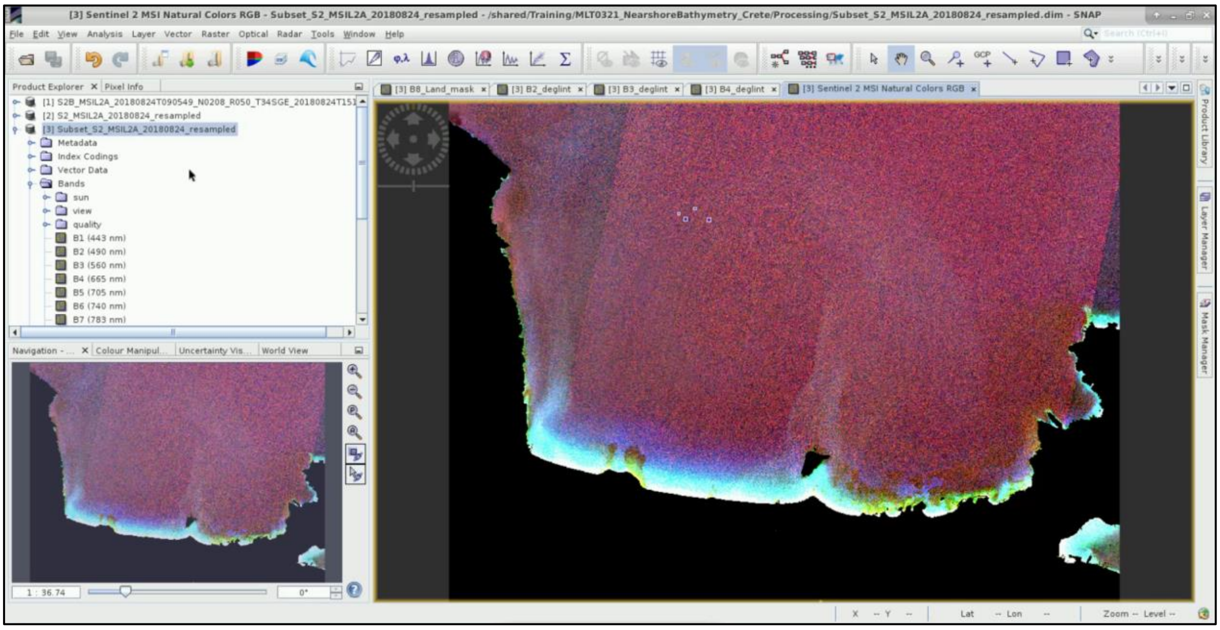
To visualize the correction for sun glint, right-click on the **Subset_S2_MSIL2A_20180824_resampled** product and select **Open RGB Image Window**.

Select the following parameters:



Red: B4_deglint
Green: B3_deglint
Blue: B2_deglint

Click **OK**.



You can open an RGB image if you want before applying the sunglint correction and compare them.

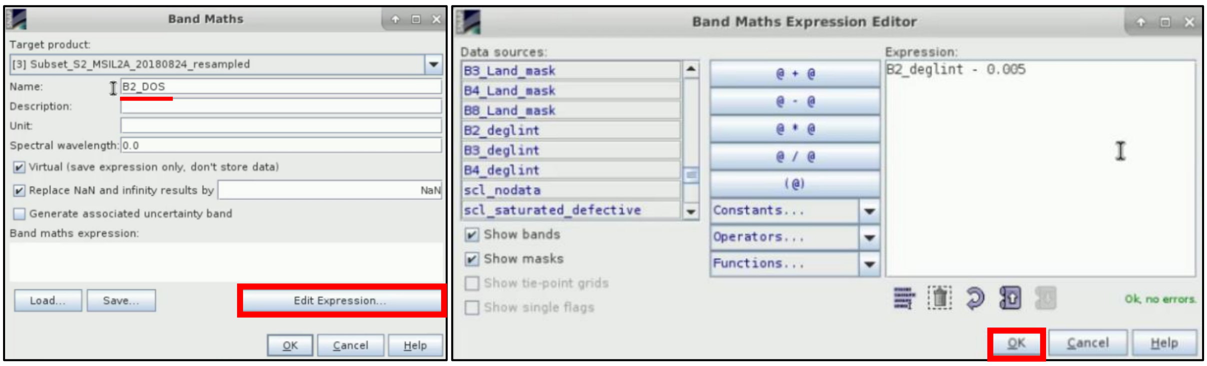
5.7 *Dark-Object Atmospheric Correction*

Dark Object Subtraction (DOS) is an empirical atmospheric correction method which assumes that reflectance from dark objects includes a substantial component of atmospheric scattering. This atmospheric offset generated from the image itself can be removed by subtracting this value from every pixel in the band. However, this value is different for each band and can be also estimated as the value of the histogram's cut-off point at the lower end (Chavez, 1998). The most effective dark target would be optically-deep water with expected zero reflectance.

Right-click again on the **Subset_S2_MSIL2A_20180824_resampled** product, go to **Band Maths** and set the parameters for band **B2_deglint**:

Name: B2_DOS

Band maths expression: B2_deglint - 0.005

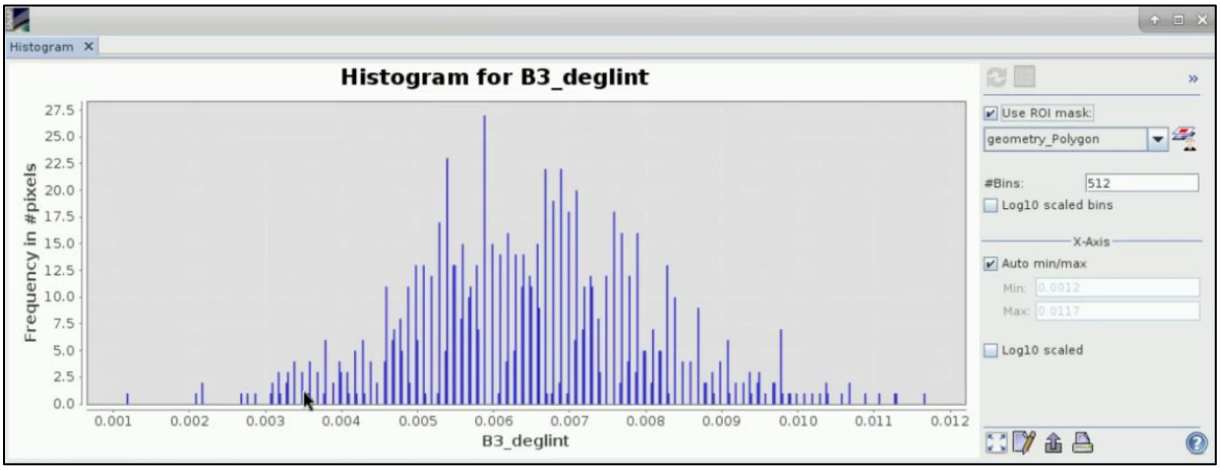


Also, set the following parameters for only the band **B3_deglint:**

Name: B3_DOS

Band maths expression: B3_deglint - 0.001

You can derive the 0.005 and 0.001 values if you create a histogram for each band, and just keep the minimum value it has. E.g.: 0.001 is the value for band B3_deglint. Right click the product and **Save** it.



5.8 *Satellite Derived Bathymetry*

For the derivation of the bathymetry data from the Sentinel-2 image we will adopt the model developed by Stumpf et al. (2003), based on the principle that each band has a different absorption level over water and this diversity level theoretically will produce the ratio between bands. This ratio then will generate a simultaneous change when the depth changes. (See NOTE 4).

For this exercise, the ratio will be applied for the pair of Blue-Green (B2-B3) bands and for n = 1000. In order to define the constants of Equation 2 (See NOTE 3), calibration dataset of points with known depths are also required. The available multi and single beam echo sounding data have been derived from the Hellenic Centre for Marine Research, Hellenic National Oceanographic Data Centre (HCMR/HNODC) (https://www.hcmr.gr/en/), published in Drakopoulou et al. (2018).

NOTE 4: The ratio model of Stumpf et al. (2003) is given in the following equation (2):

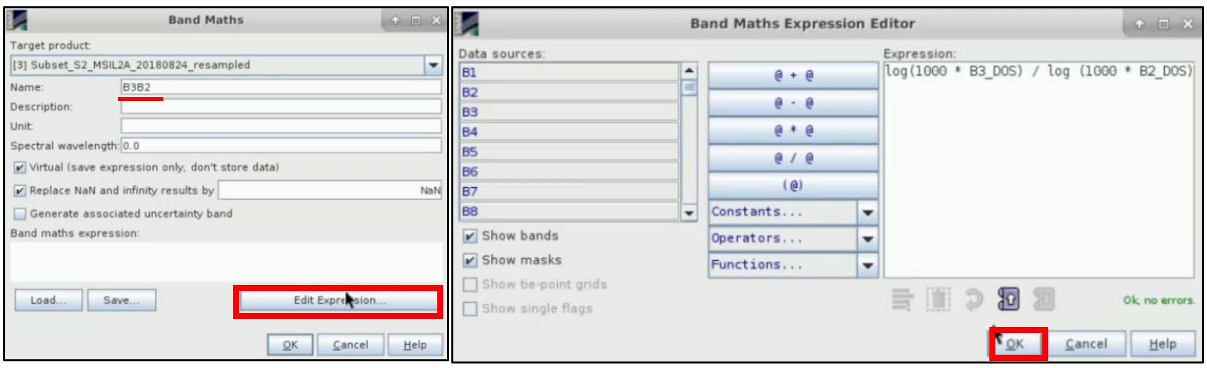
$$Z = m_1 \frac{\ln(nR_w(\lambda_i))}{\ln(nR_w(\lambda_j))} - m_0$$

where Z is the estimated depth, m_1 is a tunable constant to scale the ratio to depth, n is a fixed constant for all areas, R_w is the reflectance of water for bands i or j, and m_0 is the offset for a depth of 0 m (Z=0). The fixed value of n is chosen to assure both that the logarithm will be positive under any condition and that the ratio will produce a linear response with depth.

Right click again on the product and go to **Band Maths** to calculate the band ratio of equation (2) by setting the following parameters:

Name: B3B2

Band maths expression: log (1000 * B3_DOS) / log (1000 * B2_DOS)

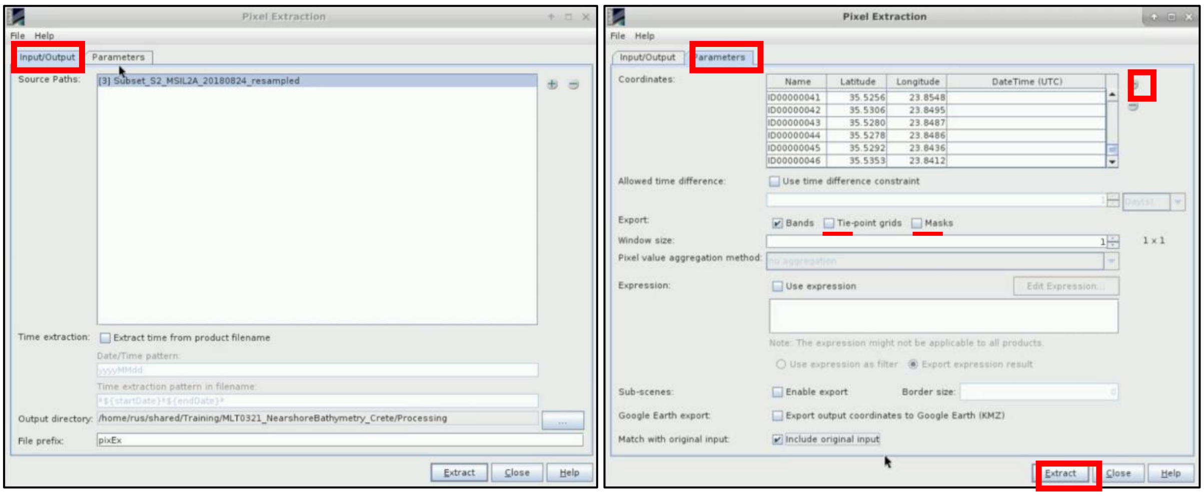


Click **OK**.

We now proceed with the automatic extraction of pixel values in both bands from geographical coordinates of all the bathymetric data points by using **text/*.csv** file. Go to **Raster → Export → Extract Pixel Values**.

Check that the product at Source path is **Subset_S2_MSIL2A_20180824_resampled** and in the **Input/Output** tab define the **Output directory** as: ***/shared/Training/COAS01_BathymetryDerivation _GreeceProcessing***

In **Parameters** tab select **Add measurements from CSV file** in the upper right corner. Add the file **bathy_coord** from ***/shared/Training/COAS01_BathymetryDerivation_Greece/AuxData*** folder. In addition, unselect **Tie-point grids** and **Masks** boxes and check **Include original input** box.



Click **Extract**.

SNAP creates the following two files in the **Processing** folder:

- pixEx_productIdMap.txt
- pixEx_S2_MSI_Level-2A_measurements.txt

Go to **Applications → Office → LibreOffice Calc** and go to **File → Open:** pixEx_S2_MSI_Level-2A_measurements.txt, from ***/shared/Training/COAS01_BathymetryDerivation_Greece/Processing***

We will perform again a Regression Analysis, like we did before. This time select **Columns BT and B**.

Go to **Insert → Chart** and select as **Chart Type** the XY (Scatter) of **Points Only**. Click **Next** until you reach the **Data Series.**

Choose the **Data Series**, set the **B3B2** band values on X-axis and the **Depth** (in meters) values on Y-axis.

Set for **X-axis**: $'pixEx_S2_MSI_Level-2A_measurements'$BT$8:$BT$54
and for **Y-axis**: $'pixEx_S2_MSI_Level-2A_measurements'$B$8:$B$54

Then, click **Finish**.

By performing the regression analysis of the data we derive the constants m_1 and m_0 as per Stumpf et al. (2003), while the R^2 indicates the correlation value.

Go to **Data → Statistics → Regression…** Under **Data**, set as before:

For **Independent variable(s) (X) range**: $'pixEx_S2_MSI_Level-2A_measurements'$BT$8:$BT$54

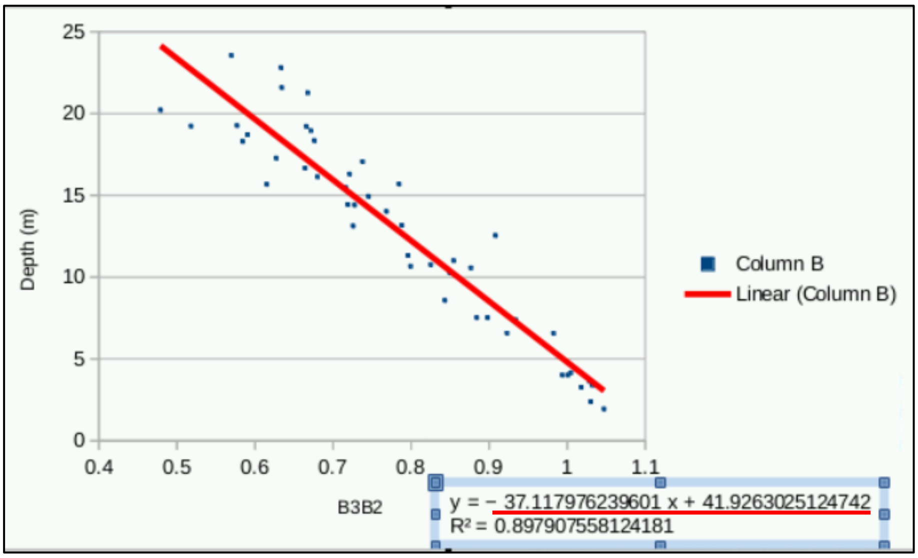
For **Independent variable(s) (Y) range**: $'pixEx_S2_MSI_Level-2A_measurements'$B$8:$B$54

For **Results to**: $'pixEx_S2_MSI_Level-2A_measurements'$BV$1

Make sure that as **Output Regression Type**, the **Linear Regression** is selected. Click **OK**.

Click on the Data Points within the chart, once. Then right-click on them and select **Insert Trend Line**. You can also modify its colour and width if you double click on it. Then right click again and select **Insert R^2 and Trend Line Equation.**

From this equation, we keep as m_1 **= -37.118** and as m_0 **= +41.926**

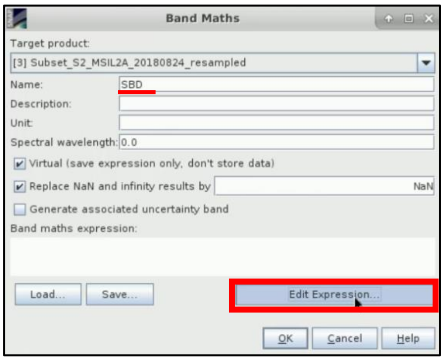


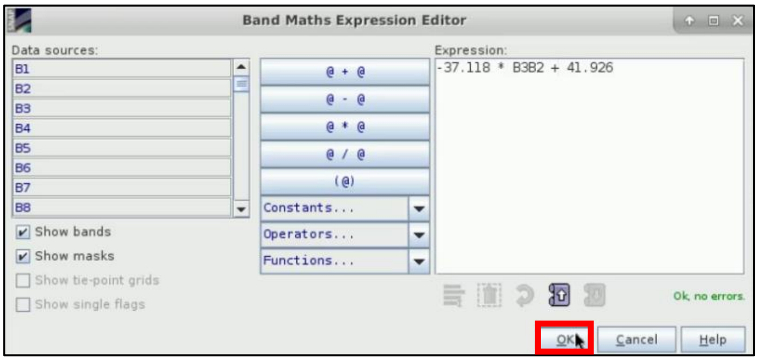
To estimate the satellite bathymetry, right click on the **Subset_S2_MSIL2A_20180824_resampled** product and go to **Band Maths**.

Set the following parameters for equation (2):

Name: SDB

Band maths expression: -37.118 * B3B2 + 41.926



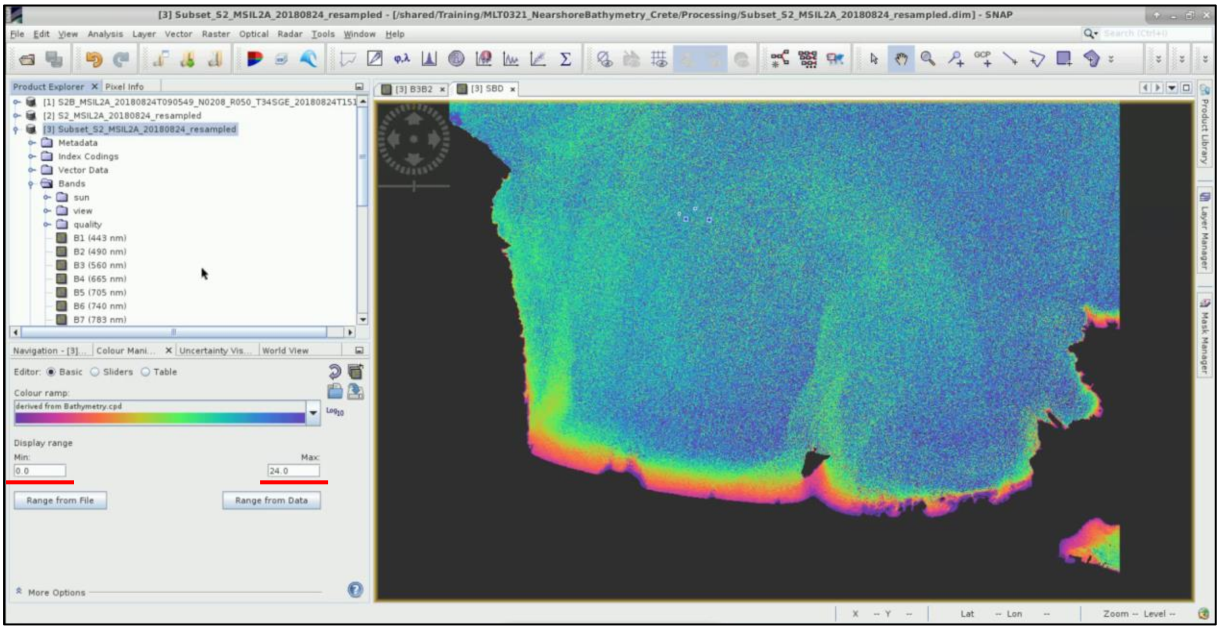


Click **OK**. Double click on the SDB band that had been created at the product on the left, to visualize it.

Go to the **Colour Manipulation** tab and load a colour palette. Click on the *Import colour palette from text file icon*, navigate to ***/shared/Training/COAS01_BathymetryDerivation_Greece/AuxData*** folder and select set the Bathymetry palette. Click **Open**. Then set the following data display range:

Min: 0.0

Max: 24.0



Go in the **Pixel Info** tab on the left, and the pixel information will be displayed while you move the mouse over the band image view.

Save the product.

We will now continue to the **Sen2Coral** Processor.

5.9 Sen2Coral

Sen2Coral plugin for SNAP toolbox is based on the exploitation of the Sentinel-2 mission for mapping (habitat, bathymetry, and water quality) and detection change for coral reef health assessment and monitoring. Sen2Coral includes the automatic processing for sun glint correction and Empirical Bathymetry Estimation:

5.9.1 Deglint Processor

Go to **Optical → Thematic Water Processing → Sen2Coral → Processing modules → Deglint Processor**.

In the **I/O Parameters** tab, select the opened image **Subset_S2_MSIL2A_20180824_resampled** in the Source Product field and leave the default output name for the target product name.

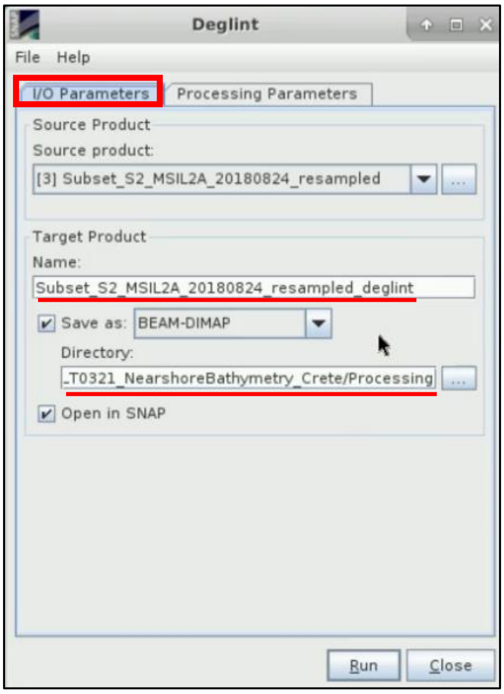
Define the directory as ***/shared/Training/COAS01_BathymetryDerivation_Greece/Processing***

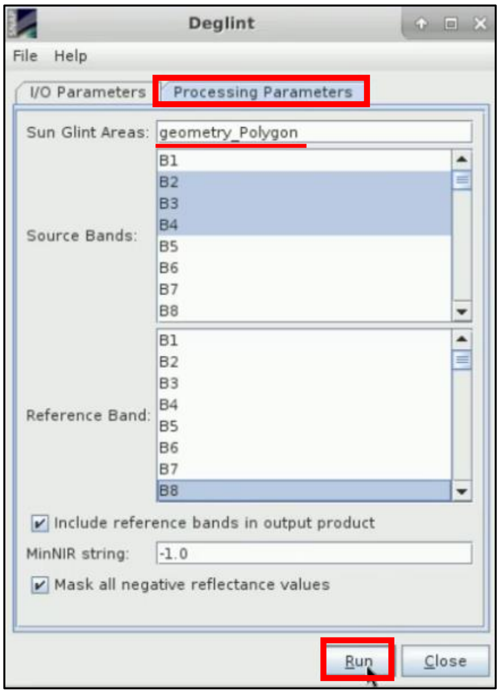
In the **Processing Parameters** tab set the following parameters:

Sun Glint Areas: geometry_Polygon (make sure you write it exactly like that, orelse, it will not be read)

Source Bands: B2, B3, B4

Reference Band: B8





Click **Run**.

5.9.2 Empirical Bathymetry Processor

The Empirical Bathymetry processor maps bathymetry based on regression of log band ratio (Lyzenga method). Ancillary data are required of known bathymetry.

Go to **Optical → Thematic Water Processing → Sen2Coral → Processing modules → EmpiricalBathymetry Processor**.

In the **I/O Parameters** tab, select the same image again in the Source Product field and <u>leave the default output name for the target product name</u>.

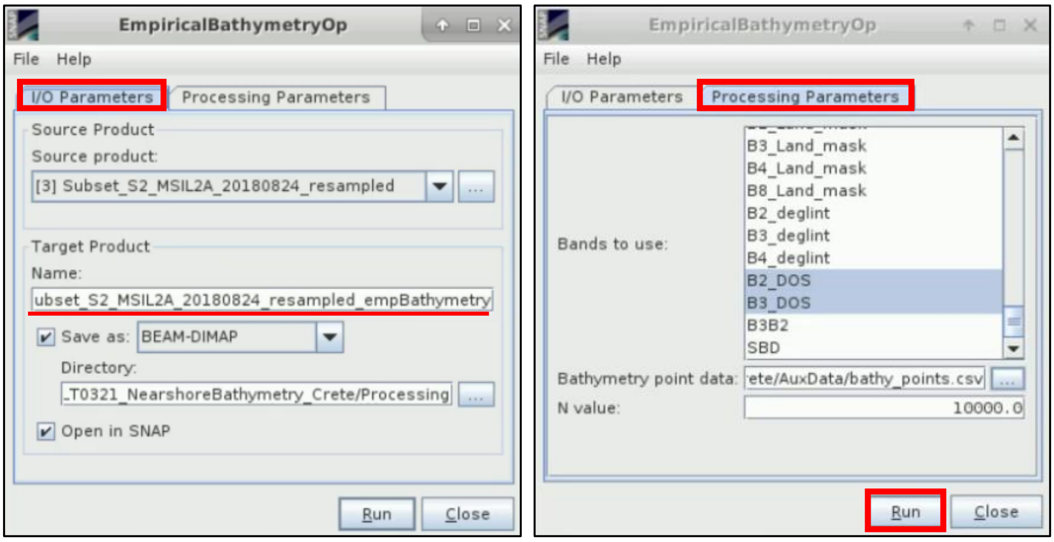
Define the directory: ***/shared/Training/COAS01_BathymetryDerivation_Greece/Processing***

In the **Processing Parameters** tab, the bands used to estimate the bathymetry have to be selected, as well as the full path to a file containing the set of bathymetry point data (latitude, longitude, depth). Set the following parameters:

Bands to be used: B2_DOS, B3_DOS

Bathymetry point data: ***/shared/Training/COAS01_BathymetryDerivation_Greece/AuxData/bathy_points.csv***

N value: 10000.0 (default)



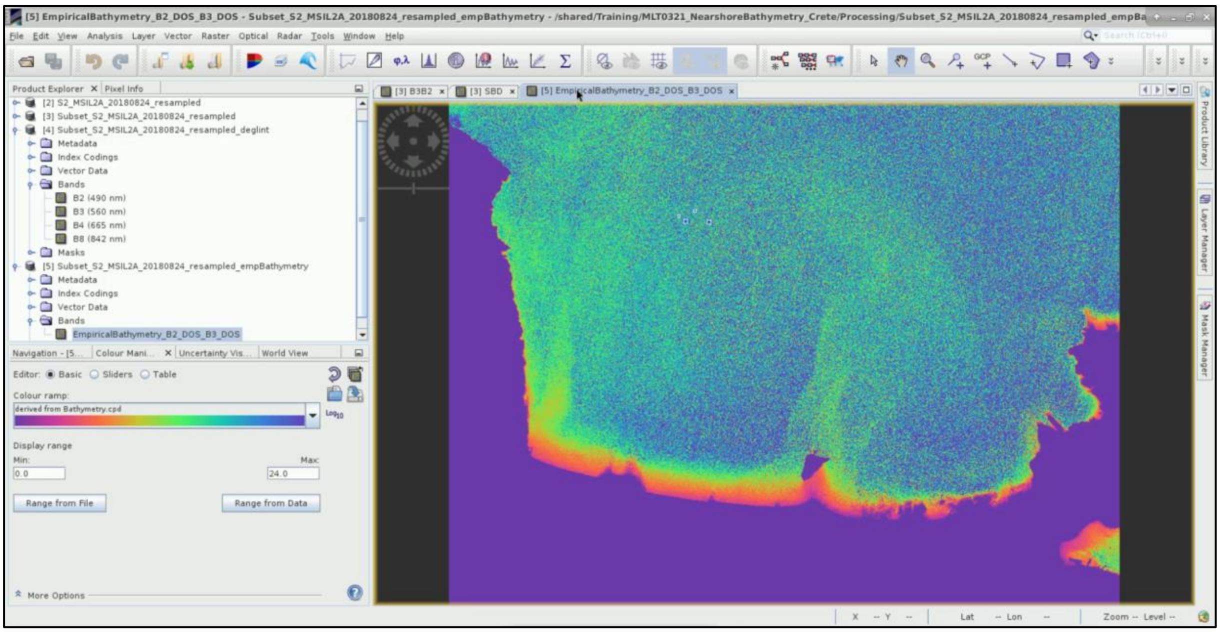
Click **Run**.

In the **Product Explorer Window,** the new product is created. Double click on its band to visualize it.

Go to the **Colour Manipulation** tab and load a colour palette. Click on the *Import colour palette from text file icon*, navigate to ***/shared/Training/COAS01_BathymetryDerivation_Greece/AuxData*** folder and select set the Bathymetry palette. Click **Open**. Then set the following data display range:

Min: 0.0

Max: 24.0



THANK YOU FOR FOLLOWING THE EXERCISE!

6 Extra steps

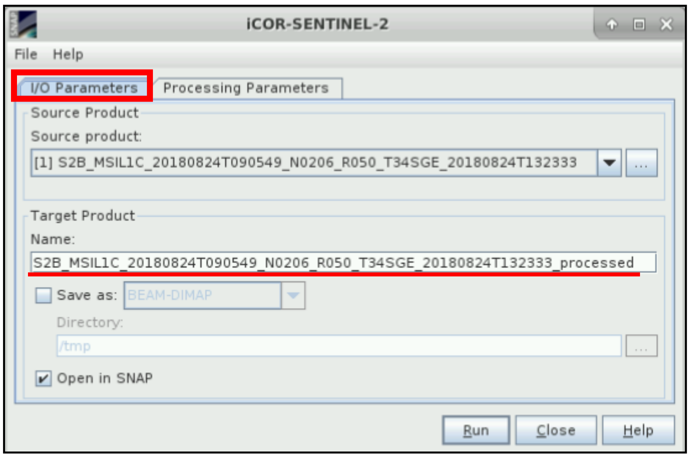
6.1 *Atmospheric Image Correction*

This step refers to the case that you use a Level-1C image instead of a Level-2A.

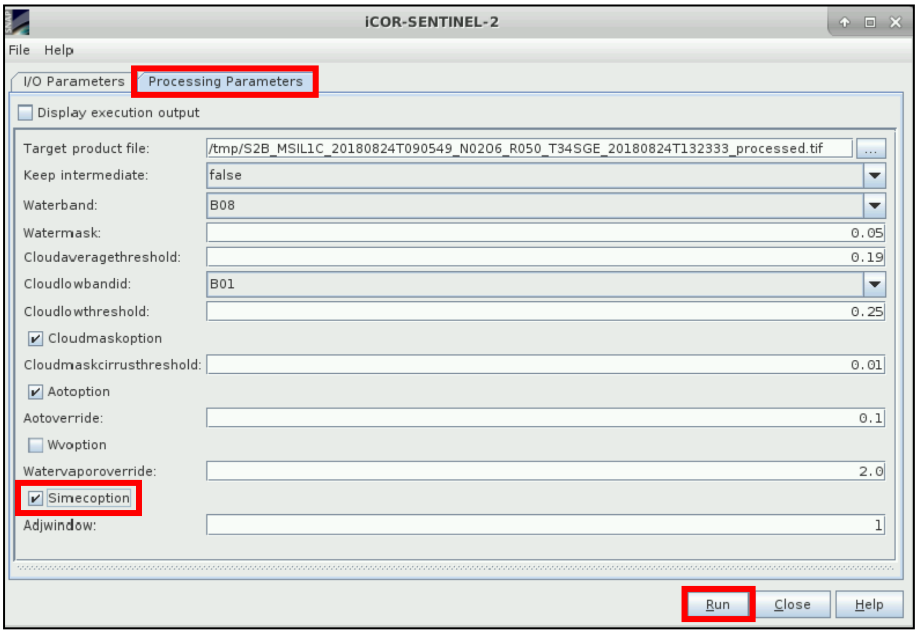
To atmospherically correct Sentinel-2 observation data over water bodies we will use iCOR Sentinel-2 plugin for SNAP toolbox. iCOR allows the corrections for atmospheric effects for coastal and transitional waters, while it corrects adjacency effects and improves the image quality at the water-land boundary. The iCOR algorithm (version 2.0) is an image-based correction which attempts to determine the aerosol optical thickness using the spectral variability of land pixels in the scene. You can find additional information in the existing literature (De Keukelaere et al., 2018). The generated output contains Bottom-Of-Atmospheric (BOA) reflectance, which are above water-leaving-reflectance. (**For more info about the installation of the plugin, click** here)

When the plugin is loaded in SNAP, the tool can be accessed through **Optical → iCOR → iCOR-S-2**.

In the **I/O Parameters** tab, select the opened image in the source product field and leave the default output name for the target product name.



In the **Processing Parameters** tab adapt the default parameters but also select the **Simecoption** to apply adjacency correction over water bodies.



Then click **Run**.

For Sentinel-2, three output files are created for each tile in the /tmp/ file:

- *_60M.tif – containing all spectral information at 60 m spatial resolution

- *_20M.tif – only bands with original spatial resolution of 20 m

- *_10M.tif – only bands with original spatial resolution of 10 m

<u>For the purpose of this exercise we will use the output product of 10-meter spatial resolution</u>. Open the product in SNAP and then expand the **Bands** folder. The product contains four bands which correspond accordingly to VIS bands B2, B3, B4, and NIR band B8.

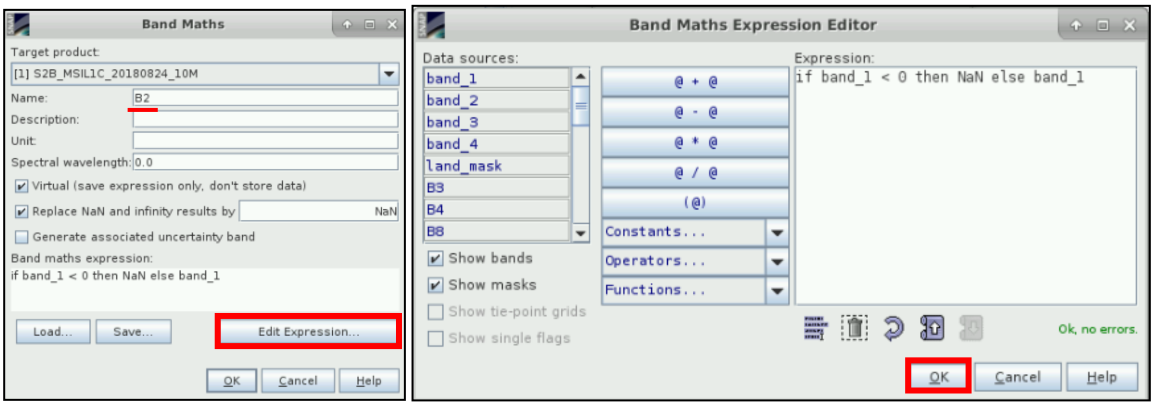
(0)1	B02	490	65	10
(1)2	B03	560	35	10
(2)3	B04	665	30	10
(3)4	B08	842	115	10

Save the product as **S2B_MSIL1C_20180824_10M** at the:
/shared/Training/COAS01_BathymetryDerivation_Greece/Processing folder and load it on SNAP.

During this process some negatives reflectance values were created in the open sea due to water conditions. In this case we have to exclude them from the bands. Right click on the product and select **Band Maths**. Set the parameters:

Name: B2

Band maths expression: if band_1 < 0 then NaN else band_1



Repeat the step for the rest of the bands, accordingly:

Name: B3

Band maths expression: if band_2 < 0 then NaN else band_2

Name: B4

Band maths expression: if band_3 < 0 then NaN else band_3

Name: B8

Band maths expression: if band_4 < 0 then NaN else band_4

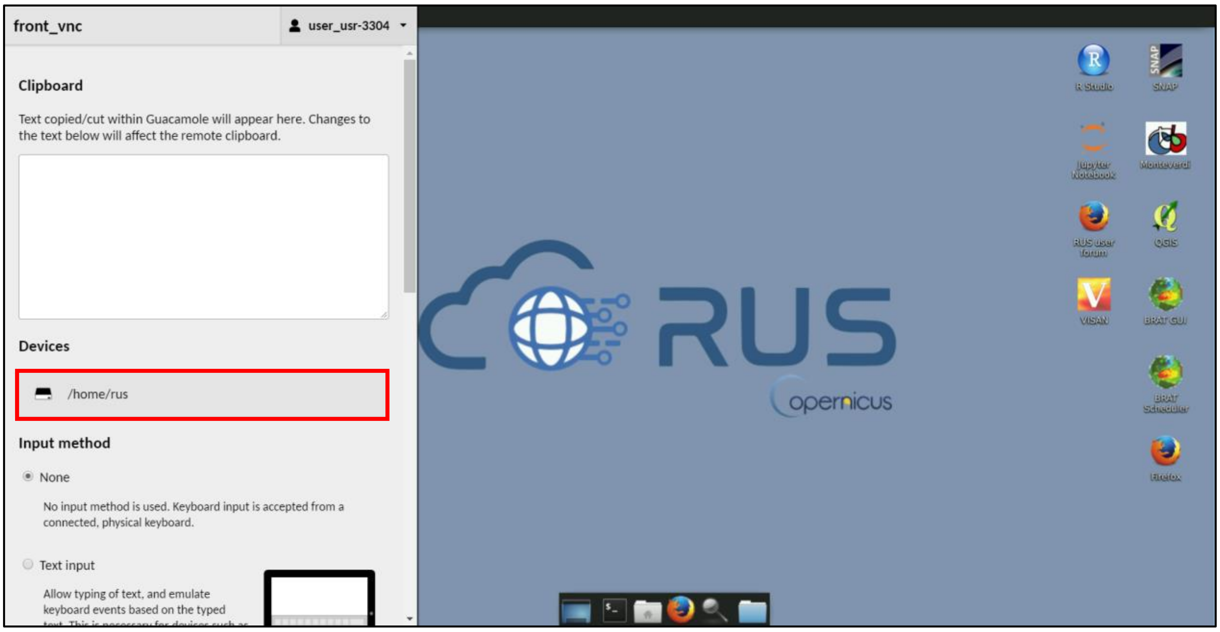
Finally, right click and **Save** the product. These will be the bands that you will use for the next steps.

Then you can continue with the exercise applying all steps from **Chapter 5.4** and on.

6.2 Downloading the outputs from the 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.



7 Further reading and resources

SENTINEL-2 MSI Introduction – https://sentinel.esa.int/web/sentinel/user-guides/sentinel-2-msi/

ESA Sentinel Online – https://sentinel.esa.int/web/sentinel/missions/sentinel-2

Science Toolbox Exploitation Platform (STEP) – http://step.esa.int/main/toolboxes/sentinel-2-toolbox/

iCOR plugin for SNAP for OLCI data – https://cdn2.hubspot.net/hubfs/2834550/marketing/MAILS/iCOR/iCORpluginUserManual_OLCI_v1.0.pdf

8 References

1. Chavez, P., "An improved Dark Object Subtraction technique for atmospheric scattering correction of multispectral data," Remote Sensing of Environment, 24, 459-479 (1988 Small D. and Schubert A., Guide to ASAR Geocoding, RSL-ASAR-GC-AD, Issue 1.0, March 2008.
2. De Keukelaere, L., Sterckx, S., Adriaensen, S., Knaeps, E., Reusen, I., Giardino, C., Bresciani, M., Hunter, P., Neil, C., Van der Zande, D., Vaiciute, D., 2018. Atmospheric correction of Landsat-8/OLI and Sentinel-2/MSI data using iCOR algorithm: validation for coastal and inland waters. Eur. J. Remote. Sens. 51, 525-542. https://doi.org/10.1080/22797254.2018.1457937.

3. Drakopoulou P., Kapsimalis V., Parcharidis Is.& Pavlopoulos K. Retrieval of nearshore bathymetry in the Gulf of Chania, NW Crete, Greece, from WorldWiew-2 multispectral imagery. Proceedings of SPIE - The International Society for Optical Engineering, 10773, art. no. 107730W. DOI: 10.1117/12.2326189.
4. Hedley, J. D., Harborne, A. R. and Mumby, P. J., "Simple and robust removal of sun glint for mapping shallowwater benthos," Int. Journal of Remote Sensing, 26(10), 2107-2112 (2005).
5. Kay S., Hedley J. D. and S. Lavender. Sun Glint Correction of High and Low Spatial Resolution Images of Aquatic Scenes: a Review of Methods for Visible and Near-Infrared Wavelengths. Remote Sens. 2009, 1, 697-730; doi:10.3390/rs1040697.
6. Lyzenga, D. R. (1978). passive remote sensing techniques for mapping water depth and bottom features. Applied Optics, 17(3), 379–383.
7. Lyzenga, D., Malinas, N. and Tanis, F., "Multispectral bathymetry using a simple physically based algorithm," IEEE Transactions on Geoscience and Remote Sensing 44(8), 2251-2259 (2006).
8. Stumpf, R. P., Holderied, K., & Sinclair, M. (2003). Determination of water depth with high-resolution satellite imagery over variable bottom types. Limnol. Oceanogr., 48, 547–556.

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