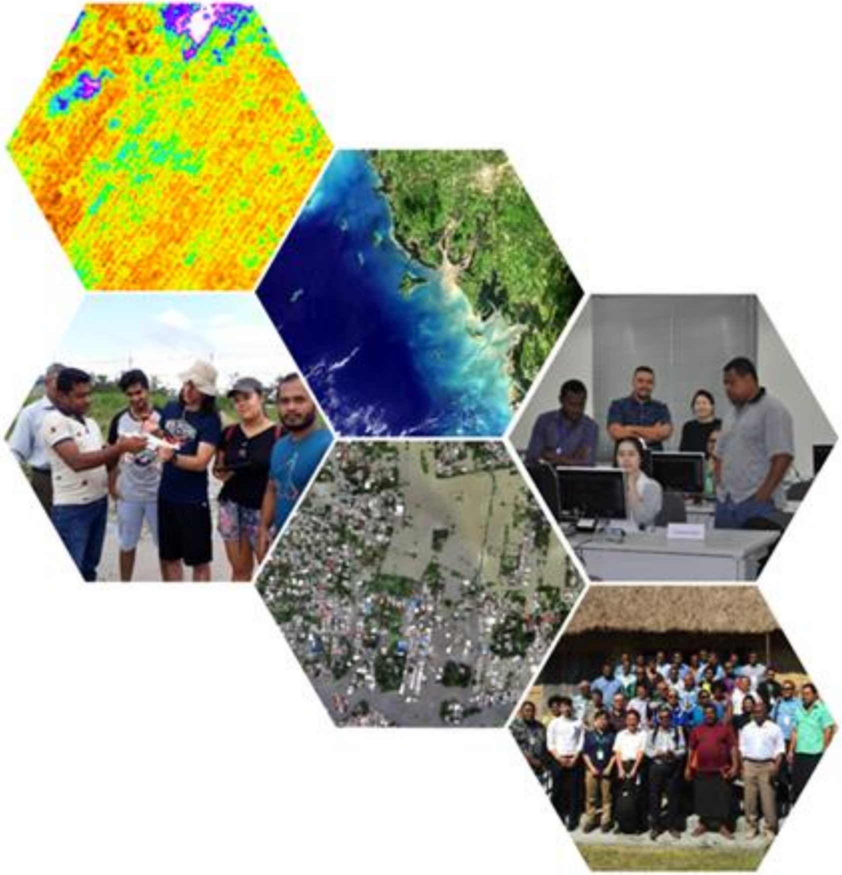

SAR Data Analysis for Flood Detection and Mapping

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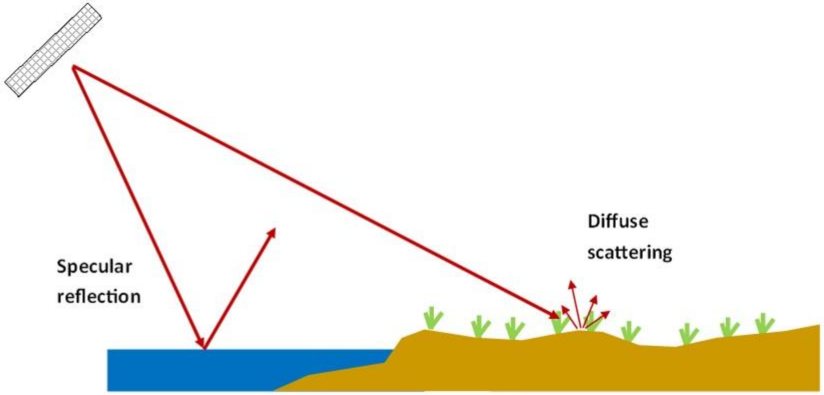
GIC

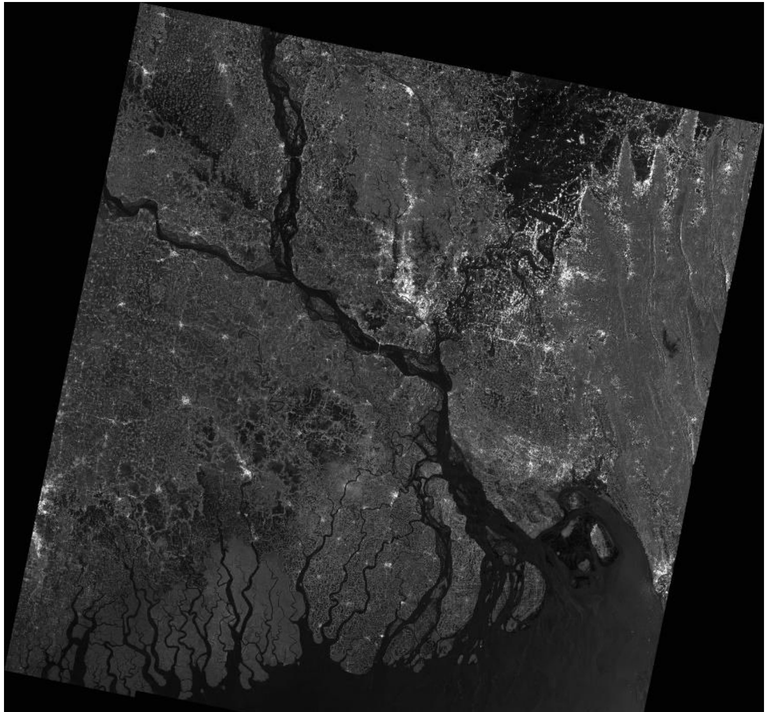
Overview

How does Synthetic Aperture Radar (SAR) detect floods?

- Water (calm) surface appears dark due to specular reflection leading to low backscatter.
- Non-water (Land) surface appear brighter due to the rough surface leading to higher backscatter.



Franz J Meyer, 2023

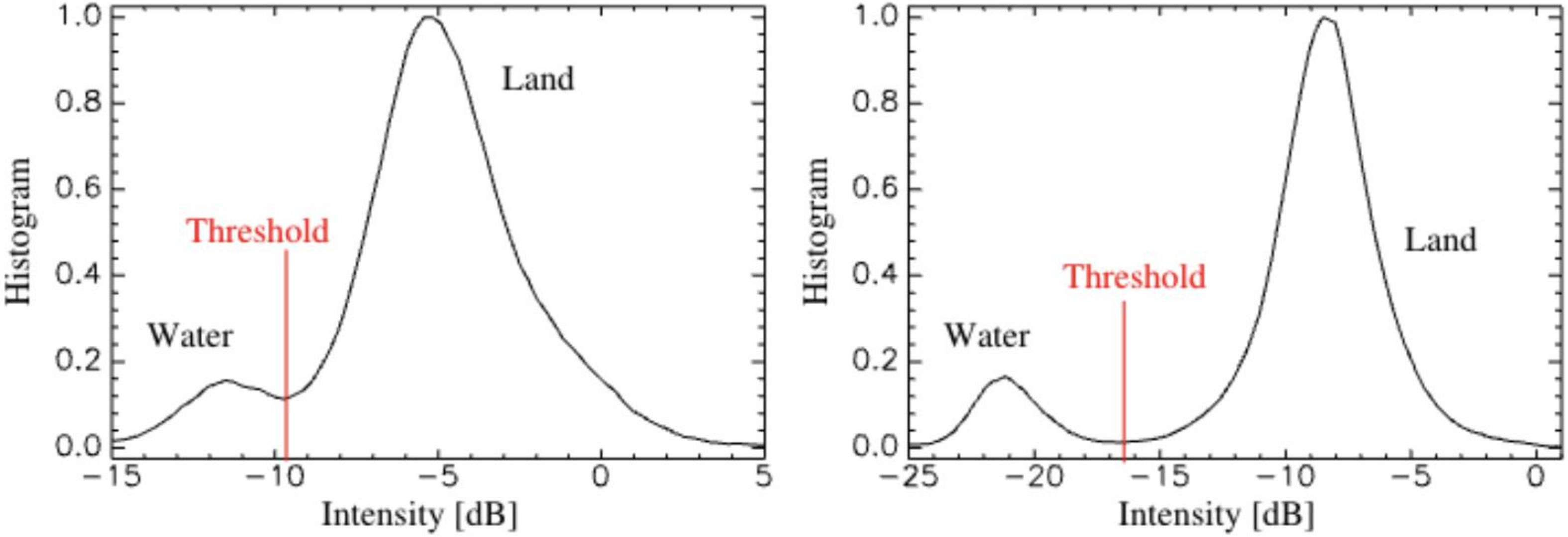


Bangladesh floods observed by ALOS-2 Level2.1
IMG HH ALOS2 43575/3150 2022/06/18 WBD R 2.1 GUD

Overview

How does Synthetic Aperture Radar (SAR) detect floods?

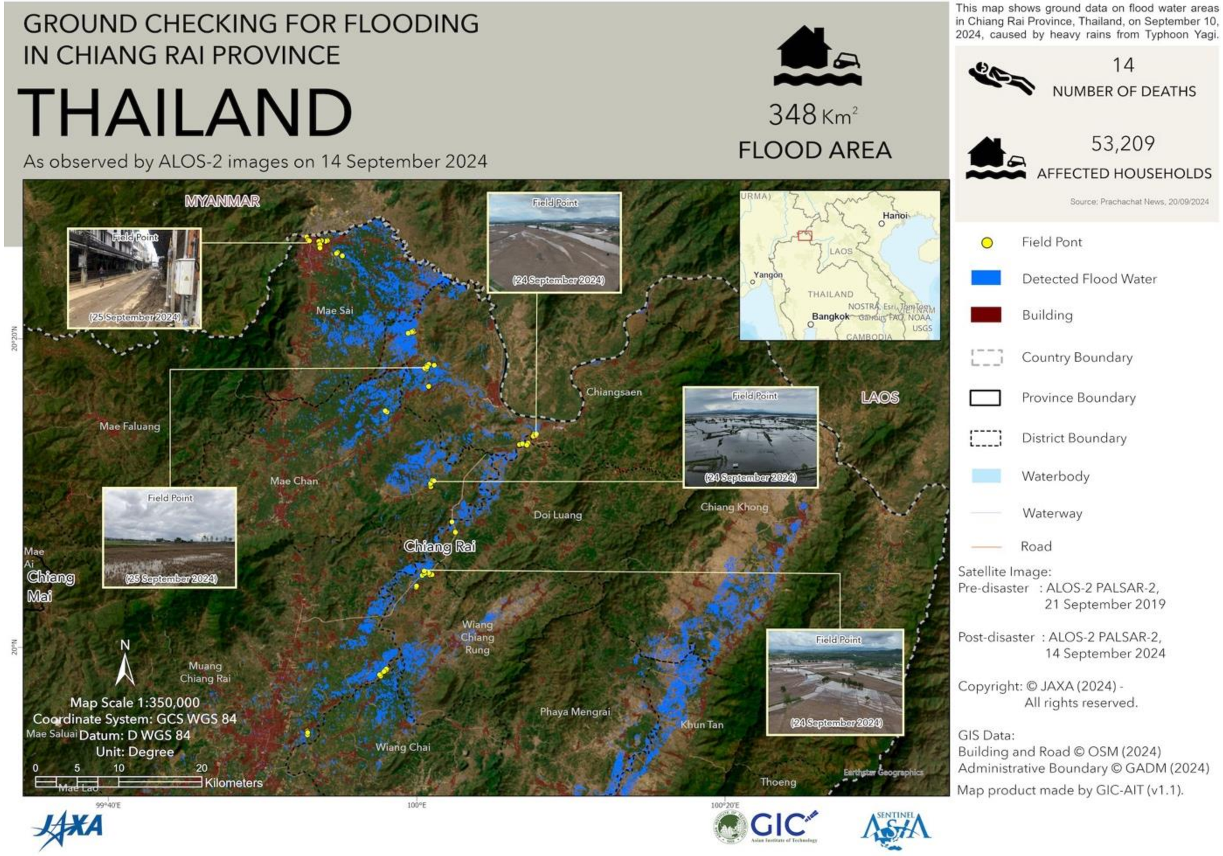
- The common method for flood detection and mapping is **thresholding**.



Histogram of two Radarsat SAR images of the same region acquired under different incidence angles. Left: Radarsat S2 (23◦ incidence angle). Right: Radarsat S7 (45◦ incidence angle) (Solbø & Solheim, 2004)

Overview

Sentinel Asia activation in Thailand



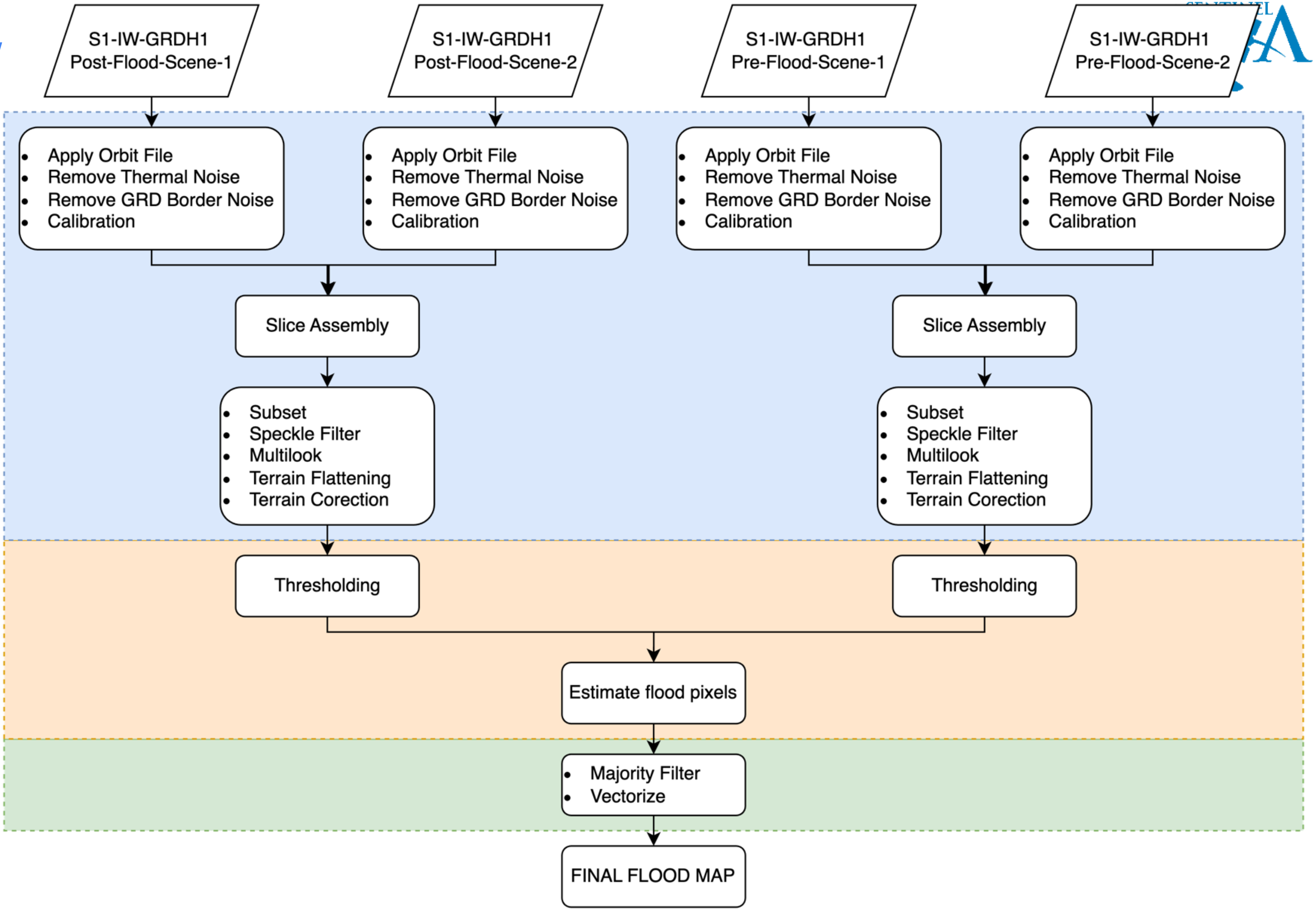
Floods in Northern Thailand

Northern Thailand, particularly Chiang Rai Province, is experiencing significant flooding due to continuous heavy rainfall intensified by Typhoon Yagi.

- Occurrence Date (UTC): 10 Sep. 2024
- SA activation Date(UTC): 12 Sep. 2024
- Requester: Geo-Informatics and Space Technology Development Agency (GISTDA)

Note: The International Disaster Charter (IDC) was also activated for this event via another mechanism.

Workflow



PRE-PROCESSING

PROCESSING

POST-PROCESSING

Overview

Data and Software

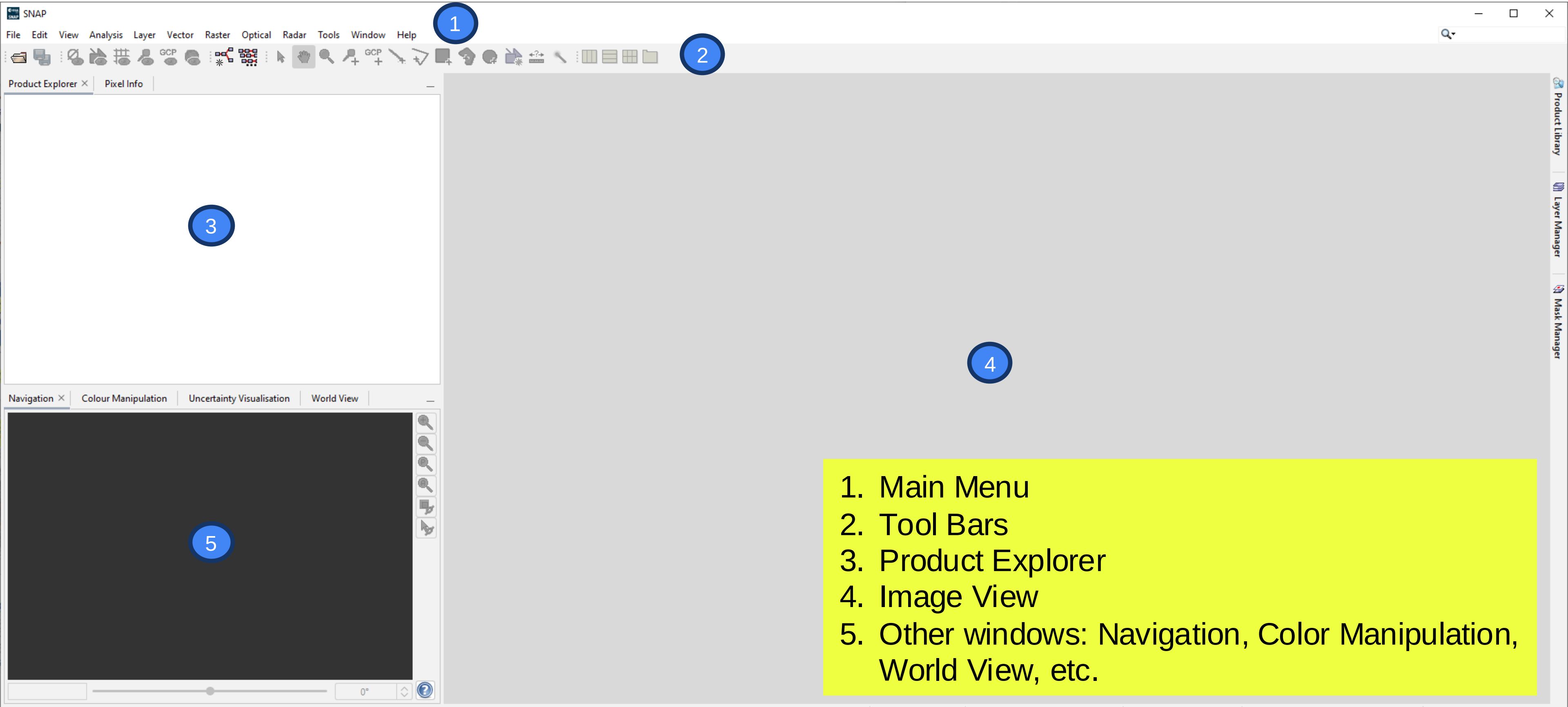
In this exercise, you will work with SNAP software to perform pre-processing from a pair of Sentinel-1 data. QGIS will be used to identify flood pixels, clean the output, and visualize the map.

Data:

- Sentinel-1 GRDH on 15 Sept. 2024 (Post-flood):
  S1A_IW_GRDH_1SDV_20240915T231601_20240915T231626_055682_06CCBA_08DA.SAFE
  S1A_IW_GRDH_1SDV_20240915T231626_20240915T231651_055682_06CCBA_F73A.SAFE
- Sentinel-1 GRDH on 21 Sept. 2023 (Pre-flood):
  S1A_IW_GRDH_1SDV_20230921T231605_20230921T231630_050432_0612B3_4935.SAFE
  S1A_IW_GRDH_1SDV_20230921T231630_20230921T231655_050432_0612B3_053E.SAFE

Data Pre-processing

Open SNAP software

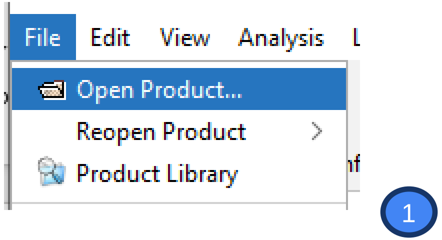


1. Main Menu
2. Tool Bars
3. Product Explorer
4. Image View
5. Other windows: Navigation, Color Manipulation, World View, etc.

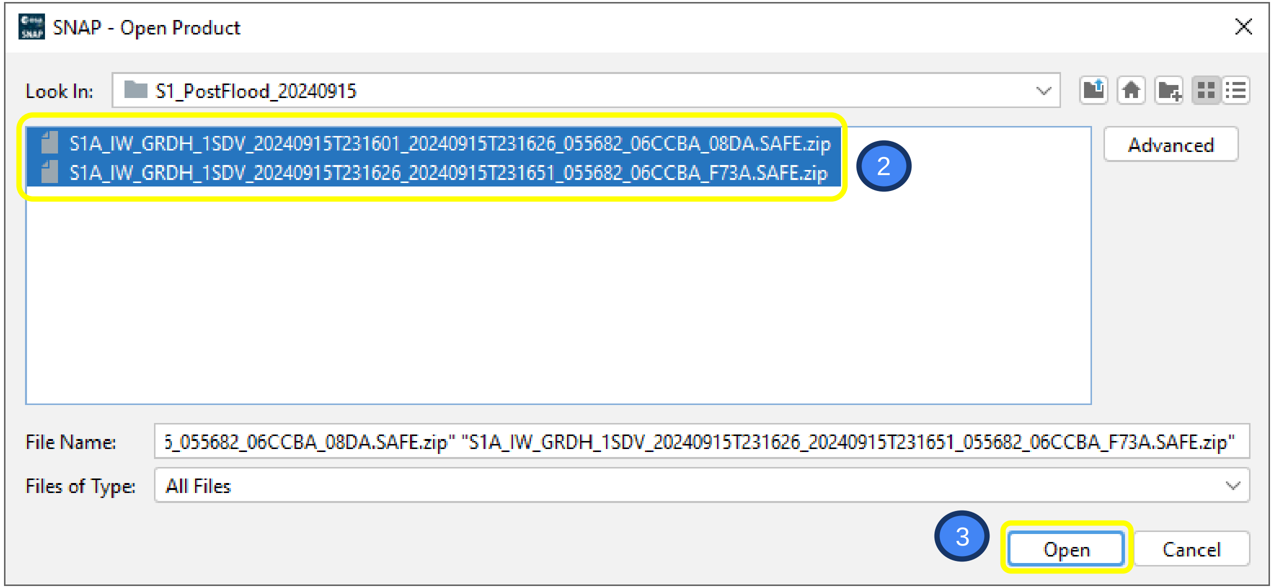
Data Pre-processing

Open Sentinel-1 Data (post-flood image)

First, let's open **Sentinel-1 images during the floods**. The area of interest is covered by two scenes, so we will open both images here.



1. In the Main Menu, go to File → Open Product…

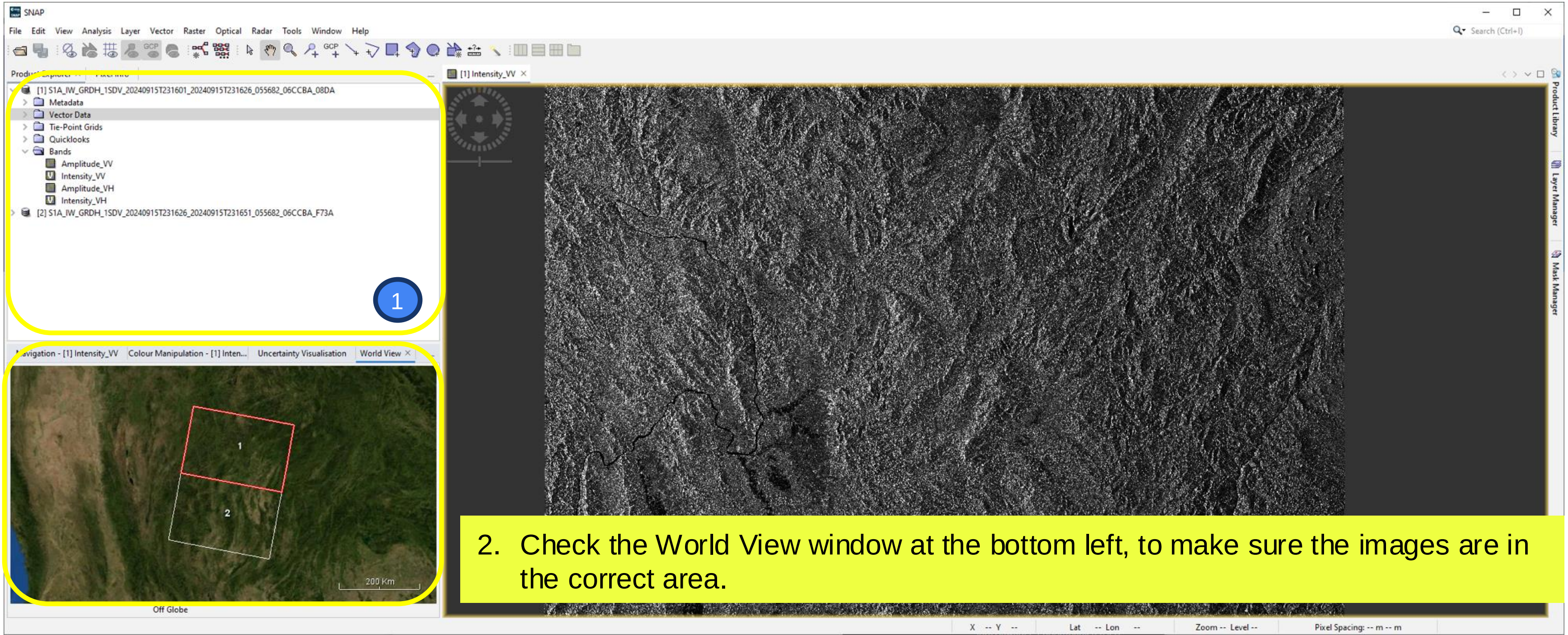


2. Browse to the location of the data. Then select both files of Sentinel-1 data. Each file refers to a different acquisition date.
3. Click Open

Data Pre-processing

Explore the Sentinel-1 Data

1. The opened products will appear in the Product Explorer window. Click > to expand the contents of the product [1], then expand the Bands folder and double-click on the Intensity_VV band to visualize it. You can also open other folders, to check the metadata and other info.

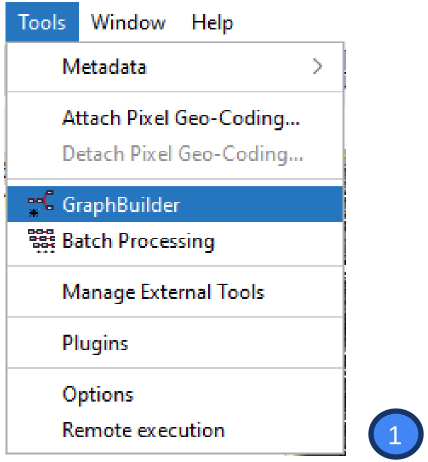


2. Check the World View window at the bottom left, to make sure the images are in the correct area.

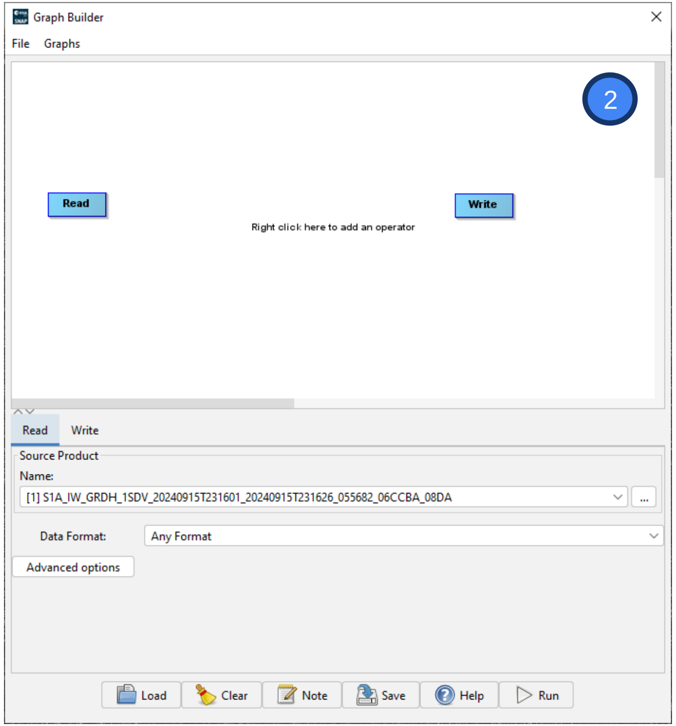
Data Pre-processing

Open Graph Builder

We will use the **Batch Processing** tool available in SNAP to apply all steps to both images in one go (this also saves disk space as only the final product is physically saved).



1. In the Main Menu, open Tools → GraphBuilder



2. The **Graph Builder** window will show up.

   In the beginning, the graph has only two operators: **Read** (to read the input) and **Write** (to write the output). We will create a step-by-step workflow to apply identical pre-processing steps to both of our scenes.

Data Pre-processing

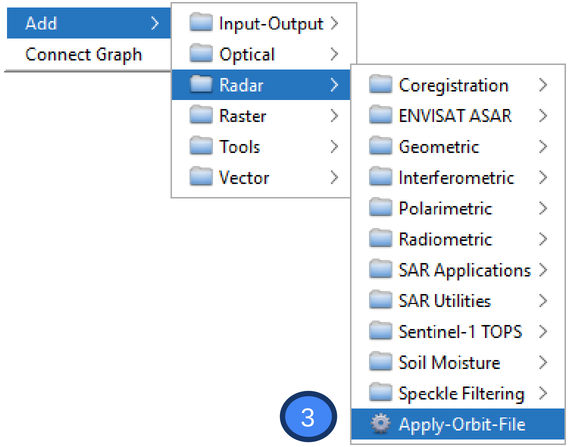
Update the orbit metadata

- The orbit state vectors provided in the metadata of a SAR product are generally not accurate and can be refined with the precise orbit files which are available days-to-weeks after the generation of the product.

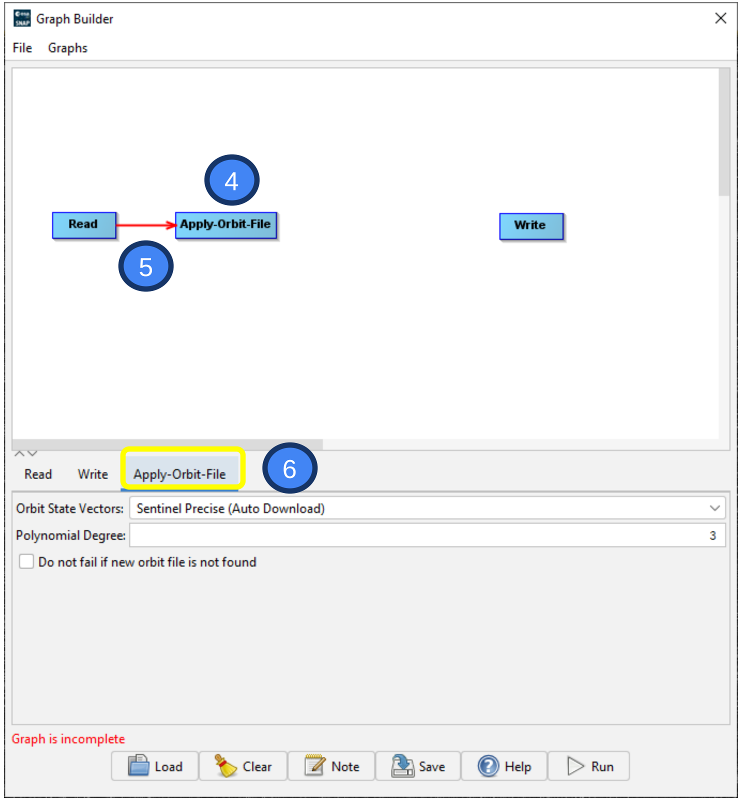
- The orbit file provides accurate satellite position and velocity information. Based on this information, the orbit state vectors in the abstract metadata of the product are updated.

Data Pre-processing

Update the orbit metadata



3. To add the operator right-click the white space between the existing operators and go to Add → Radar → Apply-Orbit-File



4. A new operator rectangle appeared in our graph.
5. Now connect the new **Apply-Orbit-File** operator with the Read operator by clicking to the right side of the Read operator and dragging the red arrow towards the **Apply-Orbit-File** operator.
6. Notice that a new tab also appeared below the graph.

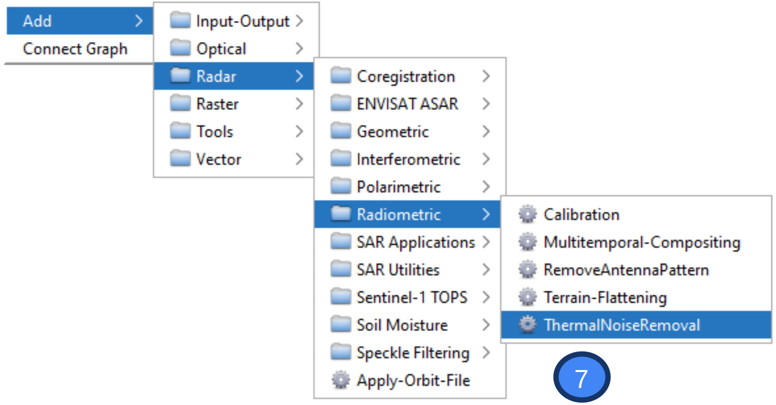
Data Pre-processing

Remove the thermal noise

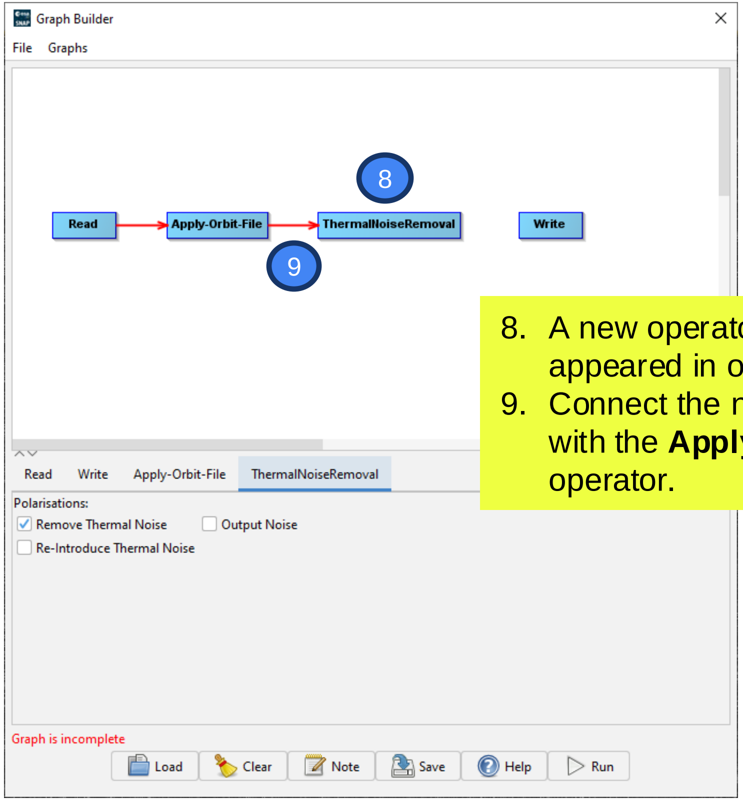
- Thermal noise in SAR imagery is the background energy that is generated by the receiver itself.
- It skews the radar reflectivity to towards higher values and hampers the precision of radar reflectivity estimates.
- Level-1 products provide a noise LUT for each measurement dataset, provided in linear power, which can be used to remove the noise from the product.

Data Pre-processing

Remove the thermal noise



7. Right-clicking the white space somewhere and go to to Add → Radar → Radiometric → ThermalNoiseRemoval



8. A new operator rectangle appeared in our graph.
9. Connect the new operator with the **Apply-Orbit-File** operator.

Data Pre-processing

Remove GRD border noise

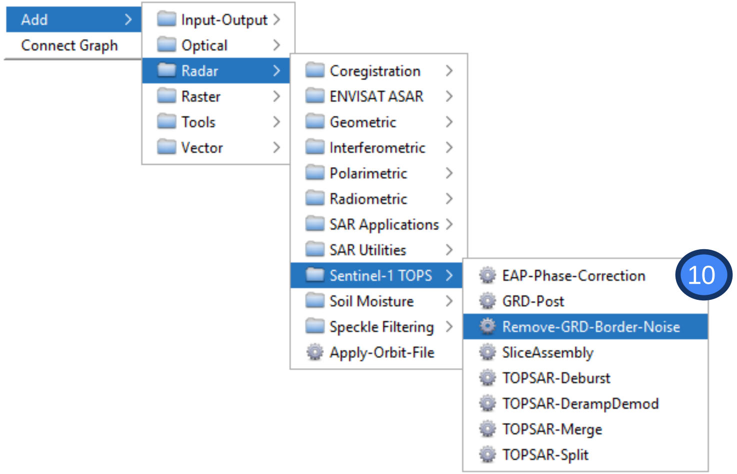
- The Sentinel-1 GRD (ground range detected) Level-1 product has noise artifacts at the image borders, which are quite consistent at both the left and right sides of the satellite's cross-track and at the start and end of the data take-along track.

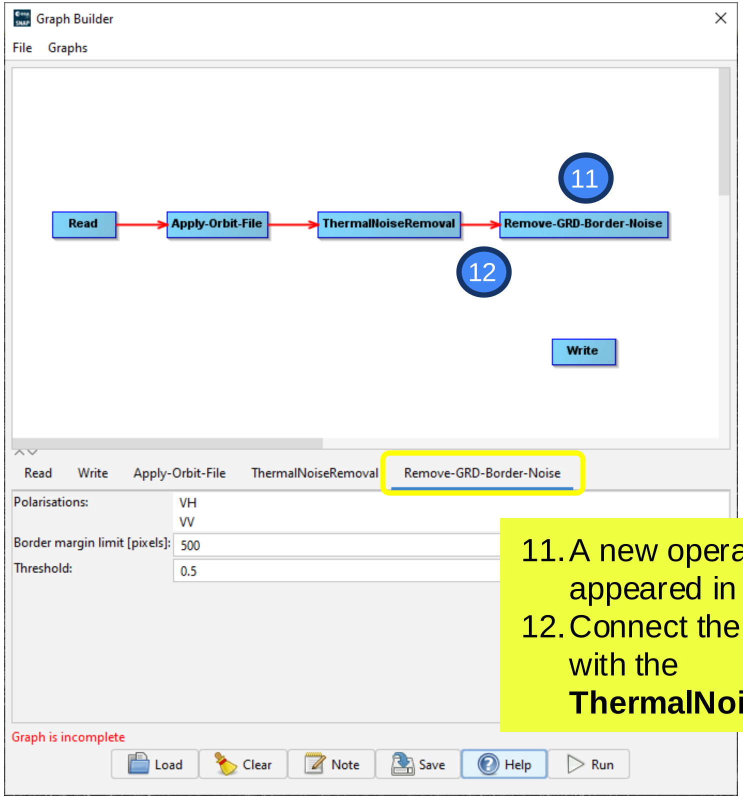
- The Sentinel-1 border noise troubles the creation of a clean and consistent time series of backscatter.

- These processing steps are mainly the azimuth and /range compression and the sampling start time changes handling that is necessary to compensate for the change of earth curvature.

Data Pre-processing

Remove GRD Border Noise





10. Right-clicking the white space somewhere and go to Add → Radar → Sentinel-1 TOPS → Remove-GRD-Border-Noise

11. A new operator rectangle appeared in our graph.
12. Connect the new operator with the **ThermalNoiseRemoval**

Data Pre-processing

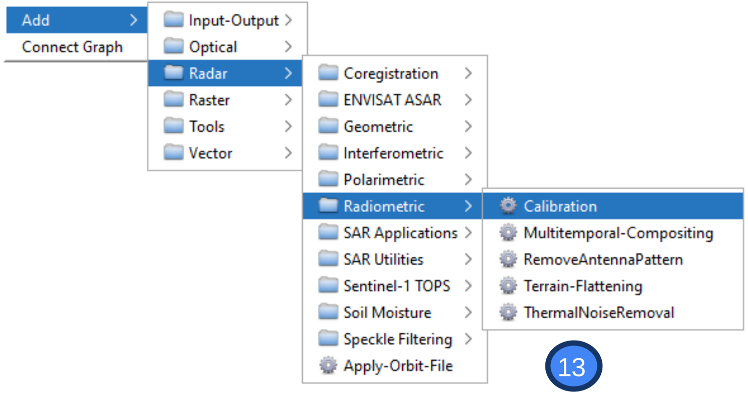
Calibration

- Typical SAR data processing, which produces level-1 images, does not include radiometric corrections and significant radiometric bias remains.

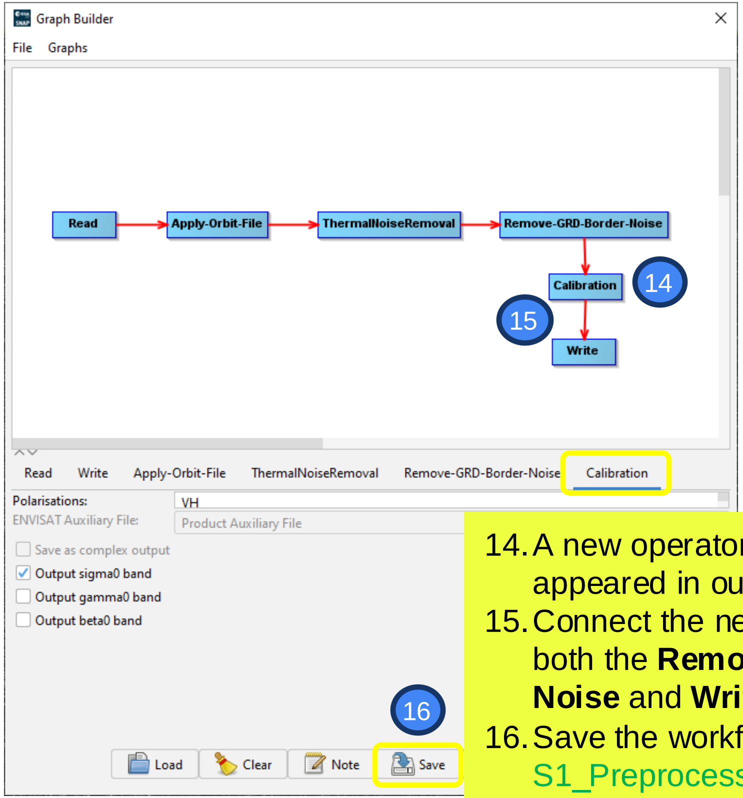
- The radiometric correction is necessary for the pixel values to truly represent the radar backscatter of the reflecting surface and therefore for comparison of SAR images acquired with different sensors or acquired from the same sensor but at different times, in different modes, or processed by different processors.

Data Pre-processing

Calibration



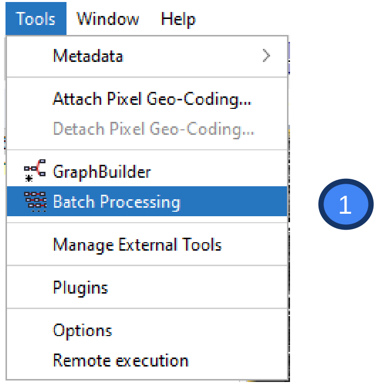
13. Right-clicking the white space somewhere and go to Add → Radar → Radiometric → Calibration



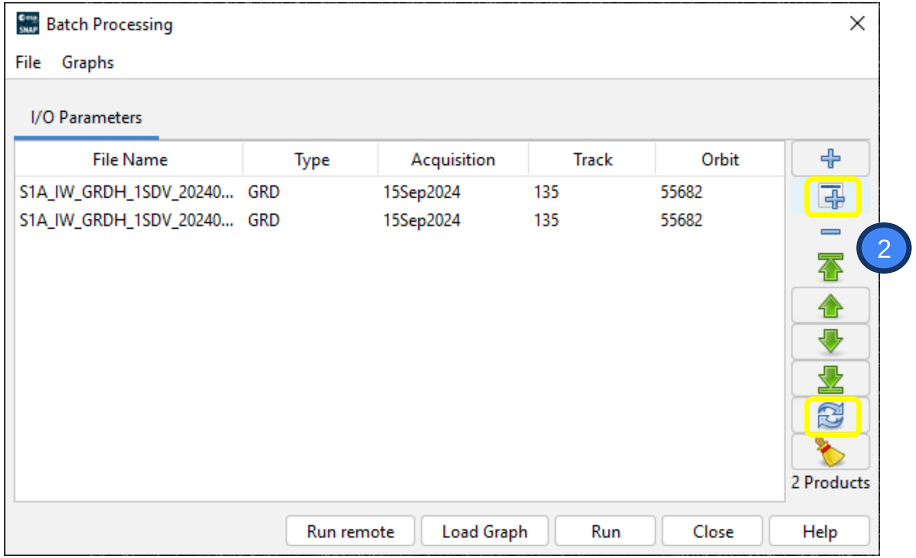
14. A new operator rectangle appeared in our graph.
15. Connect the new operator with both the **Remove-GRD-Border-Noise** and **Write** operators.
16. Save the workflow to S1_Preprocessing_1.xml
17. Close the Graph Builder window.

Data Pre-processing

Batch processing



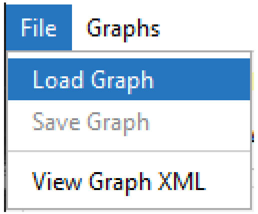
1. In the Main Menu, open the Batch Processing tool (Tools → Batch Processing).



2. We will add both opened products by clicking **Add Opened** in the upper right (the second icon from the top) and then clicking **Refresh** (the second icon from the bottom).

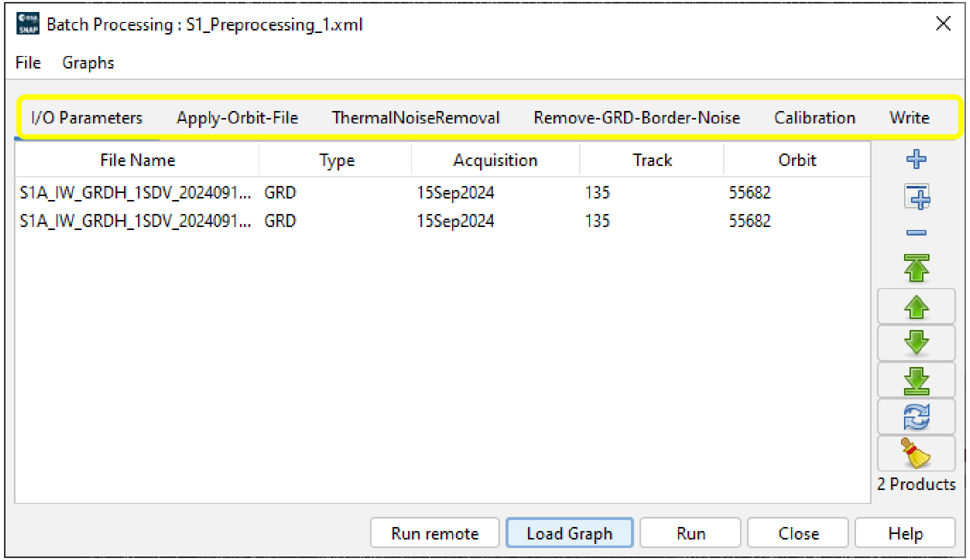
Data Pre-processing

Batch processing



3

3. In the **Batch Processing** window, click File → Load Graph and navigate to our saved graph (S1_Preprocessing_1.xml) and open it.

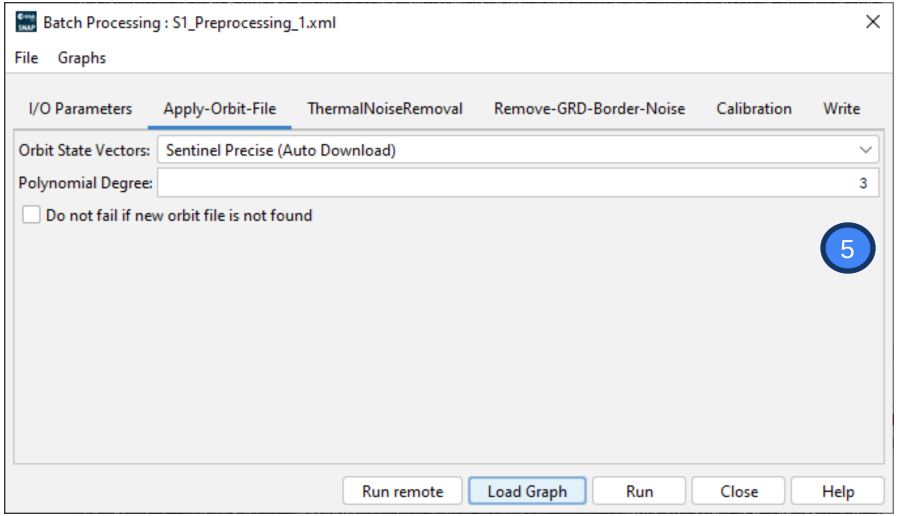


4

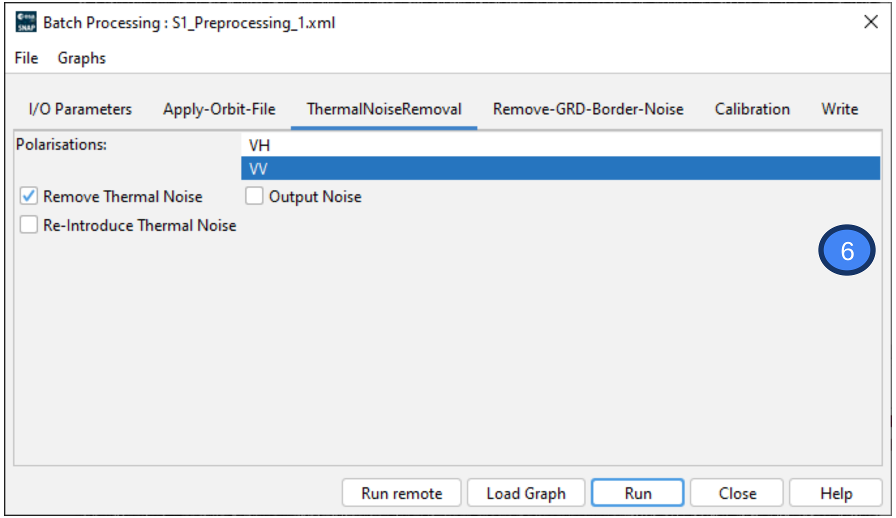
4. We see that new tabs have appeared at the top of the **Batch Processing** window corresponding to our operators. We will change the parameter of each operator in the next steps.

Data Pre-processing

Batch processing



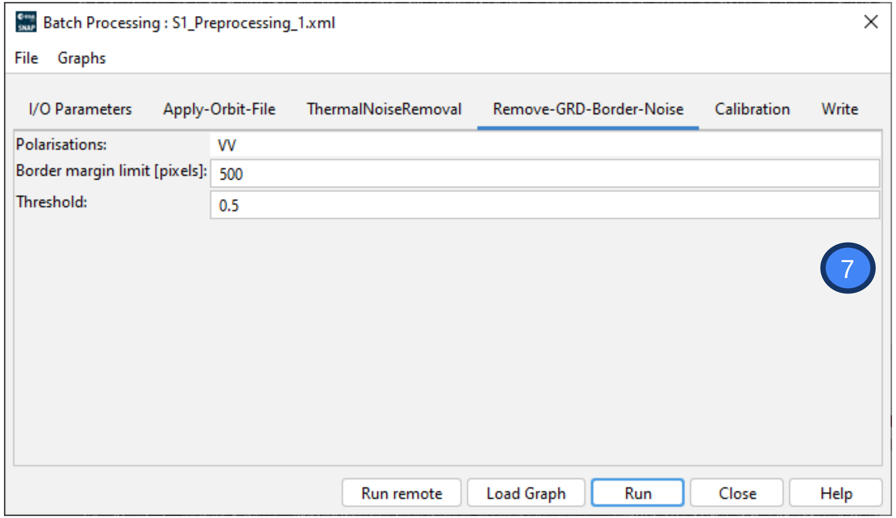
5. In the Apply-Orbit-File tab, accept the default settings.

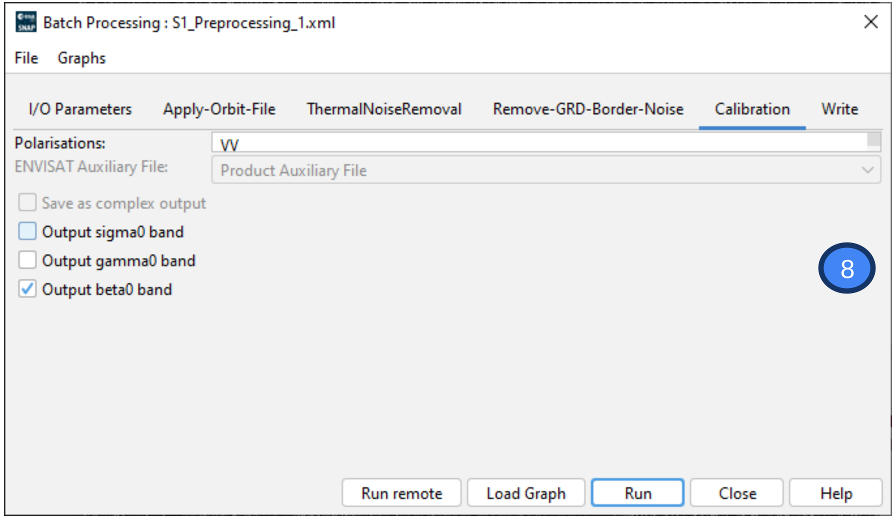


6. In the ThermalNoiseRemoval tab select VV polarization and make sure that the “Remove Thermal Noise” option is selected.

Data Pre-processing

Batch processing



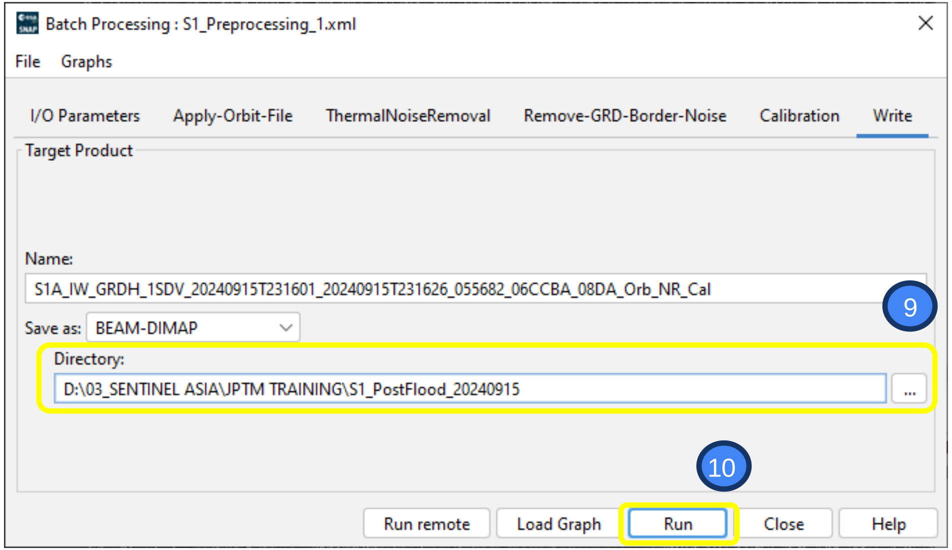


7. In the Remove-GRD-Border-Noise tab, make sure the VV polarization is selected and accept other default settings.

8. In the Calibration tab, make sure the VV polarization is selected and select the "Output beta0 band" option. The beta0 is required for another processing step (Terrain Flattening).

Data Pre-processing

Batch processing

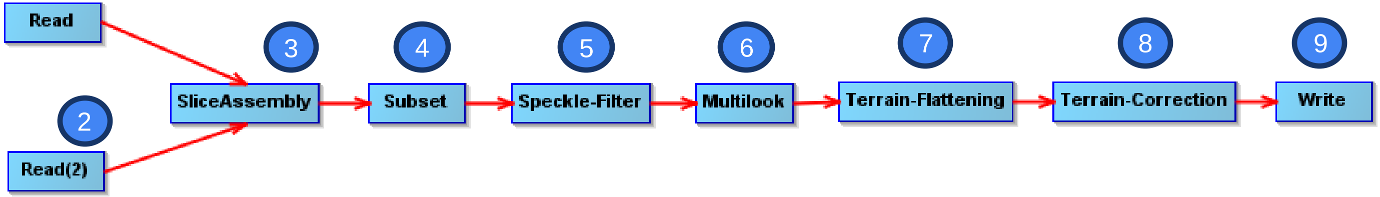


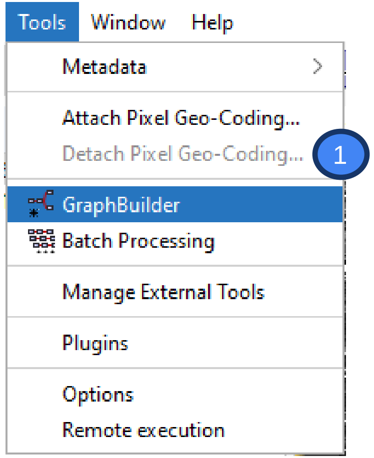
9. In the Write tab, define your output name and directory.
10. Click Run. It will take a few seconds or minutes to complete the process.

You should have 2 new products in the Product Explorer window. Close the Batch Processing window.

Data Pre-processing

Open Graph Builder again

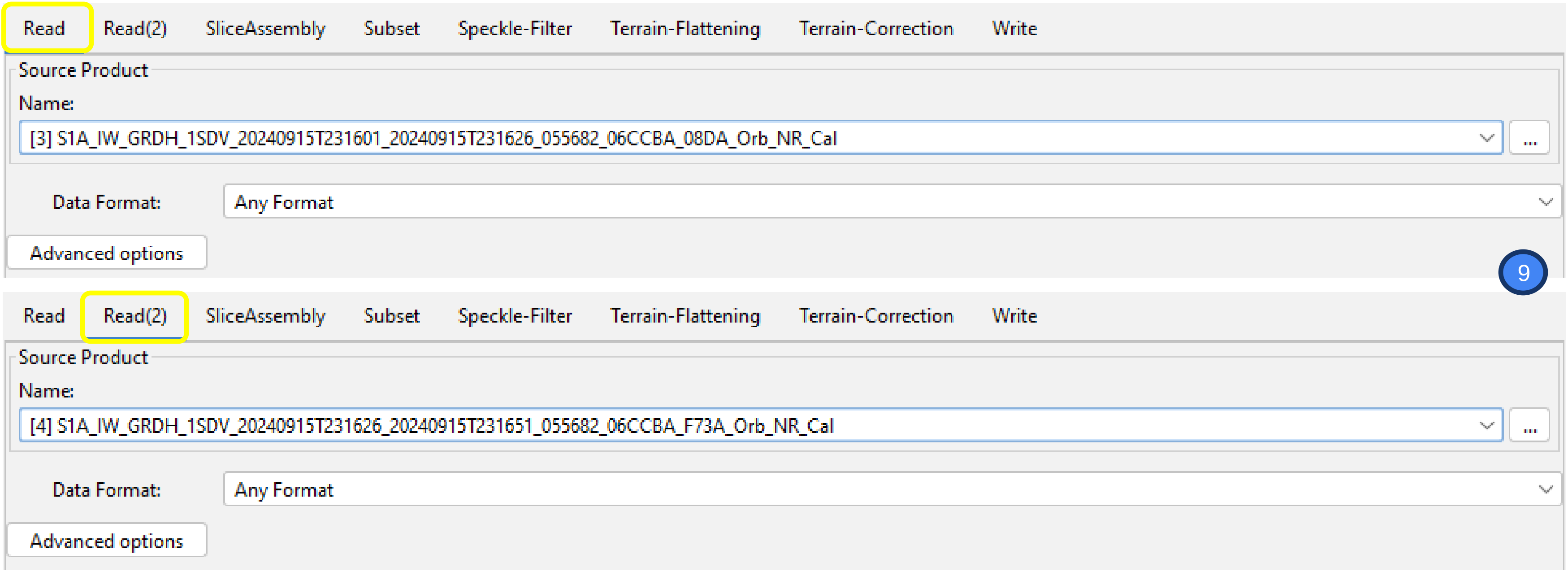




1. In the Main Menu, go to Tools → GraphBuilder

2. First, we need to delete the **Write** operator. Right click on it and select “Delete”. Then we need to add a second **Read** operator. Right-click in the white space and go to Add → Input-Output → Read.
3. We will add the **SliceAssembly** operator by going to Add → Radar → Coregistration → Add → Radar → Sentinel-1 TOPS → SliceAssembly and connect both **Read** operators to it.
4. Next, we will add the **Subset** operator (Add → Raster → Geometric → Subset) and connect the **SliceAssembly** operator to it.
5. Add the **Speckle-Filter** operator (Add → Radar → Speckle Filtering → Speckle-Filter) and connect the **Subset** operator to it.
6. (Optional) Add the **Multilook** operator (Add → Radar → SAR Utilities → Multilook) and connect the **Subset** operator to it.
7. Add the **Terrain-Flattening** operator (Add → Radar → Radiometric → Terrain-Flattening) and connect the **Speckle-Filter** operator to it.
8. Add the **Terrain-Correction** operator (Add → Radar → Geometric → Terrain Correction → Terrain-Correction) and connect the **Terrain Flattening** operator to it.
9. Lastly, we will add the **Write** operator (Add → Input-Output → Write) and connect the **Terrain-Correction** operator to it to save the final product

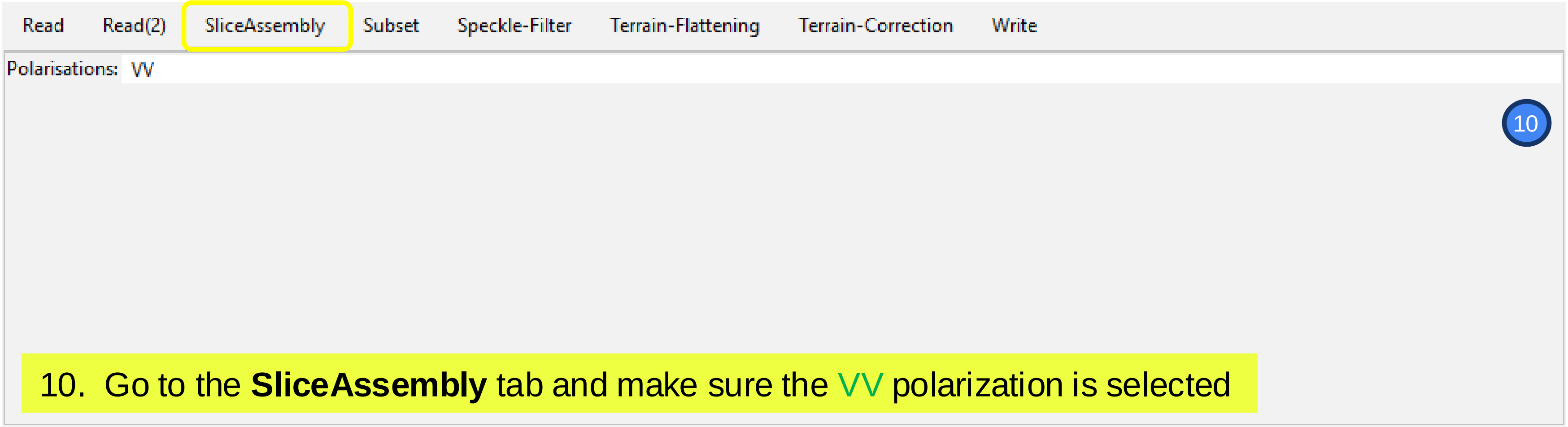
Data Pre-processing
Read data



9. First, let's go to the first **Read** tab and make sure that the pre-processed product [3] from the first scene is selected as the Source product. Then go to the **Read(2)** tab and set the pre-processed product [4] from the second scene as the Source product.

Data Pre-processing

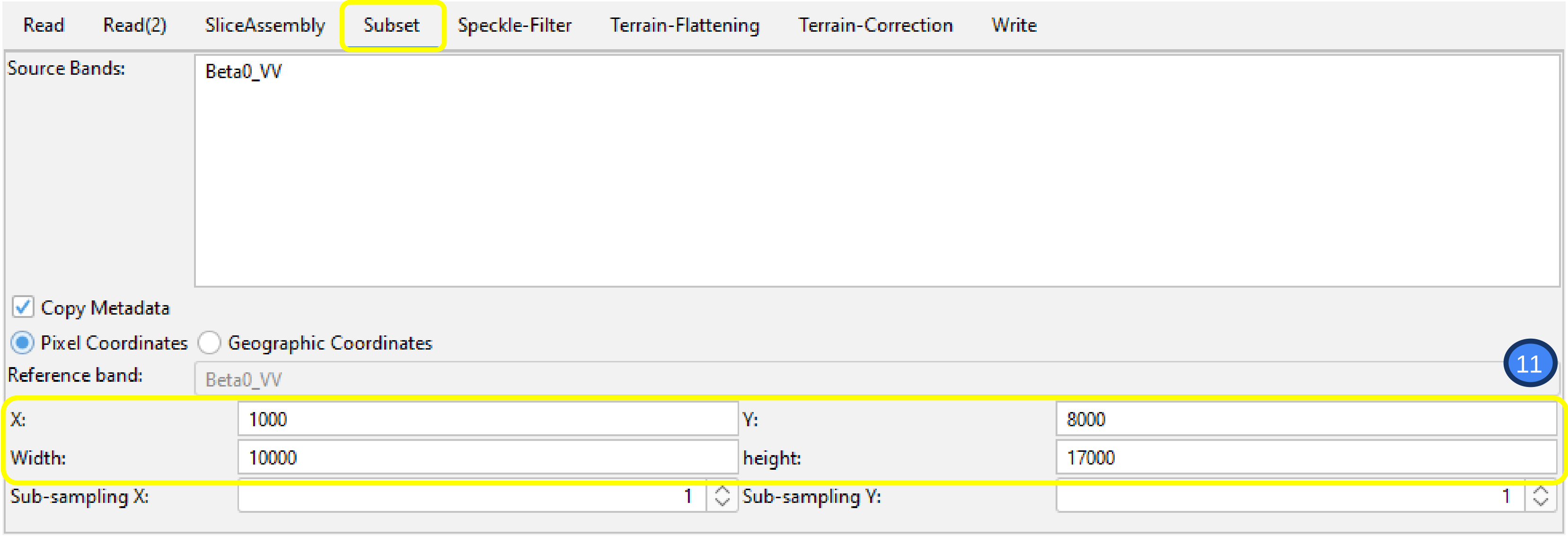
Slice assembly



- To avoid distributing huge unwieldy products to end users, the Sentinel-1 data are segmented into 'slices' of defined length along a track. Product slices make the data more manageable for users and enable the ground segment to process slice data in parallel.
- Sliced products may be seamlessly combined, including the metadata, into an assembled product. Product assembly follows specific rules for including, merging and concatenating the various components of the slice products.

Data Pre-processing

Subset image



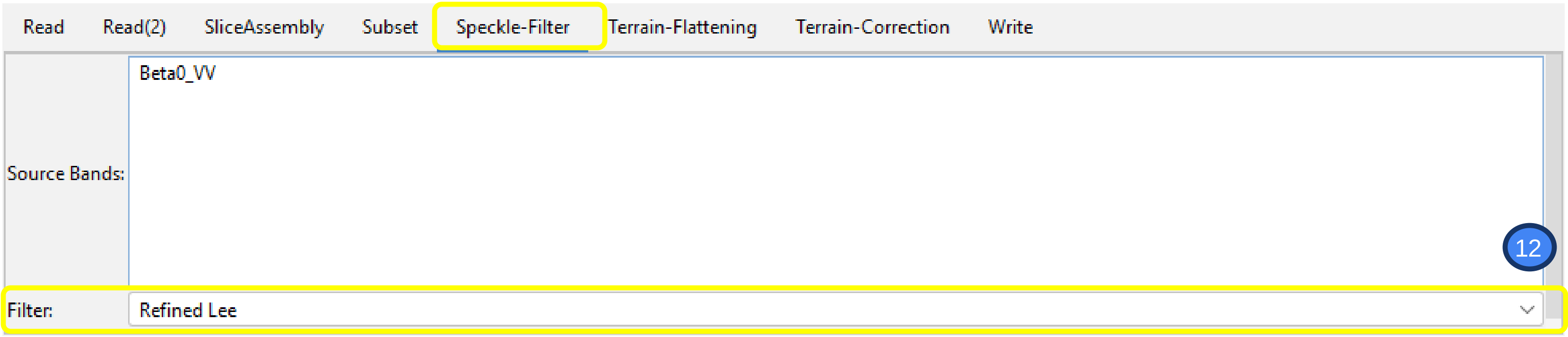
Since our Area of Interest (AOI) is less and there is no need to process the whole assembled image, we start with sub-setting the scene to a more manageable size. This will reduce the processing time in further steps and is recommended when the analysis is focused only on a specific area and not on the complete scene.

11. Go to the **Subset** tab and at “Pixel Coordinates” set:

X = 1000 Y = 8000
Width = 1000 Height = 17000

Data Pre-processing

Speckle filter



12. Go to the **Speckle-Filter** tab and select Refined Lee filter method. You can try other available filters if you'd like.

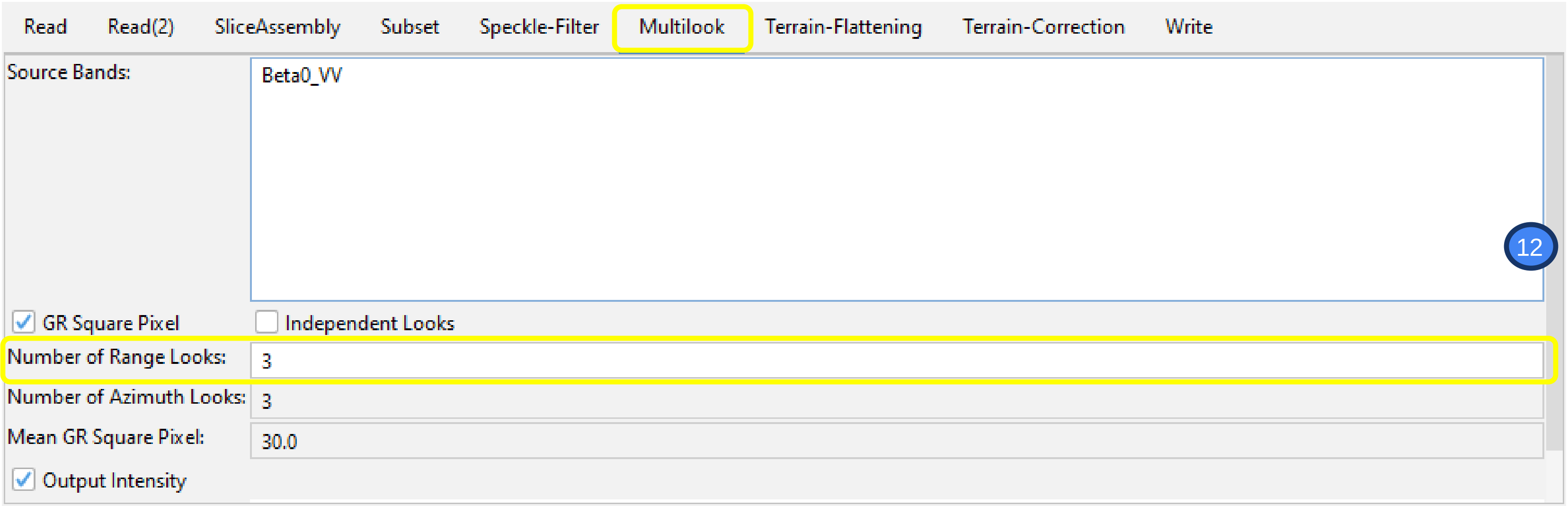
- SAR images have inherent salt and pepper like texturing called speckles which degrade the quality of the image and make interpretation of features more difficult.

- Speckles are caused by random constructive and destructive interference of the de-phased but coherent return waves scattered by the elementary scatters within each resolution cell.

- Speckle noise reduction can be applied either by spatial filtering or multilook processing. The operator supports several speckle filters for handling speckle noise of different distributions (Gaussian, multiplicative or Gamma), including Boxcar (mean), Median, Frost, Lee, Refined Lee, Gamma-MAP, Lee Sigma, IDAN.

Data Pre-processing

(Optional) Multi-look



12. Go to the **Speckle-Filter** tab and change the Number of Range Looks to 3.

- Multi-look processing can also reduce the inherent speckled appearance, thus improving the image interpretability. It can be produced by space-domain averaging of a single look image or by frequency-domain method using the sub-spectral band width.
- Additionally, multi-look processing can be used to reduce the image pixel size.

Data Pre-processing

Terrain flattening

- Terrain variations affect not only the position of a target on the Earth's surface, but also the brightness of the radar return. Without treatment, the radiometric biases caused by terrain variations are introduced into the coherency and covariance matrices.

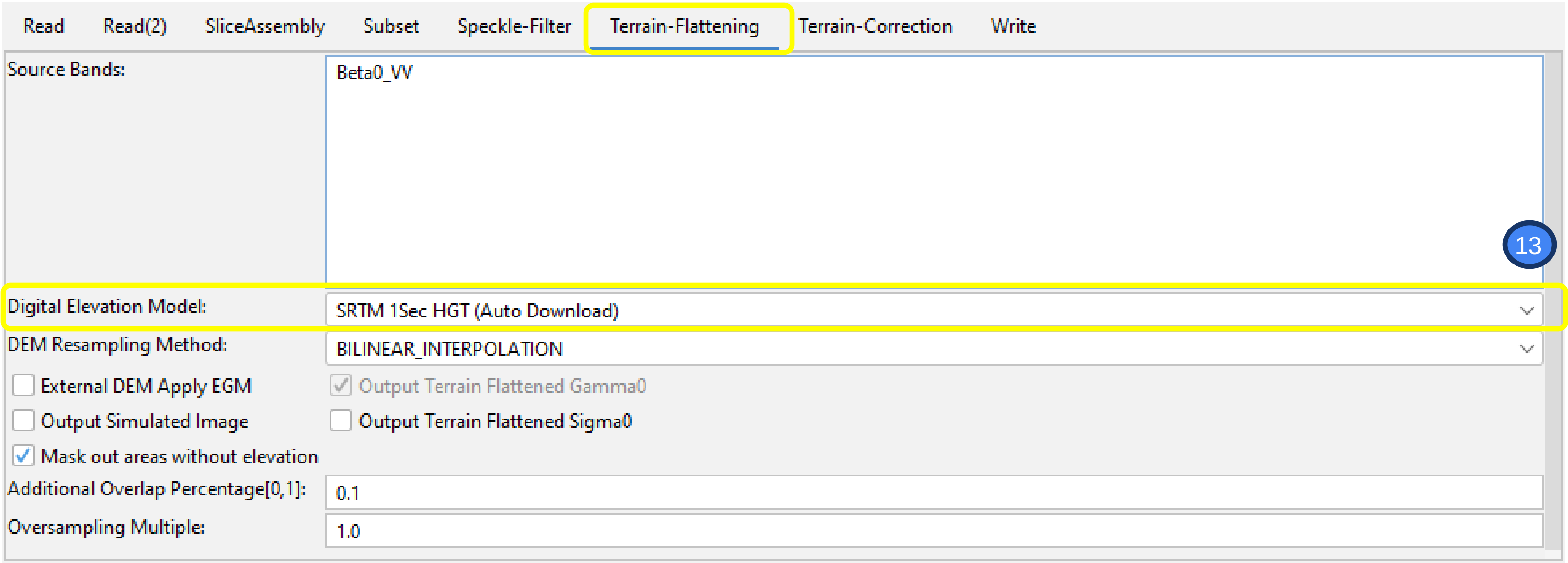
- This operator removes the radiometric variability associated with topography using the Radiometric Terrain Correction algorithm.

- In the RTC algorithm, the radiometric effect is simulated using a digital elevation model (DEM) of the imaged area. It is therefore required that the DEM resolution must be higher than the image resolution. In case that the DEM resolution is lower than the image resolution, users have two options: 1) Oversample the DEM to higher resolution, 2) Multilook the source image to lower resolution

- The input to this operator should be calibrated beta0. The output of this operator is terrain flattened gamma0.

Data Pre-processing

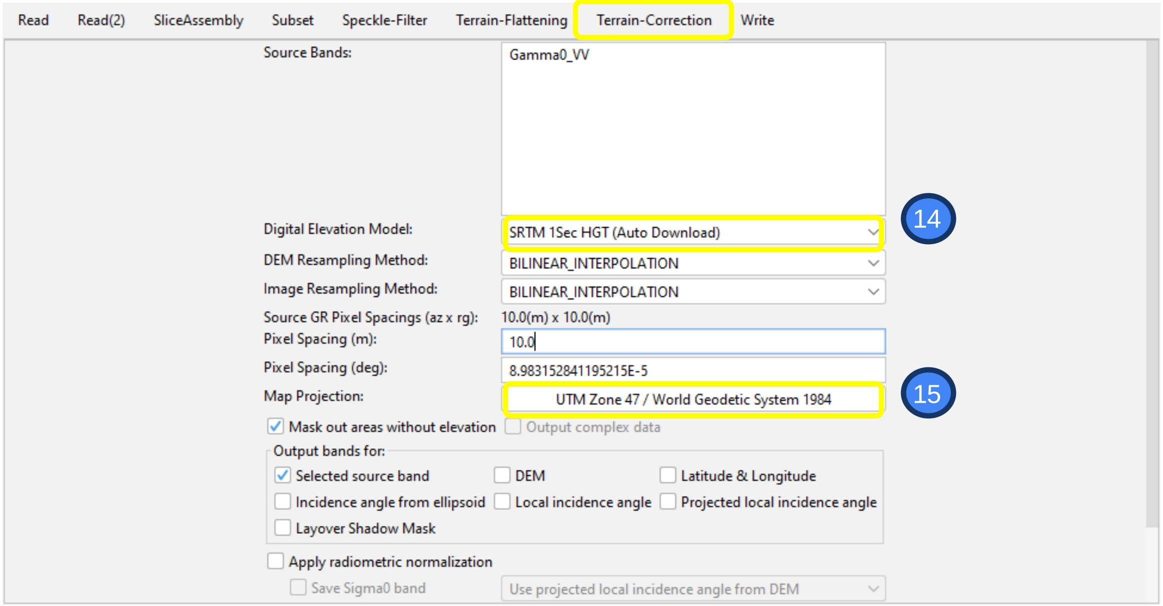
Terrain flattening

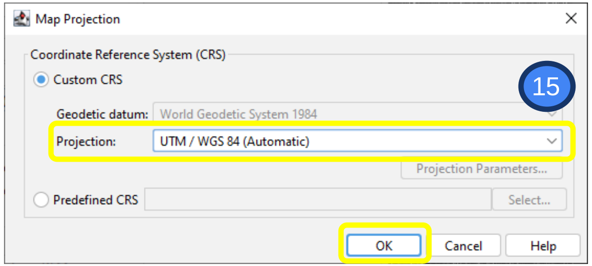


13. Go to the **Terrain-Flattening** tab and accept the default settings.

Data Pre-processing

Terrain correction



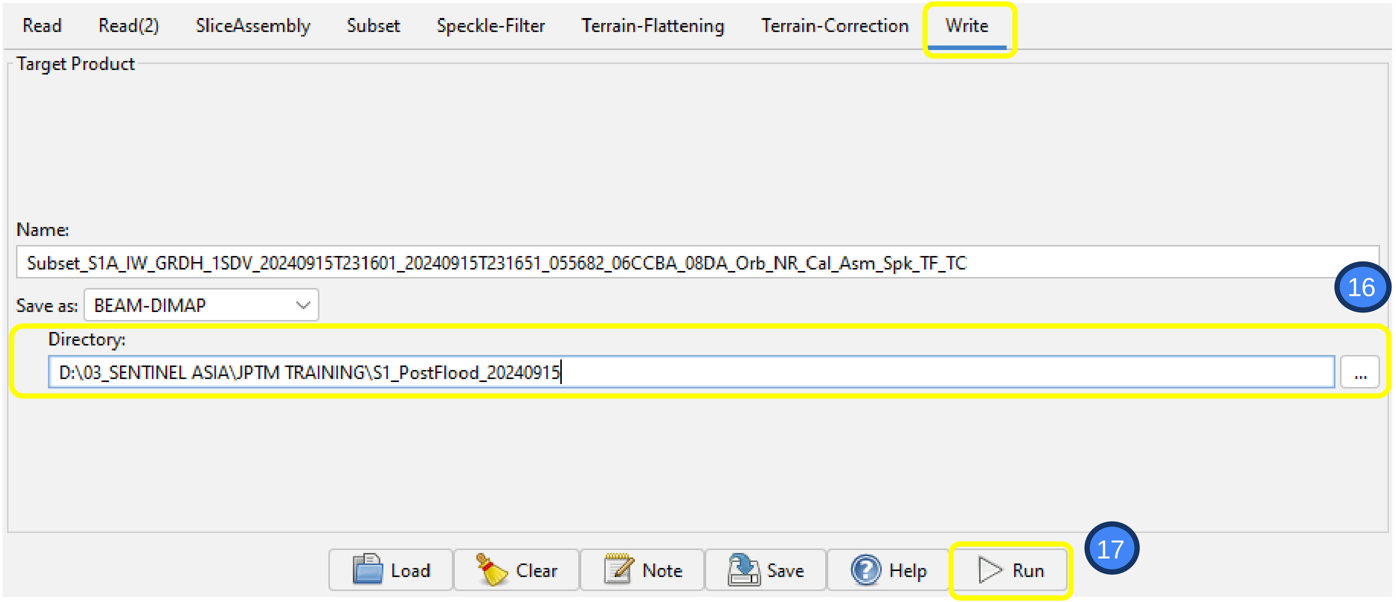


14. Go to the **Terrain-Correction** tab. In the Digital Elevation Model, select SRTM 1Sec HGT (Auto Download).
15. In the Map Projection, select projection UTM/WGS 84 (Automatic) and click OK.

- Due to topographical variations of a scene and the tilt of the satellite sensor, distances can be distorted in the SAR images.
- Image data not directly at the sensor's Nadir location will have some distortion.
- Terrain corrections are intended to compensate for these distortions so that the geometric representation of the image will be as close as possible to the real world.

Data Pre-processing

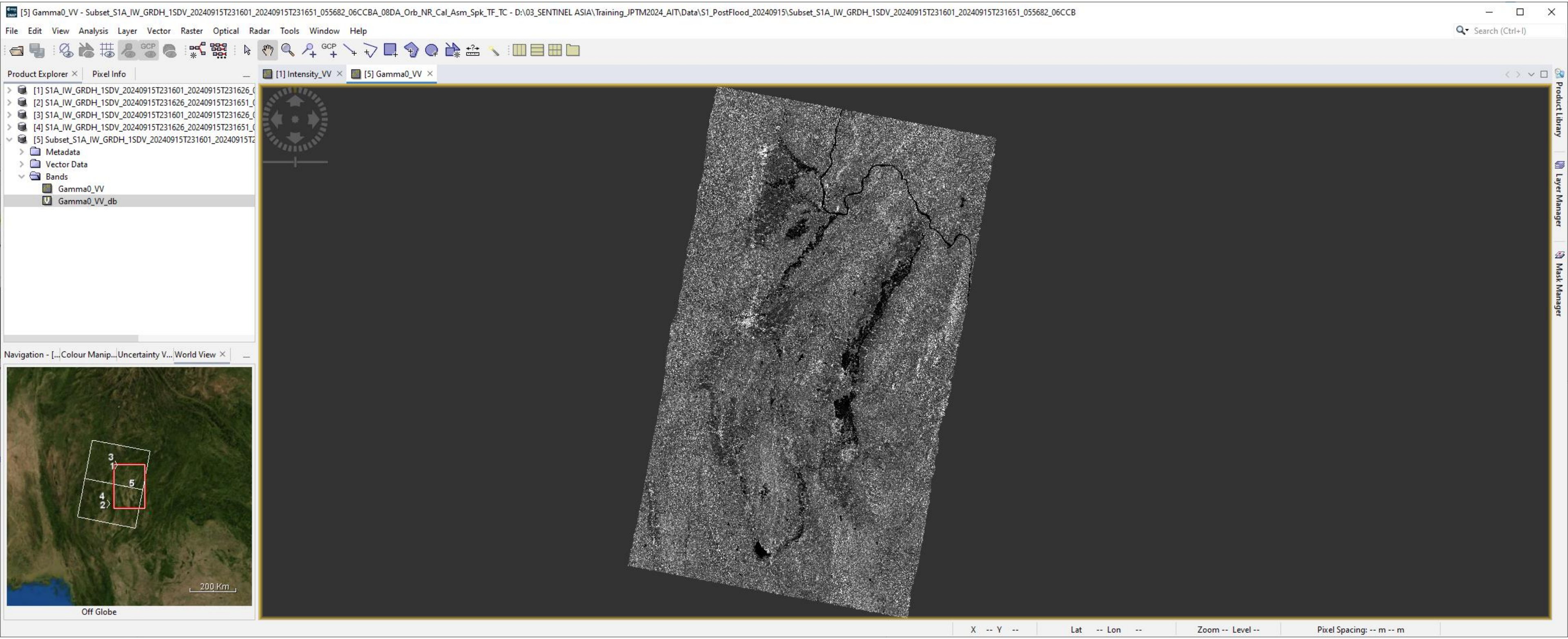
Write output and Run the Graph Builder



16. Go to the Write tab and define your output directory.
17. Now that all settings are completed. Run the Graph Builder.

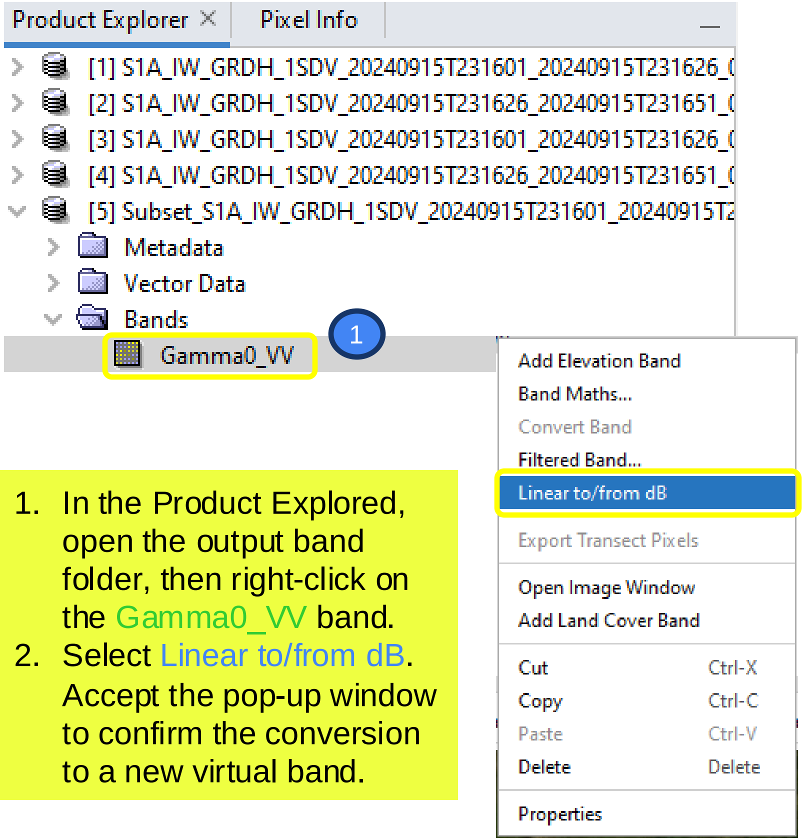
Data Pre-processing

Visualize the output

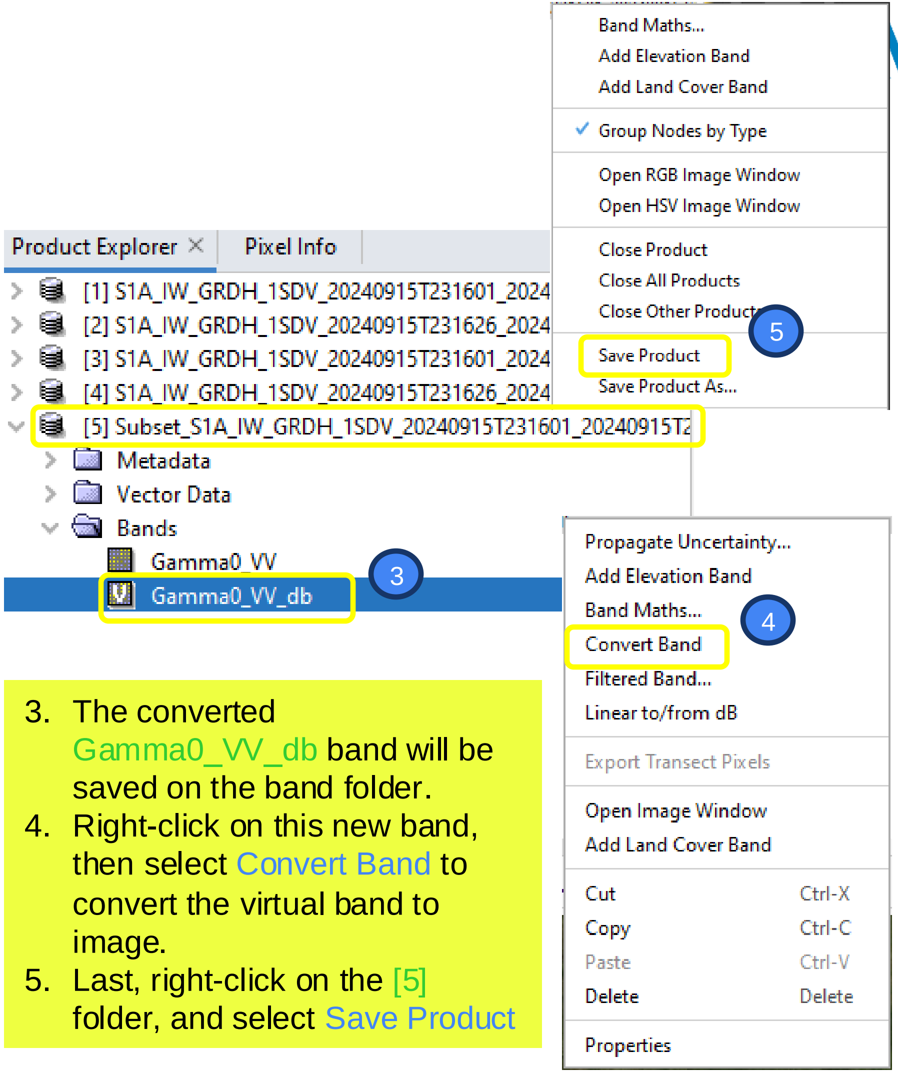


Data Pre-processing

Convert to decibel



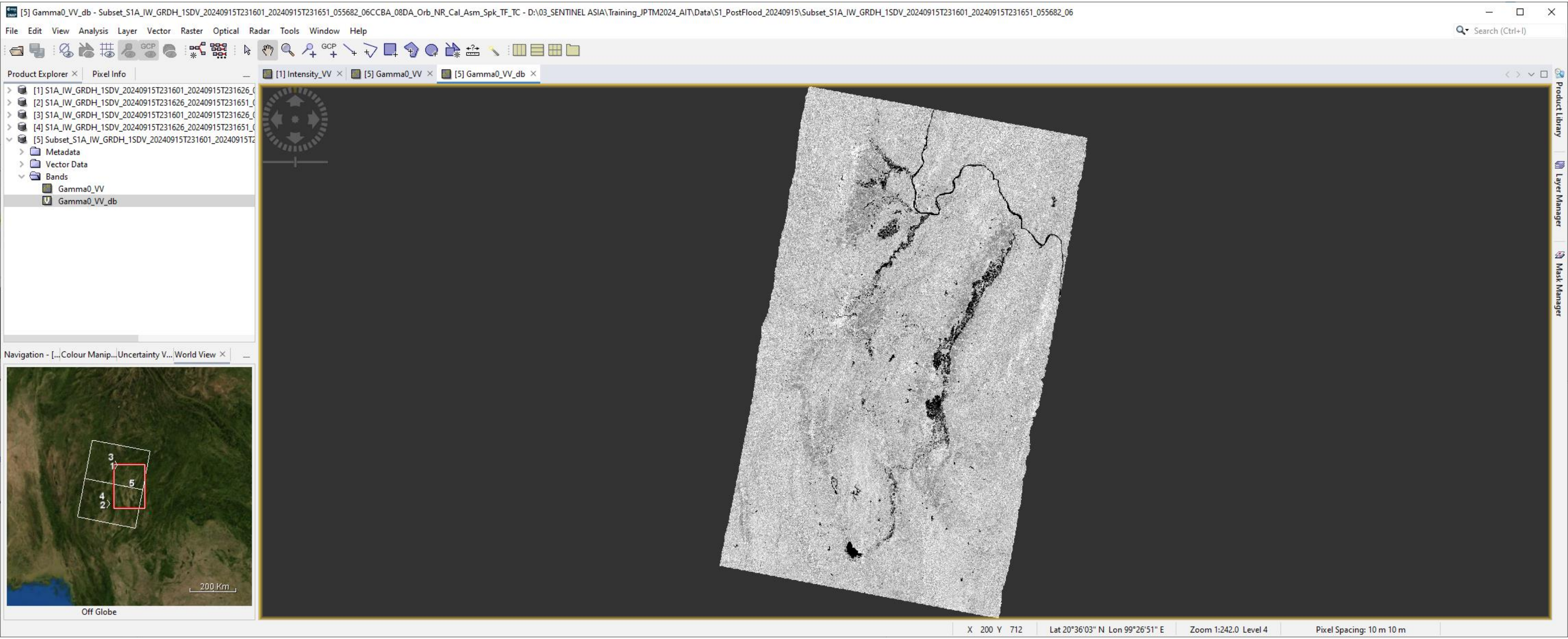
1. In the Product Explored, open the output band folder, then right-click on the Gamma0_VV band.
2. Select Linear to/from dB. Accept the pop-up window to confirm the conversion to a new virtual band.



3. The converted Gamma0_VV_db band will be saved on the band folder.
4. Right-click on this new band, then select Convert Band to convert the virtual band to image.
5. Last, right-click on the [5] folder, and select Save Product

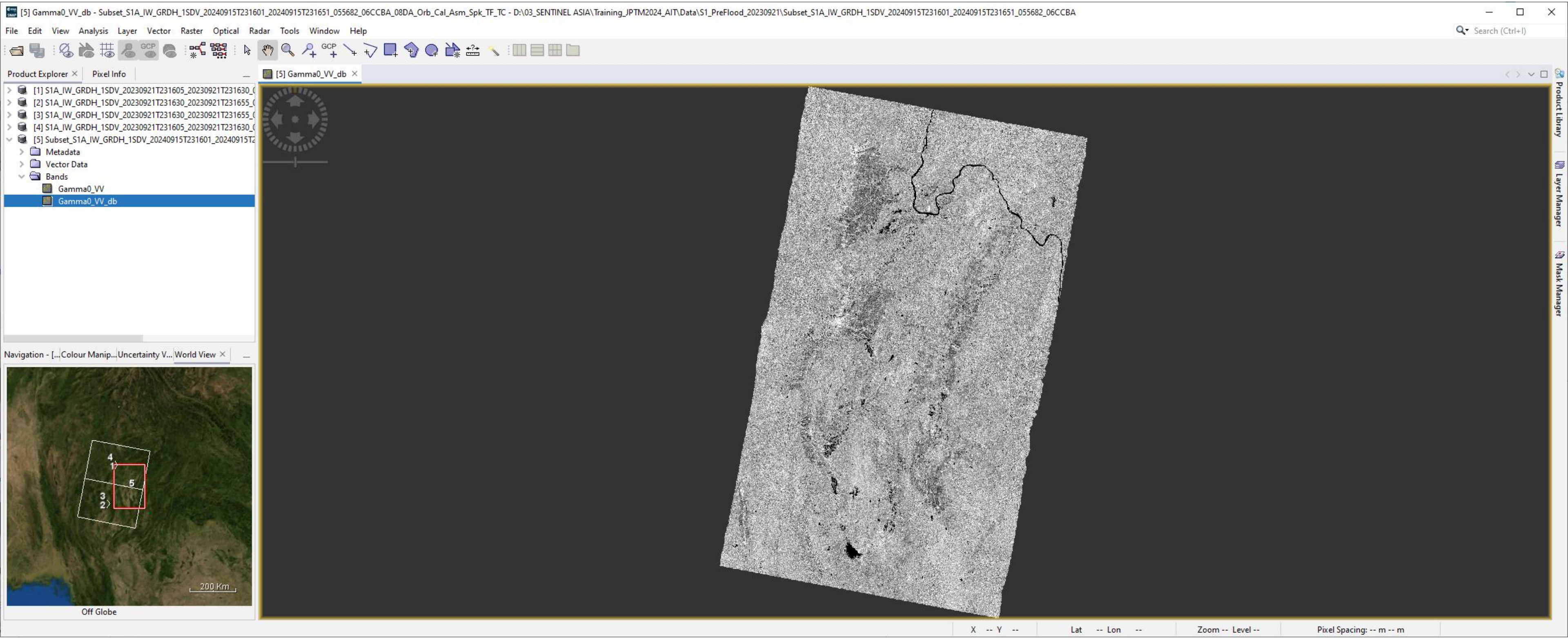
Data Pre-processing

Visualize the new output



Data Pre-processing

Repeat the same processing workflow for Pre-flood images



Data Pre-processing

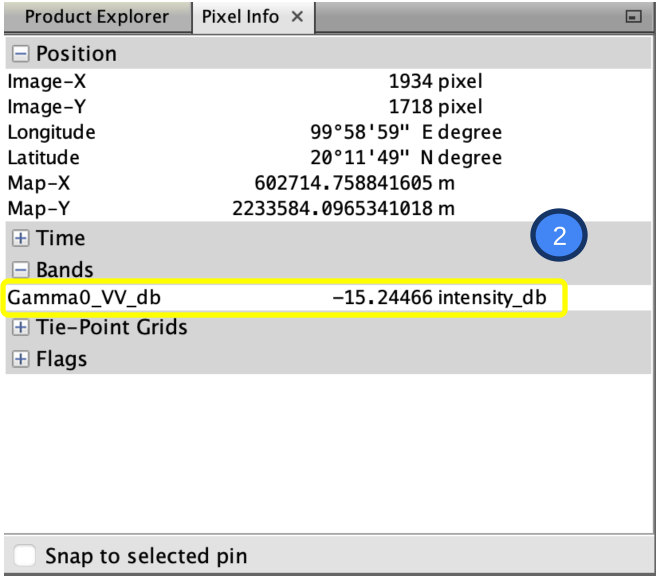
Defining a threshold value (1)

Next, we will separate water and non-water pixels. We have to define a threshold value in which we assume that the pixels whose values are below the threshold belong to the water area, and those that are above that threshold belong to the non-water area.

We can manually inspect the threshold value by visually checking the image.

1. In the Main Menu, go to View → Tool Windows → Pixel Info.

2. Hover over the image and check the value in the Pixel Info window



Data Pre-processing

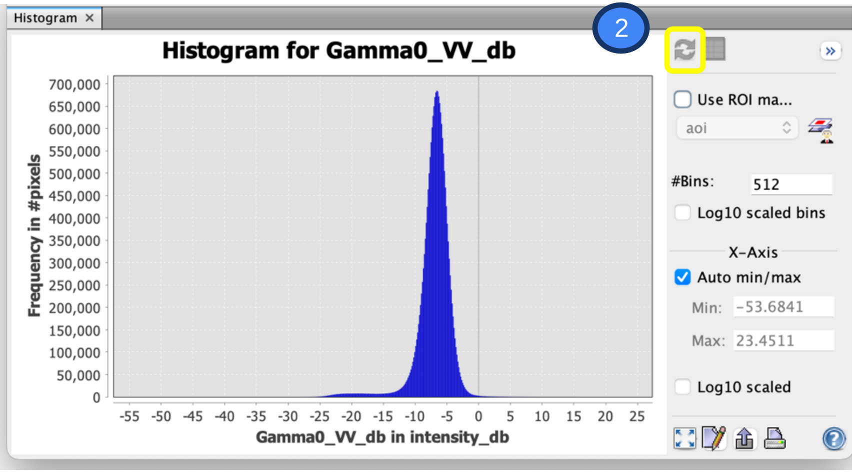
Defining a threshold value (2)

We can also calculate a histogram to define the value. Ideally, a threshold can be defined when the histogram is a bimodal distribution containing two peaks separated by a valley.

1. In the Main Menu, go to Analysis → Histogram.

2. Click Refresh  to calculate the histogram

See that the distribution does not really look like a bimodal one. This is because the full image contains much larger non-water than water areas.



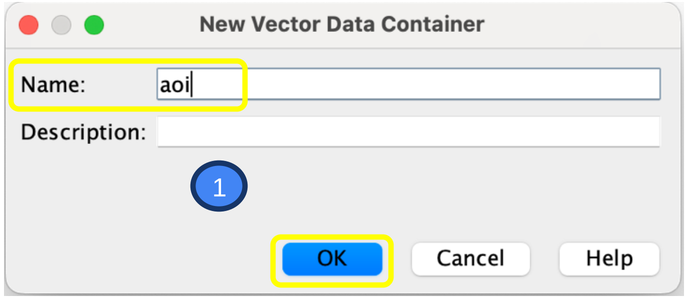
Data Pre-processing

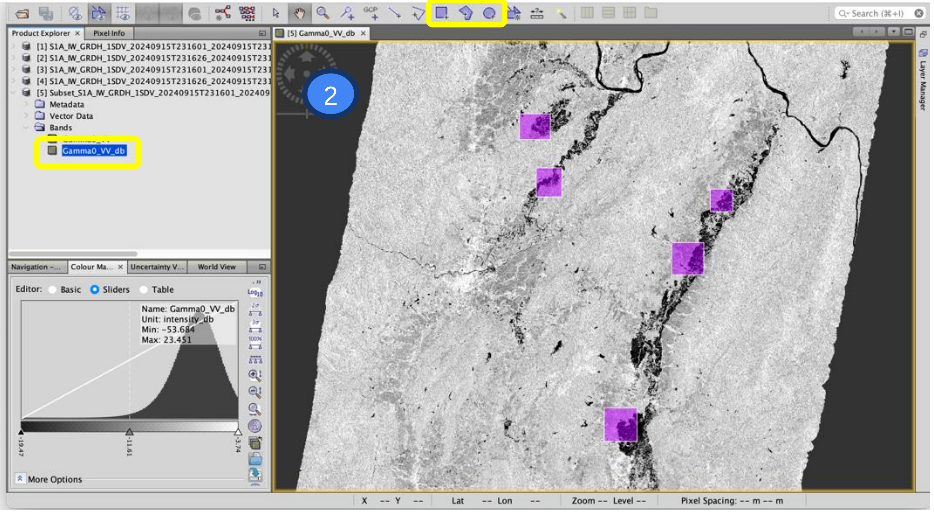
Defining a threshold value (3)

Let's create a group of polygons to get the distribution that balances water and non-water areas.

1. In the Main Menu, go to Vector → New vector Data Container. Give a name aoi to the new container and click OK.

2. Zoom in the Gamma0_VV_db image and create several polygons using the Drawing tools  in the Tool Bars.





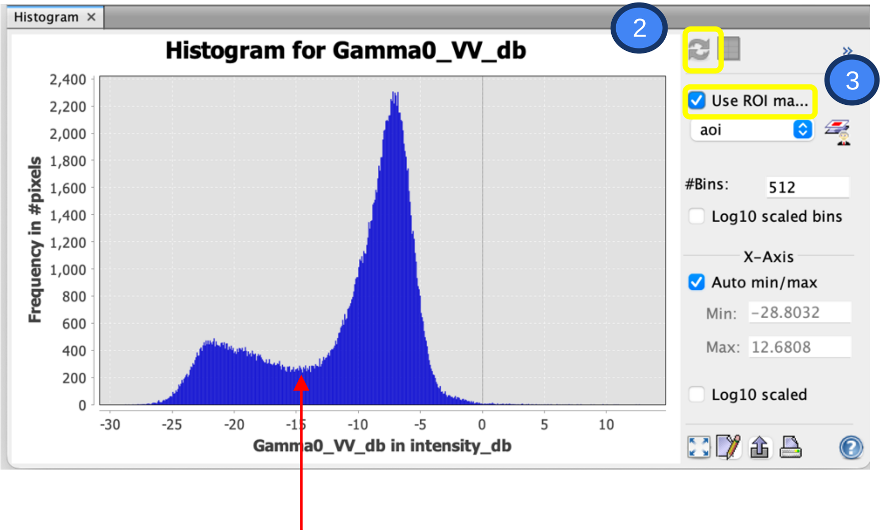
Data Pre-processing

Defining a threshold value (4)

Now, we calculate the histogram based on the aoi.

1. In the Main Menu, go to Analysis → Histogram.
2. Checklist the Use ROI mask.
3. Click Refresh  to calculate the histogram

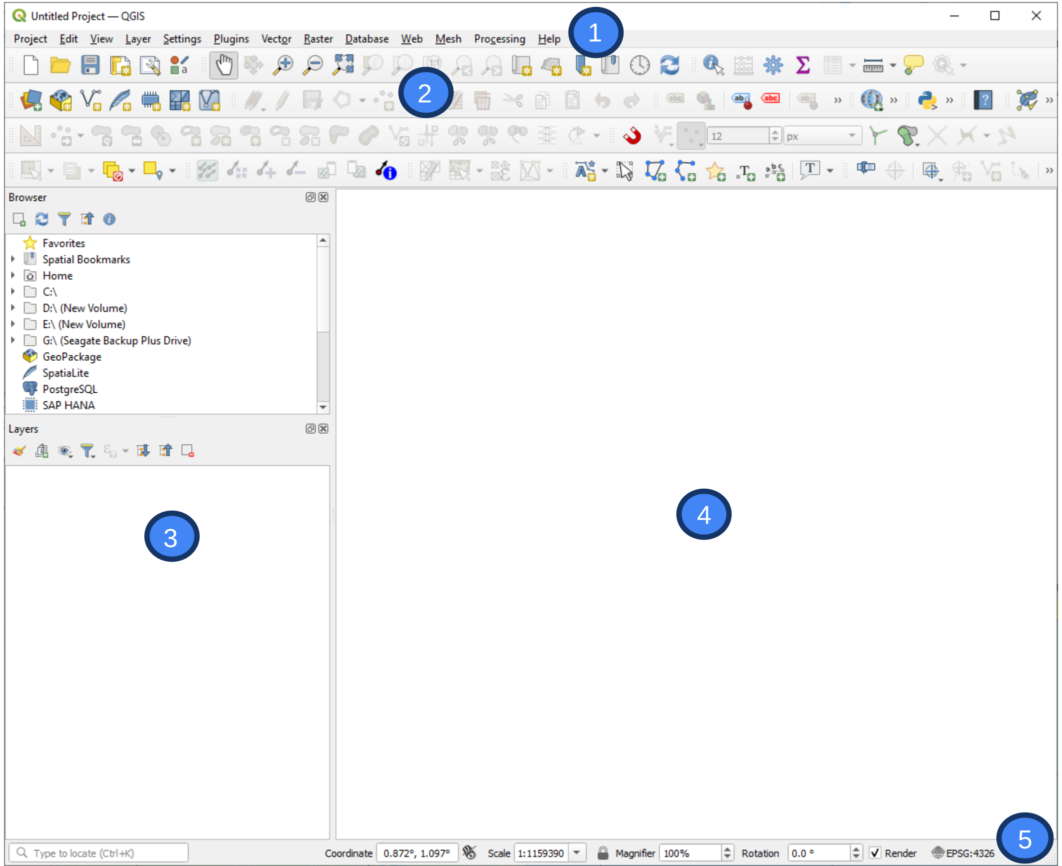
We now have the bimodal distribution. Estimate the value for the valley that we can choose as our threshold to create the binary images for the water and non-water areas.



Threshold value

Data Processing in QGIS

Open QGIS Software



- Open QGIS Desktop in your laptop/PC: QGIS Desktop
- You will have a new, blank map.

1. Menu Bar
2. Toolbars
3. Layers List / Browser Panel
4. Map View
5. Status Bar

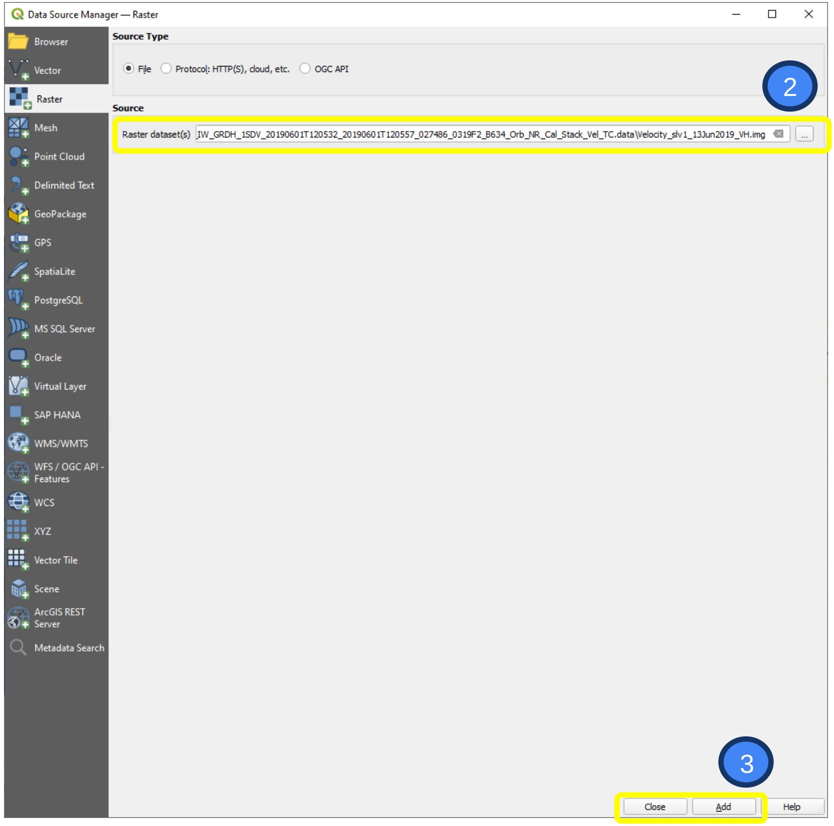
Data Processing in QGIS

Open the pre-processed Sentinel-1 data

1. In the Menu Bar, click on Layer → Add Layer → Add Raster Layer.

2. In Data Source, click on the Browse button and navigate to the file \Subset_S1A_IW_GRDH_1SDV_20240915T231601_20240915T231651_055682_06CCBA_08DA_Orb_NR_Cal_Asm_Spk_ML_TF_TC.data\Gamma0_VV_db.img in the data folder.

3. With this file selected, click Add, then Close. The data you specified will now load.



Data Processing in QGIS

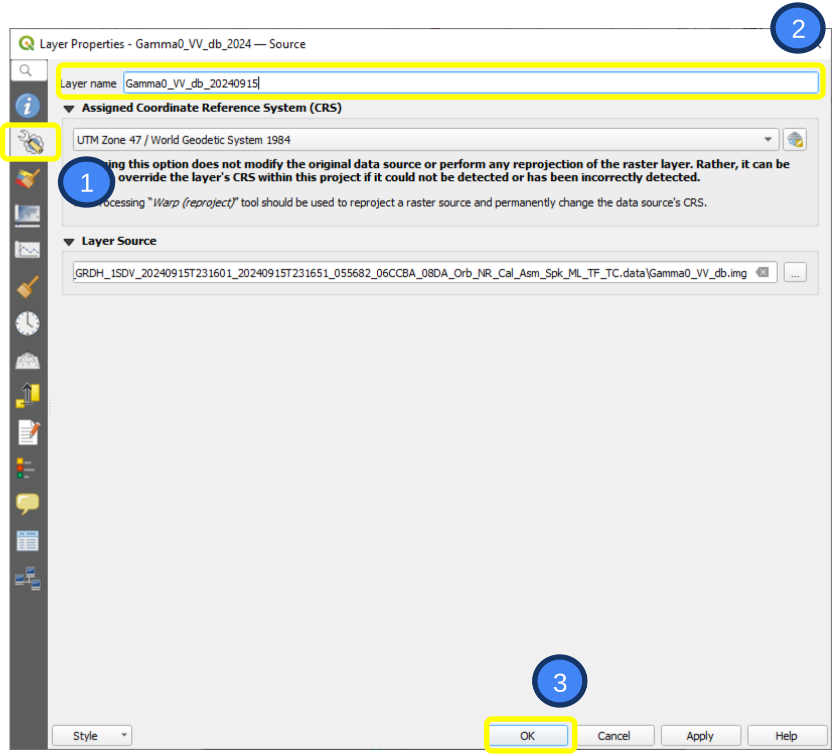
Rename the raster image

The images name for post-flood and pre-flood images are identical. To avoid confusion, we will rename the image by including the date.

1. Right-click the raster image, then go to Layer Properties and switch to the Source

2. Rename to Gamma0_VV_dB_20240915.

3. Click OK.

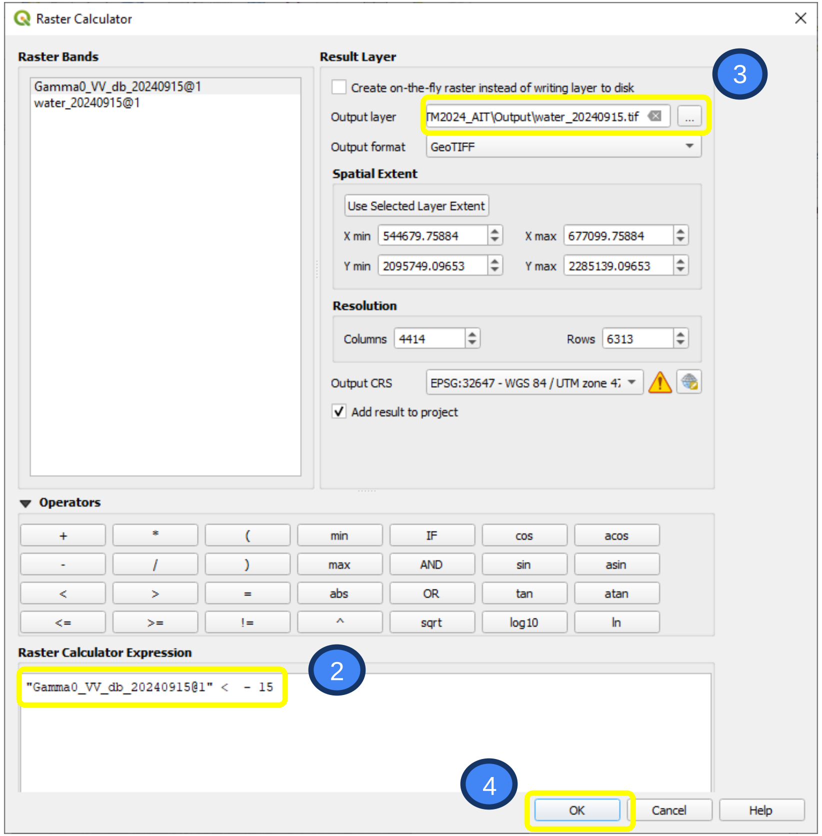


Data Processing in QGIS

Creating a binary map bases on a threshold value

We will use this threshold value: -15 dB.

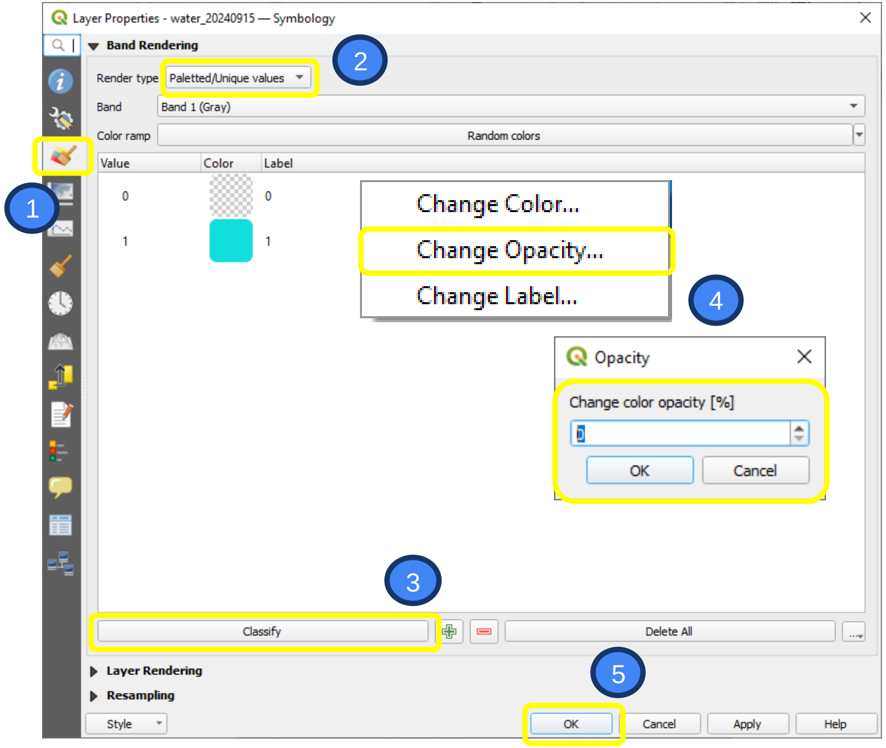
1. Click on Raster → Raster Calculator.
2. In the Raster Calculation Expression write: "Gamma0_VV_db_20240915@1" < - 15
3. Save the result to water_20240915.tif
4. Click OK.



Data Processing in QGIS

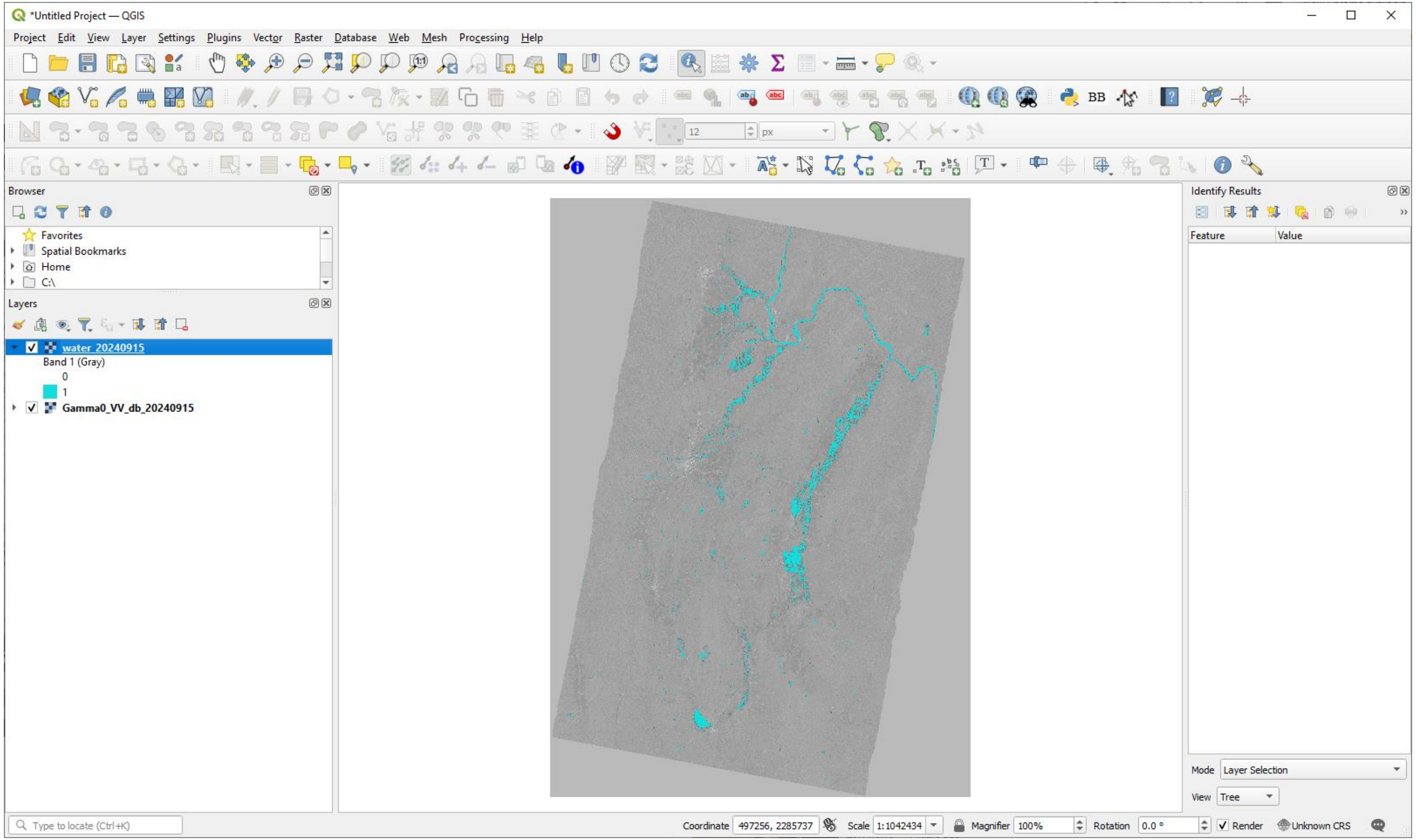
Changing visualization color scheme

1. Go to Layer Properties and switch to the Symbology
2. Change Render type to Paletted/Unique values.
3. Click Classify. You will get two values, 0 and 1.
4. Make transparent color for value 1 by changing its opacity. Right-click color of value 1, then select Change Opacity. Write 0, then OK.
5. Click OK.



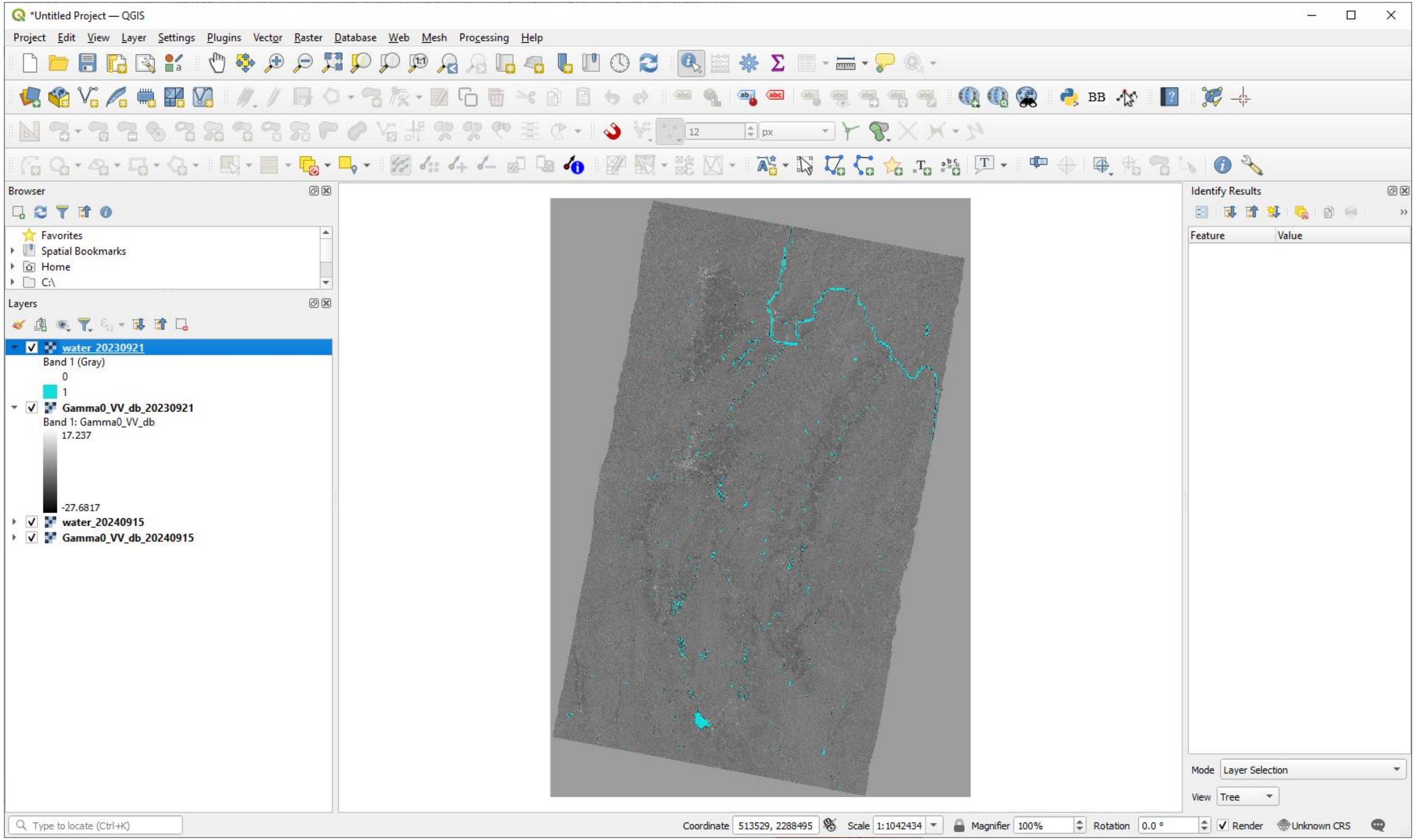
Data Processing in QGIS

Visualization: Water pixels in the post-flood image



Data Processing in QGIS

Repeat the same process for the pre-flood image



Data Processing in QGIS

Estimating the flood pixels

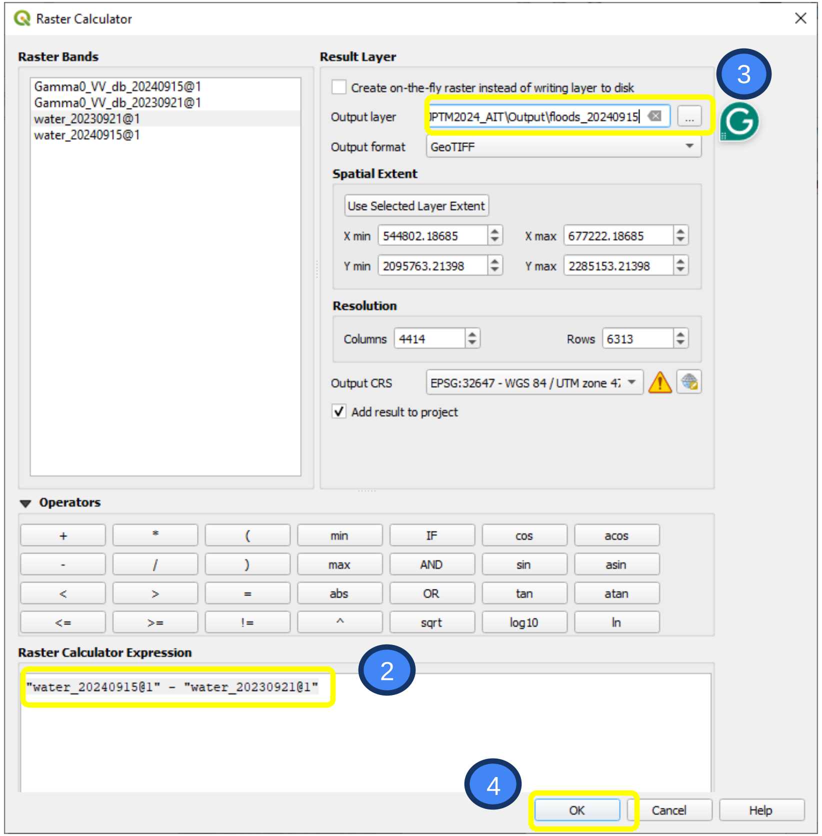
We will estimate the flood pixels by subtracting water pixels from post-flood with the pre-flood.

1. Click on Raster → Raster Calculator.

2. In the Raster Calculation Expression write: "water_20240915@1" - "water_20230921@1"

3. Save the result to flood_20240915.tif

4. Click OK.



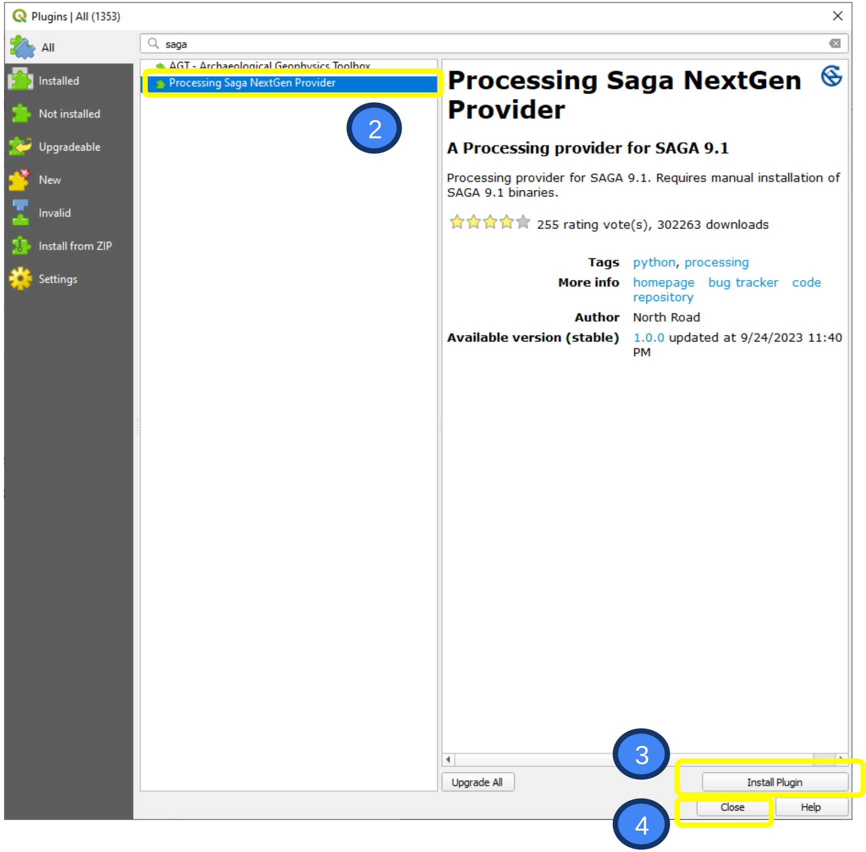
Post-processing in QGIS

Installing a plugin: SAGA Next Gen

Plugins allow you to extend the functionality QGIS offers.

1. In the Menu Bar, click on Plugins → Manage and Install Plugins.
2. In the dialog that opens, find the Processing SAGA NextGen Provider plugin.
3. Click Install Plugin.
4. Click Close.

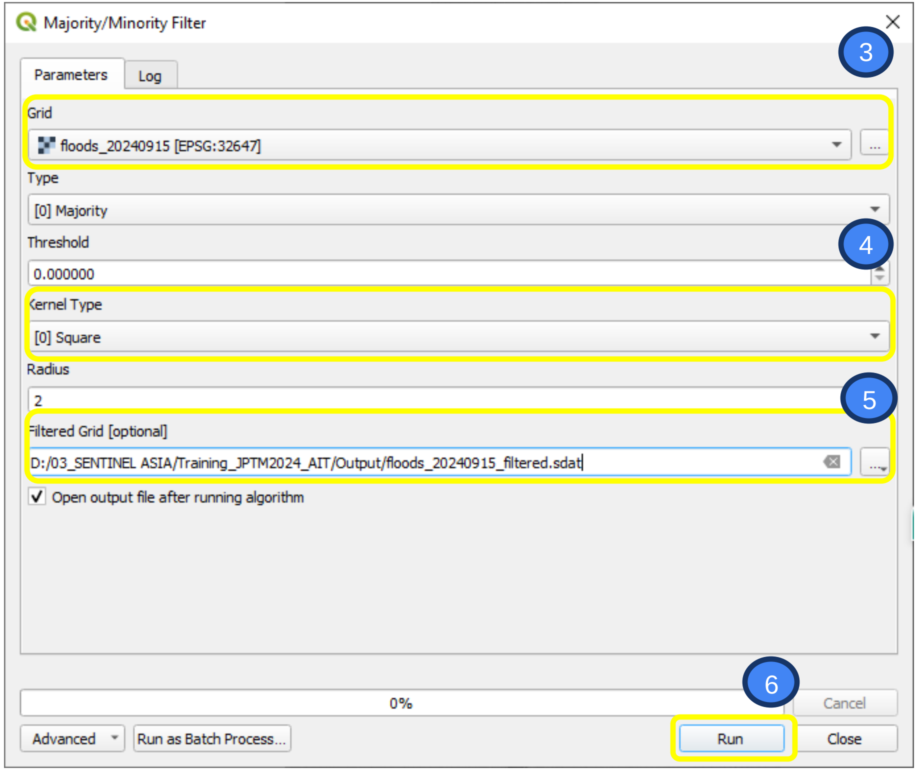
Your new plugin is installed. You will find the installed SAGA Next Gen in the processing toolbox.



Post-processing in QGIS

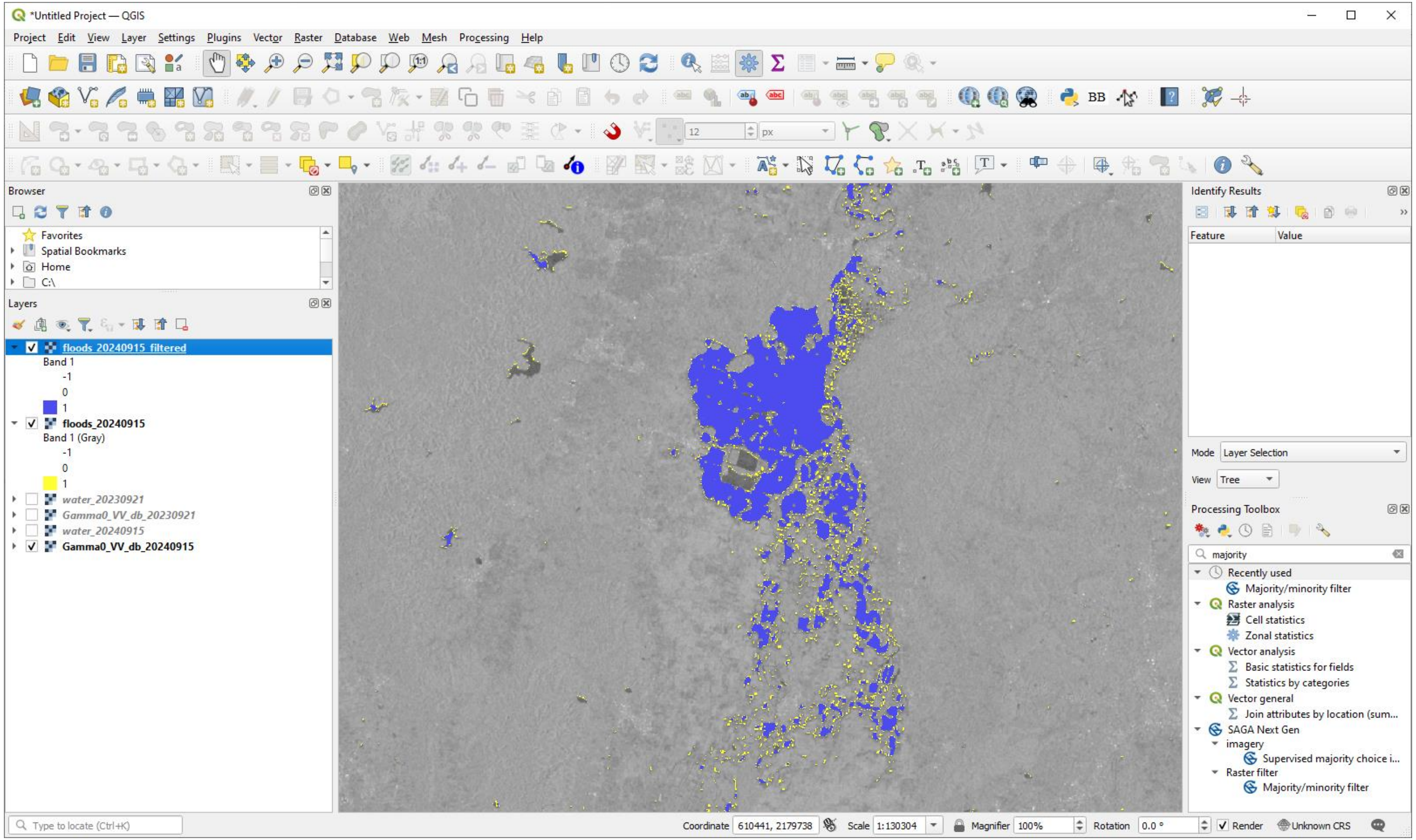
Remove isolated pixels

1. In the Menu Bar, click on Processing → Toolbox.
2. Search for Majority/minority filter processing tool, then open the tool.
3. In the Grid input, select floods_20240915.
4. Change Kernel Type to Square and keep other parameters as default. You may want to test with different threshold and radius.
5. Save the result to floods_20240915_filtered.sdat
6. Click Run



Post-processing in QGIS

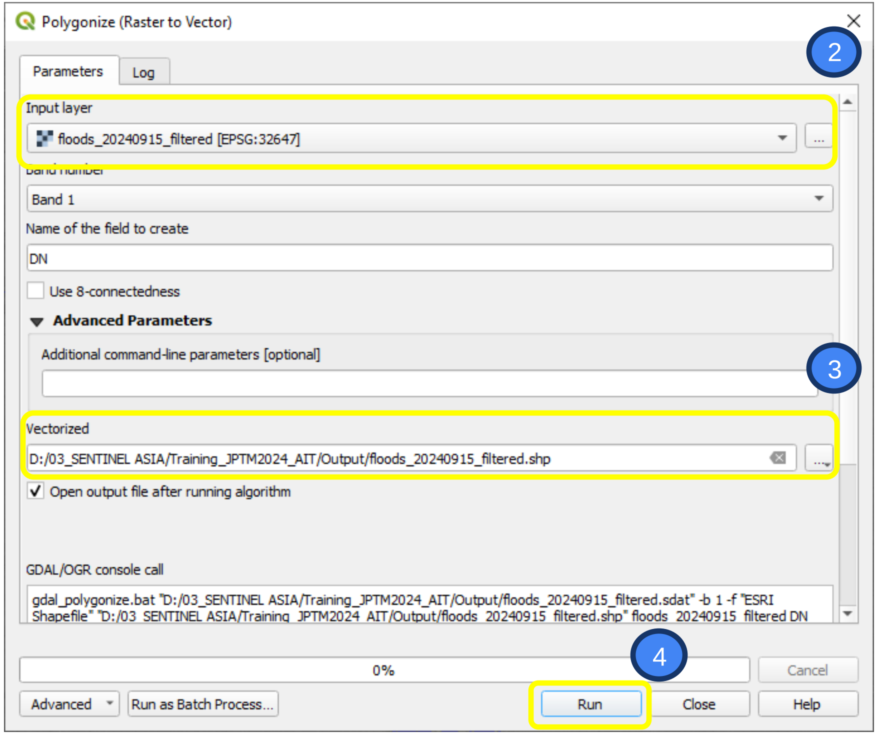
Visualization: Comparing flood pixels before and after filtered



Post-processing in QGIS

Convert flood pixels to polygon

1. In the Menu Bar, click on Raster → Conversion → Polygonize (Raster to Vector).
2. In the Input layer, select floods_20240915_filtered.
3. Save the result to floods_20240915_filtered.shp
4. Click Run



Post-processing in QGIS

Filter flood polygons from attribute

1. Right-click on the floods_20240915_filtered layer, then click Open Attribute Table

2. In the Table Toolbars, click Select features using an expression button.

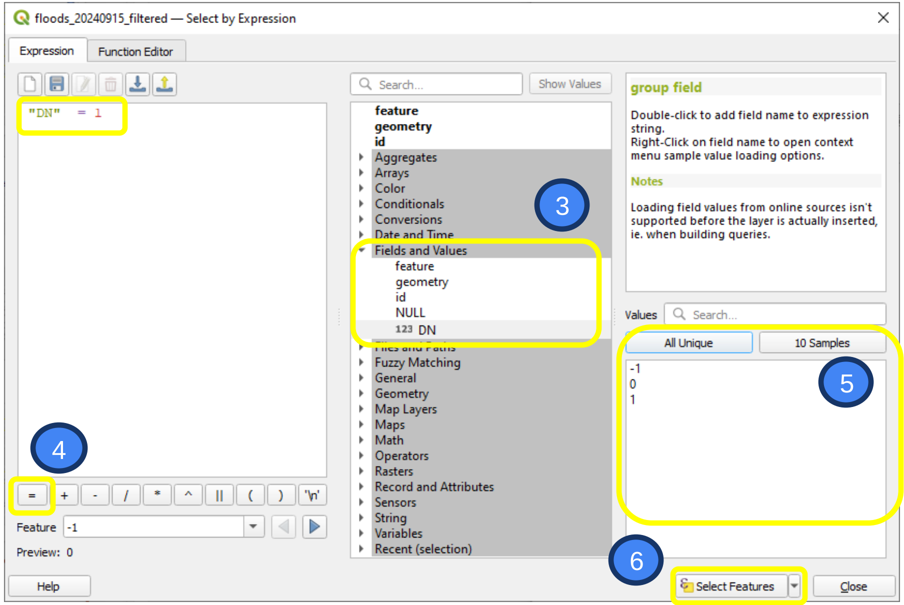
We will select polygons with value of 1 by writing in the Expression box: "DN" = 1

3. Expand the Field and Values and double-click DN. The text will be added to the Expression box.

4. Click = and the text in the Expression box will be updated.

5. Click All Unique, then double-click 1.

6. Click Select Features



Post-processing in QGIS

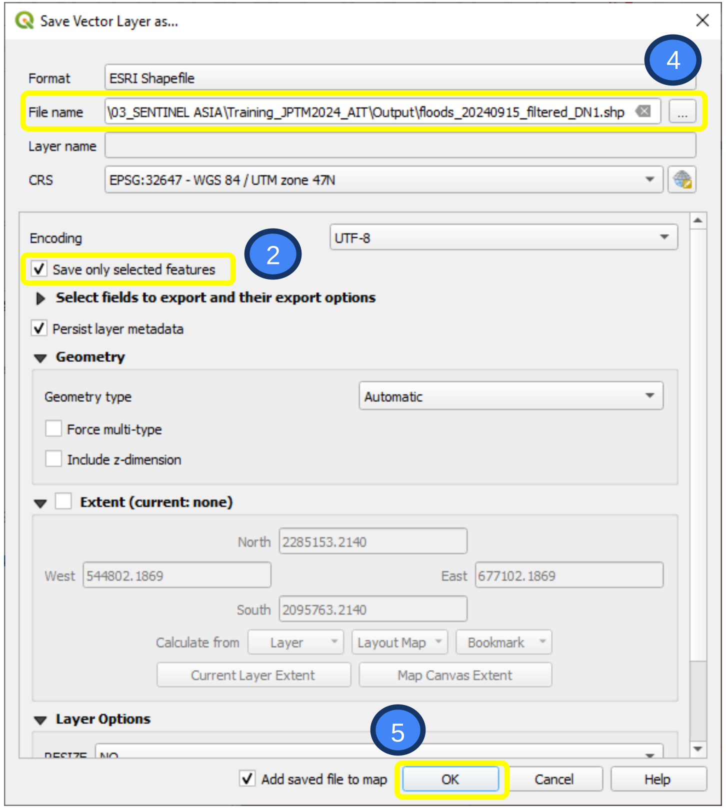
Save selected flood polygons to a new shapefile

1. Right-click on the floods_20240915_filtered layer in the Layers list, click Export → Save Selected Features As…

2. Make sure to checklist “Save only selected features”.

3. Save the result to floods_20240915_filtered_DN1.shp.

4. Click OK.

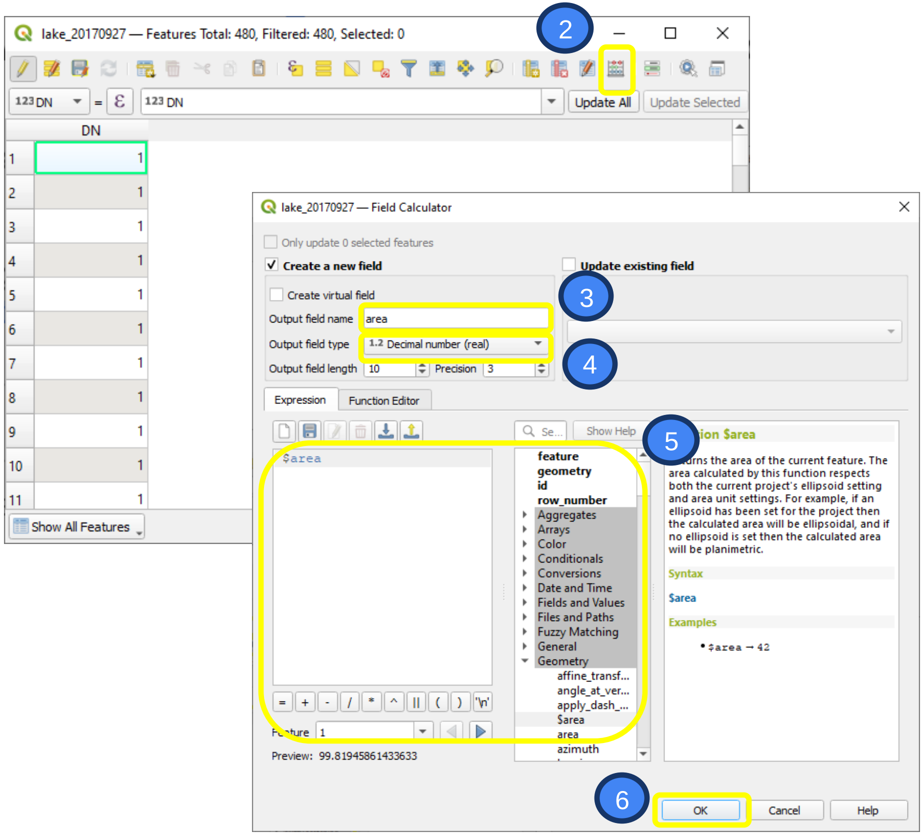


Post-processing in QGIS

Calculate the area of each polygon in the table

Calculate area of each polygon in the attribute table of floods_20240915_filtered_DN1.

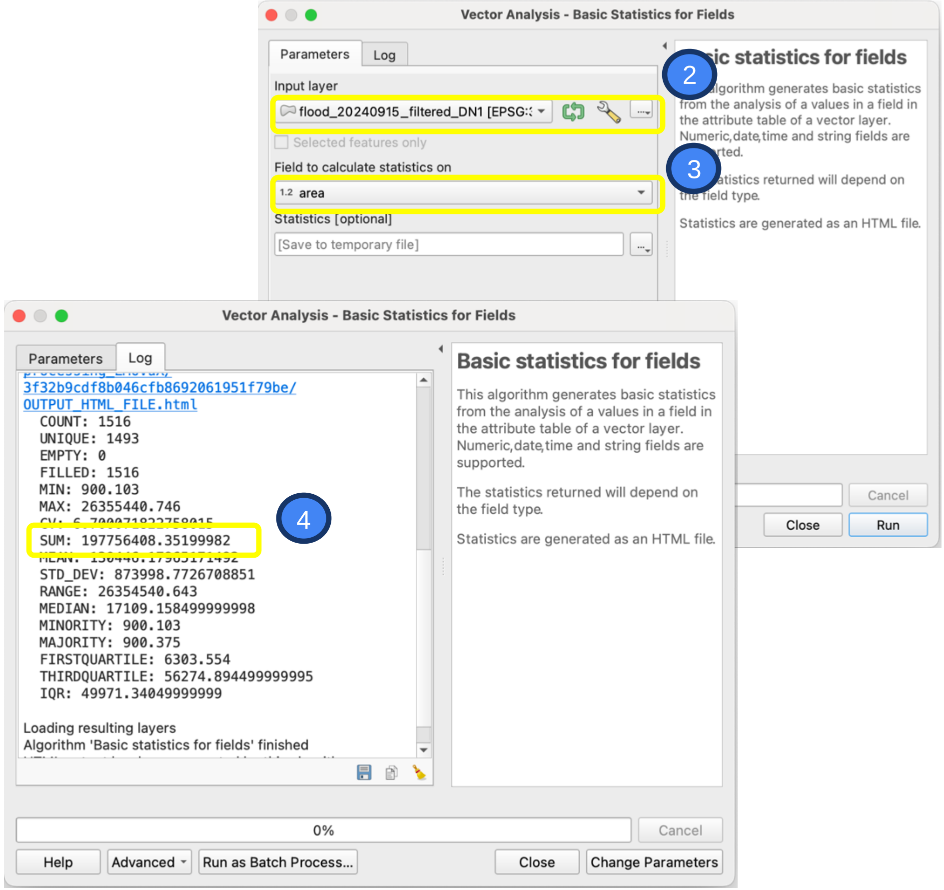
1. Right-click on the layer, then click Open Attribute Table
2. In the Table Toolbars, click Open Field Calculator button.
3. In Output field name, write area.
4. In Output field type, select Decimal number (real).
5. Expand the Geometry and double-click $area. The text will be added to the Expression box.
6. Click OK.



Post-processing in QGIS

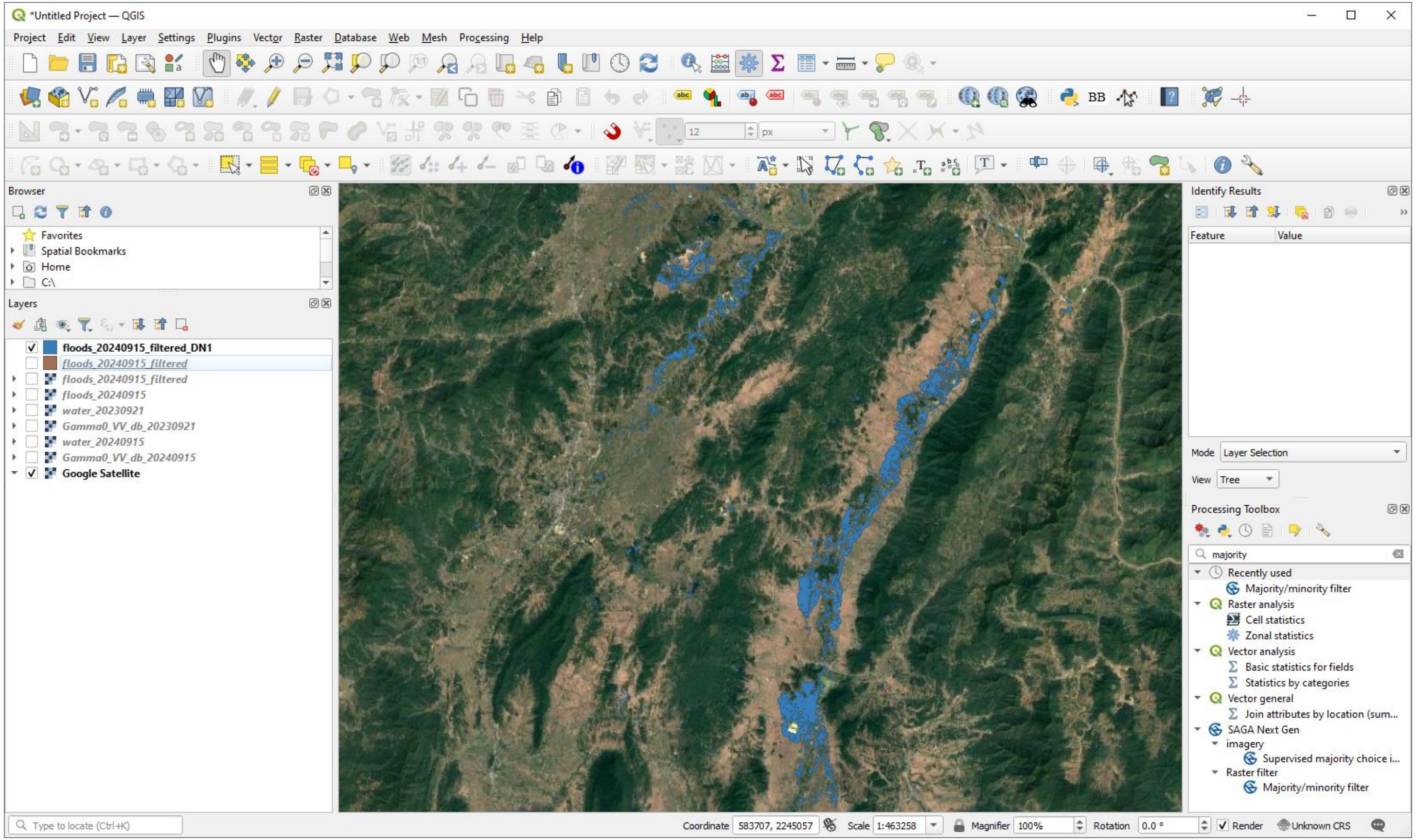
Calculate total flooded area

1. In the Menu Bar, click on Vector → Analysis Tools → Basic Statistics for Fields.
2. In the Input layer, select floods_20240915_filtered_DN1.
3. Select the field area to calculate statistics on.
4. In the output, the total flooded area is the value for **SUM**. The unit is square meters, so to get the area in square kilometers, you have to divide by 1,000,000.



Post-processing in QGIS

Visualization: Final flood map



THANK YOU

Geoinformatics Center, Asian Institute of Technology