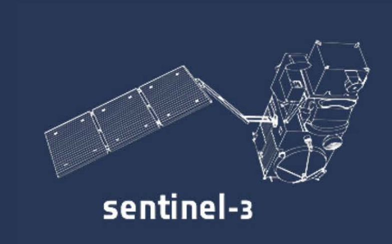
UNIVERSITY COURSE EARTH OBSERVATION WITH ESA MISSIONS

TUTORIAL FOR EXERCISE 2

Water Bodies Detection using ESA satellites



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(PLAN FOR EUROPEAN COOPERATING STATES)

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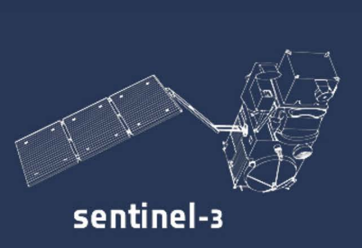

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Table of Content

1 Exercise outline

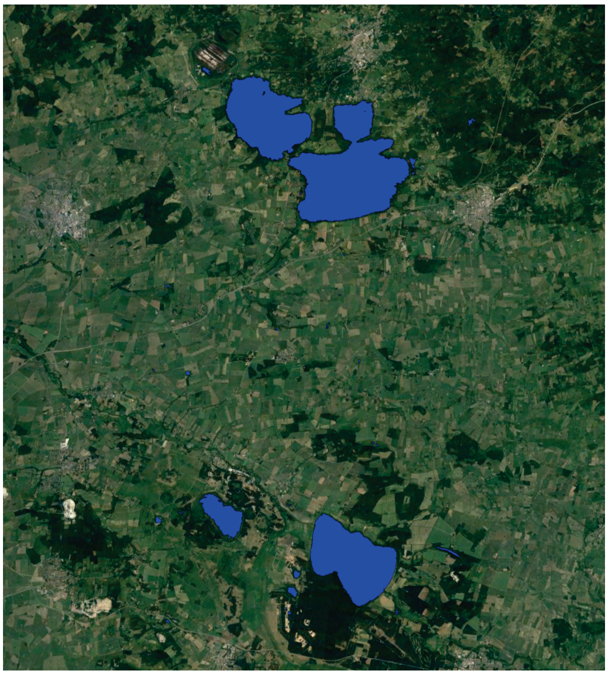
In this exercise, we will learn how to use optical and radar data from ESA satellites to map water bodies and flood extent.

In the first part, we will learn how to distinguish water spectra by detecting water bodies using optical image form Sentinel-2 by:

- Histogram
- Normalized Index (MNDWI)
- Options provided by SNAP

In the second part of this exercise, we will learn how to map flood extent:

- Pre-process radar image from the past satellite mission ENVISAT and current satellite mission Sentinel-1,
- Perform image classification for images before and after the floods,
- Extract water bodies from images.



1.2. Background

Water is an essential component of almost every human activity. Even at the beginning of the 21st century, scarce water resources were in high demand for agriculture, domestic consumption, hydropower, sanitation, industrial production, transport, recreational activities and ecosystem services. Water can also pose dangers - whether due to flooding, pollution or the spread of waterborne diseases. There are many, often very important, uses of RS in water resources management.

Given the limitations of ground-based observations, the availability of RS products serves as an important resource for researchers, water resource managers, and related stakeholders. RS is a cost-effective method for monitoring large water bodies with high temporal coverage and reasonable accuracy, which is not physically possible through in-situ measurements. Extensive coverage of areas with satellite data helps to understand the evolution of hazards, which is critical for resource management. This section considers three important areas, 1) quality assessment, 2) quantity, which includes streamflow, terrestrial water storage, and reservoir monitoring, and 3) extreme events, which include floods and droughts.

2 Water bodies detection using ESA satellite Sentinel 2

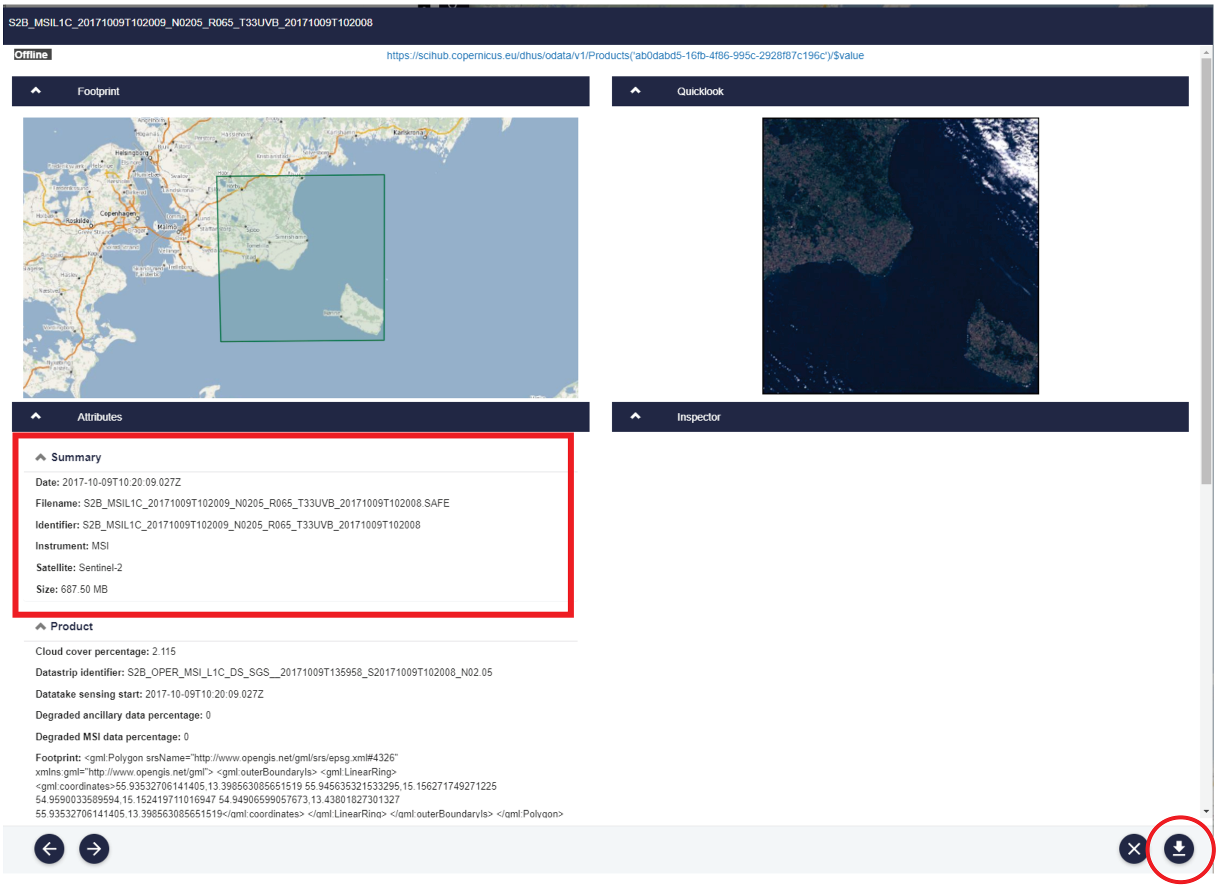
2.1. Study area and image download

In this exercise, we will use the optical image Sentinel-2 from 09.10.2017 for the area in Sweden:

S2B_MSIL1C_20171009T102009_N0205_R065_T33UVB_20171009T102008

This image can be downloaded from the Copernicus Open Access Hub.

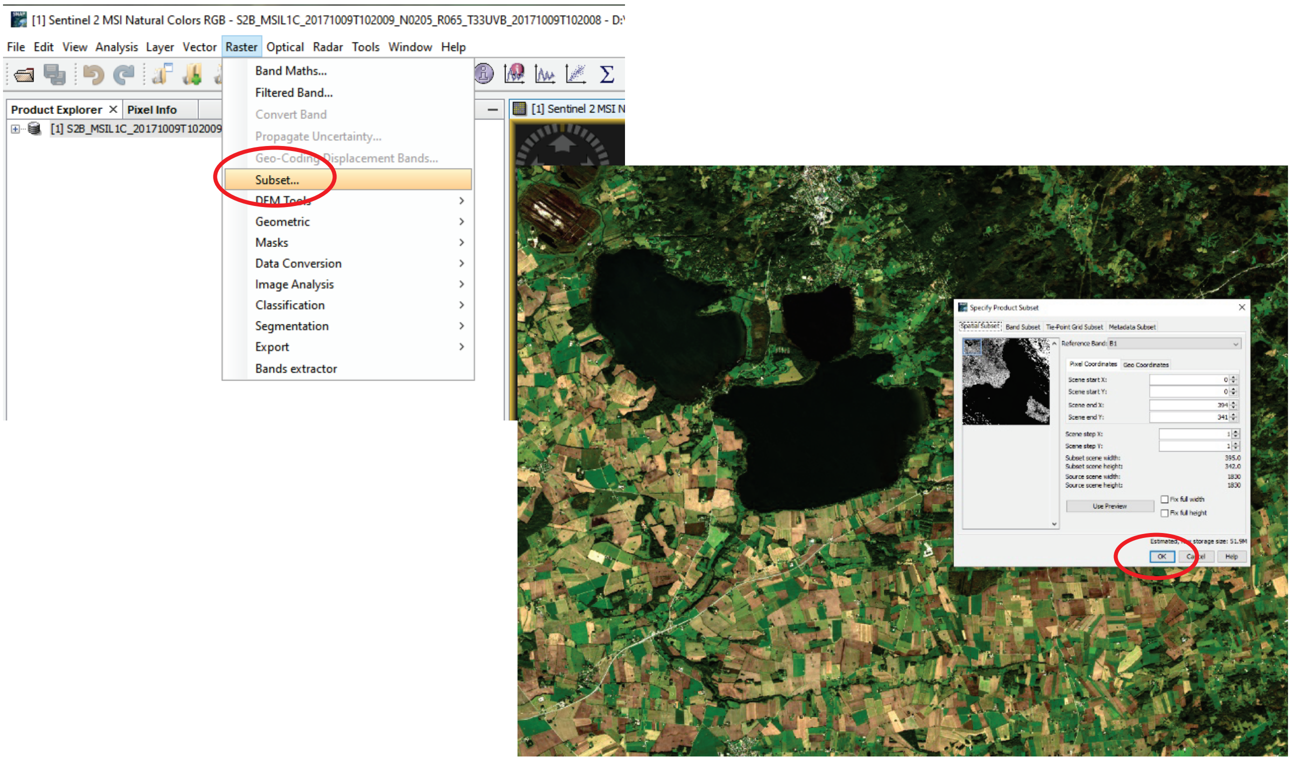
[https://scihub.copernicus.eu/dhus/#/home]



2.2. Image pre-processing

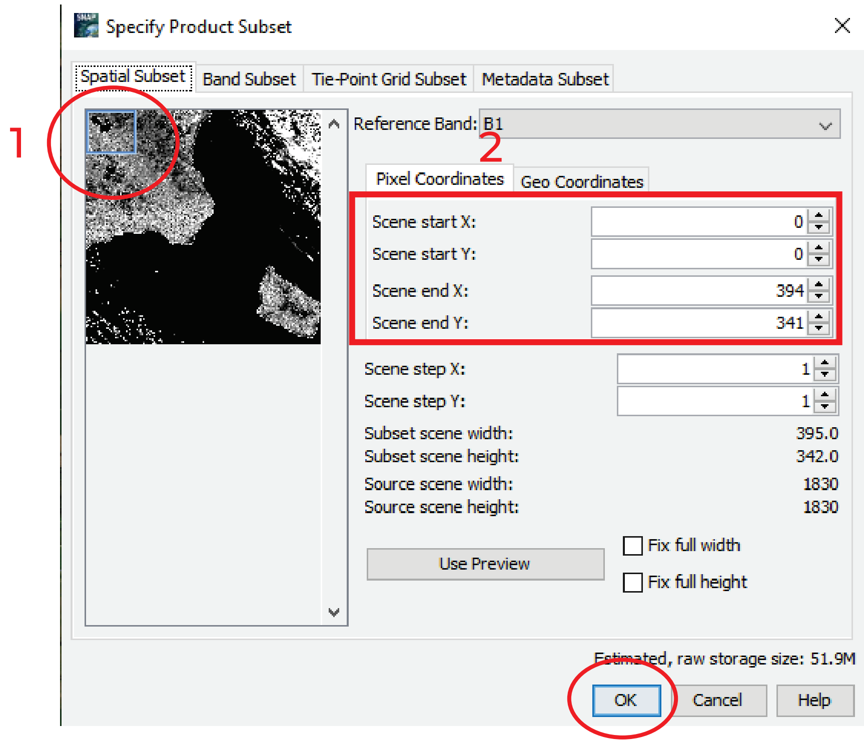
2.2.1. Creating subset

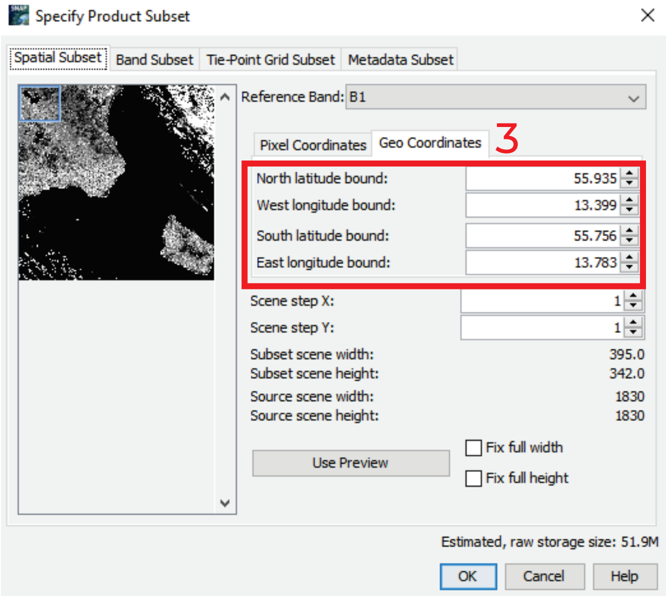
After opening the image in SNAP, we will create a subset of the region of interest.

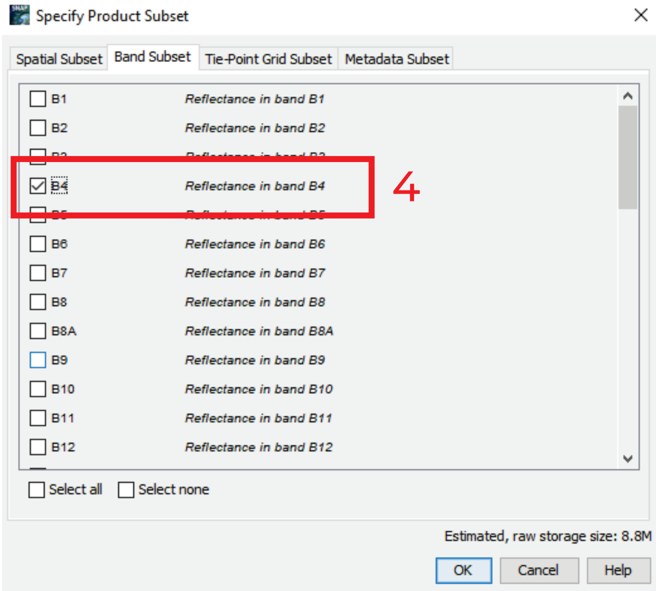


There are several ways to create a subset:

1. Specifying the subset area by setting the view area in the window,
2. Specifying the selection area in pixels,
3. Specifying the coordinates of the corners of the selection area,
4. Selecting the spectral band.



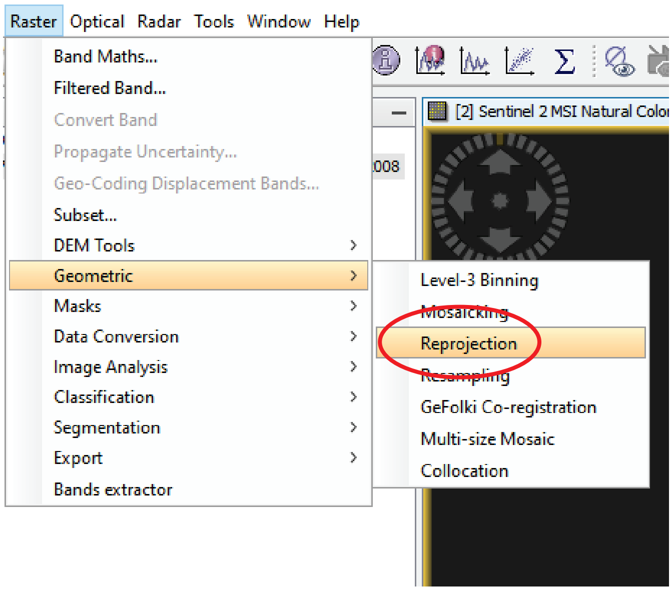


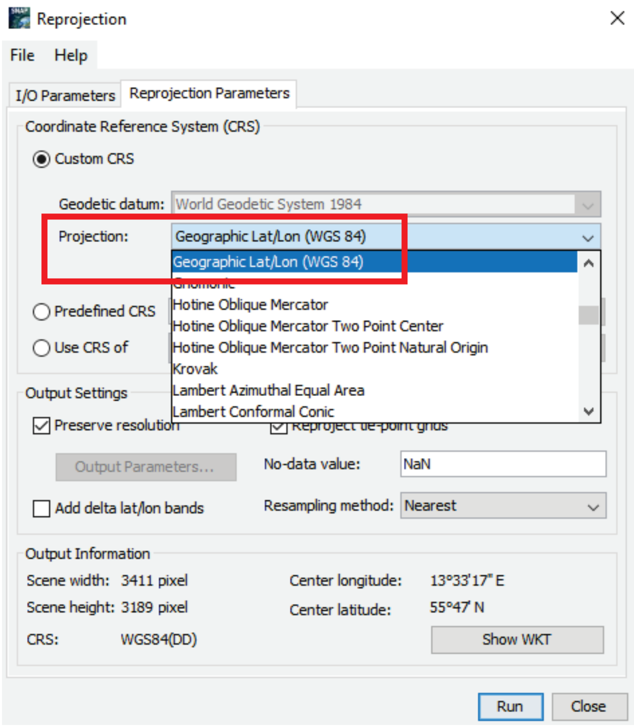


2.2.2. Reprojection to WGS-84

In the next step, the subset image can be reprojected to a suitable geographical projection by using *Geometric – Reprojection* function.

We will use the global *Geographic Latitude/Longitude* projection – WGS 84 system.





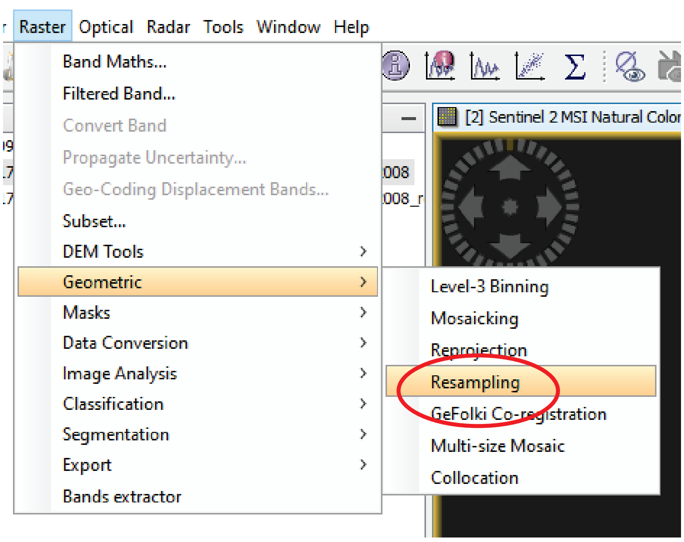
2.2.3. Resampling

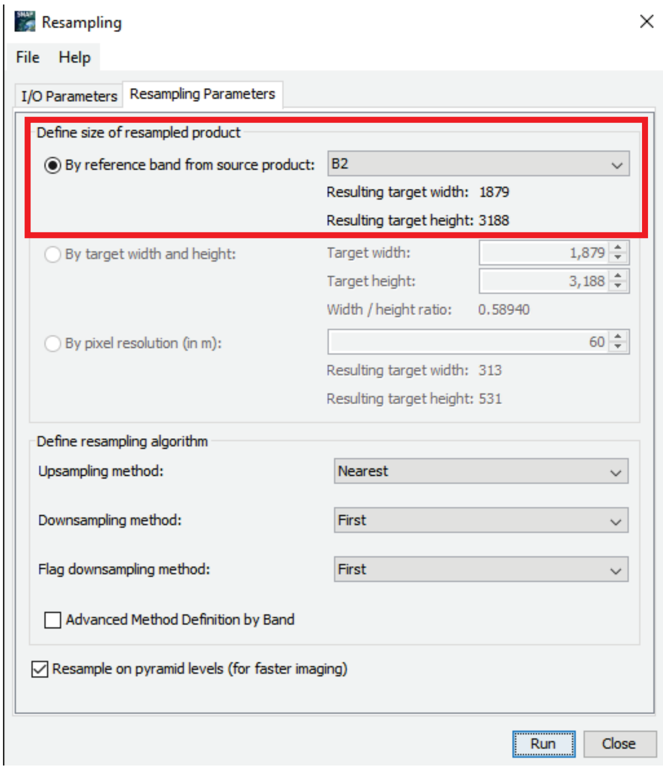
In this step, we can Resample the reprojected subset image using *Geometric – Resampling* function.

The resampling can be done by:

- reference band from source product,
- target width and height,
- pixel resolution.

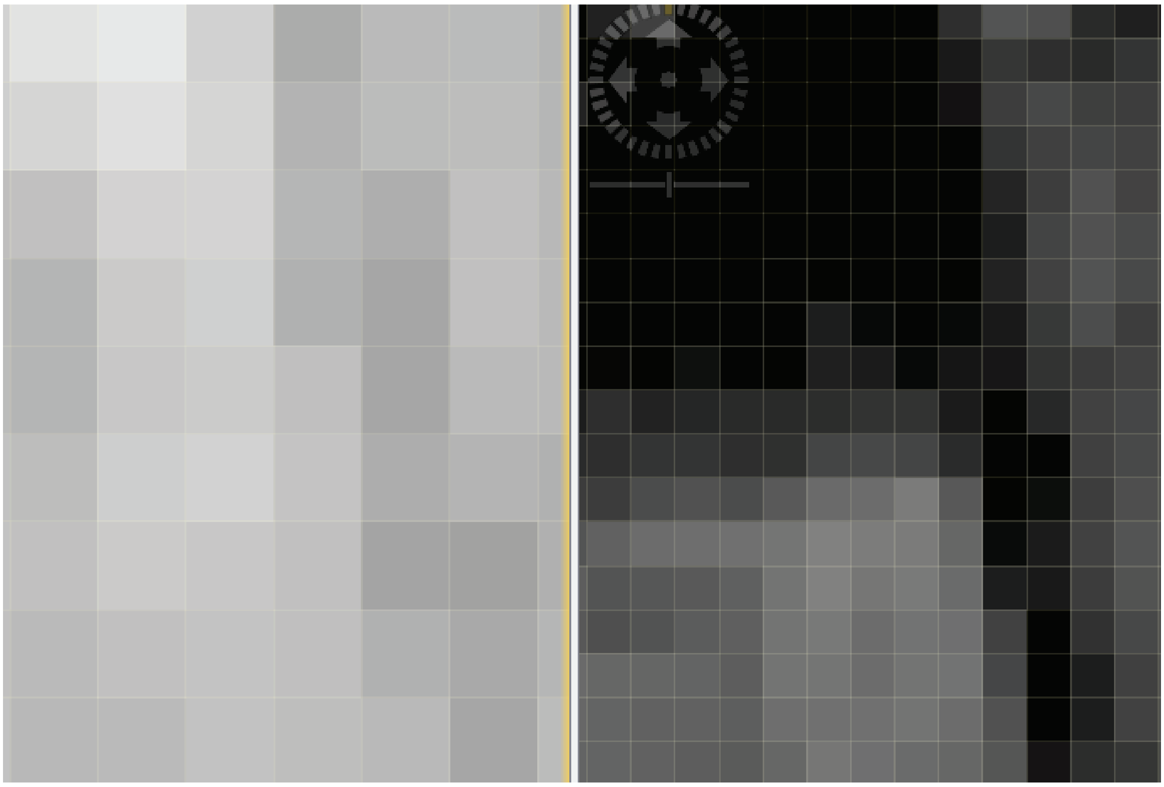
We will use the resampling by reference band – B2 (with 10 m spatial resolution).



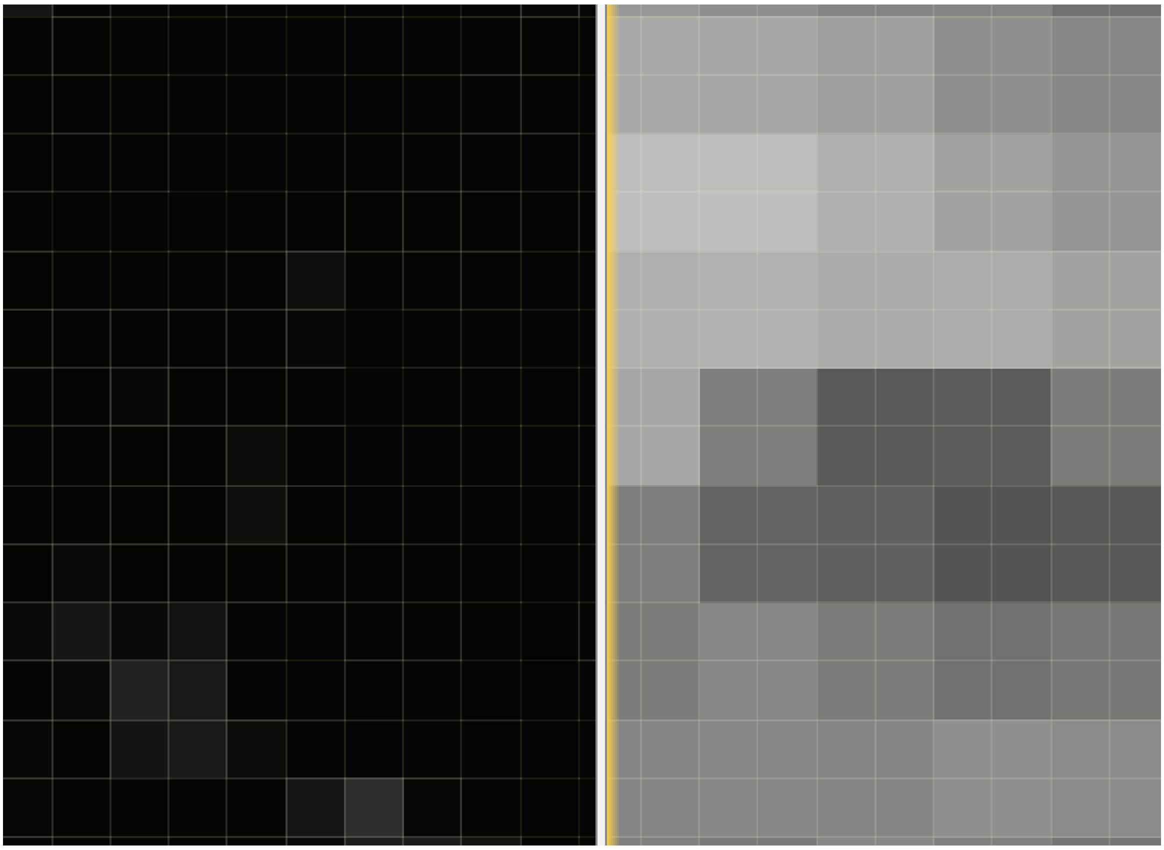


Now, we can compare the pixel size before and after resampling of B11 (20 m) and B2 (10 m) bands.

Before resampling (B11 – left; B2 – right)



After resampling (B11 – left; B2 – right)



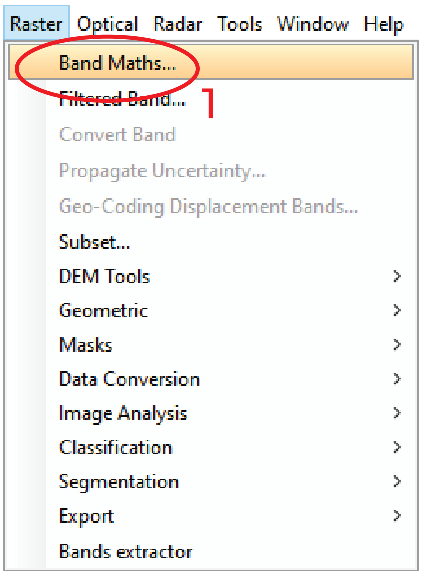
2.3. Image enhancement

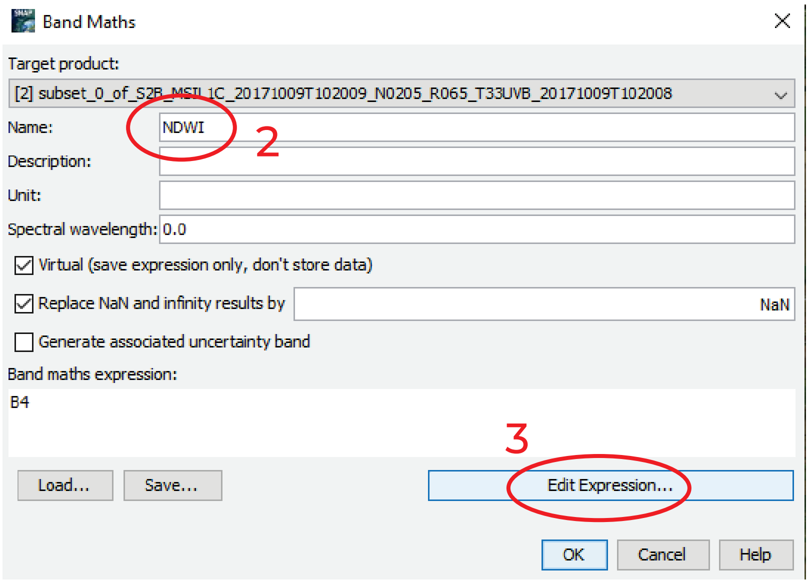
2.3.1. Creating NDWI

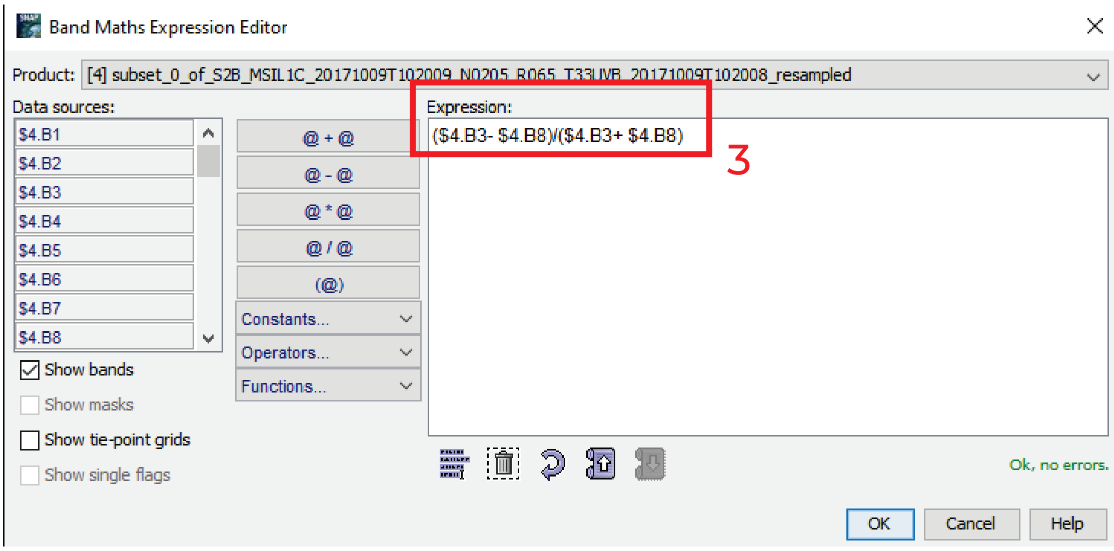
NDWI (Normalized Difference Water Index) uses the Green and NIR bands. It is sensitive to built-up areas and can result in overestimated water areas. For Sentinel-2 imagery the following applies:

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

To create NDWI band, we will use the *Band Maths* function.







The result is an NDWI band with the maximized visibility of the water surface.

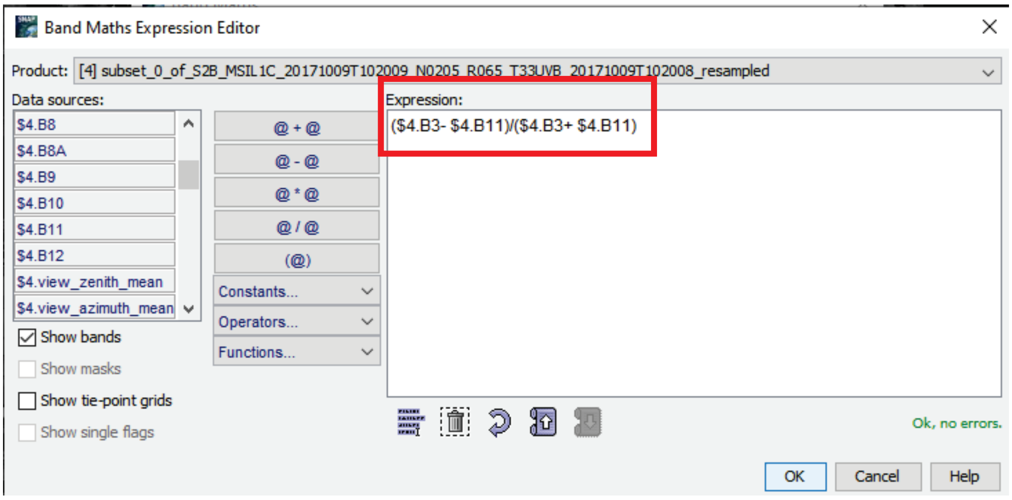
For water surfaces, the values of NDWI are > 0.5. For vegetation, it gains much smaller values, resulting in easier differentiation of vegetation from water areas. Built-up areas take values of 0 - 0.2.

2.3.2. Creating MNDWI

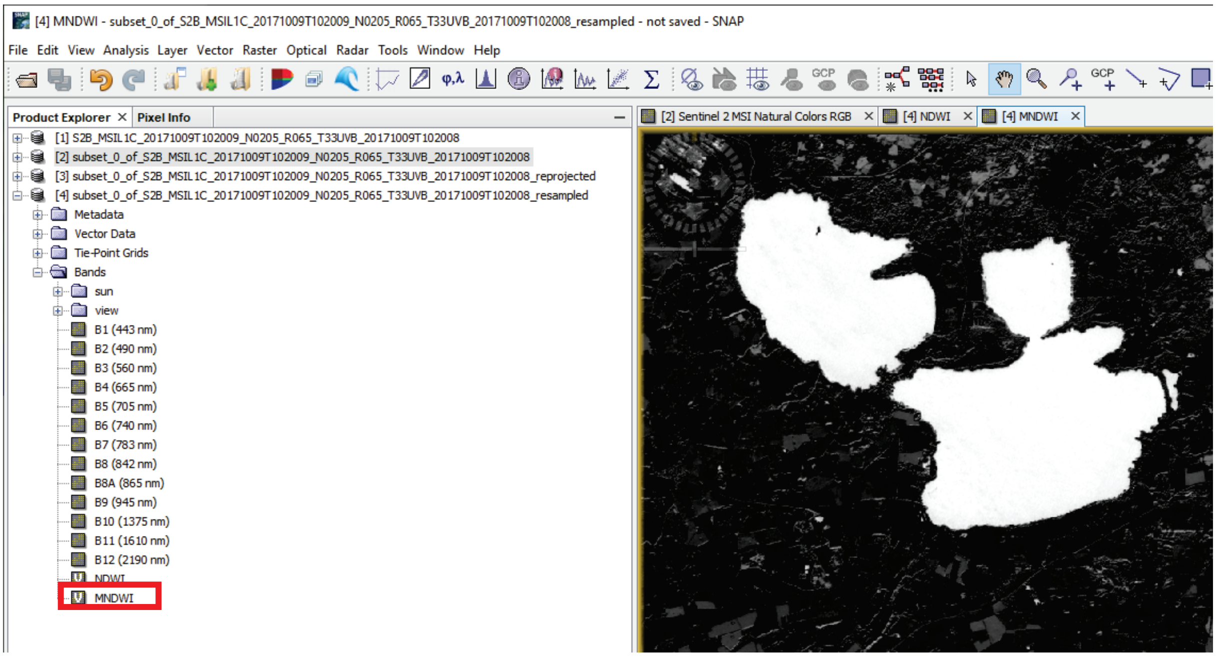
MNDWI (Modified Normalized Difference Water Index) uses Green and SWIR bands to highlight features of open water areas due to the more intense absorption of SWIR radiation compared to the NIR band. It reduces the impact of built-up areas and is more suitable for detecting water bodies in urban areas. Its disadvantage is its weaker ability to identify water bodies with high sediment concentration.

For sentinel-2 image:

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



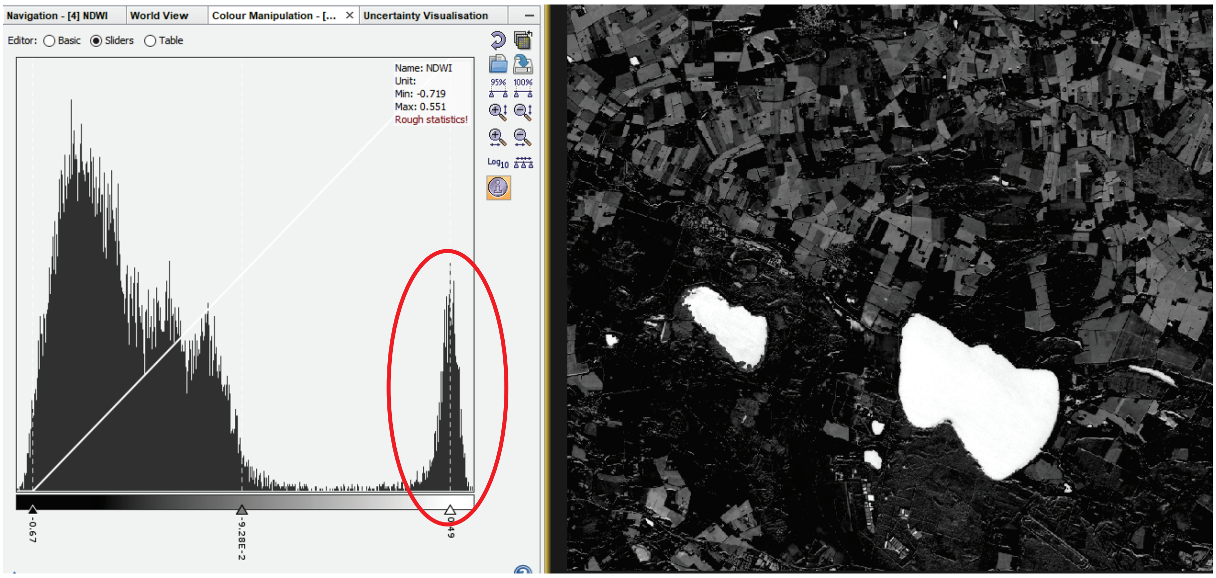
The result is an MNDWI band with the maximized visibility of the water surface.



2.4. Image classification

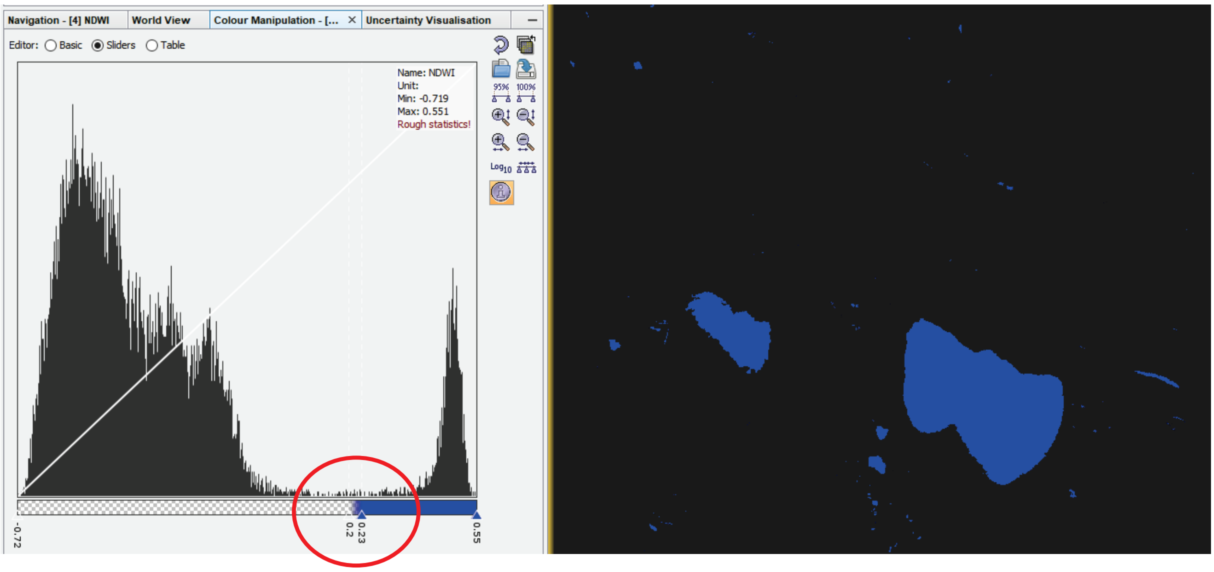
2.4.1. Grayscale thresholding

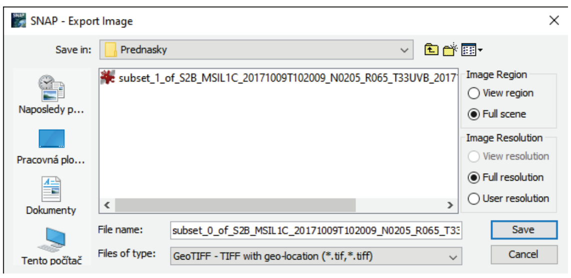
We will use the histogram representation of the number of grayscale pixels in the image, with positive NDWI index values indicating water surface pixels.



Shifting the grey threshold increases the number of pixels marked as "*water*".

This image can be exported as a GeoTiff image to a GIS software.

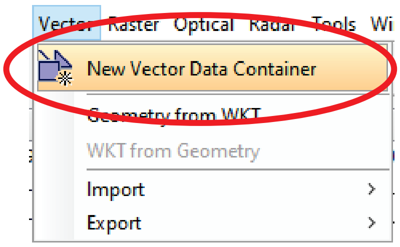


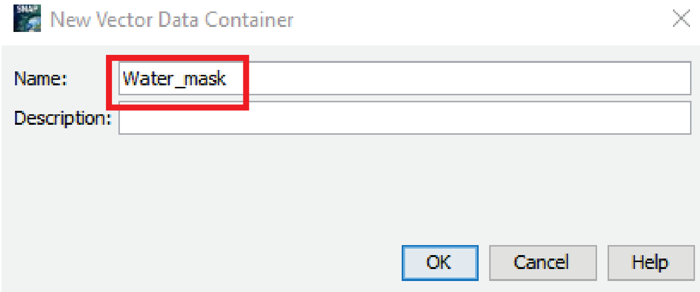


2.4.2. Bit map creation

Another way to classify water surface is by bit map creation.

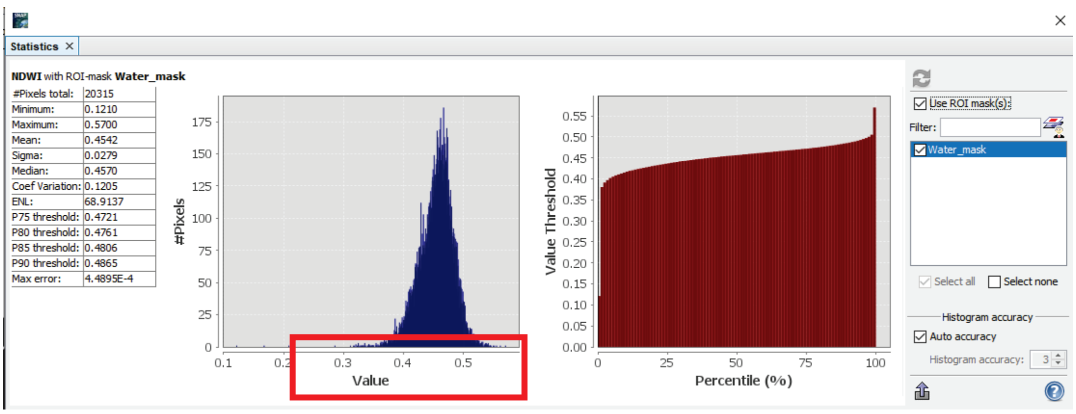
To do this, we will firstly create a *New Vector Data Container* with name *Water_mask*.



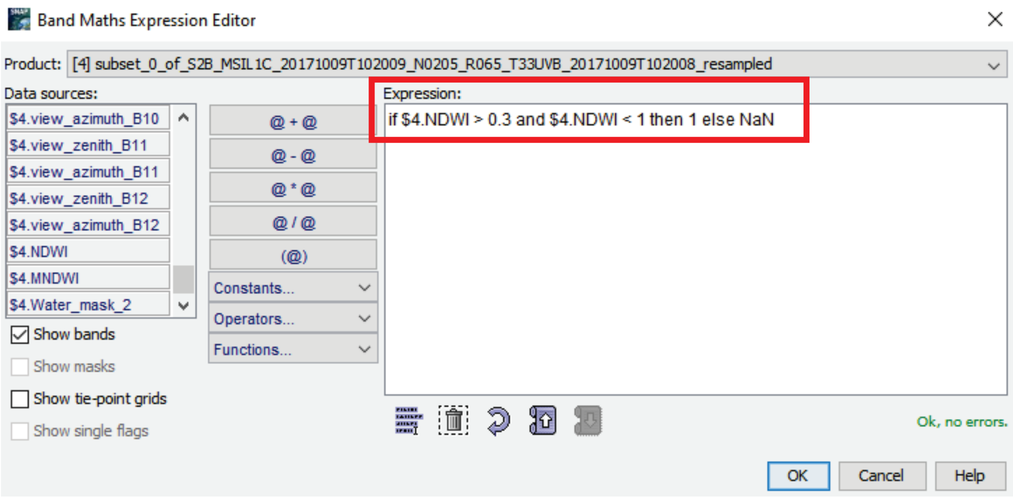


Within this container, we will define a new vector data by  and define the area of the water surface on the image.

Now we can look on the statistics of this mask.



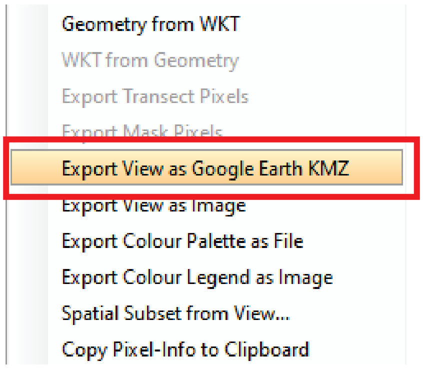
According to the data from this statistics, we can define the following Band Math expression to create the final bit map image.

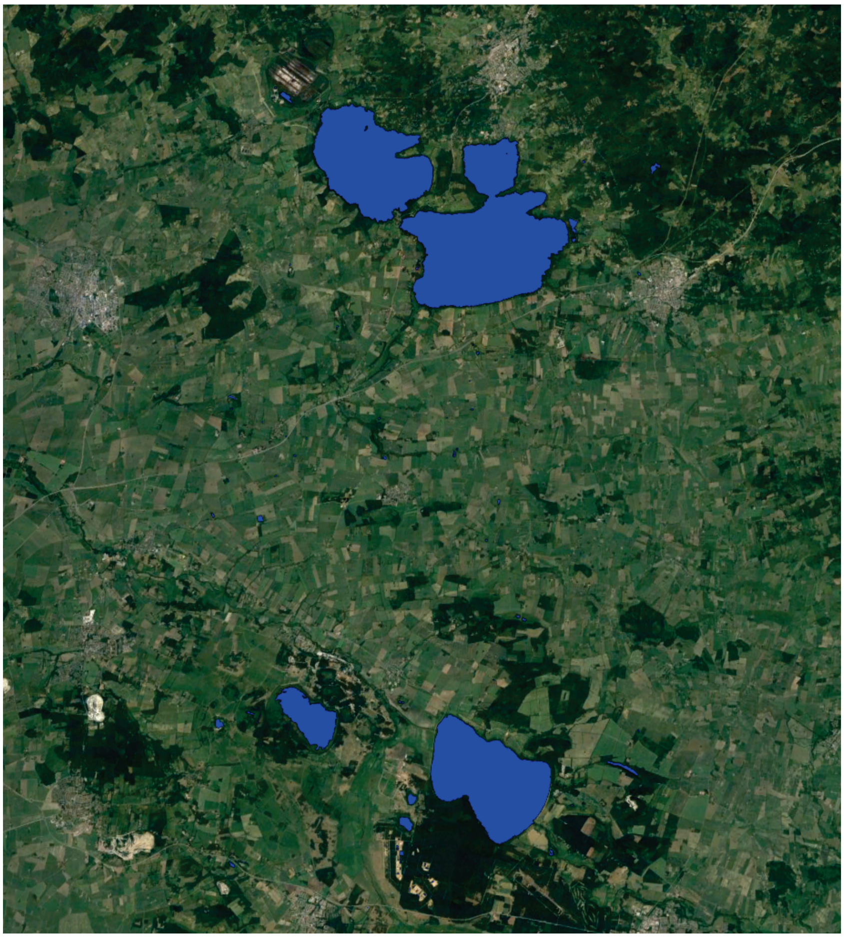


The final bit map image.

2.5. Google Earth export

We can export the created NDWI image or the created bit map to Google Earth using the *.kmz format.





3 Water bodies detection using ESA satellites Envisat and Sentinel-1

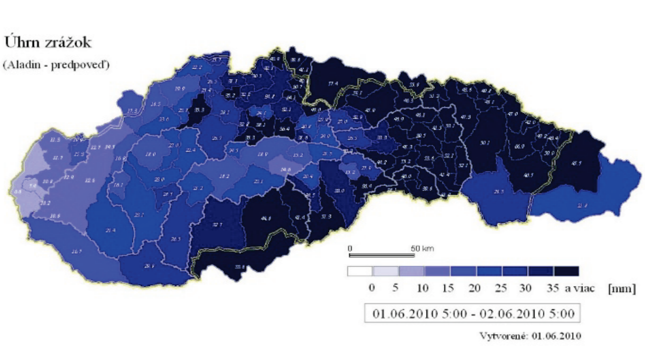
3.1. Study area and flood event

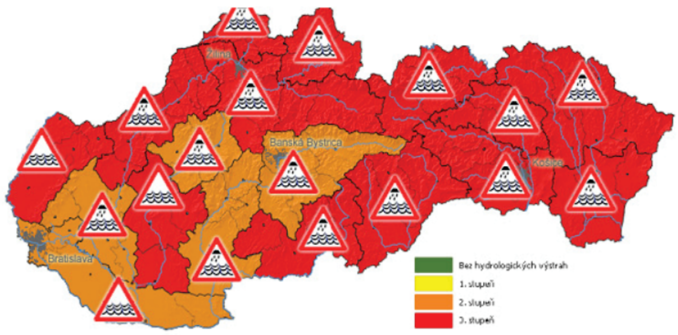
For this exercise, we will use images from the past ENVISAT mission during the 2010 floods (June and September) in Slovakia, as well as the present-day image from the Sentinel-1 satellite.




- Flood - extreme hydrological phenomenon
- May - June 2010 on middle and lower sections with catastrophic effects
- Significance 50 - 100 years
- Valid records for monthly rainfall since 1901 were exceeded at 400 rain gauge stations
- Material damage of € 700 million in SK (Alianz - Slovak Insurance Company), € 2.8 billion in the whole EU
- Largest number of insurance claims in Trebišov


Department of Hydrological Forecasts and Warnings SHMÚ Košice: *flood warnings of the 1st, 2nd and 3rd level from persistent rains and storms from 6.5.2010.*





3.2. Image download

For this exercise, we will use three satellite images:

ENVISAT flood event from 07.06.2010

ASA_IMS_1PNESA20100607_201155_000000182090_00100_43240_0000

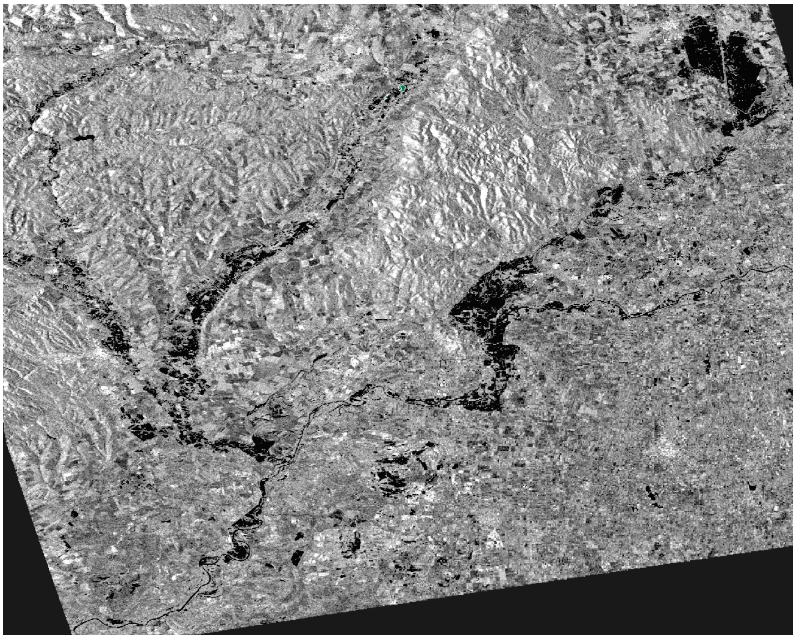
ENVISAT after floods from 20.09.2010

ASA_IMS_1PNESA20100920_201155_000000182093_00100_44743_0000

Sentinel-1 current image from 15.10.2021

S1A_IW_GRDH_1SDV_20211015T044524_20211015T044549_040125_04C05B_A10E

You can find these images in the corresponding *Data Sets* folder.



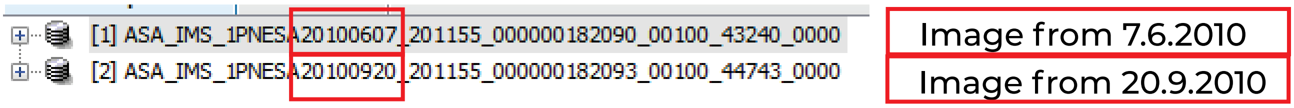
3.3. Envisat images

3.3.1. Image processing

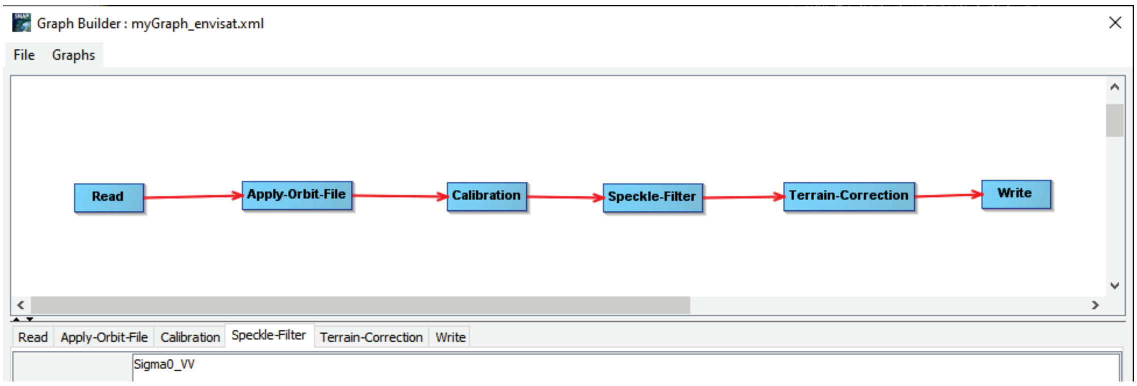
The processing procedure is following:

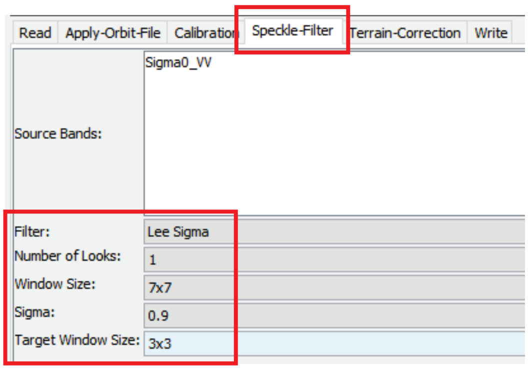
1. Create a SUBSET - the image sub-area within the processing will be performed
2. Perform preprocessing of the image by the following steps:
   - Apply Orbit File - apply orbital data
   - Remove Thermal Noise ThermalNoiseRemoval
   - Perform image calibration Calibration
   - Perform Speckle-Filter Noise Filtering
   - Perform Terrain-Correction Terrain-Correction
   - Create training region ROI - Region Of Interest
   - Create water/not water bitmap
   - Export to GIS

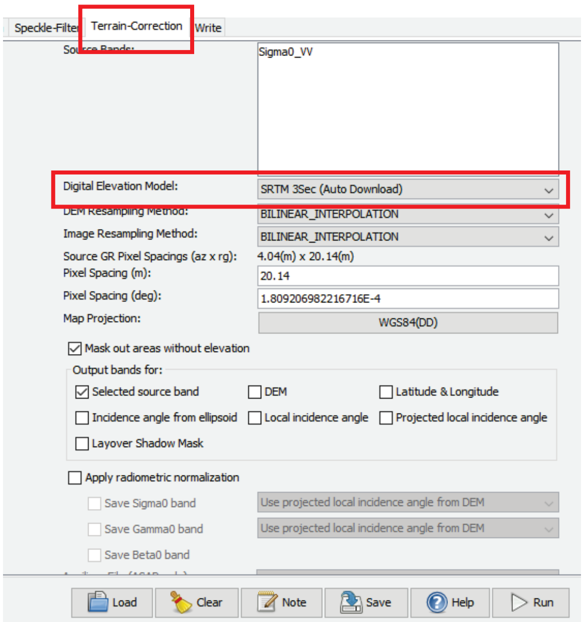
The example processing procedure for the ENVISAT images:



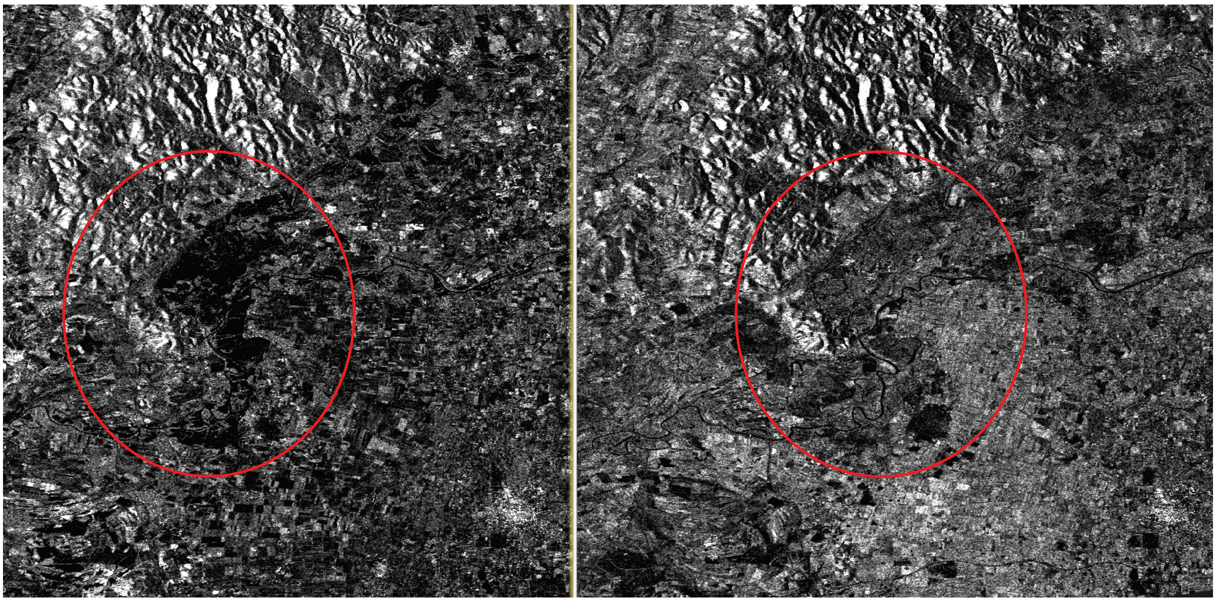
By using the Graph Builder, we will define individual steps in the processing chain – *Read – Apply Orbit File – Calibration – Speckle Filter – Terrain Correction - Write*

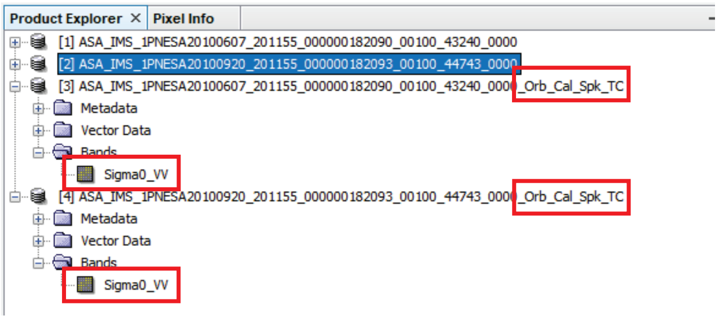




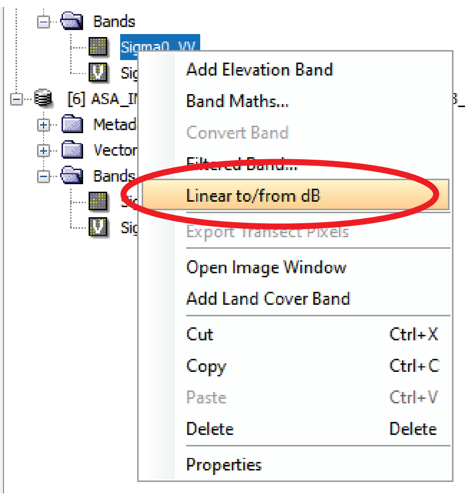


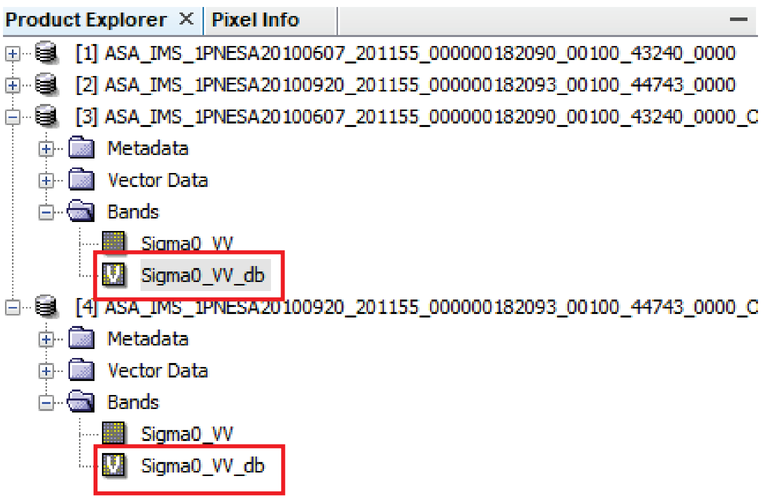
From this processing, we got terrain corrected images, with filtered noise, showing the Hornád River (right) and the flooded area (left).

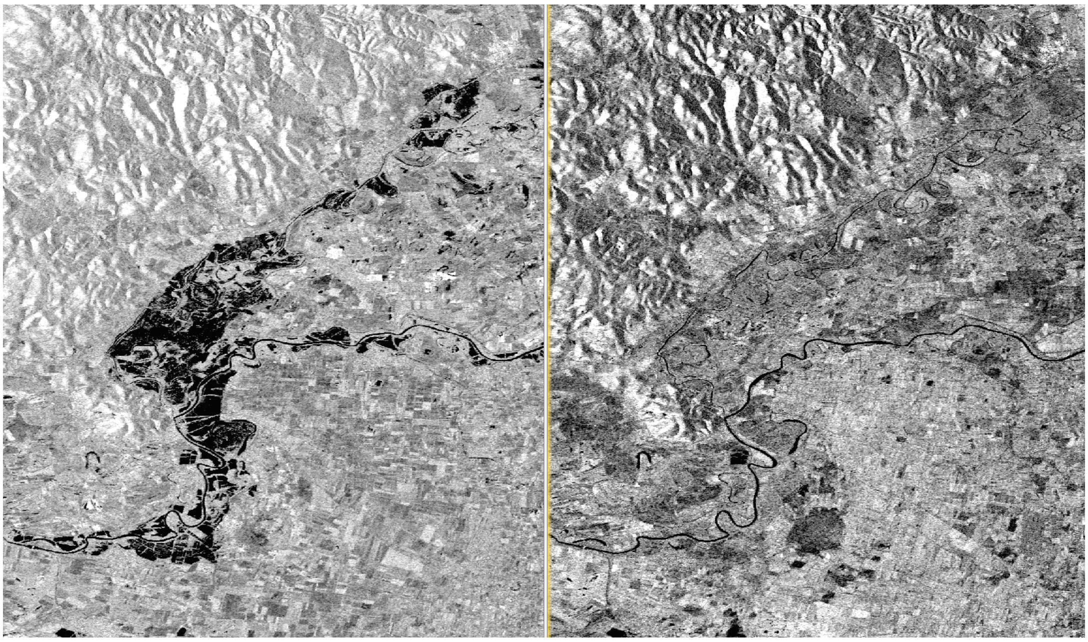




For these images, we will now use the LinearToFromdB operator that converts bands to dB (decibels) resulting in a much more pronounced representation of the water surface.



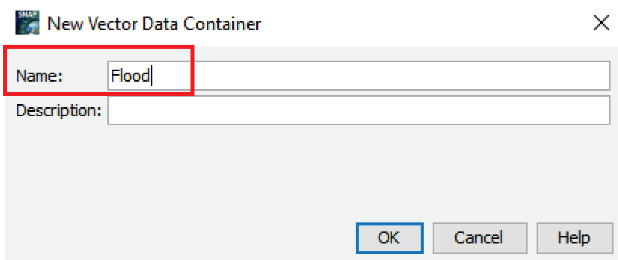


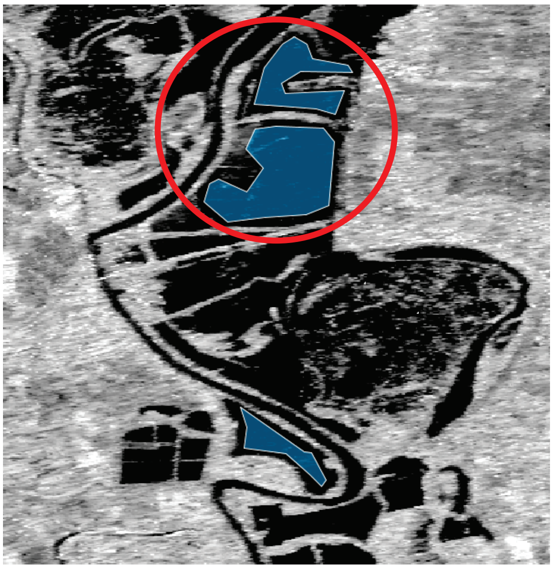


3.3.2. Image classification

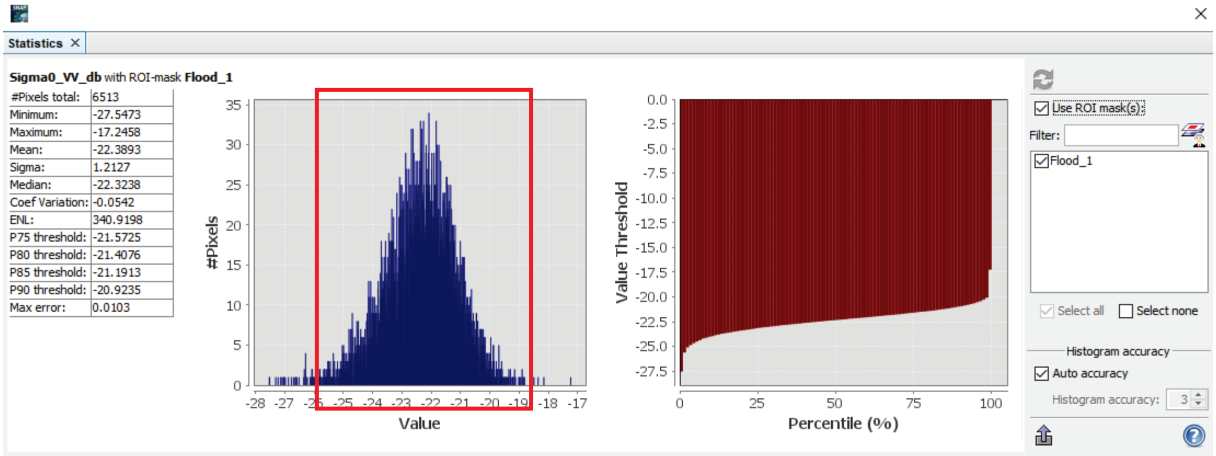
In this step, we will create again a mask in the form of a bit map by supervised classification – grayscale thresholding.

We will begin with creating a New Vector Data Container defined as "Flood" for the image showing the floods. Using this data container, we will draw and define the area of the flooded area on the image.

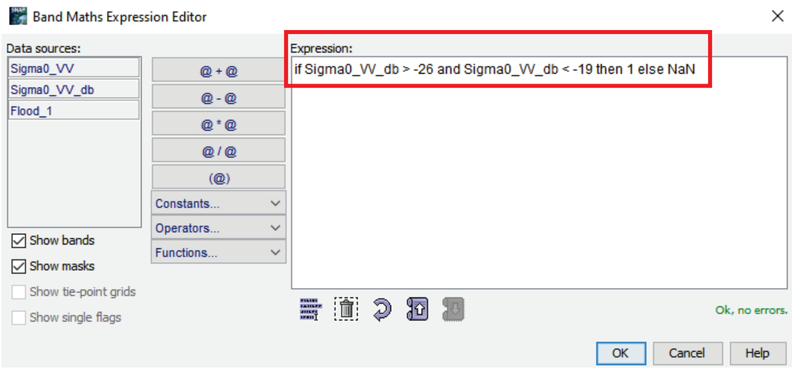




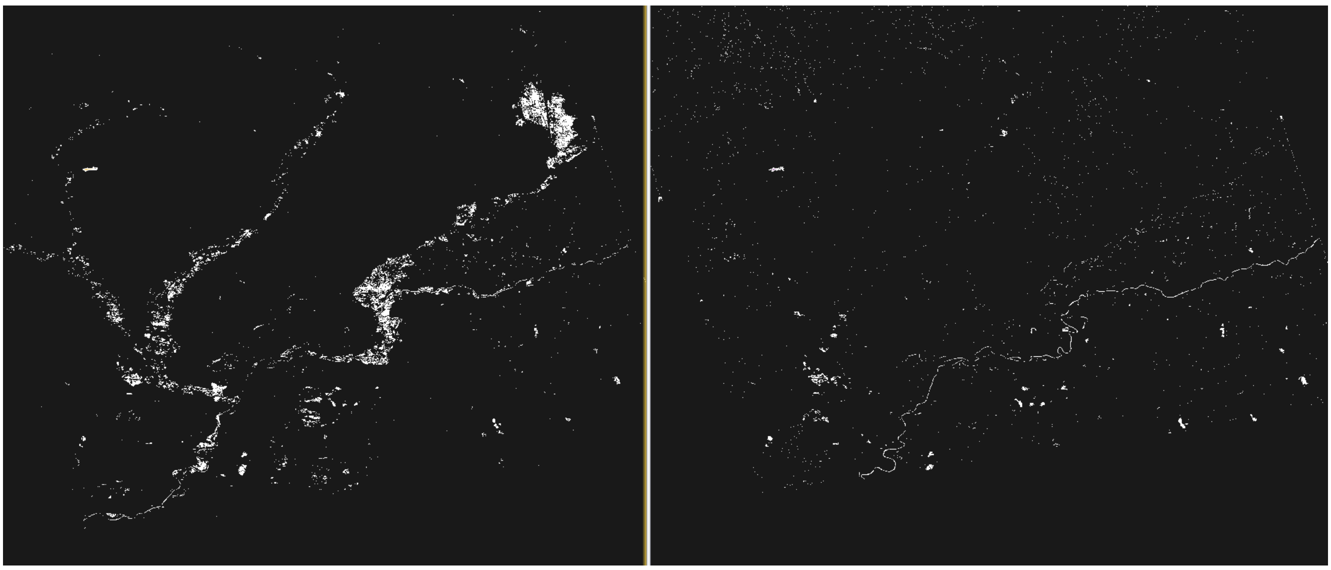
Now we can look on the statistics of the created mask.



Using values from the statistical view, we can then define the corresponding Band Math expression.

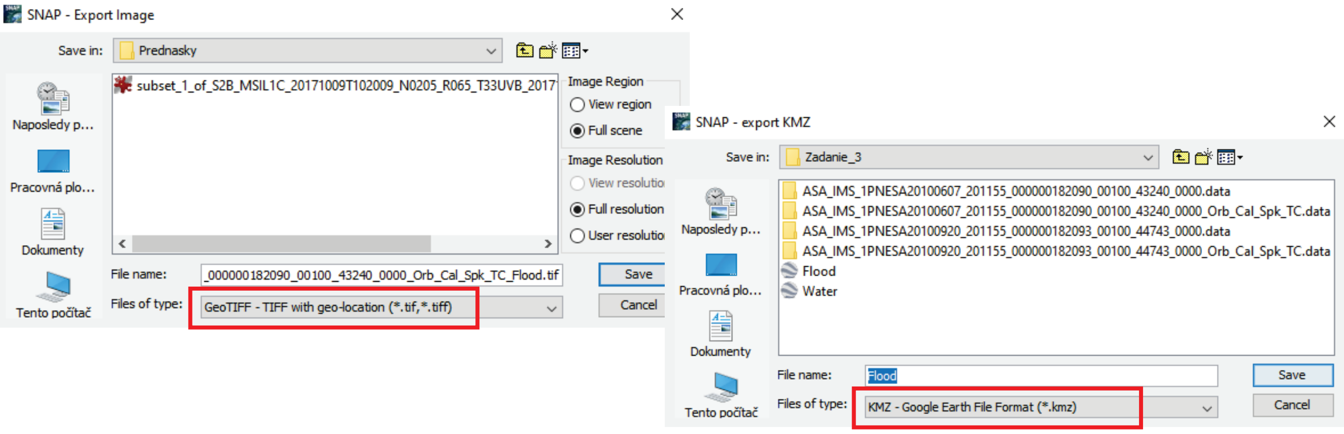


We can apply the same procedure for the second ENVISAT image. The resulting bit map masks for flooded (left) and not flooded (right) images:

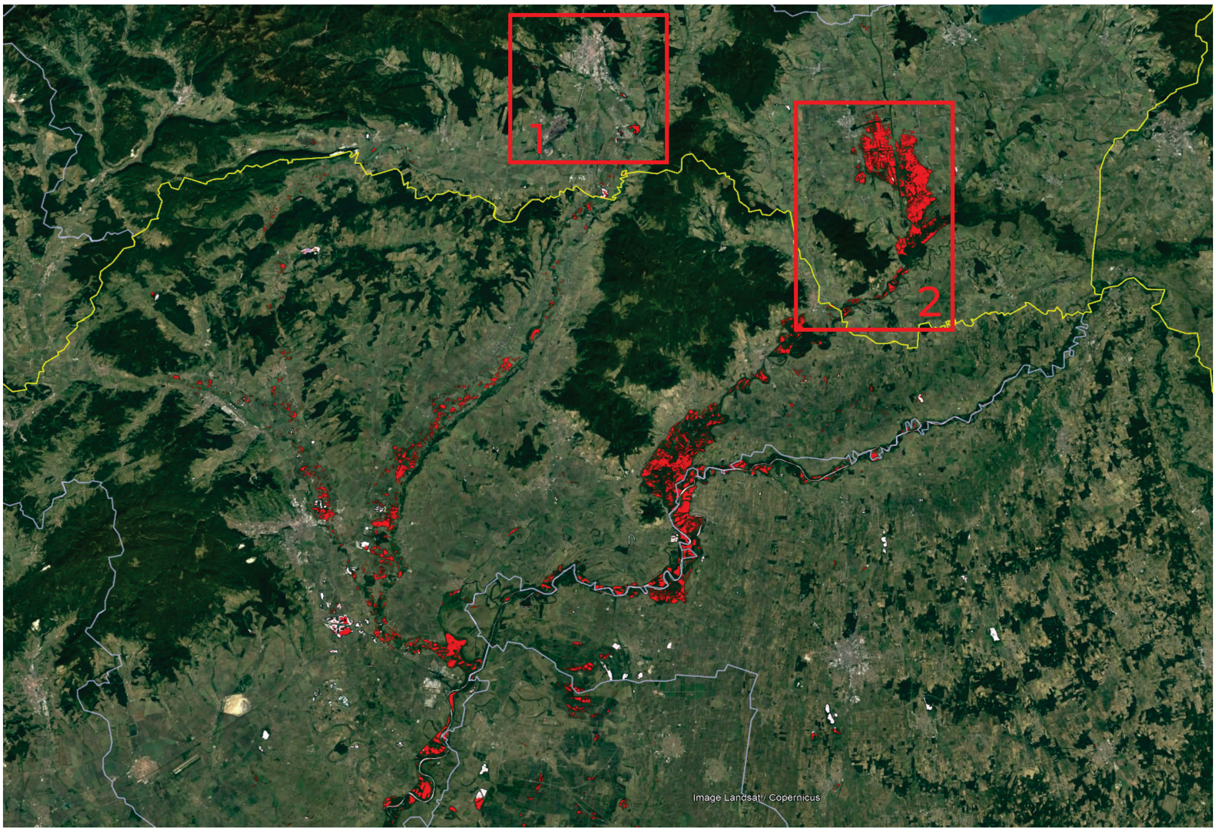


3.3.3. Visualisation

The final masks can again be exported to the GeoTIFF format and to Google Earth.



The resulting flood map in Google Earth showing the floods in Košice and Trebišov.



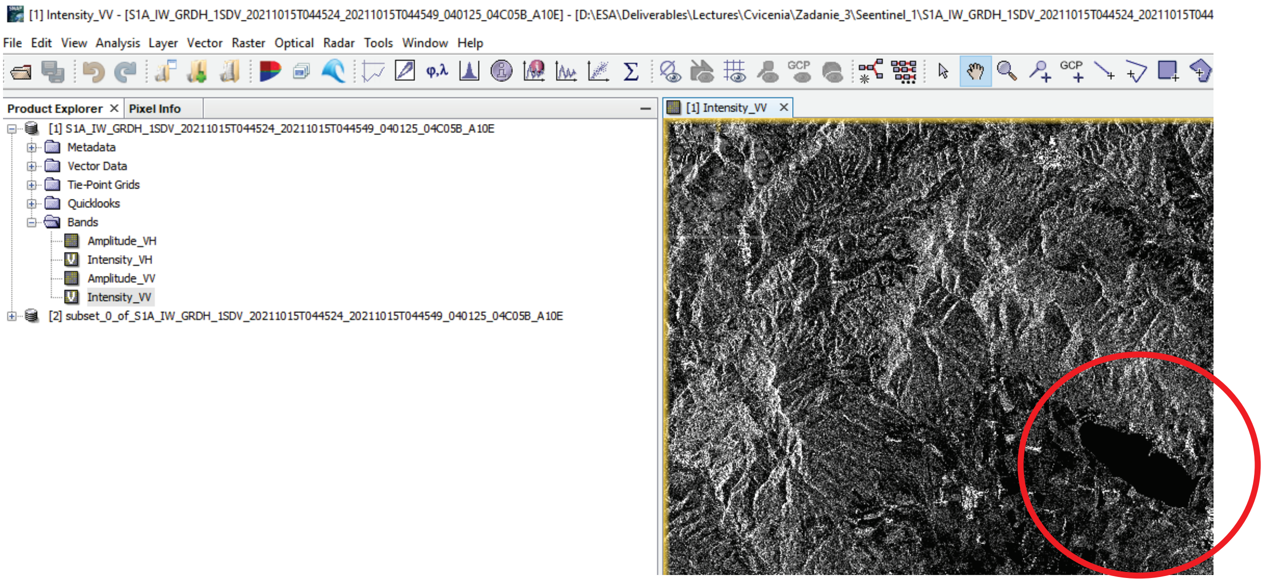
3.4. Sentinel-1 image

3.4.1. Image processing

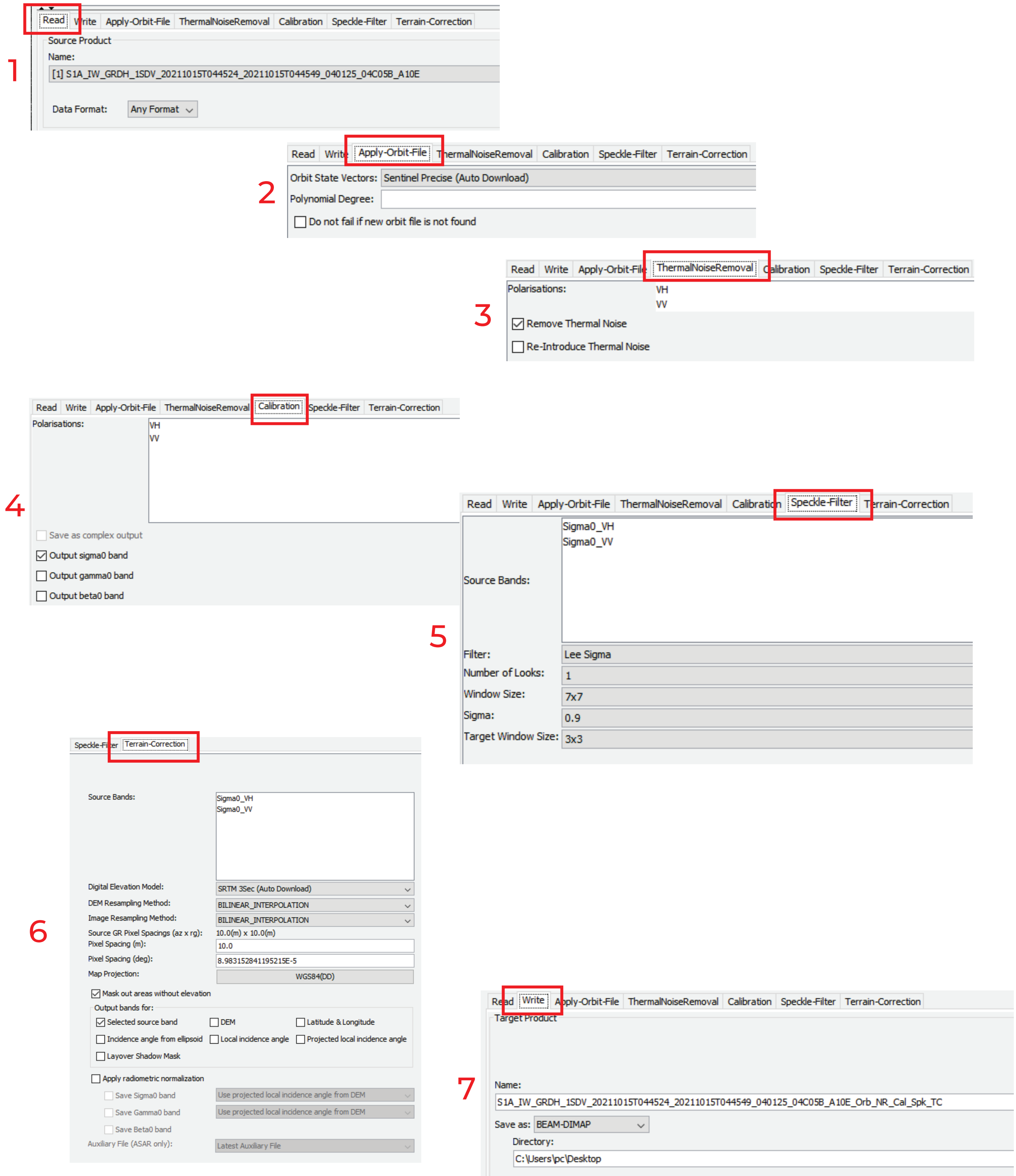
The processing procedure for Sentinel-1 image is similar to Envisat images:

1. Create a SUBSET - the image sub-area within the processing will be performed
2. Perform pre-processing of the image by the following steps:
    - Apply Orbit File - apply orbital data
    - Remove Thermal Noise ThermalNoiseRemoval
    - Perform image calibration Calibration
    - Perform Speckle-Filter Noise Filtering
    - Perform Terrain-Correction Terrain-Correction
    - Create training region ROI - Region Of Interest
    - Create water/not water bitmap
    - Export to GIS

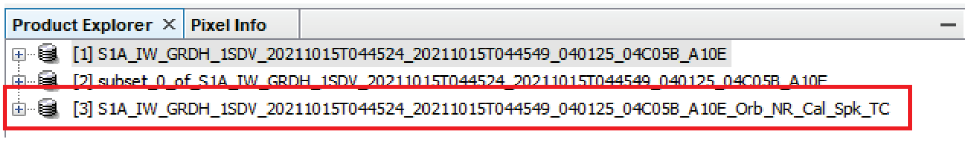
Firstly, we will open the S1 image in SNAP and create a subset image using the *Use Preview* function by zooming the image to the area containing water surface.



Now we can use the *Graph Builder* with the following steps:



The result is a processed image with orbital data, radiometric calibration of the reflected signal, with noise eliminated, after terrain corrections, on which further processing will be performed.

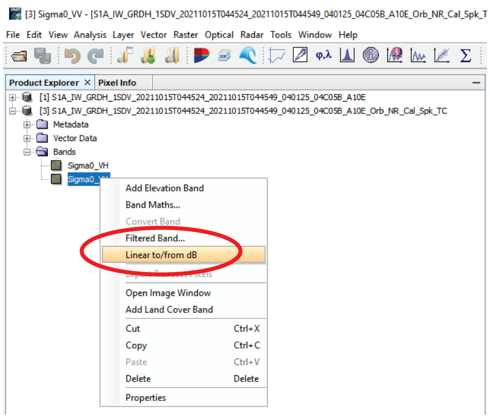


3.4.2. Water body extraction

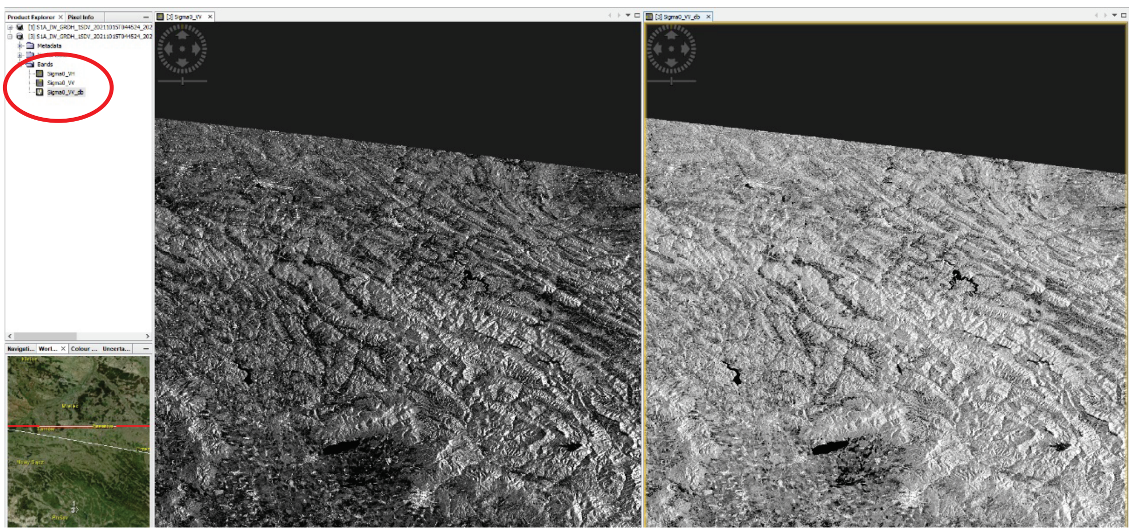
Grayscale thresholding

Firstly, we will close all product images except "_Orb_NR_Cal_Spk_TC". Save this file to keep it on disk.

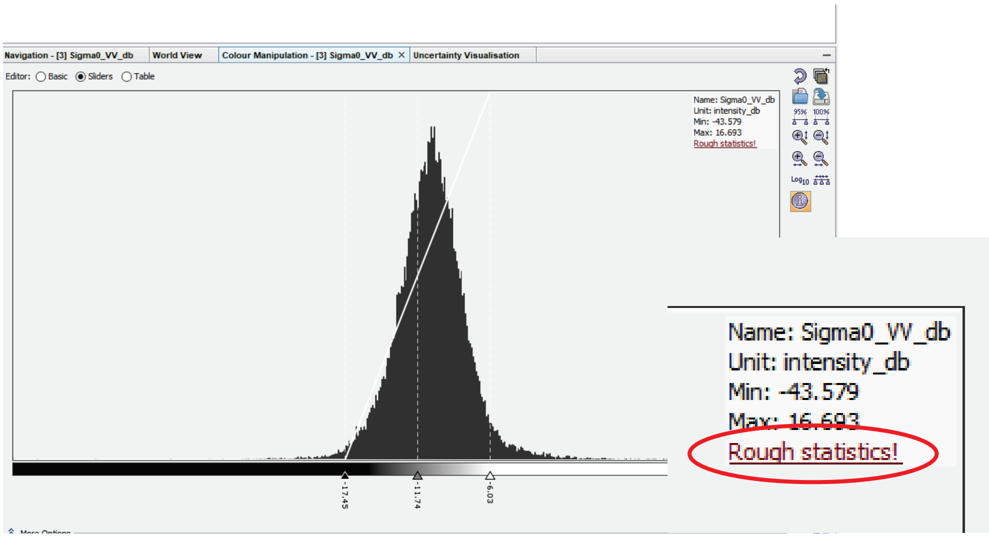
Then, we can transform Sigma0_VV into decibels dB to create a new virtual image.



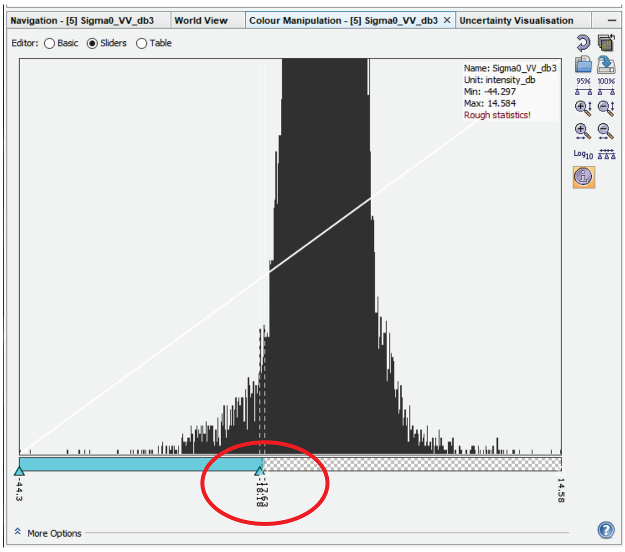
Now open the newly created file and find out the statistics of the image.



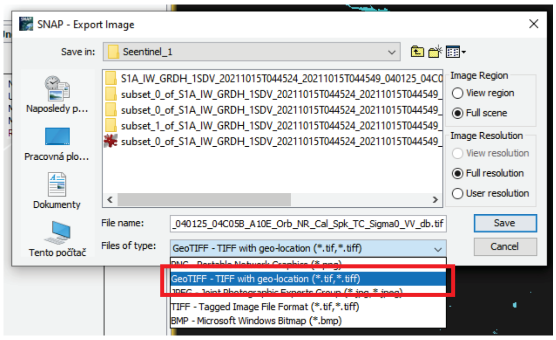
Open the new band Sigma0_VV_dB and in the *Color Manipulation tool* use the *Rough statistics*.



Vertically zoom the histogram, move the right slider to the left, and assign it a suitable colour (blue).

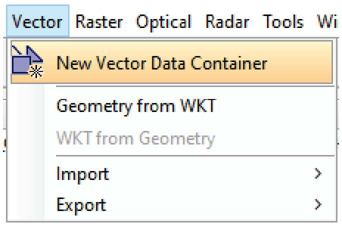


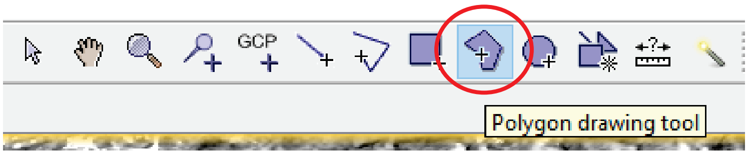
Now we can export the enhanced image to *.KMZ and GeoTIFF formats.



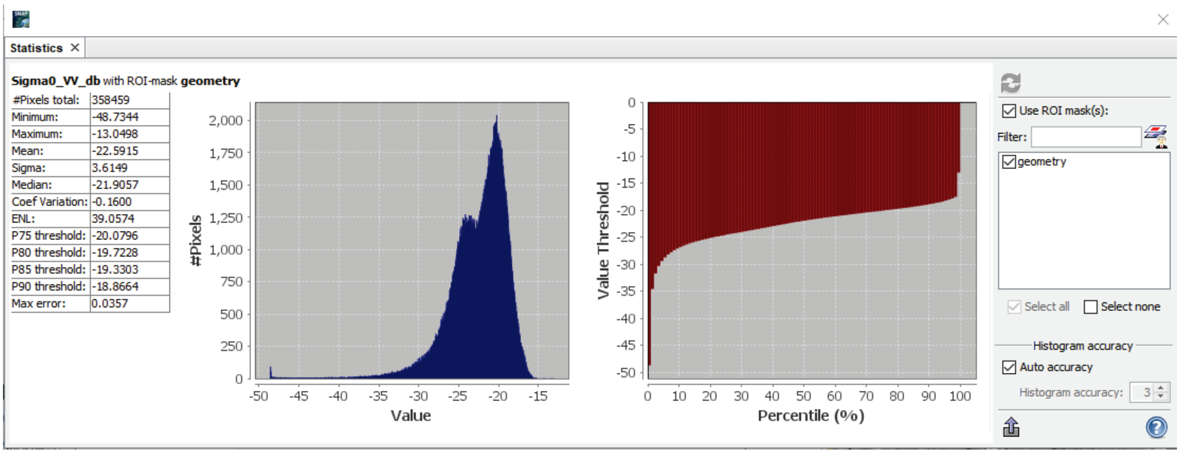
Binary map creation

As for the previous images, we will firstly create a training area using the New Vector Data Container, in which only water areas will be included.

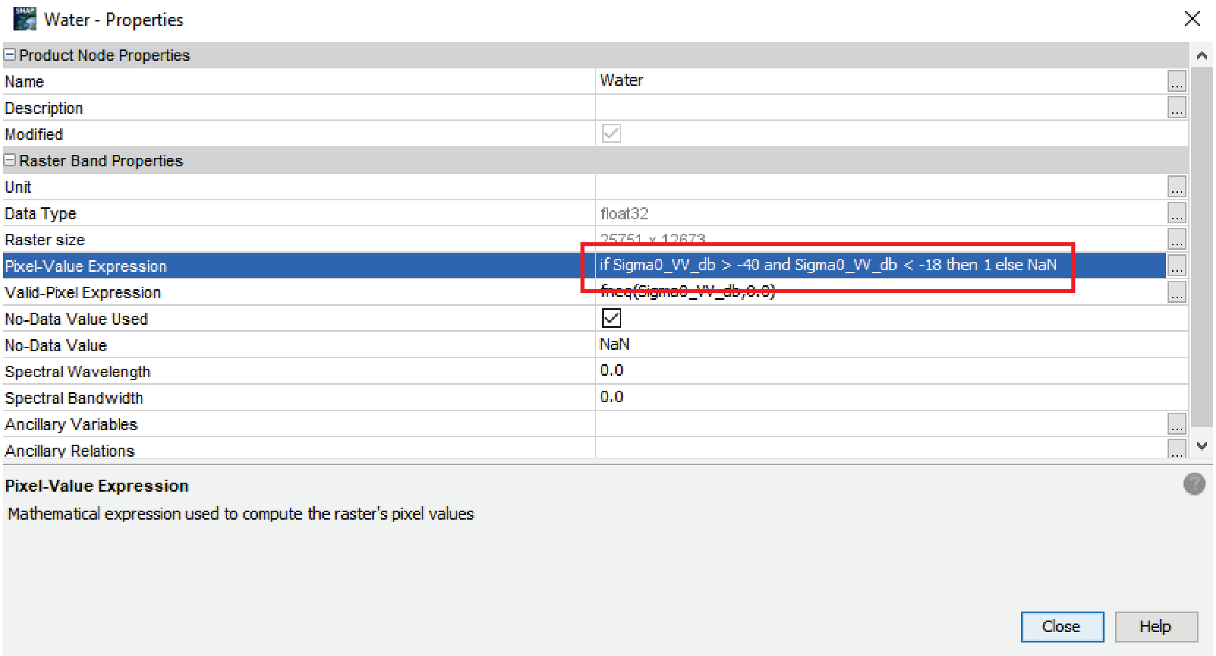




Then, we can display the statistical data of this training region and create the mathematical condition to assign "1" to water pixels and "NaN" to non-water pixels.

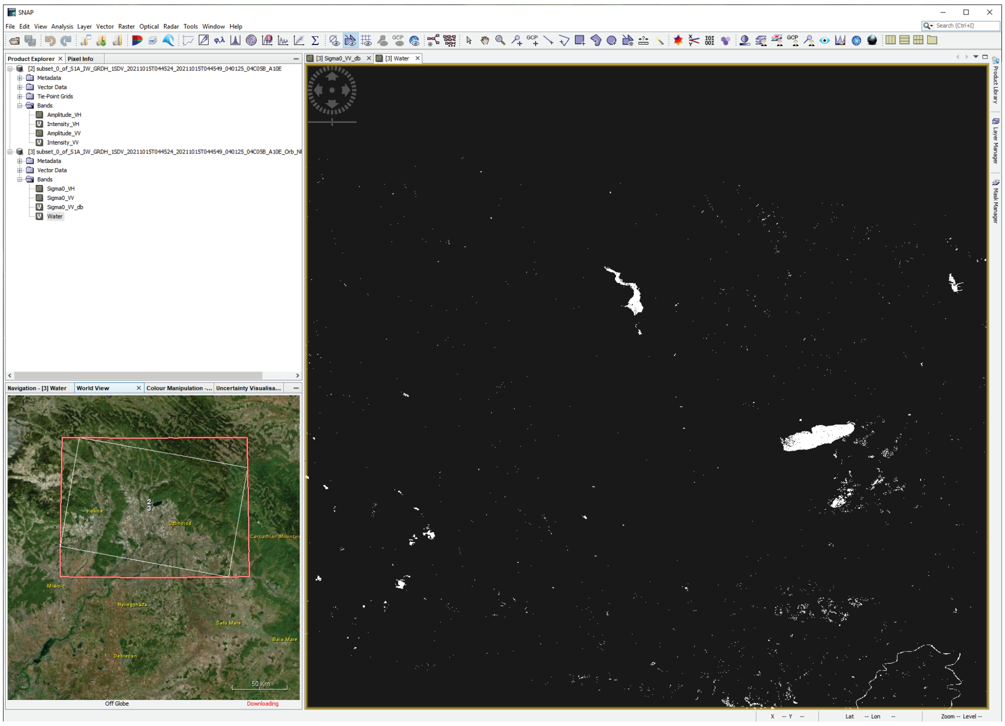


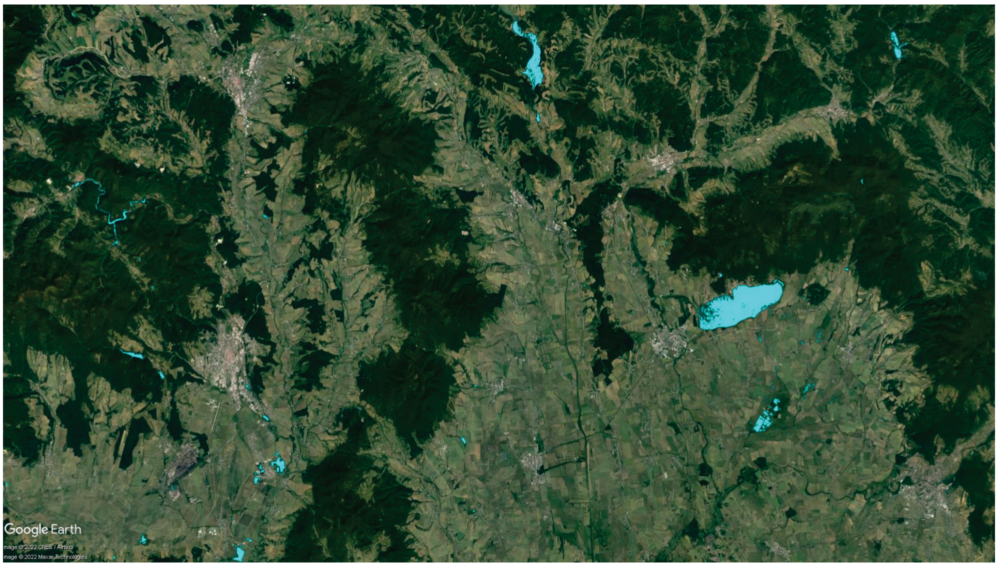
According to this statistics, the mathematical condition will be defined as:



3.4.3. Visualisation

The binary map thus created is again exported either using *.kmz or GeoTIFF to other software tools such as QGIS, ArcGIS and then the resulting map outputs can be created (for instance with the calculation of the water surface area).





THANK YOU FOR FOLLOWING THE EXERCISE!