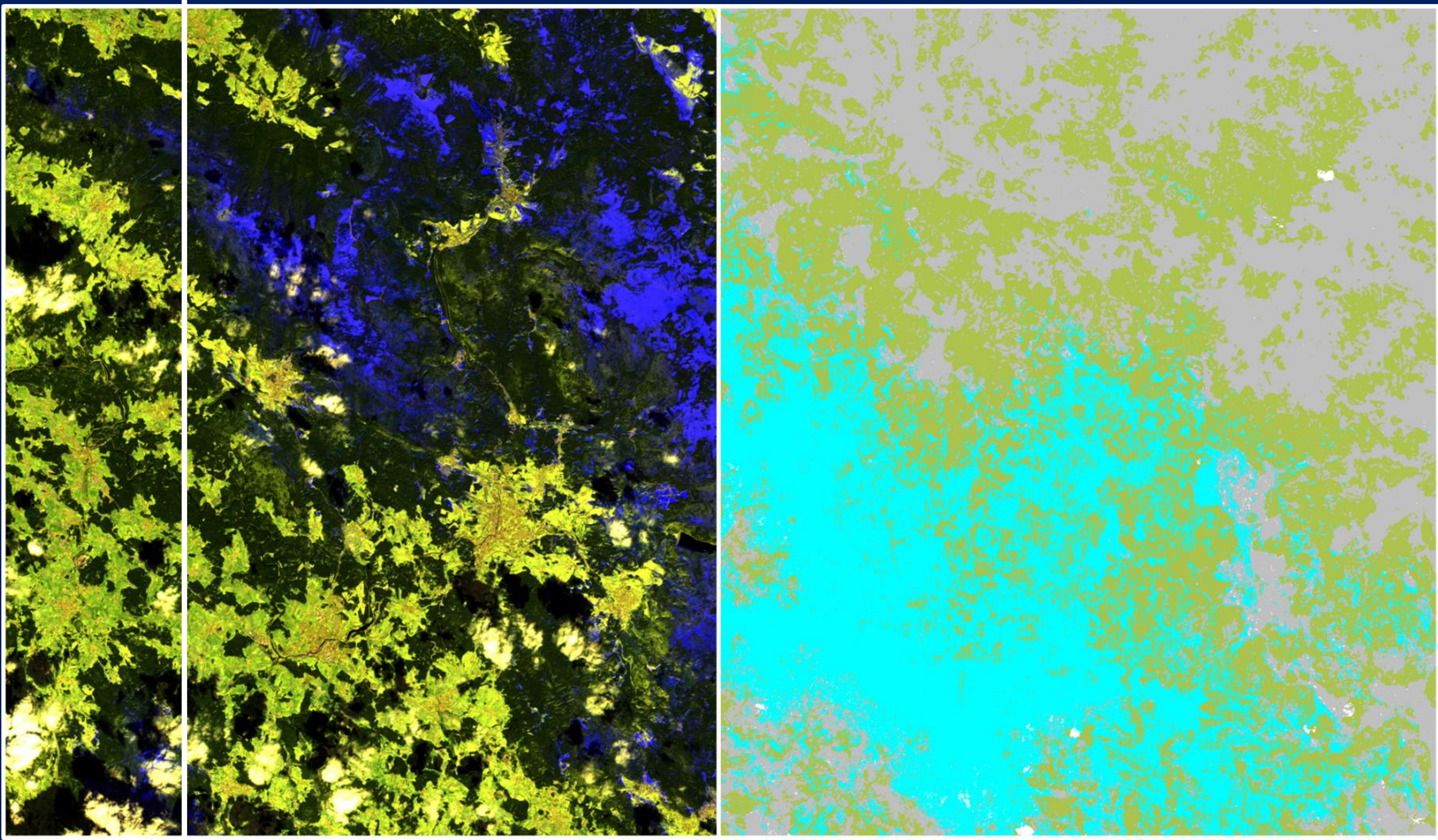

TRAINING KIT

SNOW COVER MAPPING WITH SENTINEL-2 FEBRUARY-MARCH 2019, ŠUMAVA

Research and User Support for Sentinel Core Products

The RUS Service is funded by the European Commission, managed by the European Space Agency and operated by CSSI and its partners.

Authors would be glad to receive your feedback or suggestions and to know how this material was used. Please, contact us on training@rus-copernicus.eu

Cover images produced by RUS Copernicus

The following training material has been prepared by Serco Italia S.p.A. within the RUS Copernicus project.

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Table of Contents

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.

2 Snow mapping – background

Snow cover is an important driver of many climatic, hydrological and ecological processes and is a required input to many models aiming to study and predict them. Snow cover area (SCA) is also one of the essential climate variables (ECVs) specified by the Global Climate Observing System (GCOS) to be observed by remote sensing in support of the United Nations Framework Convention on Climate Change (UNFCCC) and the Intergovernmental Panel on Climate Change (IPCC).

There are multiple methodologies designed to observe snow cover using optical and SAR satellites. In this exercise you will learn how to process low-cloud optical Sentinel-2 data using the SNAP toolbox to create snow cover maps based on the Normalized Difference Snow Index (NDSI). The methodology has been adapted and simplified from Gascoin et al. (2019) - *Theia Snow collection: high-resolution operational snow cover maps from Sentinel-2 and Landsat-8 data. Earth System Science Data* 11 (2).

3 Training

Approximate duration of this training session is one hour.

3.1 Data used

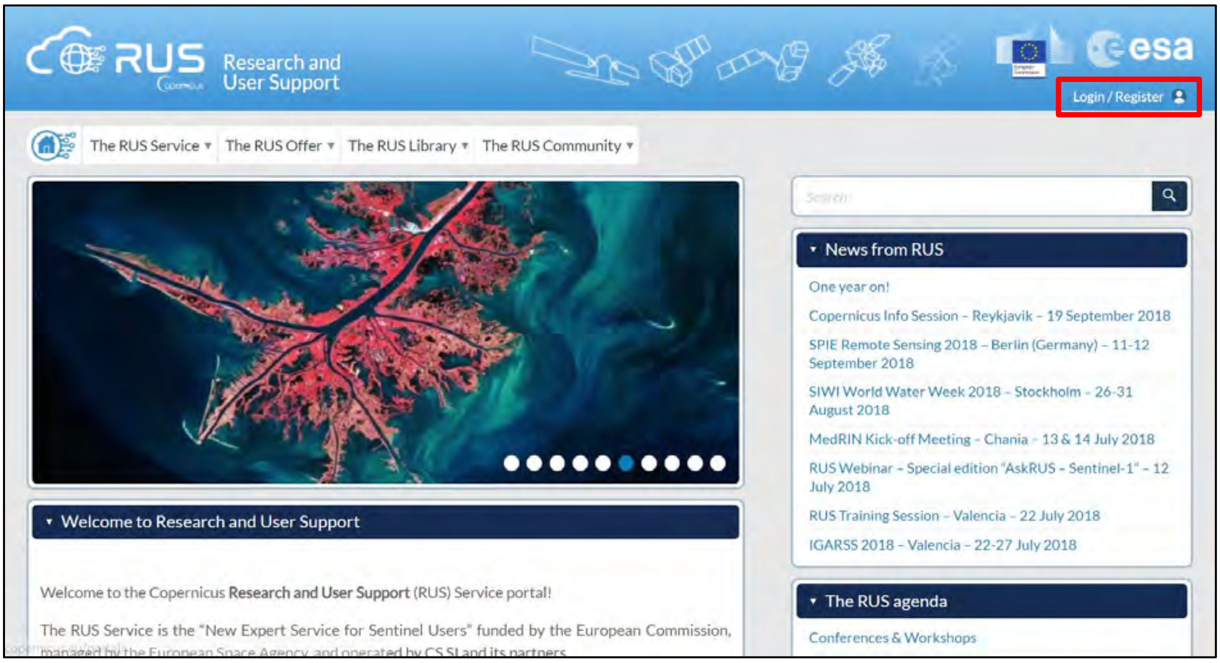
- Four low/no-cloud Sentinel-2A Level 2A products (Tile ID: *T33UUQ*) acquired during February and March 2019 [downloadable @ https://scihub.copernicus.eu/]
  - *S2B_MSIL2A_**20190218**T101059_N0211_R022_**T33UUQ**_20190218T161620.zip*
  - *S2A_MSIL2A_**20190223**T101021_N0211_R022_**T33UUQ**_20190223T123814.zip*
  - *S2B_MSIL2A_**20190228**T101029_N0211_R022_**T33UUQ**_20190228T143058.zip*
  - *S2B_MSIL2A_**20190320**T101029_N0211_R022_**T33UUQ**_20190320T195148.zip*

3.2 Software in RUS environment

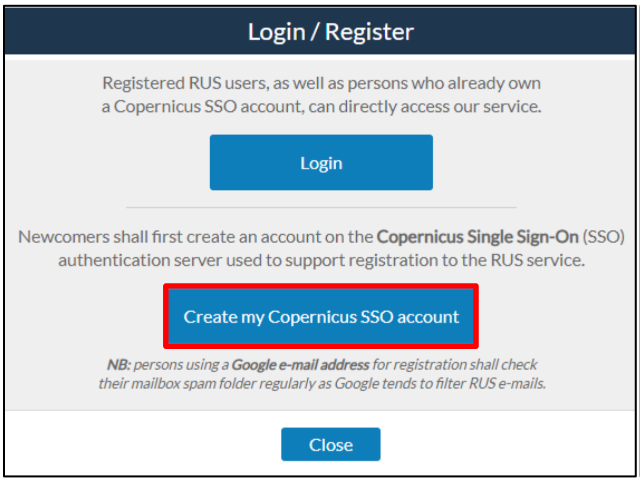
Internet browser, SNAP + Sentinel-2 Toolbox, Aria2

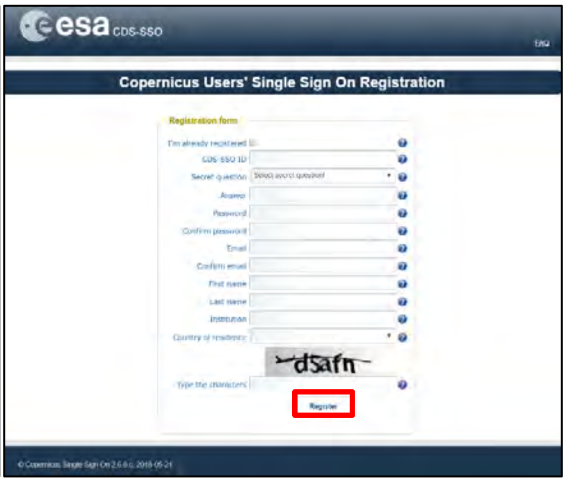
4 Register to RUS Copernicus

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.



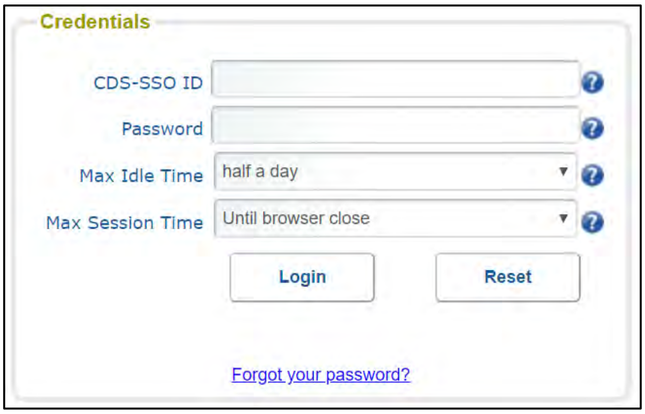
Select the option ***Create my Copernicus SSO account*** and then fill in ALL the fields on the **Copernicus Users' Single Sign On Registration**. Click ***Register***.



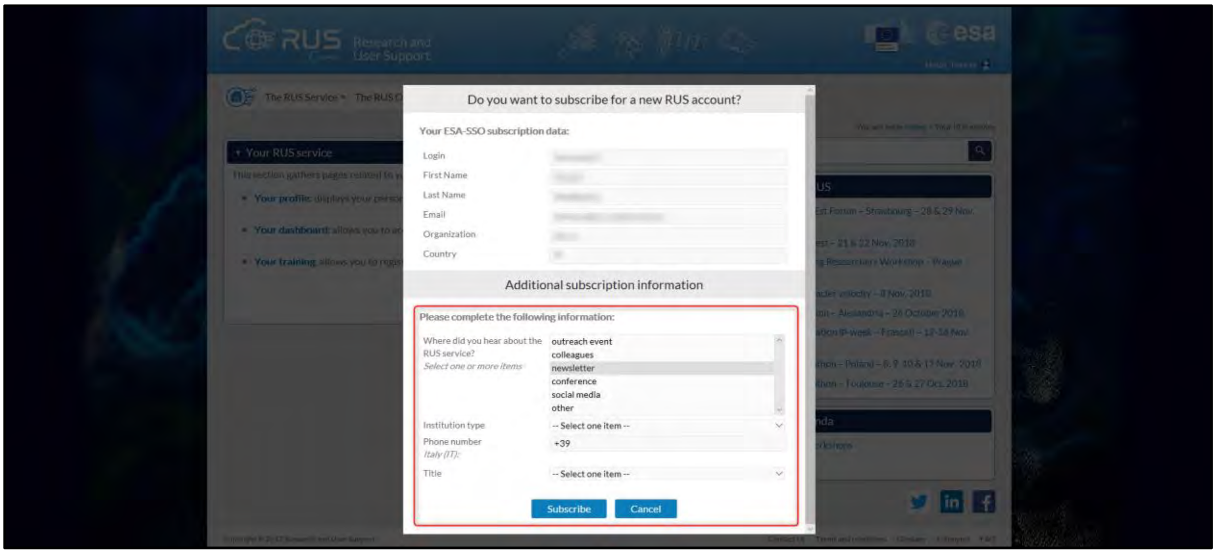


Within a few minutes you will receive an e-mail with activation link. Follow the instructions in the e-mail to activate your account.

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

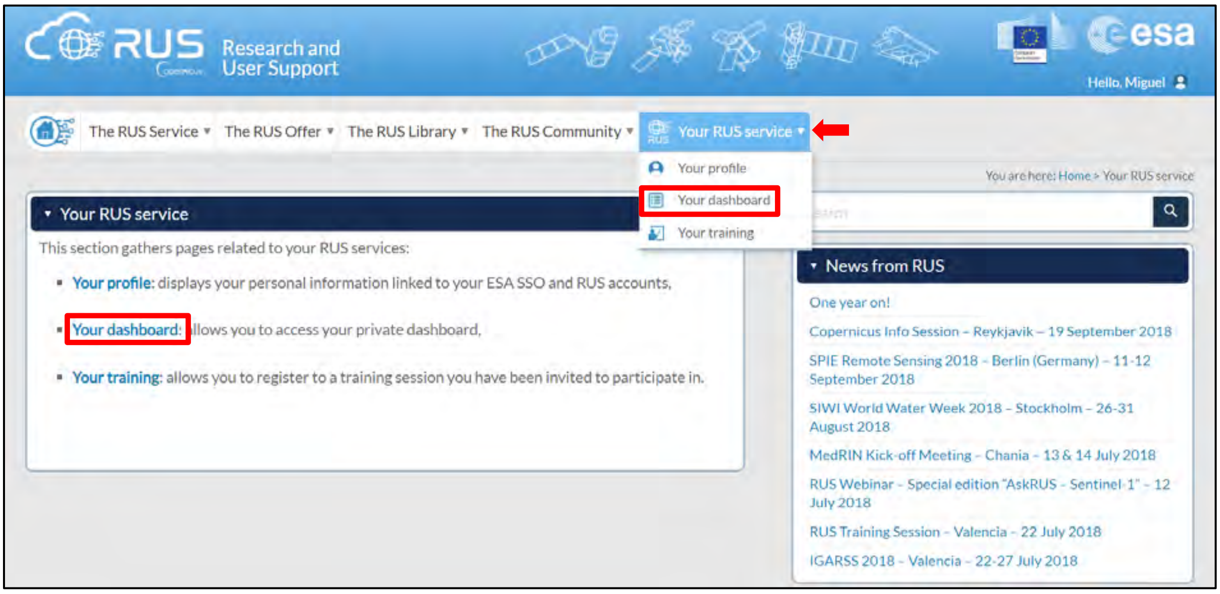


Upon your first login you will need to enter some details. You must fill all the fields.

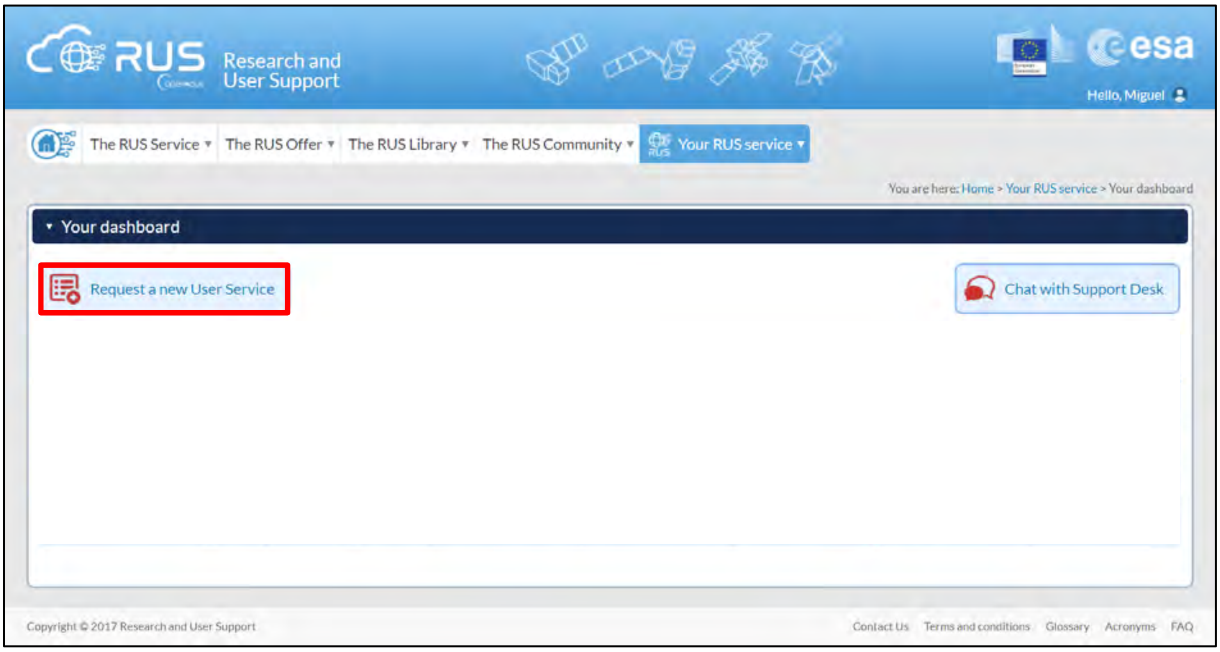


5 Request a RUS Copernicus Virtual Machine

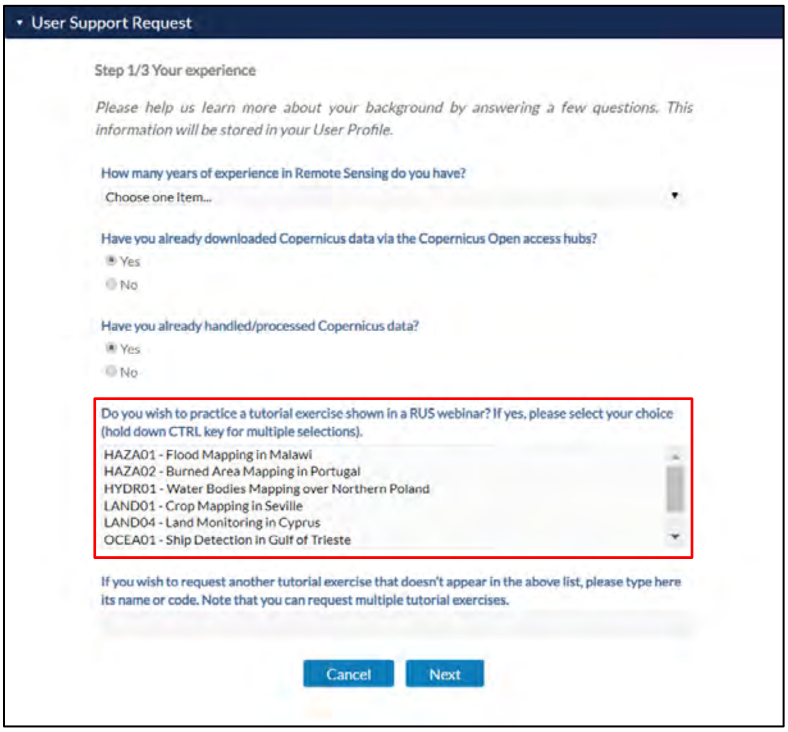
Once you are registered as a RUS user, you can request a RUS Virtual Machine to repeat this exercise or work on your own projects using Copernicus data. For that, log in and click on ***Your RUS Service → Your Dashboard***.



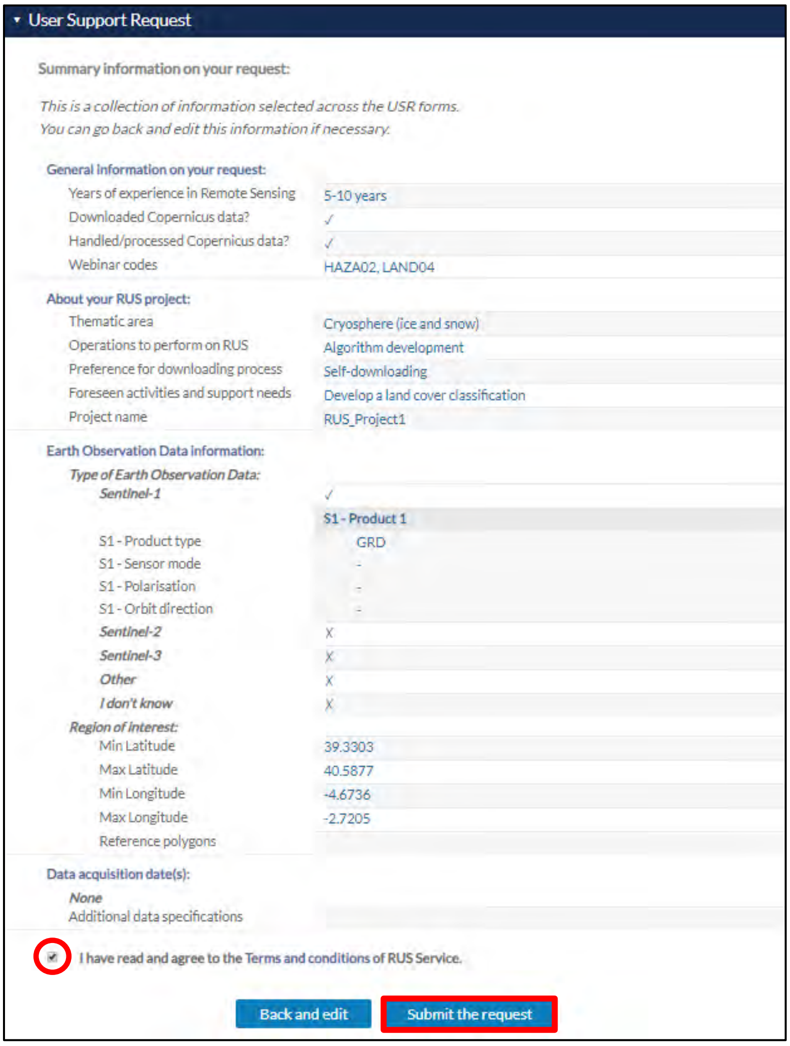
Click on ***Request a new User Service*** to request your RUS Virtual Machine. Complete the form so that the appropriate cloud environment can be assigned according to your needs.



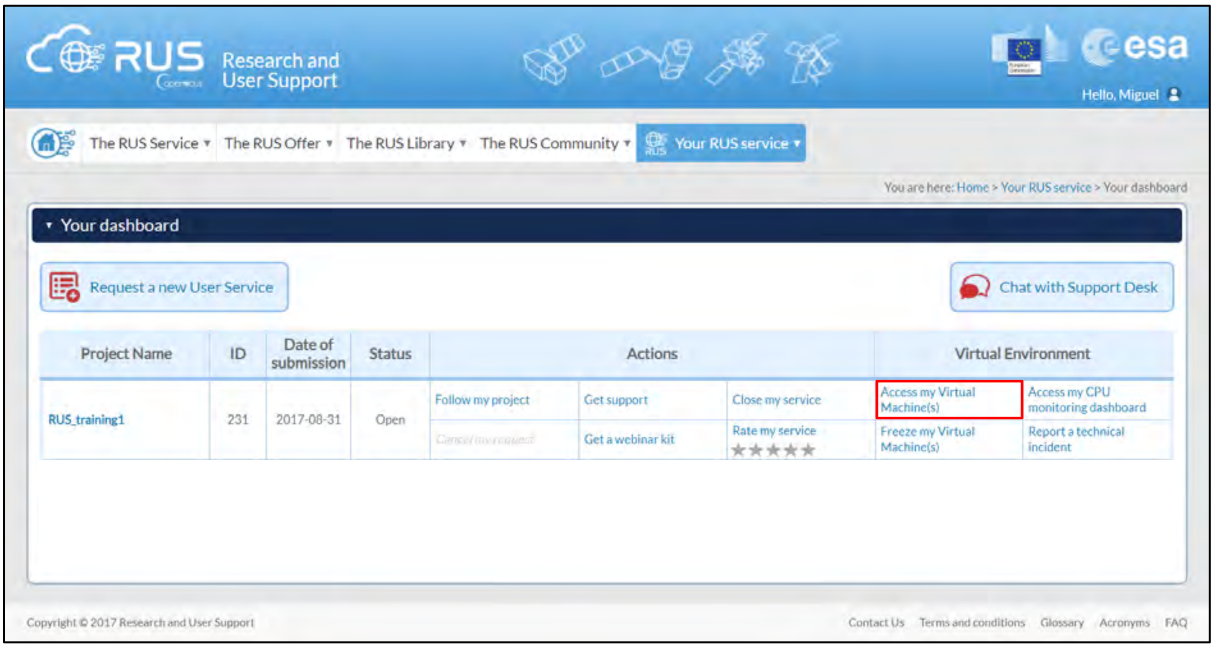
If you want to repeat this tutorial (or any previous one) select the one(s) of your interest in the appropriate field.



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.

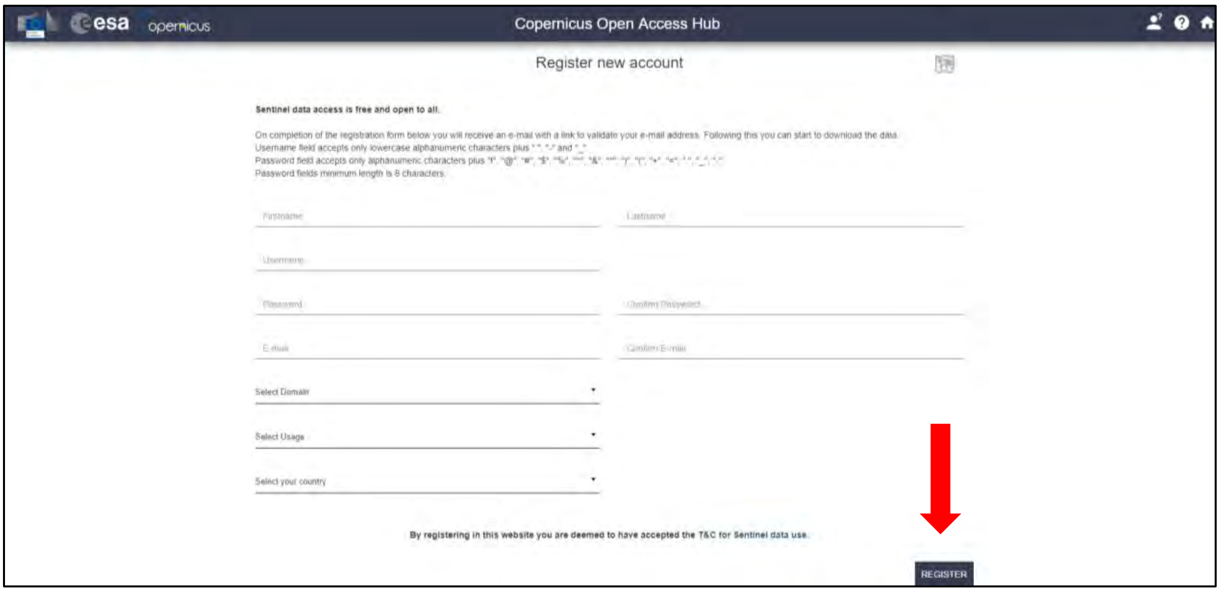
6 Step by step

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 → Firefox Web Browser** or click the link below).

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

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

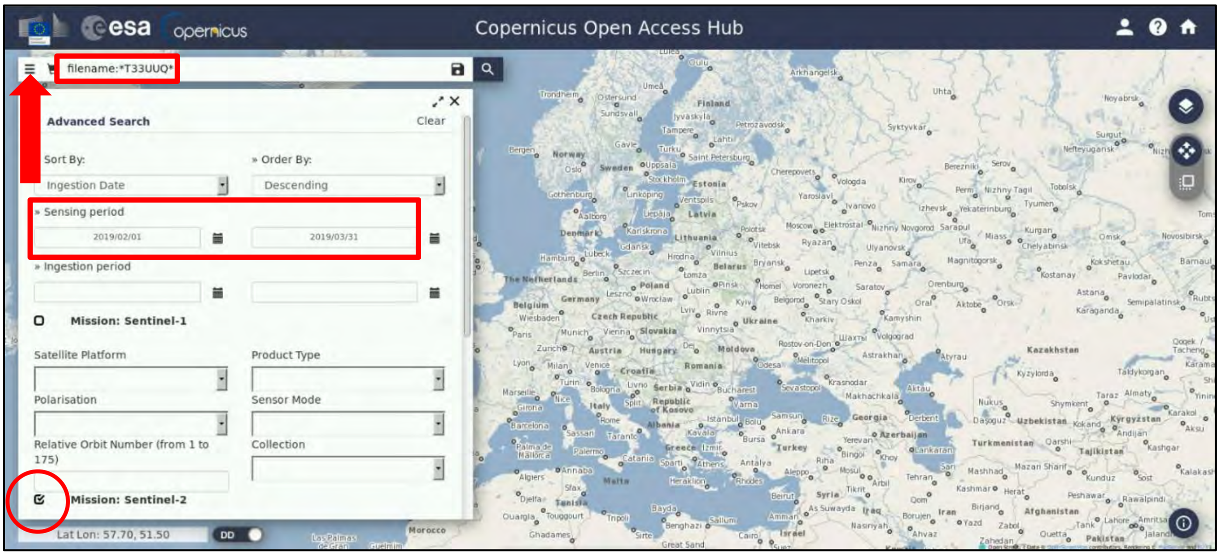


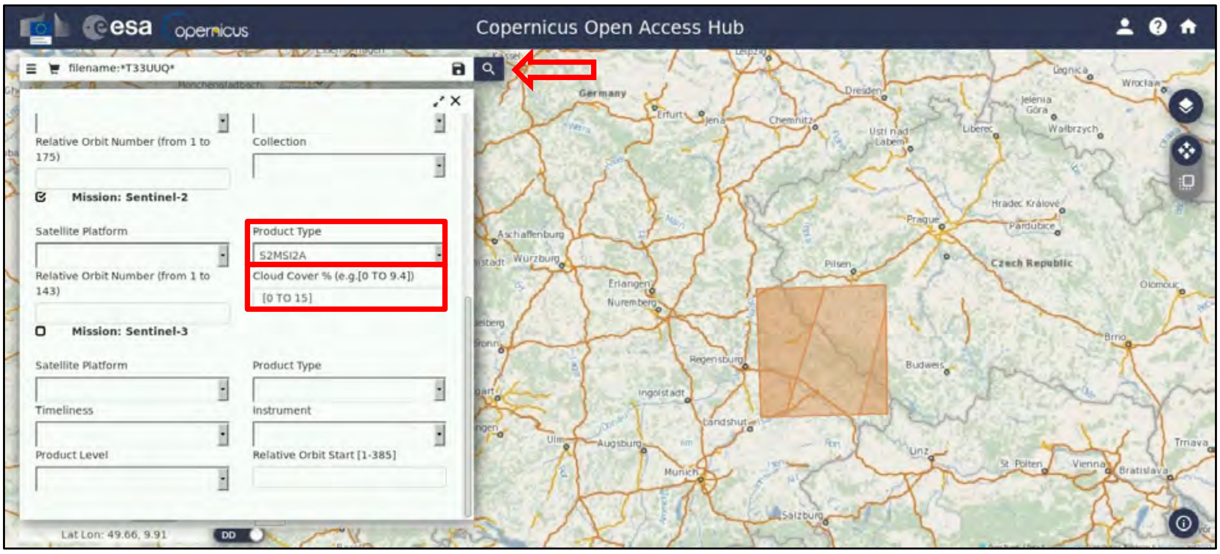
After you have filled in the registration form, you will receive an activation link by e-mail. Once your account is activated or if you already have an account, "**LOGIN**".

In the Full text search window type: *filename:*T33UUQ**

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

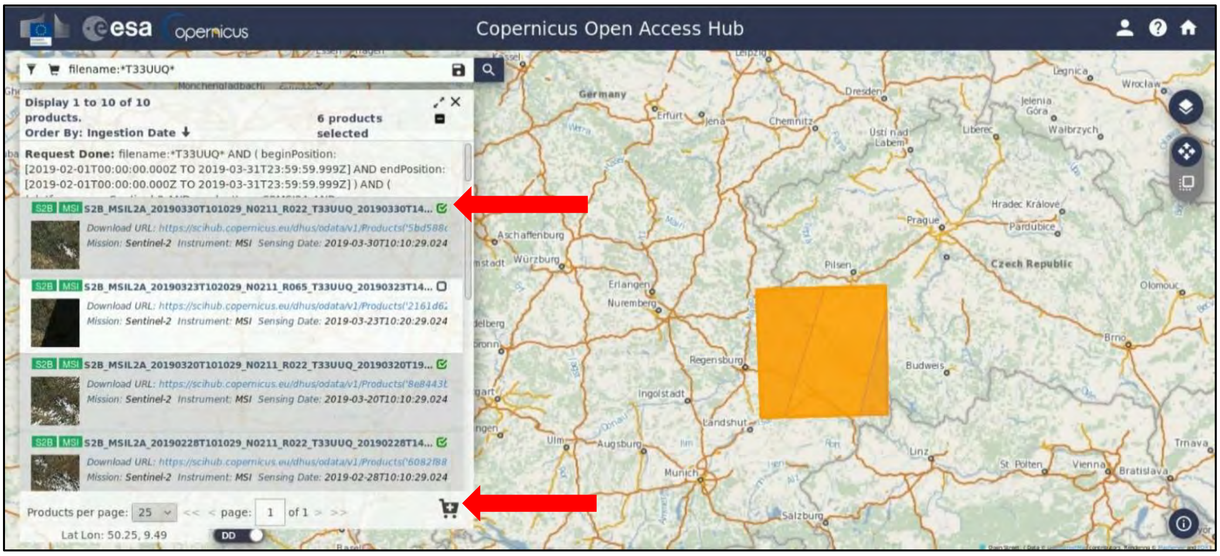
Sensing period: From 2019/02/01 to 2019/03/31
Check Mission: Sentinel-2
Product Type: S2MSIL2A
Cloud Cover %: [0 TO 15]





Clock on the looking glass symbol to start the search. In our case the search returns 10 results, but not all are of interest to us.

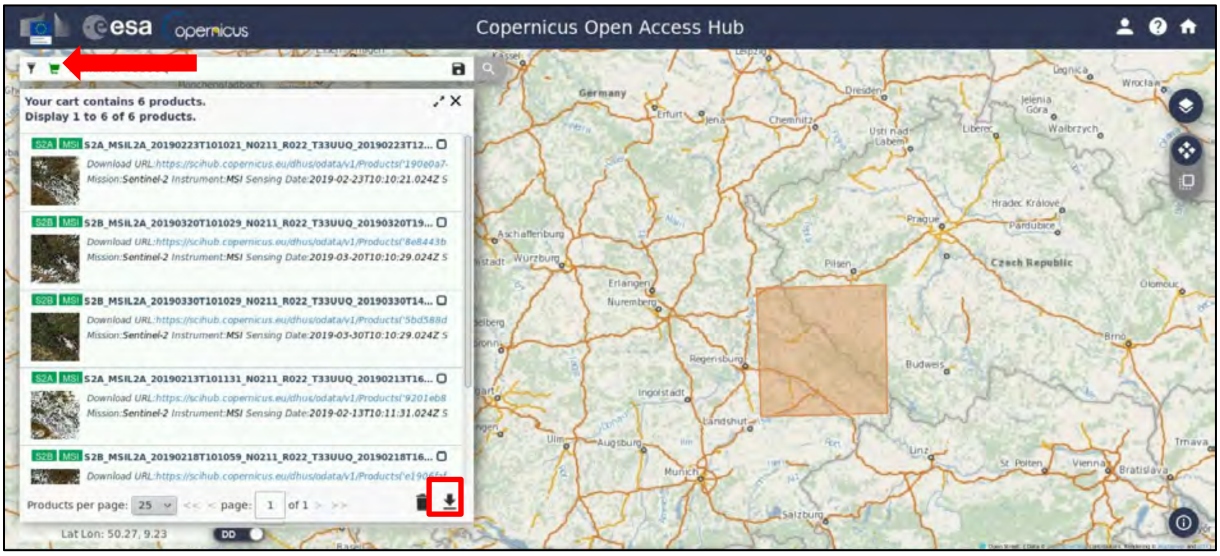
TIP: It may sometimes happen that the data used to create this exercise are temporarily unavailable. In such case, you can use other date period for the same location.



Go through the list and select these **4 full** scenes by checking the box as shown above:

- *S2B_MSIL2A_**20190218**T101059_N0211_R022_T33UUQ_20190218T161620.zip*
- *S2A_MSIL2A_**20190223**T101021_N0211_R022_T33UUQ_20190223T123814.zip*
- *S2B_MSIL2A_**20190228**T101029_N0211_R022_T33UUQ_20190228T143058.zip*
- *S2B_MSIL2A_**20190320**T101029_N0211_R022_T33UUQ_20190320T195148.zip*

Once they are all selected click on to add the products to the cart. Then go to the cart by clicking on the green cart symbol left of the full text search. Finally, let's download the cart in the form of .meta file. The file contains links to each of the files, we will need the file and download client to download the actual data.



The *products.meta4* file will be downloaded to your */home/rus* folder. To download our data, we will use **aria2** tool. To use the tool, we first need to move the *products.meta4* file to the folder where we wish our data to be downloaded to - */shared/Training/CRYO03_SnowCover_Sumava/Original/*

Then, let's test our aria2 installation. To do this we open the Command Line (in the bottom of your desktop window) and type:

```
aria2c
```

The correct response should be as follows:

If the response is "-bash aria2c: command not found" (see NOTE 1).

> NOTE 1: If (**and only if**) the response is "-bash aria2c: command not found". Then we have to install the tool, to do this in command line type: `sudo apt-get install aria2`
> When requested type: Y
> Then you can test your installation again.

If you have received the correct response, then we can run the tool by typing following commands in the command line (replace <username> and <password> with your login credentials for Copernicus Open Access Hub):

```
cd /shared/Training/CRYO03_SnowCover_Sumava/Original/

aria2c     --http-user='<username>'     --http-passwd='<password>'     --check-certificate=false --max-concurrent-downloads=2 -M products.meta4
```

The first line changes our directory to the target directory. The second line runs the download tool (Type the red text all in single line). All four products will be downloaded to the *Original* folder two products in parallel automatically (Note that the constraint of maximum two parallel downloads at a time is imposed by the Copernicus Access Hub, if you increase the number the download will fail). This might take some time.

6.2 Data exploration

Open the SNAP Toolbox by clicking the SNAP Desktop icon on the desktop. When the SNAP window opens, go to **File → Sessions → Open session** and navigate to:
/shared/Training/CRYO03_SnowCover_Sumava/ORIGINAL_DATA.snap

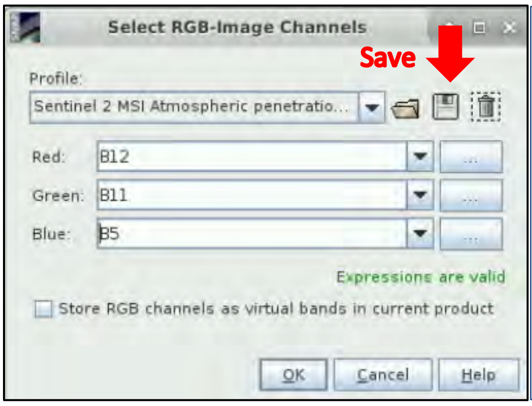
All four downloaded products should be loaded when the session opens. We can first investigate the structure of the Sentinel-2 Level 2A products. Click on the dot next to the first product name to expand the structure. The L2A products have been atmospherically and radiometrically corrected and contain (among others):

- 13 surface (bottom-of-atmosphere) reflectance bands (see NOTE 3)
- cloud and snow probability bands (we will use the snow probability band to compare with our results)
- scene classification (water, vegetation, cloud, snow/ice, shadow, unclassified)
- masks derived from cloud and snow probability bands and scene classification

> TIP: Level 2A have been systematically produced for products acquired over Europe since the spring of 2017, the coverage has increased through 2018 to reach global coverage in the beginning of 2019. If you need to run atmospheric correction on your data, see 7.2 Atmospheric correction.

Now, we can visualize the products. We could use the true (natural) colours but for distinguishing snow it is better to use the Short-Wave Infrared (SWIR) and Red bands as these provide the best separability between cloud and snow (for more explanation, check the graph in NOTE 2). Right-click the first loaded product from 18 February and click **Open RGB image window,** a new window will open.

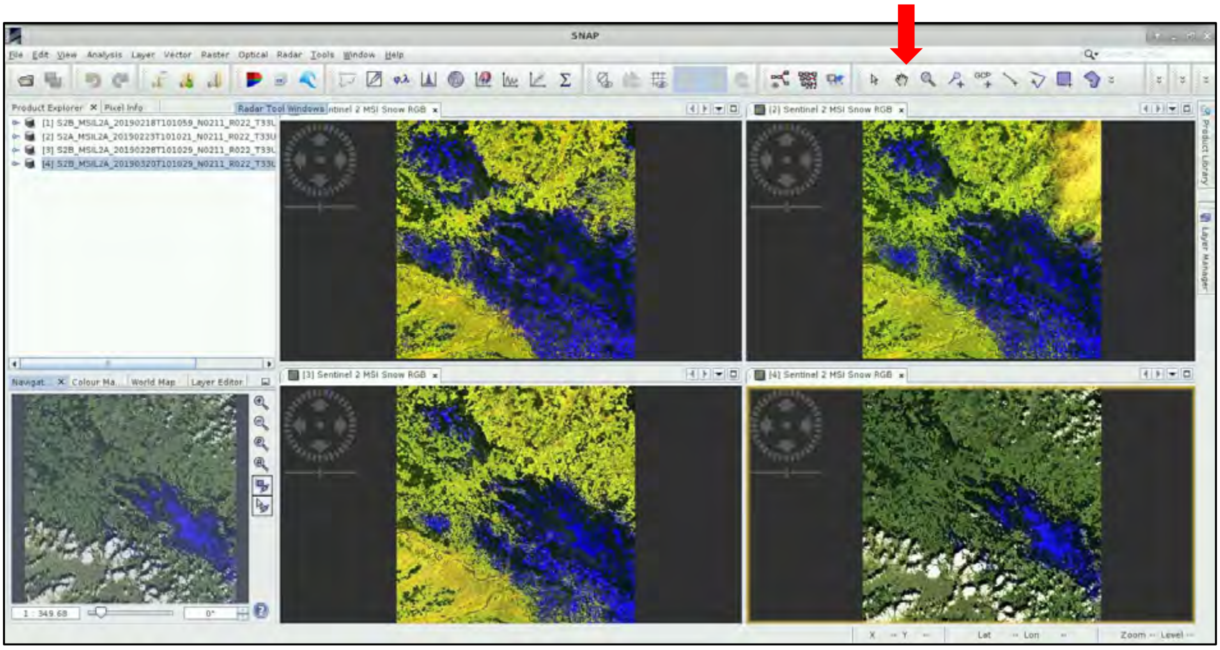
Set: **Red:** B12 **Green:** B11 **Blue:** B5



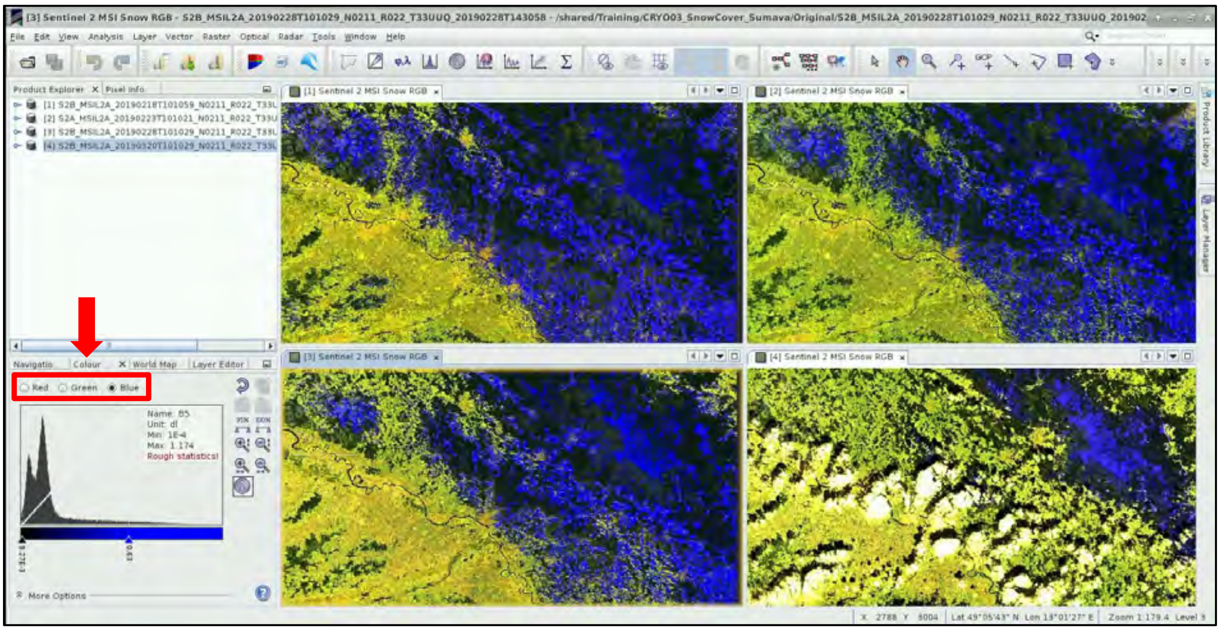
NOTE 2: This band combination provides a "natural-like" rendition while also penetrating atmospheric particles, smoke and haze. Vegetation appears dark and light green during the growing season, urban features are white, grey, cyan or purple, sands, soils. The almost complete absorption of Mid-IR bands in water, ice and snow causes snow and ice to appear as dark blue and water is black or dark blue. Hot surfaces such as forest fires and volcano calderas saturate the Mid-IR bands and appear in shades of red or yellow.

When you have selected the correct bands, click on the **Save** icon and save the new profile in the default folder as **Sentinel_2_MSI_Snow.rgb** in the default folder. Now open the RGB view for the other three products as well, using the saved profile (in drop down menu).

When you have all 4 Views opened, go to **Navigation pane** in the lower left and make sure the cursor and the views are linked. Then, go to **Window -> Tile Evenly**. Go back to **Navigation tab** and click **Zoom All** to centre the Views. All snow-covered areas appear in bright blue colour, in the four views ordered by date of acquisition you can see the decreasing extent of snow cover between 18 February (upper left) and 20 March 2019 (lower right).



The bright values of the cloud cover in the last image affect the visualization so it appears different than the other images (value distribution in the image affects the histogram stretch) but we can edit it to be visually comparable. Click on the “[4] Sentinel 2 MSI Snow RGB” window and go to **Colour Manipulation** tab, there you can edit the histogram stretch for each colour by moving the sliders. Move the red slider to 0.22, then change to green and move the green slider to 0.29, finally change to the blue histogram and move the blue slider to 0.63. Click on the **Pan** mode and zoom in to explore closer.

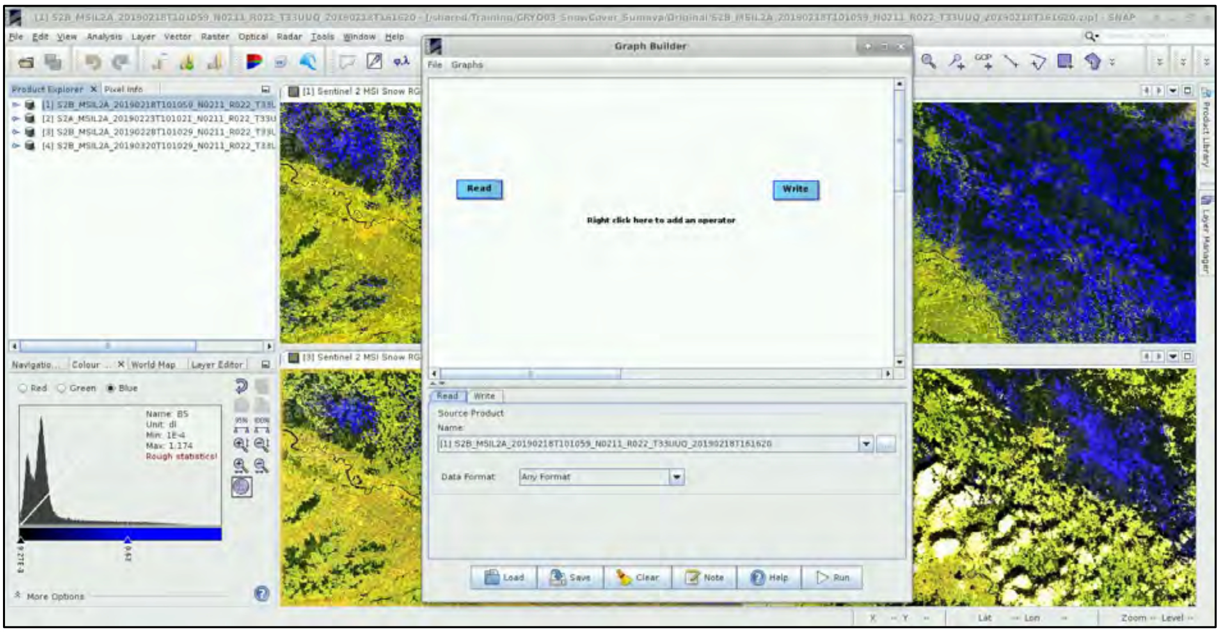


6.3 STEP 1 – Pre-processing

Processing the data one by one would be very time consuming and inconvenient. However, we can use the **Batch Processing** tool available in SNAP to process all images at the same time.

To use the tool, we first need to define the process we want to apply and all its steps. We can do this using the **GraphBuilder** tool. Another advantage of the **GraphBuilder** is that only the final product will be physically saved, and we save valuable disk space.

So, let's build our graph. First, in the **Product Explorer** select the first loaded product (so it is highlighted), then go to **Tools → GraphBuilder**.

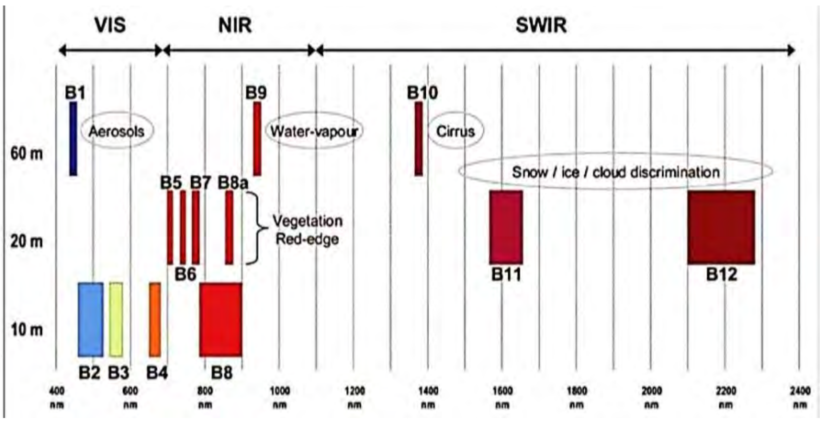


At the moment, the graph only has two operators: **Read** (to read the input) and **Write** (to write the output).

The 13 bands in Sentinel-2 products do not all have same resolution (therefore size) as mentioned in NOTE 3. Many operators do not support products with bands of different sizes so first we need to resample the bands to equal resolution.

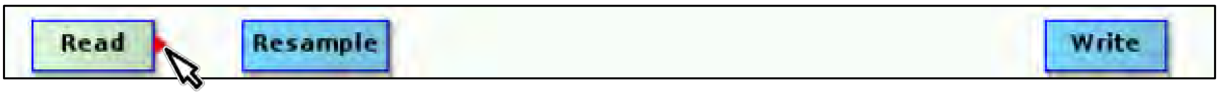
To add the appropriate operator, right-click the white space between existing operators and go to **Add → Raster → Geometric → Resample**

NOTE 3: 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.



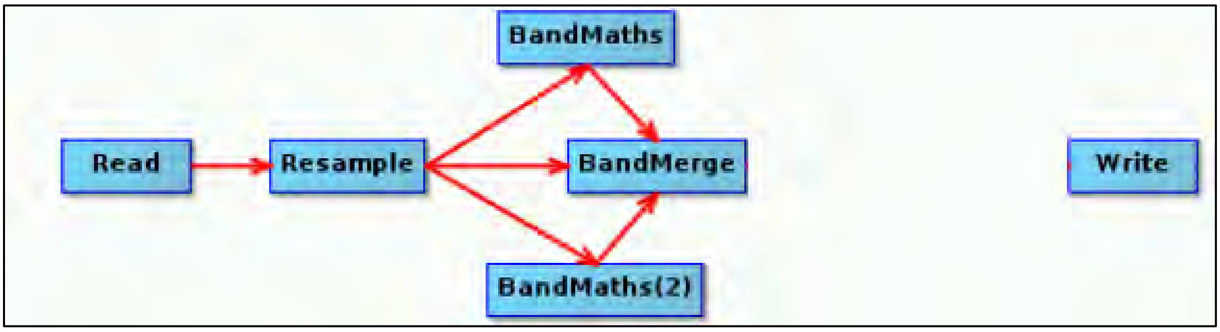
Credits: ESA 2015

A new operator rectangle appears in our graph and new tab appears below. Now connect the new **Resample** operator with the **Read** operator by clicking to the right side of the **Read** operator and dragging the red arrow towards the **Resample** operator.

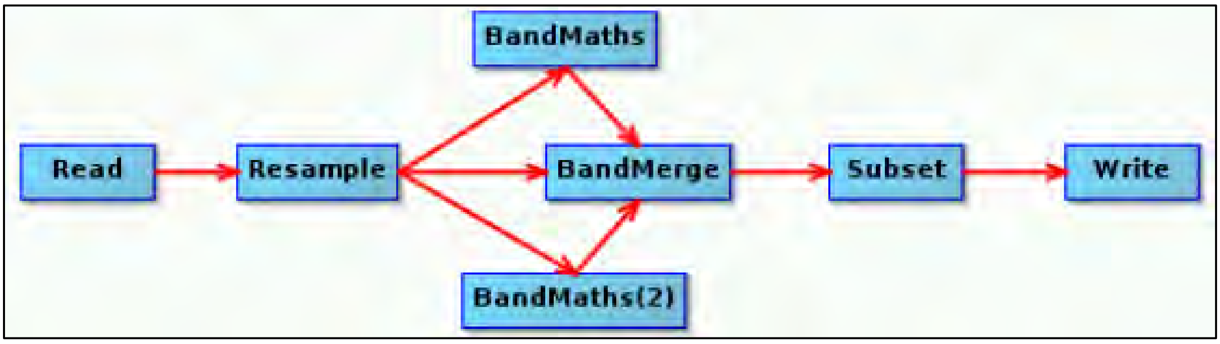


Now, we will add two BandMath operators from **Add → Raster → BandMaths** and then connect it to the **Resample** operator then repeat the operation to add BandMath(2).

Next, we add **BandMerge** operator from **Add → Raster → BandMerge.** Connect the **Resample** operator and both the **BandMaths** operators, to the **BandMerge** operator as shown below.



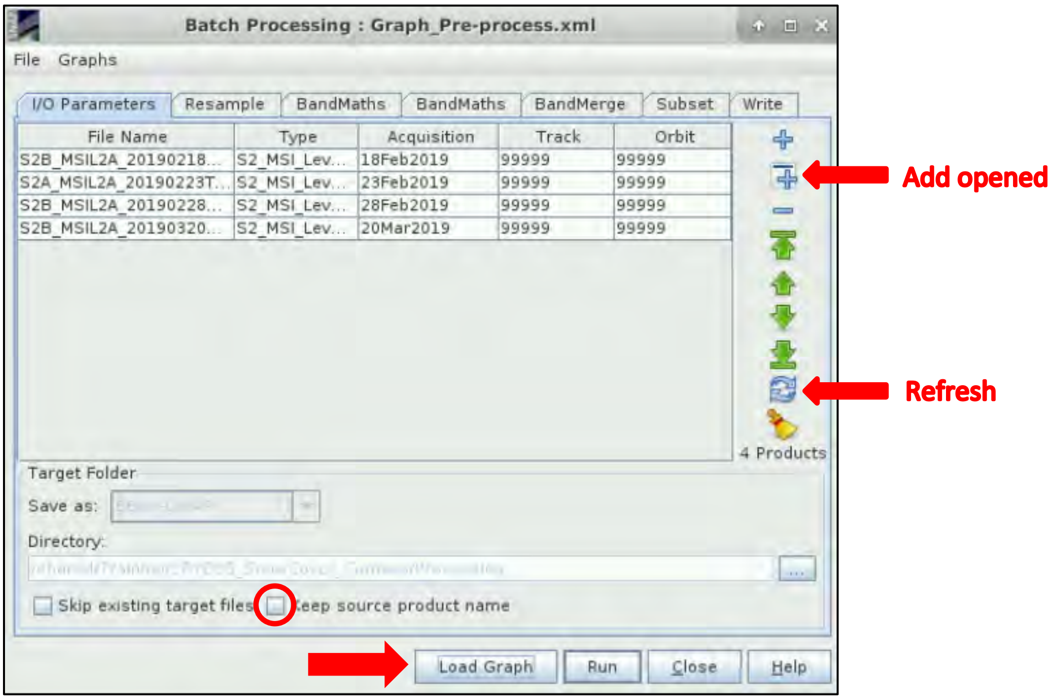
Next step will be to subset the images to the area of interest. Go to **Add → Raster → Geometric → Subset** and connect the **Subset** operator with the **BandMerge** operator. Finally, connect the **BandMerge** operator to the **Write** operator.



At the moment, do not change anything in the parameter tabs, save the graph as ***Graph_Pre-process.xml*** under ***/shared/Training/CRYO03_SnowCover_Sumava/Processing*** path by clicking **Save** at the bottom of the window and then close the **GraphBuilder** window.

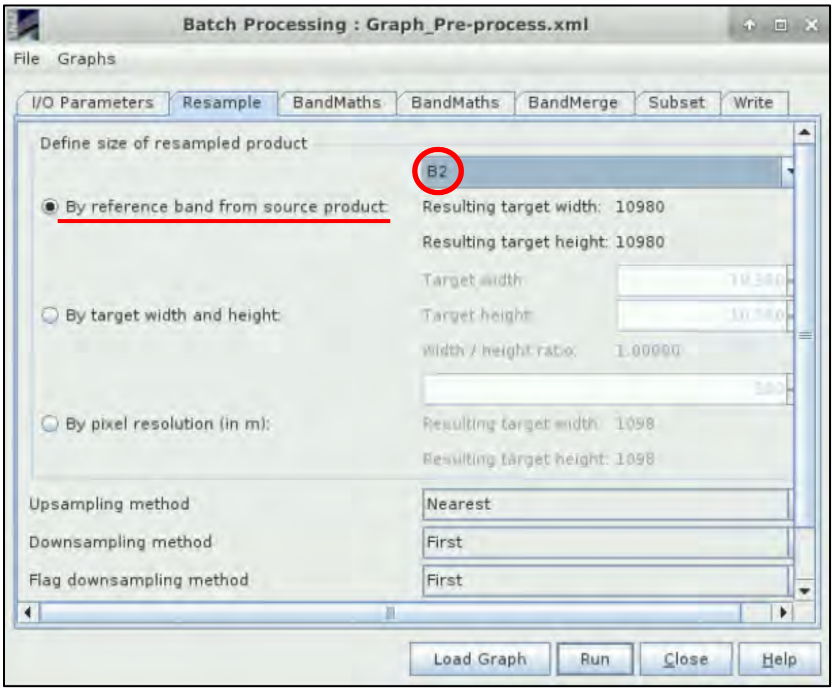
In the **Product Explorer**, make sure the product [1] (18 February 2019) is selected (highlighted). Now we can open the Batch Processing tool at **Tools → Batch Processing**.

We will add all four opened products to be processed. In the **I/O Parameters** tab, click **Add Opened** on the upper right (second from top) and click **Refresh**. Deselect the **Keep source product name**. Then click **Load Graph** at the bottom of the window, navigate to our saved graph and open it. We see that new tabs have appeared at the top of window corresponding to our operators.



Now, let's set the parameters. In **Resample** tab we set:

Under **Define size of resampled product**: Select the "**By reference band from source product**" and choose the **B2** band (we will resample all the bands to 10m resolution).

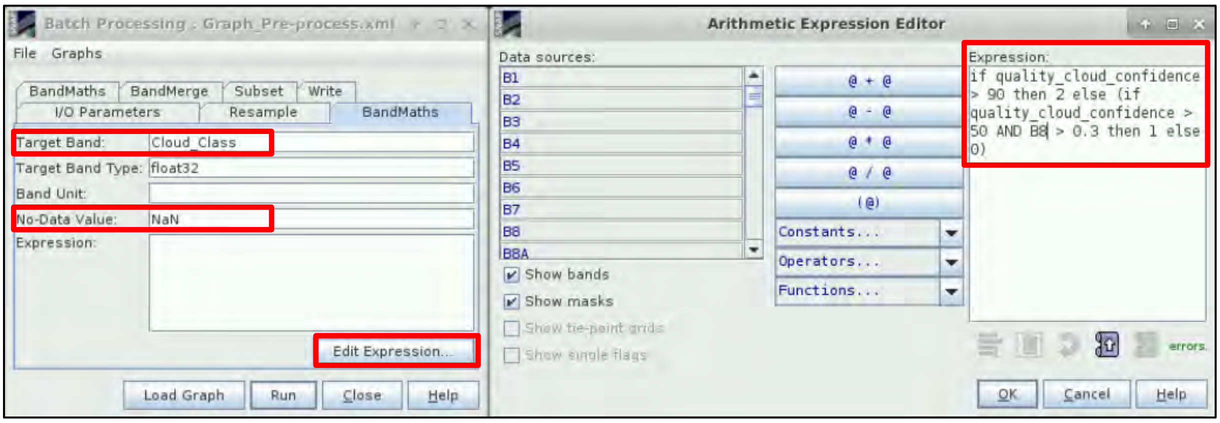


Next in the first BandMath tab, we set the expression for the calculation of a first preliminary cloud mask. The cloud mask will be based on the cloud confidence band (see NOTE 4). In the **BandMaths** tab set:

Target band: *"Cloud_Class"*
No-Data Value: "*NaN*"
Then go to **Edit Expression …** and type:

```
if quality_cloud_confidence > 90 then 2 else (if quality_cloud_confidence > 50 AND
B8 > 0.3 then 1 else 0)
```

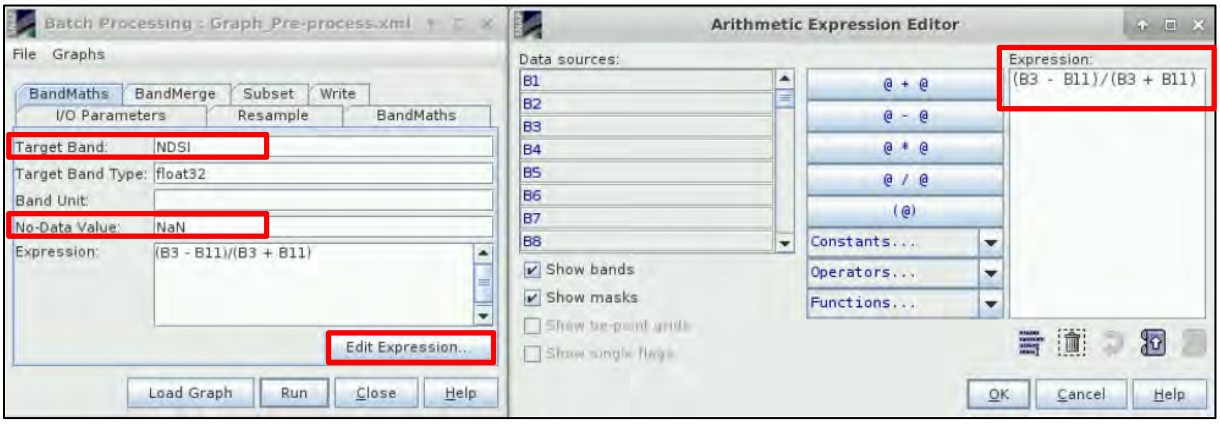
NOTE 4: The cloud masks derived by the L2A processing are very conservative because It is computed at coarser resolution and was developed to remove surface reflectance variations due to could contamination. However, some clouds are semi-transparent in the SWIR band allowing snow detection. We will therefore use only very high confidence clouds > 90%, lower confidence clouds (50 - 90%) will be filtered by thresholding the NIR band. All other pixels will be considered cloud free.



Click **OK** to close the "Arithmetic Expression Editor" window.

Next in the second BandMath tab, we set the expression for the calculation of the Normalized Difference Snow Index (NDSI, see NOTE 5). In the **BandMaths** tab set:

Target band: *"NDSI"*
No-Data Value: *"NaN"*
Then go to **Edit Expression …** and type: `(B3 – B11)/(B3 + B11)`

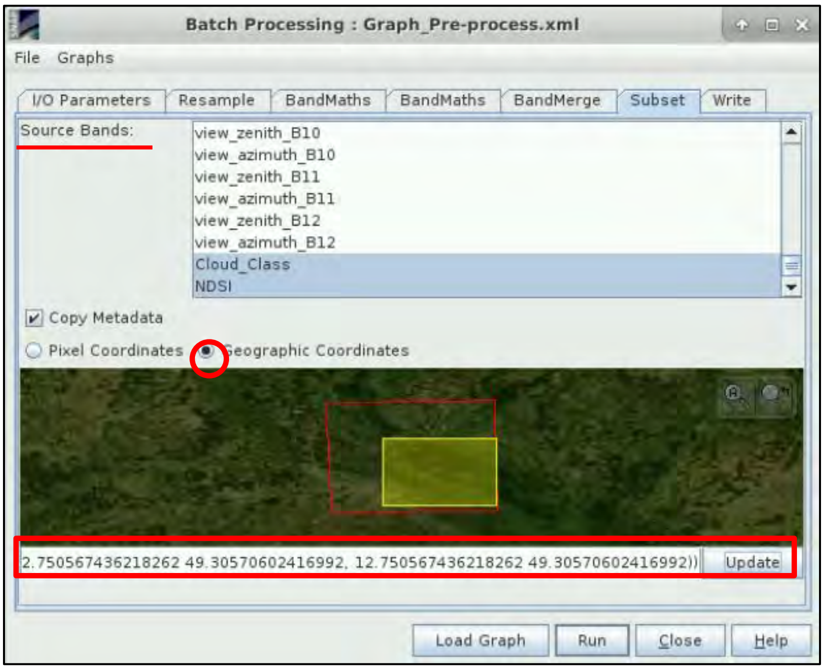


NOTE 5: When identifying the snow presence, green (~ 0.5 – 0.6 nm) and SWIR (~ 1.6mm) wavelengths are commonly used. Snow generally appears very bright at optical wavelengths as do clouds, however unlike clouds (not all) it strongly absorbs radiation SWIR wavelengths. To identify snow cover and differentiate it from most clouds we can therefore use the Normalized Difference Snow Ratio (NDSI):

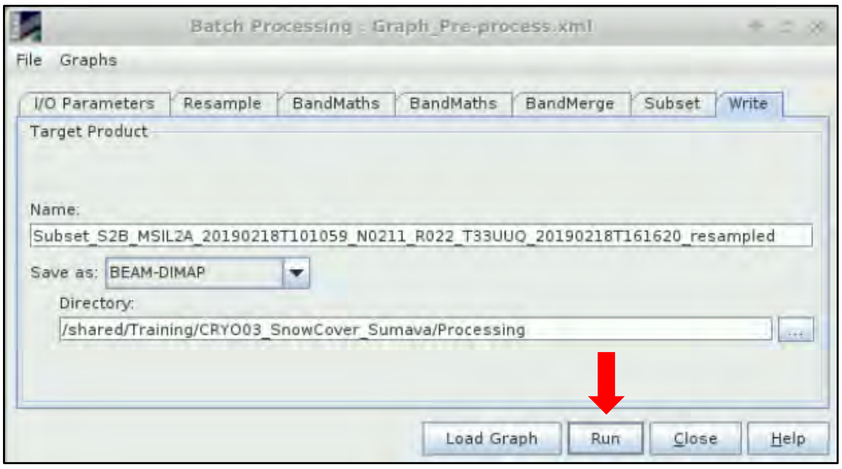
$$NDSI = \frac{Green - SWIR}{Green + SWIR}$$

In the **BandMerge** tab, keep the default parameters. In the **Subset** tab we select bands: **B3, B4, B11, B12**, **Cloud_Class** and **NDSI** (to select multiple, hold Ctrl). Then click to select the **Geographic Coordinates** option and paste the area of interest definition in WKT (well know text) format to the text window below the map. Click **Update** and then click the **Zoom-in** icon to see your subset on the map.

```
POLYGON ((12.7505 49.3057, 13.7601 49.3057, 13.76011 48.7043, 12.7505 48.7043,
12.7505 49.3057, 12.7505 49.3057))
```

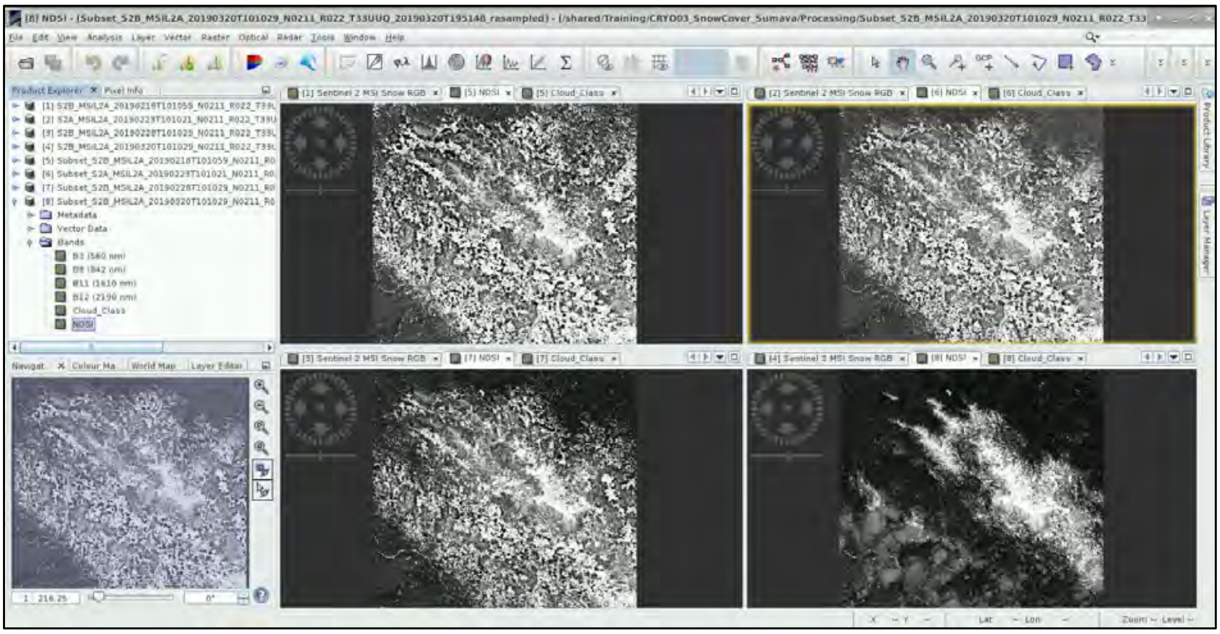


In the **Write** tab, check that the name contains **20190218** but do not change anything. Set the output directory: ***/shared/Training/CRYO03_SnowCover_Sumava/Processing***



And let's click **Run.** This might take approximately 4-5 minutes depending on your machine.

Now, you should have four new products in the **Product Explorer** window. Let's have a look at them. For that expand product [5] and in **Bands** folder, double click the NDSI band. When it opens move it by dragging the top of the tab to the corresponding RGB image window. Now do the same for products [6 – 8]. Then in **Navigation** tab at the lower left, click Zoom All .



You can also open the cloud mask in the same manner for each processed product.

6.4 STEP 2 – snow detection

The approach used in this exercise has been adapted and simplified from the method used for the Theia Snow collection (Gascoin et al. 2019). It is based on two pass detection using the NDSI:

1) First pass – We use conservative threshold applied to NDSI. Some turbid waters can have similar high NDSI value, therefore we will use an additional criterion on the red reflectance to avoid false snow detection in these areas. Cloud-free pixel is then classified as snow when:

$$(NDSI < n_1)\ AND\ (\rho_{red} < r_1)$$

Where n_1 and r_1 are the selected thresholds, during the first pass they are set conservatively high to avoid false detections. If the above expression is not fulfilled, then the pixel is marked as “no snow”

Minimum value of NDSI for the pass 1 snow test - n_1	**0.4**
Minimum value of the red band (B4) for the pass 1 snow test - r_1	**0.2**

2) Second pass – Now we can use the results from the first pass detection and a digital elevation model to estimate the elevation of the snow line (minimum snow elevation z_s). Above the snow line we can then apply less conservative thresholds for the above criterion. The approach assumes there are no large altitudinal variations in the snow line position within the study area. We will also use: Forest Type (FTY) 2015 (High Resolution Layer) provided by European Environment Agency (available from Copernicus Land Service) to remove dense forest areas that may be misclassified as no-snow. (See NOTE 5 p. 24)

Minimum value of NDSI for the pass 2 snow test – n_2	**0.15**
Minimum value of the red band (B4) for the pass 2 snow test – r_2	**0.04**
Minimum detected snow cover percentage in elevation band to identify z_s	**35 %**
Size of the elevation band in the DEM used to define z_s	**50**

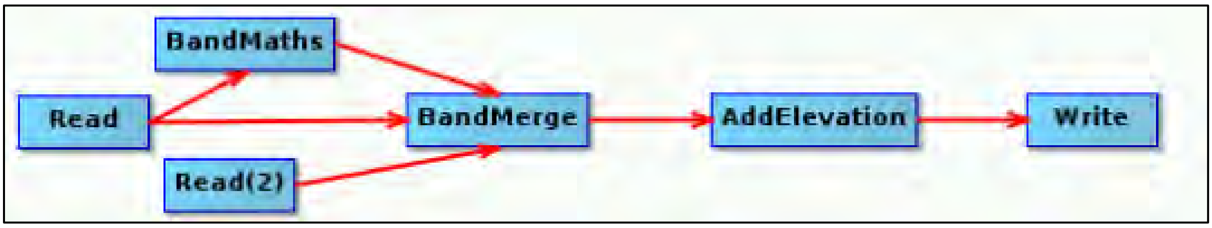
6.4.1 Snow detection – first pass

In this step we will apply the conservative thresholds as well as load supporting data (DEM and Forest Type map) for the second pass detection. As in pre-processing we will use the graph builder to enable batch processing of our four products.

So, let’s build our graph. First, in the **Product Explorer**, right-click on product [1] and go to Close Product, then click No (we do not want to save changes). Do the same for the other original data [2 - 4]. So only the pre-processed products remain open.

Then we select (highlight) the first product [5] (Subset 18 February 2019) and go to **Tools → GraphBuilder**. Add following operators and connect them as shown on the image:

- **Add → Raster → BandMaths**
- **Add → Raster → BandMerge**
- **Add → Input-Output → Read**
- **Add → Raster → DEM Tools → AddElevation**



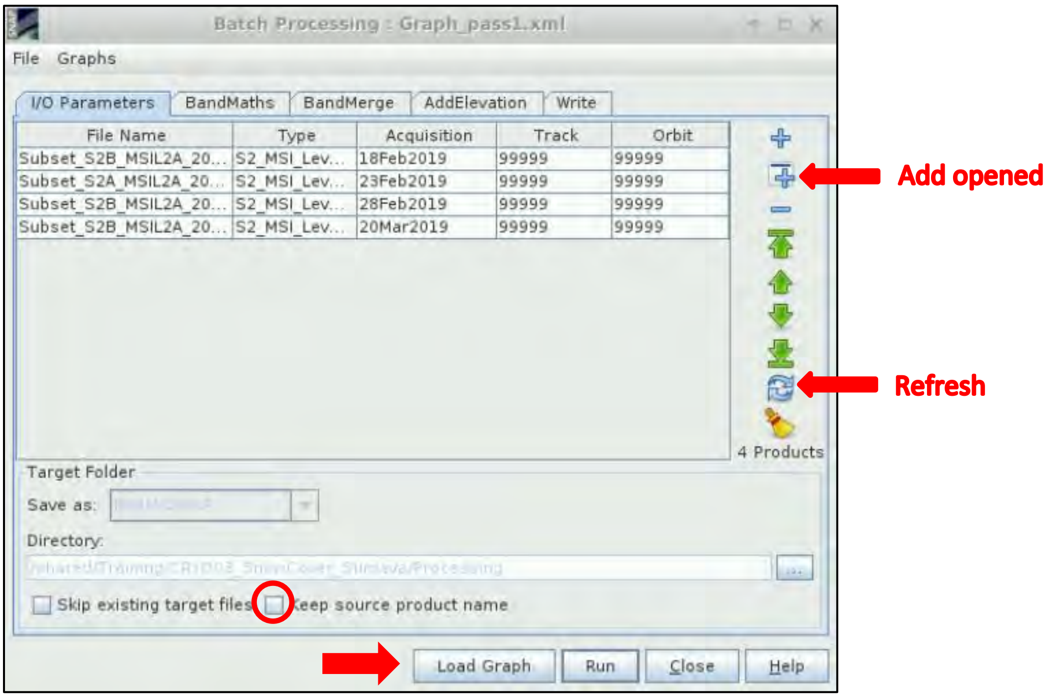
Important!!! Now go to the **Read(2)** tab below the graph and click on the ..., then navigate to the ***/shared/Training/CRYO03_SnowCover_Sumava/AuxData/*** *and select* ***Forest_Type_CLS.tif***

TIP: We have to do this due a bug in the SNAP Batch processing which at the time of writing this tutorial it has not been fixed. The bug makes it impossible to see the second Read tab in the Batch processing window. We can however bypass this problem by setting this parameter in the graph and then saving it with it (only possible if the input of the second Read operator does not change).

When done, click **Save** at the bottom of the window and save the graph as ***Graph_pass1.xml*** in: ***/shared/Training/CRYO03_SnowCover_Sumava/Processing/***

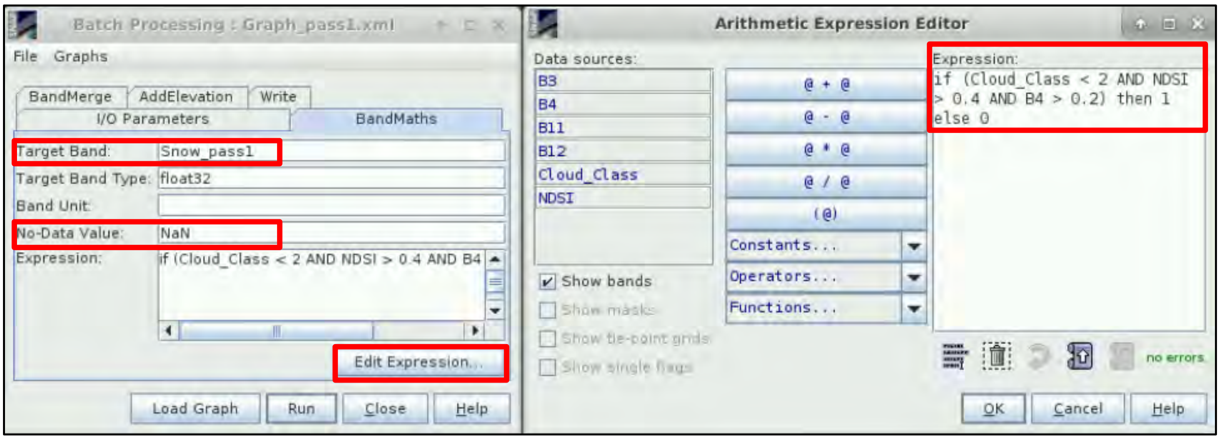
Now, we can close the **GraphBuilder** window and open the **Batch Processing** tool (**Tools -> Batch Processing**).

We will add all opened products. In the **I/O Parameters** tab, click **Add Opened** on the upper right (second from top) and click **Refresh**. Deselect the **Keep source product name**. Then click **Load Graph** at the bottom of the window, navigate to our saved graph and open it.



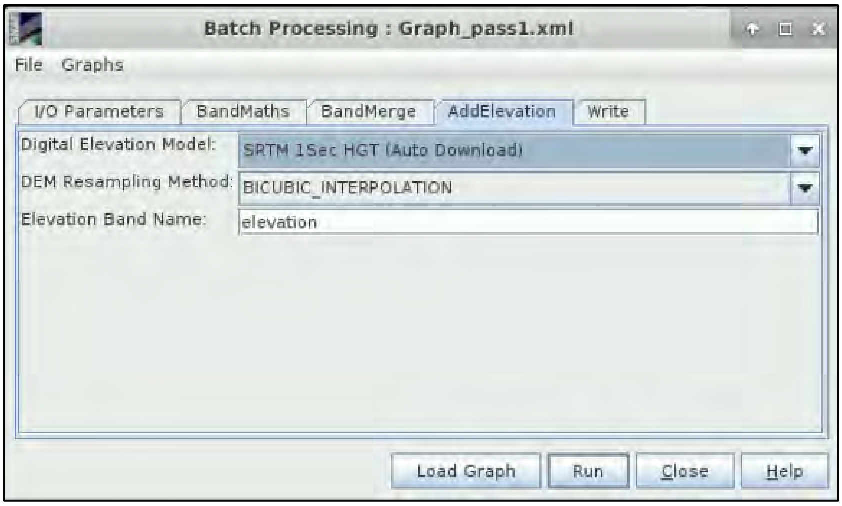
Now, let's set the parameters. In the **BandMaths** tab, set:

Target band: *"Snow_pass1"*
No-Data Value: *"NaN"*
Expression: `if (Cloud_Class < 2 AND NDSI > 0.4 AND B4 > 0.2) then 1 else 0`

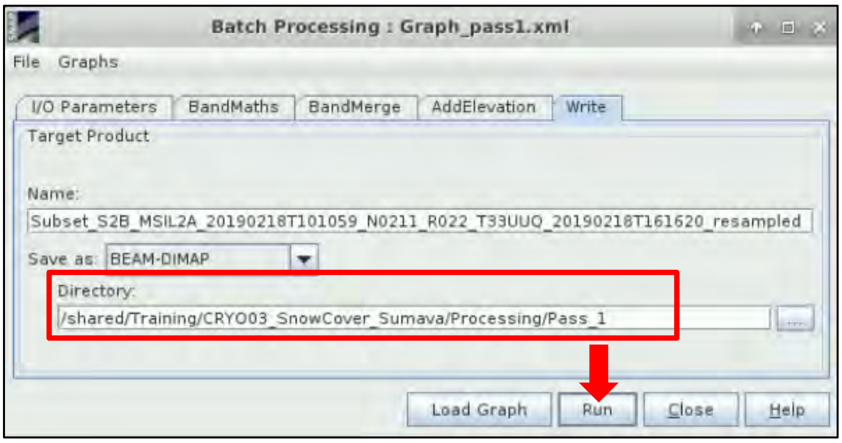


Keep the default settings in the **BandMerge** tab and in the **AddElevation** tab select:

Digital Elevation Model: *SRTM 1Sec HGT (Auto Download)*
Elevation Band Name: *"elevation"*

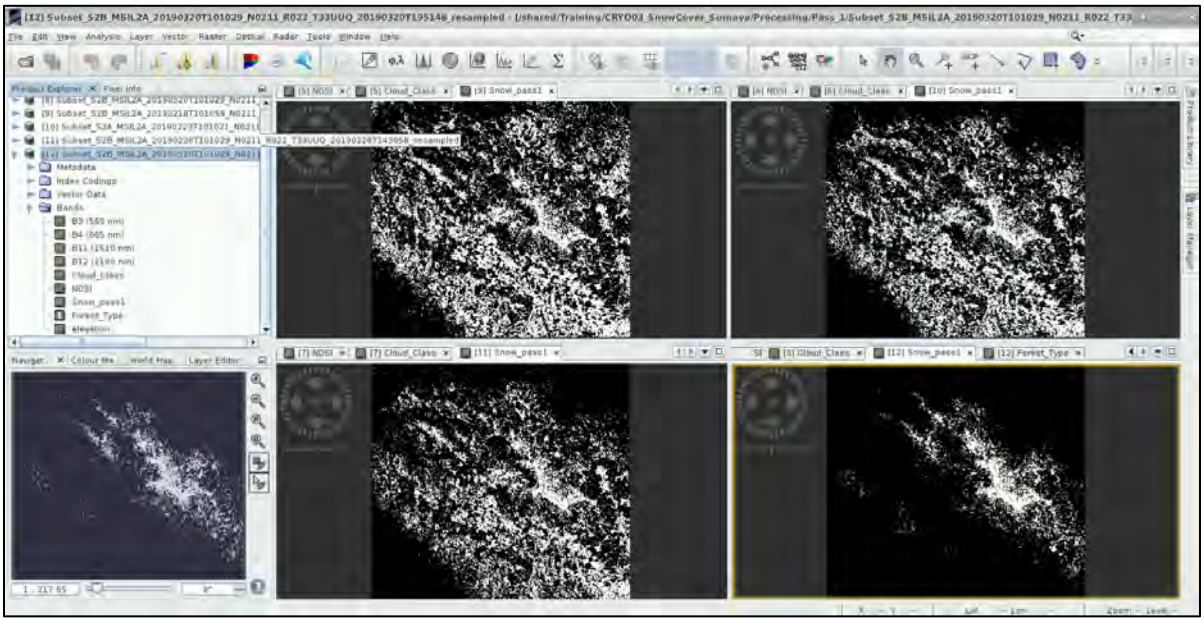


In the **Write** tab, you can notice that the ***Name*** of the output is identical to the name of input, unfortunately this is a problem of the software and in batch processing we can not change it. For this reason, we will use a different directory to save our outputs. Click on the [...], then navigate to: ***/shared/Training/CRYO03_SnowCover_Sumava/Processing/Pass_1/***



Click **Run**.

When the new products are created, let's open the "*Snow_pass1*" band for each product.



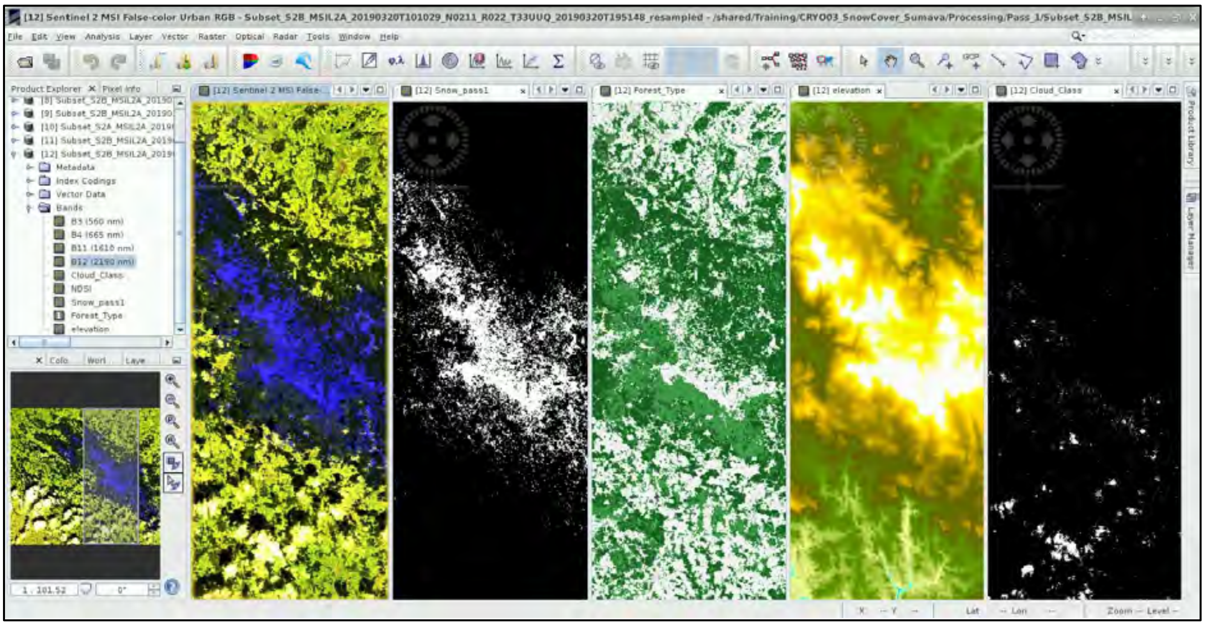
6.4.2 Snow detection – second pass

For the second pass it is not possible to use batch processing as the snow line must be estimated for each image separately. The graphical interface of SNAP is not ideal for this and script approach would be more convenient, but for the purposes of presenting the methodology we will use the graphical interface.

First let's close all opened views. Go to **Window → Tile Single**, then right-click on the tab of any view and select **Close All**. Then in **Product Explorer**, right-click on product [12] and go to Open RGB Image Window, choose the default profile (Red: B12, Green: B11, Blue: B4)

In the **Colour Manipulation** tab, move the red slider to 0.22, then change to green and move the green slider to 0.29, finally change to the blue histogram and move the blue slider to 0.63.

Then open views for bands: ***Snow_pass1***, ***Forest_Type***, ***Elevation***, ***Cloud_Class*** (in **Colour Manipulation** tab move the black slider to 0). Then go to **Window → Tile Horizontally**.



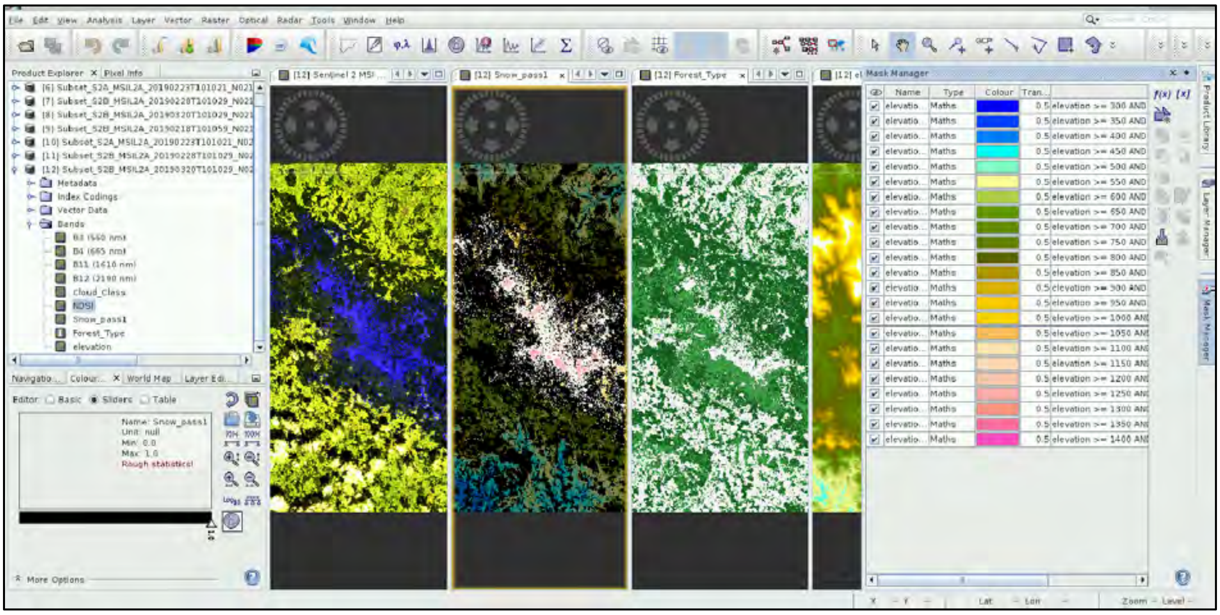
Next, we will estimate the snow line elevation. We will do this by "dividing" the image into elevation bands of 50 m from 350 m to 1450 m. For each elevation band we calculate the percentage of snow coverage for non-forest surfaces (See NOTE 5).

> NOTE 5: In dense forest (mainly coniferous), new snow covers the branches and can be usually detected. However, as the snow gets older/heavier, it slides off the branches to the forest floor and is effectively hidden from view. Such areas are then incorrectly classified as no-snow. This can skew the snow line elevation estimate as well as cause errors in estimation of total snow cover.

First, we will load our elevation classes. Go to **View → Tool Windows → Mask Manager**. A tab will open on the right side of the SNAP window. At the moment it should be empty, here you can either create masks from geometry or using pixel value thresholds and expressions or you can load mask prepared previously. We will use the last option.

Click inside the *[12] Snow_pass1* view and then in the **Mask Manager** click on and open ***/shared/Training/CRYO03_SnowCover_Sumava/AuxData/masks_elevation_noforest.xml***

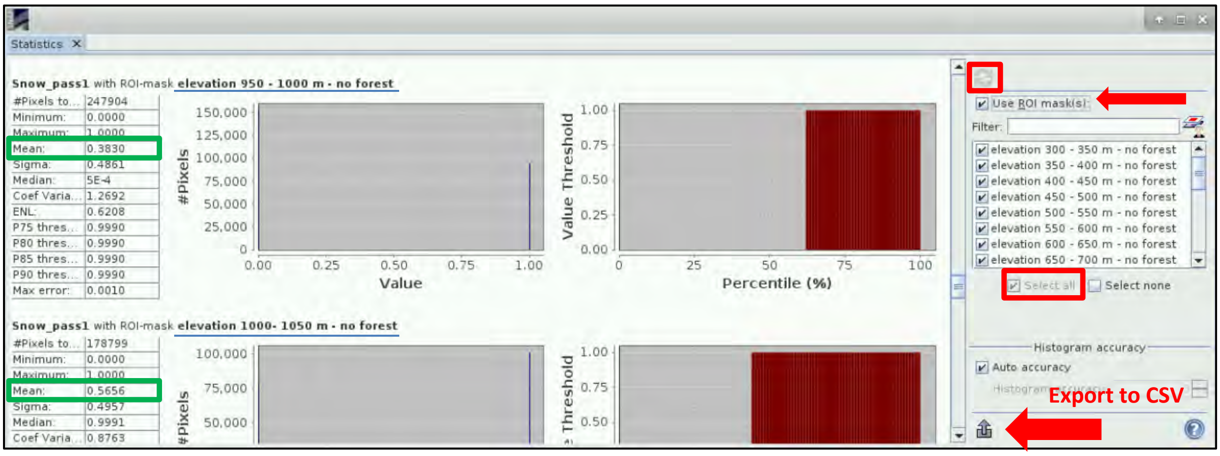
The new masks will appear, select all to be visible over the *[12] Snow_pass1* view.



These masks are created as an expression: *elevation >= i AND elevation < j AND Forest_Type == 0* where **i** and **j** are the bounds of the elevation band.

	0	All non-forest areas
	1	Broadleaved forest
	2	Coniferous forest
	254	Unclassifiable (no satellite image available, or clouds, shadows, or snow)
	255	Outside area

Now, click inside the *[12] Snow_pass1* view again and then click on **Statistics** Σ. A new window will open. Select ***Use ROI mask(s),*** then click ***Select All*** and ***Refresh*** .



The calculation will take about a minute. Once it is finished you can see statistics of Snow_pass1 for each elevation band. Since our Snow_pass1 band is binary – snow (1)/no-snow (0) - we can use the Mean*100 as equivalent for percentage cover.

By scrolling down, you can find which elevation band has Mean > 0.35. In the case of our selected image the elevation band with snow coverage > 35% is 950 m - 1000 m (statistics can also be exported to CSV format). We can now close the Statistics window.

Now, let's run the second pass, here are the parameters for each product:

Image date	n_2	r_2	z_s
18 Feb. 2019	*0.15*	*0.04*	*400 m*
23 Feb. 2019			*400 m*
28 Feb. 2019			*600 m*
20 Mar. 2019			*950 m*

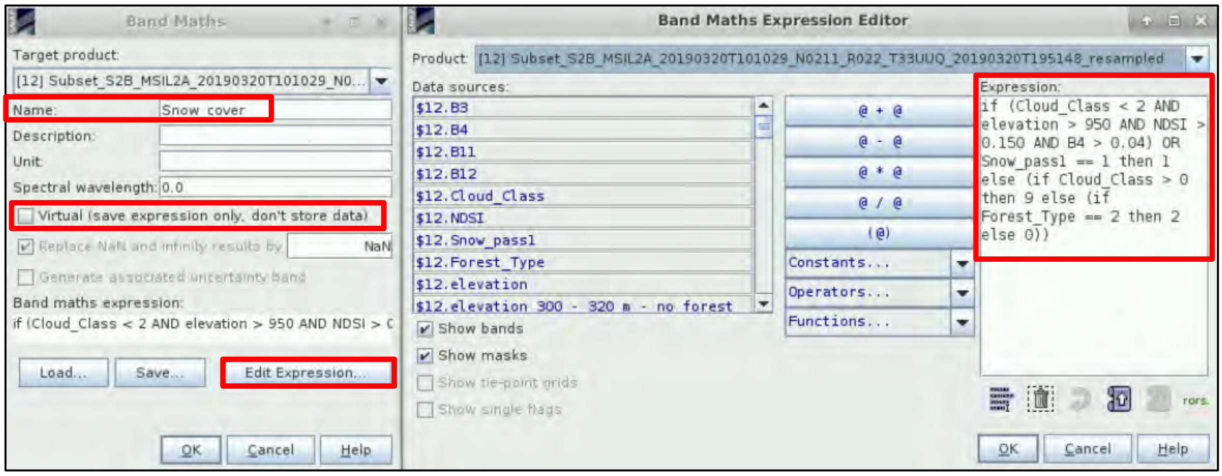
In **Product Explorer**, right-click on the product [12] and go to **Band Maths…**

Target band: *"Snow_cover"*

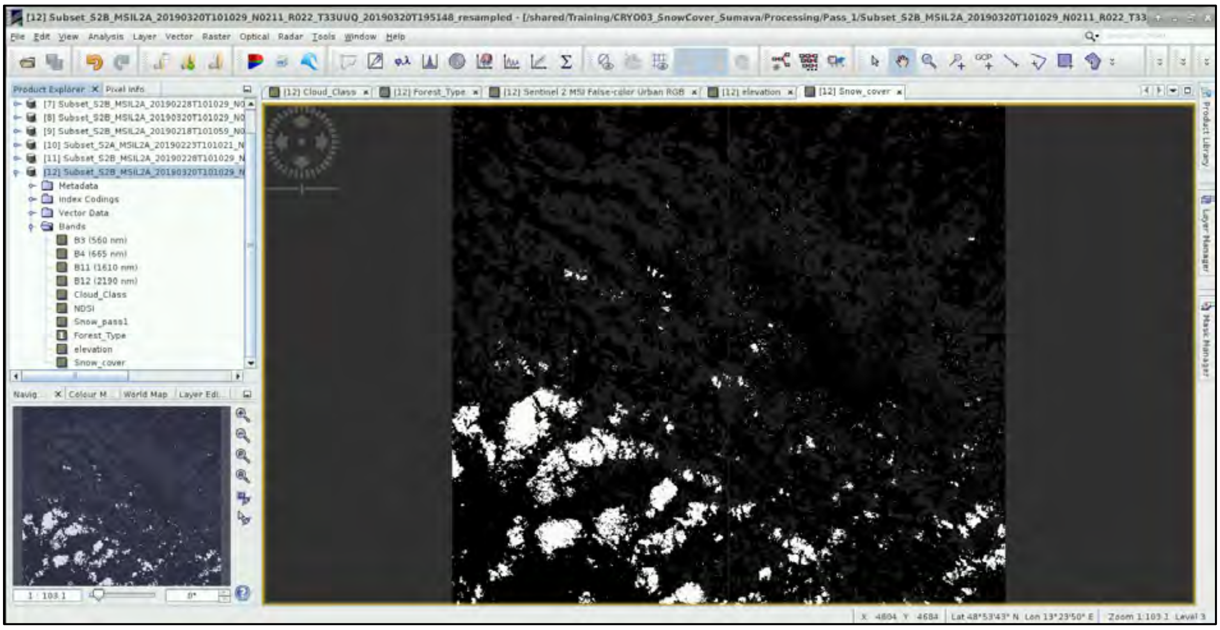
Expression:

```
if (Cloud_Class < 2 AND elevation > 950 AND NDSI > 0.150 AND B4 > 0.04)
OR Snow_pass1 == 1 then 1 else (if Cloud_Class > 0 then 9 else (if
Forest_Type == 2 then 2 else 0))
```

Deselect **Virtual (save expression only, don't store data)** – we want the band to be stored!



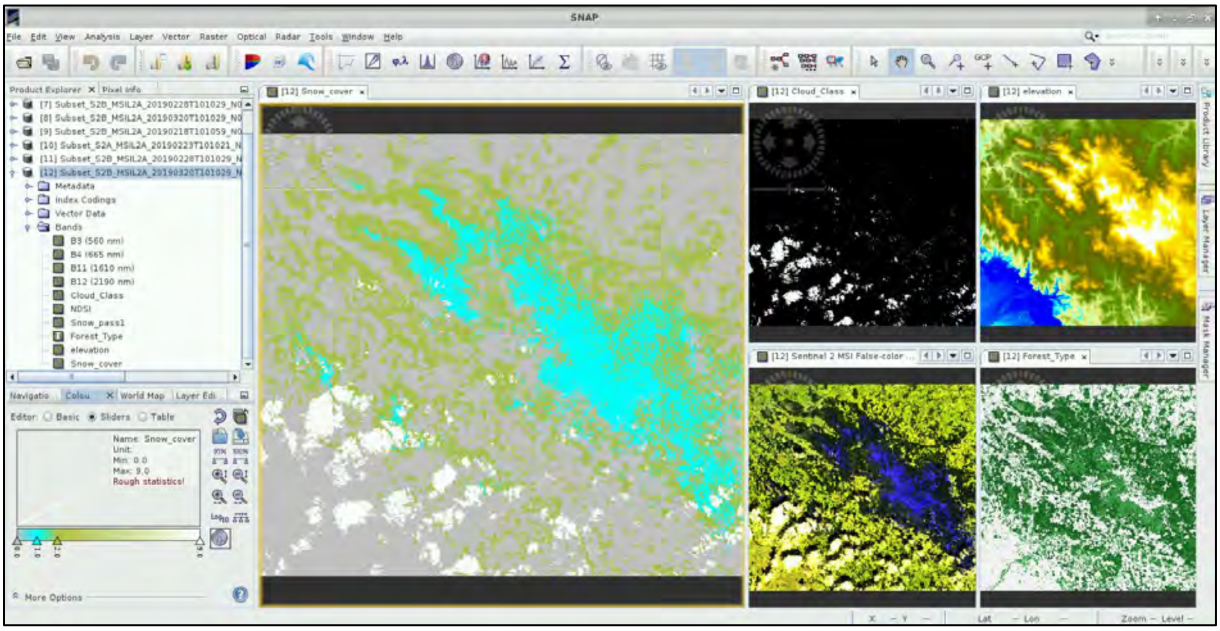
Click OK. A new band will be created and opened automatically.



Let's enhance the visualization a bit by loading prepared colour palette. In Colour Manipulation tab, click on  and open:

/shared/Training/CRYO03_SnowCover_Sumava/AuxData/Snow_cover_map_palette.cpd

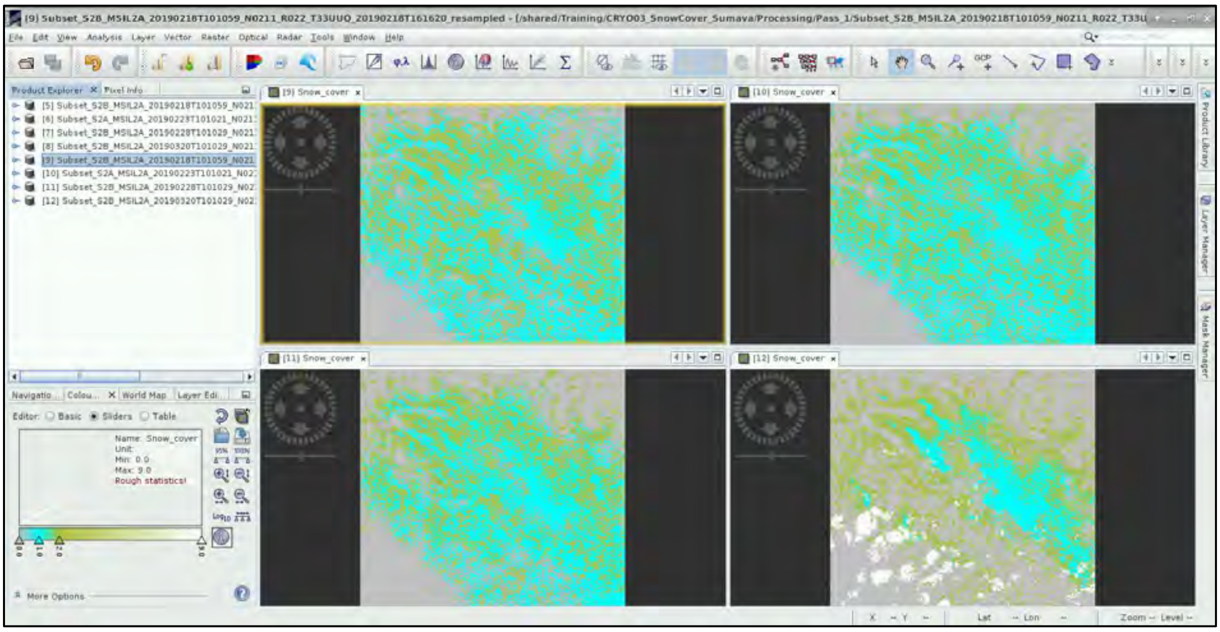
Then click **No** in the dialog that appears – We do NOT want to automatically distribute the points of colour palette between min/max.



The colours can then be interpreted as follows:

	0	No-snow
	1	Snow
	2	Coniferous forest (protentional snow cover)
	9	Cloud

Now repeat the process for the products [9-11].

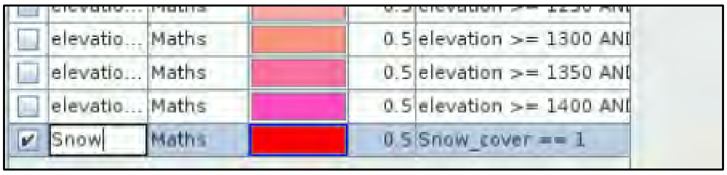


6.5 Snow cover area

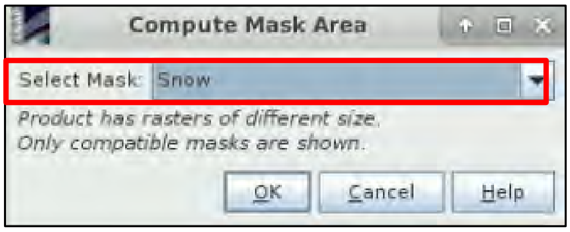
Now we can export our results to GeoTIFF for further processing or we can for example estimate the area of open snow cover (not dense forest).

To do this let's click inside the view of one of our results ([12] for example) and go to **Mask Manager** tab. Click on *f(x)* , an expression window will open (same as for Band Math), type `Snow_cover == 1`

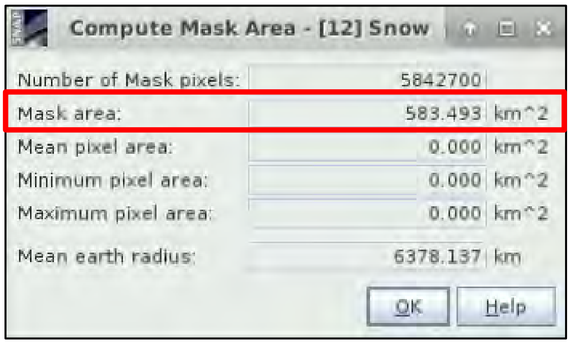
A new mask will appear at the bottom of the list. We can change the name to "Snow".



Then in the main SNAP, window go to **Raster → Masks → Mask Area ...** and select the "Snow" mask.



Click **OK**.



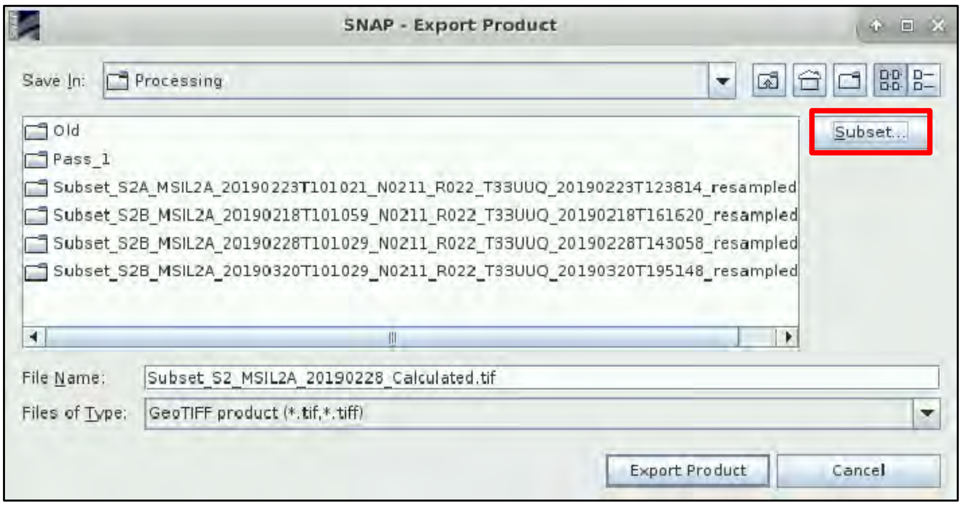
THANK YOU FOR FOLLOWING THE EXERCISE!

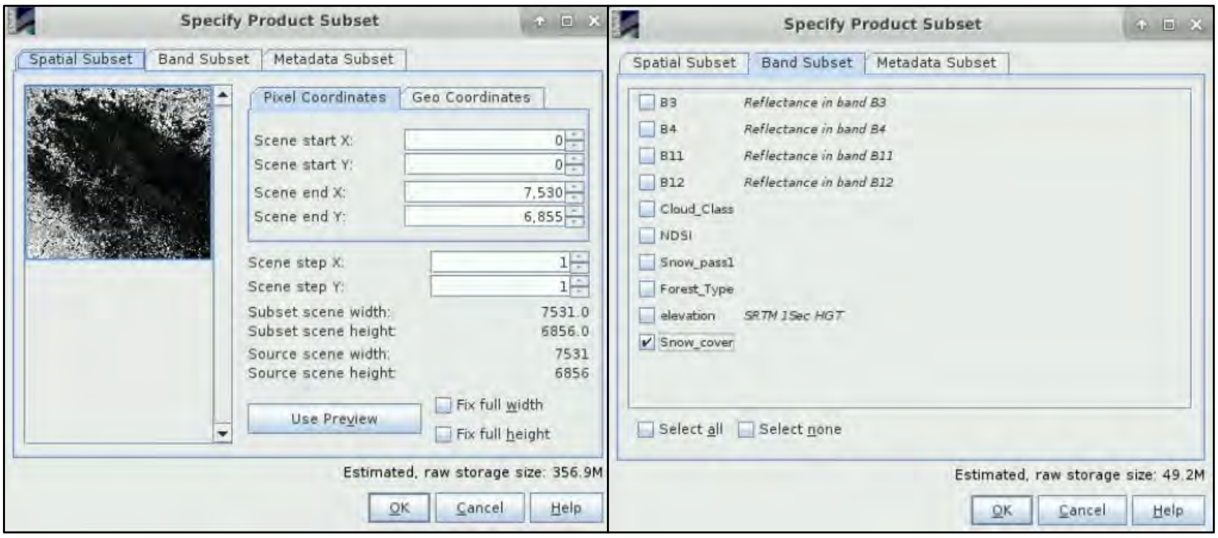
7 Extra steps

7.1 Export as GeoTIFF

To convert the results into GeoTIFF format, select (highlight) the product in **Product Explorer** and go to **File → Export → GeoTIFF**. Navigate to your desired folder and click **Save**.

If you do not wish to save the whole product with all bands, you can use the **Subset** button to perform spatial and/or band subset.





7.2 Atmospheric correction

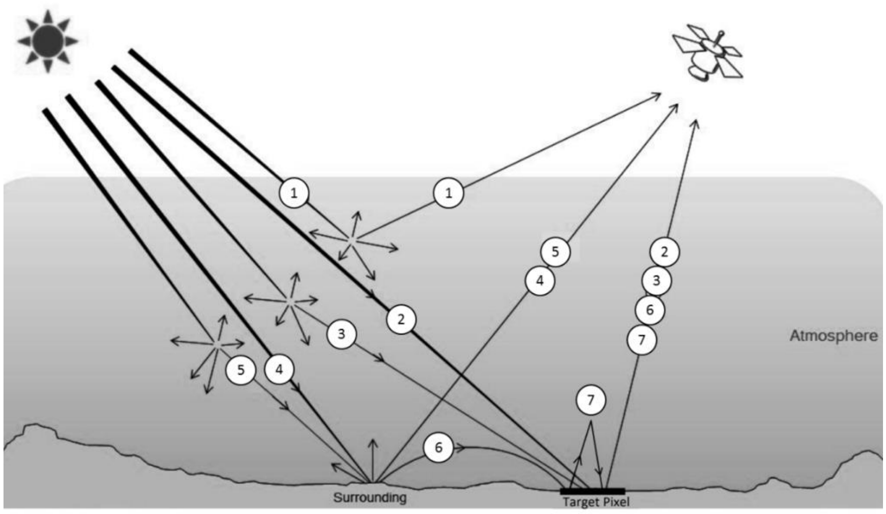
Solar radiation reflected by the Earth's surface to satellite sensors is affected by its interaction with the atmosphere. The objective of applying an atmospheric correction is to determine true surface (Bottom-Of-Atmosphere, BOA) reflectance values from the Top-Of-Atmosphere (TOA) reflectance values, by removing atmospheric effects. (See NOTE E1) Atmospheric correction is especially important in cases where multi-temporal images are compared and analysed as it is in our case. (Mousivand et al. 2015)

Sen2Cor is a 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 Vapour, Scene Classification Maps and Quality Indicators for cloud and snow probabilities.

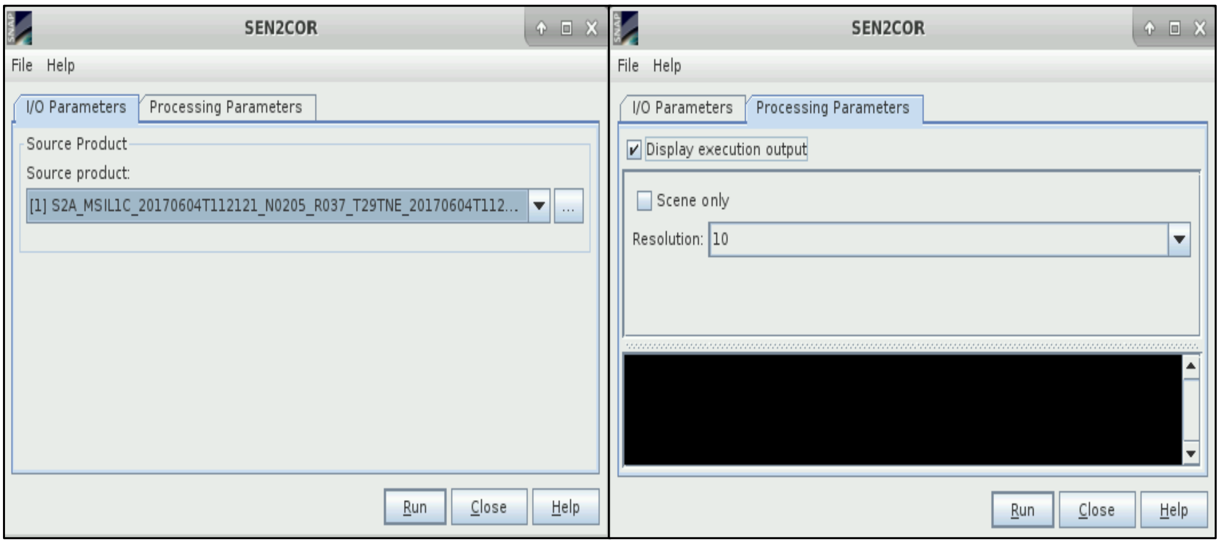
NOTE E1: The radiance reaching the sensor is a result of following components:

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[1]

In the **I/O Parameters**, make sure product [1] is selected. In the Processing Parameters tab, change the resolution to 10 m. Click **Run** …



This is rather a time demanding process and requires approximately 30 minutes per image (with 8GB RAM).

The process creates two new Level 2-A products in the ***".SAFE"*** format in the input data folder.

7.3 Downloading the outputs from VM

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

Gascoin, Simon, Manuel Grizonnet, Marine Bouchet, Germain Salgues, and Olivier Hagolle. 2019. "Theia Snow Collection: High-Resolution Operational Snow Cover Maps from Sentinel-2 and Landsat-8 Data." *Earth System Science Data* 11 (2): 493–514. https://doi.org/10.5194/essd-11-493-2019.

Mousivand, Alijafar, Wout Verhoef, Massimo Menenti, and Ben Gorte. 2015. "Modeling Top of Atmosphere Radiance over Heterogeneous Non-Lambertian Rugged Terrain." *Remote Sensing* 7 (6): 8019–44. https://doi.org/10.3390/rs70608019.

High Resolution Layer: Forest Type (FTY) 2015. European Environment Agency. Accessible at: https://land.copernicus.eu/pan-european/high-resolution-layers/forests/forest-type-1/status-maps/2015?tab=mapview

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