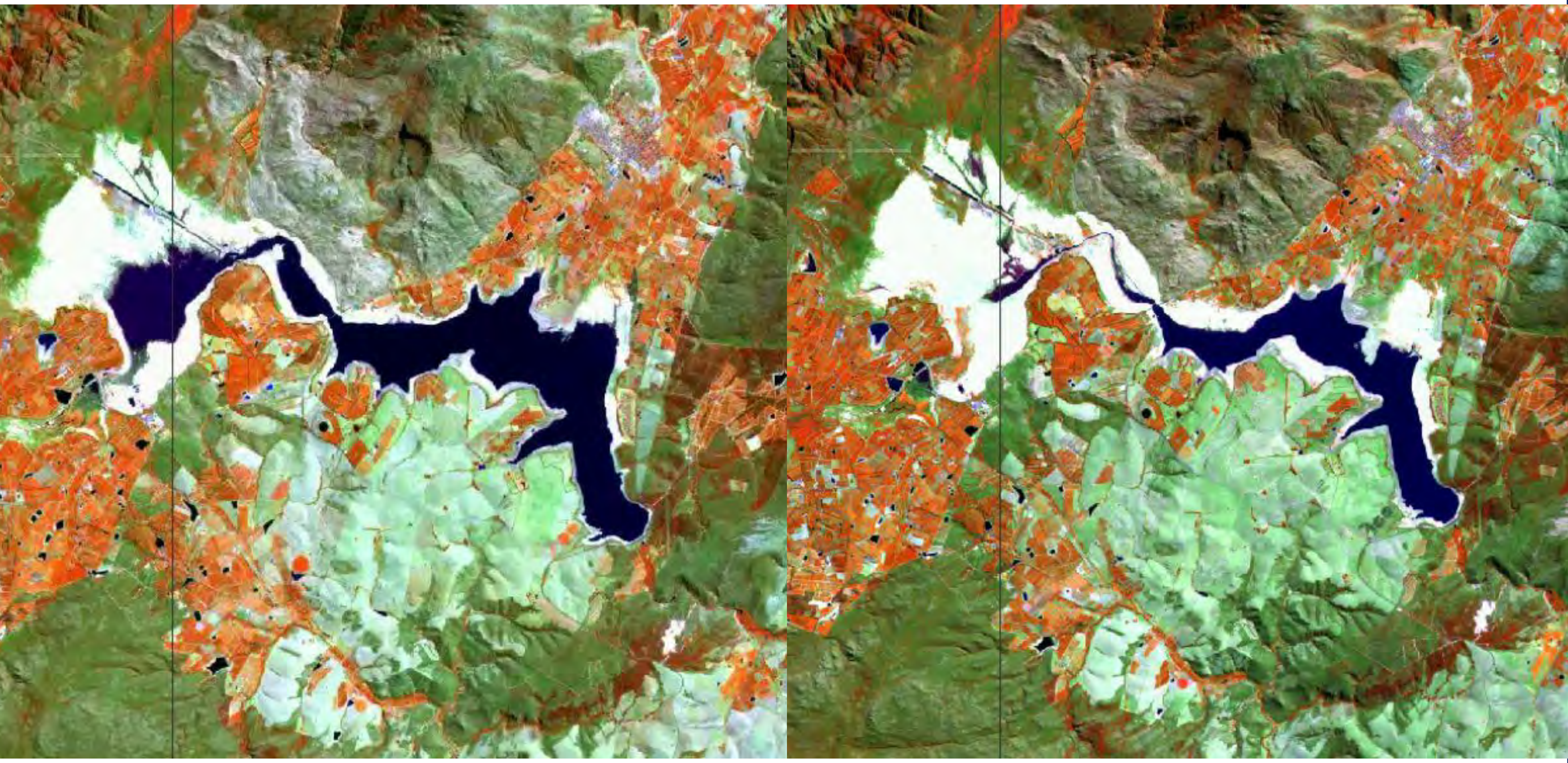

TRAINING KIT – HYDR03

DROUGHT MONITORING WITH SENTINEL-2
Case study: Western Cape Province, 2015-2020

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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1 Introduction to RUS

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

Theewaterskloof Dam outside Cape Town drying out. Source:https://memeburn.com/2018/02/theewaterskloof-dam-cofferdam/

Surface water is crucial resource sustaining human lives. It provides water for domestic and commercial use, it is used in agriculture (irrigation) and electricity production. Even small water bodies play a key role as the offer habitats to wildlife, often being a refuge for species but also provide livestock with fresh water. Therefore, in regions prone to drought such as Western Cape Province in South Africa, identification and monitoring of surface water, is necessary to assure the continuity of water supply for citizens, local economy but also to maintain natural habitats. More frequent and long-lasting droughts caused by global environmental changes are affecting many regions around the world. Warmer temperatures increase evaporation, lessening at the same time the water availability and causing soil and vegetation to dry out.

A three-year's drought threatened South Africa's Western Cape Province. From 2016 until 2018 this region suffered a drought crisis, causing water dams to shrink significantly. The Cape Town claimed this period to be the worst drought in 100 years. In February 2018, the Theewaterskloof dam, which is the biggest dam in the province and provides about 50% of Cape Town's water needs dropped to its 11% of capacity. The city water consumption has fallen from 317 million gallons per day in 2015 to about 137 million gallons per day. Fast detection of any changes in surface water extent and its availability is crucial and enables decision-makers to take proper actions, in this case responsible water management.

Satellite remote sensed data are widely used in detecting and monitoring waterbodies and with Sentinel-2 data, we will have a chance to detect waterbodies using different water indices and see changes in the water extent during the drought period.

2 Training

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

The Training Code for this tutorial is HYDR03. If you wish to practice the exercise described below within the RUS Virtual Environment, register on the RUS portal and open a User Service request from Your RUS service → Your dashboard.

2.1 Data used

- 16 low-cloud Sentinel-2A Level 1C images (Tile ID: T34HCH) acquired in wet and dry season from years 2016-2020 and one image from 2015 [downloadable at @https://scihub.copernicus.eu/ using the *.meta4 file* provided in the *Original* folder of this exercise]
- Data and instructions how to perform the exercise stored locally

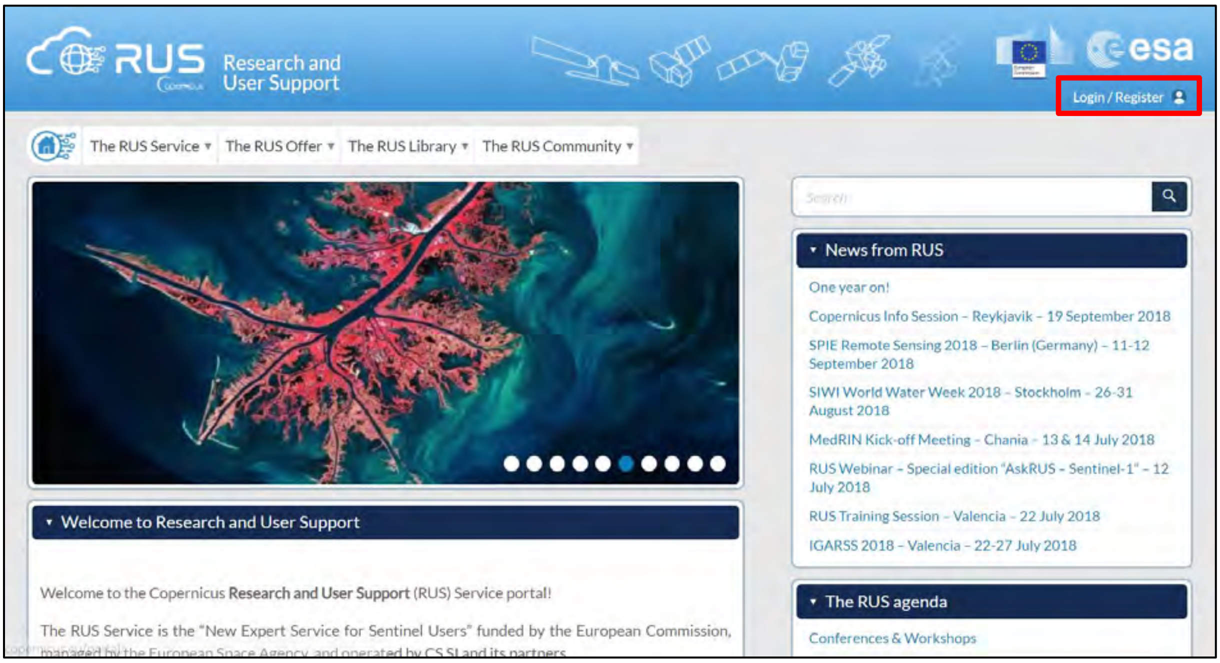
@/shared/Training/HYDR03_DroughtMonitoring_WesternCape/AuxData/

2.2 Software in RUS environment

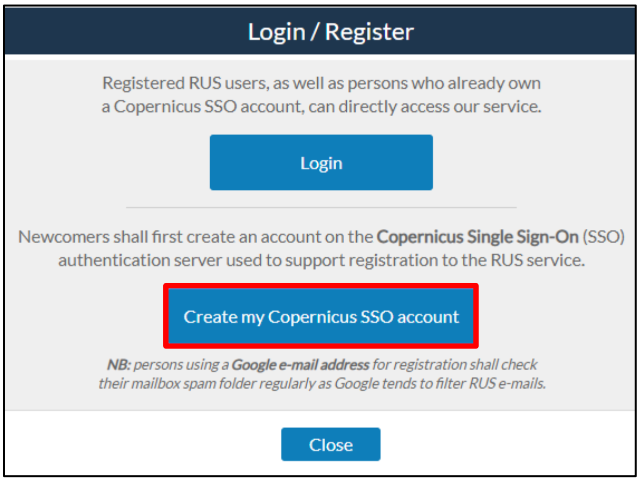
Internet browser, SNAP + GPT + Sentinel-2 Toolbox, QGIS, (Extra steps: Sen2Cor)

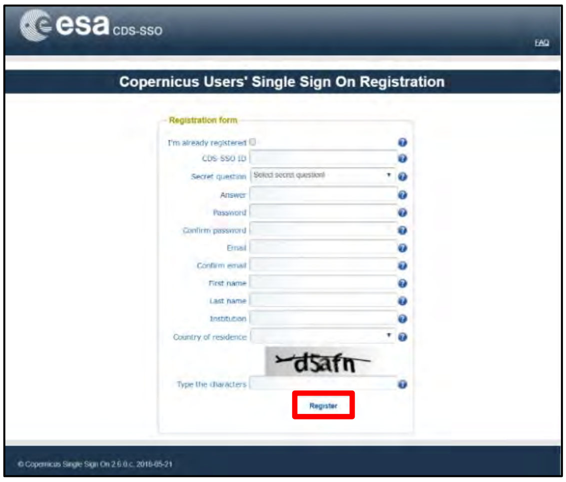
3 Register to RUS Copernicus

To repeat the exercise using a RUS Copernicus Virtual Machine (VM), you will first have to register as a RUS user. For that, go to the RUS Copernicus website (www.rus-copernicus.eu) and click on ***Login/Register*** in the upper right corner.



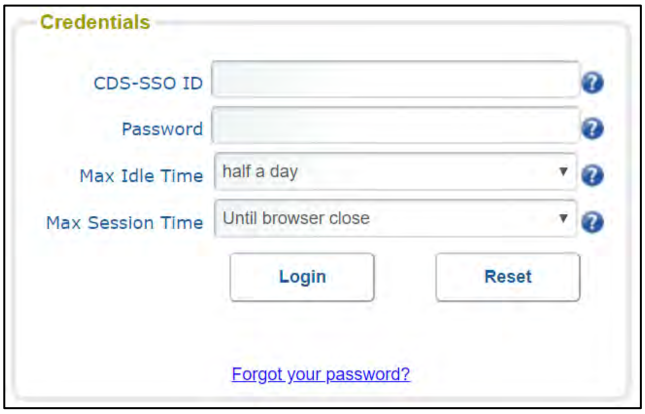
Select the option *Create my Copernicus SSO account* and then fill in ALL the fields on the Copernicus Users' Single Sign On Registration. Click *Register.*



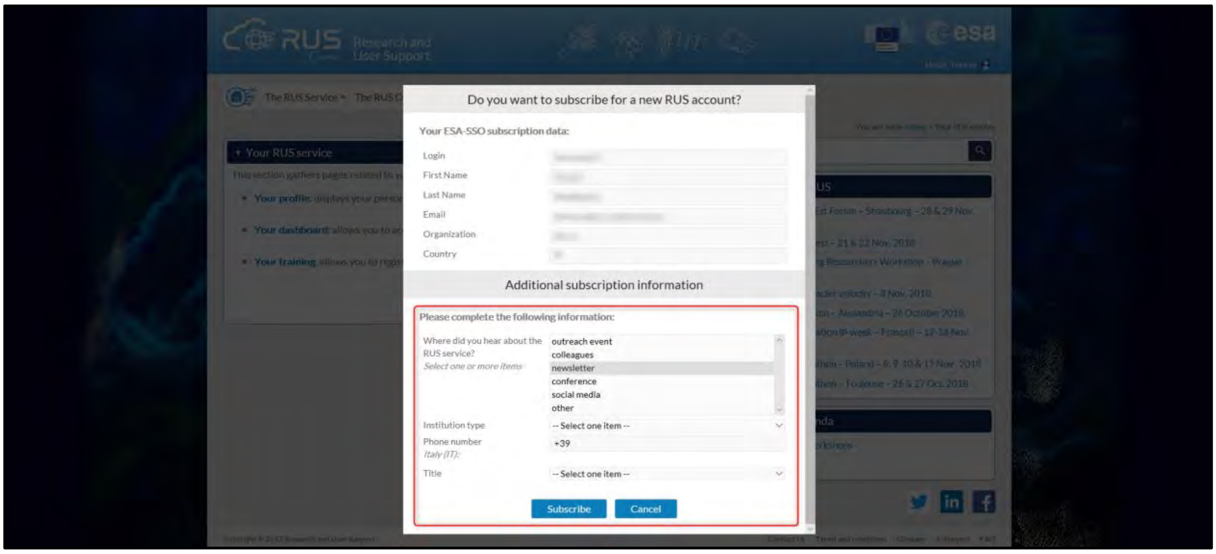


Within a few minutes you will receive an e-mail with activation link. Follow the instructions in the e-mail to activate your account.

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

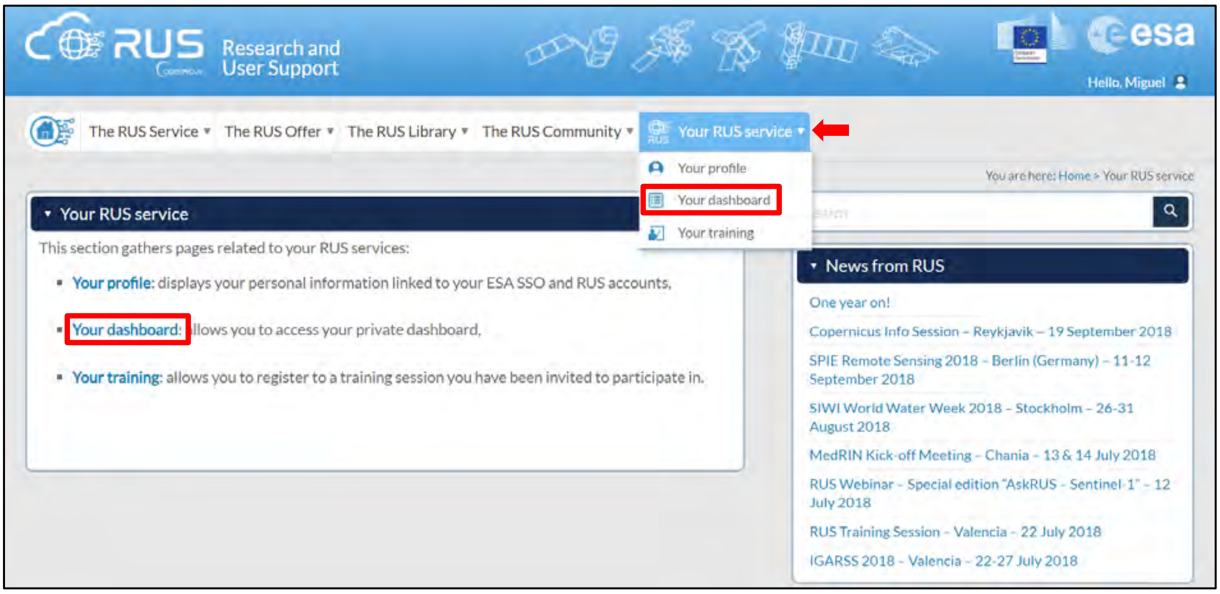


Upon your first login you will need to enter some details. You must fill all the fields.

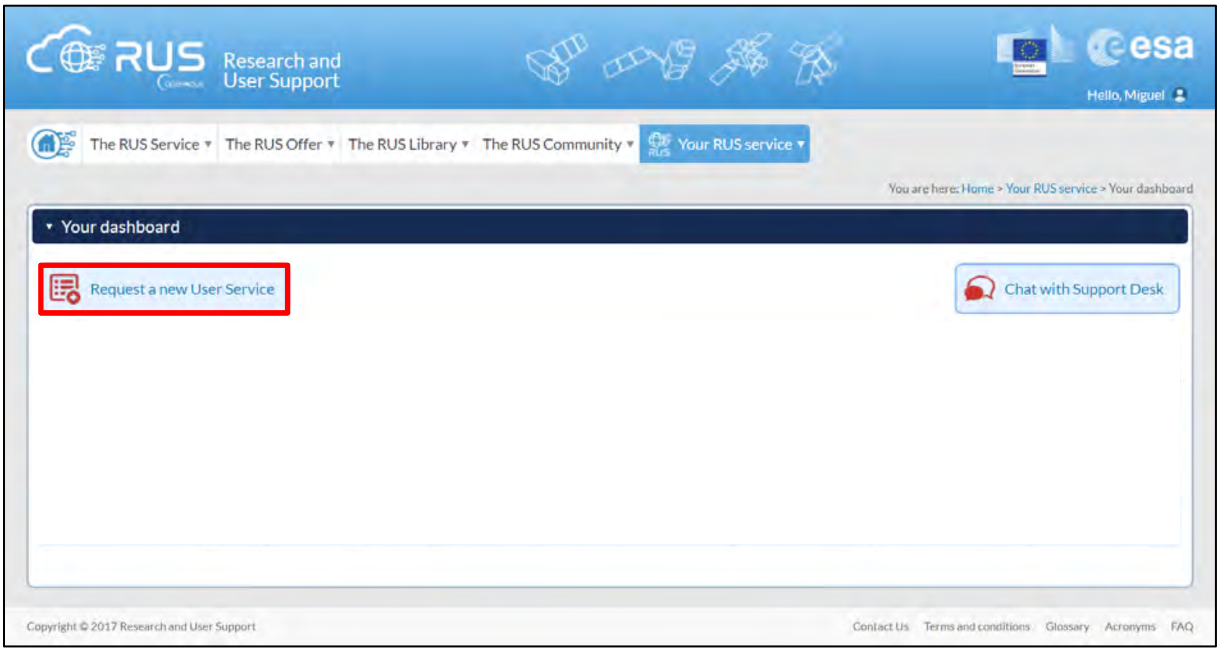


4 Request a RUS Copernicus Virtual Machine

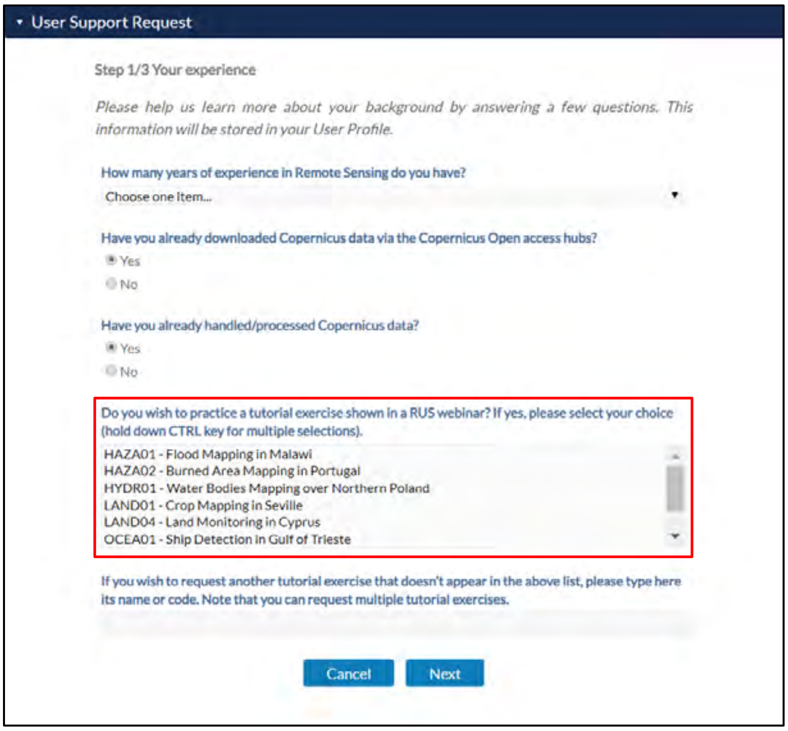
Once you are registered as a RUS user, you can request a RUS Virtual Machine to repeat this exercise or work on your own projects using Copernicus data. For that, log in and click on ***Your RUS Service → Your Dashboard***.



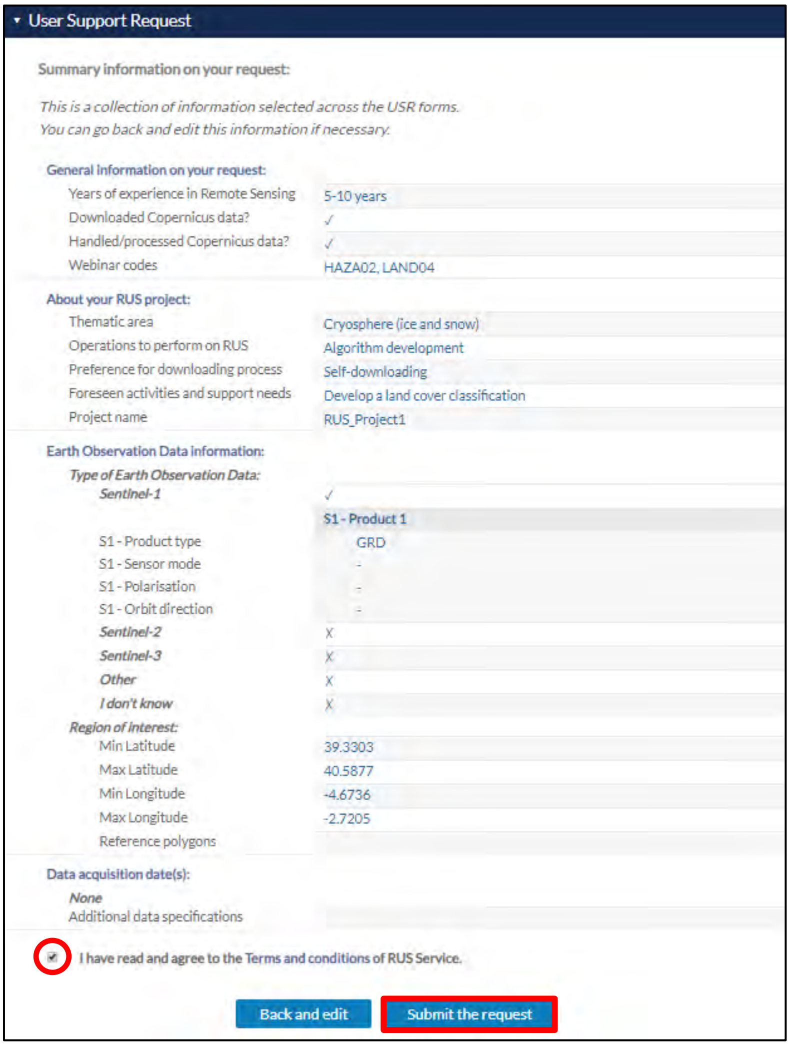
Click on ***Request a new User Service*** to request your RUS Virtual Machine. Complete the form so that the appropriate cloud environment can be assigned according to your needs.



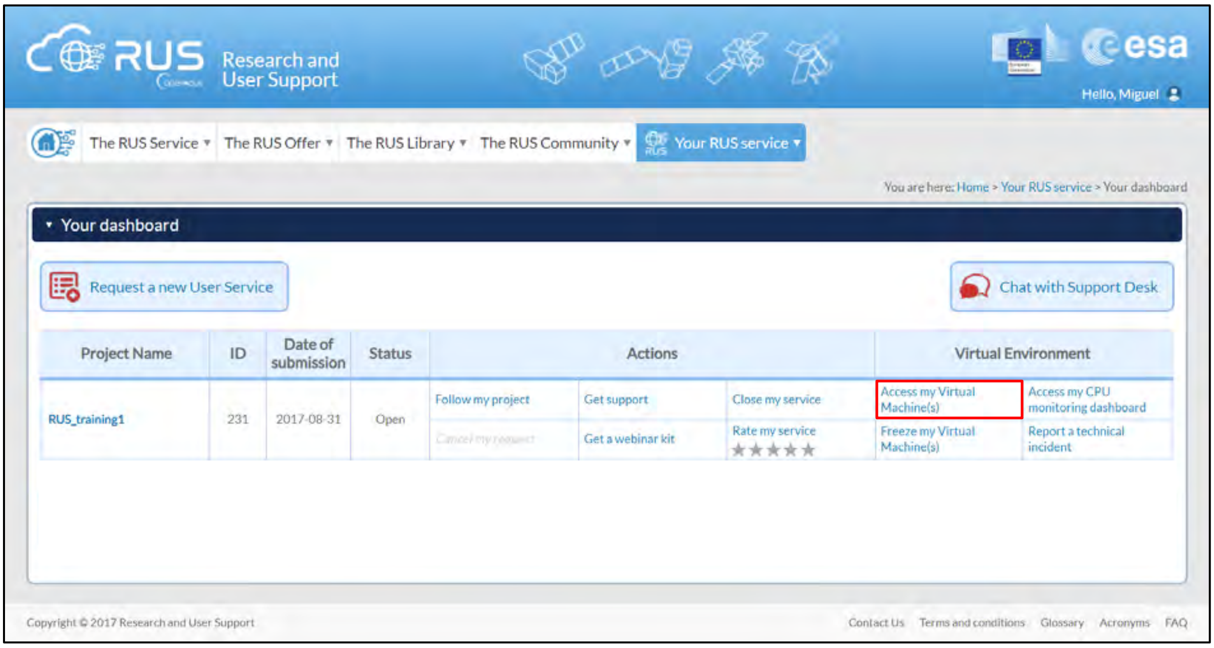
If you want to repeat this tutorial (or any previous one) select the one(s) of your interest in the appropriate field.



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



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



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

This is the remote desktop of your Virtual Machine.

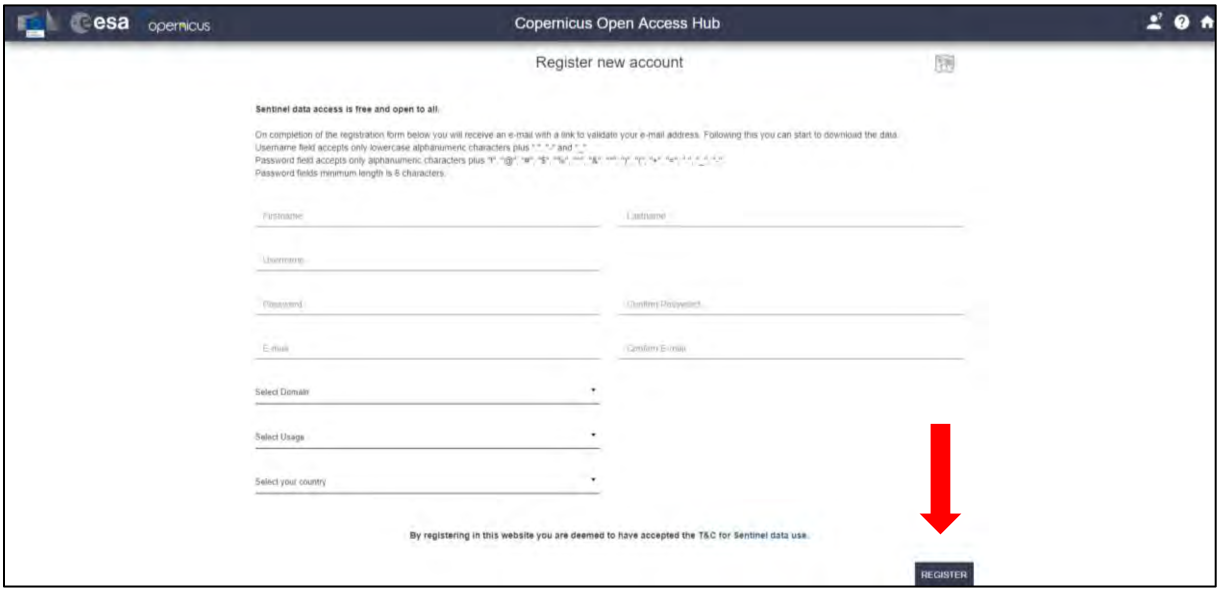
5 Step by step

5.1 Data download – ESA SciHUB

In this step, we will download Sentinel-1 scenes 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.



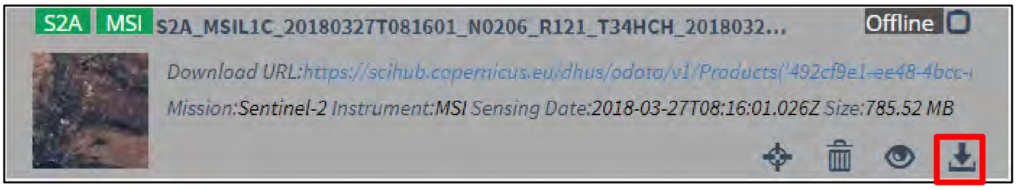
After you have filled in the registration form, you will receive an activation link by e-mail.

Once your account is activated - or if you already have an account - log-in.

5.2 Download data

In this exercise, we will analyze 16 Sentinel-2A images from years 2015-2020 from different seasons. (See NOTE 1). Table below shows the date and reference of the images that will be used:

NOTE 1: Due to ESA policy on the availability of Sentinel data on Copernicus Open Access Hub and to ensure the continued access to all Sentinel data at all time, the Long-Term Archive (LTA) Access has been implemented to roll-out the oldest data from the online access. More information about the LTA can be found in the following links:
https://scihub.copernicus.eu/userguide/#LTA_Long_Term_Archive_Access
https://scihub.copernicus.eu/userguide/LongTermArchive.



To download a product from the LTA, click on the Download Product icon - . A confirmation message will appear informing you that your request has been queued and the product added to your Cart.

You will have to manually check your Cart from time to time to know when the product is available to be downloaded (no automatic notification will be sent). Once online, the product will remain available for 4 days until been roll-out to the LTA again.
Please note that every user account is only allowed to request 1 offline product every 30 minutes, if there is free space in the queue. The number of concurrent requests for offline products from all users is limited. You may receive an error when trying to download. If so, try again later.

DATE	SEASON	IMAGE ID
2015-08-10	wet	S2A_MSIL1C_20150810T084916_N0204_R121_T34HCH_20150810T084917
2016-04-06	dry	S2A_MSIL1C_20160406T081652_N0201_R121_T34HCH_20160406T083818
2016-08-24	wet	S2A_MSIL1C_20160824T081602_N0204_R121_T34HCH_20160824T084517
2016-12-02	dry	S2A_MSIL1C_20161202T082312_N0204_R121_T34HCH_20161202T084729
2017-03-02	dry	S2A_MSIL1C_20170302T081841_N0204_R121_T34HCH_20170302T084108
2017-08-09	wet	S2A_MSIL1C_20170809T081601_N0205_R121_T34HCH_20170809T084800
2017-12-27	dry	S2A_MSIL1C_20171227T082341_N0206_R121_T34HCH_20171227T120556
2018-03-27	dry	S2A_MSIL1C_20180327T081601_N0206_R121_T34HCH_20180327T141730
2018-08-24	wet	S2A_MSIL1C_20180824T081601_N0206_R121_T34HCH_20180824T122203
2018-12-22	dry	S2A_MSIL1C_20181222T082341_N0207_R121_T34HCH_20181222T100215

2019-02-20	dry	S2A_MSIL1C_20190220T081951_N0207_R121_T34HCH_20190220T103552
2019-08-09	wet	S2A_MSIL1C_20190809T081611_N0208_R121_T34HCH_20190809T103427
2019-12-17	dry	S2A_MSIL1C_20191217T082341_N0208_R121_T34HCH_20191217T102431
2020-02-25	dry	S2A_MSIL1C_20200225T081921_N0209_R121_T34HCH_20200225T104030
2020-08-23	wet	S2A_MSIL1C_20200823T081611_N0209_R121_T34HCH_20200823T110549
2020-11-11	dry	S2A_MSIL1C_20201111T082201_N0209_R121_T34HCH_20201111T102216

To improve the data acquisition process, we will use a download manager (See NOTE 2) that will take care of downloading all products that will be used in this exercise. The metadata of the Sentinel products are contained in a *products.meta4* file created using the 'Cart' option of the Copernicus Open Access Hub.

NOTE 2: A download manager is a computer program dedicated to the task of downloading possibly unrelated stand-alone files from (and sometimes to) the Internet for storage. For this exercise, we will use aria2. Aria2 is a lightweight multi-protocol & multi-source command-line download utility. More info at: https://aria2.github.io/

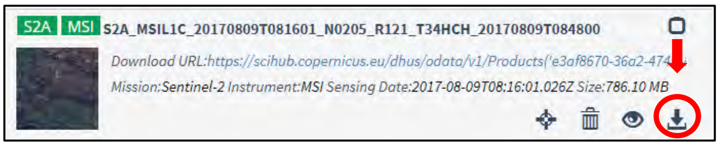
The *products.meta4* file containing the links to the Sentinel-2 products to be downloaded have been already created following the methodology explained (See NOTE 3). You can find the *products.meta4* files saved in the following path:

Path: /shared/Training/HYDR03_DroughtMonitoring_WesternCape/Original/

Before using the downloading manager and the .meta4 file, let us test if *aria2* is properly installed in the Virtual Machine. To do this, open the Command Line (in the bottom of your desktop window) and type:

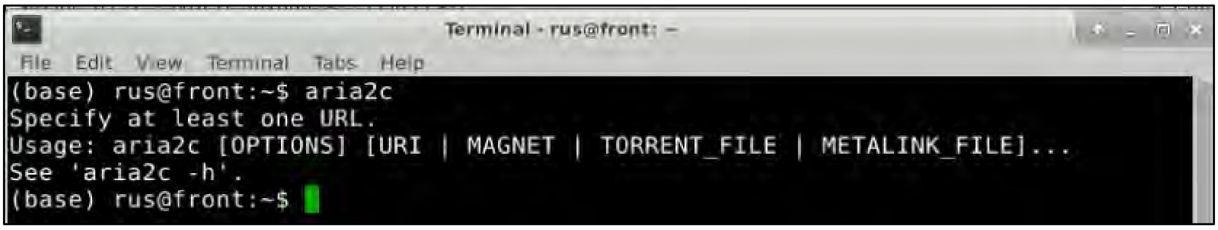
aria2c

NOTE 3: The Copernicus Open Access Hub allows you to add products to a ‘Cart’. For that, perform a query; select the desired products from the result list and click on the ‘Add Product to Cart’ icon -



To view the products present in the cart just click anytime on the User Profile icon on top right corner of the screen and then on "Cart". To download the products contained in the cart just click on "Download".

If *aria2* is properly installed, the response should be as follows. If the response is ‘*-bash aria2c: command not found’* it means *aria2* is not installed (See NOTE 4).



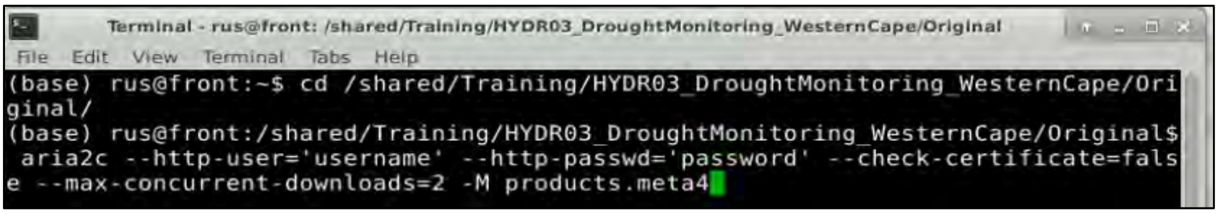
NOTE 4: If **(and only if)** the response is ‘*-bash aria2c: command not found’,* you need to install aria2. In the command line, type: *sudo apt-get install aria2*
When requested, type: Y
Once finished, test the installation as explanied before.

Once *aria2* is ready to use, we can start the download process. For that, we need to navigate to the folder where the *products.meta4* is stored. Type the following command in the terminal and run it.

```
cd shared/Training/HYDR03_DroughtMonitoring_WesternCape/Original/
```

Next, type the following command **(in a single line)** to run the download tool. Replace *username* and *password* (leave the quotation marks) with your login credentials for Copernicus Open Access Hub (COAH). Do not clear your cart in the COAH until the download process is finished. This expression is stored also in */AuxData/* folder of this training kit in text file named: *Expressions.txt*

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

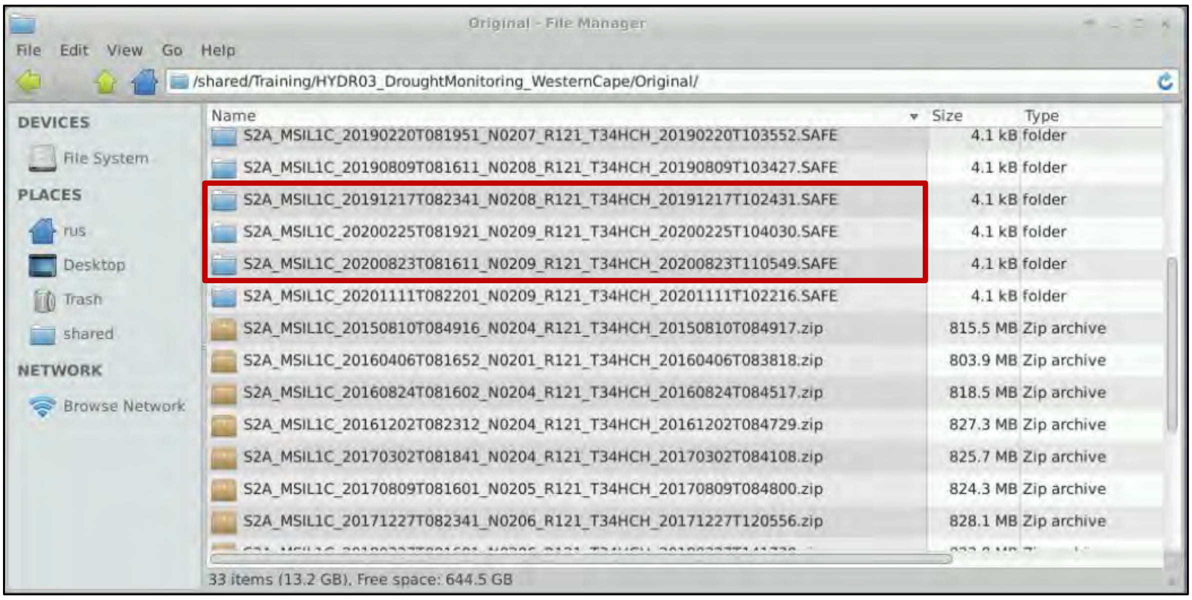


The Sentinel products will be saved in the same path where the *products.meta4* is stored. All 16 products will be downloaded to the /*Original* folder.

(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.

Lastly, navigate to the folder where our data are saved: ***shared/Training/HYDR03_DroughtMonitoring_WesternCape/Original/*** and unzip all 16 products by right-clicking each and going to **"Extract Here".**

Your folder should have the same structure as shown below.



5.3 SNAP – open and explore data

Launch SNAP (icon on desktop ). When the SNAP window opens click **Open product**  and navigate to*: **/shared/Training/ HYDR03_DroughtMonitoring_CapeTown/Original/***

Open the first S2 product **(from 10 August 2015).** We can first investigate the structure of the Sentinel 2 Level 1C products. Click on the dot next to the product name to expand the structure. The L1C products contain (among others):

- 13 TOA (top-of-atmosphere) reflectance bands
- Quality flags Now, let's visualize the product.

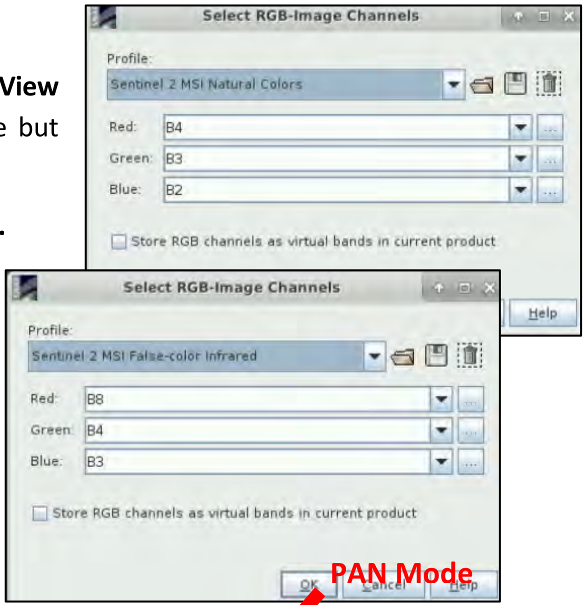
We will visualize it in true (natural) colors and as a false color composite which is better for distinguishing water surfaces. Right-click the product and click **Open RGB image window**, a new window will open. From the drop-down menu select:

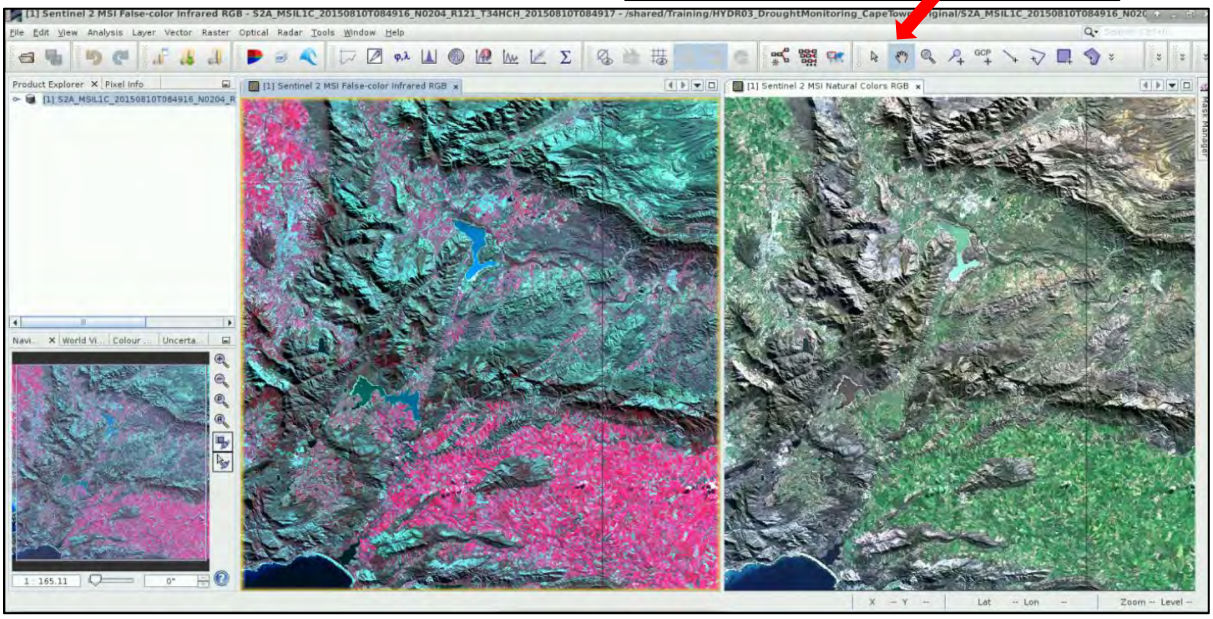
Profile: Sentinel 2 MSI Natural Colors

Click **OK**. The RGB image will be opened at the **View** window. When the image opens, repeat the same but choose the false color profile. Select:

Profile: Sentinel 2 MSI False-color Infrared. Click **OK.**

Finally, go to Window → Tile Horizontally.





For the purpose of this training atmospherically corrected (See NOTE 5). Images are stored in the folder: ***/shared/Training/ HYDR03_DroughtMonitoring_WesternCape/Original/Level-2A/***

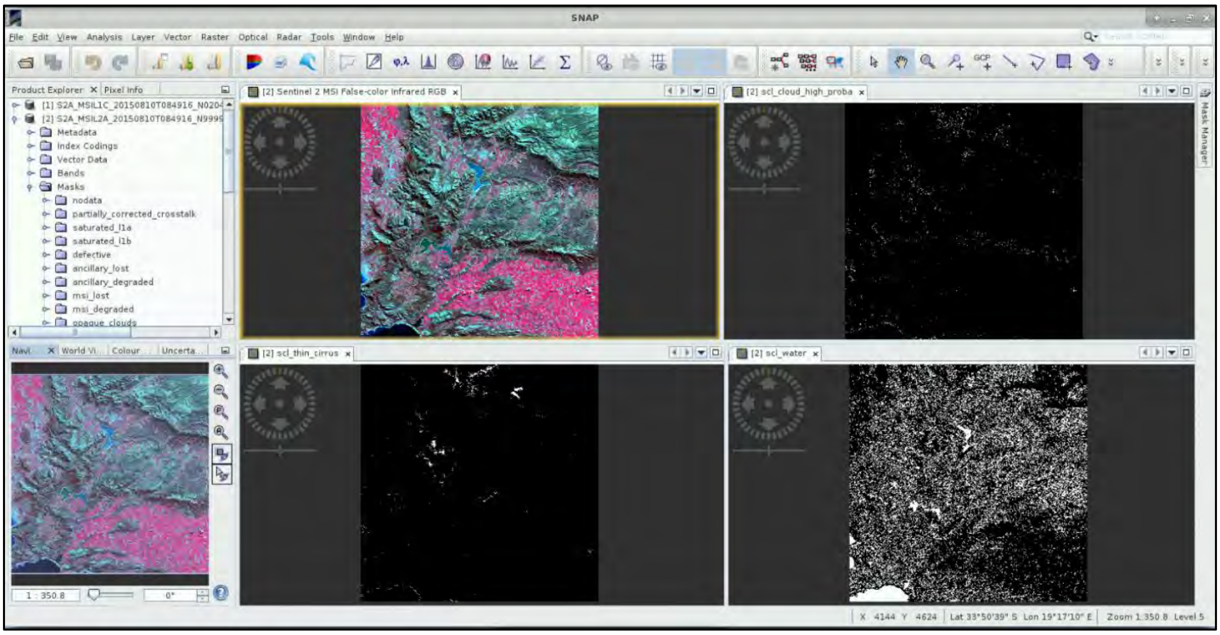
NOTE 5: The Sentinel-2 data are distributed as 100x100 km tiles resampled to a common grid in WGS84 UTM projection at two levels of processing:

- Level-1C – Top-Of-Atmosphere reflectances, systematically generated since the start of the mission.
- Level-2A – Bottom-Of-Atmosphere reflectances (atmospherically and radiometrically corrected), systematically produces for products acquired over the Europe since the spring of 2017, the coverage has increased through 2018 to reach global coverage in the beginning of 2019. Can be produced on user side by applying the Sen2Cor algorithm. (**See: Extra steps 6.1)**

Note: Atmospheric correction of one image take some time. Processing of one image in Virtual Machine environment takes about 25 minutes. For your convenience we will proceed with images already atmospherically corrected.

Now, let's investigate the **cloud cover** and **water mask bands** that are the result of atmospheric correction applied to the level 2 products. Close for now the views created. Now navigate in SNAP navigate to **File -> Session -> Open session..** and go to the path where the SNAP session is stored: to ***/shared/Training/ HYDR03_DroughtMonitoring_WesternCape/AuxData/.*** Open file called **preprocessing.snap.** In **Product Explorer** window 16 atmospherically corrected products (Level-2) should appear. Select the first product from August 2015 [1] and go to ***Masks → scl.*** Open masks ***scl_cloud_high_proba*** (Cloud high probability), ***scl_water*** (Water) and ***scl_thin_cirrus*** (Thin cirrus). Pixels with detected clouds/cirus/water will appear white in the respective masks.

Now you should have four bands open in your **View** window. Go to **Window → Tile Evenly** and then go to the **Navigation tab**, click **Zoom All** .



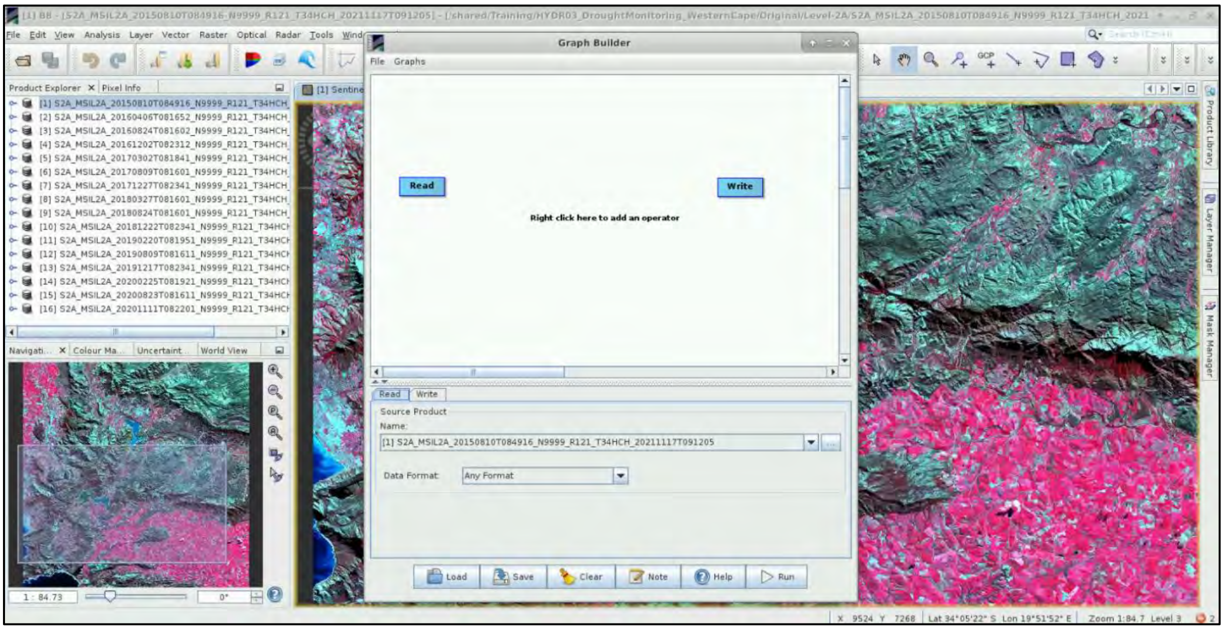
We can see that as expected our image is almost cloudless. The default water mask distributed with the Level-2 product, however, does not look very accurate.

5.4 STEP 1 – Pre-processing

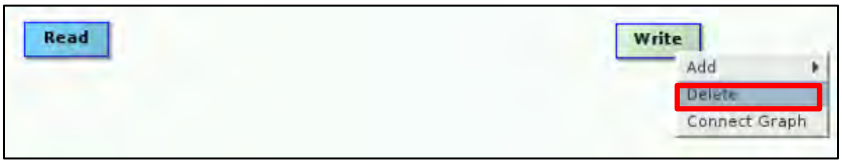
Processing the data one by one while having 16 images would not be very time effective. However, we can use either the **Batch Processing tool** available in SNAP or the GPT tool (command line) to process all images automatically.

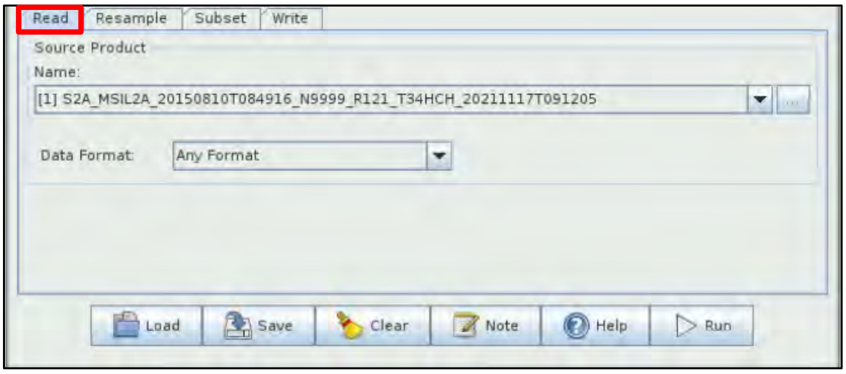
To use either method, we first need to define the process we want to apply and all its steps. We can do this using the **GraphBuilder** tool. Another advantage of the **GraphBuilder** is that only the final product will be physically saved, and we save valuable disk space.

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). First of all, we can remove **Write operator** to not create confusion. To delete the operator, **right click** on it and select **Delete**.



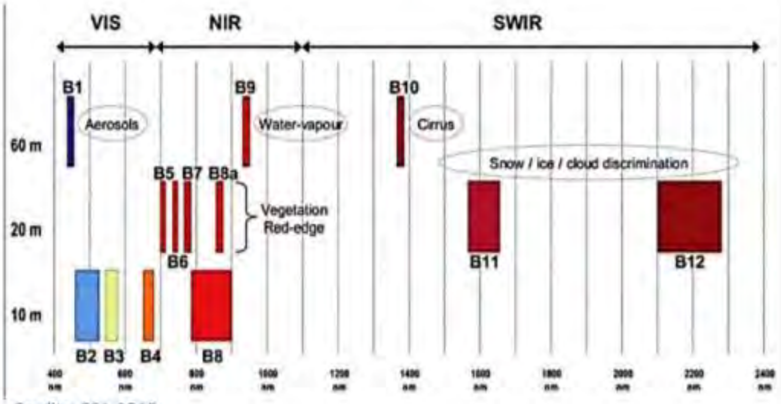


5.4.1 Resample

The 13 bands in Sentinel-2 products do not all have the same resolution (therefore size) as mentioned in NOTE 6. Many operators do not support products with bands of different sizes, so we need to resample the bands to equal resolution first.

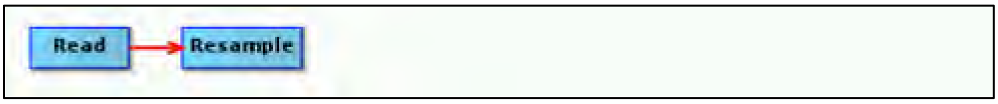
To add the operator right-click the white space between the existing operators and go to ***Add → Raster → Geometric → Resample***.

NOTE 6: 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

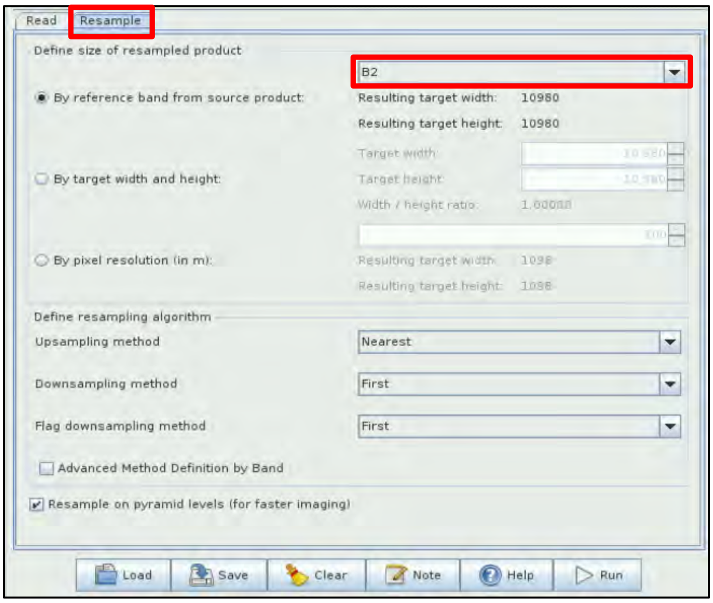
A new operator rectangle appears in our graph and a new tab appears below. Now connect the new **Resample** operator with the **Read** operator by clicking to the right side of the **Read** operator and dragging the red arrow towards the **Resample** operator.



Below the white box with the graphical representation of the tools used in a processing chain, you will find a panel which allows to change the parameters of all tools placed into processing chain. We will update the parameters one by one here.

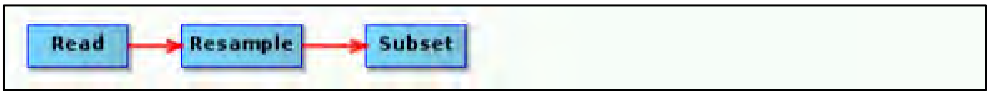
Do not change anything in the **Read** tab.

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



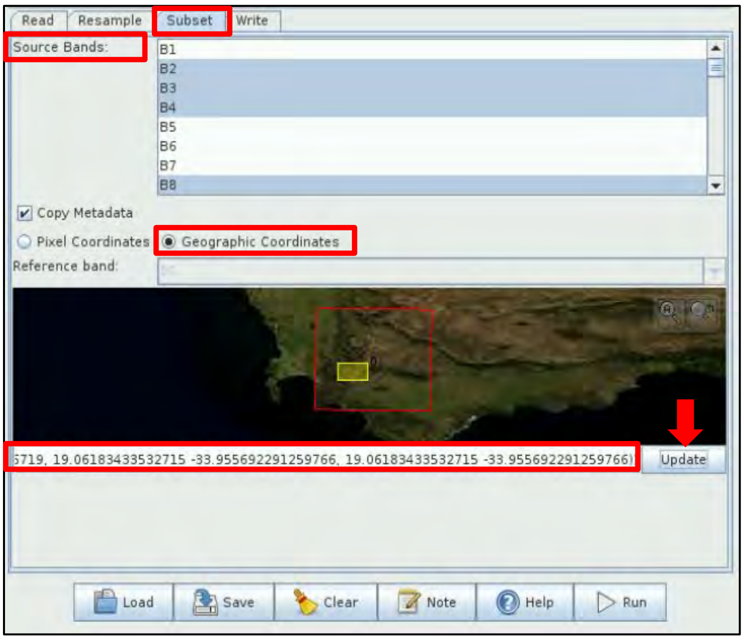
5.4.2 Subset

Next step will be to subset the images to the area of interest, we do this by right-clicking the white space somewhere right of the resample operator and going to ***Add → Raster → Geometric → Subset***. Connect the **Subset** operator with the **Resample** operator.



In the Subset tab we are going to keep only the bands which will be necessary in next steps of the analysis. In the parameter ***Source band*** select following bands to keep in the final product: **B2, B3, B4, B8, B11, B12**. Then we are going to clip our image only to the area of interest, which in our case is Theewaterskloof dam. Below the option *Copy metadata* select the option of subset ***Geographic coordinates.*** Below the world view window in the white text box copy and paste the subset polygon coordinates in Well-Known-Text format (WKT) from ***Expressions.txt*** file stored in: ***/shared/Training/HYDR03_DroughtMonitoring_WesternCape/AuxData/***

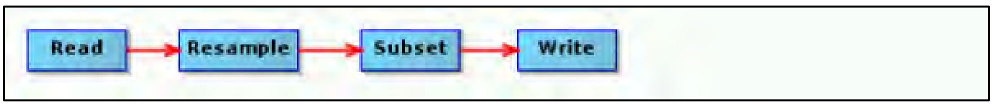
```
POLYGON ((19.061834340155283 -33.955691701708375, 19.379564169402002 -33.96
028594353146, 19.376352000158878 -34.12895277789442, 19.057993224051753 -34
.124329459334305, 19.061834340155283 -33.955691701708375))
```

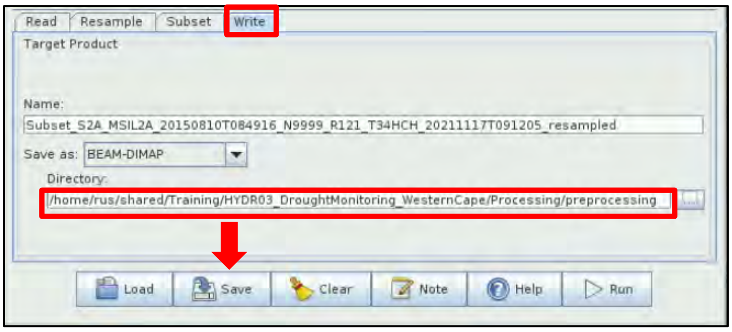


5.4.3 Write

Now, finally we can add **Write** operator and connect it to the **Subset**.

Change the directory of the output products to the path: ***/shared/Training/HYDR03_DroughtMonitoring_CapeTown/Processing/preprocessing/.***





Now, save the graph as ***Graph_preprocessing.xml*** to: ***/shared/Training/HYDR03_DroughtMonitoring_WesternCape/AuxData/*** by clicking Save at the bottom of the window.

5.4.4 Batch processing

Batch Processing is used when we want to apply identical pre-processing steps at once to multiple images. Once we have our graph with pre-processing steps created we are ready to apply the same steps to all 16 images.

There are several approaches to do batch processing in SNAP, but in this step we will make use of built-in tool in SNAP – **Batch Processing tool.** To do this first close the **Graph Builder** window**.**

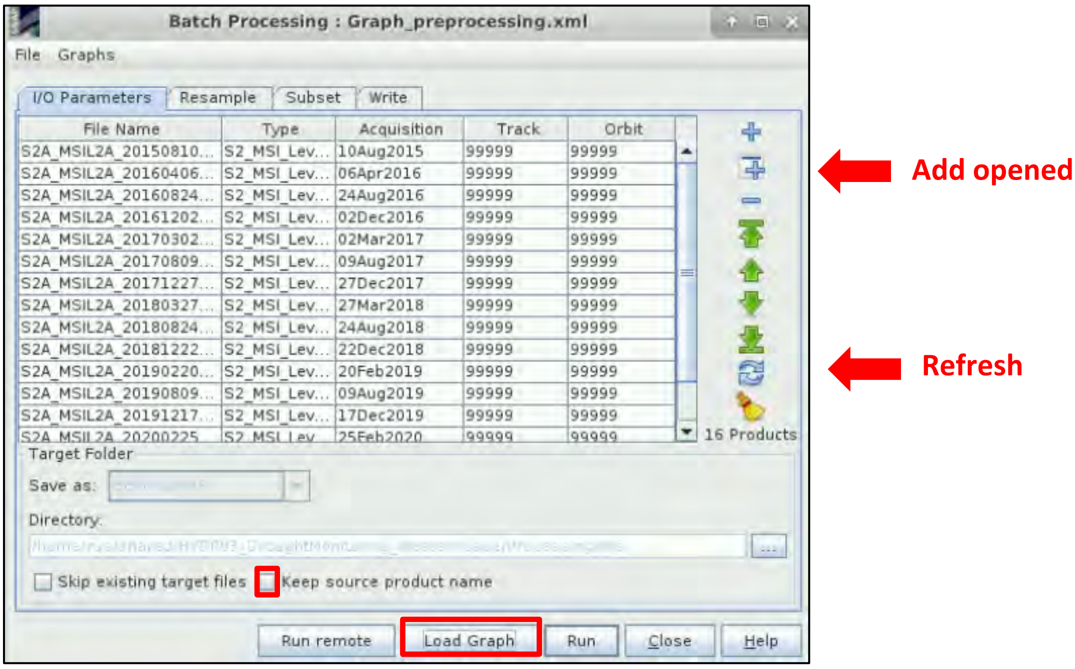
Then open **Batch Processing** tool (**Tools → Batch Processing**). In the **I/O Parameters** tab we will add all opened products from the **Product Explorer** window [1]-[16] by **Add Opened** on the upper right (second icon from the top) and then click **Refresh** (second icon from the bottom). Like this we have loaded all 16 images from 2015-2020 of the same area.

In the **I/O Parameters** tab, under the *Target Folder*:

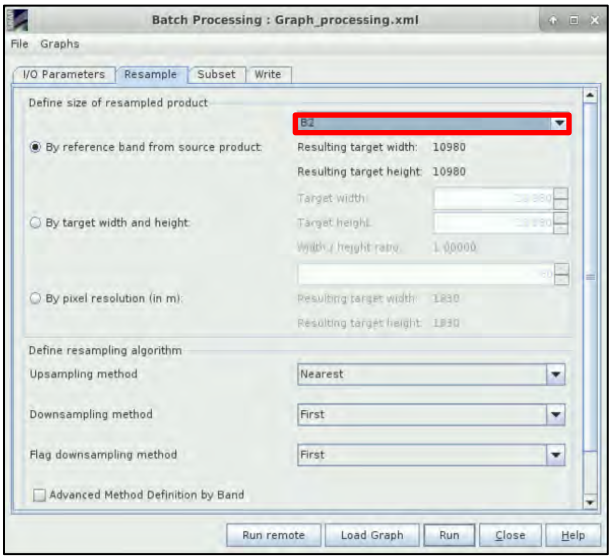
a) keep the format *(Save as)* is set to **BEAM-DIMAP**,
b) change the directory to: ***/shared/Training/HYDR03_DroughtMonitoring_WesternCape/ Processing/preprocessing/***
c) and the option "*Keep source product name*" **unchecked.** Do it **before** uploading the graph into Batch Processing Tool (See NOTE 7).

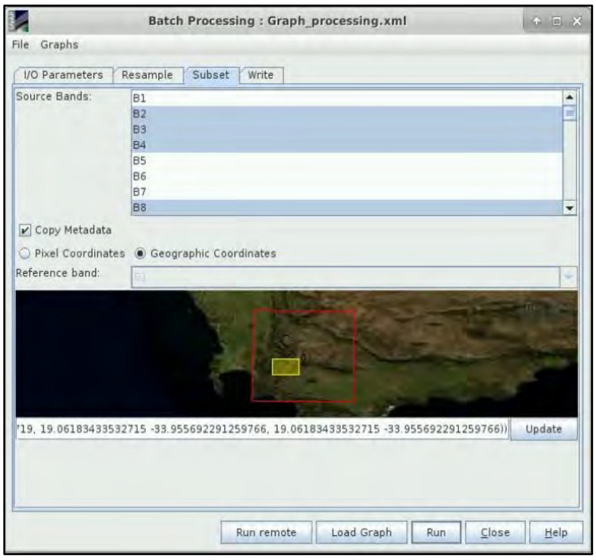
> NOTE 7: The product file names will be identical to the input file names. If you set your output directory to the folder that contains your input data, the input data will be overwritten!

Then click on **Load Graph** at the bottom of the window, and you should now navigate to saved ***Graph_preprocessing.xml*** file and open it. We see that new tabs have appeared at the top window corresponding to our operators from pre-processing graph.



In the **Resample tab** make sure that under **Define size of resampled product**, option "*By reference band from source product***"** is selected and then that the **B2** is highlighted as a reference band. This way we will ensure that all the bands will be resampled to 10 m resolution.

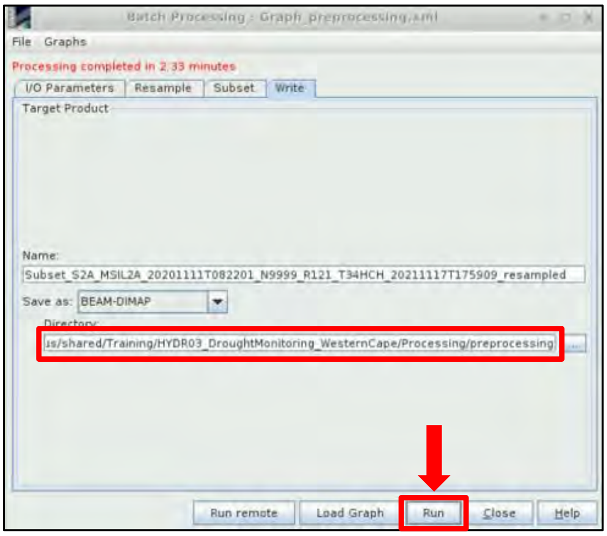




At the **Subset,** check if all parameters are exactly the same as set in **Graph Builder** previously.

In the **Write** tab, under the **Name** keep the default name (*Subset_* and *_resampled* will be added). At the directory make sure that the path to:***/shared/Training/HYDR03_DroughtMonitoring_WesternCape/Processing/preprocessing***.

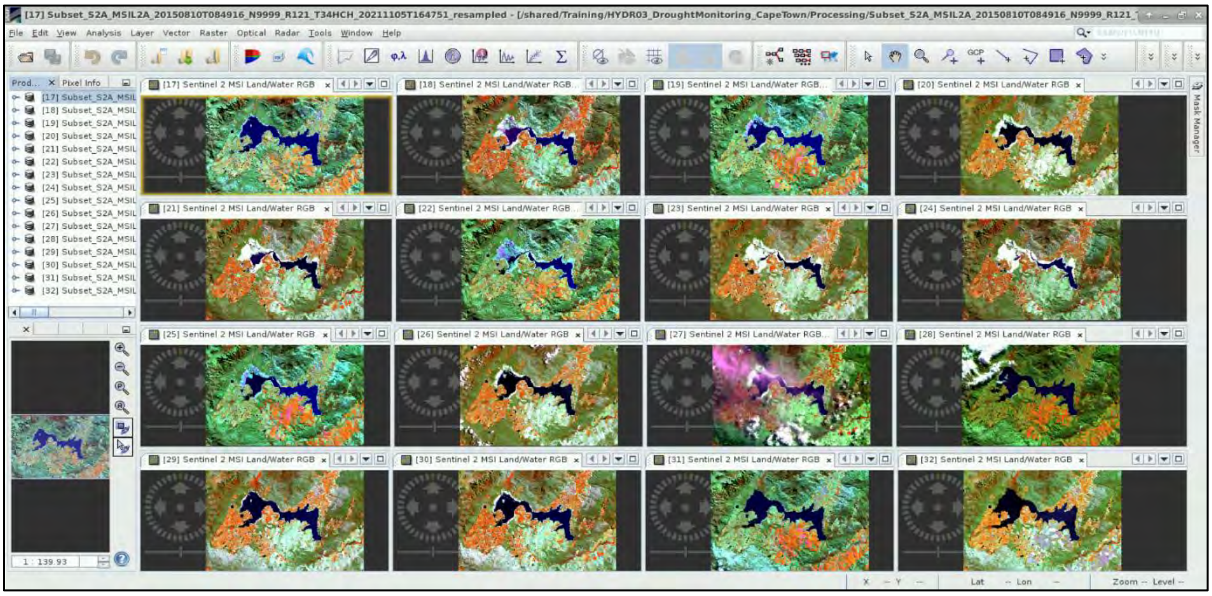
Click **Run.**



The processing time will depend on your VM setup. (Approx. 3 mins with 30GB ram).

You can check the ***/shared/Training/HYDR03_DroughtMonitoring_WesternCape/Processing/ preprocessing/*** for the output products. Once the processing is done close the **Batch Processing** window. All pre-processed products will appear automatically at the **Product Explorer** window.

Once all products are loaded [17]-[32], right-click the first and go to **Open RGB image window**. Select the profile: **Sentinel 2 MSI Land/Water** and click **OK**. You can repeat this step for all products and the go to **Window → Tile Evenly.** On the left in the Navigation panel select: Zoom all 



5.5 STEP 2 | Water radiometric indices calculation

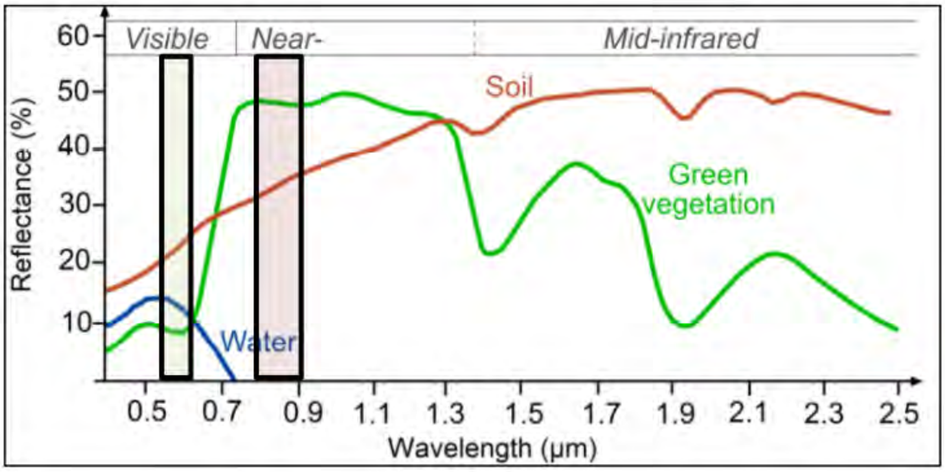
To detect water bodies, we will use several water radiometric indices from S2 data. A variety of different water indices exist and can be applied for different purposes. We will first introduce here 4 indices selected for the purpose of this training. Later we are going to calculate them for all 16 images. We will use different water radiometric indices to create later a water mask based on the results of the water response to specific band combinations. Generally, water only reflects in the visible light range. As water has almost no reflection in the near infrared range it is very distinct from other surfaces. Because of this absorption property water bodies as well as features containing water can easily be detected, located and delineated with remote sensing.

5.5.1 NDWI

To detect the water bodies, we will use several water radiometric indices proposed in the literature. First index that we will use is the ***Normalized Difference Water Index*.** It was proposed by McFeeters2 to detect surface waters in wetland environments and to allow for the measurement of surface water extent. It allows also to:

i) maximize the reflectance of the water body in the green band;
ii) minimize the reflectance of water body in the NIR band. McFeeters's NDWI is calculated as:

$$NDWI = \frac{Green - NIR}{Green + NIR} = \frac{B3 - B8}{B3 + B8}$$



5.5.2 MNDWI

The main limitation of previously described NDWI index is that it is not efficient in sites where built-up areas signal noise can affect the water surface signal. It was noticed that the water bodies have stronger absorbability in the SWIR band than in the NIR band, while the built-up areas have greater radiation in the SWIR band than in the NIR band *(Xu, 2006).* Based on this finding the ***Modified Normalized Water Index*** was proposed which allows to suppress and even removing built-up land noise as well as vegetation and soil noise and therefore enhance water bodies extraction.

The MNDWI is calculated using following equation:

$$MNDWI = \frac{Green - SWIR1}{Green + SWIR1} = \frac{B3 - B11}{B3 + B11}$$

5.5.3 MNDWI + 5

In 2015 the modification of existing ***Modified Normalized Vegetation Index was introduced (MNDVI + V).*** This index use NIR and Red band *(Zhou et al., 2017)* and it combines the Enhanced Vegetation Index and Normalized Difference Vegetation Index. This combination makes it more sensitive to surface water features, enhancing the ability to map their distribution. This index shows great performance also in flood detection and mapping as well as monitoring surface water resources *(Bhaga et al. 2020)*. Using this index surface water will have negative values (<0) so opposite to all other water indices tested in this exercise.

$$MNDWI + 5 = \frac{NIR - Red}{NIR + Red} = \frac{B8 - B4}{B8 + B4}$$

5.5.4 AWEI

This is the last index which has been tested in this training. The ***Automated Water Extraction Index*** has been introduced by *Feyisa et.at (2014).* And it was designed to improve water extraction accuracy with a stable threshold value. This index introduced two equations which are $AWEI_{sh}$ (used in this exercise) and $AWEI_{nsh}$. In this training we concentrated only on one AWEI index and it is $AWEI_{sh}$ which enhance water bodies detection by removing shadow pixels. Both indices however use combination of blue, green, NIR, SWIR1 and SWIR2 bands.

The equation used for calculating this index is following:

$$AWEI = Blue + 2.5 * Green - 1.5 * (NIR + SWIR1) - (0.25 * SWIR2) =$$
$$= B2 + 2.5 * B3 - 1.5 * (B8 - B11) - (0.25 * B12)$$

5.5.5 Water radiometric indices calculation

To calculate the water radiometric indices described we will create another short graph. We will produce four water radiometric indices for all 16 images. First we will create short graph that calculates indices for all images at once. Then newly created bands will be stacked to one product which corresponds to each sensing date of images used. Band merge will be crucial to perform later Time Series analysis in SNAP as it is one the requirements of this tool.

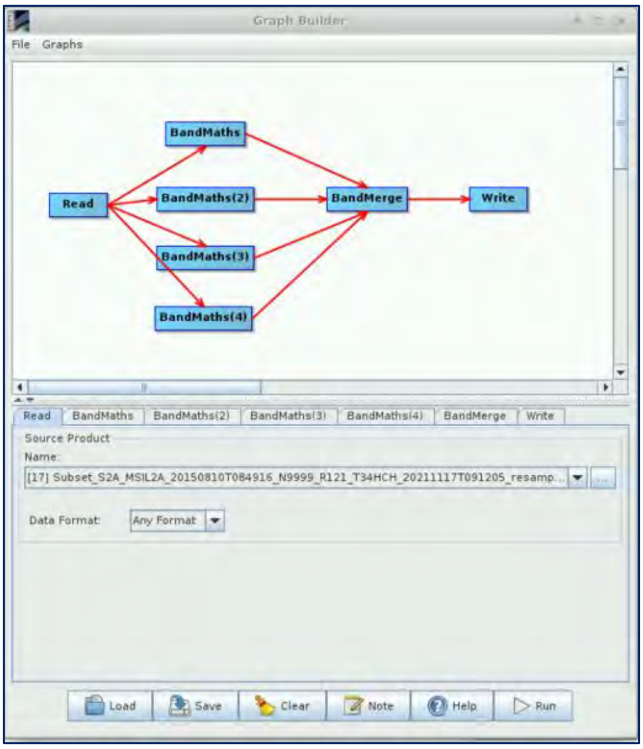
Go to **Tools → Graph Builder.** First of all, we can remove **Write operator** to not create confusion. To delete the operator, **right click** on it and select **Delete**.

Then to calculate water indices add four **Band Maths(1-4)** operators (one for each water index): **Add → Raster → BandMaths**.

We will calculate the indices based on the mathematical equations applied on different bands of the product. The expressions used to calculate these water indices are stored in file: ***Expression.txt*** (lines: 10 – 13) which is stored in: ***/shared/Training/HYDR03_DroughtMonitoring_WesternCape/AuxData/***

After you placed all four **BandMaths** operators to your graph you can edit the parameters (expressions used for calculation of each index).

After all four **BandMaths** operators are added you can click again on the white space in the graph builder go to **Add → Raster → BandMerge** and connect all four **BandMaths** operators to Band Merge. As a last step go to **Add → Input-Output → Write.** Connect **Band Merge** to **Write** operator. Your final graph should look like this below:



Now move to the tabs below the graphical representation of operators and edit parameters.

Do not change anything in the **Read** operator tab.

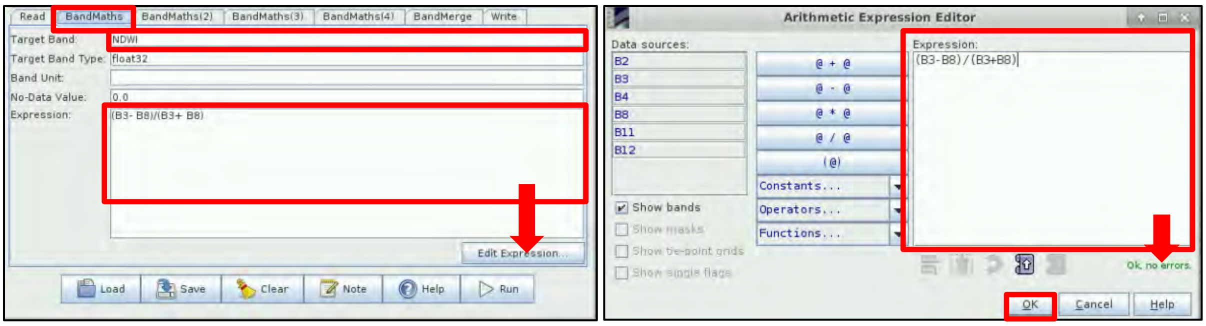
In the **BandMaths tab** which indicates the first water radiometric index to calculate:

- change *Target band name*: **NDWI**
- go to *Edit Expression* button and copy and paste following equation to calculate the new band.

> Expressions are also stored in the *Expression.txt* file in the Training folder: */shared/Training/HYDR03_DroughtMonitoring_WesternCape/AuxData/)*

Go to **Band Math** tab and copy and paste following condition statement (expression):

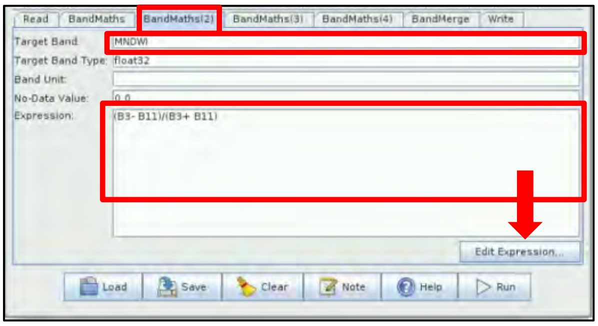
```
(B3-B8)/(B8+B3)
```

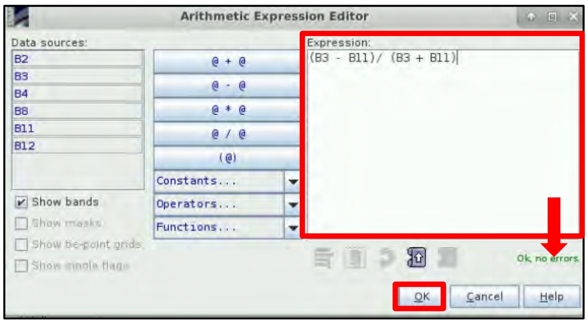


In **Band Math(2)** tab:

- change *Target band name*: **MNDWI**
- go to *Edit Expression* button and copy and paste following equation to calculate the new band:

```
(B3-B11)/(B8+B11)
```

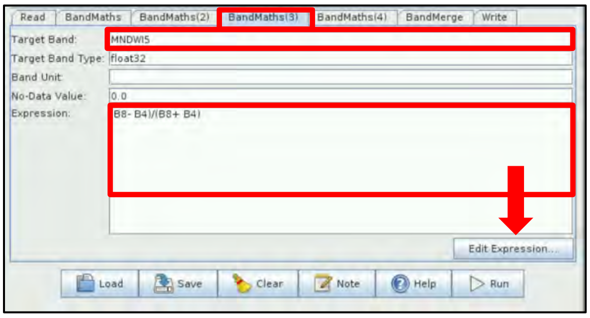


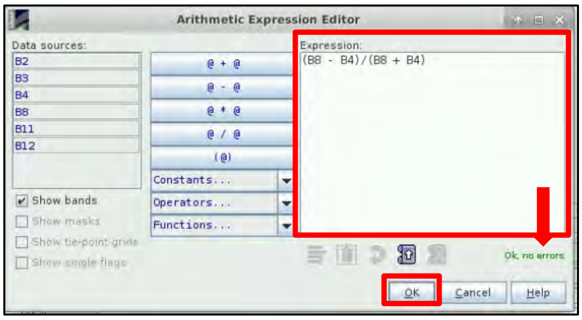


In **Band Math(3)** tab:

- change *Target band name*: **MNDWI5**
- go to *Edit Expression* button and copy and paste following equation to calculate the new band:

```
(B8-B4)/(B8+B4)
```

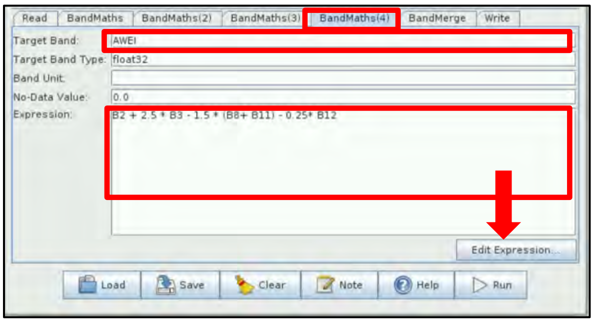


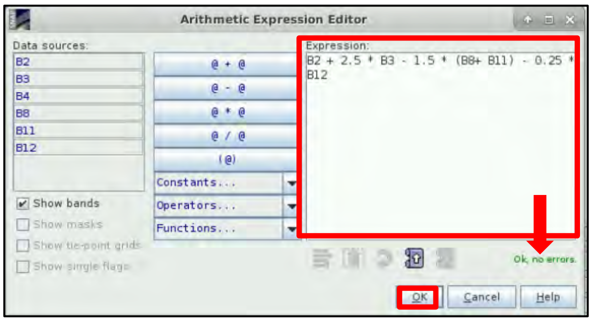


In **Band Math(4)** tab:

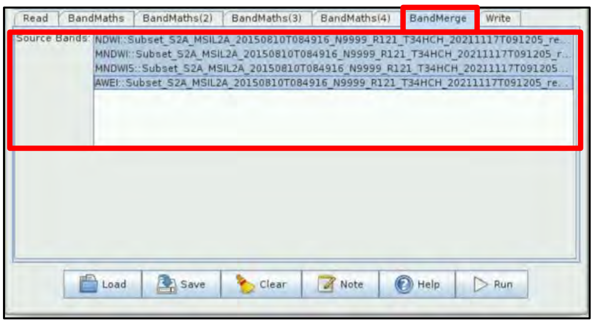
- change *Target band name*: **AWEI**
- go to *Edit Expression* button and copy and paste following equation to calculate the new band:

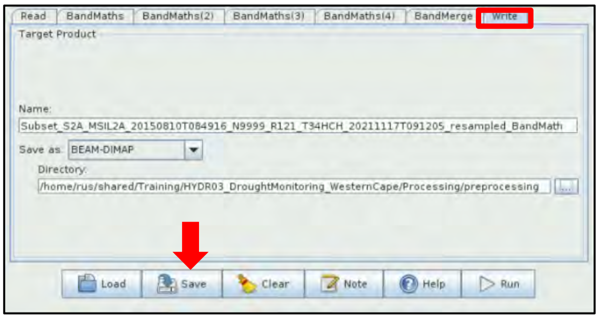
```
B2 + 2.5 * B3 – 1.5 *(B8-B11) – 0.25 * B12
```





In the next tab **BandMerge** we will merge all water radiometric indices. To do that select all bands (with CTRL key pressed) in the *Source Bands* parameter.





Do not change anything in **Write** tab.

Now, save the graph as ***Graph_WIs.xml*** to: ***/shared/Training/HYDR03_DroughtMonitoring_WesternCape/AuxData/*** by clicking Save at the bottom of the window.

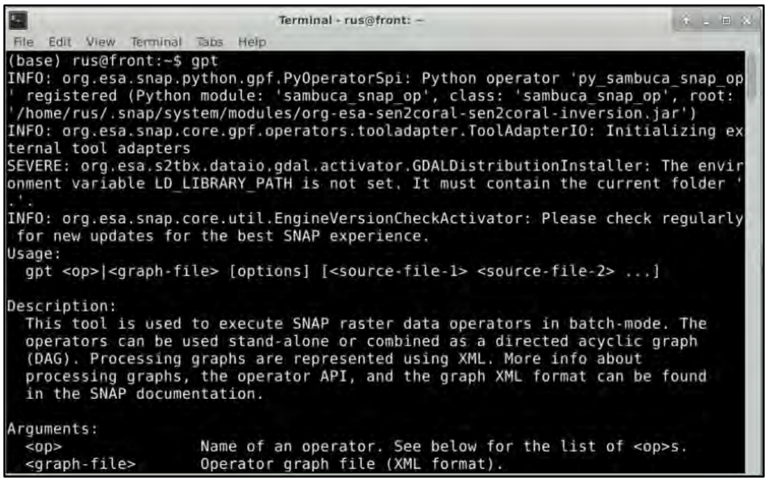
5.5.6 Graph Processing Tool | GPT

In this exercise, we will use the **SNAP GPT** command line interface (which can be found in the bin folder of the Sentinel Toolbox installation) to process our Sentinel- products. This tool is used to execute SNAP raster data operators in batch-mode. The operators can be used stand-alone or combined as a directed acyclic graph (DAG). Processing graphs are represented using XML files. Using the GPT provides a convenient way to use operators in a headless environment or in batch mode (See NOTE 8).

> NOTE 8: To run an operator using GPT, it is necessary to indicate the path to the source product(s), to the target product and to other operator-specific parameters which might be mandatory or specific. As for complex operators the call from the command line can easily become confusing, it is also possible to pass the required settings in form of a xml-encoded graph file. It will then suffice to just pass the graph as parameter to the GPT.

To access **GPT**, open a ***Terminal*** window by clicking on its icon - - write the following text and press enter (See NOTE 9).

```
gpt
```



NOTE 9: Note that in the RUS Copernicus Virtual Machines, the gpt command is an environment variable and can be called directly from the terminal. If this is not your case, you will have to set it or specify the path to gpt to call the program.

To process our images in batch mode using GPT we need to change the input and output reference to specific input/output files by variables (See NOTE 10).Navigate to the following path, right click on the graph file ***(Graph_WIs.xml)*** and select **Open With -> Open with Mousepad**.

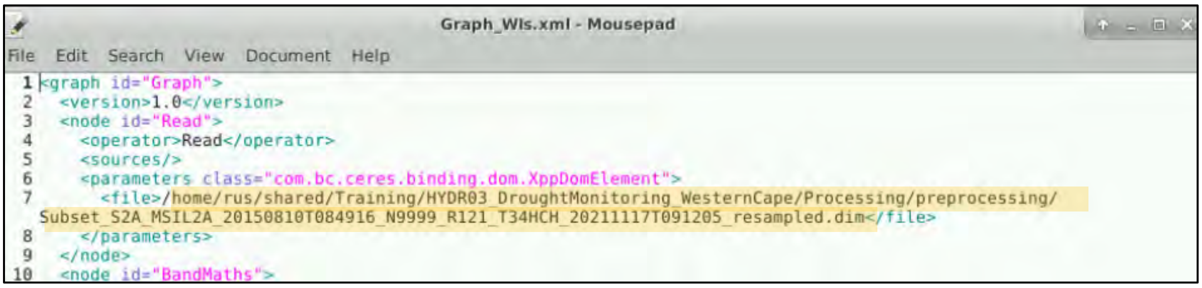
Once the xml file is opened, click on **View -> Line Numbers**.

Path: ***/shared/Training/HYDR03_DroughtMonitoring_WesternCape/AuxData/***

NOTE 10: The graph created in the **Graph Builder** tool in **SNAP** is an xml document that contains the different operators that have been added. The xml document is structured in a way that all the information of a specific operator is specified between the and tags.

In **line 7,** delete only the path to the input image highlighted in orange (do not remove *<file>* and *</file>*) and write ***$input*** (as highlighted in green). Line **7** should look like this:

```
<file>$input</file>
```



In line **105**, delete only the path to the output image highlighted in orange (do not remove *<file>* and *</file>*) and write ***$output2*** (as highlighted in green). Line **105** should look like this:

```
<file>$output</file>
```

```
<node id="Write">
  <operator>Write</operator>
  <sources>
    <sourceProduct refid="BandMerge"/>
  </sources>
  <parameters class="com.bc.ceres.binding.dom.XppDomElement">
    <file>$output</file>
    <formatName>BEAM-DIMAP</formatName>
  </parameters>
</node>
```

5.5.7 Batch processing

Once the graph is modified with the ***$input*** and ***$output*** variables, we are ready to process them in batch mode with GPT. For that, when an image is processed, the ***$input*** and ***$output*** variables have to change with the appropriate name. There are several approaches to do so but, in this exercise, we will use a bash script (See NOTE 11).

> NOTE 11: A shell script is a computer program designed to be run by the Unix shell, a command-line interpreter. The various dialects of shell scripts are considered to be scripting languages. The one used in this exercise is called Bash script (https://en.wikipeia.org/wiki/Bash (Unix shell)). Typical operations performed by shell scripts include file manipulation, program execution, and printing text.
> If you want to run this exercise on Windows, you can replicate the steps in any programming language you are familiar with, such as Python or R.

Now, go to the path: ***/shared/Training/HYDR03_DroughtMonitoring_WestrenCape/AuxData/***and open the file named: ***Script_WIs.sh***.

Script_WIs.sh - Mousepad

File Edit Search View Document Help

```
1 #!/bin/bash
2 # 1- Define path variables
3 Path_S2=/shared/Training/HYDR03_DroughtMonitoring_WesternCape/Processing/preprocessing/
4 output_folder=/shared/Training/HYDR03_DroughtMonitoring_WesternCape/Processing/WIs/
5
6 # 2- Define name variables
7 oldEnd=.dim
8 newEnd=_WIs
9
10 # 3- Extract date & run GPT
11 for i in $(ls -d -1 $Path_S2$Subset_S2A*.dim)
12 do
13         ac_datetime=$(echo $i | cut -d '_' -f 6)
14         n=$(echo $ac_datetime | cut -d 'T' -f 1)
15         date
16         gpt /shared/Training/HYDR03_DroughtMonitoring_WesternCape/AuxData/Graph_WIs_GPT.xml -Pinput=$i -Poutput=
   $output_folder$n$newEnd
17         date
18
19 done
```

On line **1,** we specify that the script should be run with Bash scripting language (See NOTE 11).

```
1 #!/bin/bash
```

On line **3, 4** we specify folder where input data are stored and output folder (respectively) where our results will be saved.

```
3 Path_S2=/shared/Training/HYDR03_DroughtMonitoring_WesternCape/Processing/preprocessing/
4 output_folder=/shared/Training/HYDR03_DroughtMonitoring_WesternCape/Processing/WIs/
```

On lines **7 and 8** we specify the pattern of the beginning of the input product (line **7**) and ending of the output (line **8**).

```
7 oldEnd=.dim
8 newEnd=_WIs
```

Line **11** signifies the start of the loop. The script will loop over all files in the specified folder ending with “*.dim*”*.* In each iteration, the path to one input file is denoted by *“i”.*

“do” on line **12** and “done” on line **19** enclose the steps that should be performed on each input product.

```
11 for i in $(ls -d -1 $Path_S2$Subset_S2A*.dim)
12 do
```

On line **13**, we extract the name of the input product; on line **14**, we extract the date of the acquisition from the Sentinel-2 product.

```
13        ac_datetime=$(echo $i | cut -d '_' -f 6)
14        n=$(echo $ac_datetime | cut -d 'T' -f 1)
```

On line **15** and **17** we specify that once the script will run, information about current date will be provided (printed) in the Terminal.

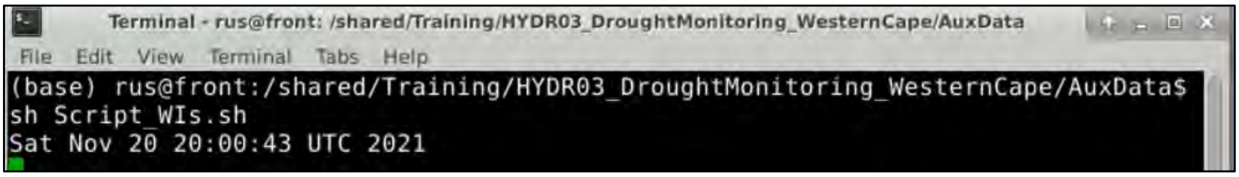
On line **16** we call GPT and specify the path to our saved and edited graph file. Then with -P{variable name} we specify the parameters to be replaced in the graph file (marked with $ in the graph file) – input and output variables. We also create the output product name combining the sensing date of the product and the suffix for each output product. On line **19,** the loop is closed.

```
15        date
16        gpt /shared/Training/HYDR03_DroughtMonitoring_WesternCape/AuxData/Graph_WIs_GPT.xml -Pinput=$i -Poutput=
   $output_folder$n$newEnd
17        date
18
19 done
```

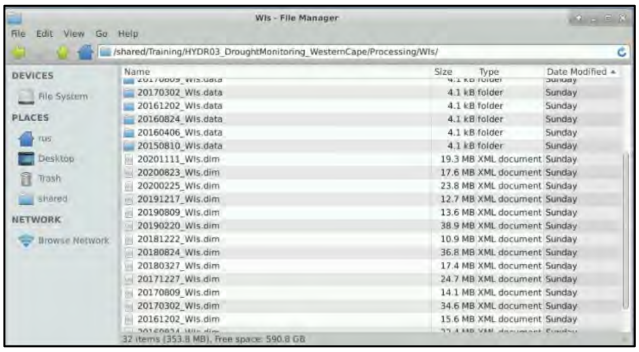
Once the script is saved, we can run it. Navigate to ***…/AuxData/*** folder where shell script file is sotred. Right-click on the white space and go to **Open Terminal Here.** In the terminal type:

```
sh Script_WIs.sh
```

where *Script_Wis.sh* is the name of the Bash script file. Click **Enter** to run the script.



The processing time will depend on your VM setup (approx. 2-3 min with 30 GB RAM). You can check the: ***/shared/Training/HYDR03_DroughtMonitoring_WesternCape/Processing/WIs/*** for the output products. Close the terminal window. Once the images are processed you should see the list of products like this:



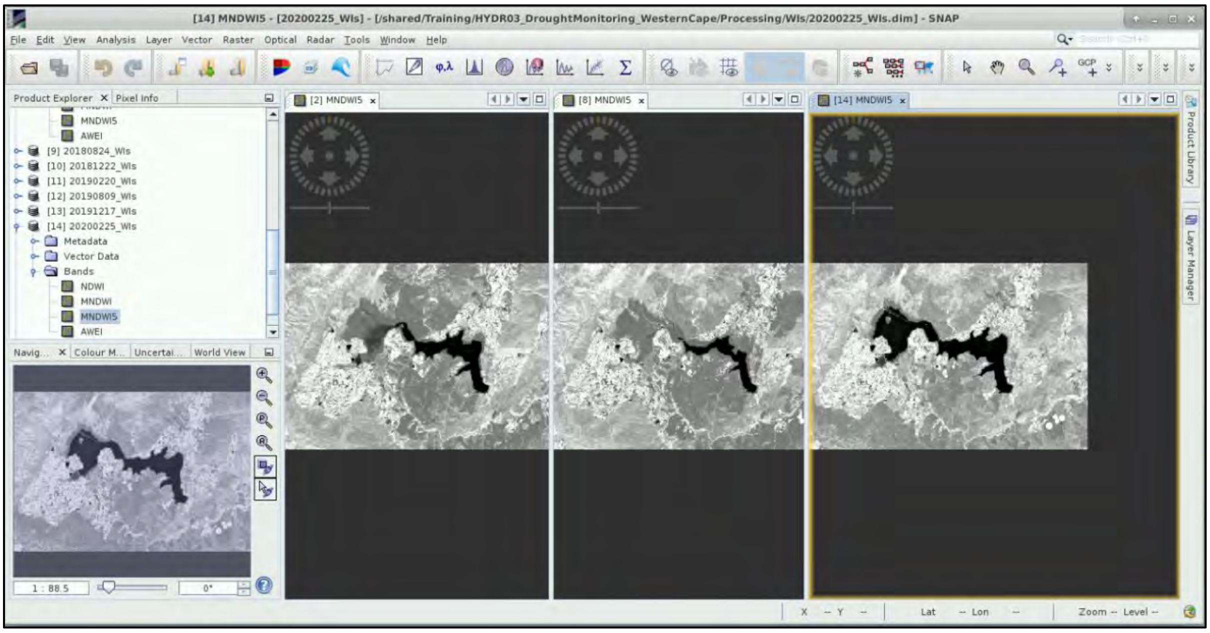
5.6 STEP 3 | Time Series

Now, let's have a look at different water radiometric indices, output from Bash processing. Go back to SNAP and go to **File -> Session -> Open session..**

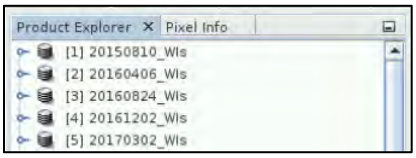
Navigate to ***/shared/Training/HYDR03_DroughtMonitoring_WesternCape/AuxData/*** and open **water_indices.snap**

You can now investigate different indices over the period from 2015 until 2020. Expand **Bands** of each product in **Product Explorer**. You will notice that all products have bands with the same name. This is the requirement of **Time Series Tool** in SNAP. In order to plot temporal changes in a graph compared bands need to have the same name.

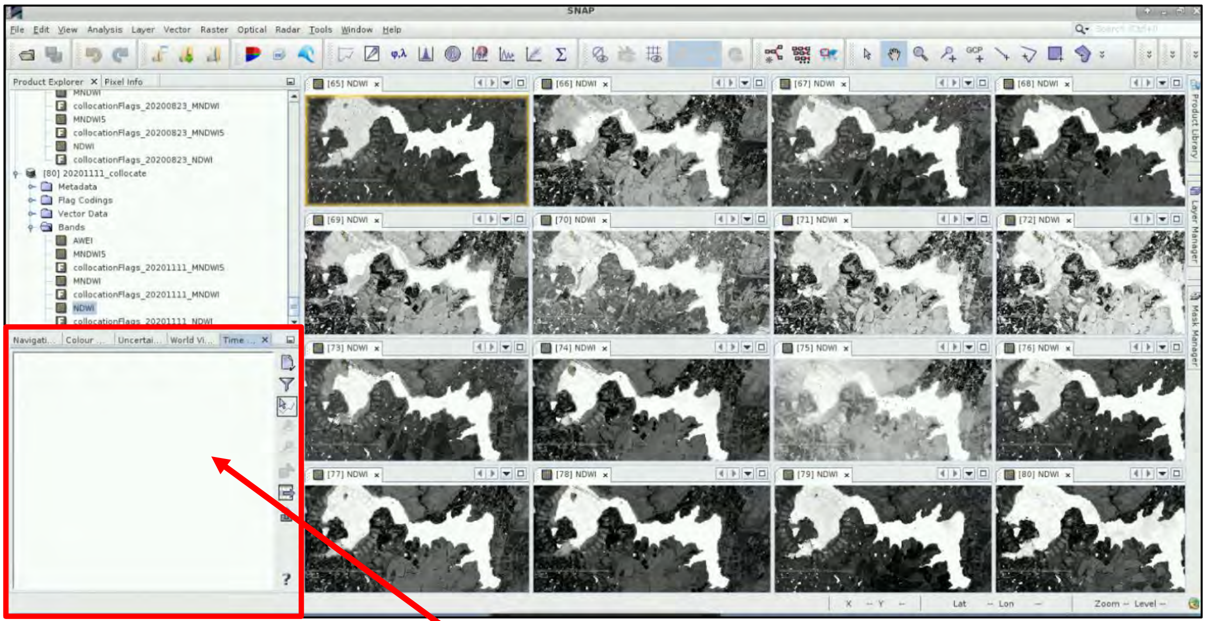
We can compare different water indices now in different period (for example in this case MNDWI5 index). We can observe how the water level changed between the 2016 (April) and in the image from 2018 (March) when the drought had its peak and finally we will compare with the image from 2020 (February).



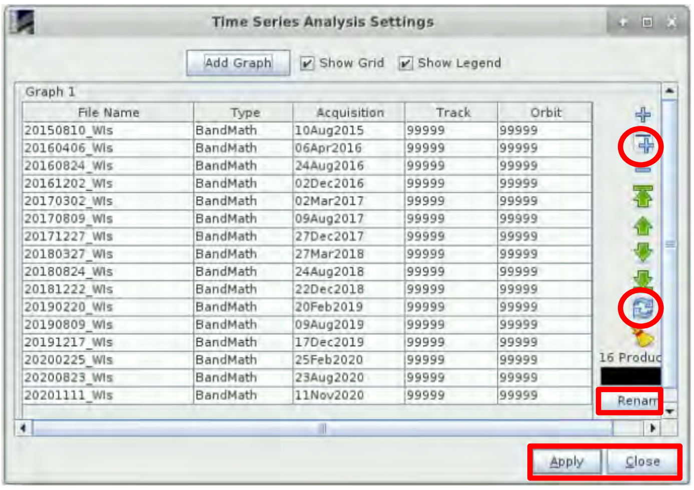
SNAP offers a time series analysis tools suitable to represent temporal evolution and improve monitoring activities. In order to be able to compare the images they were produced in batch processing in a way that they all have common naming convention (sensing date_WIs).



Expand each product and open the *Bands* folder. Double click for example on the *NDWI* band of all 16 products [1]-[16] to visualize the NDWI values in each date (wet and dry seasons). Then go to **Window -> Tile Evenly** to synchronize all views.

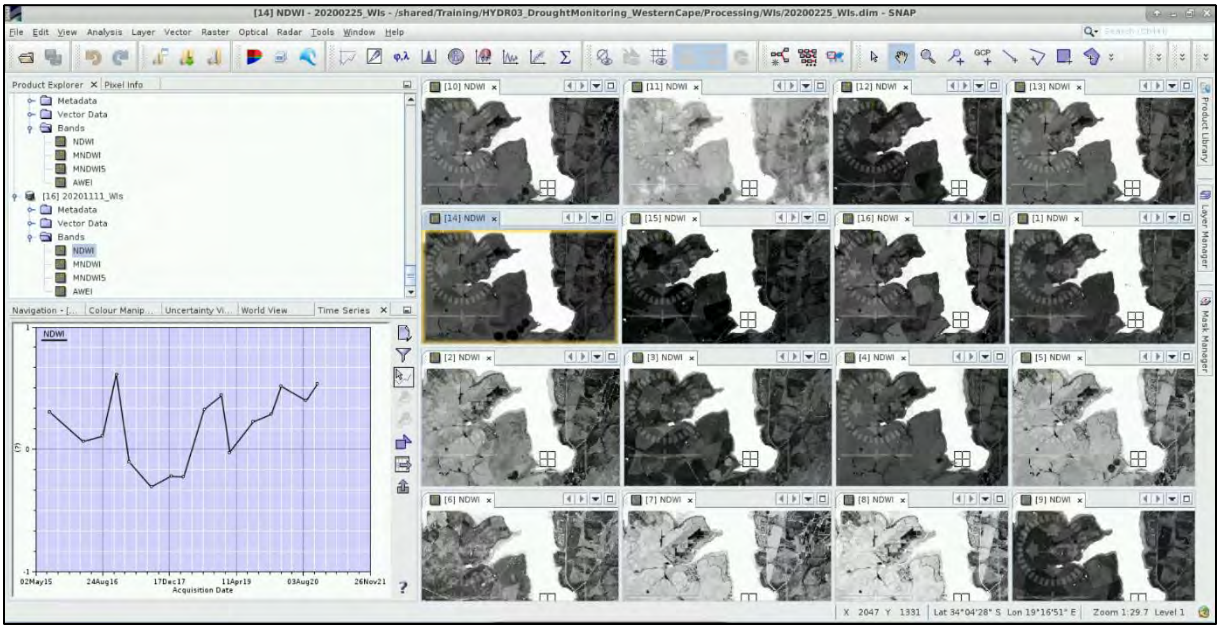


Click on the Time Series Analysis button on the main toolbar to open the toolview. In the panel below the **Product Explorer** next to **World View** new tab will appear (as indicated above). In the **Time Series Analysis** window, press the button to configure your graph and press the icon to add all the open products in SNAP to the time series analysis. Press the refresh icon ( ), rename the graph to **NDWI**. Then, click **Apply** and **Close.**

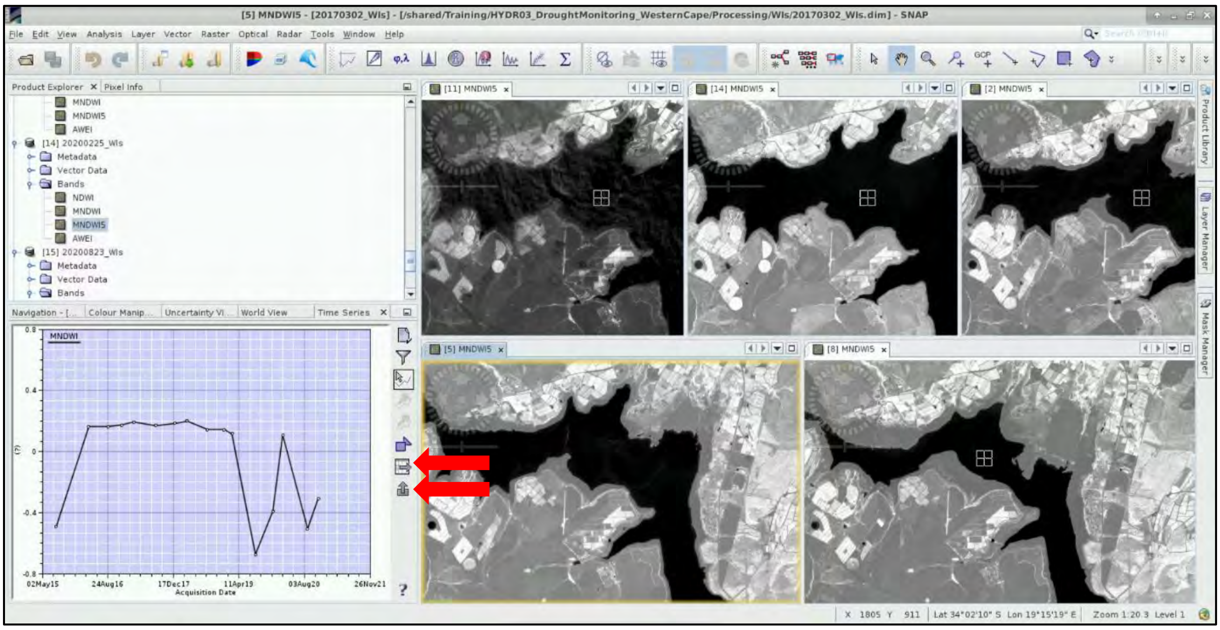


File Name	Type	Acquisition	Track	Orbit
20150810_Wis	BandMath	10Aug2015	99999	99999
20160406_Wis	BandMath	06Apr2016	99999	99999
20160824_Wis	BandMath	24Aug2016	99999	99999
20161202_Wis	BandMath	02Dec2016	99999	99999
20170302_Wis	BandMath	02Mar2017	99999	99999
20170809_Wis	BandMath	09Aug2017	99999	99999
20171227_Wis	BandMath	27Dec2017	99999	99999
20180327_Wis	BandMath	27Mar2018	99999	99999
20180824_Wis	BandMath	24Aug2018	99999	99999
20181222_Wis	BandMath	22Dec2018	99999	99999
20190220_Wis	BandMath	20Feb2019	99999	99999
20190809_Wis	BandMath	09Aug2019	99999	99999
20191217_Wis	BandMath	17Dec2019	99999	99999
20200225_Wis	BandMath	25Feb2020	99999	99999
20200823_Wis	BandMath	23Aug2020	99999	99999
20201111_Wis	BandMath	11Nov2020	99999	99999

Now click on the **Filter Bands** ( ) of the **Time Series Analysis** tool. In the pop-up window select *NDWI* and click **Ok.** Make sure you select also icon to see the select band values in the position of your cursor. You can see the evolution of the NDWI values of each pixel in the graph, labeled with the year and month. Move to the area in the southern part of the dam and inspect that we can clearly see the differences in water radiometric indices values.



You can clearly see the seasonality of the NDWI values over different period (wet and dry season). You can also conclude that in the period between late 2016 and until the beginning of 2018 there has been very low NDWI value over the selected area. It suits to the period of the worst drought in this area. Moreover this image gives you also an idea of the pixel values over the water areas (generally the water area is indicated by the NDWI values > 0. We can see that in the period of drought this value In this exact position of cursor dropped to value below 0 which indicates that this pixel was not recognized anymore as water but as non-water area in indicated period. If you want to export the graph, you can do it as a text file (.csv) or as an image. Use the dedicated buttons in the lower right corner of the **Time Series Analysis Tool** ( and ). You can investigate in the same way all other indices. You can find below Time Series graph of MNDWI +5 band which assigns values >0 to non-water areas, water is represented in this case in values 0<. What is important is that again we can see very clearly here the drought period which corresponds to known period of drought in this region.



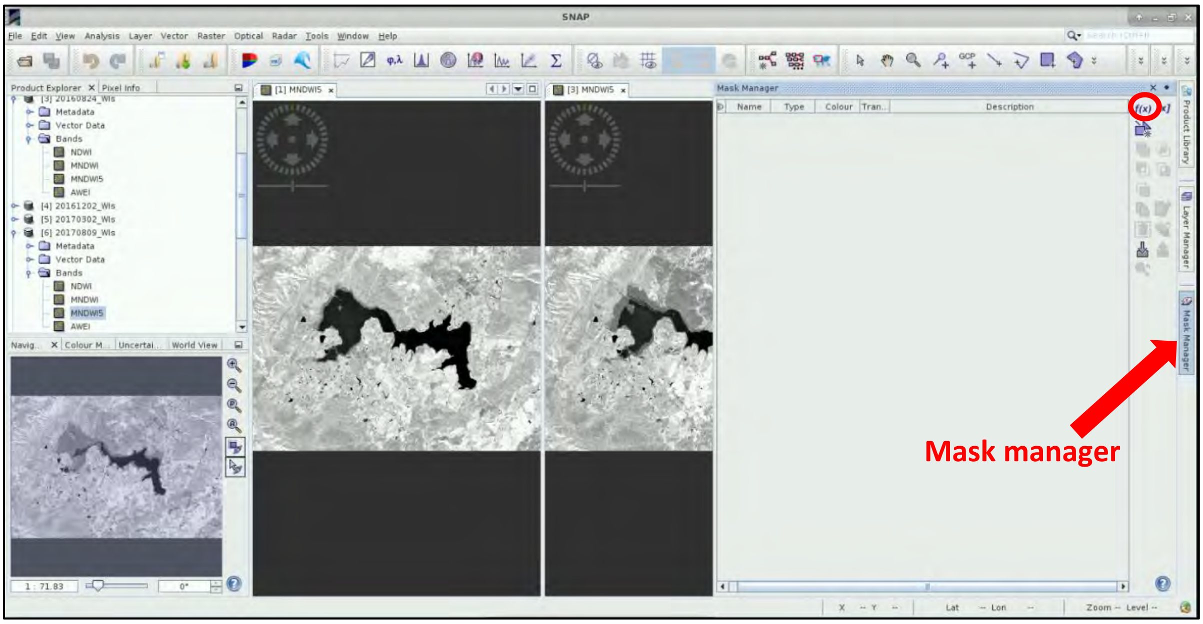
5.7 STEP 4 | Water area and water mask

The second objective of this training is to explore the differences in the extent of water during the drought period.

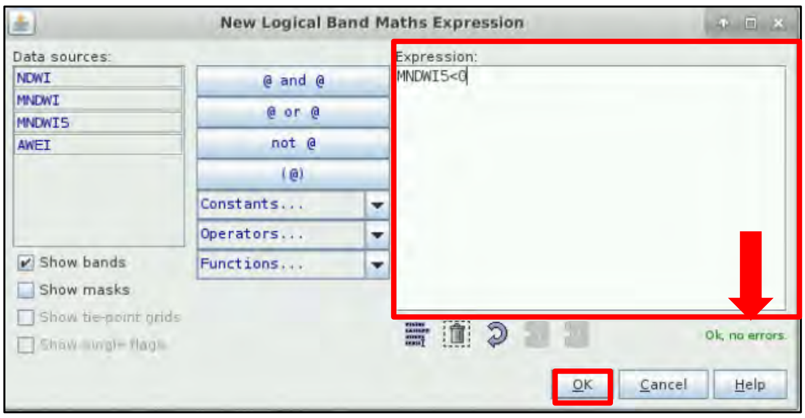
The surface water pixels generally appear much brighter than other surfaces (apart from the pixel values derived from MNDWI+5 water index). We will merge now information coming from all 4 Sentinel-2 derived water radiometric indices (NDWI, MNDWI, MNDWI+5 and AWEI) to create a new band for each acquisition date that will contain only water surfaces.

For this purpose we will use a **threshold value** for pixel to be classified as water. For the NDWI, MNDWI and AWEI bands the threshold will be equal to **>=0** but in case of pixel values derived from the MNDWI+5 index pixels with values **below 0** so **(<=0)** represent water surface. First of all simple method to extract the information on water area in different period of time will be presented here. For this purpose we will compare the water area changes in wet season. First open the **MNDWI+5 band** from 3 products: *[1]20150810_WIs*, *[3]20160824_Wis* and [6]*20170809*_WIs by double click on that band.

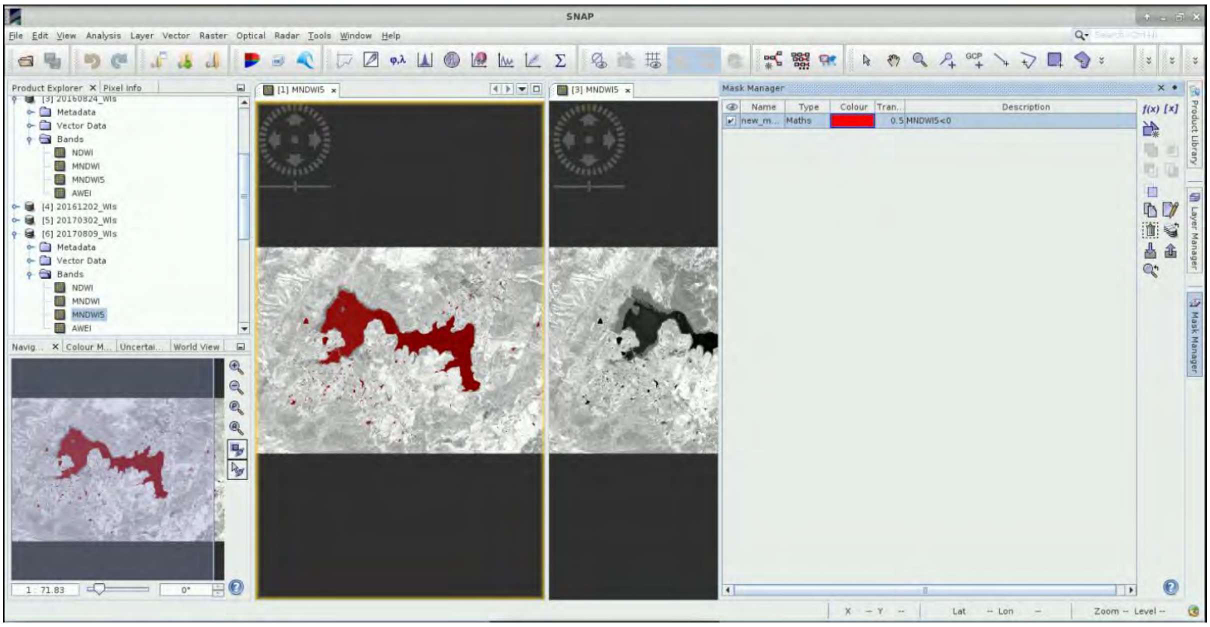
Then go to **Window -> Tile Horizontaly.** In *Navigation* click on the icon to see the whole area of all products. Then in the panel with tools on the right go to **Mask Manager** Tool.



Here we will create a virtual mask, which will separate water surface in all three images. We will create the mask based on the logical band math expression. To create the first mask click on the icon *f(x)*



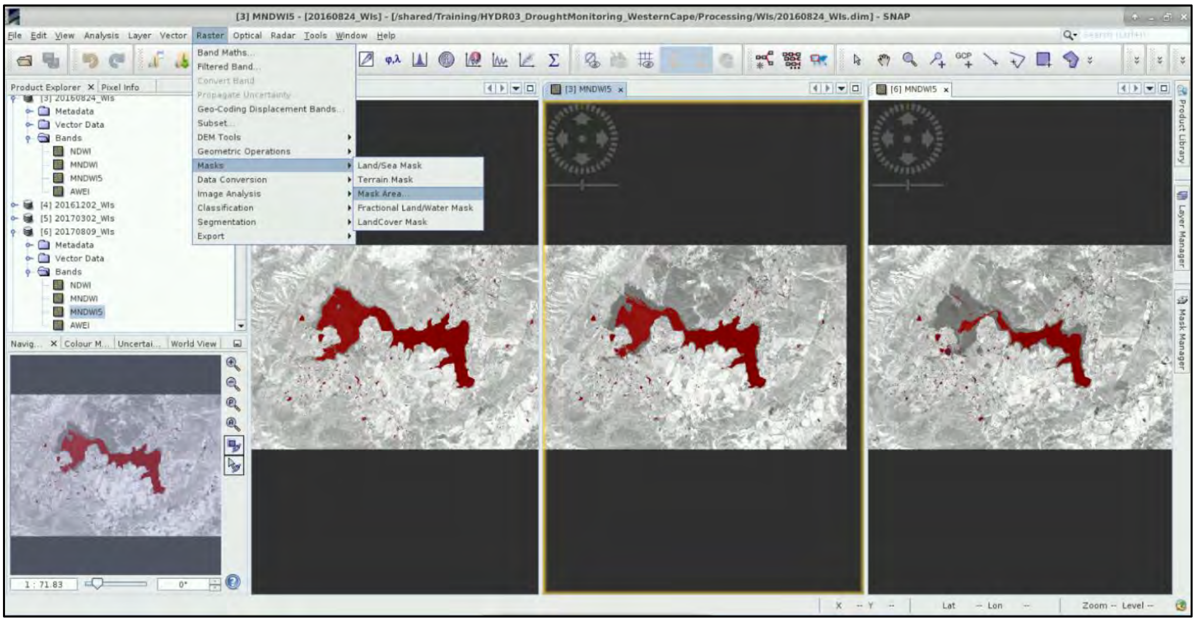
New window will open. Then you should see a list of four water indices bands stored in collocated product. In the *Expression* window type: ***MNDWI5<0.*** Like this we can select only water pixels. Save the equation by clicking **OK.**



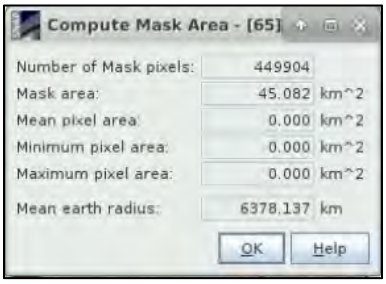
You will see that new mask has been created in **Mask Manager.** It is also overlaid over the image from 2015-08-10. Repeat the same steps for other 2 displayed products.

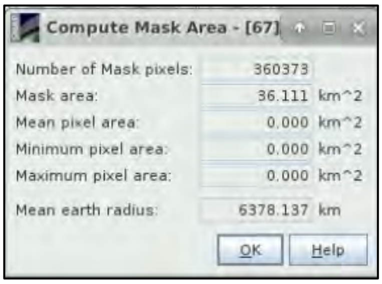
SNAP offers also a possibility to calculate the area of the mask. Because in this case the mask indicates the dam area only, we can use this option to see changes in the extent of this water body during the drought period. We will compare the area of the dam from before the drought (2015) in wet season with water extent from 2016 and 2017 also during the wet season (August).

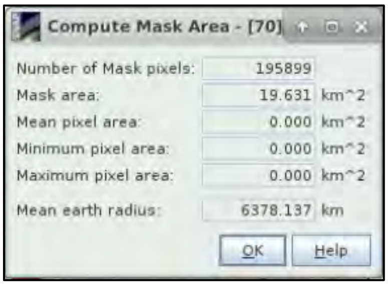
Select the first view of the image from 2015. To display the mask area navigate to main toolbar on the top of SNAP window. Go to **Raster -> Mask -> Mask area**



In the new window you will see the area of the mask (water) displayed in km^2. The area of the mask is calculated based on the number of pixels which fall within created mask. Repeat the same steps for other 2 products. Then you can compare the how the water area dropped significantly over two years. What is important is that these changes are visible during the wet season. Later we will assess the changes during all time period including images from dry season as well.





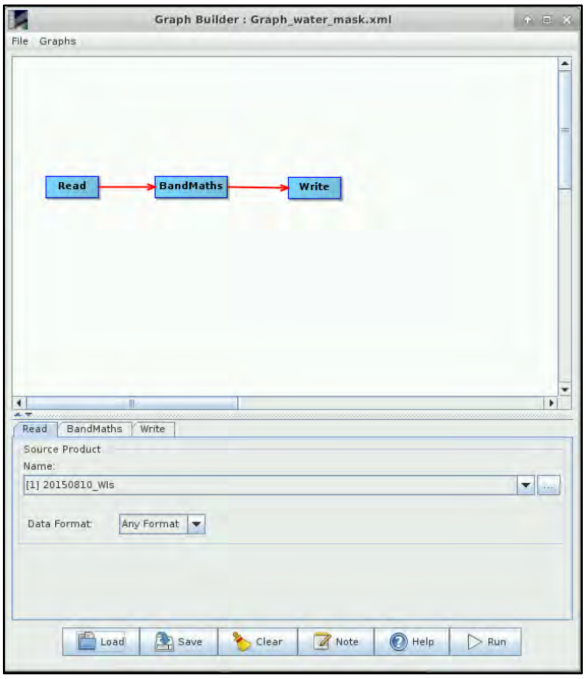


To close this window press **Ok.**

One important drawback of this mask area method in SNAP is that you cannot store the water mask area and you cannot calculate it for several images at once to compare such mask area. That is why in **Extra steps** part of this tutorial you will see how to perform such area analysis in **QGIS**.

Because we want to see the dynamics in water extent during the drought period and compare it with the water extent after the drought we will use **Batch Processing** again. For this we need to first create a new simple graph in **Graph Builder** to be able to process all 16 images simultaneously. We will extract water pixels based on pixel values coming from all four water indices. With this method we will create again a new band that will only contain the water surface**.**

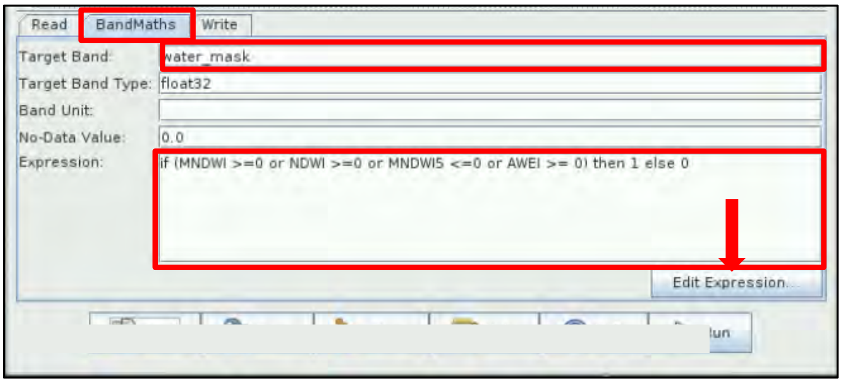
Now close the current views. Go to **Tools -> Graph Builder.** Add a **Band Math** operator, right click on it and select *Connect graph.*

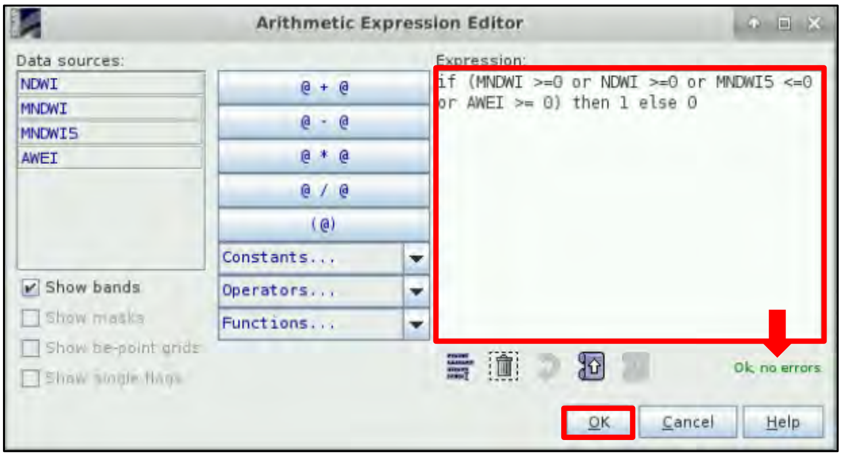


In **Read** operator leave everything as default.

Go to **Band Math** tab and copy and paste following condition statement (expression):

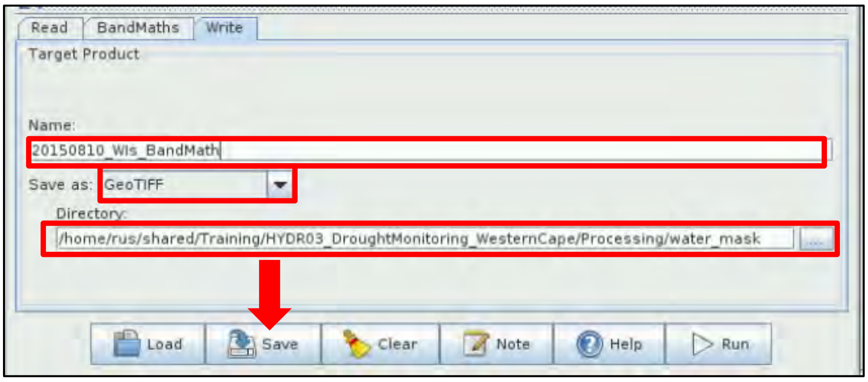
```
if (MNDWI>=0 or NDWI>=0 or MNDWI5<=0 or AWEI>=0) then 1 else 0
```





Under **Write** operator do not change anything in the name of the output product. Make sure that you select ***GeoTIFF*** as output file type. For your output set following *Directory*:

Path: ***/shared/Training/HYDR03_DroughtMonitoring_WesternCape/Processing/water_mask/***



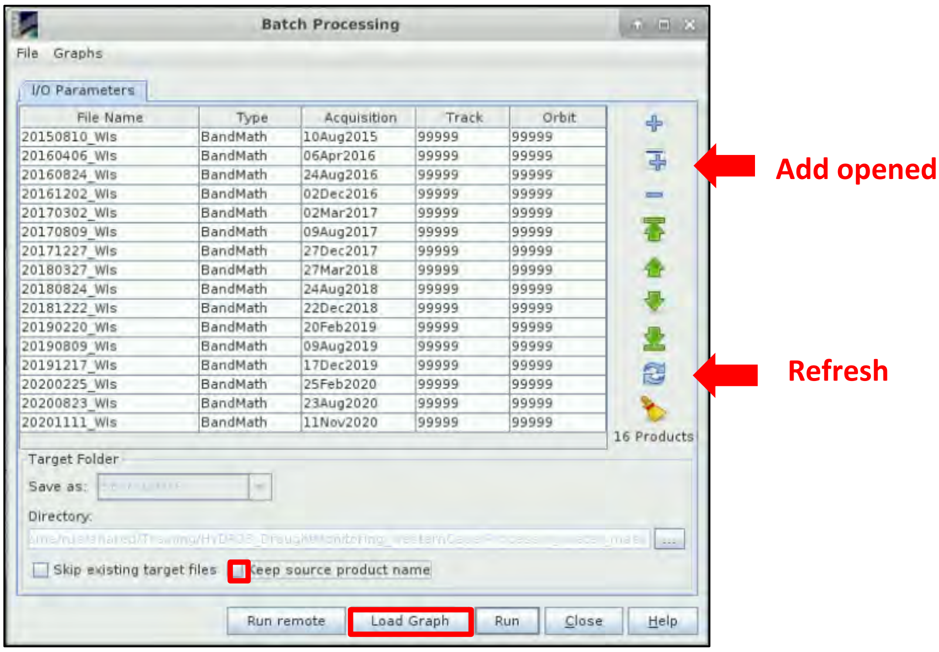
Once your graph is ready click **Save** and store the graph under the name: ***Graph_water_mask.xml.*** Store graph under following path:

/shared/Training/HYDR03_DroughtMonitoring_WesternCape/AuxData/

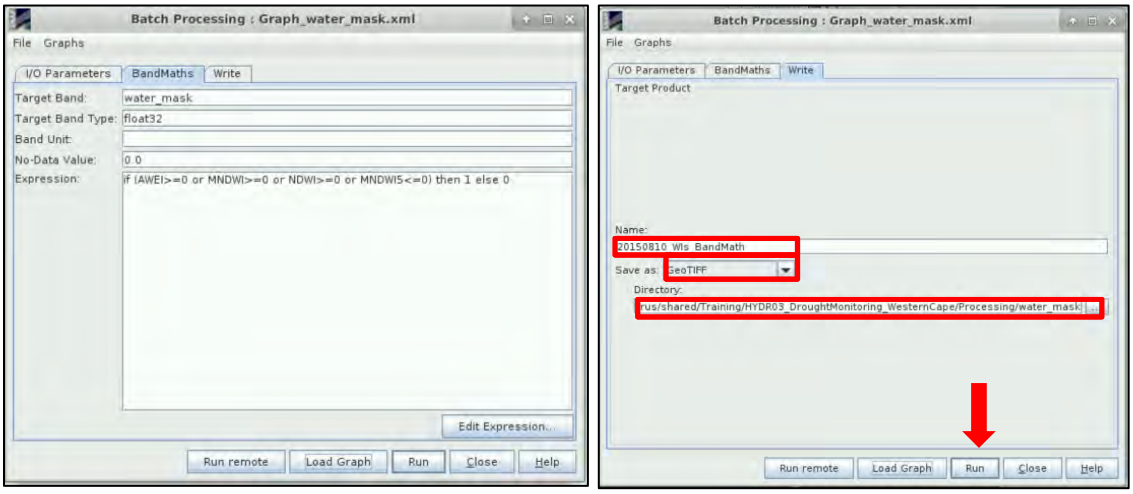
Now we can start process of extracting only water pixels from the collocated product using just created graph. Close **Graph Builder** tool. Go to **Tools -> Batch Processing.** In **I/O parameters** tab we will add all opened products from the **Product Explorer** window [1]-[16] by **Add Opened** on the upper right (second icon from the top) and then click **Refresh**  (second icon from the bottom). Like this we have loaded all 16 images from 2015-2020 of the same area. Then:

a) Deselect option *Keep source product name*

b) Click on **Load Graph** at the bottom of the window, and you should now navigate to saved ***Graph_water_mask.xml*** file and open it. We see that new tabs have appeared at the top window corresponding to our operators from pre-processing graph.

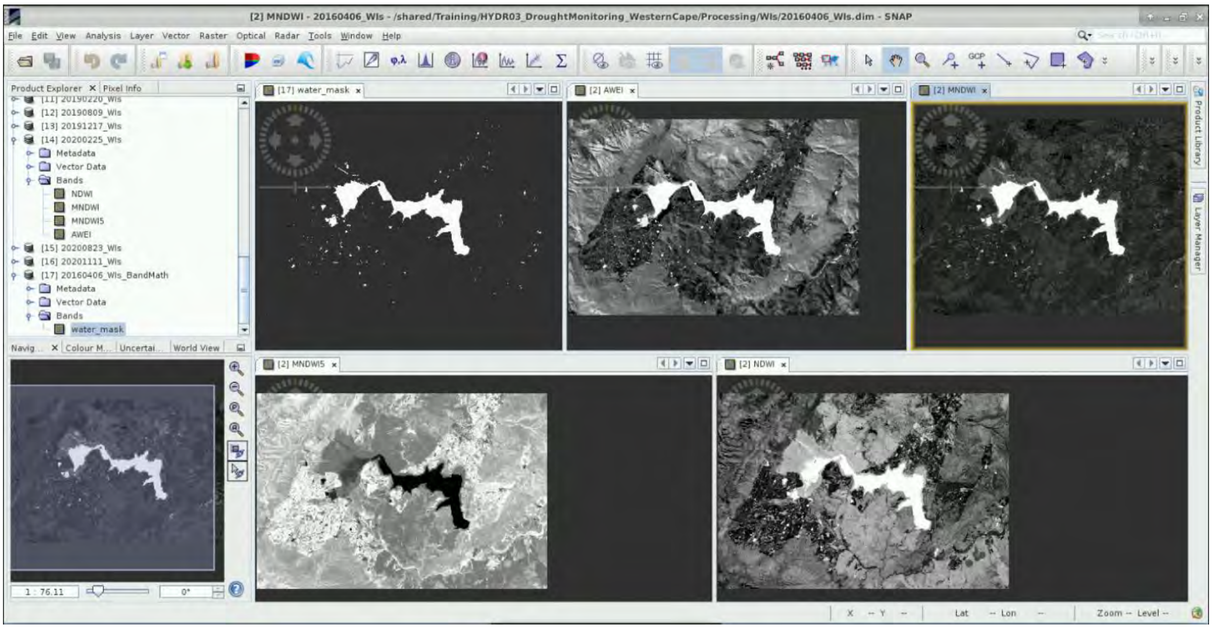


In **Band Math** tab do not change anything. In **Write** tab do not change the output product name. The suffix *"_BandMath"* will be added to all products. Make sure to save product as *GeoTIFF* file. Keep the previously set directory: ***/shared/Training/HYDR03_DroughtMonitoring_WesternCape/Procesing/ water_mask.*** Once Batch Processing parameters are ready click **Run.**



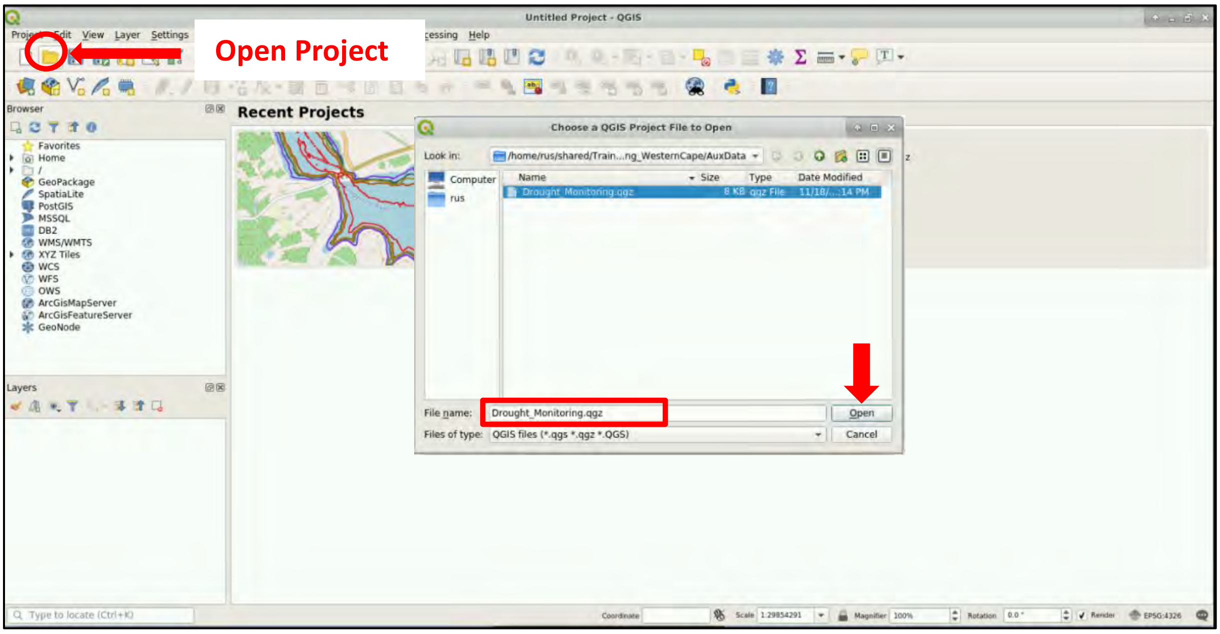
Processing will last about 1 minute.

After that we can visually compare the water mask generated with the combined threshold from different water radiometric indices with all water indices bands. Below you can see generated water mask (lower right corner) compared to bands of different water indices from 2015-08-10. You can see that this method gave satisfactory results.



5.8 *Visualization (QGIS) and comparison*

Let's compare now the extent of the Theewaterskloof dam over the years 2015-2020 to see the evolution of its area. Launch **QGIS Desktop** application. Double click on the icon in your Desktop. In the main window click on **Open Project.** Navigate to the path ***/shared/Training/HYDR03_DroughtMonitoring_WesternCape/AuxData/*** where QGIS project is stored. Click on the file named: *Drought_Monitoring.qgs* and open it.

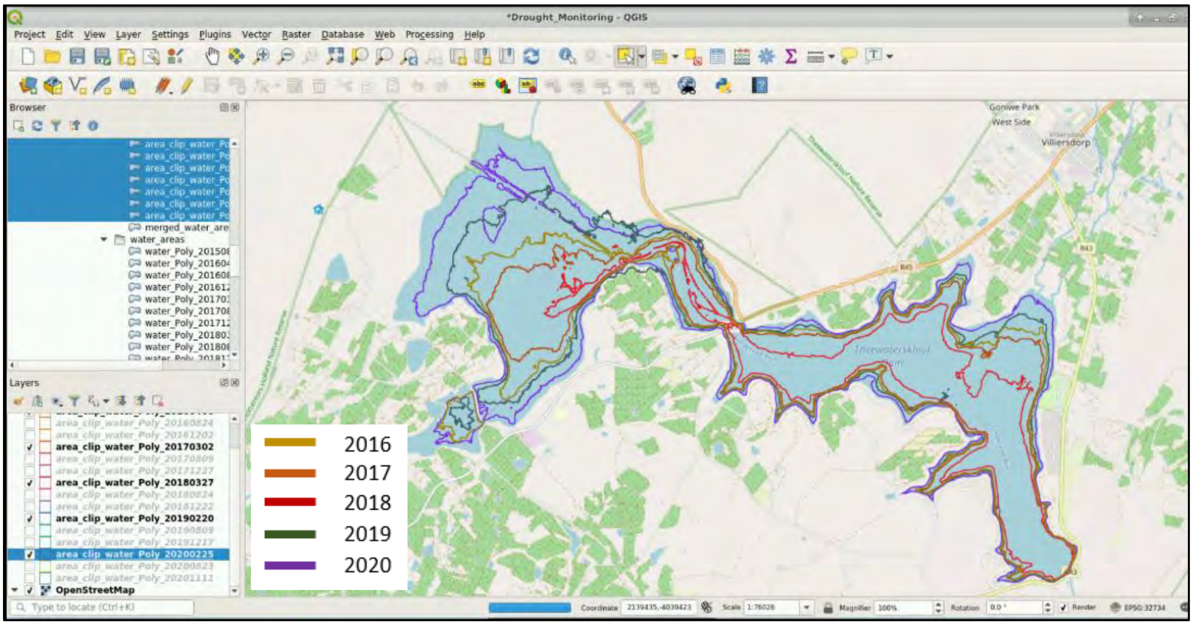


To create a visualization of the dynamics in the Theewaterskloof dam extent the water mask GeoTIFF files created in SNAP (chapter 5.6) were converted to polygons. Then the selection of water areas only was made based on the pixel values (=1) assigned to water surface in the mask. Then the area of all water surface polygons were calculated. All steps of this processing in QGIS is described in details in Extra Steps chapter (6.2).

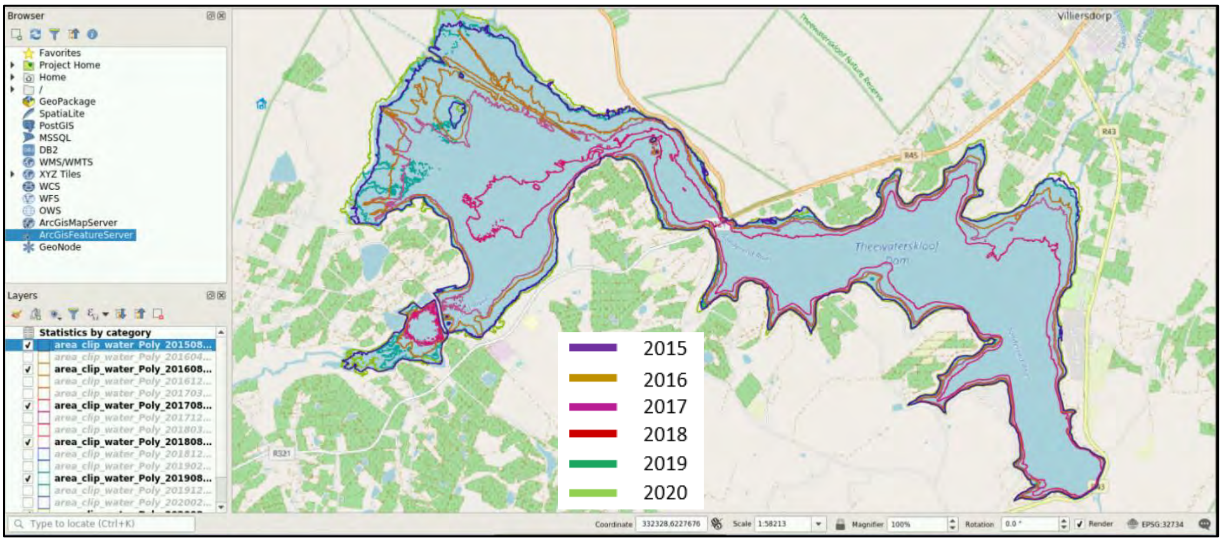
The final layers which are included in *Drought_Monitoring.qgs* QGIS project are stored in: ***/shared/Training/HYDR03_DroughtMonitoring_WesternCape/Processing/vectors/water_area_changes/*** folder.

To visualize the layers of the water extent right-click on the first polygon layer and select ***Zoom to layer***.

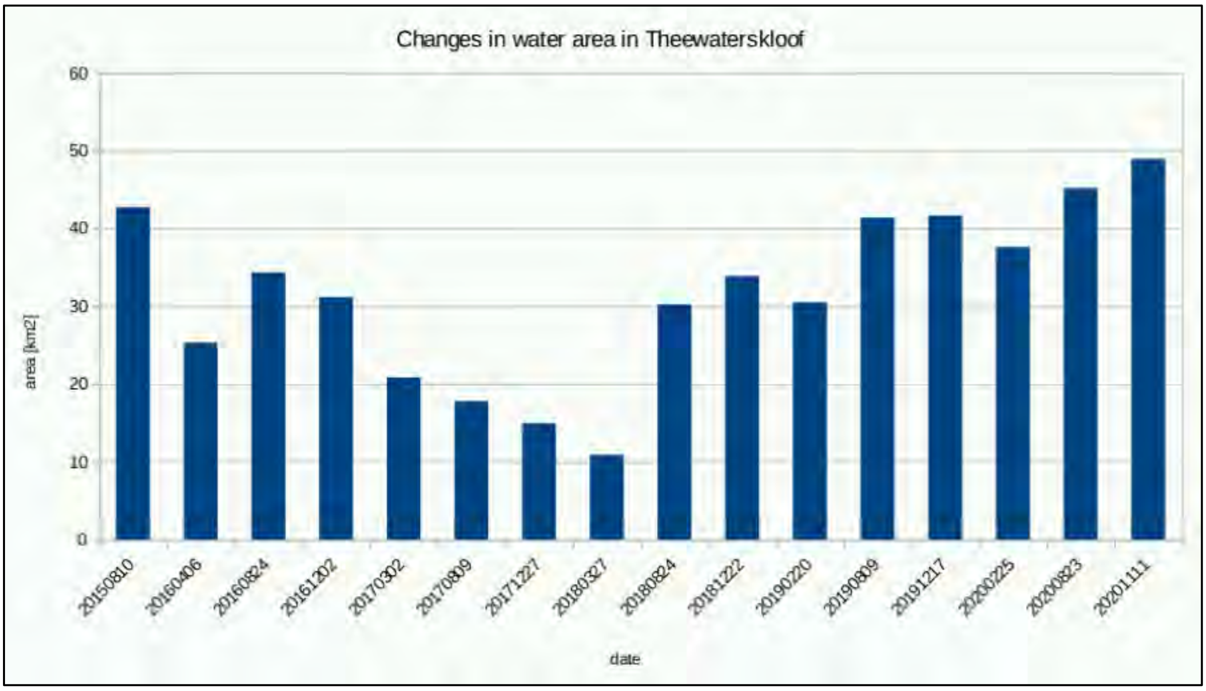
You should be able to see following visualization. Visualization below shows the dynamics in dam extent in dry period from 2016 till 2020.



You can also explore how the dam changed its shape during the wet season when you compare the images from August for all dates. We can see that the dam came back to the original shape in 2020.



Moreover the area of the dam in each 3-4 months period from 2015-2020 was calculated in QGIS. Chart below represents changes in the water surface area, indicating seasonal variations but also the drought period from 2016-2018. Water area from about 42 km2 in 2015 shrunk into about 11 km2 in 2018. We can see also that in 2020 the water area came back to its previous shape. Monitoring seasonal changes in the water level and consecutively also in water area is important in case of the crisis such as the one in 2018 when the Cape Town area almost run out of water for their citizens.



6 Extra steps

6.1 Atmospheric correction

The "Level 1C" data we have downloaded are radiometrically and geometrically corrected (including orthorectification and spatial registration). However, atmospheric correction is applied only to the Level 2A data which are not available for our study site at this time.

> TIP 1: Level 2A have been systematically produced for newly acquired products over Europe since the spring of 2017, the coverage has been increasing through 2018 to reach global coverage in the beginning of 2019.

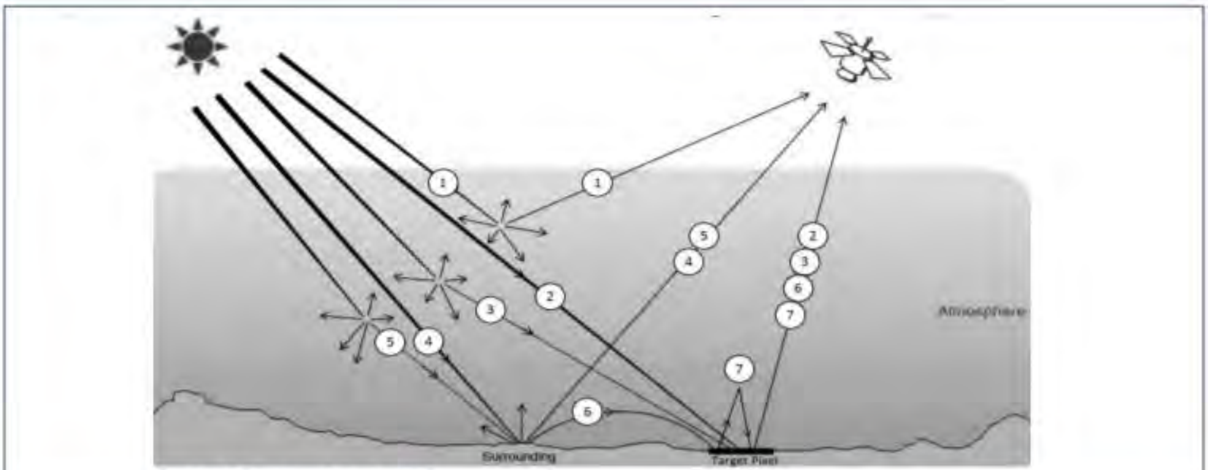
Solar radiation reflected by the Earth's surface to satellite sensors is affected by its interaction with the atmosphere. The objective of applying an atmospheric correction is to determine true surface (Bottom-Of-Atmosphere, BOA) reflectance values from the Top-Of-Atmosphere (TOA) reflectance values, by removing atmospheric effects. (See NOTE 12) Atmospheric correction is especially important in cases where multi-temporal images are compared and analysed as it is in our case.[1]

In this tutorial, we will use the Sen2Cor processor. Sen2Cor is a processor for Sentinel-2 Level 2A product generation and formatting; it performs the atmospheric, terrain and cirrus correction of TopOf-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 12: : 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.

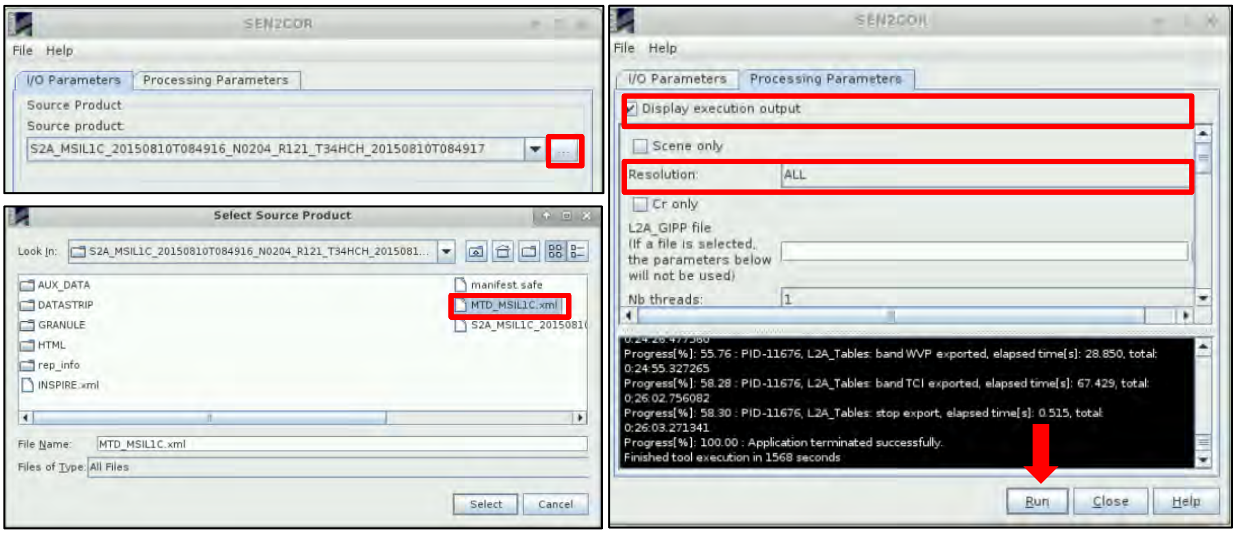
4. & 5. Direct or diffuse radiation reflected or scattered by the surrounding areas into the field of view of the sensor. This effect is so called "adjacency effect" or "blurring effect".
6. Diffuse radiation coming from the adjacent features into the field of view of the sensor.
7. So-called trapping 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]

Go to **Optical → Thematic Land Processing → Sen2Cor and select Sen2Cor280.**

In the **I/O Parameters** tab, click on "…" next to the product name and navigate to the **Original** folder. Open the **".SAFE"** folder of the 2015 product first. Then open the **MTD_MSIL1C.xml** file. In the **Processing Parameters** tab change the resolution to **"ALL"** and select **"Display execution output".** Click **Run.**



This is rather a time demanding process and requires approximately 30 minutes per image (with 30GB RAM). Unfortunately, you need to repeat the same steps for other products as well. So the same procedure should be applied to products [2]-[16]. Close **Sen2Cor** window when all processing is completed.

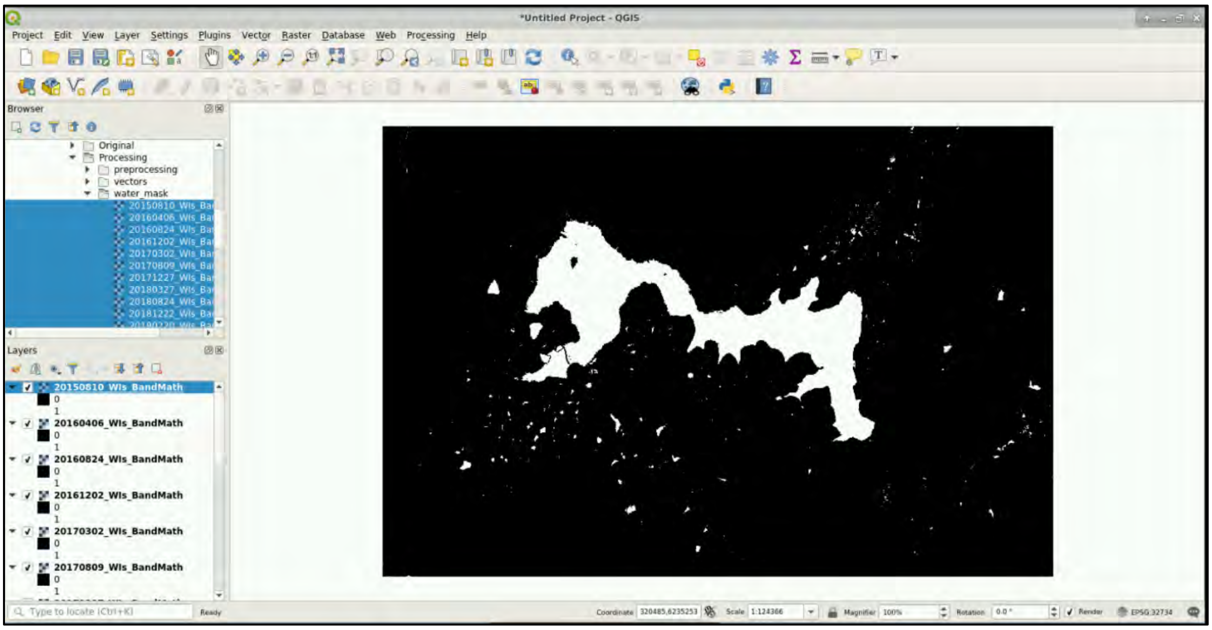
You will see three new products created at the **Product Explorer** window, named **“Output Product”.** Select them all, right click on them and select **“Close All Products”.** Click **“No”** to the following windows that will appear.

This process creates three new Level 2-A products in the **.SAFE** format in the ***Original*** folder. Move them to: ***/shared/Training/HYDR03_DroughtMonitoring_WesternCape/Original/Level-2A.***

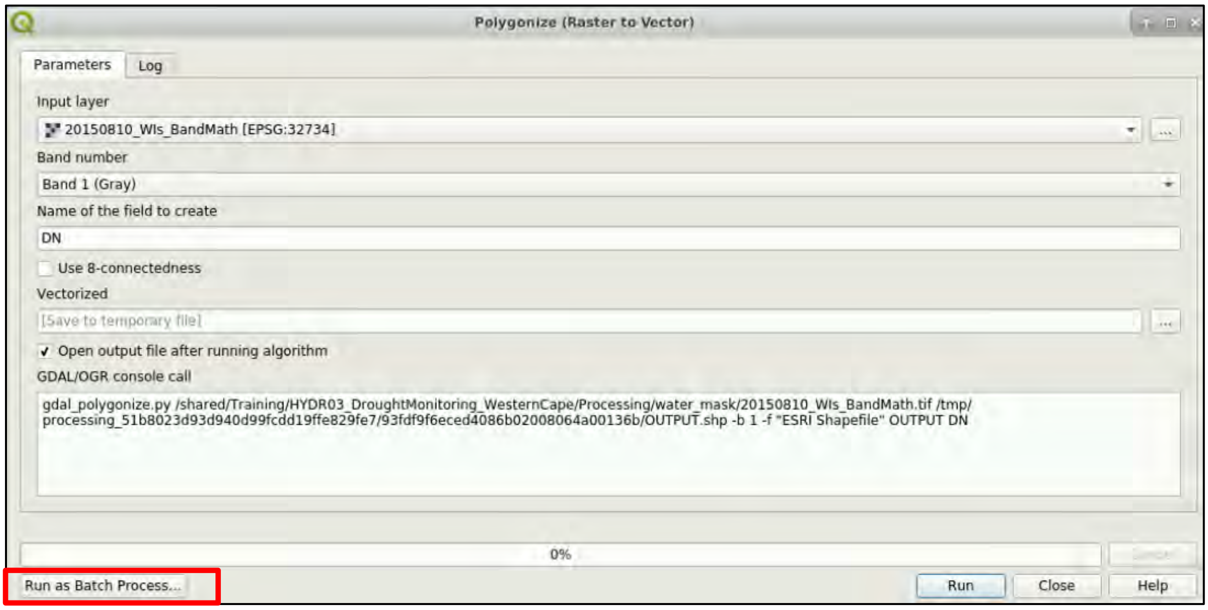
6.2 *Calculate the drought area in QGIS*

Due to the fact that SNAP software does not offer possibility to extract water area based on the water mask pixels in an automatic way for all 16 bands. This process was added to Extra steps in this tutorial and will be performed in QGIS.

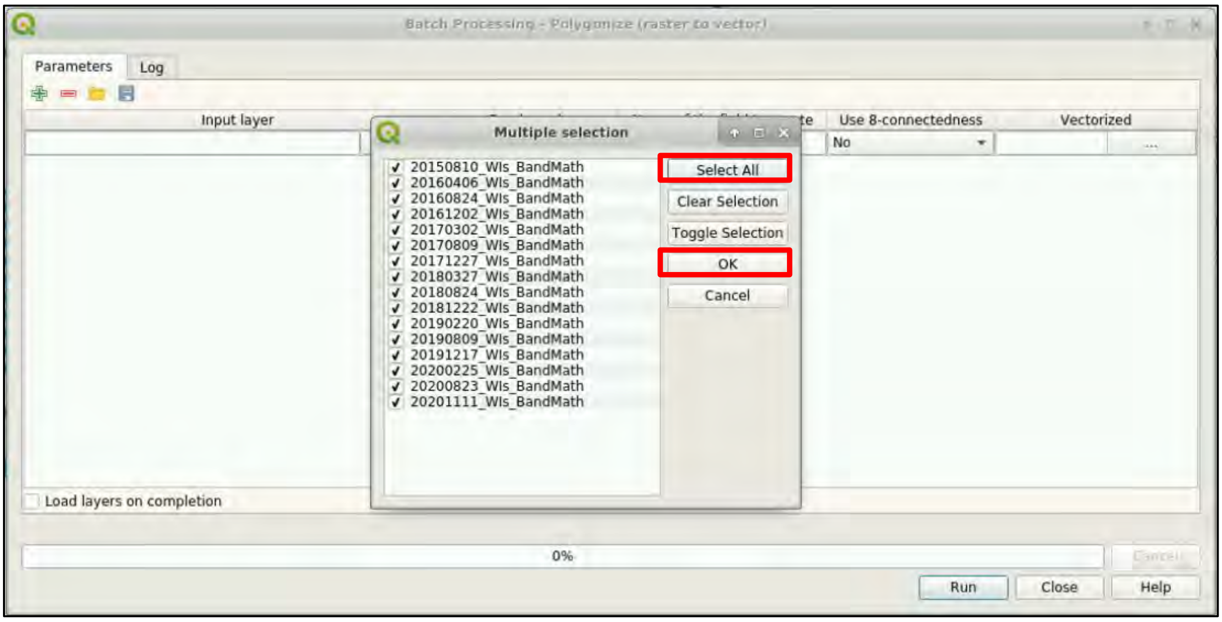
In order to process the data Open **QGIS Desktop** application. Double click on the icon in your Desktop. In the main window select icon ***New Project.*** In the panel **Browser** navigate to .tiff water masks exported from SNAP in a final step of this exercise. Navigate to the path: ***/shared/Training/HYDR03_DroughtMonitoring_WesternCape/Processing/water_masks/*** select all 16 rasters and drag and drop to the **Layers** panel below.

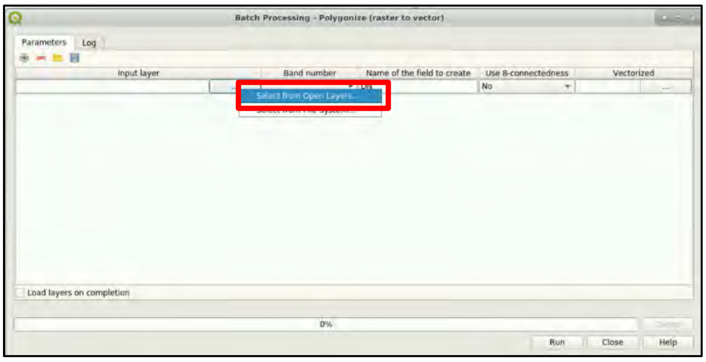


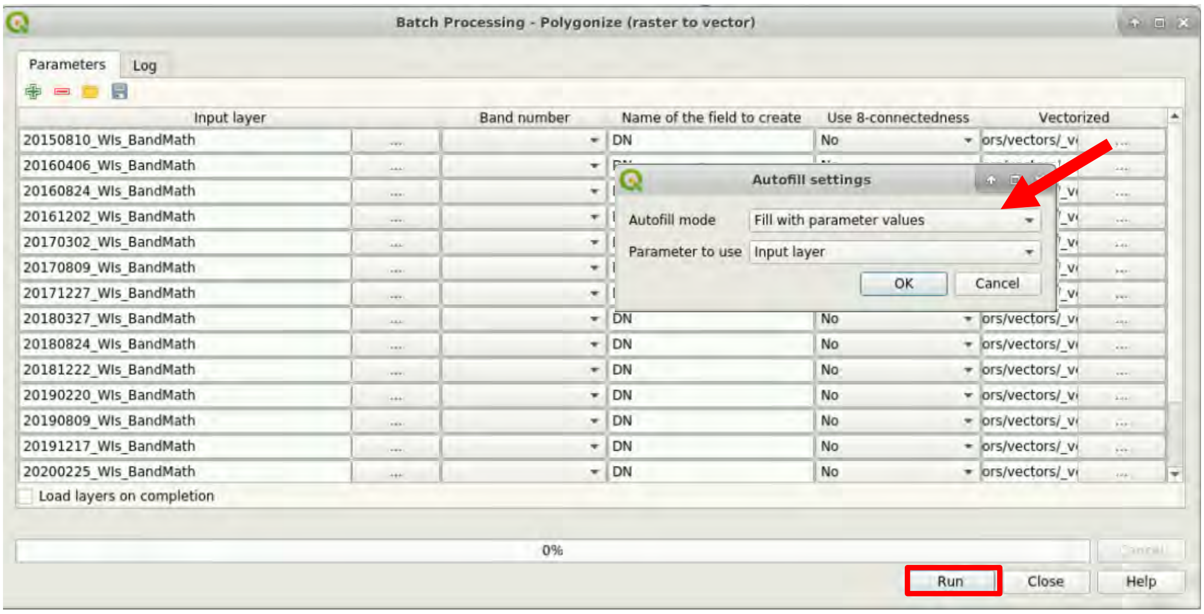
Now in order to extract the area of the dam we will need to convert raster files to vector format. To do that we will use batch processing tool in QGIS. First open **Processing Toolbox**. It should be a panel on the right. If you do not see it, in main menu bar go to **View -> Panels -> Processing Toolbox.** Now the panel on the right side of QGIS application should appear. In *Search* window write *“Polygonize”* and select tool **Polygonize (raster to vector).** Double click on this tool and new window will open.



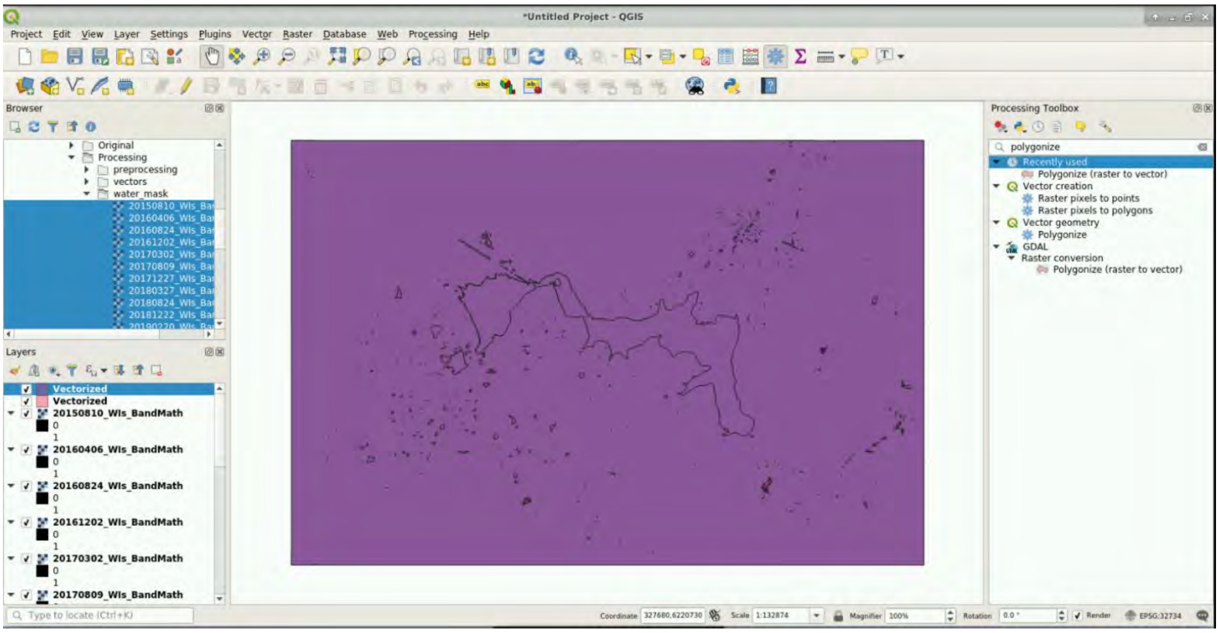
You can perform this step in Batch Processing too in QGIS (note that for this you need to make sure that your QGIS application is up to date, sometimes when new updates are not installed this processing in batch mode will not function).







If you want to run vectorization only on one image in the tool window select just the image you want to vectorize, go to *Vectorized* box and select directory where your product should be saved. Click **Run** to launch the process. Your vectorized layer should looks like below:



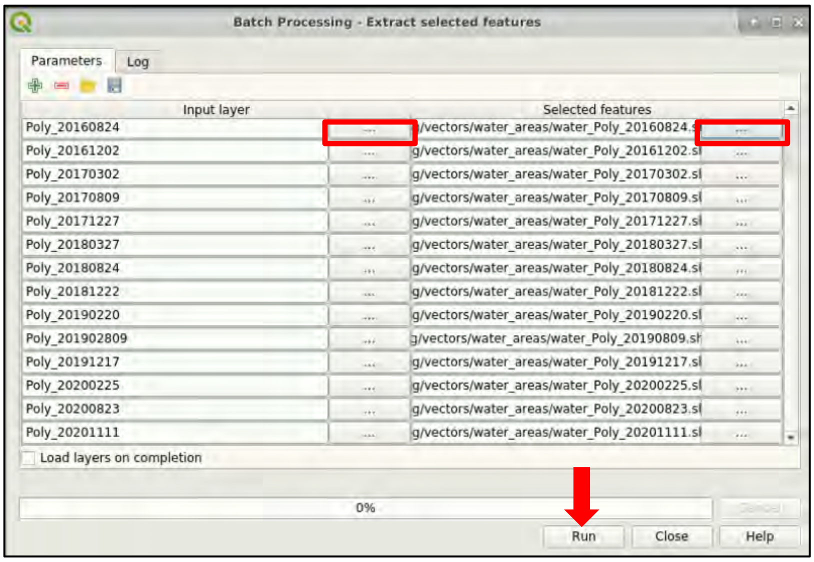
As a result you will receive a polygon layer which will be automatically opened in **Layers panel**. Open attribute table of the polygon (*Vectorized*). Right-click on it in and select ***Open Attribute table.*** You will see that the attribute table contains only one column "DN" and has two classes. In geotiff raster values = 1 corresponded to water pixels.

So next step will be to select water area from the whole vector file. Go to **Processing Toolbox** again and open tool **"Select by attribute".** In *Input Layer* select your polygon you want to process. Then in the *Selection attribute* leave "DN" column. In *Operator* select "=" and in the window *Value* type **1.** In this way you will select only water polygons. Click **Run.**

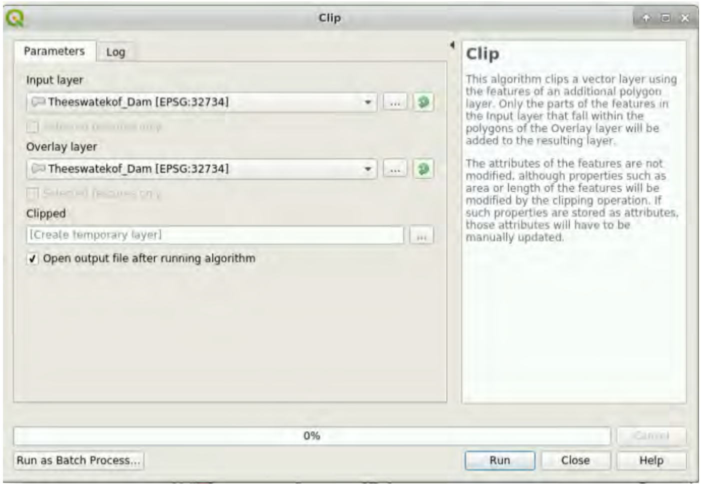
Once the water are selected you will see them highlighted in yellow in QGIS when you go to your polygon layer. Then we should extract selected features to have only the water area.

Go again to **Processing Toolbox** and select tool **Extract selected features.**

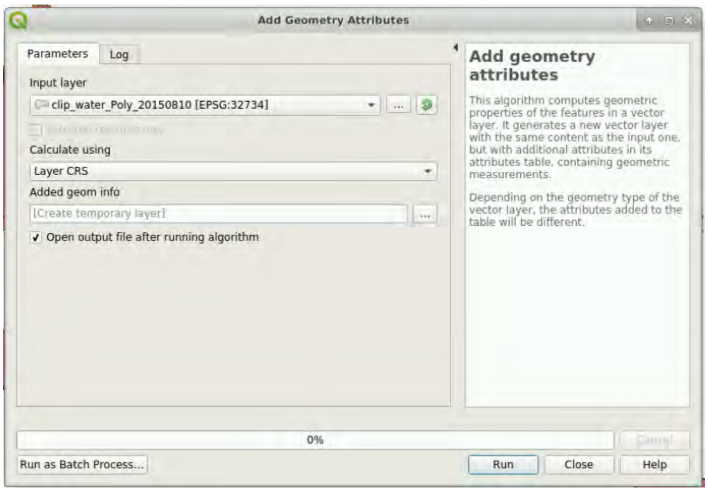
In a new window which appear you can also process the images in **Batch mode.** Click on the button **Run as Batch Process.** In **Input layer** click on the button next "…" and choose option "Select Open Layers" there click on the option "Select all" and click Ok. Next to the column **Selected features** change assign the output path. Navigate to the folder you want to store your data and select shapefile as a file type. In the small window **Autofill settings** select option "*Fill with parameter values*" . In the *Parameter to use option* leave *Input layer.* Click **Run.**



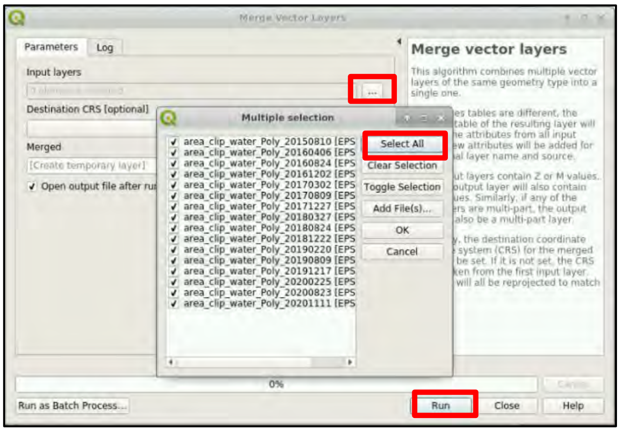
If you would like to calculate the area of the dam more precisely without having other polygons outside of the dam which have been classified as water (due to noise or other parameters) then you can use the layer named: *ThewaterskloofDam.shp* stored in */AuxData/* folder to clip your all selected polygons. This can also be run in a Batch Process in QGIS. To do this go to **Vector -- > Geoprocessing Tools -- > Clip.** As Input layer select the polygon layer you want to clip. In the option *Overlay* layer select the layer with the extent to which you want to clip your polygon file (*ThewaterskloofDam.shp).* You can also create a buffer of the original dam layer (of for example 30m and then use it to clip your polygons).



As a next step we will calculate the area of each water layer in 16 polygon shapefiles. For this go to Processing Toolbox and select tool **Add geometry attributes.** You can also run it as batch process which will speed up calculations. As input layers select clipped layers of the water areas from all dates.

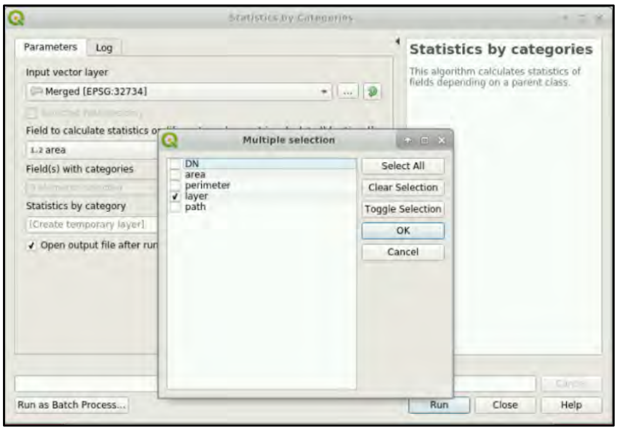


Because we would like to see the changes in the water area in all polygon layers we need to merge all the layers now into one shapefile. Go to Processing Toolbox and select tool **Merge vector layers.** In the box *Input layers* select all the layers with the geometry (area and perimeter of the polygon information). Save the file to your directory and click **Run**.

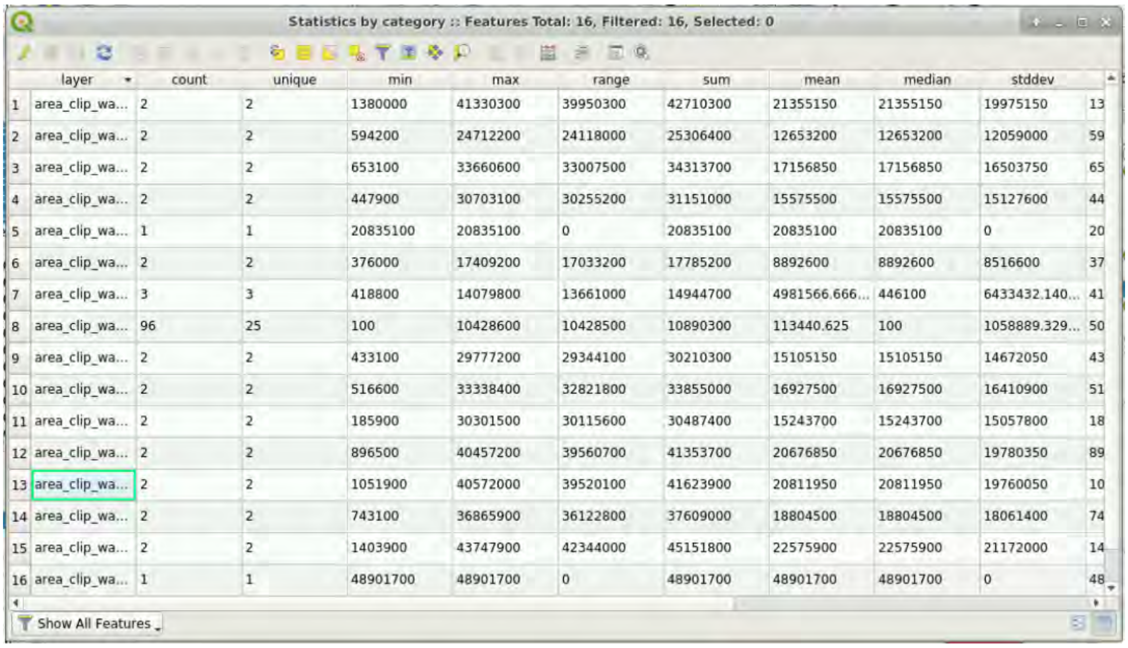


Now finally we can assess complete information on the evolution of the extent of the dam.

Go to the last tool you will use in QGIS for this training. Navigate to Processing Toolbox and choose tool **Statistics by categories.** In Input vector layer place Merged polygon. In the field *Field to calculate statistics* select **"area"** field. In the field *Field(s) with categories* select "layer" (as shown below) click Ok. Save the file in .csv format. Click **Run.** At the end you will receive a table with the area of the dam summarized by the name of the layer which indicates the exact sensing date.



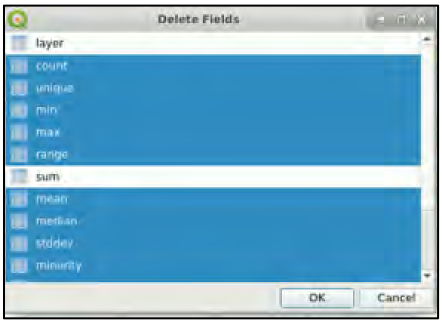
The output of this calculation should looks as below:

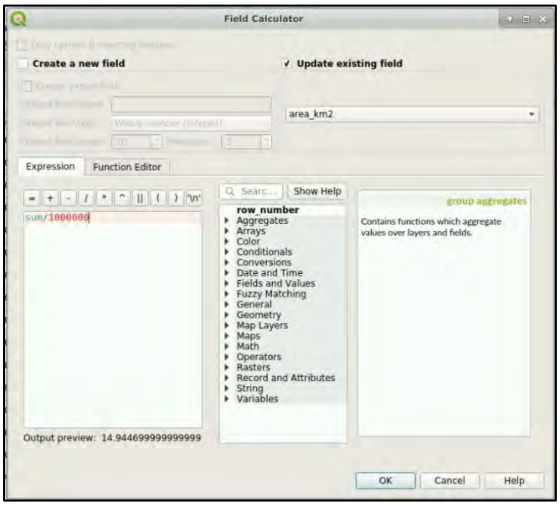

Statistics by category :: Features Total: 16, Filtered: 16, Selected: 0

	layer	count	unique	min	max	range	sum	mean	median	stddev	
1	area_clip_wa...	2	2	1380000	41330300	39950300	42710300	21355150	21355150	19975150	13
2	area_clip_wa...	2	2	594200	24712200	24118000	25306400	12653200	12653200	12059000	59
3	area_clip_wa...	2	2	653100	33660600	33007500	34313700	17156850	17156850	16503750	65
4	area_clip_wa...	2	2	447900	30703100	30255200	31151000	15575500	15575500	15127600	44
5	area_clip_wa...	1	1	20835100	20835100	0	20835100	20835100	20835100	0	20
6	area_clip_wa...	2	2	376000	17409200	17033200	17785200	8892600	8892600	8516600	37
7	area_clip_wa...	3	3	418800	14079800	13661000	14944700	4981566.666...	446100	6433432.140...	41
8	area_clip_wa...	96	25	100	10428600	10428500	10890300	113440.625	100	1058889.329...	50
9	area_clip_wa...	2	2	433100	29777200	29344100	30210300	15105150	15105150	14672050	43
10	area_clip_wa...	2	2	516600	33338400	32821800	33855000	16927500	16927500	16410900	51
11	area_clip_wa...	2	2	185900	30301500	30115600	30487400	15243700	15243700	15057800	18
12	area_clip_wa...	2	2	896500	40457200	39560700	41353700	20676850	20676850	19780350	89
13	area_clip_wa...	2	2	1051900	40572000	39520100	41623900	20811950	20811950	19760050	10
14	area_clip_wa...	2	2	743100	36865900	36122800	37609000	18804500	18804500	18061400	74
15	area_clip_wa...	2	2	1403900	43747900	42344000	45151800	22575900	22575900	21172000	14
16	area_clip_wa...	1	1	48901700	48901700	0	48901700	48901700	48901700	0	48

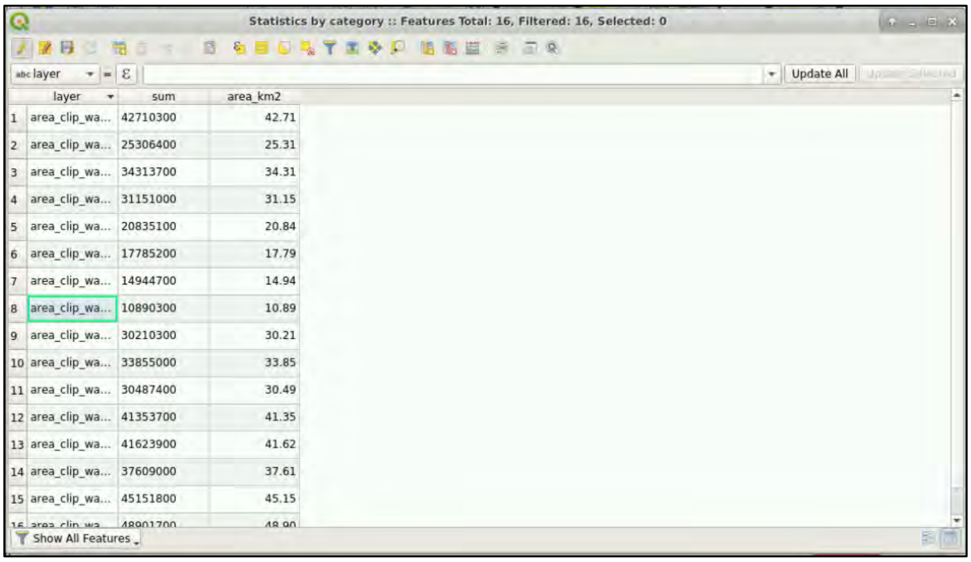
Show All Features

Here you can assess other statistical parameters. You can delete the columns which are not of your interest. Enable editing in the table and select option **Delete fields.** The area was calculated in m^2. You can convert it to km^2 using **Field calculator** in this attribute table. To do that add a new field and divide the "sum" column by 1000000.





At the end your table will look like this:



	layer	sum	area_km2
1	area_clip_wa...	42710300	42.71
2	area_clip_wa...	25306400	25.31
3	area_clip_wa...	34313700	34.31
4	area_clip_wa...	31151000	31.15
5	area_clip_wa...	20835100	20.84
6	area_clip_wa...	17785200	17.79
7	area_clip_wa...	14944700	14.94
8	area_clip_wa...	10890300	10.89
9	area_clip_wa...	30210300	30.21
10	area_clip_wa...	33855000	33.85
11	area_clip_wa...	30487400	30.49
12	area_clip_wa...	41353700	41.35
13	area_clip_wa...	41623900	41.62
14	area_clip_wa...	37609000	37.61
15	area_clip_wa...	45151800	45.15
16	area_clip_wa...	48901700	48.90

You can also visualize now your results as the data are stored in .csv file. You can plot a graph to see the differences in the water extent.

Thank you for following the exercise!

7 Further reading and resources

1. Bhaga T.D., Dube T., Shoko C. (2020). Satellite monitoring of surface water variability in the drought prone Western Cape, South Africa, Physics and Chemistry of the Earth, Parts A/B/C, 102914, ISSN 1474-7065, https://doi.org/10.1016/j.pce.2020.102914

2. Acharya, Tri & Subedi, Anoj & Huang, He & Lee, Dongha. (2019). Application of Water Indices in Surface Water Change Detection Using Landsat Imagery in Nepal. Sensors and Materials. 31. 1429. 10.18494/SAM.2019.2264.

3. Chermoshentsev A. Y. (2019) .Monitoring of water bodies using remote sensing data", Proc. SPIE 11208, 25th International Symposium on Atmospheric and Ocean Optics: Atmospheric Physics, 112085C. https://doi.org/10.1117/12.2540915

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5. M. Arreola-Esquivel, M. Delgadillo-Herrera, C. Toxqui-Quitl, A. PadillaVivanco. (2019). Index-based methods for water body extraction in satellite data," Proc. SPIE 11137, Applications of Digital Image Processing XLII, 111372N. doi: 10.1117/12.2529756

6. Feyisa, Gudina Legese & Meilby, Henrik & Fensholt, Rasmus & Proud, Simon. (2014). Automated Water Extraction Index: A New Technique for Surface Water Mapping Using Landsat Imagery. Remote Sensing of Environment. 140. 23–35. 10.1016/j.rse.2013.08.029.

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