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TRAINING KIT – OCEA04

OCEAN COLOUR WITH SENTINEL-3 OLCI
JULY 2017, NORTH SEA

serco

NOVELTIS

ALONG-TRACK

ROMANIA

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-coperenicus.eu

Cover images produced by RUS Copernicus

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Table of Contents

1 Introduction to RUS

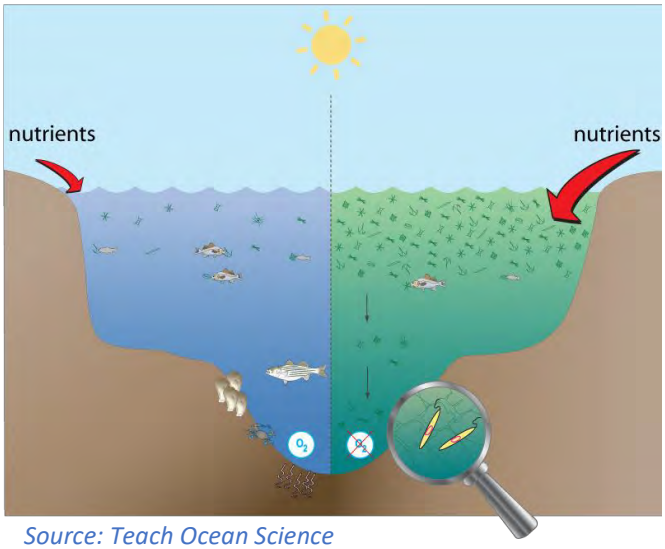
The Research and User Support for Sentinel core products (RUS) service, provides a free and open scalable platform in a powerful computing environment, hosting a suite of open source toolboxes pre-installed on virtual machines, to handle and process data derived from the Copernicus Sentinel satellites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

2 Ocean colour monitoring – background

Source: NASA - Algal bloom

Ocean colour refers to the hue of the water caused by the presence of tiny plants that containing the pigment chlorophyll, sediments and coloured dissolved organic material.

From satellite observations in the optical part of the spectrum we can estimate the concentrations of different constituents (pure water, chlorophyll, sediments, coloured dissolved organic matter) provided we know their effect on the spectral response of the water (inherent optical properties - IOPs).



Source: Teach Ocean Science (http://www.teachoceanscience.net)

Chlorophyll concentrations are perhaps of most interest to us as they are indicators of algal blooms. Phytoplankton blooms occur naturally in areas with high nutrient concentrations (coastal areas – nutrient runoff from land). When phytoplankton cells die, they sink to the seabed where they are decomposed by bacteria requiring oxygen.

In extreme cases (eutrophication), this process can result in oxygen depletion (hypoxia) and the creation of "dead zones" where all marine life either died or left the area. While the occurrence of such zones on periodic basis is natural, they have been observed more often and affecting larger areas in the past few decades. This is mainly attributed to nitrogen and phosphorous from agricultural runoff, but sewage, vehicular and industrial emissions play a role.

The study area for this exercise will be the southern part of the North Sea. Eutrophication and hypoxia have been increasingly observed in the coastal areas and the countries surrounding the North Sea have been working together for the past few decades to reduce pollution runoff. Monitoring of the chlorophyll concentrations is an important input to assessing these efforts.

3 Training

Approximate duration of this training session is 1 hour.

3.1 Data used

- One Sentinel-3A level 1 image that had been acquired on 9 July 2017 [downloadable @ https://codarep.eumetsat.int]

  S3A_OL_1_EFR____20170709T095656_20170709T095856_20171021T033004_0119_019_350_____MR1_R_NT_002

- One Sentinel-3A level 2 image that had been acquired on 9 July 2017 [downloadable @ https://codarep.eumetsat.int]

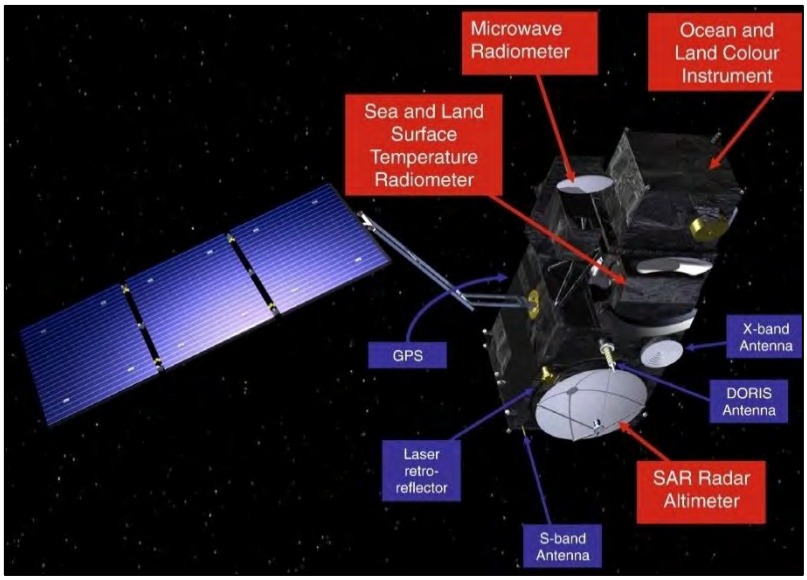
  S3A_OL_2_WFR____20170709T095656_20170709T095856_20171110T054242_0119_019_350_____MR1_R_NT_002

3.2 Software in RUS environment

Internet browser, SNAP + Sentinel-3 Toolbox

4 Sentinel-3 OLCI

Sentinel-3 is a multi-sensor mission comprising of two satellites (Sentinel-3A and Sentinel-3B) in identical orbit with a phase shift of approximately 140°. Sentinel-3A has been in orbit since February 2016 and Sentinel-3B since 25 April 2018. The mission's main objective is to measure with accuracy sea-surface topography, sea- and land-surface temperature and ocean- and land-surface colour, in support of ocean forecasting systems, and for environmental and climate monitoring. It provides Near-real time data for ocean forecasting, sea-ice charting, and maritime safety services on the state of the ocean surface, including surface temperature, marine ecosystems, water quality and pollution monitoring.

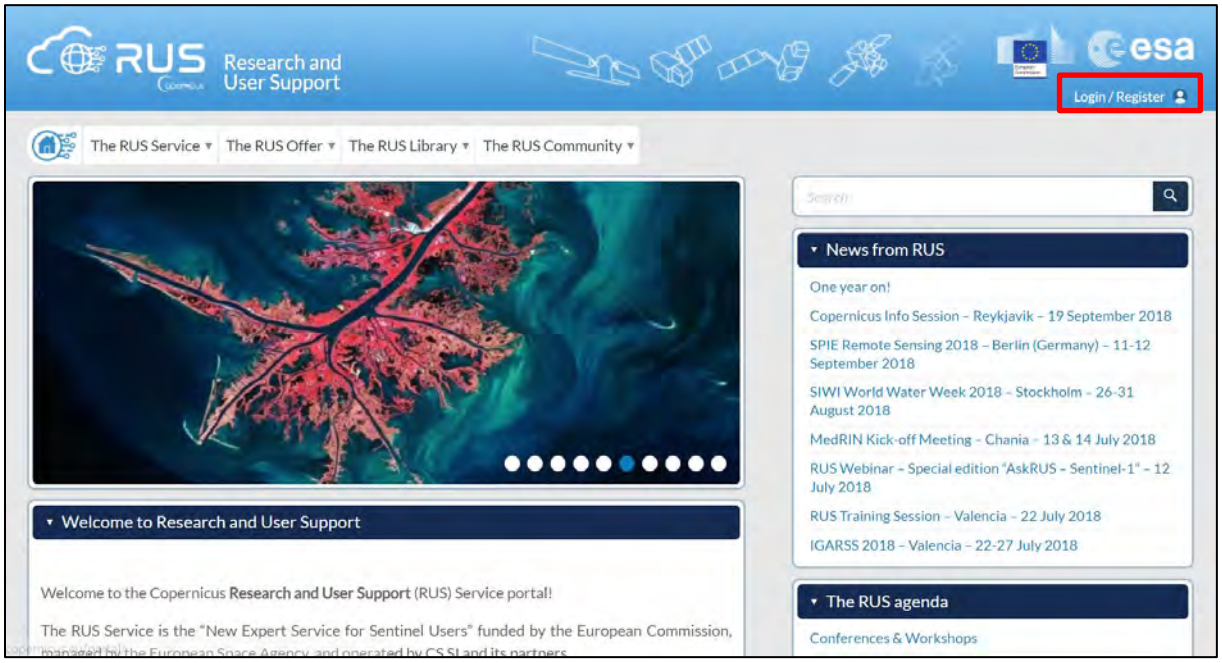


Sentinel-3 sensors (Credits: Sentinel-3 SLSTR User Guide, ESA)

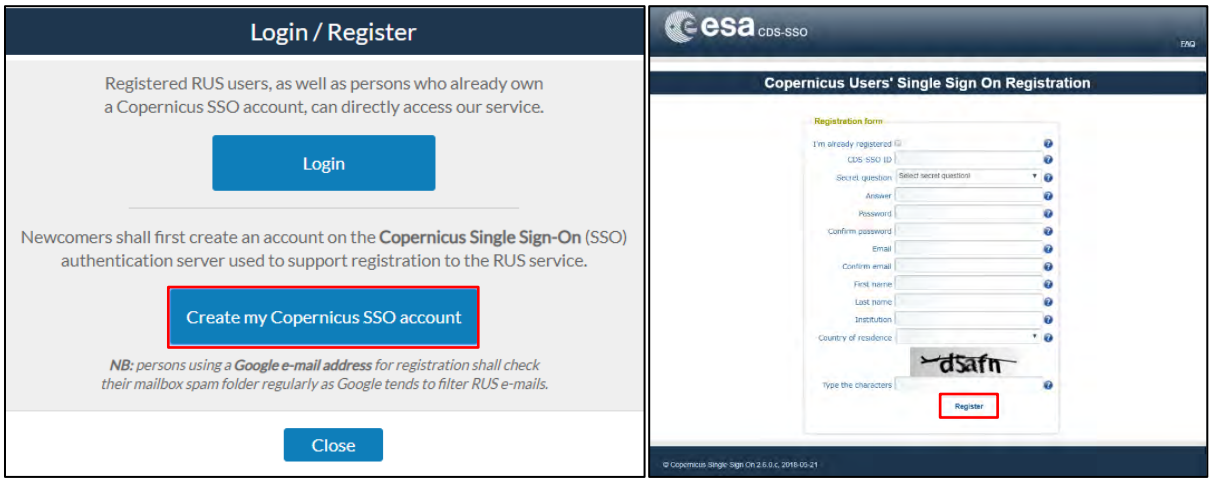
The **O**cean and **L**and **C**olour **I**nstrument (OLCI) is a medium-resolution imaging spectrometer that uses five cameras to provide a wide field of view (swath width: 1270 km). It provides 21 bands, ranging from the visible to the near infrared (400 – 1020 nm), acquired simultaneously with approximately 300 m spatial resolution.

5 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.

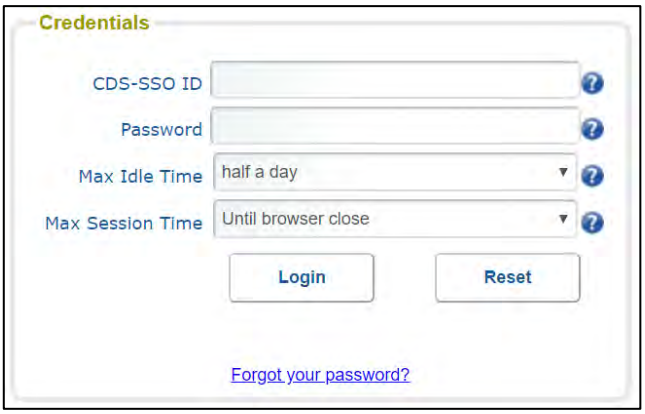


Select the option ***Create my Copernicus SSO account*** and then fill in ALL the fields on the **Copernicus Users' Single Sign On Registration**. Click ***Register***.

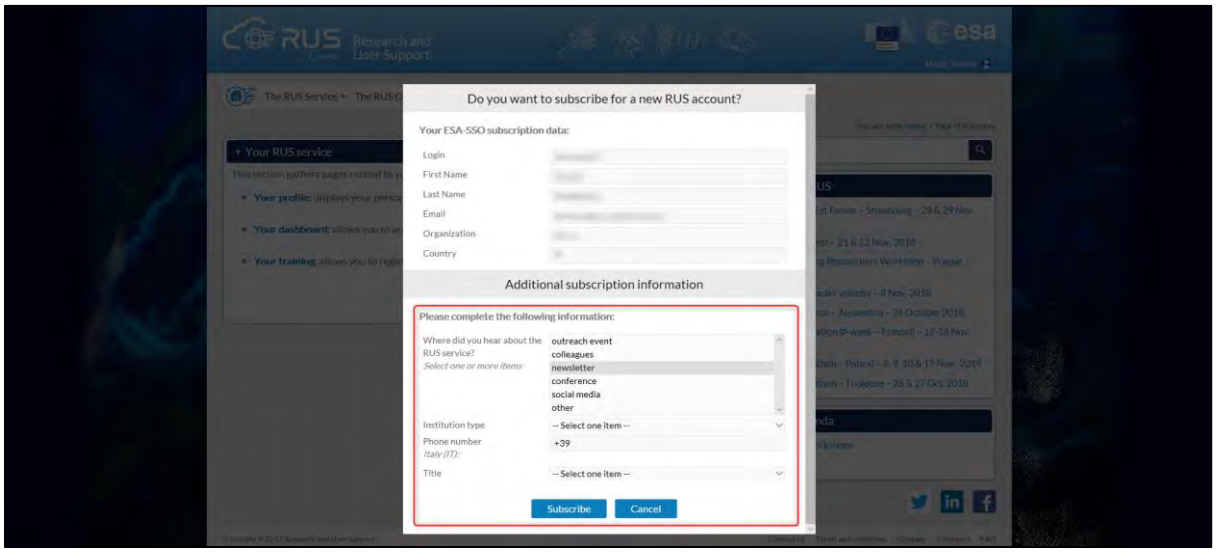


Within a few minutes you will receive an e-mail with activation link. Follow the instructions in the e-mail to activate your account.

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

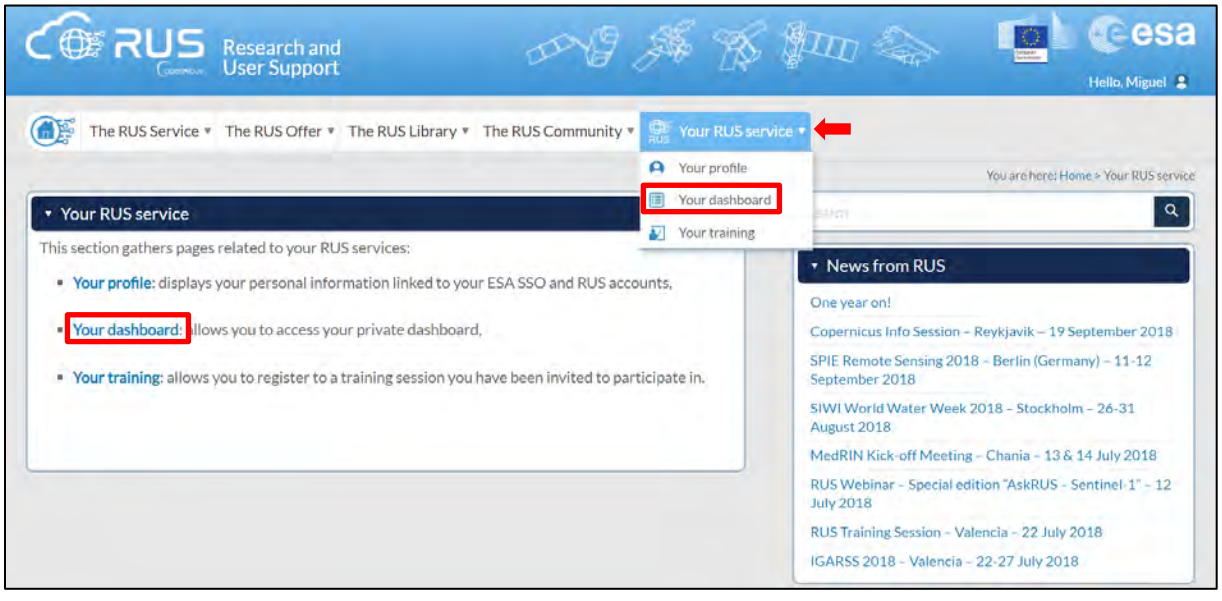


Upon your first login you will need to enter some details. You must fill all the fields.

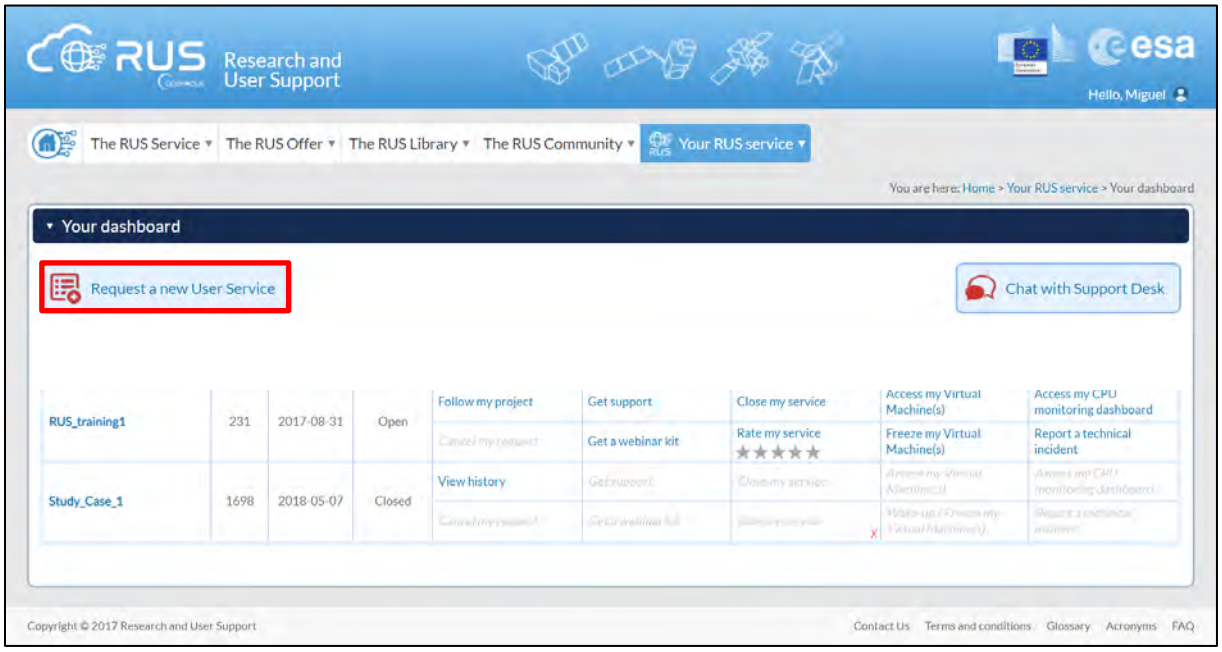


6 Request a RUS Copernicus Virtual Machine

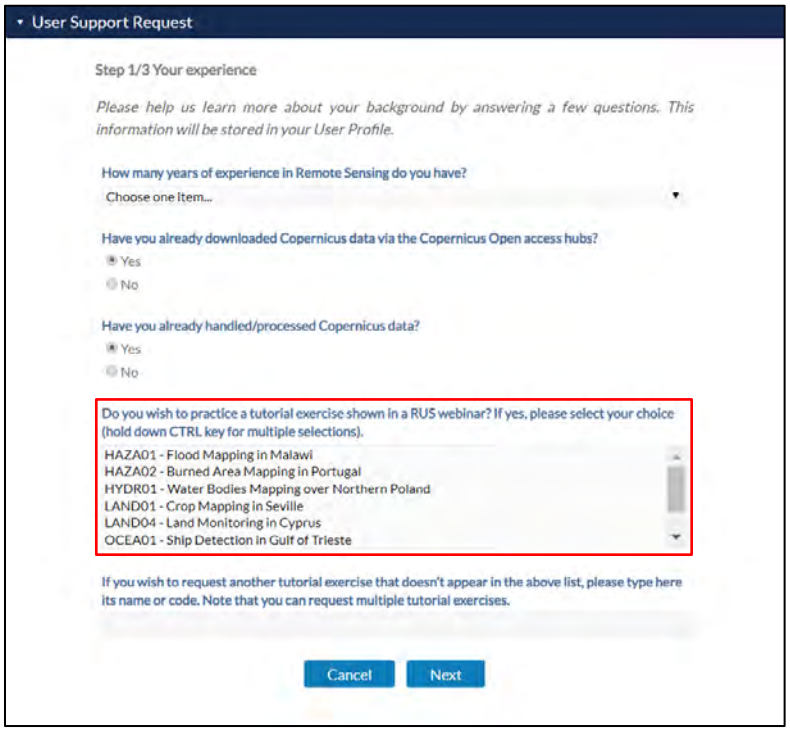
Once you are registered as a RUS user, you can request a RUS Virtual Machine to repeat this exercise or work on your own projects using Copernicus data. For that, log in and click on ***Your RUS Service*** → ***Your Dashboard***.



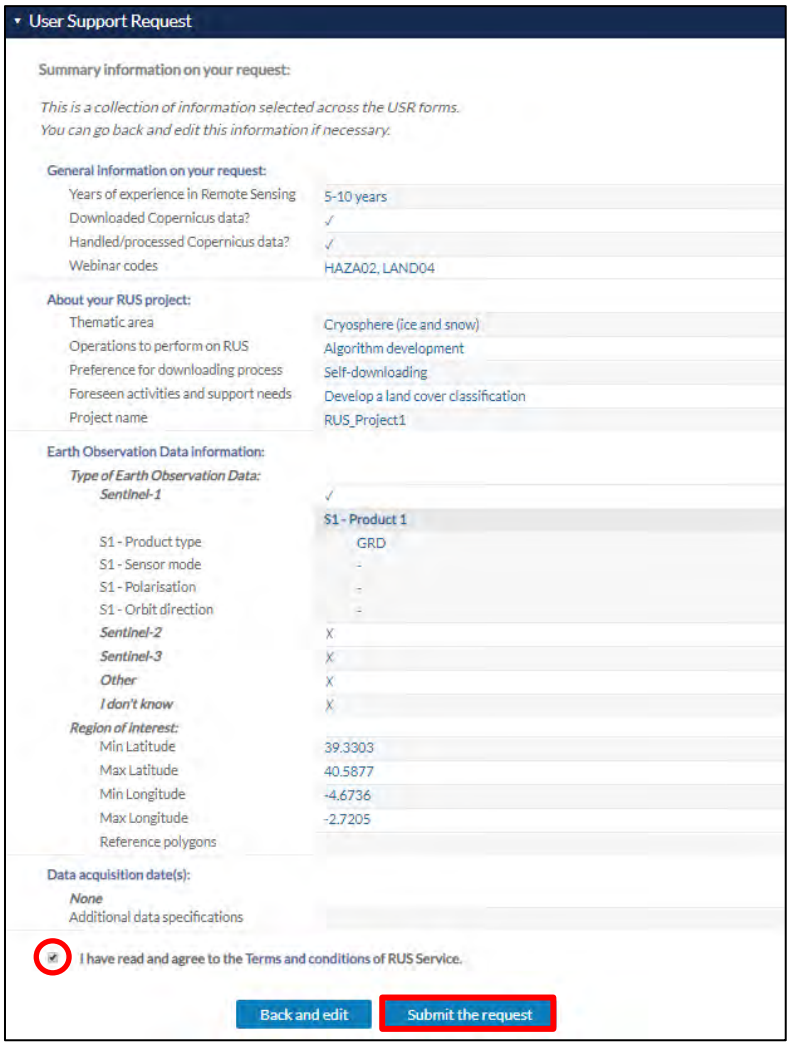
Click on ***Request a new User Service*** to request your RUS Virtual Machine. Complete the form so that the appropriate cloud environment can be assigned according to your needs.



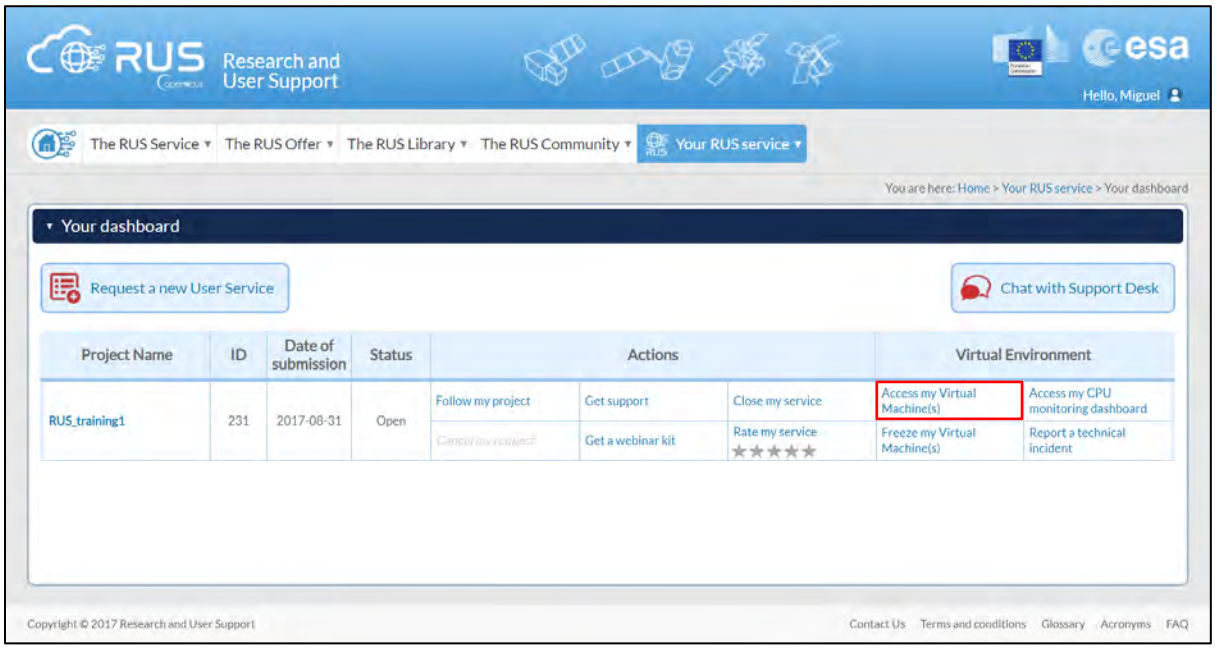
If you want to repeat this tutorial (or any previous one) select the one(s) of your interest in the appropriate field.



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.

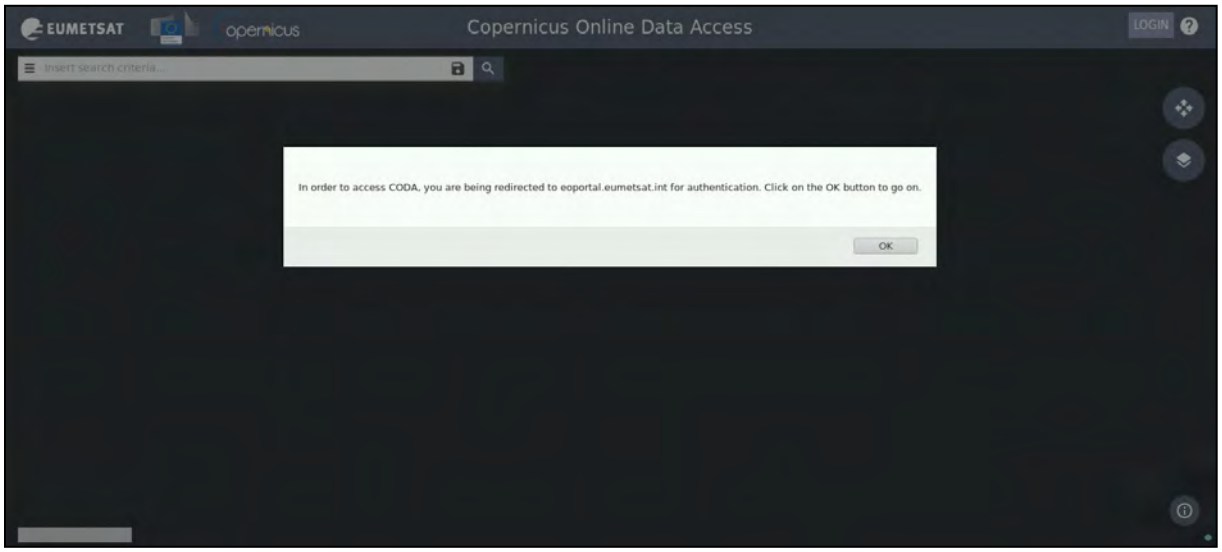
7 Step by step

7.1 Data download – CODARep

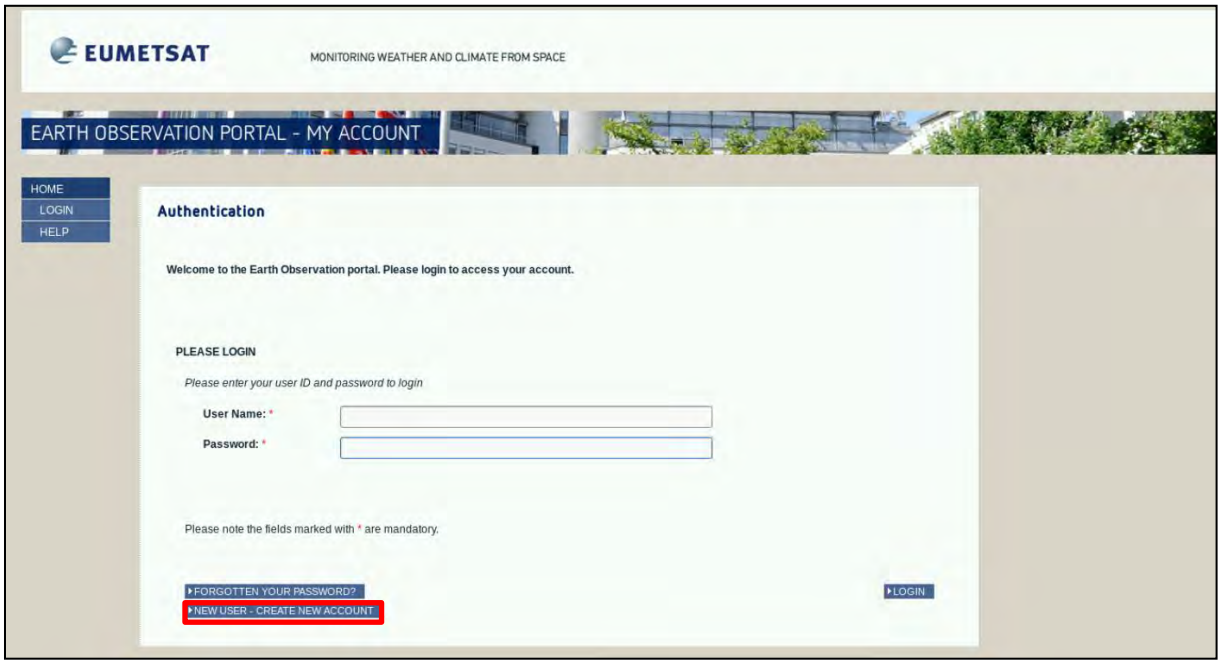
In this step, we will download the Sentinel-3A **Level-1 EFR** product (TOA radiances at **F**ull **R**esolution) and a corresponding **Level-2 WFR** product (**F**ull **R**esolution: Ocean Colour, **W**ater and atmosphere parameters), from the EUMETSAT Copernicus Online Data Access (REProcessed) using the online interface.

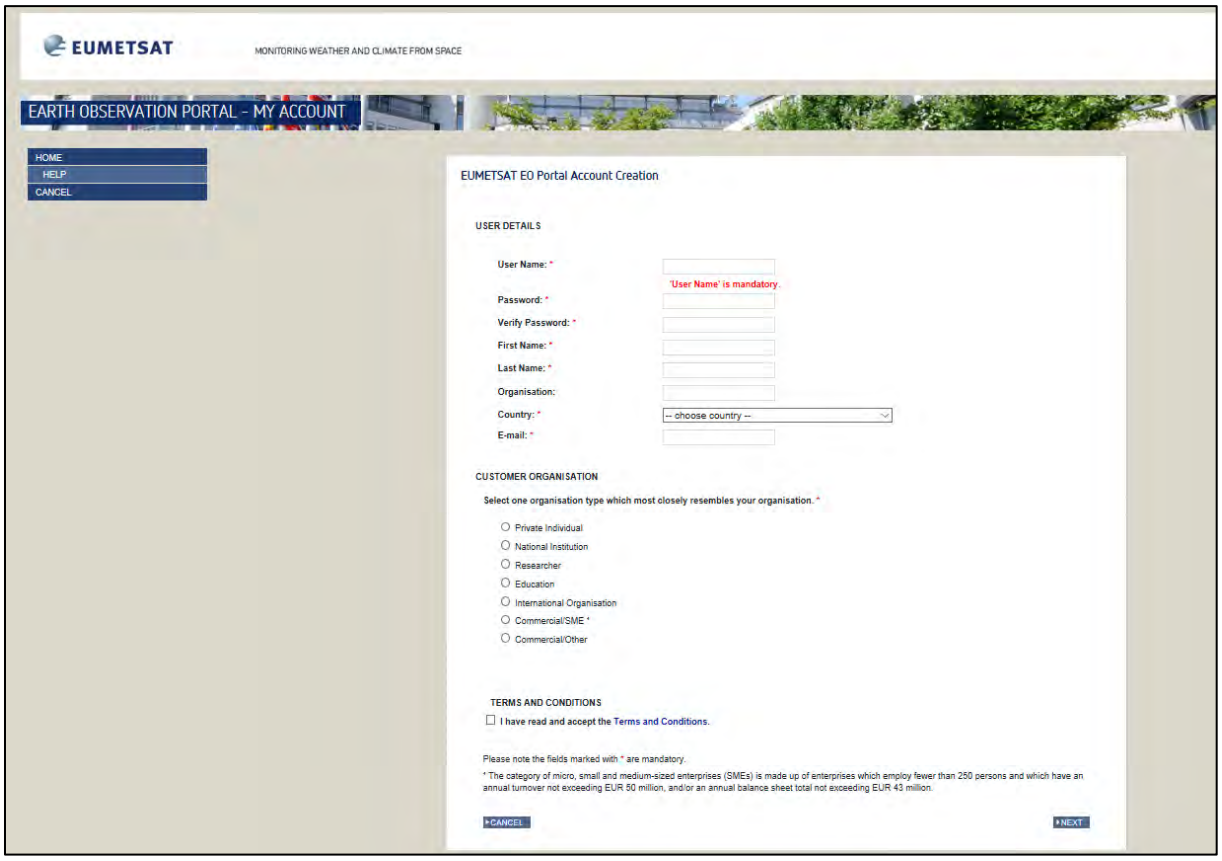
TIP: All Sentinel-3 products are available in the EUMETSAT Copernicus Online Data Access (https://coda.eumetsat.int/) only for 1 year from the acquired date. After 1 year, they are only available in the CODA REProcessed portal (https://codarep.eumetsat.int).

Go to https://codarep.eumetsat.int and click OK at the dialog that appears.



You will be redirected to a login page. If you do not have an account, please register through the **"NEW USER – CREATE NEW ACCOUNT"** as shown below and then log-in.

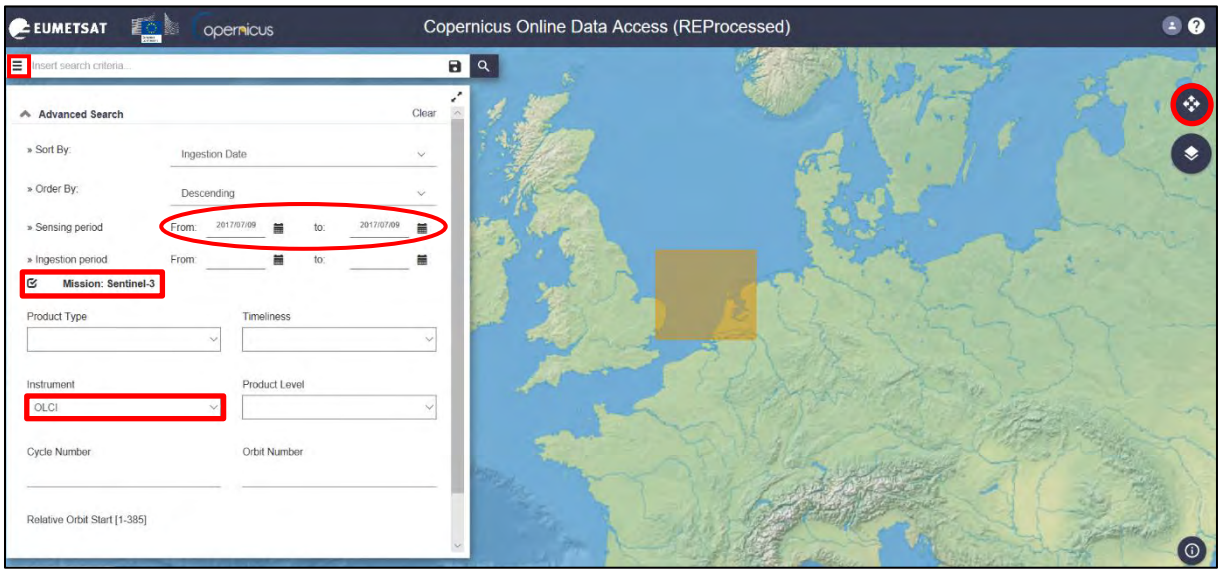




Once you are logged-in, switch the ***"rectangle-drawing mode"*** to ***"pan mode"*** by clicking on the icon in the upper right corner of the map and navigate to the northern part of the English Channel.

Then switch to ***"drawing mode"*** and draw a rectangle approximately as indicated below.
Open search menu by clicking at the left of the search bar.
Specify the following parameters and then search:

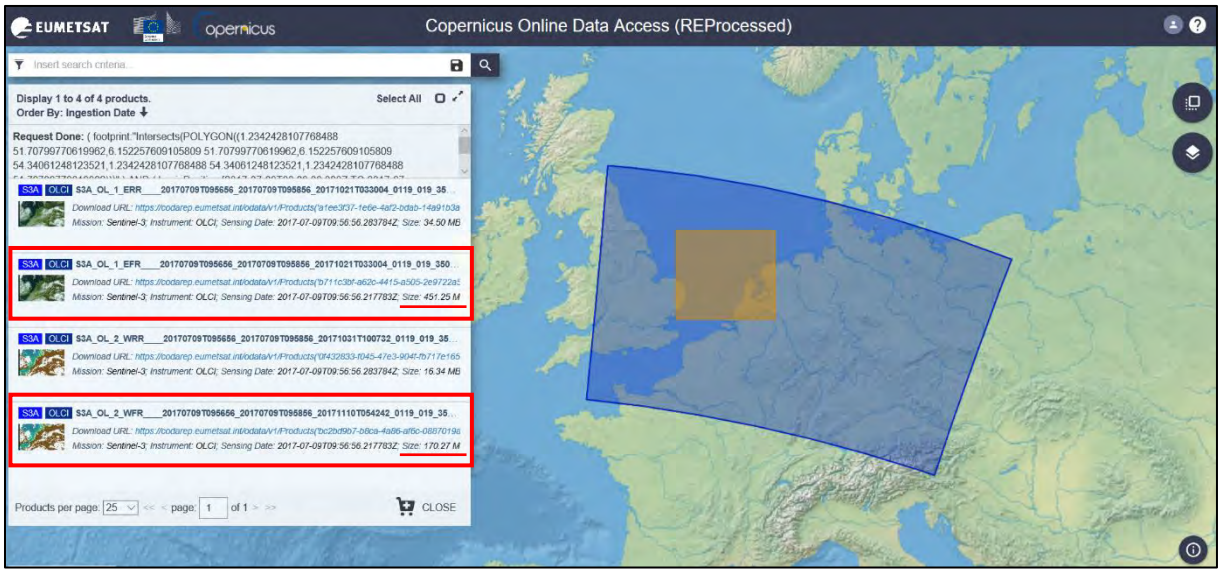
Sensing period: From 2017/07/09 to 2017/07/09
Check Mission: Sentinel-3
Instrument: OLCI



The search returns 4 results for the period we defined over our area of interest.

We need to download the 2 scenes that are of **F**ull **R**esolution (always download the products of larger size – full resolution / E**F**R and W**F**R) by clicking the download icon on each product:

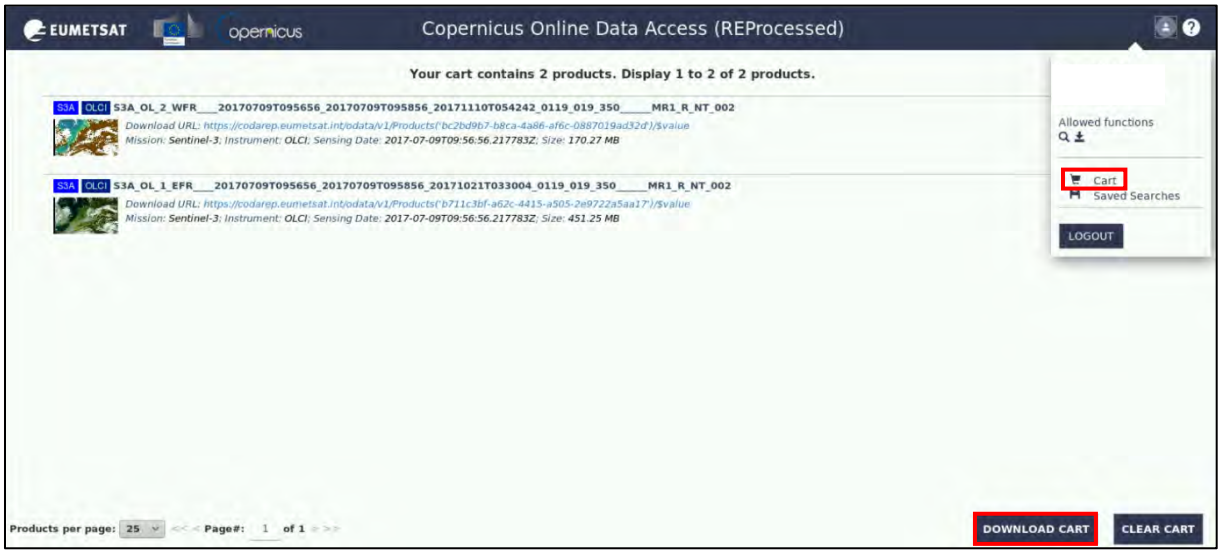
S3A_OL_1_EFR____20170709T095656_20170709T095856_20171021T023004_0119_019_350____MR_1_NT_002
S3A_OL_2_WFR____20170709T095656_20170709T095856_20171021T023004_0119_019_350____MR_1_NT_002



Once the scenes are downloaded, move them from ***/home/rus*** folder to ***/shared/Training/OCEA04_OceanColour_S3_TutorialKit/Original*** folder.

Then right-click on each of the zipped products in turn and go to **"Extract Here"**.

> NOTE 1: There might be a case that you may are not allowed to draw a rectangle at CODA using the browser at your Virtual Machine. Open the website at another browser out of your VM, find the products you need, add them to cart by clicking at this icon and then connect to your CODA account through the browser in the VM and download them from your cart.



In this case, make sure that once the scenes are downloaded, you will move them from ***/home/rus*** folder to ***/shared/Training/OCEA04_OceanColour_S3_TutorialKit/Original*** folder.

Then right-click on each of the zipped products in turn and go to **"Extract Here"**.

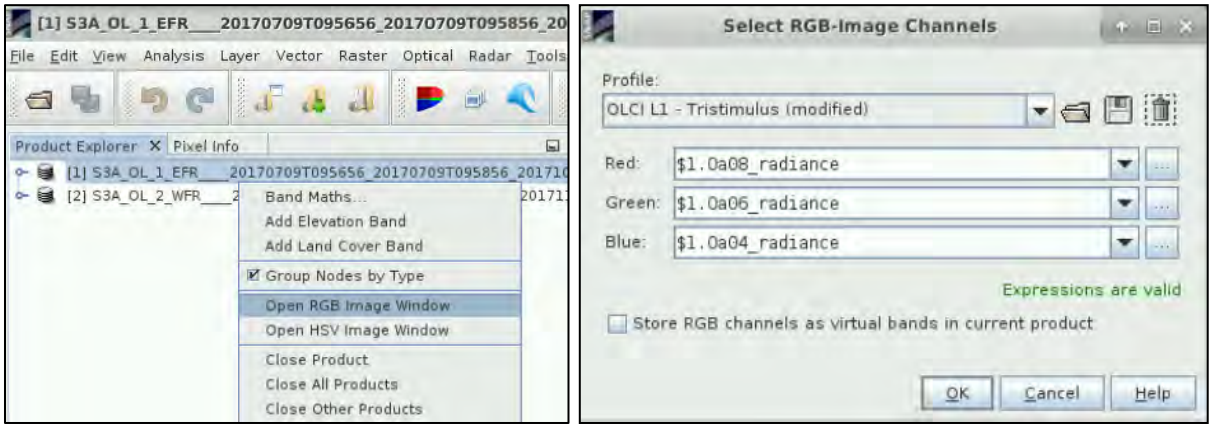
7.2 SNAP – open and explore data

Open **SNAP Desktop** from your desktop or search it in ***Applications → Processing***.

Click on the ***"Open product"*** icon or go to ***"File → Open Product"*** and find the: **/shared/Training/OCEA04_OceanColour_S3_TutorialKit/Original** folder.

Navigate to both folders of the extracted products and open in each one the ***"xfdumanifest.xml"*** file to load the products to SNAP.
The opened products will appear at the **Product Explorer** tab in the upper left part of the window. Right click on the Level-1 product **(S3A_OL_1_EFR____20170709T095656_20170709T095856_20171021T023004_0119_019_350____MR_1_NT_002)** and select **Open RGB Image Window** to create and visualize an RGB composition image.
Set: **Red:** 0a08_radiance, **Green:** 0a06_radiance, **Blue:** 0a04_radiance.

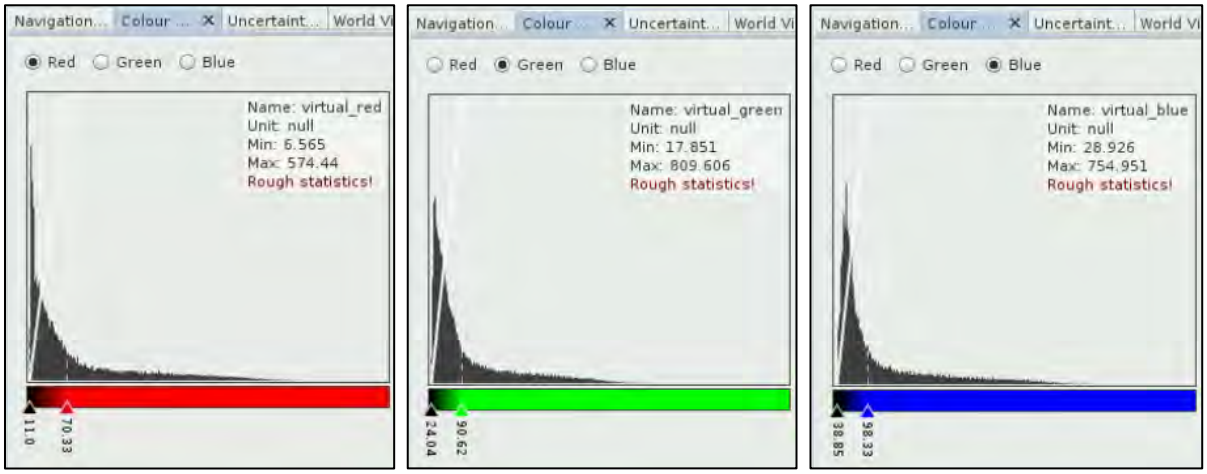
TIP: $1. Refers to the index number of the product at the **Product Explorer** tab.



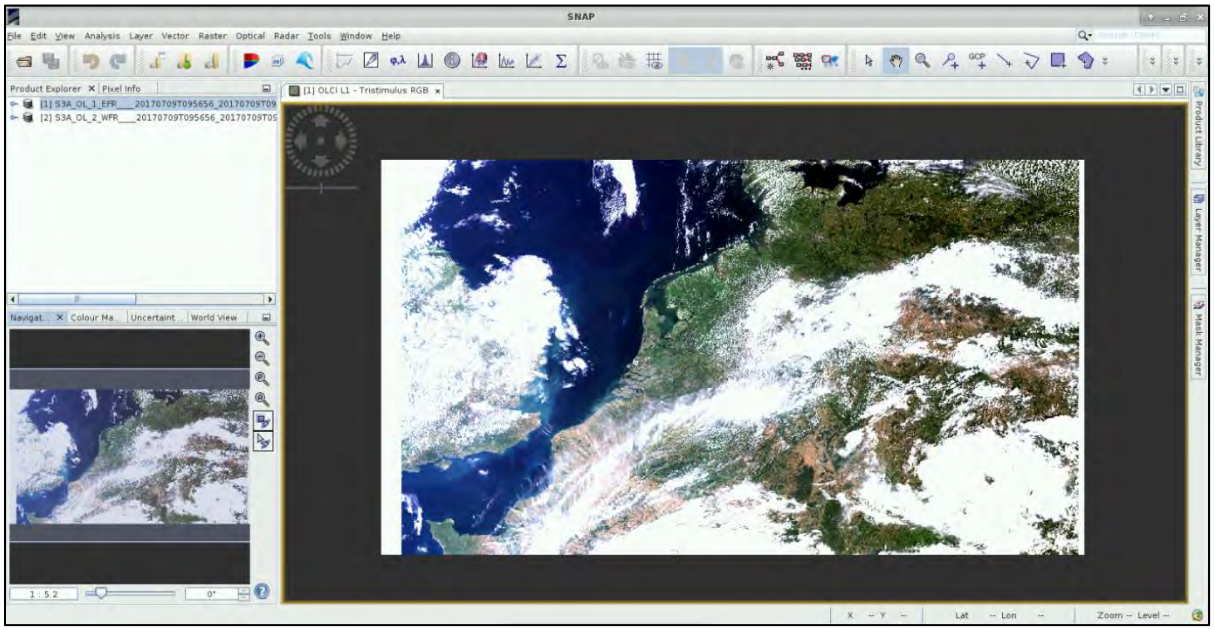
Click **OK** and the RGB image will appear in the **"View Window"**.

The view of the image is very dark and for that reason we will enhance it a bit. Go to the **Colour Manipulation** tab in the lower left corner of the SNAP window. Here we have to change the histogram stretch for each of the RGB component bands.

Check that the **Red** histogram is shown, click on the right-hand slider below the histogram and move it leftwards to approximately **70**.
Change the histogram to **Green** at the top of the tab and set the right-hand slider to approximately **90**.
Last, change the histogram to **Blue** and set the right-hand slider to approximately **100**.



As we can see, the majority of our image is covered by land or clouds and does not contain any valuable information for our purposes, so let's subset it to a smaller area of interest.



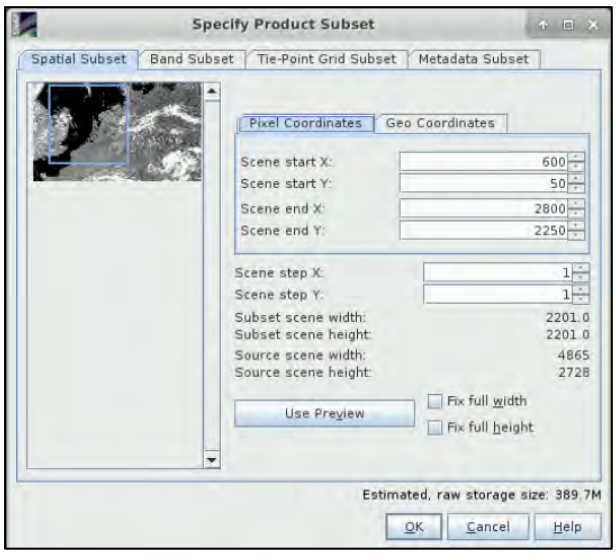
7.3 Subset

Make sure the Level-1 EFR product is selected (highlighted) in the **Product Explorer** tab, if needed click once on it even if it is highlighted.

Go to **Raster → Subset**.

At the **Spatial Subset** tab go to **Pixel Coordinates** tab and set the following coordinates:

Scene start X: 600 **Scene start Y**: 50 **Scene end X:** 2800 **Scene end Y:** 2250



The subset area is indicated by the blue rectangle on the left of the dialog window.

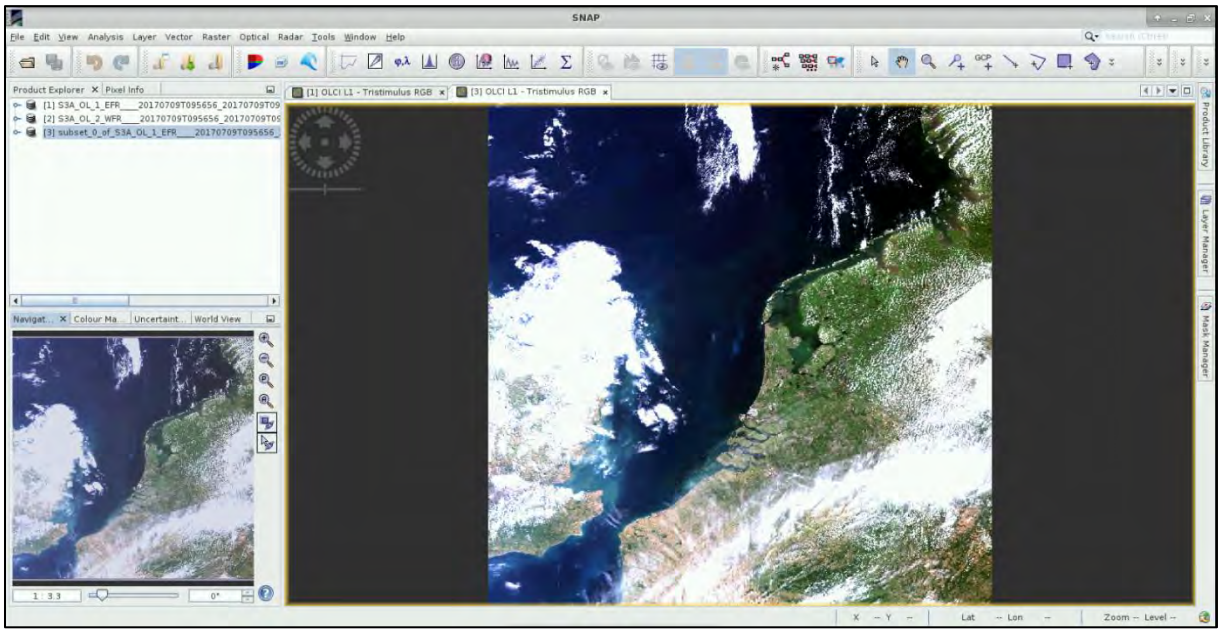
Click **OK**.

A subset product will be created and will appear at the Product Explorer tab with index number [3].

Let's open the RGB view in the same way we have done for the full product and enhance the histogram.

Right click on the **[3] subset_0_of_S3A_OL_1_EFR____20170709T095656_20170709T095856_20171021T023004_0119_019_350____MR_1_NT_002** product and select **Open RGB Image Window** to create and visualize an RGB composition image.
Set: **Red:** 0a08_radiance, **Green:** 0a06_radiance, **Blue:** 0a04_radiance.

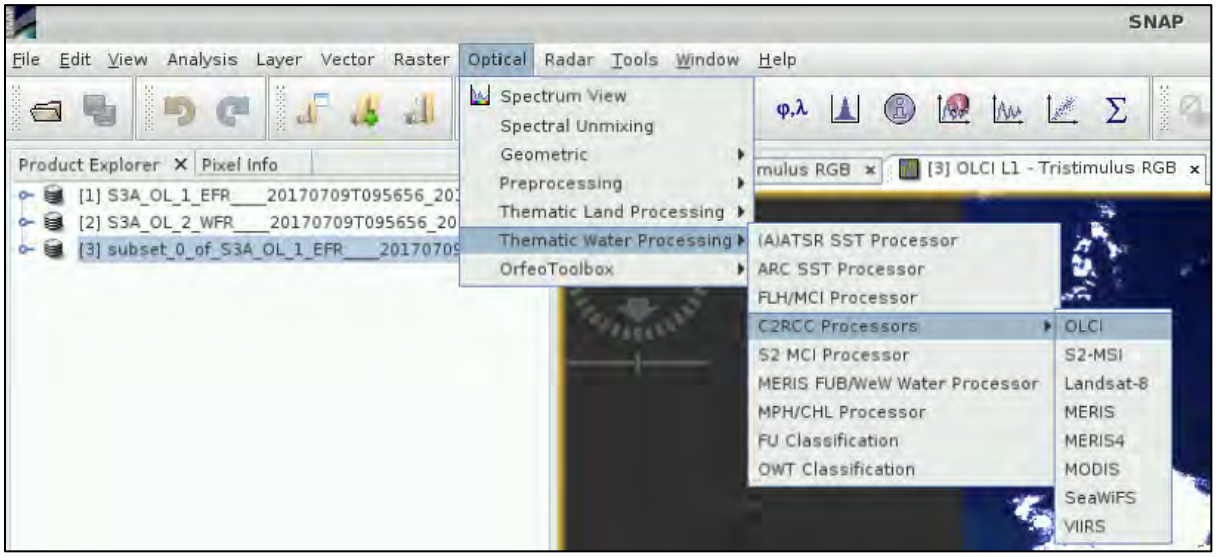
Set again the **Red** histogram to approximately **70**, the **Green** to **90** and the **Blue** to **100**.



7.4 C2RCC Processor

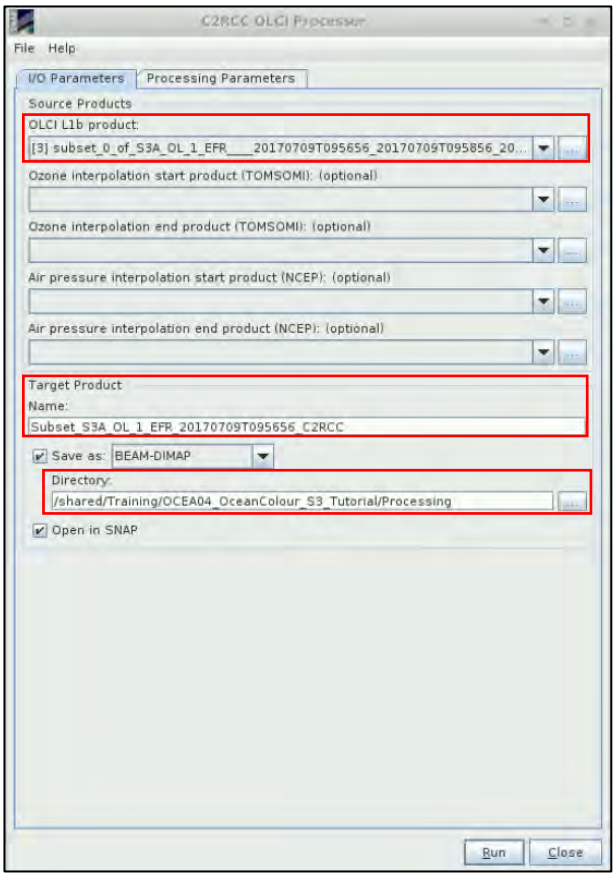
The **C**ase **2** **R**egional **C**oast **C**olour processor had originally been developed by Doerffer and Schiller for the MERIS sensor, and then it was improved through the ESA DUE CoastColour project (Brockmann et al., 2016). It is applicable to all past and current ocean colour sensors (such as Sentinel-3) as well as Sentinel-2. It has been validated in various studies and is available through ESA's Sentinel toolbox SNAP. It is also used in the Sentinel-3 OLCI ground segment processor of ESA for the generation of the Case 2 water products. We will use it here to reproduce the Level-2 Water product that we have also downloaded.

To run the processor, go to **Optical → Thematic Water Processing → C2RCC Processors → OCLI**.
You can see that the C2RCC processor is available for a variety of different sensors.



In the **I/O Parameters** tab, make sure that the subset product with index number [3] is selected as source **OLCI L1b product**.

The original name of the S3 product is quite long so let's replace it with something more manageable.



In the **Target Product** section under **"Name"**, the **"C2RCC"** ending will be added automatically.

Rename the product and keep it as: ***"Subset_S3A_OL_1_EFR_20170709T095656_C2RCC".***

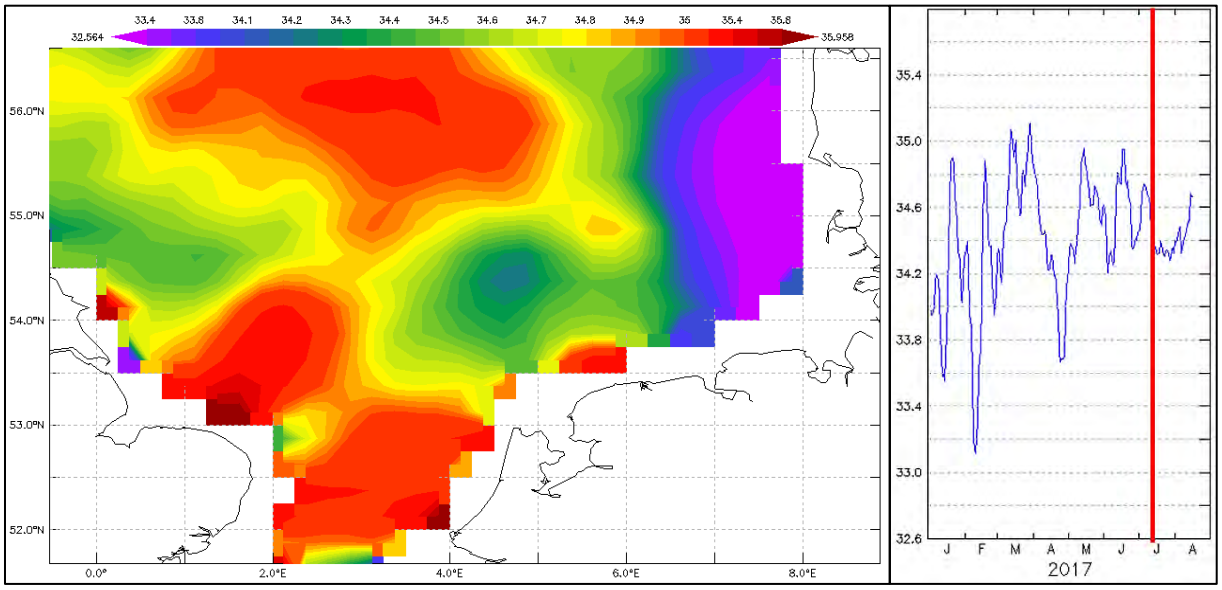
Below the **Directory**, set as output: ***/shared/Training/OCEA04_OceanColour_S3_Tutorial/Processing***.

In the **Processing Parameters** tab, we will define the values about **"salinity"** and **"temperature"** that correspond to our area of interest for that certain date, 8th of July 2017.

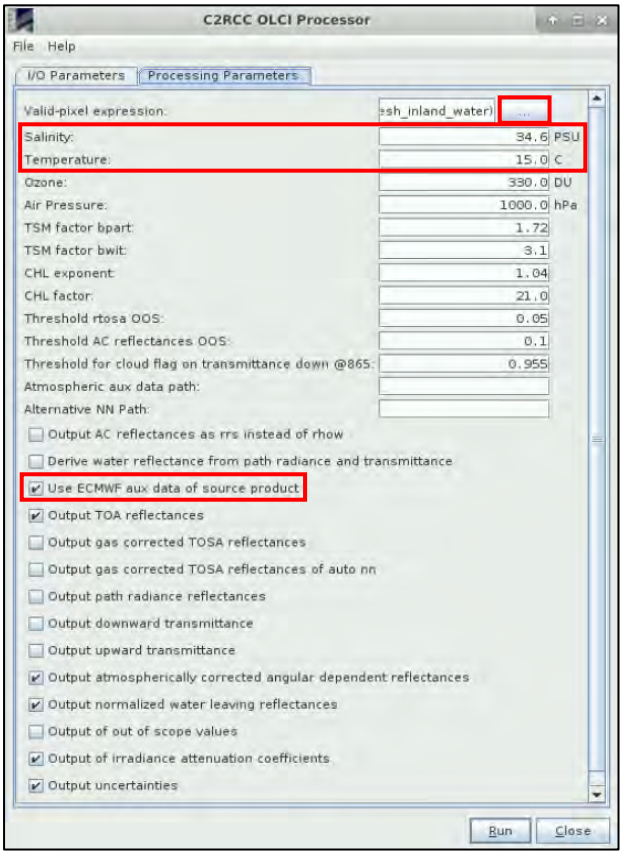
These variables among others are used to determine the absorption and scattering of pure water.

You can find and download the dataset for the specific date we need at the following link: https://opendap.jpl.nasa.gov/opendap/SalinityDensity/smap/L3/JPL/V3/8day_running/2017/185/contents.html

Instructions how to use it can be found here: https://www.youtube.com/watch?v=npOKkLtXE0w
Alternatively, you can find the values for salinity and sea surface temperature, as shown below (note that this dataset might not be available anymore):



Sea Surface Salinity SST (Dataset: JPL SMAP Level 3 CAO Sea Surface Salinity Standard Mapped Image 8-Day Running mean V3.0 Validated dataset) for 8 July 2017. Left: spatial variability; Right: study area SST average value; Source: JPL Climate Oceans and Solid Earth group. 2017)



For **"Salinity"**, set value of 34.6 PSU and for **"Temperature"** of 15°C.

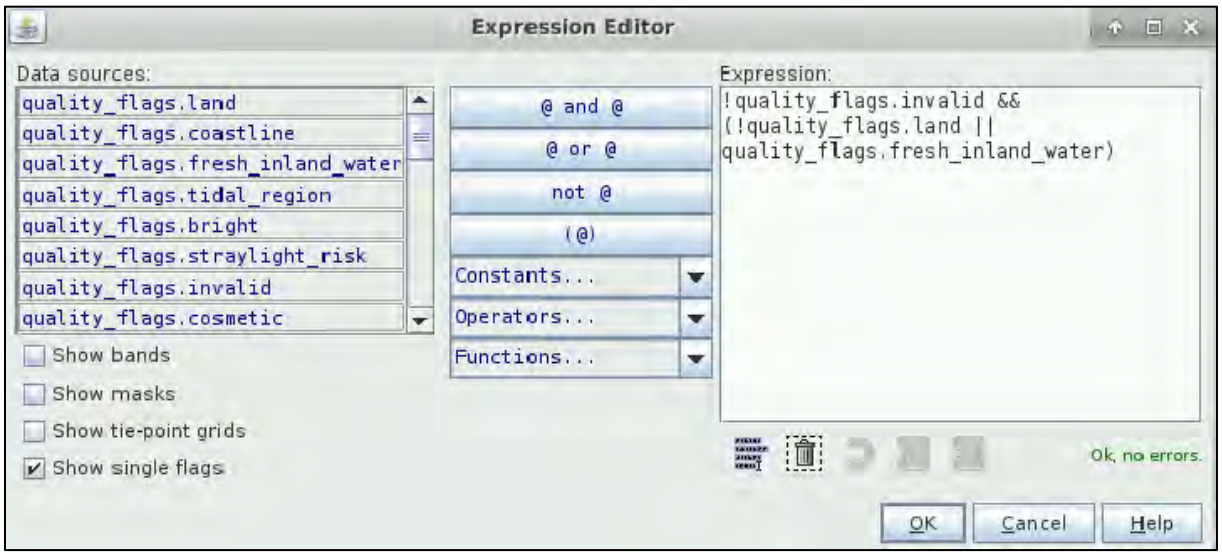
We will keep the default values for Ozone and Air Pressure, while the total ozone and sea level pressure grids that are available in the OLCI L1b products (ECMWF auxiliary met data) will be used.

This option below must be ticked (✓ **Use ECMWF aux data of source product**).

The other parameters define the arithmetic relationship between inherent optical properties (IOPs) of the water constituents (absorption by pure water, phytoplankton pigments, yellow matter, etc.) and the actual concentrations of chlorophyll and total suspended matter. We will leave all default values as these have been widely tested and validated and are also used to derive the S-3 Level 2 product.

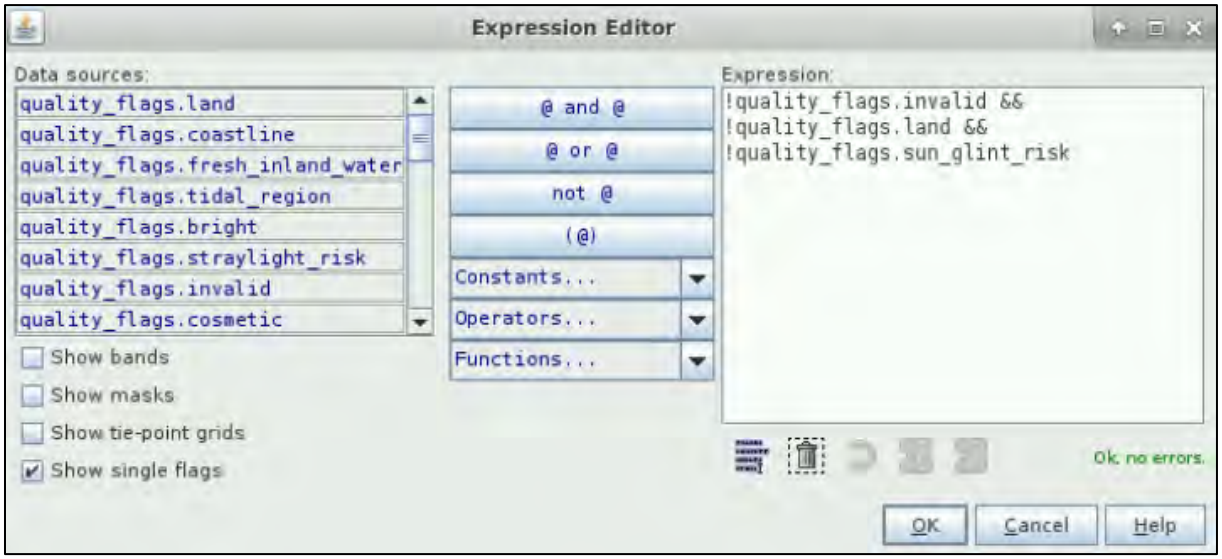
The only parameter we will change in the **Processing Parameters** tab will be the **Valid-pixel expression**. To edit the default expression, click on the three dots at the upper right corner.

Based on the default expression, pixels are valid if: the invalid flag is false, and the land flag is false as well, with the exception of inland water bodies. (**!** equals to **not**) (**&&** equals to **and)**.



We will change the expression: we will remove from the expression the inland waterbodies and we will add the sun glint risk flag because we want to also exclude these pixels from our calculations. To achieve this, the final expression will be set as:

```
!quality_flags.invalid && !quality_flags.land &&
!quality_flags.sun_glint_risk
```



Click **OK** and then click **Run** to execute the C2RCC processor. This might take up to 10 minutes depending on your VM/PC.

Once the processing has finished and notification window will appear, click **OK**.

Close the C2RCC OLCI Processor dialog window.

In your **Product Explorer** tab, you will find a new product with index number [4].

7.5 Visualization

Now let's see our outputs. Expand the new product in the **Product Explorer** tab and then expand the **Bands** folder. In the Bands folder, you will find 7 folders and 2 additional bands.

The 1st folder ***"iop"*** contains the absorption coefficient bands for different water constituents at 443 nm.

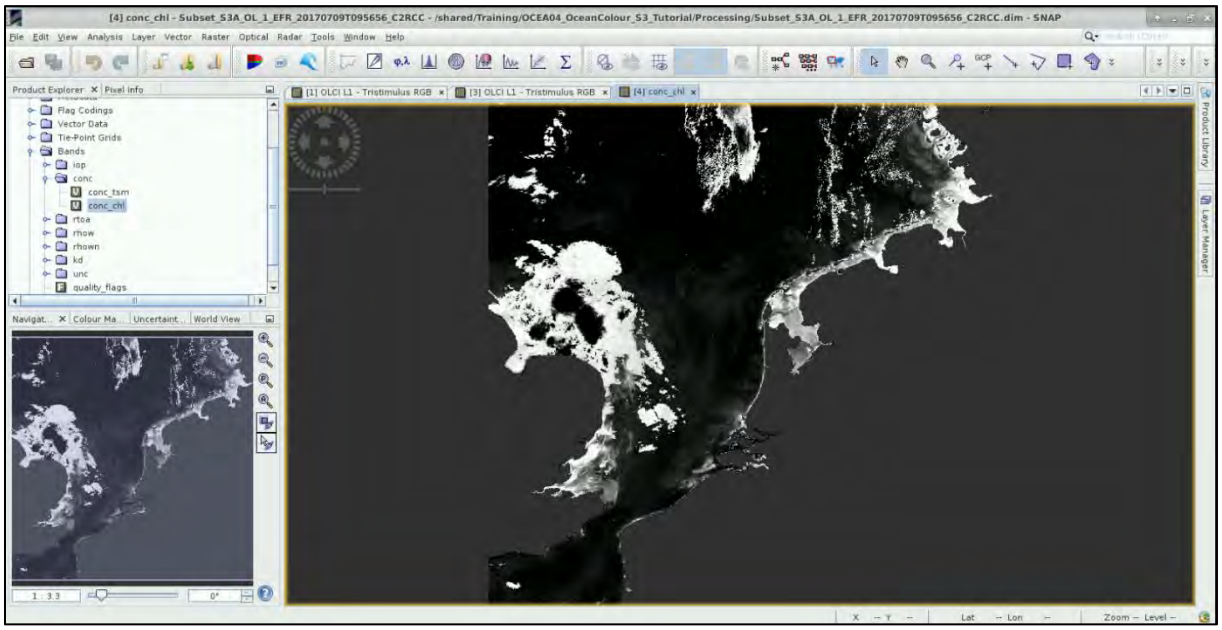
The 2nd folder ***"conc"*** contains the absolute concentration bands for total suspended matter dry weight (*conc_tsm* [g*m^{-3}]) and chlorophyll concentration (*conc_chl* [mg*m^{-3}]).

The next folder we are interested in is the 5th one, ***"rhown"*** containing the Normalized water-leaving reflectances for each original radiance band (See NOTE 2).

Lastly, we need to pay attention to the 7th, ***"unc"*** folder that contains uncertainty estimates for the IOPs and the concentration bands.

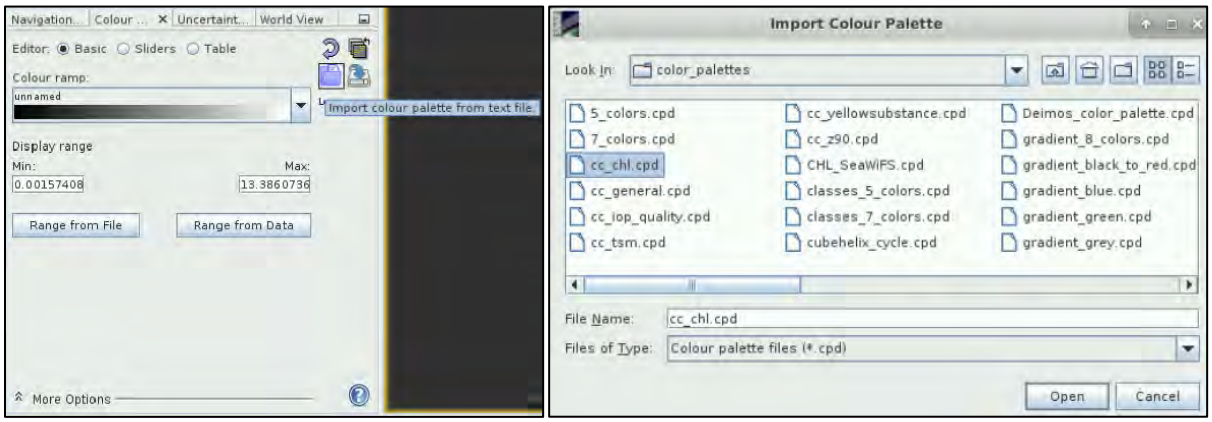
> NOTE 2: **Radiance** is the variable directly measured by remote sensing instruments. It is the amount of light seen by instrument from a surface of an object. In the SLSTR products is given as radiance of a surface per wavelength unit [mW*m^{-2}*sr^{-1}*nm^{-1} = watt per square meter per nanometer]. **Reflectance** is the ratio (percentage) of the amount of light leaving a target to the amount of light arriving to the target. It has no units. It is the property of the observed object/material.

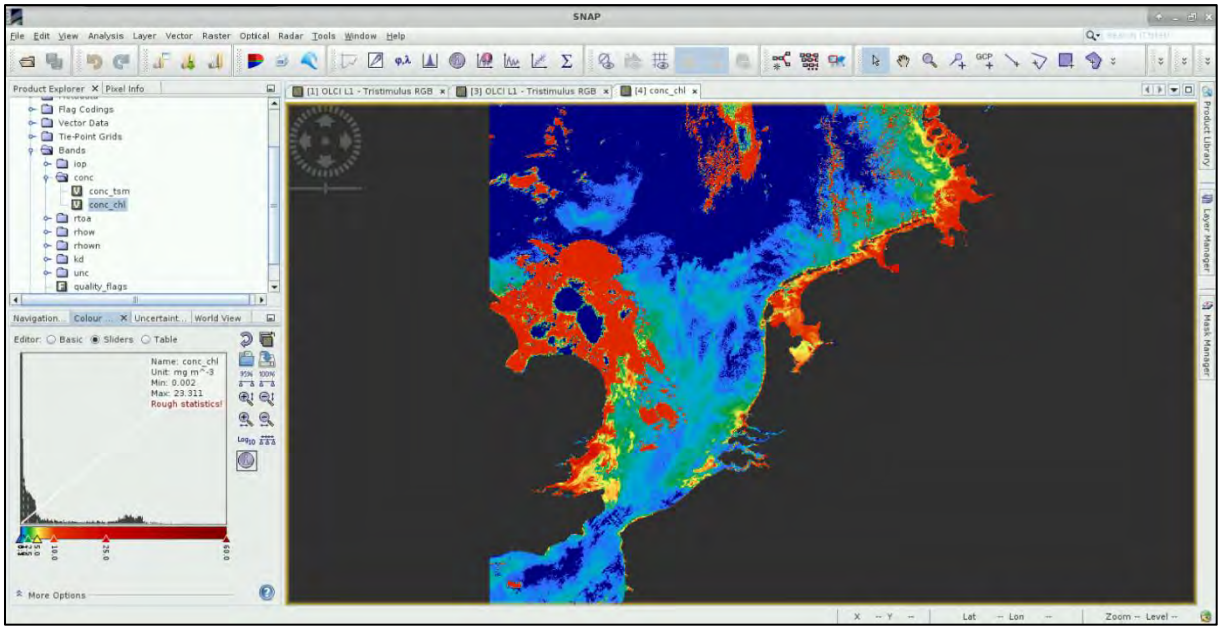
Let's expand the ***"conc"*** folder and double click on ***"conc_chl"*** band to open it in view window.



We can see that all the land areas have been removed but clouds appeared are misclassified as high concentration. We can use the masks included in the product to eliminate them.

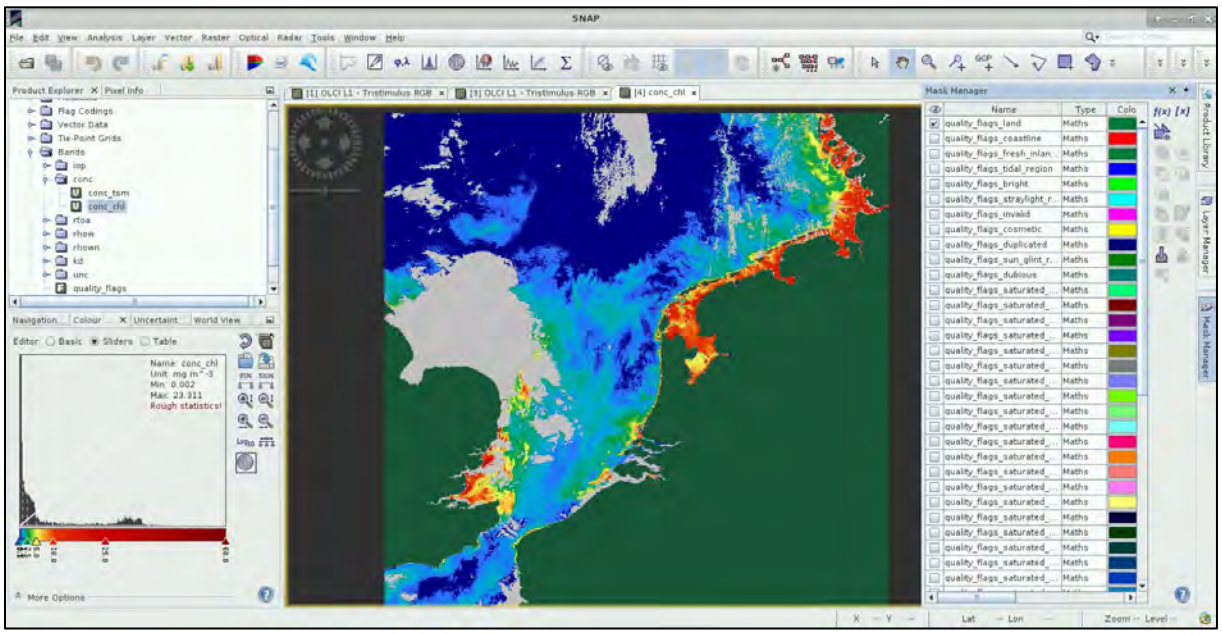
Firstly, go to **"Colour Manipulation"** tab and import/open the colour palette named ***"cc_chl.cpd"***. At the dialog that will appear at the bottom left, click **NO** to keep the predefined colour classes.





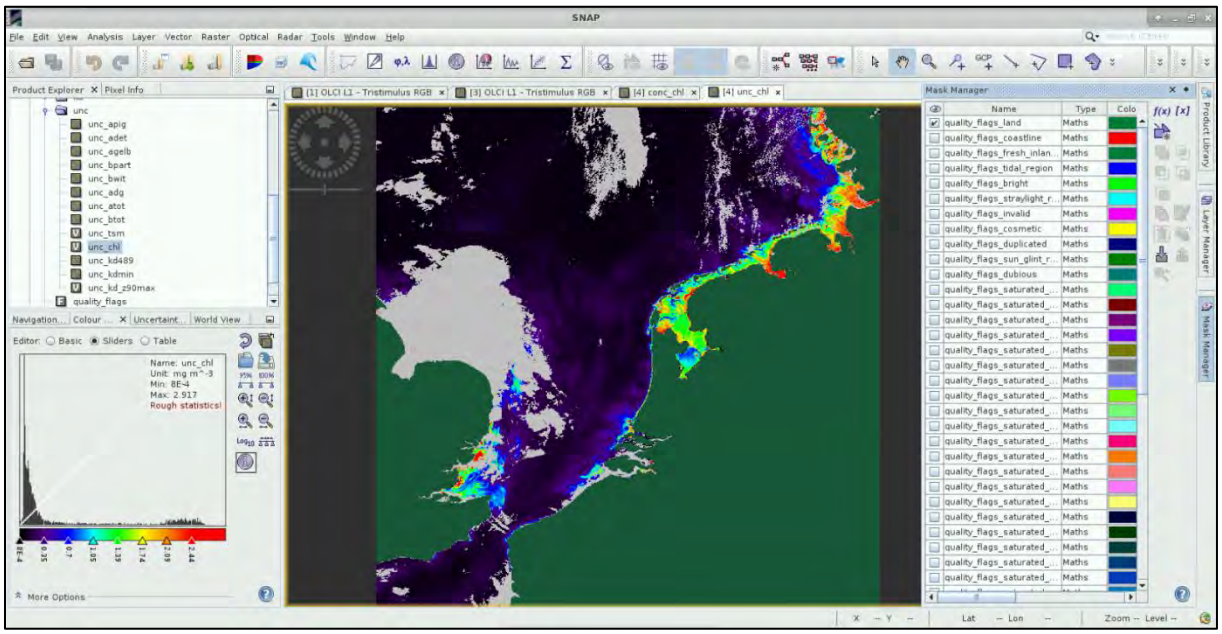
Then go to **View → Tool Windows → Mask Manager**. The **Mask Manager** window should appear docked at the right side of the SNAP window (if not already there).
There you can enable flags indicating land (***quality_flags_land*** - green) and clouds (***Cloud_risk*** - gray). You may need to zoom-in and out to load the masks properly.

IMPORTANT! The masks do not remove the values corresponding to clouds from the histogram; they only hide them from view.



You can also inspect the uncertainty of these concentration estimates.

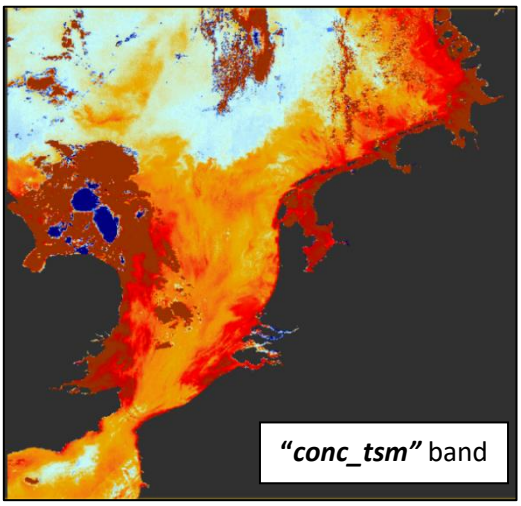
Go to the ***"unc"*** folder and open the ***"unc_chl"*** band. Then, go to **"Colour Manipulation"** tab and open the colour palette named ***"spectrum"***. You can again use the masks (***quality_flags_land*** - green) and (***Cloud_risk*** - gray) to mask out the land and cloud values.

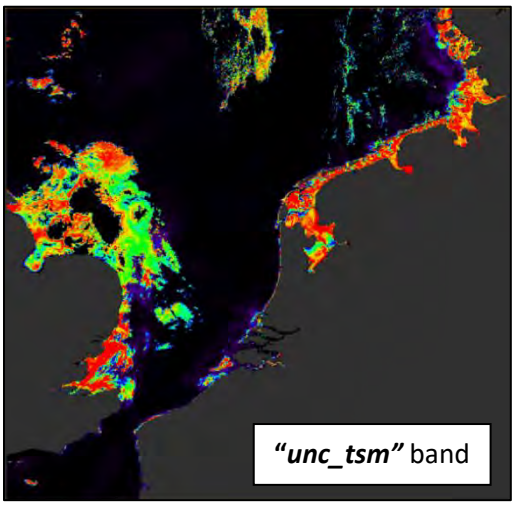


You can also explore the total suspended matter estimates.

Open the ***"conc_tsm"*** band, the go to **"Colour Manipulation"** tab and import/open the colour palette

named **"*cc_tsm.cpd*"** and click again **NO** at the dialog that will appear at the bottom left, to keep the predefined colour classes. Finally, investigate the **"*unc_tsm*"** band as well and at the **"Colour Manipulation"** tab, open the colour palette named **"*spectrum*"**.





Close all views except the "***conc_chl***" view.

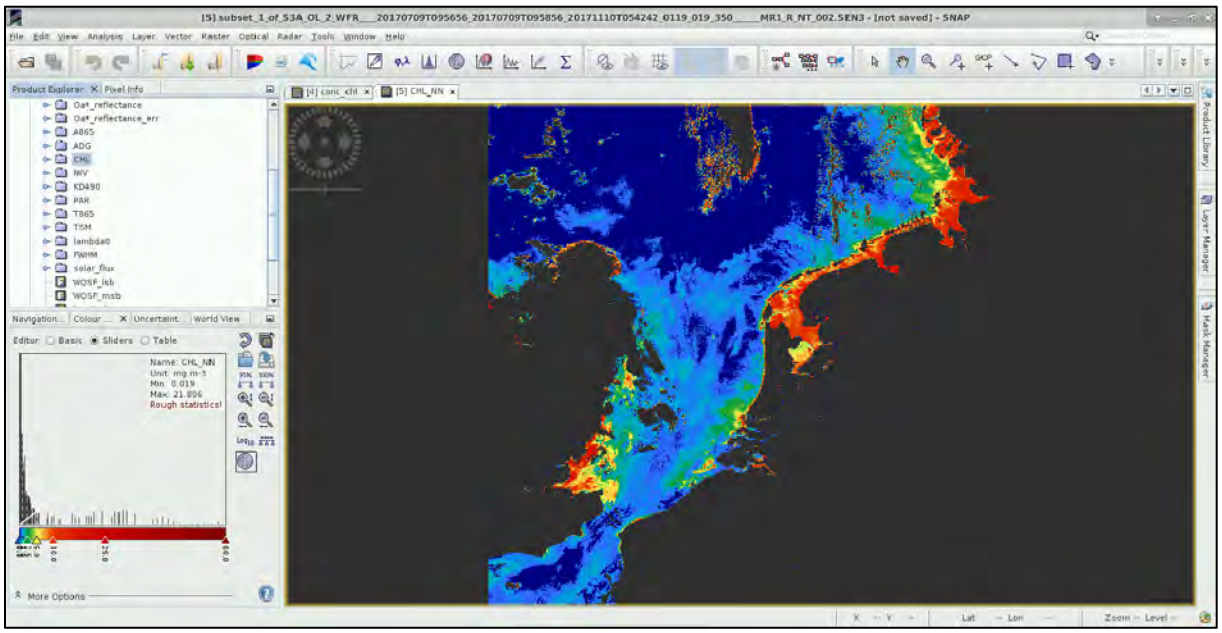
7.6 Comparison to the Level-2 WFR product

In the beginning of the exercise, we have downloaded two products, Level-1 EFR product (that we have processed) and Level-2 WFR product. Now let's compare our output to the operationally generated. In the **Product Explorer** tab, highlight the Level-2 product (index number 2).

Go to **Raster → Subset** and subset the product using the same pixel coordinates as for the Level-1. At the **Spatial Subset** tab go to **Pixel Coordinates** tab and set the following coordinates:

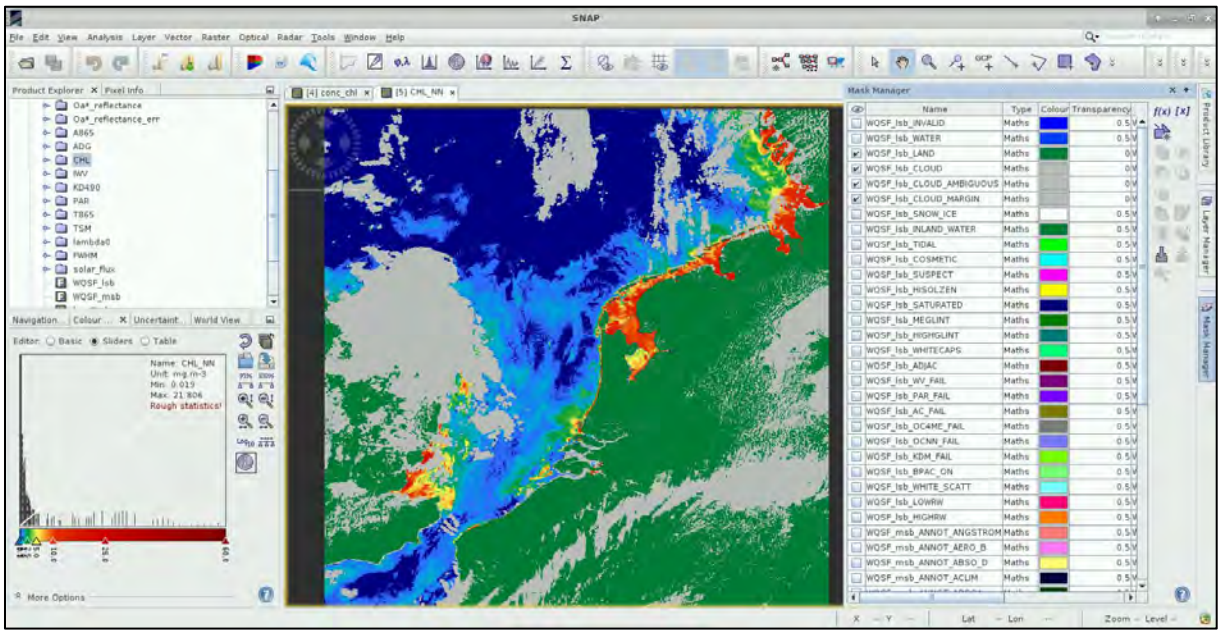
Scene start X: 600 **Scene start Y**: 50 **Scene end X:** 2800 **Scene end Y:** 2250

Expand the subset with index number [5] in the **Product Explorer** tab and expand the **Bands** folder. Expand the ***"CHL"*** folder and double click on **"*CHL_NN*"** band. Again, go to the **"Colour Manipulation"** tab and load the **"*cc_chl.cpd*"** colour palette. At the dialog that will appear at the bottom left, click **NO** to keep the predefined colour classes.

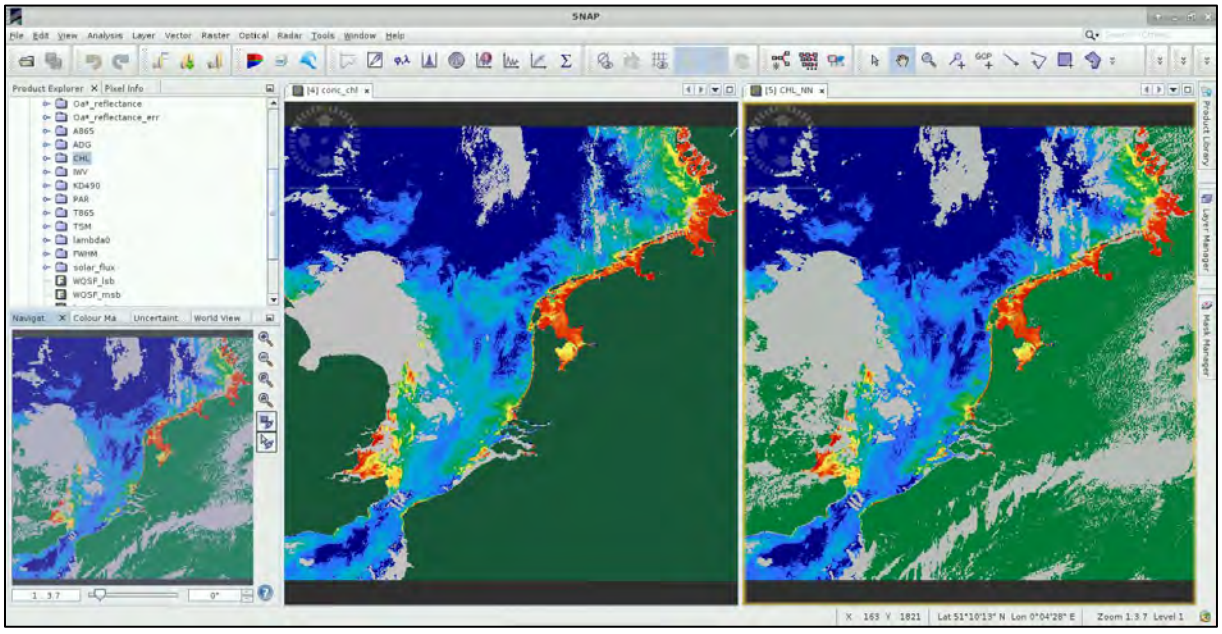


Open the **Mask Manager** and turn on the "***WQSF_lsb_LAND***" mask as well as all the cloud related masks ("***WQSF_lsb_CLOUD***", "***WQSF_lsb_CLOUD_AMBIGUOUS***", "***WQSF_lsb_CLOUD_MARGIN***").

In the **Transparency** column, change the transparency to 0 for those 4 masks.



Go to **Window → Tile Horizontally**; in **Navigation** tab select **Zoom all.**

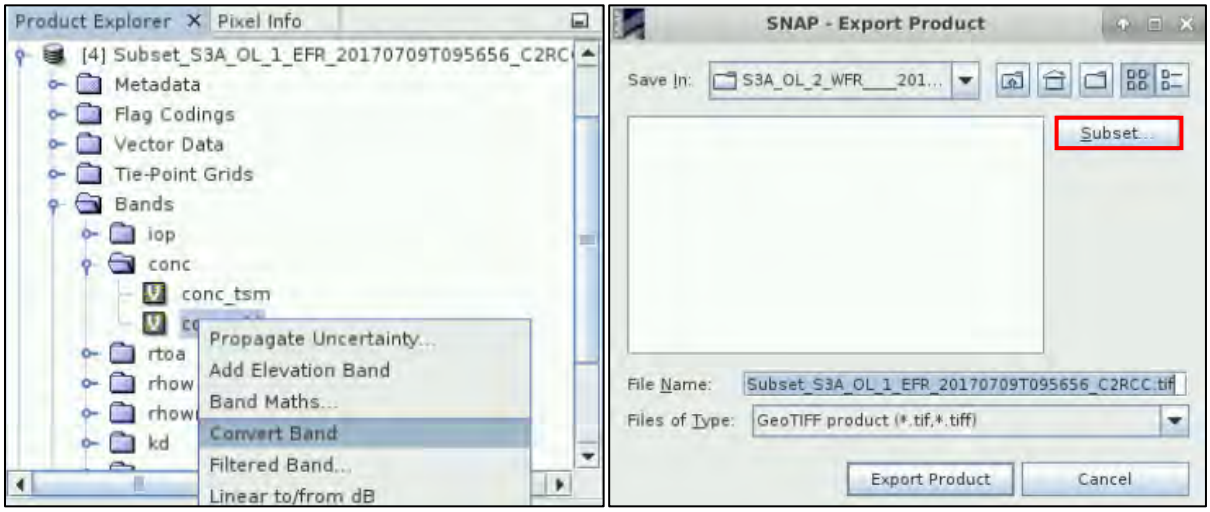


You can also open the uncertainty bands and compare them. You will see some minor differences mostly due to the additional pre-processing applied during the generation of the Level-2 WFR product by the ground segment. These pre-processing steps are not applied to the Level-1 product we have processed and are not part of the C2RCC algorithm.

7.7 Export as GeoTIFFs

Close all view windows. In **Product Explorer,** expand the Subset of the Level-1 processed product with index number [4]. Expand ***"Bands"*** folder. Then expand ***"conc"*** folder. Right-click on the ***"conc_chl"*** band and select **Convert Band** (this converts the band from virtual to physical, so we can export it).

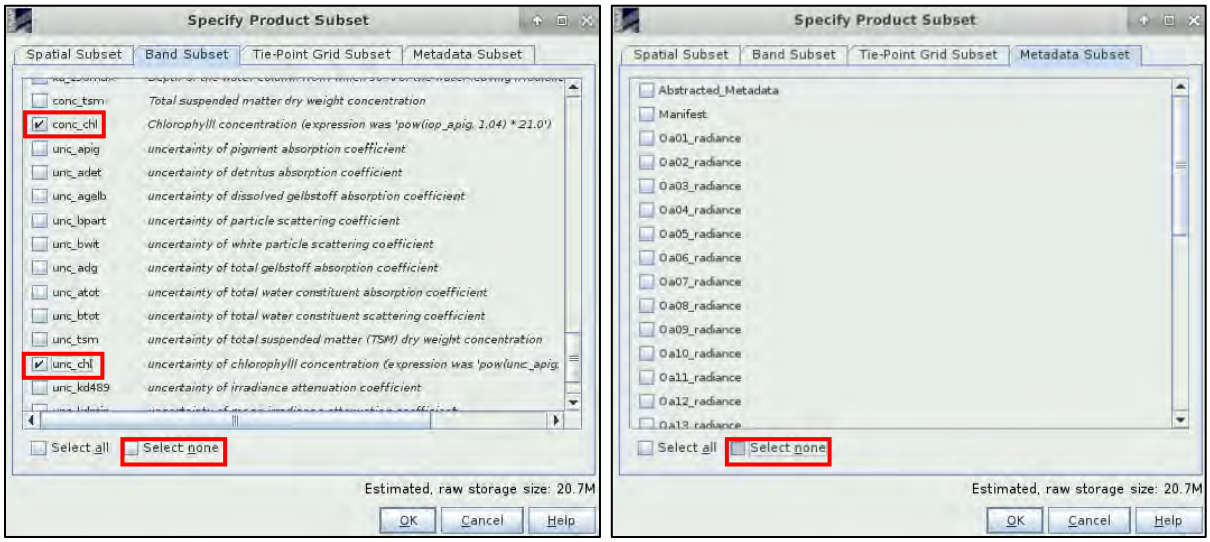
Do the same for the ***"unc_chl"*** band. Right-click the product name and select **Save Product**.



Go to **File → Export → GeoTiff** (**NOT!** Geotiff/Big Tiff). In the dialog, that opens click **Subset.**

At the **Band Subset** (second tab) use the **Select none** button to deselect them all first and then select only bands ***"conc_chl"*** and ***"unc_chl"***.

Then go to the **Metadata Subset** tab and click **Select none**.



Then click **OK**. In the dialogs (one or two), that appear, click **NO**.

*S*ave the file to the ***"Processing"*** folder as: ***Chlorophyll_conc_20170709.tif*** and press **"Export Product"**. Repeat the same for the **TSM bands** (save as ***TSM_20170709.tif***).

Now, we can import the image to another GIS/ Remote sensing software for further processing or map creation. In the extra steps of this tutorial, we will use QGIS. To download the results to your local computer, see section **6.1 Downloading the outputs from VM**.

THANK YOU FOR FOLLOWING THE EXERCISE!

8 Extra steps

8.1 Downloading the outputs from VM

Press **Ctrl+Alt+Shift.** A pop-up window will appear on the left side of the screen. Click on 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.**

9 Further reading and resources

Gower, J.F.R., Doerffer, R., Borstad, G.A., 1999. Interpretation of the 685nm peak in water-leaving radiance spectra in terms of fluorescence, absorption and scattering, and its observation by MERIS. International Journal of Remote Sensing 20, 1771–1786. https://doi.org/10.1080/014311699212470

Brockmann, C., Doerffer, R., Peters, M., Kerstin, S., Embacher, S., Ruescas, A., 2016. Evolution of the C2RCC Neural Network for Sentinel 2 and 3 for the Retrieval of Ocean Colour Products in Normal and Extreme Optically Complex Waters. Presented at the Living Planet Symposium, p. 54.

JPL Climate Oceans and Solid Earth group. 2017. JPL SMAP Level 3 CAP Sea Surface Salinity Standard Mapped Image 8-Day Running Mean V3.0 Validated Dataset. Ver. 3.0. PO.DAAC, CA, USA. Dataset accessed 2018-02-21] at http://dx.doi.org/10.5067/SMP30-3TPCS.

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