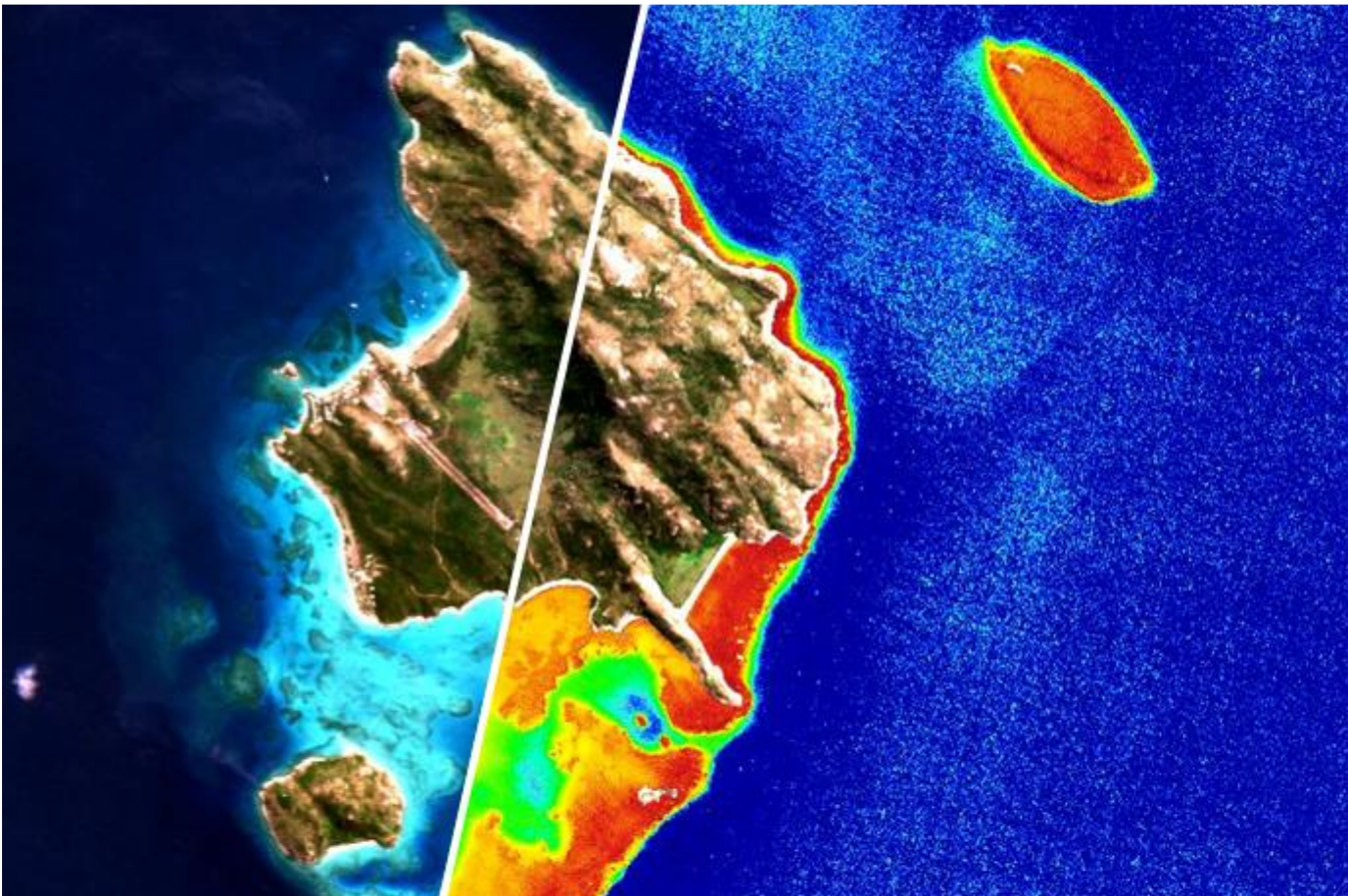TRAINING KIT – OCEA05

SEN2CORAL TOOLBOX FOR CORAL REEF MONITORING
GREAT BARRIER REEF, AUSTRALIA

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-coperenicus.eu

Cover images produced by RUS Copernicus

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1 Introduction

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

BEFORE AND AFTER Healthy coral are full of colour, like the fire coral seen on the left. But stressors, including overly warm ocean water, cause symbiotic algae to abandon coral tissues, bleaching them (right). Credits: sciencenews.org (XL CATLIN SEAVIEW SURVEY)

The Great Barrier Reef (GBR) is the largest coral reef ecosystem on Earth. It stretches for thousands of kilometres along the coast of eastern Australia. The reef represents an immense natural and economic value and has been declared UNESCO World Heritage site in 1981.

In recent decades, there has been a growing concern regarding the deterioration of the GBR ecosystem health. It has been reported that between 1985 and 2010 51% of the coral in the central and southern parts of the GBR has died as a result of combined effects of climate change-related causes such as severe heat waves, cyclones and invasive species outbreaks.

Sentinel-2 allows to monitor the majority of the world's coral reefs with increased temporal and spatial resolution. Sen2Coral toolbox available in SNAP has been specifically developed and validated for this purpose.

2 Training

Approximate duration of this training session is two hours.

The Training Code for this tutorial is OCEA05. 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

• A cloud-free Sentinel-2A Level 1C tile (Tile ID: T55LCD) acquired on July 21, 2016 [downloadable @ https://scihub.copernicus.eu/]

 S2A_MSIL1C_20160721T004002_N0204_R059_T55LCD_20160721T003959

• Bathymetry training and validation datasets provided by John Hedley and derived from the 20m DEM/DDM for Lizard island:

 Leon, Javier X; Phinn, Stuart R; Hamylton, Sarah; Saunders, Megan I (2012): *A 20 m spatial resolution seamless multisource Digital Elevation/Depth Model for Lizard Island, northern Great Barrier Reef*.

2.2 Software in RUS environment

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

3 Register to RUS Copernicus

To repeat the exercise using a RUS Copernicus Virtual Machine (VM), you will first have to register as a RUS user. For that, go to the RUS Copernicus website (www.rus-copernicus.eu) and click on *Login/Register* in the upper right corner.
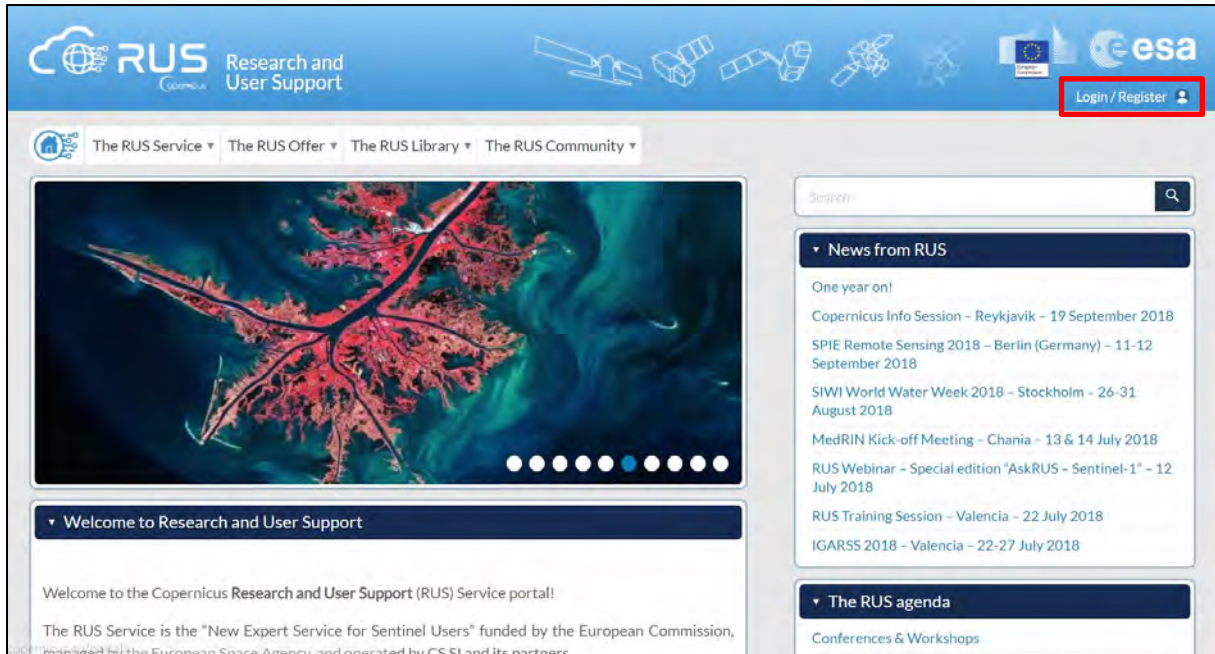
Select the option *Create my Copernicus SSO account* and then fill in ALL the fields on the **Copernicus Users' Single Sign On Registration**. Click *Register*.
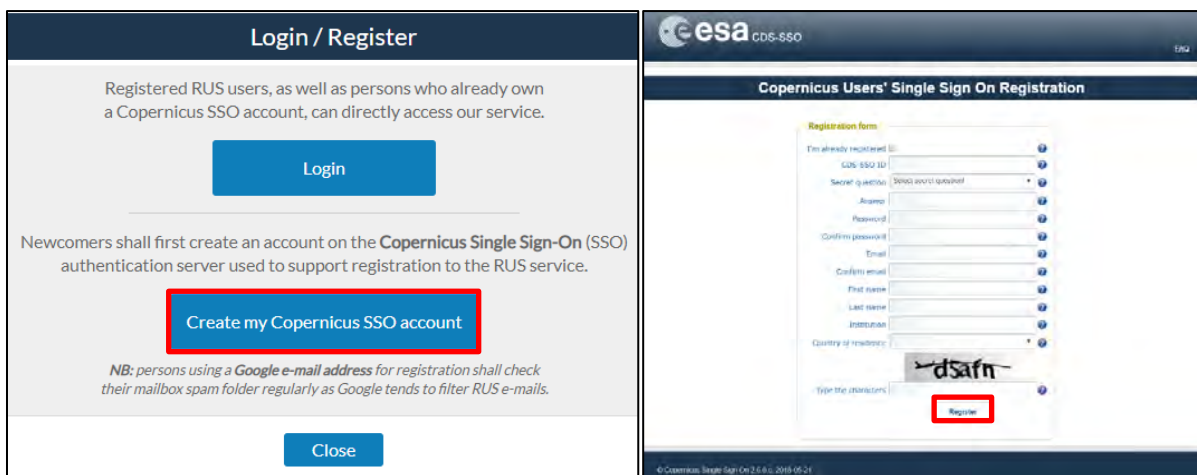
Within a few minutes you will receive an e-mail with activation link. Follow the instructions in the e-mail to activate your account.

You can now return to https://rus-copernicus.eu/, click on *Login/Register*, choose *Login* and enter your chosen credentials.
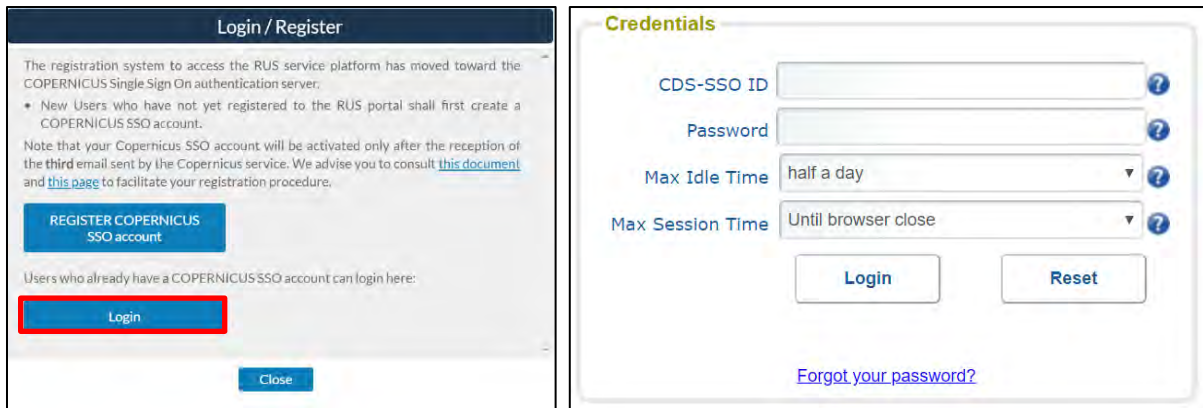
Upon your first login you will need to enter some details. You must fill all the fields.
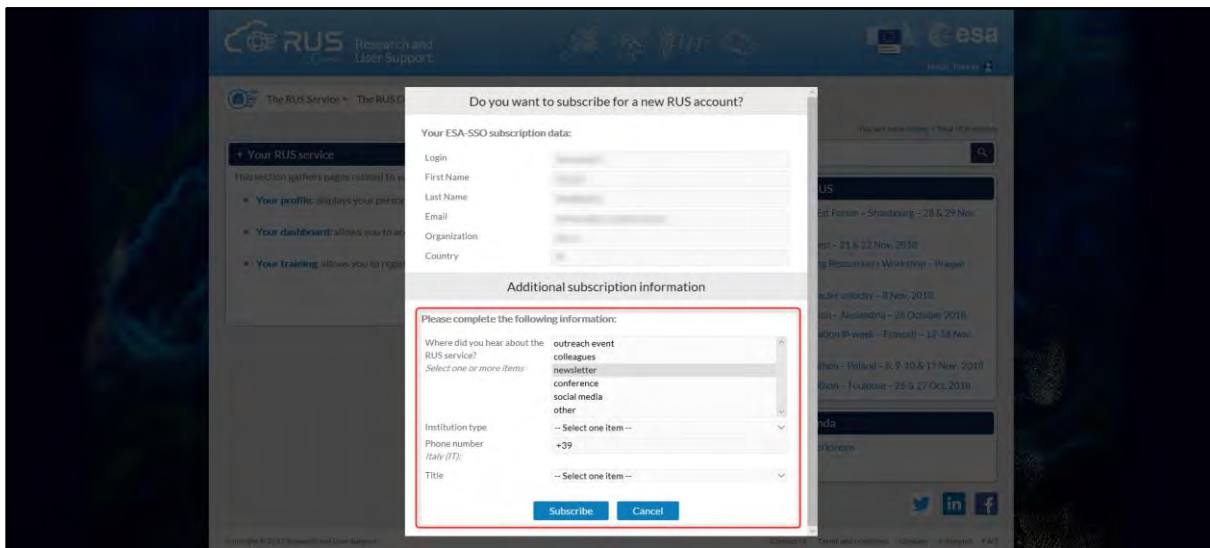
4   Request a RUS Copernicus Virtual Machine

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

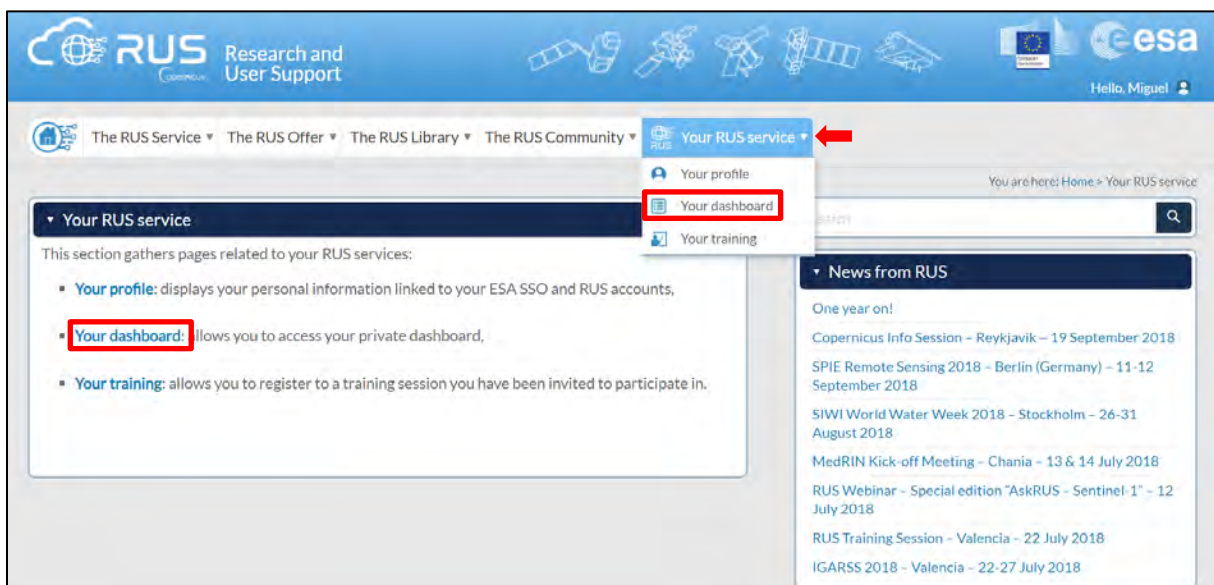Click on ***Request a new User Service*** to request your RUS Virtual Machine. Complete the form so that the appropriate cloud environment can be assigned according to your needs.
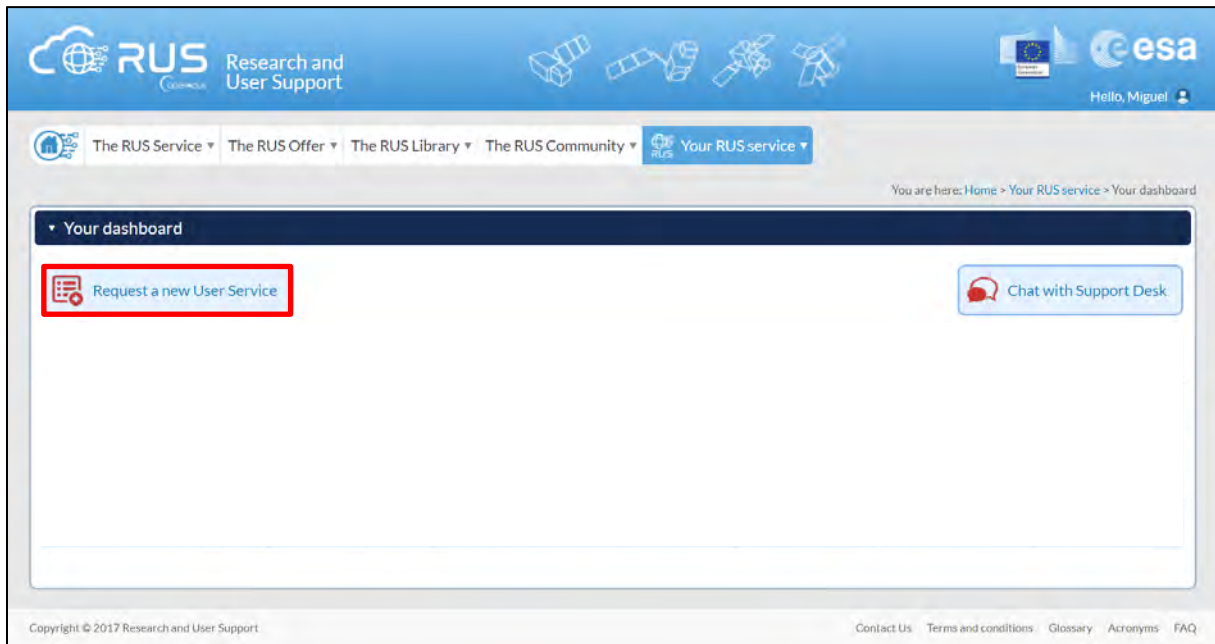
If you want to repeat this tutorial (or any previous one) select the one(s) of your interest in the appropriate field.

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

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

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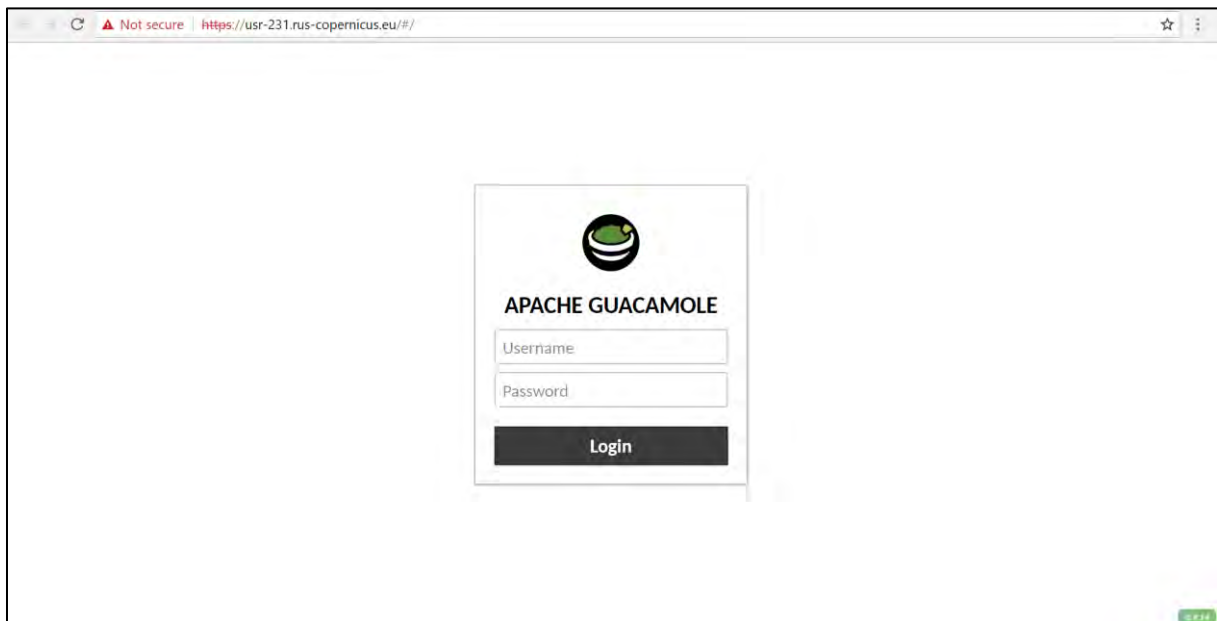
This is the remote desktop of your Virtual Machine.

5   Sen2Coral

The Sen2Coral toolbox has been developed in the scope of the ESA SEON Programme Sen2Coral the objective of which is the is the scientific exploitation and validation of Sentinel-2 imagery for coral reef mapping (habitat, bathymetry and water quality) and change monitoring. *(Sen2coral User Guide)*

The toolbox contains six modules developed to support the four main processing chains designed by the Sen2Coral project.

	Pre-processing
	Sen2Coral modules
	Further processing
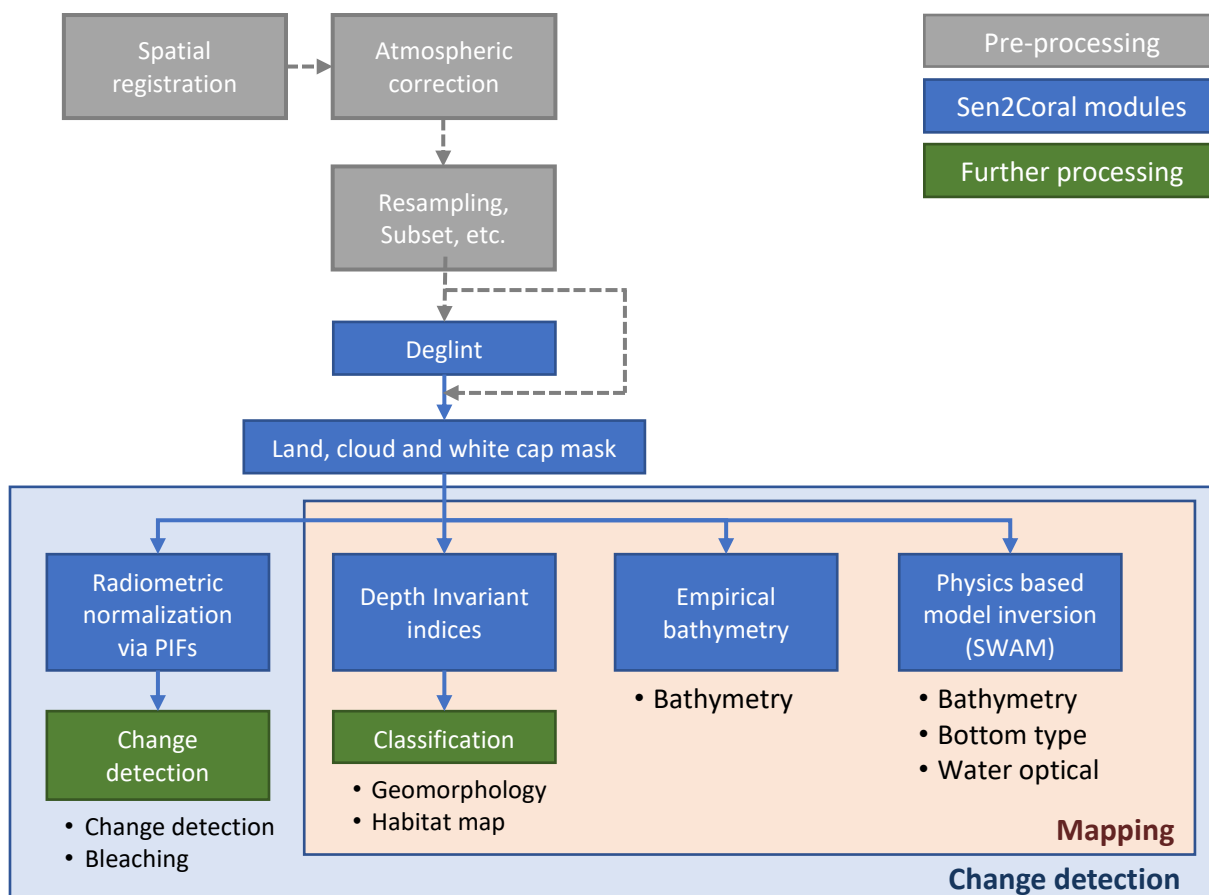
We will explore each of the available modules and their purpose, with the exception of the Physics based model inversion (SWAM).

6   Step by step

6.1   Data download – ESA SciHUB

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

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

Go to "**Open HUB**", if you do not have an account please register 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**".
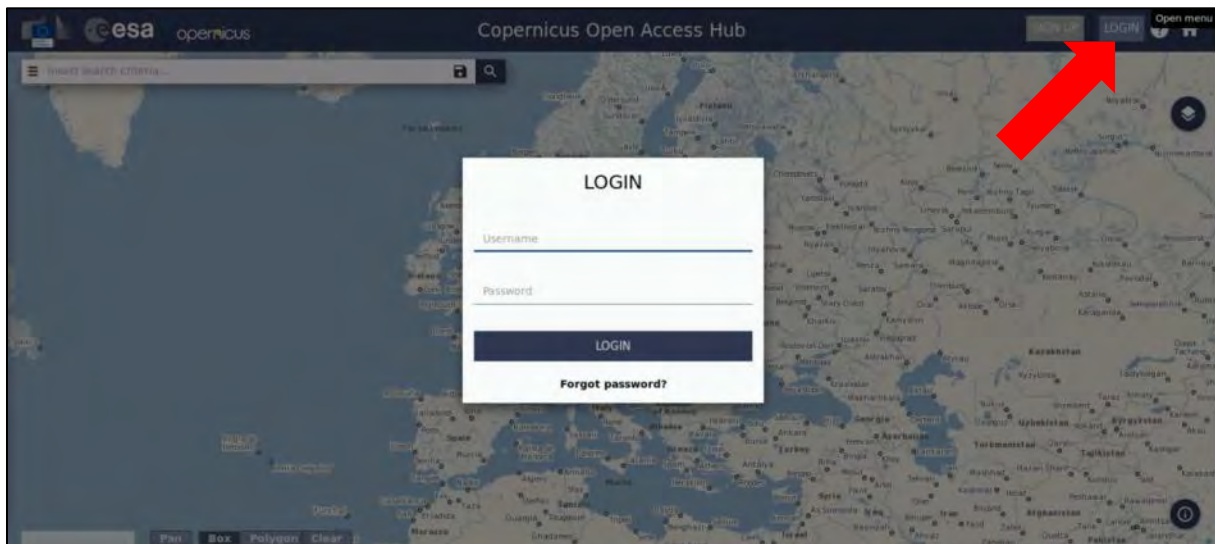
Switch the rectangle-drawing mode to pan mode by clicking on the "**Pan**" icon in the lower left corner of the map (**Green arrow**) and navigate over the Great Barrier reef (**blue rectangle**).
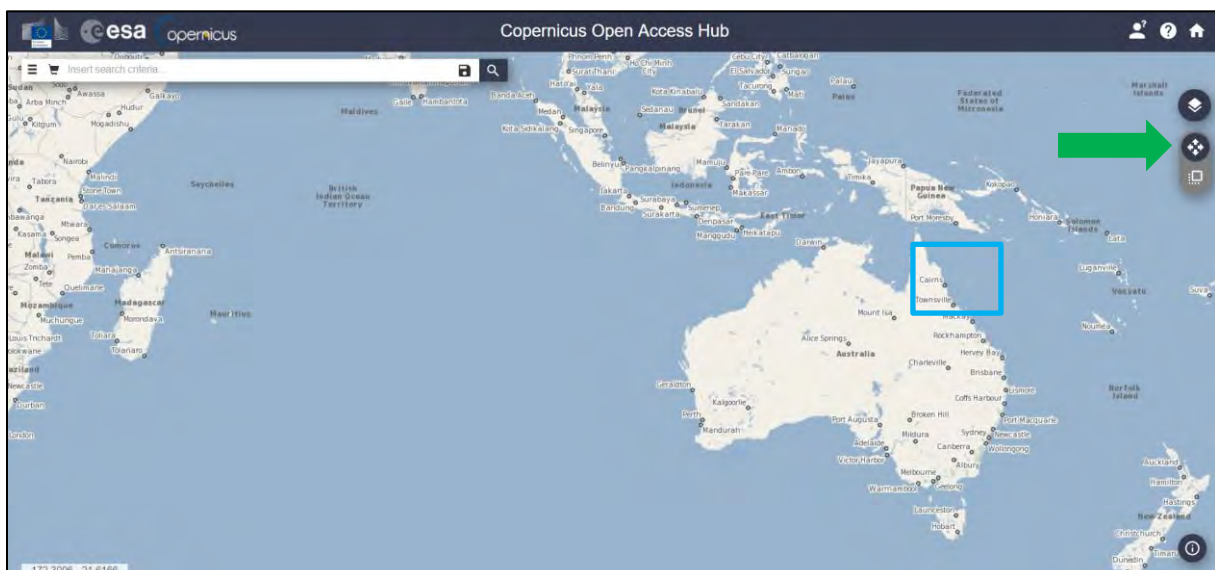
Switch to drawing mode and draw a search rectangle approximately as indicated below. Open the search menu (red arrow) and specify the following parameters:

Sensing period: From 2016/07/21 to 2016/07/21
Check Mission: Sentinel-2
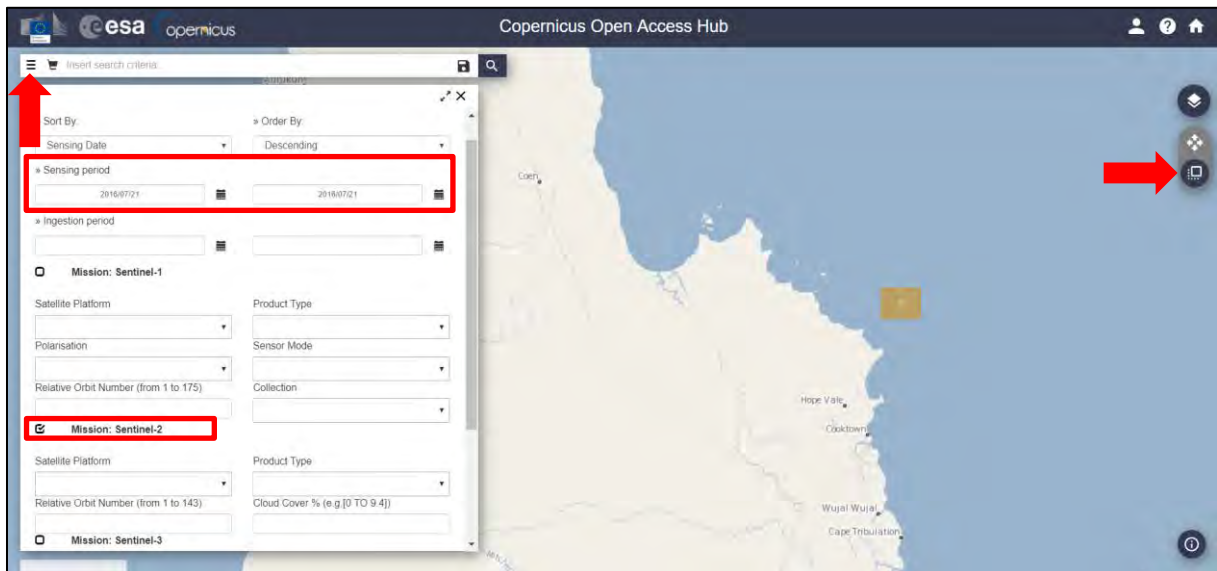
Press "**Search**" (red arrow below). In our case, the search returns a single result depending on the exact search area defined. Download the scene:

*S2A_MSIL1C_**20160721T004002**_N0204_R059_T55LCD_20160721T003959*

Data will be downloaded to /home/rus/Downloads as ZIP archive. Move the archives to ***/shared/Training/OCEA05_Sen2Coral_GBR_TutorialKit/Original***.
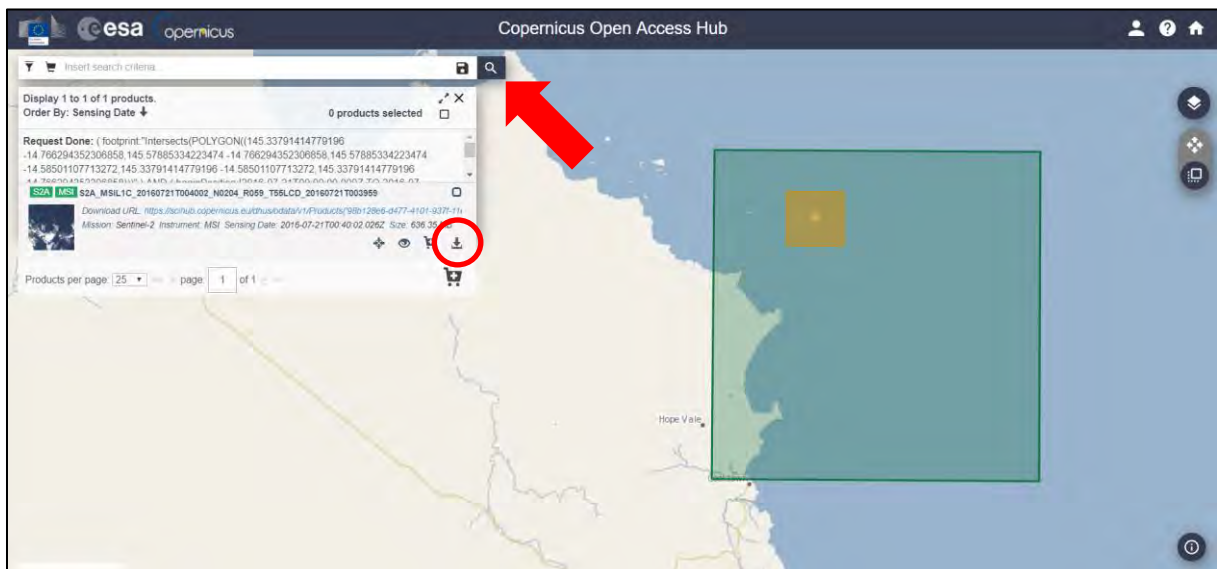
6.2 Atmospheric correction

Solar radiation reflected by the Earth's surface to satellite sensors is affected by its interaction with the atmosphere. The objective of applying an atmospheric correction is to determine true surface (Bottom-Of-Atmosphere, BOA) reflectance values from the Top-Of-Atmosphere (TOA) reflectance

values, by removing atmospheric effects. (See 🚩 NOTE 1) Atmospheric correction is especially important in cases where multi-temporal images are compared and analysed.

NOTE 1: The radiance reaching the sensor is a result of following components:

1. Radiation from the sun and, scattered into the field of view of the sensor by the atmosphere without reaching the surface.

2. Direct radiation that goes through the atmosphere without being absorbed or scattered, reaches the sensor after being reflected by the target pixel.

3. Radiation scattered by the atmosphere into the target pixel and reflected back towards the sensor.

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

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

7. So-called trapping effect and it is a part of the radiation reflected from the surface into the air column above the surface being scattered and ultimately reaches the sensor.
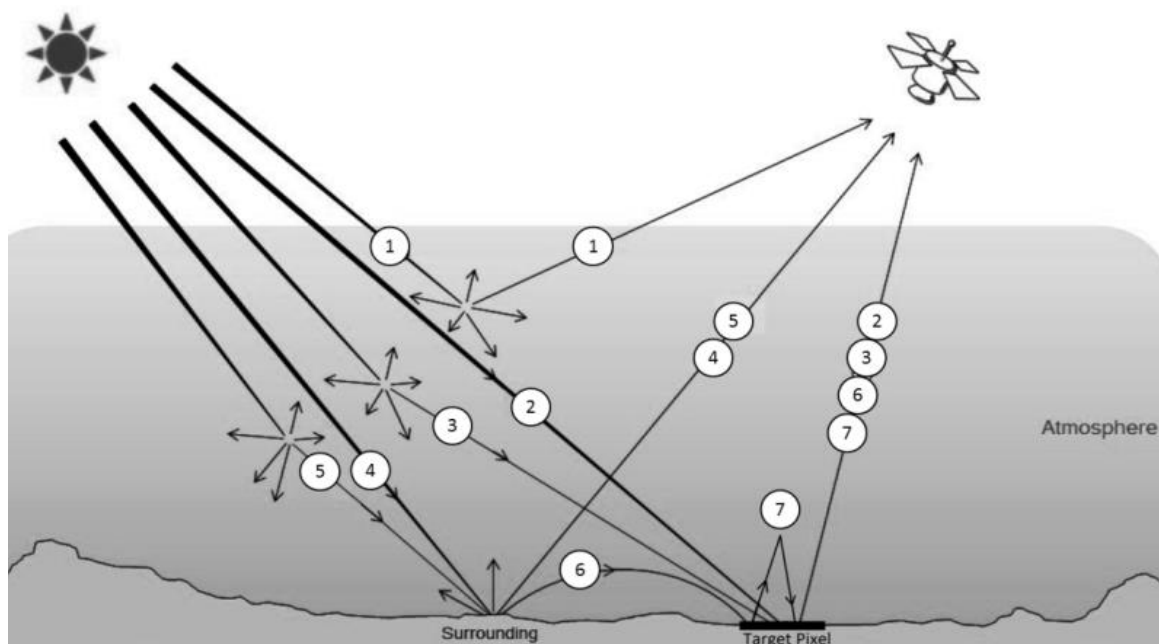
Credits: Mousivand et al. (2015)

In this tutorial, we are using the Sentinel-2 Level-1C data as Level 2A data are not yet available for our study area and acquisition date (July 2016). Level 2A have been systematically produced for newly acquired products over Europe since the spring of 2017, the coverage has been increasing through 2018 to reach global coverage in the beginning of 2019.

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

The Sen2Cor must be applied to data before any other processing steps. First, using a file manager go to **/shared/Training/OCEA05_Sen2Coral_GBR_TutorialKit/Original**

and unzip the zipped product archive. Right-click on the product and select **Extract Here**.

Sen2cor can be executed both via command line and via the graphical interface in SNAP. Here, we will use the command line. Inside the Original folder right click and select **Open Terminal Here**.
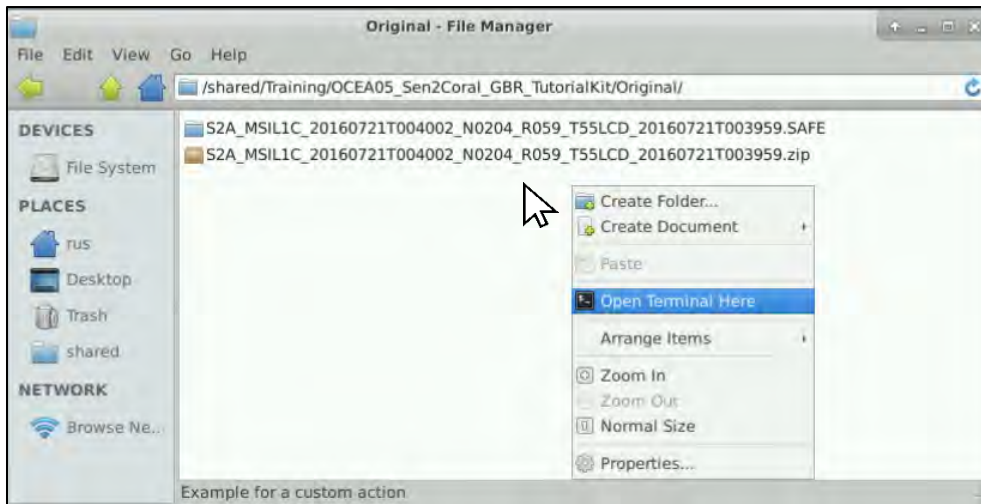
In the command line window, type:

```
L2A_Process ./S2A_MSIL1C_20160721T004002_N0204_R059_T55LCD_20160721T003959.SAFE
--resolution=10
```

Then press **ENTER**.
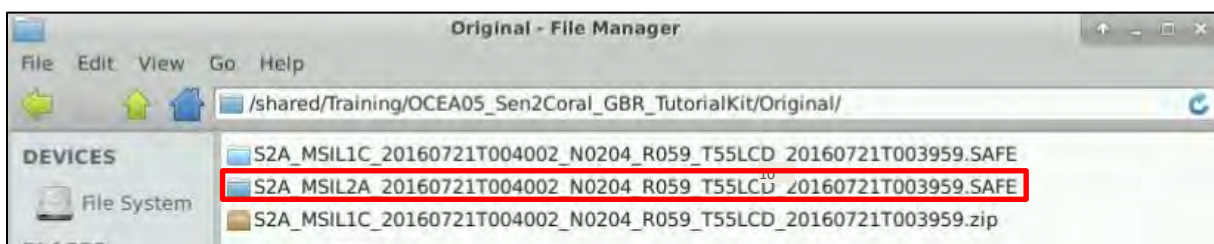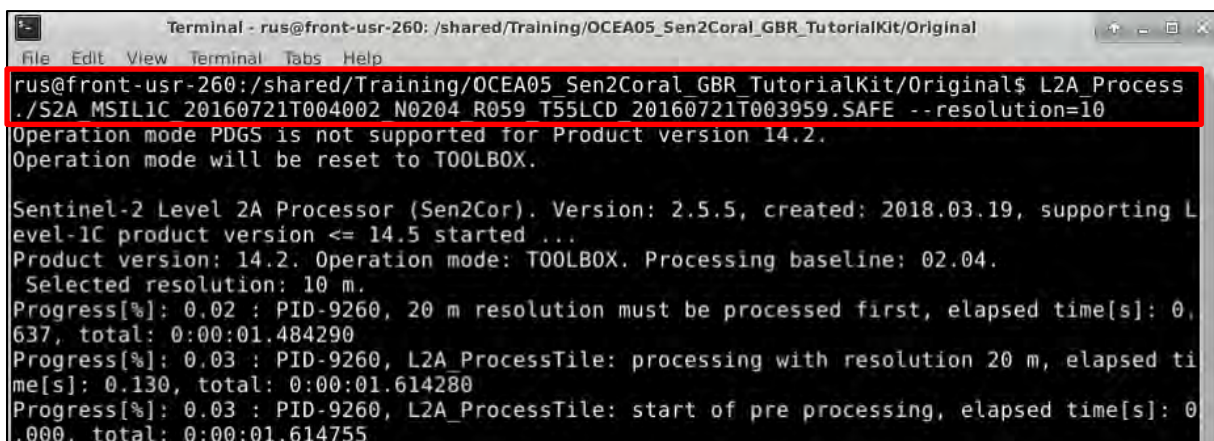
The process creates three new Level 2-A products in the "*.SAFE*" format in the original folder:
/shared/Training/OCEA05_Sen2Coral_GBR_TutorialKit/Original

6.3   SNAP – open and explore data

Launch SNAP (icon on desktop 📷). When the SNAP window opens click **Open product** 📁 and
navigate to: ***/shared/Training/OCEA05_Sen2Coral_GBR_TutorialKit/Original***

Then open the Level-2A product folder and open the ***MTD_MSIL2A.xml***

In the **Product Explorer** window, right-click the Level-2A product from 2018 and click **Open RGB image window,** a new window will open. From the drop-down menu select:

Profile: Sentinel 2 MSI Natural Colors
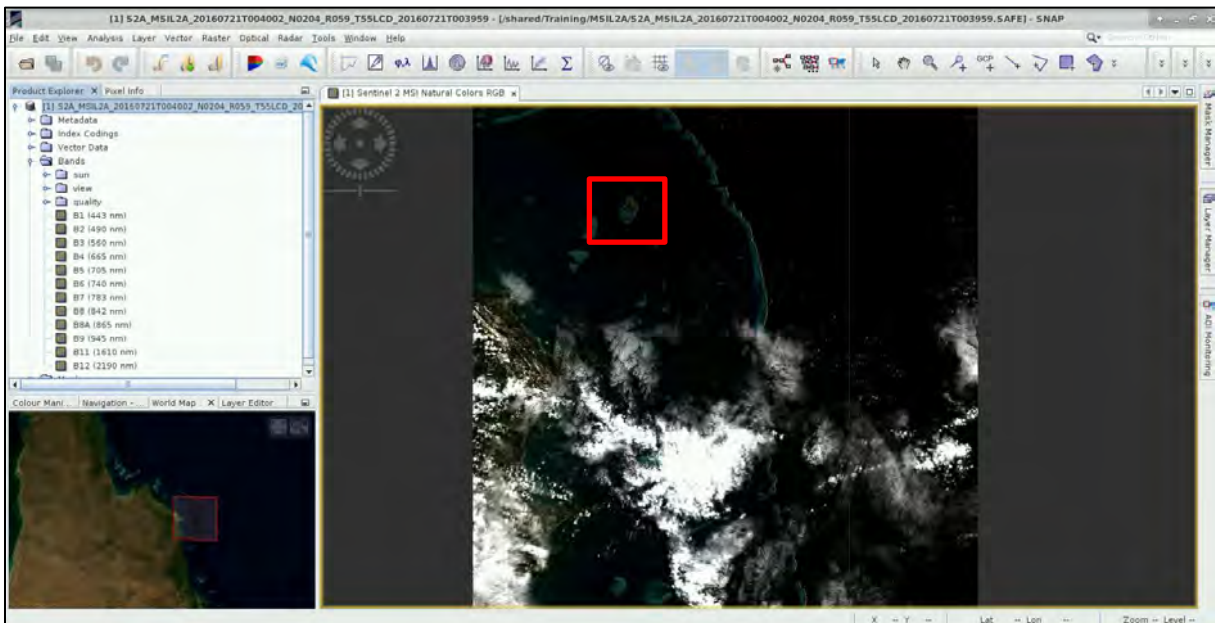
Now, let's investigate the **cloud cover over our area of interest**. Zoom in to the area of interest as indicated above. We can see that our area of interest is cloudless.
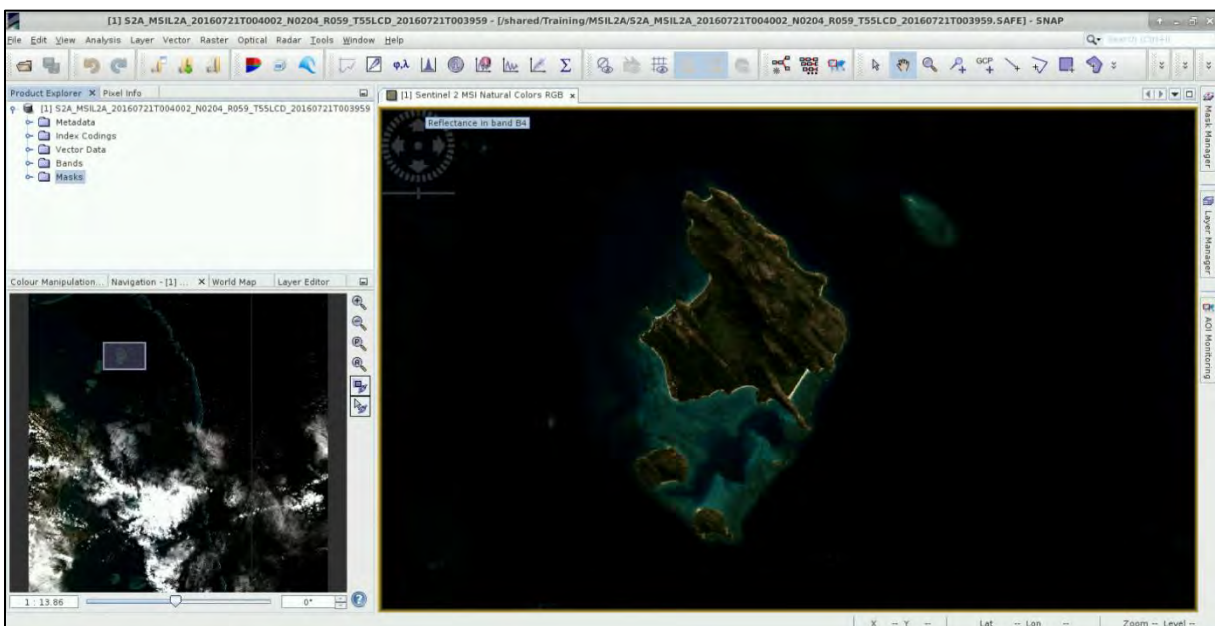
6.4   *Resample*

The 13 bands in Sentinel-2 products do not all have same resolution (therefore size, see 🔲 NOTE 2). While the *Sen2Coral* toolbox supports the products with bands of different sizes, many other operators such as *Subset*, do not. Therefore, we need to resample the bands to equal resolution first.

Go to **Raster → Geometric Operations → Resampling** (See 🔲 NOTE 3).

Do not change anything in the **I/O Parameters** tab.

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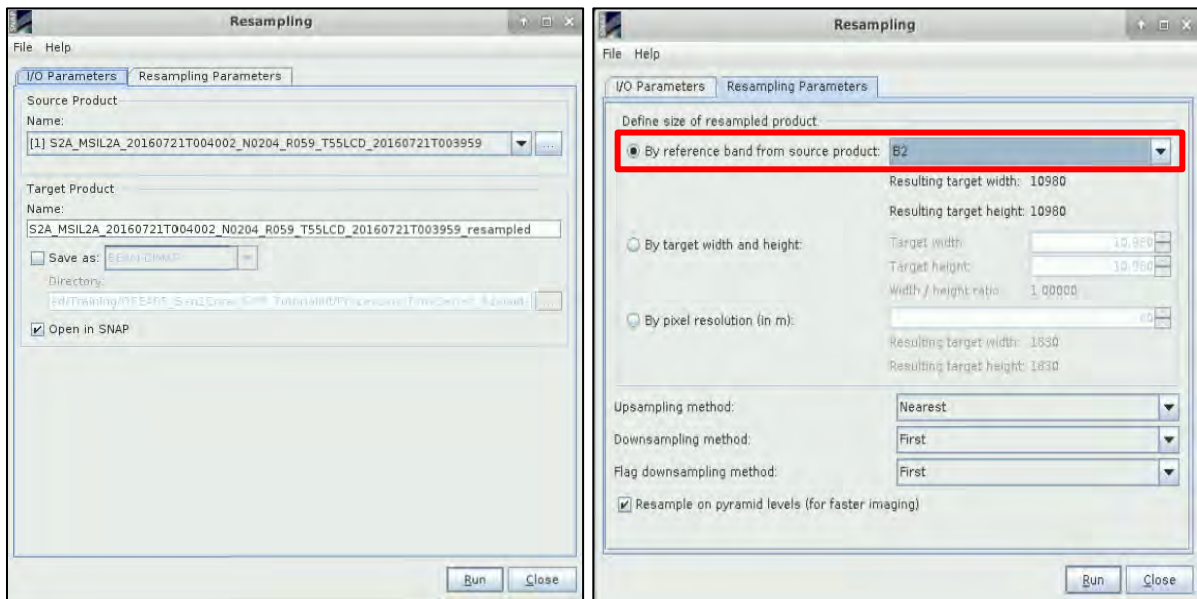
Click **Run**.

After the process is completed, if a window appears, click **Yes.**

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

NOTE 3: The resampling product appears in the Product Explorer window, but it is not physically saved. Therefore, it will be lost if you close it or if you close the source product.

A new product [2] appeared in the **Product Explorer** tab. Now we will have a look at the product. Close all the views we have open and expand the product structure by clicking the **+** sign on the left of the product name, then expand the **Band** folder and double click **B8 (842nm) - (NIR)**.

6.5   Subset

In the next step, we will subset the image to our area of interest. Click on the resampled product in the **Product Explorer** tab, to highlight it. Then go to **Raster → Subset** and in the **Spatial Subset** tab, set **Pixel coordinates** to:
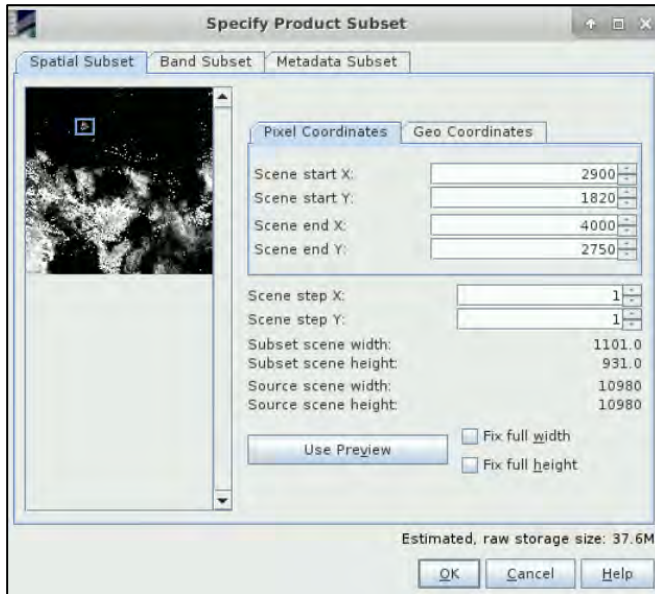
Scene start X: 2900

Scene start Y: 1820

Scene end X: 4000

Scene end Y: 2750

Keep the other Subset tabs as by default. Click **OK**.

A new product will appear in the **Product Explorer** tab [3]. Note that the resampling and the subset products are virtual products only and are not physically saved.

Right-click the product [3] and click **Open RGB image window** and from the dropdown menu select **"Sentinel 2 MSI Natural Colors"**. Click **OK**.

Then go to the **Colour Manipulation** tab and click on ↻ "Reset to defaults".
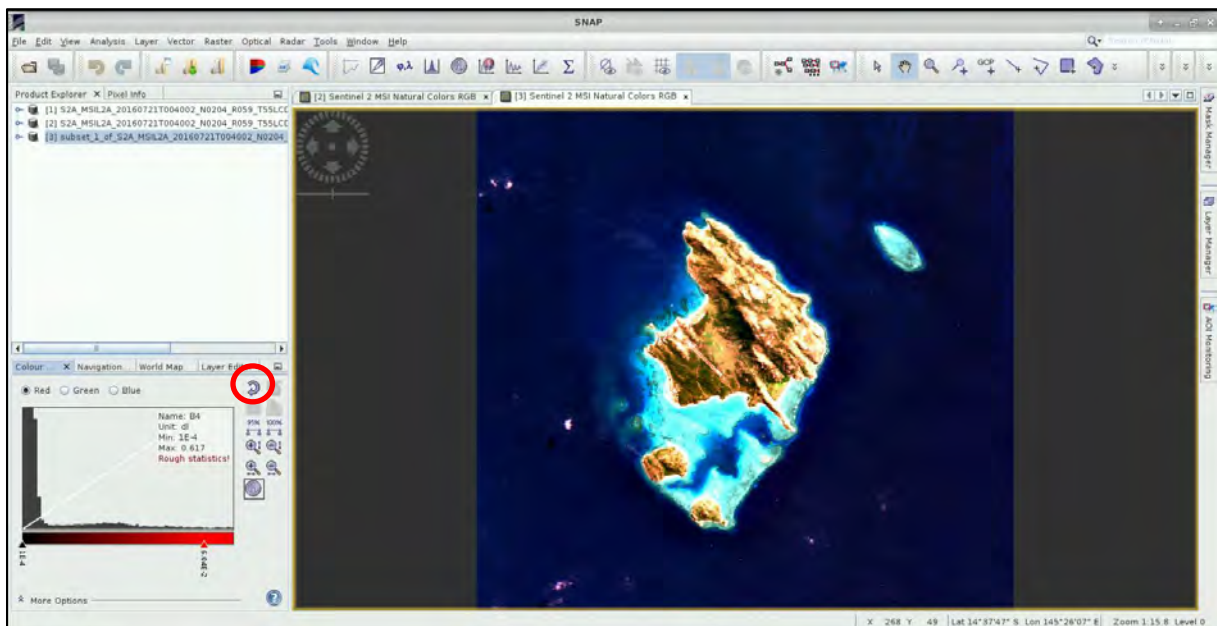
6.6 Deglint

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 (sun glint) in the direction of the satellite. The viewing geometry of Sentinel-2 satellite makes it vulnerable to sun glint contamination. In the presence of sun glint, we need to apply a glint removal algorithm in order to be able to observe the sea floor for the purpose of habitat mapping or bathymetry derivation.

There are several available sun glint removal methods for high resolution images and coastal applications. The algorithm implemented as part of the Sen2Coral toolbox was developed by Hedley et al., (2005). (See 📒 NOTE 4) While the algorithm gives reasonably good results, it is recommended to use images with minimal glint.

📒 NOTE 4: 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.
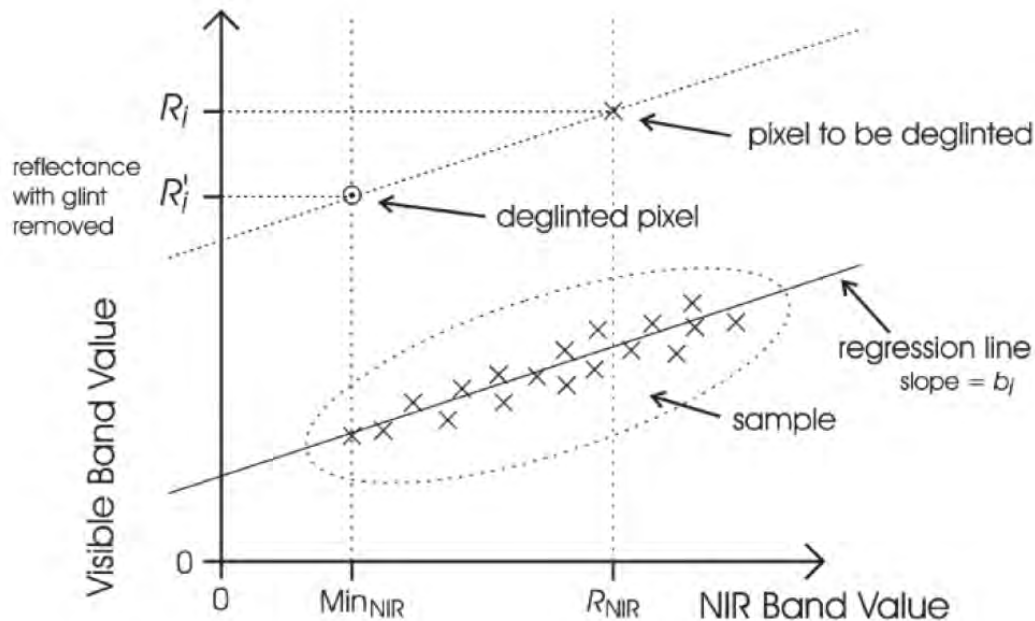
To deglint a visible wavelength band, a regression is performed between the NIR brightness and the brightness in the visible band using a sample set of pixels, which would be homogeneous if not for the presence of sun glint (e.g. deep water). For other pixels, the slope of the regression is then used 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. *(SNAP Help)*

First, we need to use the polygon drawing tool to create ROI polygons over areas of the image containing sun glint. These should be over deep-water areas where no bottom reflectance is expected and all NIR reflectance is attributed to sun glint.

In the **Product Explorer** tab, double click on the *B8* (NIR band) to open it in view. Then in the **Colour Manipulation** tab, drag the white slider to value of *3E-2*. Now we see some brighter values over the deep-water areas.
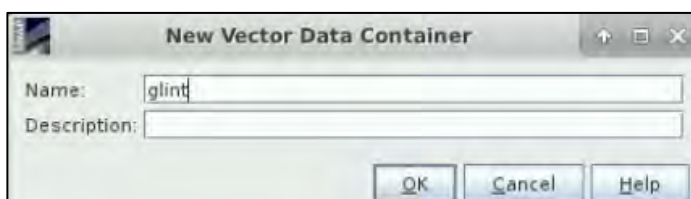
Then in the **Product Explorer** tab, select the subset product **[3]** and go to **Vector → New Vector Data Container**. In the dialog that opens, set the name to *"glint"* and click **OK**.

Finally, click on the ■ **Rectangle drawing tool** and draw polygons over the deep-water sun glint areas.
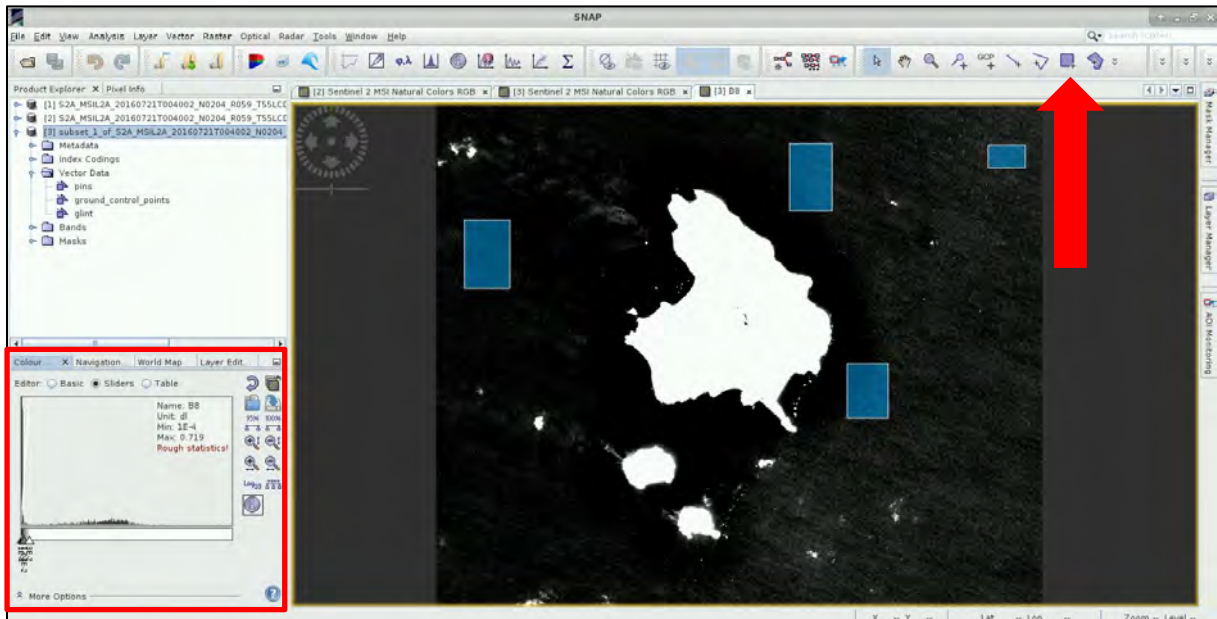
Then go to **Optical → Thematic Water Processing → Sen2Coral → Processing Modules → Deglint Processor**.

In the **I/O Parameters** tab, set the subset product [3] as **Source Product**. We can also change the **Target Product name** to something shorter and save the product to:
/shared/Training/OCEA05_Sen2Coral_GBR_TutorialKit/Processing

In the **Processing Parameters** tab, set: **Sun Glint areas:** "glint"
                                                Source Bands: B2, B3, B4, B5
                                                Reference Band: B8
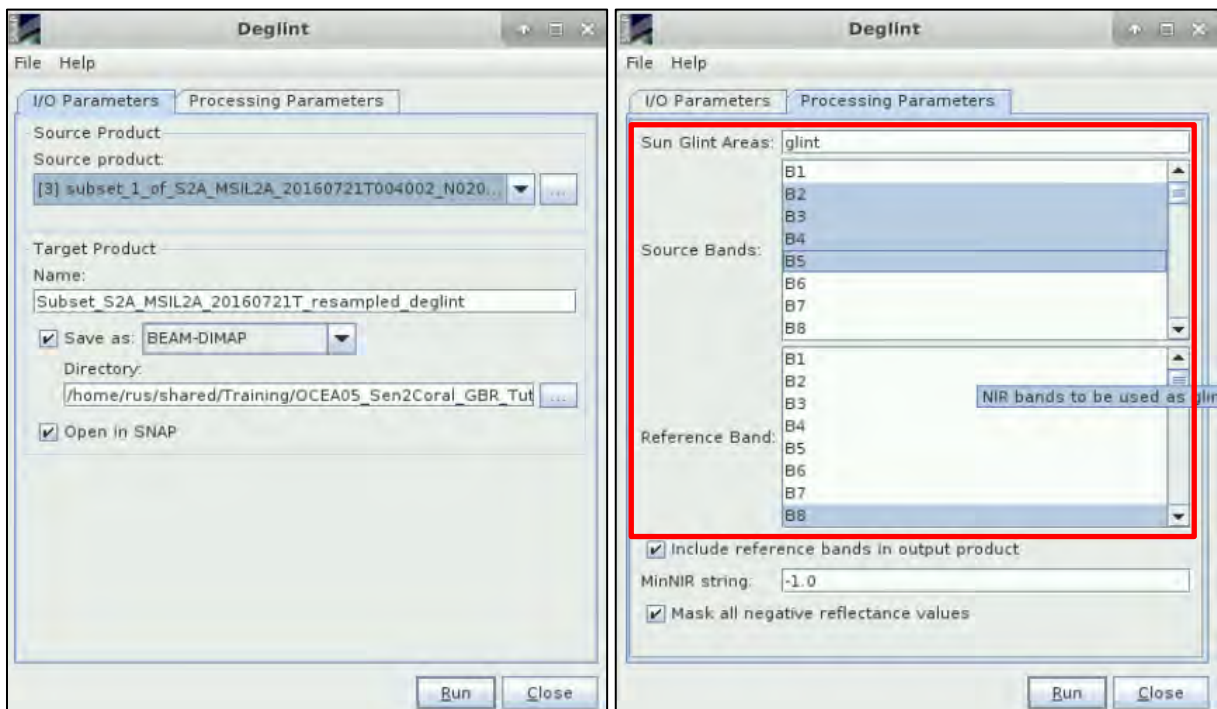
Leave other settings as default and click **Run**. When the processing is finished, a new product [4] will appear in the **Product Explorer** tab. Right-click on the product and open RGB view.
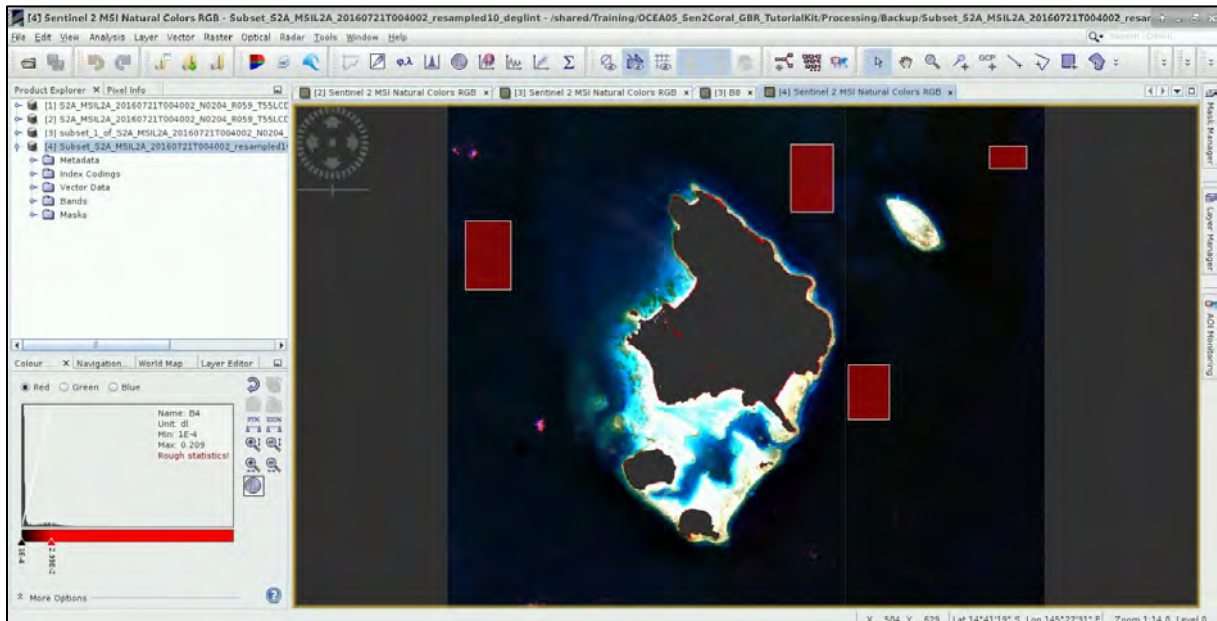
The algorithm results in majority of the land areas to have negative value and therefore be automatically masked, however we still need to apply cloud, residual land and white cap mask.

6.7   *Land, Cloud and White Cap Mask*

Another essential pre-processing step is masking of the land, white caps (sea foam crest over the waves), clouds and cloud shadows. The first three refer to bright features that can identified due to the fact that the near infrared wavelengths do not penetrate into the water, so after deglint is applied, clear areas of water appear very dark. Clouds, white caps and land typically have high reflectance in the NIR, therefore we can set a threshold to mask them (see image below).
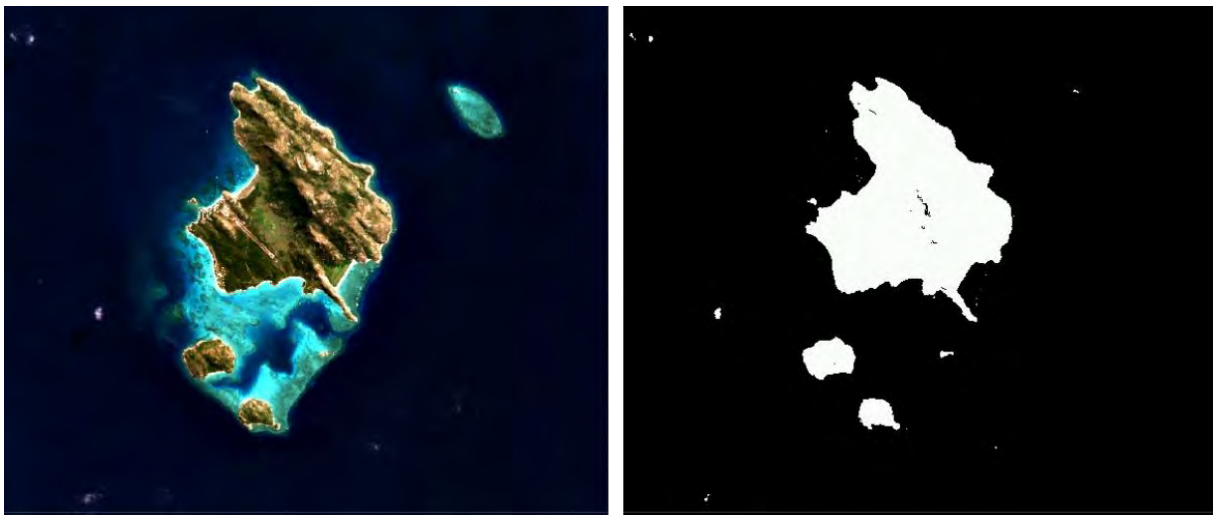
In Sen2Cor, a tool is available to create the mask. To apply it go to **Optical → Thematic Water Processing → Sen2Coral → Processing Modules → LandCloudWhiteCapMask Processor**.

In the **I/O Parameters** tab, set the subset deglint product [4] as **Source Product**. Save the product to: */shared/Training/OCEA05_Sen2Coral_GBR_TutorialKit/Processing*

In the **Processing Parameters** tab, set: **Source Bands:** B2, B3, B4, B5
Reference Band: B8
Maximum valid value: 0.05
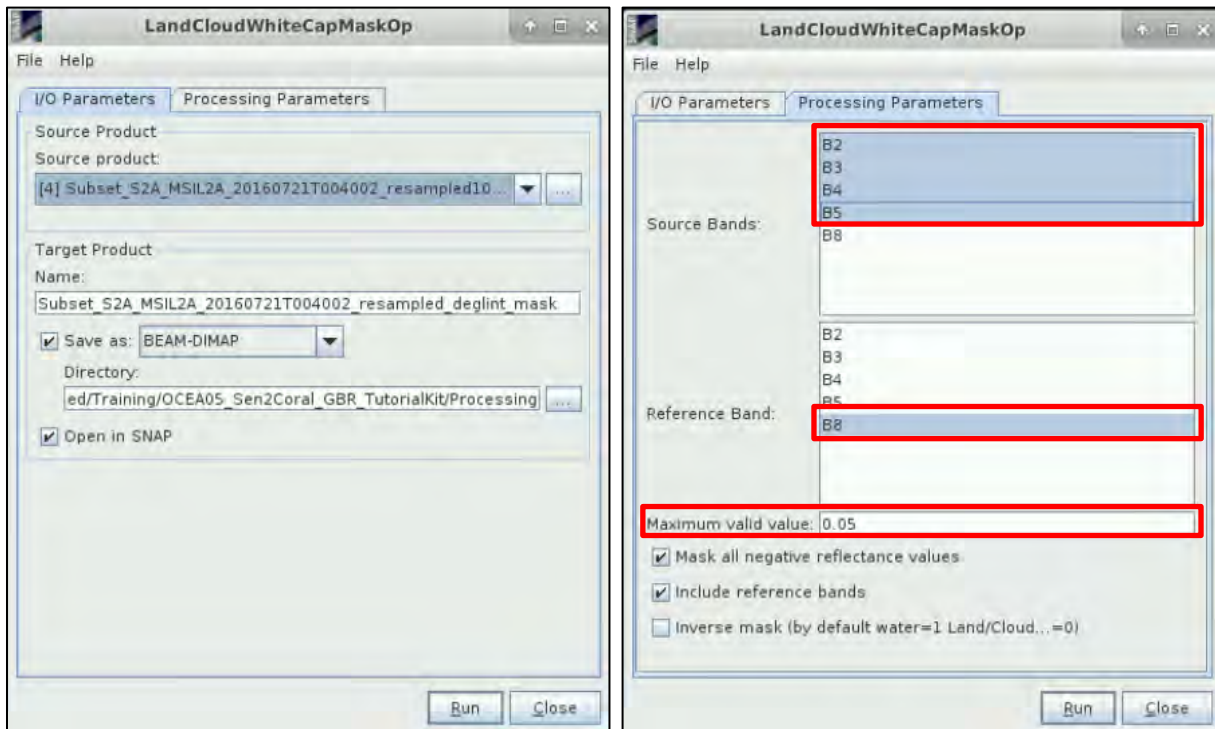
Click **Run**. A new masked product [5] containing also the mask band has been created.

However, the tool is unable to mask dark features such as cloud shadow or terrain shadow (can be seen on the above mask). The dark feature can be delineated manually, or we can use a threshold applied to band 2 to delineate them.

In the **Product Explorer**, right-click on the new masked product [5] and go to **BandMaths**. In the band math dialog set:

Name: Mask_All
Replace NaN and identify results by: NaN
Deselect **Virtual (save expression only, don't store data)**
Click on **Edit Expression** and set**:**
Expression: `if B2 > 0.01 && LandCloudWhiteCapMask_B8 == 1 then 1 else 0`
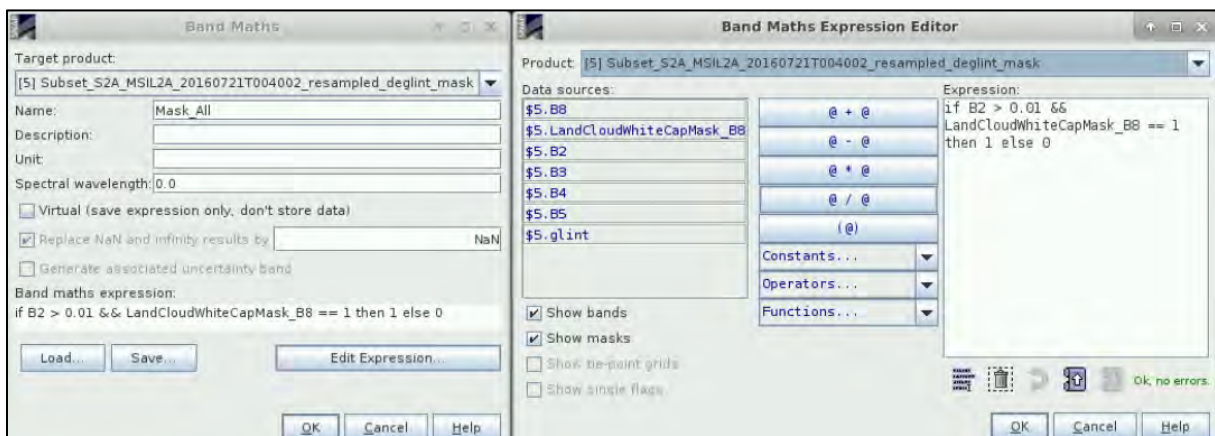
Then click **OK**. Now we can proceed to the applications.
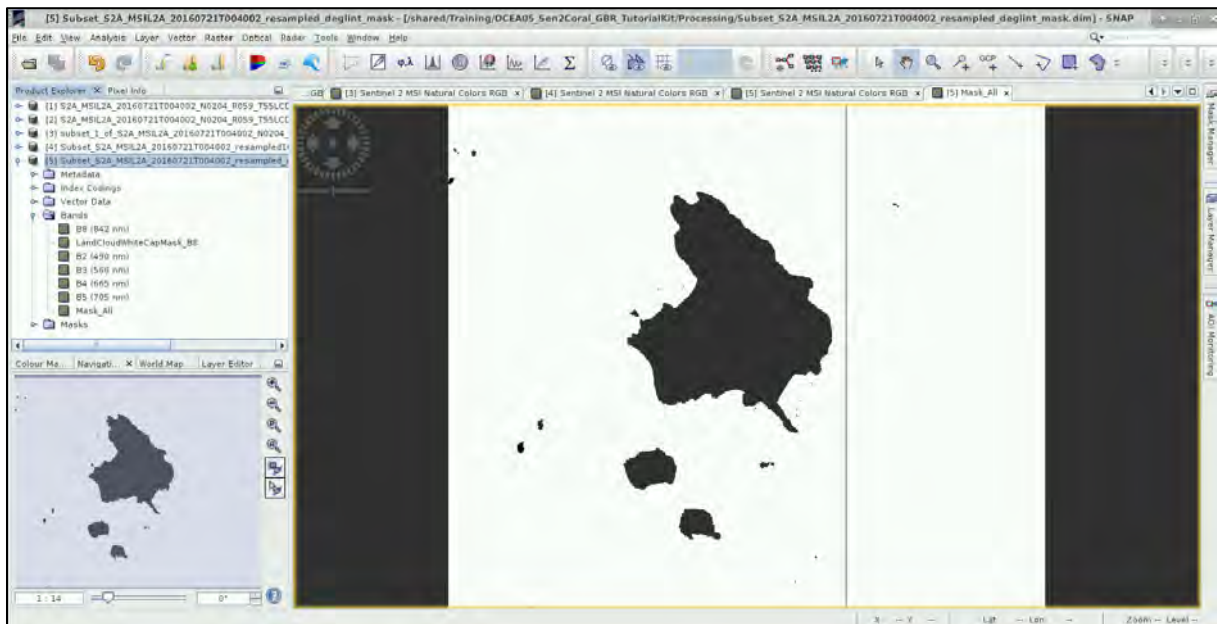
We can turn off the visualization of the glint polygons by going to **Layer Manager** (right side of the screen or go to **View → Tool Windows → Layer Manager**) and deselecting *Vector data → glint*.

6.8   *Depth invariant indices*

The calculation of depth invariant indices is a water column correction step that is frequently a useful pre-processing step for benthic classification. (See 🗒 NOTE 5)

> 🗒 NOTE 5: The implementation it Sen2Coral follows Lyzenga (1978) and Green et al. (2000). The basic ideal is that attenuation of the reflectance is approximately inverse exponential with water depth, therefore the transform,
>
> $$X_i = - \ln \left(R_i - R_i^{deep} \right)$$
>
> approximately linearizes the effect of depth on reflectance. R_i is the pixel reflectance in band i, and R_i^{deep}, is the deep-water reflectance in that band. A plot of the pixel values of two such transformed bands over a benthic type with constant reflectance but at different depths will lie on a line (following figure).
>
> In order to compute the depth invariant indices, we need to select two bands with sufficient water penetration to observe subsurface features of interest. For Sentinel-2 the bands 1-3 are the most useful, although 1-5 can fulfil the condition. We don't need to know the individual water attenuation coefficients in the two selected input bands, but we do need to know their ratio. This can be calculated from sample pixels over the same bottom type at different depths. *(SNAP Help)*

First, we need to define two groups of ROI polygons:

- Deep water – ROI over deep-water regions. From this the deep-water reflectance value is estimated (see 🗒 NOTE 5 above).
- Same bottom type at different depth – it is best to select areas of bright sand bottom as they can be identified easily and due to their brightness provide good signal-to-noise ratio.

Right-click on the masked product [5] in the **Product Explorer** and go to **Vector → New Vector Data Container**. In the dialog that opens, set the name to *"deep"*. Click on the 🔲**Rectangle drawing tool**

and draw polygons over the deep-water, it is best to use the RGB View to identify suitable areas.

Then create another **New Vector Data Container** and name it *"same_type"* and draw polygons over the bright sand areas. On the image below, you can see the "deep" polygons indicated in green and the "same_type" polygons indicated in red.
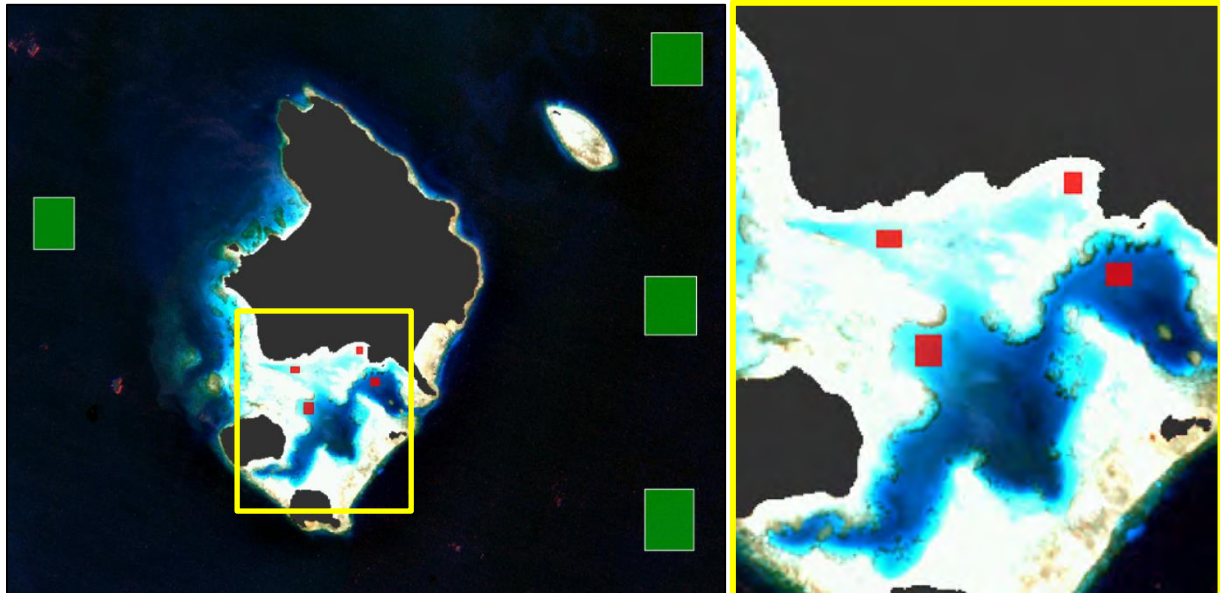
Then to apply the processor, go to **Optical → Thematic Water Processing → Sen2Coral → Processing Modules → DepthInvariantIndices Processor.**

In the **I/O Parameters** tab, set the masked product [5] as **Source Product**. Save the product to: */shared/Training/OCEA05_Sen2Coral_GBR_TutorialKit/Processing*

In the **Processing Parameters** tab, set: **Source Bands:** B2, B3
                                                                         Deep water area: "deep"
                                                                         Same bottom areas: "same_type"
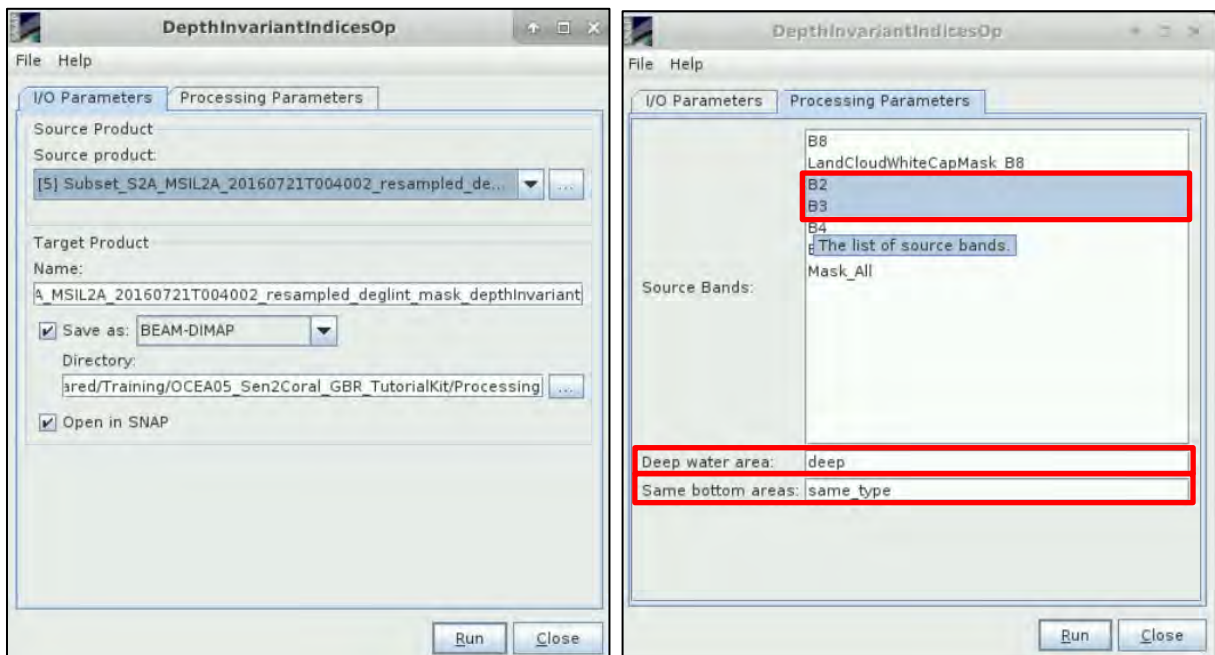
Then click **Run** and when finished close the operator dialog. A new product [6] has appeared in the **Product Explorer**. It contains only one band, double click it to visualize it. Turn off the visualization of the polygons by going to **Layer Manager** and **deselecting** *Vector data.*

You can also play with the sliders in the **Colour Manipulation** tab, to increase the contrast a bit more (▲ -2.5, ▲ -1.5, △ -0.5). We can also compare it with the original RGB image. To do this close all the except for the *[5] Sentinel 2 MSI Natural RGB* and the *[6] DepthInvariantIndicesB2B3*, then go to **Tools → Tile Horizontally**.
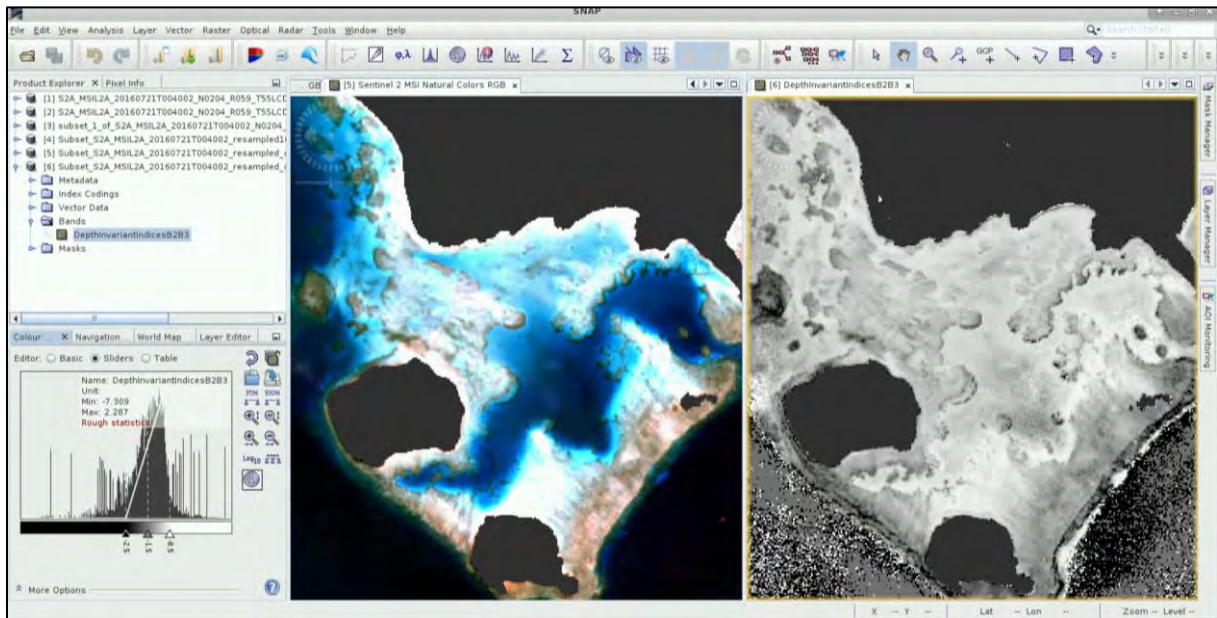
We only see valid values over shallow areas where the solar radiation can penetrate to the sea floor and is reflected from the features of interest. Over deep areas we only see noise values.

We can now proceed to use the Depth Invariant Indices as an input to change detection or to habitat classification (see example of simple classification below – using depth invariant indices, bands 2-5 and bathymetry as input). This however, is not the purpose of this training.
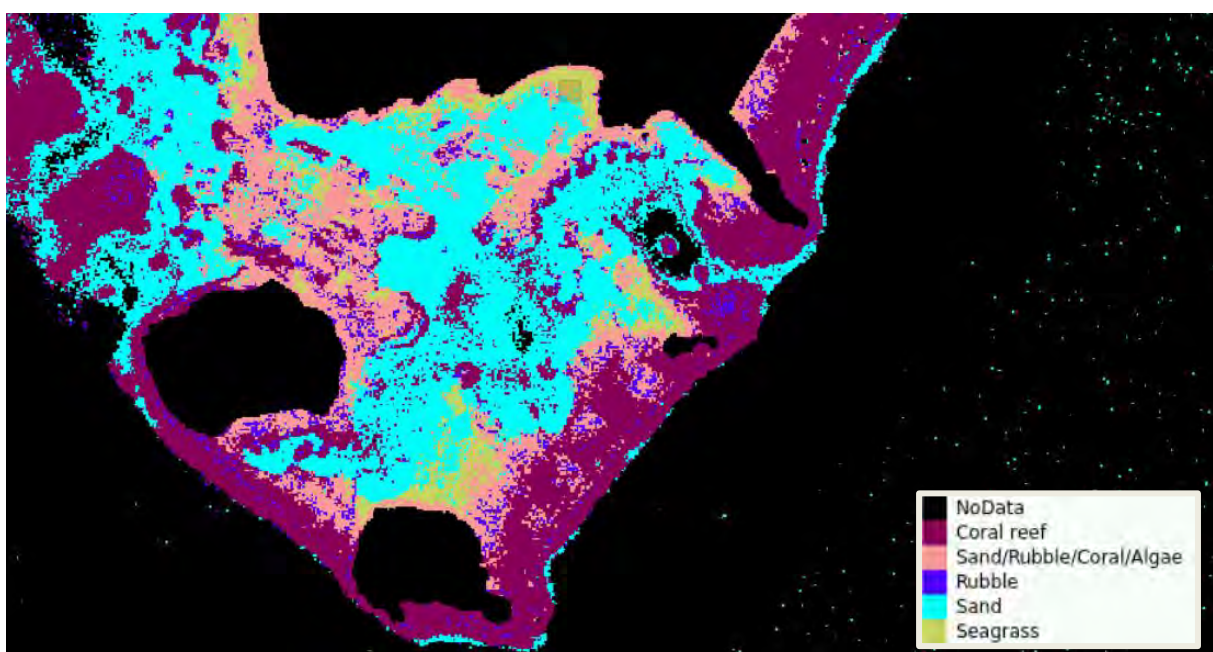
6.9   Empirical Bathymetry

The next tool we will explore is the **Empirical Bathymetry** processor. Estimation of bathymetry by empirical regression is a commonly used method for mapping shallow water areas. However, this method is only applicable if in-situ data are availbale for the area of interest. These most commonly come from boat sonar system and in combination with cloudless and calm water image can be used as an input to simple regression method and calibration of the bathymetry retrieval algorithm.

The algorithm implemented in the Sen2Coral toolbox follows the method developend by Stumpf et al. (2003). It is based on the principle that the water attenuation coefficients differ between wavelengths (bands) and we can determine the ratio between the two bands which will change with depth (similarly as for the Depth Invariant Indices calculation) (See ▢ NOTE 6).

> ▢ NOTE 6: The implementation in Sen2Coral follows by Stumpf et al. (2003). The basic ideal is that attenuation of the reflectance is approximately inverse exponential with water depth, i.e. we can estimate the depth z using following equation:
>
> $$z = m_1 \frac{ln\,(nR_w\,(\lambda_i))}{ln(nR_w\,(\lambda_j))} + m_0$$
>
> where m_1 is a tuneable 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. *(SNAP Help)*

Firstly, we need to go to **Optical → Thematic Water Processing → Sen2Coral → Processing modules → EmpiricalBathymetry Processor**.

In the **I/O Parameters** tab, select we select the pre-processed, deglinted and masked image [5] image as a source product field and save the product to:
/shared/Training/OCEA05_Sen2Coral_GBR_TutorialKit/Processing

In the **Processing Parameters** tab, we have to select two bands that will be used to estimate the bathymetry. Most commonly the bands 2 and 3 are used for Sentinel-2 as these offer the best combination of penetration depth and spatial resolution.

We also have to provide the path to the in-situ bathymetry point data. The training and validation datasets used here are in fact not in-situ data but were derived by John Hedley using random sampling of the 20m multisource Digital Elevation/Depth Model for Lizard Island (Leon et al., 2012). Only points with maximum depth of 20m have been used for the algorithm calibration, as this can be assumed as the maximum depth to which the retrieval from satellite data is possible.

The dataset must be in a CSV coma-delimited format without headers and containing columns for latitude, longitude and depth.

Bands to be used: B2, B3

Bathymetry point data:
`/shared/Training/OCEA05_Sen2Coral_GBR_TutorialKit/AuxData/lizard_leonetal_dem_bathy`
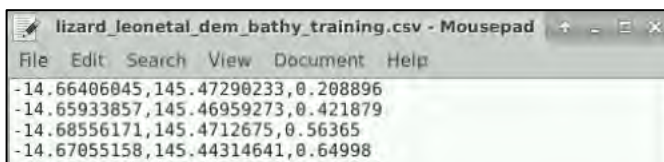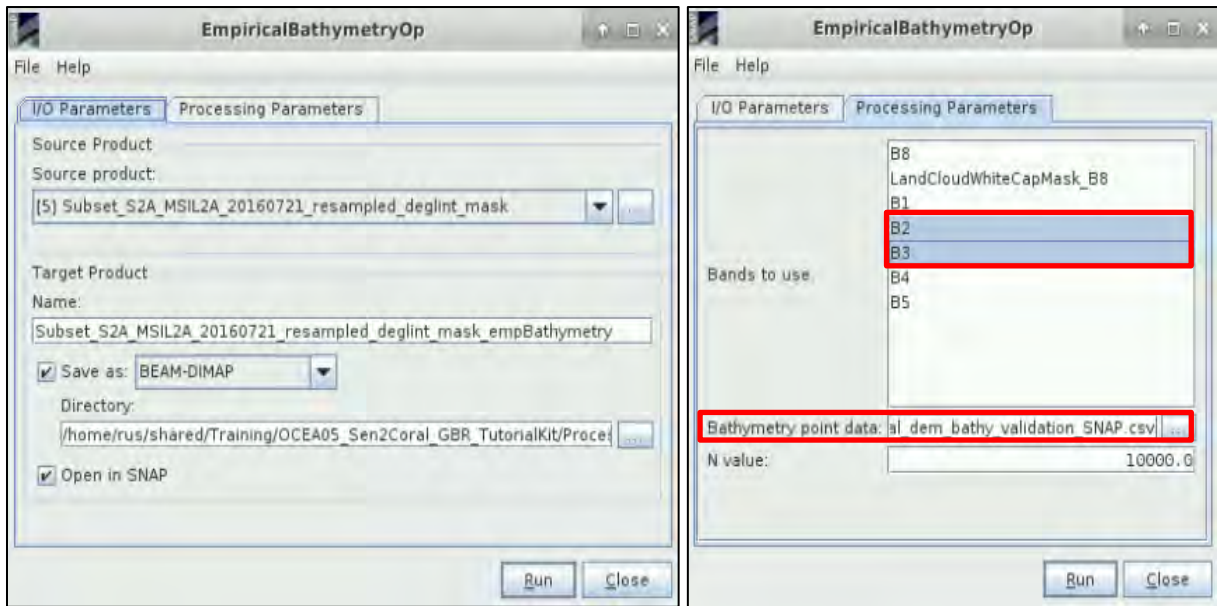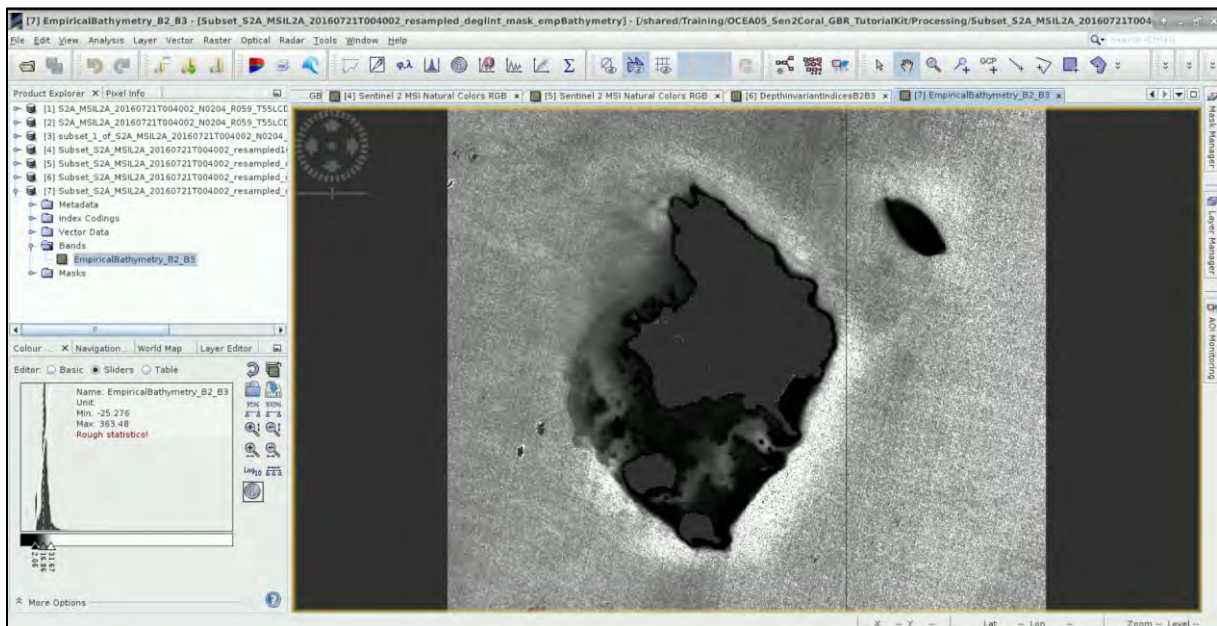`_training.csv`

N value: 1000.0 (default)

Then click **Run** and when finished close the operator dialog. A new product [7] has appeared in the **Product Explorer**. It contains only one band. Go to **Window → Tile Single** and then double click the bathymetry band to visualize it. Turn off the visualization of the polygons by going to **Layer Manager** and **deselecting** *Vector data.*

We can now use the "*Mask_All*" band to mask out all the residual land, cloud and cloud shadow. In the **Product Explorer**, right-click on the new bathymetry product [7] and go to **BandMaths**. In the band math dialog set:

Name: EmpiricalBathymetry_B2_B3_masked
Replace NaN and identify results by: NaN
Deselect **Virtual (save expression only, don't store data)**Click on **Edit Expression** and set**:**

Expression:
```
if $5.Mask_All == 1 then $7.EmpiricalBathymetry_B2_B3 else NaN
```

Note that we are using a band "Mask_All" from a different product, for this reason we can not use virtual band. We also have to pay attention to correct reference numbers in our expression.
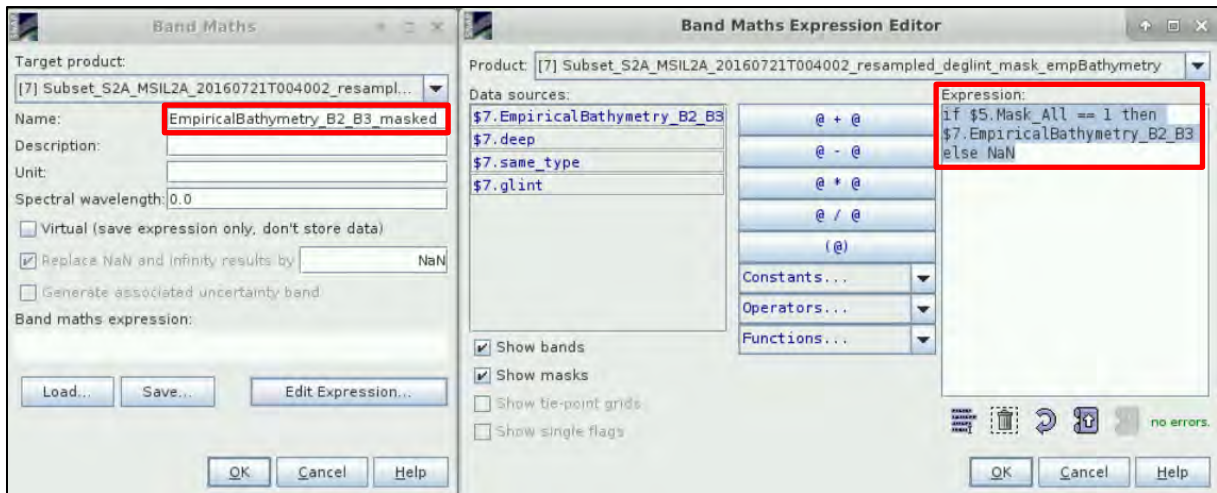
Then click **OK**. Now we can visualize the band. In **Product Explorer**, go to the Vector data folder and delete the following: *"glint", "deep", "same_type"* (right-click → Delete)

Then go to the **Colour Manipulation** tab and click on **Import Colour Palette**, navigate to **/shared/Training/OCEA05_Sen2Coral_GBR_TutorialKit/AuxData/** and open *Bathymetry_Col.cpd* In the dialog that opens click **No**.
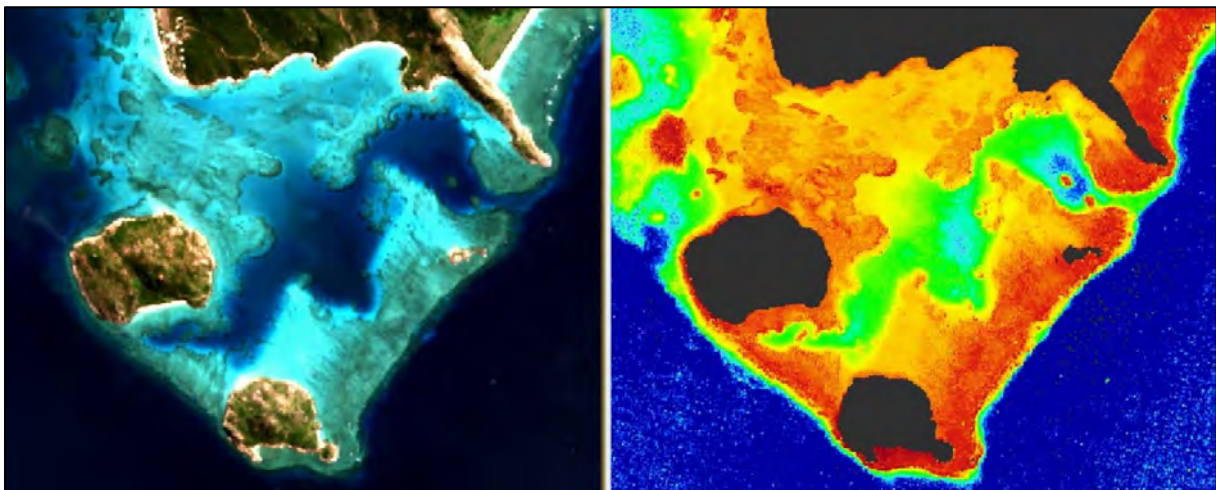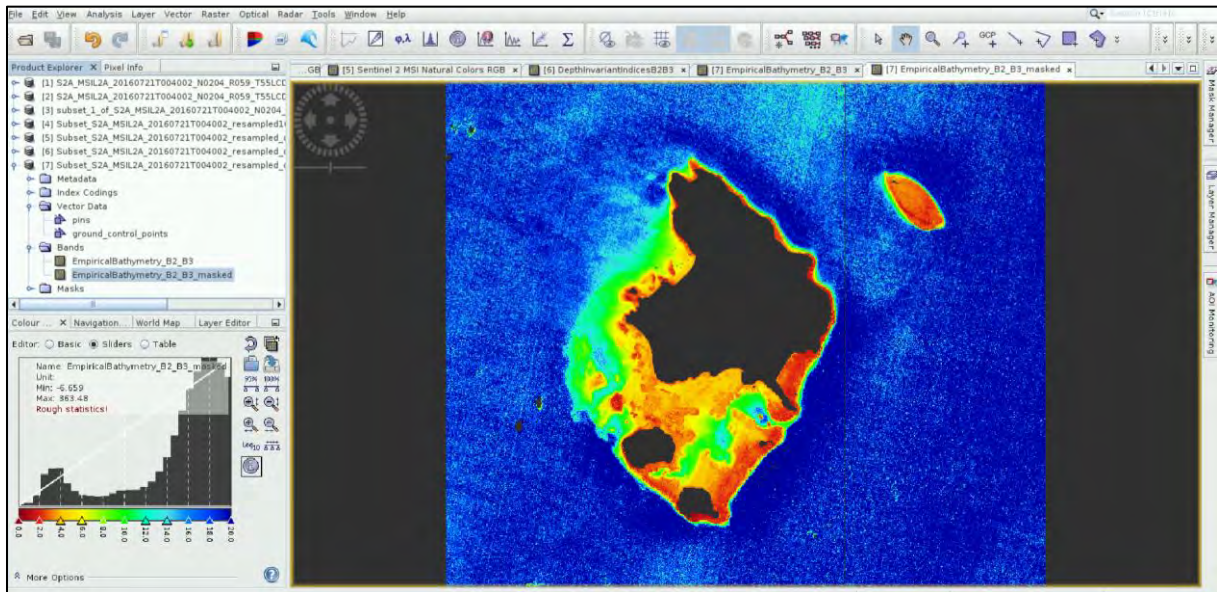
6.9.1 Validation

In SNAP we can also do a quick validation using a validation dataset also derived from the 20m multisource Digital Elevation/Depth Model for Lizard Island (Leon et al. 2012).
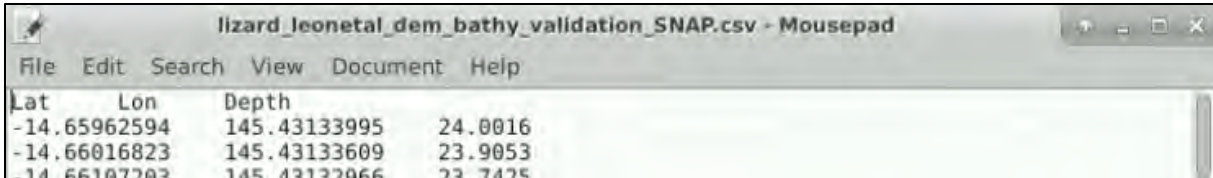
First, we need to load this dataset to as a vector from CSV file (or shapefile). In this case we use tab-delimited CSV with headers.

In **Product Explorer**, select the bathymetry product, then go to **Vector → Import → Vector from CSV**. Navigate to ***/shared/Training/OCEA05_Sen2Coral_GBR_TutorialKit/AuxData/*** and open *lizard_leonetal_dem_bathy_validation_SNAP.csv*

In the **Import CSV Data** dialog, select **Custom CRS → Geographic Lat/Lon (WGS 84).** Click **OK.** In the next dialog accept the default option.
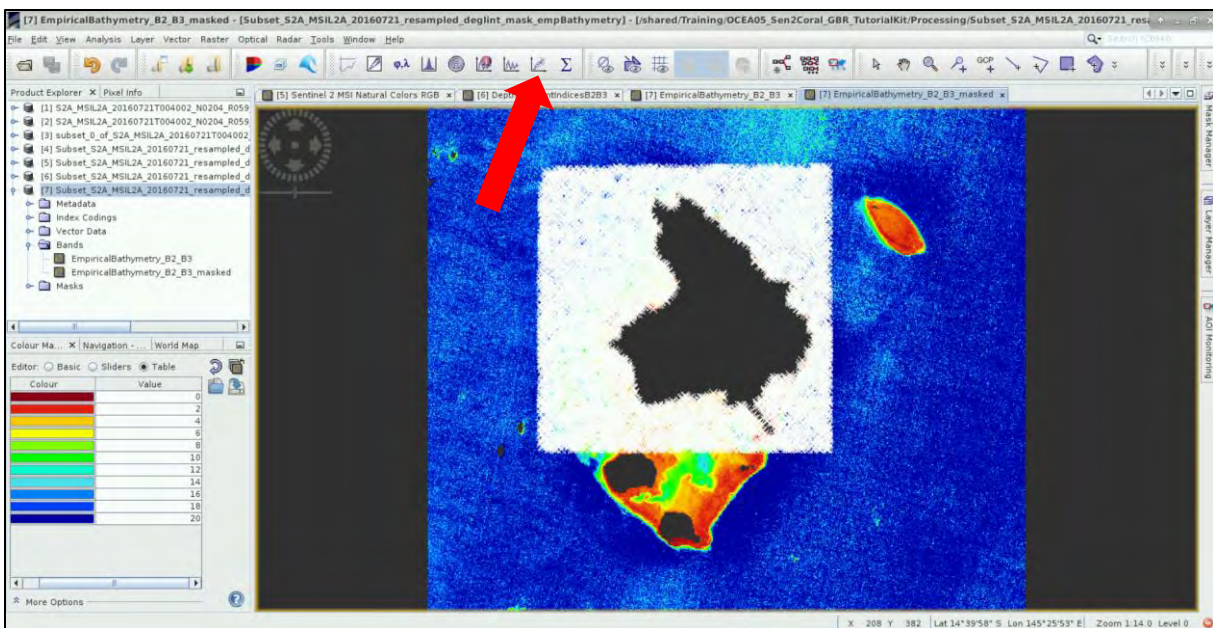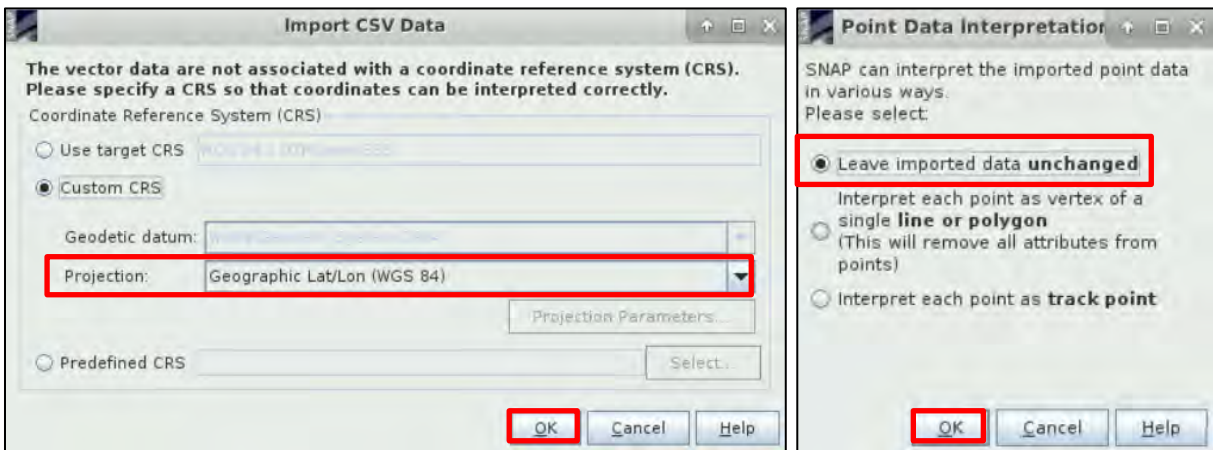
Then click on the **Correlative plot** tool on the top panel. In the dialog, deselect **Use ROI mask**, and set: **Point data source:** *lizard_leonetal_dem_bathy_validation_SNAP*
          Data field: *Depth*
In **Y-Axis (EmpiricalBathymetry_B2_B3_masked)** deselect *Auto min/max* and set **Max:** *50*
Select **Show tolerance range** and **Show regression line**.

We can export the graph and the bathymetry data for further use for example as one of the inputs for benthic habitat classification. When you are done examining the graph, close the graph window.
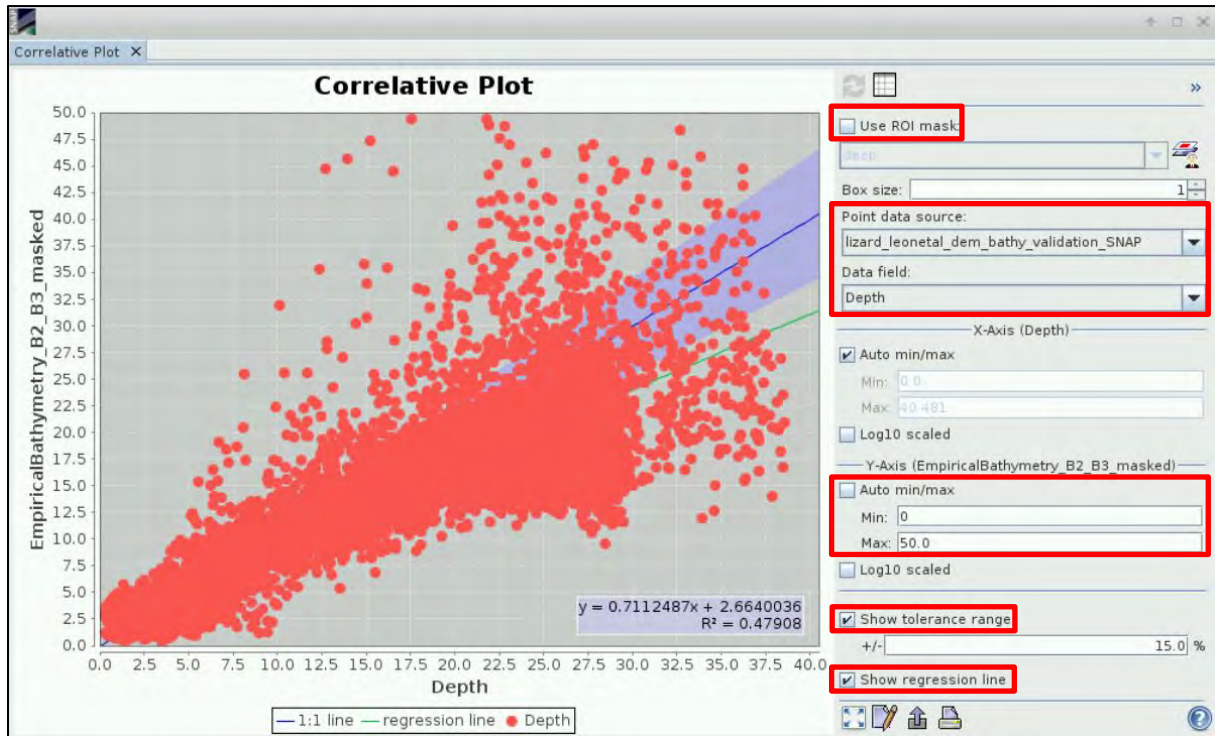
6.10 Radiometric Normalization via PIFs

The last tool we will have a look at is the **Radiometric Normalisation via PIFs**. This tool enables us to apply radiometric normalisation to imagery so values corresponding to the same surface are comparable throughout a timeseries. The method is based on the use of pseudo invariant features corresponding to optically bright (sand) or optically dark (seagrass) targets, deep waters, human made infrastructures (roofs, roads, airstrips) to intercalibrate two different images.

For this part of the exercise we will use a different study area – Adelaide reef - which shows some interesting results possibly related to the detection of bleaching event. The following pre-processing steps have already been applied to the images:

- Atmospheric correction – Sen2Cor
- Resampling
- Subset
- Deglint
- Land Cloud and White Cap mask

Click on **Open product** and navigate to:
 /shared/Training/OCEA05_Sen2Coral_GBR_TutorialKit/Original/Adelaide_Reef/

and open the two images *.dim* files. Open the RGB view for both and then go to **Window → Tile Horizontally**.

We will use the first image from 2016 as a master for the calibration of the second image from 2017. First, we need to draw polygons over features we expect not to change over time, such as bright sand, man made infrastructure or dark pelagic water.
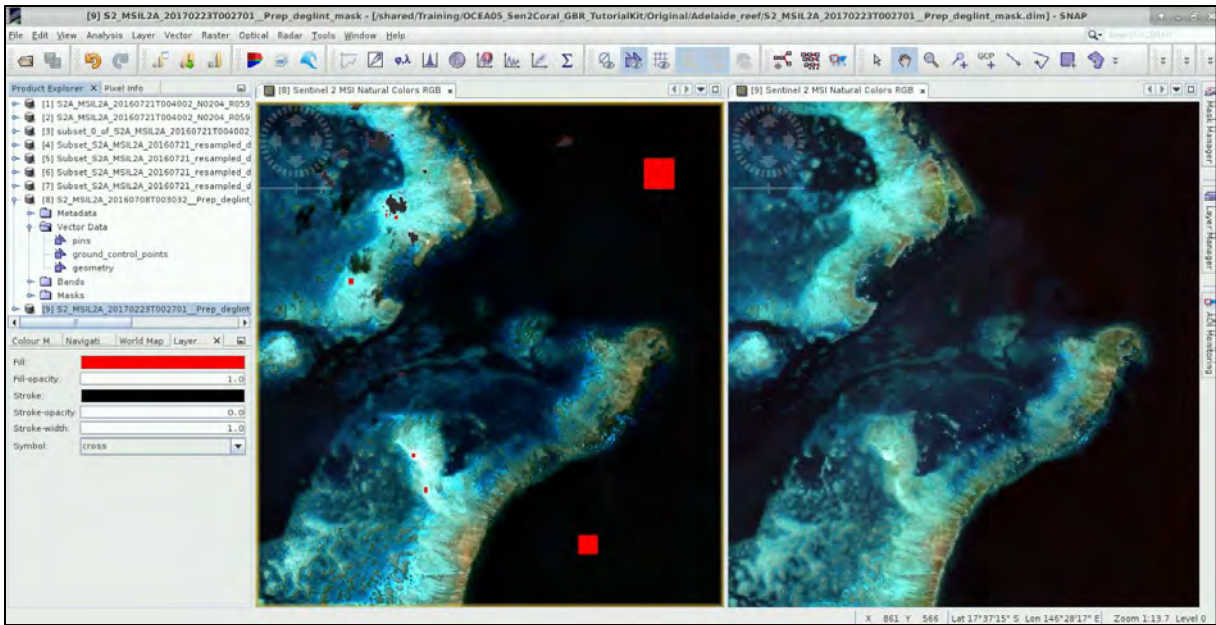
Once you are done drawing the polygons, go to **Optical → Thematic Water Processing → Sen2Coral → Processing modules → RadiometricNormalizationPIFs Processor.**

In the **I/O Parameters** tab, set the masked product [8] as **Source Product**. Save the product to: ***/shared/Training/OCEA05_Sen2Coral_GBR_TutorialKit/Processing***

In the **Processing Parameters** tab, set: **Source Bands:** B1, B2, B3, B4, B5

Deep water area: geometry
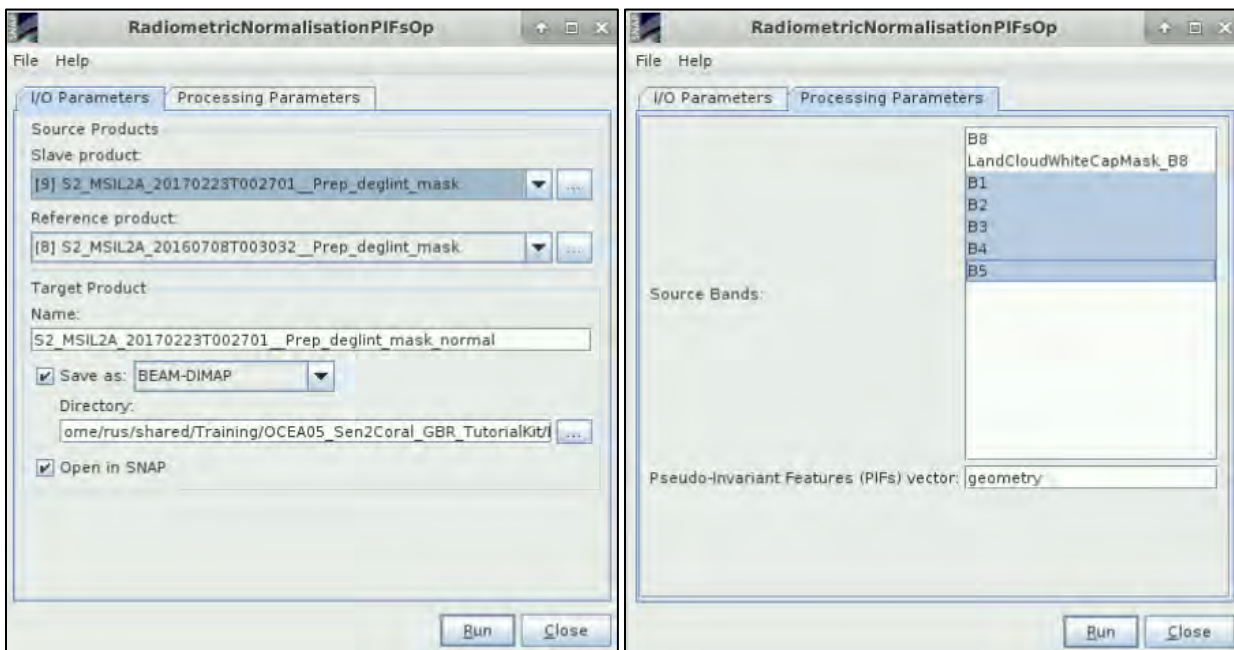
Click **Run.** A new product [10] had been created in the **Product Explorer**. If you try to visualize the image you will receive an error, this is due to a bug in the handling of the valid pixel expression. The visualization tool is searching for the *LandCloudWhiteCapMask_B8* band that does not exist in the new product. We have to add it from the original pre-processed product [9].
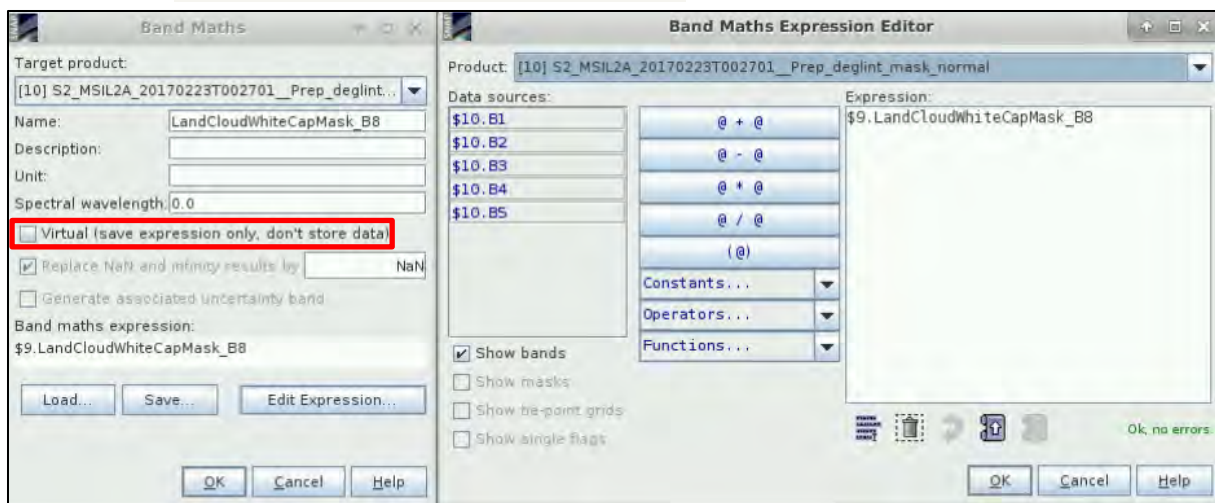
In **Product Explorer**, right-click on the new normalized product [10] and go to **BandMaths**. In the band math dialog set:

Name: LandCloudWhiteCapMask_B8
Replace NaN and identify results by: NaN
Deselect **Virtual (save expression only, don't store data)** Click on **Edit Expression** and type**:**
Expression: `$9.LandCloudWhiteCapMask_B8`

Click **OK**. Now we can visualize the result.

Open and arrange windows so the image from 2016 and the new normalized image from 2017 are displayed side by side (close all the other views and then go to **Window → Tile Vertically**). Zoom-in to the area indicated below.
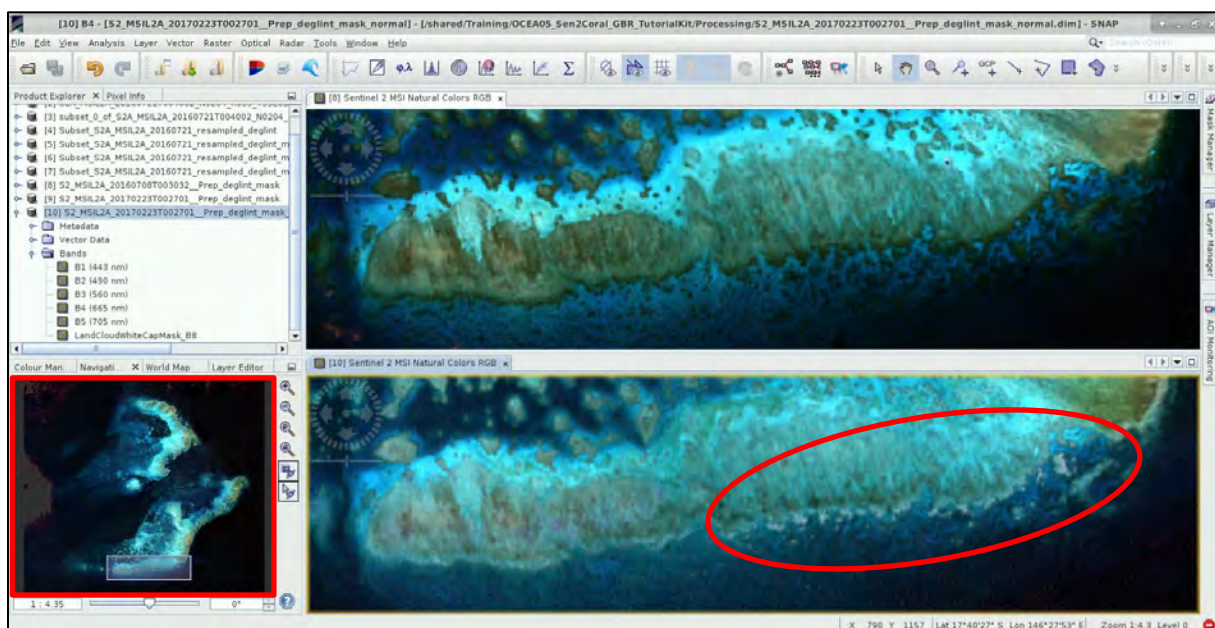
This image has been reported in Hedley et al. (2018) as it potentially captures a bleaching event. The coral in the second image appears much brighter, almost white. Bleaching is in general very difficult to capture in satellite images as the event generally occurs on the scale of weeks.

7 Extra steps

7.1 *Downloading the outputs from VM*

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

8 References

Green, E., Mumby, P., Edwards, A., and Clark, C. (2000). Remote Sensing: Handbook for Tropical Coastal Management (United Nations Educational, Scientific and Cultural Organization (UNESCO)).

Hedley, J.D., Harborne, A.R., and Mumby, P.J. (2005). Technical note: Simple and robust removal of sun glint for mapping shallow-water benthos. Int. J. Remote Sens. *26*, 2107–2112.

Hedley, J.D., Roelfsema, C., Brando, V., Giardino, C., Kutser, T., Phinn, S., Mumby, P.J., Barrilero, O., Laporte, J., and Koetz, B. (2018). Coral reef applications of Sentinel-2: Coverage, characteristics, bathymetry and benthic mapping with comparison to Landsat 8. Remote Sens. Environ. *216*, 598–614.

Leon, J.X., Phinn, S.R., Hamylton, S., and Saunders, M.I. (2012). A 20 m spatial resolution seamless multisource Digital Elevation/Depth Model for Lizard Island, northern Great Barrier Reef. PANGAEA, https://doi.org/10.1594/PANGAEA.804566

Lyzenga, D.R. (1978). Passive remote sensing techniques for mapping water depth and bottom features. Appl. Opt. *17*, 379–383.

Mousivand, A., Verhoef, W., Menenti, M., and Gorte, B. (2015). Modeling Top of Atmosphere Radiance over Heterogeneous Non-Lambertian Rugged Terrain. Remote Sens. *7*, 8019–8044.

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