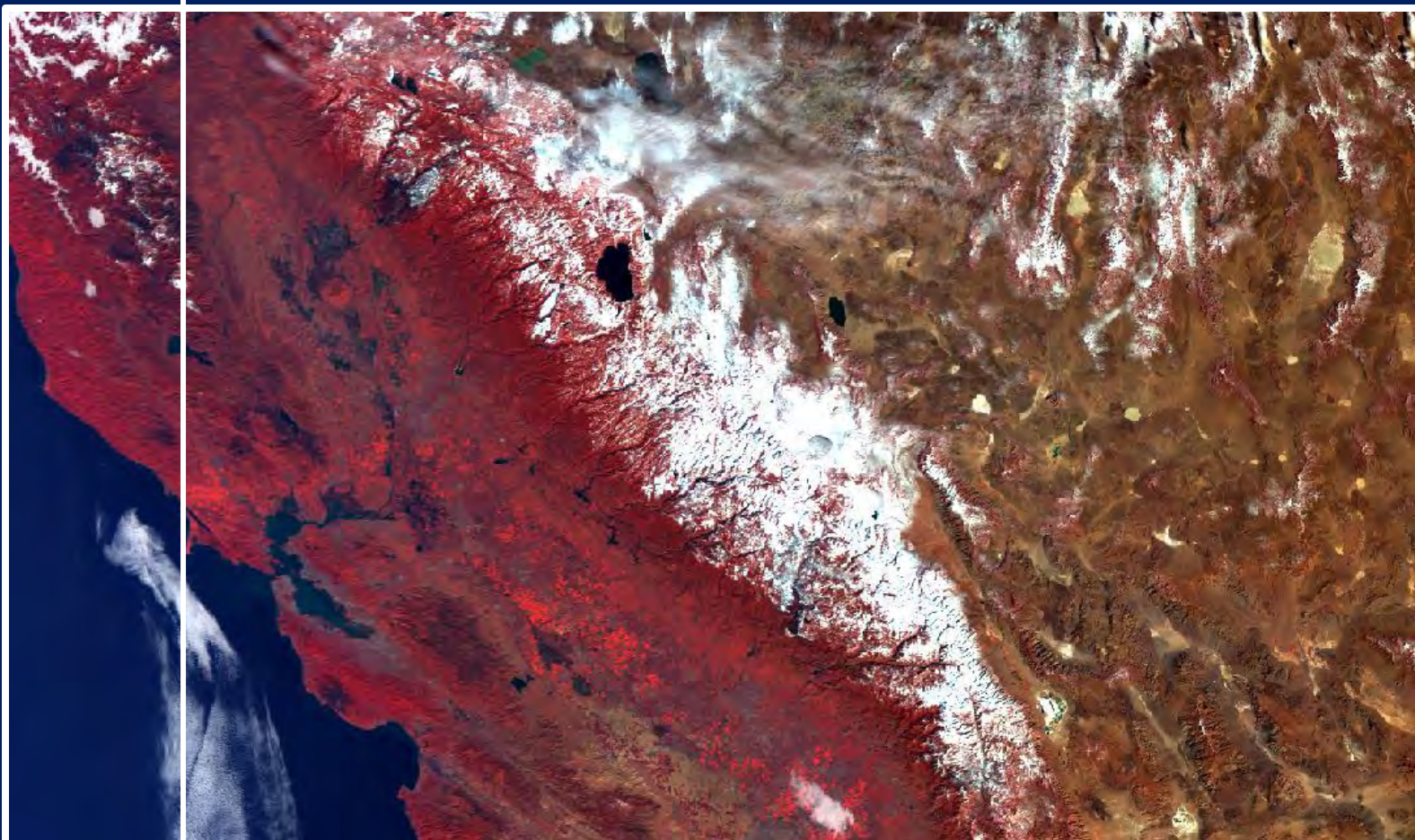


RUS

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TRAINING KIT – CRYO05

SNOW COVER MAPPING WITH SENTINEL-3

Case Study: Sierra Nevada, California, Feb. - May 2021



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 simon.b@rus-copernicus.eu

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Table of Contents

1	Introduction to RUS.....	3
2	Snow Cover Mapping - Background	3
3	Training.....	4
3.1	Data used.....	4
3.2	Software in RUS environment	4
4	Register to RUS Copernicus	4
5	Request a RUS Copernicus Virtual Machine to repeat a Webinar	6
6	Step by step	9
6.1	Data download – ESA SciHUB.....	9
6.2	SNAP – Open and Explore data	14
6.2.1	Create RGB Image – Natural Colours Oa08, Oa06, Oa04	16
6.2.2	Create RGB Image – Oa17, Oa6, Oa3	17
6.3	The Normalized Difference Snow Index (NDSI).....	19
6.4	SNAP – Sentinel-3 Pre-processing	19
6.5	SNAP – Sentinel-3 Processing.....	21
6.5.1	Graph Builder	22
6.5.2	Batch Processing.....	24
6.5.2.1	Subset	25
6.5.2.2	BandMath – snow_flag.....	26
6.5.2.3	Reproject	26
6.5.2.4	Write.....	27
6.6	Analysis of the processed products.....	28
6.7	Checking the accuracy of the computed snow flag by visual inspection	28
6.8	Snow cover time series.....	34
6.8.1	Collocation of the outputs.....	34
6.8.2	Snow cover decrease assessment	35
7	Conclusions.....	38
8	Extra steps – Export to QGIS.....	39
8.3	Export as a GeoTIFF	39
8.4	Opening the File in QGIS.....	40
9	Further reading and resources	42
		2

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 acquired by the Copernicus Sentinel satellites constellation.

In this tutorial, we will map the snow cover evolution in the Sierra Nevada from February to May 2021 based on Sentinel-3 OLCI products. We will carry out this study in the SNAP software on RUS virtual machines.

2 Snow Cover Mapping - Background



Snow cover is the land area blanketed in snow at a given time. Air temperature is one of the main factors that determines the amount of precipitation that falls on land as snow and its melting rate. In many regions of the world, warming trends are inducing fewer snow falls and earlier snowmelt.

While snow cover in winter has remained fairly steady and has increased in the fall since 1972 in

North America, the United States Environmental Protection Agency (EPA) has found that spring and summer snow cover have been plummeting. In fact, the U.S snow season has shortened by more than two weeks in roughly 50 years, the last day of snow now being 19 days earlier than it was in 1972.

In particular, climate change has made California dryer and hotter which means that more rain than snow is now falling. Since much of the rainfall evaporates, spring and summer snowpack constitutes the main water source to fill up reservoirs that fuel human activities such as agriculture or hydropower generation.

The decreasing snow cover and the shift in snow season are contributing factors to the megadrought California has been experiencing since the year 2000. These past 22 years have been the driest years in at least 1200 years based on tree ring records. This has now major impacts on human lives and food production in this American state. For the first time, the federal government is thinking about cutting water supplies by 25%.

Hence monitoring snow cover is of prime importance to determine the amount of available water in California. With their high spatial and temporal resolution and coverage, earth observation satellites constitute key tools to assess the snow cover on a regular basis. In particular, it is possible to compute the Normalized Difference Snow Index (NDSI) from the data collected by the Ocean and Land Colour Instrument (OLCI) on board Sentinel-3A and Sentinel-3B. The NDSI is a key indicator of the presence of snow. The methodology presented here has been adapted from Kokhanovsky et al. (2019)

3 Training

Approximate duration of this training session is **one hour and a half**.

The Training Code for this tutorial is **CRY005**. If you wish to practice the exercise described below within the RUS Virtual Environment, register on the [RUS portal](#) to request a Virtual Machine. Go to Your RUS Service → Your training activities and *Request a Webinar Training*.

3.1 Data used

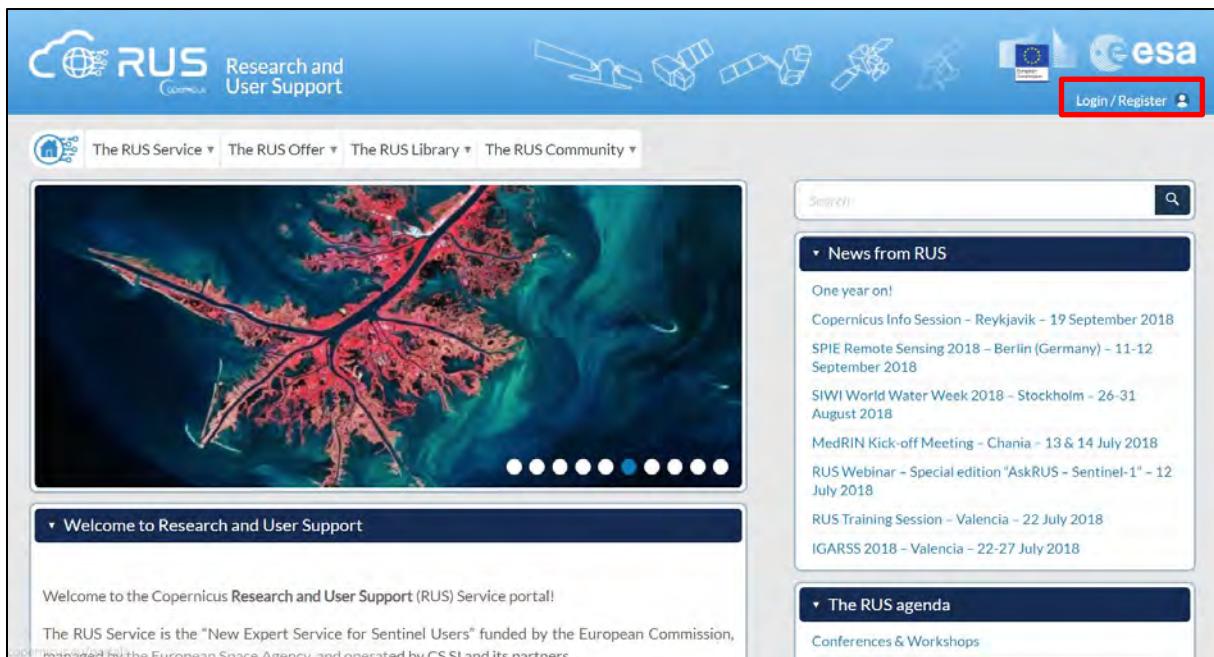
- 4 low/no-cloud Sentinel-3A images acquired on February 6th, March 5th, April 1st, and May 6th 2021 (one image per month):
[downloadable @ <https://scihub.copernicus.eu/>]
S3A_OL_1_EFR____20210206T181455_20210206T181755_20210207T232248_0179_068_141_2340_LN1_O_NT_002.zip
S3A_OL_1_EFR____20210305T181452_20210305T181752_20210307T000051_0179_069_141_2340_LN1_O_NT_002.zip
S3A_OL_1_EFR____20210401T181454_20210401T181754_20210402T222055_0179_070_141_2340_LN1_O_NT_002.zip
S3A_OL_1_EFR____20210506T180730_20210506T181030_20210507T222424_0179_071_255_2340_LN1_O_NT_002.zip

3.2 Software in RUS environment

Internet browser, SNAP+Sentinel-3 Toolbox, QGIS

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 an 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.

Login / Register

The registration system to access the RUS service platform has moved toward the COPERNICUS Single Sign On authentication server.

- New Users who have not yet registered to the RUS portal shall first create a COPERNICUS SSO account.

Note that your Copernicus SSO account will be activated only after the reception of the third email sent by the Copernicus service. We advise you to consult [this document](#) and [this page](#) to facilitate your registration procedure.

REGISTER COPERNICUS SSO account

Users who already have a COPERNICUS SSO account can login here:

Login

Close

Credentials

CDS-SSO ID

Password

Max Idle Time

Max Session Time

Login **Reset**

[Forgot your password?](#)

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

Do you want to subscribe for a new RUS account?

Your ESA-SSO subscription data:

Login

First Name

Last Name

Email

Organization

Country

Additional subscription information

Please complete the following information:

Where did you hear about the RUS service?
Select one or more items:

outreach event
colleagues
newsletter
conference
social media
other

Institution type

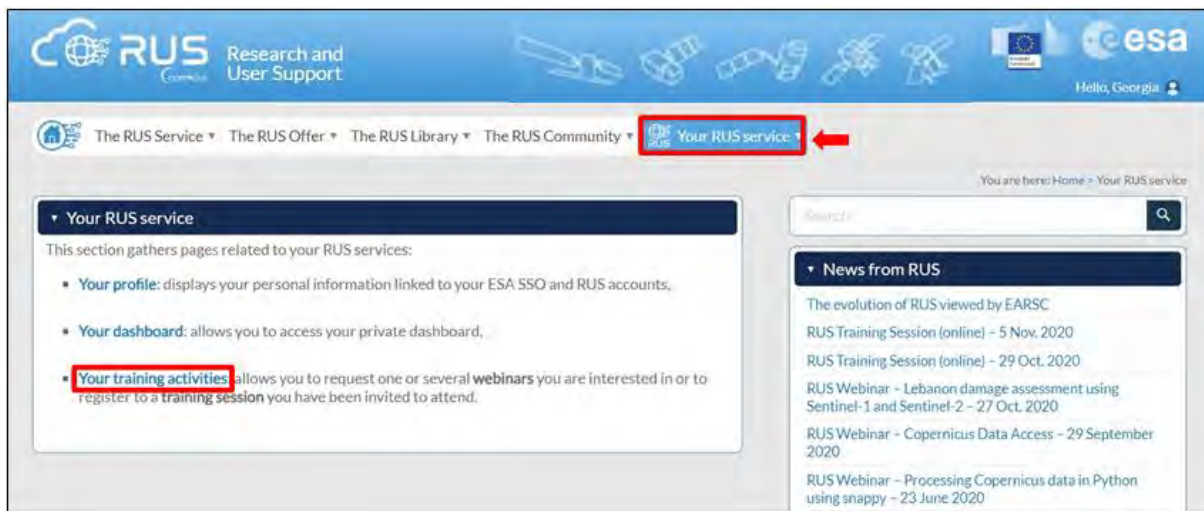
Phone number

Title

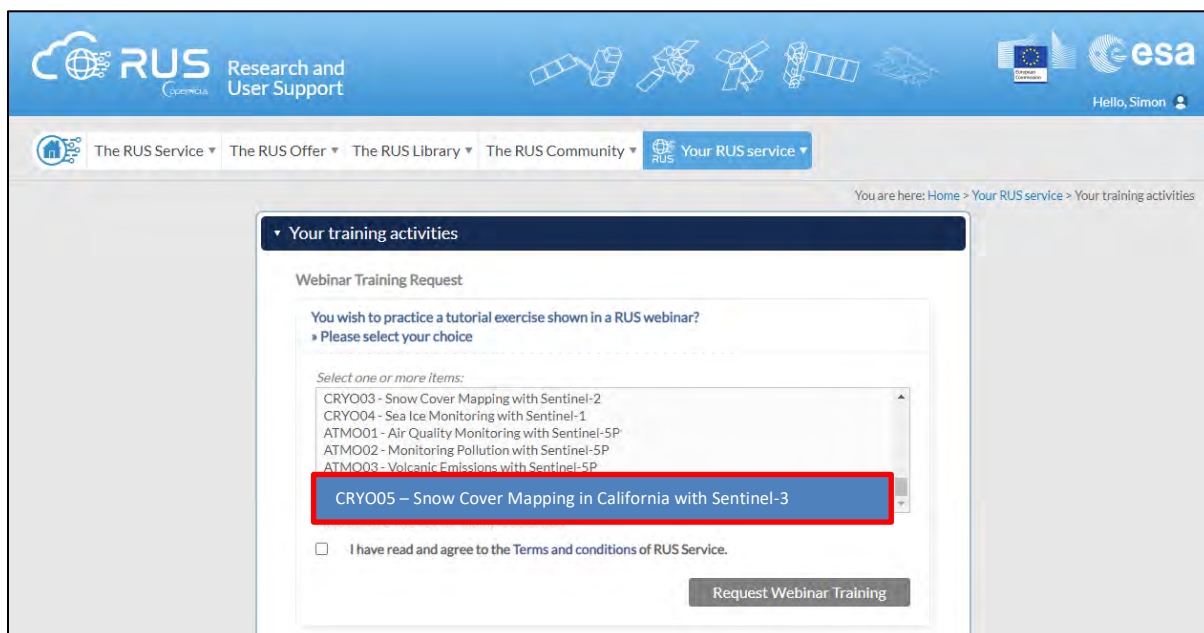
Subscribe **Cancel**

5 Request a RUS Copernicus Virtual Machine to repeat a Webinar

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



Select **CRYO05 – Snow Cover Mapping in California with Sentinel-3**, check the field “*I have read and agree to the Terms and conditions of RUS Service*” and then click on **Request Webinar Training** to request your RUS Virtual Machine.



Further to the acceptance of your request by the RUS Helpdesk, you will receive a notification email with all the details about your Virtual Machine.

To access it, go to **Your RUS Service → Your Dashboard** and click on **Access my Virtual Machine**.

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

RUS Research and User Support

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Hello, Georgia

The RUS Service ▾ The RUS Offer ▾ The RUS Library ▾ The RUS Community ▾ Your RUS service ▾

You are here: Home > Your RUS service > Your dashboard

▼ Your dashboard

Request a new User Service

Chat with Support Desk

Project Name	ID	Date of submission	Status	Actions			Virtual Environment	
RUS_training1			Open	Follow my project	Get support	Close my service	Access my Virtual Machine(s)	Access my CPU monitoring dashboard
				Cancel my request	Get a webinar kit	Rate my service ★★★★★	Freeze my Virtual Machine(s)	Report a technical incident
Study_Case_1	1698	2018-05-07	Closed	View history	Get support	Cancel my service	Access my Virtual Machine(s)	Access my CPU monitoring dashboard
				Cancel my request	Get a webinar kit	Rate my service ★★★★★	Freeze my Virtual Machine(s)	Report a technical incident

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Contact Us Terms and conditions Glossary Acronyms FAQ

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

RUS Copernicus

RUS Desktop

Username

Password

Login

WELCOME TO RUS' DESKTOP

This is the remote desktop of your Virtual Machine.



6 Step by step

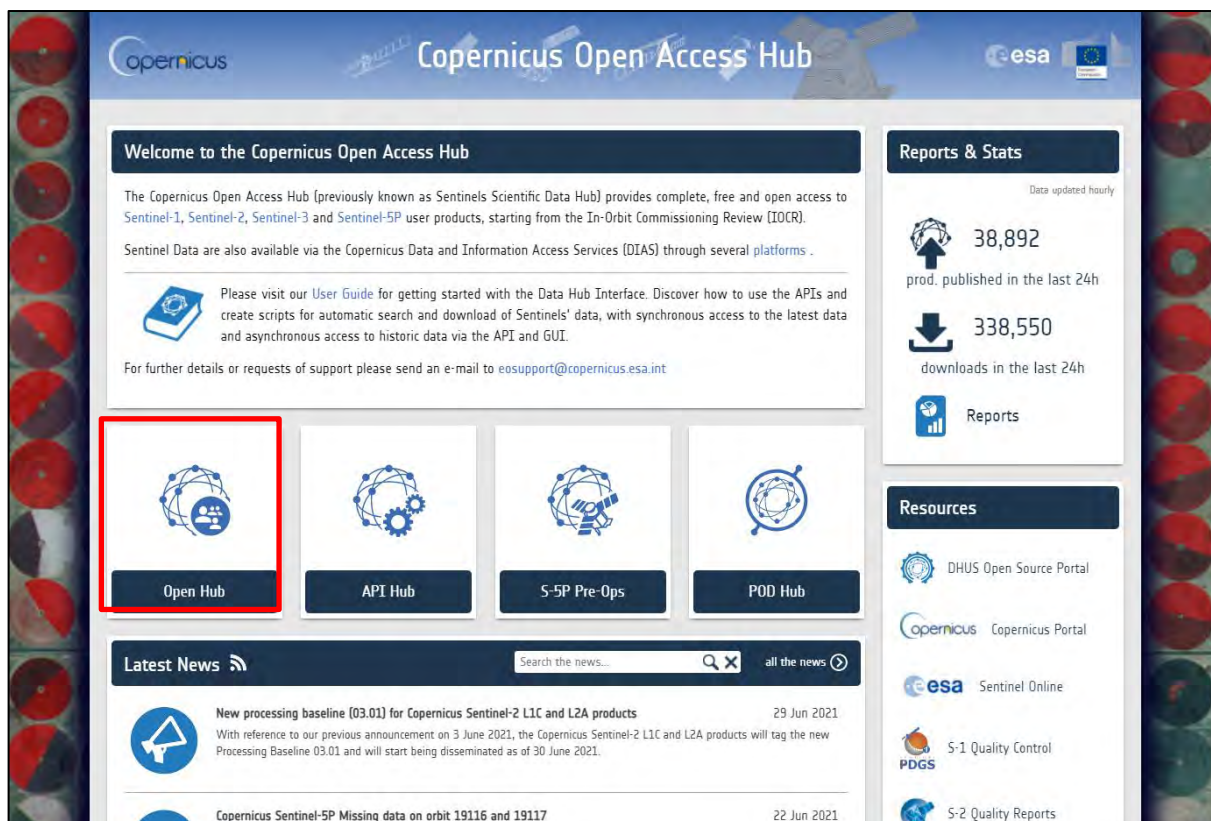
6.1 Data download – ESA SciHUB

In this step, we will download the Sentinel-3 scenes used for the exercise, from the Copernicus Open Access Hub using the online interface.

Go to **Applications** → **Network** → **Firefox Web Browser** or click the link below.

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

Before starting the exercise, make sure you are registered in the Copernicus Open Access Hub so that you can access the free data provided by the Sentinel satellites.






Go to “**Open Hub**”. If you do not have an account, sign up in the upper right corner, fill in the details and click register.

The screenshot shows the 'Register new account' page on the Copernicus Open Access Hub. The page has a dark header with the ESA and Copernicus logos. The main content area is white and contains a registration form. The form includes fields for 'Firstname', 'Lastname', 'Username', 'Password', 'Confirm Password', 'E-mail', 'Confirm E-mail', 'Select Domain', 'Select Usage', and 'Select your country'. Below the form, there is a checkbox for 'By registering in this website you are deemed to have accepted the T&C for Sentinel data use.' and a red 'REGISTER' button. A red arrow points to the 'REGISTER' button.

You will receive a confirmation email at the e-mail address you have specified: open the email and click on the link to finalize the registration.

Once your account is activated – or if you already have an account – **LOGIN**.



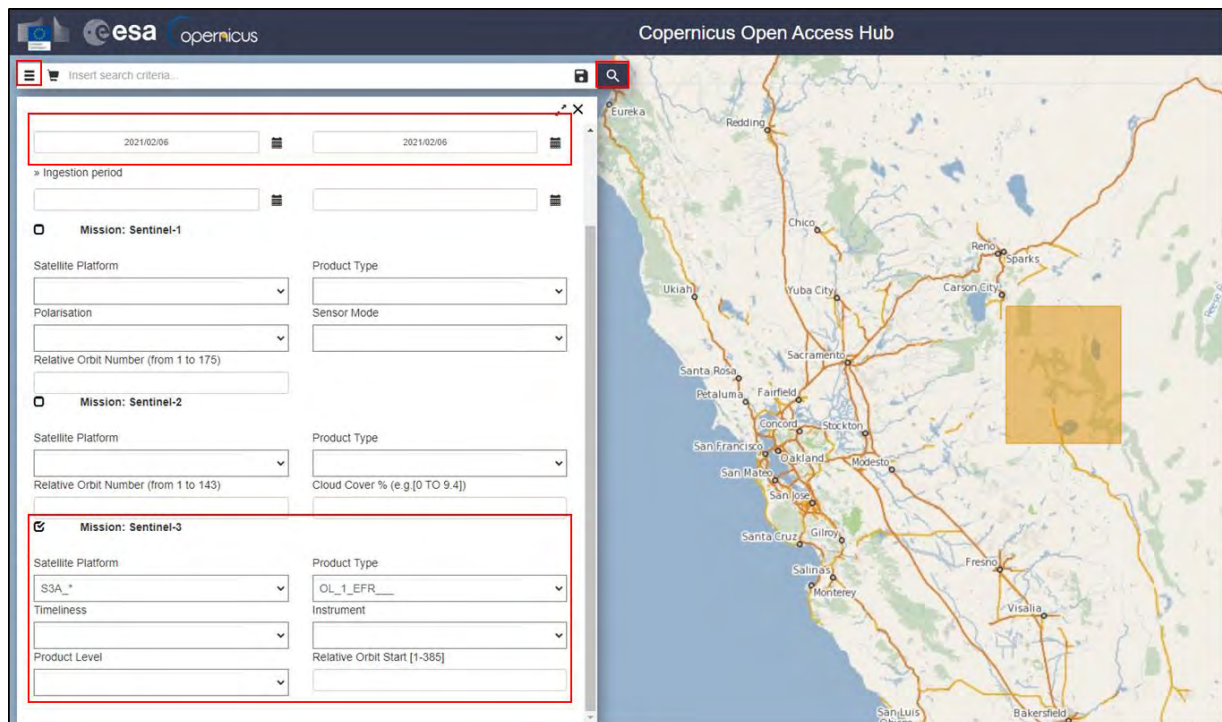
In this guide, we describe the procedure to download the 4 Sentinel-3A images. Drag the Map to California and define the study area using the  button (approximate area – orange rectangle located east of San Francisco and just South East of Carson City). Then, open the search menu by clicking on the left part of the search bar () and specify the parameters below. Press the search button () after that.

Sensing period: From 2021/02/06 to 2021/02/06

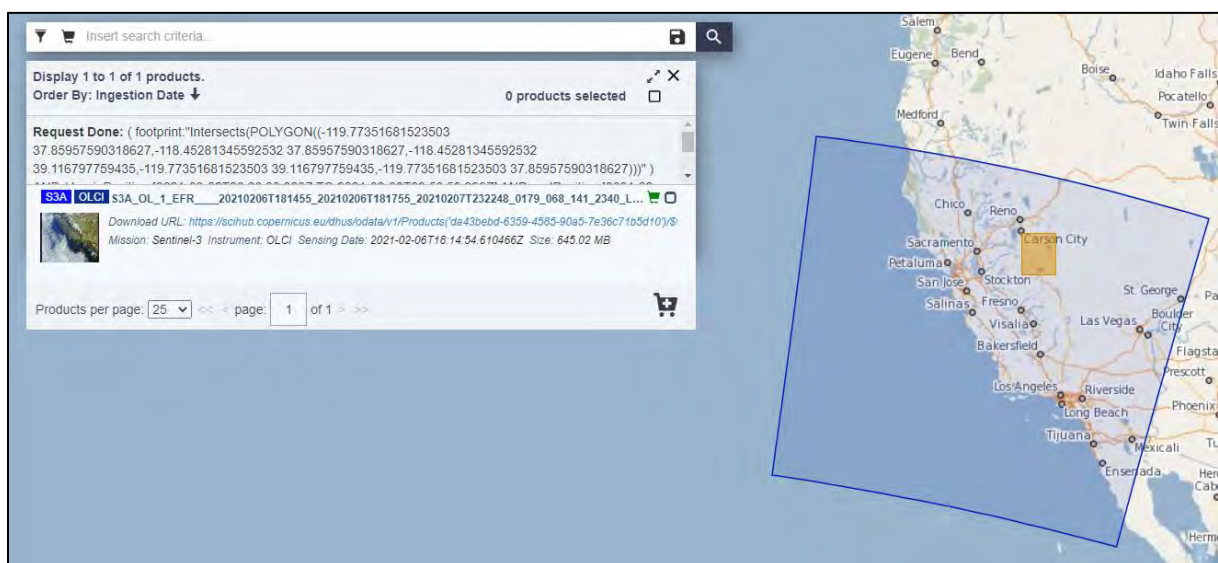
Check mission: Sentinel-3

Satellite Platform: S3A_*

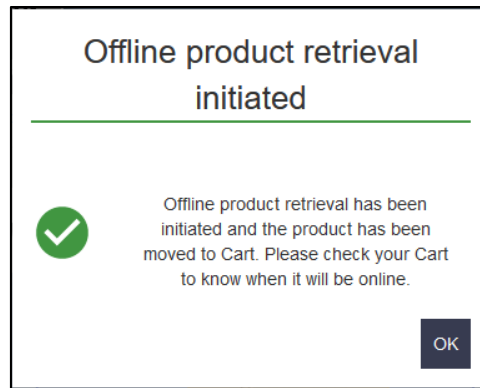
Product type: OL_1_EFR







In this case, the search returns 1 result (**blue** tile).




As you can see, the product appears **Offline**. Hitting the download icon  will trigger the offline product retrieval:




This will automatically add the product to the “**Cart**” . In case an error message appears, try again a bit later – you can request one offline product per account per hour. (See  NOTE 1 and  NOTE 2). The product will be online within a few hours. Once online, the product will remain available for download for at least 3 days before it is moved back offline.

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


 **NOTE 2:** You can find more information about the retrieval of offline/long term archive products here: <https://scihub.copernicus.eu/userguide/DataRestoration>. Most Sentinel products remain online for a month after they are published. They are then moved offline and need to be requested back online as previously shown. In a more general way, the [scihub user guide](#) is a very useful resource to check.

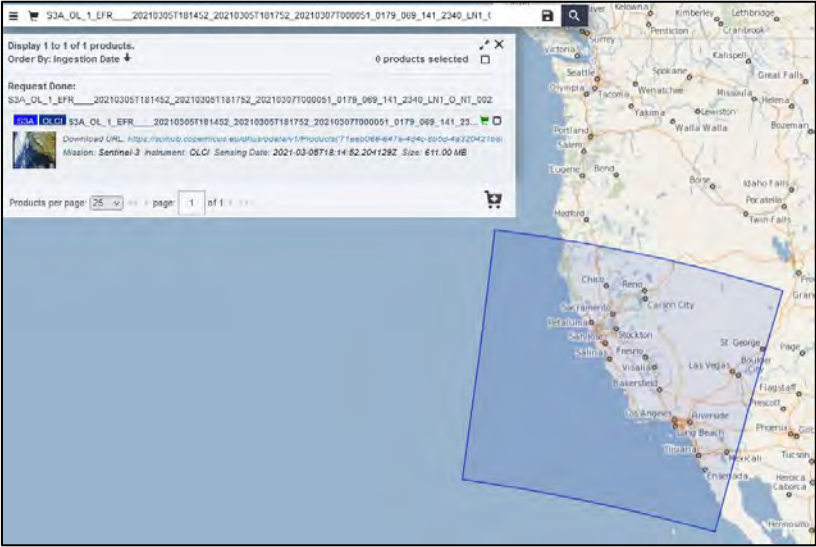
You need to repeat the same process for the following images and adapt the search criteria:

- S3A product from March 5th 2021:
- S3A_OL_1_EFR____20210305T181452_20210305T181752_20210307T000051_0179_069_141_2340_LN1_O_NT_002
 - **Sensing period:** From 2021/03/05 to 2021/03/05
 - **Check mission:** Sentinel-3
 - **Satellite Platform:** S3A_*
 - **Product type:** OL_1_EFR
- S3A product from April 1st 2021:
- S3A_OL_1_EFR____20210401T181454_20210401T181754_20210402T222055_0179_070_141_2340_LN1_O_NT_002
 - **Sensing period:** From 2021/04/01 to 2021/04/01
 - **Check mission:** Sentinel-3
 - **Satellite Platform:** S3A_*
 - **Product type:** OL_1_EFR
- S3A product from May 6th 2021
- S3A_OL_1_EFR____20210506T180730_20210506T181030_20210507T222424_0179_071_255_2340_LN1_O_NT_002
 - **Sensing period:** From 2021/05/06 to 2021/05/06
 - **Check mission:** Sentinel-3
 - **Satellite Platform:** S3A_*
 - **Product type:** OL_1_EFR



Each search should give you a unique product. The products will be downloaded to **/home/rus/** as zip archives. Move them to the below path and unzip the archives: **Right-click on the product → Extract Here**  **Extract Here**. These 4 products were chosen because of their very low cloud coverage over our area of interest.

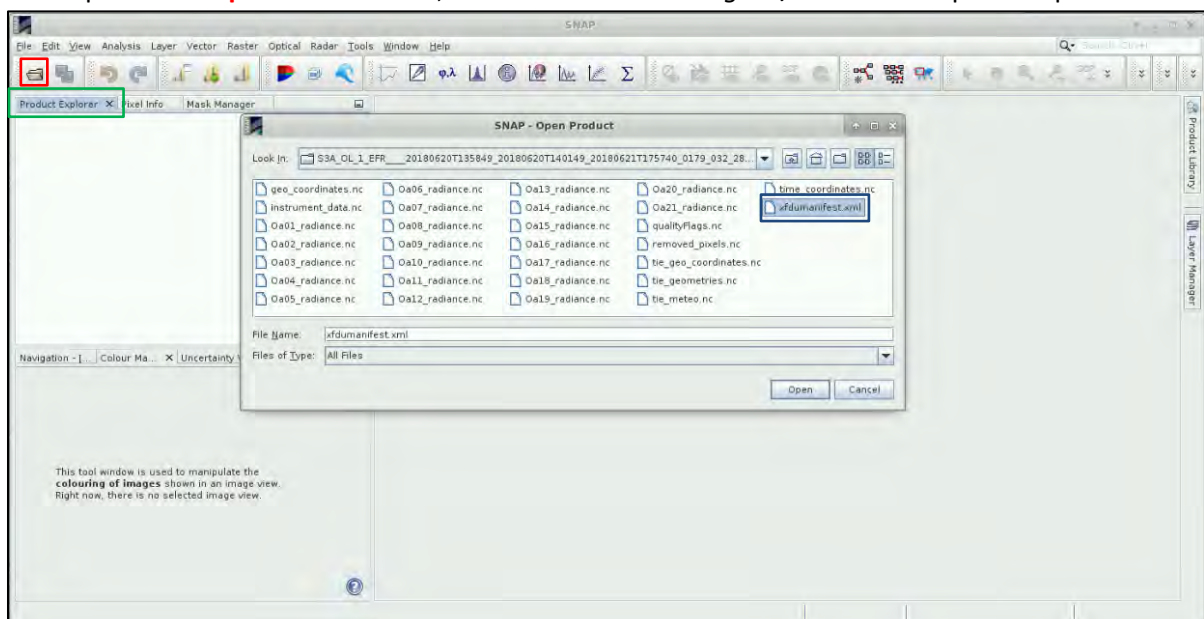
Path: **/shared/Training/CRYO05_SnowCover_California/Original/**

 **NOTE 3:** Copy-paste the S-3 Image name in the Search Criteria box (upper left corner) of the Copernicus Open Access Hub to find the images faster (make sure to clear all other search criteria first).




6.2 SNAP – Open and Explore data

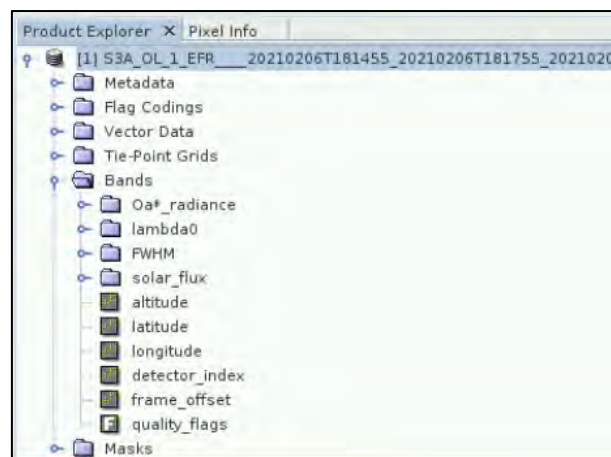
Once you have extracted the archives, open the SNAP software from the icon  located on the desktop. Hit the **Open Product** icon,  browse to the *Original/* folder and open the product from



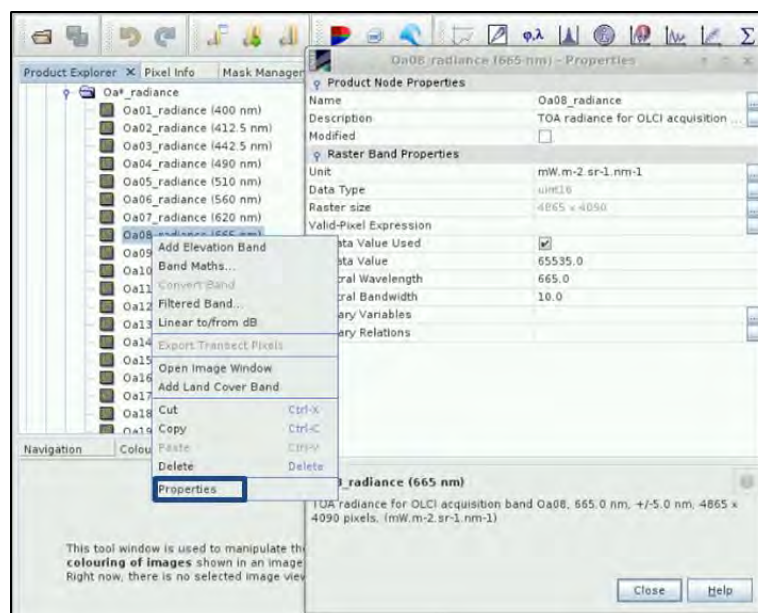
February 6th by selecting its [xfdunmanifest.xml](#) file. You can also navigate to the product folder from a product browser and drag and drop the [xfdunmanifest.xml](#) file in the **Product Explorer Tab**.

The product is now open in the **Product Explorer Tab** of the SNAP software. Feel free to expand the product tree by hitting the key  button left of the open product. Unfold the product content and appreciate how SNAP conveniently gathers the data into several folders.

The main data of interest (top of atmosphere radiances in the 21 spectral bands of OLCI is stored in the **Bands** → **Oa*_radiance** folder. The other folders contain data that give additional information on the context of the measurements. For example, the **Masks** folder encloses very useful information on the quality of the retrieval. **MetaData** contains static information about the product such as the timestamp, the platform name, the observation mode, etc.

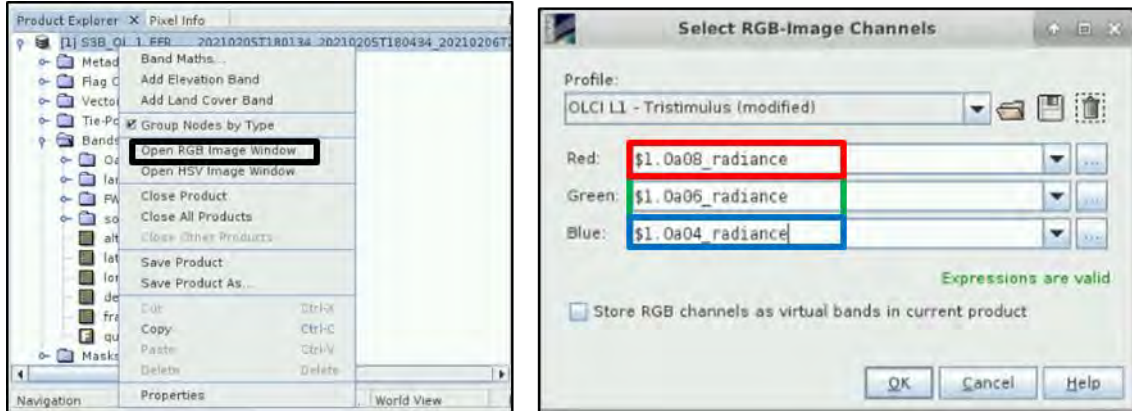


If you want to check the properties of a band, right-click on the band and hit **Properties**.



6.2.1 Create RGB Image – Natural Colours Oa08, Oa06, Oa04

To visualize our product content, right click on the S3A product name and select **Open RGB Image Window**. Select **Oa08 for Red**, **Oa06 for Green** and **Oa04 for Blue**. Hit **OK** and the RGB view will open in the **View Window**

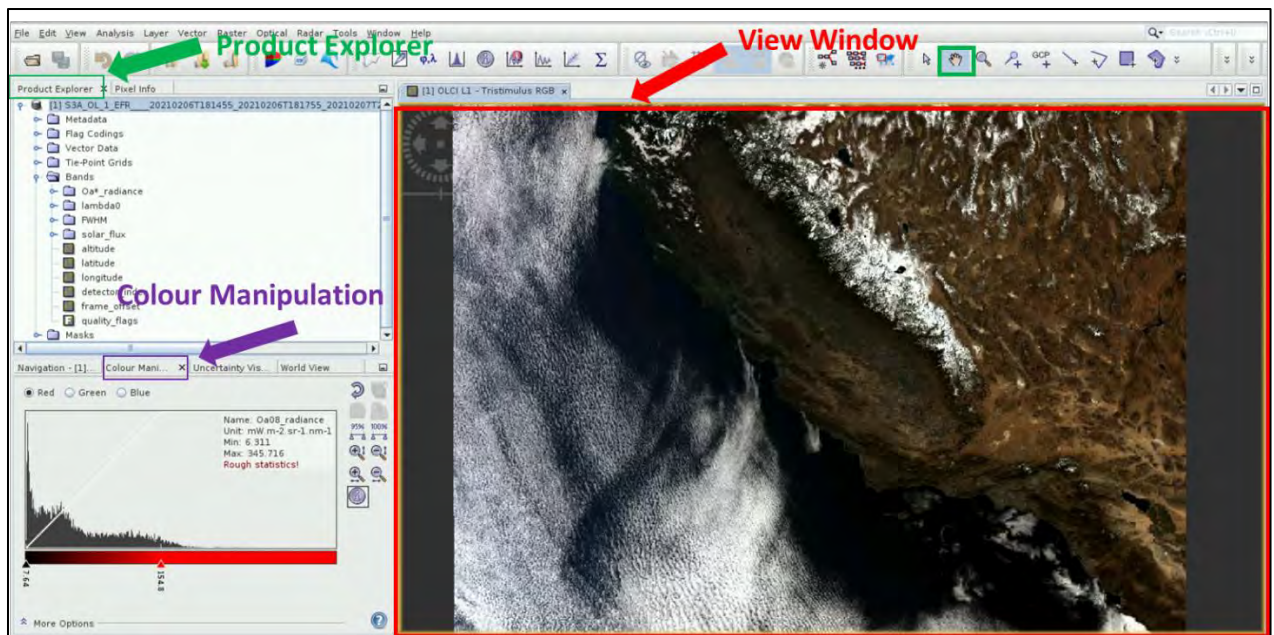


TIP 1: \$1 Refers to the index number of the product in the **Product Explorer Tab**

When on the view, select the **Hand** button to drag the view to your area of interest. Simply use the centre wheel of your mouse to zoom in and out. You can go to the **World View** tab and zoom in to see the location of the opened product on the globe.

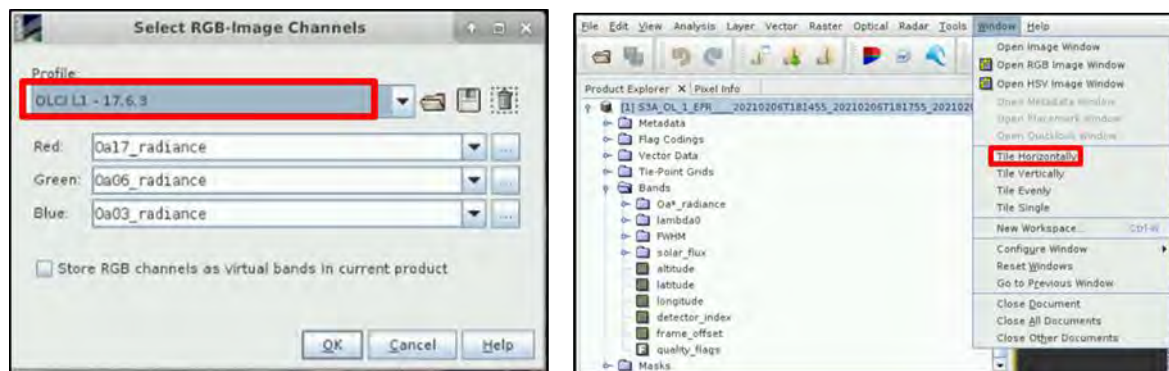


On the generated view, you can notice that most of the Sierra Nevada mountain chain is covered in snow on February 6th 2021.

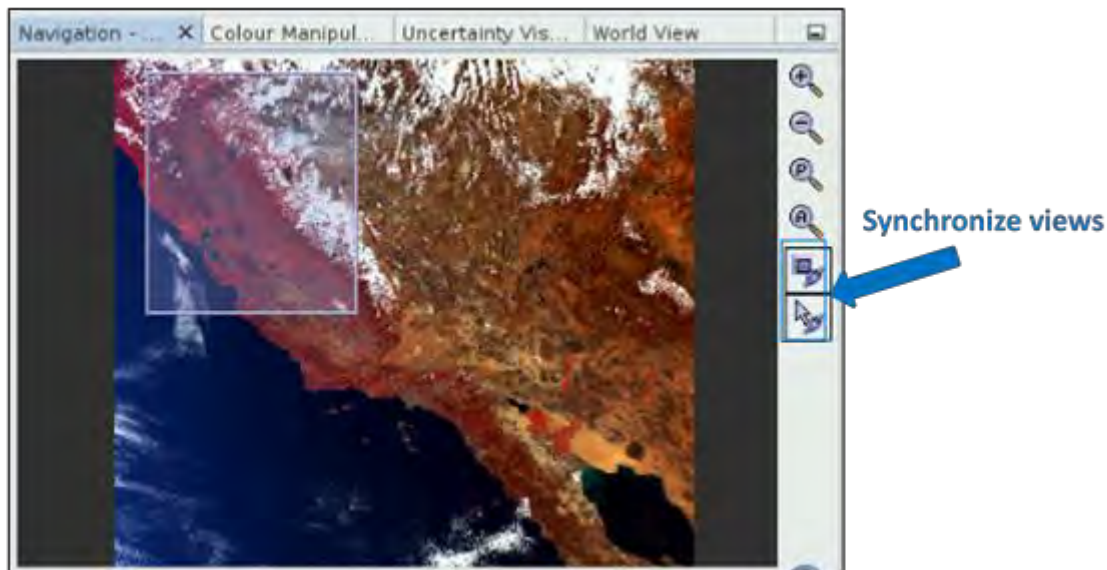


6.2.2 Create RGB Image – Oa17, Oa6, Oa3

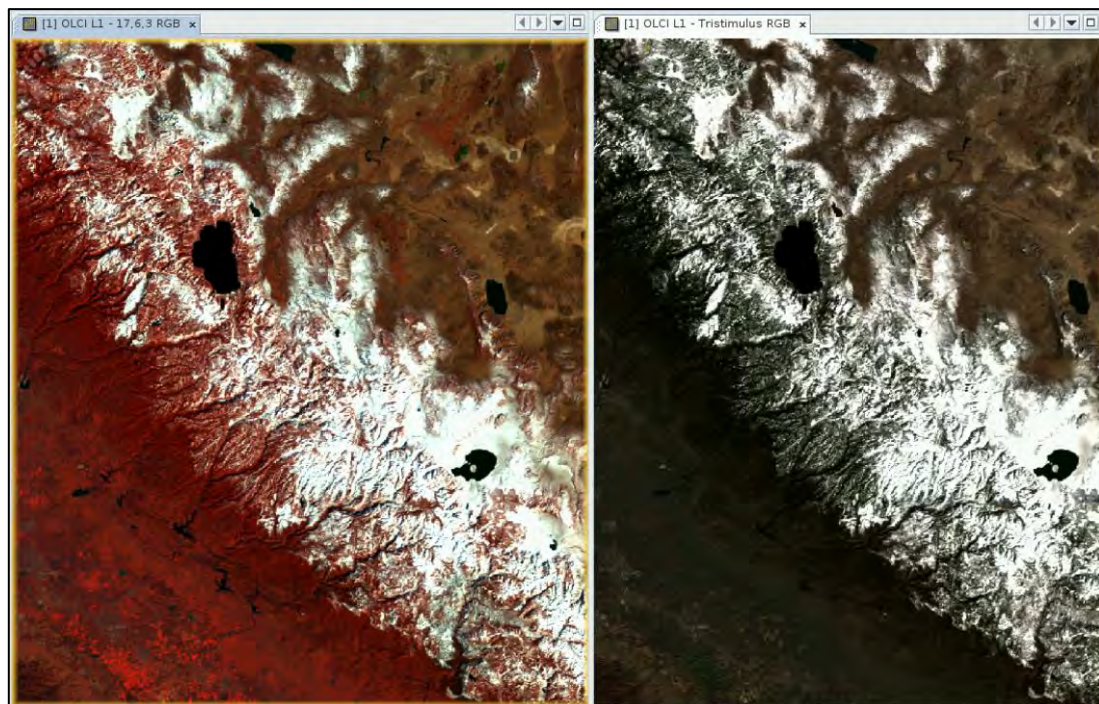
In order to enhance the snow visualization, we are going to open a second view with different OLCI bands. Just like in section 6.2.1, right click again on the product name and select **Open an RGB Image Window**. Then in the profile section, choose OLCI L1 – 17.6.3. Then, to make both views simultaneously visible, go to **Window → Tile Horizontally**



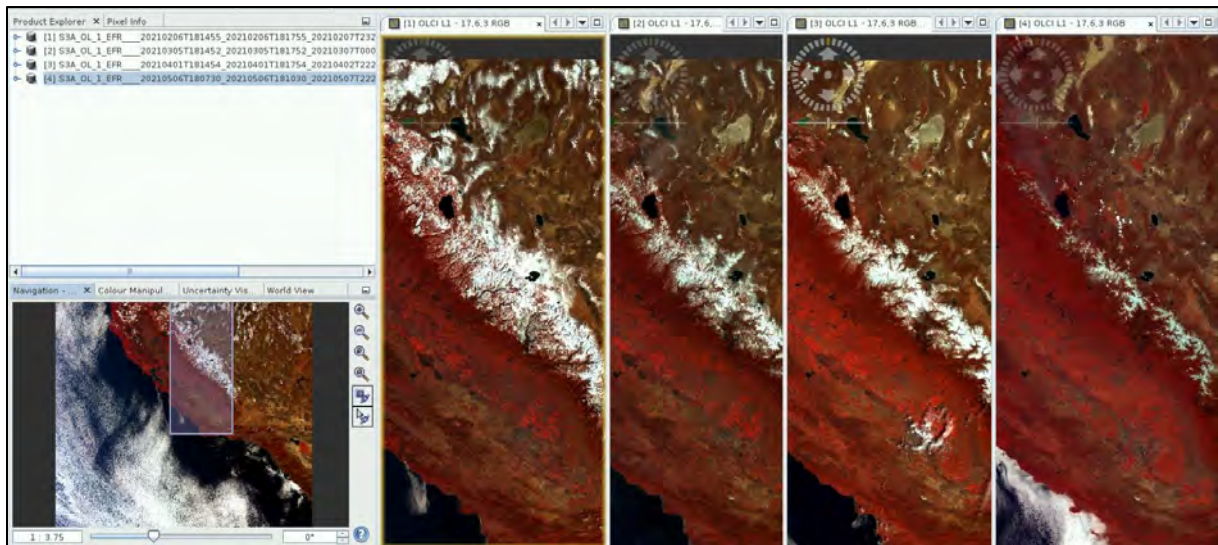
Then, in the Navigation tab, click on the two icons shown within the **blue rectangle** below, to synchronize the views and the cursor position across the views.




Now, feel free to navigate on the views, zoom in and out to explore the different features of the pictures!




Close the RGB View opened with the natural colours (Tristimulus RGB view). Open the three remaining S3A products in SNAP in **chronological order** (products from March, April and May 2021) and open RGB views with the OLCI L1 – 17.6.3 profile for each of them. Finally, go to **Window→ Tile Horizontally** to simultaneously inspect the 4 months. It is possible to visually assess the snow cover decrease from February to May 2021.



6.3 The Normalized Difference Snow Index (NDSI)

Visual inspection of the products clearly shows a strong snow cover decrease over the course of spring 2021. To more quantitatively assess the snow cover extent, we will compute the so-called Normalized Difference Snow Index (NDSI, see  NOTE 3).


 NOTE 3: NDSI is related to the presence of snow in a pixel and allows to distinguish snow from most cloud types. Indeed, on satellite images, snow may appear as bright as clouds. In the SWIR part of the spectrum, snow strongly absorbs solar radiation as opposed to clouds. As OLCI has no SWIR band, Kokhanovski et al. (2019) have adapted the NDSI computation to the OLCI sensor:

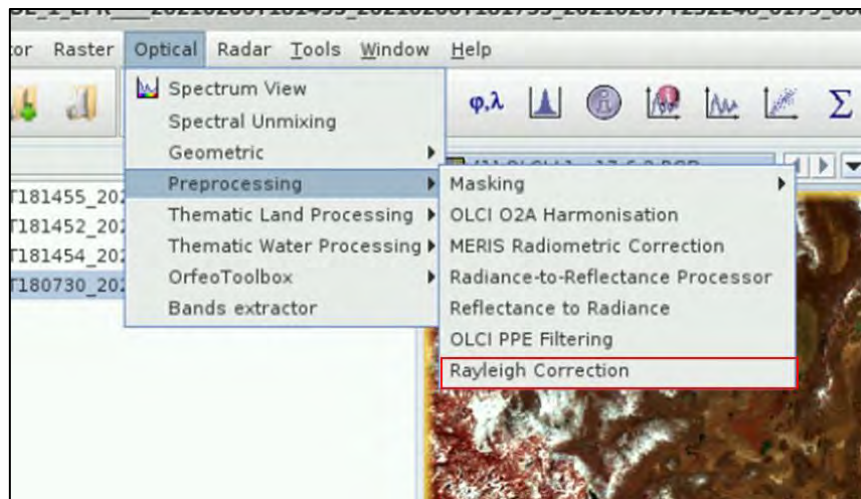
$$NDSI = \frac{R(\lambda_1) - R(\lambda_2)}{R(\lambda_1) + R(\lambda_2)}$$

Where $R(\lambda_n)$ are the **atmospherically corrected radiances** for:

- $\lambda_1 = 865 \text{ nm}$ (band 17)
- $\lambda_2 = 1020 \text{ nm}$ (band 21)

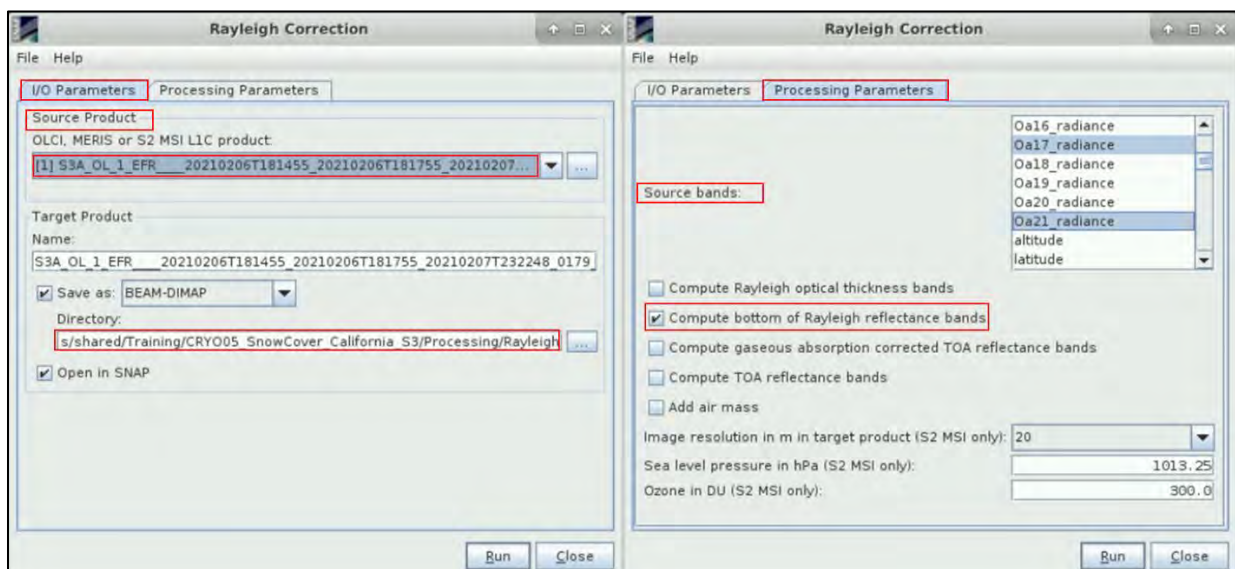
6.4 SNAP – Sentinel-3 Pre-processing

As you may have noticed, computing NDSI out of OLCI products involves using **atmospherically corrected radiances**. The native OLCI L1B products only contain Top of Atmosphere (TOA) radiances for the 21 spectral bands (see  NOTE 4). Our pre-processing step will therefore consist in using **Optical→Preprocessing→Rayleigh Correction**. At the time of writing this exercise, this module does not work in batch mode and we need to apply it to each individual scene one by one. The Rayleigh correction module fully corrects the selected bands for molecular absorption and scattering to compute the so-called Bottom of Rayleigh reflectances (rBRR). This module does not account for aerosol absorption and scattering, so these effects will be neglected in our study.

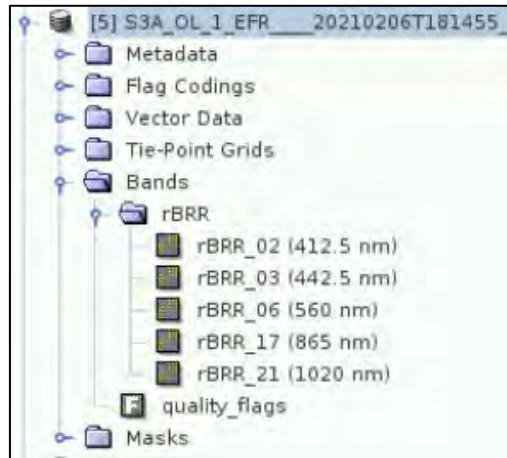


NOTE 4: Radiance is the variable directly measured by remote sensing instruments. It is the amount of light seen by an instrument from a surface of an object. In the OLCI products, it is given as $\text{mW.m}^{-2}.\text{sr}^{-1}.\mu\text{m}^{-1}$. This amount of light is hence measured at the Top of Atmosphere. Some applications may require that the TOA radiances are first corrected for atmospheric effects (molecular and aerosol scattering and absorption) to work with Bottom of Atmosphere (BOA) radiances. BOA radiances is the amount of light leaving a target at the bottom of our atmosphere.

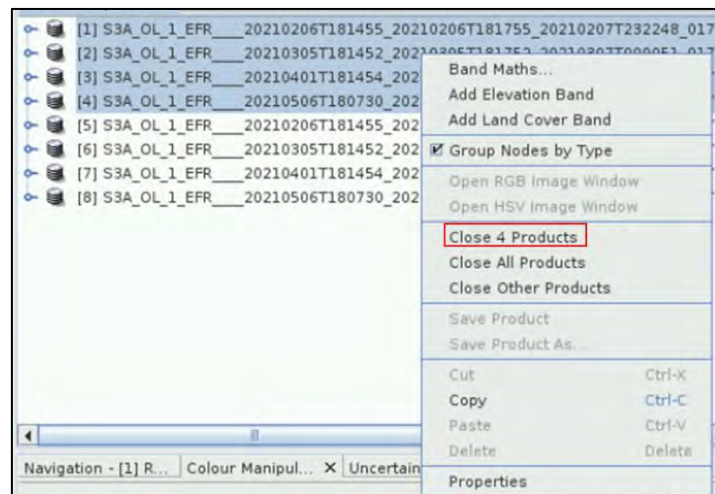
Let's first apply the Rayleigh correction to the S3A product from February 6th. First go to **Optical→Preprocessing→Rayleigh Correction**. In the **I/O Tab**, make sure the product from February 6th is selected as **Source Product**. Then set the Directory to */home/rus/shared/Training/CRYO05_SnowCover_California_S3/Processing/Rayleigh/*. In the Processing Parameters Tab, select the **Oa02, Oa03, Oa06, Oa17 and Oa21_radiance** source bands. You can select all 5 source bands at once by holding down the Ctrl key. Make sure that only the **Compute bottom of Rayleigh reflectance bands** option is selected.



Finally, hit Run! The processing may take up to 10mn per OLCI product. The output product automatically opens in SNAP. You need to repeat this step for the three remaining products (March, April and May 2021). You can see that only the selected rBRR bands have been written to the output products.



Once this is done, you can close the 4 original OLCI L1B products. For this, select the 4 products and right click on the selection and hit **Close 4 products**.



6.5 SNAP – Sentinel-3 Processing

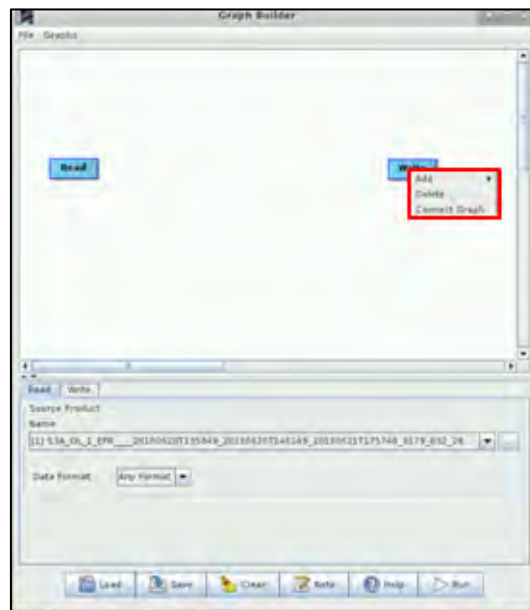
Now that we have computed the bottom of Rayleigh reflectances for the 4 products, we are going to apply the following processing steps:

- Spatial subset to crop the products to our region of interest
- NDSI and snow flag computation
- Reprojection to set a Coordinate Reference System (CRS) to our products
- Collocation of the four products to stack the snow flags for the individual months altogether

Repeating the analysis for every image one by one would be very time consuming. For this reason, we can create a graph containing all steps of our methodology and use the batch processing option of SNAP to run bulk processing.

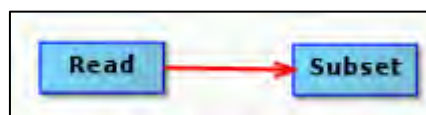
6.5.1 Graph Builder

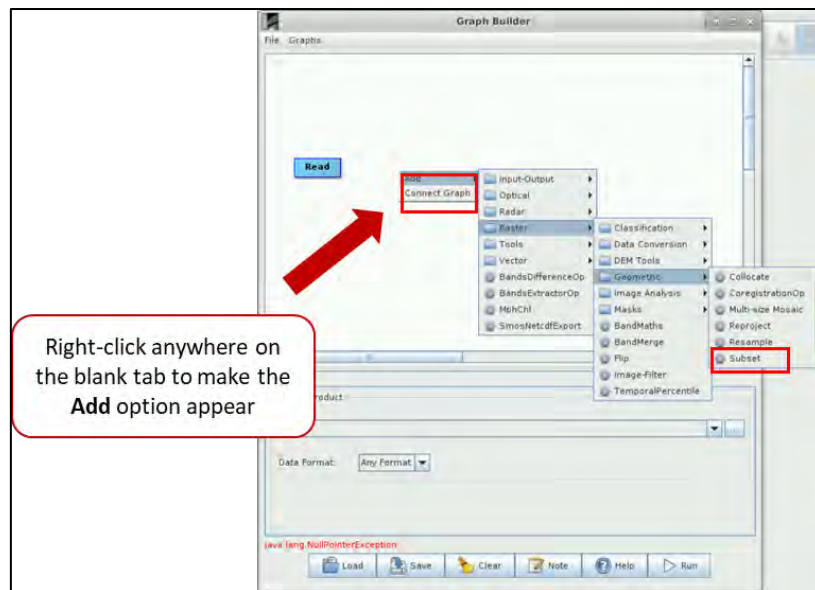
We will use the **GraphBuilder** tool, to create a chain with the processing steps we want to apply and at the end, only the final product will be physically saved (this way we will also save disk space since the products of the intermediate steps will not be stored). To create an empty graph, go to **Tools → GraphBuilder**. At the creation, the graph only has two operators: *Read* (to read the input) and *Write* (to write the output). To avoid any confusion, **right click on the Write operator and delete it**.



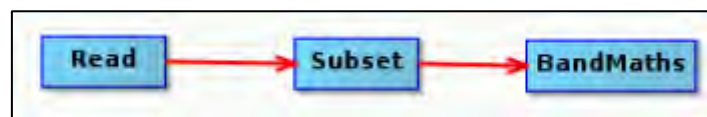
In the Graphbuilder, we will not define any parameters in the tabs (they will be defined in the Batch Processing step where we will apply this processing for the images we have downloaded, at once). We will only create and save the graph.

First, we need to create a **Subset** of the image, since we want to focus only over a defined area and we do not need the whole extent of the products. To add the **Subset** operator, right click on the Graph Builder and go to **Add→Raster→Geometric→ Subset**. Then, connect the Read operator to the subset tab. To connect two blocks, start from the right of the block to create a red arrow and drag it to the following block.

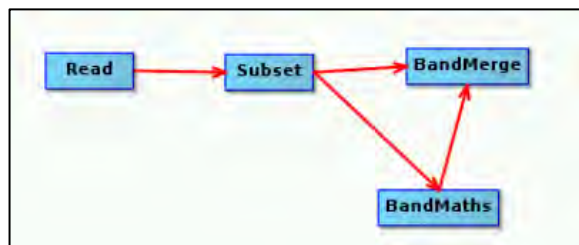




The next processing step will consist in deriving the NDSI and snow flag over land pixels. For this task, we will use the **Band Math** operator. Right-click and go to **Add→Raster→BandMaths**. Connect the operators as shown below (see NOTE 5).

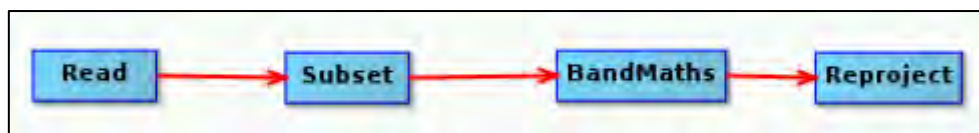


NOTE 5: In batch processing mode, the output of the BandMaths operator is the computed band (NDSI) only. If in your product, you would like to save additional data such as the reflectances or the quality flags, use the Add→Raster→BandMerge operator as follows.



This way, you will be able to select the bands to be written to the output product.

Then to set a defined CRS to our output, right click and go to **Add→Raster→Geometric→Reproject**.



Finally, we just need to properly save the output. For that, right click and navigate to **Add→Input-Output→Write**. Your final graph should be similar to the one shown below:



Finally, click on Save in the lower part of the panel and save the graph in the following path as 'NDSI.xml' without setting any parameter (see TIP 2). Once the graph is saved, close the Graph Builder.

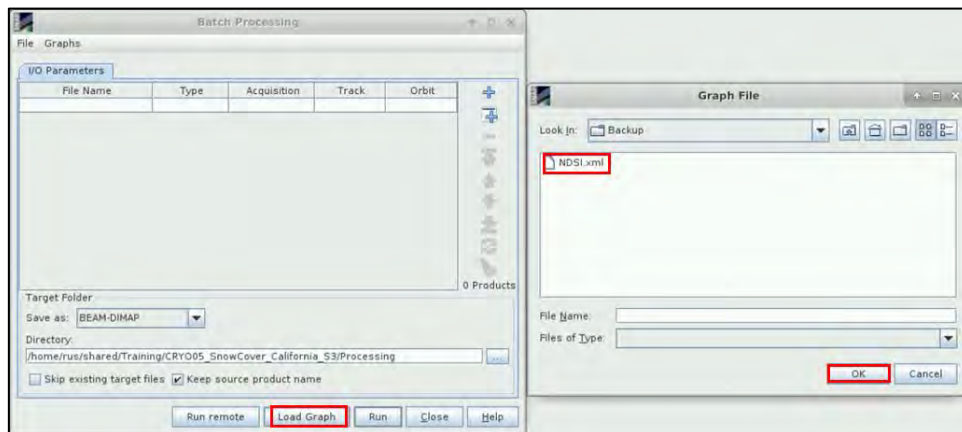
Path: `/shared/Training/CRYO05_SnowCover_California/AuxData/`





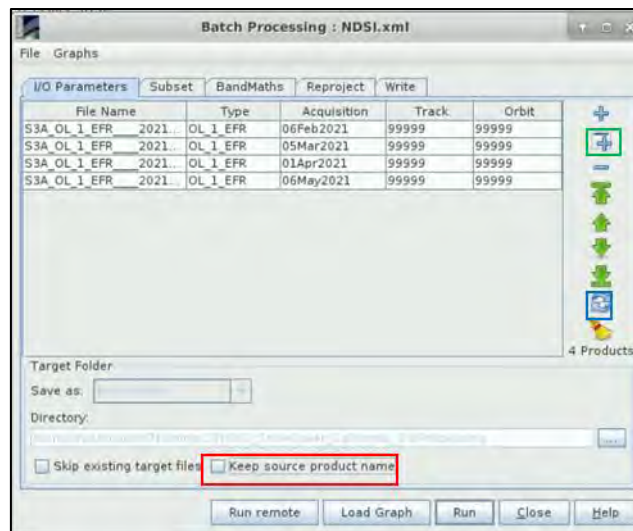
TIP 2: As we have created an empty graph, the Graph builder may display an error message *Expression is invalid*. This is normal as we have not set any parameters yet. If you did not succeed to create the processing graph, you will find a backup version in `/shared/Training/CRYO05_SnowCover_California/AuxData/Backup/`

6.5.2 Batch Processing


If the same processing scheme is applied to multiple images, the **Batch Processing** tool is what you are looking for. To use the **Batch Processing** tool go to **Tools→Batch Processing**. First, you need to **Load the Graph** you want to run. Hit **Load Graph**, browse to `/shared/Training/CRYO05_SnowCover_California/AuxData/` and load the *NDSI.xml* you just created. New tabs corresponding to our operators appear at the top of the window.



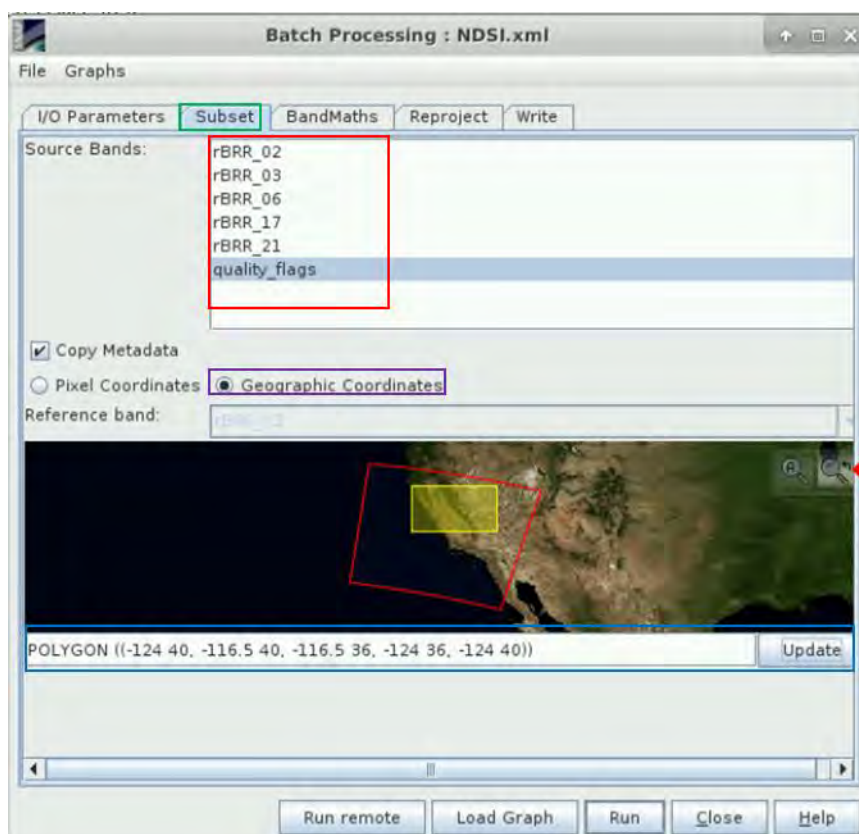
In the **I/O Parameters** tab, unselect the **"Keep source product name"** option. In the same tab, we will add all opened products from the Product Explorer window by clicking **Add Opened button**  at the right and then hit **Refresh** . In our case, we have loaded the 4 pre-processed S3A images from February, March, April and May 2021.



6.5.2.1 Subset

In the **Subset** tab, first **select all Source Bands** (use the ctrl+A keyboard shortcut). Then select **Geographic Coordinates**, copy-paste the following Well-Known Text (WKT) into the box below the graph and hit **Update** to define the area and hit  to Zoom-in.

POLYGON ((-124 40, -116.5 40, -116.5 36, -124 36, -124 40))



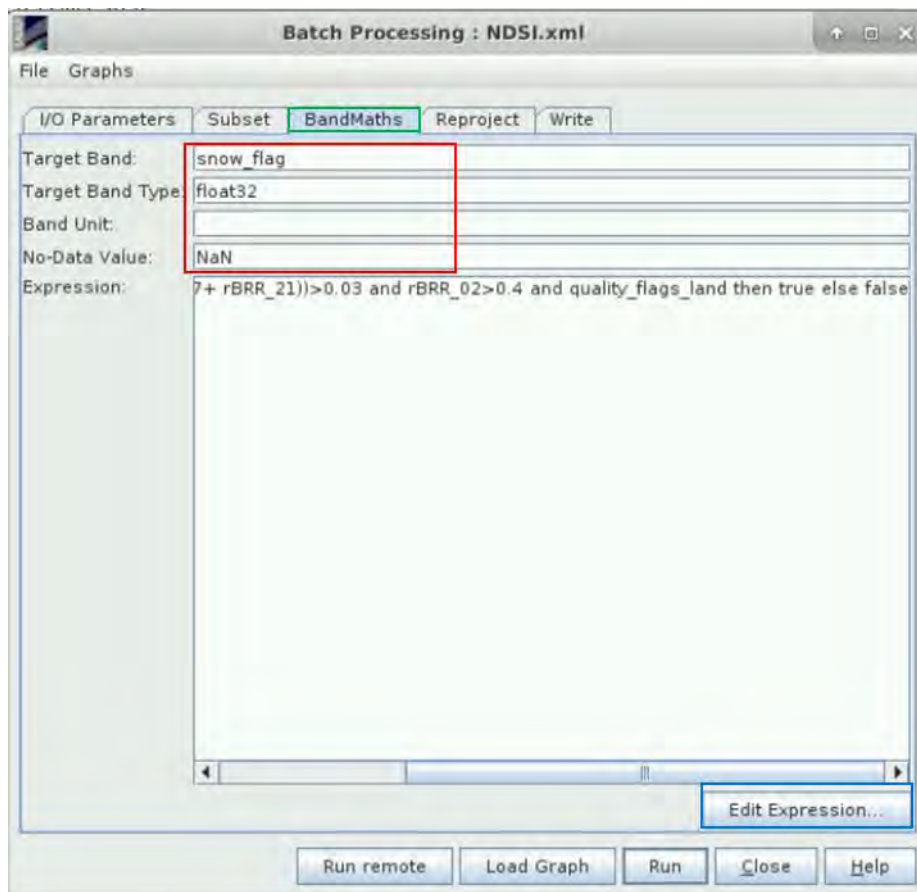
Zoom in

6.5.2.2 BandMath – snow_flag

Click now on the **BandMaths** tab, set the target band name to **snow_flag** set the **No-Data value** to **NaN**, click on **Edit Expression** and copy-paste the following expression. Click Ok afterwards.

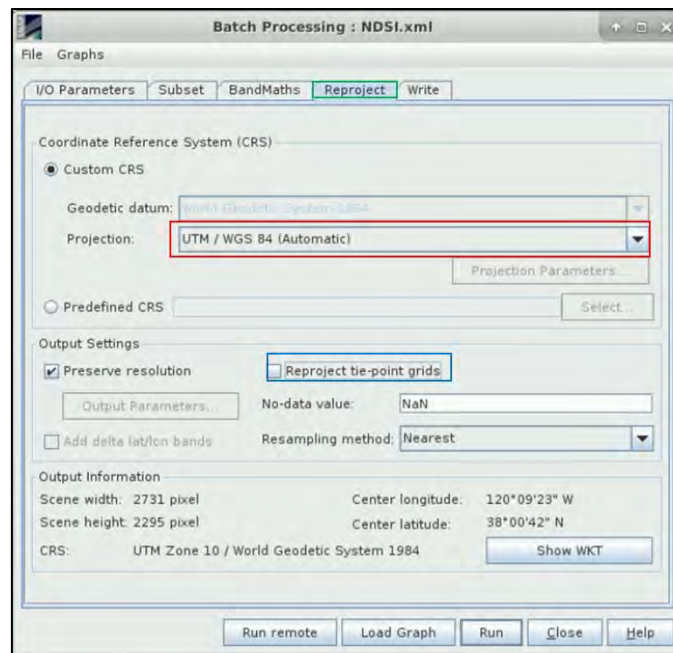
if ((rBRR_17- rBRR_21)/(rBRR_17+ rBRR_21))>0.03 and rBRR_02>0.4 and quality_flags_land then true else false

This expression means that a land pixel is considered as covered in snow if the NDSI is greater than 0.03 and the rBRR_02 greater than 0.4 (threshold from Kokhanovsky et al. (2019)).



6.5.2.3 Reproject

In the **Reproject** tab, define the Custom CRS as **UTM / WGS 84 (Automatic)** located towards the bottom of the list and **unselect Reproject tie-point grids**.

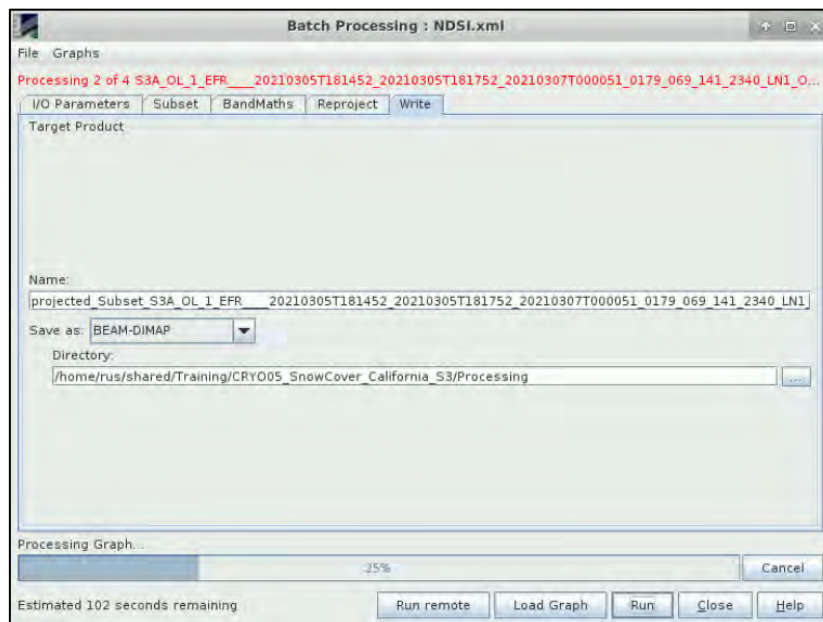


6.5.2.4 Write

In the **Write** tab, under **Name** keep the default name (projected_Subset and Bandmath will be added). For the Directory set the path to

/shared/Training/CRYO05_SnowCover_California/Processing/

Finally Hit **Run**!

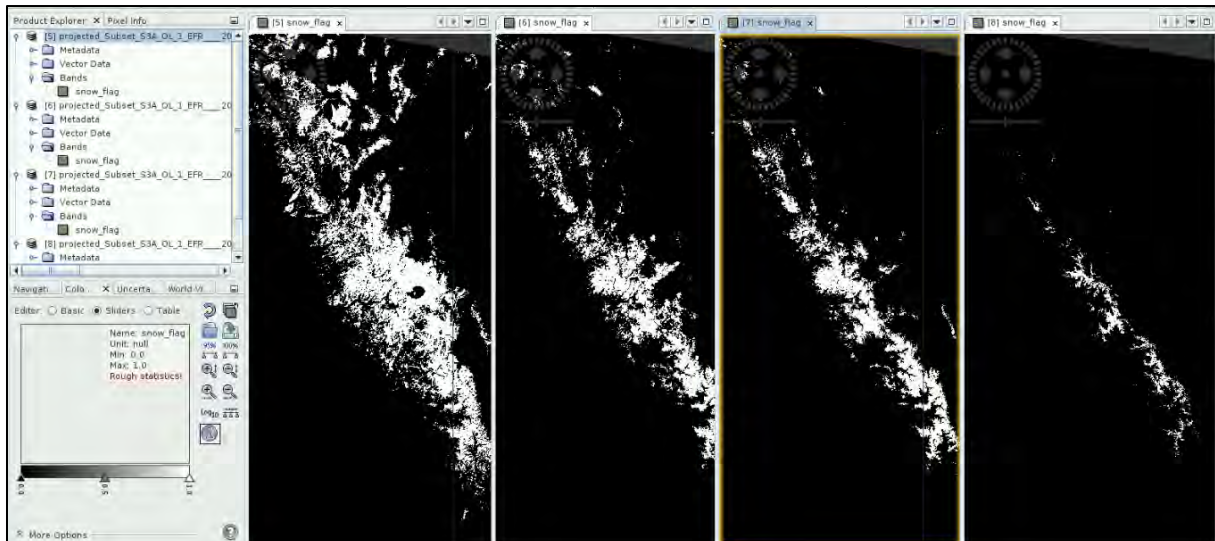


The processing may take up to 3mn. The processed products will automatically open in the **Product Explorer Window** when the processing is completed. Close the Batch Processing window and the 4

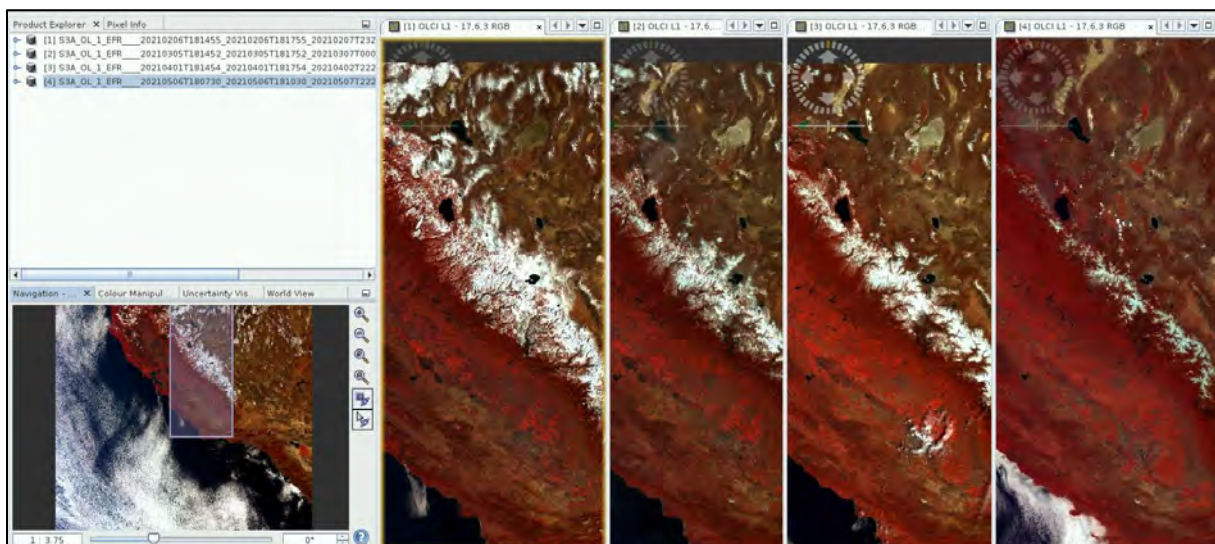
Rayleigh products that were used as inputs. Keep only the 4 projected_Subset_S3A_OL_1_EFR* products.

6.6 Analysis of the processed products

The 4 processed products now contain only a single band called snow flag. Let's open each snow-flag band by double-clicking on snow_flag and then go to **Window→Tile Horizontally**.



You can notice that all products have effectively been cropped to our polygon of interest and have been reprojected. The areas blanketed in snow appear in white as opposed to snow-free areas in black. For comparison purposes, below is an image of the four RGB views we generated earlier.



6.7 Checking the accuracy of the computed snow flag by visual inspection

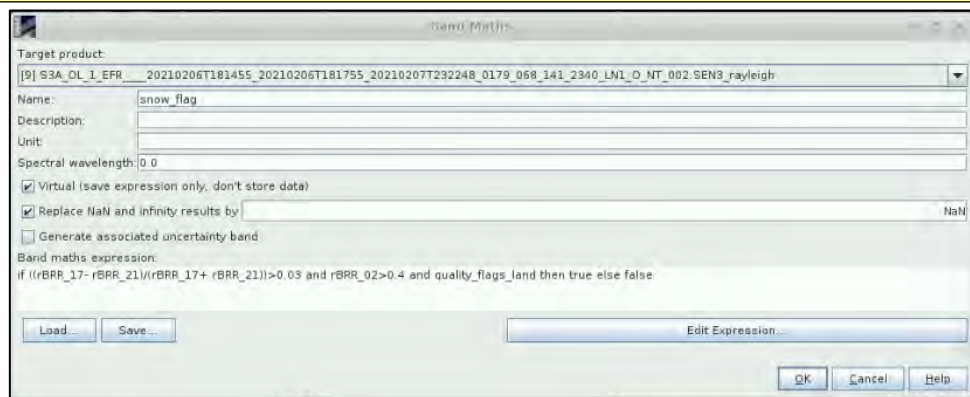
If you want to check the accuracy of your snow flag on one product, then follow the steps described in this section. Otherwise, you can jump to the following 6.8 section. Checking the accuracy is useful

when you are developing your algorithm to tune the different thresholds on the NDSI and the rBRR_02 channel.

Let's open the Rayleigh product from February 6th again. Go to */shared/Training/CRYO05_SnowCover_California/Processing/Rayleigh* and drag and drop the *S3A_OL_1_EFR____20210206T181455_20210206T181755_20210207T232248_0179_068_141_2340_LN1_O_NT_002.SEN3_rayleigh.dim* file to the Product Explorer Tab of SNAP. Close the 4 snow flag views opened earlier. Do not close the products, only the views.

Right click on the product and hit **Band Maths**. Call the new band snow_flag and after clicking on the **Edit Expression...** button, copy and paste the snow flag expression we used earlier and hit OK. Make sure that the **Virtual** option is selected. This will allow us to easily adapt the snow_flag expression later on.

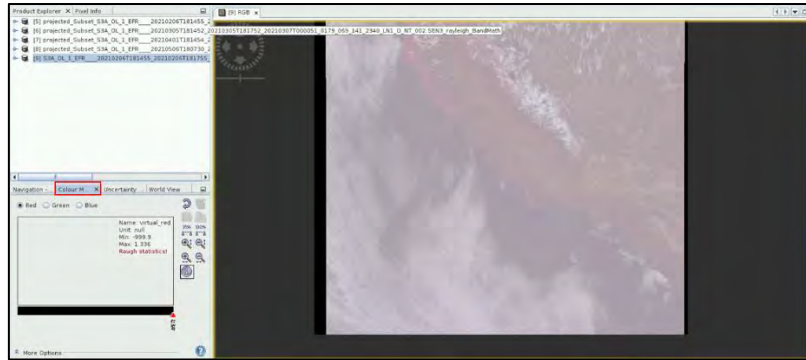
if ((rBRR_17- rBRR_21)/(rBRR_17+ rBRR_21))>0.03 and rBRR_02>0.4 and quality_flags_land then true else false




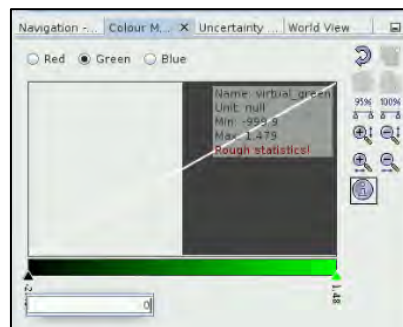
Now, open an RGB view of the Rayleigh corrected product using the **rBRR_17** for Red, **rBRR_06** for Green and **rBRR_03** for Blue



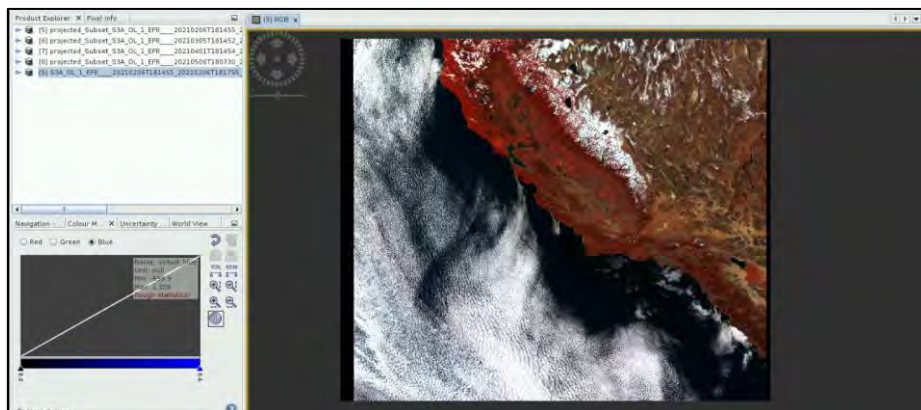
The generated image has a white veil on it. This is due to the settings in the **colour manipulation** tab.



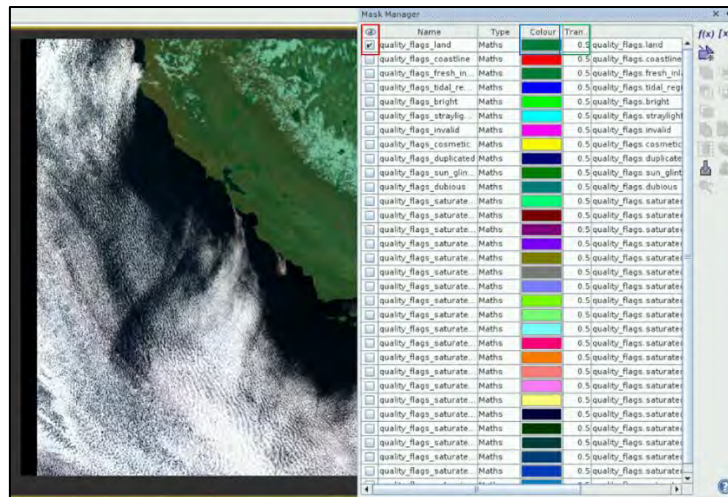
In this tab for each colour, hit the  button and define the slider values so they are between **0** and **0.6** for the 3 colours (Red, green and Blue). To change a slider value, you can move it along the colour bar or double click on a slider value to define a new value.



Our view now looks better.

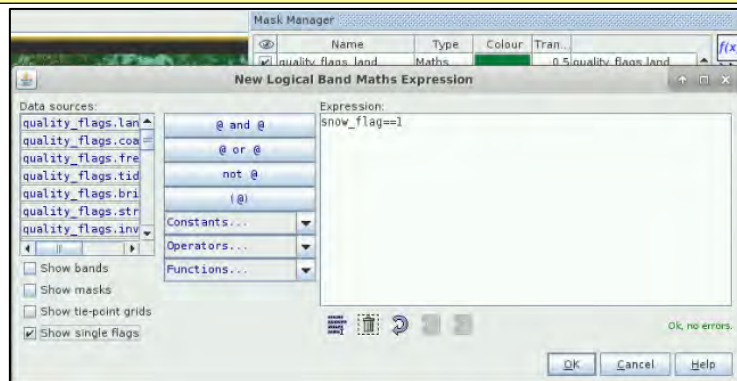


Now, go to **View→Tool Window→ Mask Manager**. This opens up all the available masks in the product. There you can **activate and deactivate a mask**, **change the colour of a mask** or **set its transparency**.

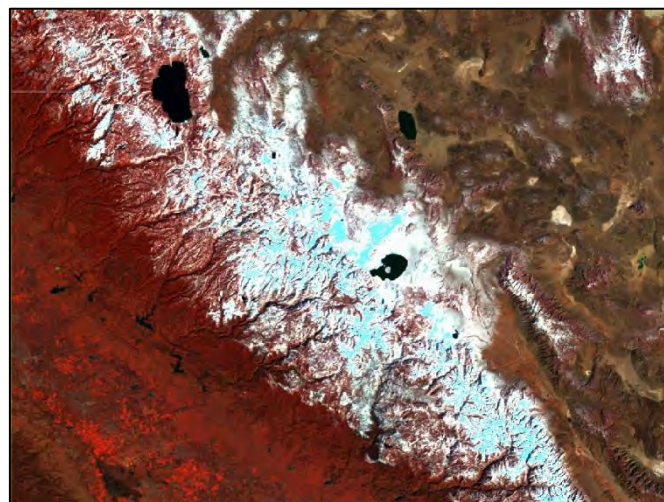
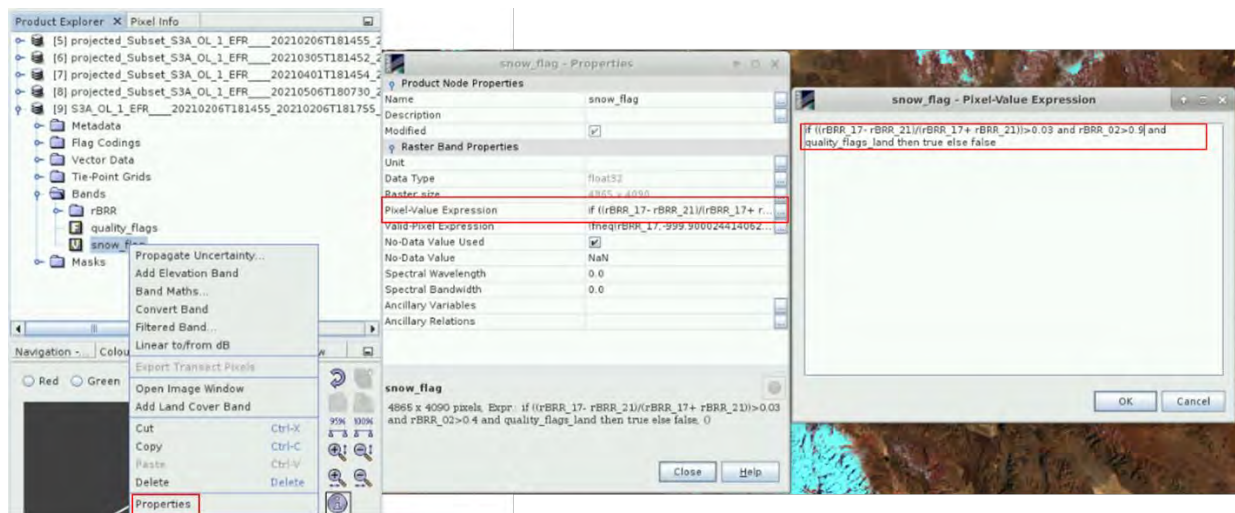


We are going to create a snow_mask out of our snow flag band. Hit the $f(x)$ button at the upper right corner of the mask manager tab. In the Expression tab write the following expression and hit OK:

snow_flag==1



The created mask appears at the bottom of the mask list. Let's name it snow_mask and switch its colour to cyan.



You can of course repeat this procedure for the other products.

Finally, go to **Raster**→**Masks**→**Mask Area...** Select the snow_mask and hit OK: approx. 30,000 km² of our region of interest was covered in snow on February 6th 2021.

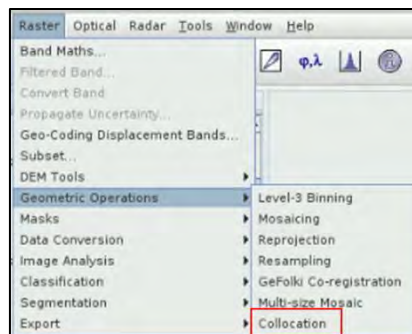



After this, close the view and close the Rayleigh product(s) (do not forget to save the changes if you wish to!)

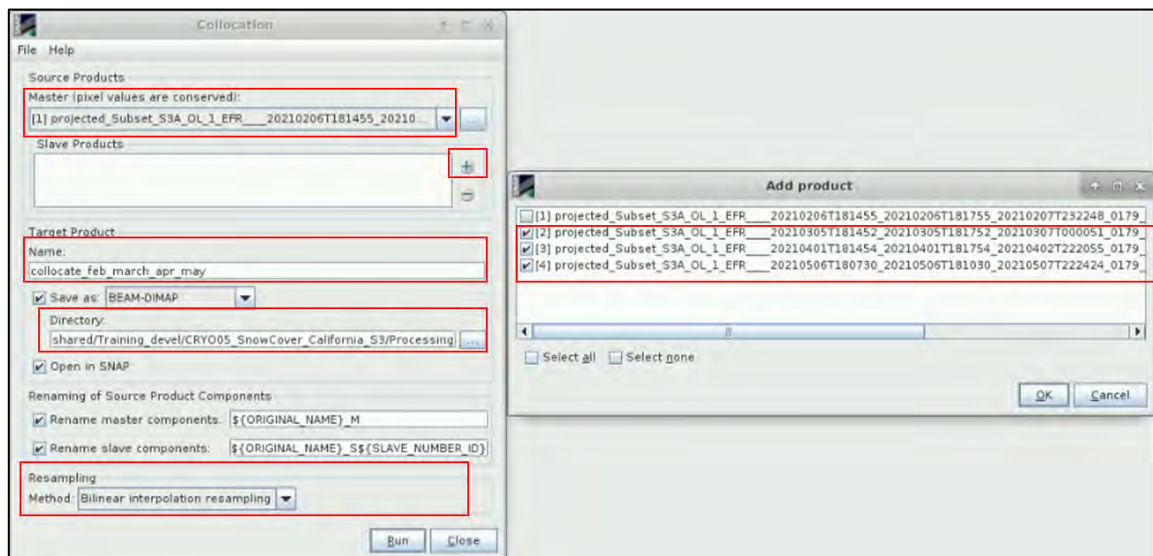
6.8 Snow cover time series

6.8.1 Collocation of the outputs


After batch processing the products, we end up with 4 products cropped to the same area of interest in the same CRS containing a single band (snow_flag). The following step will aim at stacking all the snow flag outputs of the batch processing in a single product to allow further processing. For this task, we will use the **Collocation tool**, which enables the user to collocate spatially overlapping products. Collocating products implies that the pixel values of all slave products are resampled into the geographical raster of the master one. Here we will choose the product from February 6th as the master and the products from March, April and May as slaves. Click on **Raster → Geometric Operations → Collocation**.




Make sure to select **projected_Subset_S3A_OL_1_EFR___20210206*** as Master. Then hit the  button from the Slave Products section and hit Add product(s). Select the snow_flag products from March, April and May 2021 and hit OK. Name the Target Product **collocate_feb_march_apr_may** and set the output Directory to **/shared/Training/CRYO05_SnowCover_California/Processing/**. Select the **Bilinear interpolation method resampling** at the bottom of the window. And hit Run!



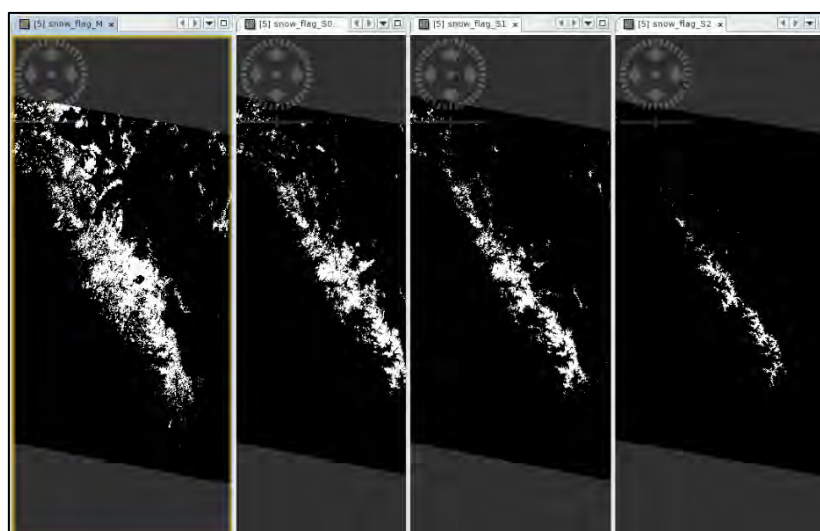
After a few seconds, the **collocate_feb_march_apr_may** product opens in the product explorer tab. Close the Collocation window, and now let's expand the Bands of the collocated product. The following

table shows you the correspondence between the band names and the product month (see  NOTE 6).

Band name	Significance
snow_flag_M	Snow flag band of the master product (Feb. 6 th 2021)
snow_flag_S0	Snow flag band of the first slave product (March 5 th 2021)
snow_flag_S1	Snow flag band of the second slave product (April 1 st 2021)
snow_flag_S2	Snow flag band of the third slave product (May 6 th 2021)

 NOTE 6: If you did not open the OLCI L1B products in chronological order in SNAP, then *_S0 will correspond to the first item of the slave product list, *_S1 to the second item of the slave product list and *_S2 to the last item of the slave product list. And you will have to adapt the classification expression of part 6.8.2 accordingly.

Feel free to open the snow flag bands in SNAP to check them out.



6.8.2 Snow cover decrease assessment

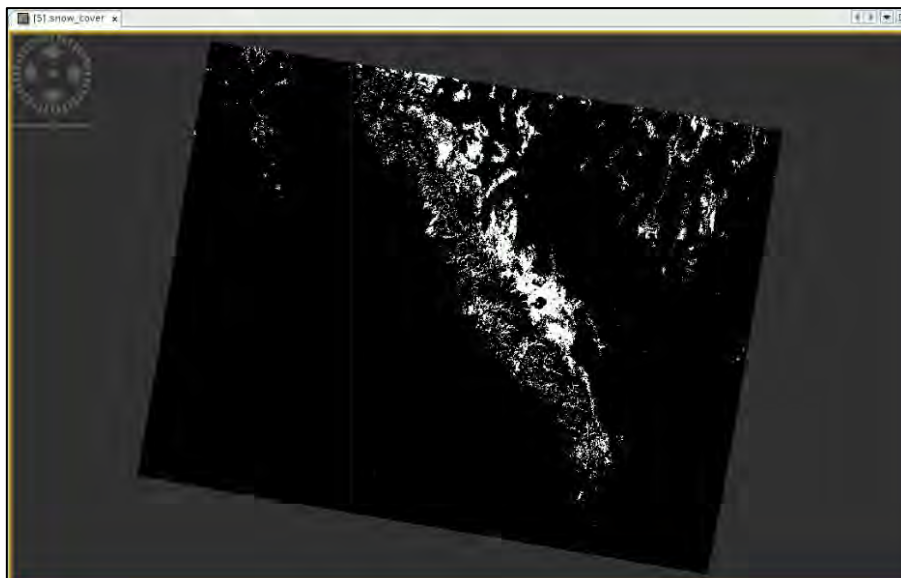
The last step of our processing is to derive a single band out of the 4 snow flag bands to classify the pixels depending on when they were identified as snow-covered. The classes are summarized in the following table

Class number	Significance	Colour
1	Pixel is snow-covered from Feb. to May OR in May only	
2	Pixel is snow-covered from Feb. to April OR in April only	
3	Pixel is snow-covered from Feb. to March OR in March only	
4	Pixel is snow-covered in February only	

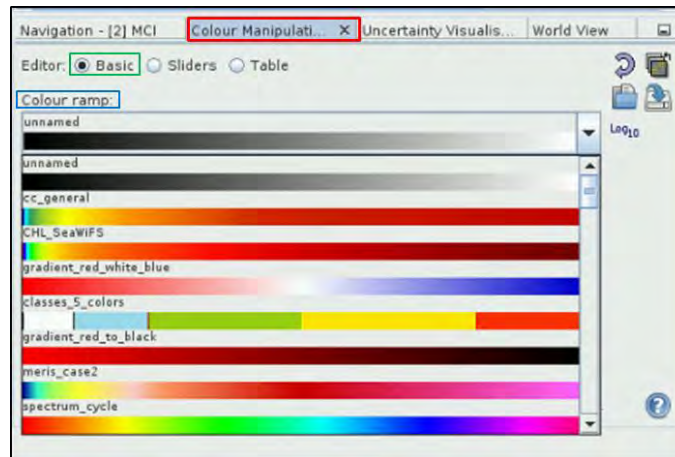
To create the band, right click on the collocated product and hit **Band Maths**. Name the band snow_cover, unselect the Virtual option and copy and paste the following expression in the Edit Expression tab.


```
if ((snow_flag_S2 and snow_flag_S1 and snow_flag_S0 and snow_flag_M) or (snow_flag_S2 and !snow_flag_S1 and !snow_flag_S0 and !snow_flag_M)) then 1  
else if ((!snow_flag_S2 and snow_flag_S1 and snow_flag_S0 and snow_flag_M) or (!snow_flag_S2 and snow_flag_S1 and !snow_flag_S0 and !snow_flag_M)) then 2  
else if ((!snow_flag_S2 and !snow_flag_S1 and snow_flag_S0 and snow_flag_M) or (!snow_flag_S2 and !snow_flag_S1 and !snow_flag_S0 and !snow_flag_M)) then 3  
else if ((!snow_flag_S2 and !snow_flag_S1 and !snow_flag_S0 and snow_flag_M)) then 4  
else NaN
```


The new band automatically opens in SNAP as a black and white view.

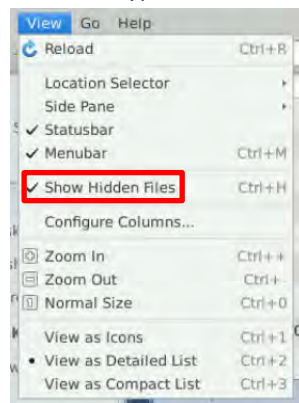


To add a colour ramp, go to **Colour manipulation** → **Basic** → **Colour Ramp**. There, you should find a set of pre-defined colour bars that are saved in `/home/rus/.snap/auxdata/color_palettes/`.

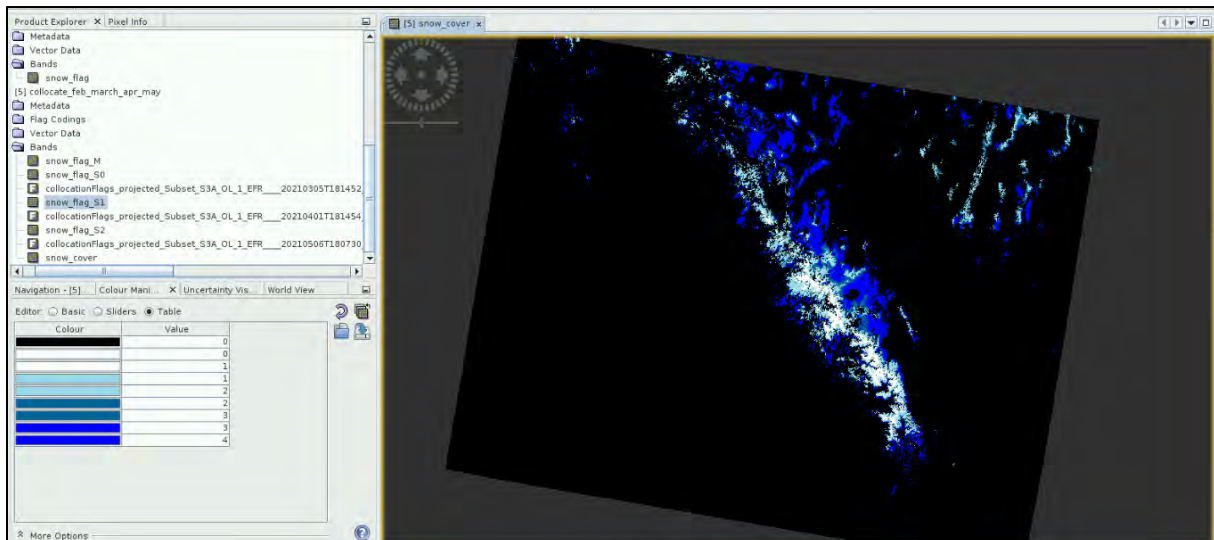


To correctly visualize the snow cover decrease, we are going to use a colour ramp created ahead of this webinar. For this, hit the **Import colour palette from text file** button  and navigate to `/shared/Training/CRY005_SnowCover_California/AuxData/` and select `snow_cover.cpd`. When opening the file, a window appears, hit No.

 **TIP 3:** The SNAP default colour ramps are in `/home/rus/.snap/auxdata/color_palettes/`. You can copy the `snow_cover.cpd` file to this folder and have it appear as a default colour ramp. Once in the `home/rus/` folder, go to `View→Show Hidden Files` to make the `.snap/` folder appear. If you wish to open these files within snap, you have to type the name of the `.snap` folder in the searchbar.



You can now assess the snow cover decrease between February and May 2021 in the Sierra Nevada.



Again, you can use the **Mask Manager** to create new masks (f(x) button) and then select the **Raster→Mask→Mask Area...** tool of SNAP to create new masks out of the snow cover band to assess the area covered in snow at a particular time. For example you can create a mask with the following expression:

```
snow_cover>0
```

This will tell you the global snow coverage extent from February to May (~28,000km² in our case).

Then it is possible to assess which fraction of this area was still covered in snow in May with the following expression:

```
snow_cover==1
```

Approx. 2,500km² (less than 10% of the initial area) was snow-covered in May.

7 Conclusions

Satellite imagery is widely used to map and assess snow cover extent, especially in remote areas. Space-borne technologies offer a frequent and global coverage of our continents. As this exercise highlighted, simple index computations based on the spectral properties of snow in the near infrared part of the spectrum allow a relatively easy assessment of the snow cover extent. The Sentinel-3 constellation constitutes a valuable asset to monitor the snow cover evolution at a large scale on a frequent basis. Furthermore, the OLCI products could be combined with other sensors to create multi-sensor products and hence ensure a gap-free coverage of the Sierra Nevada.

In this exercise, we have used low/no-cloud coverage images. Even though NDSI allows to distinguish snow from most cloud types, it remains challenging to accurately assess the snow cover extent under very cloudy conditions. Furthermore, OLCI only acquires data during daytime. The observations are hence limited at higher/lower latitudes during the winter season when daytime is limited.

This demonstration also does not take into account the forest coverage of the area. Indeed, when fresh snow falls, it first falls on trees. As the snow gets older and heavier, it falls off the tree branches and

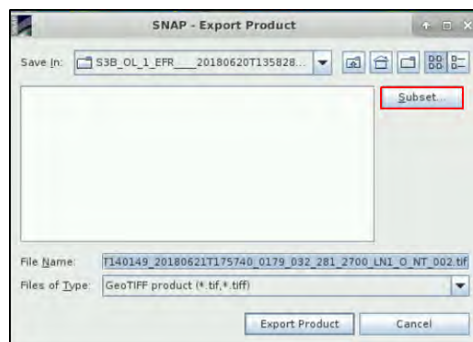
may be hidden from view. Some forest areas may be covered in snow even though they do not directly appear as snow covered from space. This could lead to an underestimation of the snow-covered area. If you want to learn more about this topic, you should watch our previous [CRYO03 webinar](#).

Finally, monitoring the snow cover area is one way of monitoring snow cover. One could also study the fractional snow cover, the snow water equivalent, the snow depth or the liquid water content

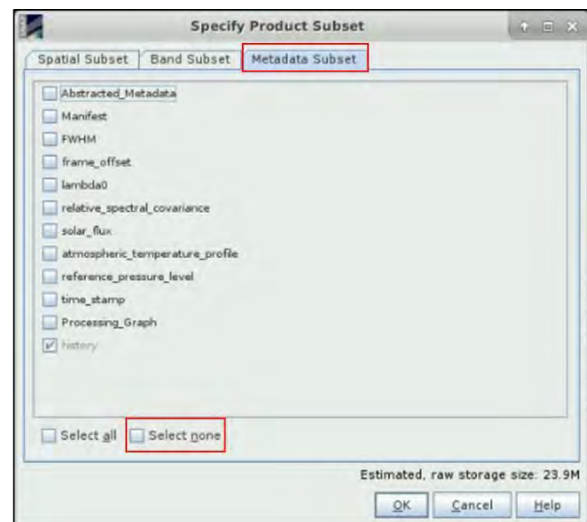
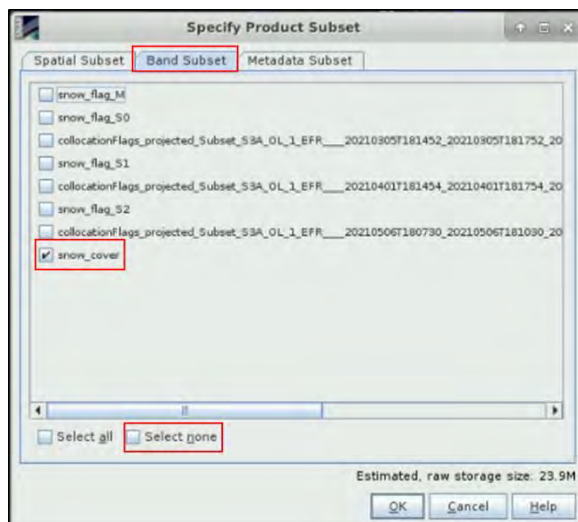
8 Extra steps – Export to QGIS

8.3 Export as a GeoTIFF

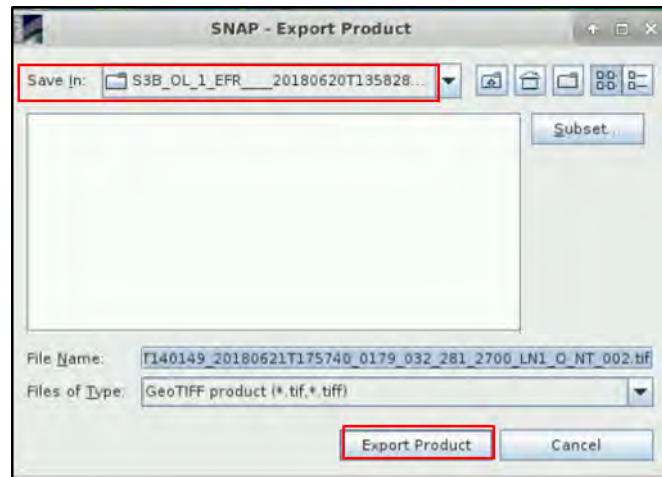
SNAP allows the user to export the outputs as GeoTIFF for further analysing and processing in a GIS software such as QGIS. To do this, **make sure to select the collocate_feb_march_april_may product in the Product Explorer Tab**. Then from **File→Export**, choose the **GeoTIFF** option. In the dialog tab that opens, hit **Subset**.




At the **Band Subset** (second tab) use the **Select none** button to deselect them all first and then select only the snow_cover band. Then go to the **Metadata Subset** tab and click **Select none**. Finally, hit **OK** and hit **No** in both dialog tabs that open.

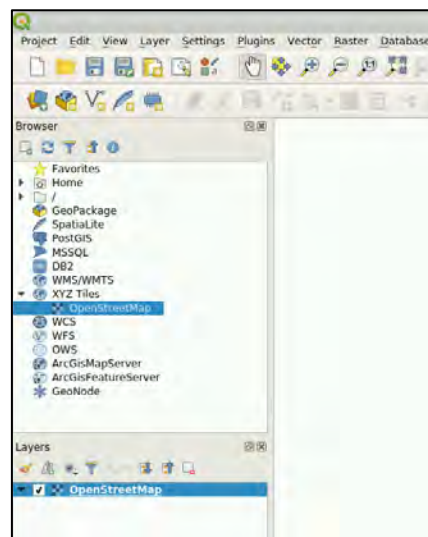


Define your export folder thanks to the Save in option and hit Export Product.

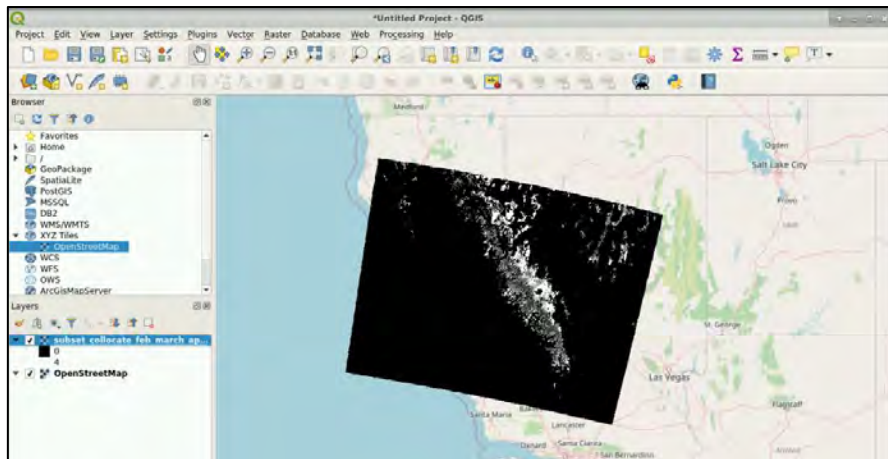



8.4 Opening the File in QGIS

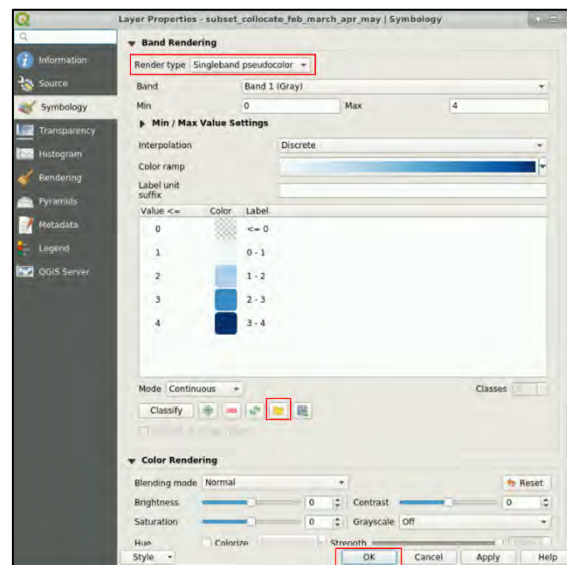
Your GeoTIFF is now ready to be opened in QGIS ( icon from your VM desktop)! First open the software. From the **left panel**, expand the **XYZ Tiles** and drag the **OpenStreetMap** and drop it to the **layer panel**.



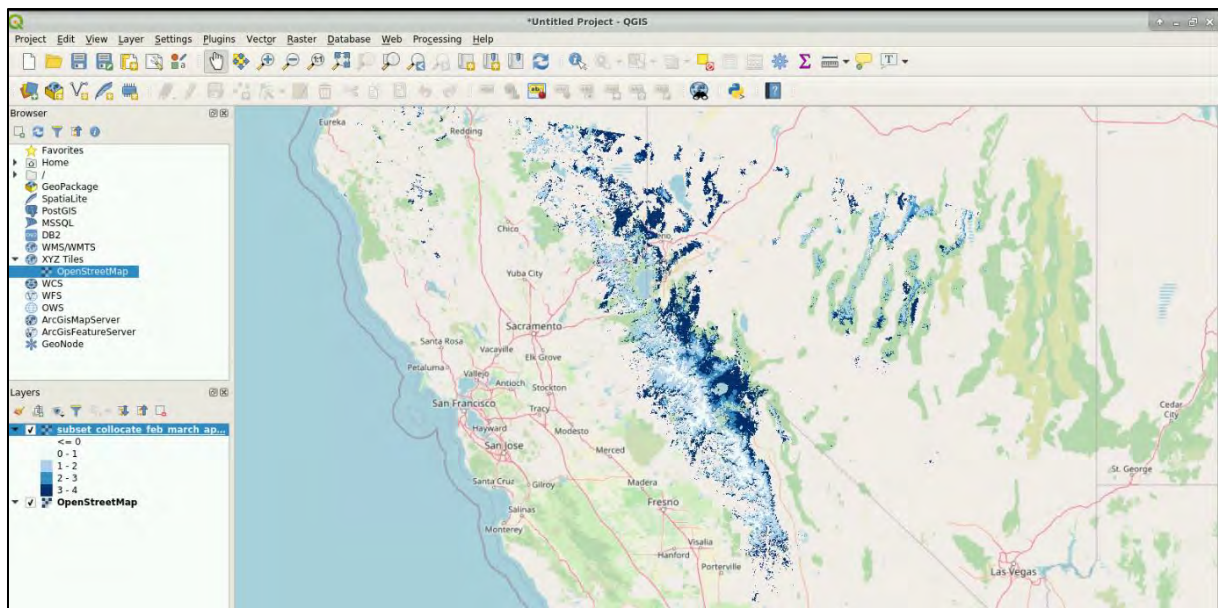
Then, from a file browser, drag and drop your generated GeoTIFF in QGIS and zoom in to the Sierra Nevada using the central wheel of your mouse. A black & white view of the snow cover has opened.



Double-click on the GeoTIFF layer. This will open the properties of your layer. In the Symbology section, set the **Render Type** as **Singleband pseudocolor**. Then with the  button, navigate to `/shared/Training/CRYO05_SnowCover_California/AuxData/` and open the `snow_cover_QGIS.txt` file which is a pre-defined colour ramp. Then simply hit OK.



Enjoy the result!



THANK YOU FOR FOLLOWING THE EXERCISE!

9 Further reading and resources

[Sentinel-3 OLCI User Guide](https://sentinel.esa.int/web/sentinel/user-guides/sentinel-3-olci)

<https://sentinel.esa.int/web/sentinel/user-guides/sentinel-3-olci>

[Sentinel-3 OLCI Technical Guide](https://sentinel.esa.int/web/sentinel/technical-guides/sentinel-3-olci)

<https://sentinel.esa.int/web/sentinel/technical-guides/sentinel-3-olci>

[Sentinel-3 Marine User Handbook](https://earth.esa.int/eogateway/documents/20142/1564943/Sentinel-3-OLCI-Marine-User-Handbook.pdf)

<https://earth.esa.int/eogateway/documents/20142/1564943/Sentinel-3-OLCI-Marine-User-Handbook.pdf>

[Climate Change Indicators: Snow Cover](https://www.epa.gov/climate-indicators/climate-change-indicators-snow-cover)

<https://www.epa.gov/climate-indicators/climate-change-indicators-snow-cover>

[What the megadrought means to the American West \(CBS\)](https://www.youtube.com/watch?v=K9hUNufKIKw)

<https://www.youtube.com/watch?v=K9hUNufKIKw>

[Retrieval of Snow Properties from the Sentinel-3 Ocean and Land Colour Instrument](https://doi.org/10.3390/rs11192280)

<https://doi.org/10.3390/rs11192280>

10 References

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