ESA contract 4000140187/23/NL/SC/rp (ENEUM)

Deliverable 5.2

Applied Radar Remote Sensing

Practical Exercise Workbook

esa
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UNIVERZITA PAVLA JOZEFA ŠAFÁRIKA V KOŠICIACH
FUNDED BY EUROPEAN SPACE AGENCY UNDER THE PLAN FOR EUROPEAN COOPERATING STATES, 7TH CALL FOR SLOVAKIA

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UNIVERSITY COURSE APPLIED RADAR REMOTE SENSING

EXERCISE 1 – TUTORIAL

Radar Earth Observation – ESA EO Data Access and resources, applications, Copernicus OA Hub

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1 | Exercise outline

In this exercise, we will:

- acquire skills in retrieving satellite imagery from both ESA and third-party missions
- conduct specific analyses utilizing the EO Browser
- install ESA SNAP and execute fundamental image operations
- explore the spectral curve of various surface types

2 | Background

Most of the ESA's Earth observation datasets are easily accessible online, free of charge. Users can acquire access by completing a simple registration process.

The Copernicus Data Space Ecosystem provides full, free and open access to large amount of Earth observation data, along with scalable interfaces integrated with the Copernicus Sentinel satellites. This includes a range of both new and historical Sentinel images, commercial datasets, as well as Copernicus Contributing Missions.

Sentinel data is also accessible through Copernicus Data and Information Access Services (DIAS), which are platforms designed to facilitate the discovery, retrieval, and use of Copernicus satellite data, including data from the Sentinel missions. There are several DIAS platforms available, each offering a user-friendly interface and tools for working with the data.

The ESA Hub allows checking searches online by browsing and viewing product metadata and measurements without downloading them. Sentinel products are provided for download over HTTP in *.ZIP archive file format.

Sentinel Hub is a cloud-based platform that provides access to satellite data, particularly from the ESA Sentinel missions. The platform offers a variety of services and tools for the retrieval, processing, and analysis of satellite imagery. It is commonly used by researchers, developers, and businesses to access Earth observation data for various applications, including environmental monitoring, agriculture, urban planning, and more. EO Browser is an online platform developed by Sentinel Hub that allows users to visualize and explore satellite imagery, particularly from the Copernicus Sentinel missions. Sentinel Hub provides the backend infrastructure and access to the satellite data, while EO Browser serves as the user interface for interacting with that data.

ESA not only provides satellite data from its own Earth Observation (EO) satellite resources, but also facilitates access to Third Party Missions (TPMs), which are non-ESA EO missions. Integrating data from these diverse sources is crucial for enhancing the sustainability of satellite services, expanding the scope of monitored parameters, and promoting scientific development. Researchers and students alike can request third-party data, but it's important to be aware of licensing conditions, especially for users in certain countries, where national legislation on data access may apply.

3 | How to access ESA data

To access data from the European Space Agency (ESA), user can use various platforms and tools provided by ESA. Here are some key sources:

Earth Online Portal

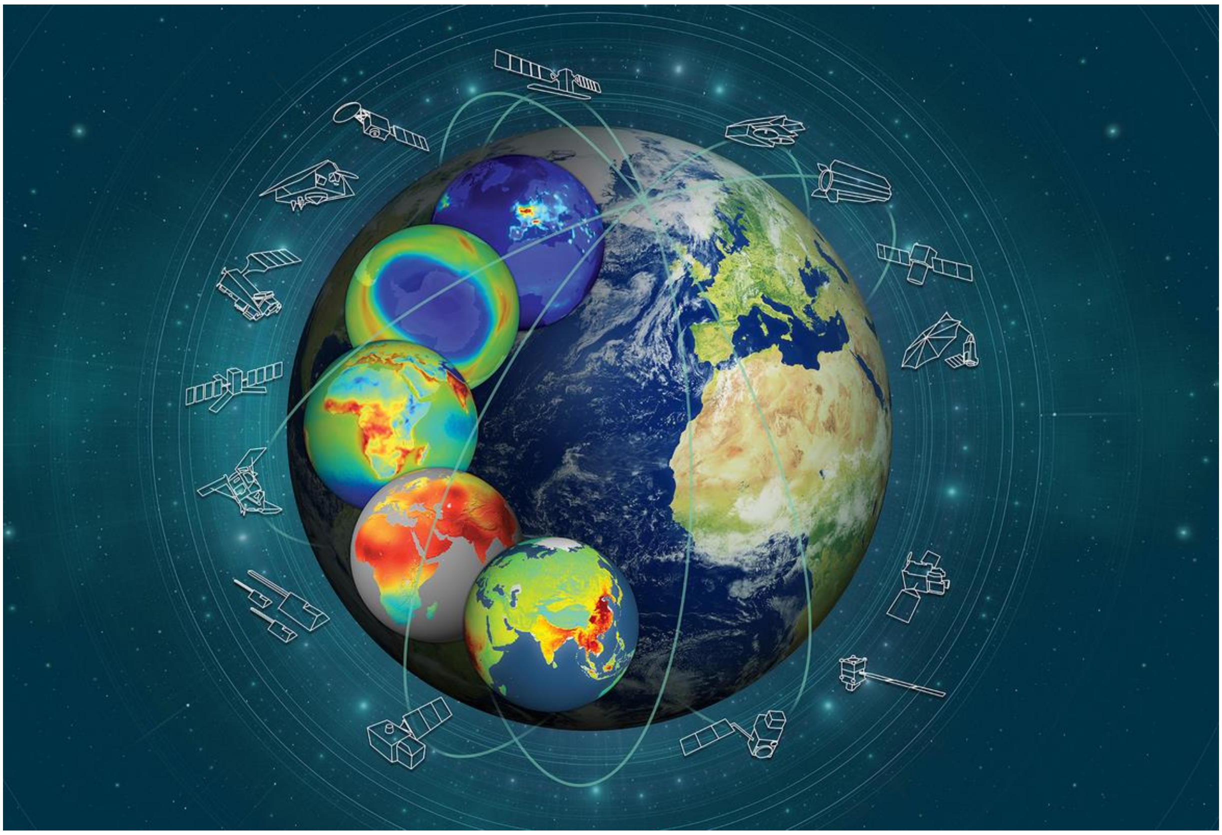
The Earth Online Portal serves as a gateway to a diverse range of Earth observation resources. It includes a directory for discovering missions and datasets, offering convenient access to satellite data, operational updates, events, and tools to enhance data utilization.

Sentinel Online

The Sentinel online platform offers technical details about the Copernicus Sentinel missions and allows systematic access to processed data, which is readily accessible on the website. User registration is required for access.

Copernicus Contributing Missions Online

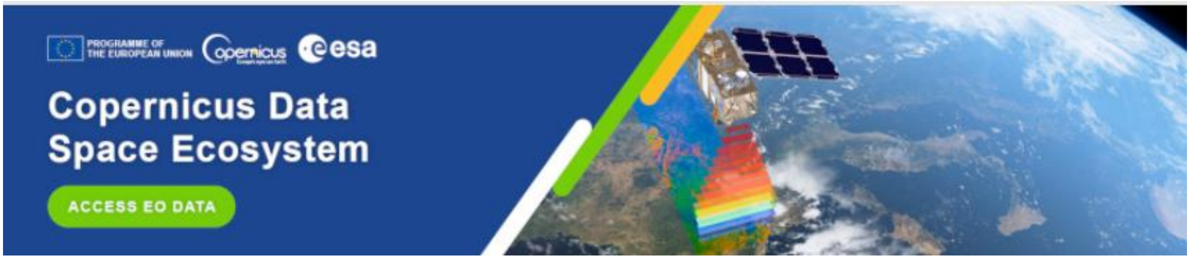
To obtain data with higher resolution, users can visit the Copernicus Contributing Missions website. This platform offers comprehensive information on all Contributing Missions that provide data complementing the Copernicus Sentinels, addressing the requirements of the Copernicus Services. Eligible users can access the data for free upon registration and confirmation of their user category.



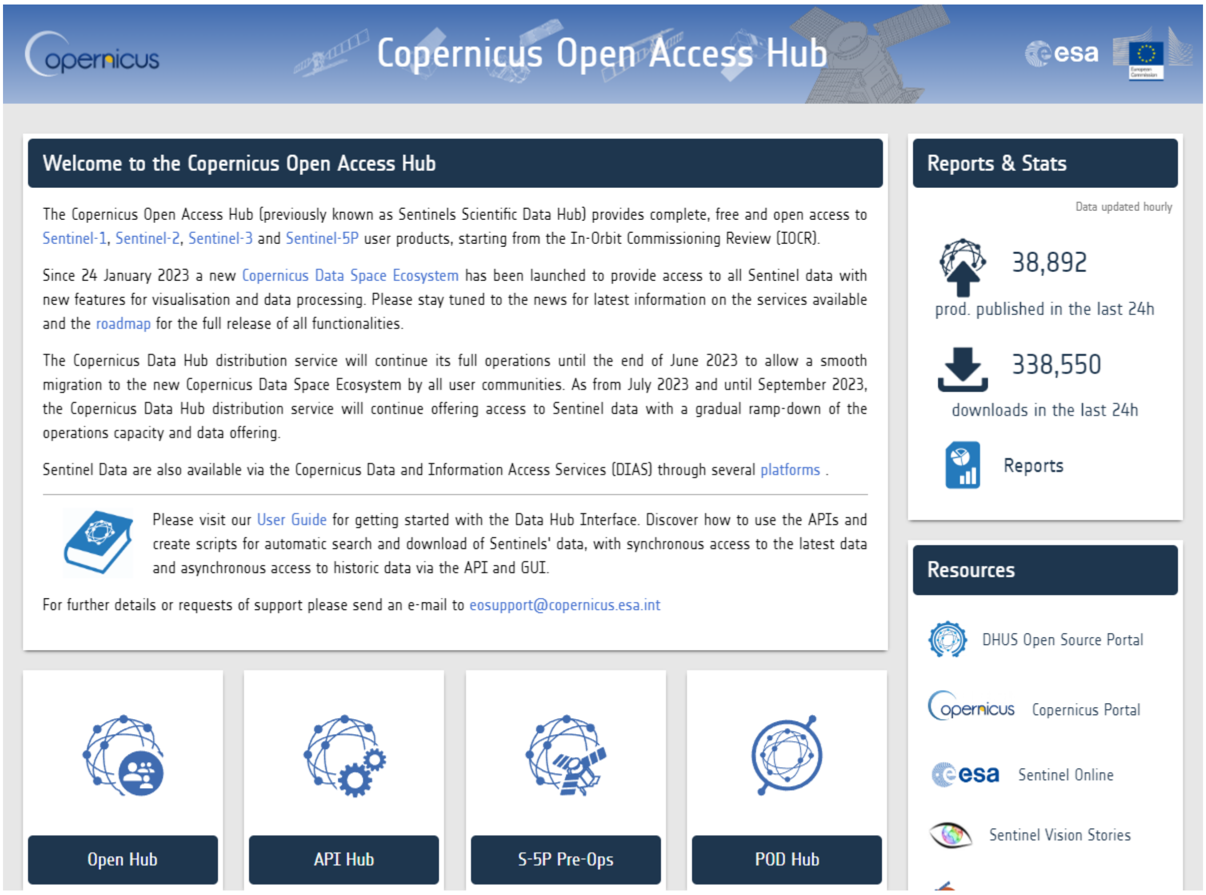
4 | Copernicus Data Space Ecosystem

https://dataspace.copernicus.eu/

- Since 24 January 2023 a new Copernicus Data Space Ecosystem has been launched to provide free and open access to Earth Observation data from all Sentinel satellites with new features for visualisation and data processing.



- The previous Copernicus Data Hub distribution service that has been providing access to Copernicus data is offering access to Sentinel data with a gradual ramp-down of the operations capacity and data offering.

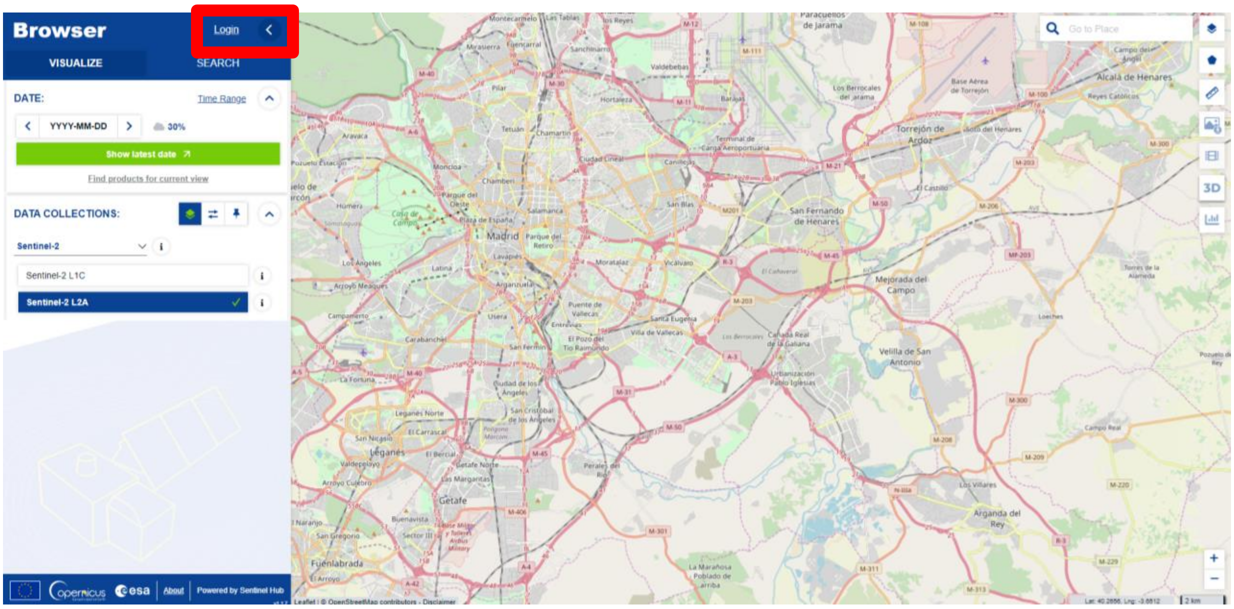


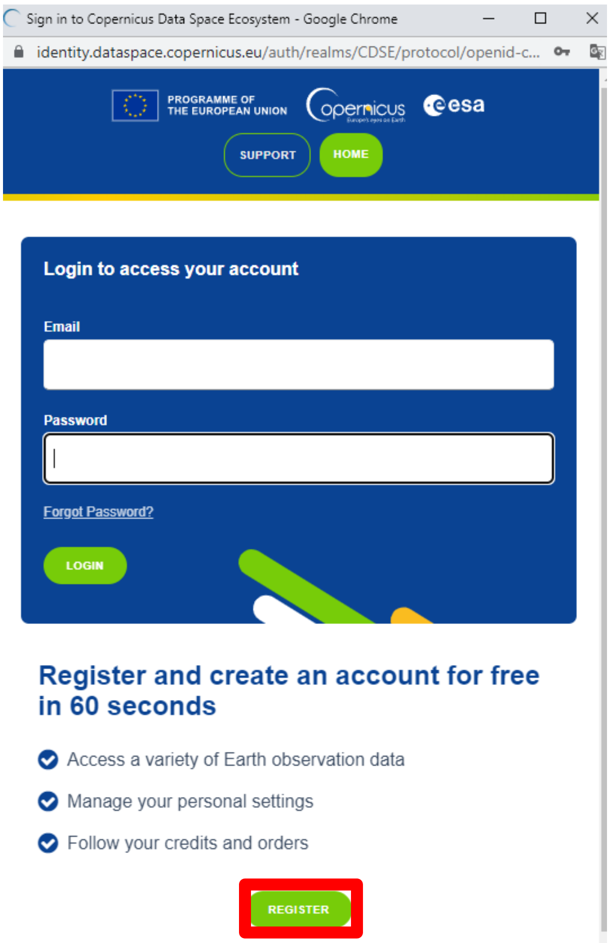
- Sentinel Data are also available via the Copernicus Data and Information Access Services (DIAS) through several platforms.

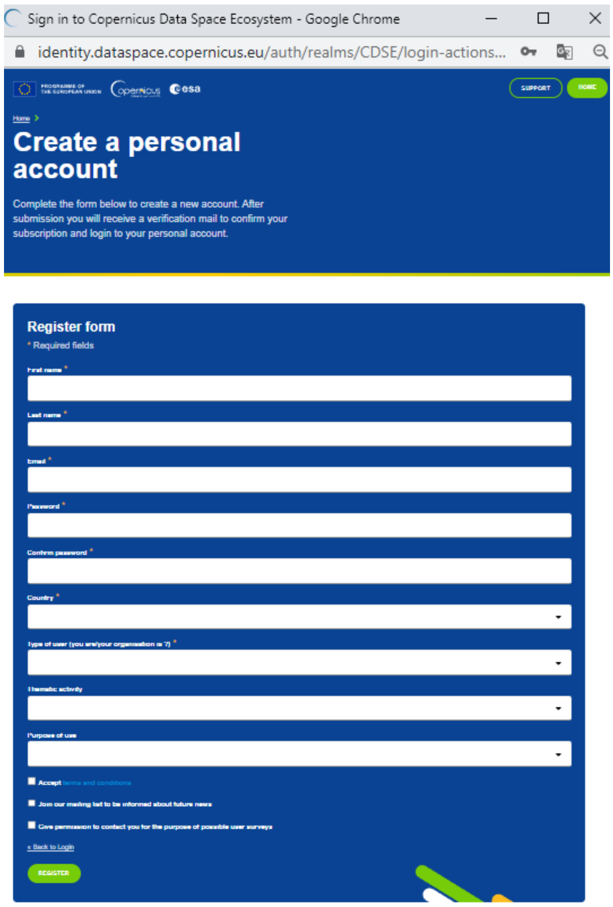
The Copernicus Data Space Ecosytem allows us to access a wide range of Earth observation data from the Copernicus Sentinel missions and more. The Copernicus Data Space Ecosytem provides tools for easy discovery, visualization and download which will be continuously upgraded.

4.1. Registration and login

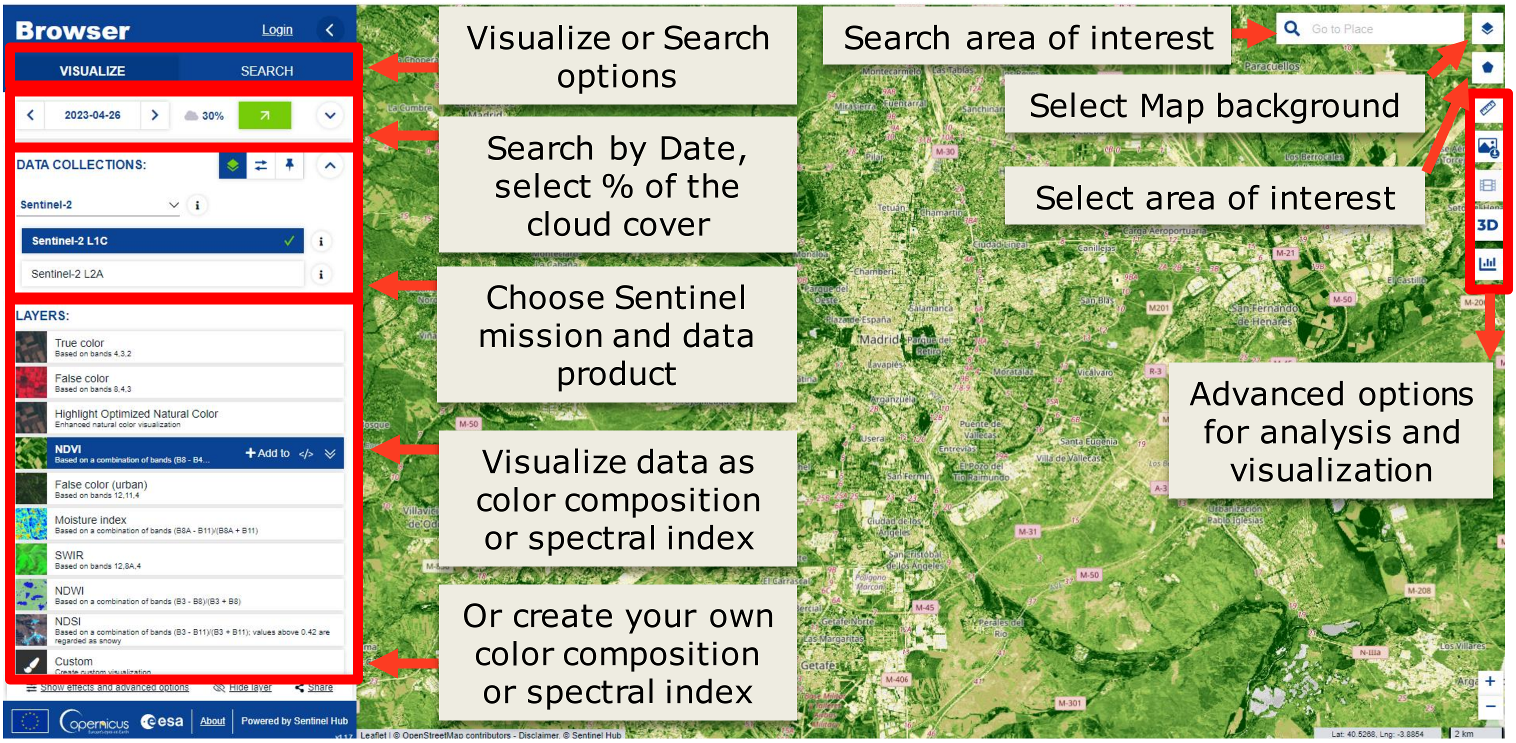
- We can register a new user or log in as an existing user to the portal.
- The Copernicus Data Space Ecosytem allows us to browse and visualize satellite images freely, but we need to register and create an account to be able to download them.

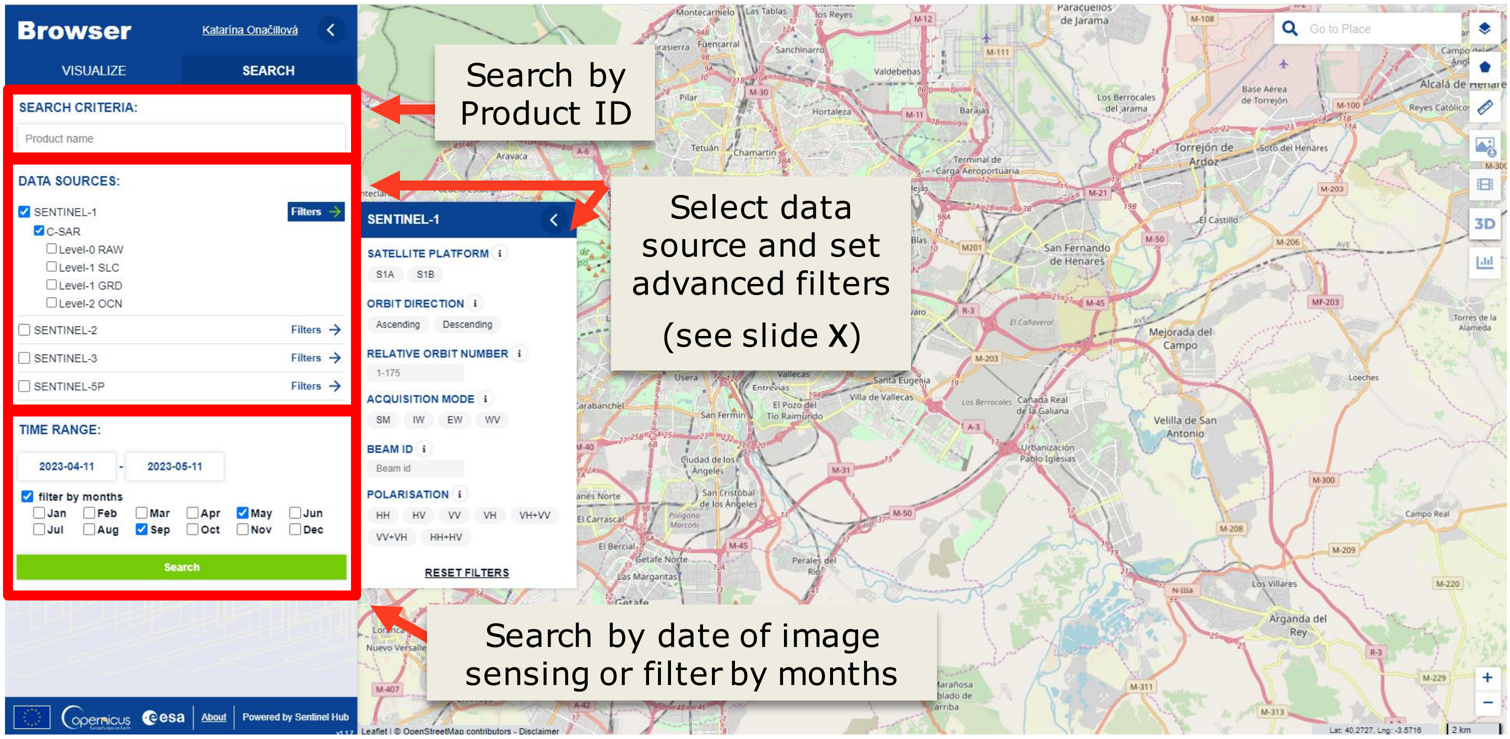




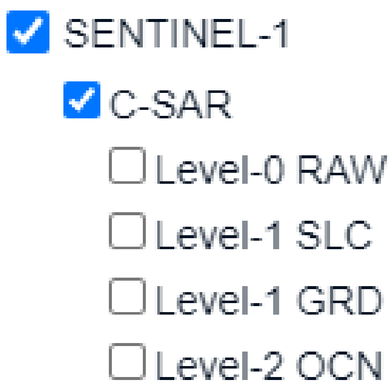


After registration and login, it is possible to visualize or search EO data products within portal. We can choose various satellite platforms, product types, polarizations, and sensing modes for individual satellites:



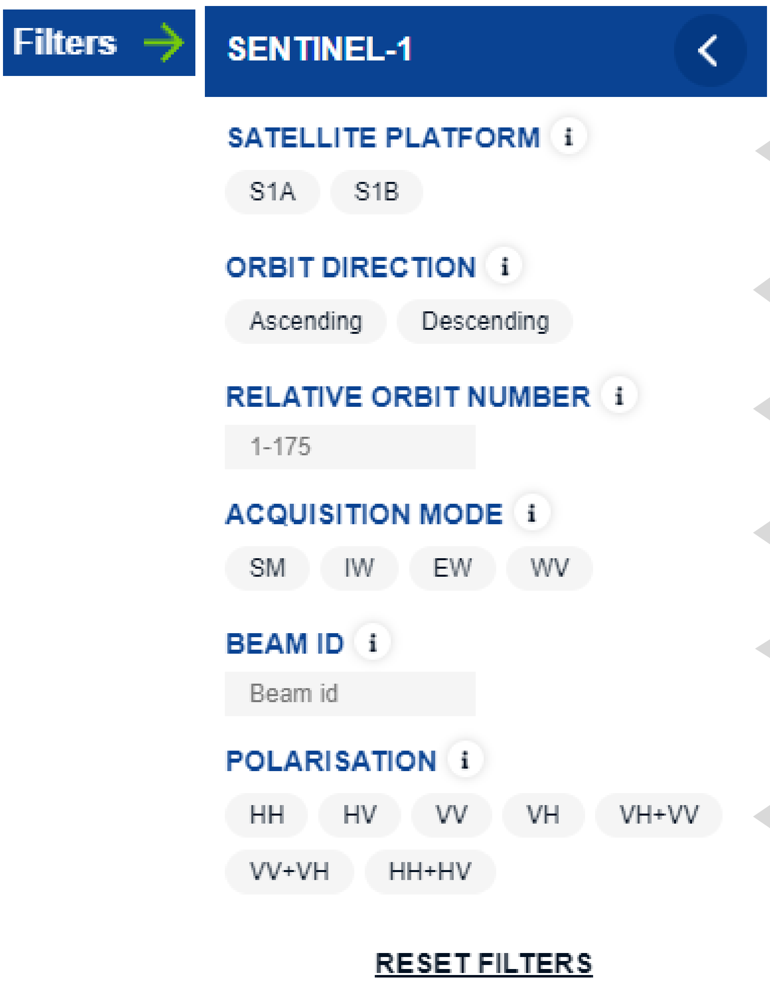


E.g. Sentinel-1 C-SAR - SAR Instrument that provides an all-weather, day and night imagery at C-band at high and medium resolutions for land, coastal zones and ice observations.



Levels of product types

- unprocessed raw data
- (Single Look Complex) contains complex images with amplitude and phase in the slant range by azimuth imaging plane, in the image plane of satellite data acquisition
- (Ground Range Detected) consists of focused SAR data that has been detected, multi-looked and projected to ground range using an Earth ellipsoid model
- (Ocean) provide geo-located geophysical products derived from Level-1 for wind, wave and currents applications



The available Sentinel-1 data includes products from the Sentinel-1 satellite constellation, including Sentinel-1A (operational since 2014) and Sentinel-1B (operational from 2016 to 2022)

Determines wheter the data was recorded during a descending orbit (flight direction: north-south) or an ascending orbit (flight direction: south-north)

The Relative Orbit Number is the number of full orbits since the relative orbit 1 to the end of a cycle

Sentinel-1 operates in 4 instrument acquisition modes: Stripmap (SM), Interferometric Wide Swath (IW), Extra-Wide Swath (EW), Wave (WV)

Depending on the acquisition mode, different swaths and identifiers are possible

Determines with which polarisation the data was acquired. The first letter indicates the polarisation when sending the signal, the second letter when receiving the signal. Data can be acquired in single polarisation HH or VV or in dual polarisation HHHV or VVVH depending on the instrument mode

4.2. Search results

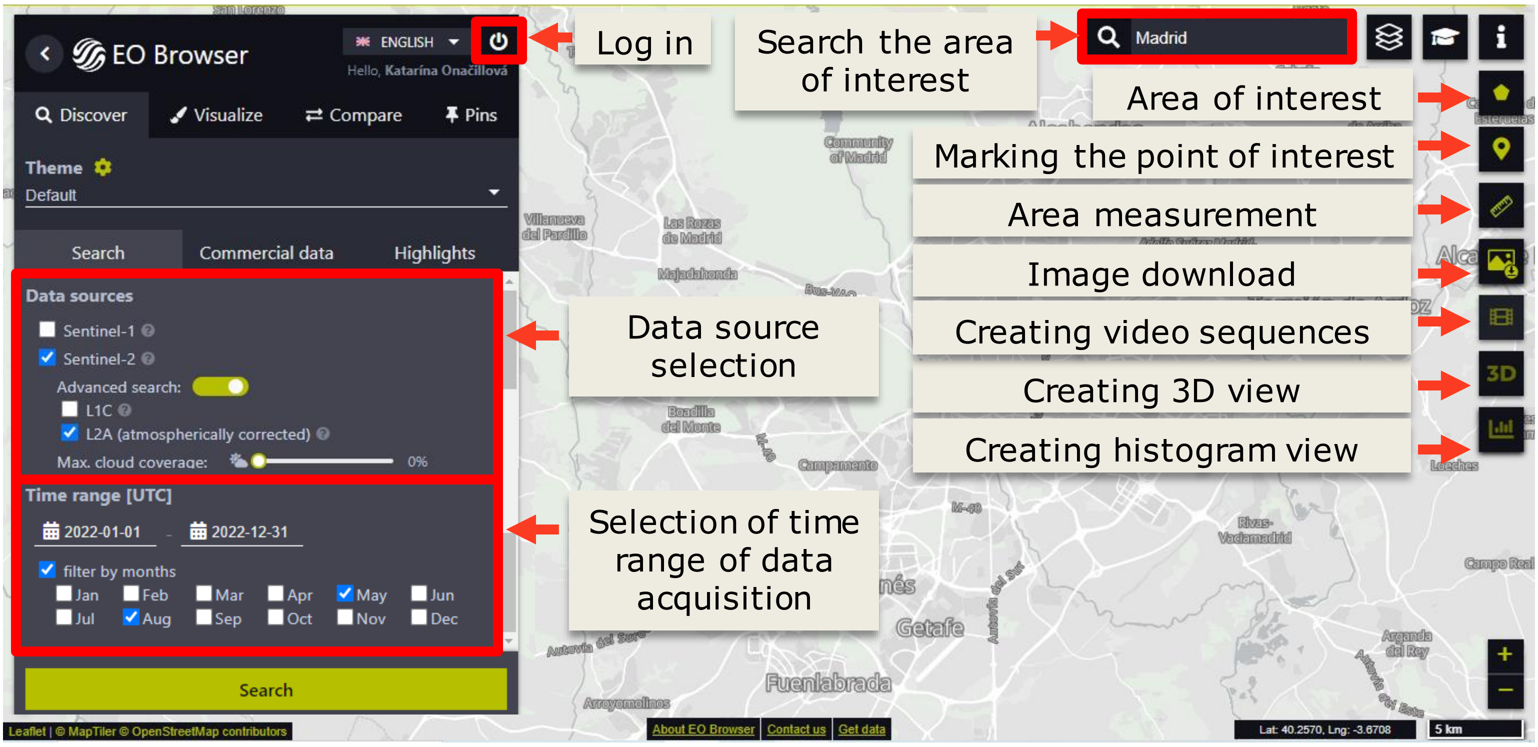
After defining the search criteria, we get the results that can be further viewed, analysed or downloaded.

5 | Sentinel Hub - EO Browser

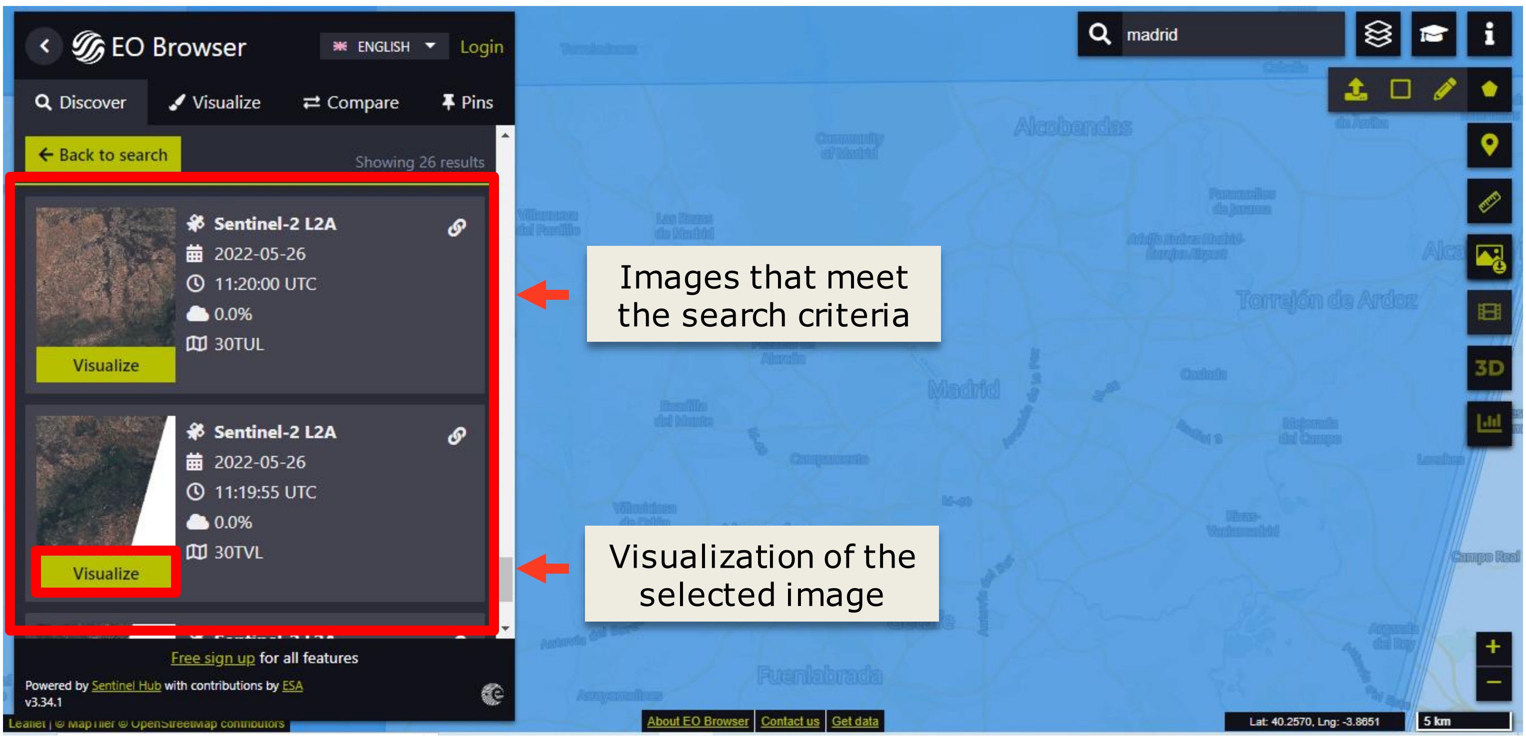
https://apps.sentinel-hub.com/eo-browser/

EO Browser, developed by Sentinel Hub, is an online platform that empowers users to explore and visualize satellite imagery from Earth observation (EO) missions, with a focus on the Copernicus program. Offering an intuitive and user-friendly interface, the platform is widely utilized for educational, research, and environmental monitoring purposes. Key features encompass direct access to Copernicus Sentinel data, enabling users to visualize and analyze imagery within the browser. Customization options allow users to tailor their view by adjusting parameters like date and cloud cover, catering to specific research needs. The platform's educational utility is evident in its use in educational settings, introducing students to Earth observation and remote sensing through its accessible interface. Additionally, EO Browser facilitates time-lapse creation for monitoring changes in the Earth's surface over time. EO Browser is a valuable tool for those interested in exploring and understanding satellite imagery for a wide range of applications, including environmental monitoring, agriculture, forestry, and urban planning.

Registration or Log in



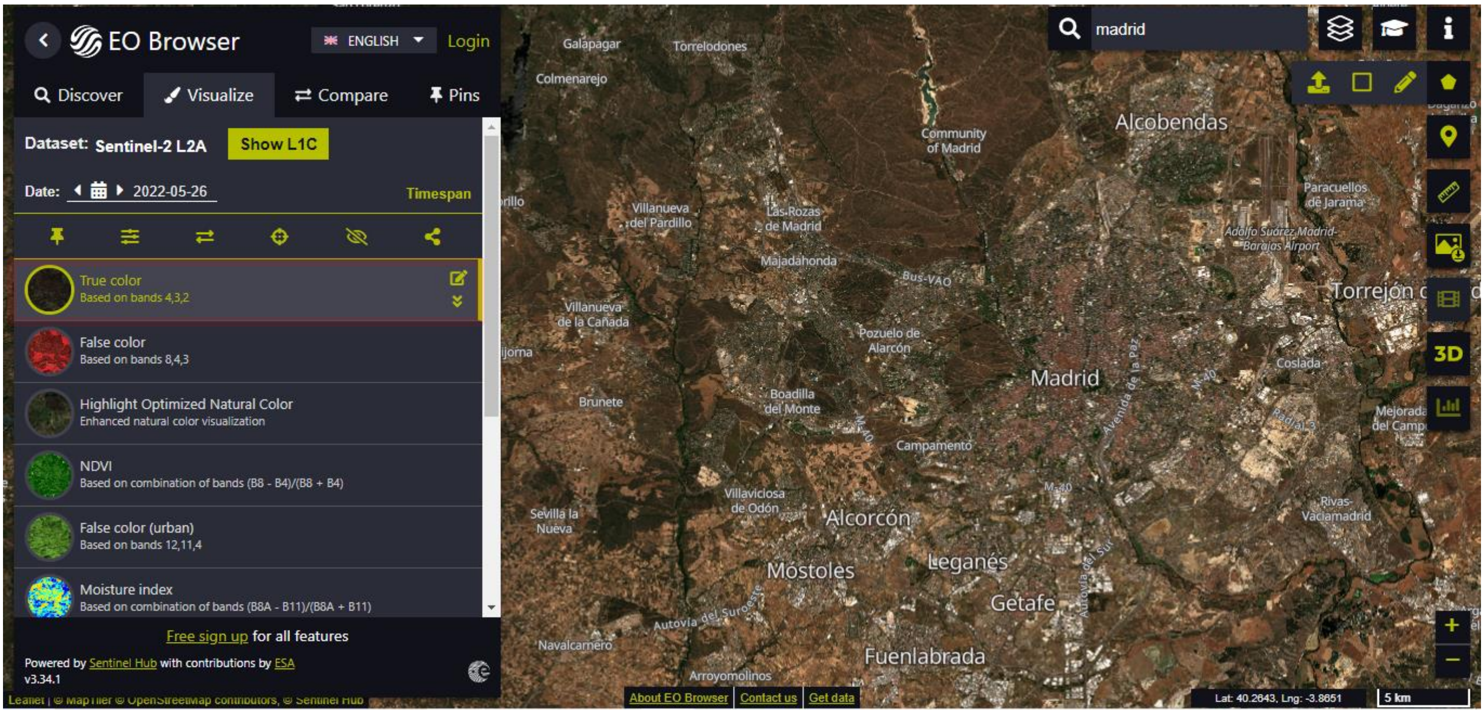
After the search, the selected image can be visualised in the browser.



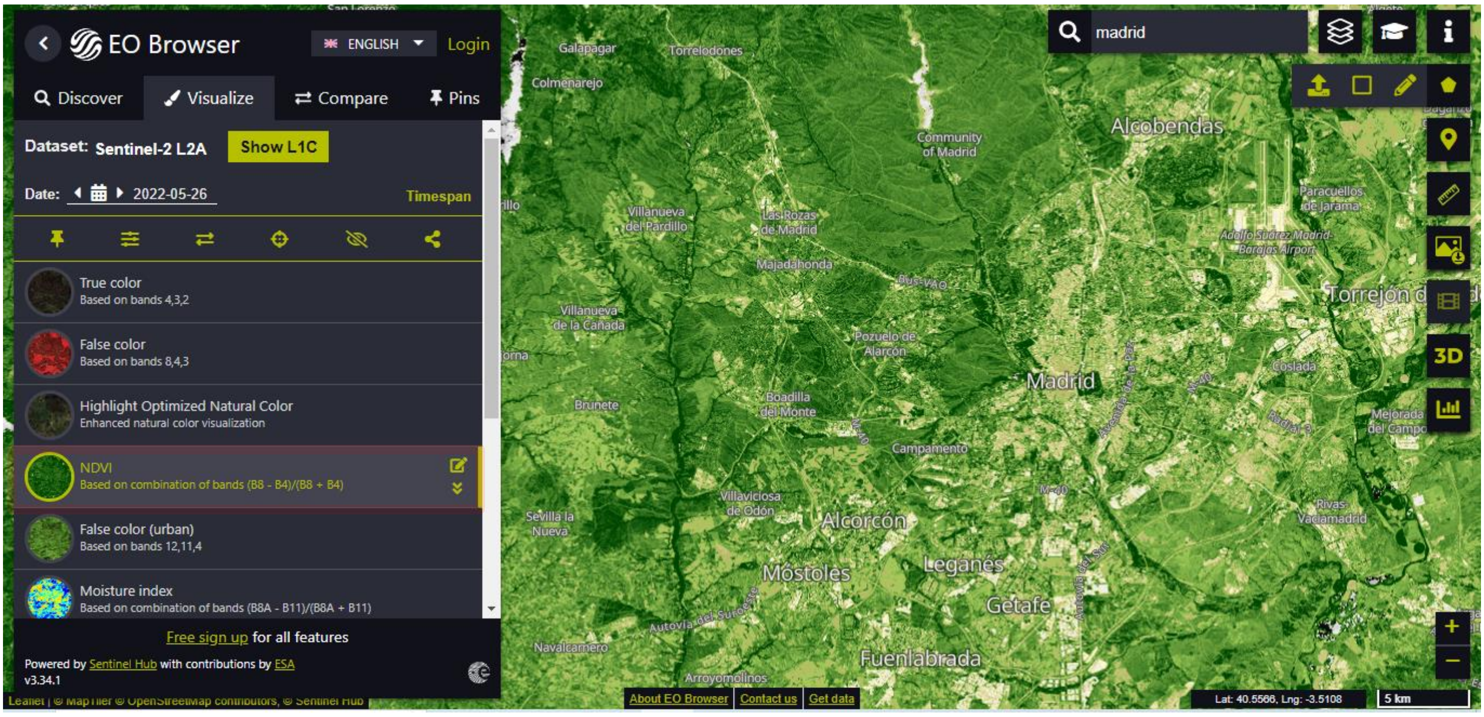
5.1 Optical data

In the visualisation tab, we can change the view mode (available are visualization options in the form of color compositions and spectral indices).

True color composition (R-G-B)



Normalised difference vegetation index (NDVI)



Other visualization options

Available color compositions:

- True colour (bands: Red-Green-Blue)
- False colour (bands: NIR-Red-Green)
- Highlight Optimized Natural Color
- False colour (urban) (bands: 12-11-4)
- SWIR (bands: 12-8A-4)

Available spectral indices:

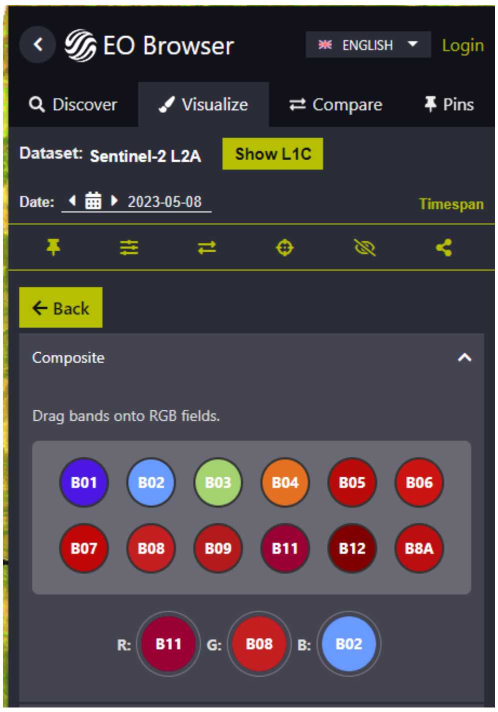
- NDVI - for vegetation monitoring
- NDWI - for water monitoring
- NDSI - for snow monitoring
- Moisture index - for moisture monitoring

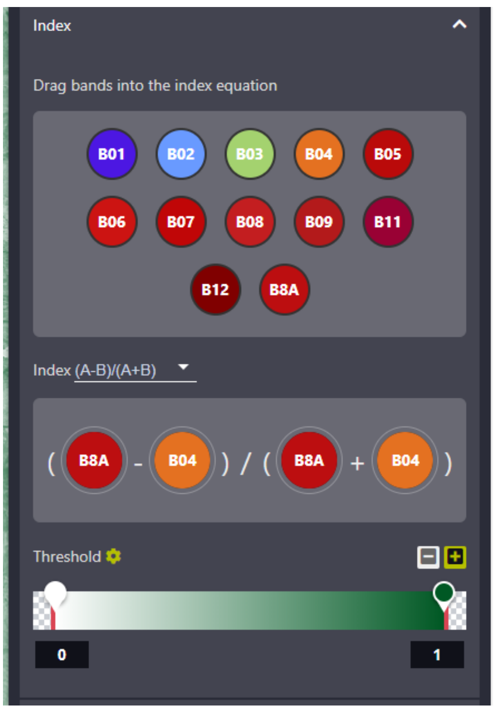
Available classifications:

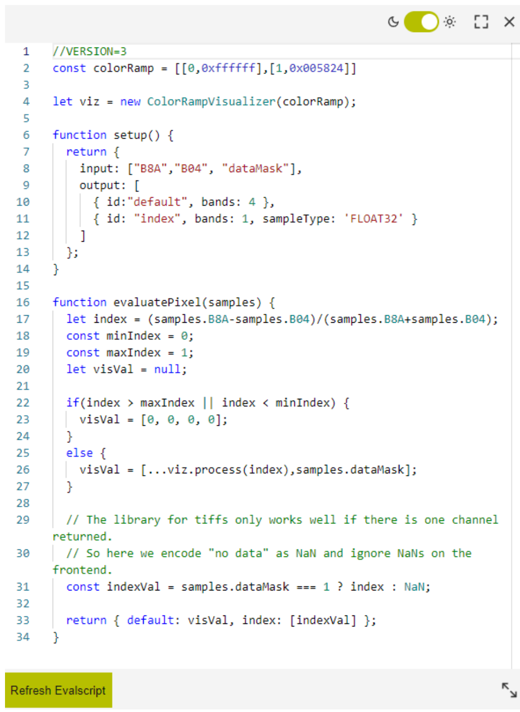
- Scene classification map - classification display based on ESA algorithms

+ Available custom visualization

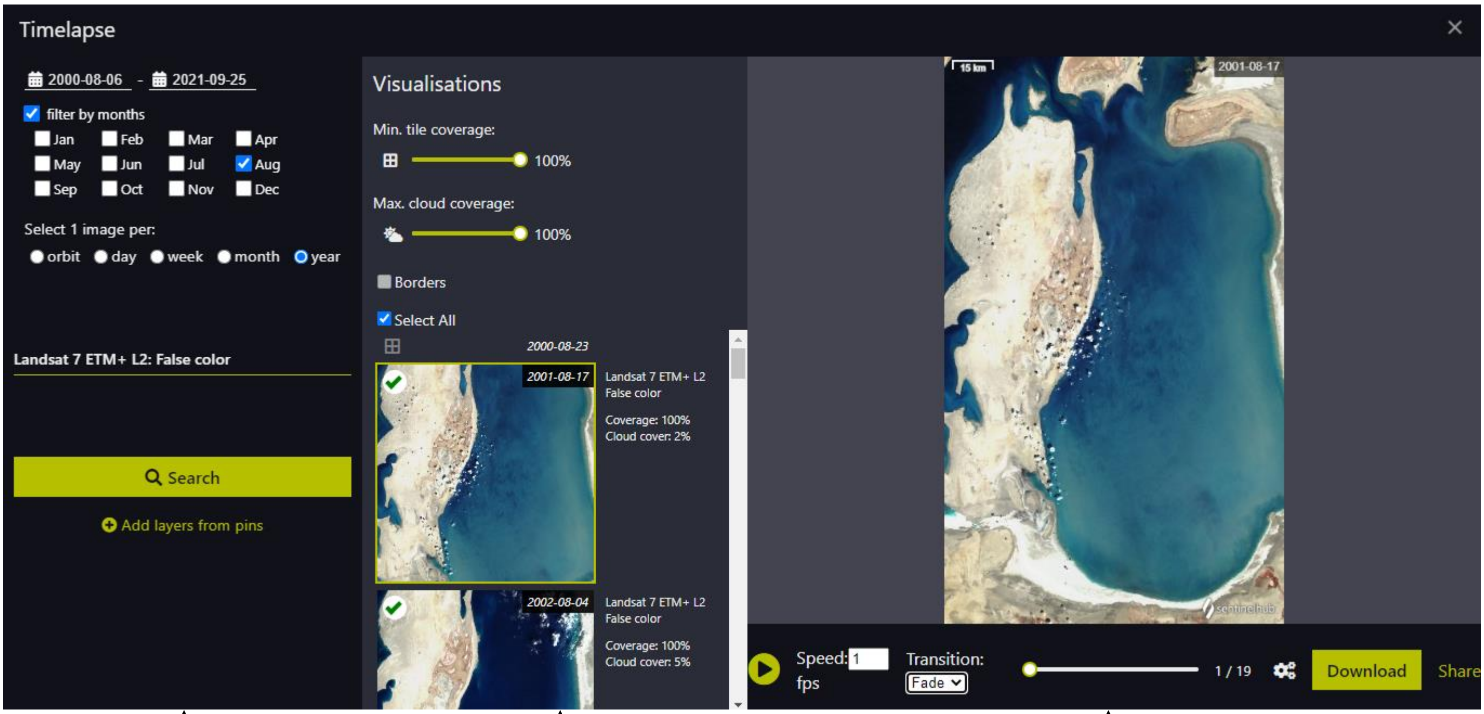
We can also use a visualisation for custom color combinations or spectral indices of default bands or the scripting tool and use additional datasets.







An important visualisation tool of EO Browser is the *Timelapse* function. We can choose multiple images filtered by date or month and select one image per orbit, day, week, month or year. We can set prefered tile coverage and % of cloud cover. Then we can select all or only some images and play, download or share the timelapse visualisation.



Select time range

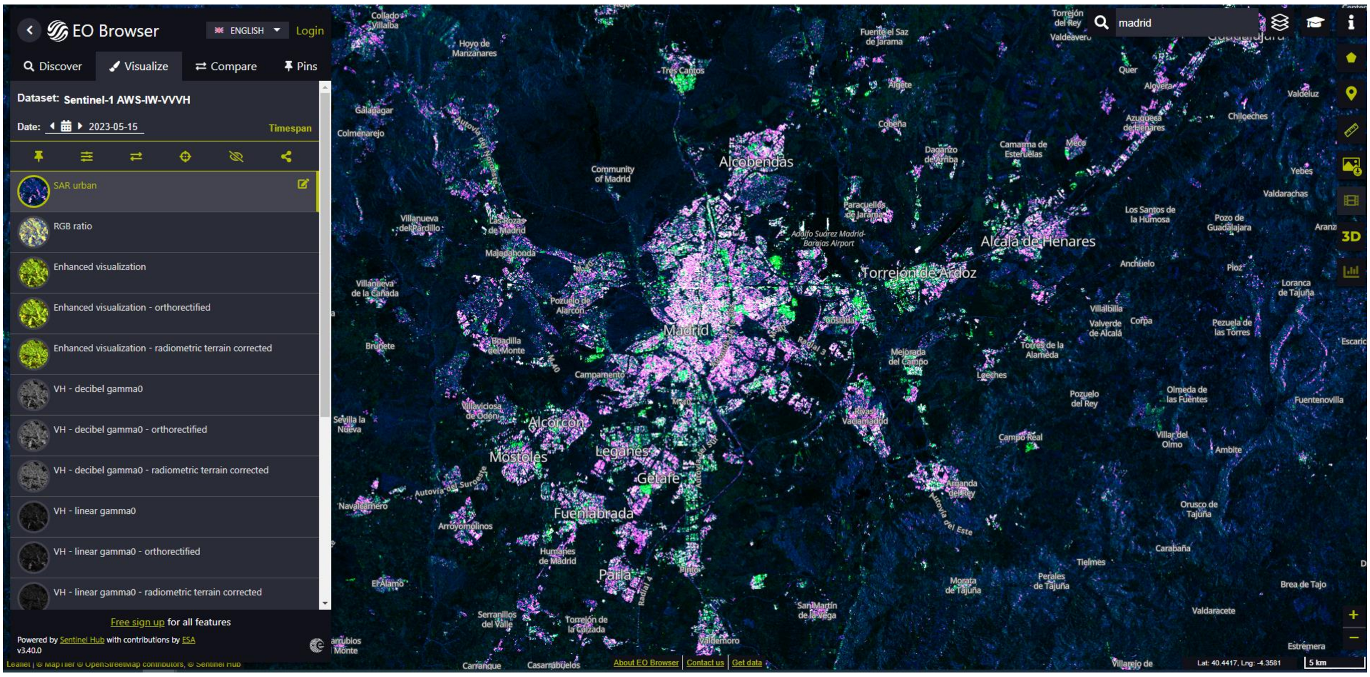
Select/deselect image

Play a video, select transition mode, download or share your created timelapse

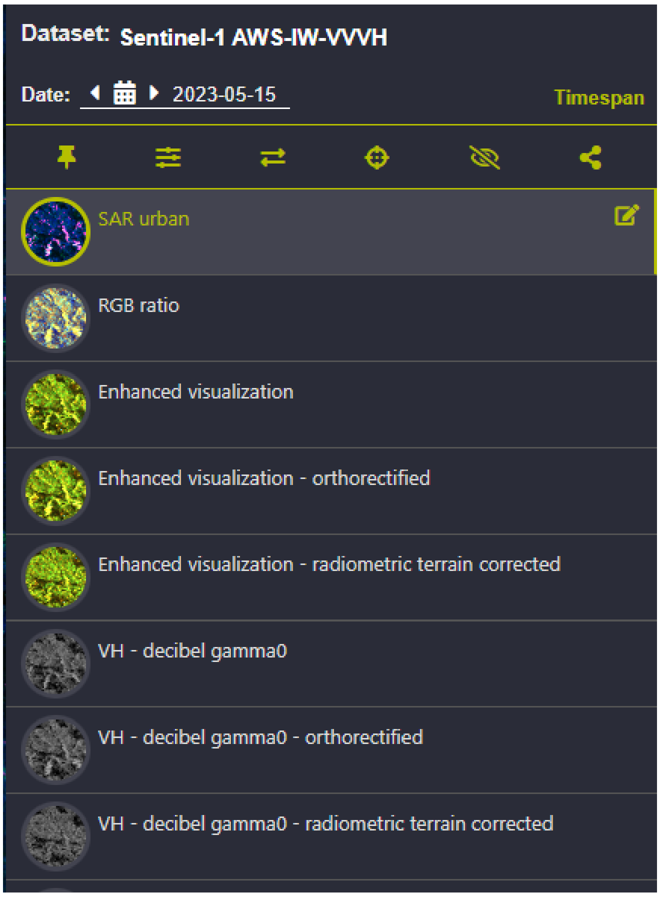
The resulting timelapse of images from the Landsat 7 satellite showing the disappearance of the Aral Sea by 2020

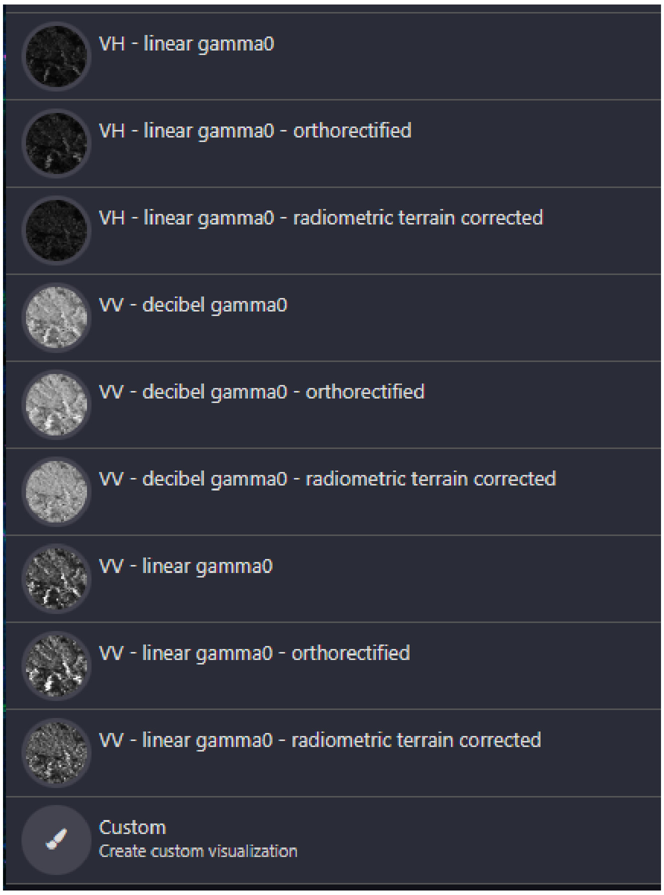
5.2. Radar data

When displaying radar data, we have the option to choose from various types of visualizations.



In accordance with specific requirements, the terrain can be displayed using different polarizations, cross- polarizations, and corrections.

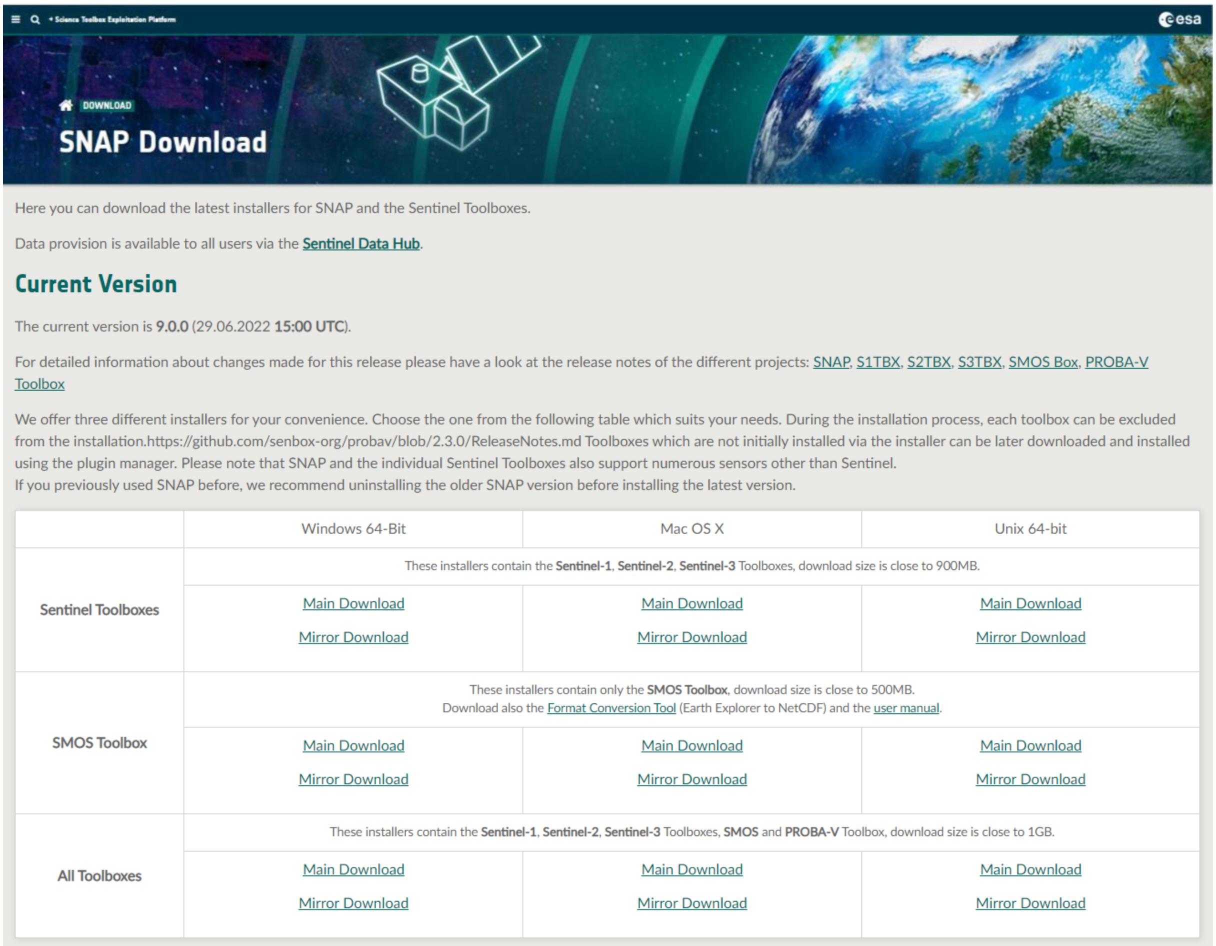




6 | Sentinel Application Platform (SNAP)

https://step.esa.int/main/download/snap-download/

ESA Sentinel Application Platform (SNAP) is a software toolkit developed by the European Space Agency (ESA) for processing and analyzing Earth observation data, particularly data from the Sentinel satellites. SNAP is part of the Sentinel Toolbox and is freely available to the public. It provides a user-friendly interface and a comprehensive set of tools also for working with a variety of other remote sensing data.



SNAP Download

Here you can download the latest installers for SNAP and the Sentinel Toolboxes.

Data provision is available to all users via the Sentinel Data Hub.

Current Version

The current version is **9.0.0** (29.06.2022 **15:00 UTC**).

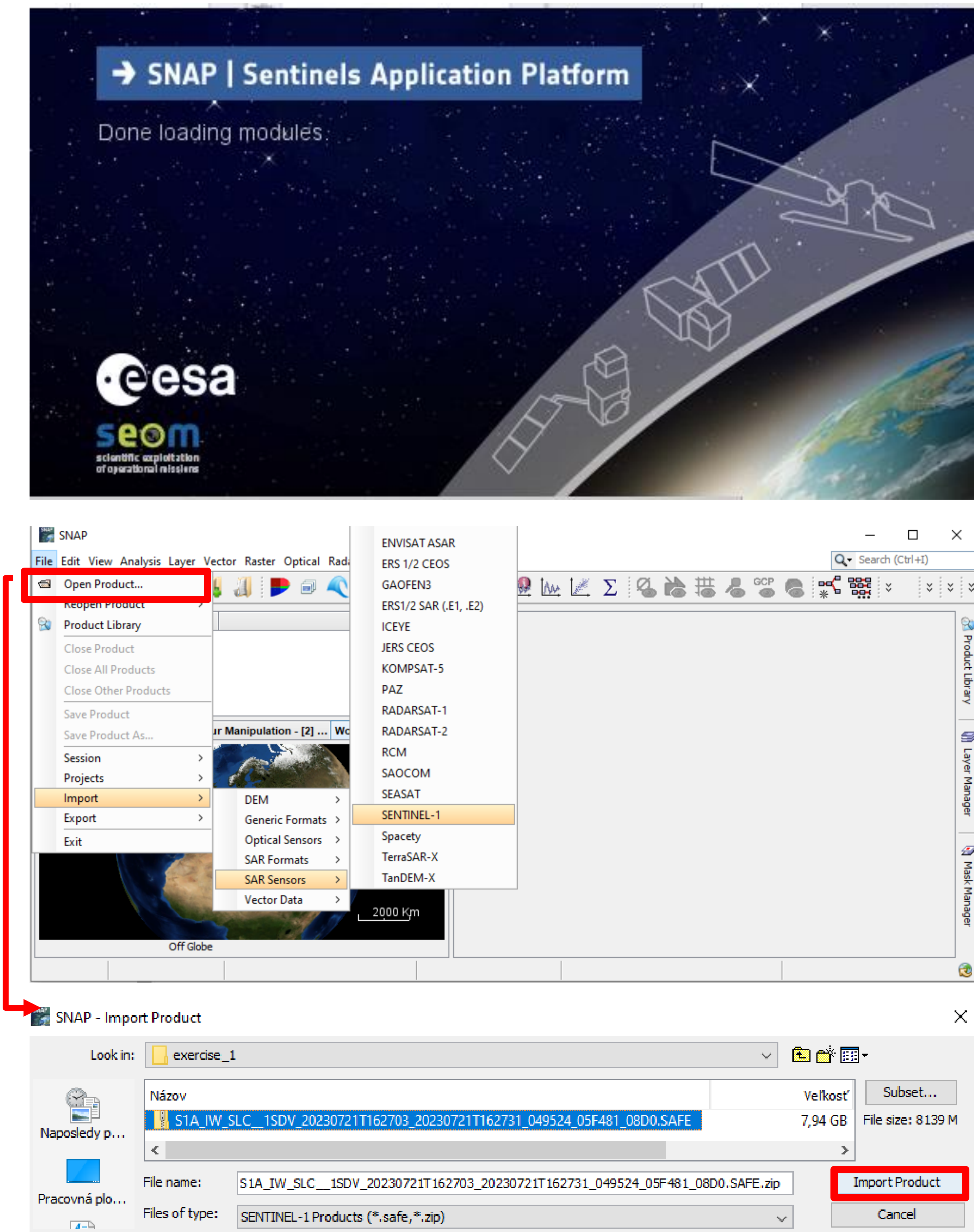
For detailed information about changes made for this release please have a look at the release notes of the different projects: SNAP, S1TBX, S2TBX, S3TBX, SMOS Box, PROBA-V Toolbox

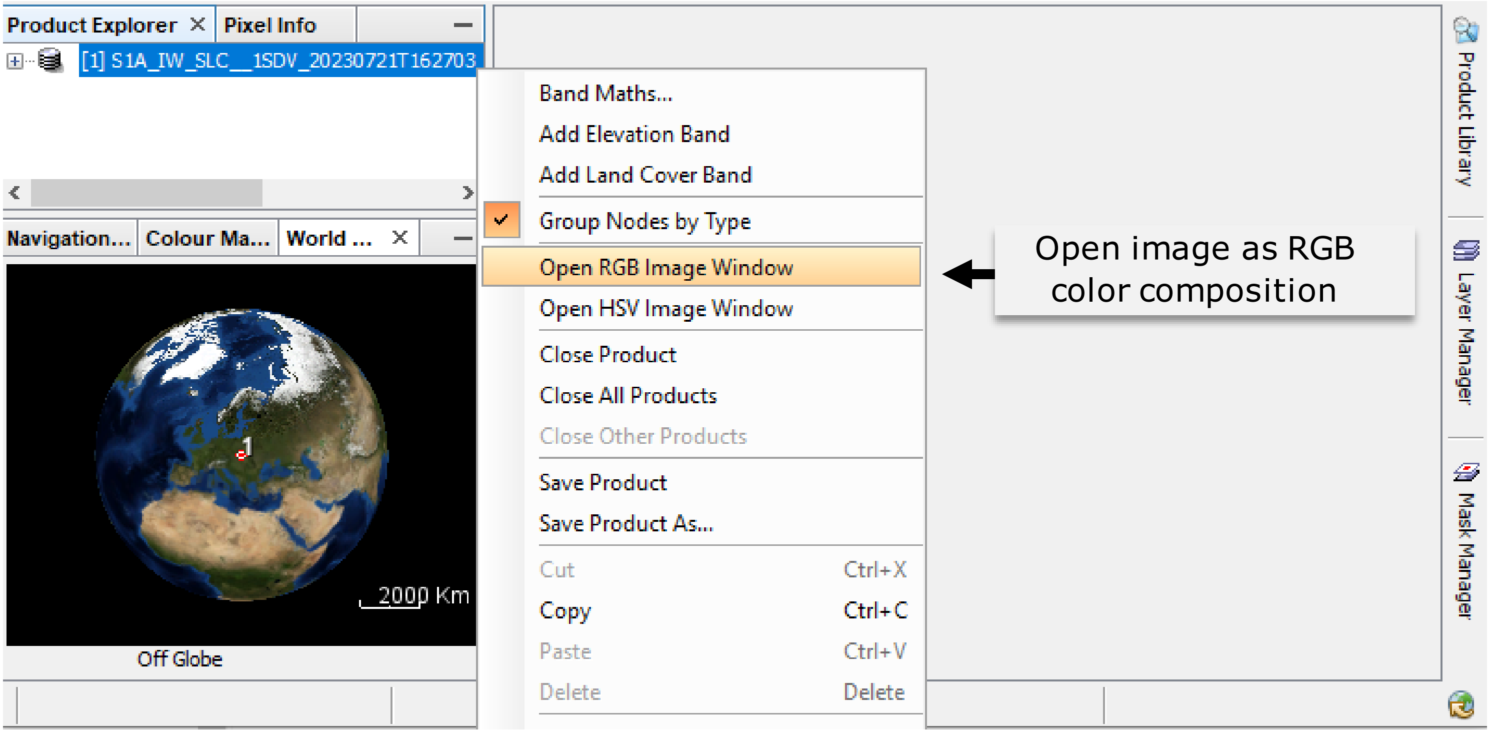
We offer three different installers for your convenience. Choose the one from the following table which suits your needs. During the installation process, each toolbox can be excluded from the installation.https://github.com/senbox-org/probav/blob/2.3.0/ReleaseNotes.md Toolboxes which are not initially installed via the installer can be later downloaded and installed using the plugin manager. Please note that SNAP and the individual Sentinel Toolboxes also support numerous sensors other than Sentinel.
If you previously used SNAP before, we recommend uninstalling the older SNAP version before installing the latest version.

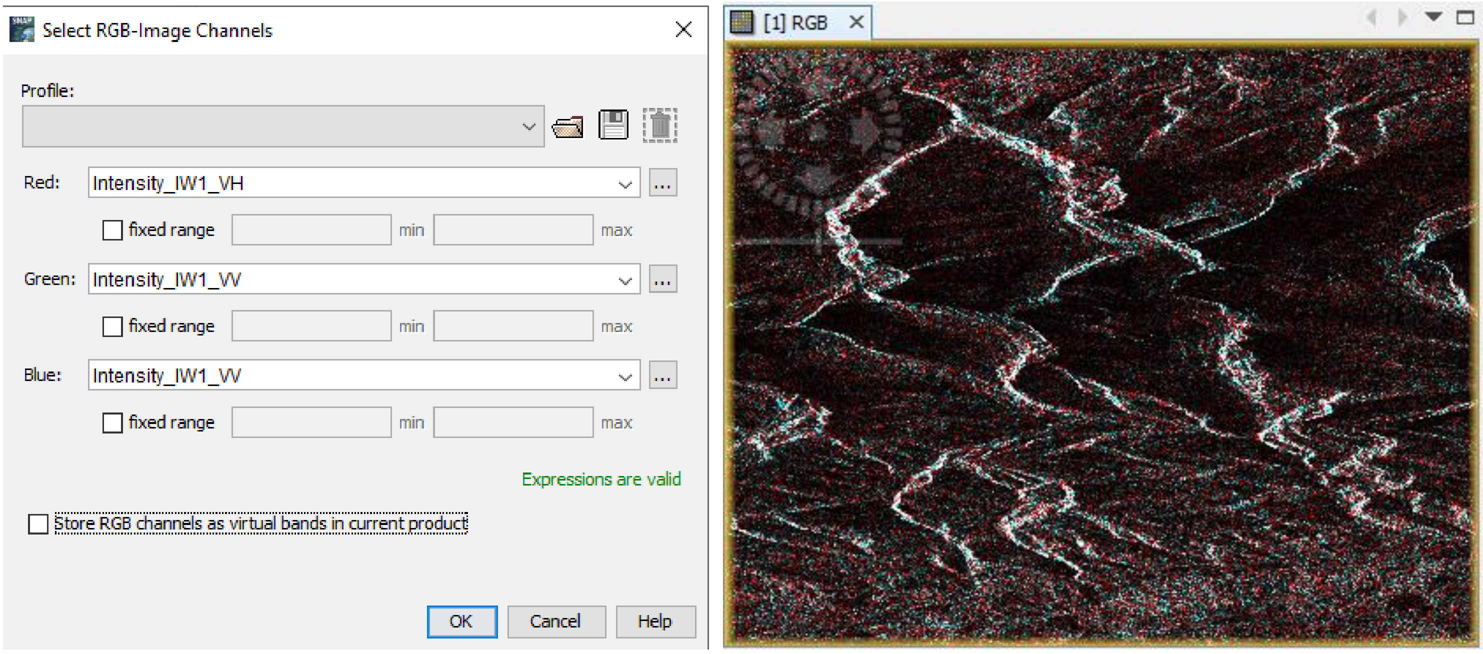
	Windows 64-Bit	Mac OS X	Unix 64-bit
Sentinel Toolboxes	These installers contain the **Sentinel-1**, **Sentinel-2**, **Sentinel-3** Toolboxes, download size is close to 900MB.		
	Main Download Mirror Download	Main Download Mirror Download	Main Download Mirror Download
SMOS Toolbox	These installers contain only the **SMOS Toolbox**, download size is close to 500MB. Download also the Format Conversion Tool (Earth Explorer to NetCDF) and the user manual.		
	Main Download Mirror Download	Main Download Mirror Download	Main Download Mirror Download
All Toolboxes	These installers contain the **Sentinel-1**, **Sentinel-2**, **Sentinel-3** Toolboxes, **SMOS** and **PROBA-V** Toolbox, download size is close to 1GB.		
	Main Download Mirror Download	Main Download Mirror Download	Main Download Mirror Download

SNAP is widely used in the scientific community and by remote sensing professionals for a variety of applications, including land cover mapping, environmental monitoring, and disaster response. It is an open-source tool, and its modular architecture allows for the integration of plugins and additional functionalities.

After installing and starting the software, we can open an image using File – Open Image or by Import option:

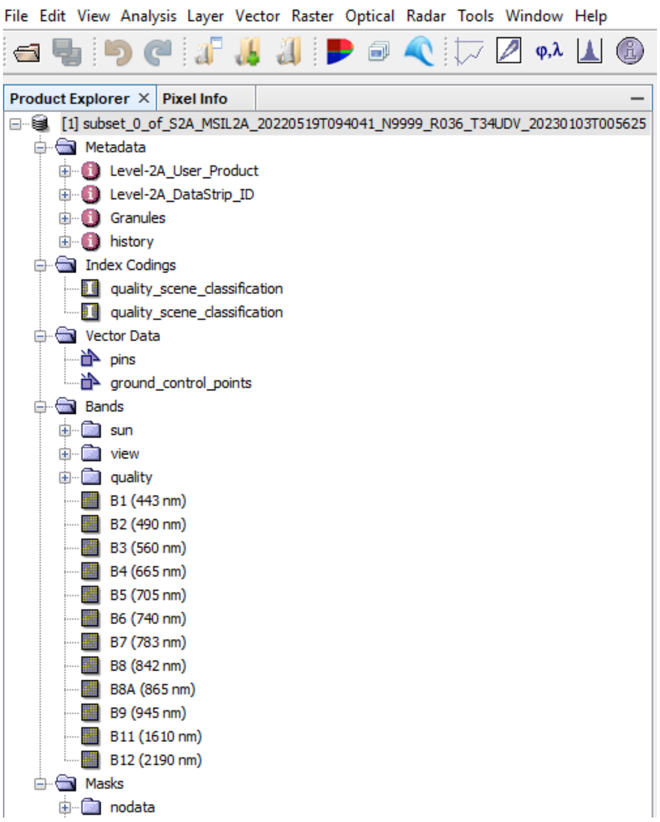


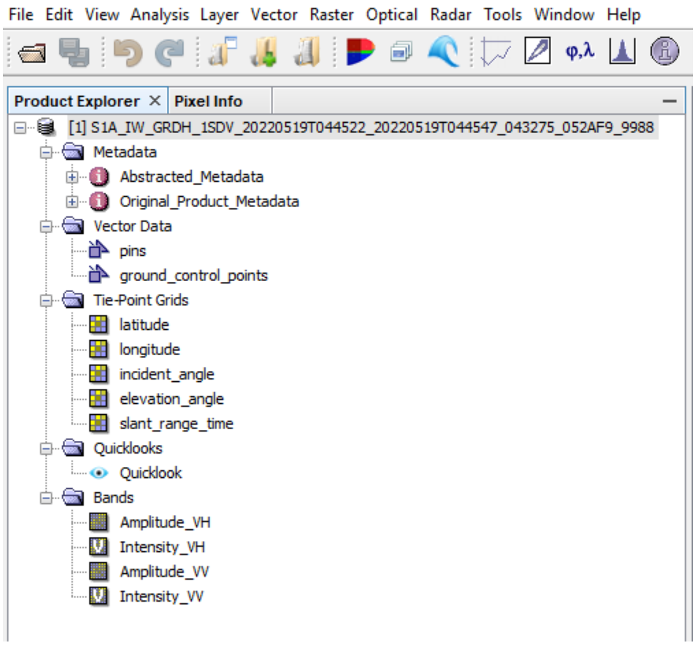




Display image in different polarizations

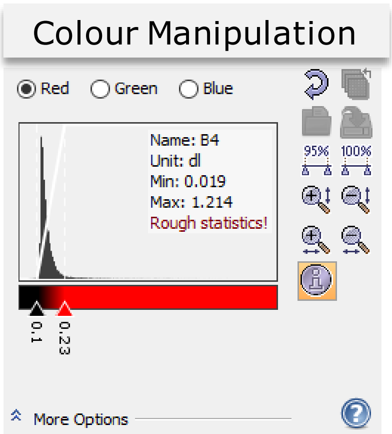
Upon opening an image, users can explore the image data through the Product Explorer window. This encompasses opening RGB composite images, navigating metadata, inspecting spectral bands, and reviewing image masks. In the case of radar images, amplitude or intensity can be visualized in various polarizations.





In the bottom-left Window Group, we can see 4 tools:

- *Navigation tool* – to navigate within the opened image
- *Colour Manipulation* – to view the histogram for the opened image and manipulate individual channels or assign new colours to the image
- *Uncertainty Visualisation* – to visualise the uncertainty information associated with a band shown in an image view
- *World View* – to see the position of our selected image

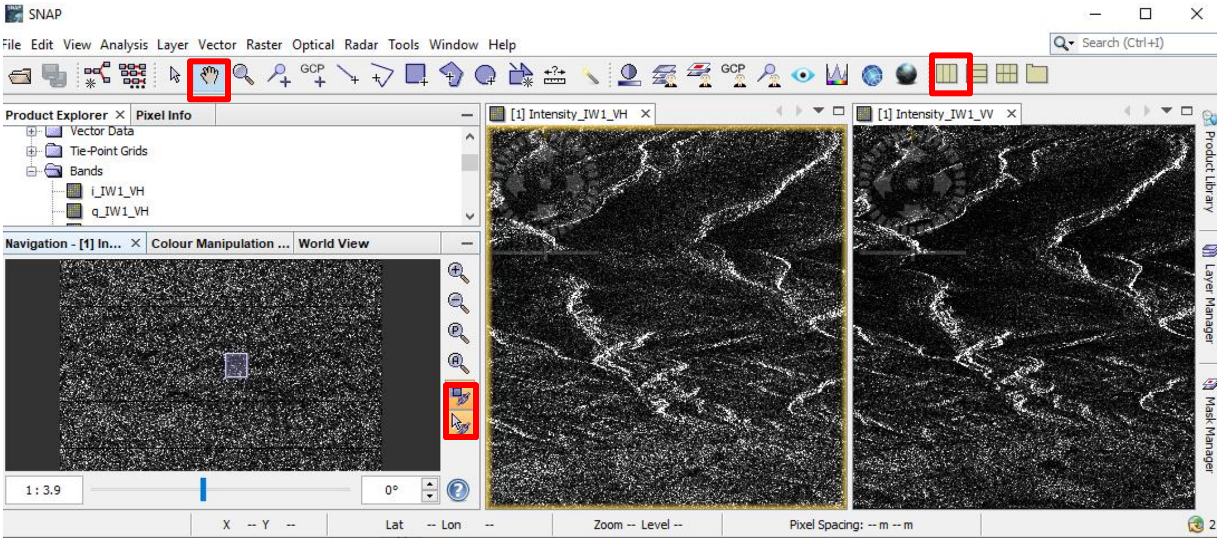


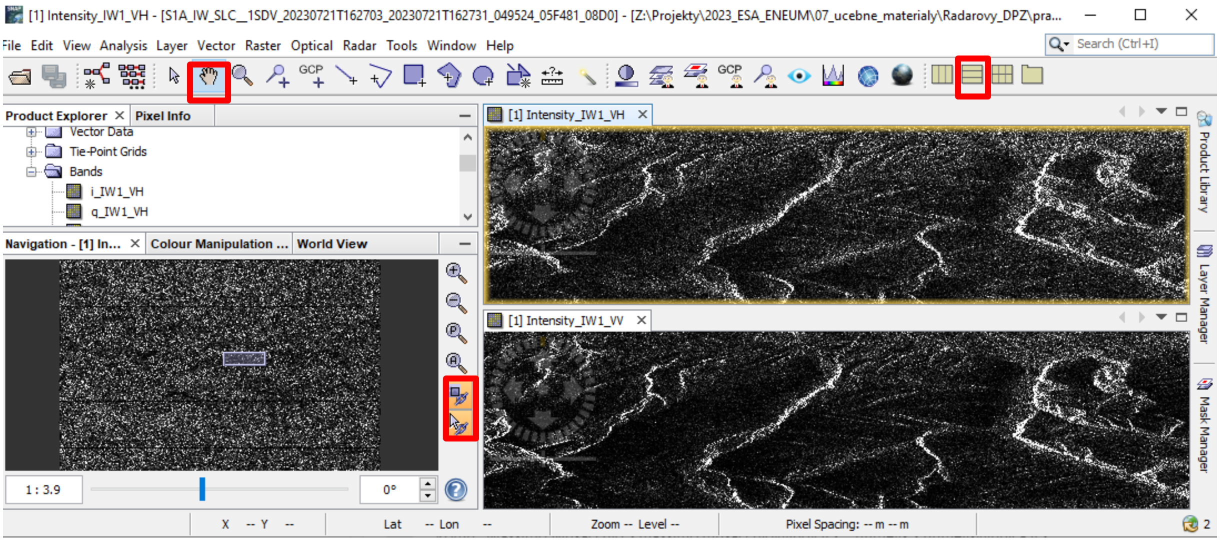
To simultaneously view and compare multiple opened images, utilize the *Tile* function (e.g. *"Tile Horizontally" or „Tile Vertically").*

Ensure that the cursor is visible and that simultaneous manipulation of all images is possible by navigating to the Navigation tab and verifying that the following is checked:

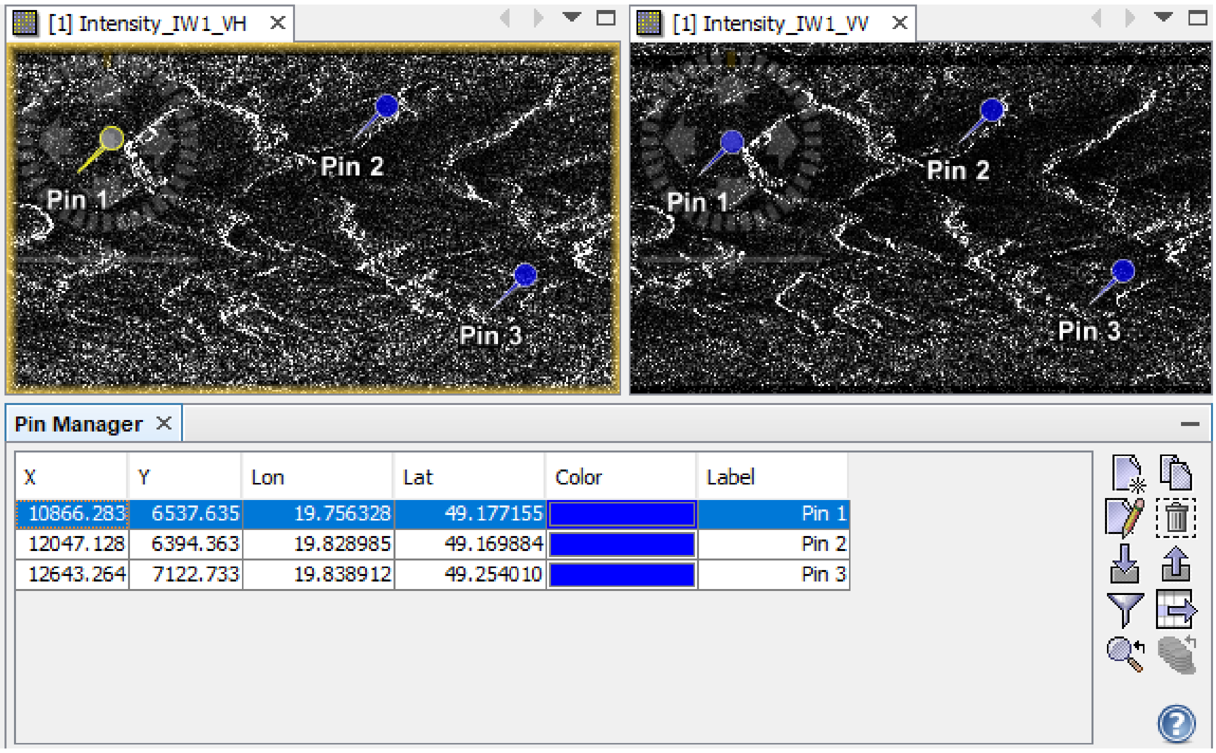
synchronises views across multiple image windows

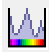
synchronises cursor positions across multiple image windows

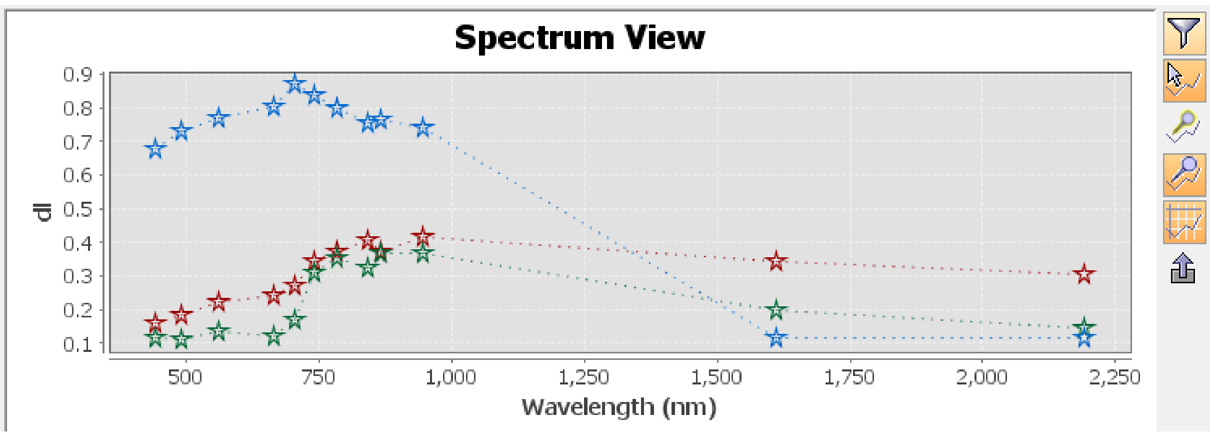




For localization purposes, we can add various pins to different pixels and add the description to them (*View – Tool Windows – Pin Manager* or by clicking on the icon of *Pin placing tool* 



To observe spectral information of these various pins, we can use the tool Spectrum View 



7 | Third party missions

https://earth.esa.int/eogateway/missions/third-party-missions

In addition to providing users with data from its own Earth observing (EO) satellites, the European Space Agency (ESA) has played a significant role in providing access to Earth Observation missions not under ESA ownership or operation—referred to as Third Party Missions (TPM). With a history spanning over 45 years, the TPM program involves a series of Earth Observation-focused satellites owned by various commercial and public organizations worldwide. The TPM initiative currently includes over 50 missions, contributing data from more than 60 instruments to support users engaged in research and development endeavors.

7.1. Access to TPM data

Users have the ability to explore and download Earth Observation (EO) data from the extensive catalog of missions operated and supported by the European Space Agency through the ESA EO Catalogue (EO-CAT):

- https://eocat.esa.int/sec/#data-services-area

User can find here:

- mission, instrument and product news and descriptions;
- collection descriptions;
- data access links;
- information on selected Earth/environmental topics and applications of satellite data

Data are also accessible through the TPM L-OADS web interface:

- https://tpm-ds.eo.esa.int/collections/

For more information, see the lecture: 1. Radar Earth Observation and evolution – current and next generation missions, ESA EO Data Access and resources, applications

THANK YOU FOR FOLLOWING THE EXERCISE!

UNIVERSITY COURSE APPLIED RADAR REMOTE SENSING

EXERCISE 2 – TUTORIAL

SAR for Land Applications 1 – SAR basics for Land monitoring using SNAP software

esa ÚSTAV GEOGRAFIE Prírodovedecká fakulta UPJŠ v Košiciach UNIVERZITA PAVLA JOZEFA ŠAFÁRIKA V KOŠICIACH

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1 | Exercise outline

In this exercise, we will:

- Learn how to retrieve a land-use / land cover (LULC) classification based on Sentinel-1 image products
- Explore different types of analysis for the detection of discrete land cover classes.
- Use supervised and unsupervised classification algorithms to classify the satellite image into classes

2 | Background

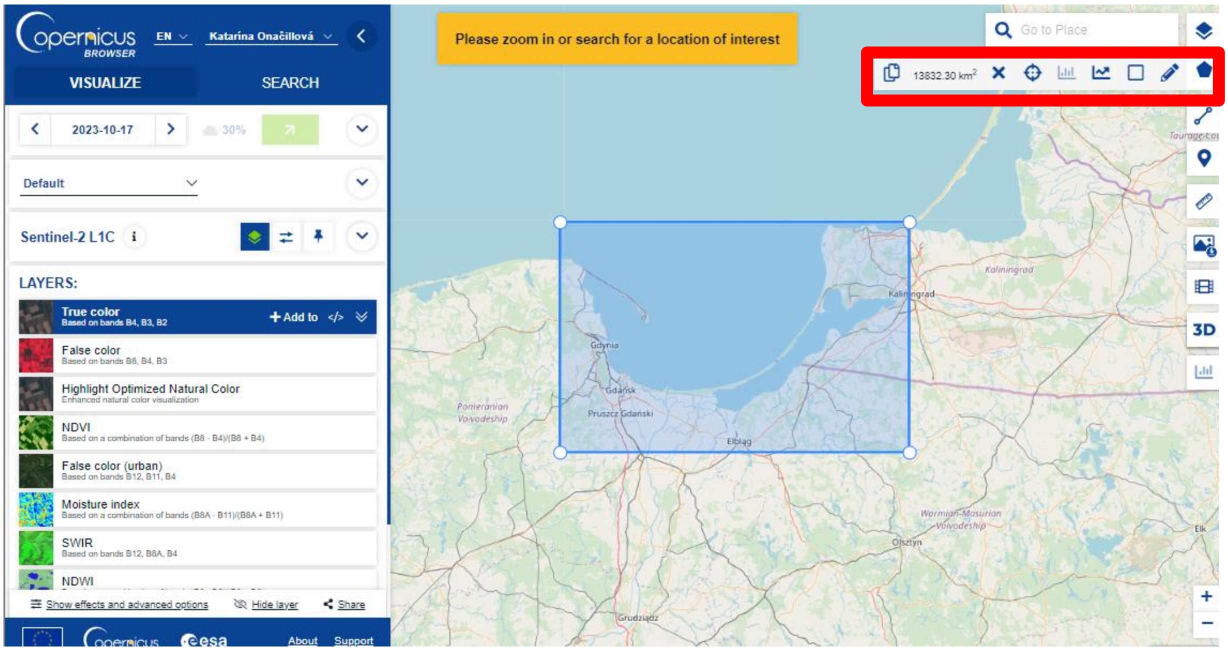
Mapping land cover using Sentinel-1 data

Mapping land cover using Sentinel-1 data relies on the radar backscatter signals obtained from the satellite. The backscatter intensity, polarization, and texture of the radar imagery are analyzed to distinguish between different land cover types. Supervised classification methods involve training a classifier with labeled samples of land cover types, while unsupervised methods group pixels based on their spectral similarity without prior training. The accuracy of the land cover classification is validated using ground truth data, and the results can be refined iteratively to improve accuracy. The final land cover maps provide valuable information for various applications, including urban planning, agriculture, forestry, and environmental monitoring.

Source: https://eo4society.esa.int/event/7th-advanced-training-course-radar-polarimetry/

2.1 Study area and data used

For this exercise, we will use two Sentinel-1 images of the same area in northern Poland, downloaded for year 2023 from the Dataspace Copernicus Open Access Hub [@https://dataspace.copernicus.eu/].



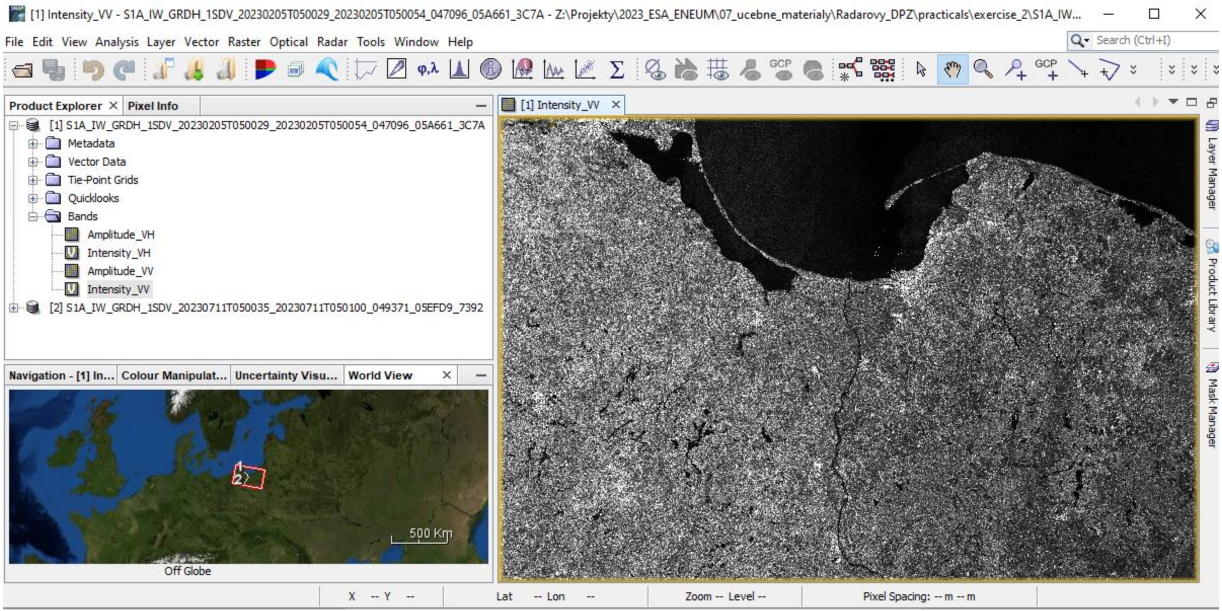
However, the feature space of S1 data, referring to the number of variables available for predicting target classes, is restricted when compared to optical data. As a result, this tutorial utilizes two images captured in the same year but during different seasons. This approach enables the characterization of surfaces based on their temporal attributes to some extent. Consequently, Image 1 was obtained during the month with minimal precipitation (February), while Image 2 was acquired towards the beginning of July, a period associated with the highest precipitation.

2.2. SNAP - Open and explore product

Open SNAP Desktop, click Open Product and open 2 Sentinel-1 GRDH downloaded products with HH and HV polarizations acquired on 5 February and 11 July 2023 by double click on the zipped folders. The opened products will appear in Product Explorer window:

S1A_IW_GRDH_1SDV_20230205T050029_20230205T050054_047096_05A661_3C7A.zip
S1A_IW_GRDH_1SDV_20230711T050035_20230711T050100_049371_05EFD9_7392.zip

Click + to expand e.g. the content of product [1] from 5 February 2023, then expand Bands folder and double click on Intensity_VV band to visualize it. Depending on your computer's capabilities, this process could take some time. To minimize the data load, the next step involves creating a subset that encompasses only a portion of the dataset.



Preview of the S1 GRDH product

Note: The image appears inverted because it was captured during an ascending pass.

3.1 Pre-processing

We need to apply identical pre-processing steps to both of our scenes:

Create a subset

There is no need to process the whole image, instead, we can reduce the loaded data to a more manageable size – creating subset. This approach will decrease processing time in subsequent stages, especially when the analysis is concentrated on a specific area rather than the entire scene.

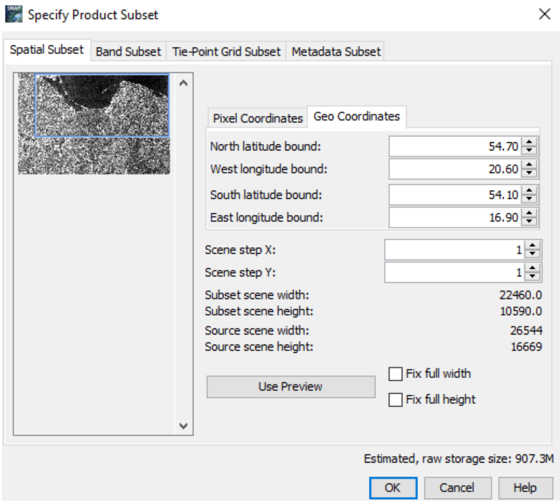
Navigate to Raster – Subset tab

and at Switch to "Geo Coordinates"

Enter the following numbers:

North latitude bound: 54.70
West longitude bound: 20.60
South latitude bound: 54.10
East longitude bound: 16.90

Confirm with Run and repeat the step for the second S1 image.



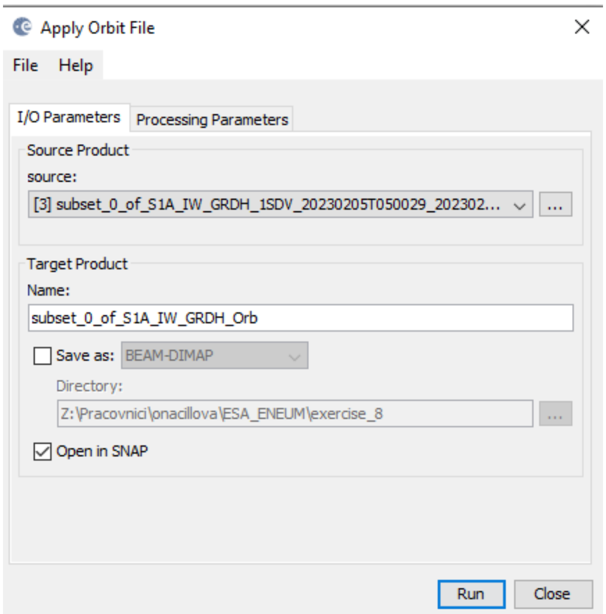
Apply orbit file

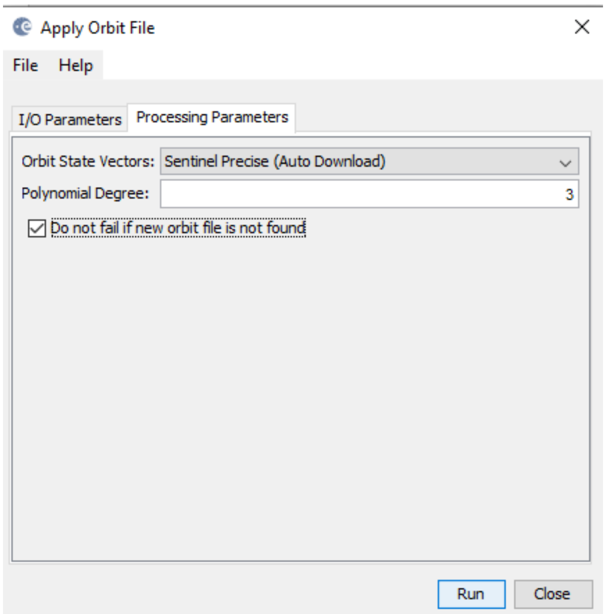
Navigate to Main Menu – Radar – Apply orbit file

In the I/O Parameters tab, select the first product and name the target product. There is no need to save the output as BEAM-DIMAP (we will save the time this way)

In the Processing Parameters accept the default settings and select the option „Do not fail if new orbit file not found"

Repeat for the second image.





Note: If precise orbits are not yet available for your product, restituted orbits can be selected which may not be as accurate as the Precise orbits but will be better than the predicted orbits available within the product

Radiometric calibration

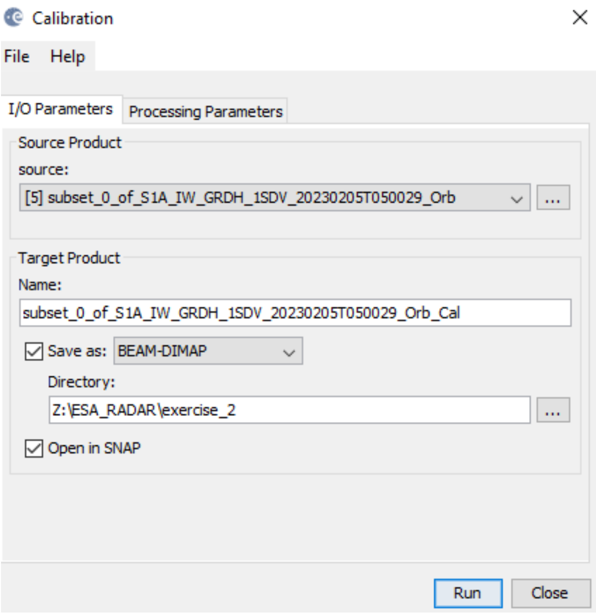
Navigate to Main Menu – Radar – Radiometric - Calibrate

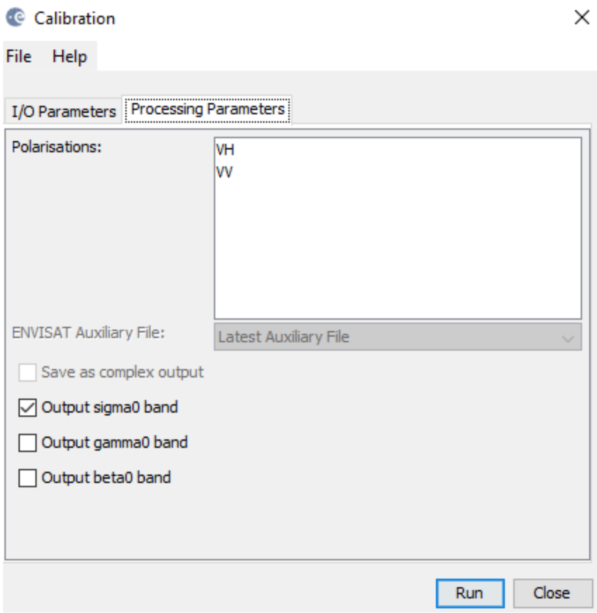
In the I/O Parameters tab, select the product from the previous step (_Orb) as a source product. For the target product name, add _Cal at the end of the name as suggested In the case of this final product of preprocessing, please, save it to your folder for this exercise

In the Processing Parameters accept all default settings and then click Run.

Repeat for the second image. The saving might take some time.

Note: Thermal Noise Removal is not applied in this tutorial but should be considered when working with larger subsets or entire images.

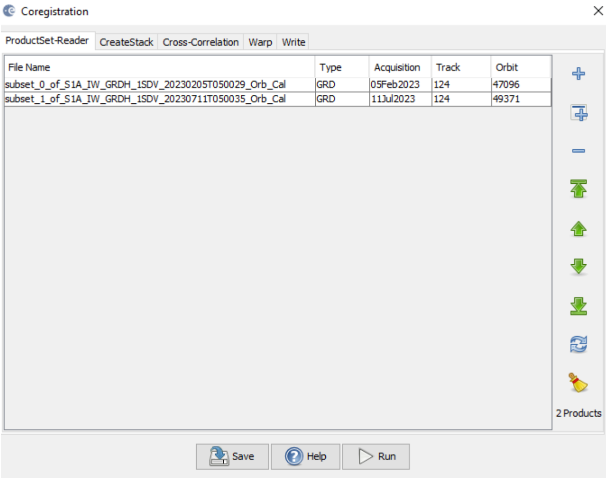


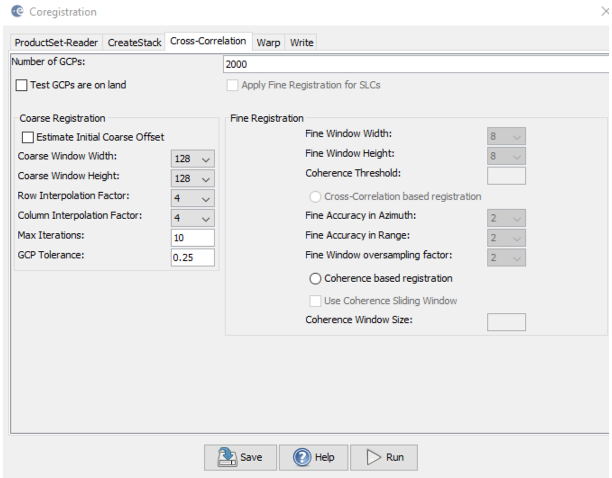


3.2 Coregistration

After both images were radiometrically calibrated in the previous step, the coregistration brings both into one stack. Image coregistration is the process that involves aligning two or more images geometrically, ensuring that corresponding pixels depict the same area on the Earth's surface. While orbit state vectors alone can suffice to coregister images, for precise offset tracking, additional data from a digital elevation model (DEM) is necessary to enhance coregistration accuracy.

Navigate to Main Menu – Radar – Coregistration – Coregistration
In the ProductSet-Reader tab, load the last two preprocessed products (calibrated and with orbit files applied)
In the Write tab name the target product and set the directory to save it
Leave all other settings as predefined



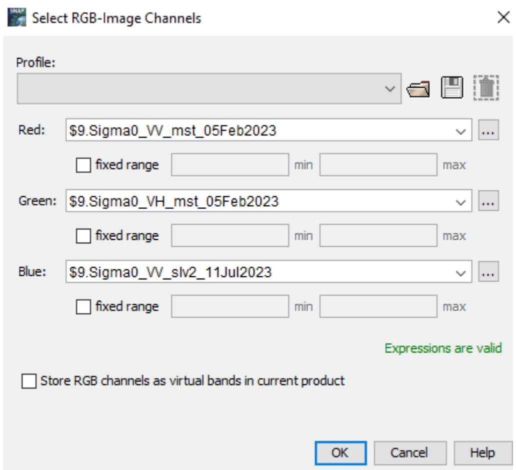


Note: If the coregistration fails it is advisable to increase the number of GCPs and also to have the initial coarse offset estimated by the operator.

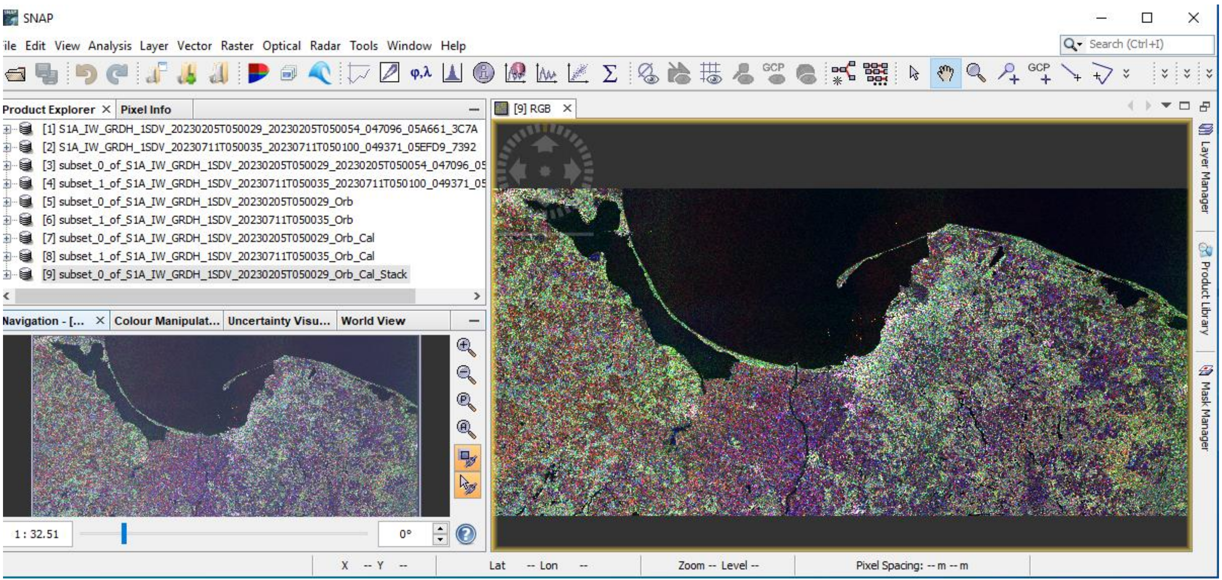
In addition to verifying the accuracy of the residuals, it is advisable to visually inspect the stack's quality. One way to do this is by creating an RGB representation of both the master and slave products, which helps determine if the images are properly aligned.

Right click on the output stack product
– Open RGB Image Window:

Choose February VV for the red channel,
February VH for the green channel,
and July VV for the blue channel.



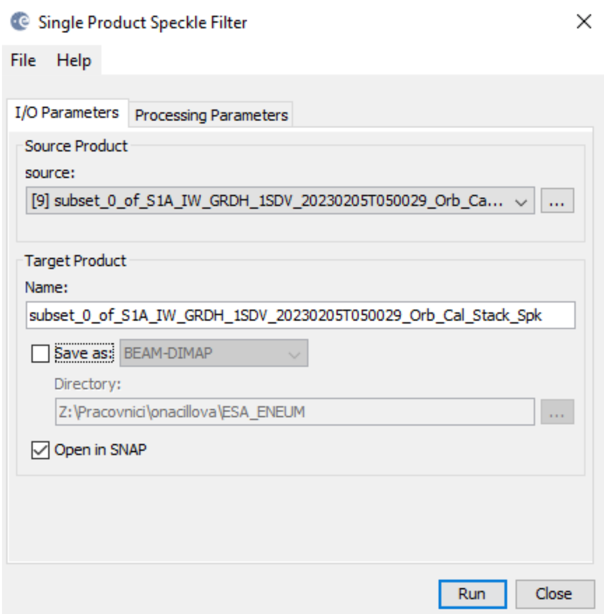
Magnify an area featuring distinct surfaces, such as the boundary between land and water. The RGB image should be vivid and well-defined, except for alterations in land cover or scattering mechanisms that may have transpired between the first and second image acquisitions. In the figure, rivers, roads, and agricultural fields are distinctly depicted in all colors. White pixels represent high backscatter in all three bands (urban areas), while black pixels denote low backscatter values in all three bands (water). Blue pixels signify a slightly shifted shoreline in July compared to February.

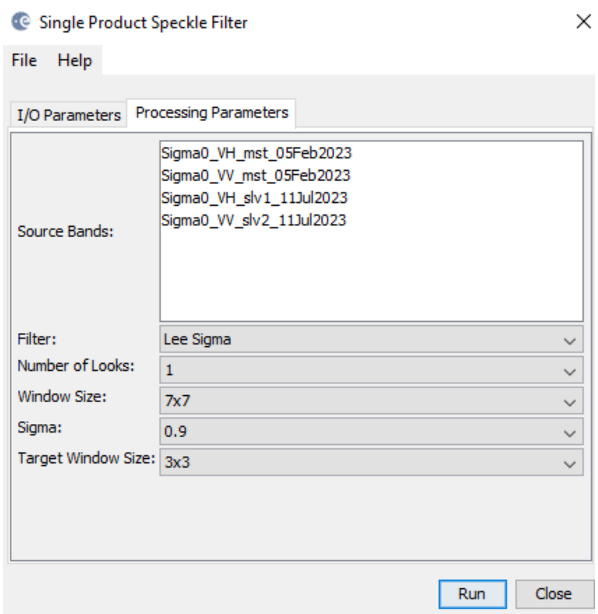


Speckle Filter

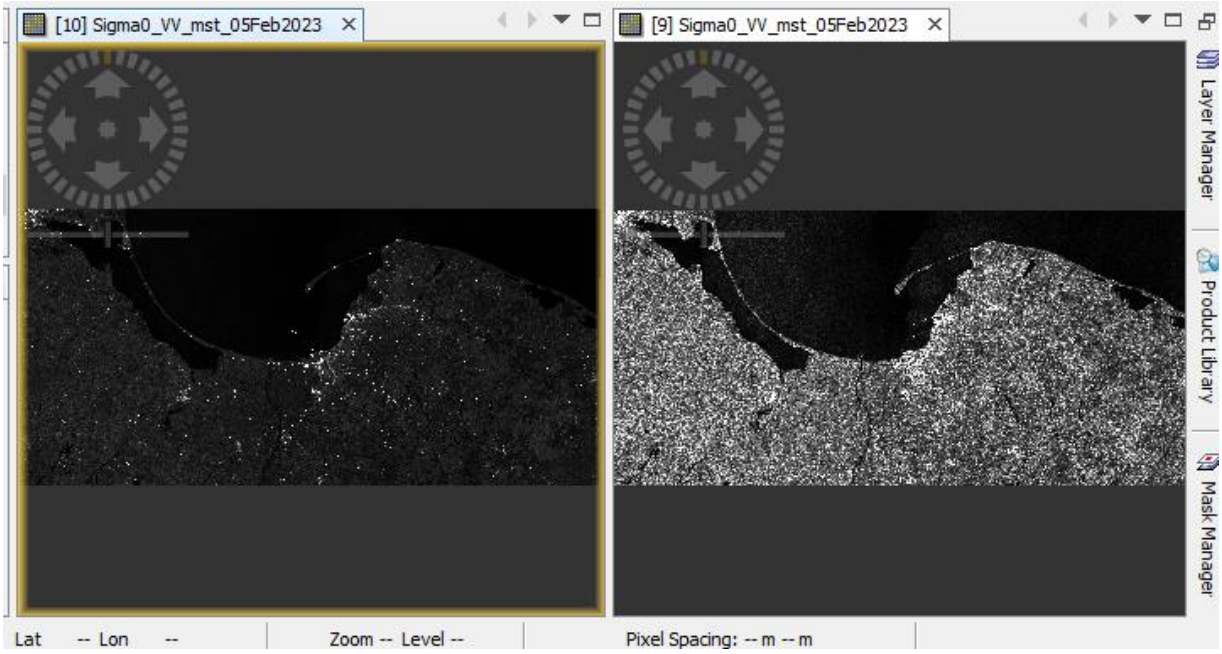
Despeckling removes thermal noise introduced by the sensor from the image to remove potential sources of error in analysis.

Navigate to Radar > Speckle Filtering Single Product Speckle Filter. In the I/O Parameters select the last stack product and in the Speckle-Filter tab, choose the simple Lee Sigma filter with default window sizes.





You can compare the image pre and post-filtering by doule-click on the VV polarizations anfd utilizing the Split Window feature found in the toolbar. As usual, different types of filters will yield somewhat varied outcomes.



Sigma0 VV before (left) and after (right) application of a speckle filter

Terrain-Correction

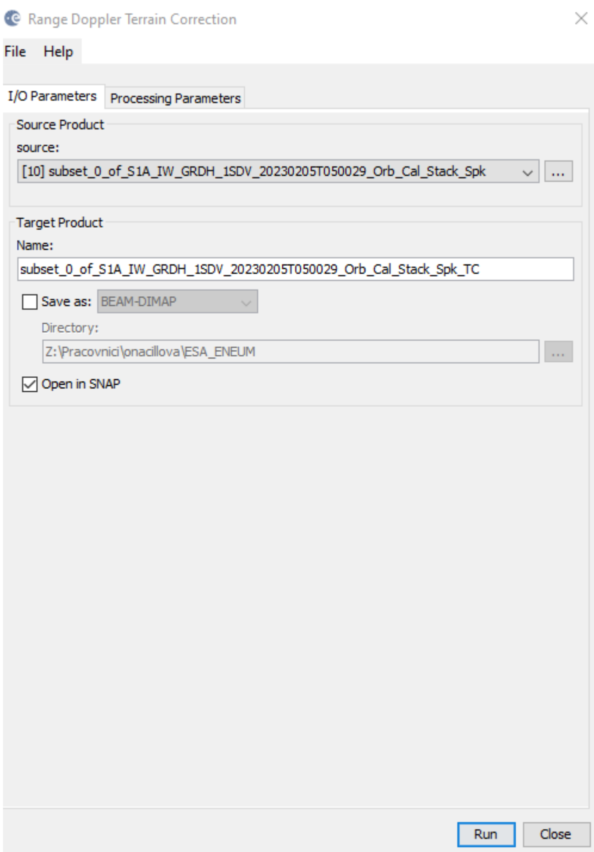
Navigate to Radar – Geometric – Terrain Correction – Range Dopler Terrain Correction. The last step in our graph for image pre-processing is to apply terrain correction to the product, ensuring that all the pixels are moved to the right locations (eg if the nadir angle of the image is off, it will align the pixels correctly so it is closer to a top-down view of the imagery).

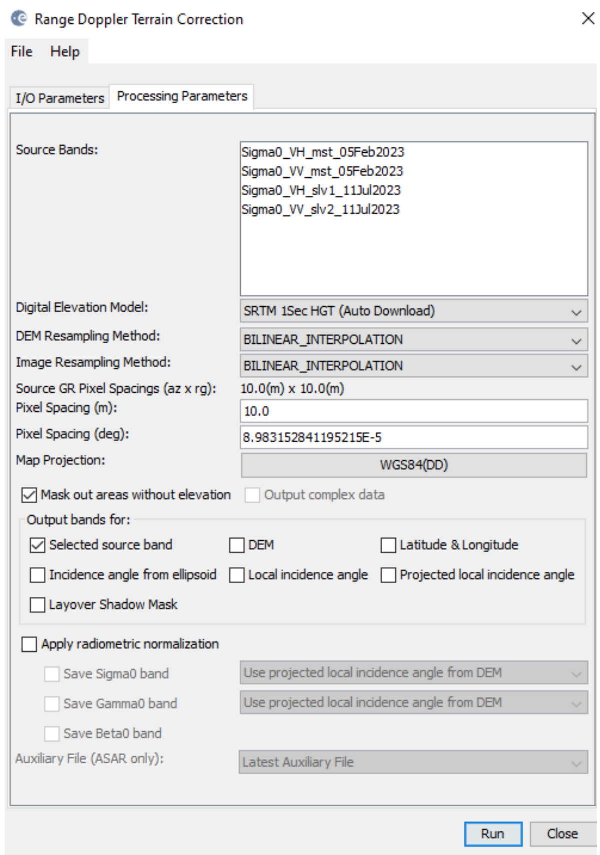
Our data are still in radar geometry, moreover due to topographical variations of a scene and the tilt of the satellite sensor, the distances can be distorted in the SAR images. We need to apply Terrain Correction to compensate for the distortions and reproject the scene to geographic projection.

Navigate to Main Menu: Radar - Geometric - Terrain Correction - Range-Doppler Terrain Correction
In the I/O Parameters tab set as “Source Product” the velocity product.
In “Target Product”, keep the default name and set the Directory
In the Processing Parameters tab set:
Digital Elevation Model: SRTM 1Sec HGT (AutoDownload)

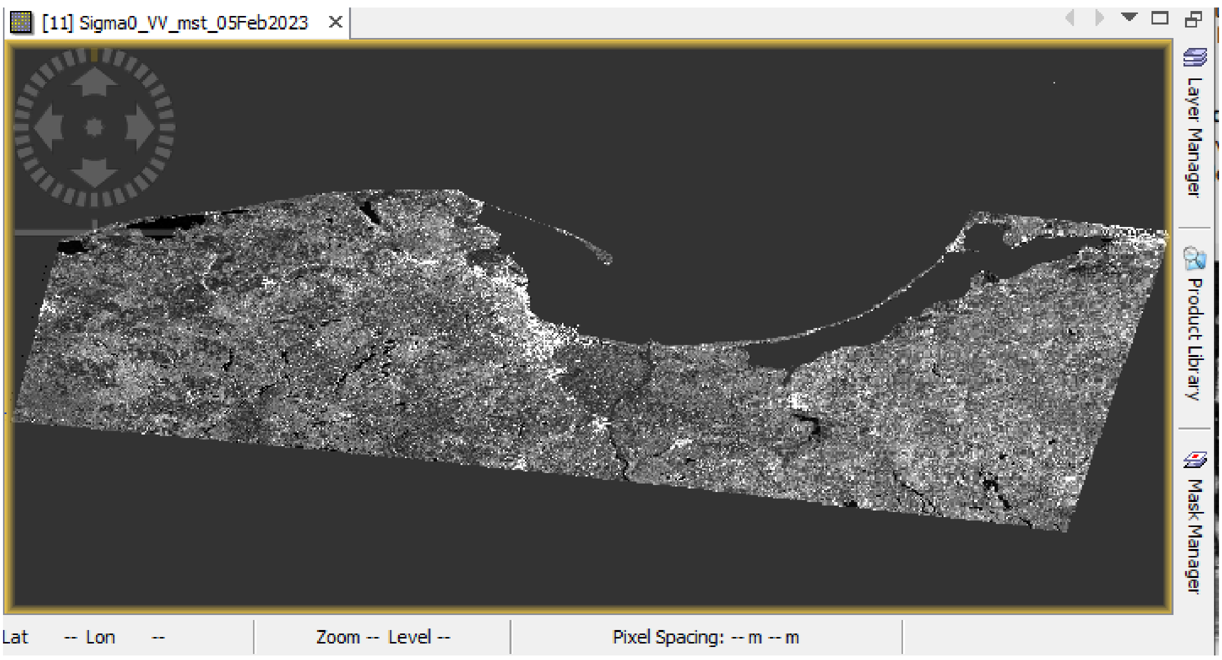
Map Projection: In this tutorial, we opt for WGS84 as the Map Projection, which relies on geographic coordinates (latitude and longitude). However, for subsequent utilization in a geographic information system (GIS), projected coordinate systems like UTM (Automatic) could also be chosen.

Keep defaults values for the other parameters. Click Run.





Geocoded image product after Terrain Correction

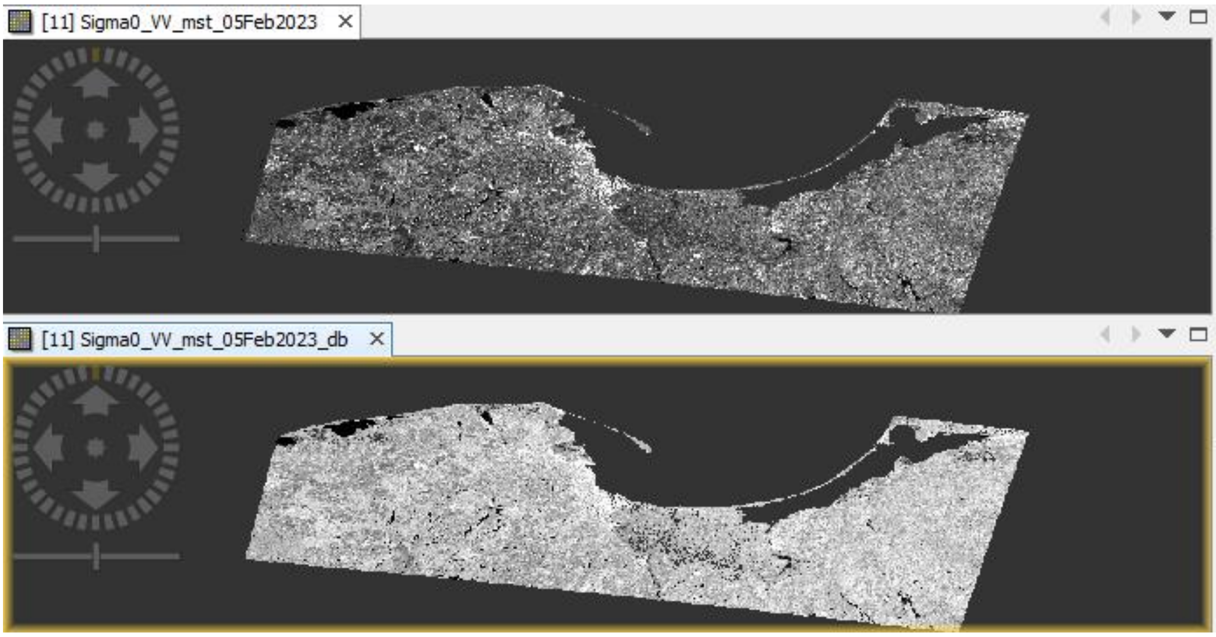


Conversion to dB scale

Sigma0_VV values typically fall within the range of 0 to 1, with mean backscatter values of 0.07 (VV) and 0.02 (VH). This indicates a prevalence of dark pixels and a scarcity of bright pixels with higher values, resulting in diminished visual contrasts from a statistical perspective.

To rectify this and achieve a more standardized distribution of values, the logarithmic function is applied to the radar image. This transformation converts pixel values into a logarithmic scale, enhancing contrasts by shifting brighter values towards the mean while expanding the range of darker values (as depicted in Figure 18, on the right). The calibrated dB data typically spans from approximately -35 to +10 dB.

To execute this transformation, right-click on each of the four terrain-corrected bands and choose **Linear to/from dB**. Confirm by selecting Yes to generate a virtual band, denoted by the symbol and the "_db" suffix. These virtual bands are not physically stored on the hard drive but can still be displayed based on the underlying mathematical expression.

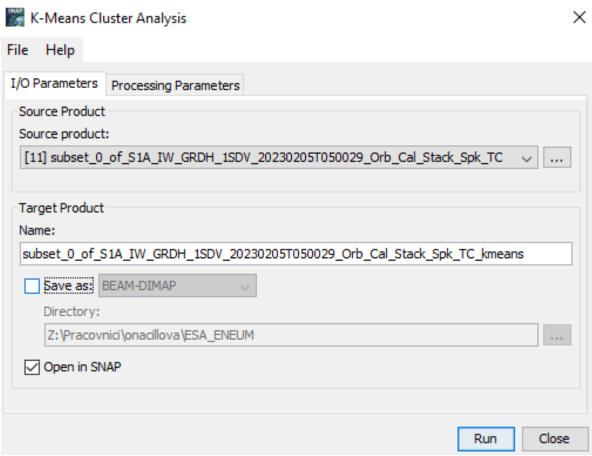


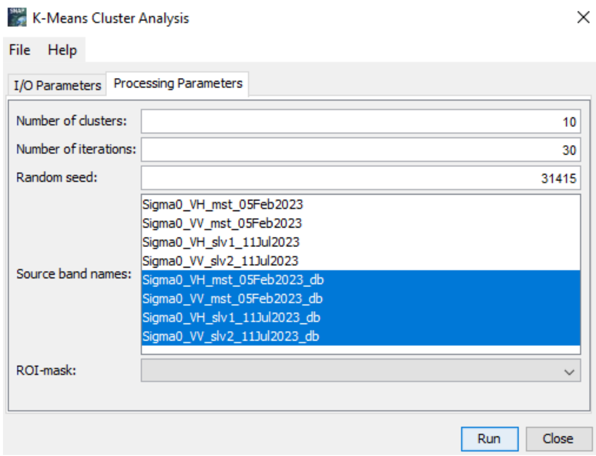
Sigma0 VV before (top) and after (bottom) conversion to dB scale

Unsupervised classification

An unsupervised classification serves as an effective method for identifying and grouping pixels that share similar characteristics.

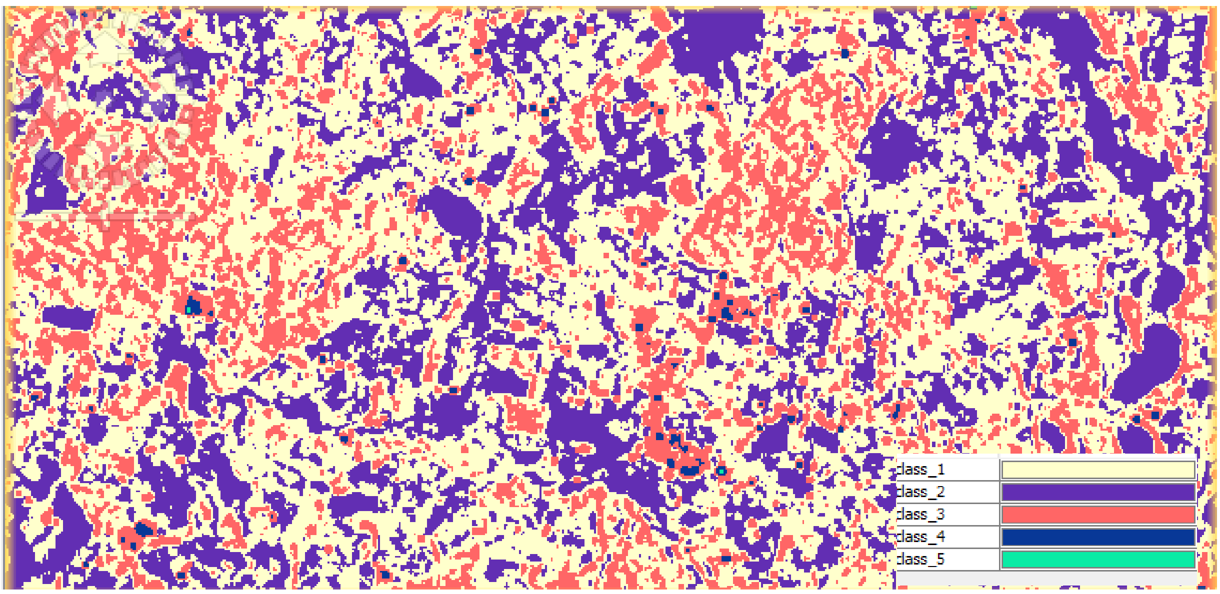
To initiate the K-Means Cluster Analysis, navigate to **Raster > Classification > Unsupervised Classification** and select the terrain-corrected stack as the input product. In the second tab, specify the number of clusters as e.g. 5, choose all dB bands as the source bands, and confirm by clicking Run. This process may take several minutes as the classifier iterates 30 times, utilizing random cluster centers within the multi-dimensional feature space to identify pixels with similar properties.



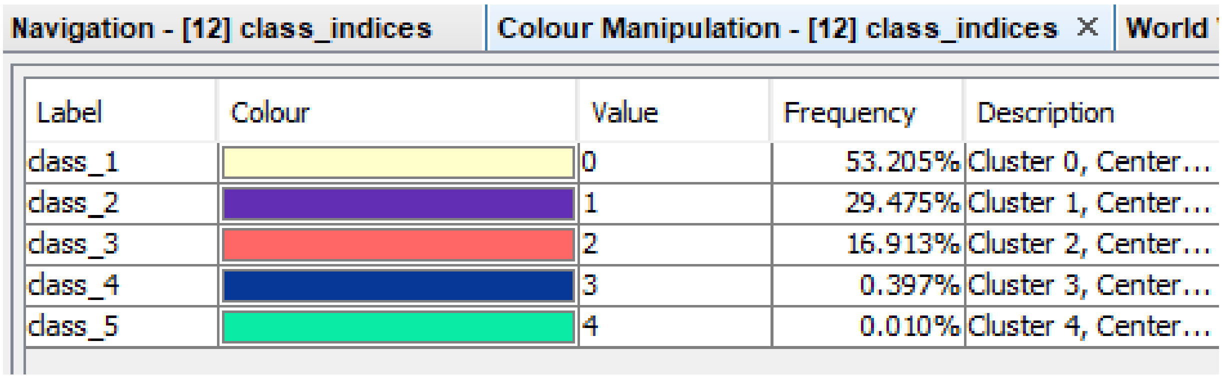


The output is a product with a single band (class_indices), where each pixel is assigned to one of the 5 clusters. While these clusters may not directly represent semantic land cover classes, they exhibit homogeneity in terms of their backscatter characteristics.

Double click to open the „class_indices" band under Bands folder. Zoom into the area and explore the most frequent classes and their distribution.



As depicted in Figure, you can utilize the Color Manipulation tab to allocate colors and even labels to these clusters, enabling you to assess how well they align with general land use and land cover classifications.



Label	Colour	Value	Frequency	Description
class_1		0	53.205%	Cluster 0, Center...
class_2		1	29.475%	Cluster 1, Center...
class_3		2	16.913%	Cluster 2, Center...
class_4		3	0.397%	Cluster 3, Center...
class_5		4	0.010%	Cluster 4, Center...

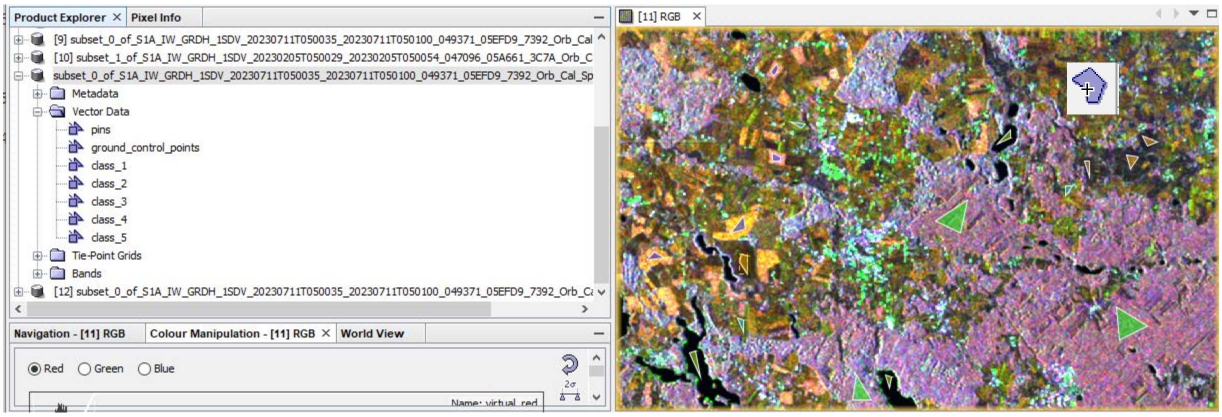
The benefit of employing an unsupervised classification lies in its independence from prior knowledge about the study area or the data, yet it effectively groups pixels with similar traits. However, the drawback is that the usefulness of the result heavily depends on the chosen number of classes. As illustrated in the example, water is segmented into five distinct classes (3-7), whereas urban areas are consolidated into a single class (8). If there is overlap between classes, it may be necessary to opt for a higher number of clusters and then merge them afterward. Conversely, having too many classes can complicate the identification of patterns within the data.

Supervised classification

Now, we will perform the one type of supervised classification – Random forest classification. For this we will create some training data by identifying polygons containing the different land cover types:

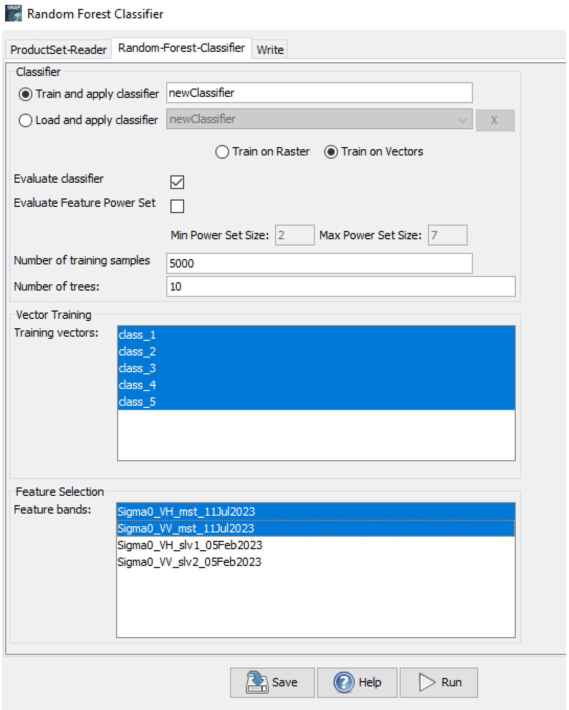
- Select the last subset product by clicking on it. Navigate to Vector > New Vector Data Container.
- Create new data containers – e.g. for 5 different classes.
- Start with creating the data container for, e.g. „class1".Click OK.

The newly created vector data container should appear under "Vector Data" in the Product Explorer. Now let´s start creating training polygons for these different containers on ice type using the Polygon drawing tool:



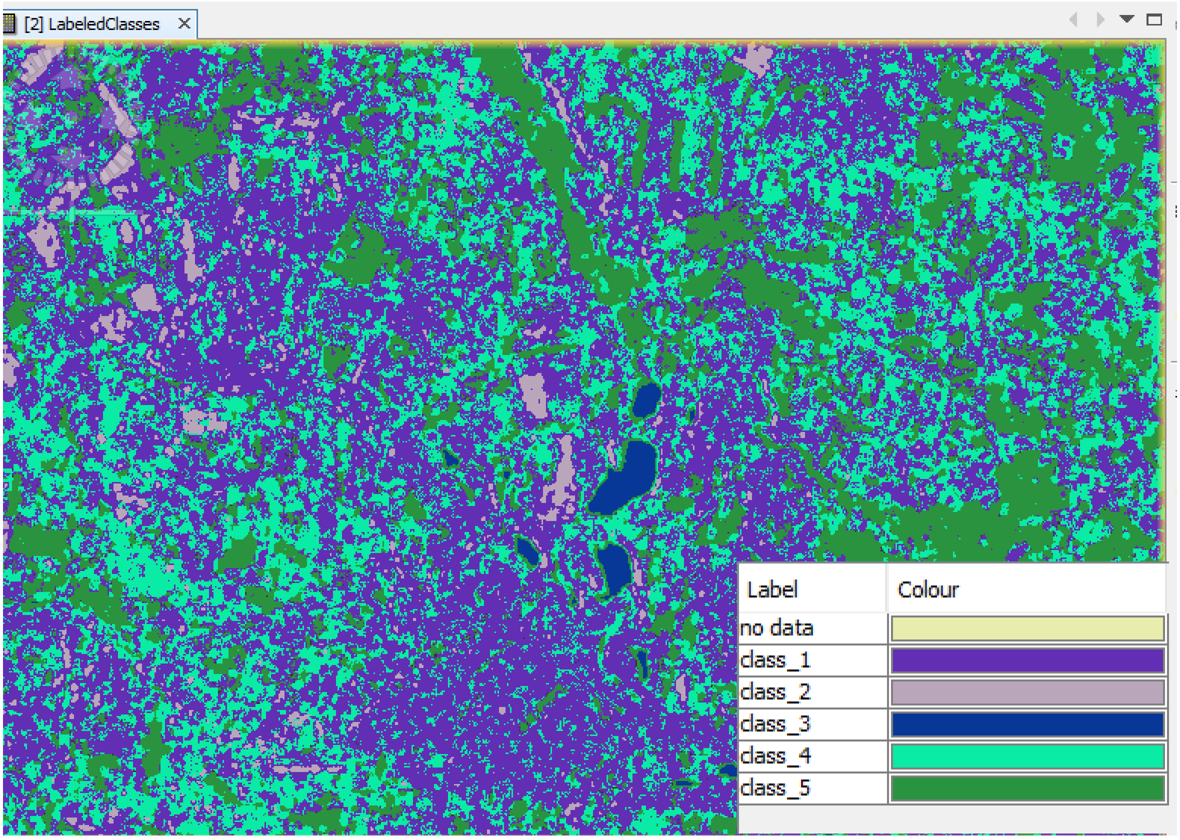
Random forest classifier

Navigate to Raster > Classification > Supervised classification >Random Forest classifier



- In the Random-Forest-Classifier select the all Training vectors that we have created.
- Select at least two Feature bands (poalrisations)
- Click on RUN.

The output final product should be now opened in the Product Explorer Window. Double-click on the „LabeledClasses" band under Bands folder to visualize it.



Compare the results of supervised and unsupervised classification.

For more information, see the lecture: [2. SAR remote sensing for land applications 1 – SAR basics]

THANK YOU FOR FOLLOWING THE EXERCISE!

UNIVERSITY COURSE APPLIED RADAR REMOTE SENSING

EXERCISE 3 – TUTORIAL

SAR for Land Applications 2 – Interferometric SAR data processing, using SNAP software

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1 | Exercise outline

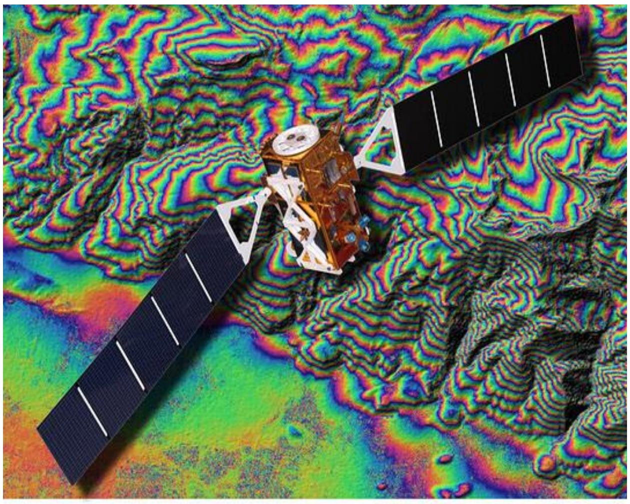
In this exercise, we will:

- Learn how to retrieve Digital elevation model (DEM)
- Perform necessary data processing for making an interferogram
- Understand the information content in SAR interferometric images

2 | Background

Deformation Mapping and Change Detection using Sentinel-1 data

Satellites constantly monitor Earth from space, providing vital data essential for rapid land cover change assessment and disaster management. The radar on board the Copernicus Sentinel-1 mission can detect ground conditions and penetrate clouds, functioning day and night.



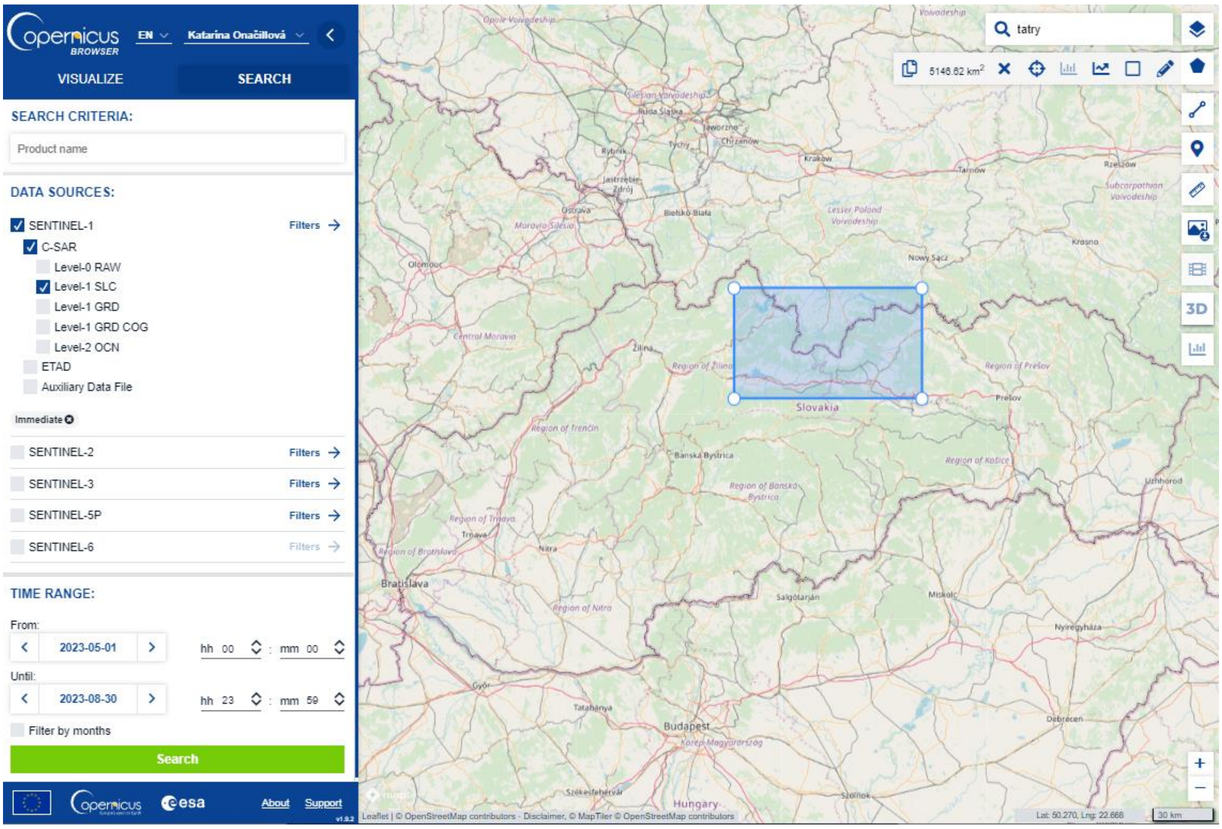
DEM generation with Sentinel-1 data offers a powerful method for deriving accurate and detailed elevation information over large areas, especially in regions with limited ground survey data or challenging terrain conditions.

DEM generation with Sentinel-1 data involves acquiring pairs of SAR images, processing them into interferograms, unwrapping the interferometric phase to obtain absolute phase values, removing the topographic phase contribution, converting the corrected phase into elevation values using appropriate algorithms, assessing the quality of the generated DEM, refining it if necessary, validating the accuracy, and utilizing the DEM for visualization and various applications such as terrain analysis and environmental monitoring.

Sentinel-1 derived DEMs find applications in topographic mapping, hydrological modeling for water flow and flood risk assessment, environmental monitoring for changes like erosion and landslides, natural resource management for agriculture and forestry, disaster management for assessing terrain accessibility and planning evacuation routes, infrastructure planning for designing roads and bridges, climate change studies for analyzing impacts on coastal erosion and glacier retreat, and remote sensing applications including orthorectification and 3D visualization.

2.1 Study area and data used

For this exercise, we will use two Sentinel-1 SLC images of the same area for High Tatras, Slovakia, downloaded from the Dataspace Copernicus Open Access Hub [@https://dataspace.copernicus.eu/].



To ensure successful DEM generation, selecting image pairs with specific properties is crucial. These include:

• A short **temporal baseline**, minimizing the time between acquisitions to reduce temporal decorrelation risks, particularly over changing surfaces like vegetation or water areas. Sentinel-1 radar (C-band) is susceptible to decorrelation, especially over vegetation, so image pairs with minimal vegetation cover are preferable.

• A suitable **perpendicular baseline**, ideally between 150 and 300 meters, to capture topographic variations effectively through parallax-like effects. Smaller baselines may not produce pronounced topographic effects, while larger ones can lead to decorrelation.

• Consideration of the primary mission focus of Sentinel-1 for deformation retrieval rather than DEM generation, resulting in predominantly short baselines below 30 meters. Finding image pairs with short temporal and large perpendicular baselines can be challenging.

• Ensuring **suitable atmospheric conditions**, avoiding images acquired during rainy periods or with high water vapor content in the atmosphere to minimize phase delays and maintain measurement quality.

2.2. SNAP - Open and explore product

Open SNAP Desktop, click Open Product and open 2 downloaded products by double click on the zipped folders. The opened products will appear in Product Explorer window.

S1A_IW_SLC__1SDV_20230721T162703_20230721T162731_049524_05F481_08D0.SAFE.zip
S1A_IW_SLC__1SDV_20230802T162703_20230802T162731_049699_05F9EC_E68C.SAFE.zip

To access the information within the product, double-click on it to reveal the directories, which include:

- Metadata: containing parameters pertaining to orbit and data.
- Tie Point Grids: providing interpolation data for latitude/longitude, incidence angle, etc.
- Quicklooks: presenting a visible image of the entire scene in radar coordinates.
- Bands: consisting of complex values for each subswath "i" and "q", along with intensity

Select intensity image for swath IW1 VV – double click on it to View it
Note: Each SAR image is flipped north—south it maintains the same orientation as its acquisition (in this case, ascending track).

Check baseline information

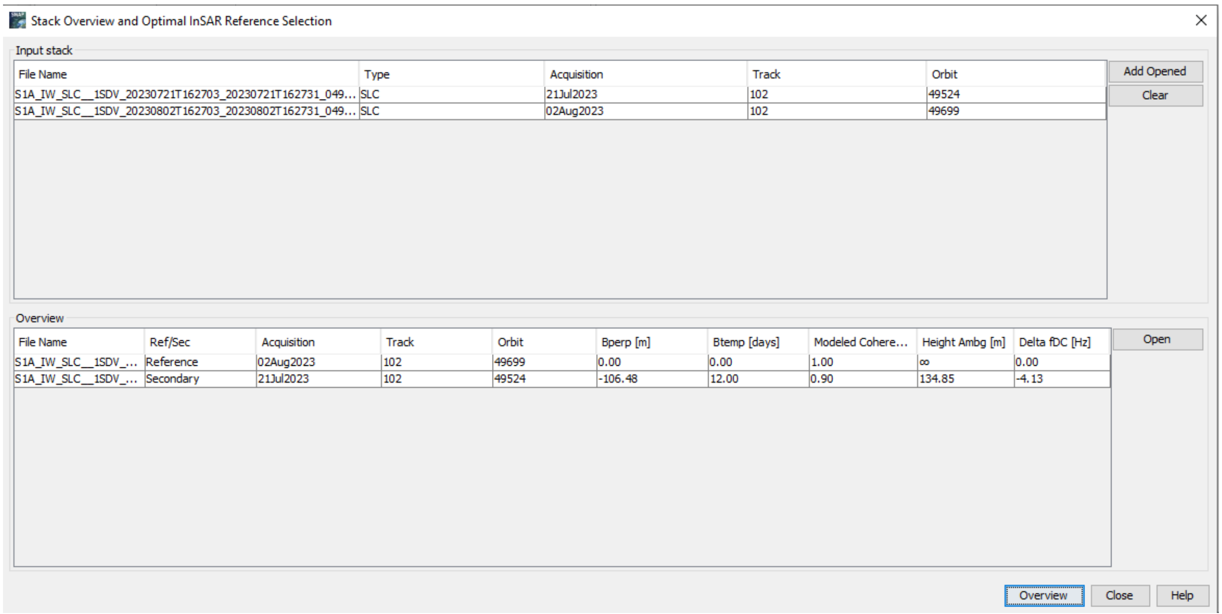
As previously mentioned, the quality of DEM generation relies heavily on the characteristics of the satellite images, particularly the spatial arrangement of the satellites during acquisition, termed the perpendicular baseline. A larger perpendicular baseline yields more detailed interferograms, enhancing the representation of elevation changes. For instance, a perpendicular baseline of 151 meters, as illustrated in Figure 8, produces denser fringe patterns, facilitating better terrain change description compared to baselines of 67 meters or 27 meters.

The time interval between the first and second images, known as the temporal baseline, also significantly impacts interferogram quality. Shorter temporal baselines, ideally around 6 or 12 days for Sentinel-1 data, minimize phase decorrelation issues, particularly over natural surfaces. As illustrated in Figure 9, longer temporal baselines result in poorer interferogram quality, particularly over areas with natural surfaces, where reliable height information cannot be extracted. If such areas dominate the interferogram, DEM extraction becomes unfeasible.

To examine the baseline details of your image pair, navigate to Radar > Interferometric > InSAR Stack Overview.

Initially, select "Add Opened" to import the two Sentinel-1 products into the list above, where their acquisition date, track, and orbit information should appear.
Next, click on "Overview" to access their metadata.
In the lower list, you'll find details such as:

- the perpendicular baseline (Bperp) in meters,
- the temporal baseline (Btemp) in days,
- the modelled coherence ranging from 0 to 1,
- the height ambiguity indicating the height difference represented by one color cycle in the interferogram,
- the mean Doppler centroid frequency difference.



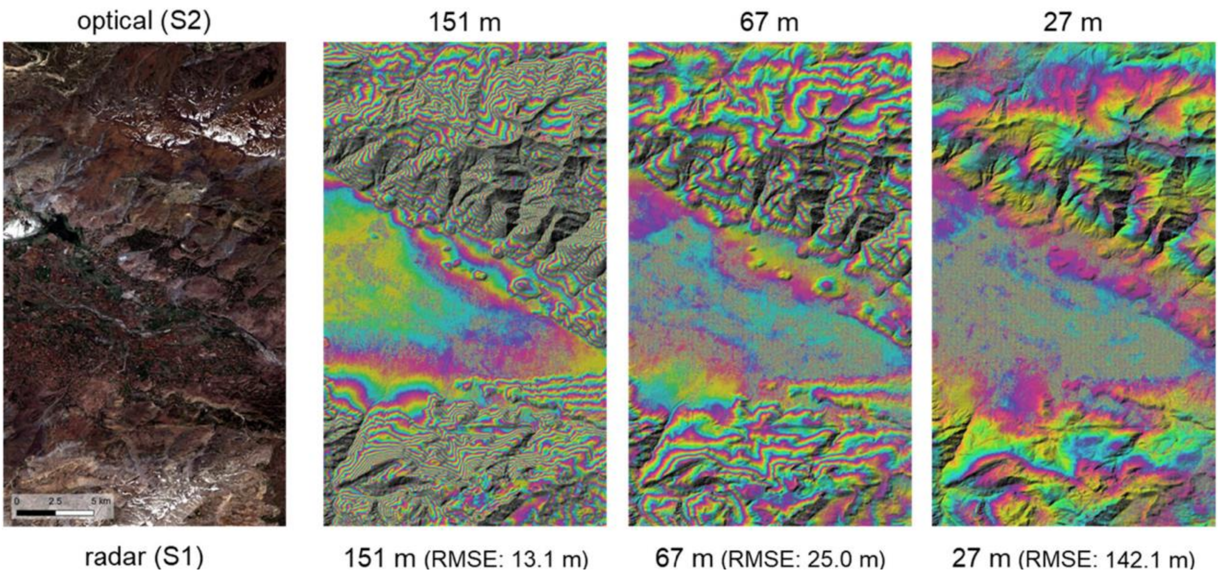


Figure: Effect of the perpendicular baseline on the interferogram (Braun 2021)

2.3 Coregistration

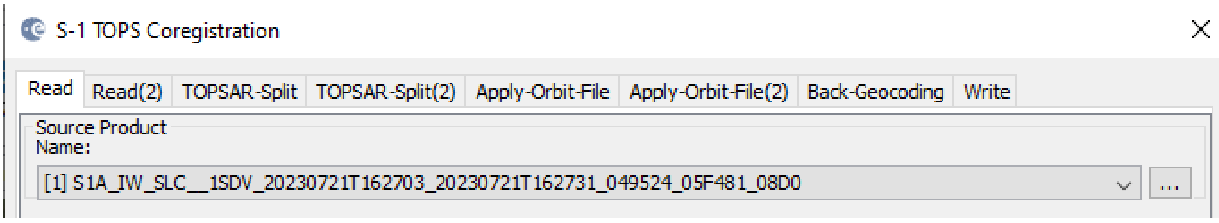
To utilize the phase difference between the acquisitions, it is necessary to initially construct a stack comprising both products. Image coregistration makes use of image statistics to align both products at sub-pixel accuracy. While orbit state vectors alone can suffice to coregister images, for precise offset tracking, additional data from a digital elevation model (DEM) is necessary to enhance coregistration accuracy.

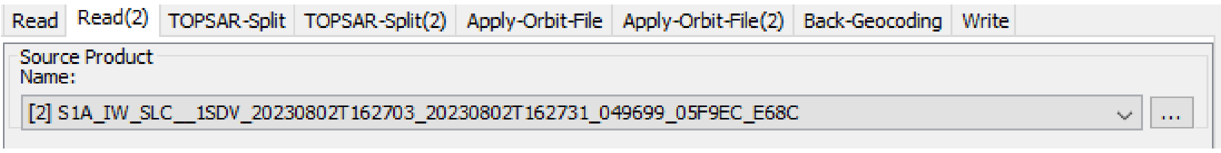
Navigate to Main Menu – Radar – Coregistration – S1 TOPS Coregistration –S1 TOPS Coregistration

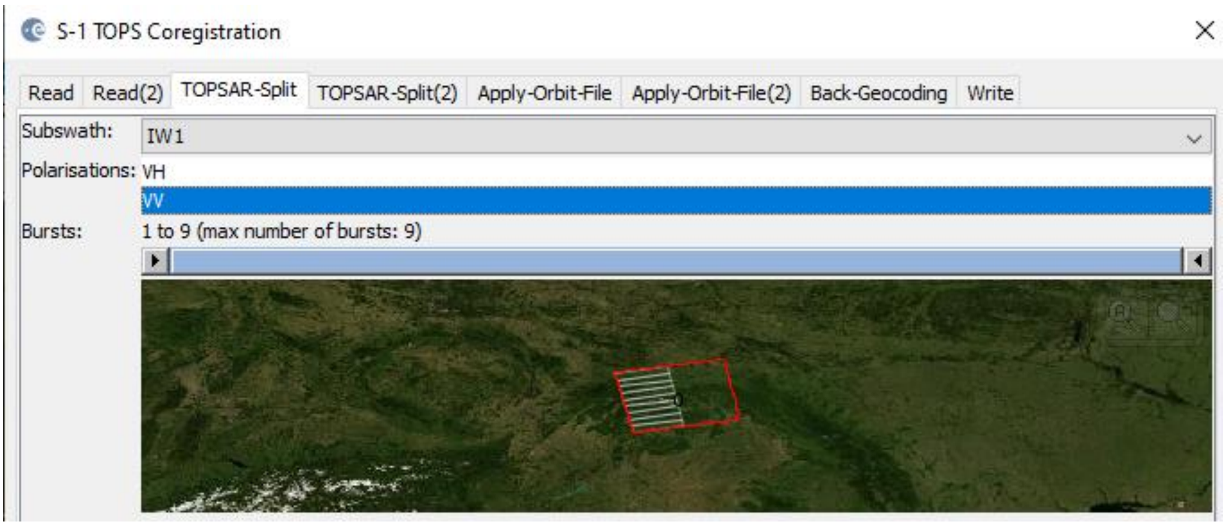
In the Read tab, select the 20230721 SLC product and in the Read(2) tab select the 20230802 SLC product

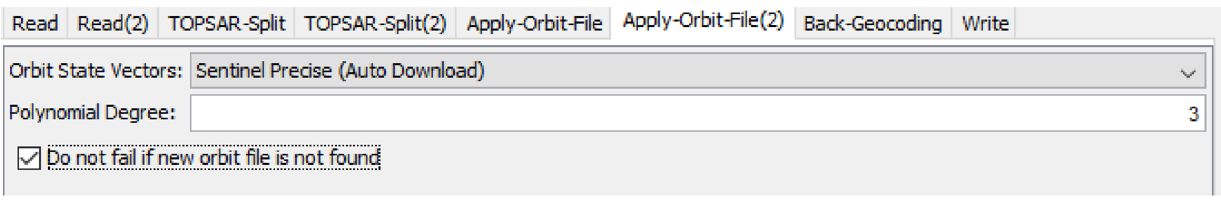
In TOPSAR-Split and TOPSAR-Split(2) tabs select Subswath: IW1 Polarizations:VV

In the Apply Orbit File and Apply Orbit File(2) tabs select leave default parameters and uncheck „Do not fail if new orbit is not found" option



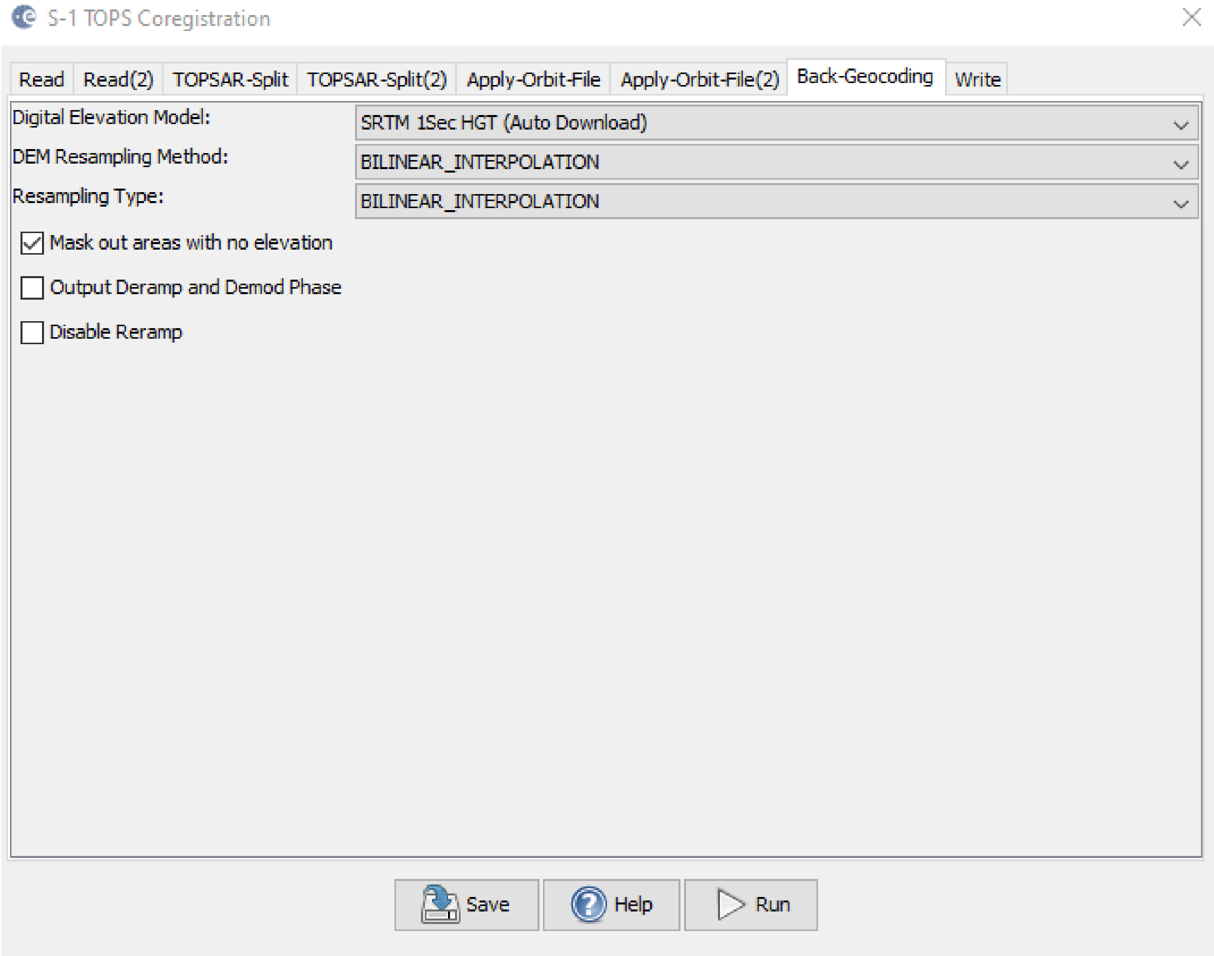






In the Back-Geocoding select SRTM 1Sec HGT (AutoDownload)
In the Write tab, select the directory to save your processing outputs

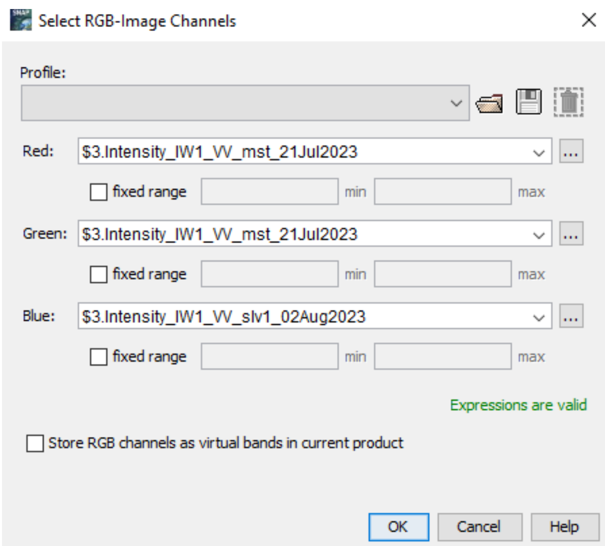
Note: SRTM data is accessible only within the latitudinal range of 60° North to 54° South. If your area falls outside this coverage, alternative DEMs with AutoDownload functionality can be utilized, or an external DEM stored as a GeoTiff and projected in geographic coordinates/WGS84 can be employed.



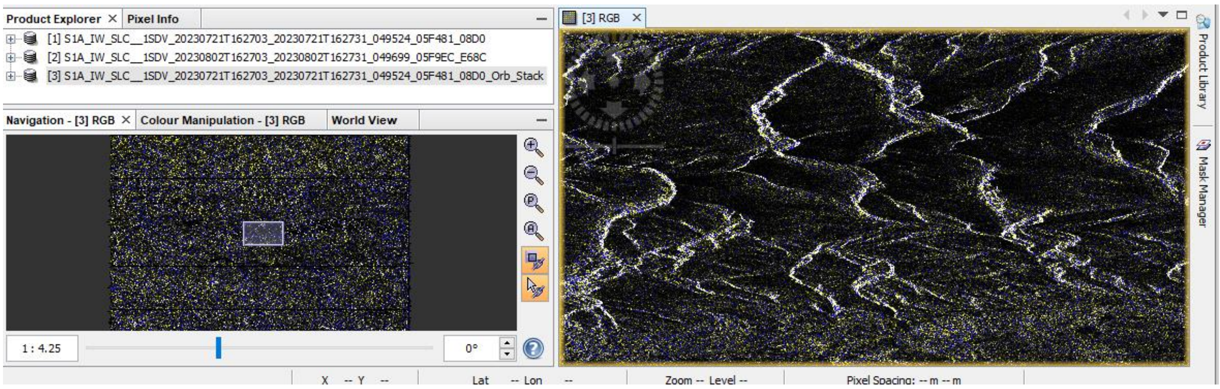
Once coregistration is finalized, it is recommended to visually inspect the stack's quality. This can be achieved through an RGB representation of the reference and secondary products, indicating if the images are appropriately aligned:

Right-click on the output coregistrated product – Open RGB Image Window

Choose the reference for red and green channels, and the secondary image for the blue channel.Click OK.



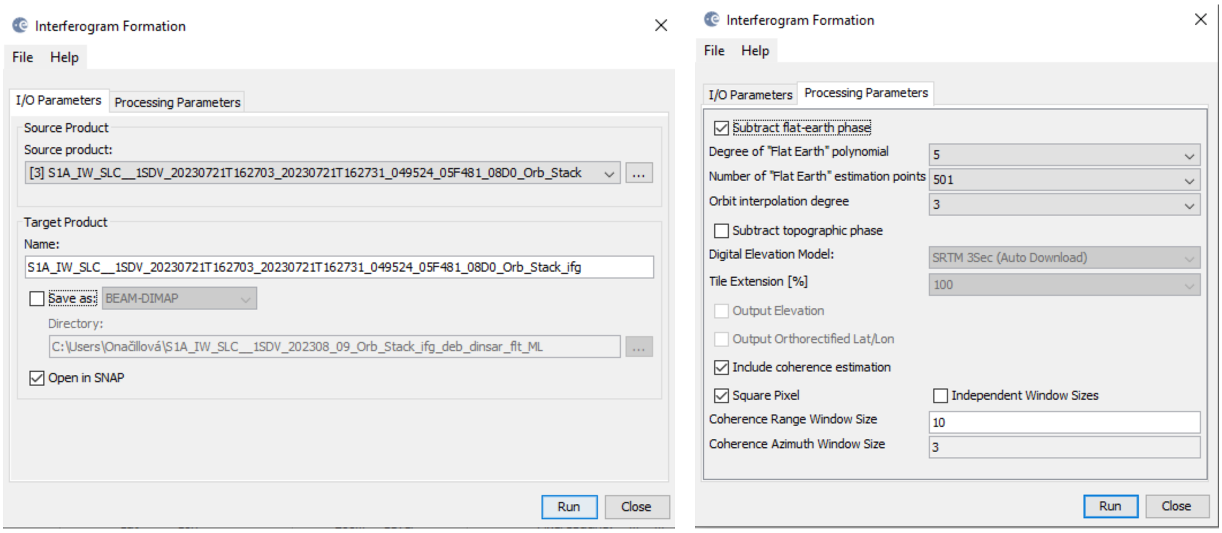
Zoom into a region with contrasting surfaces, such as the boundary between land and water. The RGB image should be clear and sharp, without being overly influenced by one of the images (e.g., appearing yellow for the reference or blue for the secondary image). The only acceptable exceptions are changes in land cover or scattering mechanisms which occurred in the time between the image acquisitions.



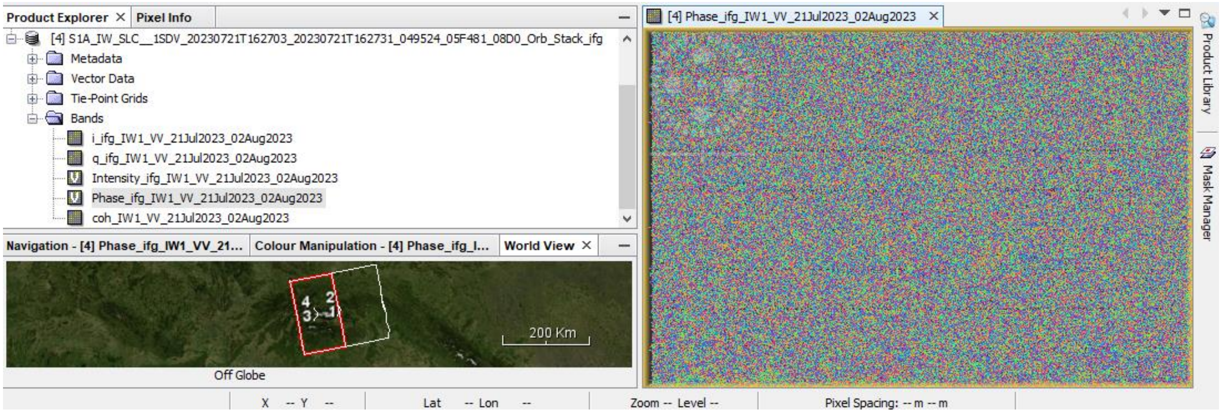
2.4 Forming a Raw Interferogram

The next phase of interferometry involves generating an interferogram using the coregistered SLC images. To do this, follow these steps:

From the main menu bar, go to **Radar – Interferometric - Products** and finally select **Interferogram Formation**.
In the I/O Parameters tab, choose the "Orb_Stack" product that was generated during the coregistration process.
By default, the output target is set to the same directory and appends "ifg" to the filename.
For standard processing, there's no need to modify the defaults in the Processing Parameters tab.



Raw Interferogram — Phase Image should appear int he View tab.

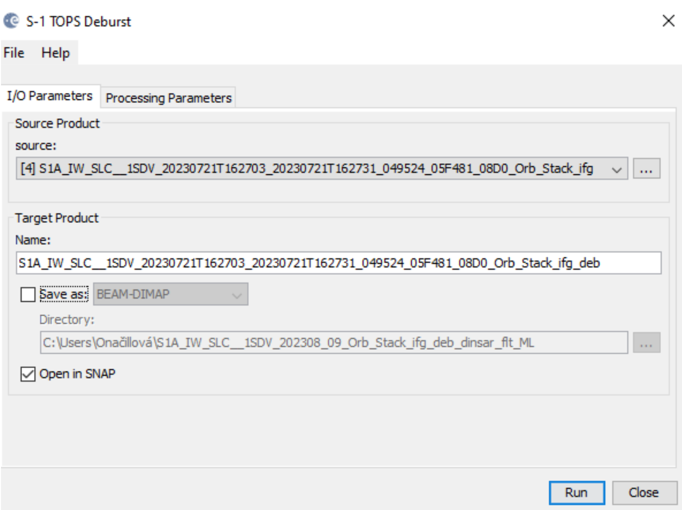


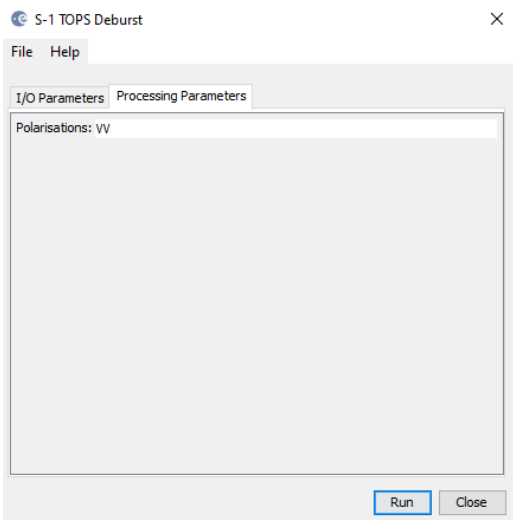
The interferogram is displayed in a rainbow color scale ranging from -topography, atmosphere and potential surface deformation (considered zero). The patterns, also called fringes appear in an interferogram as cycles of arbitrary colors, with each cycle representing half the sensor's wavelength.

2.5 TOPS Debursting

The next stage in interferometry using Sentinel-1 TOPS mode (IWS) data involves "debursting" or merging the bursts to remove the seamlines, a step not required with Sentinel-1 or other stripmap SAR data.

To perform debursting, follow these steps:
From the main menu bar, navigate to Radar, then Sentinel-1 TOPS, and finally S-1 TOPS deburst.
In the I/O Parameters tab, choose the "Orb_Stack_ifg" product generated during the interferogram formation process. By default, the output appends "deb" to the filename.
There is no need to make changes in the Processing Parameters tab.





2.6 Goldstein Phase Filtering

There are two methods to minimize noise in the interferogram: filtering and multi-looking. While our standard procedure involves applying filtering initially, it's also possible to opt for multi-looking first.

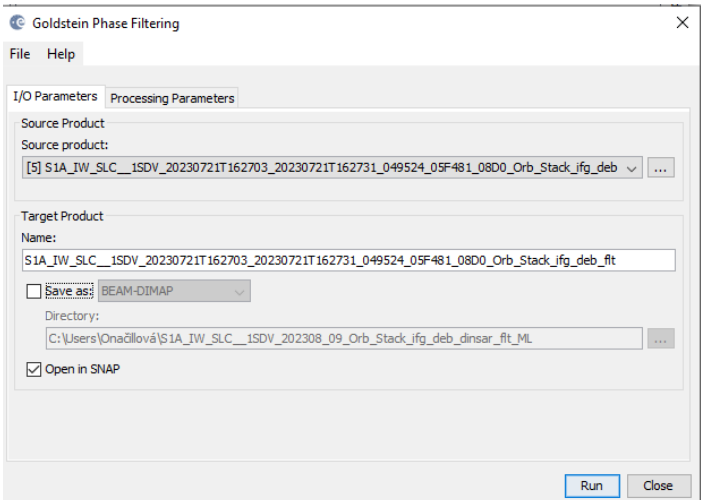
To begin filtering:

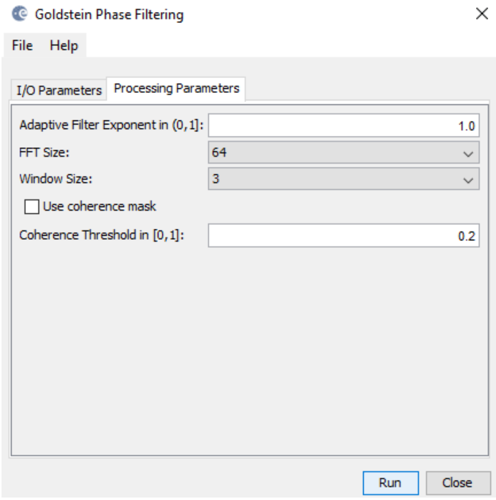
Go to Radar, then Interferometric, then Filtering, and select Goldstein Phase Filtering from the top main menu bar.

In the I/O Parameters tab, choose the "deb" product generated in the previous step.

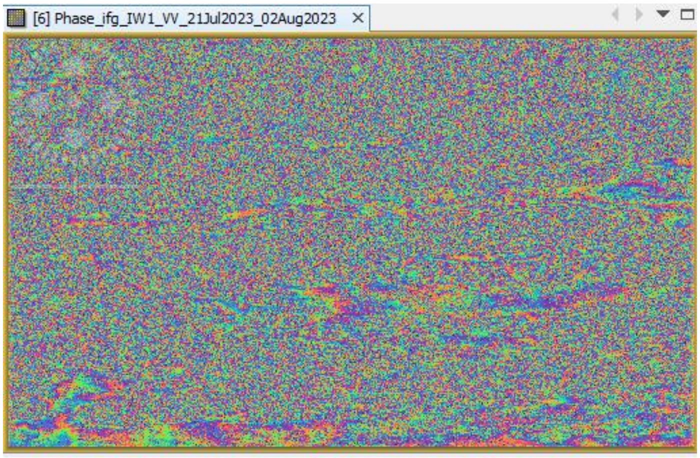
By default, the output name includes "flt."

There's no necessity to adjust the default settings in the Processing Parameters tab for basic processing.





Double-click on the output raster in the Bands folder of the new product to see the result.



Create subset (optional)

In the earlier stages of processing, empty pixels along the interferogram's perimeter may have been created, particularly in regions not overlapped by both input images. To remove these sections, employ the Subset function found under Raster. This approach will also decrease processing time in subsequent stages, especially when the analysis is concentrated on a specific area rather than the entire scene.

2.7 Phase Unwrapping

Unwrapping in SNAP follows three distinct steps:

1. **Export of the wrapped phase** (and definition of the parameters)
2. **Unwrapping of the phase** (performed outside SNAP by snaphu)
3. **Import of the unwrapped phase** back into SNAP

Export of the wrapped phase

Export your interferogram or your subset interferogram from Sentinel-1 Toolbox to SNAPHU:

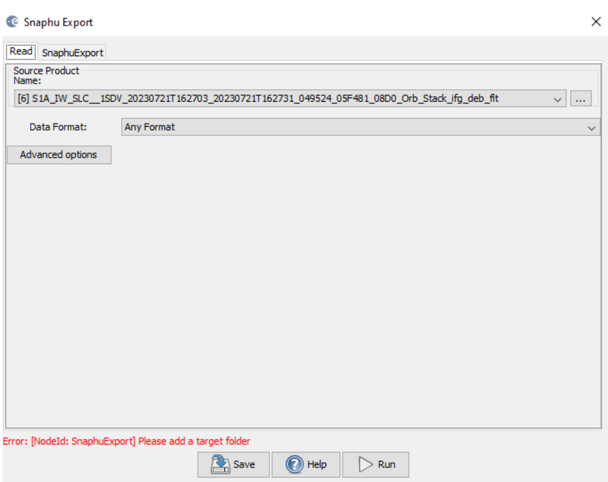
From the top main menu bar, navigate to **Radar > Interferometric > Unwrapping > Snaphu Export:**

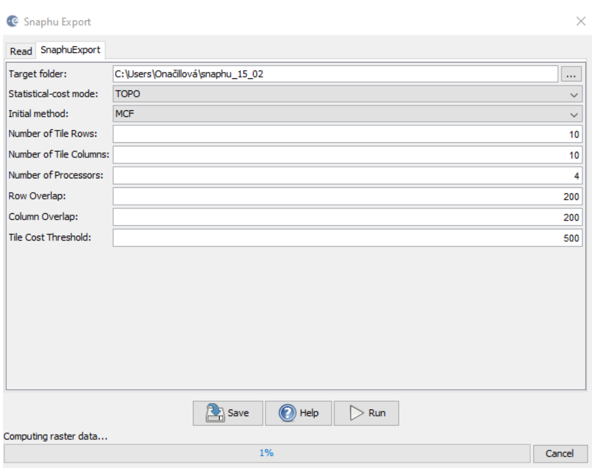
In the Snaphu Export window:
In Read tab, select the product created in the previous step
In Snaphu Export tab, you also need to specify a target folder for exported files. Create a new target folder for this step by entering a path and new folder name (e.g. „snaphu_export). If the selection of the directory does not work, simply copy and paste the path of your working directory into the text field.

In Snaphu Export tab, select TOPO as Statistical-cost mode and select 200 pixels for Row Overlap and Column Overlap if you want to multilook. Depending on the number of processors of your computer, you can also increase the Number of Processors variable.

Select MCF.

Click Run to create the SNAPHU_Export file
The folder now holds files used for phase unwrapping: the coherence image (*.img) and metadata (*.hdr), the wrapped phase: image (*.img) and metadata (*.hdr), the unwrapped phase: only the metadata (*.hdr), because the image (*.img) is first to be created by snaphu in the next step, a configuration file (snaphu.conf) containing the parameters defined in the export operator





Unwrapping of the phase

You should see the wrapped interferogram phase "Phase_ifg*.img", coherence "coh_*.img", and a "snaphu.conf" file.

For the next step, you will need to instal SNAPHU in Windows. SNAPHU is a tool for phase unwrapping of interferometric information. To use it as an executable file (*.exe) in Windows it has to be compiled first so all required drivers (*.dll) are installed correctly. Follow the steps for installation here: file:///C:/Users/Ona%C4%8Dillov%C3%A1/Downloads/Installation_SNAPHU_English_ABraun.pdf

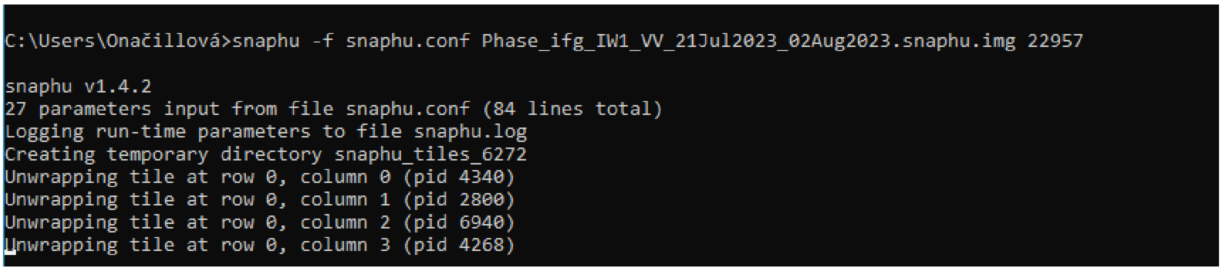
To start unwrapping, check the location of the interferogram exported from SNAP. If snaphu.exe is not in your system's PATH variable: Copy it in there as well. It is recommended to store the data and snaphu on the same disk. Open Command Window Here.

Type snaphu and hit Enter. The help menu should be displayed.

```
Príkazový riadok
C:\Users\Onačillová>snaphu

snaphu v1.4.2
usage:  snaphu [options] infile linelength [options]
most common options:
  -t               use topography mode costs (default)
  -d               use deformation mode costs
  -s               use smooth-solution mode costs
  -f <filename>    read configuration parameters from file
  -o <filename>    write output to file
  -a <filename>    read amplitude data from file
  -c <filename>    read correlation data from file
  -b <decimal>     perpendicular baseline (meters)
  -i               do initialization and exit
  -l <filename>    log runtime parameters to file
  -v               give verbose output
  --mst            use MST algorithm for initialization (default)
  --mcf            use MCF algorithm for initialization

type snaphu -h for a complete list of options
```

The command to start the unwrapping is shown in the file snaphu.conf. Open it with a text editor. The beginning of the "snaphu.conf" file shows the command to call Snaphu

```
snaphu – Poznámkový blok
Súbor  Úpravy  Formát  Zobraziť  Pomocník
# CONFIG FOR SNAPHU
# ---------------------------------------------------------------
# Created by SNAP software on: 12:23:26 15/02/2024
#
# Command to call snaphu:
#
#       snaphu -f snaphu.conf Phase_ifg_IW1_VV_21Jul2023_02Aug2023.snaphu.img 22957

#########################
# Unwrapping parameters #
#########################
```

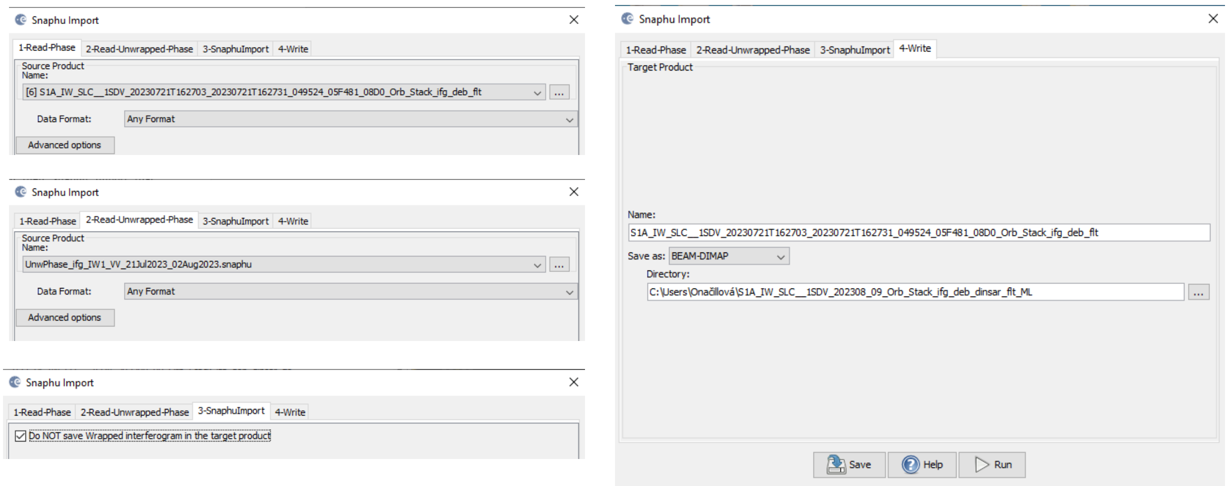


The Snaphu program can take a long time to run. At the end it writes **unwrapped phase to "Unw_ifg*.img" file**

Import of the unwrapped phase

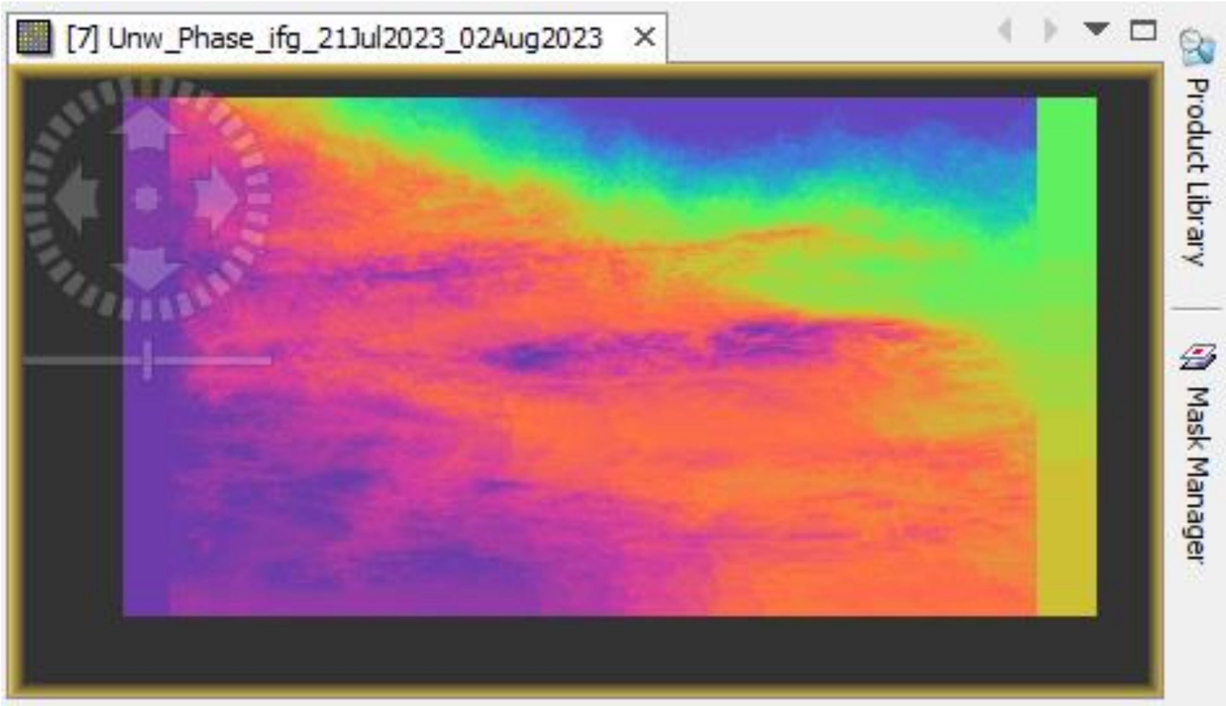
Now, we import the unwrapped phase. From the top main menu bar, select Radar > Interferometric > Unwrapping, and then Snaphu Import that converts it back into the BEAM DIMAP format and adds the required.

Read-Phase: should be set to the wrapped product that you exported(before the export)
Read-Unwrapped-Phase: select the unwrapped phase product: Navigate to folder where you exported for Snaphu. Select the "UnwPhase_ifg*.snaphu.hdr" file. Note: The error message will then vanish if you proceed to the next tab.
SnaphuImport: Leave the option "Do NOT save Wrapped interferogram in the target product"
unchecked, because it is required in the later step.
Write: To store the imported unwrapped band in a separate product (recommended), add '_unw' to the end of the output name and click Run.



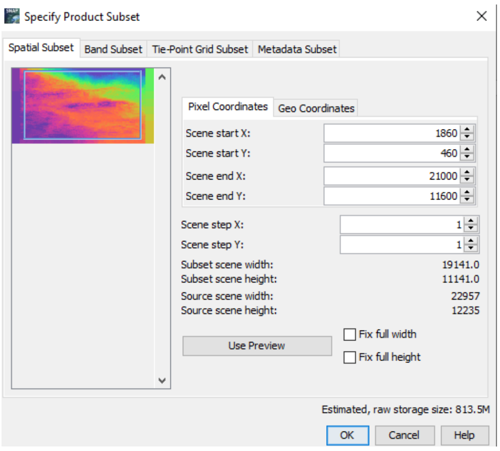
Finally, a new product is added to the Product Explorer which contains the the unwrapped phase that we can display.

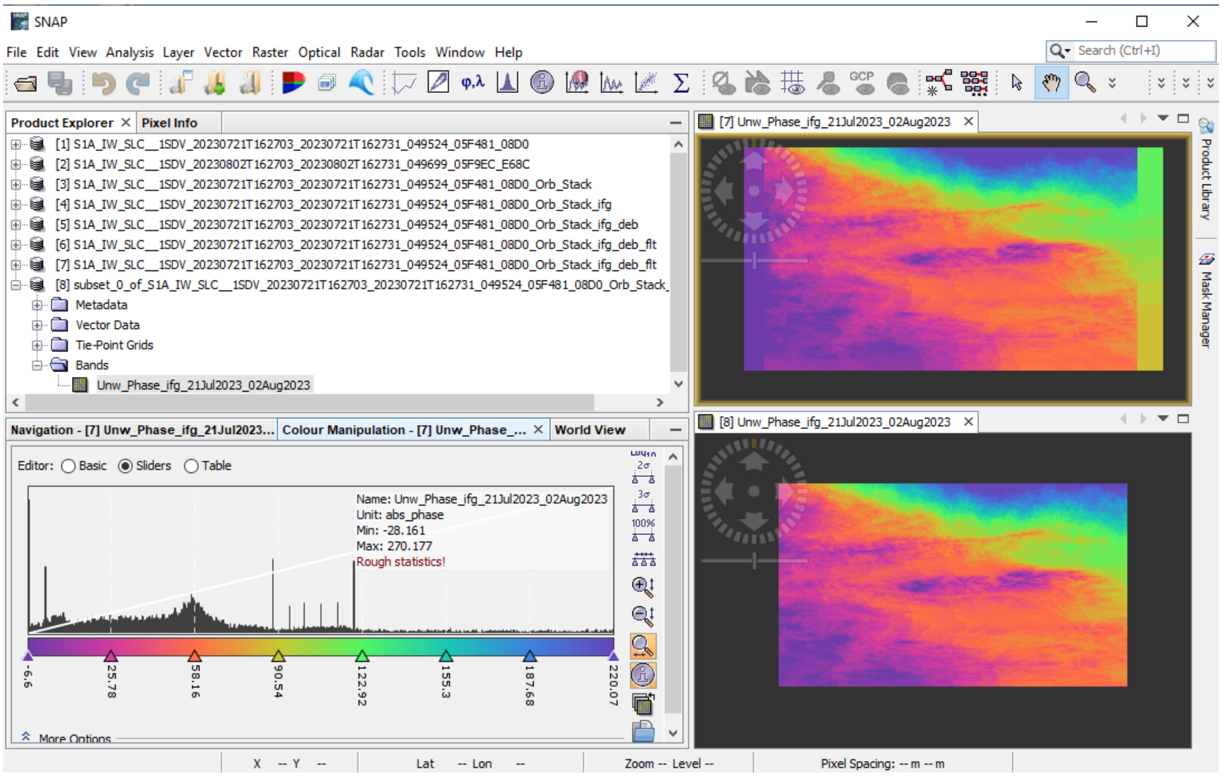
Select the Unw_Phase_ifg band. Double click on this unwrapped phase to see if the unwrapping was successful. It should be a smooth raster with little variation except for the areas of expected deformation.
All fringe patterns are summarized to absolute changes. Go to the Colour Manipulation tab and select "100%" to stretch color scale to full range of unwrapped data. Unwrapped phase is still in radians. Phase is reference image minus coregistered image. If reference image is earlier, then negative phase is land moving toward satellite (negative range change)



Create subset (optional)

In the earlier stages of processing, empty pixels along the interferogram's perimeter may have been created, particularly in regions not overlapped by both input images. To remove these sections, employ the Subset function found under Raster. This approach will also decrease processing time in subsequent stages, especially when the analysis is concentrated on a specific area rather than the entire scene.





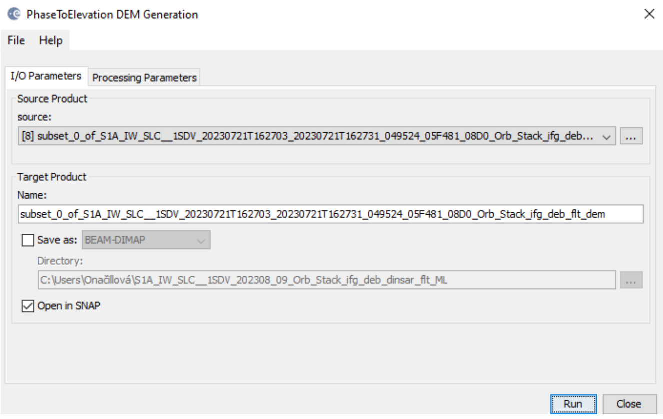
2.8 Phase to elevation

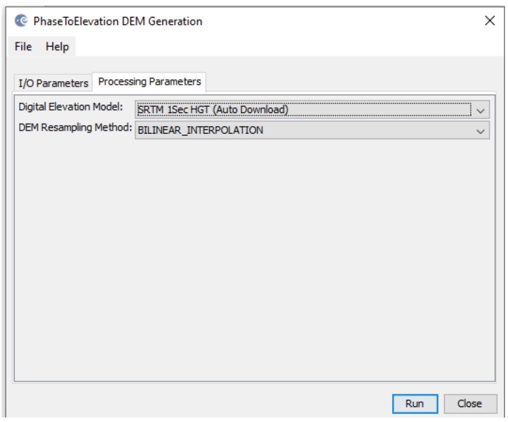
The unwrapped phase data is now a continuous raster, but it has not yet been converted into a metric measure. To achieve this conversion from radian units to absolute heights, the Phase to Elevation operator, found under **Radar > Interferometric > Products**, is employed. This operator translates the phase values into surface elevations along the line-of-sight (LOS) in meters. The LOS represents the direct line between the sensor and a specific pixel. To ensure accuracy, a Digital Elevation Model (DEM) is utilized to align the elevation values correctly.

The I/O Parameters tab should be set to the last subset unwrapped product

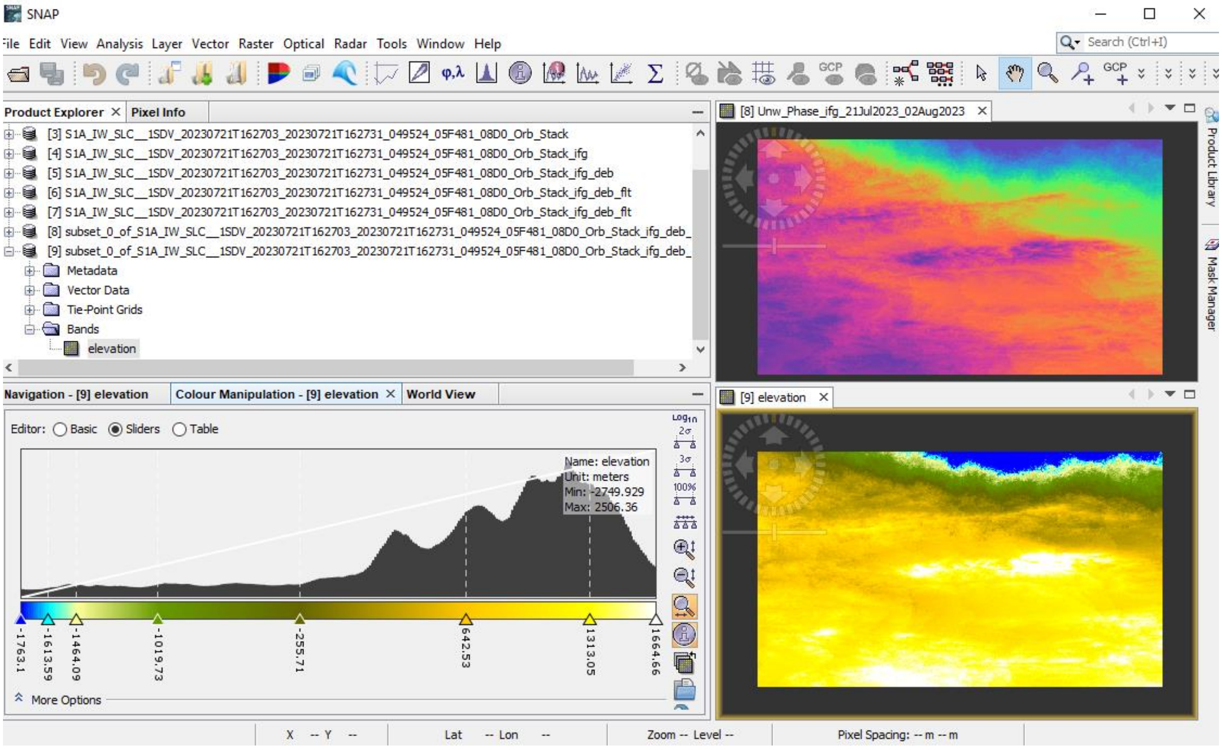
Default for target product name is to add "_dem" to the name

Navigate to the Processing Parameters tab and select SRTM 1Sec HGT (AutoDownload) as the input DEM.

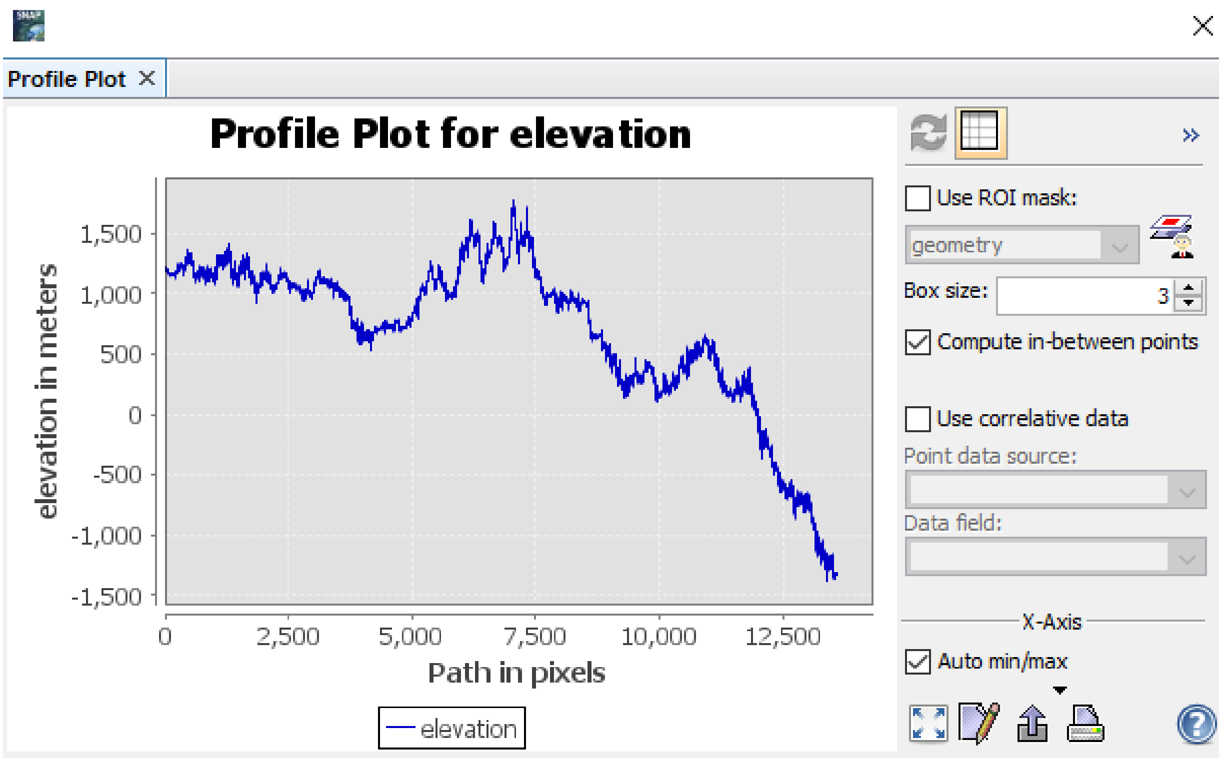




Now, we can display elevation result. Again, better to stretch colors. Displacements is now in meters.
Sign was changed so positive displacement is “up” towards satellite



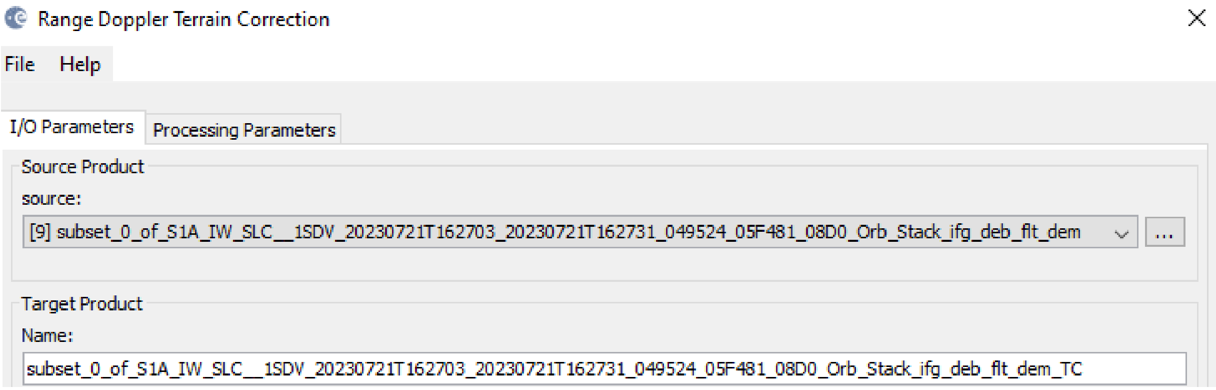
Profile plot



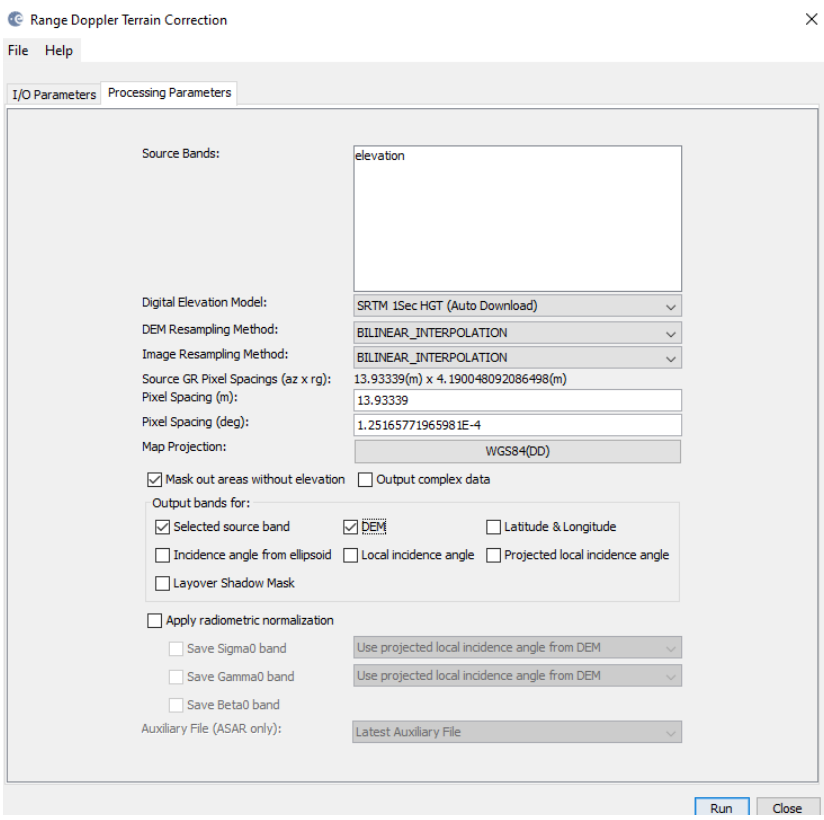
2.9 Terrain Correction

SNAP calls geocoding with topography "Terrain Correction." From the top main menu bar, select Radar, then Geometric, then Terrain Correction, and then Range-Doppler Terrain Correction.

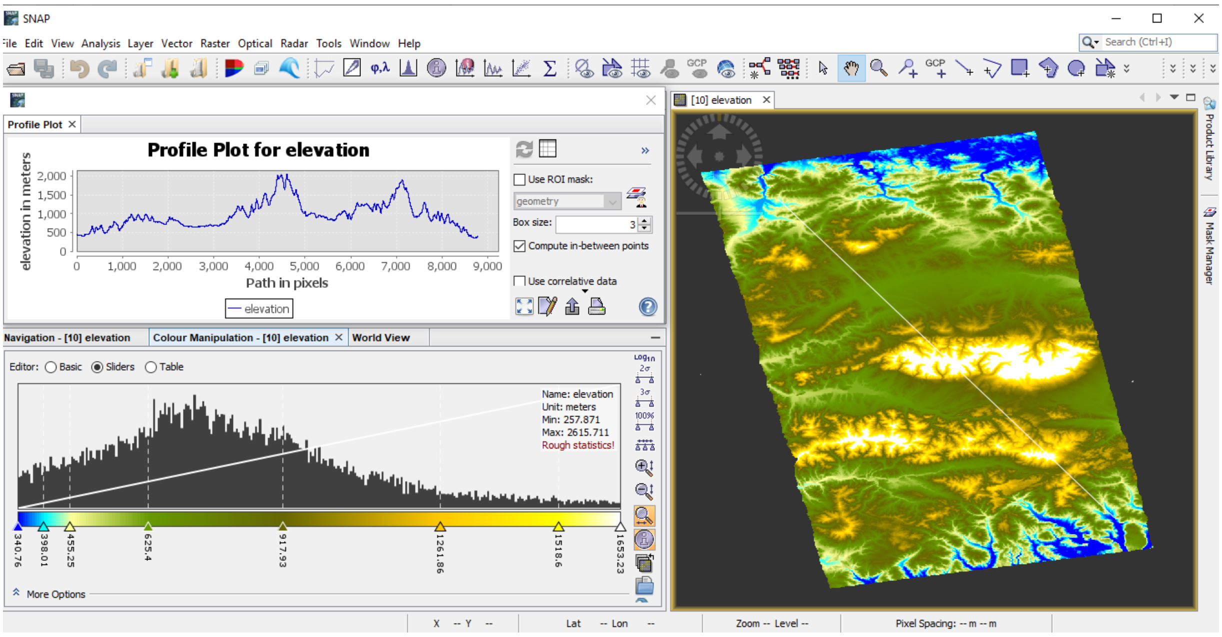
The I/O Parameters tab should be set to the last elevation product
Default for target product name is to add "_TC" to the name



Under Processing Parameters tab, select the elevation band as the input
Select SRTM 1Sec HGT (AutoDownload) as input DEM.
If you want to export the data as a KMZ file to view it in Google Earth, WGS84 must be selected as Map Projection (latitude and longitude).
If you want to compare the quality of the InSAR DEM, you can select DEM as a further output.



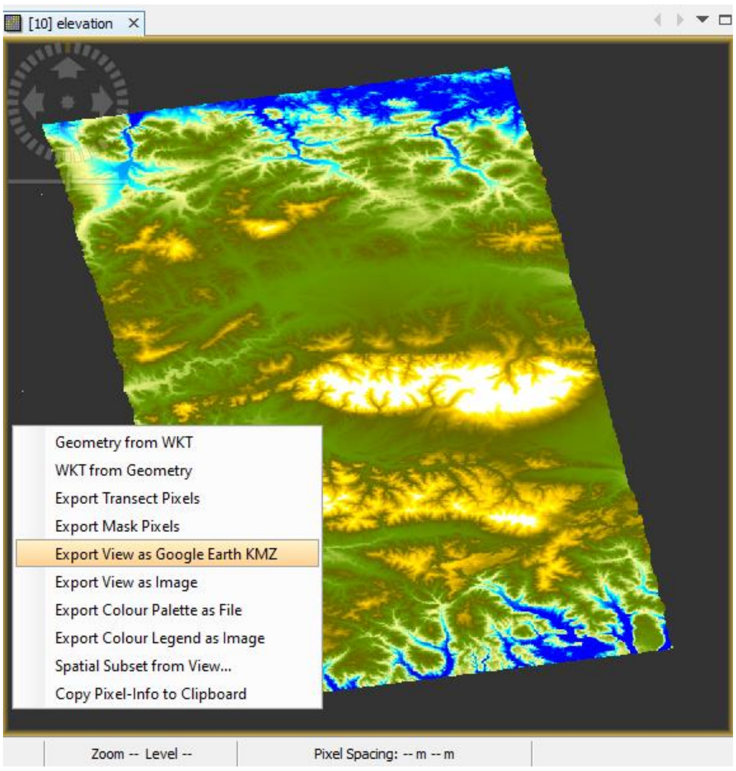
Now, double-click on the „elevation" raster to display the geocoded elevation raster output. Product is now evenly spaced in latitude and longitude and shows the elevation for the study area. You can create profile to see the elevation diversity.



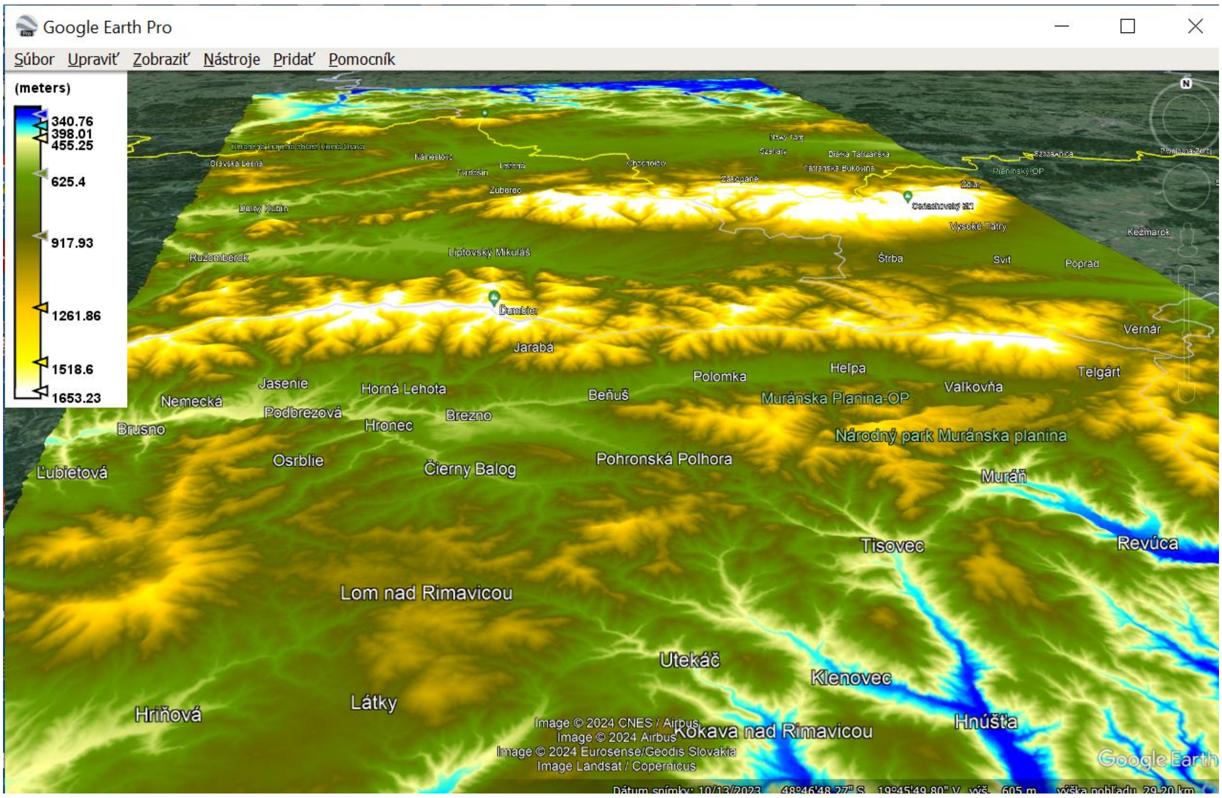
2.10 Export .kmz to Google Earth

Geocoded products (projected to WGS84) can be exported as a KMZ file to view in Google Earth (Pro):

Select an appropriate color scale and color ramp from the Color Manipulation tab.
Right click on the elevation raster in the View tab (or navigate to File > Export > Other > View As Google Earth KMZ)
Choose a directory to save the output .kmz and provide a fitting filename, then confirm with Save.



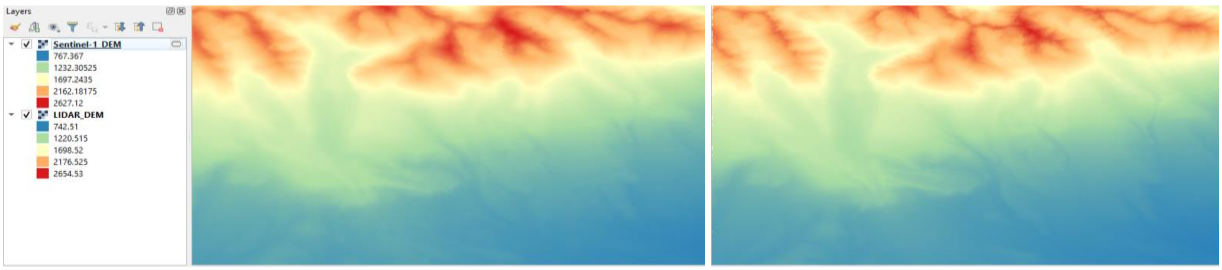
Open the resulting KMZ file in Google Earth to observe the elevation patterns overlaid on the satellite image base map.



Compare with LiDAR-derived DEM

Compare your Sentinel-1 derived DEM with Digital Elevation Model (DEM 5.0) with a resolution of 1 meter per pixel created from airborne laser scanning data by ÚGKK SR. „Source of ALS data: ÚGKK SR".

Open QGIS and comapre small LiDAR-derived DEM sample with our resulted DEM derived using Sentinel-1 data. We can observe that there are small differences in the elevation.



Comparing Sentinel-1 derived DEMs and LiDAR derived DEMs, LiDAR typically offers higher precision. This is because LiDAR directly measures the distance between the sensor and the Earth's surface using laser pulses, resulting in highly accurate elevation data. On the other hand, Sentinel-1 derived DEMs are generated using synthetic aperture radar (SAR) data, which can be affected by factors such as vegetation cover and terrain roughness, potentially leading to less precise elevation measurements compared to LiDAR. Therefore, in terms of precision, LiDAR derived DEMs are generally considered more accurate and reliable.

However, Sentinel-1 derived DEMs may be more cost-effective compared to LiDAR due to the lower cost associated with satellite data acquisition and processing. In this case, Sentinel-1 data are free of charge, available for everyone after the registration. Also, for large-scale mapping, monitoring, or areas with limited budget or accessibility, Sentinel-1 derived DEMs may be preferable.

For more information, see the lecture: 3. SAR remote sensing for land applications 2 – Introduction to Interferometric SAR

THANK YOU FOR FOLLOWING THE EXERCISE!

EXERCISE 4 – TUTORIAL

Forestry with Sentinel-1: Single Image Analysis and Time Series to detect forest change using SNAP software

esa
ÚSTAV GEOGRAFIE
Prírodovedecká fakulta UPJŠ v Košiciach
UNIVERZITA PAVLA JOZEFA ŠAFÁRIKA V KOŠICIACH
FUNDED BY EUROPEAN SPACE AGENCY UNDER THE PLAN FOR EUROPEAN COOPERATING STATES, 7TH CALL FOR SLOVAKIA

1 | Exercise outline

In this exercise, we will:

- Generate Radiometrically Terrain Corrected (RTC) Images from Sentinel-1 GRD products to monitor forest extent, structure and biomass
- Perform statistical analyses using Scatterplots, Histogram Analysis, Profile Plot etc.
- Process SAR data with SNAP using single-date and multi-temporal processing and generate time series analysis of multi-temp dataset
- Emphasize the critical role of SAR in sustainable resource management and forest conservation

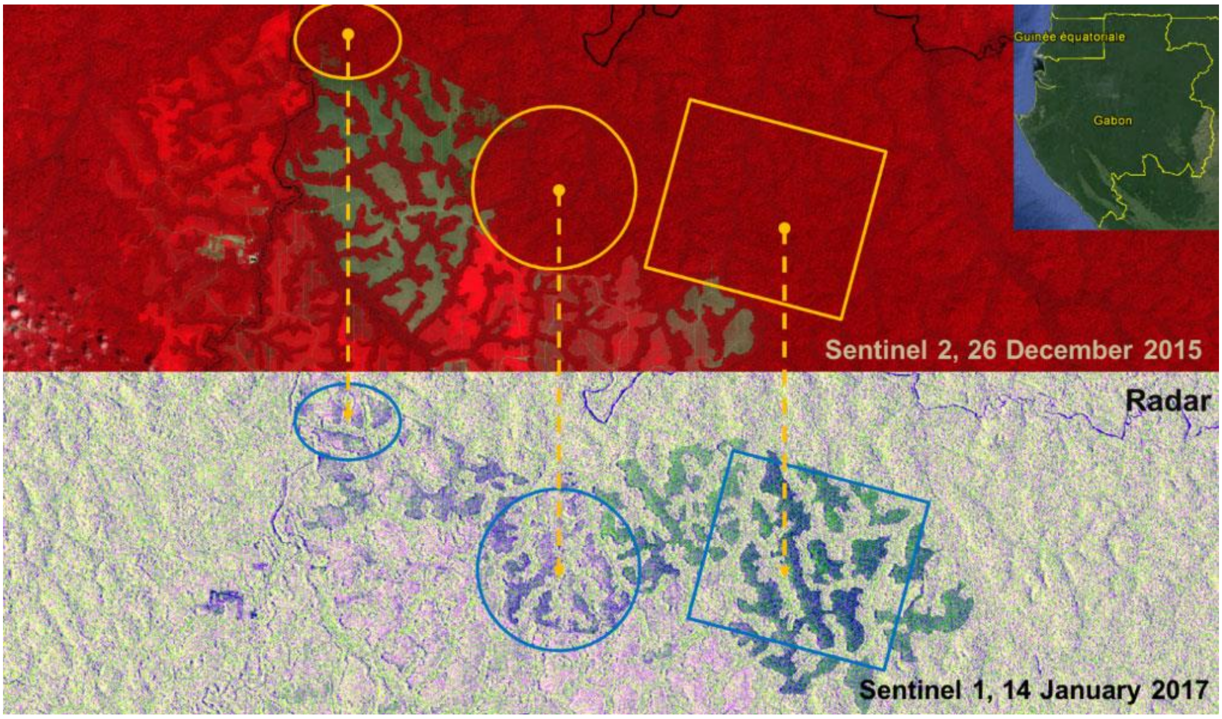
2 | Background

Forestry Mapping with Sentinel-1 data

Sentinel-1 synthetic aperture radar (SAR) data presents a versatile tool for comprehensive forestry mapping and monitoring. By analyzing SAR images acquired at different times, changes in forest cover can be effectively detected, providing insights into deforestation, reforestation, and forest degradation.

Sentinel-1 has a significant potential in sustainable forest management through its ability to detect clear-cut and partial-cut areas, classify forest types, estimate biomass, and identify disturbances. Regarding climate change mitigation, the mapping of forest fire scars using Sentinel-1 data is crucial for understanding a forest's carbon history and accurately estimating carbon emissions.

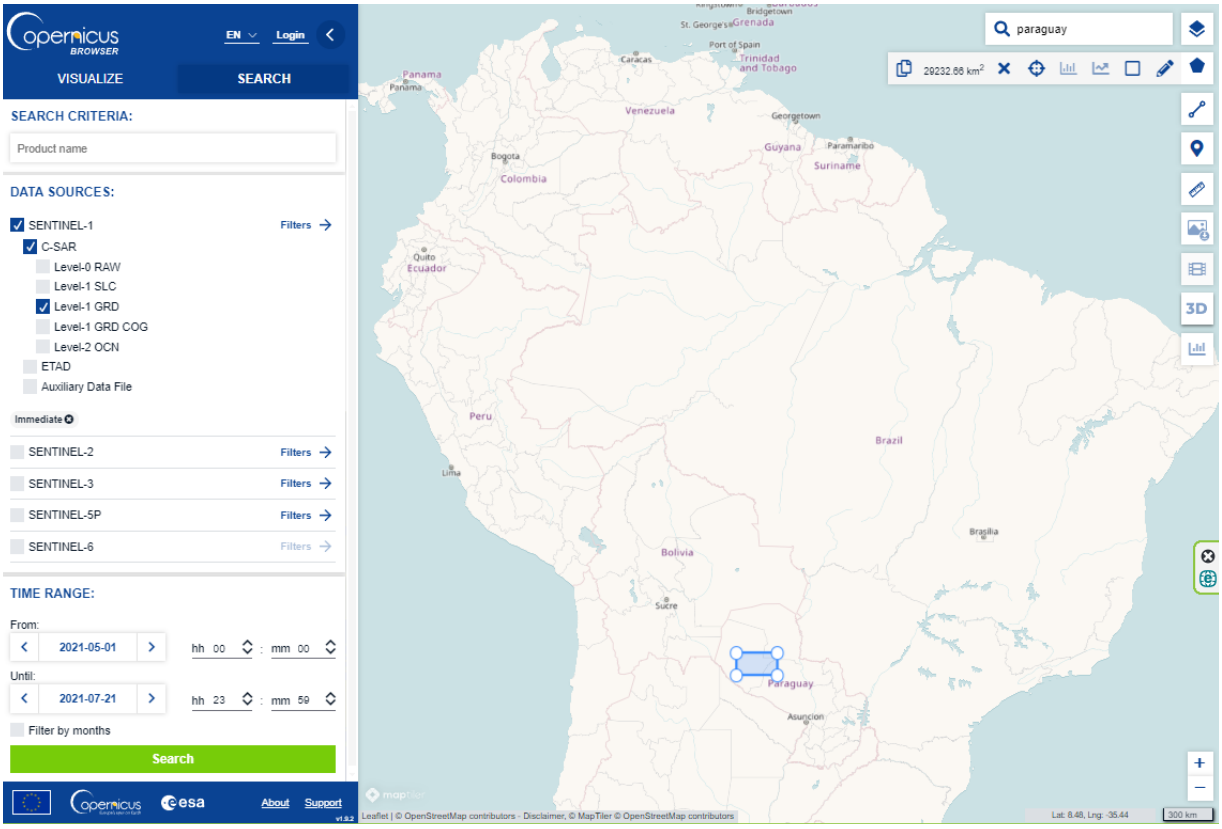
Additionally, SAR data allows for the classification of various forest cover types, aiding in forest management and conservation efforts. Furthermore, SAR data offers valuable information for assessing habitat quality and carbon stocks.



Source: https://sentinels.copernicus.eu/documents/247904/3428726/Sentinel-1-2-rubber-plantation-full.jpg

2.1 Study area and data used

For this exercise, we will use two Sentinel-1 GRDH images using dual polarization (VV/VH) acquired in interferometric wide swath mode for the area in Paraguay, downloaded from the Dataspace Copernicus Open Access Hub [@https://dataspace.copernicus.eu/].



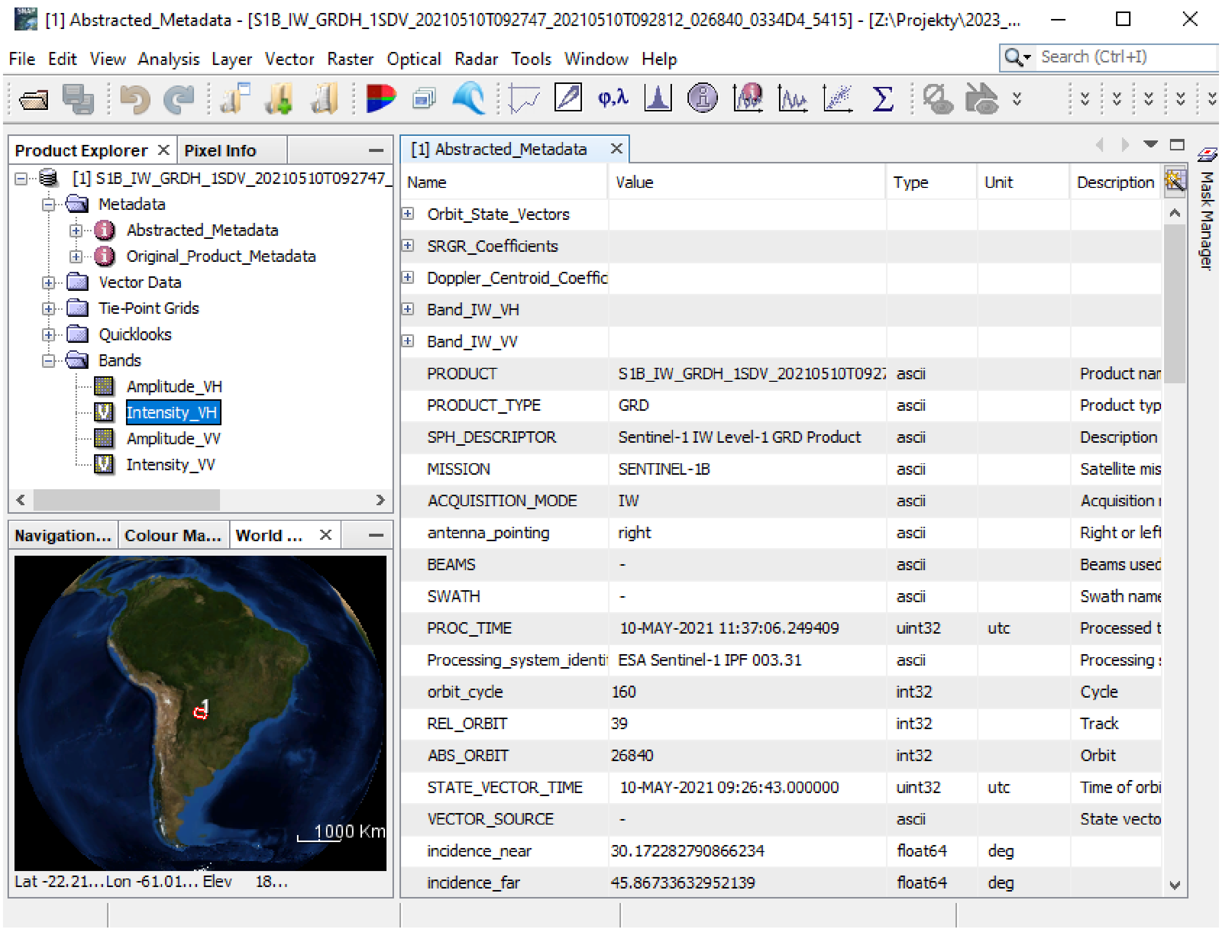
2.2. SNAP - Open and explore product

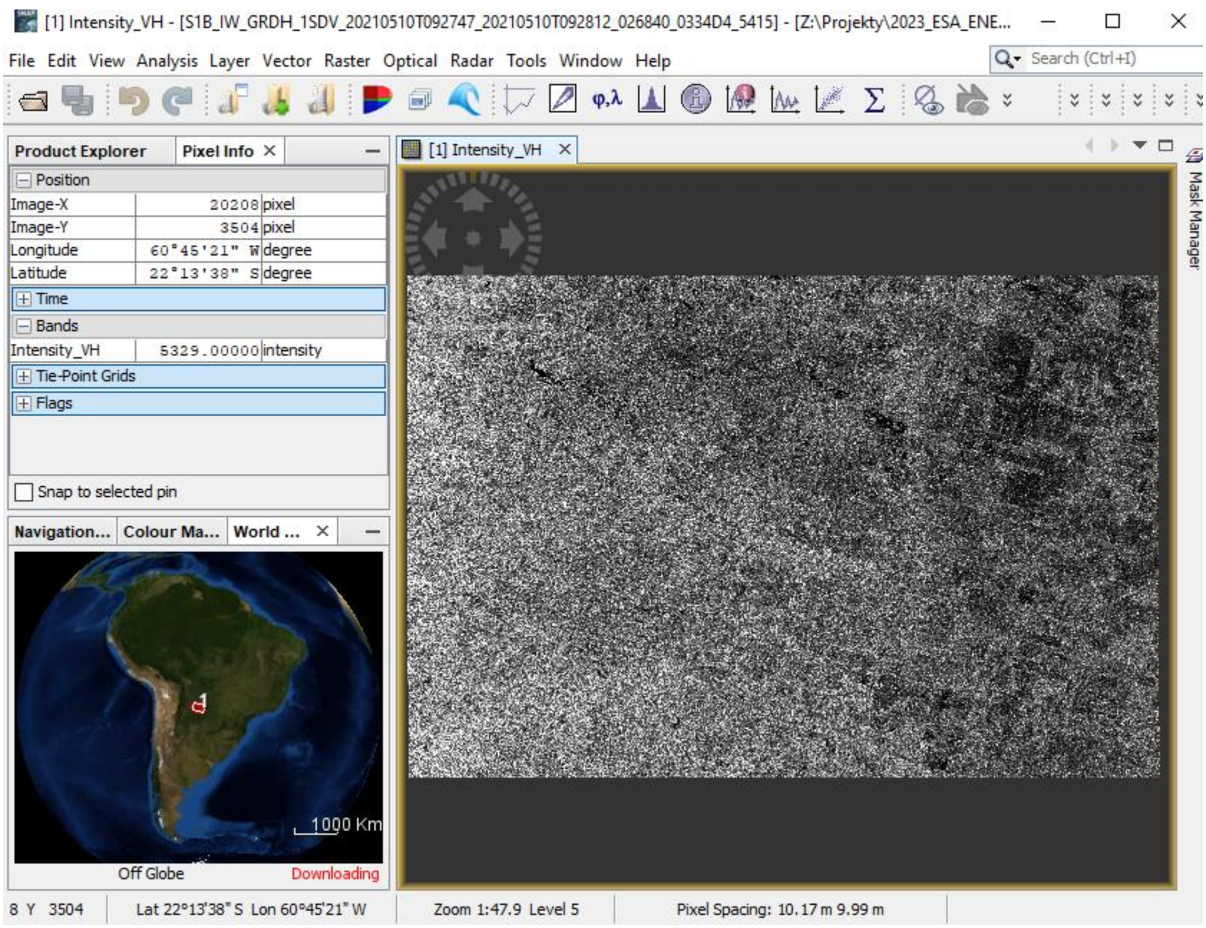
Open SNAP Desktop, click Open Product and open one of the downloaded products by double click on the zipped folders. The opened products will appear in Product Explorer window. The Navigation and World View tabs above the preview window can help you to locate the scene.

S1B_IW_GRDH_1SDV_20210510T092747_20210510T092812_026840_0334D4_5415.SAFE

To access the information within the product, double-click on it to reveal the directories, open the Metadata folder and double click on Abstracted Metadata.

If you open one of the bands of the image by double clicking the band name, you can see also information on the pixels in the scene by opening the tab Pixel Info (next to Product Explorer) and sliding the mouse over the pixels of interest.


[1] Abstracted_Metadata - [S1B_IW_GRDH_1SDV_20210510T092747_20210510T092812_026840_0334D4_5415] - [Z:\Projekty\2023_...
File Edit View Analysis Layer Vector Raster Optical Radar Tools Window Help
Search (Ctrl+I)
Product Explorer
Pixel Info
[1] S1B_IW_GRDH_1SDV_20210510T092747_
Metadata
Abstracted_Metadata
Original_Product_Metadata
Vector Data
Tie-Point Grids
Quicklooks
Bands
Amplitude_VH
Intensity_VH
Amplitude_VV
Intensity_VV
Navigation...
Colour Ma...
World ...
1000 Km
Lat -22.21...Lon -61.01... Elev 18...
[1] Abstracted_Metadata
Name
Value
Type
Unit
Description
Orbit_State_Vectors
SRGR_Coefficients
Doppler_Centroid_Coeffic
Band_IW_VH
Band_IW_VV
PRODUCT S1B_IW_GRDH_1SDV_20210510T0927 ascii Product nar
PRODUCT_TYPE GRD ascii Product typ
SPH_DESCRIPTOR Sentinel-1 IW Level-1 GRD Product ascii Description
MISSION SENTINEL-1B ascii Satellite mis
ACQUISITION_MODE IW ascii Acquisition
antenna_pointing right ascii Right or left
BEAMS - ascii Beams used
SWATH - ascii Swath name
PROC_TIME 10-MAY-2021 11:37:06.249409 uint32 utc Processed t
Processing_system_identi ESA Sentinel-1 IPF 003.31 ascii Processing
orbit_cycle 160 int32 Cycle
REL_ORBIT 39 int32 Track
ABS_ORBIT 26840 int32 Orbit
STATE_VECTOR_TIME 10-MAY-2021 09:26:43.000000 uint32 utc Time of orbi
VECTOR_SOURCE - ascii State vecto
incidence_near 30.172282790866234 float64 deg
incidence_far 45.86733632952139 float64 deg
Mask Manager


[1] Intensity_VH - [S1B_IW_GRDH_1SDV_20210510T092747_20210510T092812_026840_0334D4_5415] - [Z:\Projekty\2023_ESA_ENE...
File Edit View Analysis Layer Vector Raster Optical Radar Tools Window Help
Search (Ctrl+I)
Product Explorer
Pixel Info
Position
Image-X 20208 pixel
Image-Y 3504 pixel
Longitude 60°45'21" W degree
Latitude 22°13'38" S degree
Time
Bands
Intensity_VH 5329.00000 intensity
Tie-Point Grids
Flags
Snap to selected pin
Navigation...
Colour Ma...
World ...
1000 Km
Off Globe
Downloading
[1] Intensity_VH
Mask Manager
8 Y 3504
Lat 22°13'38" S Lon 60°45'21" W
Zoom 1:47.9 Level 5
Pixel Spacing: 10.17 m 9.99 m

A: SINGLE-DATE ANALYSIS

Create a subset

There is no need to process the whole image, instead, we can reduce the loaded data to a more manageable size – creating subset. This approach will decrease processing time in subsequent stages, especially when the analysis is concentrated on a specific area rather than the entire scene.

You can define the subset area by either zooming into the region of interest or by defining pixel or geographic coordinates. In this exercise we use the following geographic coordinates, that you can enter manually:

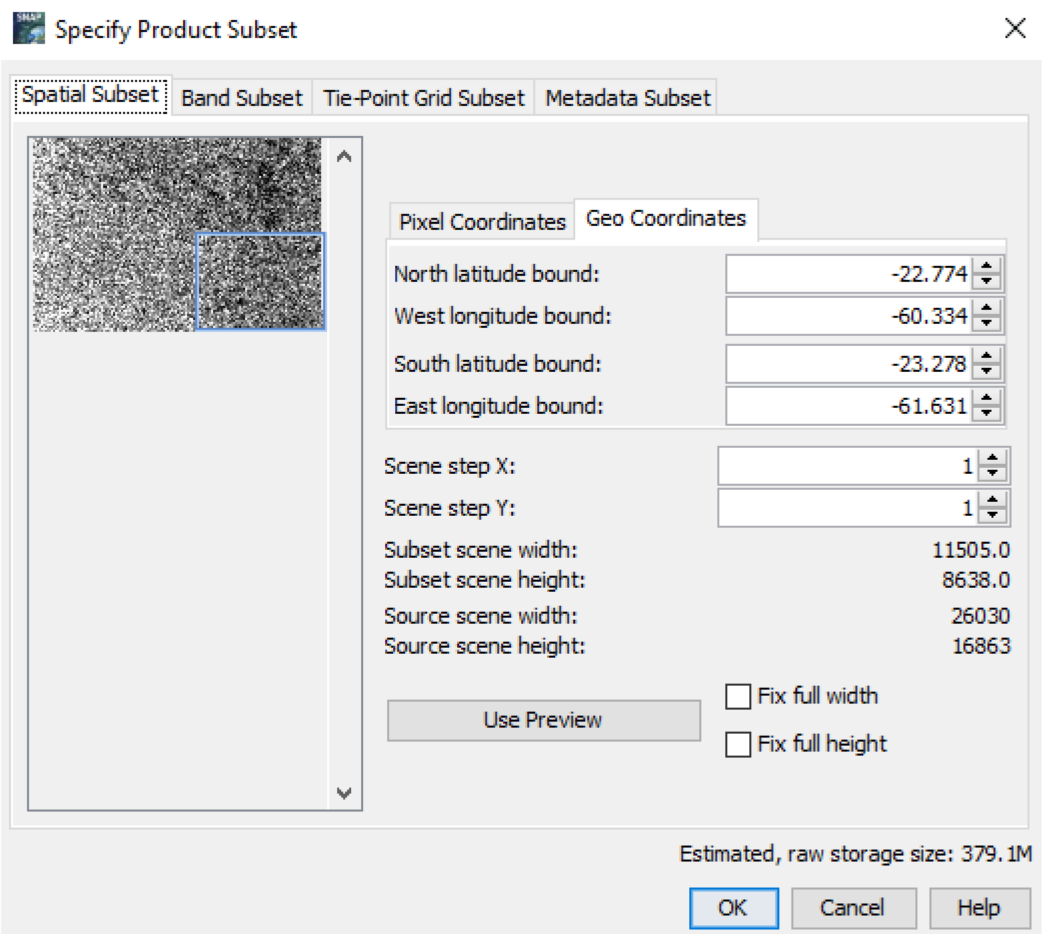
Navigate to Raster – Subset tab

and at Switch to "Geo Coordinates" in Spatial Subset tab

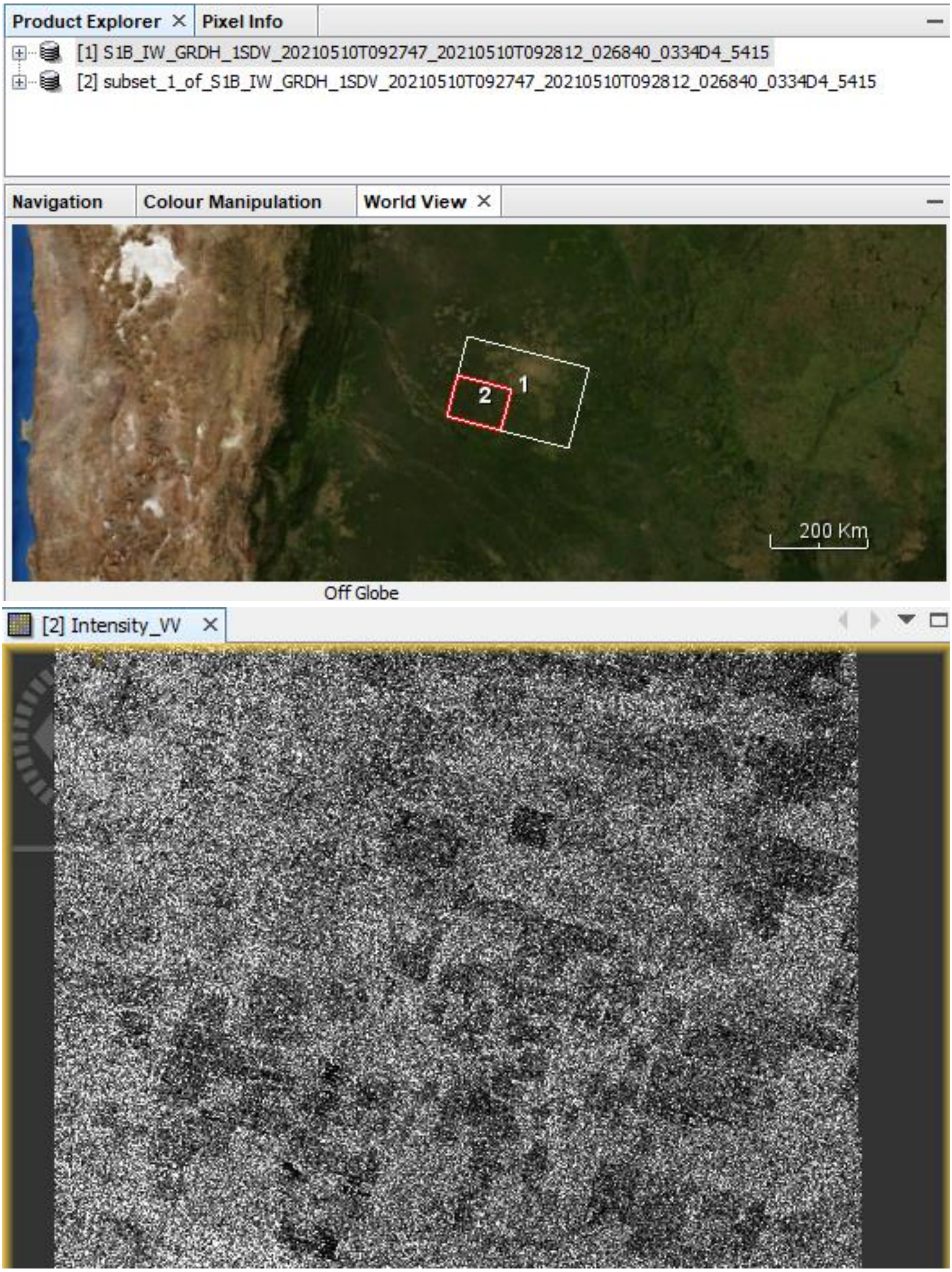
Enter the following numbers:

North latitude bound: -22.774
West longitude bound: -60.334
South latitude bound: -23.278
East longitude bound: -61.631

Confirm with OK.



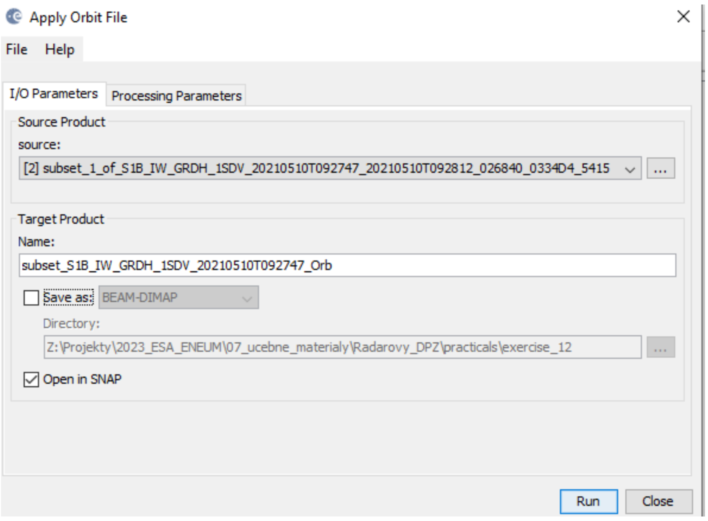
The new subset will appear in your Product Explorer window. You can open one of its bands by double-click on the selected band if you expand Bands folder within the product.

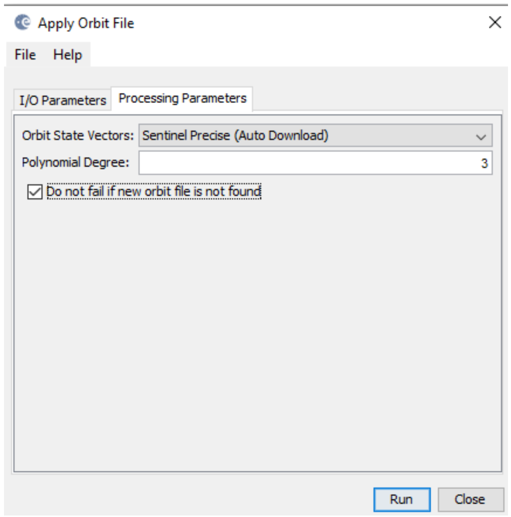


Apply orbit file

- Navigate to Main Menu – Radar – Apply orbit file
- In the I/O Parameters tab, select the subset product and name the target product. There is no need to save the output as BEAM-DIMAP
- In the Processing Parameters accept the default settings and select the option „Do not fail if new orbit file not found"

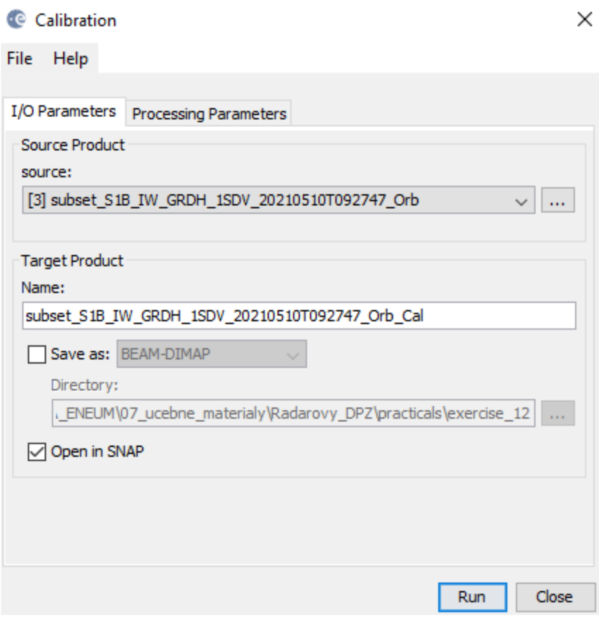
Note: If precise orbits are not yet available for your product, restituted orbits can be selected which may not be as accurate as the Precise orbits but will be better than the predicted orbits available within the product.

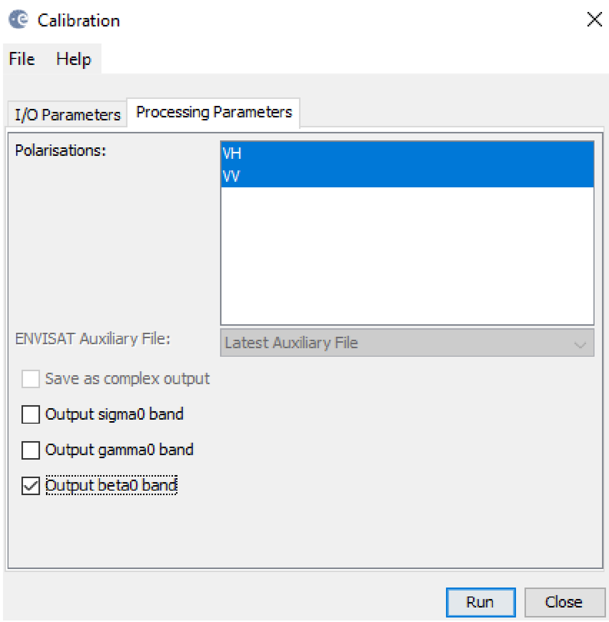




Apply radiometric correction

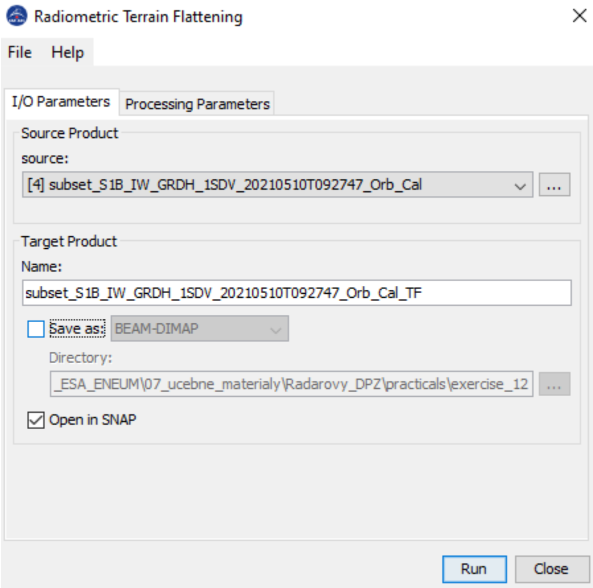
- Go to Radar > Radiometric > Calibrate and select the result product from previous step
- Under the Processing Parameters tab select both polarizations and select the **Output beta0** band option. The radiometric correction is necessary to remove any image-dependent radiometric bias.

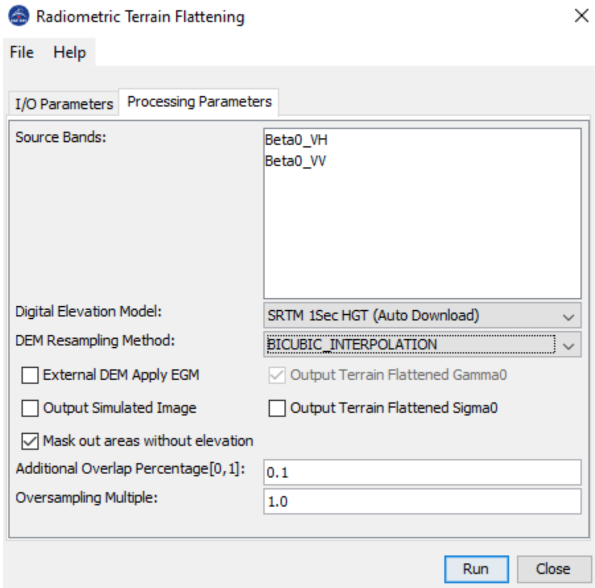




Radiometric Terrain Flattening

- Flatten Terrain
- Go to Radar > Radiometric > Radiometric Terrain Flattening
- Under Processing Parameters select SRTM 1Sec HGT (Auto Download)
- For DEM Resampling Method, use Bicubic_interpolation



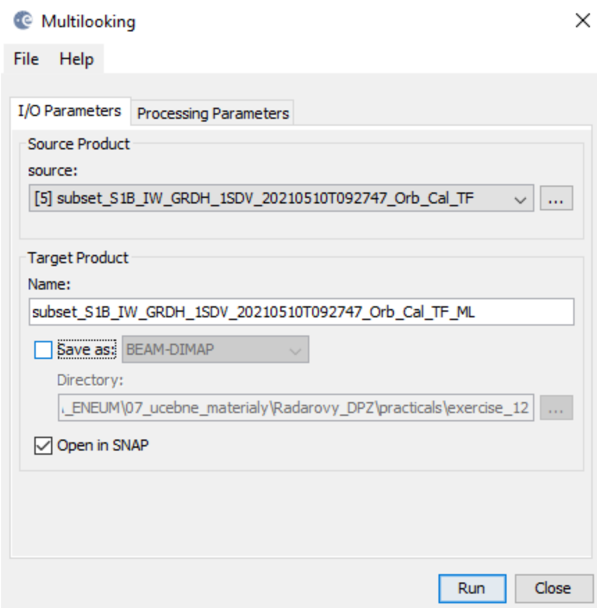


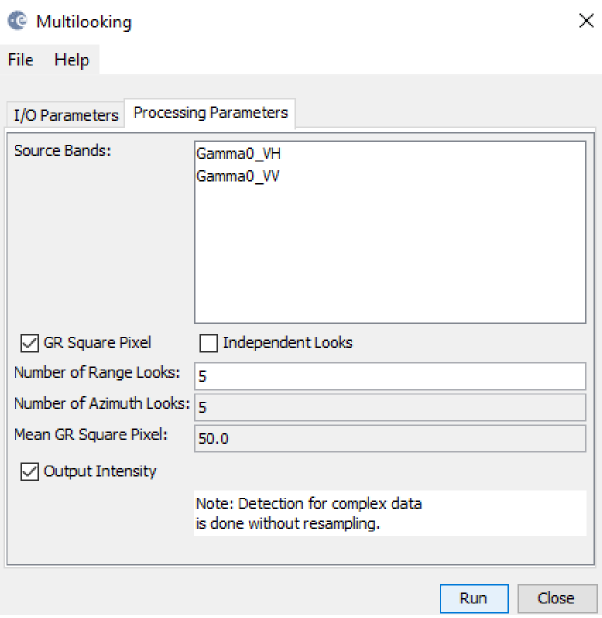
The output of this process will be transformed Beta0 into Gamma0

Multilooking

Go to Radar > Multilooking:

In "Processing Parameters" multilook the image by a factor 5x5 - change "Number of Range Looks" and "Number of Azimuth Looks" both to 5. If the "GR Square pixel" option is enabled, an equal number of looks will be applied in both the azimuth and range directions.

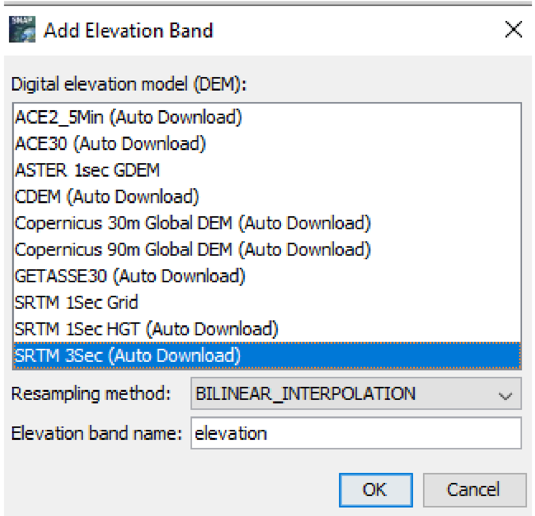


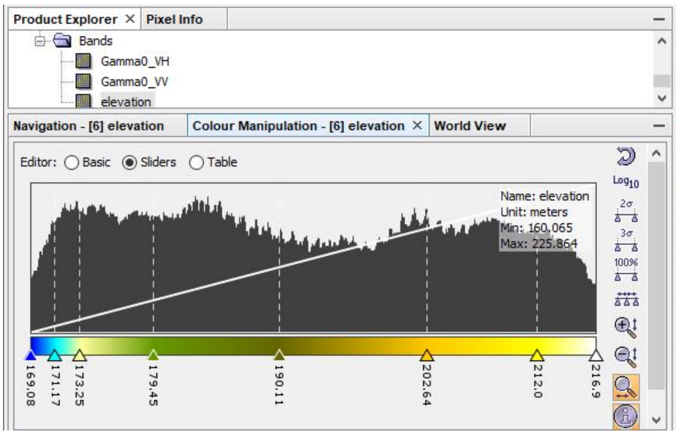


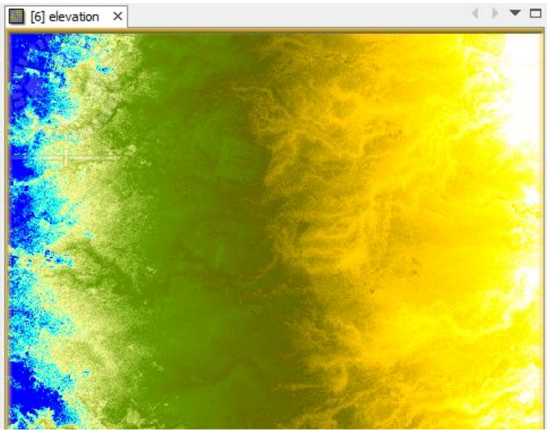
Create elevation band

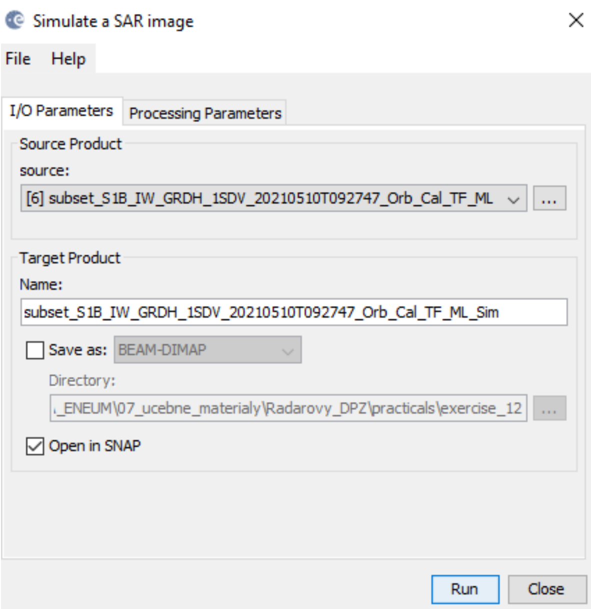
Go to Raster > DEM Tools > > Add Elevation Band:

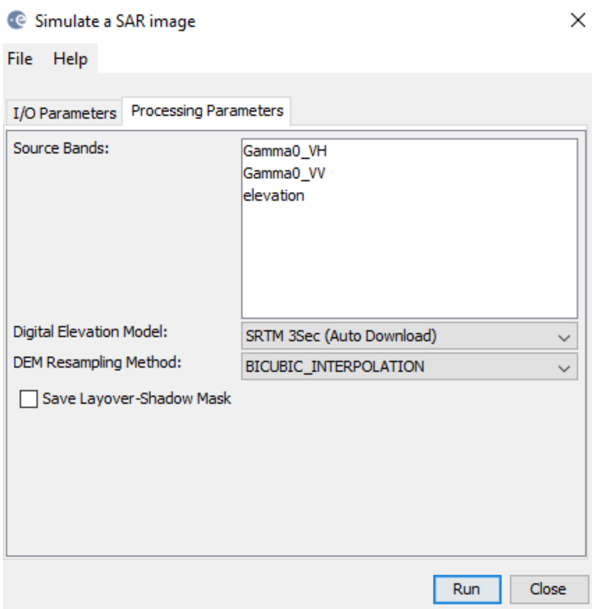
- Select the appropriate elevation band to add to the image, e.g. SRTM 3 sec (AutoDownload)
- After having added the elevation band, go to Radar > Geometric > Terrain Correction > SAR Simulation and run the SAR simulation.







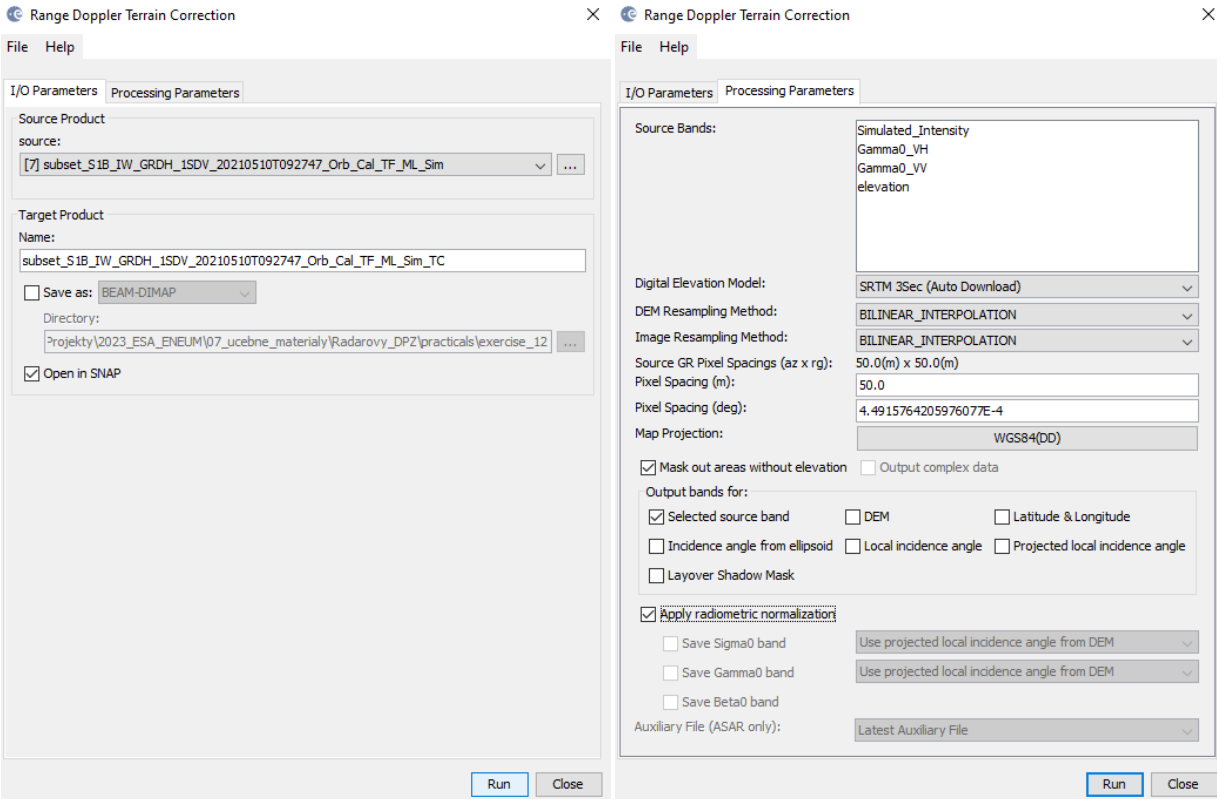




Terrain Correction

Go to Radar > Geometric > Terrain Correction > Range-Doppler Terrain Correction

- In the I/O Parameters select the last simulated product
- Under Processing Parameters tab select:
  - Digital Elevation Model: SRTM 3Sec (Auto Download)
- - DEM Resampling Method: Bilinear Interpolation
  - Check the "Mask out areas without elevation" box
  - Check the "Apply radiometric normalisation" box



Convert gamma0 to dB

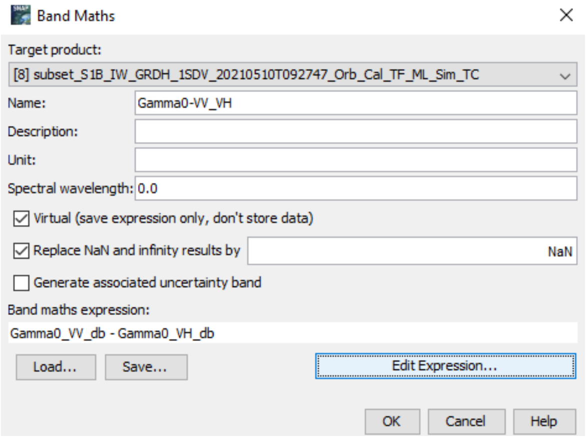
In the Product Explorer select first the Gamma0_VH band, then go to Raster > Data Conversion > Linear to/from dB and repeat with the Gamma0_VV band.

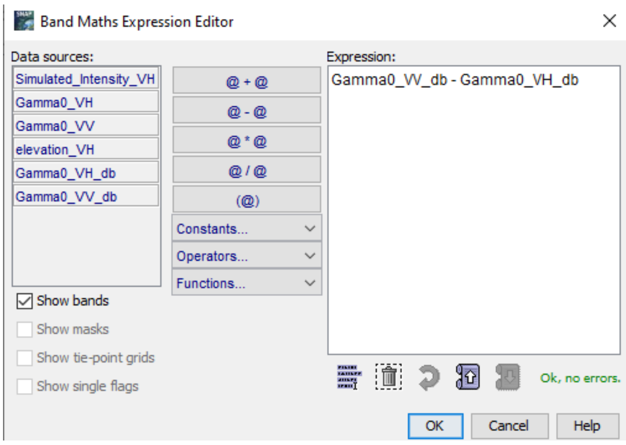
This will create two Virtual bands (with a V icon). Right click on each > Convert Band to transform them.

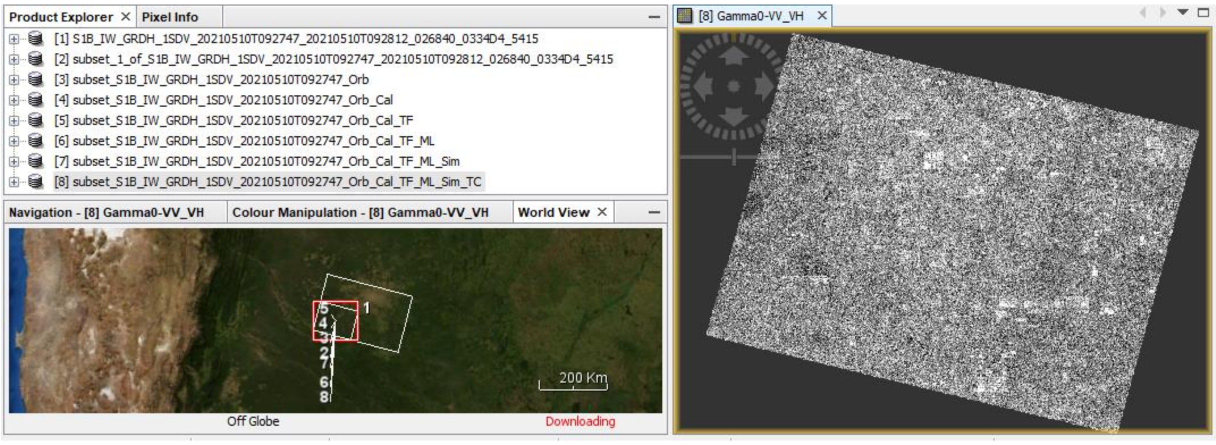
Compute difference image from gamma0 [dB]: VV-VH

Open Raster > Band Maths:
Name it "Gamma0-VV_VH". Click on 'Edit Expression' and enter the expression Gamma0_VV_dB – Gamma0_VH_dB

Convert virtual raster

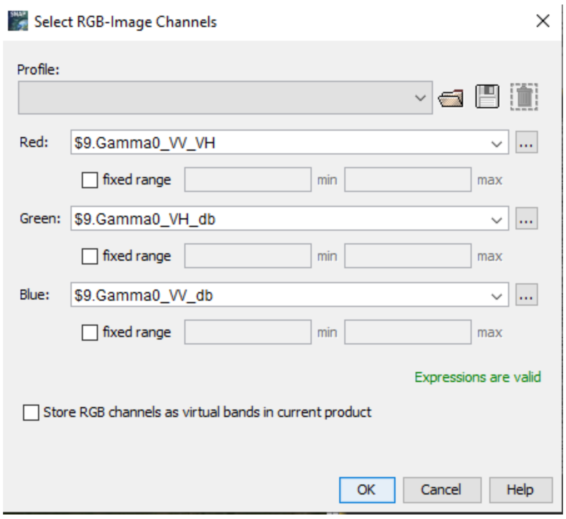


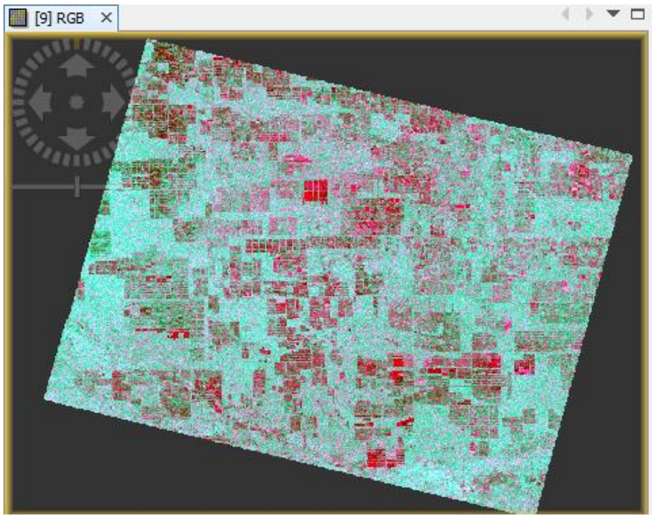




Display as RGB view

Go to Window > Open RGB Image Window (or right-click on the last product in the Product Explorer and Open RGB window) and select:
Red: the difference band „Gamma0_VV_VH"
Green: „Gamma0_VH_db"
Blue: „Gamma0_VV_db"

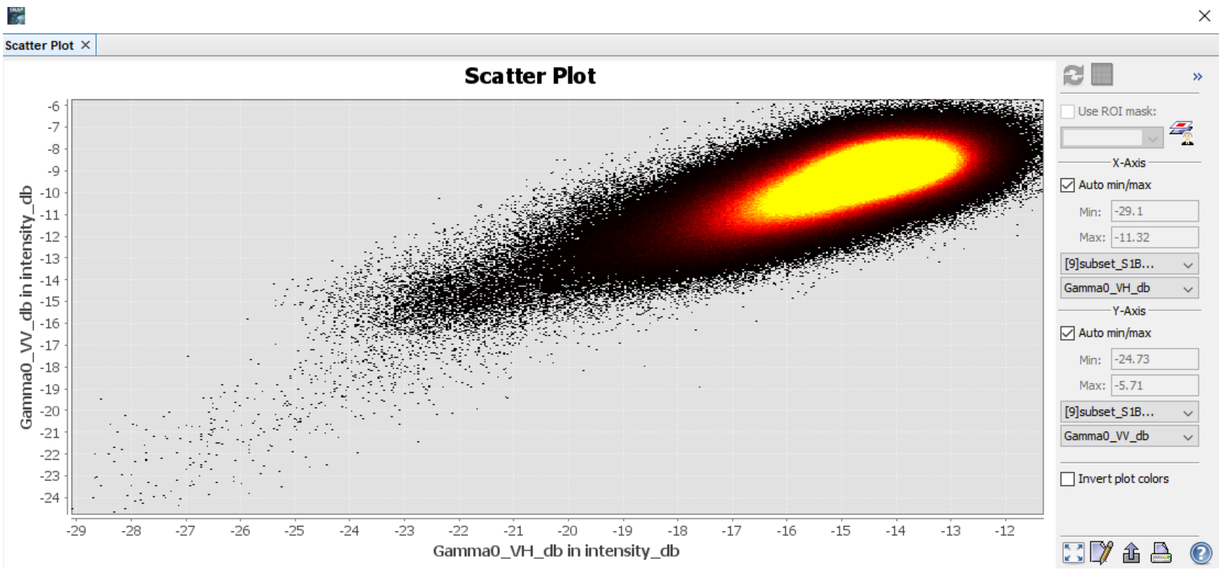




Statistical analysis

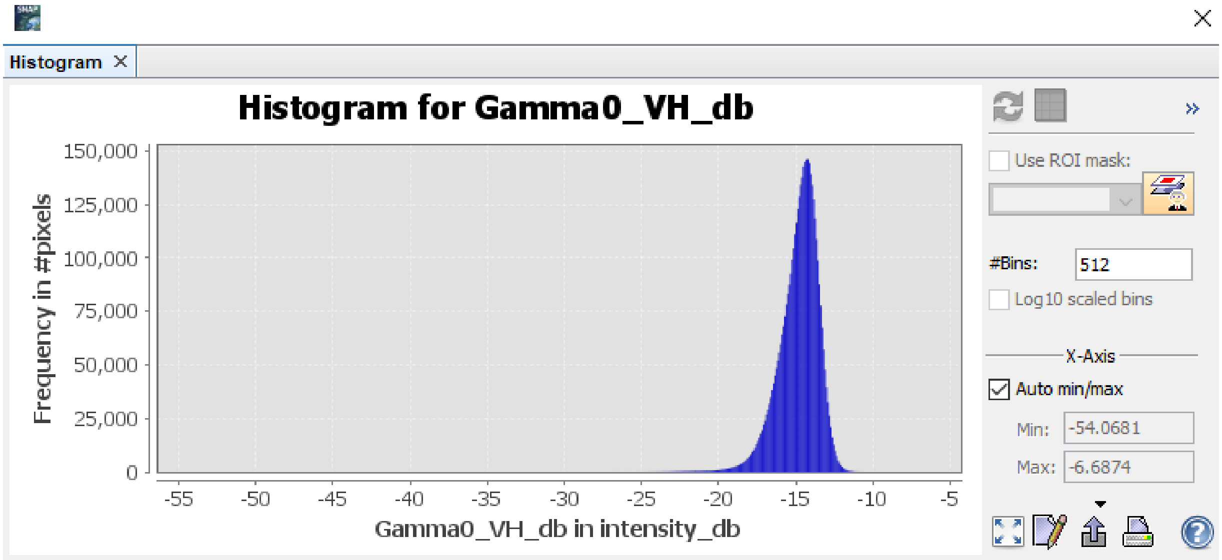
Scatterplot

Open Analysis > Scatter Plot and in the right panel select the Gamma0_VH_dB as X-axis input and Gamma0_VV_dB as Y-axis input, then click the Refresh View button.



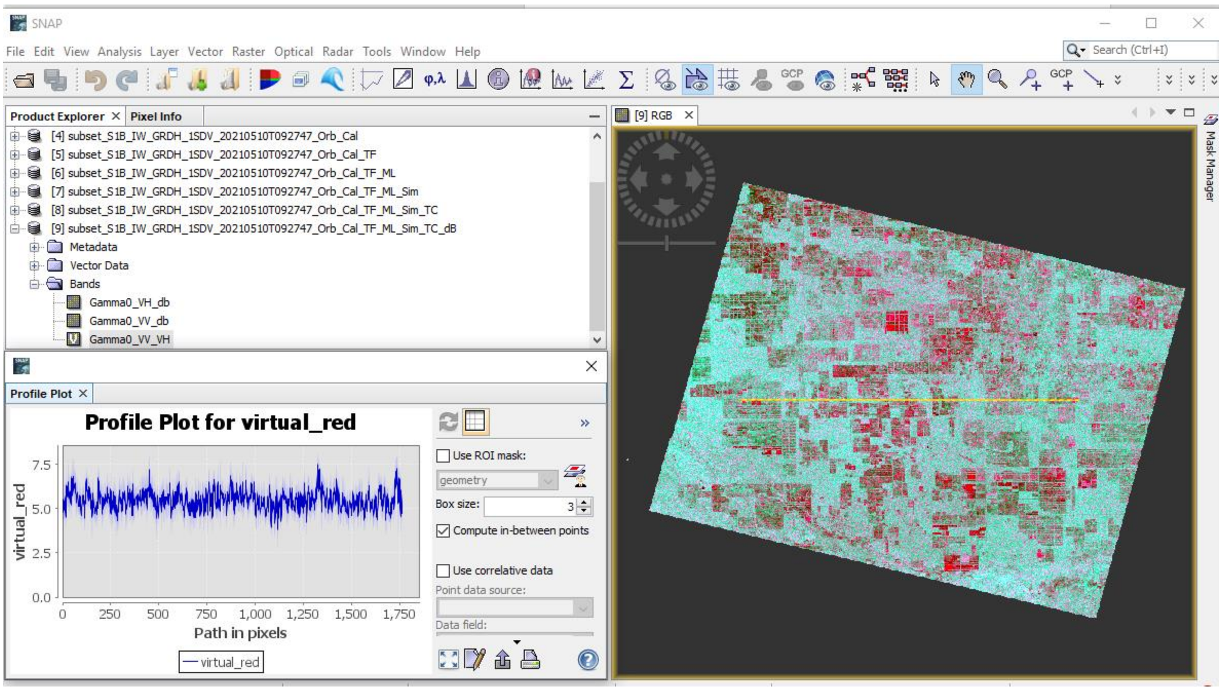
Histogram

Select e.g. the Gamma0_VH_dB band and open Analysis > Histogram. Click the Refresh View button.



Profile Plot

Select the Gamma0_VV_VH band. In the toolbar select the Polygon or the Line tool and draw a shape on your region of interest. Open Analysis > Profile Plot. This operation can be done for any of the other bands.



B: MULTITEMPORAL ANALYSIS

Load both Sentinel-1 products by navigating to File - Open Product.

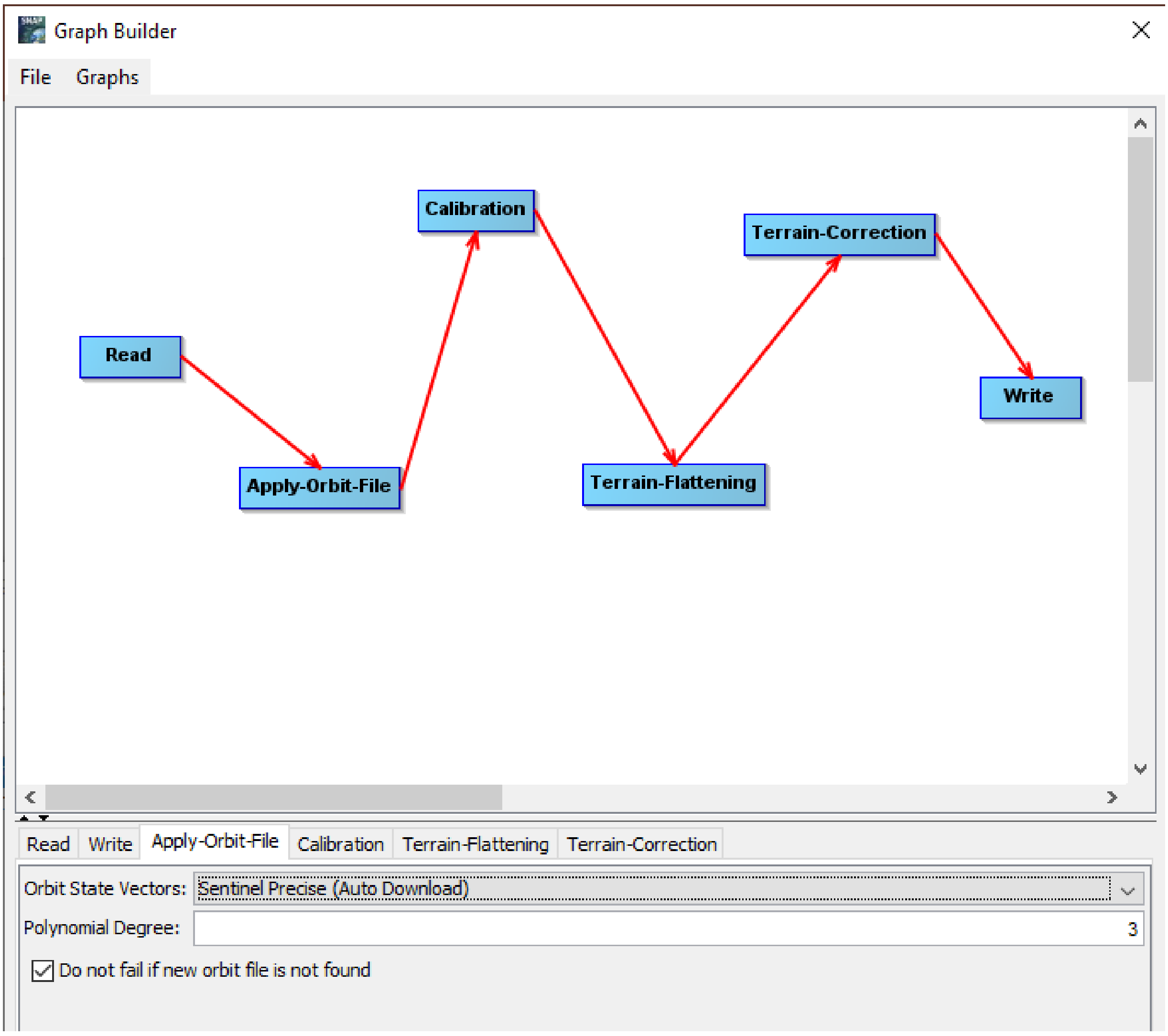
Build a pre-processing graph

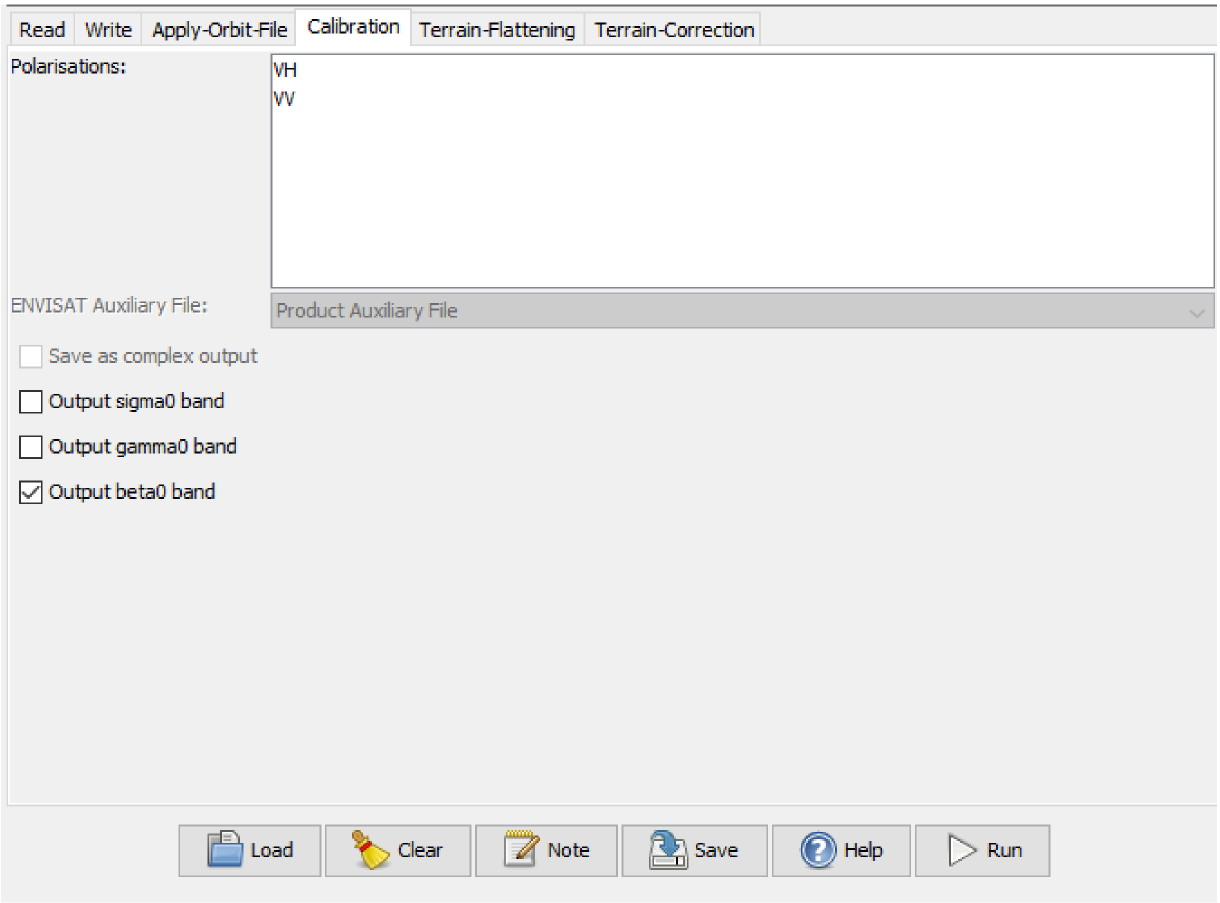
Use the graph builder tool to create workflow for data processing:

Go to Tools>GraphBuilder
Right click and add, in the order below, each of the preprocessing steps:

The first tool is Read
Add>Radar>Apply-Orbit-File and keep pre-defined parameters. Check „Do not fail if new orbit file is not found"
Add>Radar>Radiometric>Calibration and select Output beta0 band
Add>Radar>Radiometric>Terrain Flattening will add terrain flattening
Add>Radar>Geometric> Terrain Correction>Terrain Correction
The last tool is Write

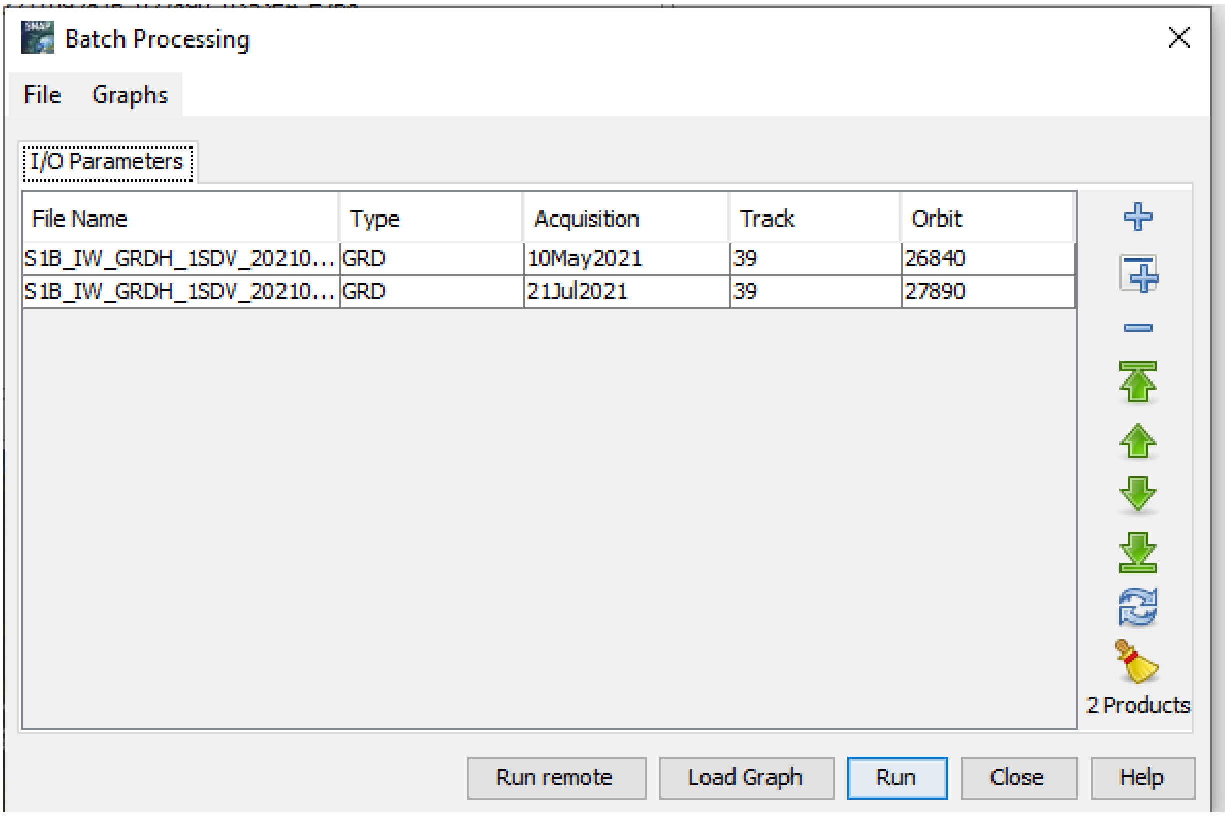
Click on each tool, and connect them by dragging the red arrows from one tool to the next, respecting the order above
Then got to File>Save Graph to save the workflow as a XML file.



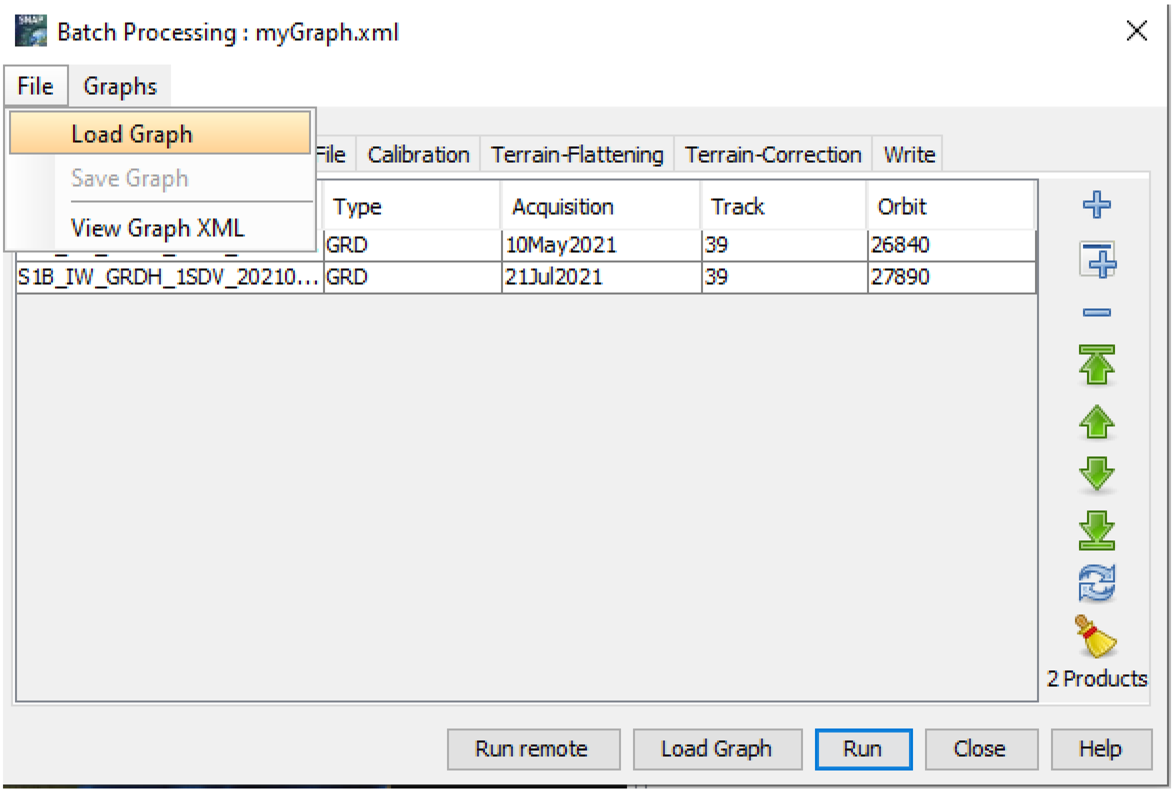


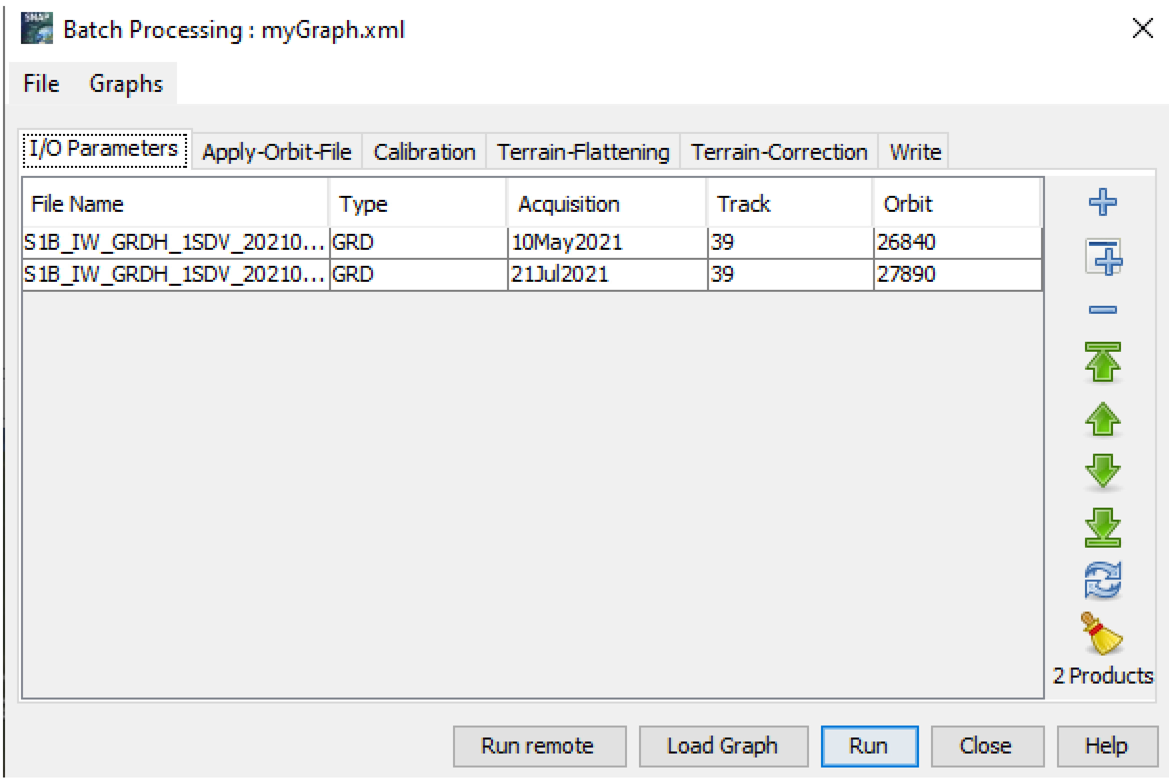
Batch processing

Navigate to Tools > Batch Processing:
Using the Add opened symbol select the files you want to process.



Using the Load Graph button, load the .xml-file you just saved

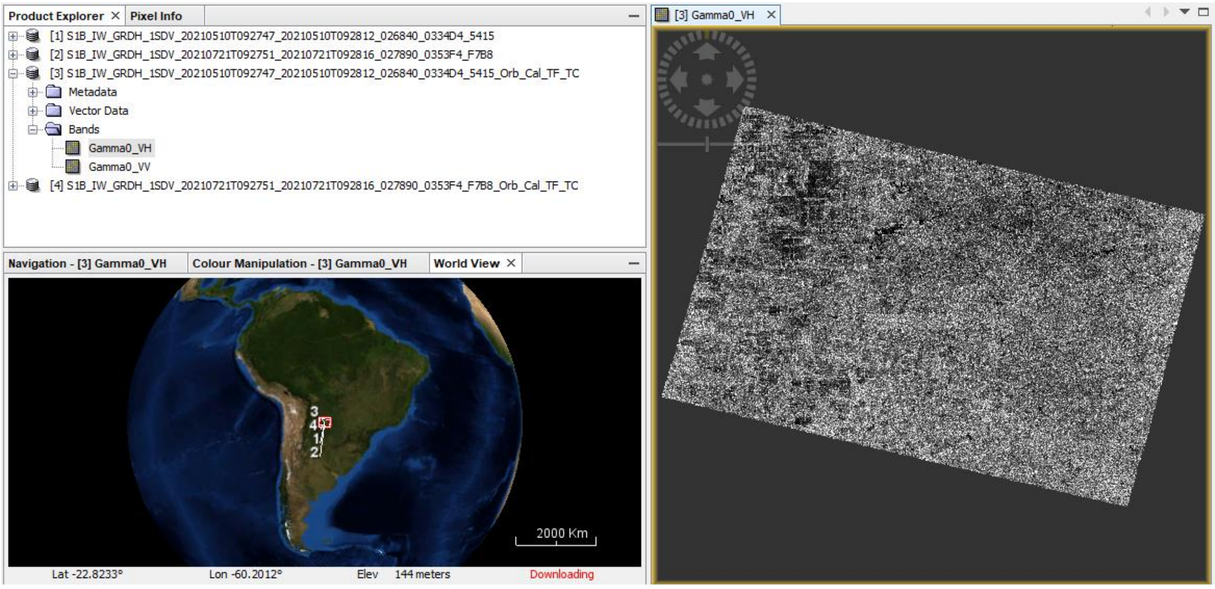




Adjust the output folder, click Run.

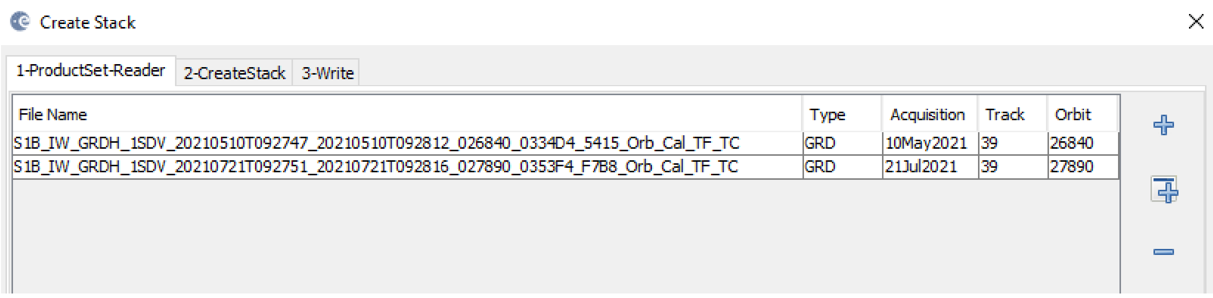
Note: this step might take several minutes/hours to run.

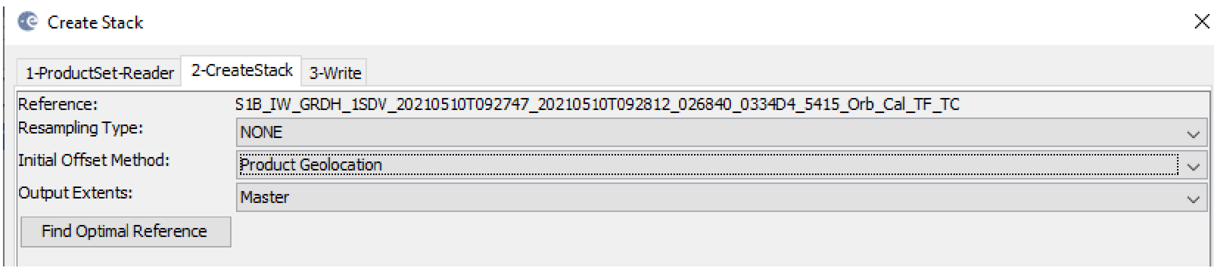
View the output product, e.g. by doulble-click on Gamma0_VH terrain corrected band.

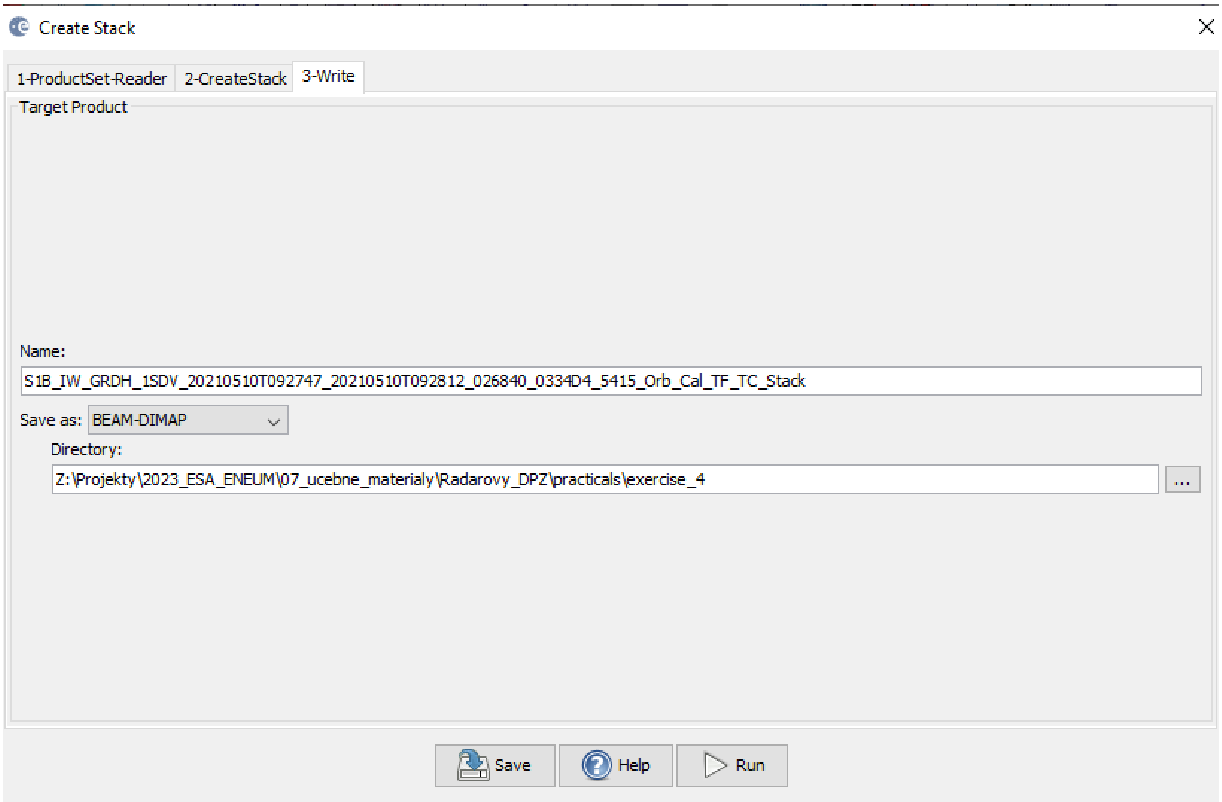


Create stack

Go to Radar > Coregistration > Stack Tools > Create Stack
In the CreateStack tab, select Product Geolocation as Initial Offset Method
In the Write tab, adjust the stack name if needed, adjust the output folder and click Run. This step will might take few minutes.

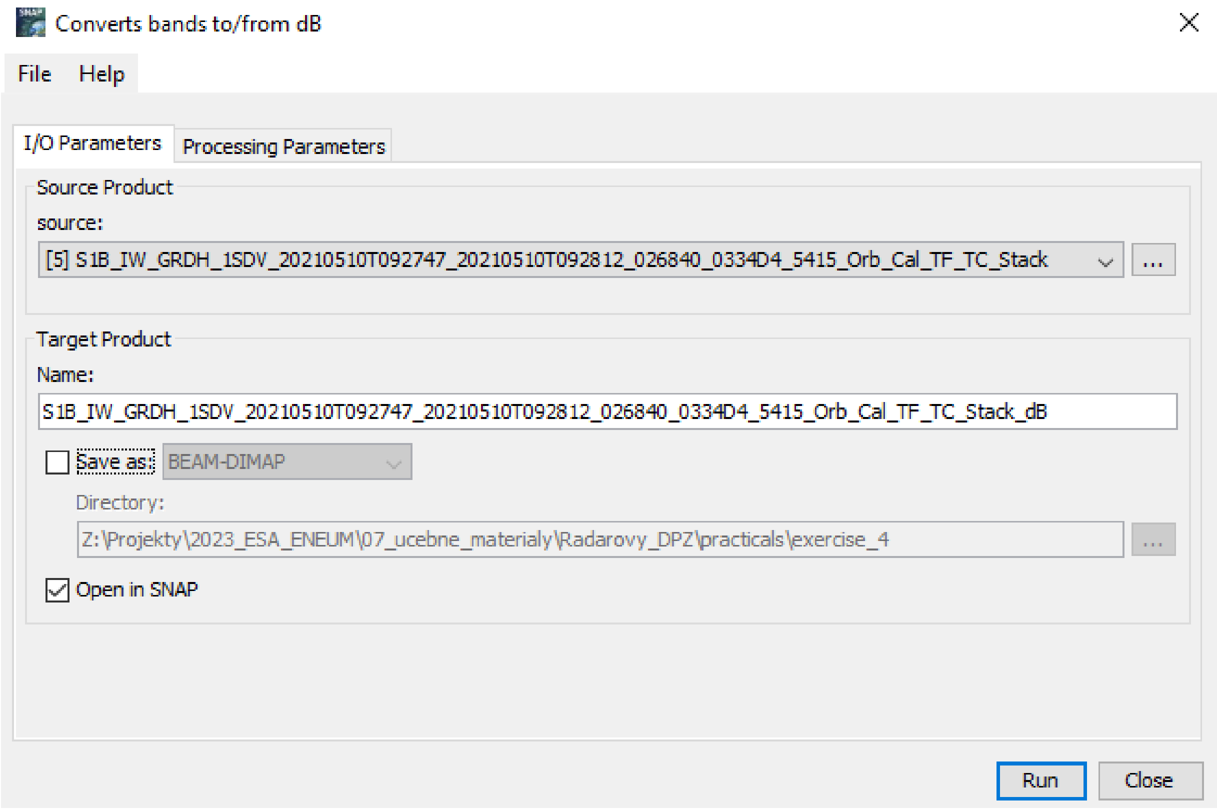






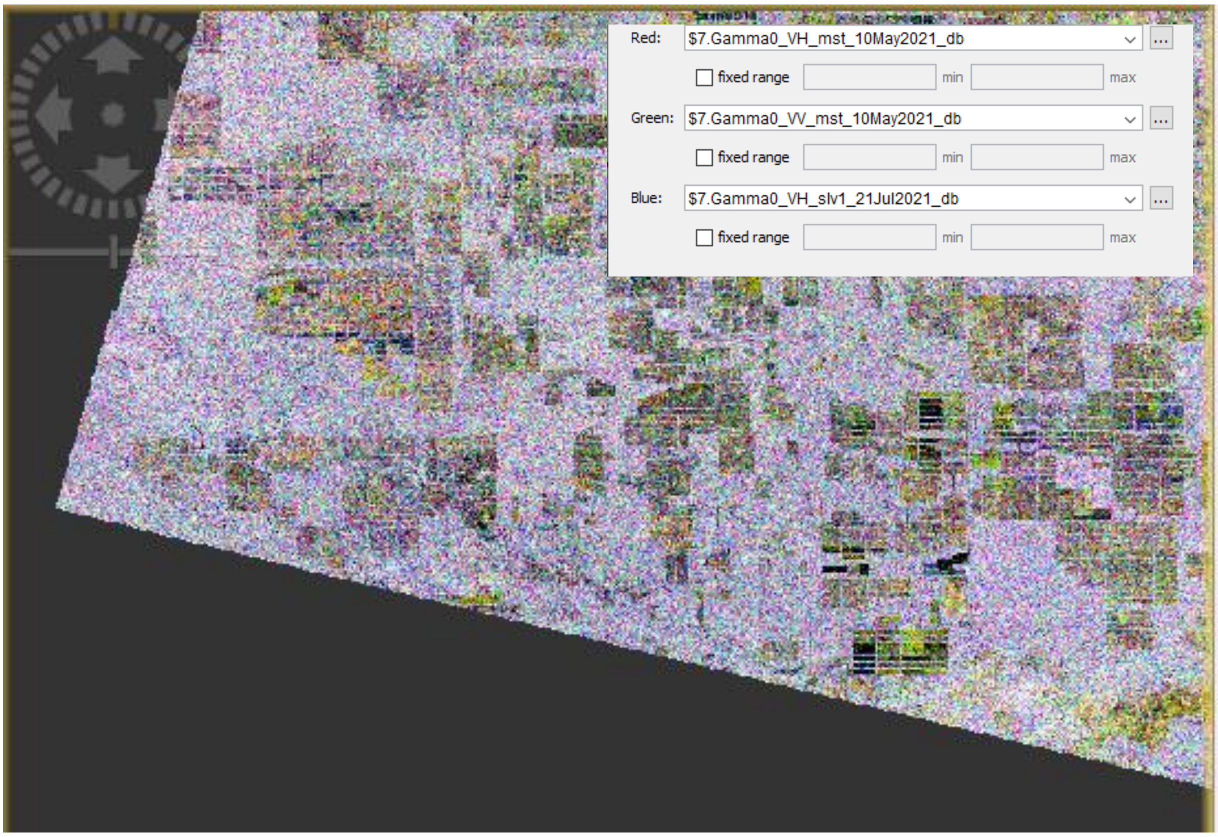
Convert bands to dB

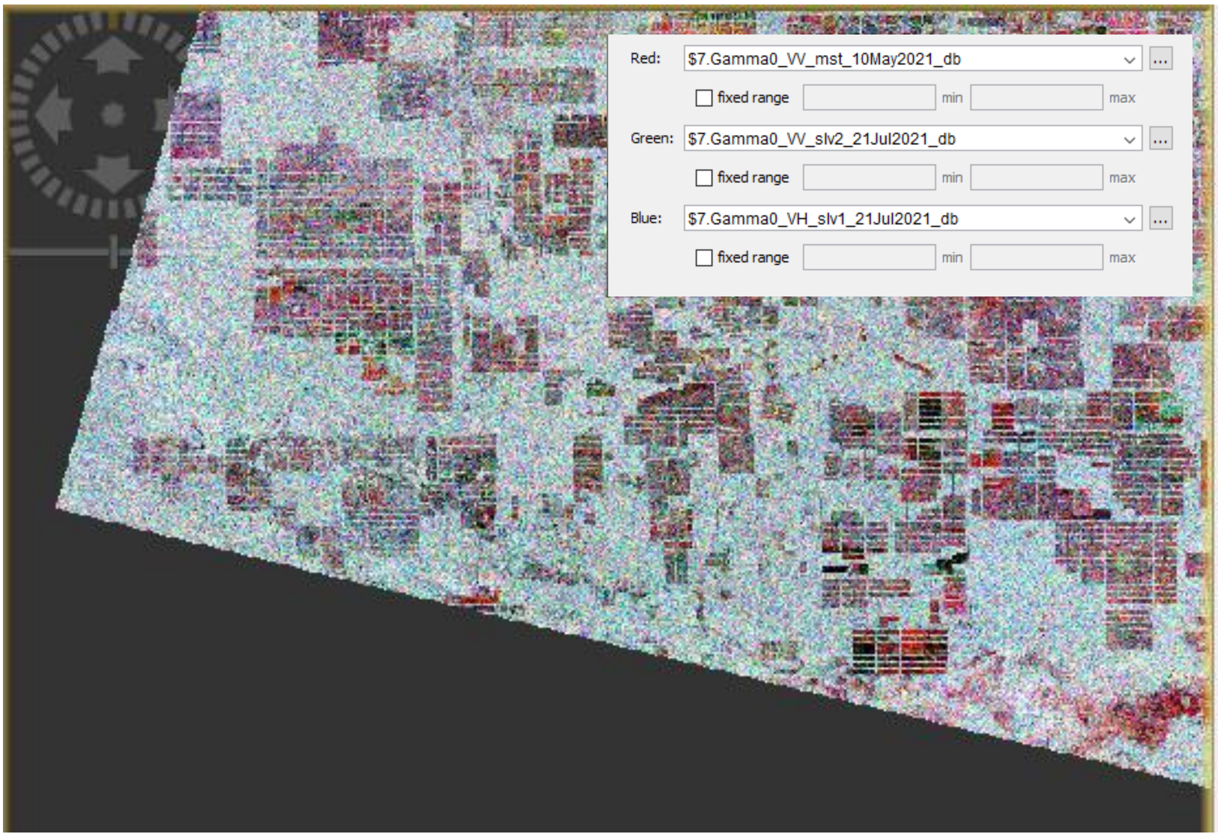
In the Product Explorer select the processed Gamma0_VH band, then go to Raster > Data Conversion > Linear to/from dB and repeat with the Gamma0_VV band.



Display an RGB

Right-click on the last product – Open RGB Image Window and select different band combinations to see the change of backscatter between different acquisitions. Explore values over forest area and fields.

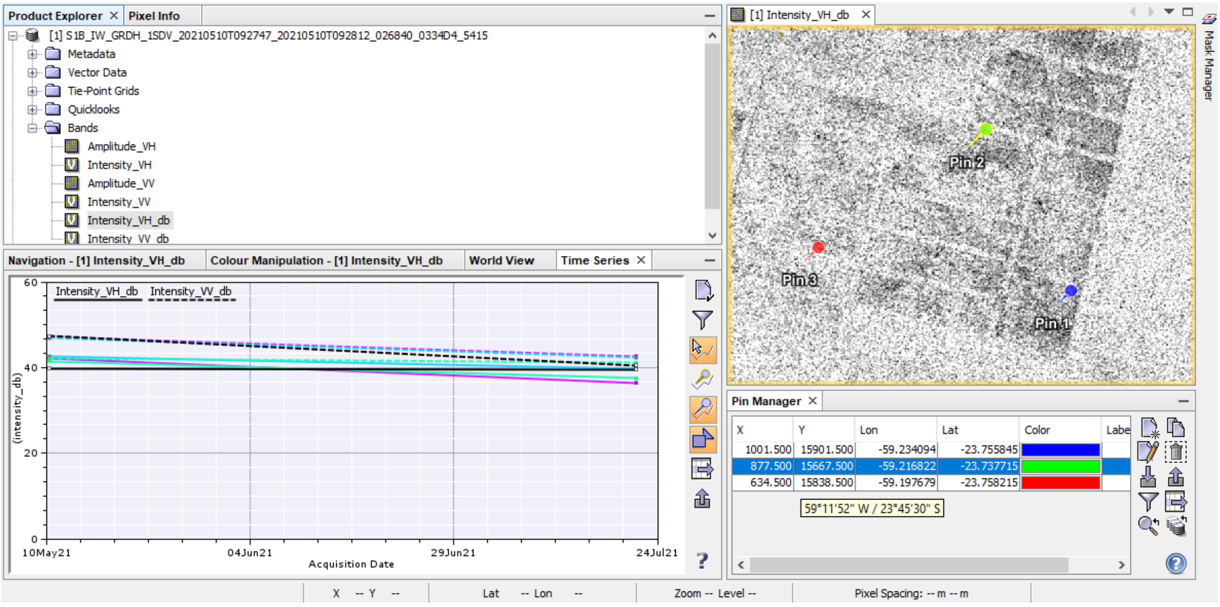




Time Series Analysis (using single scenes, not a stack)

Tool cannot use a stack, it needs single images instead

Navigate to View > Tool Windows > Radar > Time Series to open the Time Series tab at the bottom left of your SNAP window.
Click on Settings (top right of Time Series tab) and add individual (pre-processed) images. Click Apply.
Using the time series tab, hover your mouse over the area to see the behaviour of single pixels over or use Pin Manager to see the behaviour of the selected Pins.



Explore values to identify forest area and fields.

For more information, see the lecture: [4. SAR remote sensing for forestry]

THANK YOU FOR FOLLOWING THE EXERCISE!

EXERCISE 5 – TUTORIAL

Crop Classification with S1 and S2 data using the SNAP software

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UNIVERZITA PAVLA JOZEFA ŠAFÁRIKA V KOŠICIACH

FUNDED BY EUROPEAN SPACE AGENCY UNDER THE PLAN FOR EUROPEAN COOPERATING STATES, 7TH CALL FOR SLOVAKIA

1 | Exercise outline

In this exercise, we will:

- Use radar (Sentinel-1) and optical (Sentinel-2) data to classify and analyse different crop types and their health over an area
- Data pre-processing will be perfomed, an then the crop types will be estimated by classification of the data, based on the Random Forest algorithm
- Land crops growth and health will be observed using NDVI time series

2 | Background

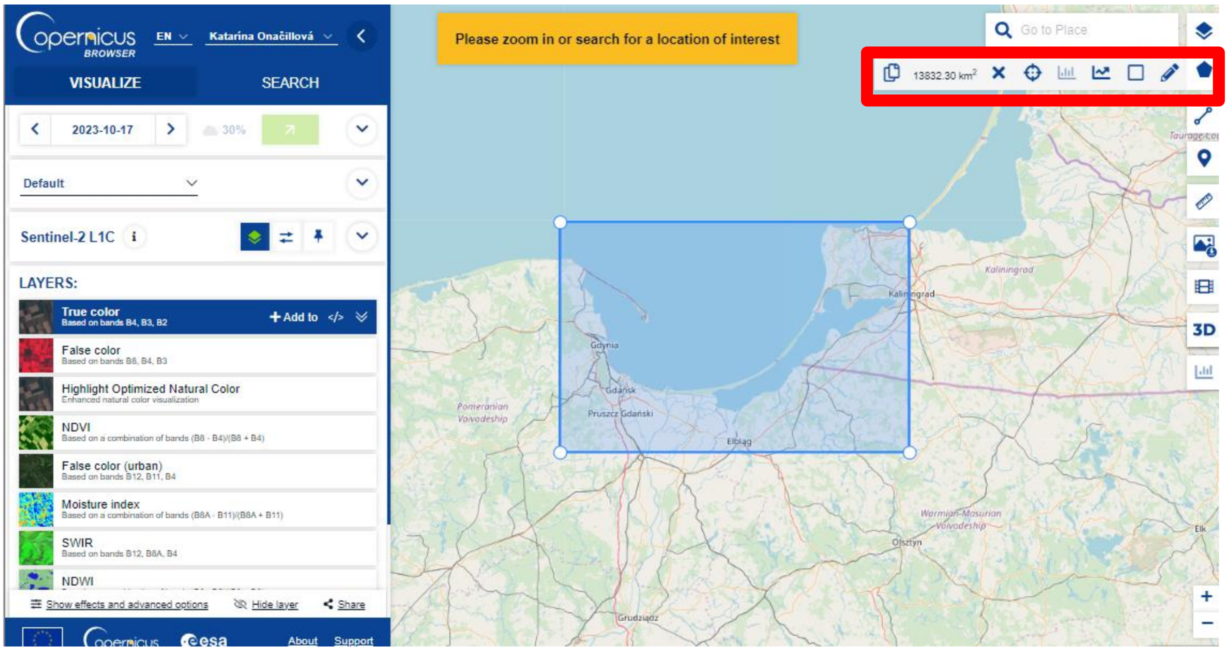
Crop classification using Sentinel-1 and Sentinel-2 data

Crop classification using Sentinel-1 data relies on the radar backscatter signals obtained from the satellite. The backscatter intensity, polarization, and texture of the radar imagery are analyzed to distinguish between different crop types.

Supervised classification methods involve training a classifier with labeled samples of land cover types, while unsupervised methods group pixels based on their spectral similarity without prior training. The accuracy of the land cover classification is validated using ground truth data, and the results can be refined iteratively to improve accuracy. The final land cover maps provide valuable information for various applications, including urban planning, agriculture, forestry, and environmental monitoring.

2.1 Study area and data used

For this exercise, we will use Sentinel-1 and Sentinel-2 images to explore fields in Kacik, near Gdansk and Baltic Sea coast northern Poland, downloaded for year 2023 from the Dataspace Copernicus Open Access Hub [@https://dataspace.copernicus.eu/].

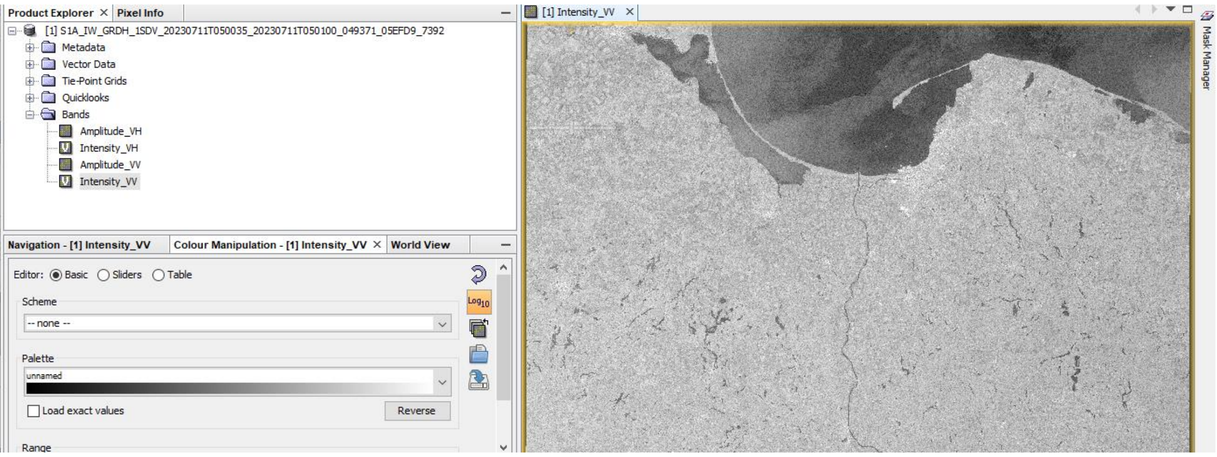


2.2. SNAP - Open and explore product

Open SNAP Desktop, click Open Product and open Sentinel-1 GRDH downloaded products with HH and HV polarizations acquired on 11 July 2023 by double click on the zipped folders. The opened products will appear in Product Explorer window:

S1A_IW_GRDH_1SDV_20230711T050035_20230711T050100_049371_05EFD9_7392.SAFE

Click + to expand the content of product, then expand Bands folder and double click on Intensity_VV band to visualize it. Depending on your computer's capabilities, this process could take some time. To minimize the data load, the next step involves creating a subset that encompasses only a portion of the dataset.



3. Pre-processing

For classification purposes, three bands are utilized per acquisition: VV (or HH for Sentinel-1), VH, and their ratio VV/VH (or HH/VH for PALSAR). Out of the 13 bands per Sentinel-2 data acquisition, only the 10 with spatial resolutions of 10 m or 20 m are utilized.

3.1 Sentinel-1 preprocessing

The Sentinel-1A data were obtained in IW mode and retrieved from the ESA Scientific Data Hub at https://scihub.copernicus.eu/ in GRDH format. These data require calibration (converting from Digital Numbers to Radar Backscattering Coefficient s0) and orthorectification (transforming from image geometry to a geographical projection) within a geographical subset. Subsequently, a filter is applied to mitigate Speckle noise, which is inherent in radar imagery.

Apply orbit file

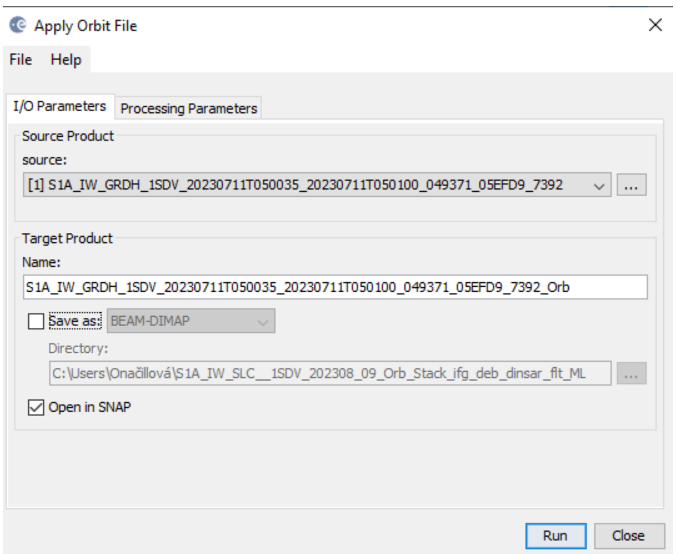
Satellite positions are recorded using a Global Navigation Satellite System (GNSS). To ensure the fast delivery of Sentinel-1 products, orbit details produced by an onboard navigation system are included in the Sentinel-1 products. Subsequently, the Copernicus Precise Orbit Determination (POD) Service further enhances the accuracy of the orbit positions.

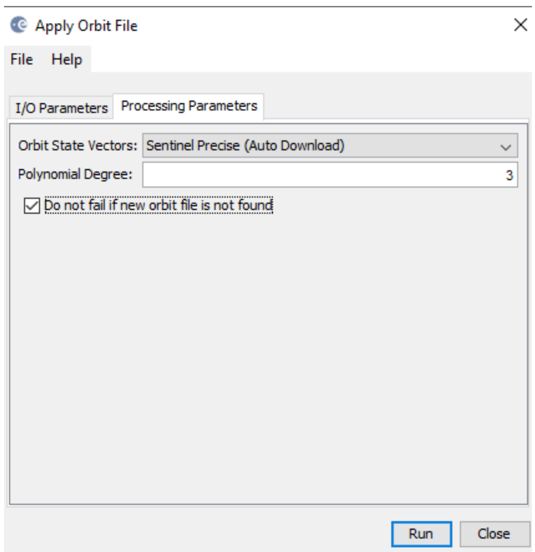
Navigate to Main Menu – Radar – Apply orbit file

In the I/O Parameters tab, select the first product and name the target product. There is no need to save the output as BEAM-DIMAP (we will save the time this way)

In the Processing Parameters accept the default settings and select the option „Do not fail if new orbit file not found"

Note: If precise orbits are not yet available for your product, restituted orbits can be selected which may not be as accurate as the Precise orbits but will be better than the predicted orbits available within the product.



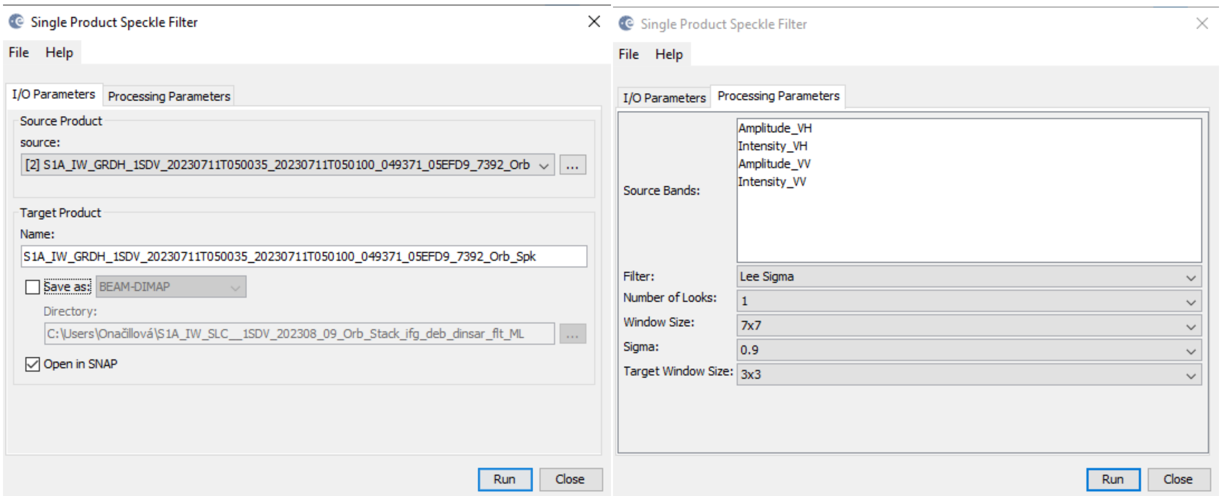


Speckle Filter

Despeckling removes thermal noise introduced by the sensor from the image to remove potential sources of error in analysis.

Navigate to Radar > Speckle Filtering > Single Product Speckle Filter:
In the Processing Parameters tab, choose the Lee filter with default window sizes and click Run.

Note: Selecting the size of the speckle filter depends on the targets (point target, distributed target) and the target size (for example field sizes).



Open the output of the Lee sigma filter and compare it with the image before Speckle filtering. Filtered image looks sharpened and without noise comparing with the image before applying Speckle filter.

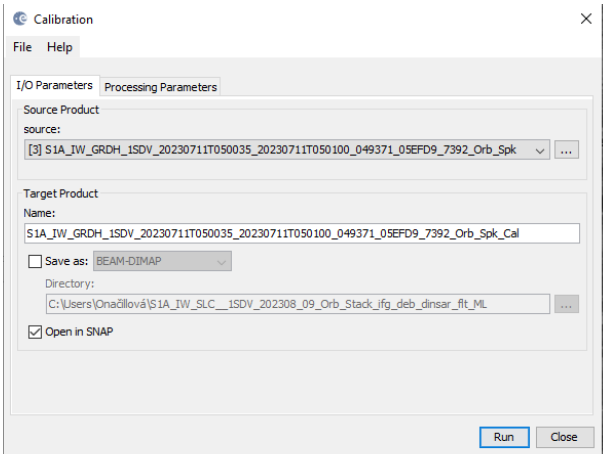
Calibration

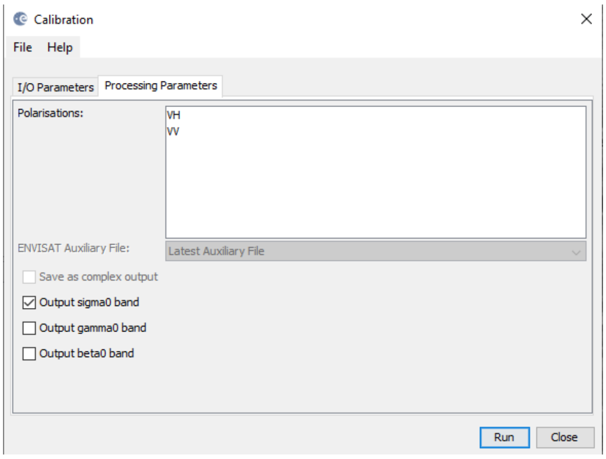
S1 Level-1 products are not radiometrically corrected or calibrated, by default1. Radar reflectivity is stored as Digital Numbers (DNs) in S1 products, and must be converted to physical units (radar backscatter).

Navigate to Main Menu – Radar – Radiometric – Calibrate

In the I/O Parameters tab, select the last filtered product and name the target product.

In the Processing Parameters you can select one or both polarization and accept all default settings and then click Run





Terrain-Correction

The last step in our graph for image pre-processing is to apply terrain correction to the product, ensuring that all the pixels are moved to the right locations (eg if the nadir angle of the image is off, it will align the pixels correctly so it is closer to a top-down view of the imagery).

Navigate to Main Menu: Radar - Geometric - Terrain Correction - Range-Doppler Terrain Correction

In the I/O Parameters tab set as "Source Product" the last calibrated product.

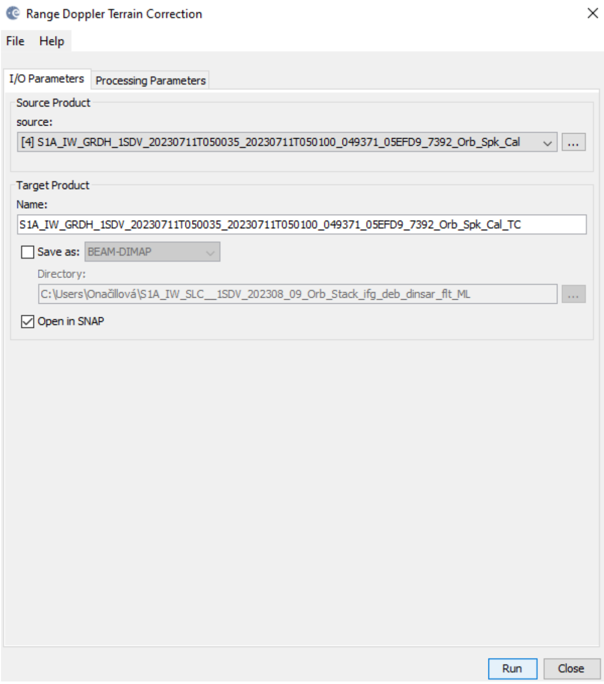
In "Target Product", keep the default name and set the Directory

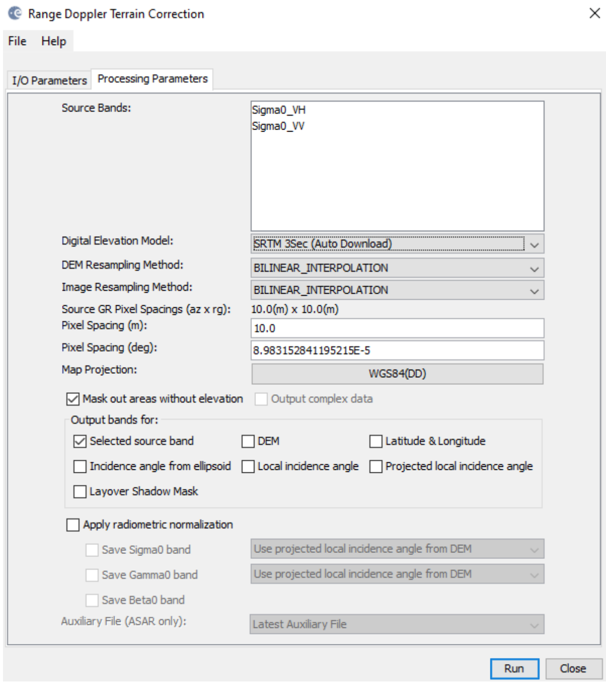
In the Processing Parameters tab set:

Digital Elevation Model: SRTM 3Sec (Auto Download)

Map Projection: WGS84(DD)

Keep defaults values for the other parameters. Click Run. Approximate processing time: 2.5 minutes.





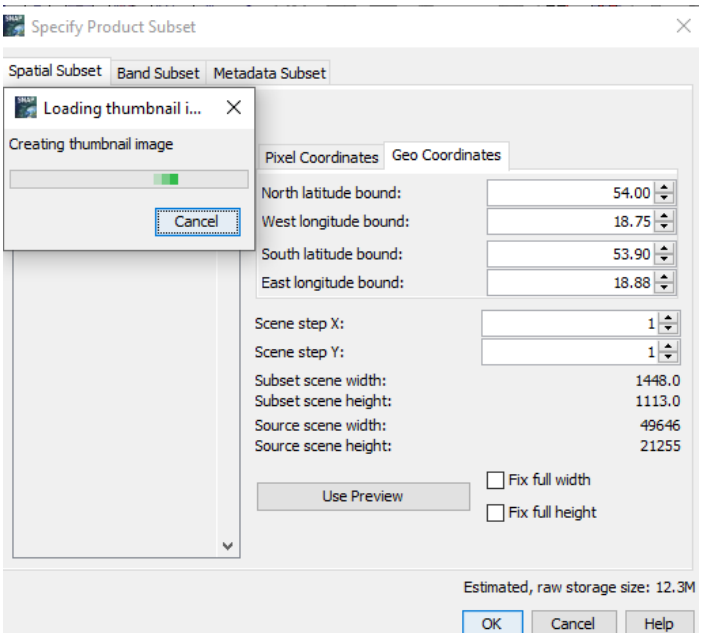
3.1 Create subset

There is no need to process the whole image, instead, we can begin by narrowing down the scene to a more manageable size – creating subset. This approach will decrease processing time in subsequent stages, especially when the analysis is concentrated on a specific area rather than the entire scene.

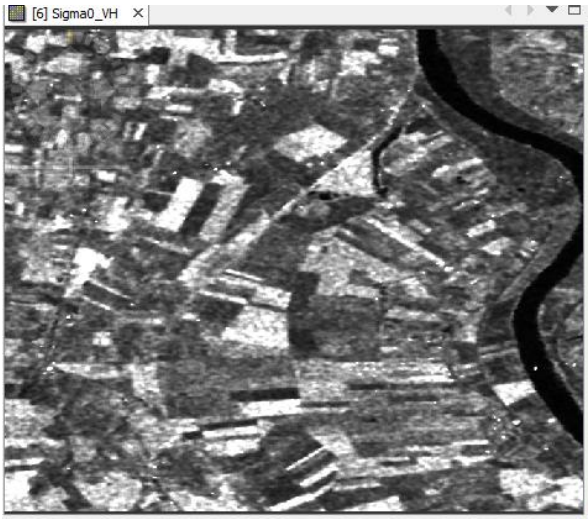
Go to the Subset tab and at "Geo Coordinates" set:

North latitude bound: 54.00
West longitude bound: 18.75
South latitude bound : 53.90
East longitude bound : 18.88

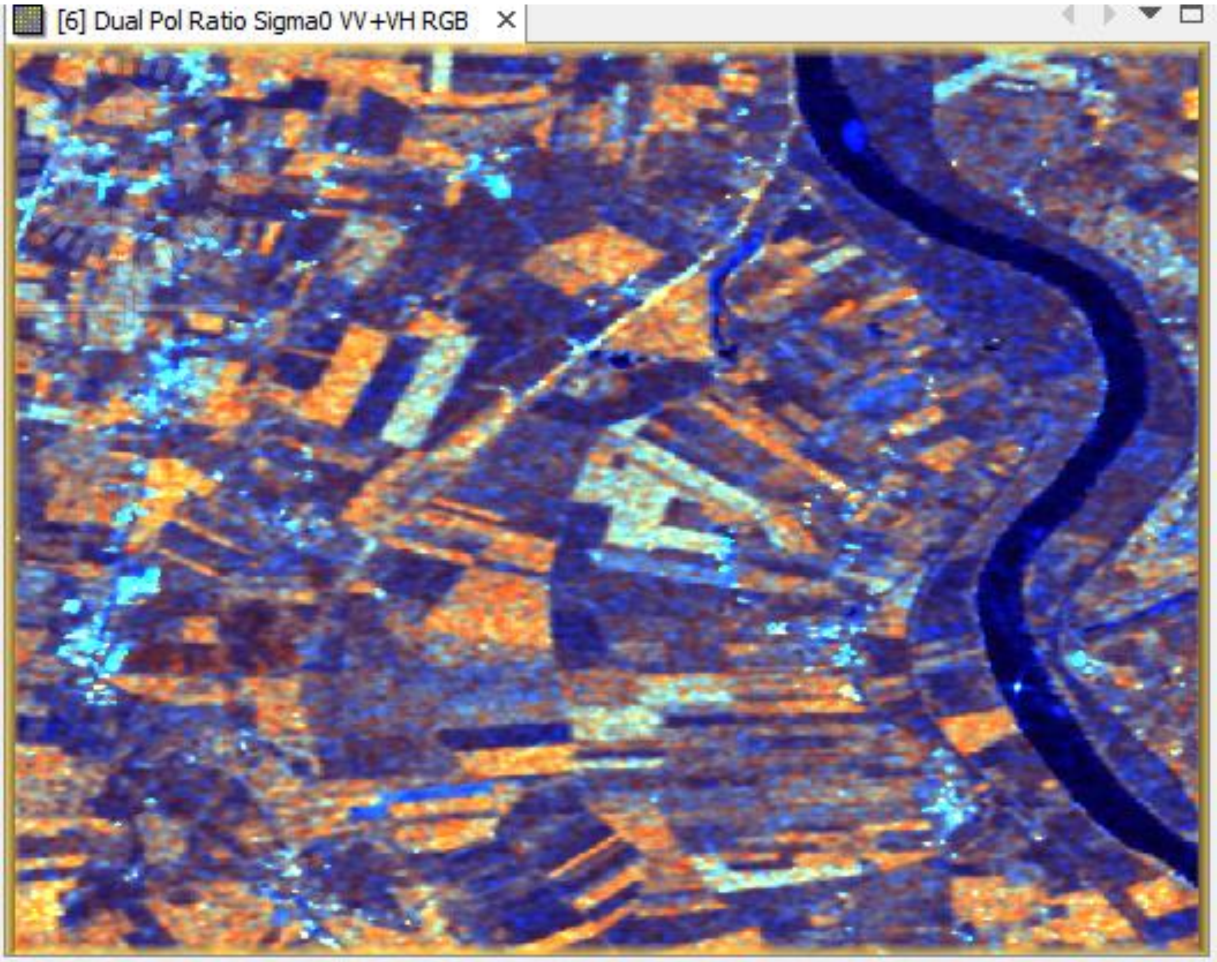
Note: There is no need to wait till thumbnail image will be created when entering coordinates.



Visualize the output subset by double-click on VH and VV polarization.



Visualize the final subset image using RGB:
Go to Window > Open RGB Image Window (or right-click on the last product in the Product Explorer and Open RGB window) and select the band combinations for final RGB image: VH, VV, VV/VH.

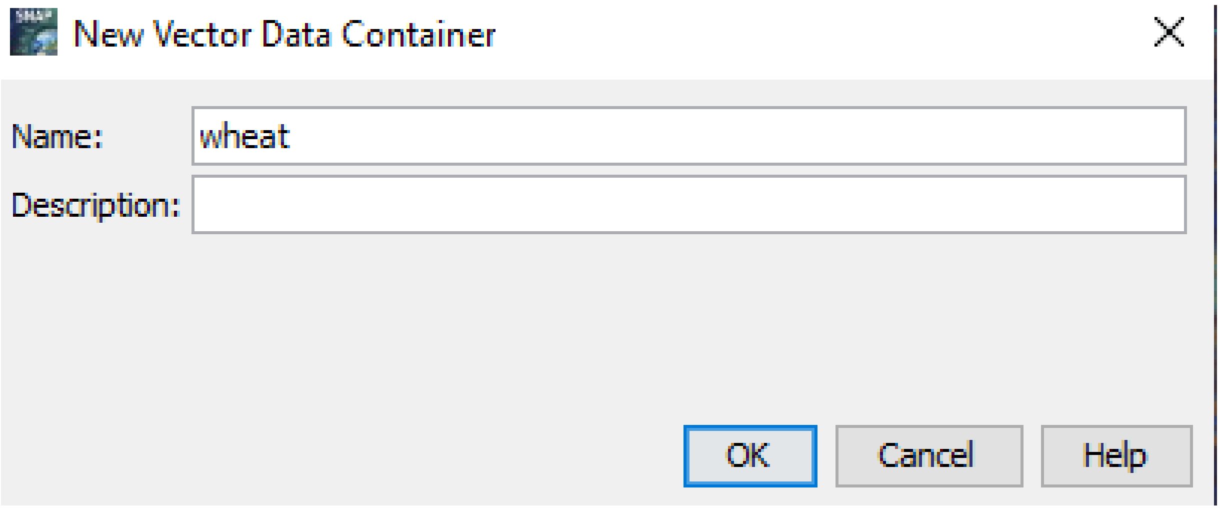


2.4 Image classification

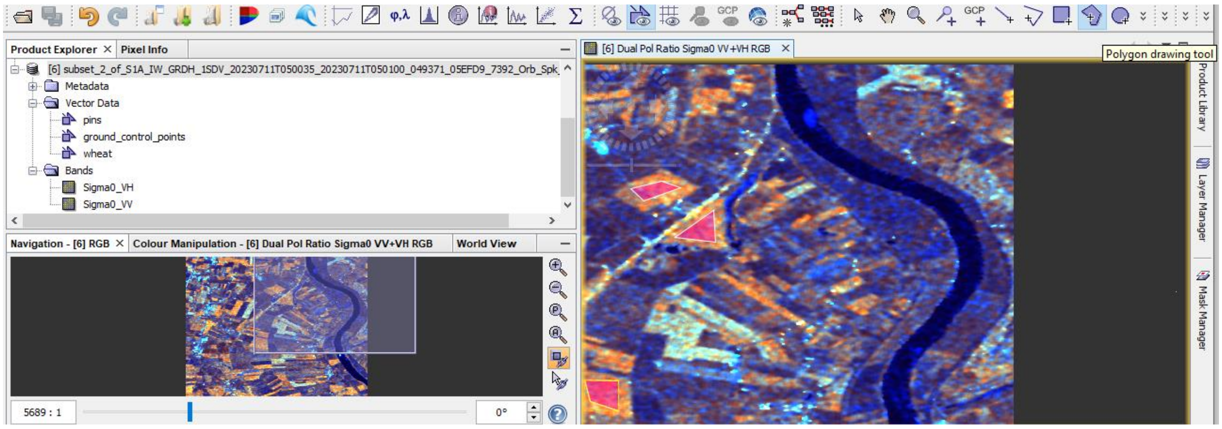
We will perform a random forest classification. For this we will create some training data by identifying polygons containing the different crop/land cover types:

– wheat
- maize
- Rapeseed
- barley
- grassland
- river

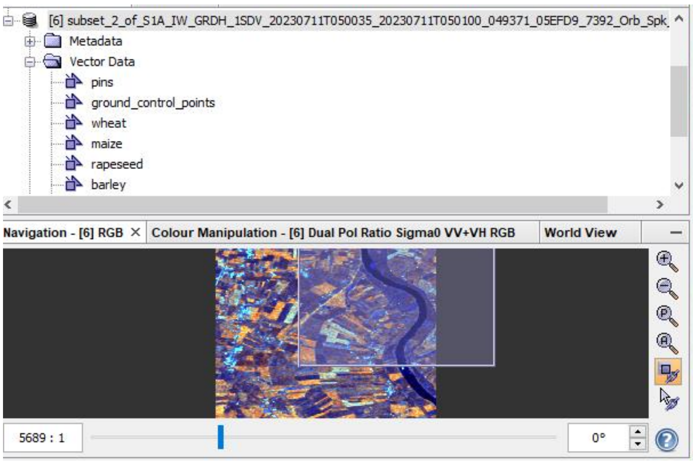
Select the last subset product by clicking on it. Navigate to Vector > New Vector Data Container.
Create new data containers – separate for each type of ice mentioned above. Start with creating the data container for, e.g. „wheat".Click OK.

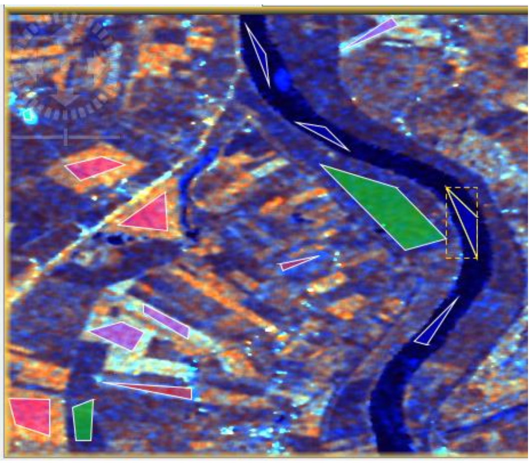


The newly created vector data container should appear under "Vector Data" in the Product Explorer. Now let´s start creating training polygons for these different containers on ice type using the Polygon drawing tool:



Repeat this step and create training polygons for all remaining classes.

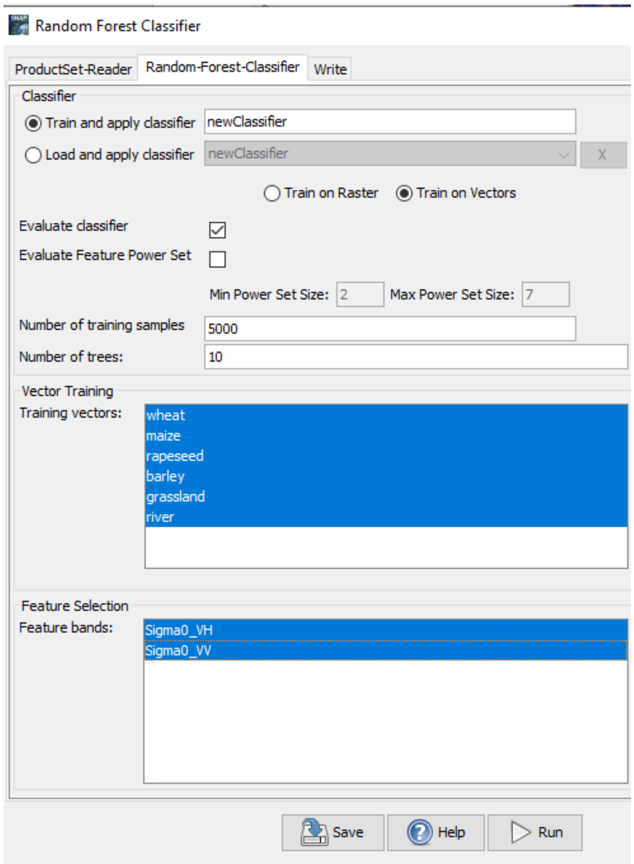




Wheat (red), maize (violet), rapeseed (light blue), barley (cyan), grassland (green) and water (blue) training polygons. Save the final product with your created vector data containers to your folder.

Random Forest image classification

Navigate to Raster > Classification > Supervised classification > Random Forest Classifier

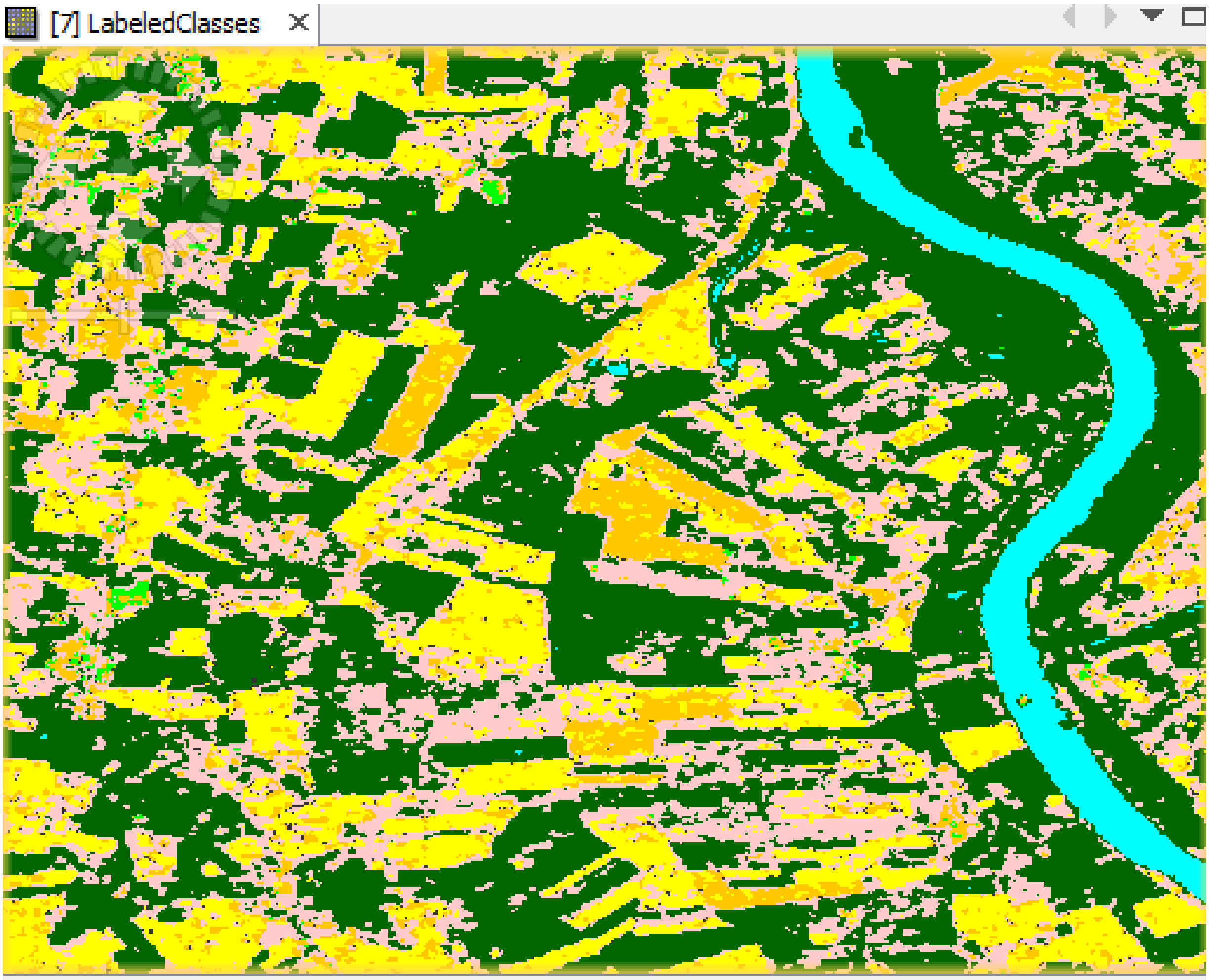


- In the ProductSetReader tab select the saved product with your training data.
- In the Random-Forest-Clasiffier select the classes/training vectors (all polygon vector containers) and feature bands (select both Sigma0_VH and Sigma0_VV polarisations) that you'd like to include into image classification.
- In the Write tab by default, the output target is set to the same directory and appends „RF" to the filename.
- Click RUN.

2.5 Post-processing

The final product should now appear in the ProductExplorer. Visualize this output classified image and classes by double-click on the layer „LabeledClasses" under Bands folder in the Product Explorer.

Navigate to Colour Maniulation tab to change the colours of individual crop type classes and other ones and explore the frequency and distribution of these classes through the classified image and table.



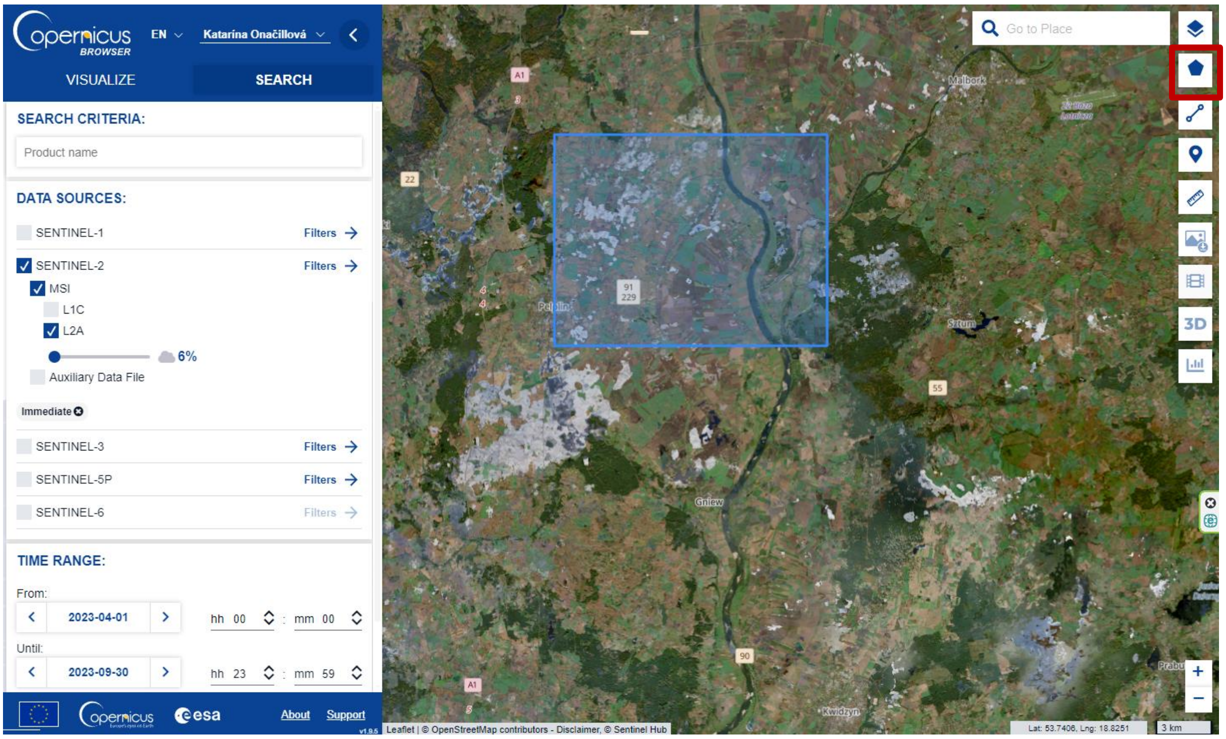
Navigation - [7] LabeledClasses | Colour Manipulation - [7] LabeledClasses

Label	Colour	Value	Frequency	Description
no data		-1	0.000%	no data
wheat		0	17.464%	
maize		1	6.689%	
rapeseed		2	0.453%	
barley		3	25.091%	
grassland		4	46.439%	
river		5	3.863%	

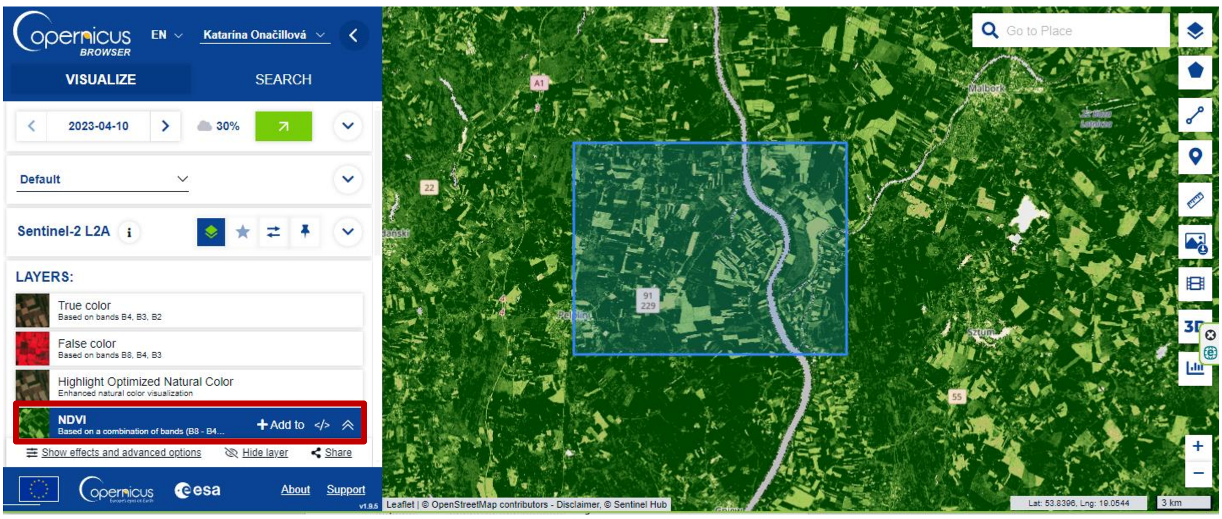
2.6 Crop types characteristics using spectral indices

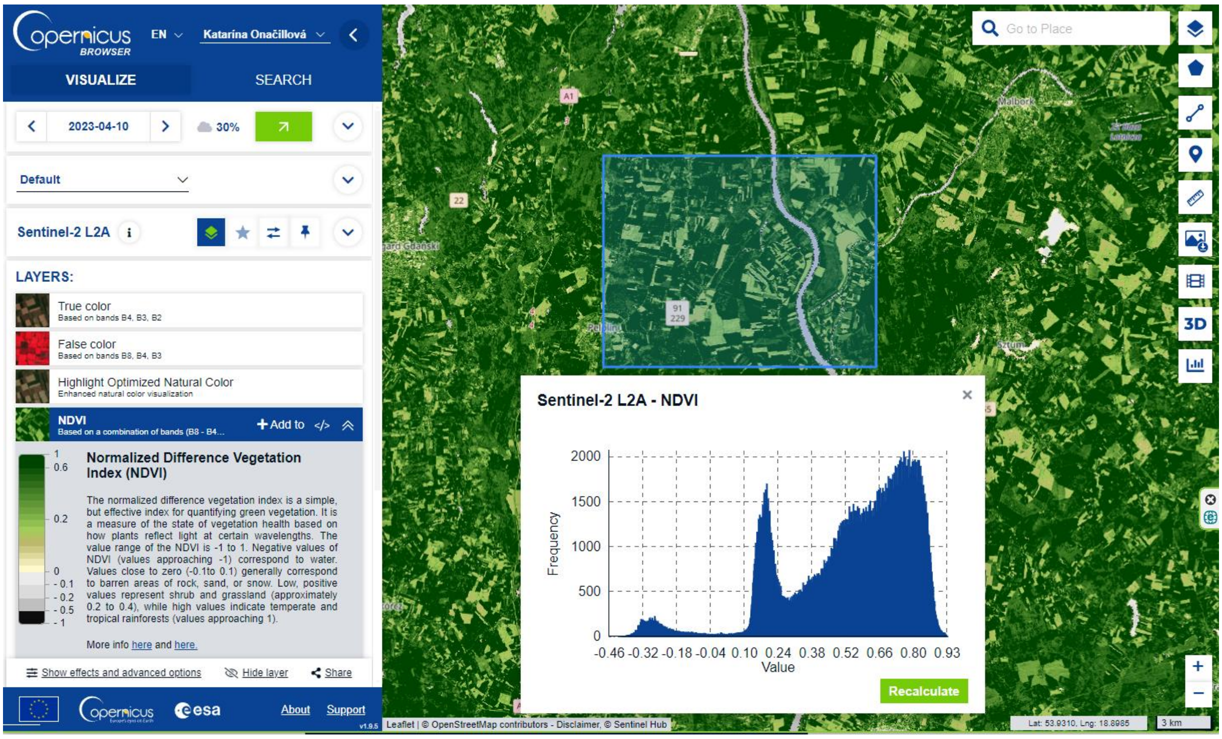
Now, let´s explore also Sentinel-2 data for the same area.

- Navigate to the Copernicus Browser website:
- https://browser.dataspace.copernicus.eu
- Create the area of interest by using rectangle.
- For the best results, search for Sentinel-2 L2A products with low cloud cover, e.g. less than 6%.
- Set the time range from 01-04-2023 to 31-09-2023 to monitor crops during the growth season. And click on Search.

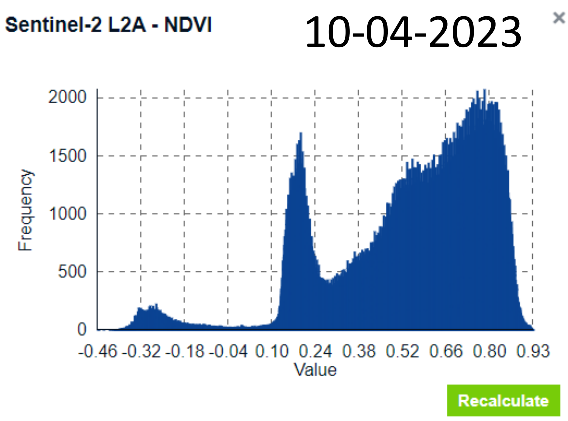


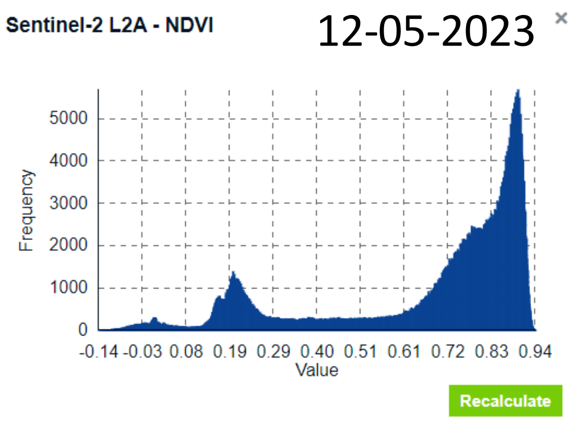
- Visualise at least one of the images – start e.g. from 10-04-2023 and select, e.g. NDVI layer.
- At the top right panel select Histogram option.
- Explore NDVI values for the selected image.

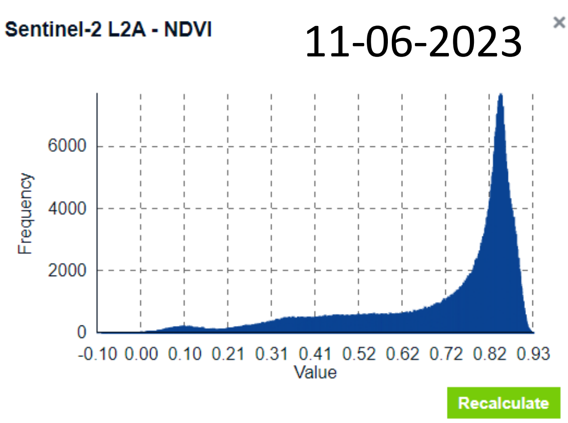


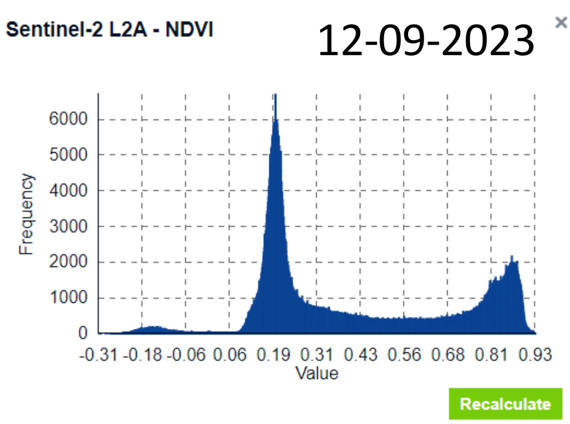


Then, move to another date, e.g. 27-05-2023 and click on „Recalculate" to refresh the histogram values for this acquisition date. Explore the NDVI values during the growth season by visualising histogram for NDVI values of several dates.









During the growth season, NDVI (Normalized Difference Vegetation Index) values typically exhibit fluctuations reflecting changes in vegetation dynamics. At the beginning of the season (April), NDVI values may be relatively low as vegetation starts to emerge and develop. As the season progresses and vegetation becomes more abundant and healthier, NDVI values tend to increase, reaching their peak during the peak of the growing season when vegetation is at its fullest and most vibrant (May). This period is characterized by high NDVI values, indicating dense and healthy vegetation rich in chlorophyll and other nutrients. After reaching the peak, NDVI values may start to decline as vegetation undergoes senescence or experiences stress due to factors such as water scarcity or disease (June-September). Monitoring NDVI values throughout the growth season provides valuable insights into vegetation health, growth patterns, and overall ecosystem dynamics.

For more information, see the lecture: 5. SAR and optical remote sensing for precision agriculture 1

THANK YOU FOR FOLLOWING THE EXERCISE!

UNIVERSITY COURSE APPLIED RADAR REMOTE SENSING

EXERCISE 6 – TUTORIAL

Crop Classification with S1 time series data using the SNAP software

FUNDED BY EUROPEAN SPACE AGENCY UNDER THE PLAN FOR EUROPEAN COOPERATING STATES, 7TH CALL FOR SLOVAKIA

1 | Exercise outline

In this exercise, we will:

- Use radar Sentinel-1 data to classify and analyse time-series for different types of crop fields
- Data pre-processing will be perfomed, an then the crop types will be estimated by classification of the data, based on the Random Forest algorithm
- Land crops growth and health will be observed using RGB composites and backscatter values of different crop types using time series

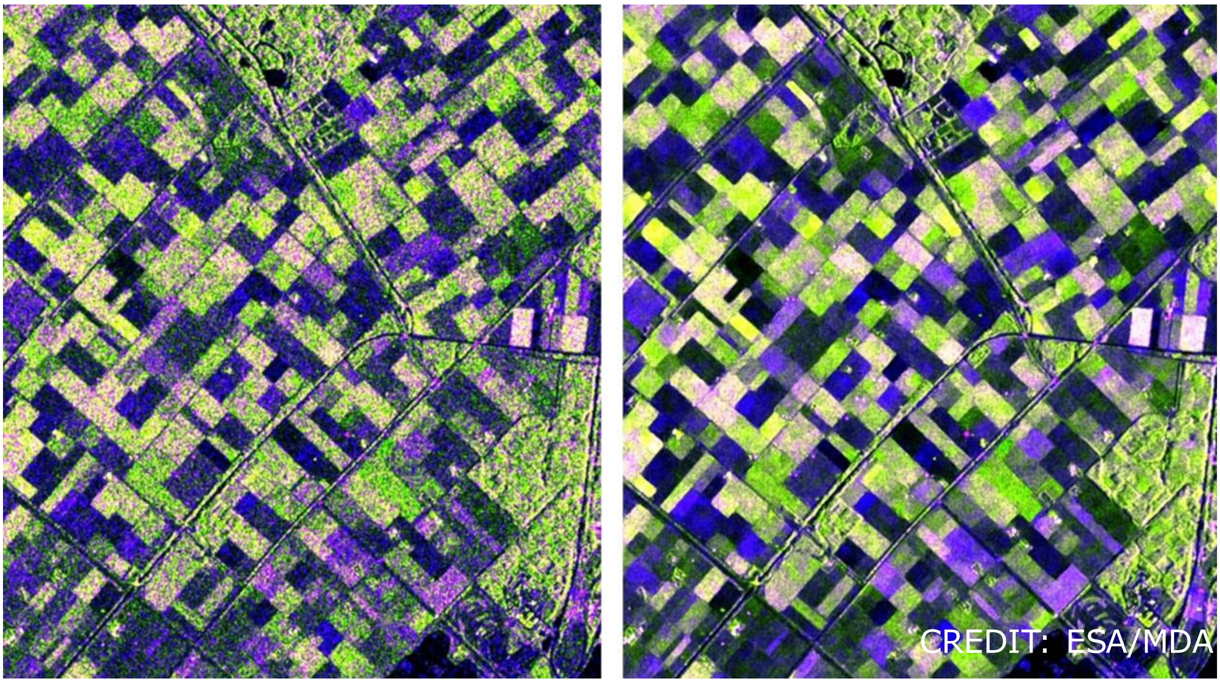
2 | Background

Crop classification using Sentinel-1 time-series

Crop classification using Sentinel-1 data involves the analysis of radar backscatter signals to differentiate between different types of crops based on their unique radar signatures.

Sentinel-1 data, with its frequent revisit times and all-weather capability, is particularly useful for crop classification as it provides consistent and reliable information regardless of weather conditions.

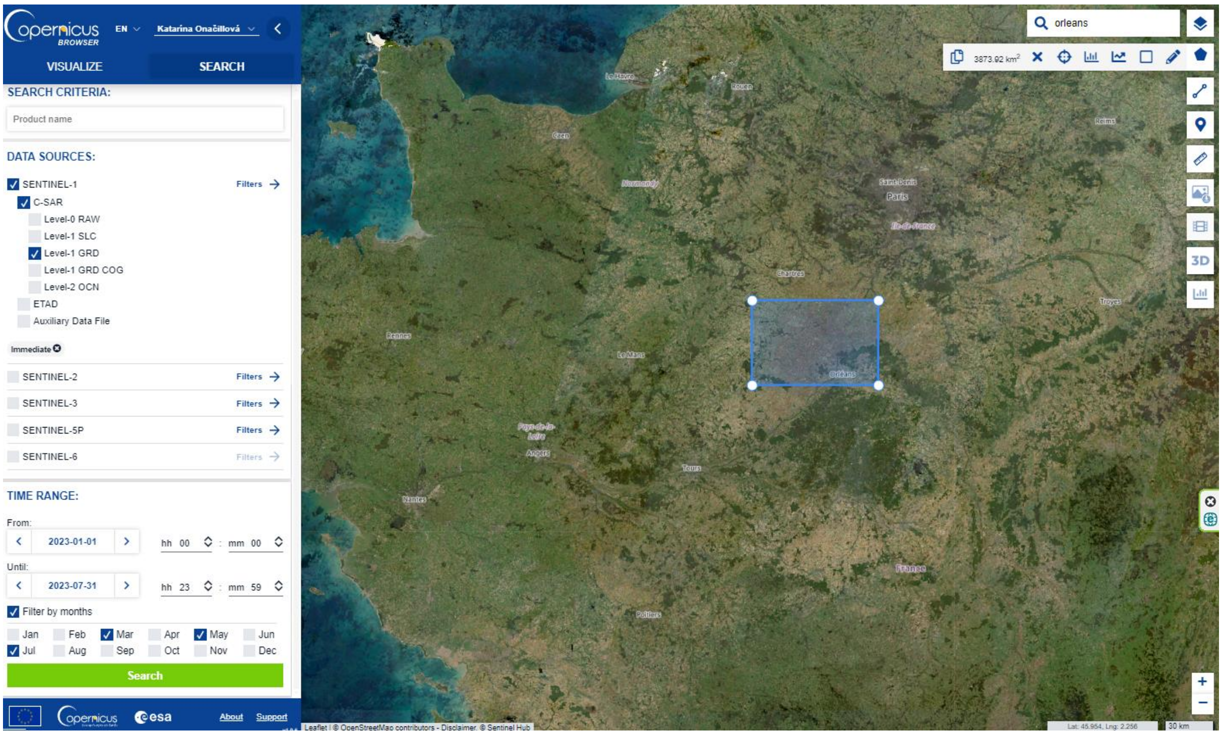
Crop classification using Sentinel-1 data relies on the radar backscatter signals obtained from the satellite. The backscatter intensity, polarization, and texture of the radar imagery are analyzed to distinguish between different crop types.



These images show the same multi-temporal radar composite acquired over the Flevoland test site in the Netherlands. The grainy appearance of the left image is characteristic of radar images and often a limiting factor in using them at high resolution. The right image demonstrates how a new mathematical technique based on multiple images, which was improved in the campaign, can dramatically enhance the appearance of the image and data quality.

2.1 Study area and data used

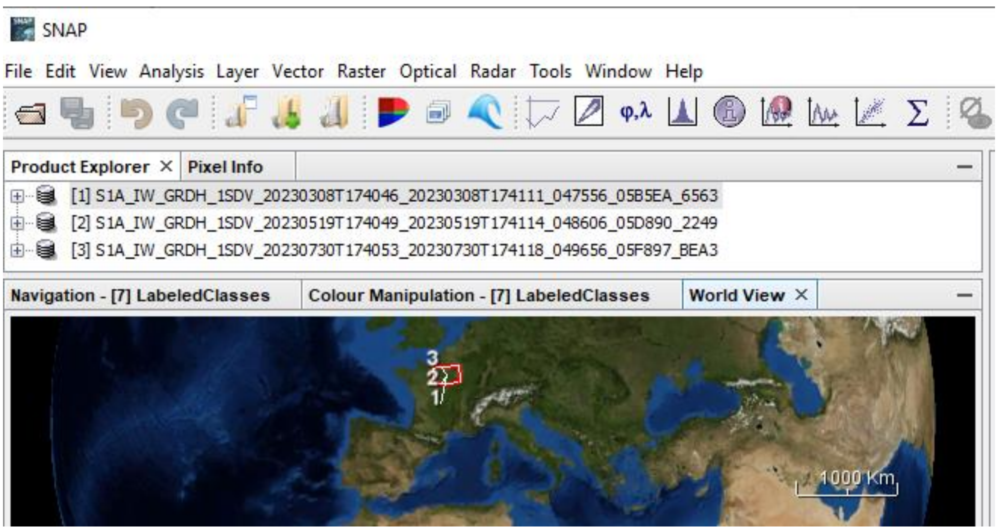
For this exercise, we will use three Sentinel-1 images to explore fields in Orleans, France, downloaded for year 2023 from the Dataspace Copernicus Open Access Hub [@https://dataspace.copernicus.eu/].



2.2. SNAP - Open and explore products

Open SNAP Desktop, click Open Product and open three Sentinel-1 GRDH downloaded products with HH and HV polarizations acquired on 11 July 2023 by double click on the zipped folders. The opened products will appear in Product Explorer window:

S1A_IW_GRDH_1SDV_20230308T174046_20230308T174111_047556_05B5EA_6563.SAFE
S1A_IW_GRDH_1SDV_20230519T174049_20230519T174114_048606_05D890_2249.SAFE
S1A_IW_GRDH_1SDV_20230730T174053_20230730T174118_049656_05F897_BEA3.SAFE



3. Pre-processing

3.1 Create subsets

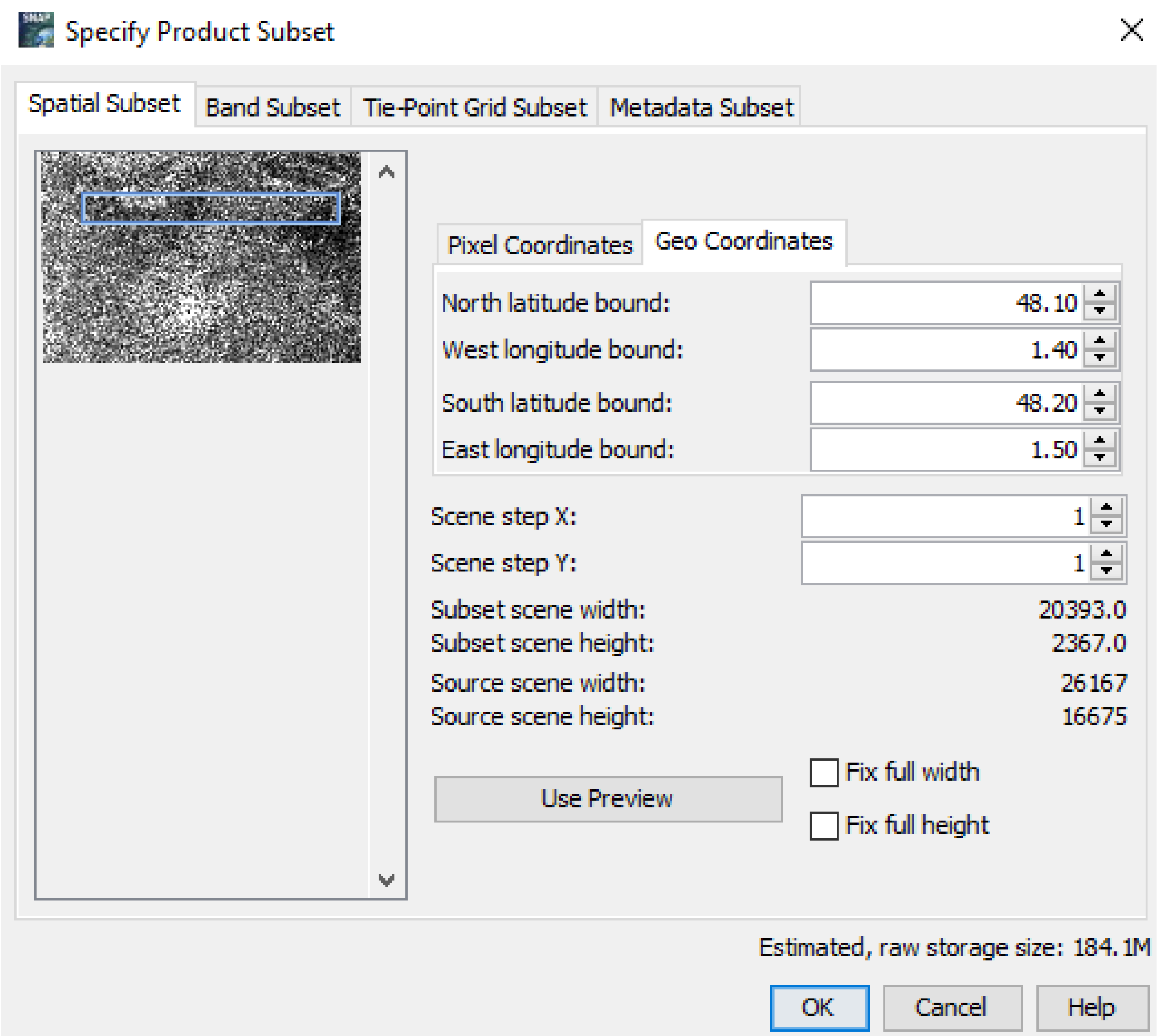
There is no need to process the whole image, instead, we can begin by narrowing down the scene to a more manageable size – creating subset. This approach will decrease processing time in subsequent stages, especially when the analysis is concentrated on a specific area rather than the entire scene.

Go to the Subset tab and at "Geo Coordinates" set:

North latitude bound: 48.10
West longitude bound: 1.40
South latitude bound : 48.20
East longitude bound : 1.50

Note: There is no need to wait till thumbnail image will be created when entering coordinates.

Save the output subsets to your folder – we will need them for the next step.



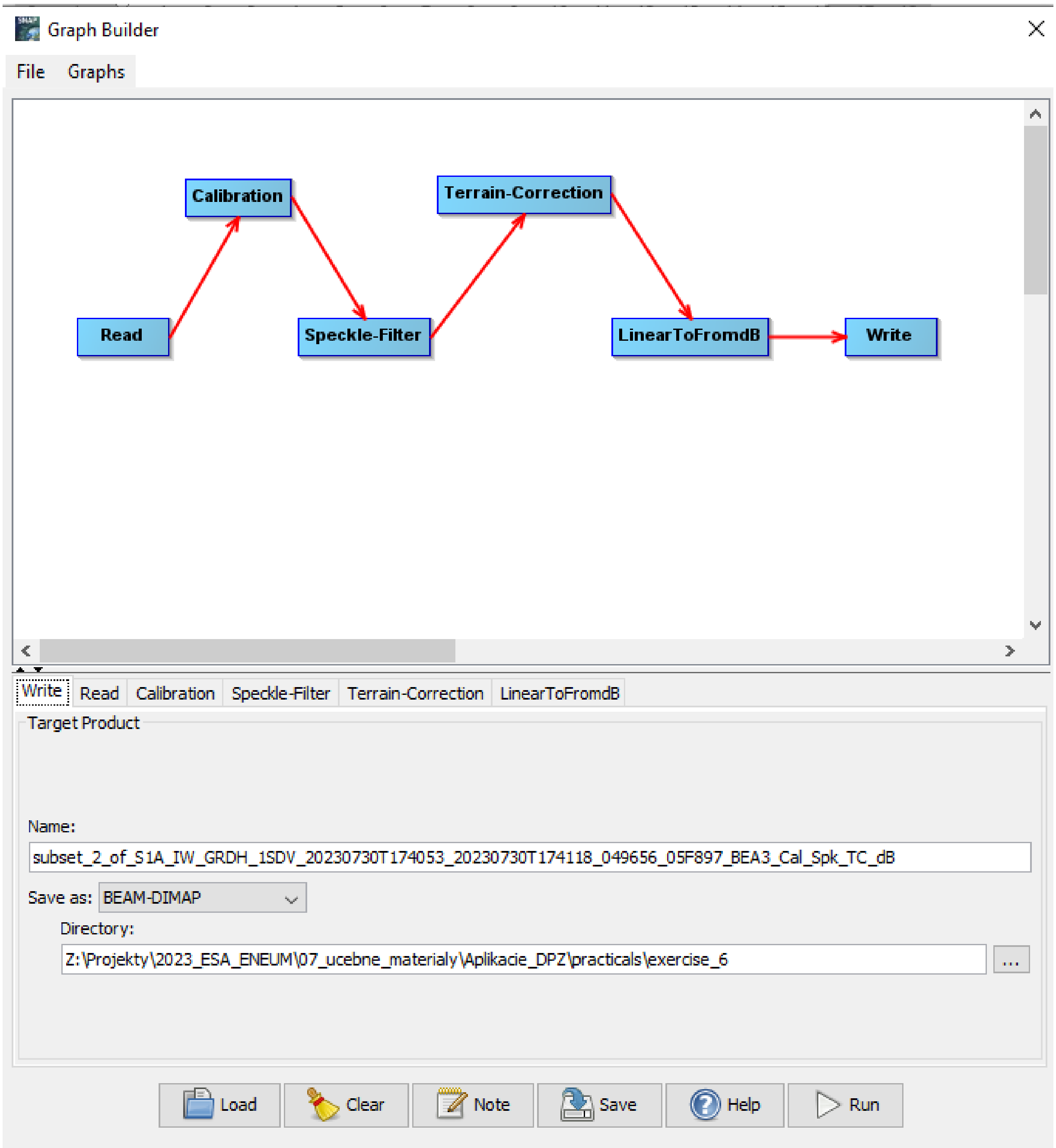
3.2 Build a pre-processing graph

Use the graph builder tool to create workflow for data processing:

Go to Tools > GraphBuilder
Right click and add, in the order below, each of the preprocessing steps:

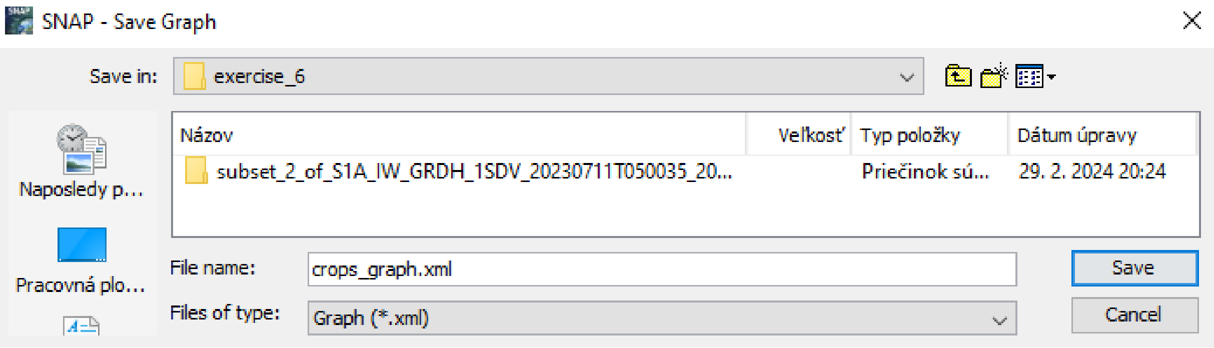
- The first tool is Read
- Add>Radar>Radiometric>Calibration
- Add>Radar>Speckle Filtering>Speckle-Filter
- Add>Radar>Geometric>Terrain Correction>Terrain Correction
- Add>Raster>Data Conversion>LinearToFromdB
- The last tool is Write

Click on each tool, and connect them by dragging the red arrows from one tool to the next, respecting the order above.



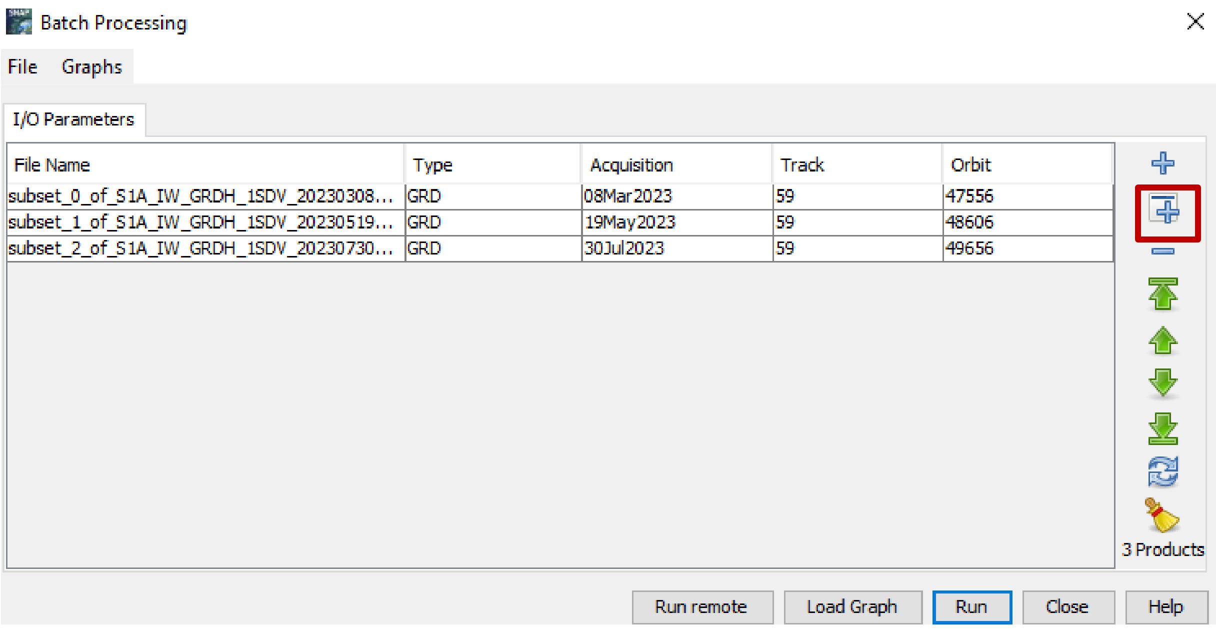
Leave the default parameters for individual tools, except Speckle-Filter:
- here, select Filter: Lee

Then got to File>Save Graph to save the workflow as a XML file „crops_graph".

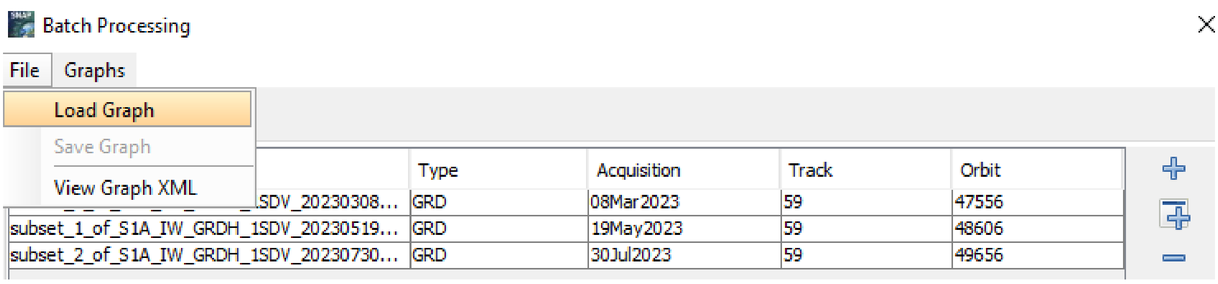


Batch processing

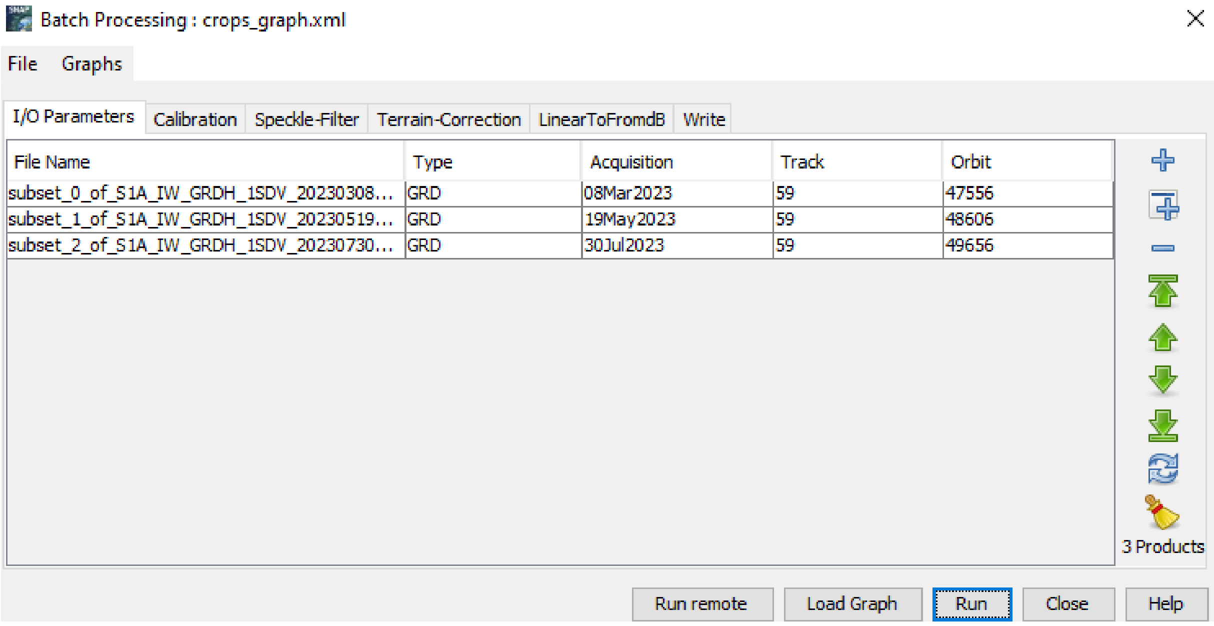
Navigate to Tools > Batch Processing:
Using the Add opened symbol select the files you want to process.



Using the Load Graph button, load the .xml-file you just saved

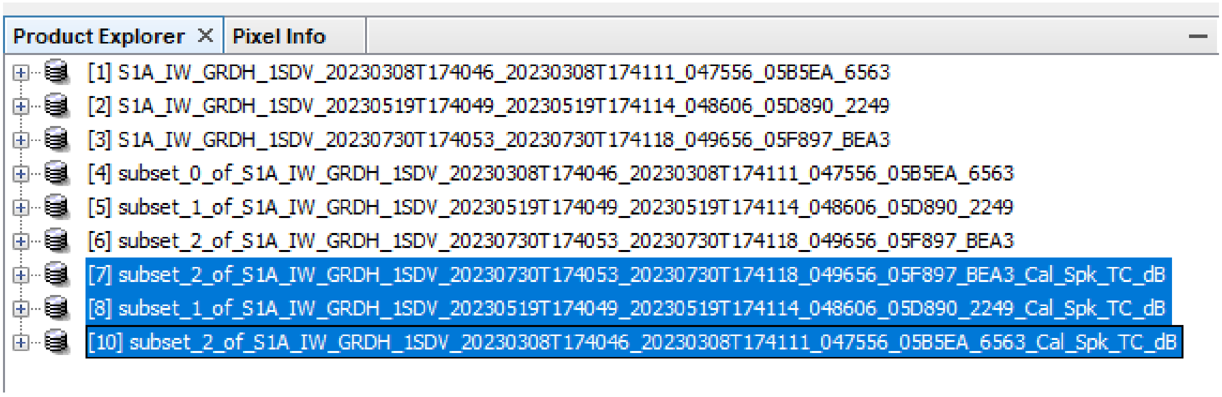


Adjust the output folder, click Run.



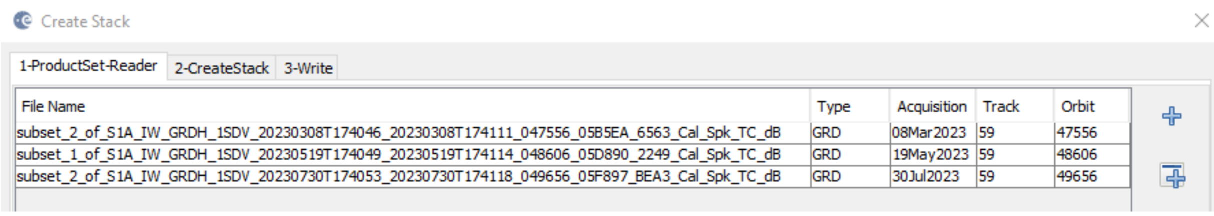
Note: this step might take several minutes to run.

When the process finishes it opens all of the output products in the Product Explorer window.

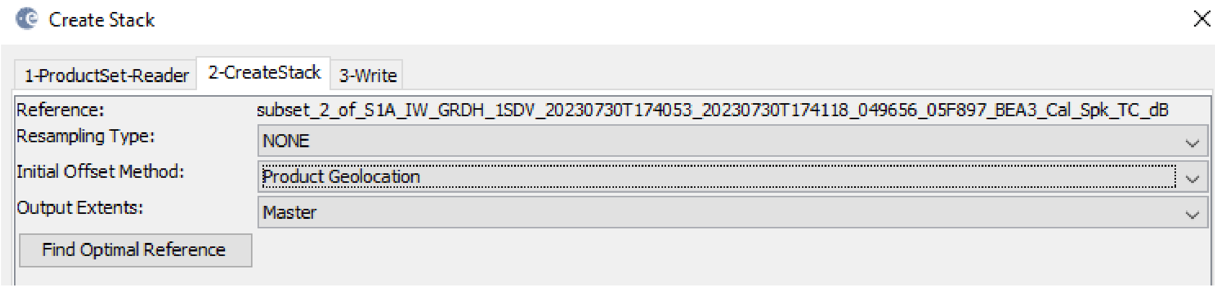


Create stack

Go to Radar > Coregistration > Stack Tools > Create Stack
In the Product-Set-Reader tab select the last three products from the previous step.



In the CreateStack tab, select Product Geolocation as Initial Offset Method (Note: we did not use apply orbit file function, but the product geolocation is accurate enough for the purpose of our analysis)



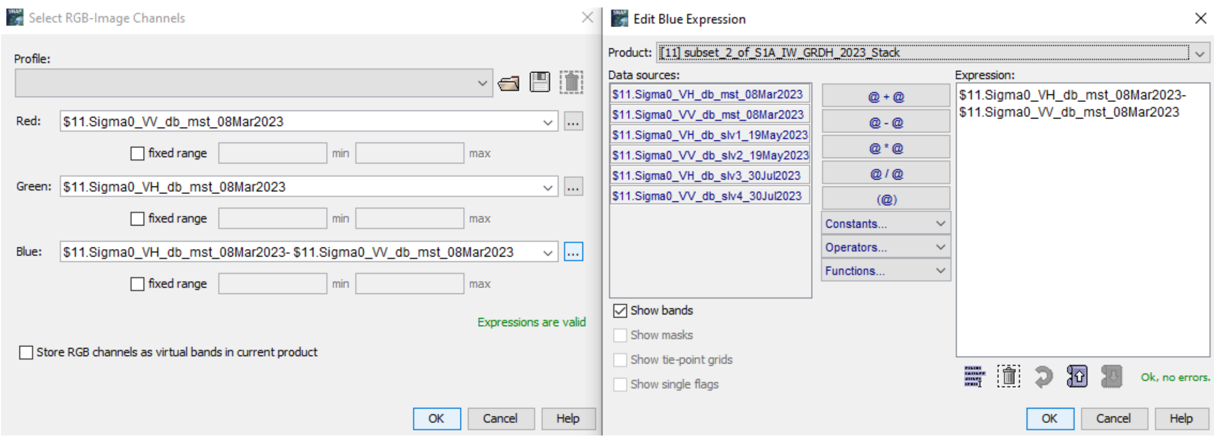
In the Write tab, adjust the stack name if needed, adjust the output folder and click Run. This step will might take few minutes.

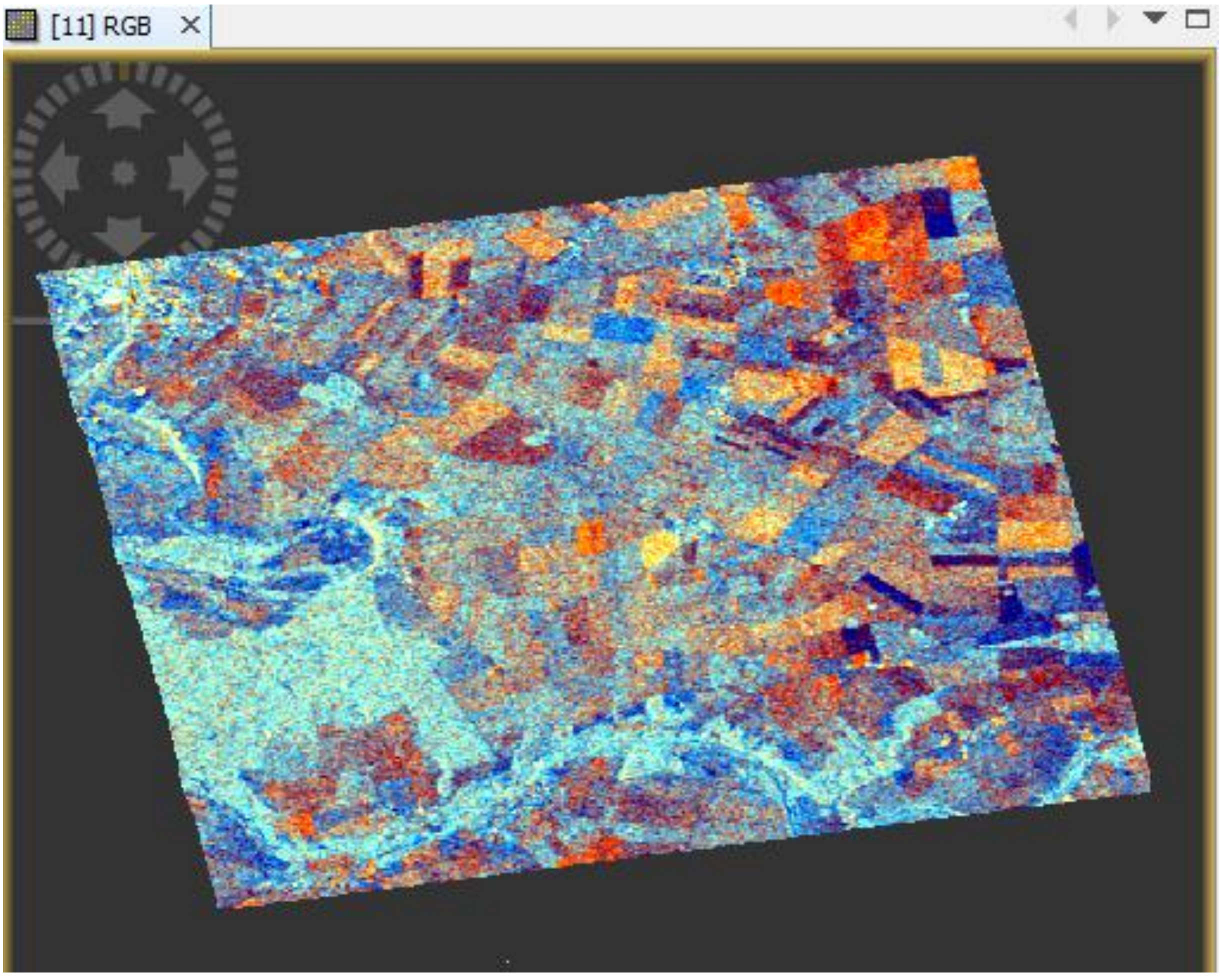
After the process is finished, we can see the new final „Stack" product in the Product Explorer window.

Display RGB time series

Now we can look at some RGB composites of this time series
Right-click on the last „Stack" product – Open RGB Image Window and select different band combinations to see the change of backscatter between one-day acquisition.

Firstly, we can look at polarimetric composite of the same day. For this, select:
Red: Sigma0_VV_db_mst_08Mar2023
Green: Sigma0_VH_db_mst_08Mar2023
Blue: Sigma0_VH_db_mst_08Mar2023-Sigma0_VV_db_mst_08Mar2023





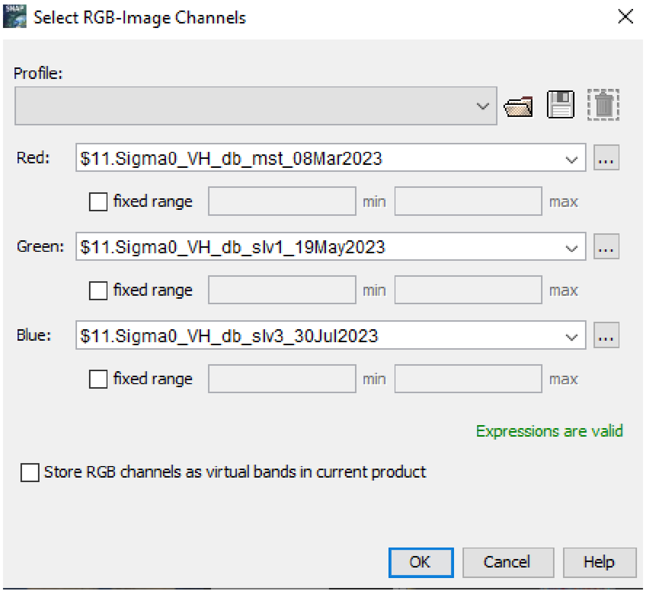
Another RGB composition we can generate is to look at images of the same polarisation but for different dates:

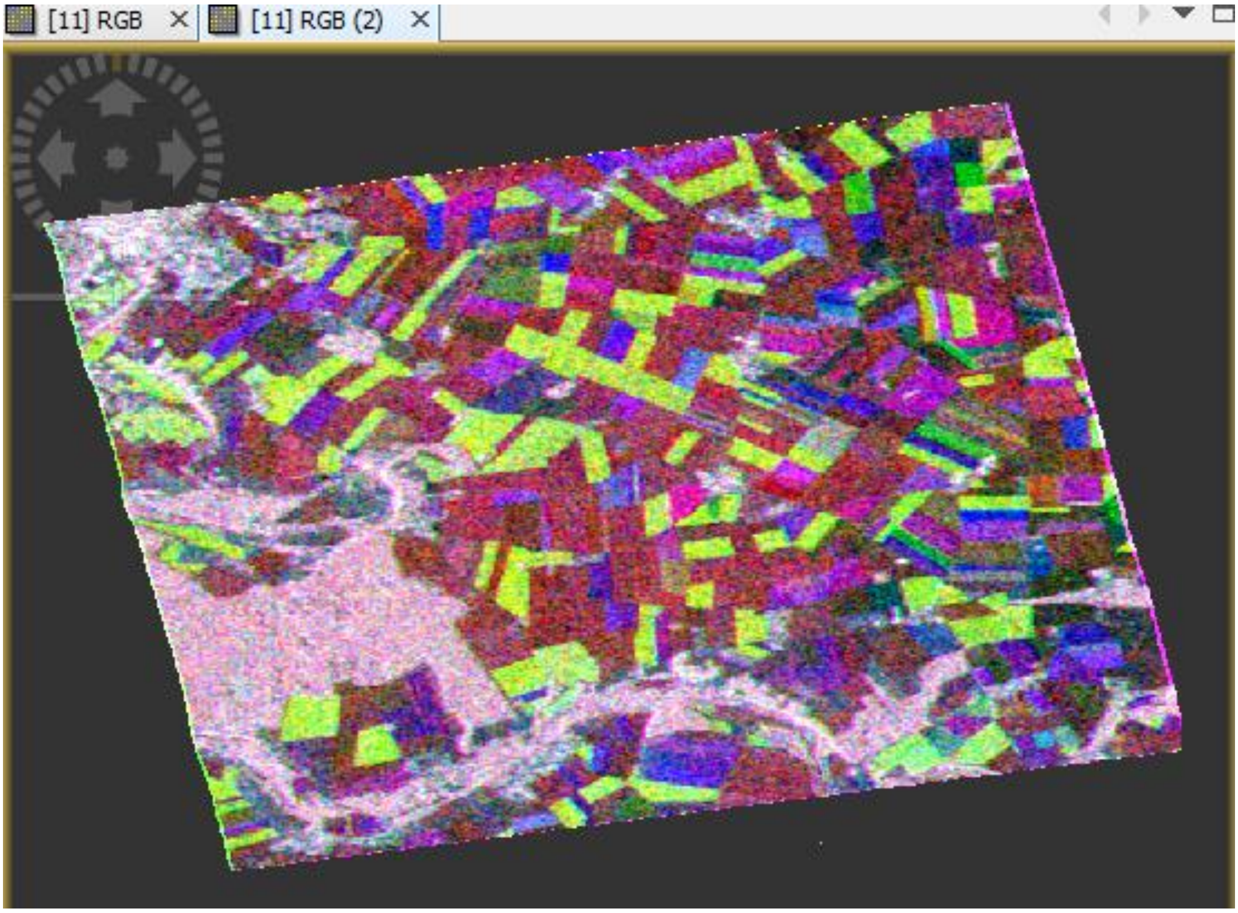
Right-click on the last „Stack" product – Open RGB Image Window and select different band combinations to see the change of backscatter for different acquisitions. For this, select:

Red: Sigma0_VH_db_mst_08Mar2023

Green: Sigma0_VH_db_slv_18May2023

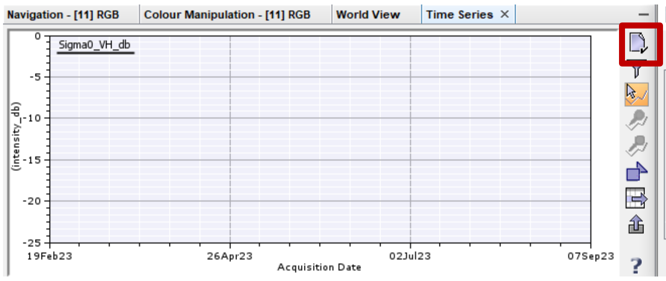
Blue: Sigma0_VH_db_slv_30Jul2023

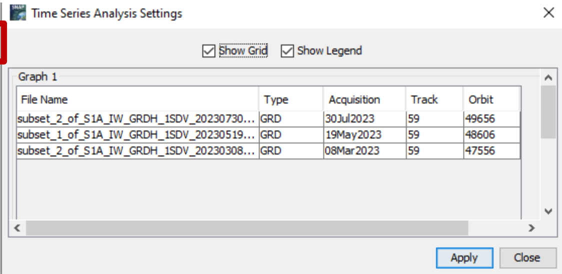




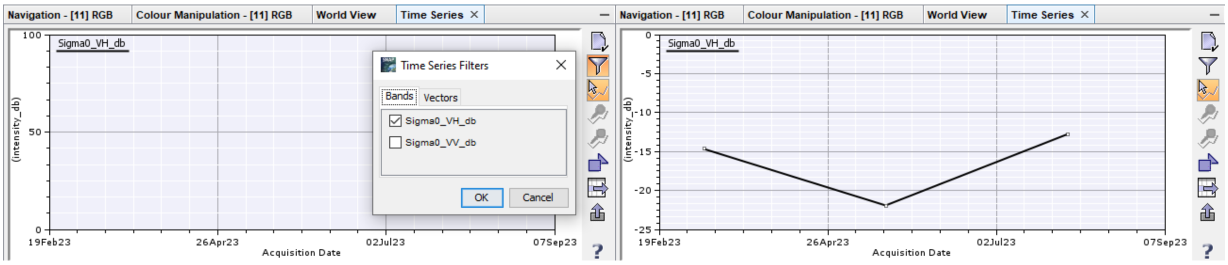
Time Series Analysis (using single scenes, not a stack)
Tool cannot use a stack, it needs single images instead

Navigate to View > Tool Windows > Radar > Time Series to open the Time Series tab at the bottom left of your SNAP window.
Click on Settings (top right of Time Series tab) and add individual (pre-processed) images. Click Apply.

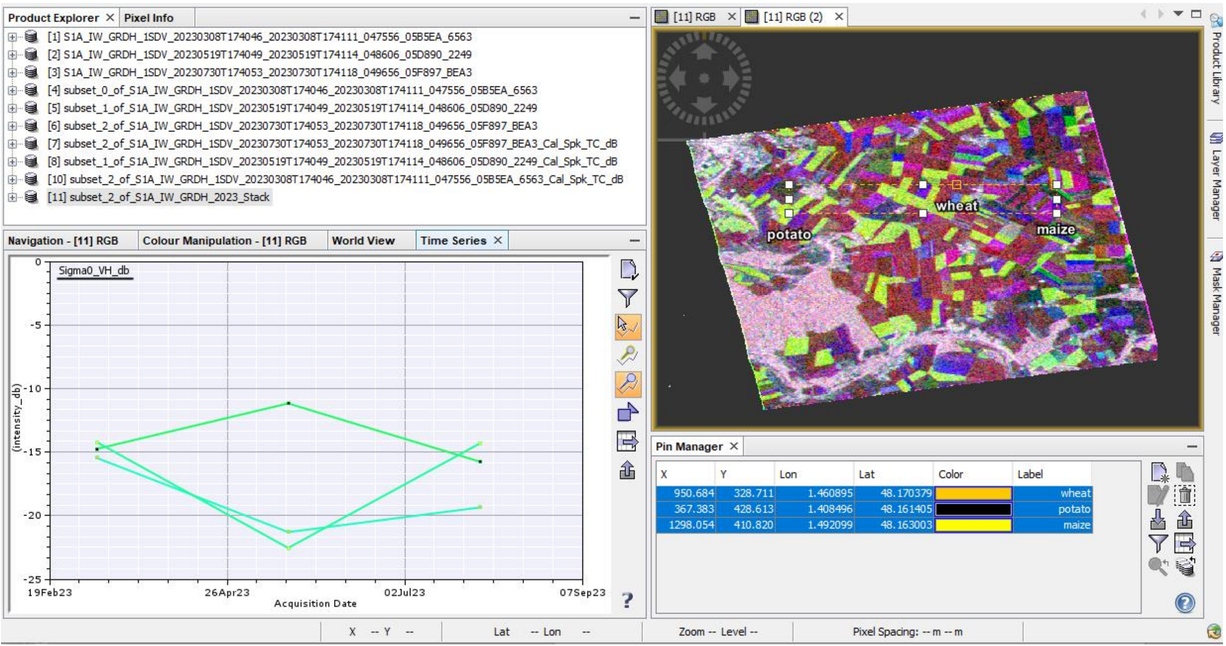




Select also polarisation for which you want to explore time-series and click OK.



Using the time series tab, hover your mouse over the area to see the behaviour of single pixels over or use Pin Manager (View-Tool Windows-Pin Manager) to see the behaviour of the selected Pins.



Explore backscatter values of different crop types within the time range.

For more information, see the lecture: [6. SAR and optical remote sensing for precision agriculture 2]

THANK YOU FOR FOLLOWING THE EXERCISE!

EXERCISE 7 – TUTORIAL

Wildfire Mapping with Sentinel-1 & Sentinel-2 using the SNAP software

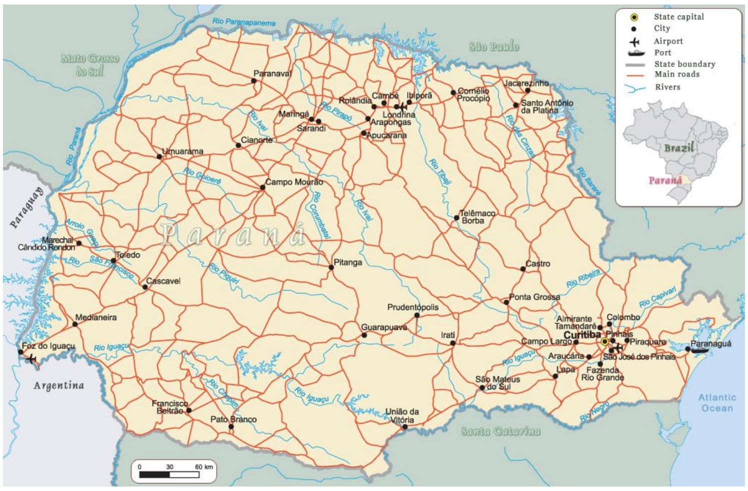
esa
ÚSTAV GEOGRAFIE
Prírodovedecká fakulta UPJŠ v Košiciach
UNIVERZITA PAVLA JOZEFA ŠAFÁRIKA V KOŠICIACH
FUNDED BY EUROPEAN SPACE AGENCY UNDER THE PLAN FOR EUROPEAN COOPERATING STATES, 7TH CALL FOR SLOVAKIA

1 | Exercise outline

In this exercise, we will:

- Detect wildfires on Sentinel-1 and Sentinel-2 images
- Export subset as image to perform another analysis in QGIS
- Map burned areas and quantify burn severity using Normalised Burn Ratio index
- Develop a graph for automated processing using Batch processing
- Create Stack and RGB composites for two Sentinel-1 temporal datasets to observe wildfire burn scars

2 | Background



Fires in the grasslands close to a vital South American river delta present serious threats to both nearby wetland ecosystems and human well-being, caution environmental experts.

The wildfires around the important riverside port of Rosario, essential for transporting Argentina's extensive grain harvest, have raised concerns among local residents and activists.

Fires in the grasslands close to a vital South American river delta present serious threats to both nearby wetland ecosystems and human well-being, caution environmental experts. The wildfires around the important riverside port of Rosario, essential for transporting Argentina's extensive grain harvest, have raised concerns among local residents and activists.

The Parana River, South America's second-longest river after the Amazon, experienced its lowest water levels since 1944 in 2021 as reported by official data. This decline is attributed to multiple cycles of drought and reduced rainfall in upstream Brazil. In August 2022, the water level remained exceptionally low. The wildfires, many intentionally set by farmers preparing the land for new crops, generated a thick haze that reached Buenos Aires, located approximately 190 miles (300 km) south of Rosario. Residents were displeased with the presence of soot in the air, leading popular weather apps to issue forecasts simply describing the conditions as "smoke."

Wildfires burning in the wetlands of the Paraná River Delta, Argentina, 19 August, 2022

2.1 Study area and data used

For this exercise, we will use two Sentinel-2 images and two Sentinel-1 GRDH images of the same area in Paraná River Delta, Argentina, using the Tile Number *20HQJ* downloaded for two days of summer 2022 (before and after the wildfires) from the Dataspace Copernicus Open Access Hub [@https://dataspace.copernicus.eu/].

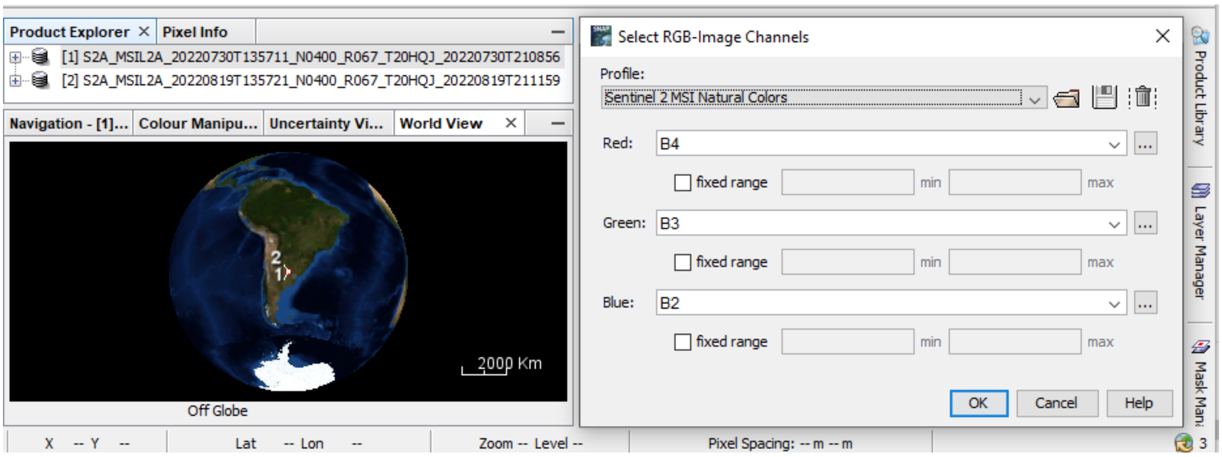
2.2. SNAP - Open and explore product

Open SNAP Desktop, click Open Product and open 2 downloaded products (unzipped) by double click on the metadata „MTD_MSIL2A.xml" inside the folder. The opened products will appear in Product Explorer window.

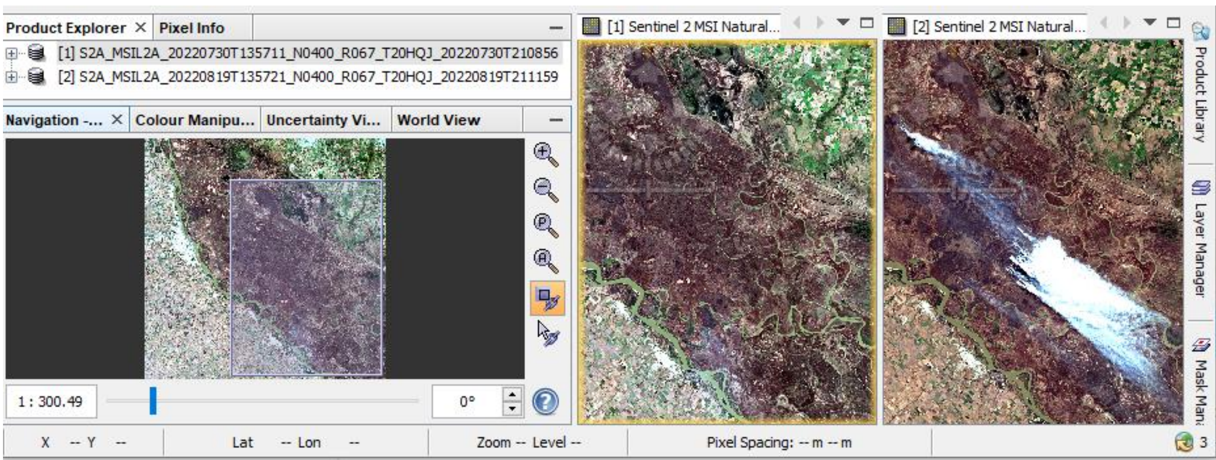
S2A_MSIL2A_20220730T135711_N0400_R067_T20HQJ_20220730T210856.SAFE.zip
S2A_MSIL2A_20220819T135721_N0400_R067_T20HQJ_20220819T211159.SAFE.zip

A: Detecting wildfires on Sentinel-2 image

1. Select the first product in the Product Explorer window.
2. Right click on the product.
3. Open RGB Image Window.
4. In the pop-up window select 'Sentinel 2 MSI Natural colors (Red: B4; Green: B3; Blue: B2)'.

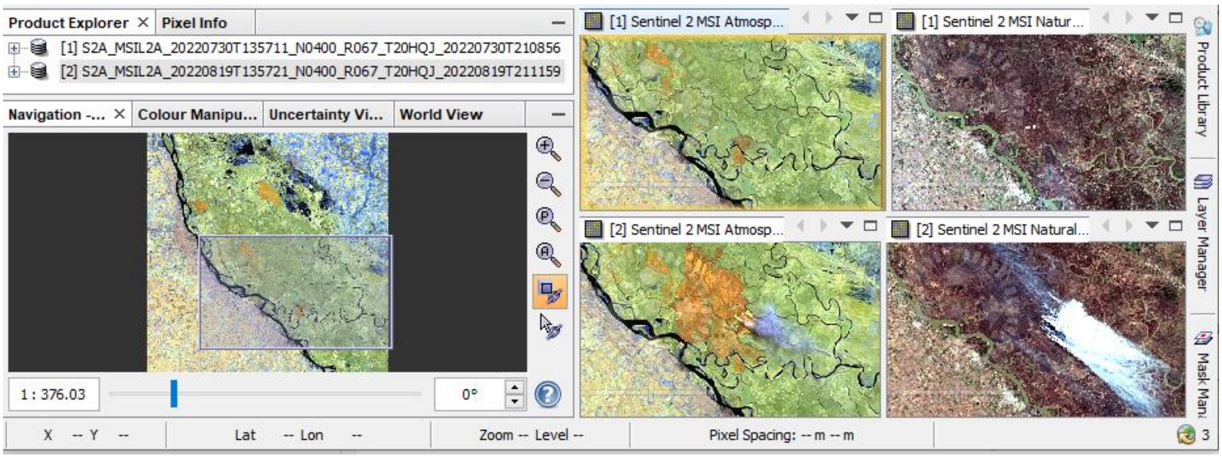


5. Repeat the process for the second product.
6. Tile two opened RGB Windows, e.g. horizontally
7. In the Navigation window, zoom in to the wildfire region and syhnchronise views to see the same area before and after wildfires



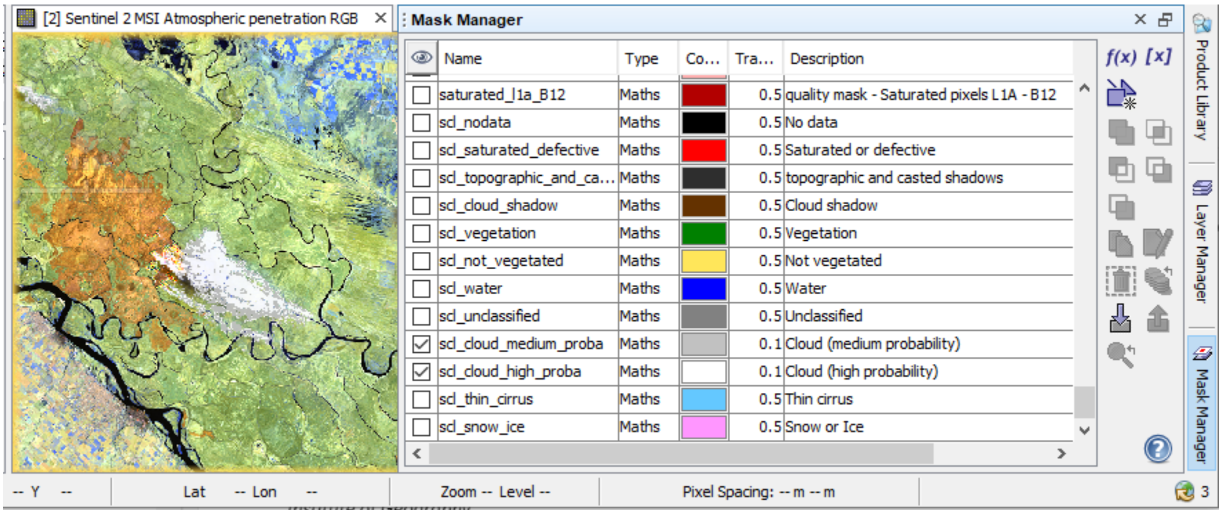
Do the same process for obtaining the color composition in false colors:

1. Select the first product in the Product Explorer window.
2. Right click on the product.
3. Open RGB Image Window.
4. In the pop-up window select 'Sentinel 2 MSI Atmospheric penetration (Red: B12; Green: B11; Blue: B8A)'.
5. Apply color manipulation (stretching) for RGB
6. Repeat the process for the second product.
7. Tile opened RGB Windows, e.g. evenly
8. If necessary, in the Navigation window, zoom in again to the wildfire region and syhnchronise views to see area before and after wildfires



Now let's detect the smoke plume:

1. Keep only the Sentinel 2 MSI Atmospheric penetration composition with visible smoke plume from 19 August open
2. Go to Mask Manager, and scroll down to the Maths masks
3. Select: "scl_cloud_medium_prob" and "scl_cloud_high_proba"
4. To visualize the masked areas better, lower the transparency(e.g. 0.1)

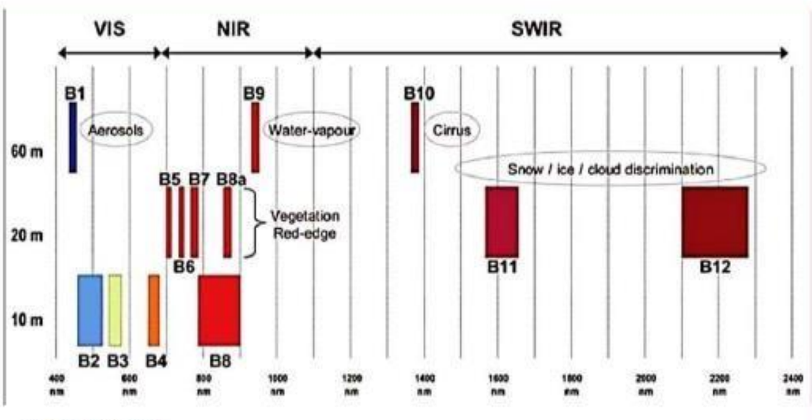


Fire + cloud plume map

Let’s export this View as an image and safe as a GeoTIFF:

Because of multiple S2 spatial sizes, we first have to resample the data. Resample to highest spatial resolution: 10 m (e.g. B2).

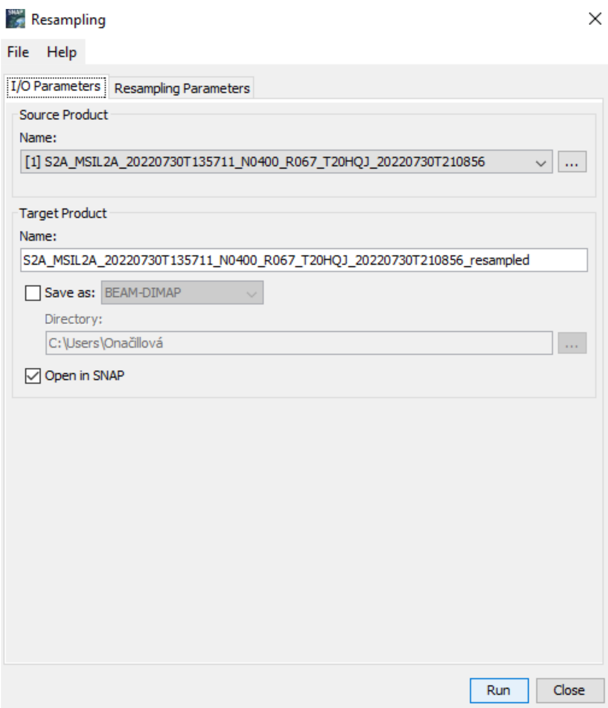
NOTE 1: The input product contains 13 spectral bands in 3 different spatial resolutions (The surface area measured on the ground and represented by an individual pixel). When we open the RGB view all our input bands have 20 m resolution, however, the view is displayed in the full 10 m resolution.

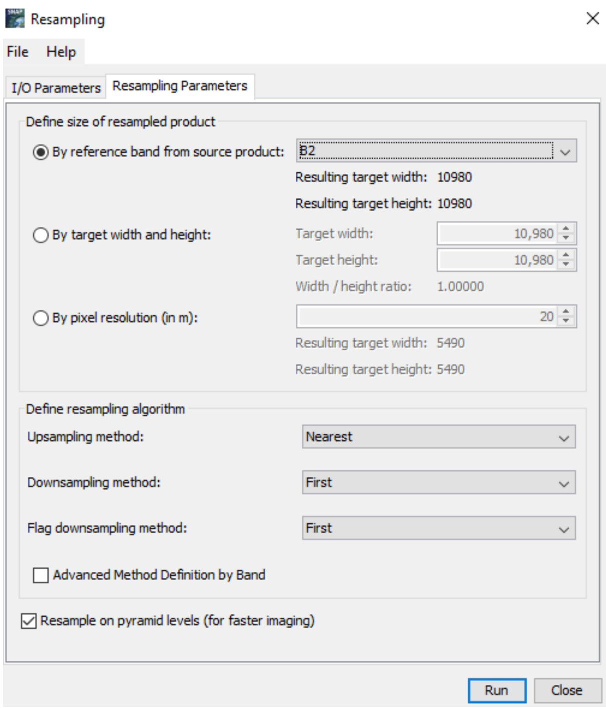


Credits: ESA 2015

Raster->Geometric->Resampling:

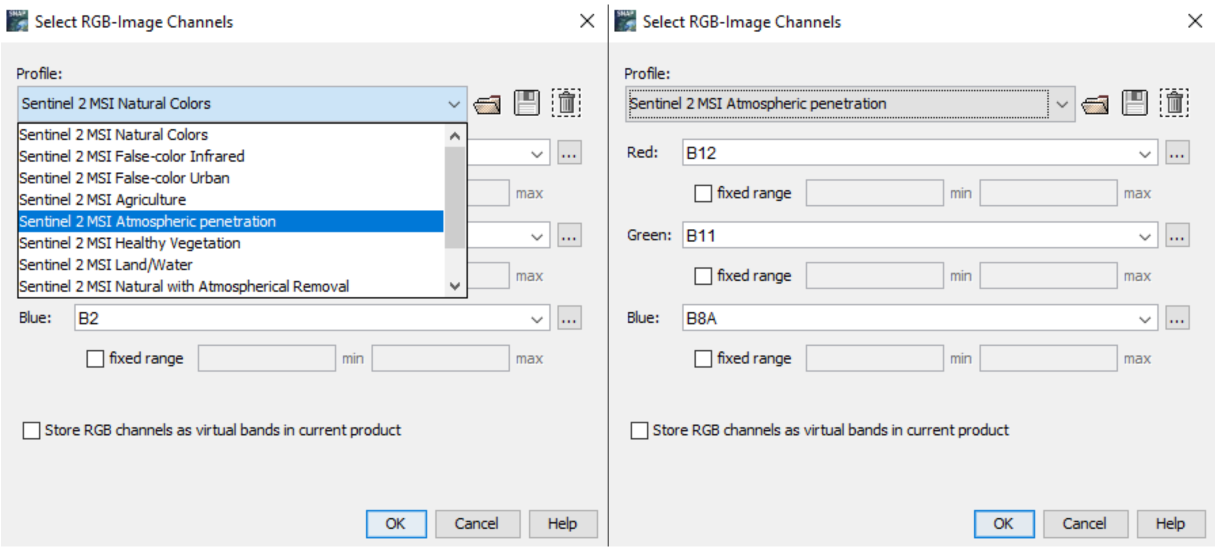
- Keep I/O names
- In Resampling Parameters, select B2 (10 m)



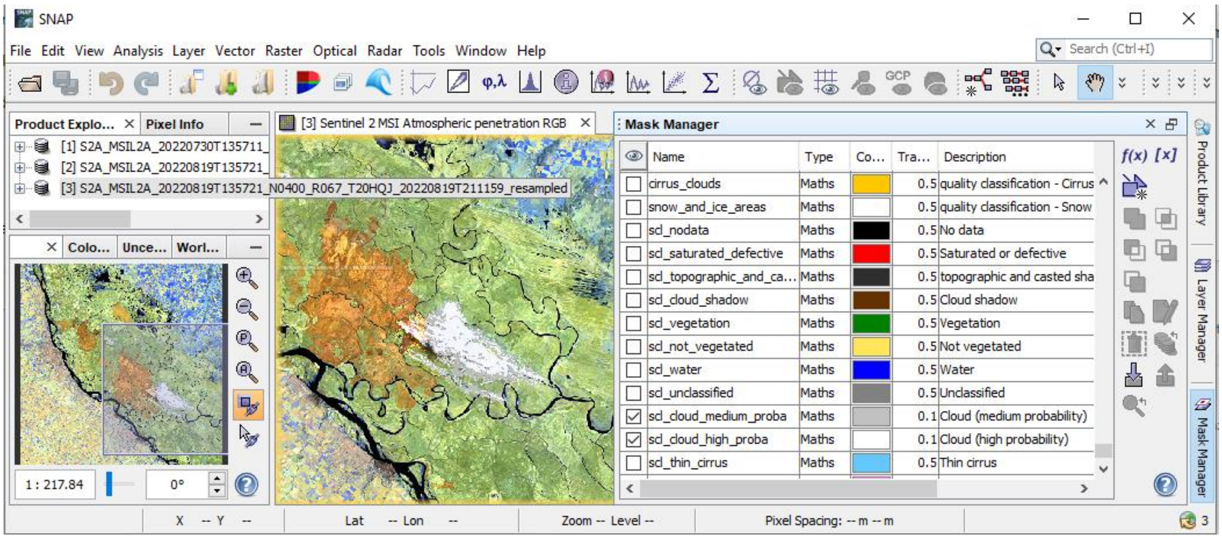


Let’s create a subset based on the current view

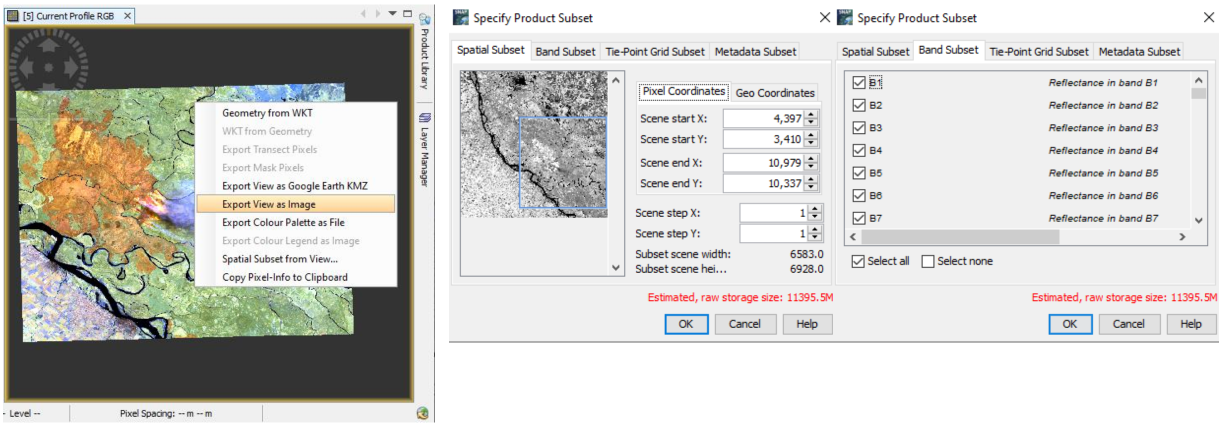
- Display the image. Note that now many more color options are available. Select MSI Atmospheric penetration



- Make a zoom and add the cloud masks again

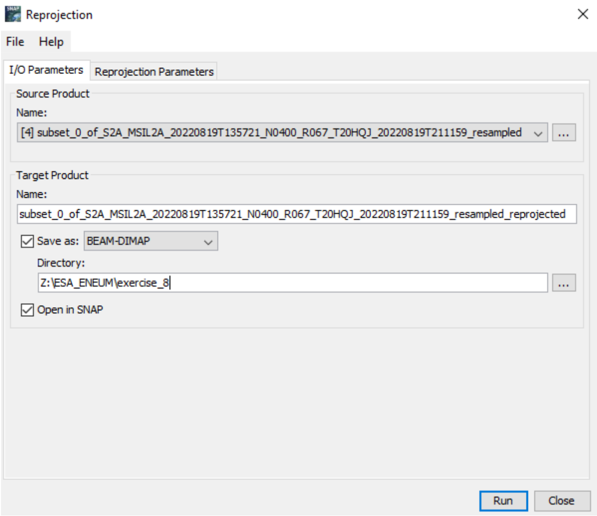


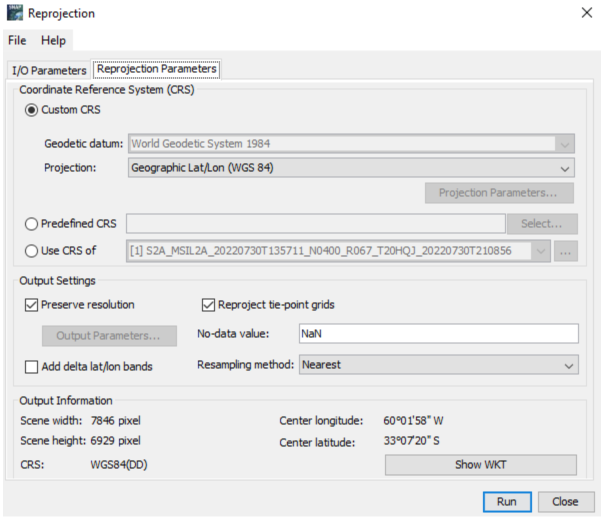
- Right-mouse button -> Spatial Subset from View – in the Band Subset you can select all or only few bands to be exported



Let’s reproject the image in Latitude & Longitude coordinates

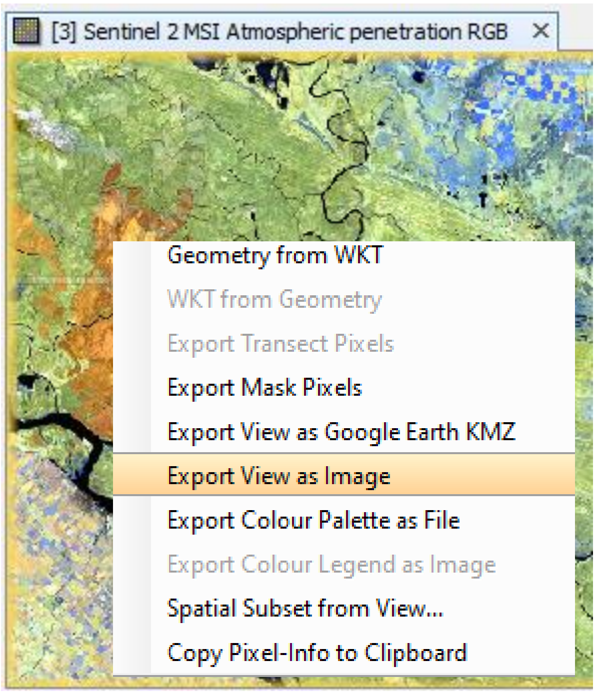
- Raster->Geometric Operations->Reprojection
- Select the default: Geographic Lat/lon (WGS 84)
- Run (writing might take some time)

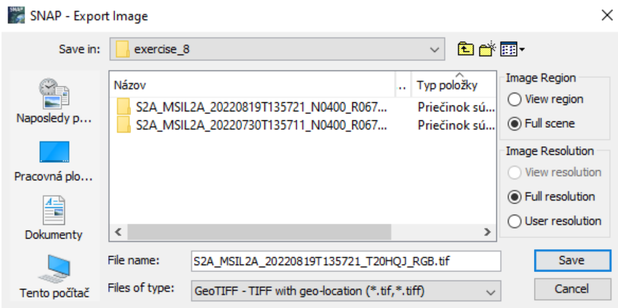




Now we can export View as GeoTiff

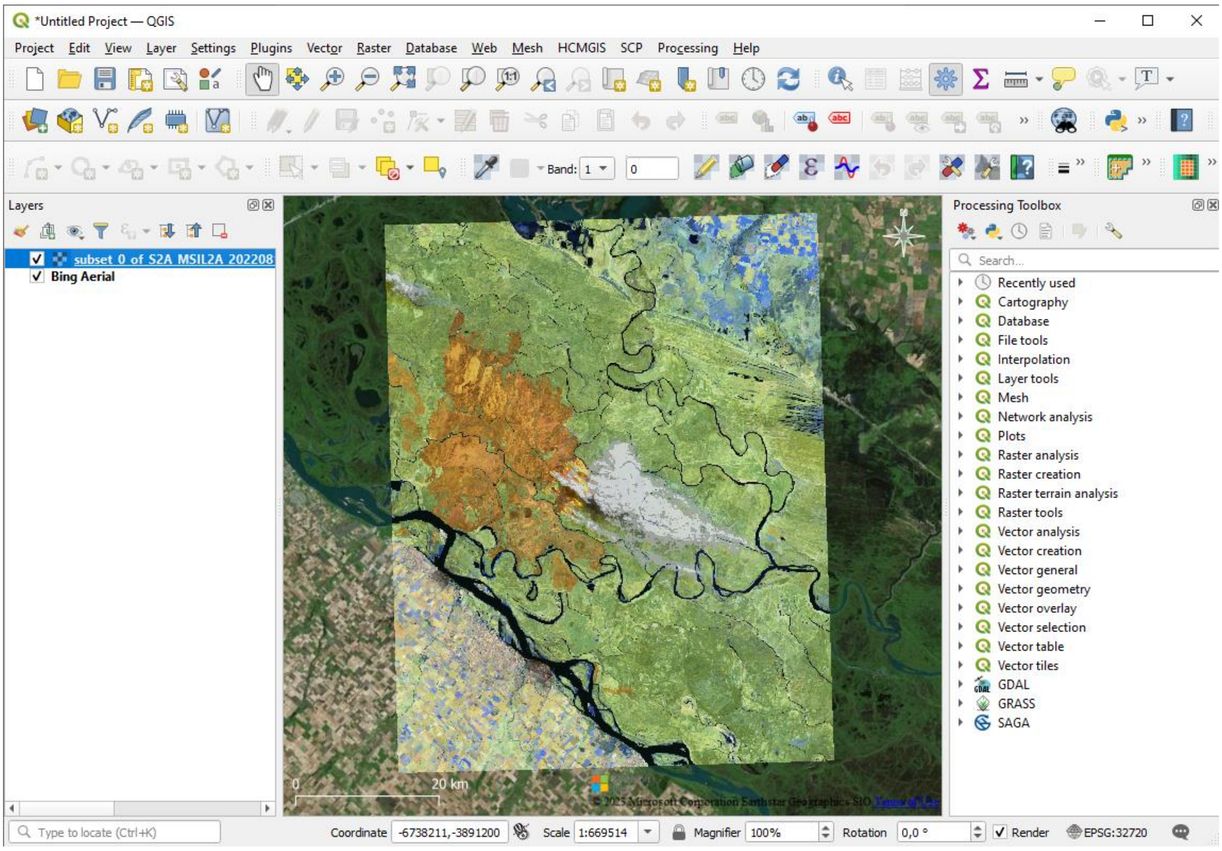
- Right mouse button: Export View as Image
- Select: Full scene, Full resolution, GeoTIFF





Now we open the output image in QGIS

- We can overlay it to e.g. Google Satellite or Bing aerial image:
- Web->OpenLayers plugin->Google Maps->Google Satellite
- Move the Subset above the satellite
- Play with Transparency: Properties->Transparency (e.g. 80%)

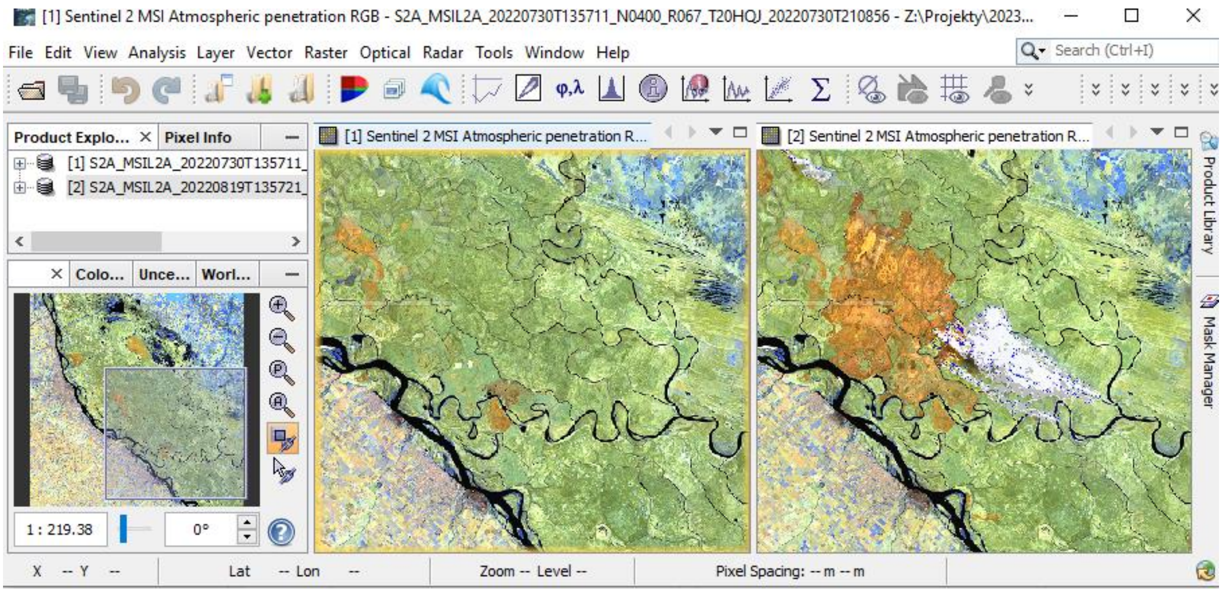


B: Burned area mapping with Sentinel-2

How to quantify the impact of the Paraná wildfire?

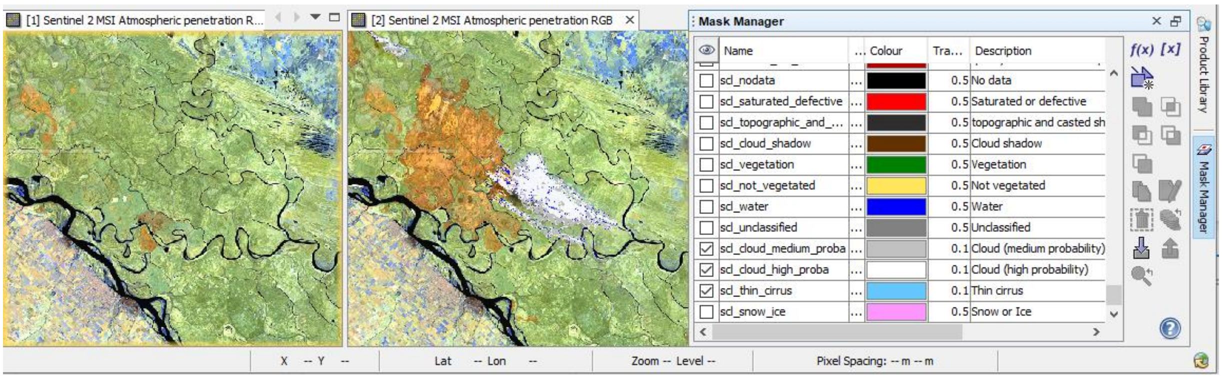
Let's have look to the before & after images:

- Open RGB Image Window:
- Select: MSI Atmospheric penetration
- Window-> Tile horizontally, zoom in



Let's create a cloud mask:

- Go to Mask Manager, and scroll down to the Maths masks
- Select: cloud medium & cloud high probability & Thin cirrus
- To visualize them better, lower the transparency (e.g. 0.1)

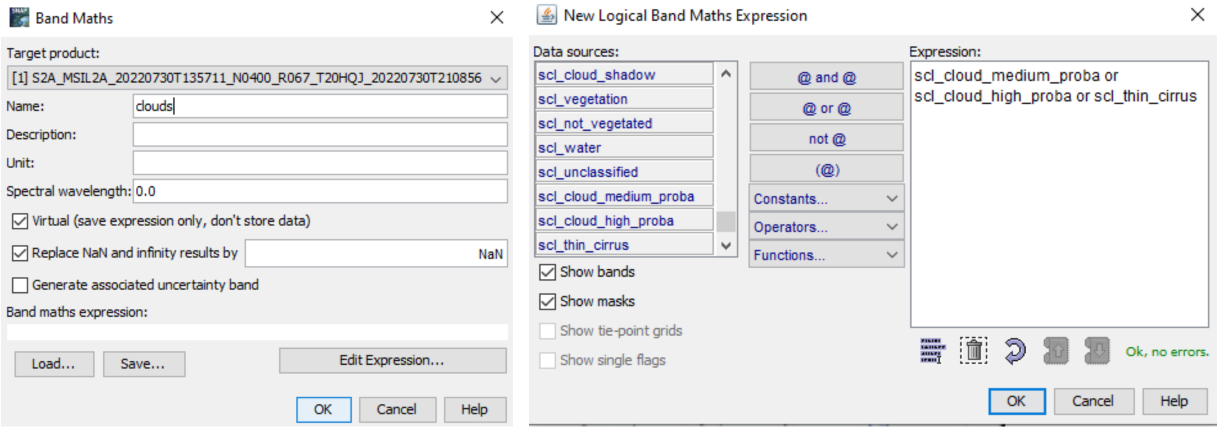


Now we make a cloud band based on the selected mask

- Band math expression

We make a cloud band based on the selected mask

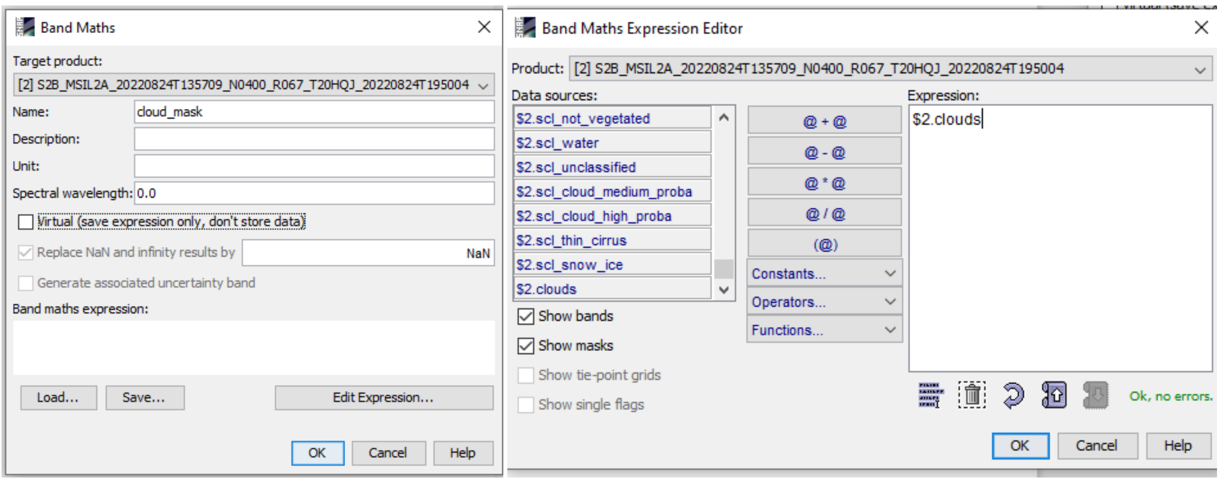
- Navigate to Raster - Band Maths
- Name the new mask: ***clouds***



Adding the cloud mask as a band

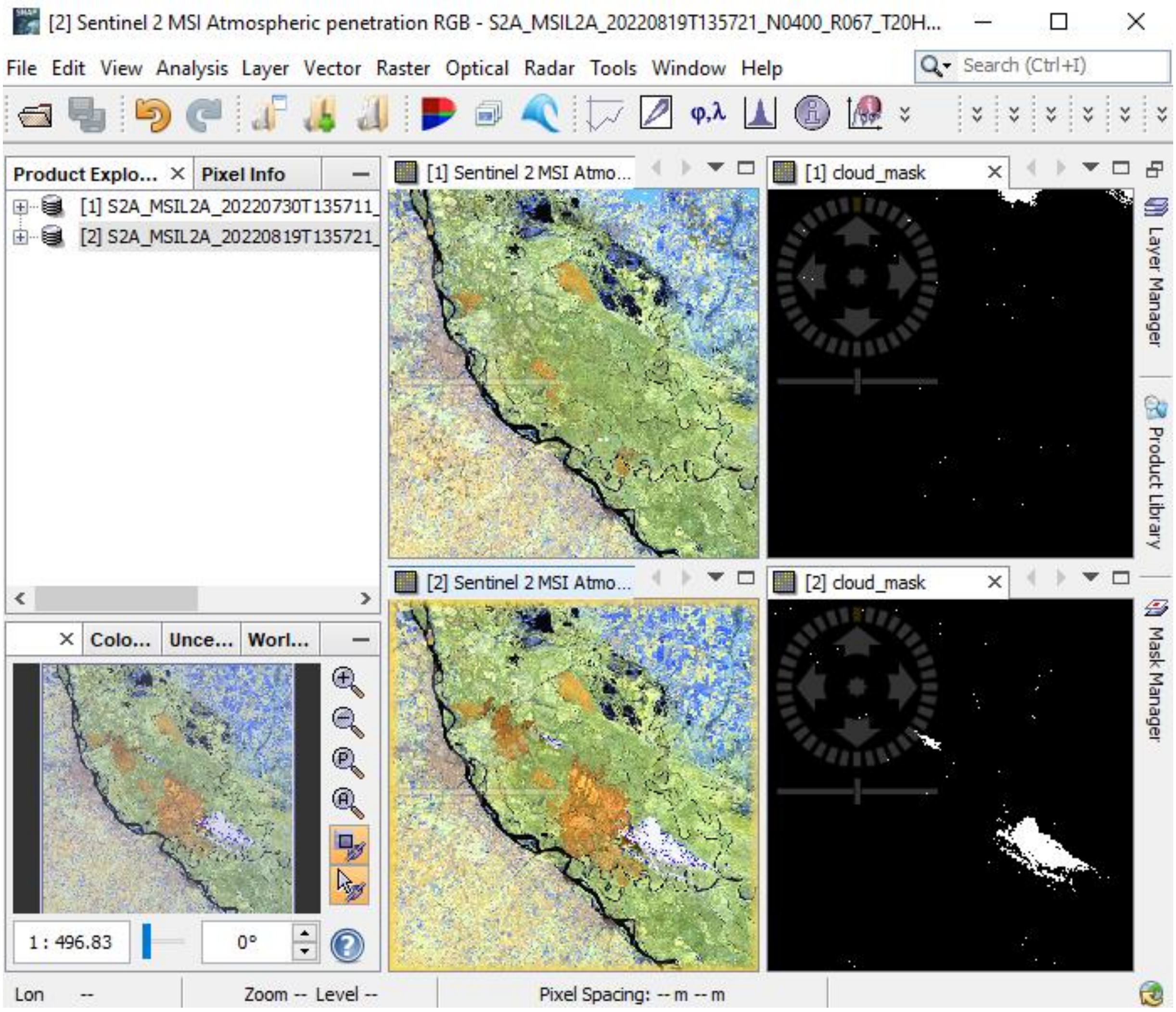
- On the image, right click-> Band Maths
- Make sure to deactivate "Virtual". We want to store the data!
- Go to "Edit Expression"
- Select Clouds

Repeat for the second image

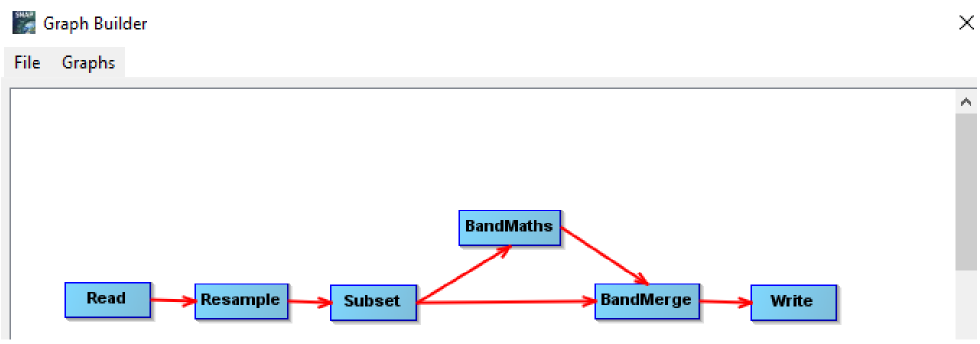


Vizualize all products

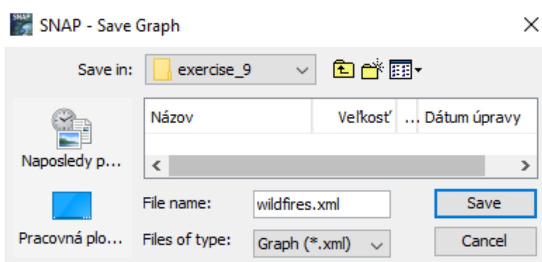
- Windows: Tile evenly
- Navigation: zoom all



Tools – Graph Builder



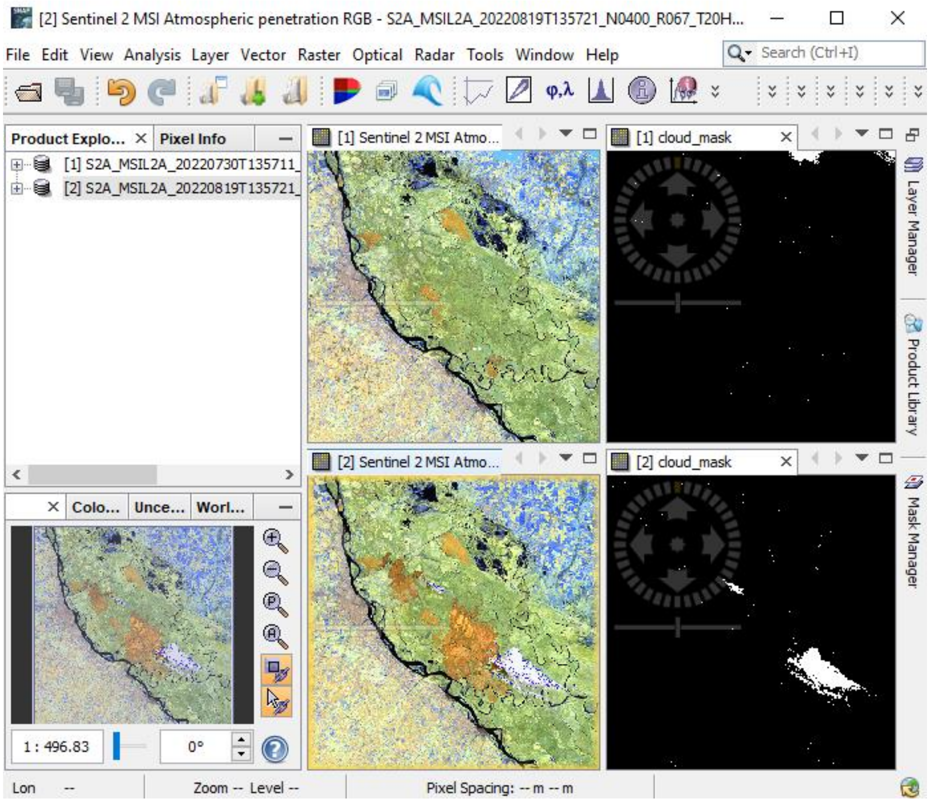
- Add->Raster->Geometric->Resample
- Add->Raster->Geometric->Subset
- Add->Raster->BandMaths
- Add->Raster->BandMerge
- Save your created graph

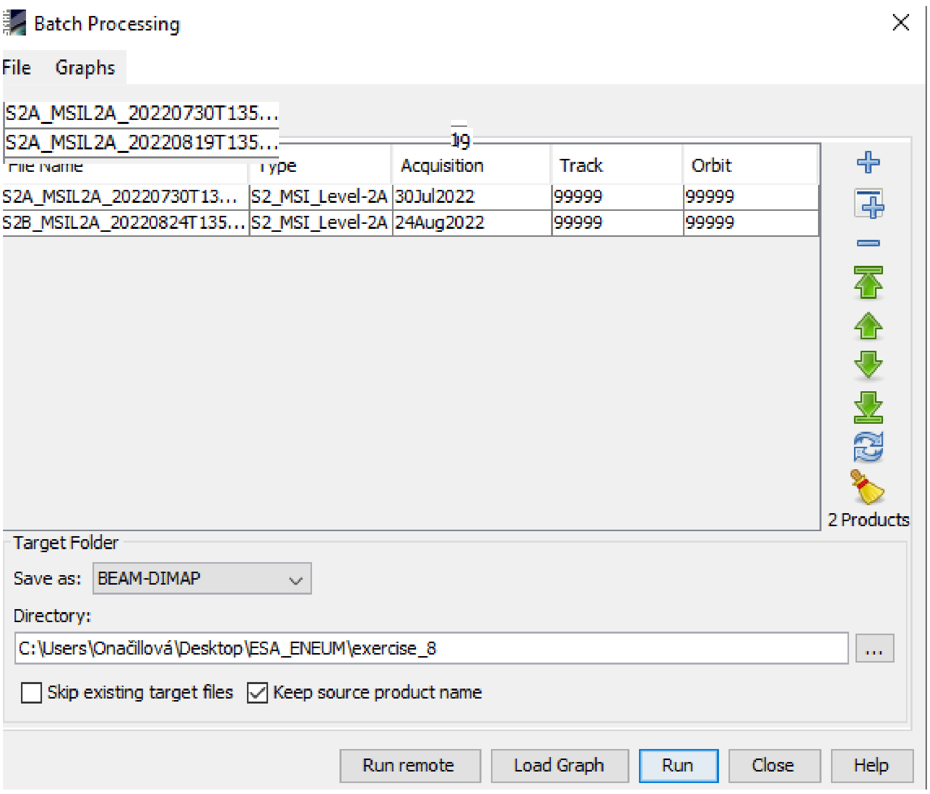


Tools – Batch processing

This allows to process both images at the same time.

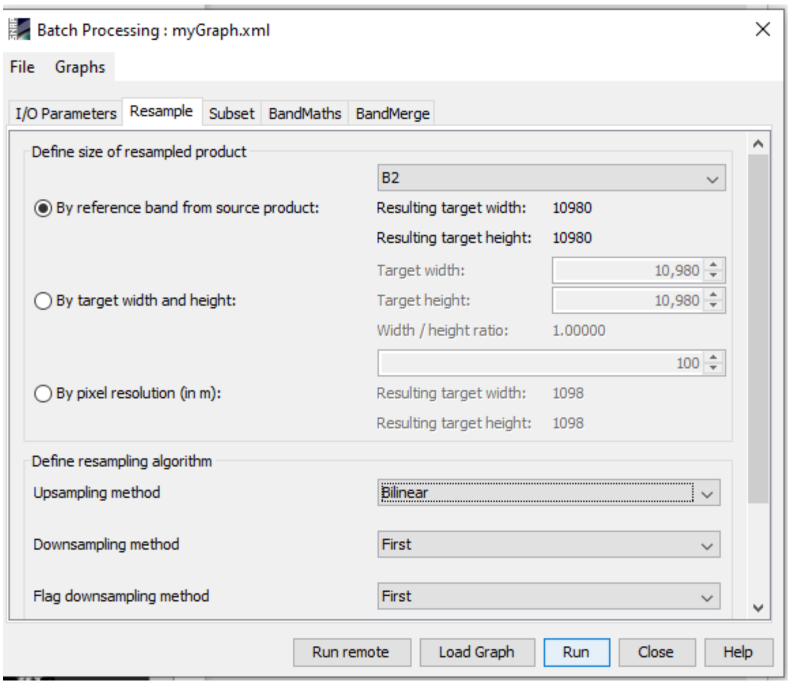
- Click on Add opened
- Load your graph
- Make sure to refresh





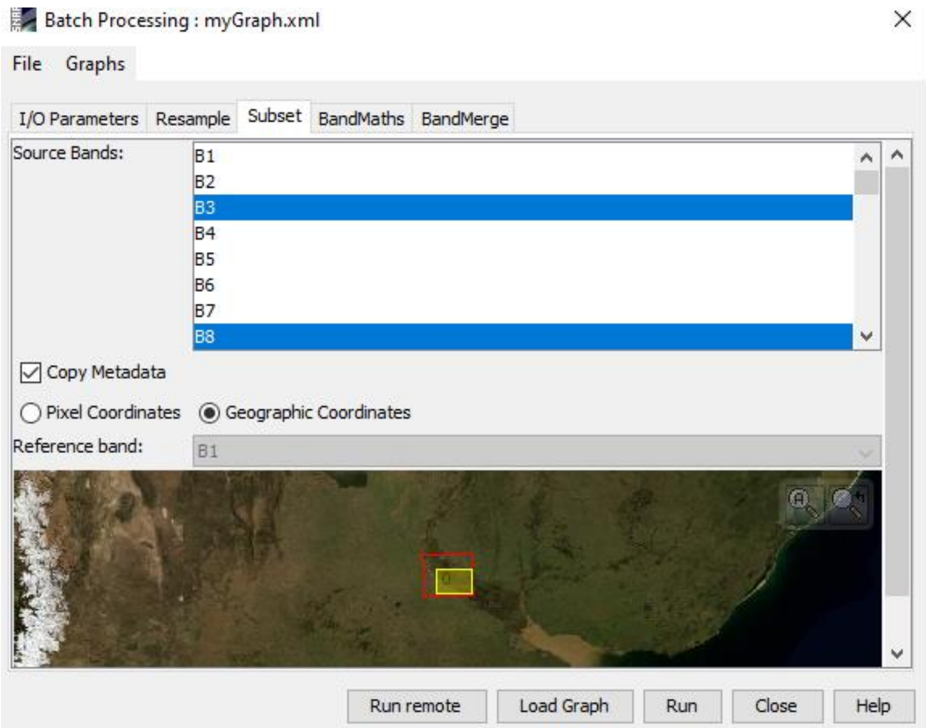
Resample

- Select a reference band: B2 at 10 m.
- Resampling method: Bilinear



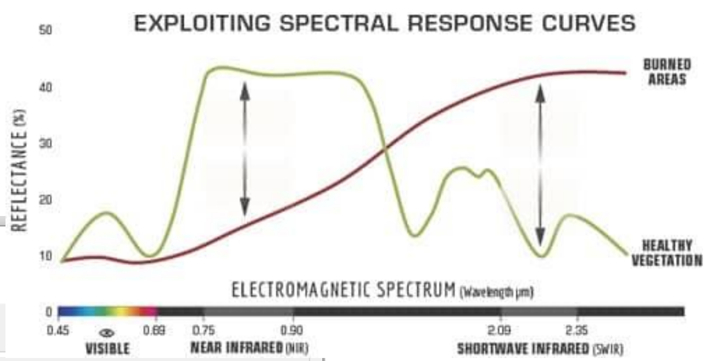
Subset

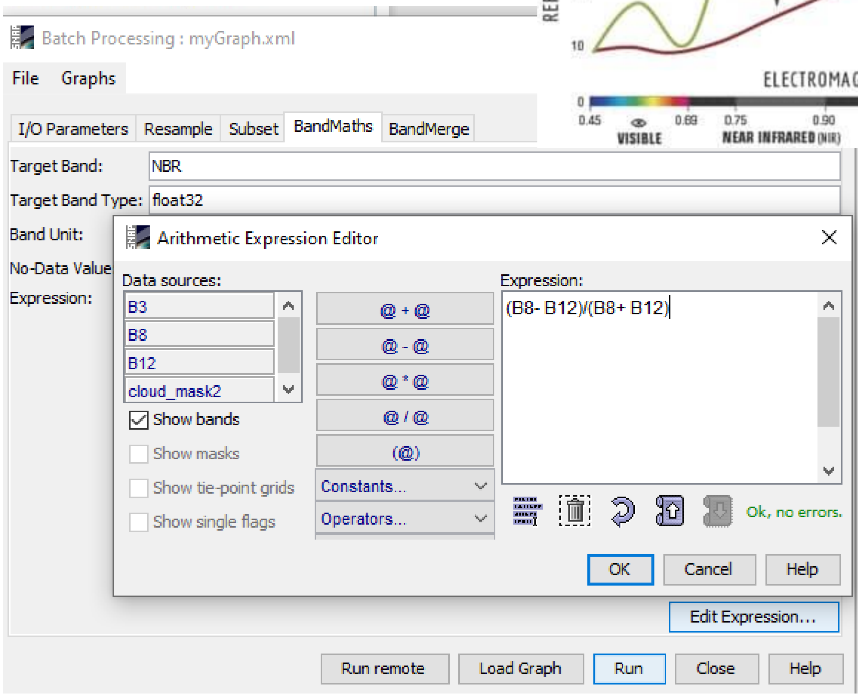
- Select bands: B3, B8, B12, Cloud_mask
- Select Geographic coordination
- Click on A, zoom in to the area of interest
- Select a yellow box within the red square



Band Math

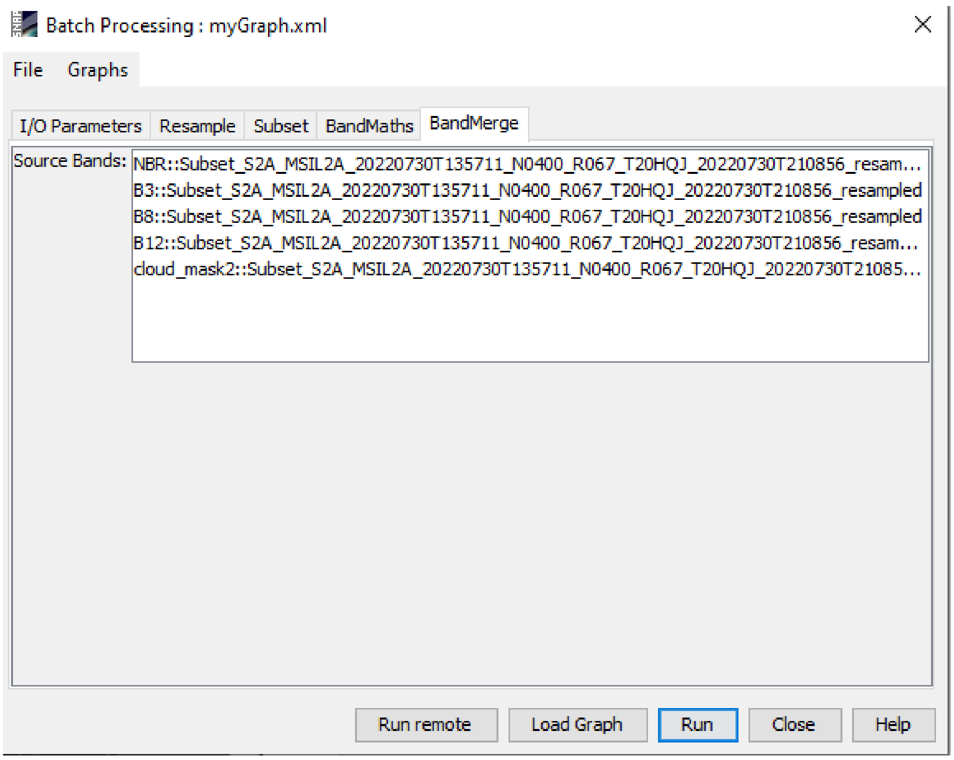
- Go to "Edit Expression"
- NBR: Normalized Burn Ratio: (B8-B12)/(B8+B12)





Band merge

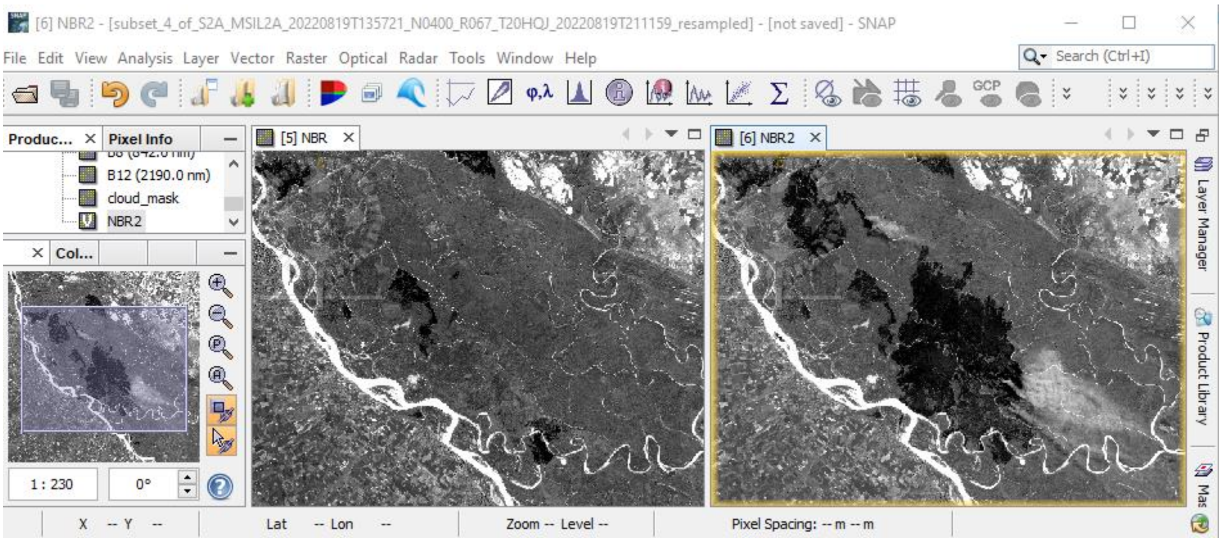
- Keep the source bands: **NBR, B3, B8, B12, cloud_mask**

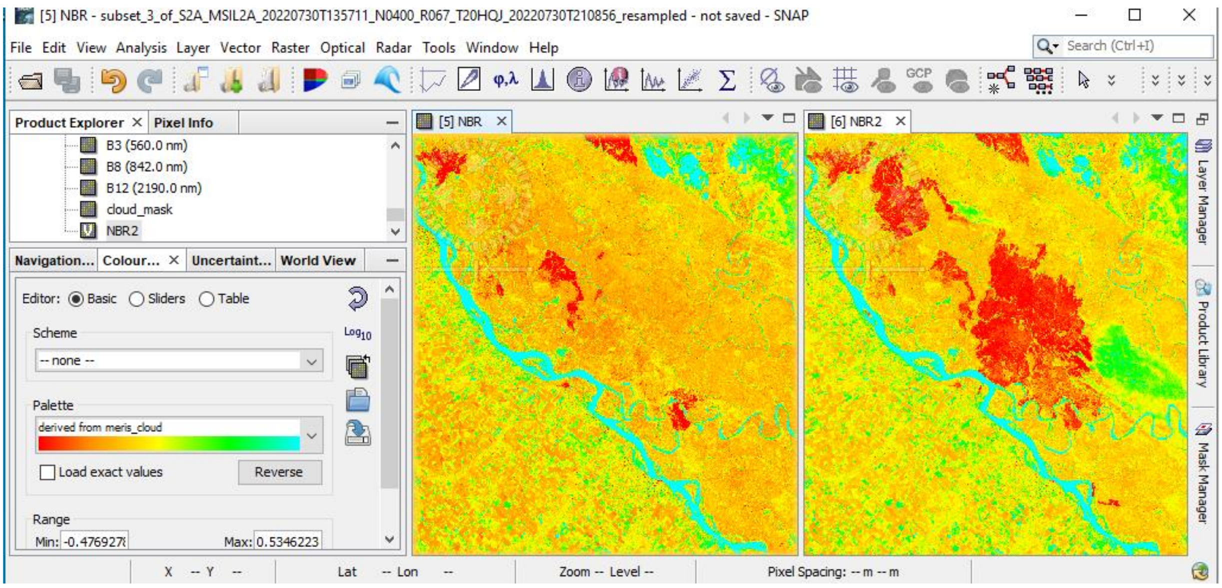


Running and visualizing the NBR band

Try a color table:

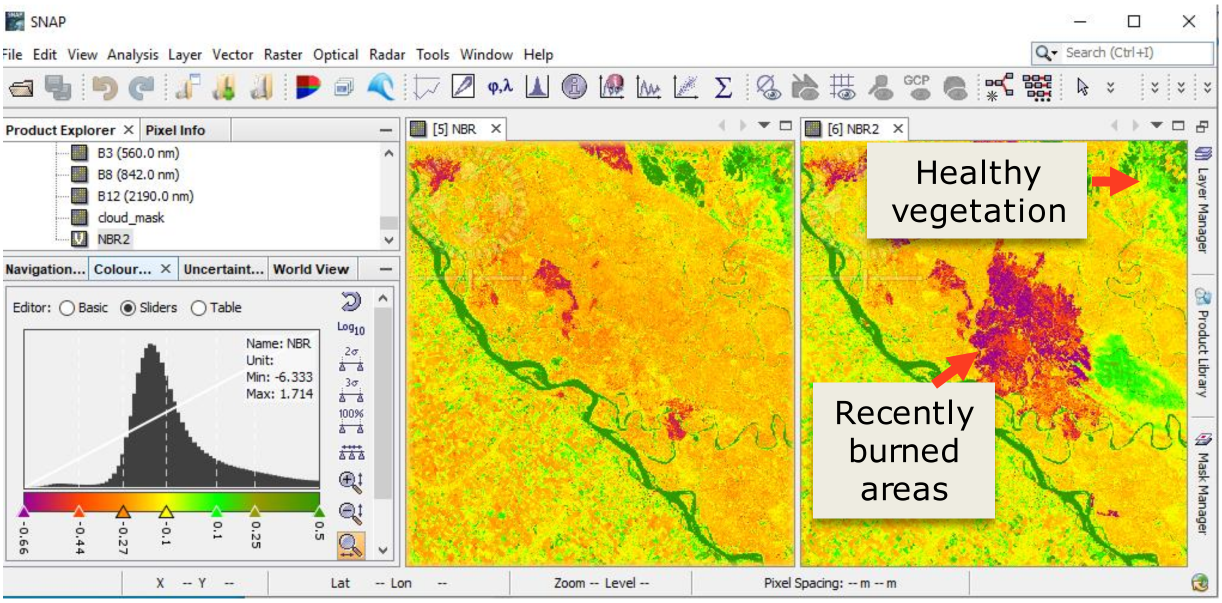
• Colour manipulation: Open color table, choose a color gradient, e.g. „derived from meris_cloud"





You can also set the position of sliders and color them for better visualization or change ranges of values in the Table tab.

NBR ranges between -1 and 1. A high NBR value indicates healthy vegetation. A low value indicates bare ground and recently burnt areas. Non-burnt areas usually have values close to zero.

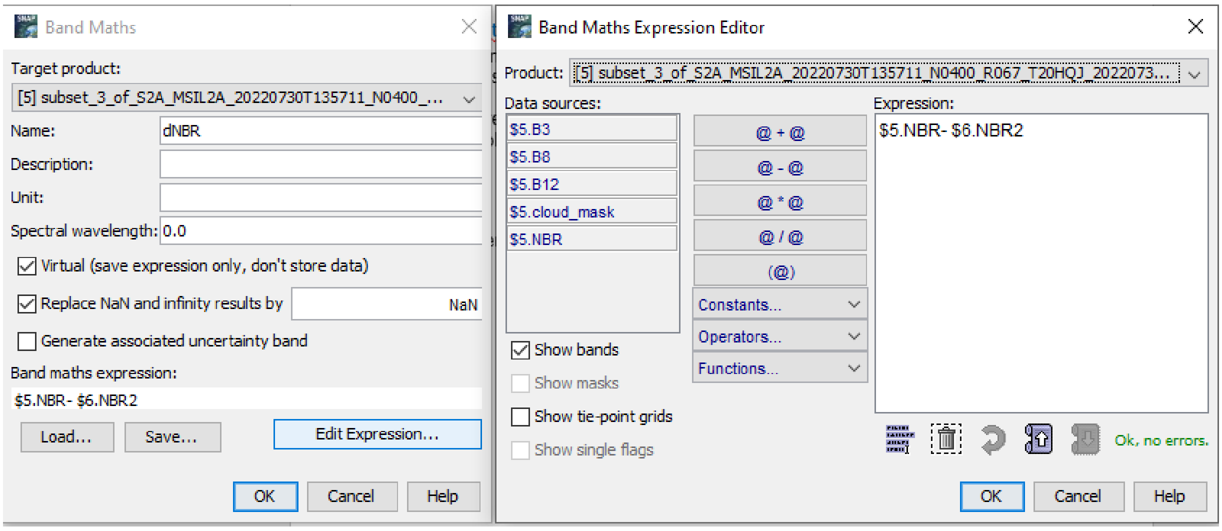


Burn severity - dNBR

The difference between the pre-fire and post-fire NBR obtained from the images is used to calculate the delta NBR (dNBR or ΔNBR), which then can be used to estimate the burn severity. A higher value of dNBR indicates more severe damage, while areas with negative dNBR values may indicate regrowth following a fire. The formula used to calculate dNBR is illustrated below:

$$dNBR \text{ or } \Delta NBR = PrefireNBR - PostfireNBR$$

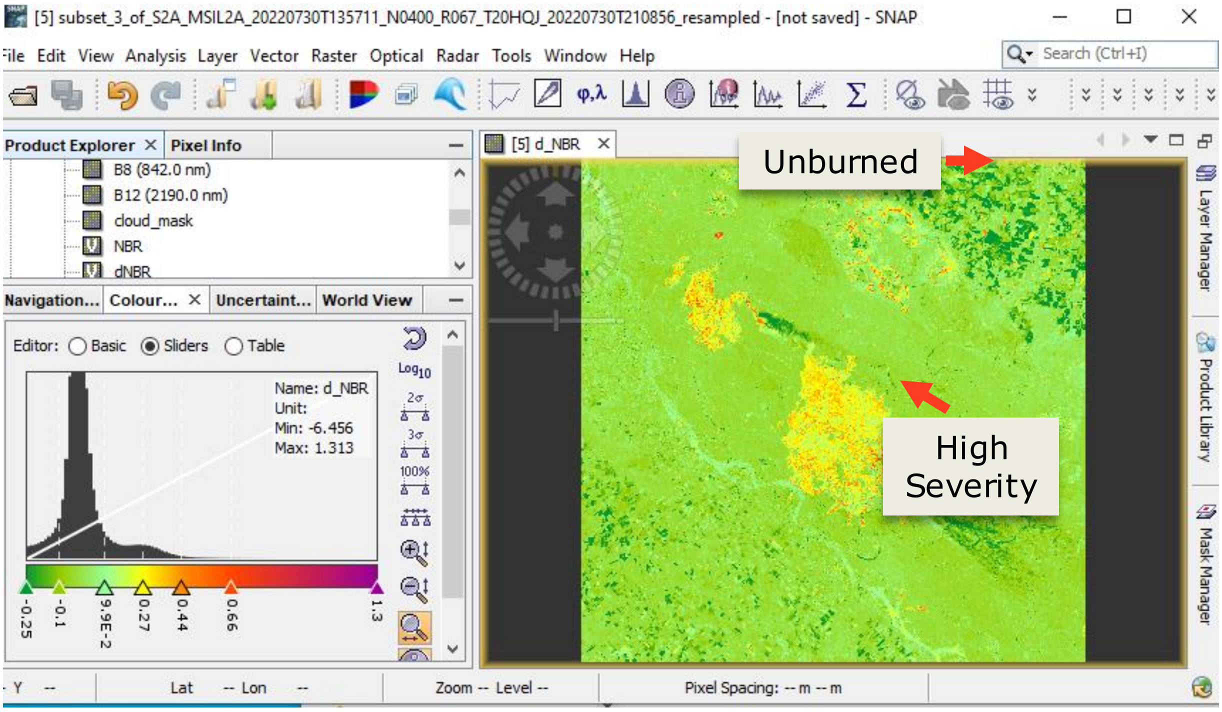
Go to Raster – Band Maths and Edit Expression



Set the position of sliders and color them for better visualization or change ranges of values in the Table tab.

NBR ranges between -1 and 1. A high NBR value indicates healthy vegetation. A low value indicates bare ground and recently burnt areas. Non-burnt areas usually have values close to zero.

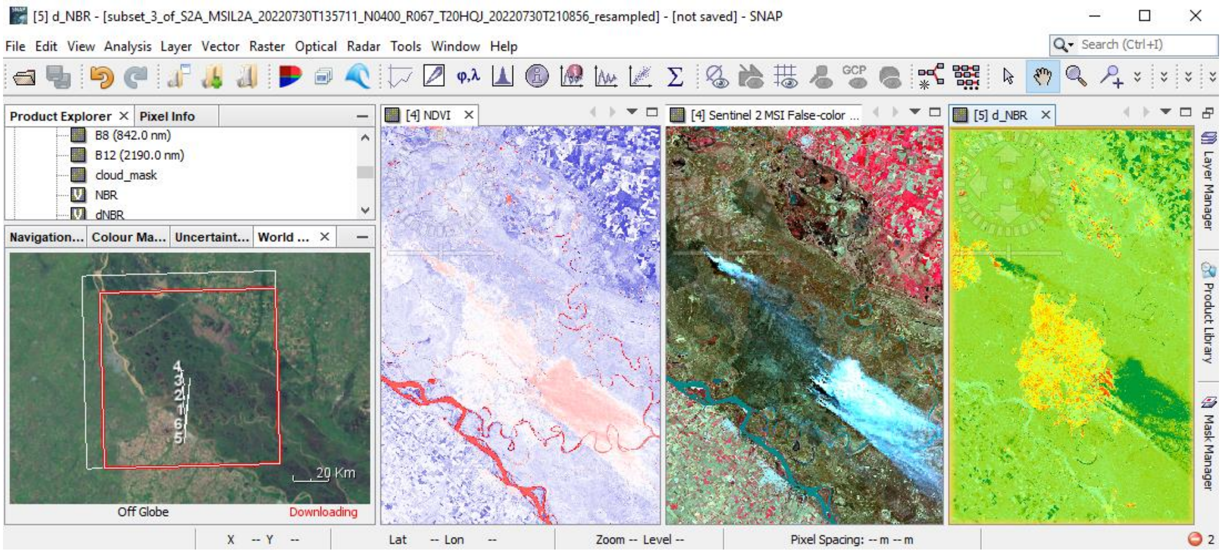
dNBR values can vary from case to case, and so, if possible, interpretation in specific instances should also be carried out through field assessment; in order to obtain the best results. However, the United States Geological Survey (USGS) proposed a classification table to interpret the burn severity, which can be seen below in the table.



Severity Level	dNBR Range (scaled by 10^3)	dNBR Range (not scaled)
Enhanced Regrowth, high (post-fire)	-500 to -251	-0.500 to -0.251
Enhanced Regrowth, low (post-fire)	-250 to -101	-0.250 to -0.101
Unburned	-100 to +99	-0.100 to +0.99
Low Severity	+100 to +269	+0.100 to +0.269
Moderate-low Severity	+270 to +439	+0.270 to +0.439
Miderate-high Severity	+440 to +659	+0.440 to +0.659
High Severity	+660 to +1300	+0.660 to +1.300

Comparison: Severity map, NDVI and false color composition

To compare different views of the same area and explore it more in detail, create also NDVI and false color composition. You can observe, that areas with high NDVI values correspond to the barren areas affected by wildfires. False color composition also depicts areas affected by fire – these areas are shown in dark pixels. False color composite B8-B4-B3 of the Sentinel 2 image (during fire), with superimposed ongoing wildfire sites, note that the smoke direction is corresponding to the wind direction.

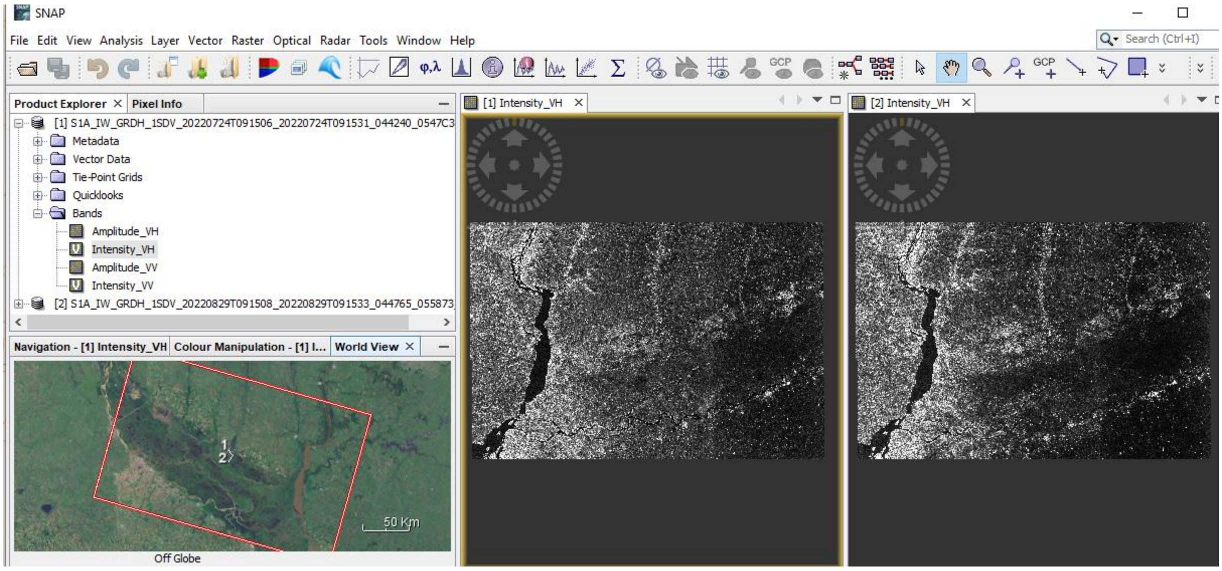


C: Burned area mapping using Sentinel-1

Load both Sentinel-1 products (pre-fire and post-fire) that you have in tjhe folder for this exercise by navigating to File - Open Product.

S1A_IW_GRDH_1SDV_20220724T091506_20220724T091531_044240_0547C3_961B.SAFE
S1A_IW_GRDH_1SDV_20220829T091508_20220829T091533_044765_055873_EED3.SAFE

Visualize the input products – open e.g. Intensity_VH for both products by double-click on it under the Bands folder.



1. Pre-processing

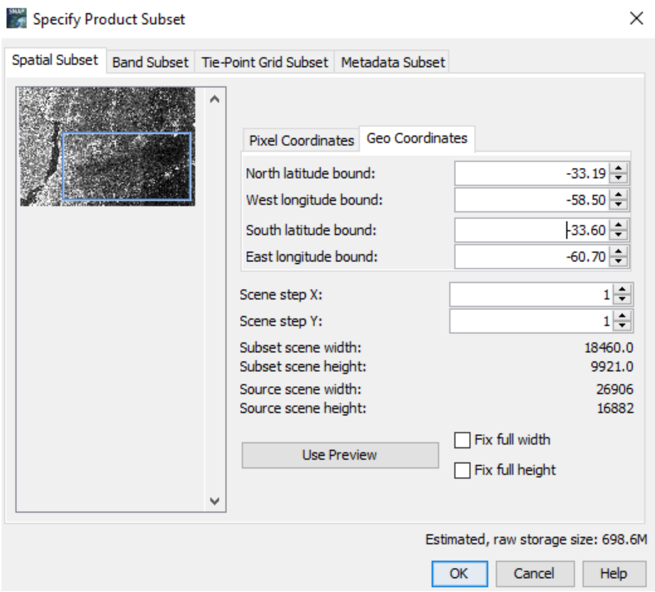
We need to apply identical pre-processing steps to both of our scenes:

Create subset

There is no need to process the whole image, instead, we can begin by narrowing down the scene to a more manageable size – creating subset. This approach will decrease processing time in subsequent stages, especially when the analysis is concentrated on a specific area rather than the entire scene.

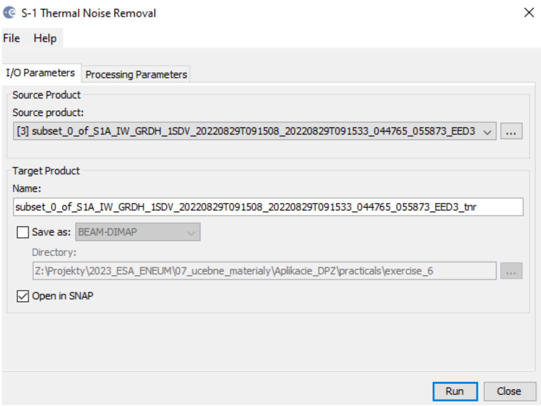
Select the first product and Go to the Subset tab and at “Geo Coordinates” set:
North latitude bound: -33.19
West longitude bound: -58.50
South latitude bound : -33.60
East longitude bound: -60.70

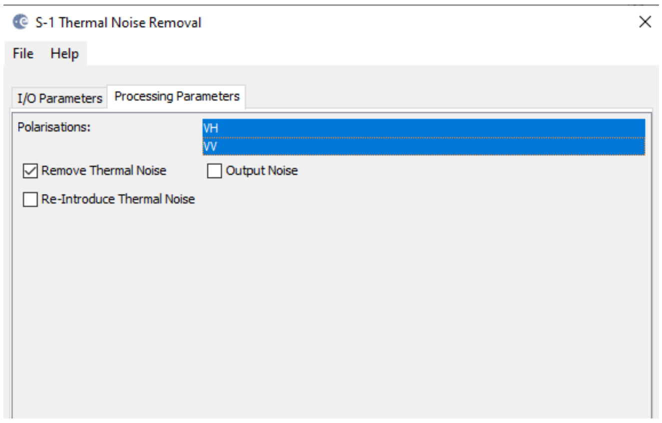
Repeat for the second image.



Thermal noise removal

Navigate to Main Menu – Radar – Radiometric – S-1 Thermal Noise Removal
In the I/O Parameters tab, select the last subset product with applied orbit file and name the target product. There is no need to save the output as BEAM-DIMAP (we will save the time this way)
In the Processing Parameters you can select both polarization and make sure that the "Remove Thermal Noise" option is selected.
Repeat for the second subset image.

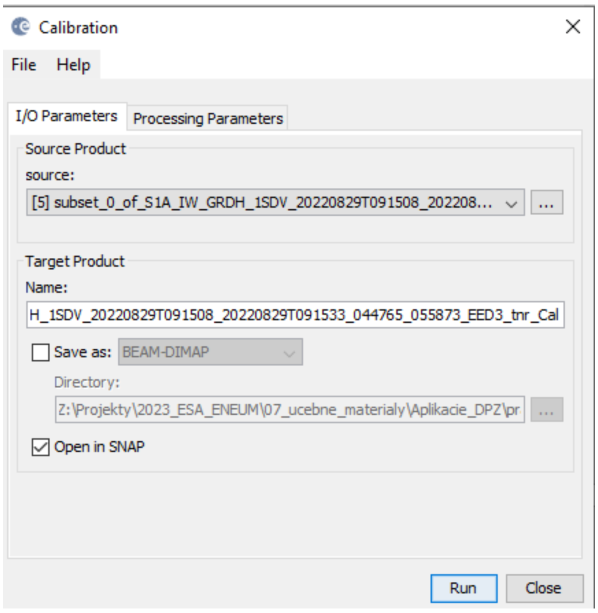


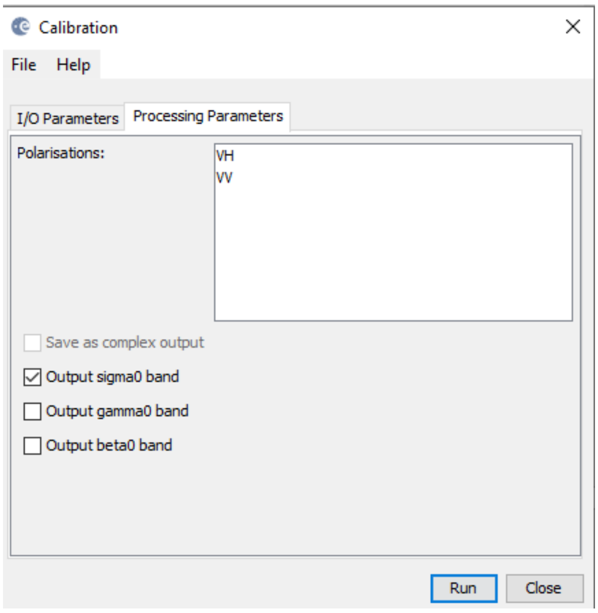


Calibration

With our image now subsetted and with TNR, we must apply image calibration. This step is necessary to normalize the values in the image into backscatter values so we can compare multiple images in a time series.

Navigate to Main Menu – Radar – Radiometric – Calibrate
In the I/O Parameters tab, select the product with thermal noise removal and name the target product. In the case of this final product of preprocessing, please, save it to your folder for this exercise
In the Processing Parameters select both bands as input and accept all default settings and then click Run
Repeat for the second image. The saving might take some time.

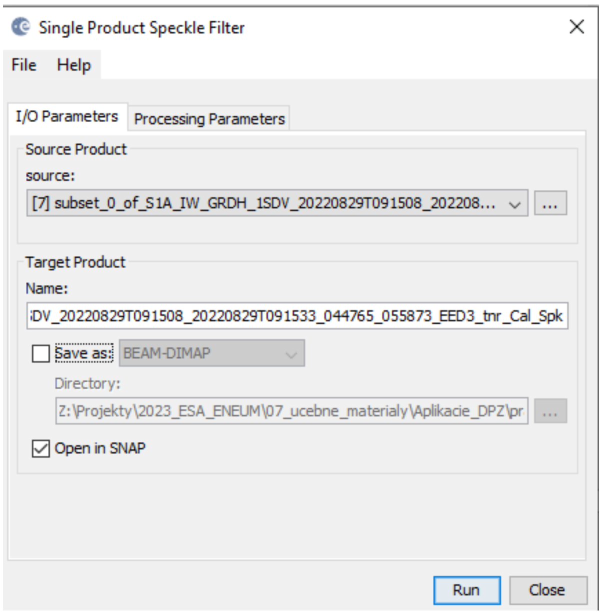


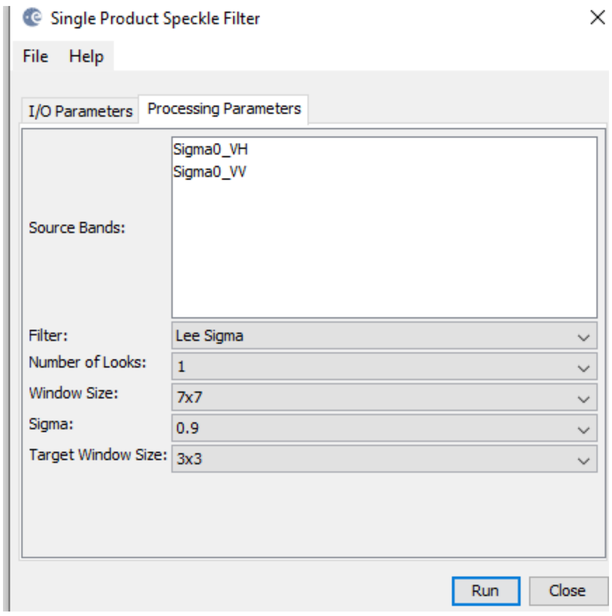


Speckle Filter

Despeckling removes thermal noise introduced by the sensor from the image to remove potential sources of error in analysis.

Navigate to Radar > Speckle Filtering Single Product Speckle Filter. In the Speckle-Filter tab, choose the simple Lee Sigma filter with default window sizes.





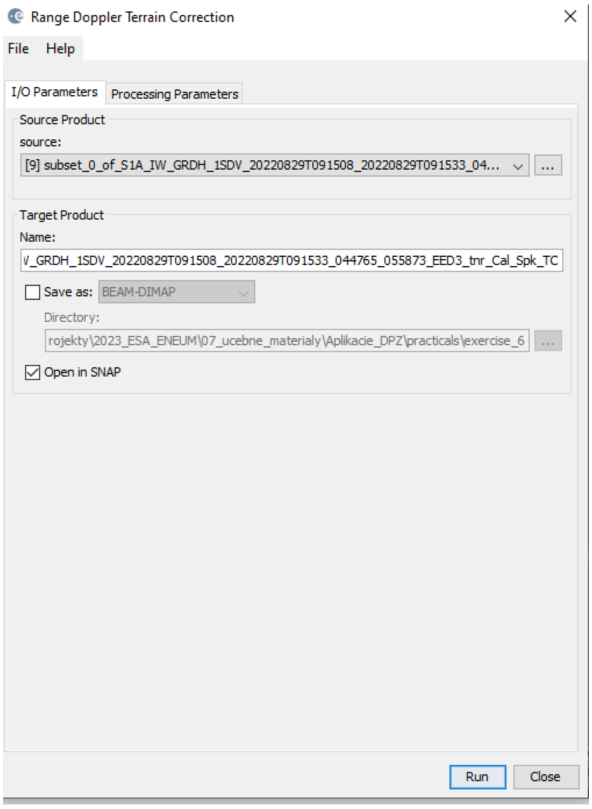
Terrain-Correction

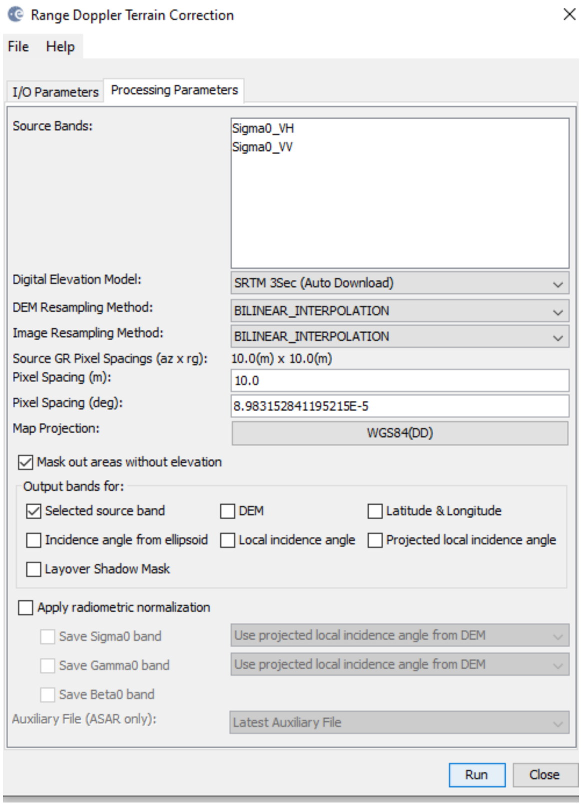
Our data are still in radar geometry, moreover due to topographical variations of a scene and the tilt of the satellite sensor, the distances can be distorted in the SAR images. We need to apply Terrain Correction to compensate for the distortions and reproject the scene to geographic projection.

Navigate to Main Menu: Radar - Geometric - Terrain Correction - Range-Doppler Terrain Correction

- In the I/O Parameters tab set as "Source Product" the speckle-filtered product.
- In "Target Product", keep the default name and set the Directory
- In the Processing Parameters tab set:
- Digital Elevation Model: SRTM 3Sec (Auto Download)
- Keep defaults values for the other parameters. Click Run.

Approximate processing time: 2.5 minutes.



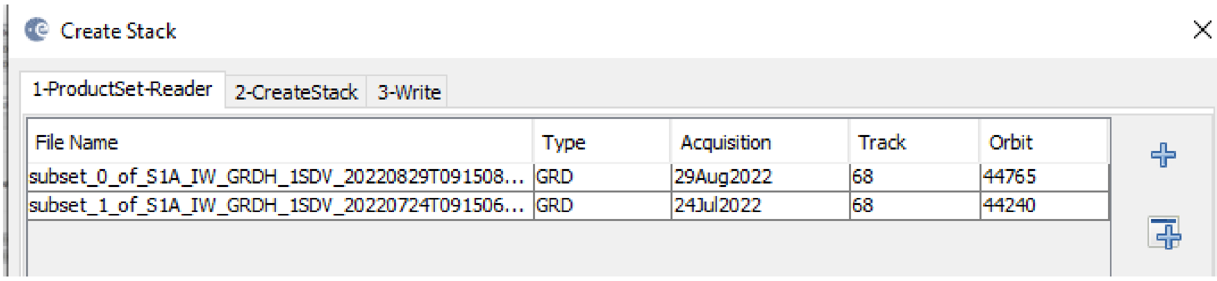


Do not forget to save these two output terrain corrected products. We will need them saved for the next step.

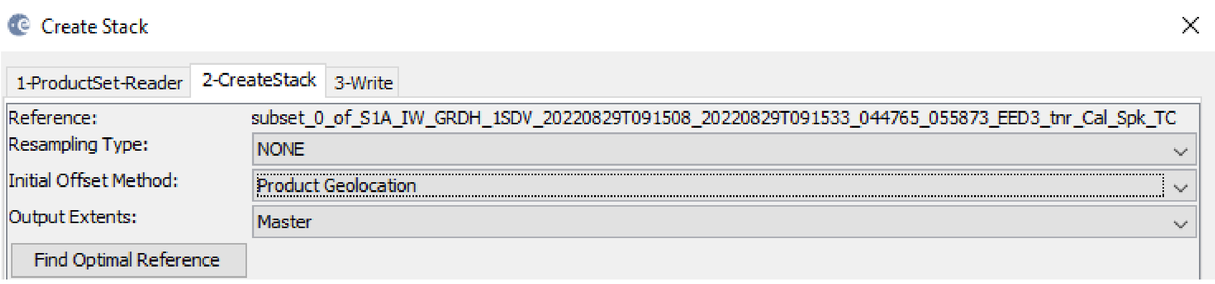
Create stack

Go to Radar > Coregistration > Stack Tools > Create Stack

In the Product-Set-Reader tab select the last three products from the previous step.



In the CreateStack tab, select Product Geolocation as Initial Offset Method (Note: we did not use apply orbit file function, but the product geolocation is accurate enough for the purpose of our analysis)



In the Write tab, adjust the stack name if needed, adjust the output folder and click Run. This step will might take few minutes.

After the process is finished, we can see the new final „Stack" product in the Product Explorer window.

2 Display RGB time series

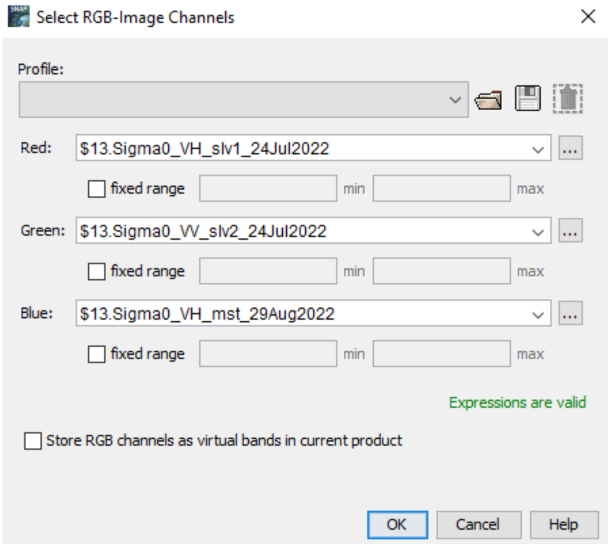
Now let´s have a look at some RGB composite of this time series Right-click on the last „Stack" product – Open RGB Image Window and select different band combinations to see the change of backscatter signal for different dates:

Right-click on the last „Stack" product – Open RGB Image Window and select different band combinations to see the change of backscatter for different acquisitions. For this, select :

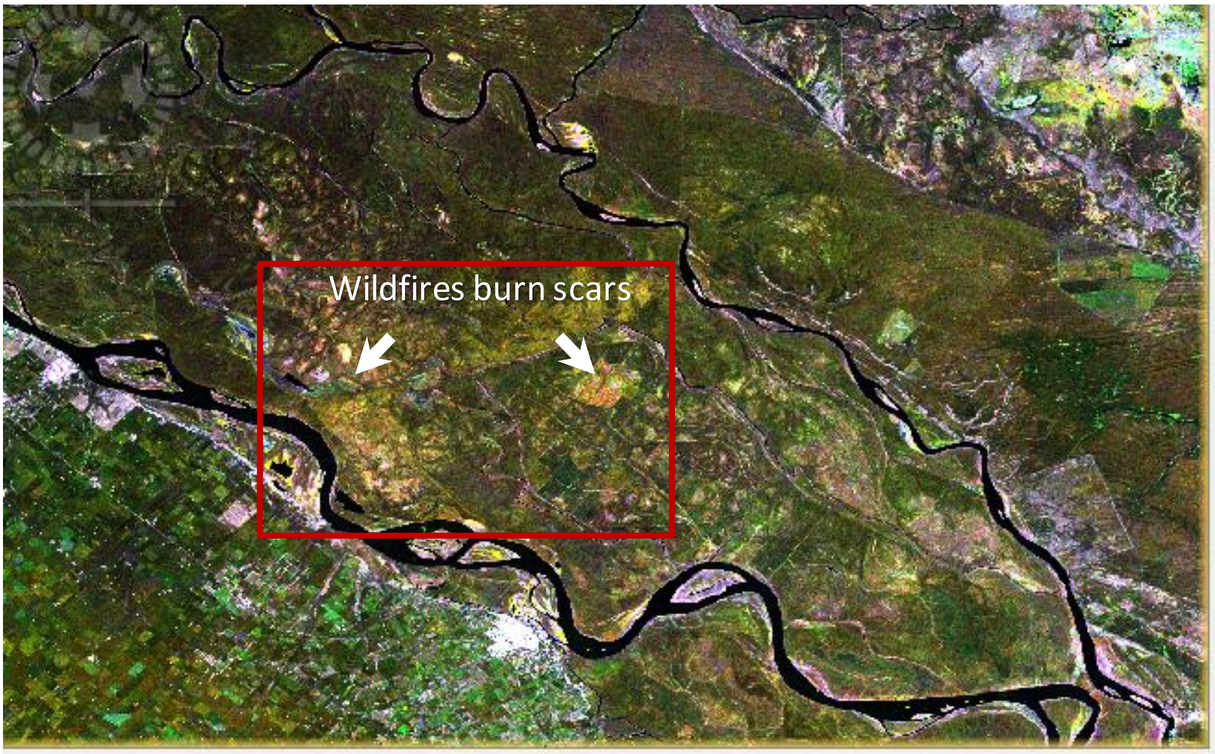
Red: Sigma0_VH_slv_24Jul2022

Green:Sigma0_VV_slv2_24Jul2022

Blue: Sigma0_VH_mst_29Aug2022



Explore the final RGB composite to identify wildfires.



For more information, see the lecture: [7. SAR and optical remote sensing for mapping wildfires]

THANK YOU FOR FOLLOWING THE EXERCISE!

UNIVERSITY COURSE APPLIED RADAR REMOTE SENSING

EXERCISE 8 – TUTORIAL

Sentinel-1 & Sentinel-2 for Snow and Ice using the SNAP software and EO Browser

esa

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Prírodovedecká fakulta UPJŠ v Košiciach

UNIVERZITA PAVLA JOZEFA ŠAFÁRIKA V KOŠICIACH

FUNDED BY EUROPEAN SPACE AGENCY UNDER THE PLAN FOR EUROPEAN COOPERATING STATES, 7TH CALL FOR SLOVAKIA

1 | Exercise outline

In this first exercise for mapping snow and ice, we will:

- Learn the basic steps to calculate glacier velocity using Sentinel-1 data
- Perform preprocessing of data
- Use velocity vector to see direction and speed of glacier flow

2 | Background

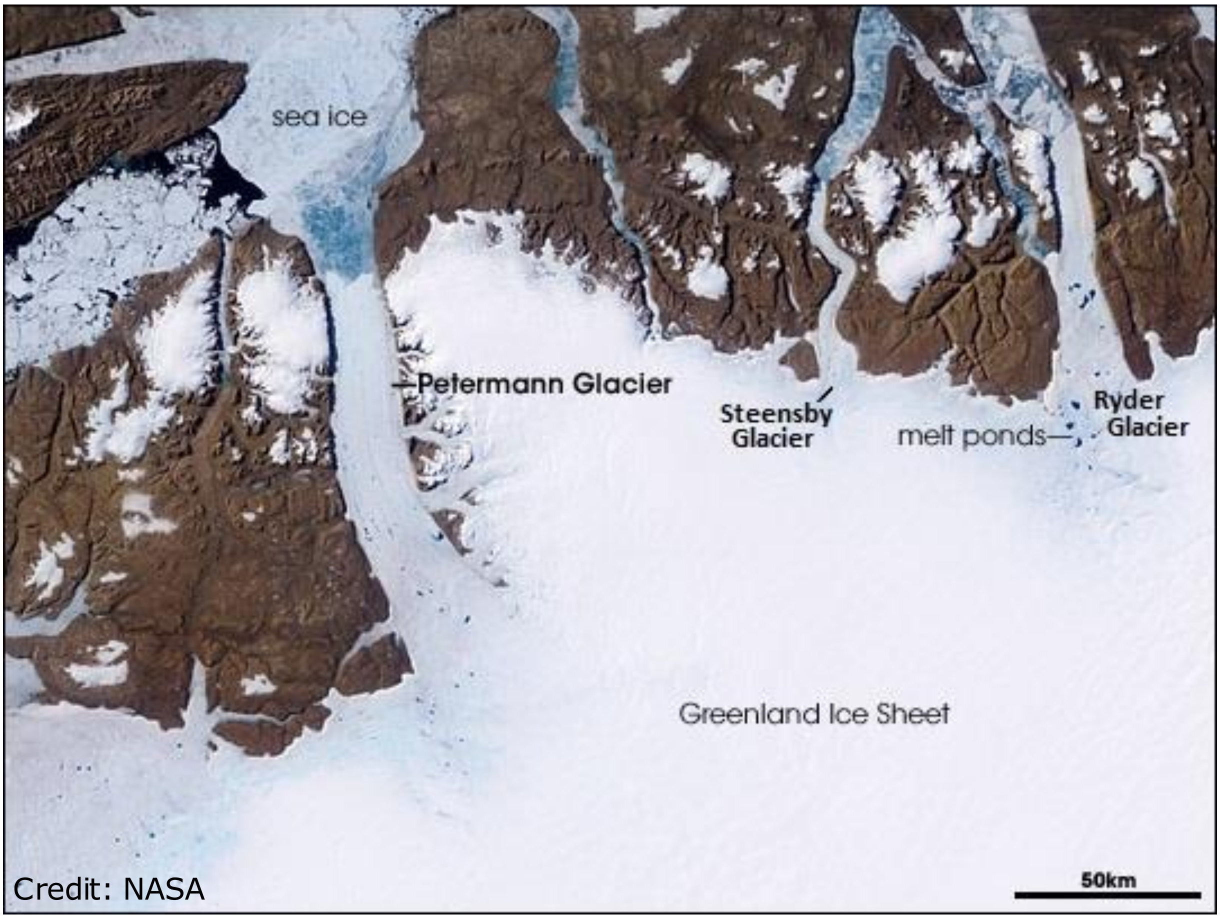
Mapping snow and ice using Sentinel-1 and Sentinel-2 data

The Greenland ice sheet ranks as the Earth's second-largest mass of ice. As the climate undergoes changes, there's a notable increase in surface melting of the ice sheet, leading to a greater discharge of freshwater into the ocean. This phenomenon significantly contributes to the global rise in sea levels.

Monitoring glacier velocity is crucial for understanding glacier dynamics and its impact on global sea levels. Satellite data serves as a valuable tool for tracking glacier velocity across expansive areas.

Monitoring glacier velocity is crucial for understanding glacier dynamics and its impact on global sea levels. Satellite data serves as a valuable tool for tracking glacier velocity across expansive areas. Two primary methods are commonly employed to measure ice flow speed using satellite data: SAR interferometry and feature/speckle tracking (utilizing optical or SAR data) between consecutive acquisitions. This tutorial will focus on the latter method, specifically applied to Sentinel-1 data.

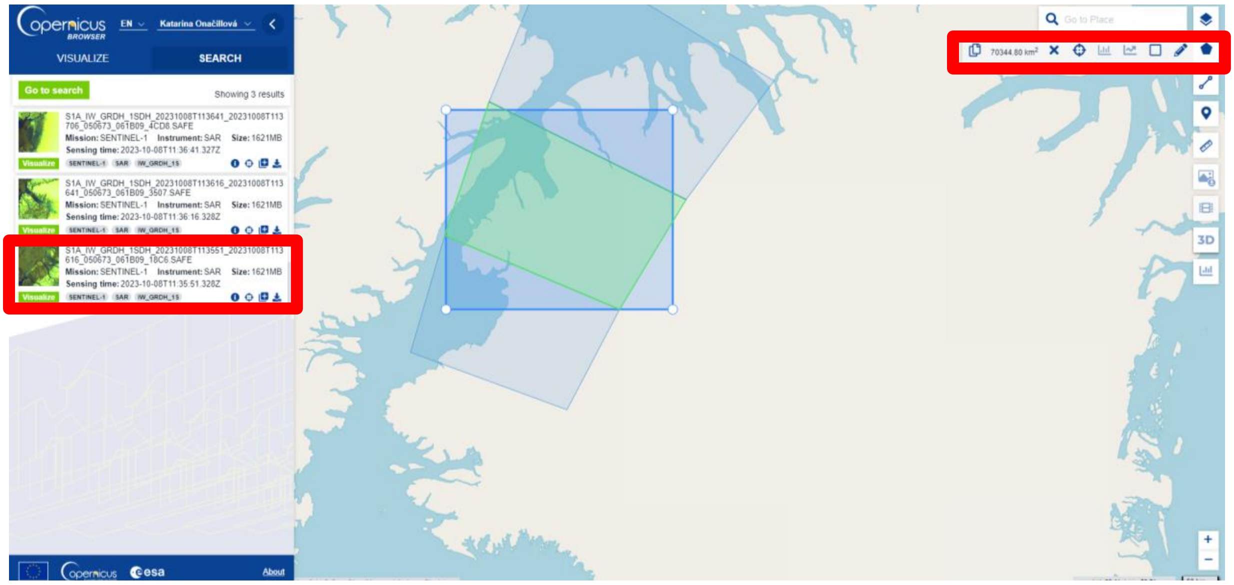
The Petermann Glacier, a substantial tidewater glacier, drains over 4% of the Greenland ice sheet via the 90 km long Petermann Fjord, ultimately terminating in a floating ice tongue spanning an area of approximately 900 km². An estimated 12 billion tonnes of ice are discharged into the ocean annually, with an approximate ice flow speed of 1 km/year.



Credit: NASA

2.1 Study area and data used

For this exercise, we will use two Sentinel-1 images of the same area in northern Greenland, downloaded for year 2023 from the Dataspace Copernicus Open Access Hub [@https://dataspace.copernicus.eu/].

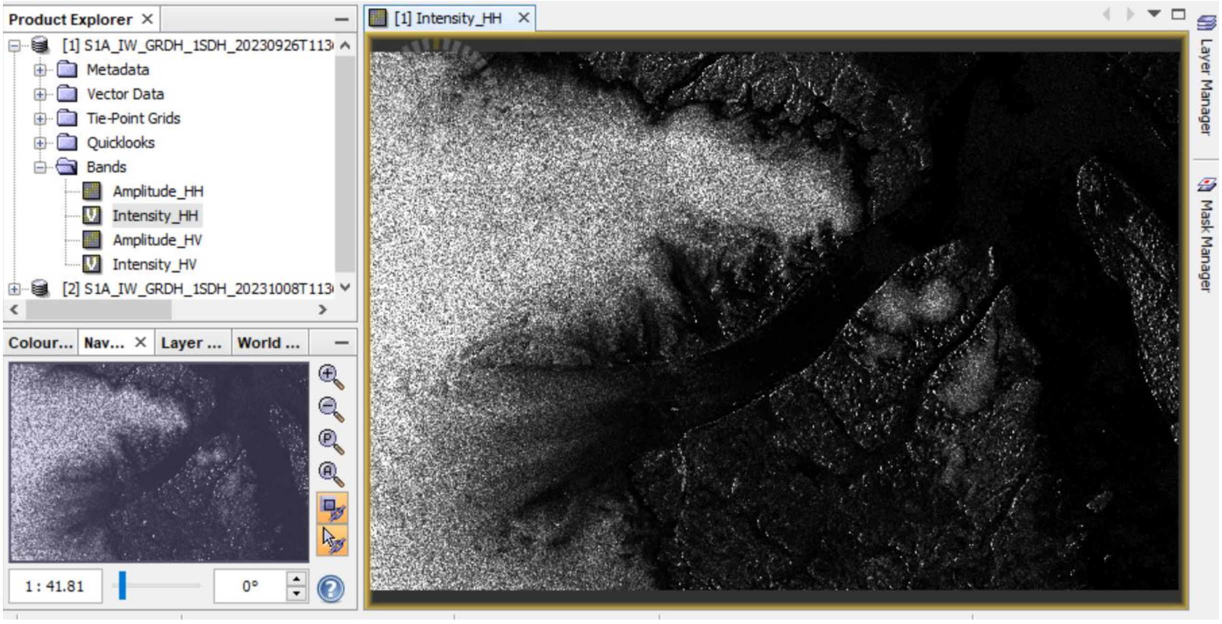


2.2. SNAP - Open and explore product

Open SNAP Desktop, click Open Product and open 2 Sentinel-1 GRDH downloaded products with HH and HV polarizations acquired on 26 September and 8 October 2023 by double click on the zipped folders. The opened products will appear in Product Explorer window:

S1A_IW_GRDH_1SDH_20230926T113616_20230926T113641_050498_061508_2030.zip
S1A_IW_GRDH_1SDH_20231008T113616_20231008T113641_050673_061B09_3507.zip

Click + to expand the contents of product [1] from 26 September 2023, then expand Bands folder and double click on Intensity_HH band to visualize it.



The scene appears to be "mirrored" due to the fact that it was captured during a descending pass, with the satellite moving from north to south and looking towards the right (in this case, west). As a result, the view displays pixels in the order of data acquisition, as the image has not yet been projected into cartographic coordinates.

3.1 Pre-processing

We need to apply identical pre-processing steps to both of our scenes:

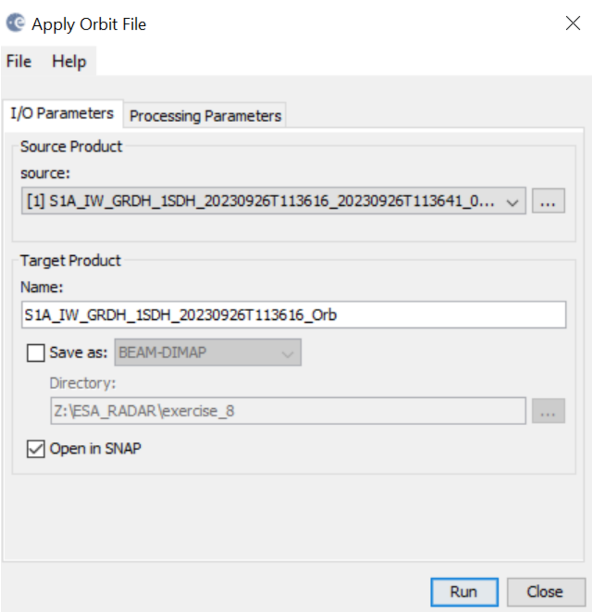
Apply orbit file

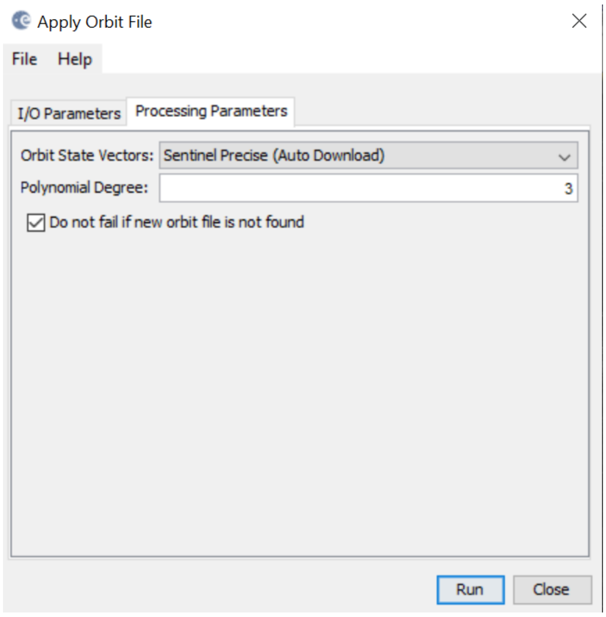
Navigate to Main Menu – Radar – Apply orbit file

In the I/O Parameters tab, select the first product and name the target product. There is no need to save the output as BEAM-DIMAP (we will save the time this way)

In the Processing Parameters accept the default settings and select the option „Do not fail if new orbit file not found"

Repeat for the second image.





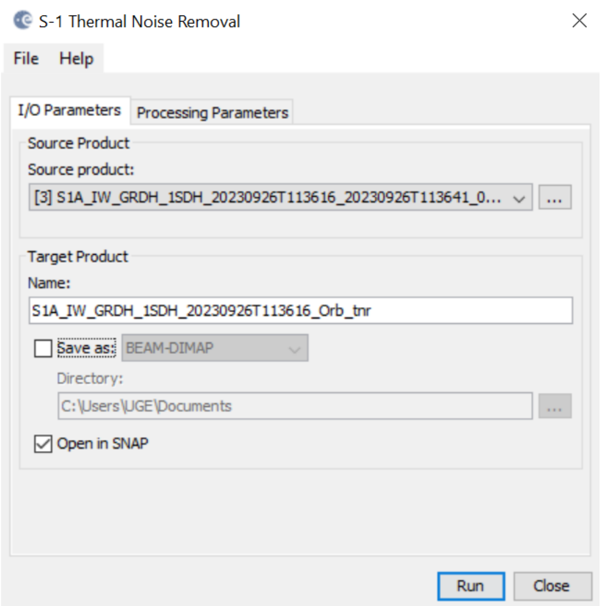
Thermal noise removal

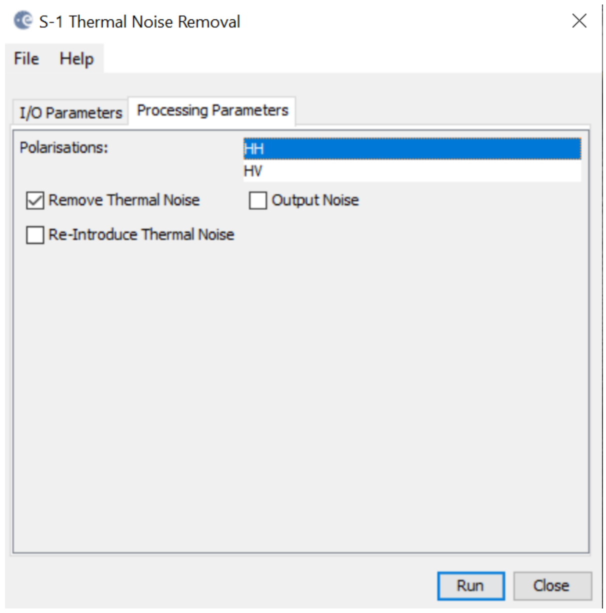
Navigate to Main Menu – Radar – Radiometric – S-1 Thermal Noise Removal

In the I/O Parameters tab, select the product with applied orbit file and name the target product. There is no need to save the output as BEAM-DIMAP (we will save the time this way)

In the Processing Parameters you can select only HH polarization (or it is possible within the next step calibration) and make sure that the "Remove Thermal Noise" option is selected.

Repeat for the second image.





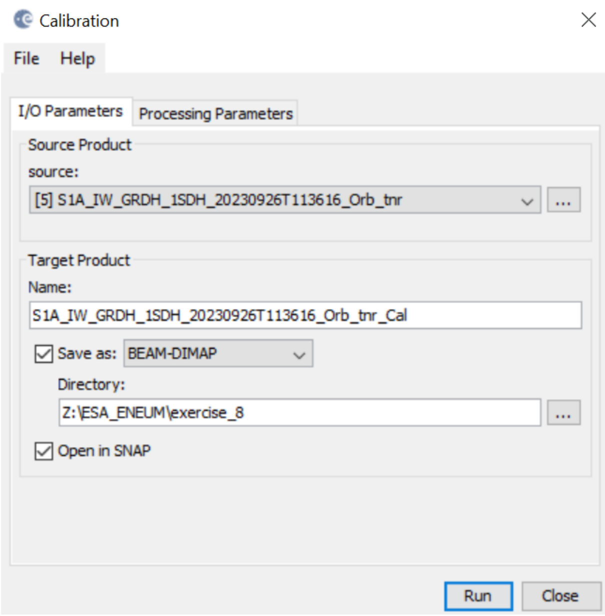
Calibration

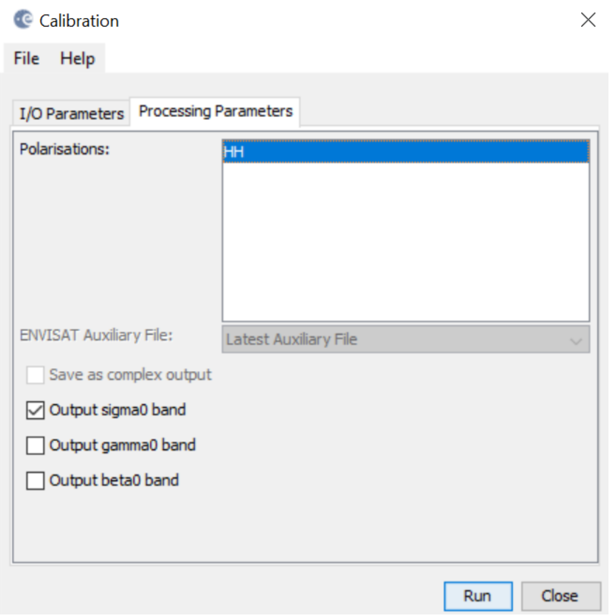
Navigate to Main Menu – Radar – Radiometric – Calibrate

In the I/O Parameters tab, select the product with thermal noise removal and name the target product. In the case of this final product of preprocessing, please, save it to your folder for this exercise

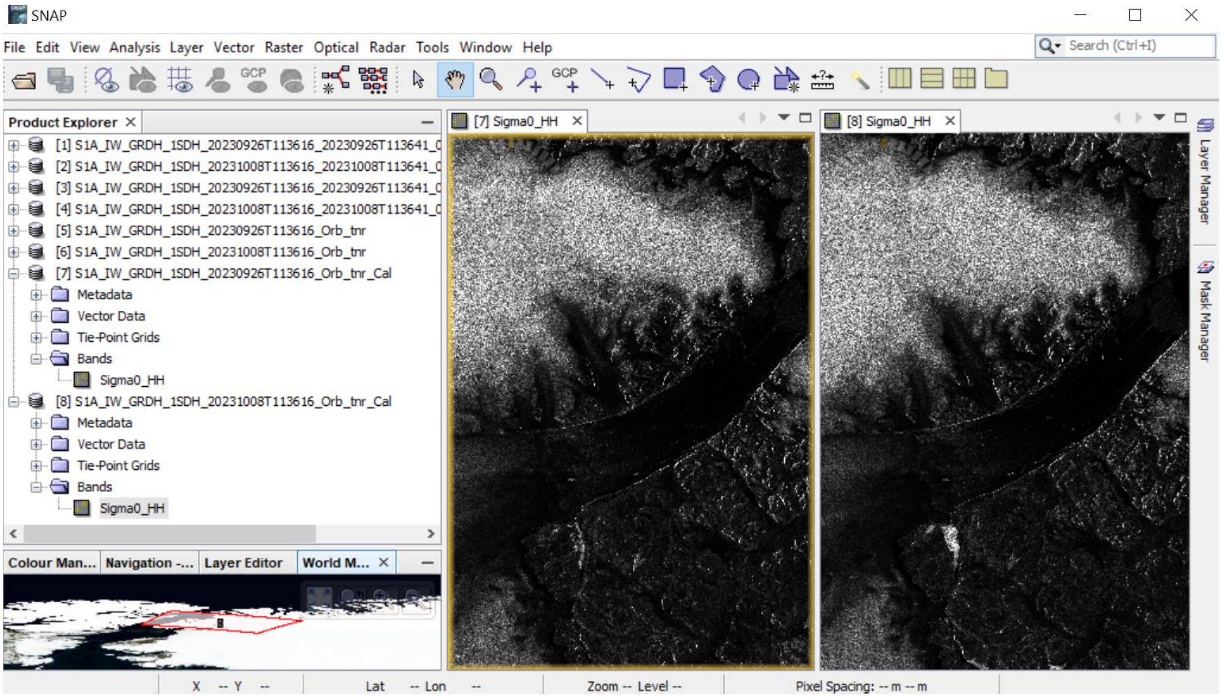
In the Processing Parameters you can select only HH polarization and accept all default settings and then click Run

Repeat for the second image. The saving might take some time.





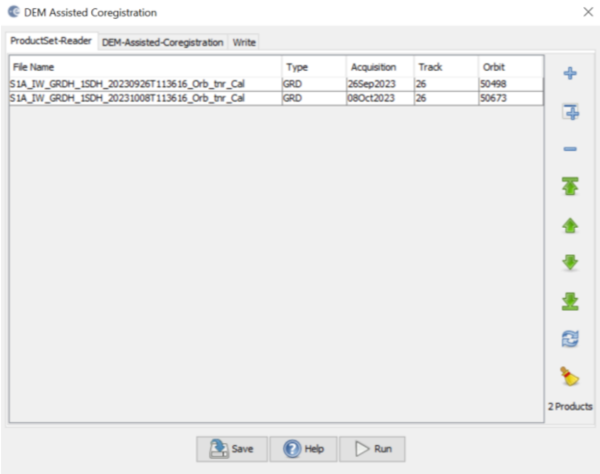
If you finish all preprocessing steps, you should have eight products in the Product Explorer. Open the Bands folder of the last two products, double click on Sigma_HH for both of the products and Tile them Horizontally. You can see little differences between these two acquisition dates.
Let´s corregistrate these images and track the offset.

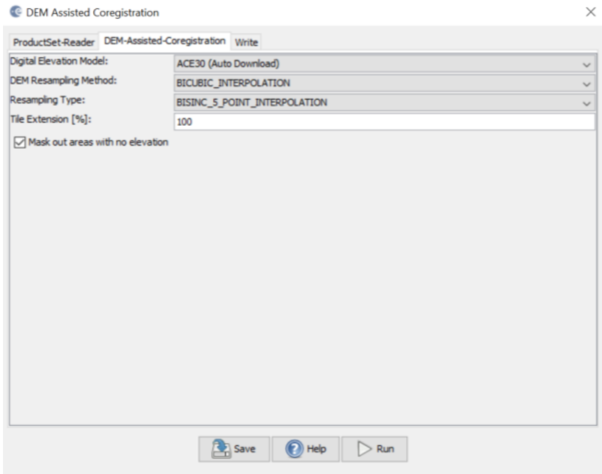


3.2 Coregistration

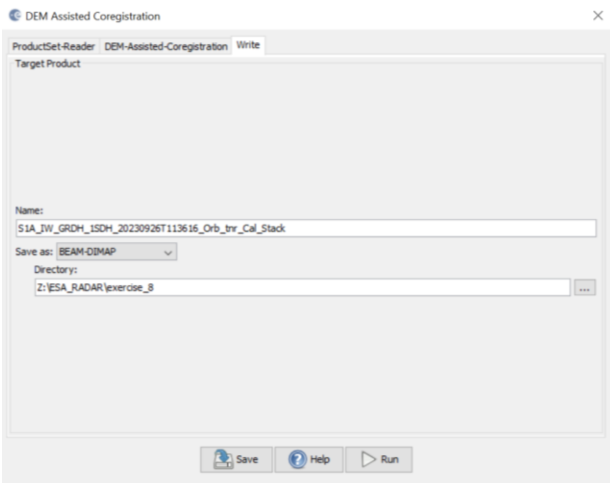
Image coregistration is the process that involves aligning two or more images geometrically, ensuring that corresponding pixels depict the same area on the Earth's surface. While orbit state vectors alone can suffice to coregister images, for precise offset tracking, additional data from a digital elevation model (DEM) is necessary to enhance coregistration accuracy.

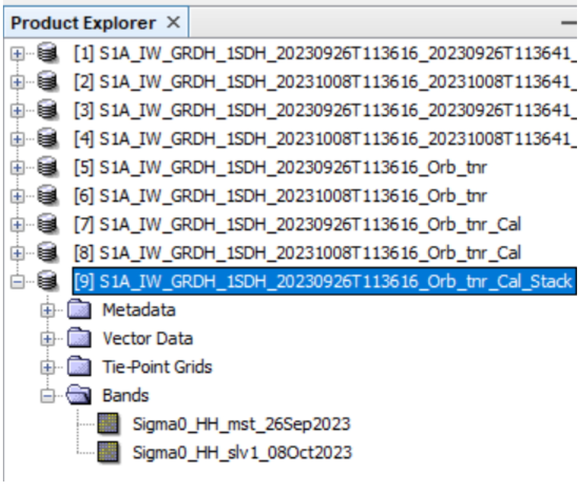
Navigate to Main Menu – Radar – Coregistration – DEM-Assisted Coregistration
In the ProductSet-Reader tab, select/leave only the last two preprocessed products and name the target product
In DEM-Assisted-Coregistration tab set:
"Digital Elevation Model": ACE30 (Auto Download)
DEM Resampling method: BICUBIC_INTERPOLATION
Resampling Type: BISINC_5_POINT_INTERPOLATION





In Write tab name the output product and select the directory to save it. Then, click on RUN. This process may take some time. The resulting product will include two HH polarizations - "mst" = master (the main/first image used for co-registration) and "slv" = slave image.

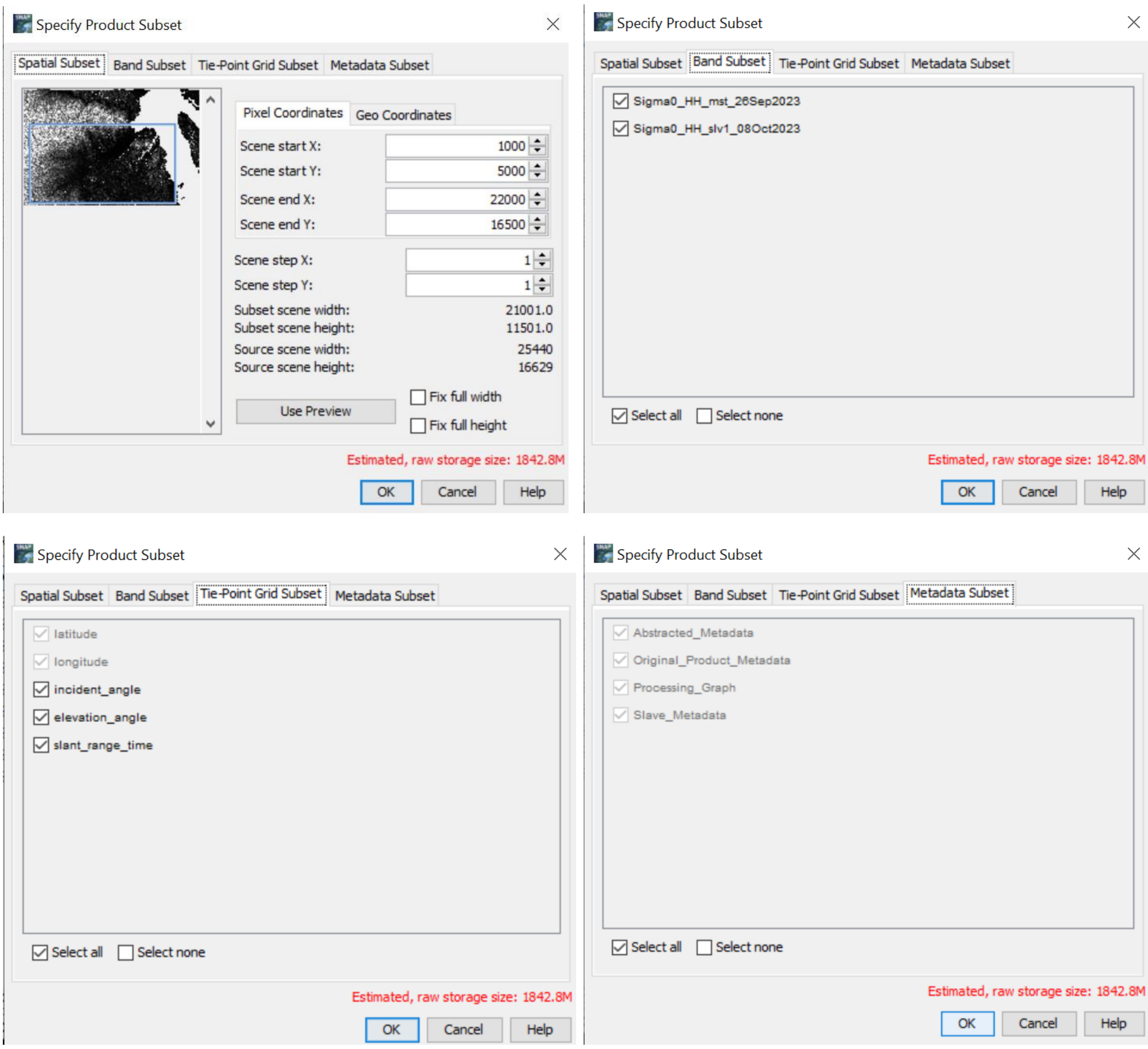




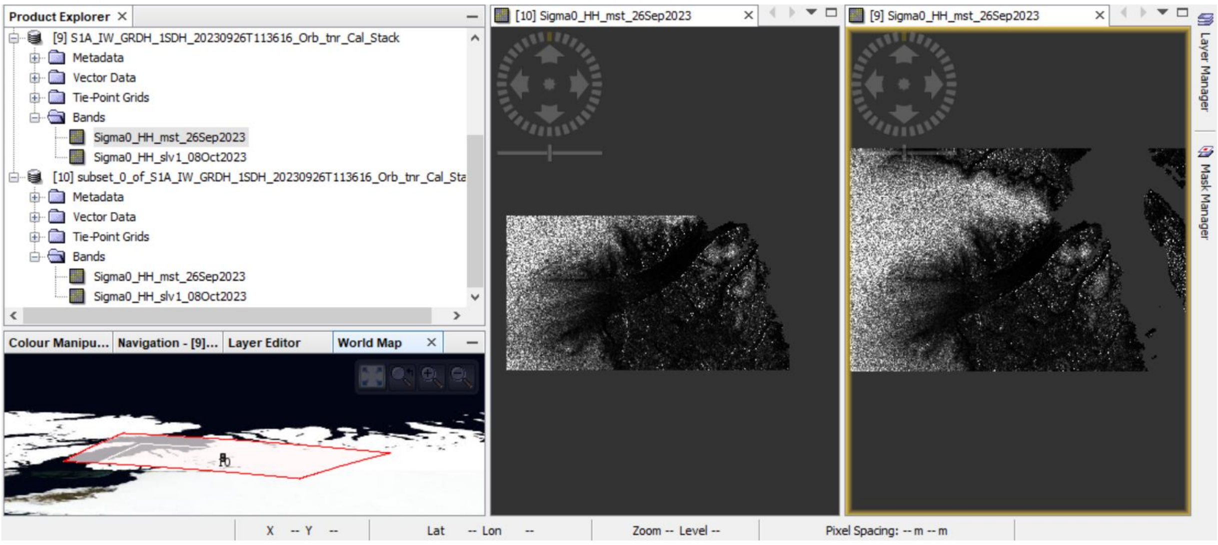
3.1 Create subset

There is no need to process the whole image, instead, we can begin by narrowing down the scene to a more manageable size – creating subset. This approach will decrease processing time in subsequent stages, especially when the analysis is concentrated on a specific area rather than the entire scene.

Go to the Subset tab and at “Pixel Coordinates” set:
Scene start X: 1000
Scene start Y: 5000
Scene end X: 22000
Scene end Y: 16500



Open the subset image and compare it with previous product image of the entire area. Double click on HH polarization rasters in Bands folder to open them. Tile them e.g. Horizontally to compare them.



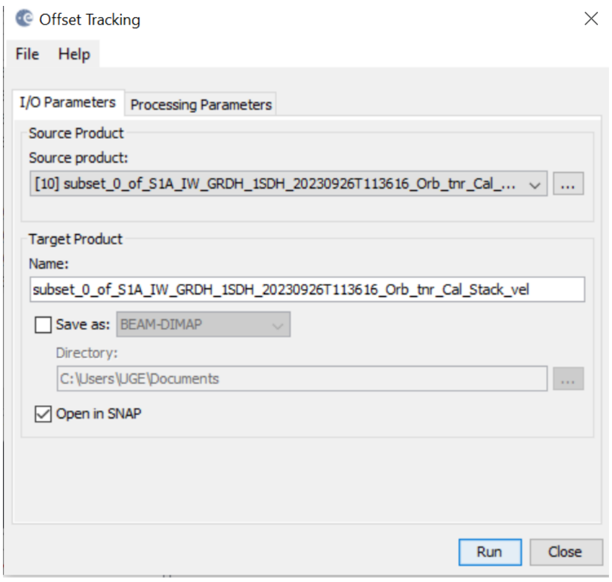
Offset Tracking

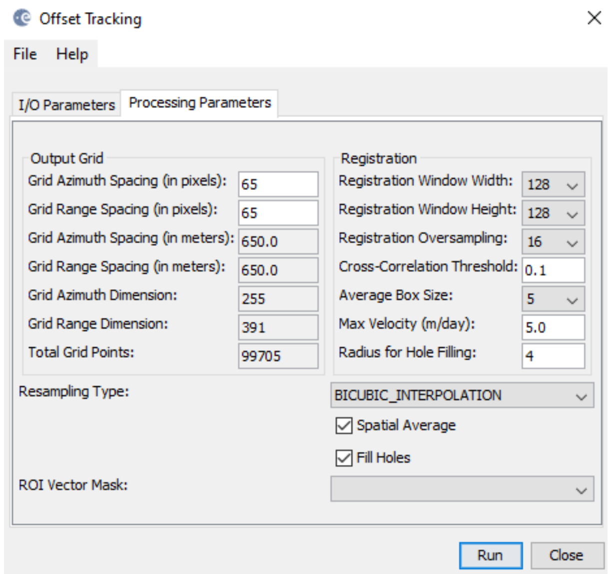
Offset Tracking is employed to determine the movement of a feature between two acquisitions by conducting cross-correlation on designated Ground Control Points (GCP) within coregistered images (master and slave) in both slant-range and azimuth directions. The velocity of movement is subsequently calculated using the offsets derived from the cross-correlation (refer to NOTE 5). The velocities calculated on the GCP grid are then interpolated to generate a velocity map. This method is commonly utilized for estimating glacier motion.

To conduct Offset-Tracking, we must configure various parameters. Initially, we establish the spacing of the Ground Control Point (GCP) grid in pixels in the range and azimuth directions. We opt for a spacing of 60 pixels (equivalent to 600 meters) in both directions, striking a balance between detail and smoothness in our output. It's worth noting that higher resolutions entail longer processing times.

Subsequently, we address the dimensions of the Registration Window. The size of this window hinges on the maximum velocity of the glacier, gleaned from literature or historical data, and the time span between data acquisitions. Given that our images were captured 13 days apart and the maximum speed of the Petermann Glacier is approximately 5 meters per day, the surface of the glacier could potentially shift by a maximum of 60 meters. Consequently, we maintain the default setting of 128 pixels (equivalent to 1280 by 1280 meters). Additionally, to mitigate false high values, we specify the known maximum glacier velocity as 5 meters per day. Therefore, we need to establish:

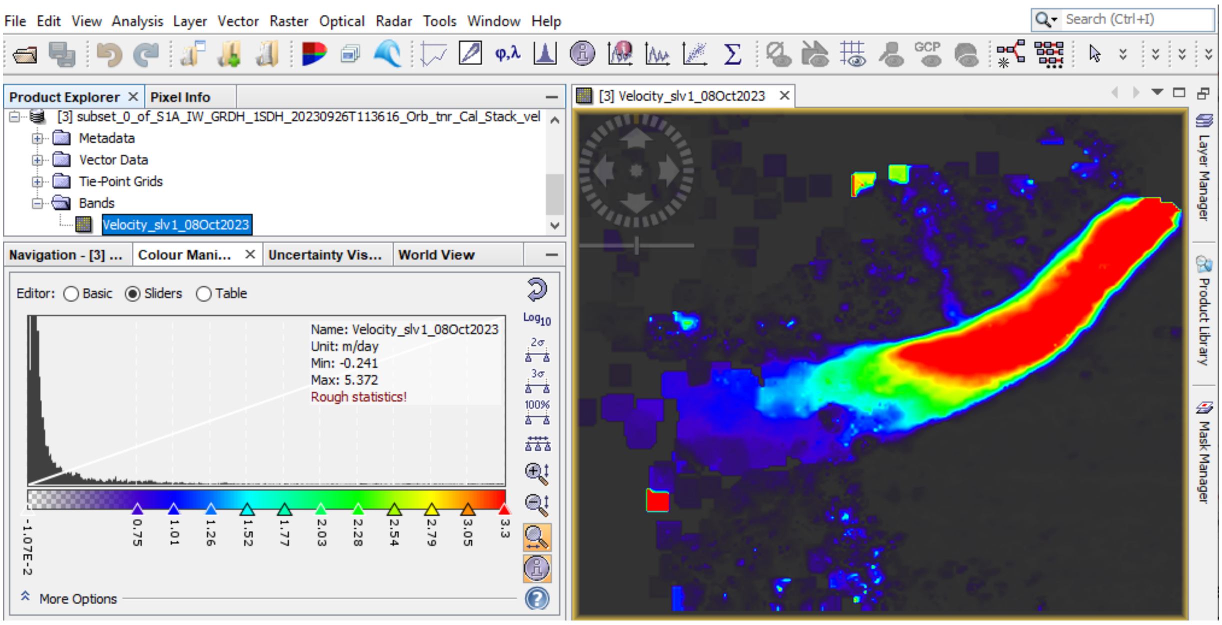
Grid Azimuth Spacing (in pixels): 65
Grid Range Spacing (in pixels): 65
Max Velocity (m/day): 5.0





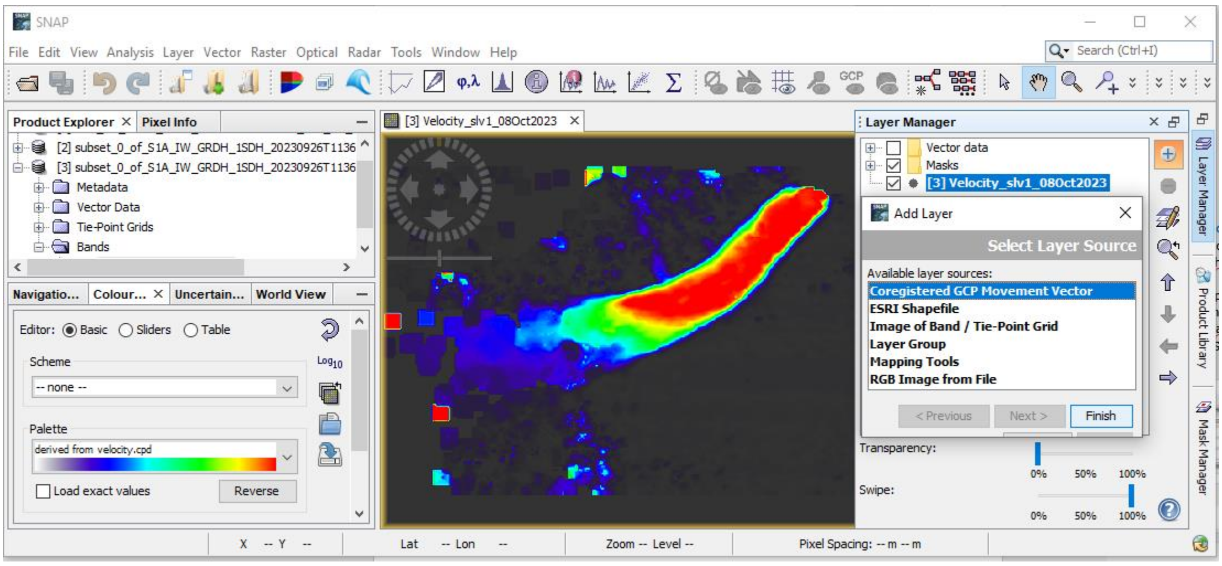
Offset Tracking

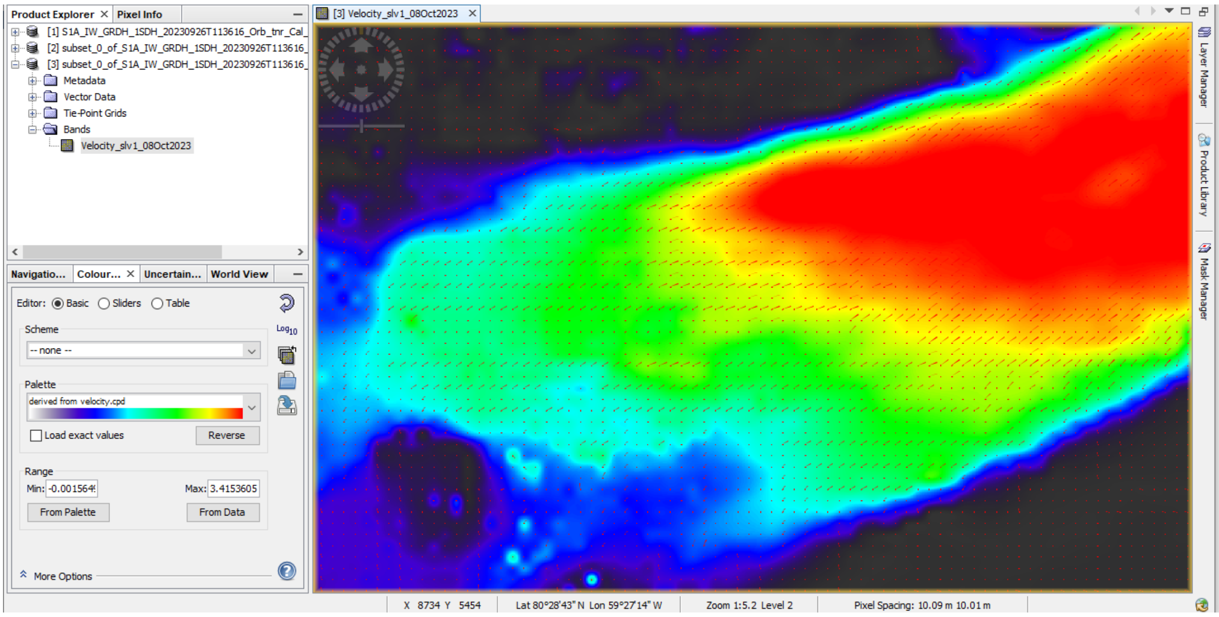
Once the processing finishes, a new product emerges in the Product Explorer window. Extend the velocity product and click twice on the Velocity_slv1_08Oct2023 band to unveil it in the View window.
Open Colour Manipulation tab – select sliders and explore velocity values in m/day in this area.



Add velocity vector to see direction and speed

Navigate to Layer > Layer Manager
From the Layer Manager window, deselect Vector data to remove the grid
Click on the "+" button to open the Add Layer window
In the Add Layer window, click Coregistered GCP Movement Vector and click on Finish. You will see the velocity vectors displayed on the GCP grid showing direction and speed.





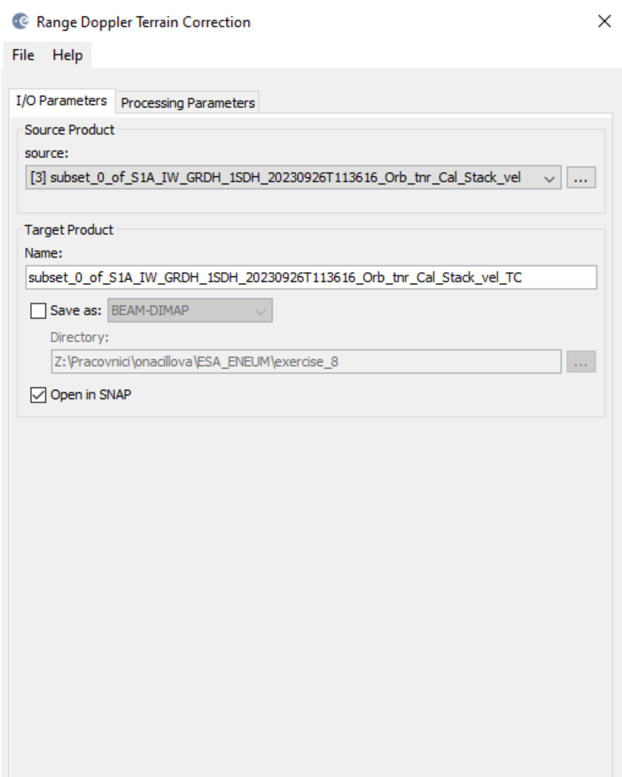
Peterman Glacier velocity vectors. Contains modifed Copernicus Sentinel data 2023

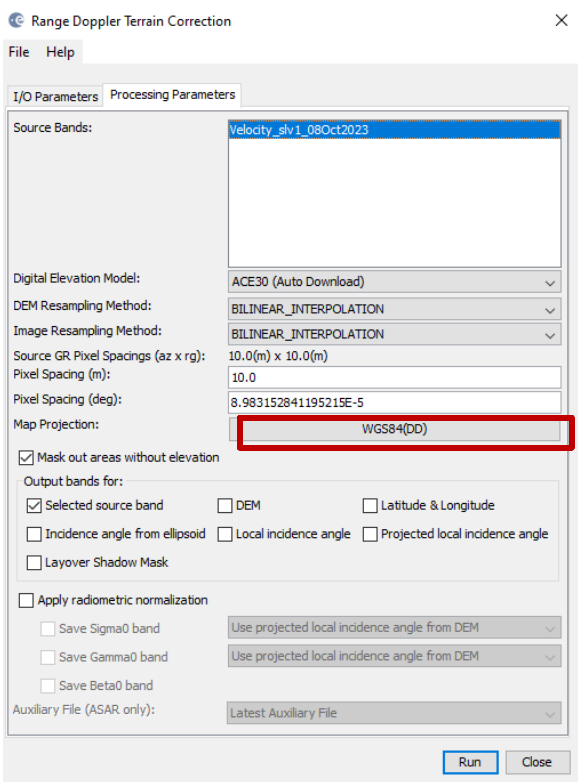
Terrain correction

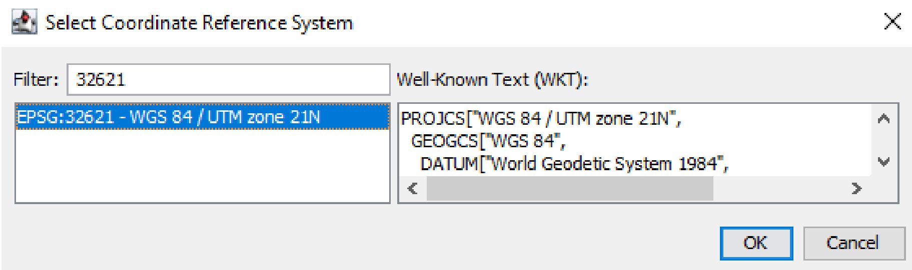
Our data are still in radar geometry, moreover due to topographical variations of a scene and the tilt of the satellite sensor, the distances can be distorted in the SAR images. We need to apply Terrain Correction to compensate for the distortions and reproject the scene to geographic projection.

- Navigate to Main Menu: Radar - Geometric - Terrain Correction - Range-Doppler Terrain Correction
- In the I/O Parameters tab set as "Source Product" the velocity product.
- In "Target Product", keep the default name and set the Directory
- In the Processing Parameters tab set:
- Digital Elevation Model: ACE30 (Auto Download)
- Map Projection: Click on the tab next to Map projection (WGS84(DD) – select Predefined CRS and click on "Select". In "Filter" search for 32621 (EPSG: 32621 – WGS84 / UTM Zone 21N) and when you find it click OK to both windows.

Keep defaults values for the other parameters. Click Run. Approximate processing time: 2.5 minutes.



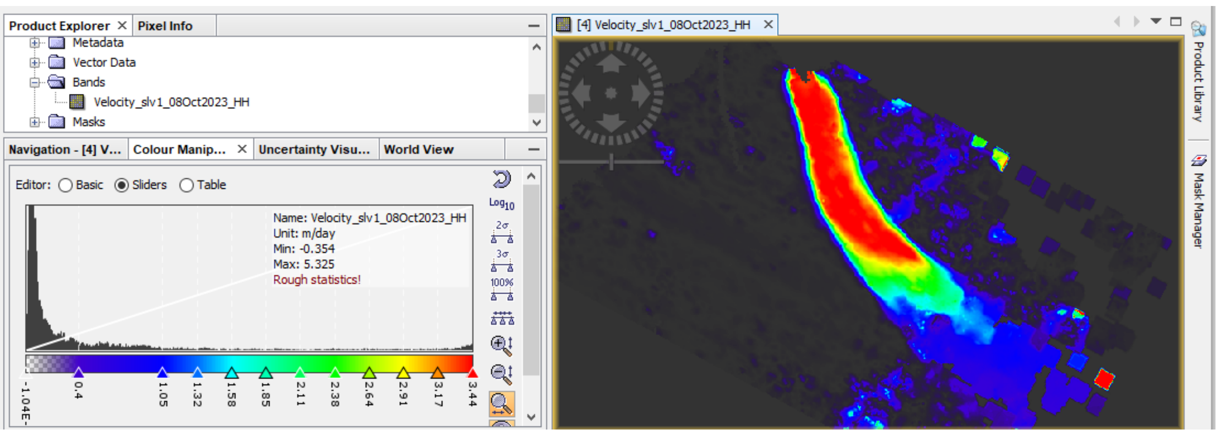




Visualize

Close Range Doppler Terrain Correction window. Let's open the terrain corrected velocity. Expand the new georeferenced product and open the Velocity_slv1_08Oct2023_HH band by double click on it in View window.

We can stretch the histogram a little in the Colour Manipulation tab (move the white slider on the right, to approx. 0.45).



For more information, see the lecture: [9. SAR and optical remote sensing for mapping ice]

THANK YOU FOR FOLLOWING THE EXERCISE!

UNIVERSITY COURSE APPLIED RADAR REMOTE SENSING

EXERCISE 9 – TUTORIAL

Sentinel-1, Sentinel-2 for Snow and Ice using the SNAP software

FUNDED BY EUROPEAN SPACE AGENCY UNDER THE PLAN FOR EUROPEAN COOPERATING STATES, 7TH CALL FOR SLOVAKIA

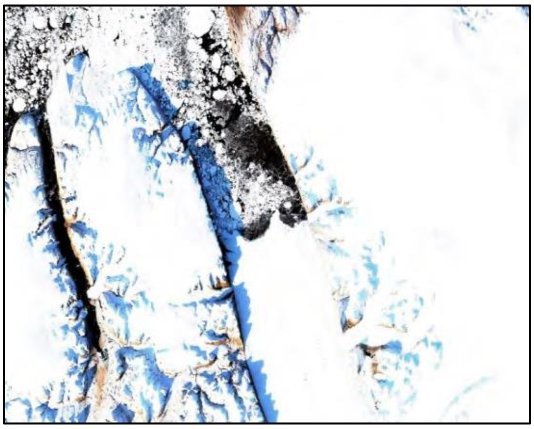
1 | Exercise outline

In this exercise, we will:

- Perform our own sea ice classification using created training data and Random forest classificator
- Understand the capabilities and limitations of Synthetic Aperture Radar (SAR) in detecting and monitoring sea ice.
- Discriminate between open water and different types of the sea ice
- Identify areas with varying degrees of ice deformation
- Perform classification using Sentinel-2 data NDSI

2 | Background

Mapping snow and ice using Sentinel-1 and Sentinel-2 data



Sea ice refers to frozen seawater that forms when ocean water freezes due to low temperatures. It typically occurs in polar regions, such as the Arctic and Antarctic, where temperatures drop low enough for the surface of the ocean to freeze. Sea ice can vary in thickness and extent, ranging from thin, seasonal ice that forms and melts each year to thicker, multi-year ice that persists through multiple seasons.

Sea ice plays a crucial role in regulating the Earth's climate, reflecting sunlight back into space and influencing ocean circulation patterns. Additionally, sea ice provides habitat for various species of marine life and serves as a platform for indigenous communities and scientific research.

Sea ice encompasses various types, including first-year ice formed during a single winter season, and multi-year ice, which survives multiple melt seasons and is thicker and more consolidated. Sea ice can also be categorized into additional types such as deformed ice, level ice, young ice, and open water ice:

Deformed Ice: results from the compression and ridging of sea ice due to the movement and collision of ice floes

Level Ice: refers to relatively flat and uniform sea ice surfaces that have not undergone significant deformation or ridging

Young Ice: Young ice is newly formed sea ice that has not yet reached its maximum thickness or strength.

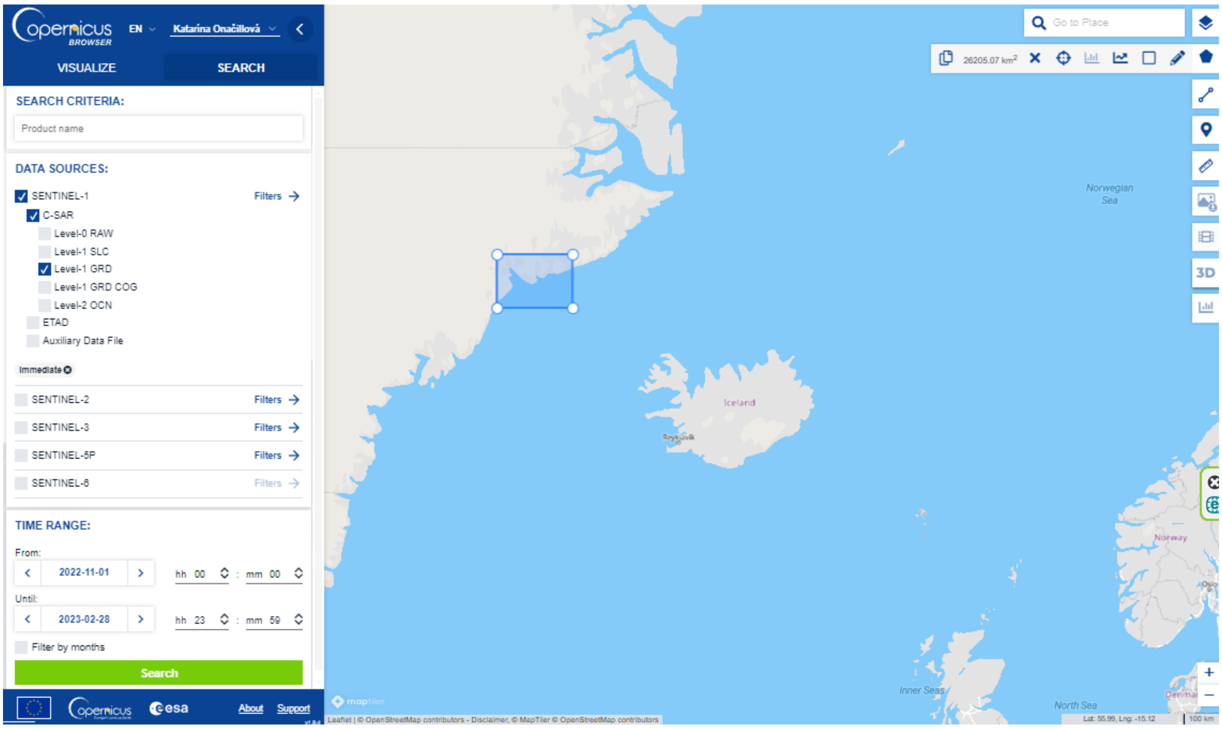
Open Water Ice: describes areas of sea ice where the ice cover has become fragmented or broken, leaving patches of open water exposed.

Sentinel-1 SAR imagery provides all-weather, day-and-night capability, allowing for continuous monitoring of sea ice regardless of atmospheric conditions or sunlight. By analyzing Sentinel-1 SAR images, researchers can monitor changes in sea ice extent, thickness, and movement over time, providing valuable information for climate studies, navigation, and environmental management. Additionally, these data can be used to detect and monitor other features, such as icebergs, ice floes, enhancing our understanding of polar environments and their role in the Earth's climate system.

Sentinel-2 satellite imagery is also valuable for mapping ice due to its high spatial resolution and multispectral capabilities. By capturing detailed images of ice-covered regions, Sentinel-2 facilitates the monitoring of ice extent, ice type classification, glacier movement, and changes in ice dynamics over time.

2.1 Study area and data used

For this exercise, we will use Sentinel-1 GRDH image and Sentinel-2 L2A image over the Straight of Denmark between Greenland and Iceland, downloaded from the Dataspace Copernicus Open Access Hub [@https://dataspace.copernicus.eu/].

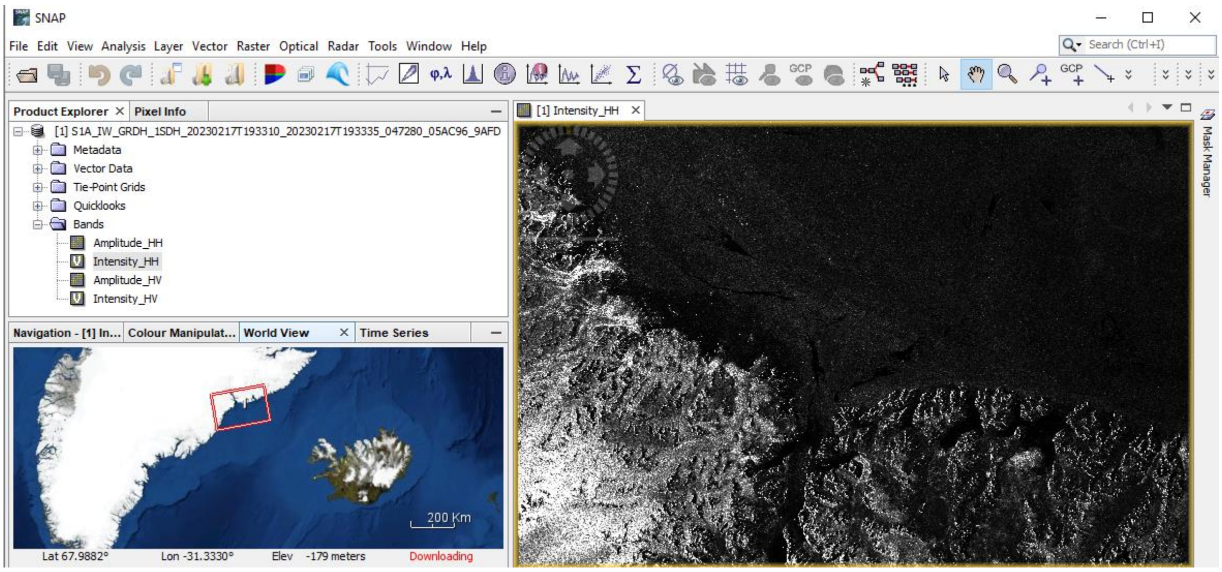


Part A: Sea ice mapping with Sentinel-1

2.2. SNAP - Open and explore product

Open SNAP Desktop, click Open Product and open downloaded Sentinel-1 GRDH product by double click on it. The opened product will appear in Product Explorer window. The Worldview window (at the bottom-left corner) shows the coverage of the image opened. Double click on e.g. „Intensity_HH" band within Bands folder to visualize it.

S1A_IW_GRDH_1SDH_20230217T193310_20230217T193335_047280_05AC96_9AFD.SAFE.zip



2.3 Pre-processing

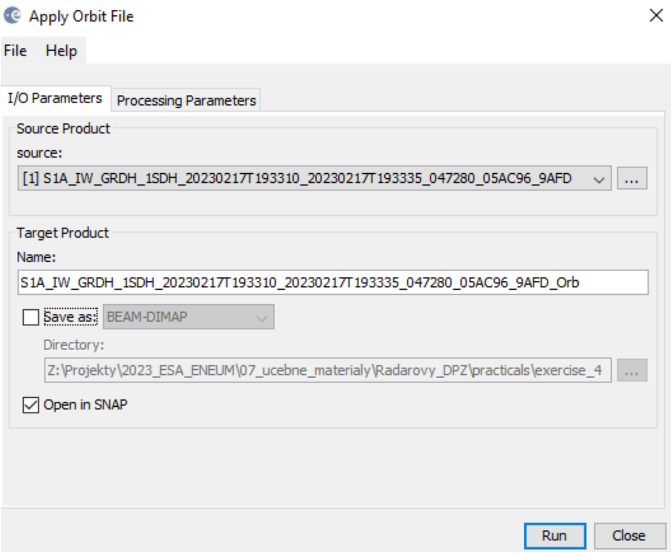
We need to apply identical pre-processing steps to our scene:

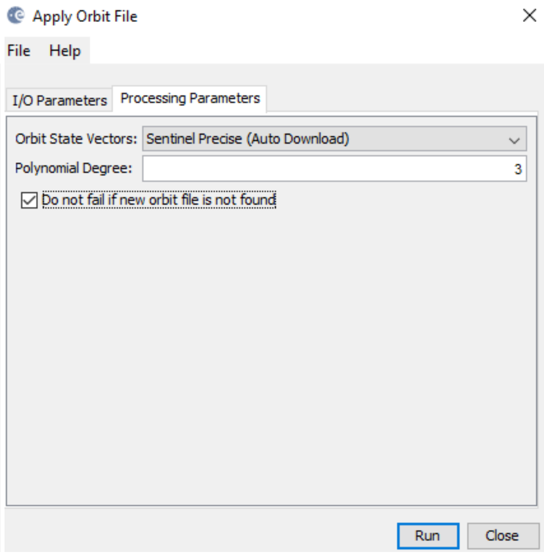
Apply orbit file

Navigate to Main Menu > Radar > Apply orbit file

In the I/O Parameters tab, select the opened product. By default, the output target is set to the same directory and appends „Orb" to the filename. There is no need to save the output as BEAM-DIMAP (we will save the time this way).

In the Processing Parameters accept the default settings and select the option „Do not fail if new orbit file not found"



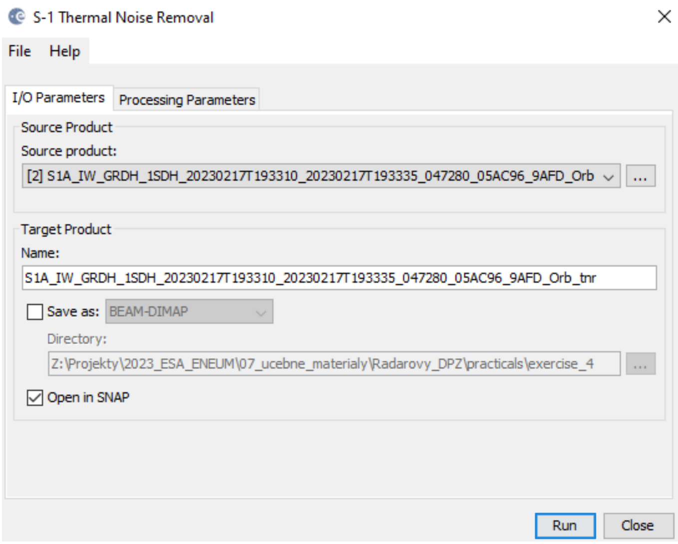


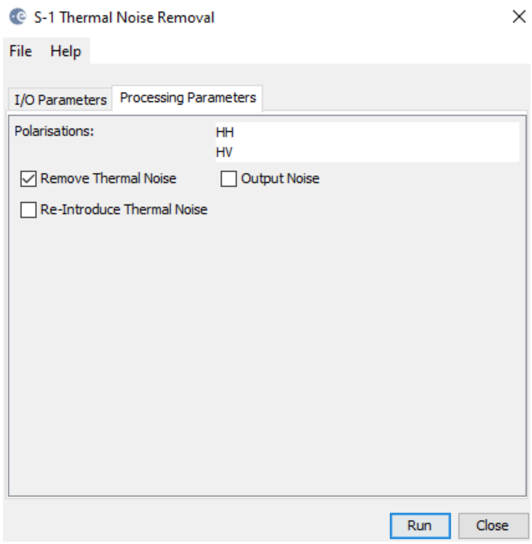
Thermal noise removal

Navigate to Main Menu – Radar > Radiometric > S-1 Thermal Noise Removal

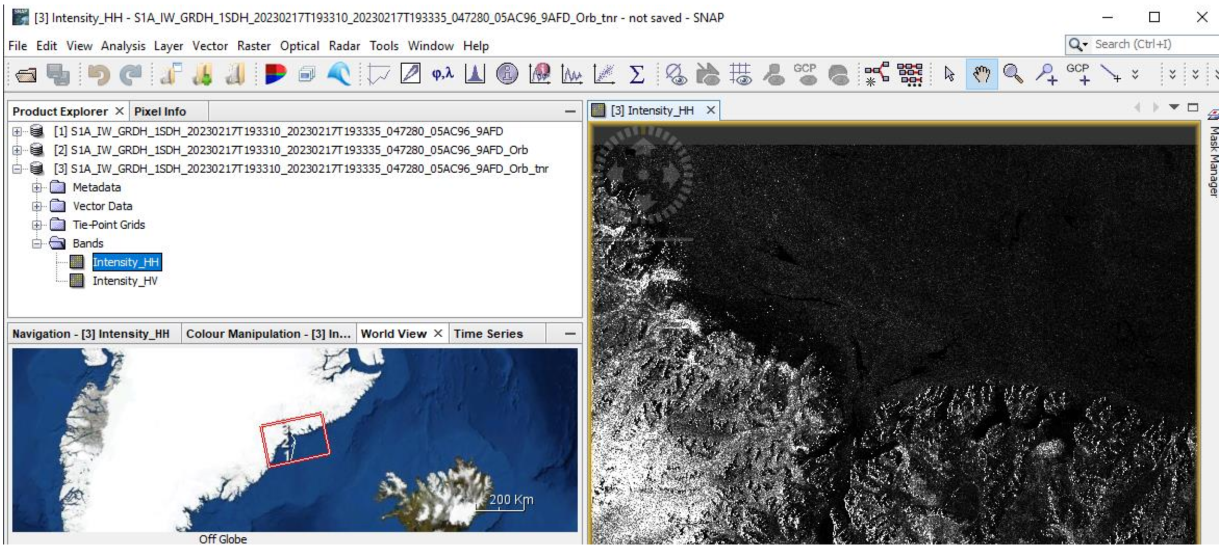
In the I/O Parameters tab, select the product with applied orbit file. By default, the output target is set to the same directory and appends „tnr" to the filename. There is no need to save the output as BEAM-DIMAP.

In the Processing Parameters keep both HH and HV polarisations and make sure that the "Remove Thermal Noise" option is selected.





The image should then look something like this (view e.g. Intensity_HH):



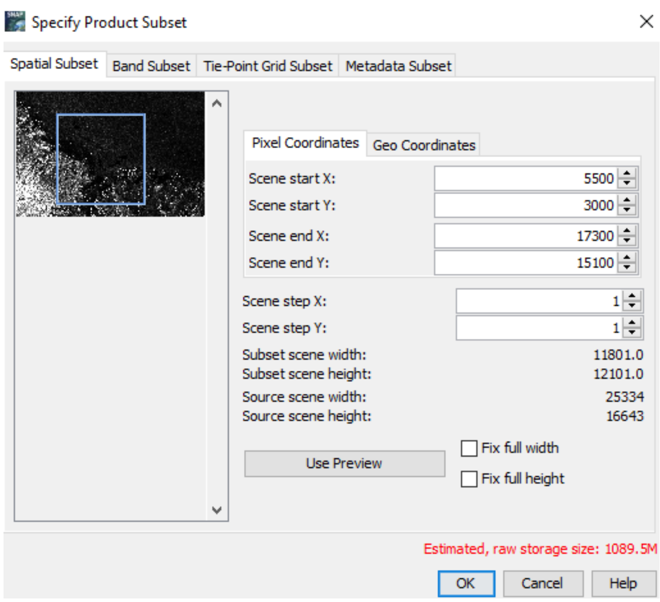
Create subset

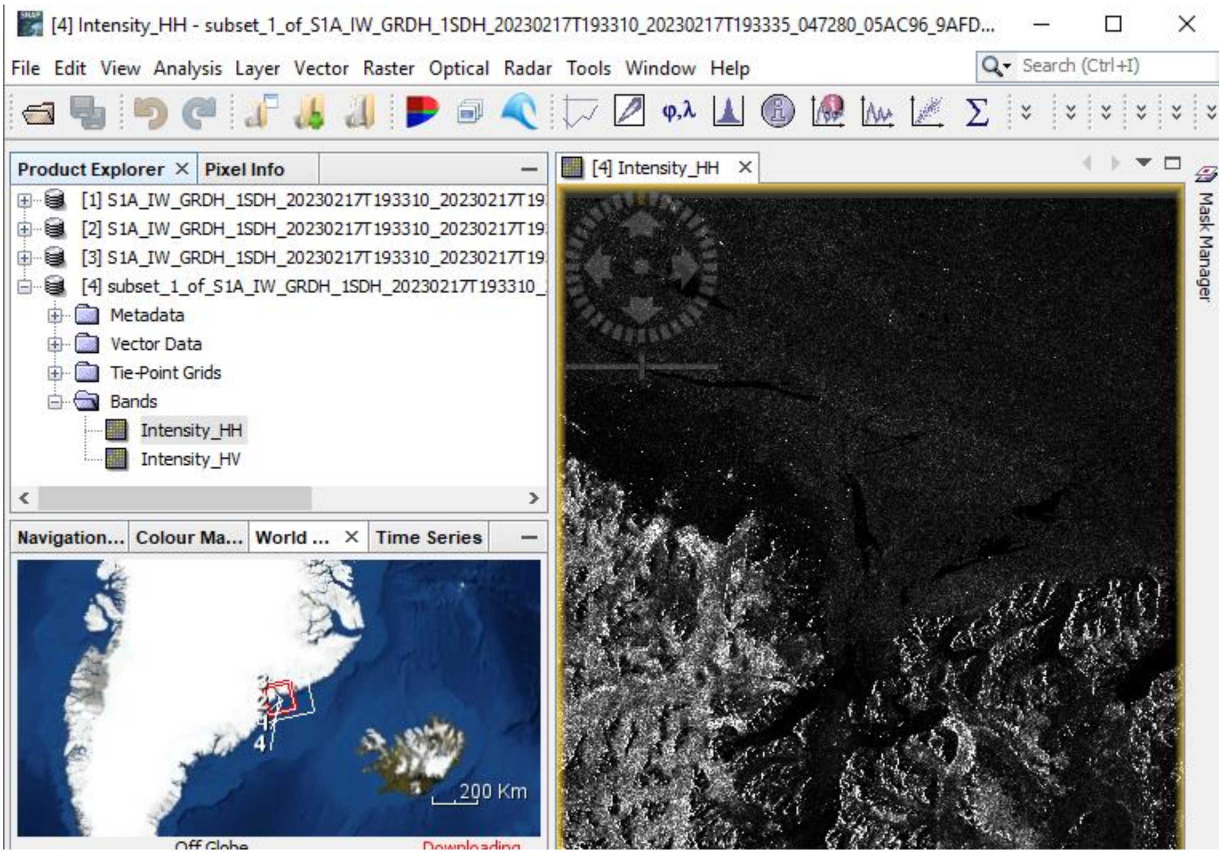
There is no need to process the whole image, instead, we can begin by narrowing down the scene to a more manageable size – creating subset. This approach will decrease processing time in subsequent stages, especially when the analysis is concentrated on a specific area rather than the entire scene.

Select the last product with applied Thermal noise removal. Go to the Subset tab and at "Pixel Coordinates" set:

Scene start X: 5500
Scene start Y: 3000
Scene end X: 17300
Scene end Y: 15100

Now, the image is prepared for classification. Open the final product, e.g. Intensity_HH to see the output image.



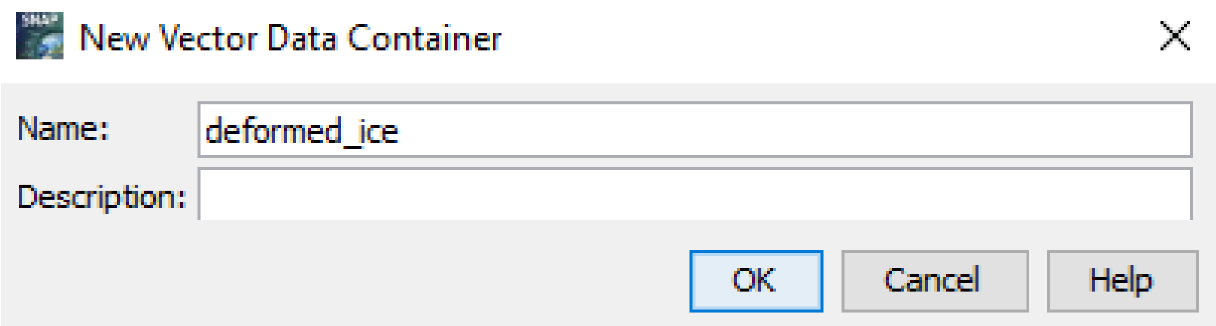


2.4 Image classification

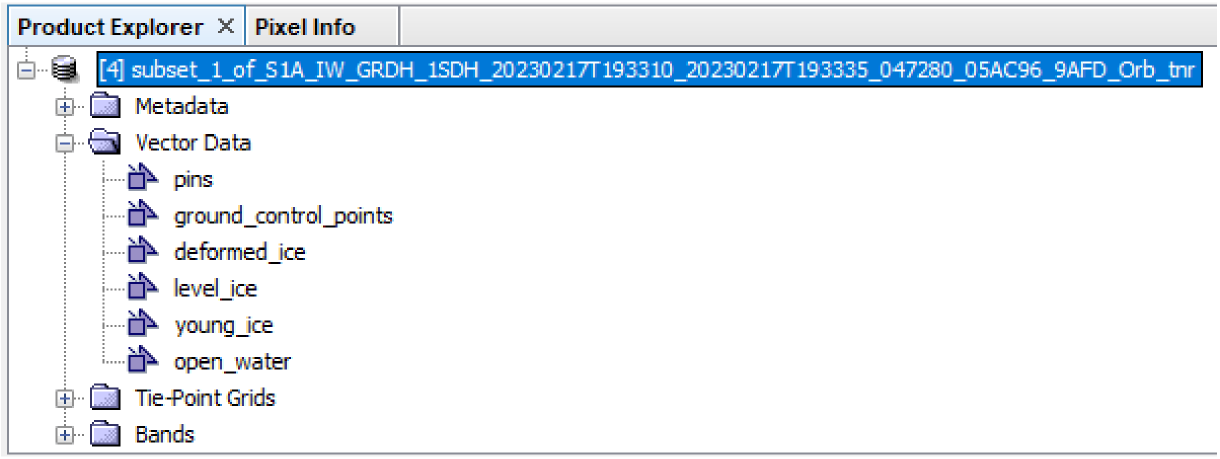
Today we will perform a random forest classification. For this we will create some training data by identifying polygons containing the different ice types:

– Deformed Ice
– Level Ice
– Young Ice
– Open Water

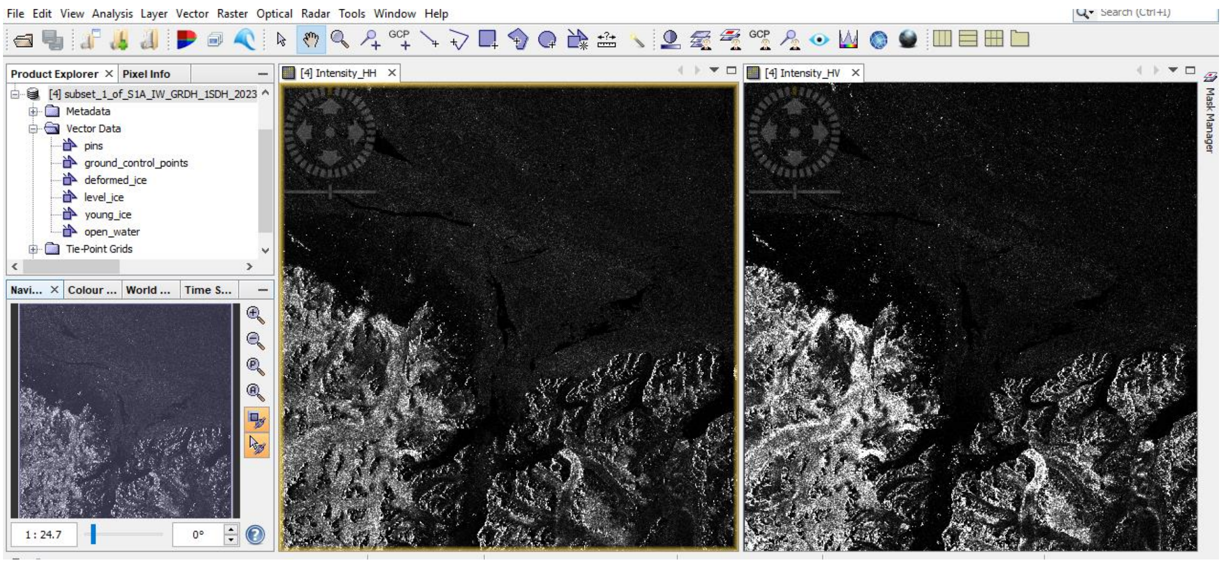
Select the last subset product by clicking on it. Navigate to Vector > New Vector Data Container.
Create four new data containers – separate for each type of ice mentioned above.
Start with creating the data container for, e.g. deformed_ice" and repeat this step for other three types.

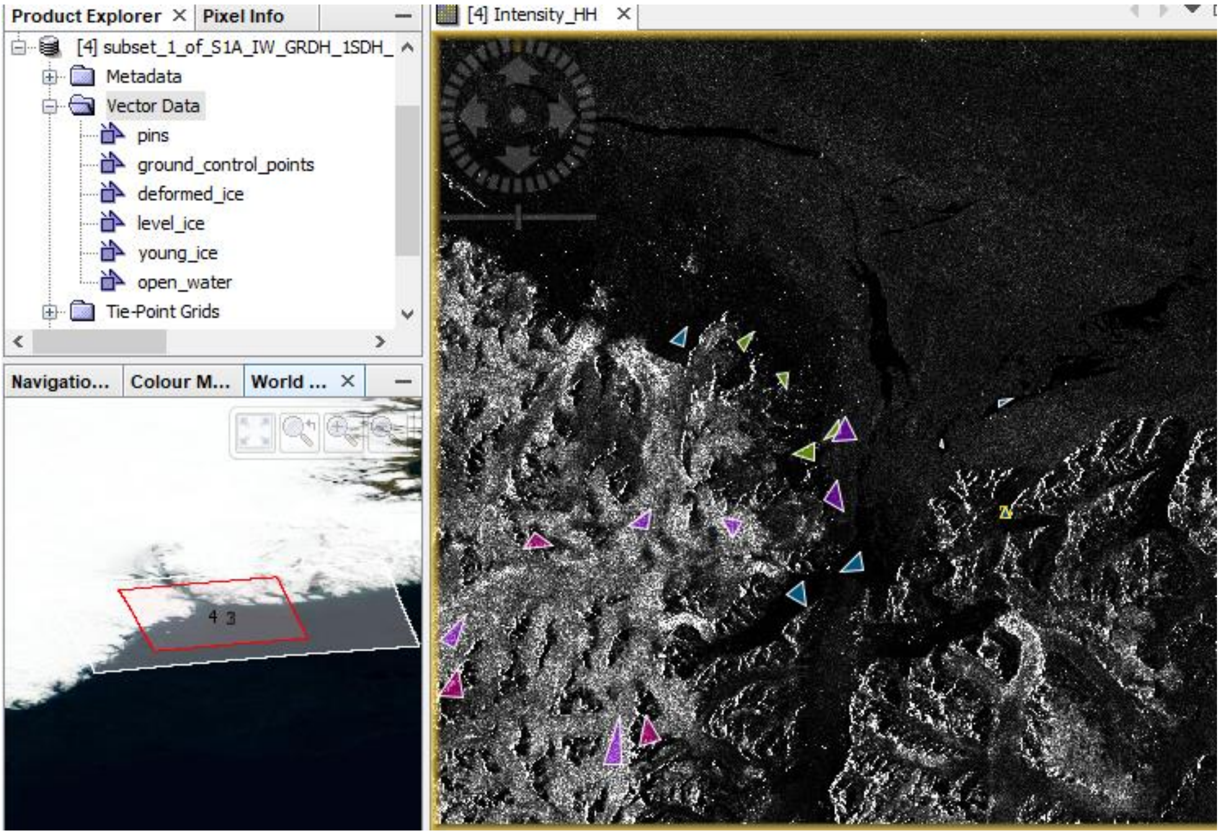


The newly created four vector data containers for each ice type should appear under "Vector Data" in the Product Explorer.



Now let´s start creating training polygons for these different containers on ice type using the Polygon drawing tool:
Open both HH and HV polarisations to better identify different types of ice.by double clicking on them.
Then, click on the icon Tile Horizontally (or navigate to the main menu - Window and select this option).



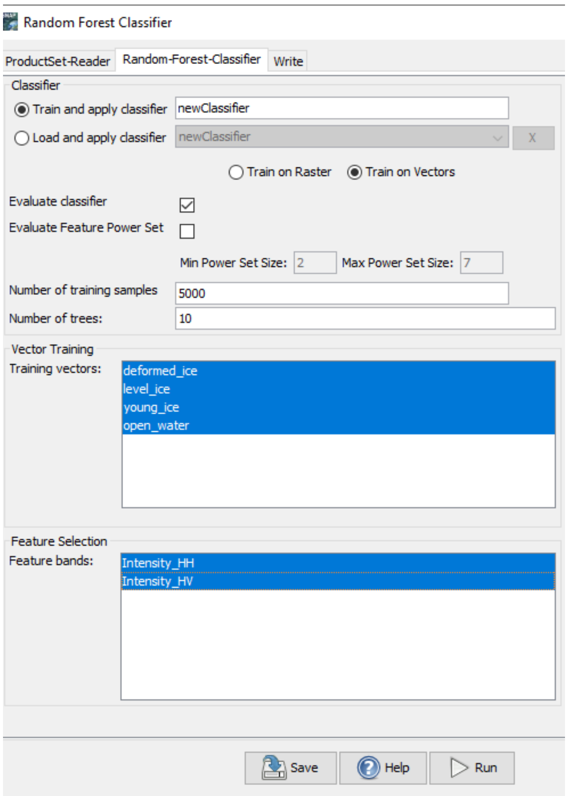


Deformed (Pink), Level (Violet), Young ice (Green) and Open water (Blue) Sea Ice Polygons. Save the final product with your created vector data containers to your folder.

Random Forest image classification

Navigate to Raster > Classification > Supervised classification > Random Forest Classifier

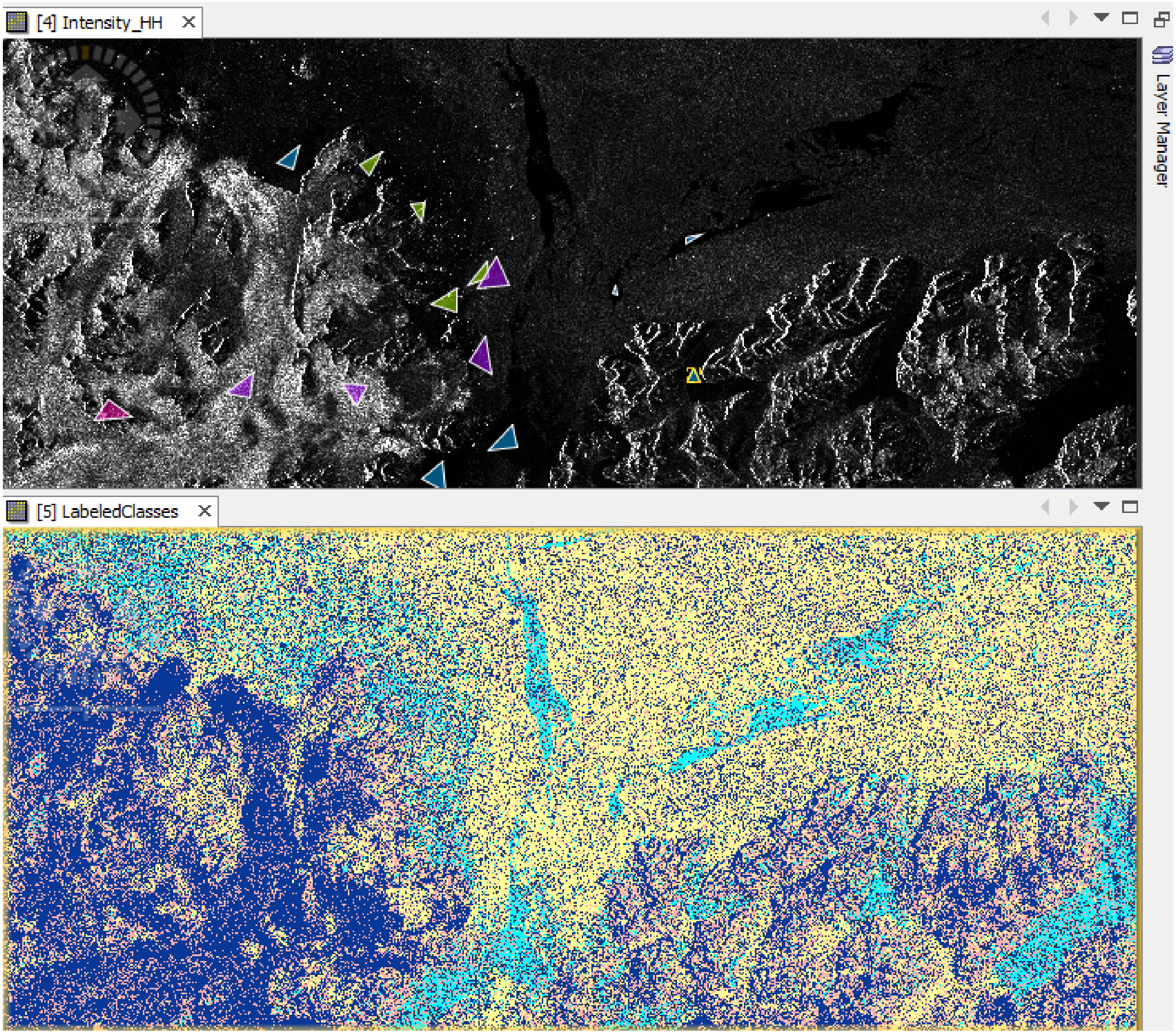
- In the ProductSetReader tab select the saved product with your training data.
- In the Random-Forest-Clasiffier select the classes/training vectors (all our sea ice polygon vector containers) and feature bands (select both Intensity_HH and Intenisty_HV polaristaions) that you'd like to include into image classification.
- In the Write tab by default, the output target is set to the same directory and appends „RF" to the filename.
- Click RUN.



2.5 Post-processing

The final product should now appear in the ProductExplorer. Visualize this output classified image and classes by double-click on the layer „LabeledClasses" under Bands folder in the Product Explorer.

Navigate to Colour Maniulation tab to change the colours of individual sea ice classes and exlore the frequency of these classes through the classified image and table.



Navigation - [5] LabeledClasses | Colour Manipulation - [5] Label... | World Map

Label	Colour	Value	Frequency	Description
no data		-1	0.000%	no data
deformed_ice		0	19.440%	
level_ice		1	42.332%	
young_ice		2	33.787%	
open_water		3	4.442%	

Part B: Sea ice mapping with Sentinel-2

2.6 SNAP - Open and explore product

Open SNAP Desktop, click Open Product and open downloaded Sentinel-2 by double-clik on the metadata „MTL.txt" inside the unzipped folder (or click on Import Product). The opened product will appear in Product Explorer window.

S2A_MSIL2A_20230221T140211_N0509_R010_T25WER_20230221T185001.SAFE.zip

Select (by clicking on it) the product in the Product Explorer window. The Worldview window (at the bottom-left corner) shows the coverage of the image opened.

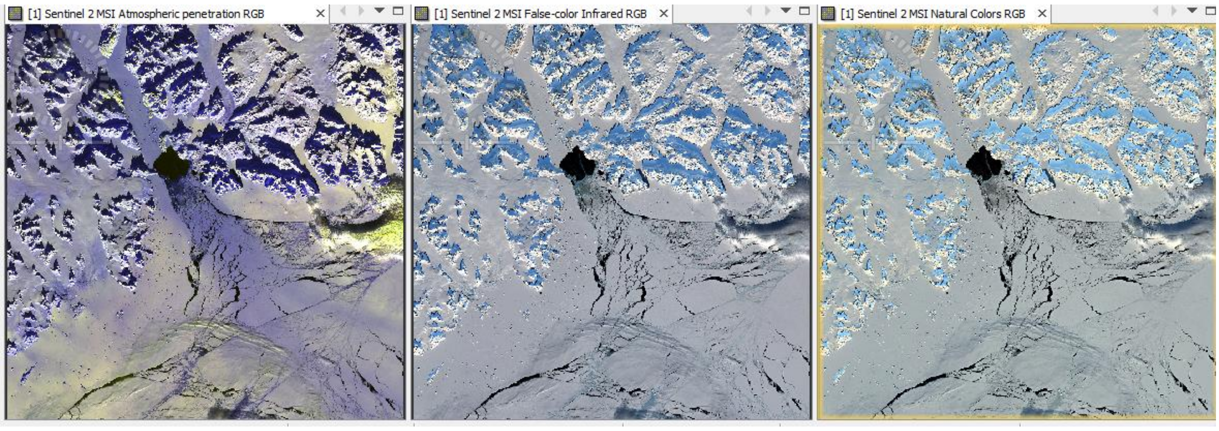
Now, let´s visualize the image using True colour composition:

- Right click on the product.
- Open RGB Image Window.
- In the pop-up window select 'Sentinel 2 MSI Natural colors' (Red: B4; Green: B3; Blue: B2)

Now, let´s visualize the image using False colour composition:
- Right click on the product.
- Open RGB Image Window.
- In the pop-up window select 'Sentinel 2 MSI False Colour-Infrared' (Red: B8; Green: B4; Blue: B3)

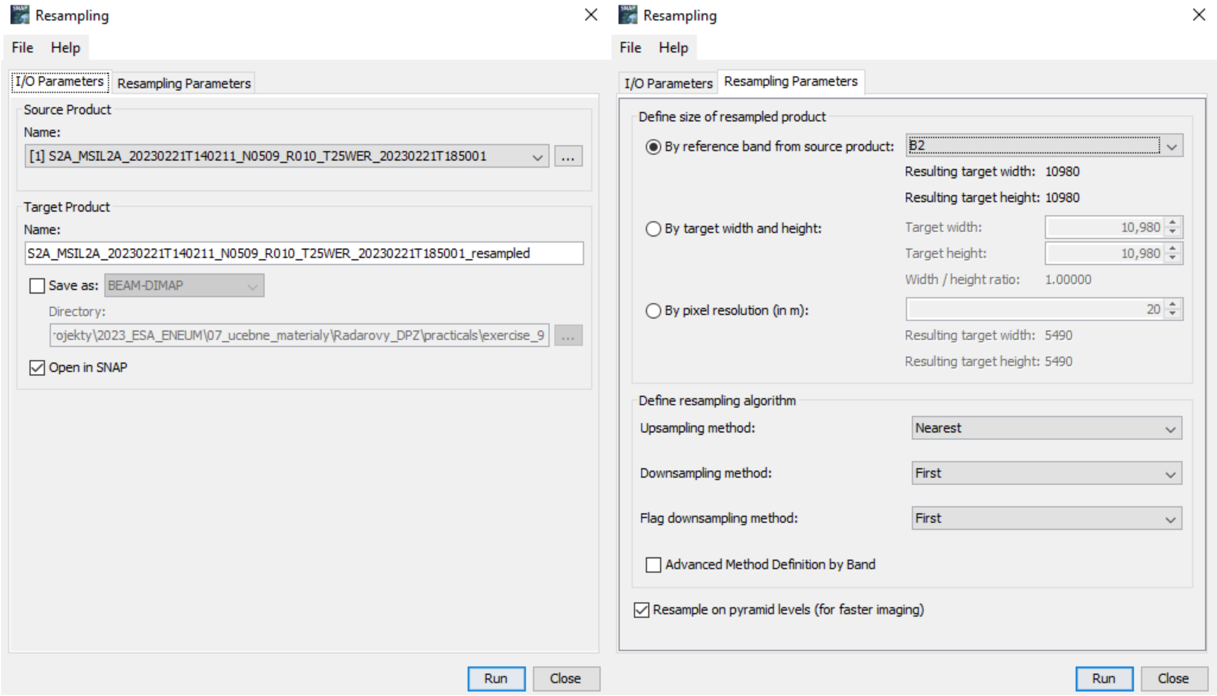
Now, let´s visualize the image using another False colour composition:
- Right click on the product.
- Open RGB Image Window.
- In the pop-up window select 'Sentinel 2 MSI Atmospheric-Penetration' (Red: B12; Green: B11; Blue: B8A)

Tile Windows, e.g. Horizontally, to explore the Sentinel-2 image features.



2.7 Resample

Resample the bands to the pixel size of the VIS bands:
In the main SNAP menu, select Raster > Geometric > Resampling
In the I/O Parameters tab, the source product is set to our only product in the SNAP, change the name of the target resampled product if needed
Do not save the output product - disable the box "Save as:" (if selected).
In the Processing Parameters tab, use e.g. B2 with 10 m resolution to resample all the bands to 10 m as output spatial resolution.



2.8 Normalized Difference Snow Index

Next, we will calculate Normalized Difference Snow Index (NDSI) in SNAP.

The Sentinel-2 NDSI is a ratio of two bands: one in the VIR (Band 3) and one in the SWIR (Band 11). Values above 0.4 are usually snow. The Sentinel-2 NSDI can be used to differentiate between cloud and snow cover as snow absorbs in the short-wave infrared light, but reflects the visible light, whereas cloud is generally reflective in both wavelengths. Most potential cloudy pixels have NDSI values in a range between -0.1 and +0.2.

To calculate NDSI, select the last subset product, navigate to the main SNAP menu and select Raster - Band Maths (deselect the box "Virtual").

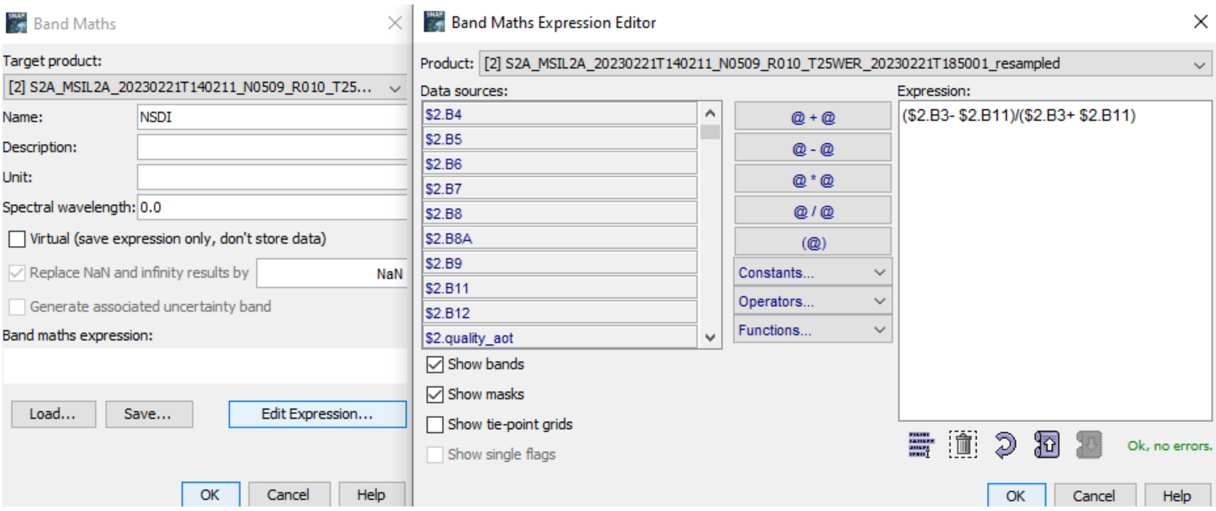
SNAP menu and select Raster - Band Maths (deselect the box "Virtual"). Click on Edit Expression to calculate the NDSI using the equation below and click OK:

$$\rho(VIS) - \rho(SWIR) / \rho(VIS) + \rho(SWIR)$$

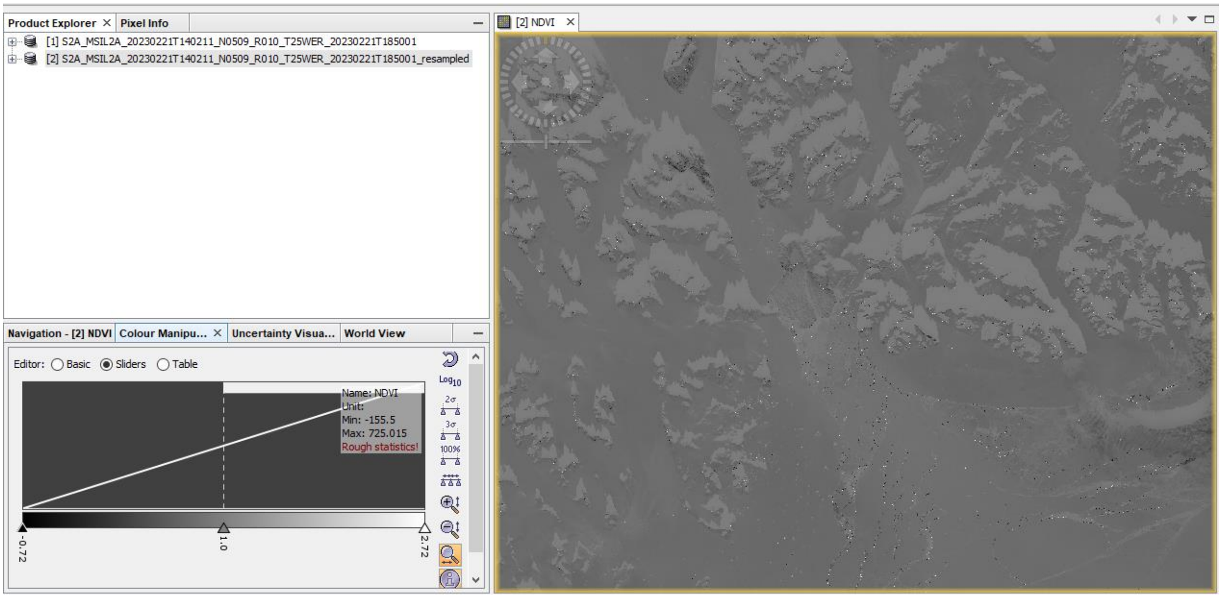
ρ = Top of atmosphere reflectance
VIS = Visible band (0.56 μm)
SWIR = Short-Wave Infrared Band (1.6 μm)

Replace the bands in the equation with the corresponding bands for Sentinel 2:

$$\rho(B3) - \rho(B11) / \rho(B3) + \rho(B11)$$

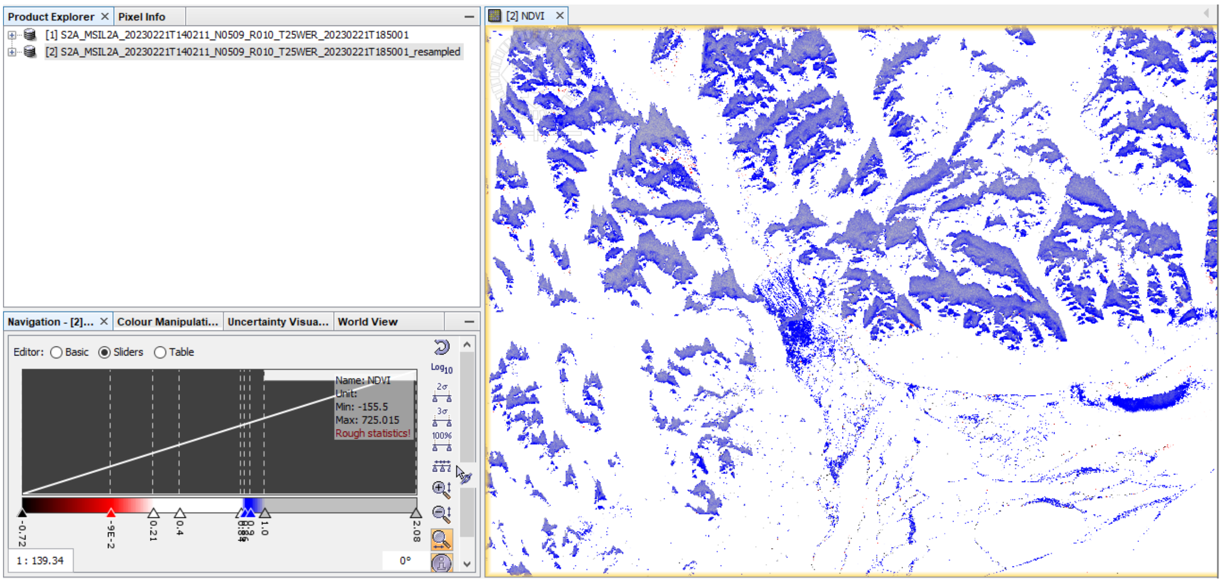


Open the output product in the Product Explorer by double click on the new raster NDSI within Bands folder.
Go to Color Manipulation tab and go to Table – set the thresholds of slider to three values – minimum value, up to 0.4 (usually pixels with no snow), higher than 0.4 (usually snow pixels) and maximum value.



Explore the image: values above 0.4 are usually snow pixels (shades of grey for the lowest probability of snow and shades of white for the highest probability of snow). The Sentinel-2 NSDI can be also used to differentiate between cloud and snow cover as snow absorbs in the short-wave infrared light, but reflects the visible light, whereas cloud is generally reflective in both wavelengths.

Most potential cloudy pixels have NDSI values in a range between -0.1 and +0.2. Add 4 new sliders and change their colour to e.g. red to highlight these values of potentially cloudy pixels.



For more information, see the lecture: [8. SAR and Optical remote sensing for mapping snow]

THANK YOU FOR FOLLOWING THE EXERCISE!

UNIVERSITY COURSE APPLIED RADAR REMOTE SENSING

EXERCISE 10 – TUTORIAL

Flood Monitoring with Sentinel-1 & Sentinel-2 using the SNAP software

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FUNDED BY EUROPEAN SPACE AGENCY UNDER THE PLAN FOR EUROPEAN COOPERATING STATES, 7TH CALL FOR SLOVAKIA

1 | Exercise outline

In this first exercise for mapping floods, we will:

- Detect floods on Sentinel-1 images
- Develop a graph for automated processing using Batch processing
- Create binary mask for flood mapping

2 | Background

Floods, a commonly occurring natural disaster, result in significant damage to both lives and property. Timely information on floods is critical for emergency response. Rapid estimation of flood extent is essential for disaster risk assessment and spatial planning. Remote sensing and satellite imagery play pivotal roles in flood monitoring and mapping. Optical remote sensing, for instance, is utilized for dynamic flood monitoring by exploiting water's low reflectance in infrared bands and high reflectance in blue/green bands.

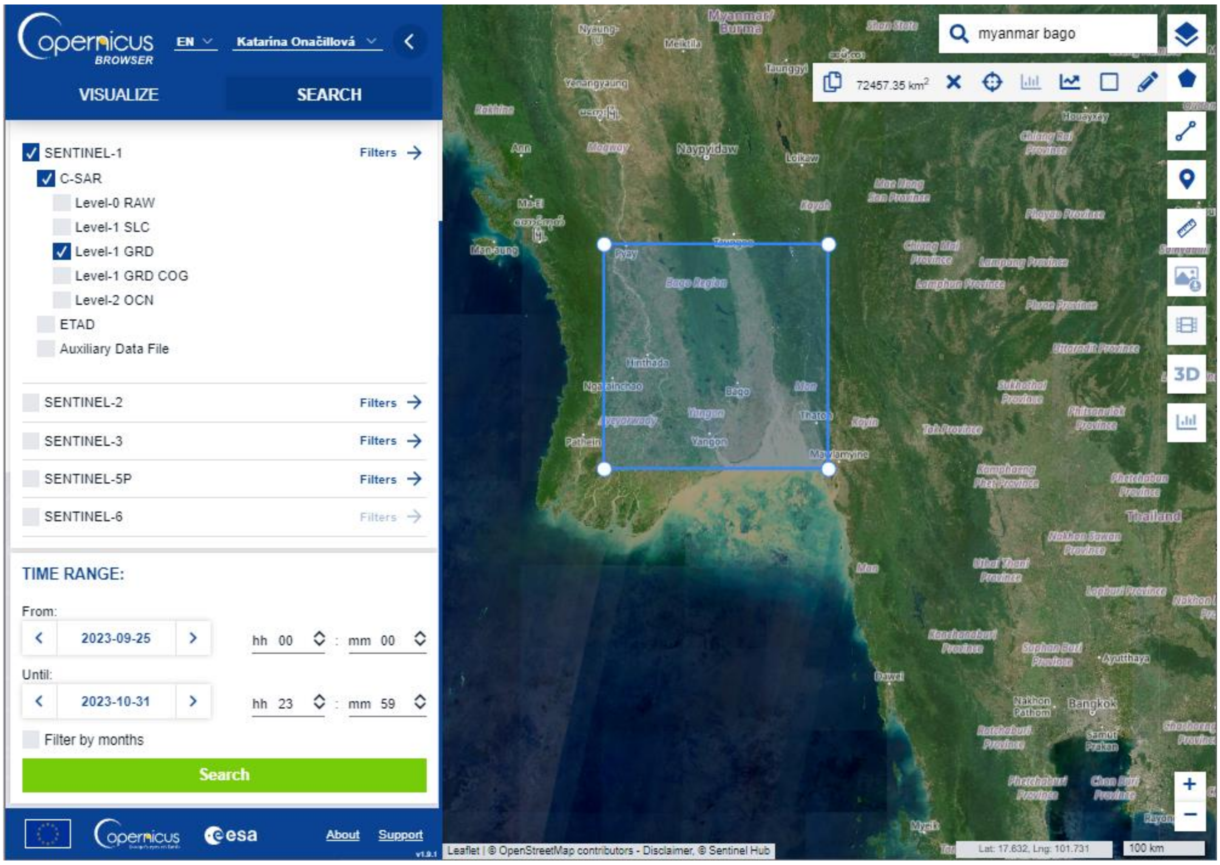
However, during severe weather conditions with heavy rainfall and intense cloud cover, optical remote sensing may struggle to provide accurate information due to a lack of cloud-free, high-quality images and difficulty in detecting water under vegetation cover.

Since October 4, 2023, the Myanmar Department of Meteorology and Hydrology (DMH) has been issuing flood advisory warnings and weather system alerts regarding water levels in major rivers. Between October 5 and 9, heavy rainfall during the late monsoon season resulted in extensive flooding in southern Myanmar. On October 9, the DMH reported that Bago township received an unprecedented 7.87 inches (200 millimeters) of rainfall, the highest recorded in 59 years. By October 10, the water level of the Bago River rose 4 feet above the danger level, leading to widespread flooding in urban and suburban areas. The impact of this flooding has been significant, affecting families, croplands, and causing displacement of people in areas including Bago City, Yangon, Taik Kyi, Hlegu, and Hmawbi townships. (DREF OPERATION Myanmar Flood 2023)

Synthetic Aperture Radar (SAR) datasets offer significant benefits in flood observation as they emit electromagnetic waves that are unaffected by weather and time of day. The Sentinel-1 satellite, which provides extensive global data coverage, can effectively detect flooding in vegetated or urban areas due to its high penetration capability.

2.1 Study area and data used

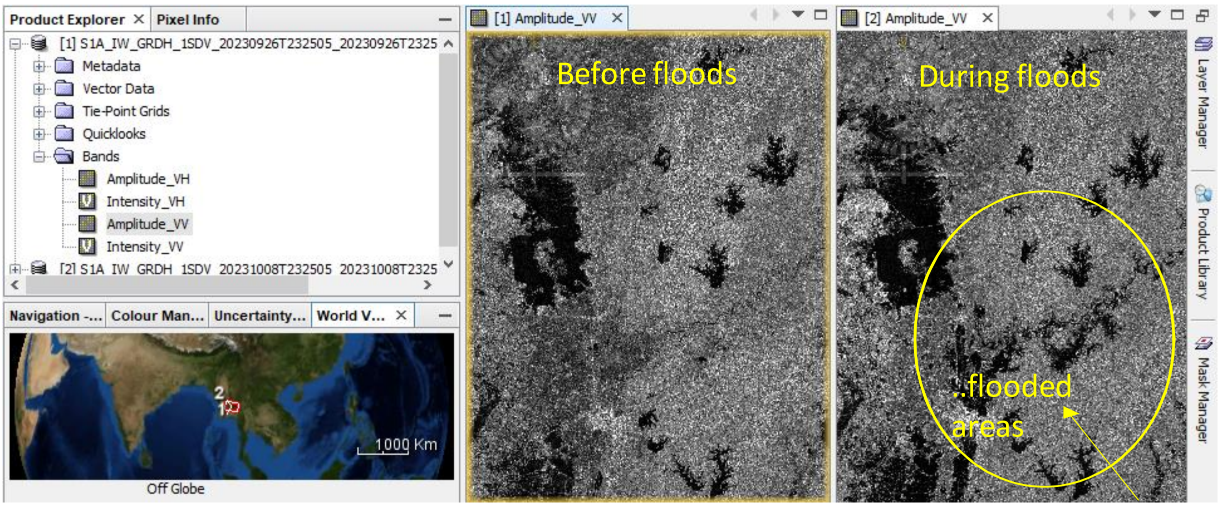
For this exercise, we will use two Sentinel-1 GRD images of the same area near Bago city, Myanmar, downloaded from the Dataspace Copernicus Open Access Hub [@https://dataspace.copernicus.eu/].



2.2. SNAP - Open and explore product

Open SNAP Desktop, click Open Product and open 2 downloaded products by double click on them. The opened products will appear in Product Explorer window. Go to Windows – Tile them e.g. Horizontally.

S1A_IW_GRDH_1SDV_20230926T232505_20230926T232530_050505_061540_C745.SAFE.zip
S1A_IW_GRDH_1SDV_20231008T232505_20231008T232530_050680_061B43_DCF8.SAFE.zip



3.1 Pre-processing

We need to apply identical pre-processing steps to both of our scenes:

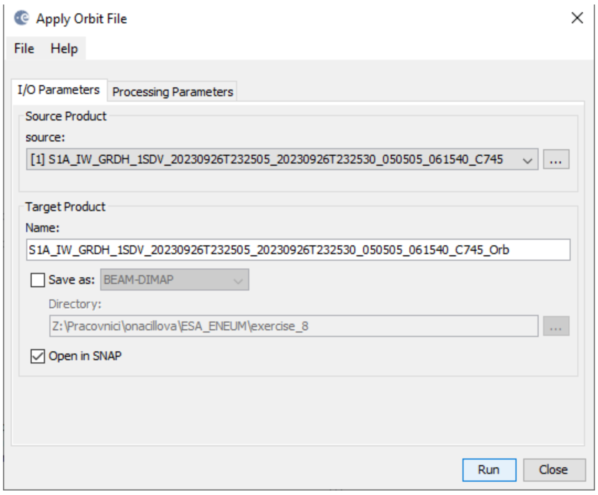
Apply orbit file

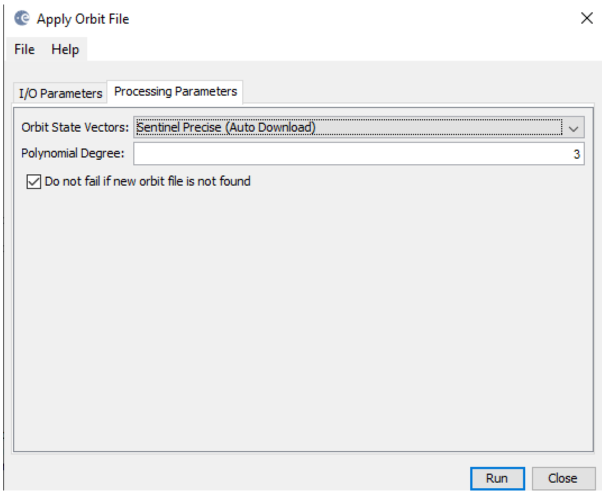
Navigate to Main Menu – Radar – Apply orbit file

In the I/O Parameters tab, select the first product and name the target product. There is no need to save the output as BEAM-DIMAP (we will save the time this way)

In the Processing Parameters accept the default settings and select the option „Do not fail if new orbit file not found"

Repeat for the second image.





Create subset

There is no need to process the whole image, instead, we can begin by narrowing down the scene to a more manageable size – creating subset. This approach will decrease processing time in subsequent stages, especially when the analysis is concentrated on a specific area rather than the entire scene.

Select the last product with applied orbit file.

Go to the Subset tab and at "Pixel Coordinates" set:

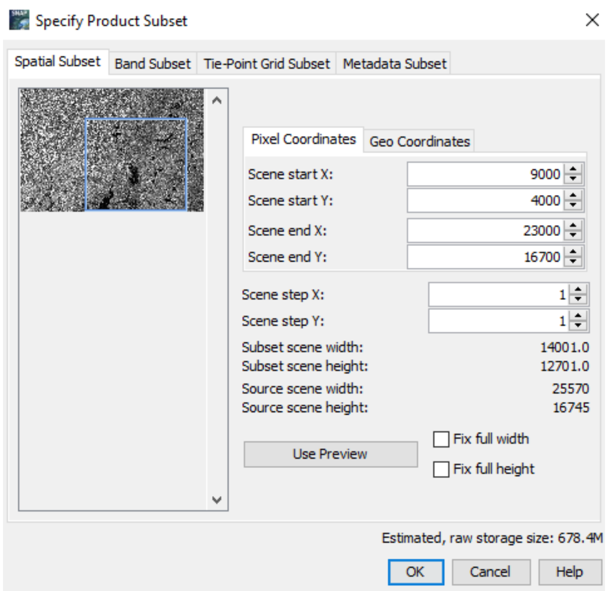
Scene start X: 9000

Scene start Y: 4000

Scene end X: 23000

Scene end Y: 16700

Repeat for the second image.



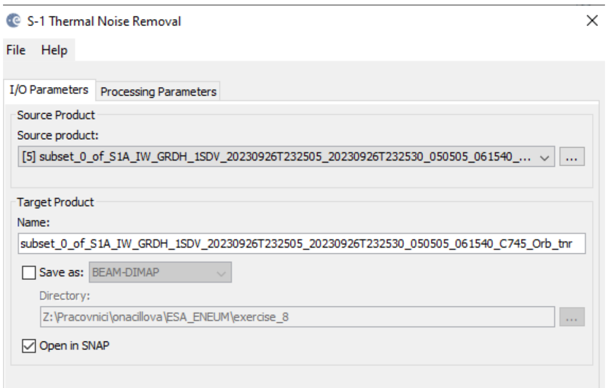
Thermal noise removal

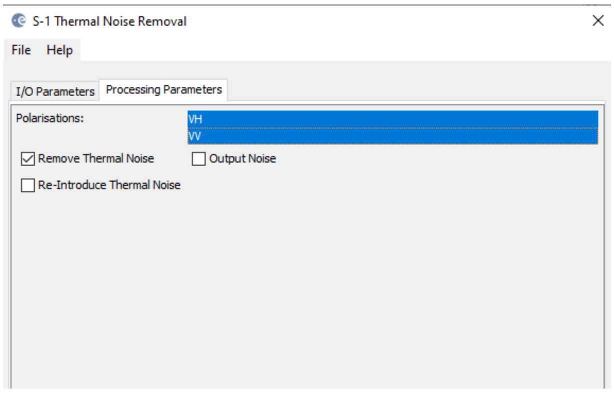
Navigate to Main Menu – Radar – Radiometric – S-1 Thermal Noise Removal

In the I/O Parameters tab, select the last subset product with applied orbit file and name the target product. There is no need to save the output as BEAM-DIMAP (we will save the time this way)

In the Processing Parameters you can select both polarization and make sure that the "Remove Thermal Noise" option is selected.

Repeat for the second subset image.





Calibration

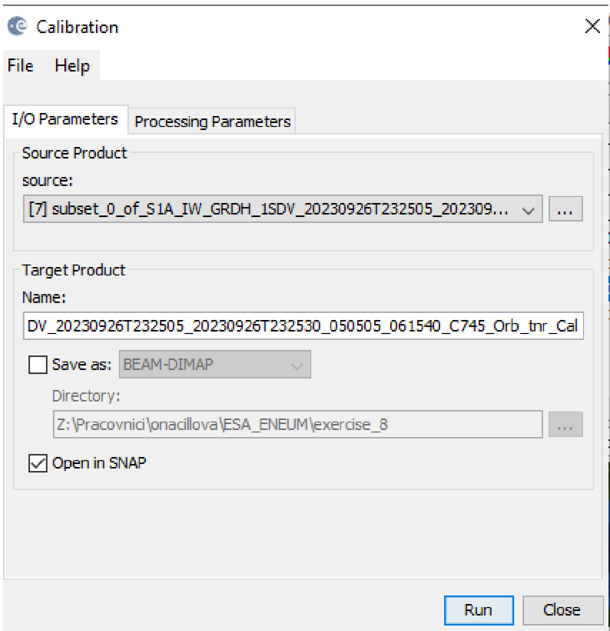
With our image now subsetted and with TNR, we must apply image calibration. This step is necessary to normalize the values in the image into backscatter values so we can compare multiple images in a time series.

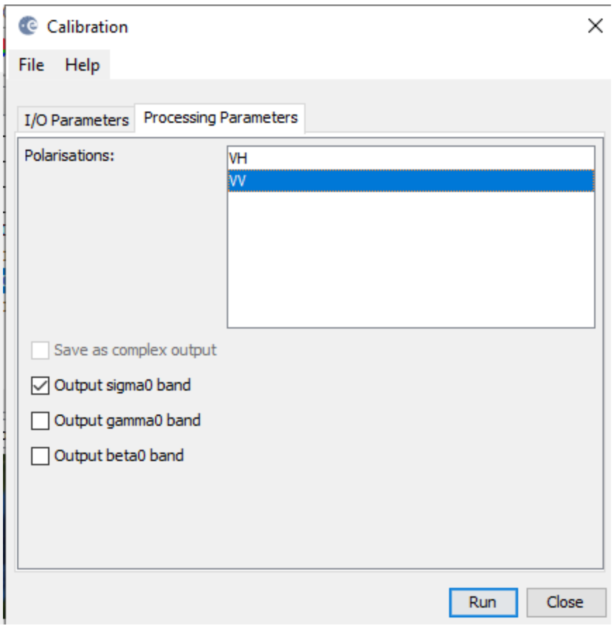
Navigate to Main Menu – Radar – Radiometric – Calibrate

In the I/O Parameters tab, select the product with thermal noise removal and name the target product. In the case of this final product of preprocessing, please, save it to your folder for this exercise

In the Processing Parameters select the VV band as input and accept all default settings and then click Run

Repeat for the second image. The saving might take some time.

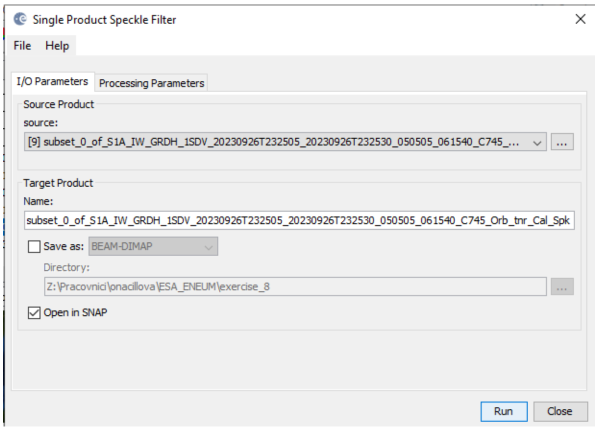


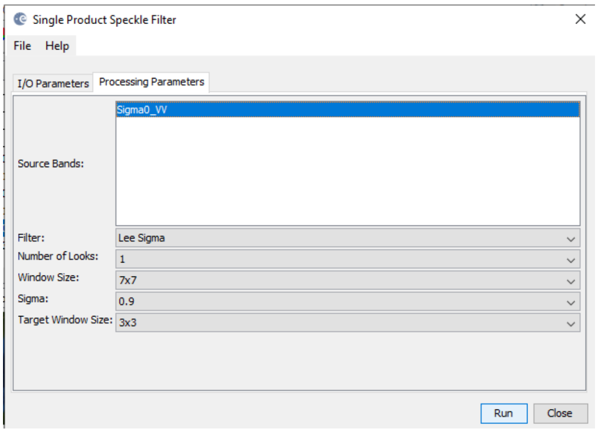


Speckle Filter

Despeckling removes thermal noise introduced by the sensor from the image to remove potential sources of error in analysis.

Navigate to Radar > Speckle Filtering Single Product Speckle Filter. In the Speckle-Filter tab, choose the simple Lee Sigma filter with default window sizes.



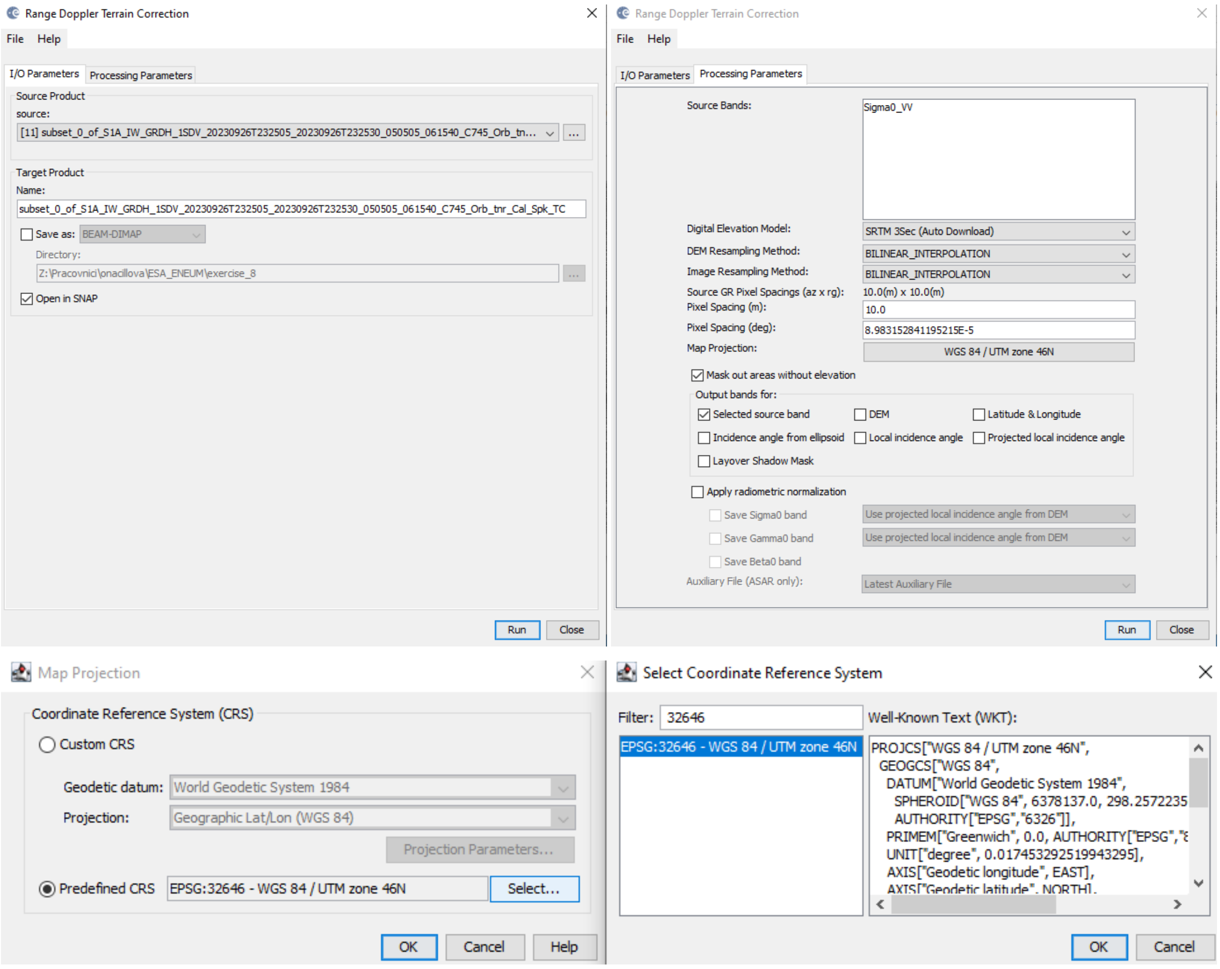


Terrain-Correction

Navigate to Radar – Geometric – Terrain Correction – Range Dopler Terrain Correction. The last step in our graph for image pre-processing is to apply terrain correction to the product, ensuring that all the pixels are moved to the right locations (eg if the nadir angle of the image is off, it will align the pixels correctly so it is closer to a top-down view of the imagery).

Our data are still in radar geometry, moreover due to topographical variations of a scene and the tilt of the satellite sensor, the distances can be distorted in the SAR images. We need to apply Terrain Correction to compensate for the distortions and reproject the scene to geographic projection.
Navigate to Main Menu: Radar - Geometric - Terrain Correction - Range-Doppler Terrain Correction
In the I/O Parameters tab set as "Source Product" the velocity product.
In "Target Product", keep the default name and set the Directory
In the Processing Parameters tab set:
Digital Elevation Model: ACE30 (Auto Download)
Map Projection: Click on the tab next to Map projection (WGS84(DD) – select Predefined CRS and click on "Select". In "Filter" search for 32621 (EPSG: 32646 – WGS84 / UTM Zone 46N) and when you find it click OK to both windows.

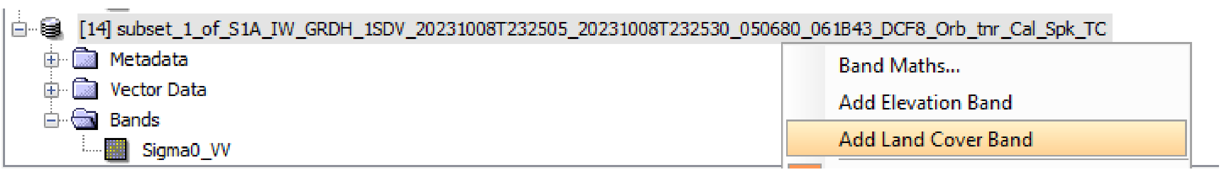
Keep defaults values for the other parameters. Click Run. Approximate processing time: 2.5 minutes.



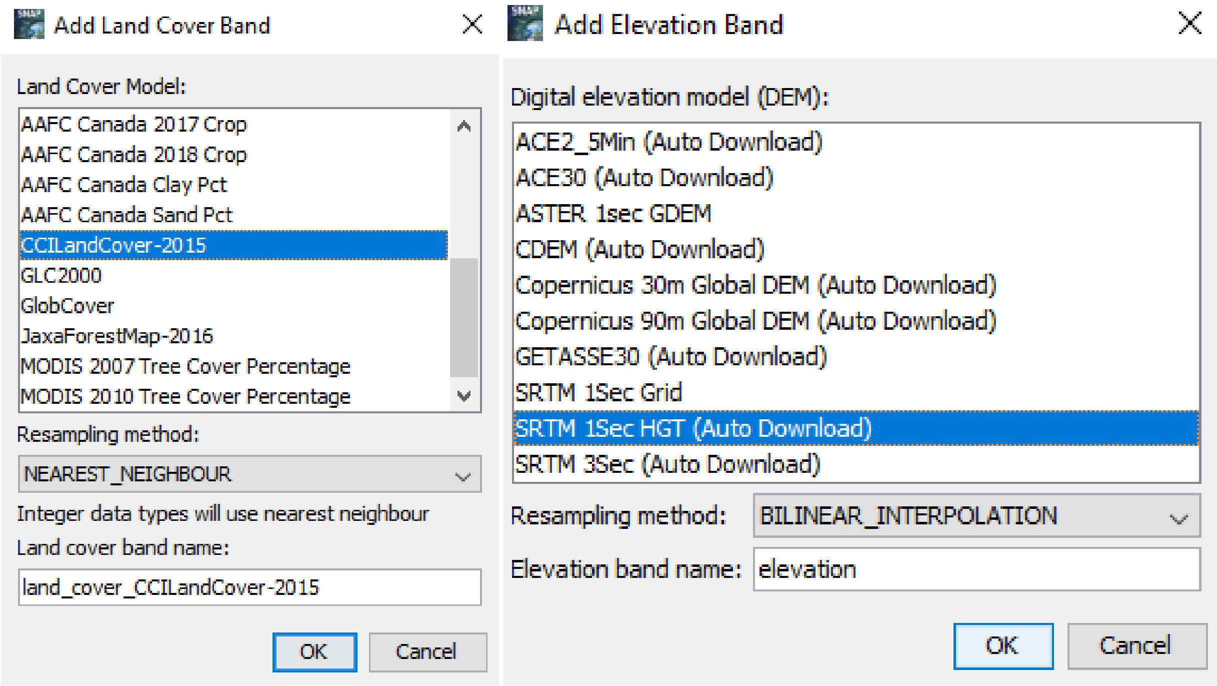
3.2 Flood assessment

After execution, your resulting two preprocessed products should contain a single bands called Sigma0_VV. Open all two (preprocessed) Sigma0_VVs in the View and then go to Window -> Tile Horizontally

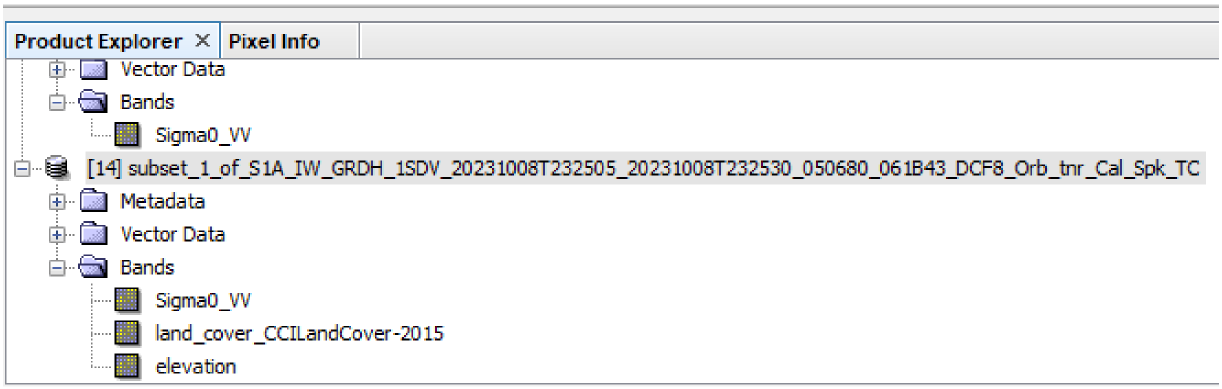
After ensuring that our products feature calibrated backscatter values, it's time to conduct flood assessments on the data to automatically ascertain the extent of flooding across the series of images. Areas with low backscatter indicate wet areas. Since our calibrated images contain calibrated backscatter coefficients, we can create a binary image from the products, highlighting areas below a cutoff threshold. Since the River traverses Bago city, it's crucial not to include recognized water sources in our flood mapping. To achieve this, we can incorporate the land cover band into our product in SNAP by right-clicking on the product in Product Explorer and selecting "Add Elevation Band."



Additionally, we aim to include an elevation band to prevent misidentification of high-elevation regions as flooded. To add an elevation band, right-click on the product and choose "Add Elevation Band," then select "SRTM 1Sec HGT (Auto Download).„



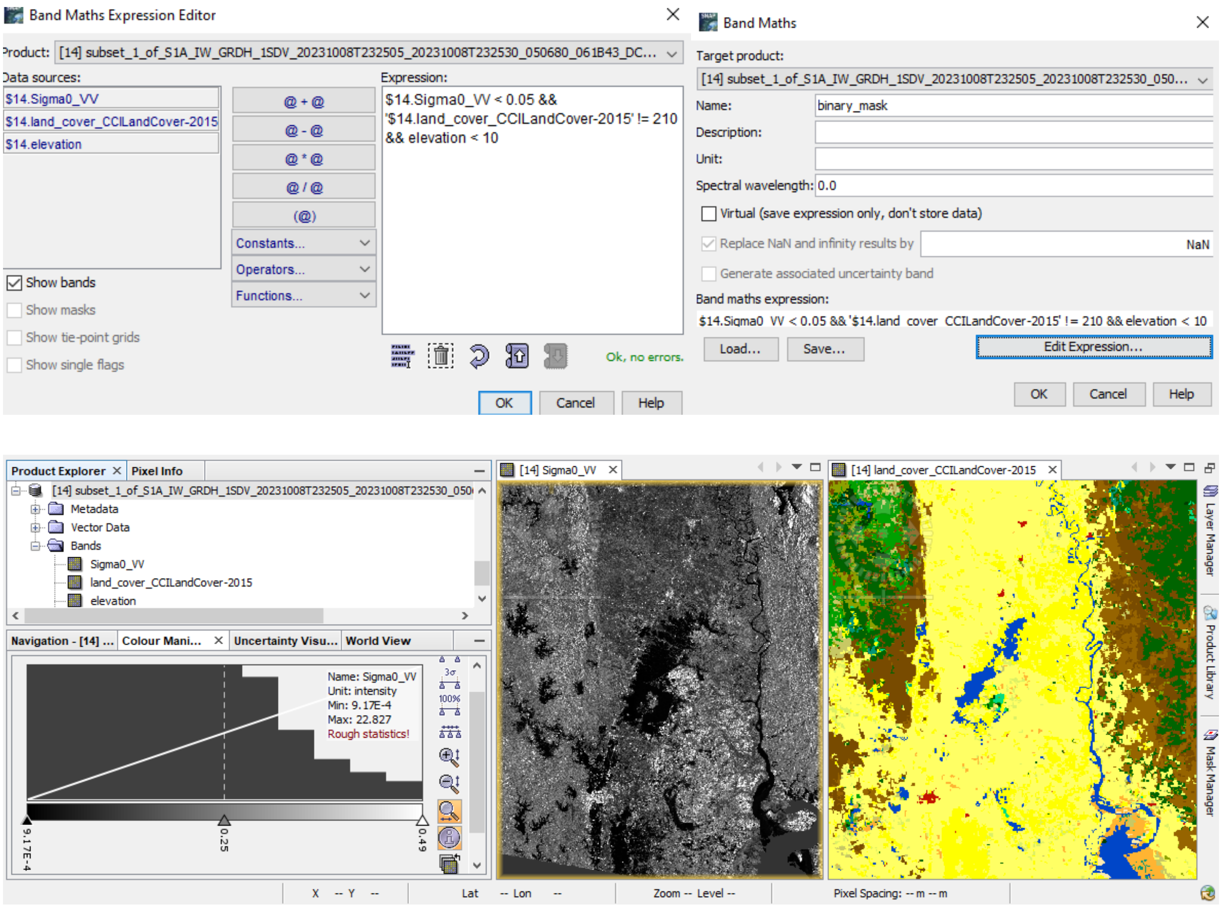
Your product now should include land cover band and also elevation band



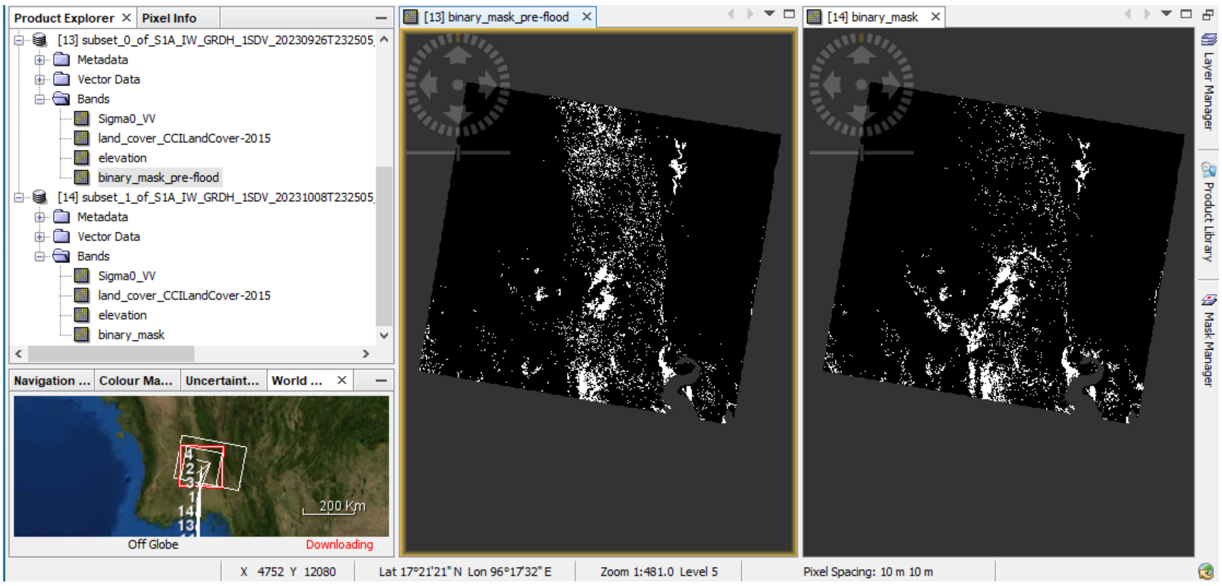
Now that we've added all the required bands, it's time to generate our new flooding band. Right-click on the product and choose "Band Maths." Enter the following expression into the text box:

Sigma0_VV < 0.05 && land_cover != 20 && elevation < 10

This will produce a binary mask indicating areas where the backscatter is below our threshold of 0.05, not categorized as water (Class 210) in land cover, and with an elevation below 10 meters above sea level.



Repeat the process for the second Sentinel product. Display the two masks to check they have been generated correctly. Our output flooding binary band should look like this (For September 26th – start of flodding and October 10th - peak of flooding):



3.3 Export and open binary masks in QGIS

To export this product for viewing in other GIS software and to map the changes in flooding over time, you need to save our two binary mask (start of floods and peek of floods) in TIF format in the proper folder using File-> Export->GeoTiff/BigTiff tool.

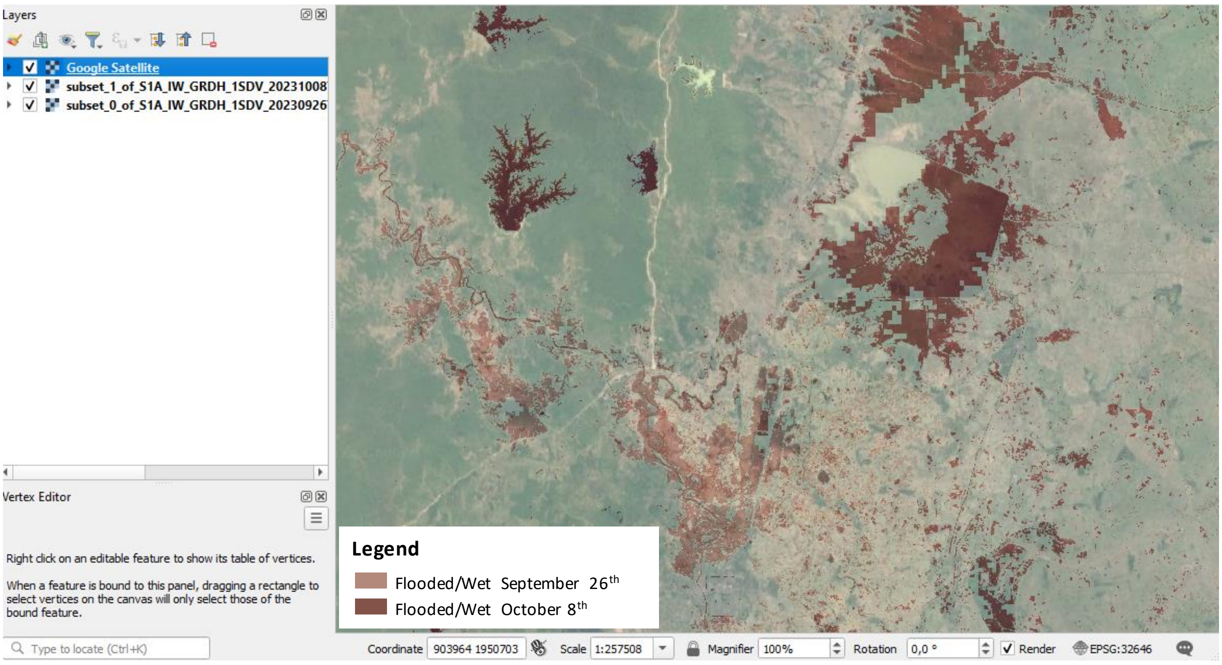
To visualize the output of our multi-temporal flood analysis, we will open the masks saved in GeoTIFF format using QGIS:

In QGIS click on the Add Raster Layer button located in the left panel, navigate to the folder containing the binary masks in TIFF format, and click Open (or drag&drop).

Now we open the output image in QGIS

- We can overlay it to e.g. Google Satellite or Bing aerial image:
- Web->OpenLayers plugin->Google Maps->Google Satellite
- Move the Subset above the satellite
- Play with Transparency: Properties->Transparency (e.g. 80%)

As observed, the floodwaters gradually subside over time, yet areas near the riverbanks remain saturated, displaying low backscatter and thus continuing to appear flooded.



For more information, see the lectures:
10. SAR and optical remote sensing for mapping floods
11. SAR and optical remote sensing for post-flood assessment and recovery

THANK YOU FOR FOLLOWING THE EXERCISE!

UNIVERSITY COURSE APPLIED RADAR REMOTE SENSING

EXERCISE 11 – TUTORIAL

Flood Monitoring with Sentinel-1, Sentinel-2 data using the SNAP software

esa
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FUNDED BY EUROPEAN SPACE AGENCY UNDER THE PLAN FOR EUROPEAN COOPERATING STATES, 7TH CALL FOR SLOVAKIA

1 | Exercise outline

In this second exercise for mapping floods, we will:

- Detect floods using Sentinel-2 images
- Create NDVI and NDWI spectral indices to explore floods
- Create binary water mask for flood mapping
- Compare results for flood mapping using Sentinel-1 and Sentinel-2 images

2 | Background

Floods, a commonly occurring natural disaster, result in significant damage to both lives and property. Timely information on floods is critical for emergency response. Rapid estimation of flood extent is essential for disaster risk assessment and spatial planning. Remote sensing and satellite imagery play pivotal roles in flood monitoring and mapping. Optical remote sensing, for instance, is utilized for dynamic flood monitoring by exploiting water's low reflectance in infrared bands and high reflectance in blue/green bands.

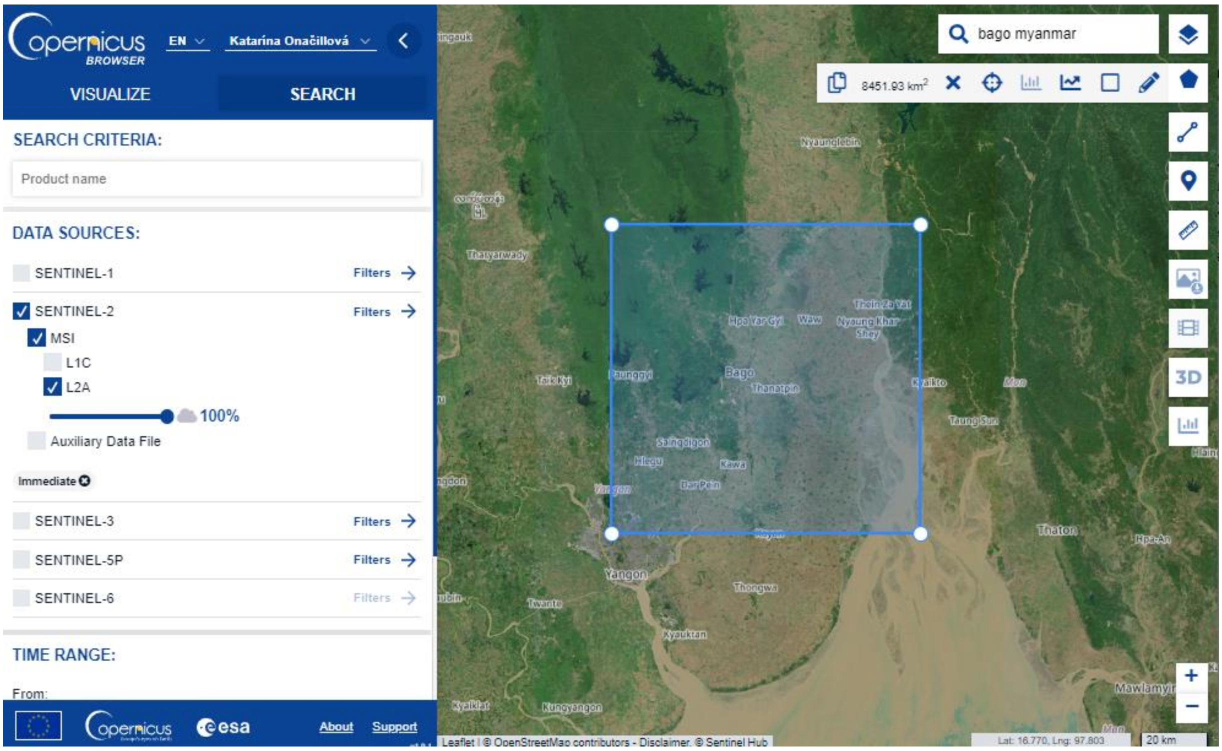
However, during severe weather conditions with heavy rainfall and intense cloud cover, optical remote sensing may struggle to provide accurate information due to a lack of cloud-free, high-quality images and difficulty in detecting water under vegetation cover.

Since October 4, 2023, the Myanmar Department of Meteorology and Hydrology (DMH) has been issuing flood advisory warnings and weather system alerts regarding water levels in major rivers. Between October 5 and 9, heavy rainfall during the late monsoon season resulted in extensive flooding in southern Myanmar. On October 9, the DMH reported that Bago township received an unprecedented 7.87 inches (200 millimeters) of rainfall, the highest recorded in 59 years. By October 10, the water level of the Bago River rose 4 feet above the danger level, leading to widespread flooding in urban and suburban areas. The impact of this flooding has been significant, affecting families, croplands, and causing displacement of people in areas including Bago City, Yangon, Taik Kyi, Hlegu, and Hmawbi townships. (DREF OPERATION Myanmar Flood 2023)

Besides Synthetic Aperture Radar (SAR) data that we used in the first part of the exercise for mapping floods, Sentinel-2 satellites are also extensively used for flood mapping due to their ability to capture high-resolution optical imagery of the Earth's surface. By analyzing these images, particularly before and after flood events, analysts can identify changes in water extent and detect flooded areas. The multispectral capabilities of Sentinel-2 allow for the differentiation of water bodies from other land cover types, enabling accurate mapping of flood-affected areas. Moreover, Sentinel-2's frequent revisits and openly available data make it a valuable resource for monitoring flood events in near real-time and supporting disaster response efforts.

2.1 Mapping floods with Sentinel-2 data

For the second part of this exercise, we will use two Sentinel-2 L2A images of the same area near Bago city, Myanmar, downloaded from the Dataspace Copernicus Open Access Hub [@https://dataspace.copernicus.eu/].

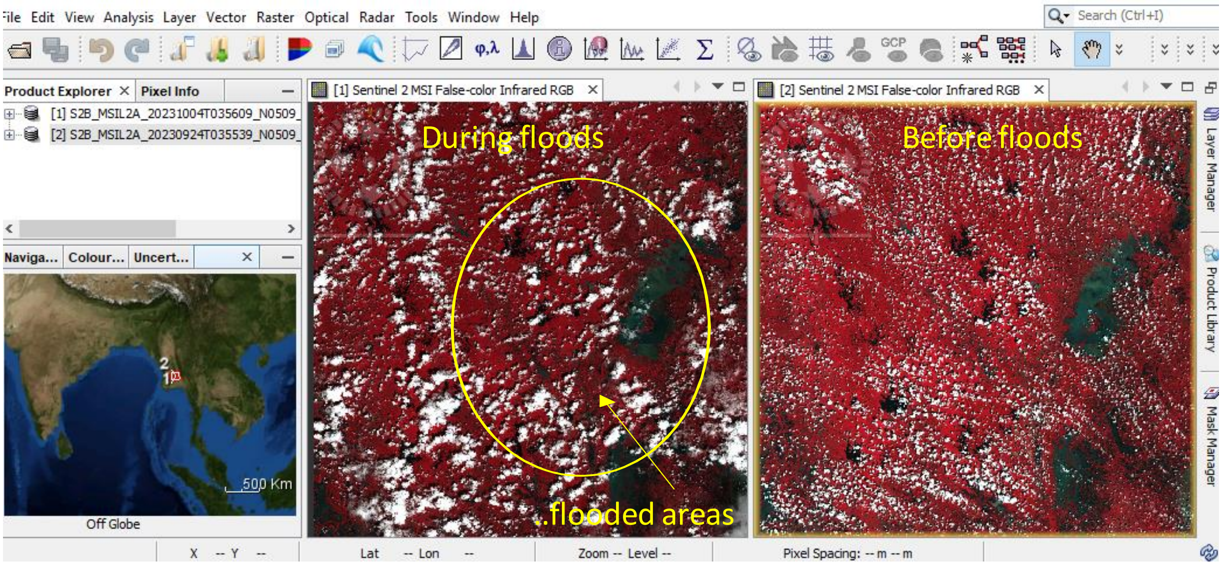


2.2. SNAP - Open and explore product

Open SNAP Desktop, click Open Product and open 2 downloaded products (unzipped) by double click on the metadata „MTD_MSIL2A.xml" inside the folder. The opened products will appear in Product Explorer window. Go to Windows – Tile them e.g. Horizontally.

S2B_MSIL2A_20231004T035609_N0509_R004_T46QHE_20231004T070950.SAFE.zip
S2B_MSIL2A_20230924T035539_N0509_R004_T46QHE_20230924T071828.SAFE.zip

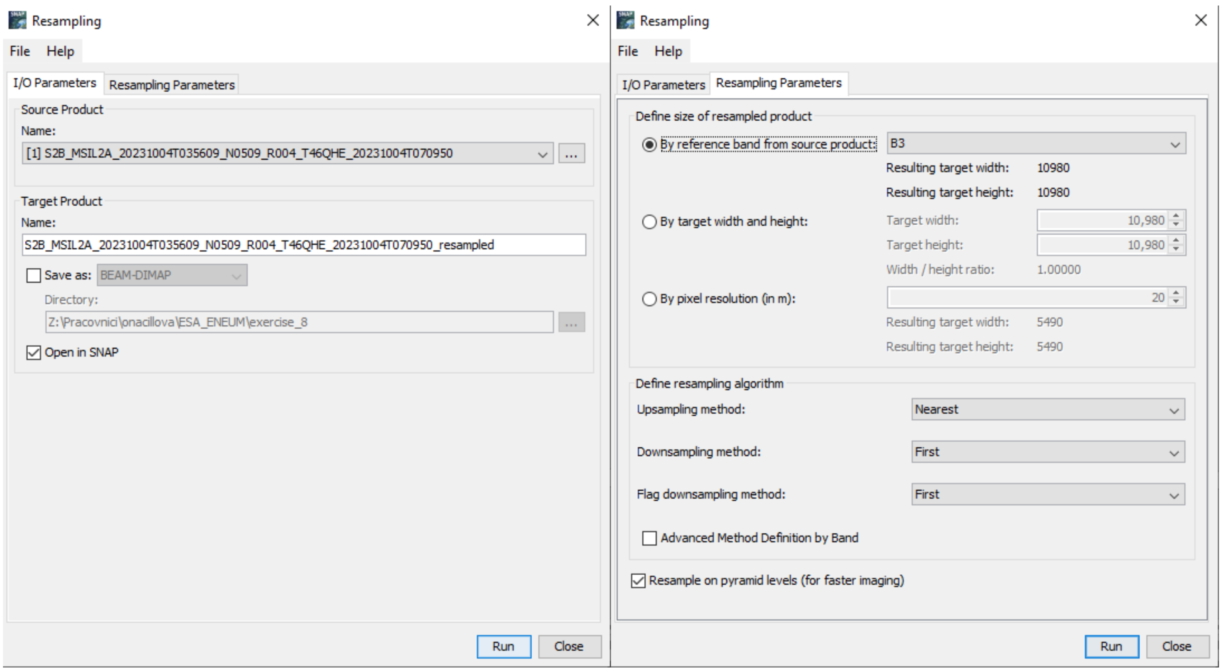
1. Select the first product in the Product Explorer window.
2. Right click on the product.
3. Open RGB Image Window.
4. In the pop-up window select e.g. 'Sentinel 2 MSI False-color Infrared (Red: B8; Green: B4; Blue: B3)'.
5. Repeat the process for the second product.
6. Tile two opened RGB Windows, e.g. horizontally
7. In the Navigation window, zoom in to the flooded region and syhnchronise views to see the same area



2.3 Preprocessing

Resample

Resample the bands to the pixel size of the VIS bands:
In the main SNAP menu, select Raster - Geometric - Resampling
In the I/O Parameters tab, the source product is set to our only product in the SNAP, change the name of the target resampled product if needed
Do not save the output product - disable the box "Save as:" (if selected).
In the Processing Parameters tab, use e.g. B3 with 10 m resolution to resample all the bands to 10 m as output spatial resolution.
Resample both of the products.



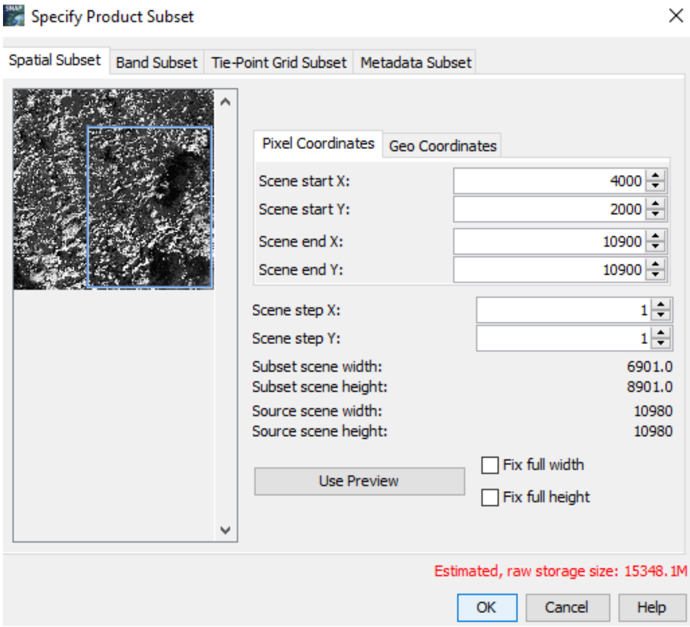
Create subset

Click on the resampled product in the Product Explorer, go to the main SNAP menu and select Raster - Subset…:

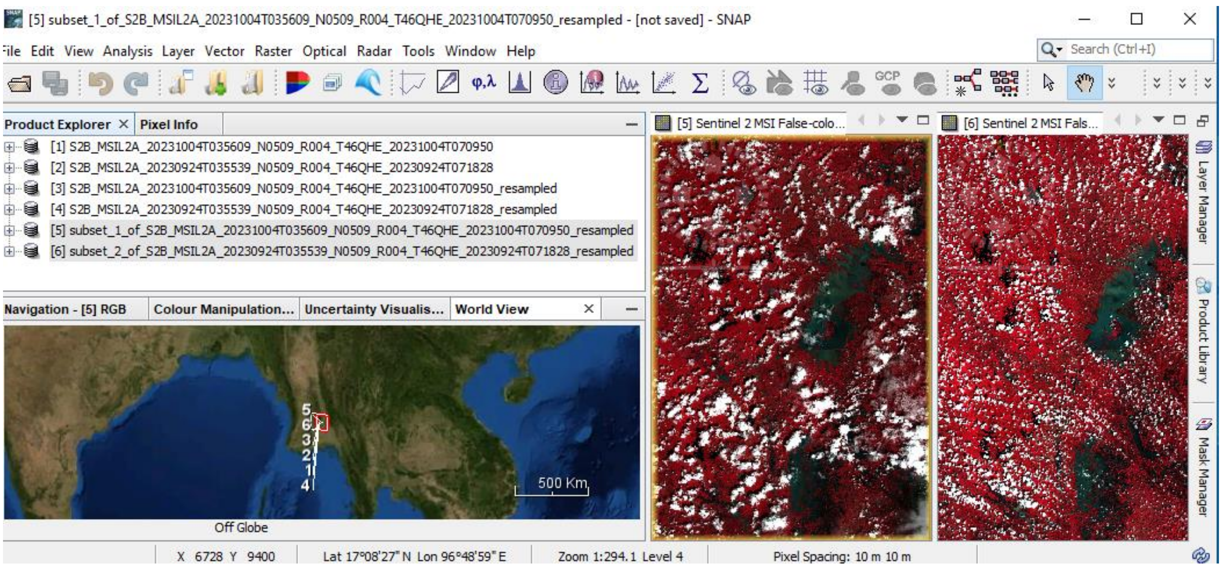
Create a subset with the following settings:

Spatial subset - Geo Coordinates:
North latitude bound: 18.00,
West longitude bound : 96.20,
South latitude bound : 17.00,
East longitude bound : 97.00

Keep the remaining parameters as default and click OK



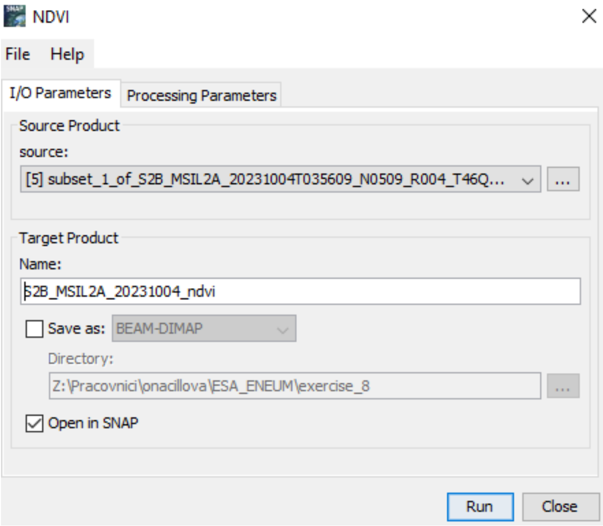
In the end, you should have two resampled subsets. Close original visualizations and display subsets in False color with Tile Horizontally option.

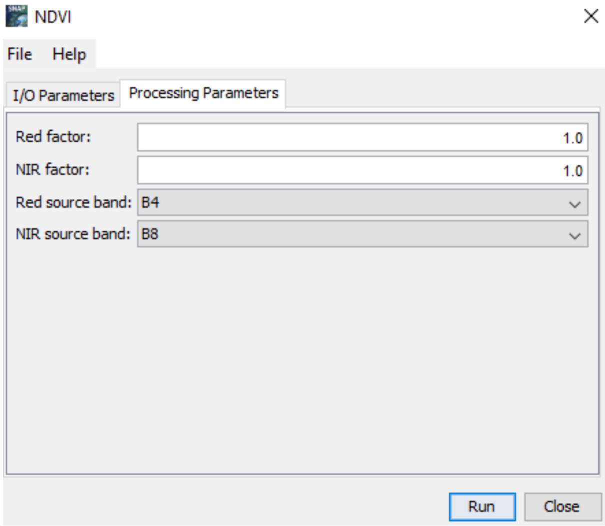


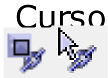
2.4 Image analysis
NDVI

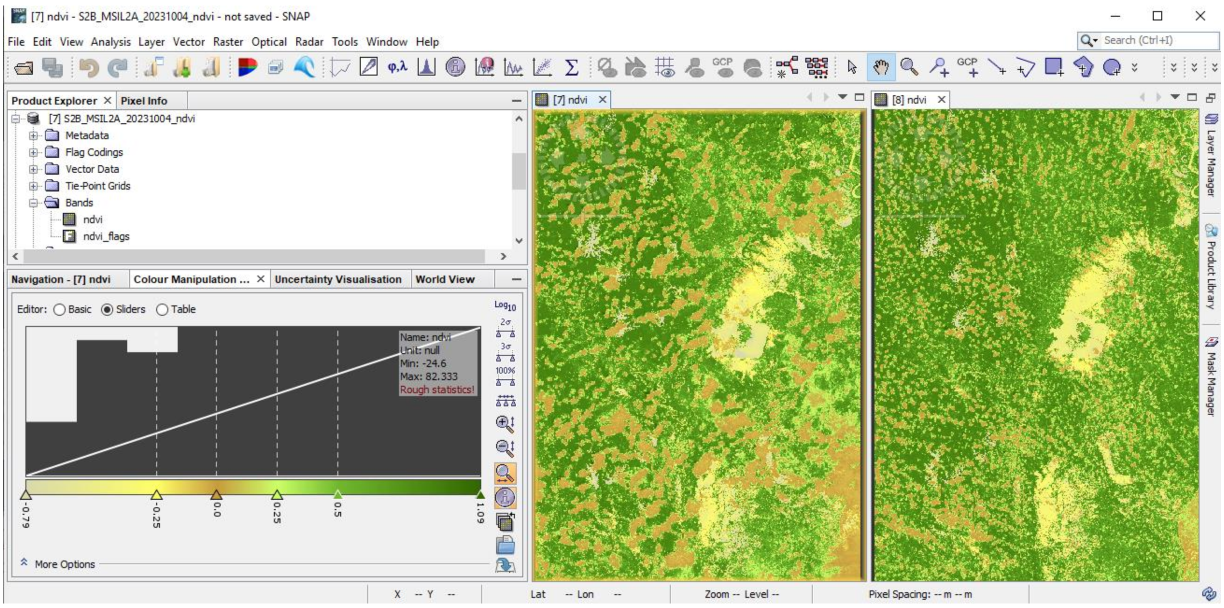
Let´s calculate NDVI for the two subset images.

Navigate to Main Menu: Optical – Thematic Land Processing – Vegetation Radiometric Indices – NDVI Processor and set parameters:





In the Product Explorer tab double click to open resulted two new NDVI bands for each date.
Go to Colour Manipulation tab and select appropriate colour palette for vegetation index. Apply the same colour palette and set the sliders to the same values for both of the images. Synchronize Cursor Position and Views activating the two buttons in Navigation tab. 

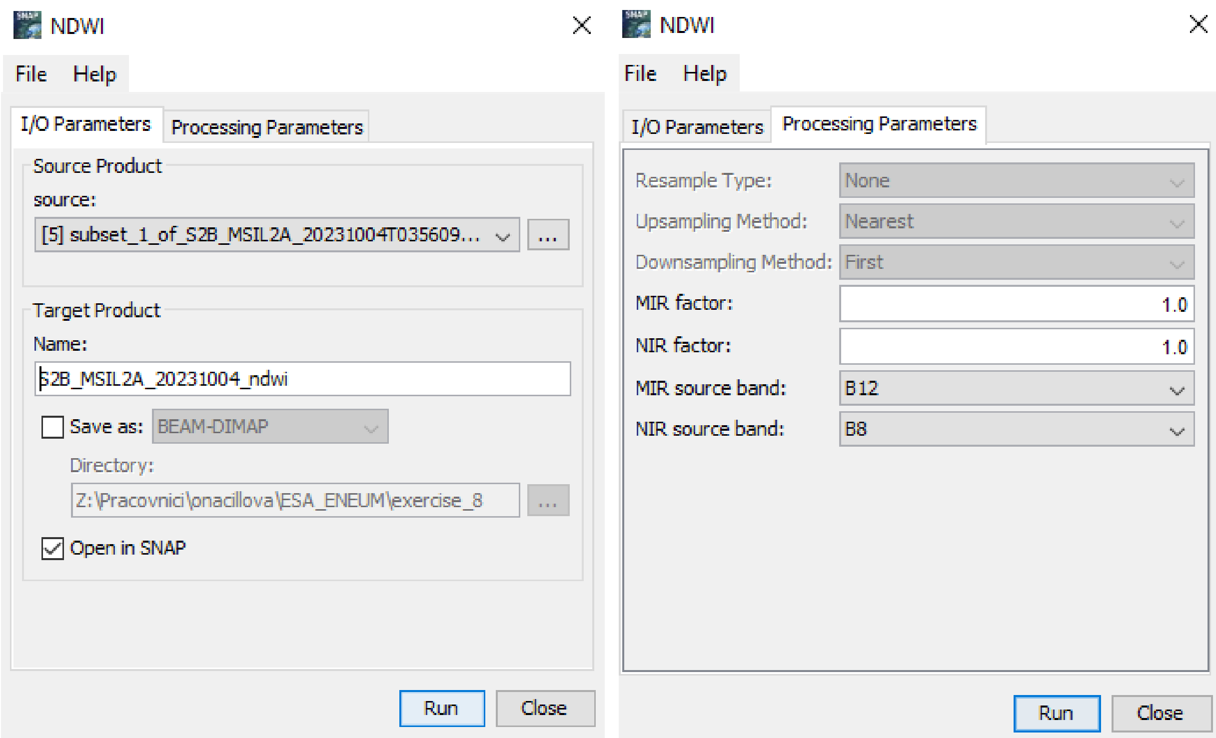


NDVI image has usually values from < -1, 1 >, where forested areas are displayed in values higher than 0.

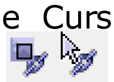
NDWI

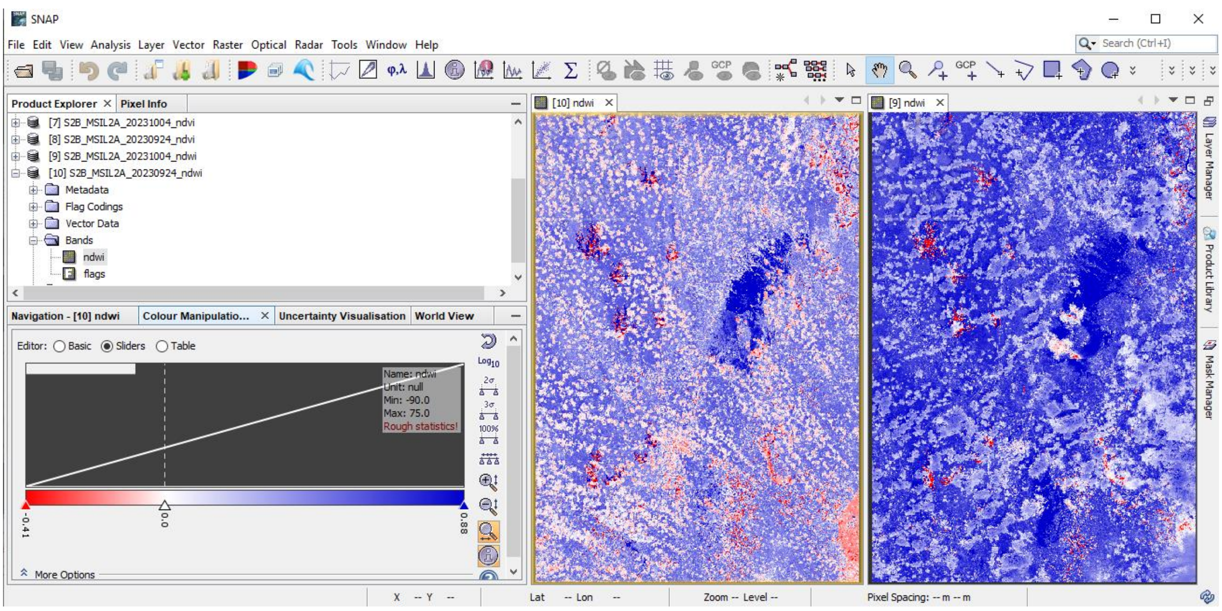
Let´s calculate also NDWI for the two subset images.

Navigate to Main Menu: Optical – Thematic Land Processing – Water Radiometric Indices - NDWI Processor and set parameters:



In the Product Explorer tab double click to visualize resulted two new NDWI layers.

Go to Colour Manipulation tab and select appropriate colour palette for vegetation index. Apply the same colour palette and set the sliders to the same values for both of the images. Synchronize Cursor Position and Views activating the two buttons in Navigation tab. 

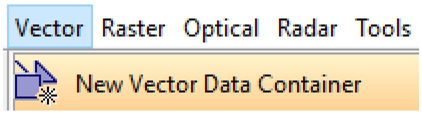


2.5 Water Mask Generation

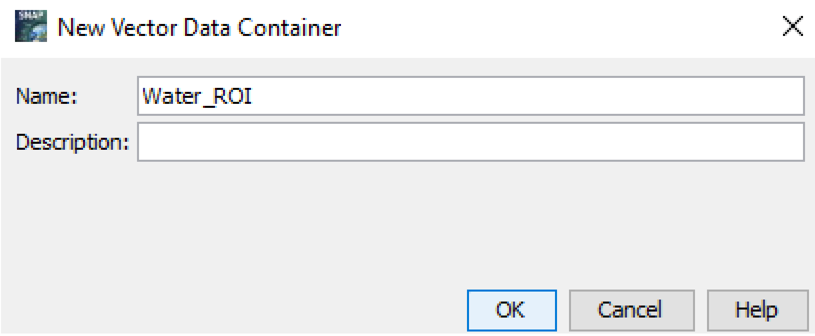
The utilization of both NDVI and NDWI together can be advantageous for specifically identifying water bodies.

Let´s create a binary mask of water and non-water pixels with a thresholding condition. Open e.g. False-color composition and define a Waterbody Region of Interest (ROI)

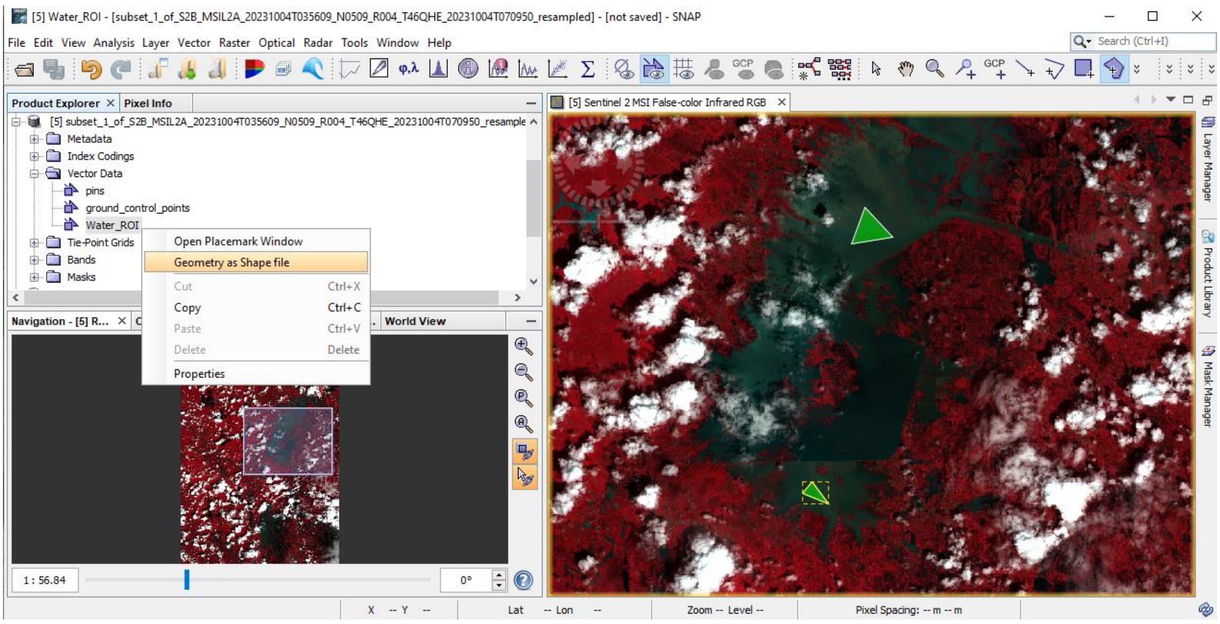
Define a new ROI (Vector->New Vector Data Container)



Define ROI name (f.e. Water_ROI) and description (optional)



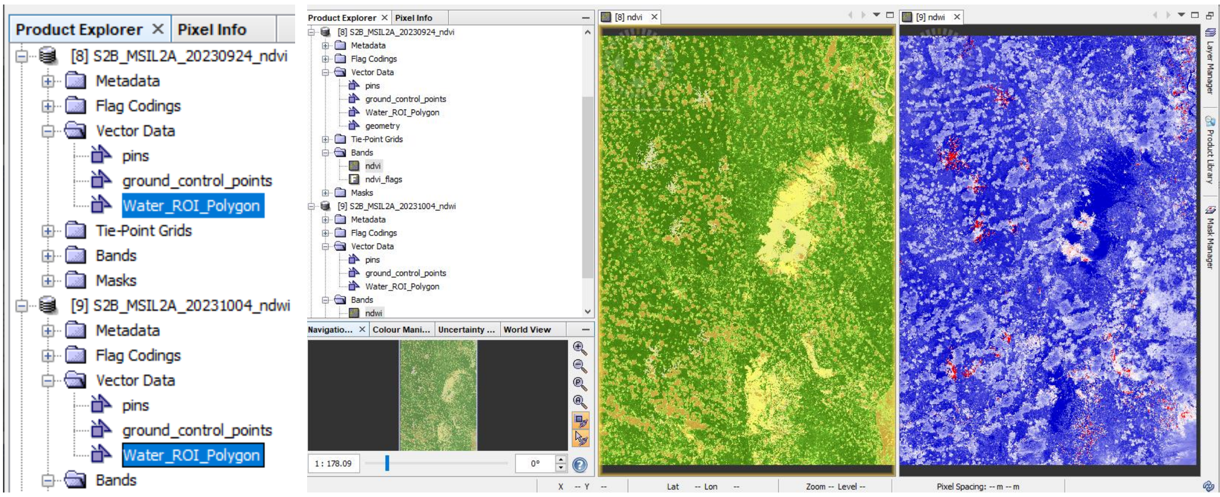
Check in VectorData folder corresponding to the active image to check the ROI has been created. Define Tool for ROI construction (Polygons Drawing Tool) and draw polygon over water area e.g. according False-color Infrared composition and double-click to close it



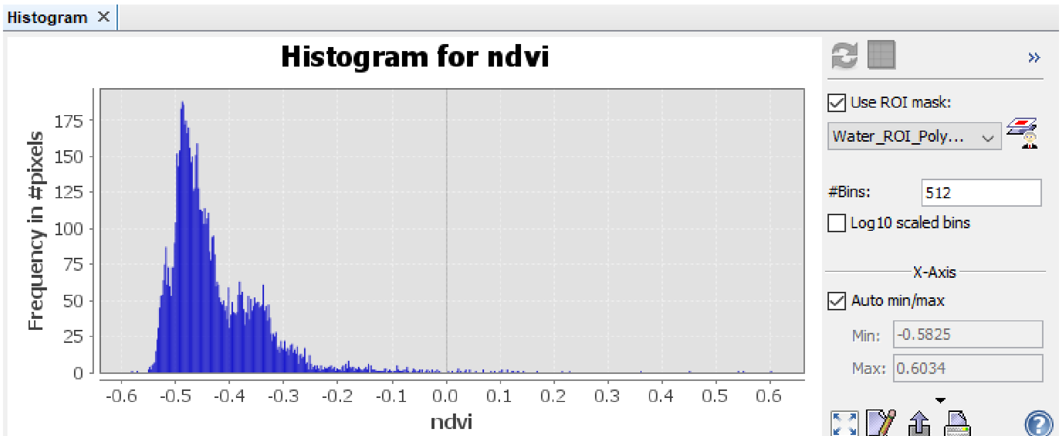
Export ROI as SHAPE file (f.i. as Water_ROI.shp) – right click on the layer – Geometry as Shapefile – set the directory for export and close the visualization

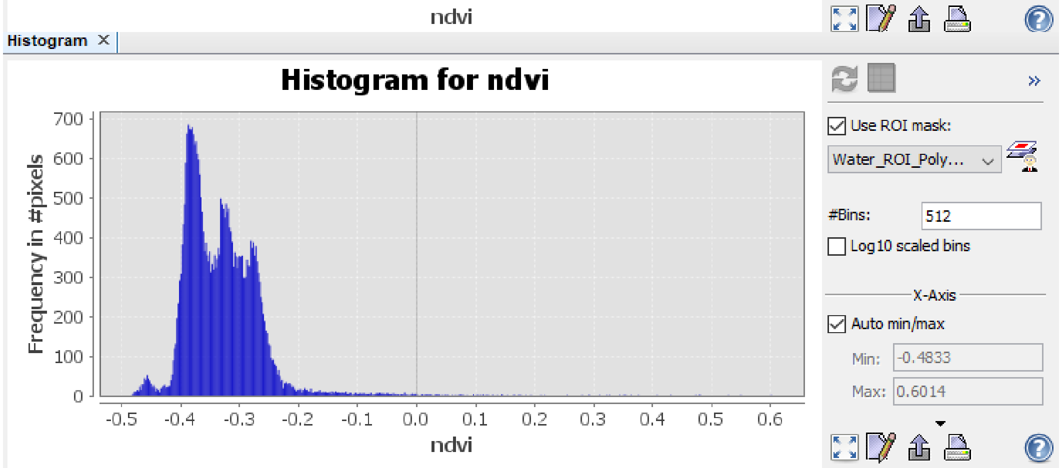
Import SHAPE file to make it available in NDVI and NDWI layers:
Select NDVI product - File – Import- Vector data – ESRI Shapefile – and import your saved Water_ROI polygon

Select NDWI product - File – Import- Vector data – ESRI Shapefile – and import your saved Water_ROI polygon. Select NDVI and NDWI layers from Product Explorer panel and visualize them.

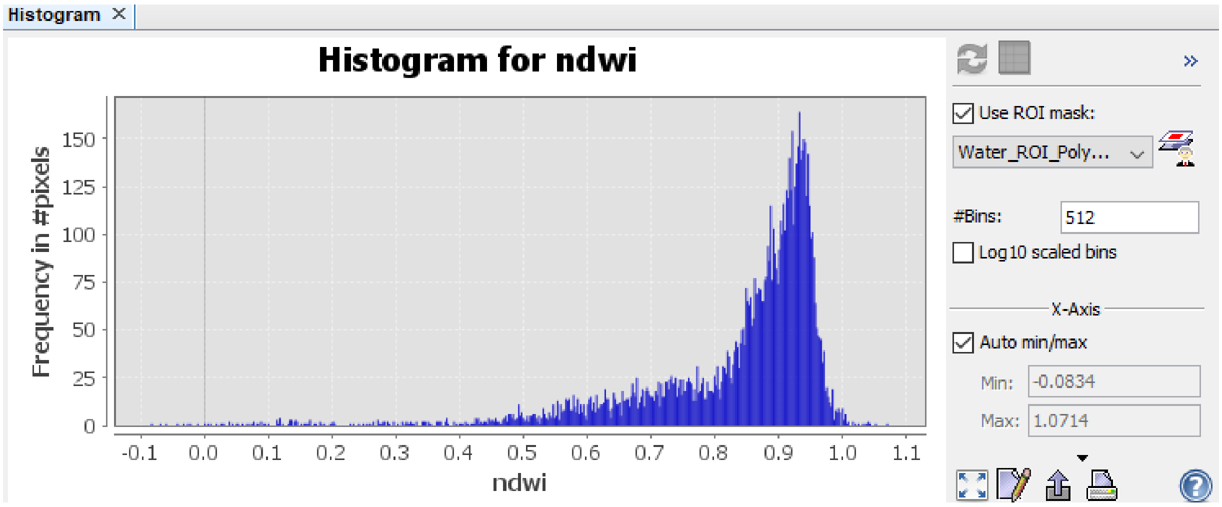


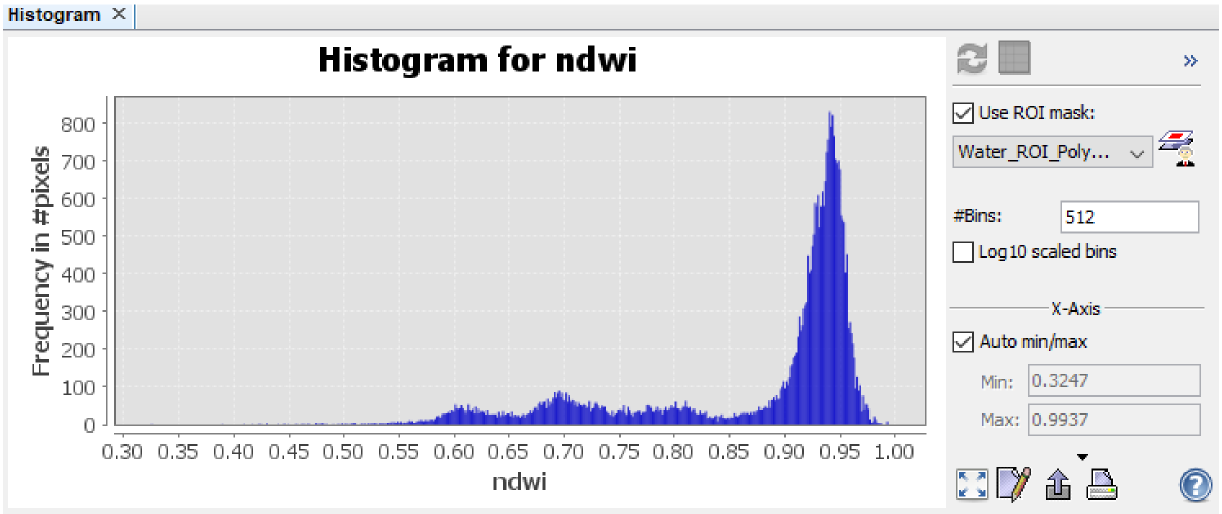
Calculate Histogram over ROI for NDVI and NDWI during pre-flood and during flood events:
click on NDVI layer – Navigate to Analysis->Histogram – activate Use ROI Mask tab – select Water ROI Polygon mask and press refresh button.





Repeat for NDWI layer.



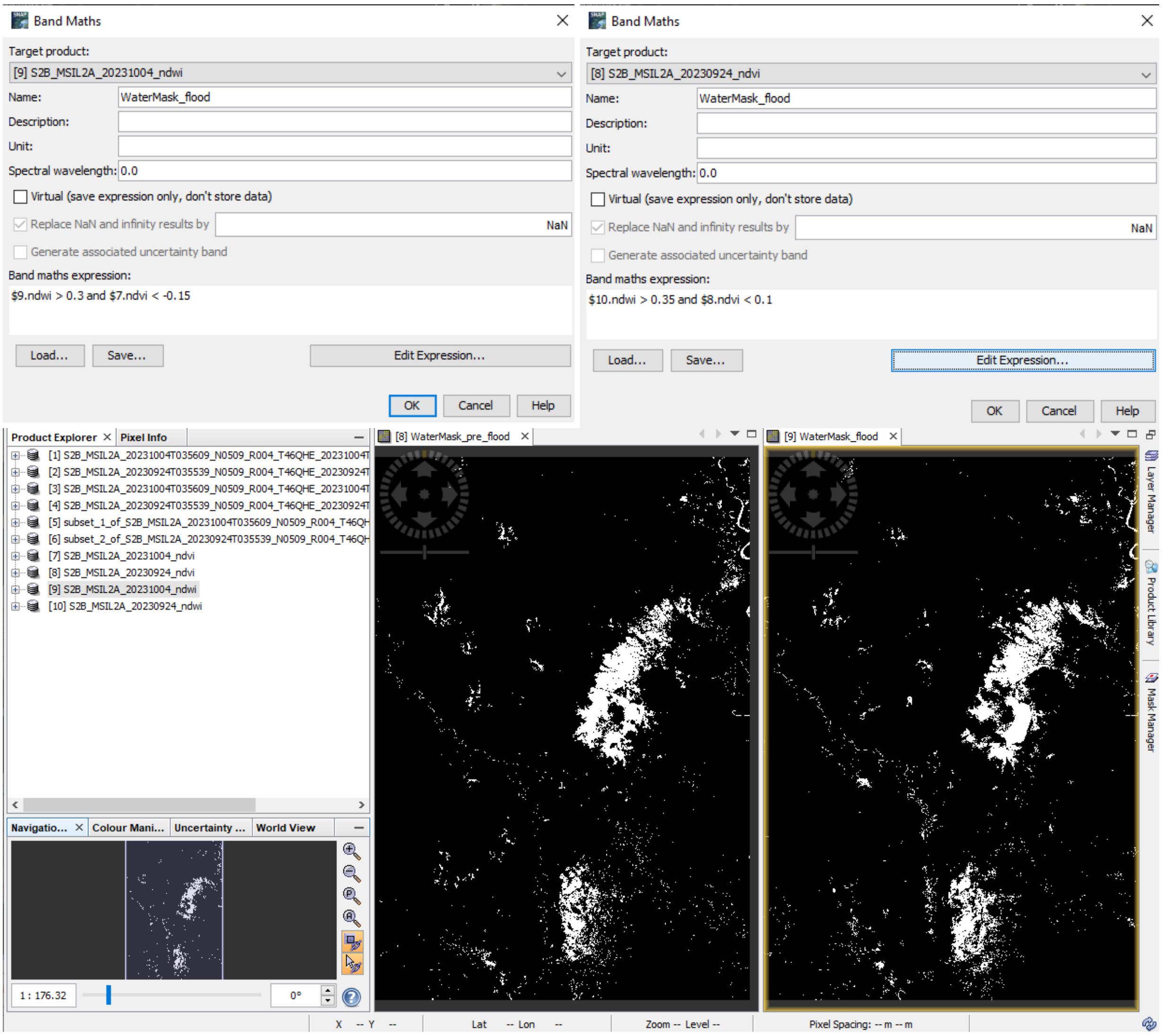


Proposed thresholding values

No-flooded	NDVI<-0.15 and NDWI > 0.3
Flooded	NDVI< 0.1 and NDWI > 0.35

Create masks for NDVI and for NDWI with a combined (AND) condition: Open Band Maths window from Raster>Band Maths or by selecting any available layer (f.i. NDWI) and clicking on the mouse's right button. Edit the formula by selecting the NDVI and NDWI properly (corresponding to the same acquisition) and applying the proper thresholds).

Calculate new masks for pre-flood and flood events.



2.6 Export and open binary masks in QGIS

To export this product for viewing in other GIS software and to map the changes in flooding over time, you need to save our two binary mask (start of floods and peek of floods) in TIF format in the proper folder using File-> Export->GeoTiff/BigTiff tool.

To visualize the output of our multi-temporal flood analysis, we will open the masks saved in GeoTIFF format using QGIS:

In QGIS click on the Add Raster Layer button located in the left panel, navigate to the folder containing the binary masks in TIFF format, and click Open (or drag&drop).

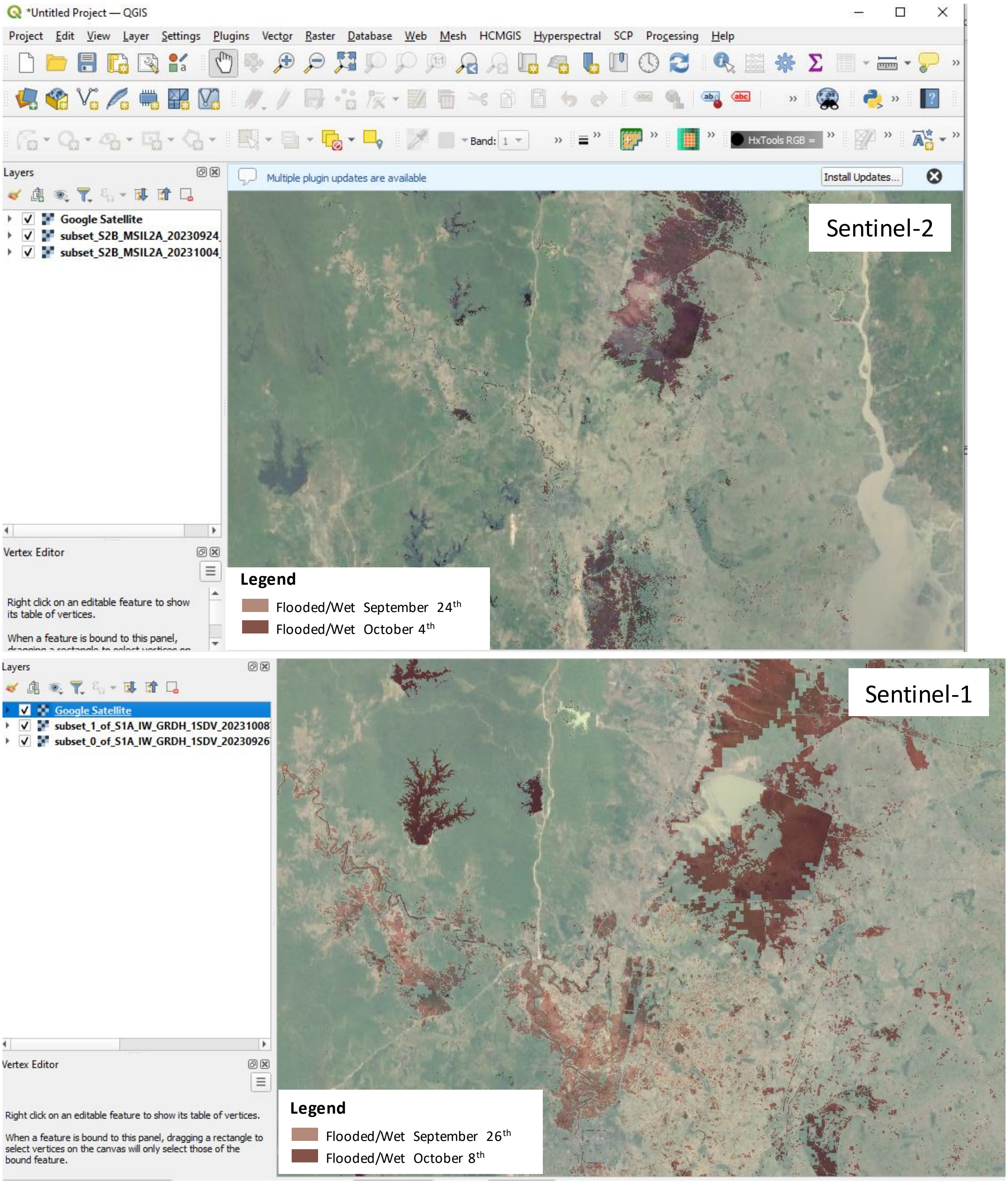
Now we open the output image in QGIS

- We can overlay it to e.g. Google Satellite or Bing aerial image:
- Web->OpenLayers plugin->Google Maps->Google Satellite
- Move the Subset above the satellite

- Play with Transparency: Properties->Transparency (e.g. 80%)

As observed, the floodwaters gradually subside over time, yet areas near the riverbanks remain saturated, displaying low backscatter and thus continuing to appear flooded.

Compare masks retrieved via S1 and S2 using S2-RGB data as (quasi simultaneous) ground truth.



For more information, see the lectures: [10. SAR and optical remote sensing for mapping floods](), [11. SAR and optical remote sensing for post-flood assessment and recovery]()

THANK YOU FOR FOLLOWING THE EXERCISE!

EXERCISE 12 – TUTORIAL

Land subsidence mapping using SAR interferometry (InSAR) using the SNAP software

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FUNDED BY EUROPEAN SPACE AGENCY UNDER THE PLAN FOR EUROPEAN COOPERATING STATES, 7TH CALL FOR SLOVAKIA

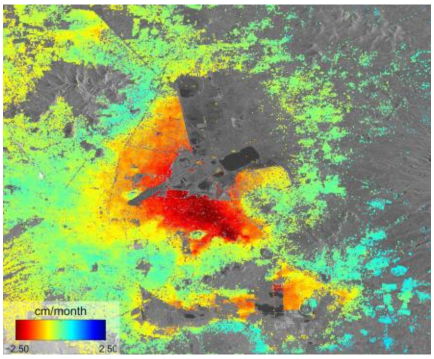
1 | Exercise outline

In this exercise, we will:

- Explore the role of synthetic aperture radar (SAR) in detecting and mapping land subsidence using Sentinel-1 data.
- Understand how to process SAR data to obtain information and understanding of surface deformations
- Emphasise the sensitivity of SAR to small surface changes and provide a comprehensive view of the subsidence dynamics.
- Learn how to detect displacement by means of band Math expression and visualize results of displacement in Google Earth.

2 | Background

Land subsidence, the gradual sinking of the Earth's surface, caused by natural processes like sediment compaction and human activities such as groundwater extraction, poses risks to infrastructure and ecosystems. Effective monitoring and mitigation strategies are crucial to address its impacts and ensure sustainable land use.



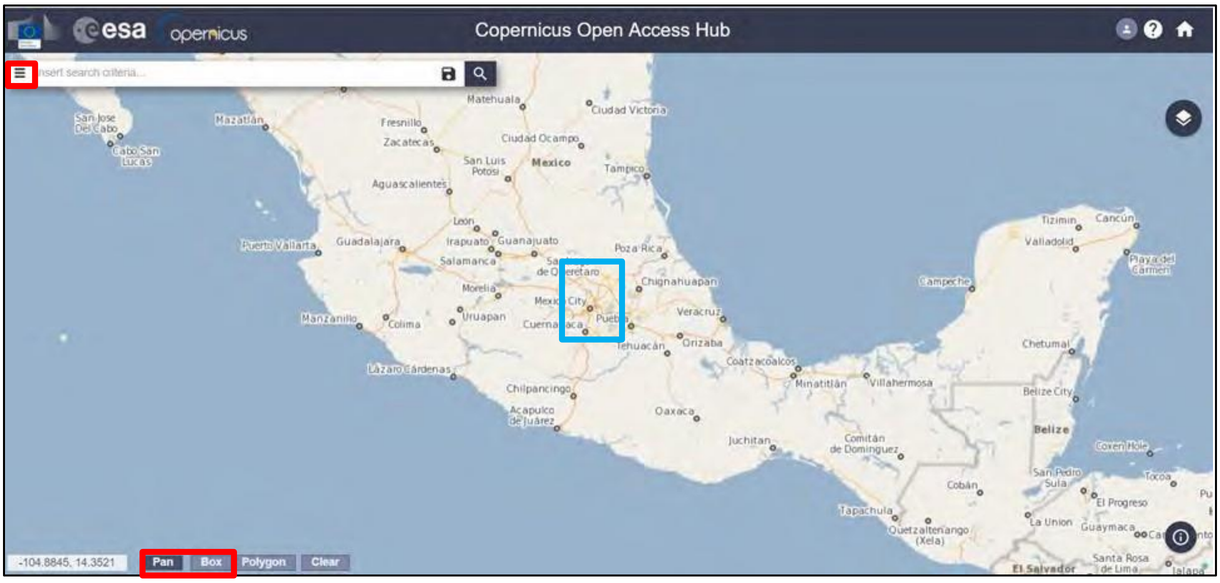
Subsidence in Mexico City is a significant issue that has been occurring for several decades. Excessive groundwater pumping, primarily for residential and industrial use, has been one of the primary drivers of subsidence in Mexico City. The groundwater extraction causes the clay soils to compact, leading to the sinking of the ground surface. The consequences of subsidence in Mexico City are severe. Infrastructure such as buildings, roads, and pipelines can suffer damage or even collapse as the ground sinks unevenly. Subsidence also increases the risk of flooding during periods of heavy rainfall, as the ground settles below the level of drainage systems.

Sentinel-1 satellite data through radar interferometry techniques, can monitor subtle movements of the Earth's surface. With its frequent revisits and global coverage, Sentinel-1 enables continuous monitoring over large areas, aiding researchers and policymakers in assessing risks and implementing mitigation measures for sustainable land management.

Image sources: https://www.science.org/content/article/sinking-mexico-city-linked-metro-accident-more-come, https://www.esa.int/ESA_Multimedia/Images/2014/12/Mexico_City_subsidence

2.1 Study area and data used

For this exercise, we will use two Sentinel-1 GRD images of the same area near Bago city, Myanmar, downloaded from the Dataspace Copernicus Open Access Hub [@https://dataspace.copernicus.eu/].

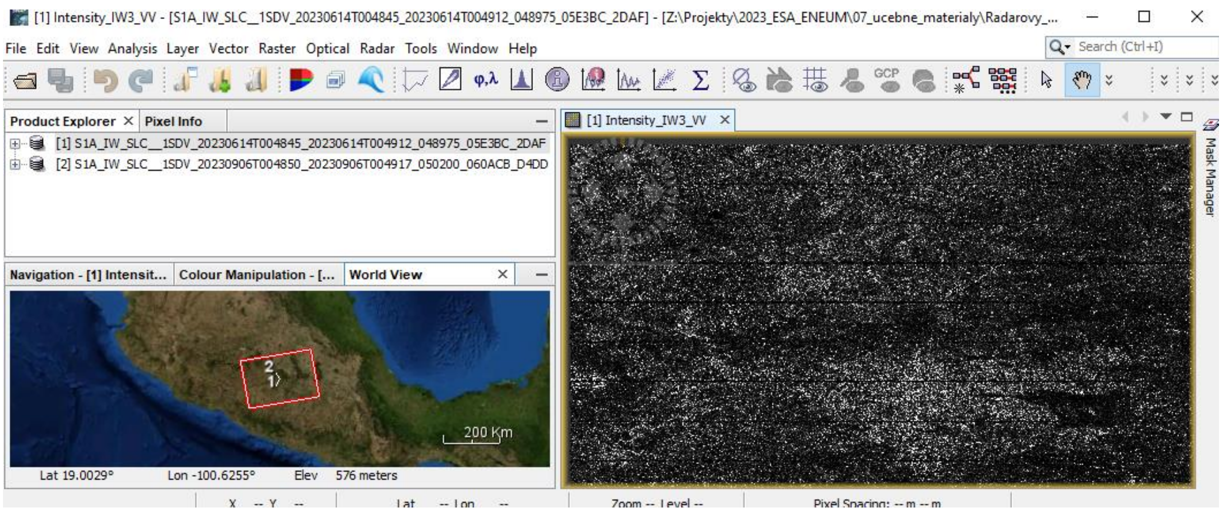


2.2. SNAP - Open and explore product

Open SNAP Desktop, click Open Product and open 2 downloaded products by double click on them. The opened products will appear in Product Explorer window.

S1A_IW_SLC__1SDV_20230614T004845_20230614T004912_048975_05E3BC_2DAF.zip
S1A_IW_SLC__1SDV_20230906T004850_20230906T004917_050200_060ACB_D4DD.zip

Right-click on the "Intensity_IW3_VV" band and select Open Image Window to create and visualize the image of the band (or double-click on it).



2.3 Pre-processing

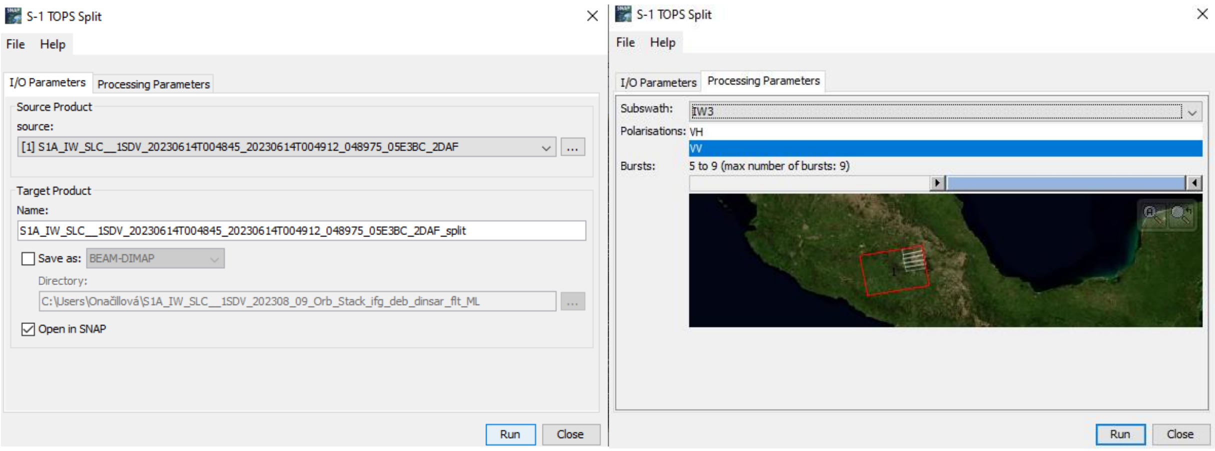
S-1 TOPS Split

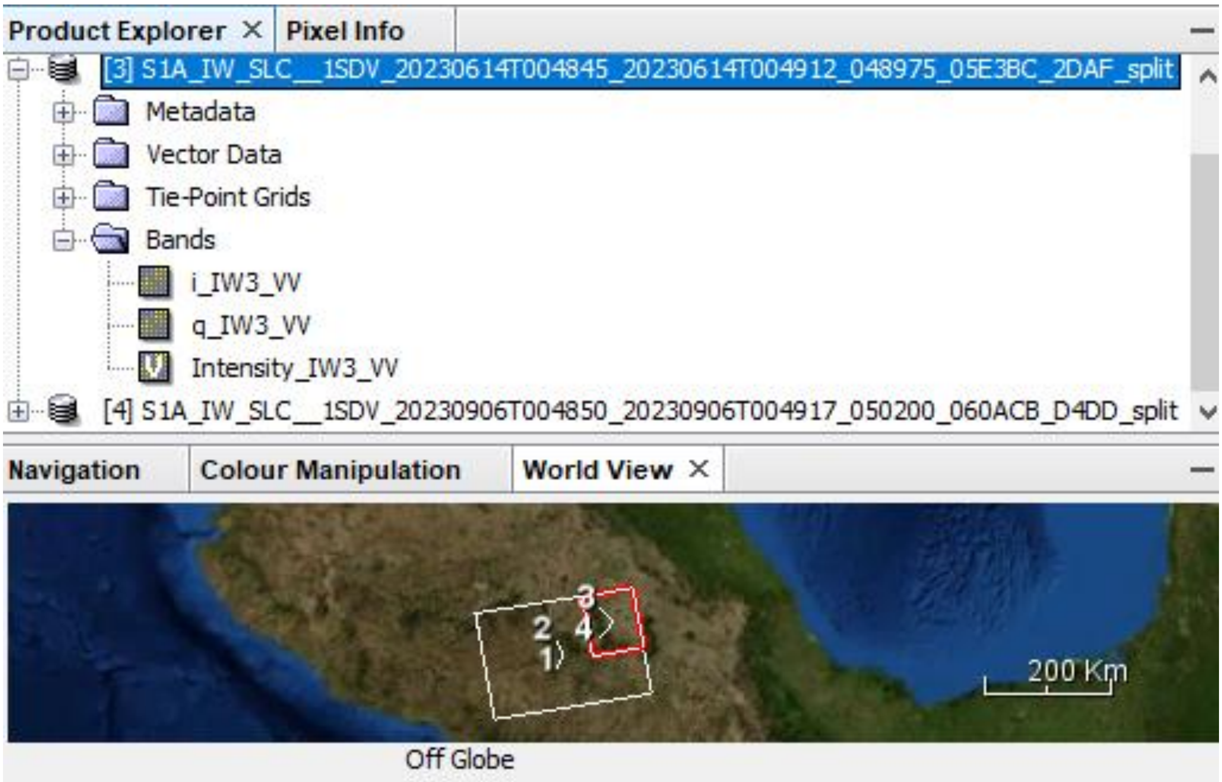
As the region of interest falls within 3 bursts of the Sentinel-1 image, there's no need to process the entire sub-swath with all bursts. Instead, extraction of Sentinel-1 TOPS bursts will be conducted per acquisition and per sub-swath. This approach reduces processing time.

Navigate to Radar > Sentinel-1 TOPS > S-1 TOPS Split.

In the I/O Parameters tab, leave the default output name for the target product name. The system inserts automatically the suffix of the split process in order to discriminate the split product from the original data.

In the Processing Parameters tab, select the following parameters:
Subswath: IW3 Polarisations: VV Bursts: 3 to 5
In Bursts selection drag arrows to the specified number of bursts. Then click RUN. Repeat the split process for the second Sentinel-1 image:





2.4 Co-registration

The first processing step is to apply the orbit files in Sentinel-1 products in order to provide accurate satellite position and velocity information.

Apply orbit file

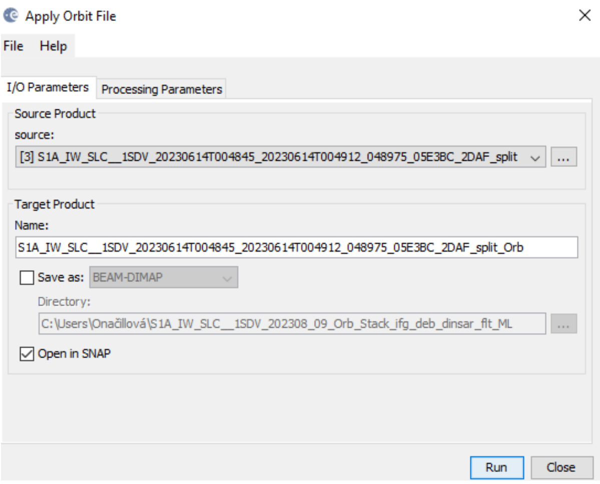
Navigate to Main Menu – Radar – Apply orbit file

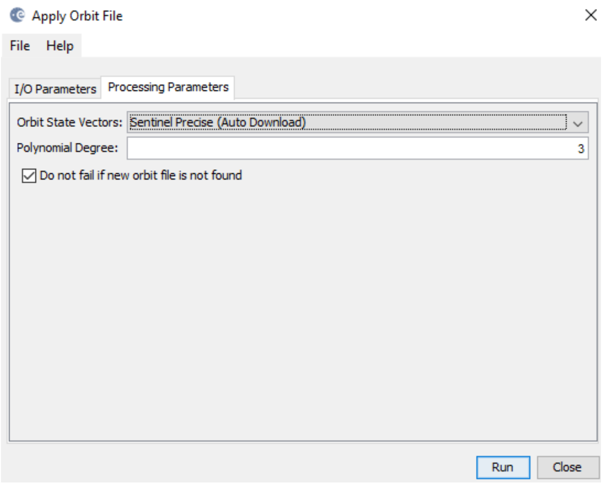
In the I/O Parameters tab, select the first product and name the target product. There is no need to save the output as BEAM-DIMAP (we will save the time this way)

In the Processing Parameters accept the default settings and select the option „Do not fail if new orbit file not found"

Repeat for the second image.

Save the products with applied orbit files.



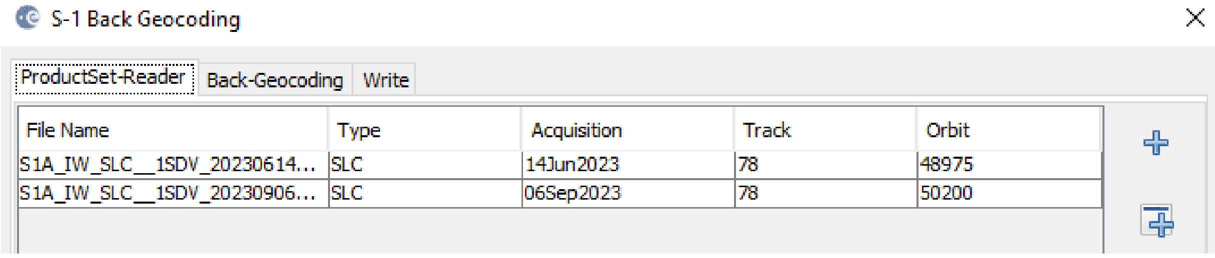


Back-Geocoding

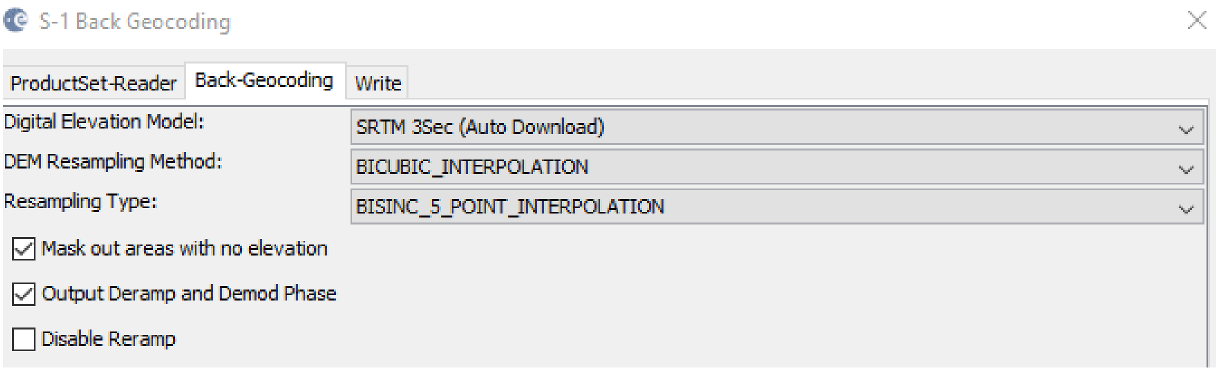
Next step will be to co-register the two Sentinel-1 images. For this reason the second image (slave) will be co-registered with respect to the first image (master). Sentinel-1 Back Geocoding operator co-registers two S-1 split products (master and slave) of the same sub-swath using the orbits of the two products and a Digital Elevation Model (DEM).

Navigate to Radar > Coregistration > S-1 TOPS Coregistration > S-1 Back-Geocoding:

In the ProductSet-Reader click on Add Opened icon and keep only the products with the applied orbit files (in case there is more products, use remove icon to delete them).



Back-Geocoding tab use default parameters, but also check "Output Deramp and Demod Phase" option.



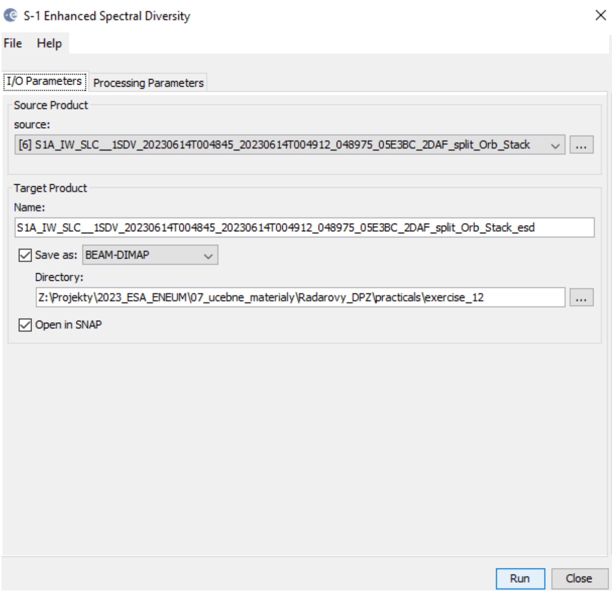
In the Write tab, select the directory to save your processing outputs.

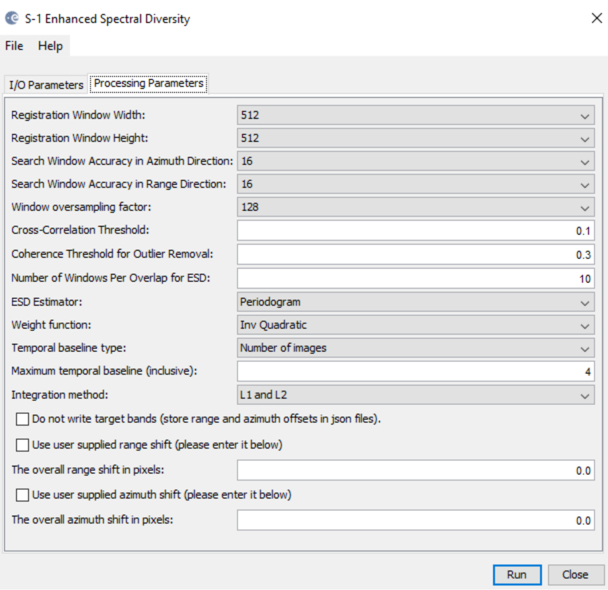
Enhanced Spectral Diversity

In the next step, the Enhanced Spectral Diversity (ESD) operator is applied after Back-Geocoding. The ESD method utilizes data from the overlapping area of adjacent bursts and conducts range and azimuth corrections for each burst.

Go to Radar > Coregistration > S-1 TOPS Coregistration > Enhanced-Spectral-Diversity

In the I/O Parameters tab, select the last back-geocoded product.
By default, the output target is set to the same directory and appends „esd" to the filename.
In the Enhanced-Spectral-Diversity tab use the default parameters.

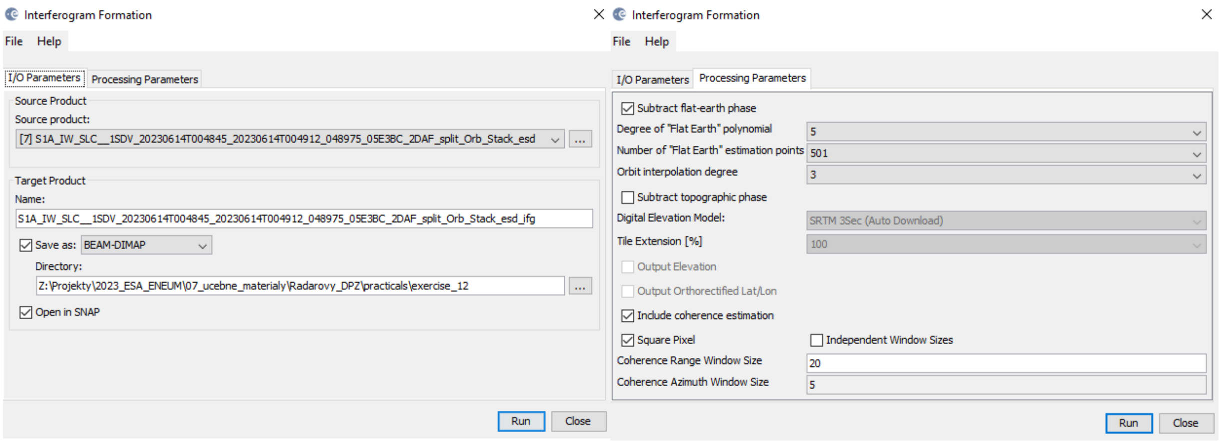




2.5 Forming a Raw Interferogram

The next phase involves generating an interferogram using the the interferometric pair (master and slave), while a coherence image estimation from the stack of the coregistered complex images is included. To do this, follow these steps:

From the main menu bar, go to Radar > Interferometric > Products and finally select Interferogram Formation.
In the I/O Parameters tab, choose the „esd" product that was generated during the previous step.
By default, the output target is set to the same directory and appends "ifg" to the filename.
In the Processing Parameters tab set the following parameters:
Coherence Range Window Size: 20
Coherence Azimuth Window Size: 5

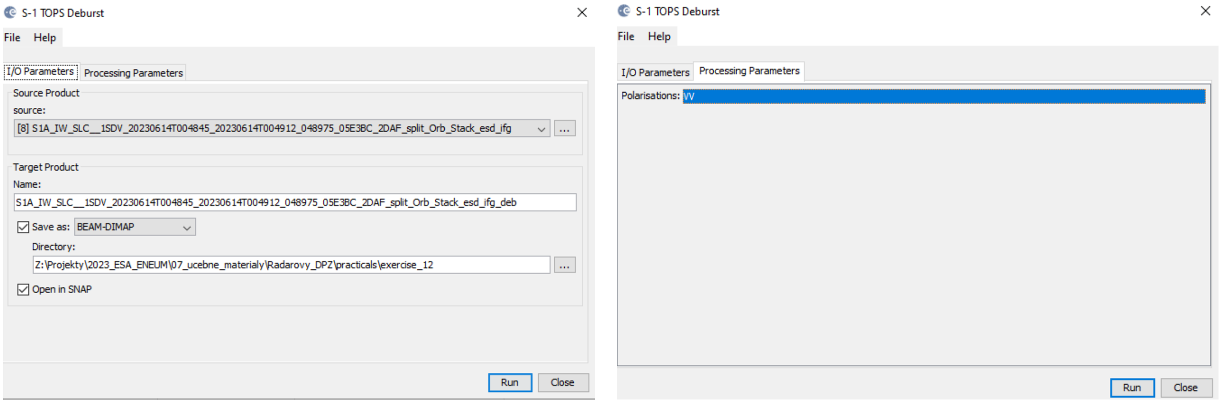


TOPS Deburstring

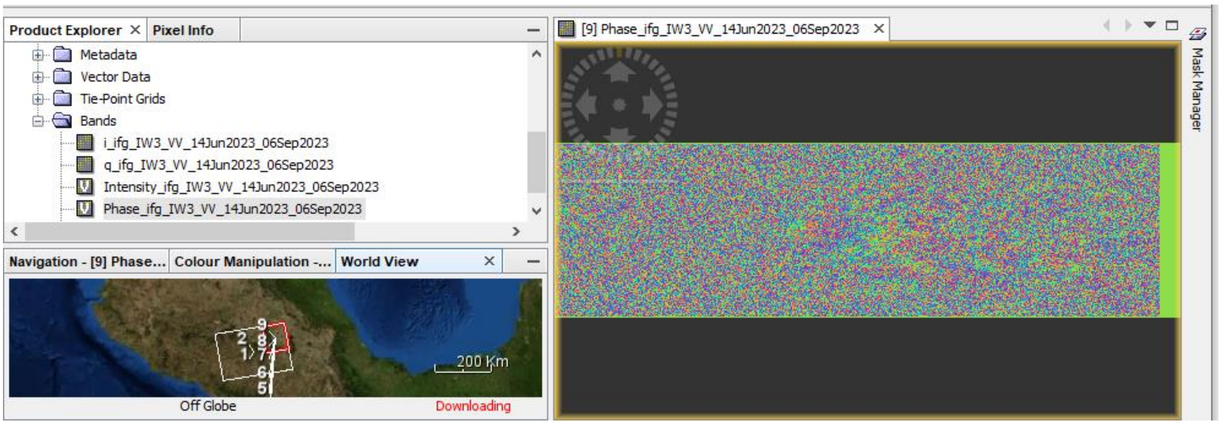
The next stage in interferometry using Sentinel-1 TOPS mode (IWS) data involves "debursting" or merging the bursts - the focused complex burst images are assembled in azimuth-time sequence to form a unified sub-swath image, with black-fill borders separating them. There is ample overlap between neighboring bursts and sub-swaths to guarantee continuous ground coverage. All burst images in all sub-swaths are resampled to a consistent pixel spacing grid in both range and azimuth, while retaining the phase data.

From the main menu bar, navigate to Radar > Sentinel-1 TOPS > S-1 TOPS deburst:
In the I/O Parameters tab, choose the "Orb_Stack_esd" product generated during the interferogram formation process. By default, the output appends "deb" to the filename.

In the TOPSAR-Deburst tab select Polarizations: VV. Click on the „RUN".

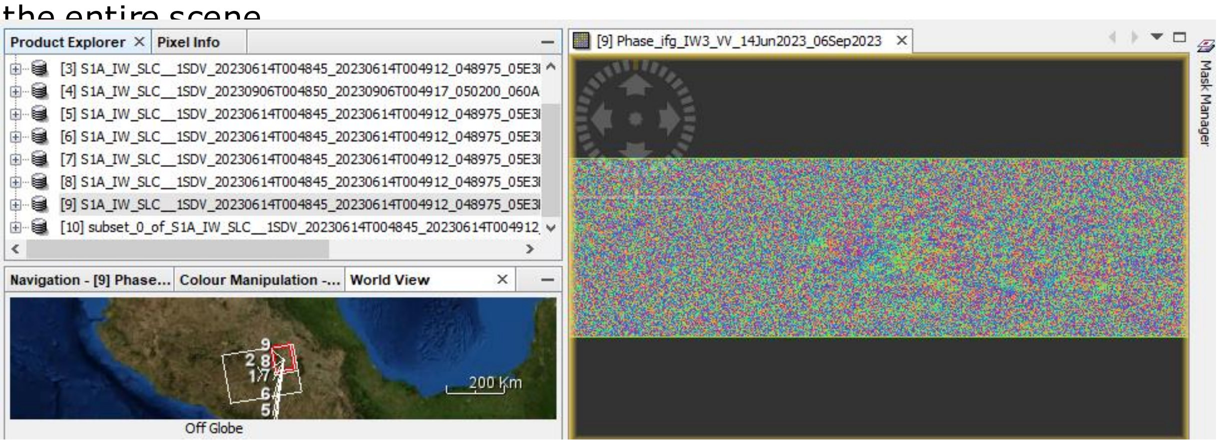


The new product will appear in the Product Explorer window. The processing might take some time depending on your machine.



Create subset (optional)

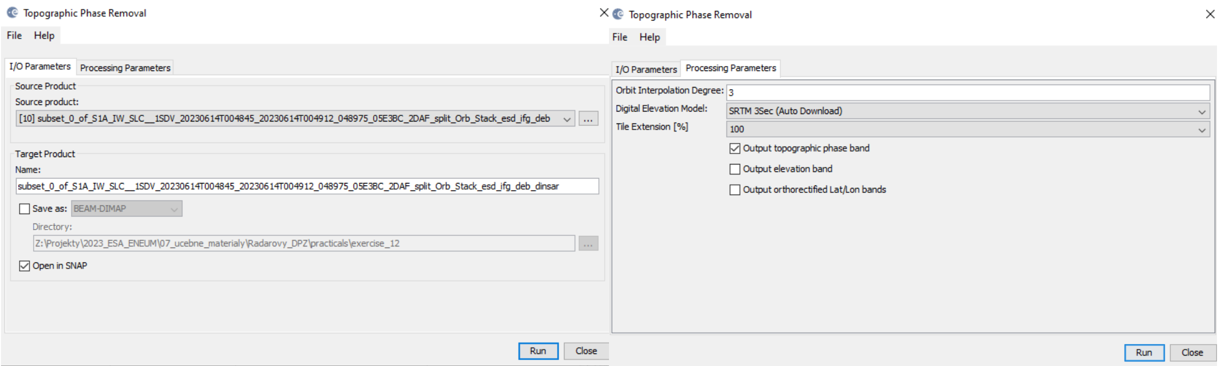
In the earlier stages of processing, empty pixels (green pixels on the interferogram) along the interferogram's perimeter may have been created, particularly in regions not overlapped by both input images. To remove these sections, employ the Subset function found under Raster. This approach will also decrease processing time in subsequent stages, especially when the analysis is concentrated on a specific area rather than the entire scene.



The next step involves removing the topographic phase from the debursted interferogram using a Digital Elevation Model (DEM).

To proceed with topographic phase removal, follow these steps:

From the main menu bar, navigate to Radar > Interferometric > Products Topographic Phase Removal:
In the I/O Parameters tab, choose the "Orb_Stack_ifg_deb" product generated during the deburst step.
By default, the output appends "dinsar" to the filename.
The Processing Parameters tab indicates that the default setting is to download the SRTM 3-arcsecond DEM, which is suitable for basic processing. Select the "Output topographic phase band" option and keep the default parameters.



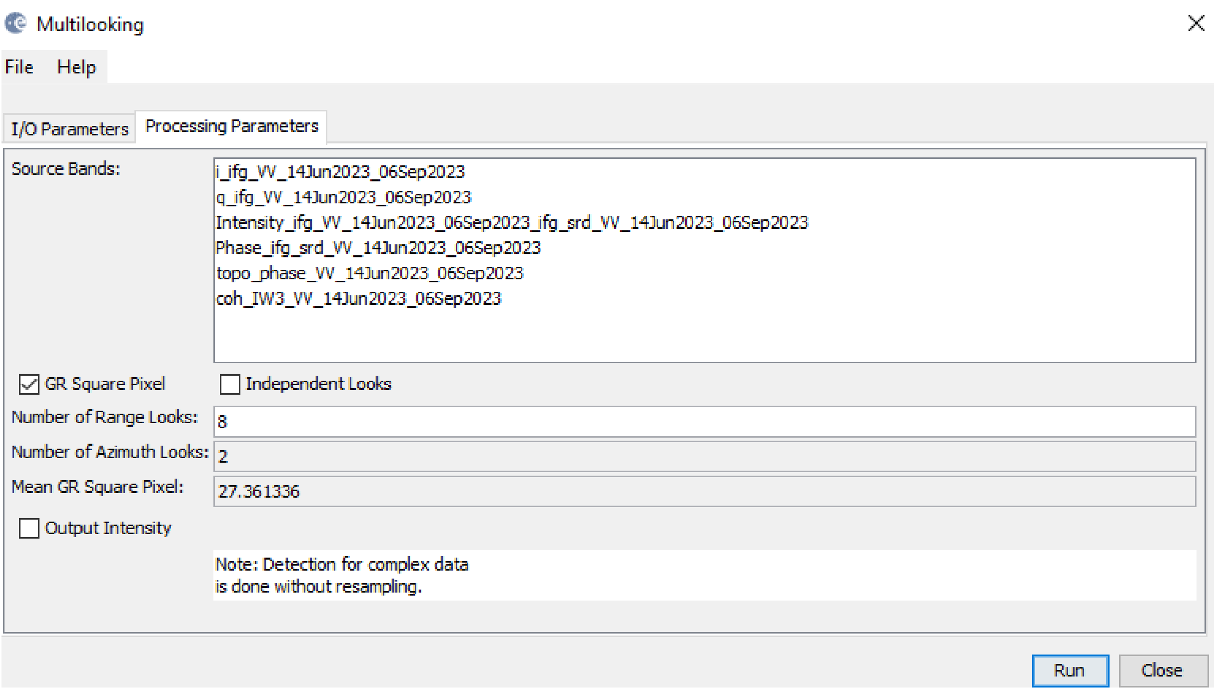
Multi-Looking and Filtering

There are two methods to minimize noise in the interferogram: filtering and multi-looking. While standard procedure involves applying filtering initially, it's also possible to opt for multi-looking first.

Multilooking

Multi-looking involves averaging several pixels in each direction, a process referred to by radar engineers as "taking multiple looks." This leads to larger pixels and has the potential to significantly diminish noise.
The extent of multi-looking required depends on the desired spatial resolution and the spacing of the fringes.

To initiate multi-looking:
From the top main menu bar, select Radar > SAR Utilities > Multilooking.
In the I/O Parameters tab, choose the "dinsar" product generated by the previous step. By default, "ML" is appended to the output name.
In the Processing Parameters tab set the following parameters:
Number of Range Looks: 8
Number of Azimuth Looks: 2



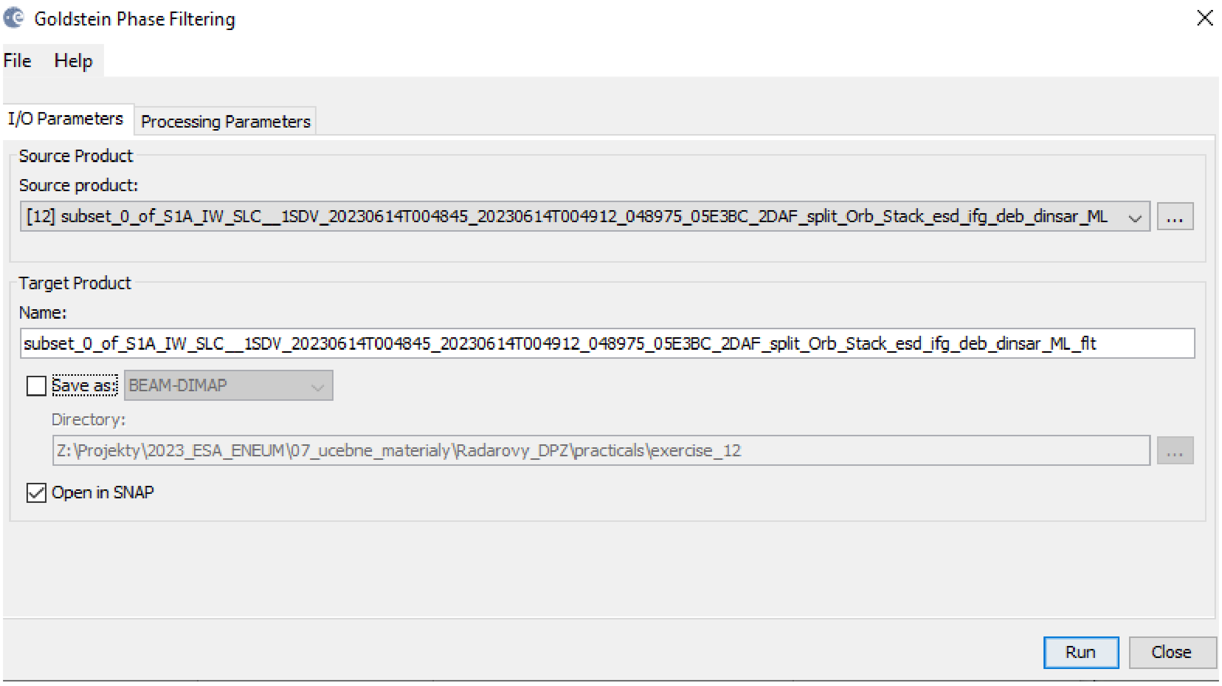
Filtering

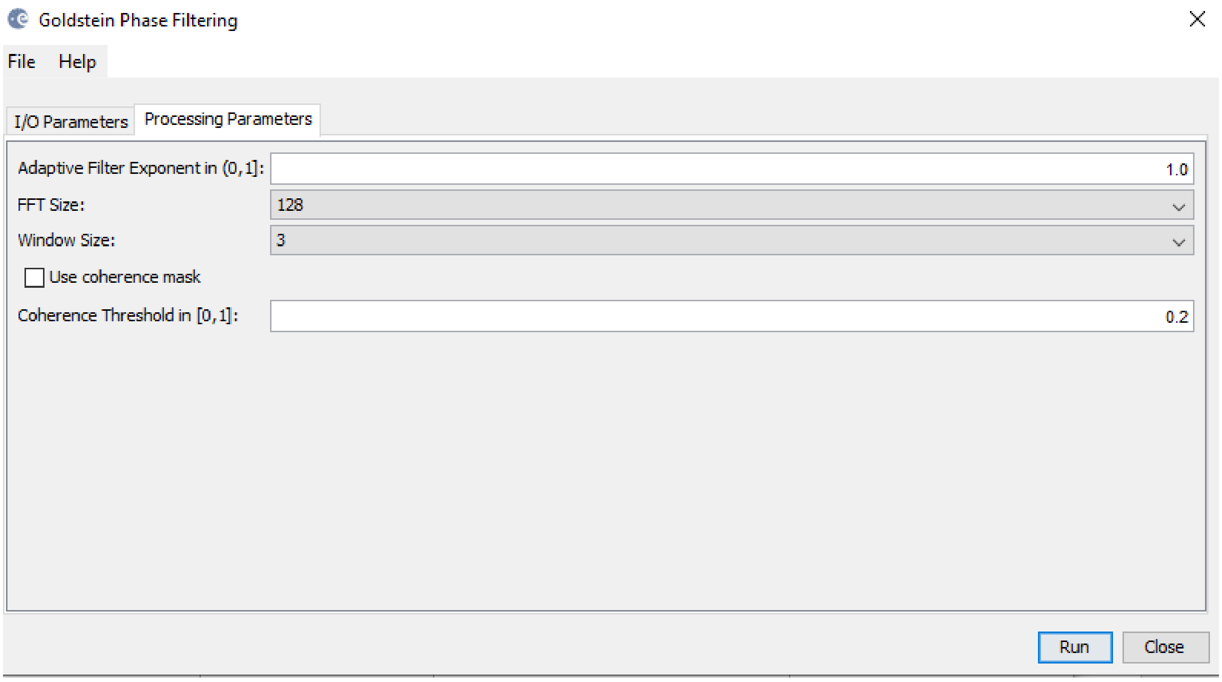
To begin filtering, navigate to Radar > Interferometric > Filtering > Goldstein Phase Filtering from the top main menu bar.

In the I/O Parameters tab, choose the „ML" product generated in the previous step.

By default, the output name includes "flt."

In the Processing Parameters tab set the parameters as defined below:
Adaptive Filter Exponent in (0,1]: 1.0
FFT Size: 128





In this step we have to save the output, which is the multilooked and filtered differential interferogram.

2.6 Phase Unwrapping

Unwrapping in SNAP follows three distinct steps:

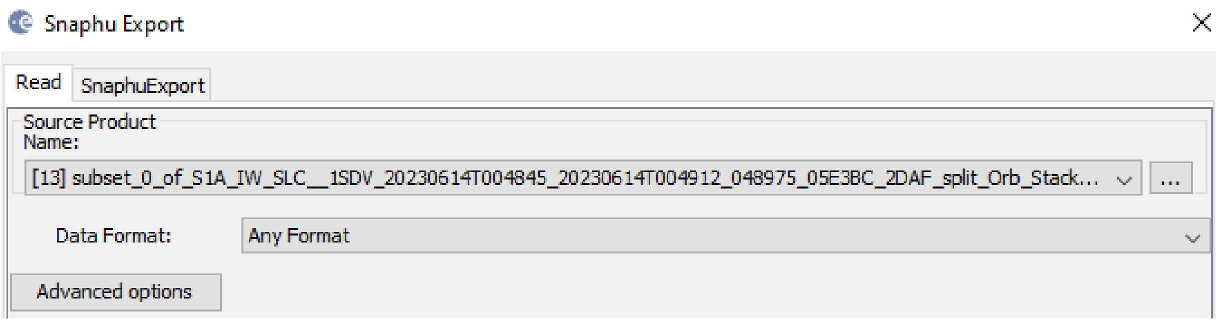
1. Export of the wrapped phase (and definition of the parameters)
2. Unwrapping of the phase (performed outside SNAP by snaphu)
3. Import of the unwrapped phase back into SNAP

Export of the wrapped phase

Export your interferogram or your subset interferogram from Sentinel-1 Toolbox to SNAPHU:

From the top main menu bar, navigate to Radar > Interferometric > Unwrapping > Snaphu Export.

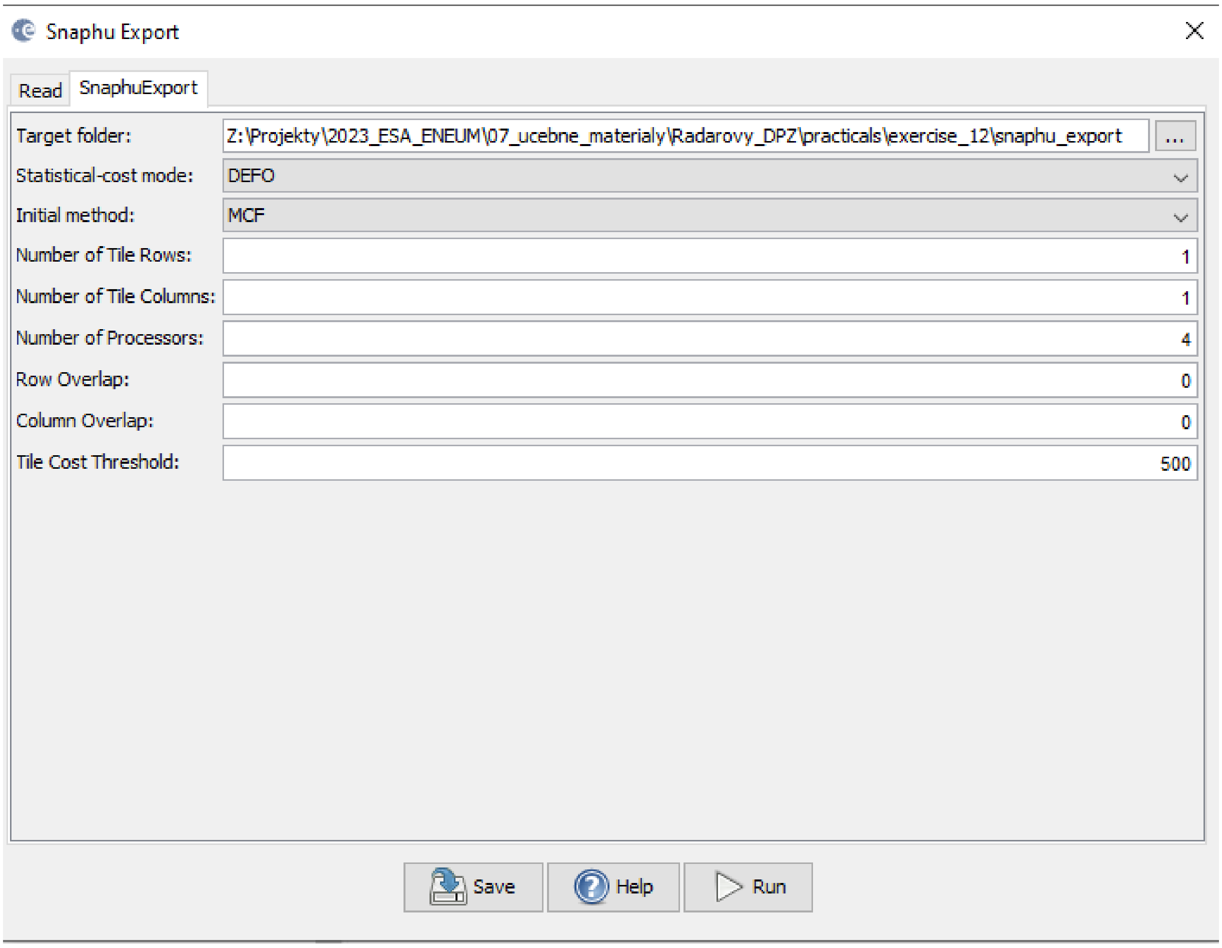
In the Snaphu Export window:
In Read tab, select the last "fit" product created by the Goldstein Phase Filtering step



In Snaphu Export tab specify a target folder for export. Create a new target folder for this step by entering a path and new folder name (e.g. „snaphu_export). If the selection of the directory does not work, simply copy and paste the path of your working directory into the text field.

Also, set the parameters as indicated below:
Statistical-cost mode: DEFO
Initial method: MCF
Number of Tile Rows: 1
Number of Tile Columns: 1
Row Overlap: 0
Column Overlap: 0

Note: The number of tile rows, columns can be changed to e.g. "1" because we don't need multiple tiles after multilooking. Depending on the number of processors of your computer, you can also increase the Number of Processors variable.



Click Run to create the SNAPHU_Export file. This step might take some time depending on your PC.

The folder now holds files used for phase unwrapping:
▪ the coherence: image (*.img) and metadata (*.hdr)
▪ the wrapped phase: image (*.img) and metadata (*.hdr)
▪ the unwrapped phase: only the metadata (*.hdr), because the image (*.img) is first to be created
by snaphu in the next step.
▪ a configuration file (snaphu.conf) containing the parameters defined in the export operator

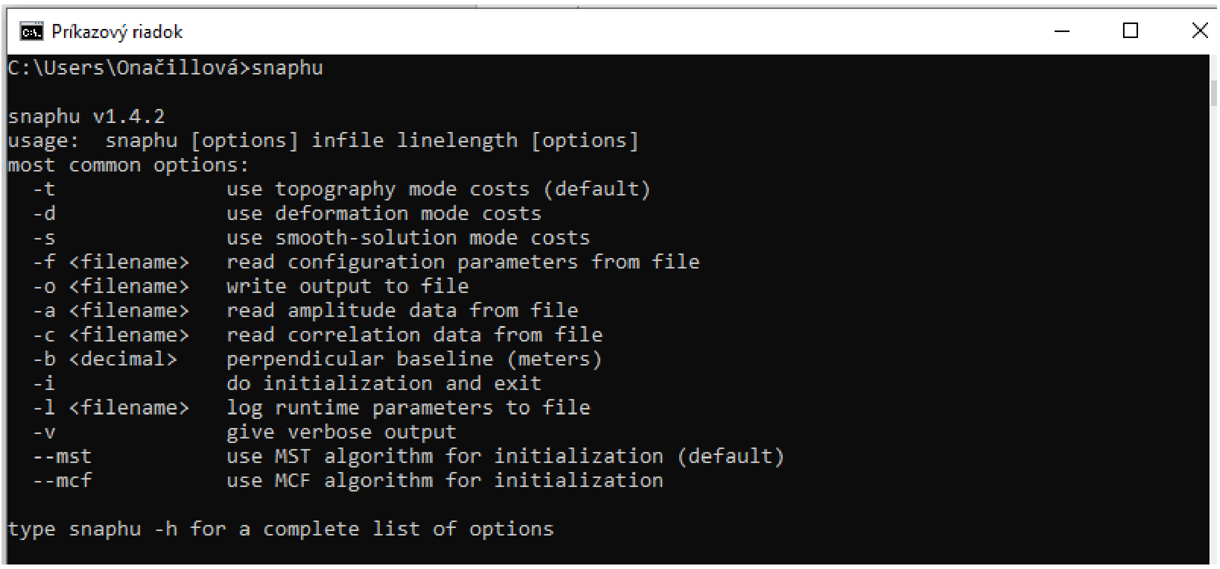
Unwrapping of the phase

You should see the wrapped interferogram phase "Phase_ifg*.img", coherence "coh_*.img", and a "snaphu.conf" file.

For the next step, you will need to instal SNAPHU in Windows. SNAPHU is a tool for phase unwrapping of interferometric information. To use it as an executable file (*.exe) in Windows it has to be compiled first so all required drivers (*.dll) are installed correctly. Follow the steps for installation here: file:///C:/Users/Ona%C4%8Dillov%C3%A1/Downloads/Installation_SNAPHU_English_ABraun.pdf

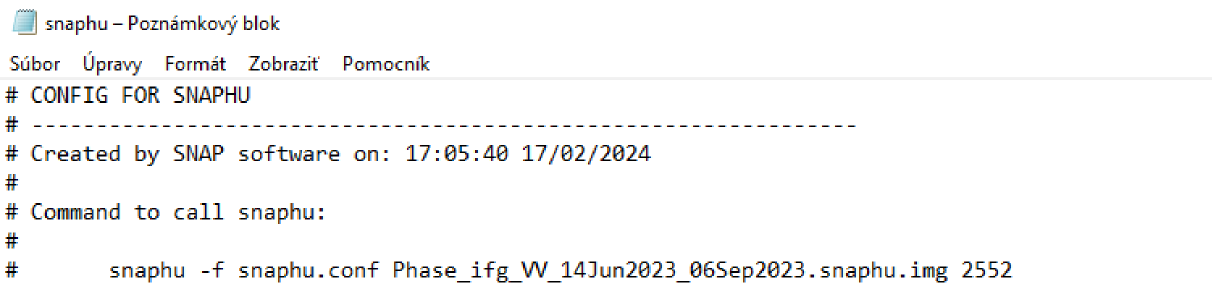
To start unwrapping, check the location of the interferogram exported from SNAP. If snaphu.exe is not in your system's PATH variable: Copy it in there as well. It is recommended to store the data and snaphu on the same disk. Open Command Window Here.

Type snaphu and hit Enter. The help menu should be displayed.

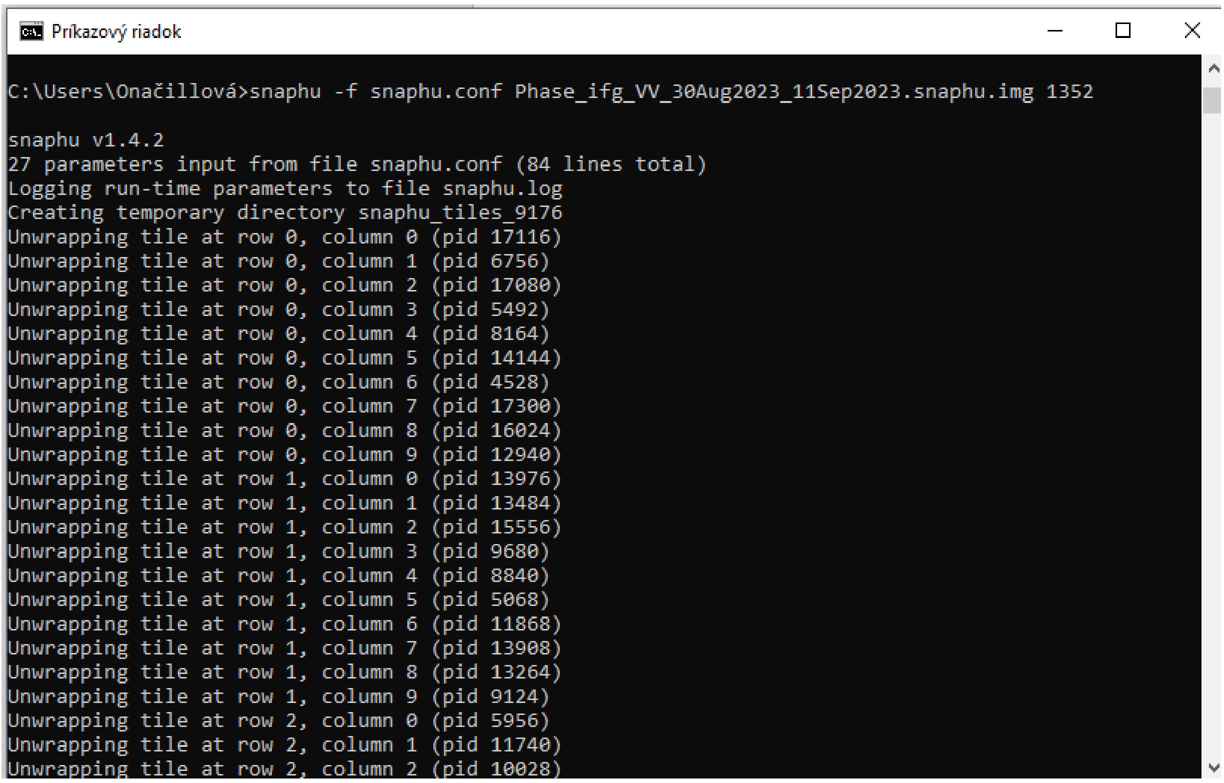


```
Príkazový riadok
C:\Users\Onačillová>snaphu

snaphu v1.4.2
usage:  snaphu [options] infile linelength [options]
most common options:
  -t               use topography mode costs (default)
  -d               use deformation mode costs
  -s               use smooth-solution mode costs
  -f <filename>    read configuration parameters from file
  -o <filename>    write output to file
  -a <filename>    read amplitude data from file
  -c <filename>    read correlation data from file
  -b <decimal>     perpendicular baseline (meters)
  -i               do initialization and exit
  -l <filename>    log runtime parameters to file
  -v               give verbose output
  --mst            use MST algorithm for initialization (default)
  --mcf            use MCF algorithm for initialization

type snaphu -h for a complete list of options
```

The command to start the unwrapping is shown in the file snaphu.conf. Open it with a text editor. The beginning of the "snaphu.conf" file shows the command to call Snaphu



```
snaphu – Poznámkový blok
Súbor  Úpravy  Formát  Zobraziť  Pomocník
# CONFIG FOR SNAPHU
# ---------------------------------------------------------------
# Created by SNAP software on: 17:05:40 17/02/2024
#
# Command to call snaphu:
#
#       snaphu -f snaphu.conf Phase_ifg_VV_14Jun2023_06Sep2023.snaphu.img 2552
```



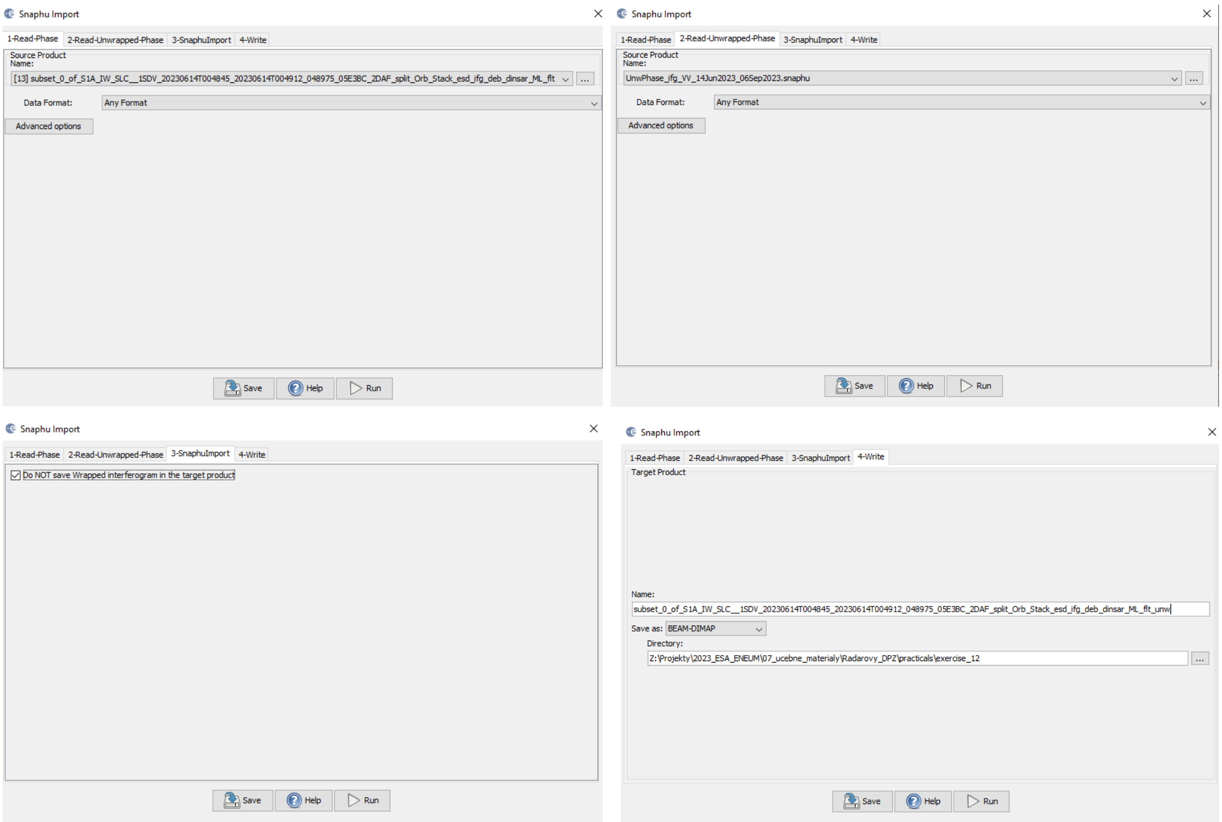
The Snaphu program can take a long time to run. At the end it writes **unwrapped phase to "Unw_ifg*.img" file**

Import of the unwrapped phase

Now, we import the unwrapped phase. From the top main menu bar, select Radar > Interferometric > Unwrapping, and then Snaphu Import that converts it back into the BEAM DIMAP format and adds the required.

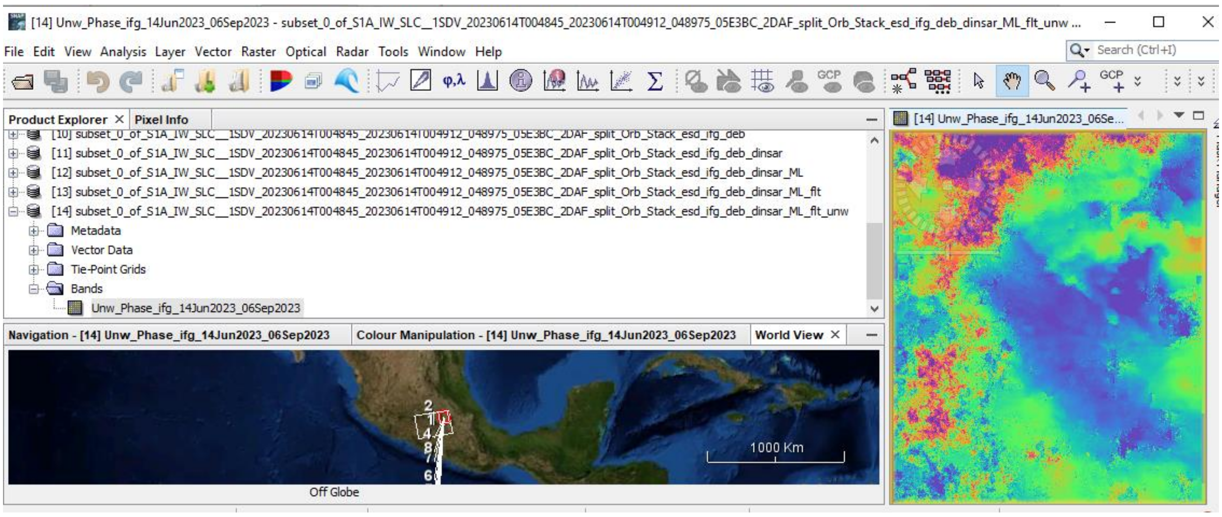
Read-Phase: should be set to the wrapped product that you exported(before the export)
Read-Unwrapped-Phase: select the unwrapped phase product: Navigate to folder where you exported for Snaphu. Select the "UnwPhase_ifg*.snaphu.hdr" file. Note: The error message will then vanish if you proceed to the next tab.
SnaphuImport: Leave the option "Do NOT save Wrapped interferogram in the target product" unchecked, because it is required in the later step.
Write: To store the imported unwrapped band in a separate product (recommended), add '_unw' to the end of the output name and click Run.

Finally, a new product is added to the Product Explorer which contains the the unwrapped phase that we can display.



Select the Unw_Phase_ifg band. Double click on this unwrapped phase to see if the unwrapping was successful. It should be a smooth raster with little variation except for the areas of expected deformation.

All fringe patterns are summarized to absolute changes. Go to the Colour Manipulation tab and select "100%" to stretch color scale to full range of unwrapped data. Unwrapped phase is still in radians. Phase is reference image minus coregistered image. If reference image is earlier, then negative phase is land moving toward satellite (negative range change)

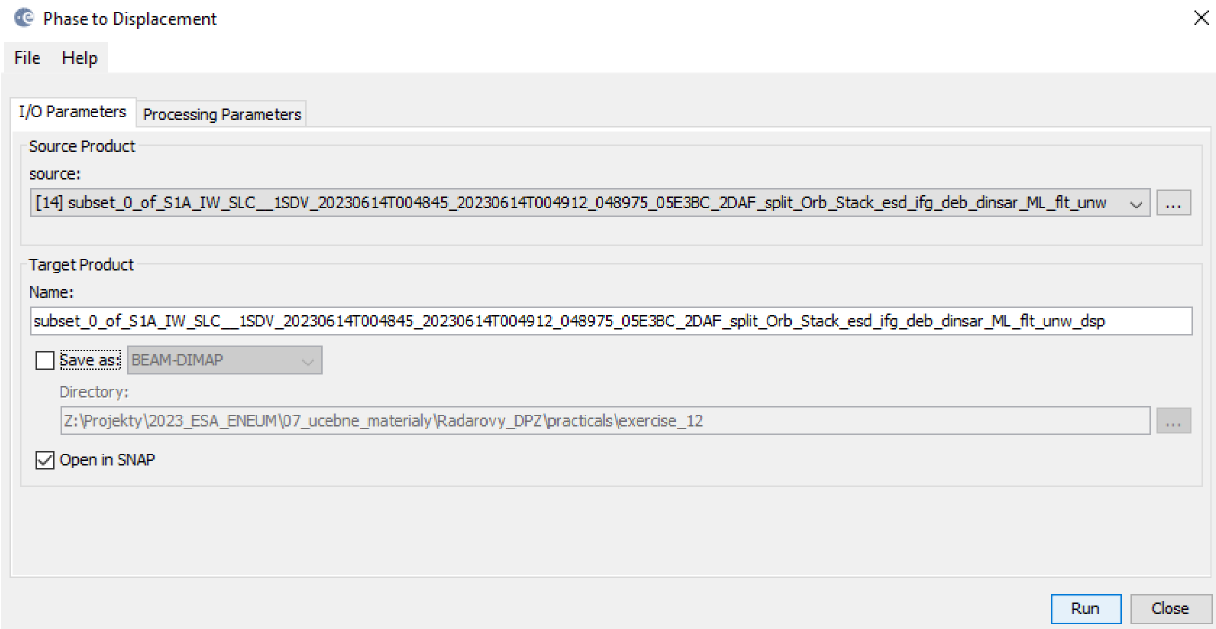


2.7 Phase to displacement

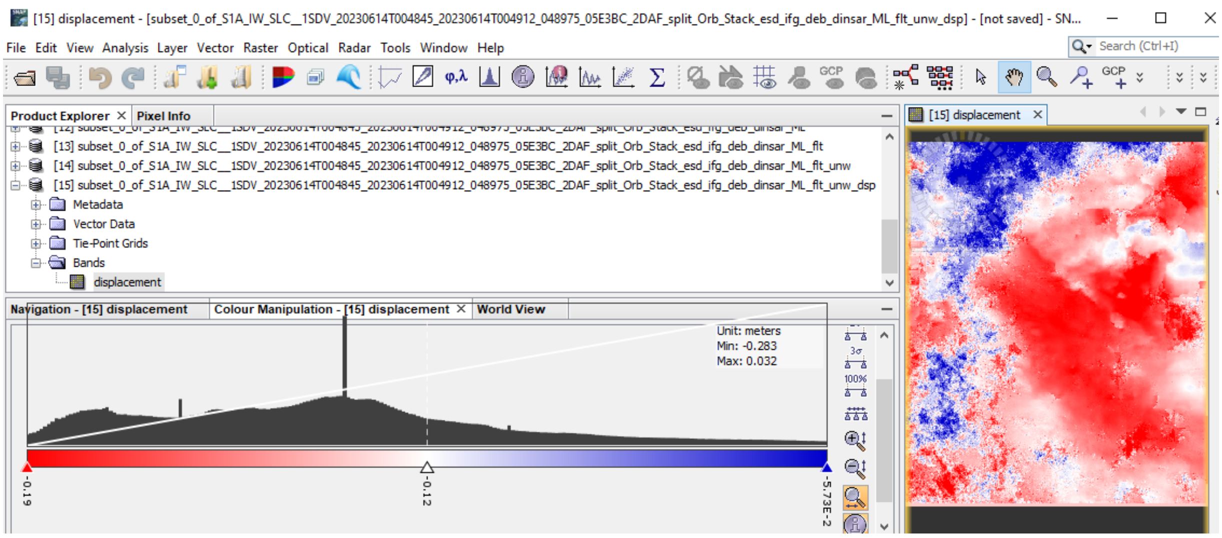
We can convert the unwrapped phase to displacements. From the top main menu bar, select Radar, then Interferometric, then Products, and then Phase to Displacement.

The I/O Parameters tab should be set to the unwrapped product that you imported.

Default for target product name is to add "_dsp" to the name



In the Product Explorer window select the "displacement" band from the new opened product to open the displacement product in the view window. Displacements is now in meters.

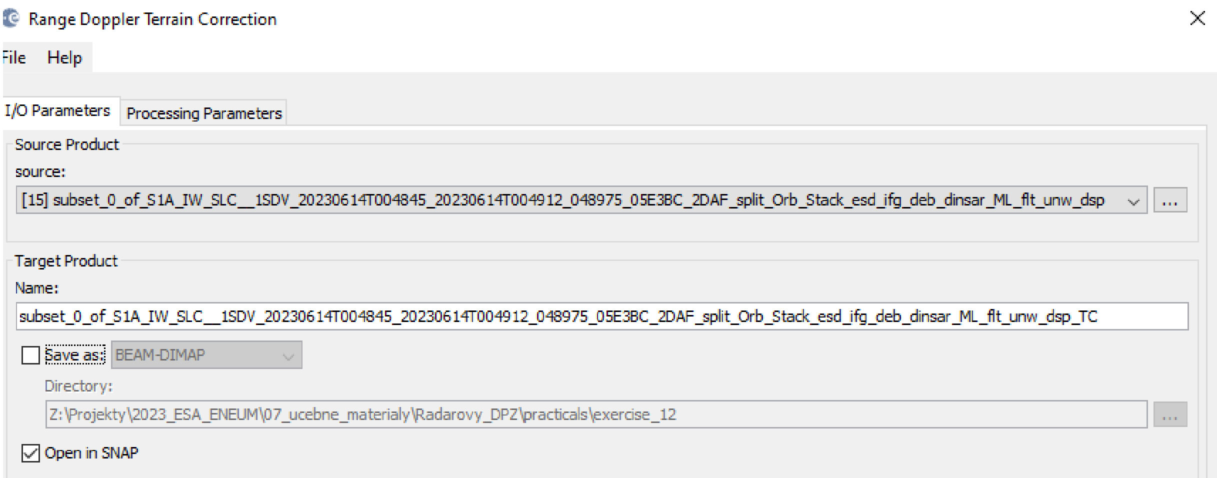


2.8 Geocoding results—Terrain Correction

Terrain corrections aim to mitigate distortions in SAR images caused by topographical variations in the scene and the tilt of the satellite sensor. These corrections seek to ensure that the geometric representation of the image closely aligns with real-world conditions. SNAP calls geocoding with topography "Terrain Correction."

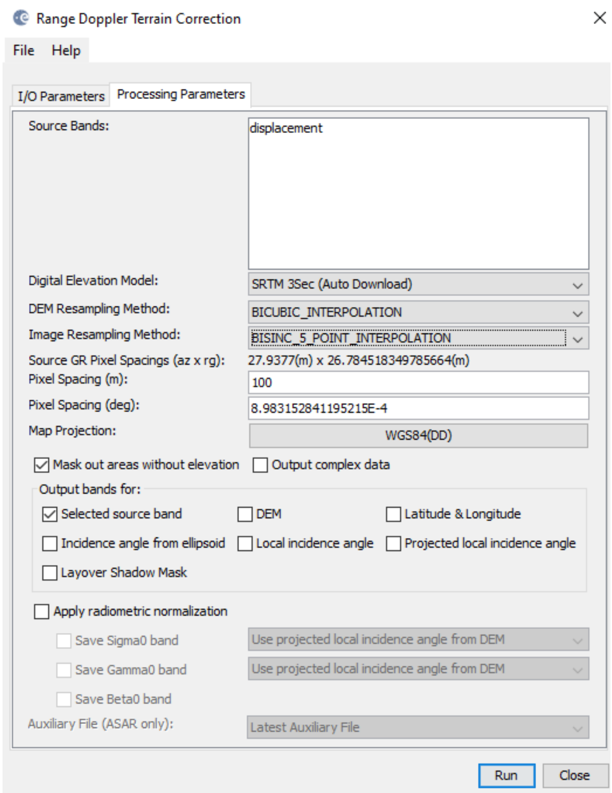
From the top main menu bar, select Radar, then Geometric, then Terrain Correction, and then Range-Doppler Terrain Correction:

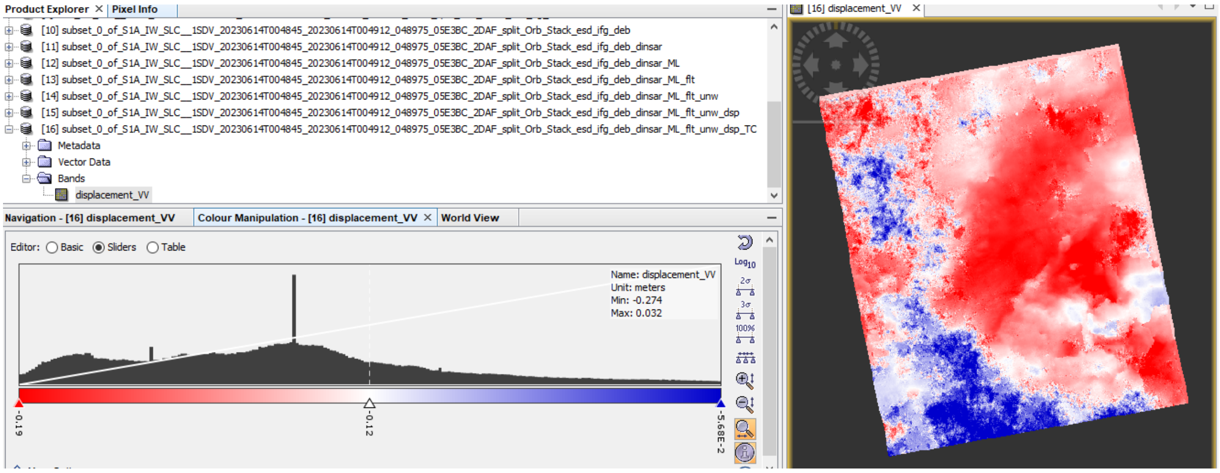
The I/O Parameters tab should be set to the displacement product that you.
Default for target product name is to add "_TC" to the name



In the Processing Parameters tab, select the Source Band („displacement").
Set also these parameters as following:
Pixel Spacing (m): 100
Map Projection: WGS84(DD)

Now, we can display displacement_vv band of geocoded result.
Again, better to stretch colors.
Product is now evenly spaced in latitude and longitude.





Note: By appropriate post-processing of the displacement product (masking of the incoherent values) more accurate measurements can be produced.

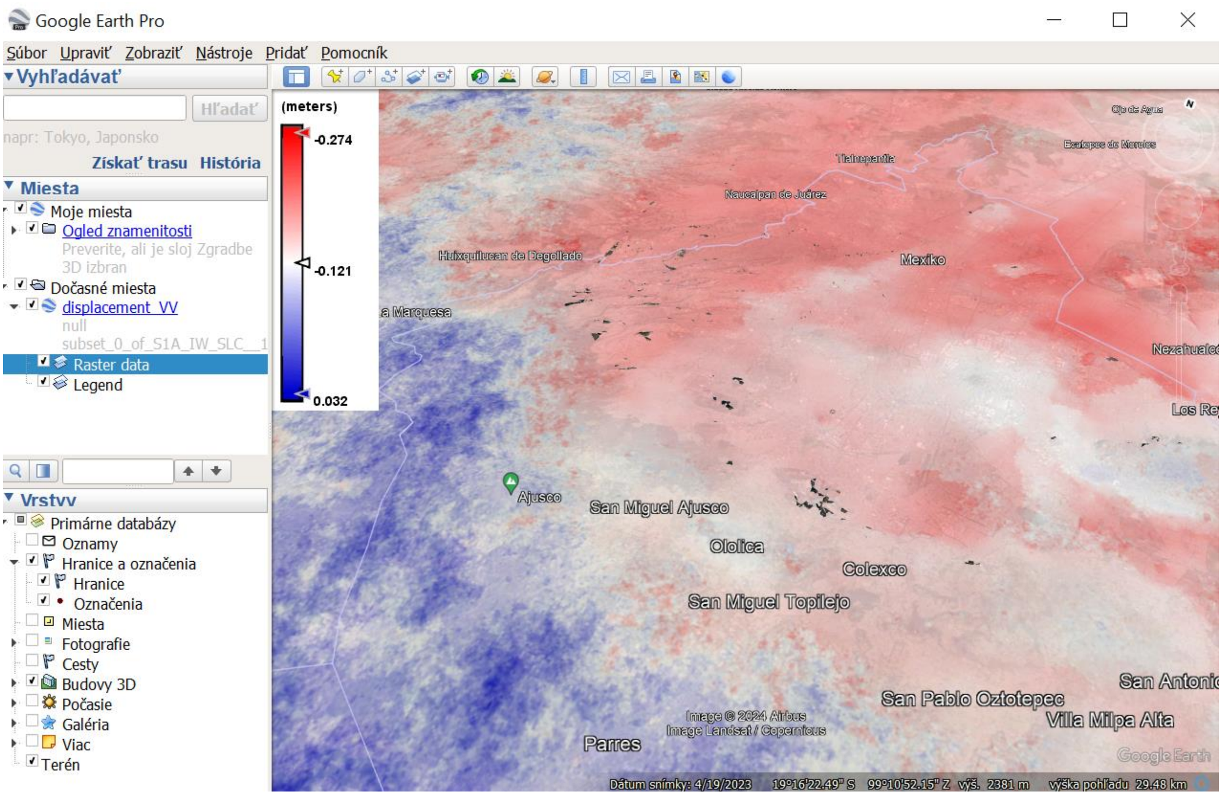
2.9 Export .kmz to Google Earth

Geocoded products (projected to WGS84) can be exported as a KMZ file to view in Google Earth (Pro):

In the SNAP - right click on the elevation raster in the View tab (or navigate to File > Export > Other > View As Google Earth KMZ)

Choose a directory and name to save the output .kmz, confirm with Save.

Open the resulting KMZ file in Google Earth (Pro) to observe the elevation patterns overlaid on the satellite image base map.



For more information, see the lecture: [12. SAR for land subsidence](#)

THANK YOU FOR FOLLOWING THE EXERCISE!

UNIVERSITY COURSE APPLIED RADAR REMOTE SENSING

EXERCISE 13 – TUTORIAL

Earthquake deformation with Sentinel-1 using the SNAP software

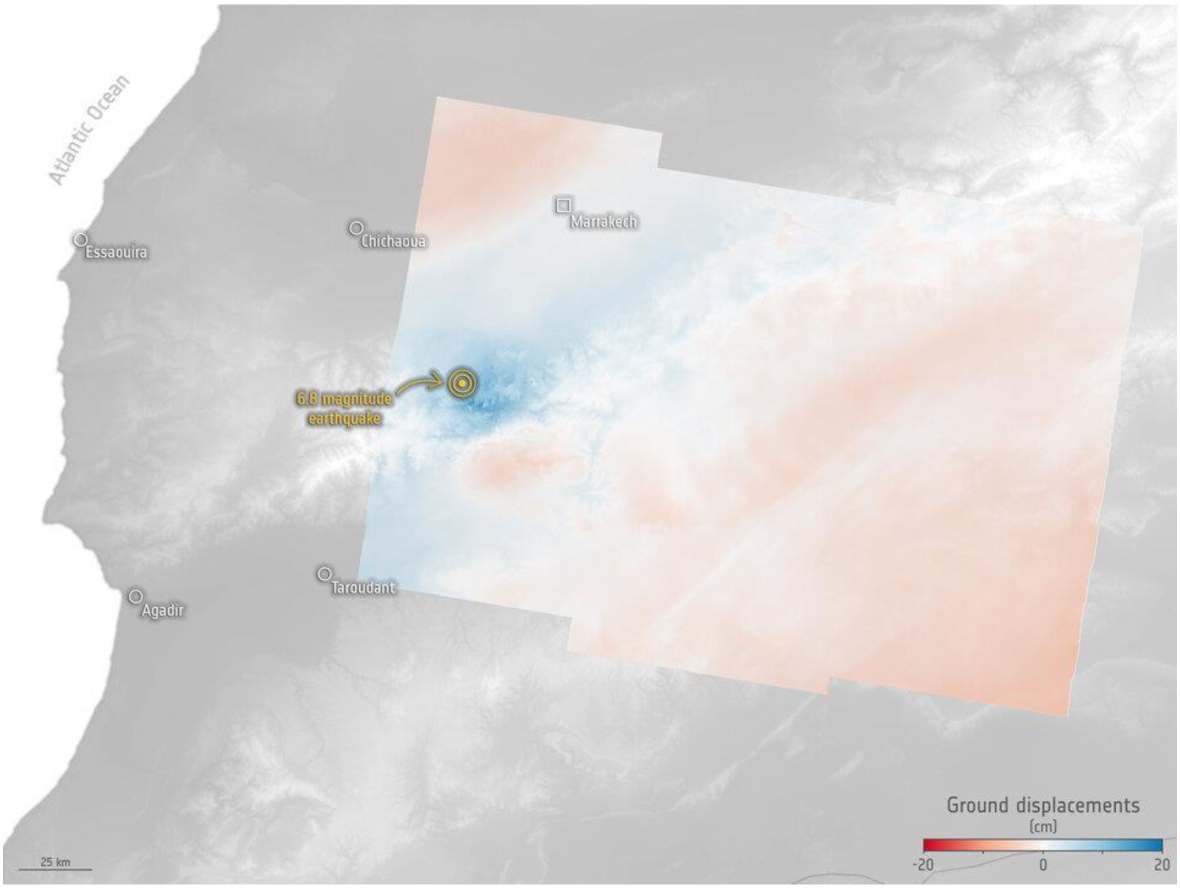
Přírodovedecká fakulta UPJŠ v Košiciach
UNIVERZITA PAVLA JOZEFA ŠAFÁRIKA V KOŠICIACH

FUNDED BY EUROPEAN SPACE AGENCY UNDER THE PLAN FOR EUROPEAN COOPERATING STATES, 7TH CALL FOR SLOVAKIA

1 | Exercise outline

In this exercise, we will:

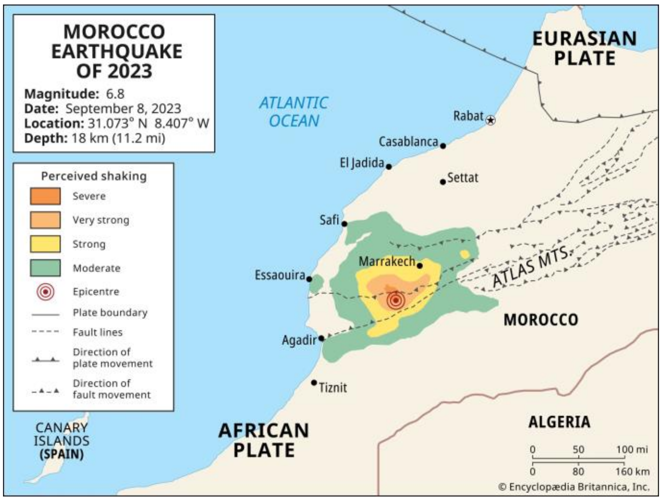
- Learn the basic physics of SAR interferometry
- Perform necessary data processing for making an interferogram
- Understand the information content in SAR interferometric images



Morocco earthquake deformation
Source: contains modified Copernicus Sentinel data (2023), processed by Aristotle University of Thessaloniki and the DIAPASON InSAR service of CNES integrated by TRE Altamira on the Geohazard Exploitation Platform GEP/ESA.

2 | Background

Deformation Mapping and Change Detection using Sentinel-1 data



Satellites constantly monitor Earth from space, providing vital data essential for rapid damage assessment and disaster management. The radar on board the Copernicus Sentinel-1 mission can detect ground conditions and penetrate clouds, functioning day and night.

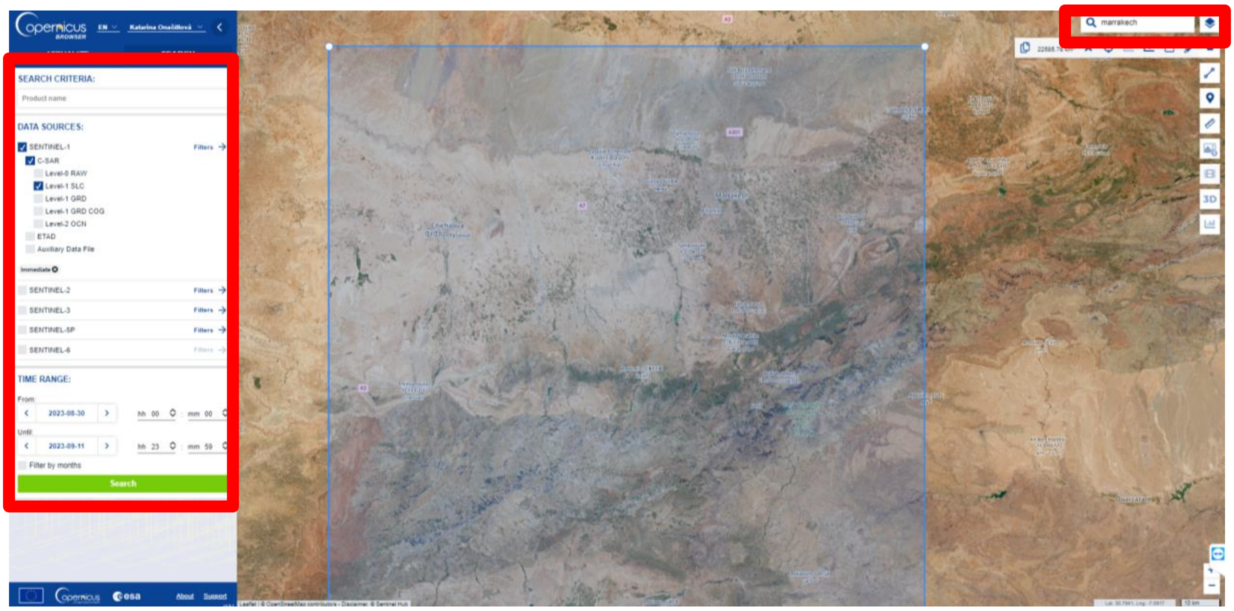
One of the mission's primary functions is to regularly monitor subtle alterations in the Earth's surface elevation. During an earthquake event, surface changes are notably more conspicuous compared to gradual movements such as subsidence or uplift. These radar images enable scientists to meticulously observe and analyze the specific impacts of earthquakes on the Earth's land surface.

On Friday 8 September 2023, the powerful 6.8 magnitude earthquake struck the Atlas Mountains, about 75 km from Marrakech. Tragically, the earthquake resulted in a significant loss of life, widespread building and home collapses, and the blockage of roads. Its impact extended to the extent that buildings even swayed on the country's northern coast.

In response to the Moroccan earthquake, the Copernicus Emergency Mapping Service was mobilized to facilitate the exchange of satellite data.

2.1 Study area and data used

For this exercise, we will use two Sentinel-1 SLC images of the same area near Marrakech, Morocco, downloaded from the Dataspace Copernicus Open Access Hub [@https://dataspace.copernicus.eu/].



2.2. SNAP - Open and explore product

Open SNAP Desktop, click Open Product and open 2 downloaded products by double click on the zipped folders. The opened products will appear in Product Explorer window.

S1A_IW_SLC__1SDV_20230830T062919_20230830T062946_050101_06076B_20BE.SAFE.zip
S1A_IW_SLC__1SDV_20230911T062920_20230911T062947_050276_060D5E_D10D.SAFE.zip

To access the information within the product, double-click on it to reveal the directories, which include:

- Metadata: containing parameters pertaining to orbit and data.
- Tie Point Grids: providing interpolation data for latitude/longitude, incidence angle, etc.
- Quicklooks: presenting a visible image of the entire scene in radar coordinates.
- Bands: consisting of complex values for each subswath "i" and "q", along with intensity (where intensity represents the squared amplitude and functions as a virtual band).

Select intensity image for swath IW1 VV – double click on it to View it
Note: Each SAR image is flipped north—south it maintains the same orientation as its acquisition (in this case, ascending track).

3.2 Coregistration

Image coregistration is the process that involves aligning two or more images geometrically, ensuring that corresponding pixels depict the same area on the Earth's surface. While orbit state vectors alone can suffice to coregister images, for precise offset tracking, additional data from a digital elevation model (DEM) is necessary to enhance coregistration accuracy.

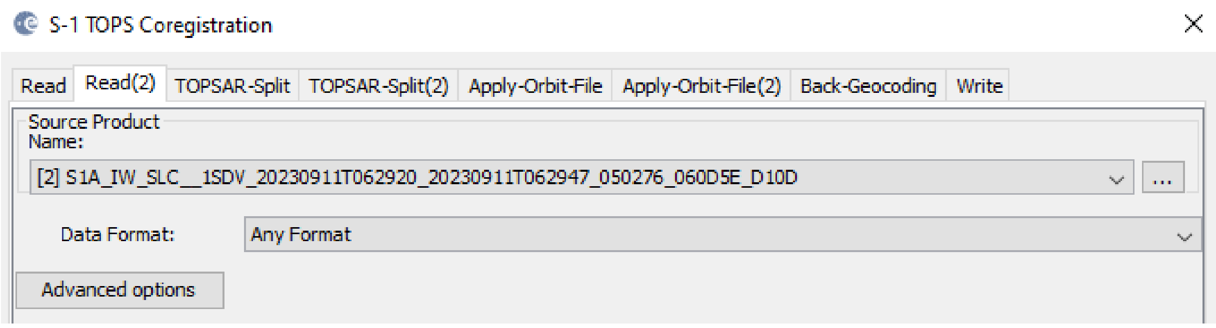
Navigate to Main Menu – Radar – Coregistration –S1 TOPS Coregistration – S1 TOPS Coregistration

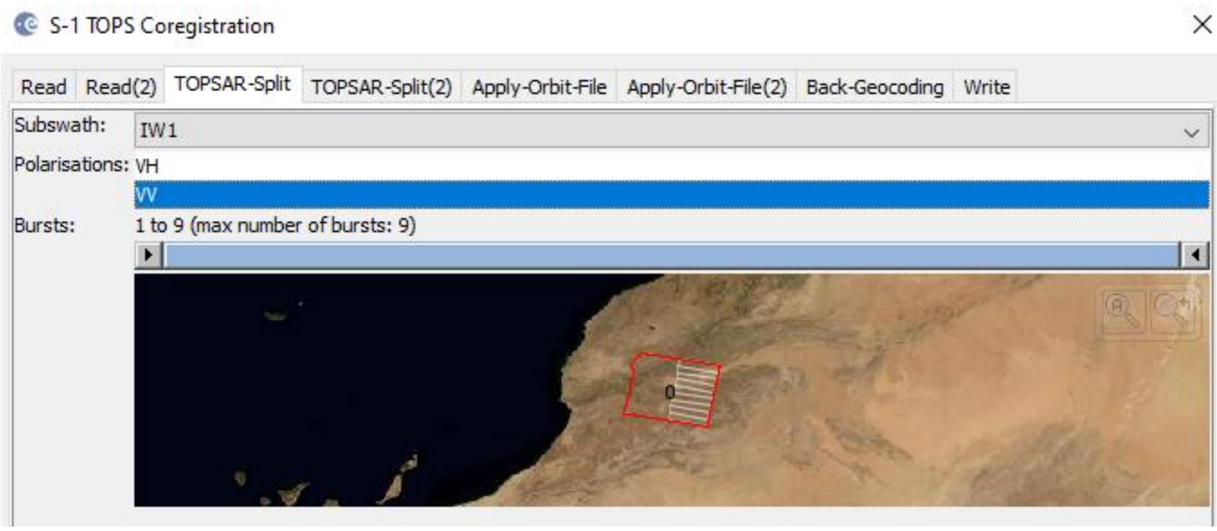
In the Read tab, select the 20230830 SLC product and in the Read(2) tab select the 20230911 SLC product

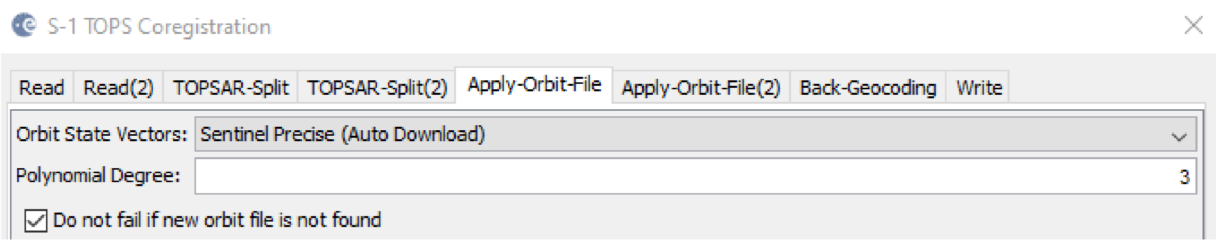
In TOPSAR-Split and TOPSAR-Split(2) tabs select Subswath: IW1 Polarizations:VV

In the Apply Orbit File tab select leave default parameters and uncheck „Do not fail if new orbit is not found" option

In the Write tab, select the directory to save your processing outputs



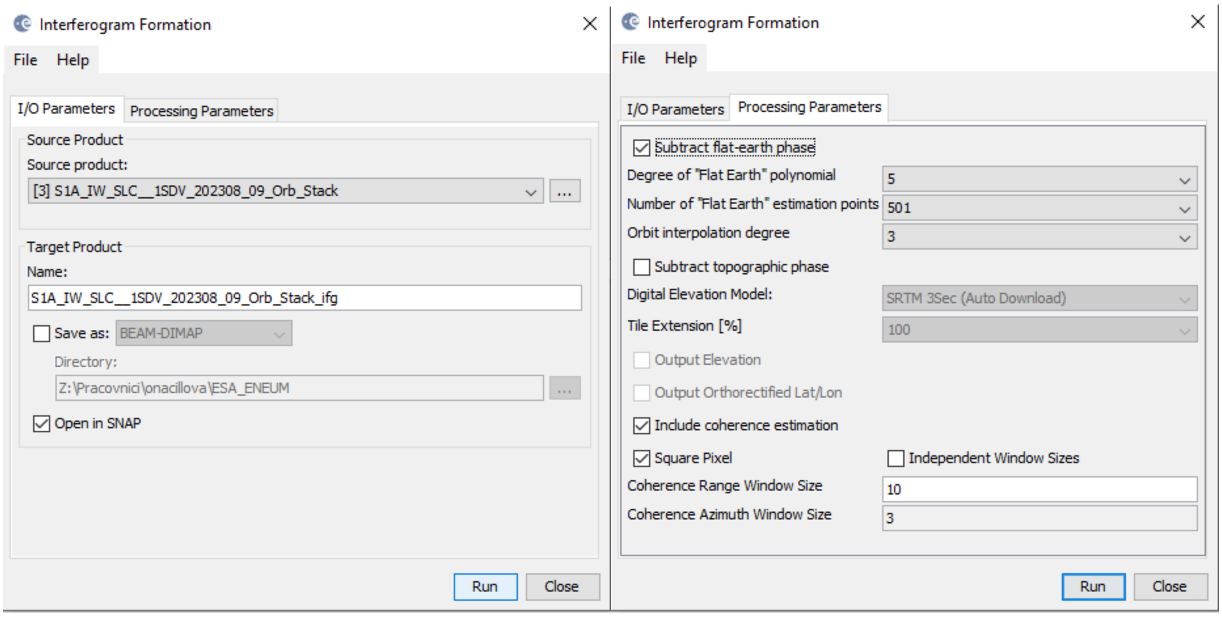




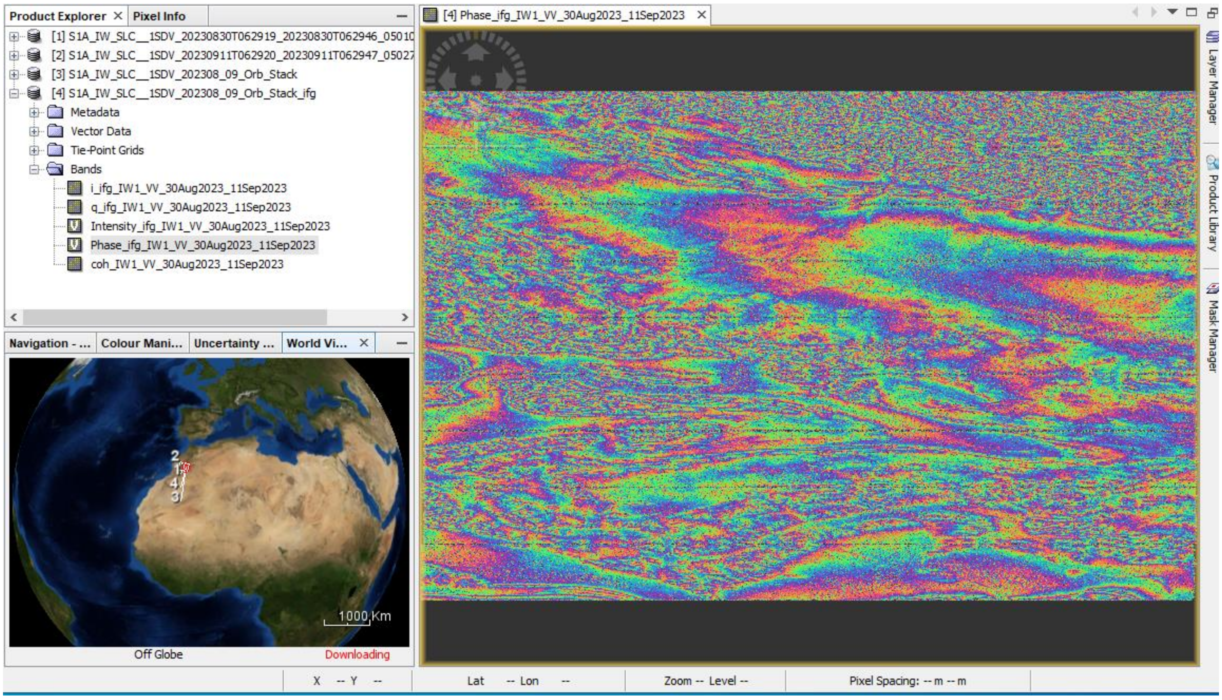
3.3 Forming a Raw Interferogram

The next phase of interferometry involves generating an interferogram using the coregistered SLC images. To do this, follow these steps:

From the main menu bar, go to Radar – Interferometric - Products and finally select Interferogram Formation.
In the I/O Parameters tab, choose the "Orb_Stack" product that was generated during the coregistration process.
By default, the output target is set to the same directory and appends "ifg" to the filename.
For standard processing, there's no need to modify the defaults in the Processing Parameters tab.



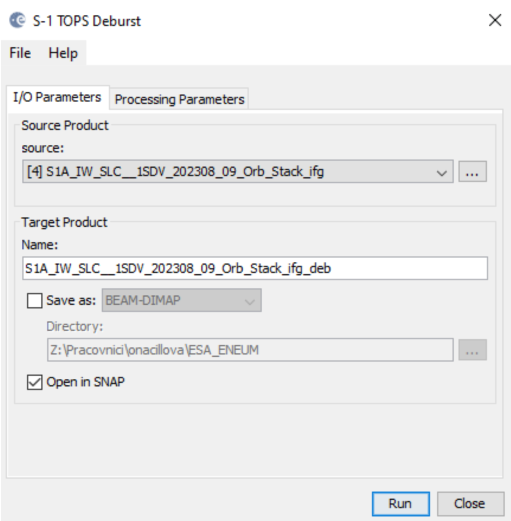
Raw Interferogram — Phase Image should appear int he View tab.

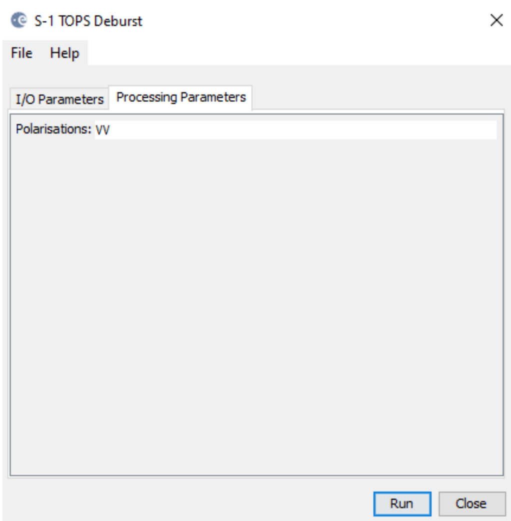


3.4 TOPS Debursting and Topographic Phase Removal

The next stage in interferometry using Sentinel-1 TOPS mode (IWS) data involves "debursting" or merging the bursts, a step not required with Sentinel-1 or other stripmap SAR data.

To perform debursting, follow these steps:
From the main menu bar, navigate to Radar, then Sentinel-1 TOPS, and finally S-1 TOPS deburst.
In the I/O Parameters tab, choose the "Orb_Stack_ifg" product generated during the interferogram formation process. By default, the output appends "deb" to the filename.
There is no need to make changes in the Processing Parameters tab.

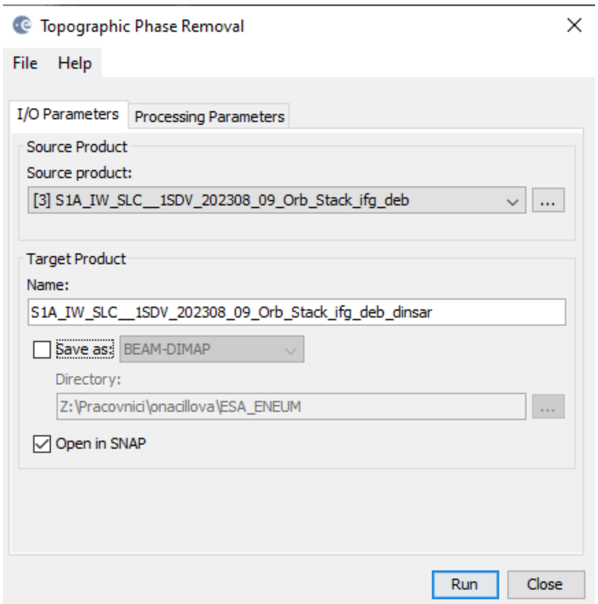


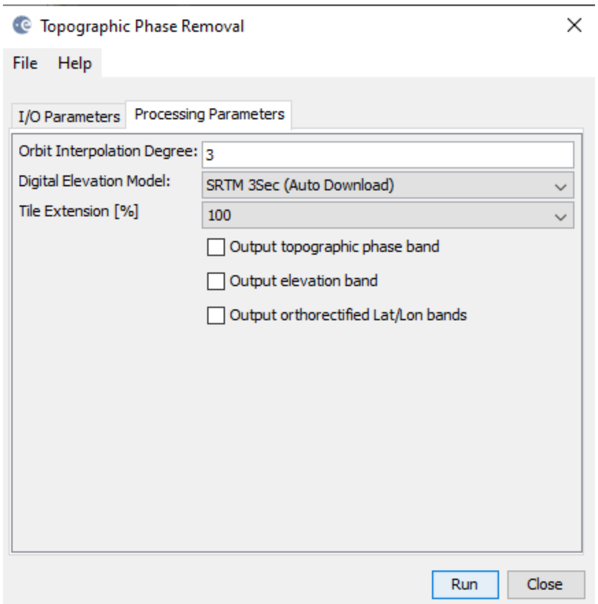


The subsequent stage in all interferometry processes involves eliminating the topographic phase using a Digital Elevation Model (DEM).

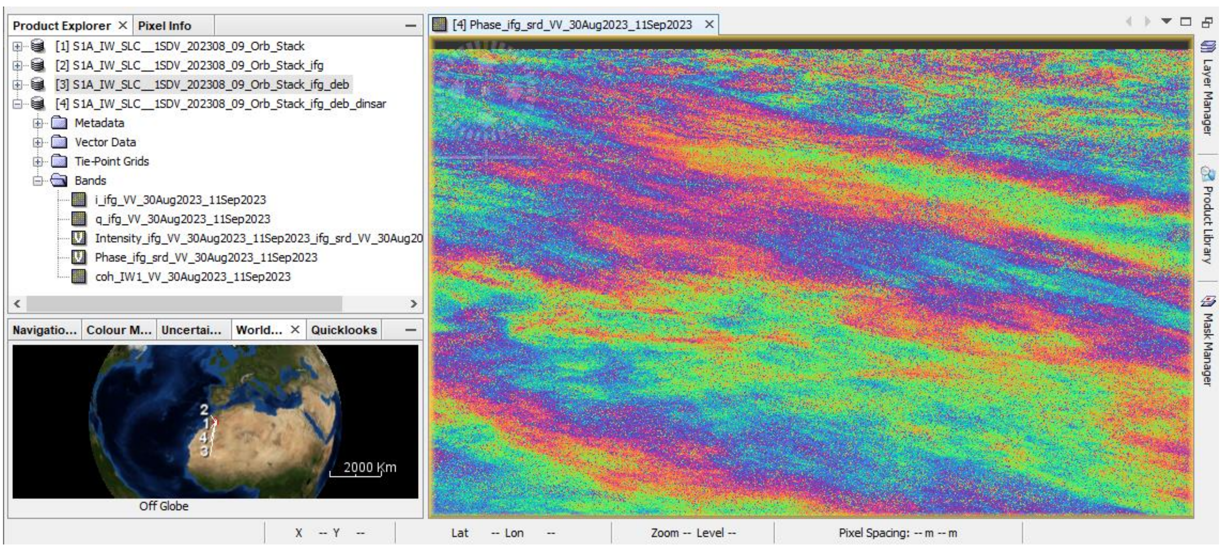
To proceed with topographic phase removal, follow these steps:

From the main menu bar, navigate to Radar, then Interferometric, then Products, and finally Topographic Phase Removal.
In the I/O Parameters tab, choose the "Orb_Stack_ifg_deb" product generated during the deburst step. If not using TOPS mode, select "Stack_ifg" instead.
By default, the output appends "dinsar" to the filename.
The Processing Parameters tab indicates that the default setting is to download the SRTM 3-arcsecond DEM, which is suitable for basic processing. However, in certain cases, you may require a different DEM.





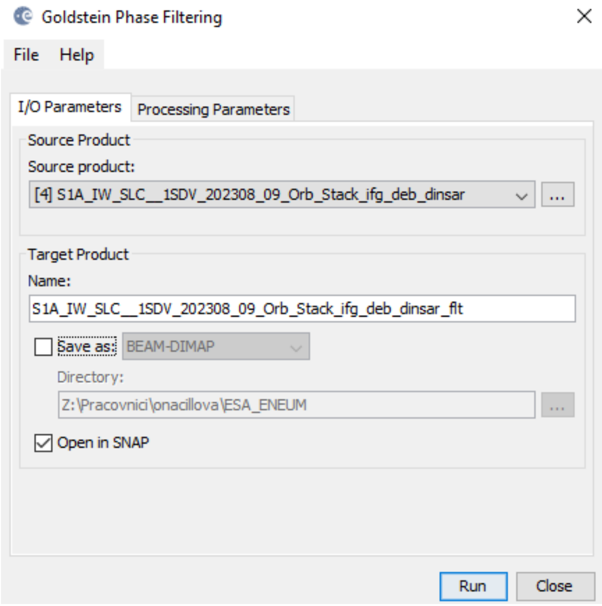
Viewing Differential Interferogram — Phase Image

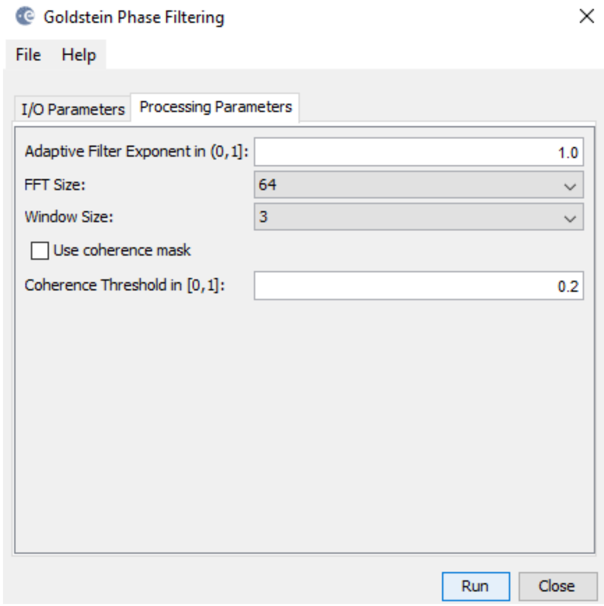


3.5 Filtering and Multi-Looking Interferogram

There are two methods to minimize noise in the interferogram: filtering and multi-looking. While our standard procedure involves applying filtering initially, it's also possible to opt for multi-looking first.

To begin filtering:
Go to Radar, then Interferometric, then Filtering, and select Goldstein Phase Filtering from the top main menu bar.
In the I/O Parameters tab, choose the "dinsar" product generated in the previous step.
By default, the output name includes "flt."
There's no necessity to adjust the default settings in the Processing Parameters tab for basic processing.



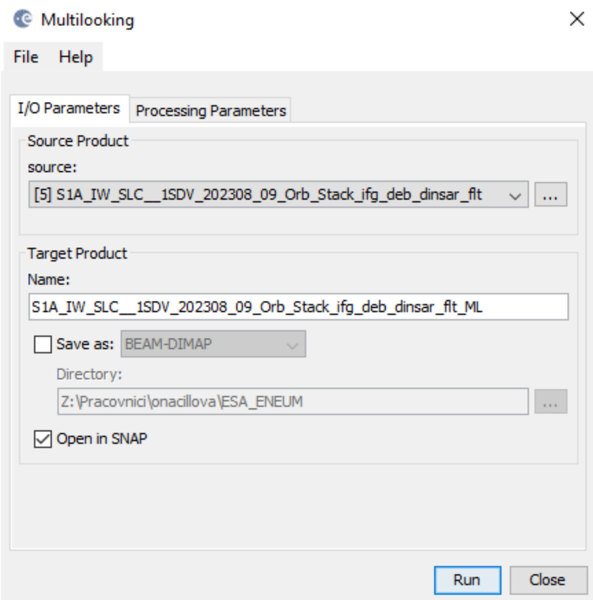


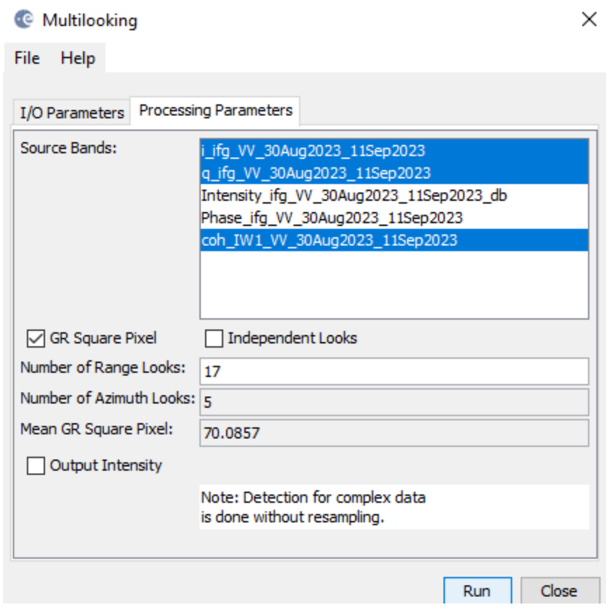
3.6 Multi-Looking Interferogram

Multi-looking involves averaging several pixels in each direction, a process referred to by radar engineers as "taking multiple looks." This leads to larger pixels and has the potential to significantly diminish noise.
The extent of multi-looking required depends on the desired spatial resolution and the spacing of the fringes.

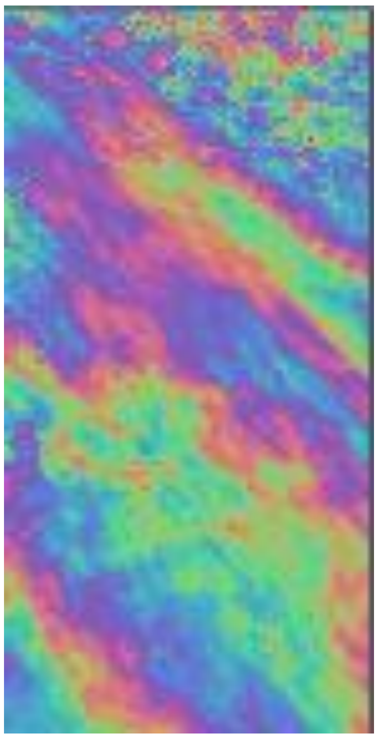
The Morocco earthquake, with a depth of approximately 18 km, exhibits widely spaced fringes. Additionally, there is no surface rupture, allowing for increased spatial averaging without sacrificing the earthquake signal.

To initiate multi-looking:
From the top main menu bar, select Radar, then SAR Utilities, and finally Multilooking.
In the I/O Parameters tab, choose the "dinsar_flt" product generated by the filtering step. By default, "ML" is appended to the output name.
In the Processing Parameters tab, select the Source Bands "i_ifg", "q_ifg", and "coh". For this scene, 17 range looks are utilized, with the calculation of 5 azimuth looks resulting in approximately 70 m output pixels.
Do not select the "Phase" band.





Viewing Multi-Looked Interferograms
Initially, we must generate a new virtual phase band after multi-looking the complex interferogram.



To do this:
From the top main menu bar, navigate to Raster, then Data Conversion, and select Complex i and q to Phase.
Subsequently, you can display the newly created phase band.
As a result of this process, the fringes exhibit significantly reduced noise, and the aspect ratio has been modified, resulting in pixels that are approximately square on the ground. The new image now measures considerably smaller number of pixels than the original image.

3.7 Phase Unwrapping

Unwrapping in SNAP follows three distinct steps:

1. Export of the wrapped phase (and definition of the parameters)
2. Unwrapping of the phase (performed outside SNAP by snaphu)
3. Import of the unwrapped phase back into SNAP

Export of the wrapped phase

Export your interferogram or your subset interferogram from Sentinel-1 Toolbox to SNAPHU:

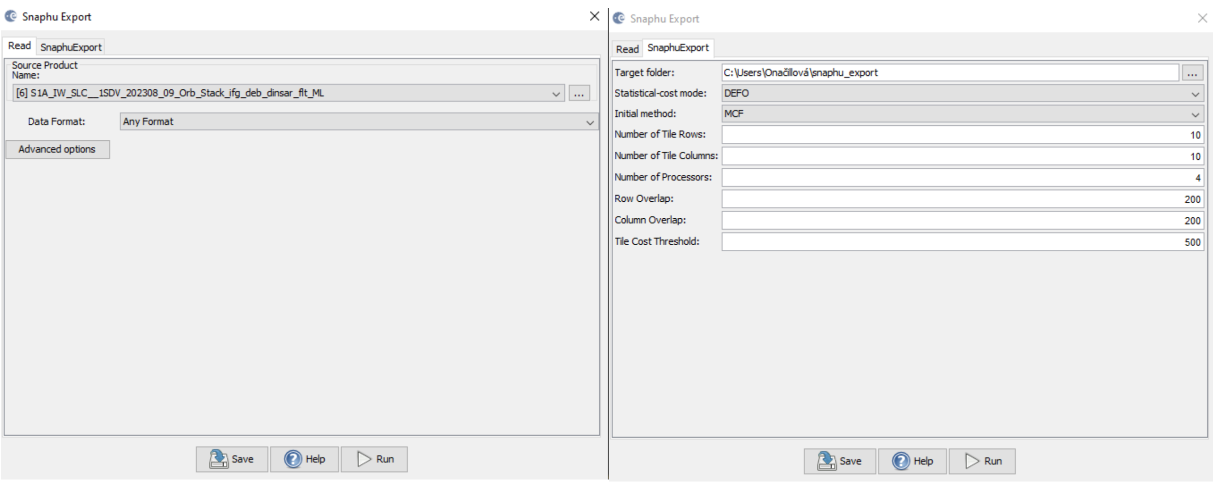
From the top main menu bar, navigate to Radar > Interferometric > Unwrapping > Snaphu Export.

In the Snaphu Export window:
In Read tab, select the "ML" product created by the multilooking step
In Snaphu Export tab, you also need to specify a target folder for exported files. Create a new target folder for this step by entering a path and new folder name (e.g. „snaphu_export). If the selection of the directory does not work, simply copy and paste the path of your working directory into the text field.

In Snaphu Export tab, select DEFO as Statistical-cost mode
Select MCF.

Note: You can also change the number of tile rows, columns and number of processors to e.g. "1" because we don't need multiple tiles after multilooking or select 200 pixels for Row Overlap and Column Overlap if you want to multilook. Depending on the number of processors of your computer, you can also increase the Number of Processors variable.

Click Run to create the SNAPHU_Export file



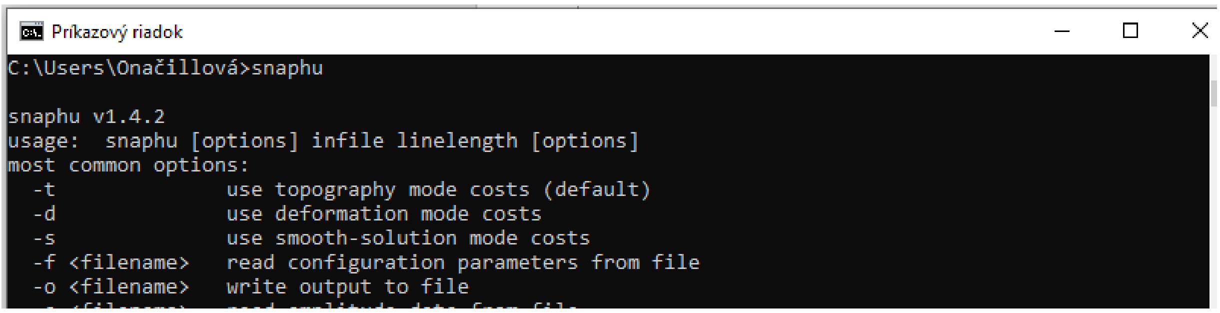
The folder now holds files used for phase unwrapping:
▪ the coherence: image (*.img) and metadata (*.hdr)
▪ the wrapped phase: image (*.img) and metadata (*.hdr)
▪ the unwrapped phase: only the metadata (*.hdr), because the image (*.img) is first to be created
by snaphu in the next step.
▪ a configuration file (snaphu.conf) containing the parameters defined in the export operator

Unwrapping of the phase

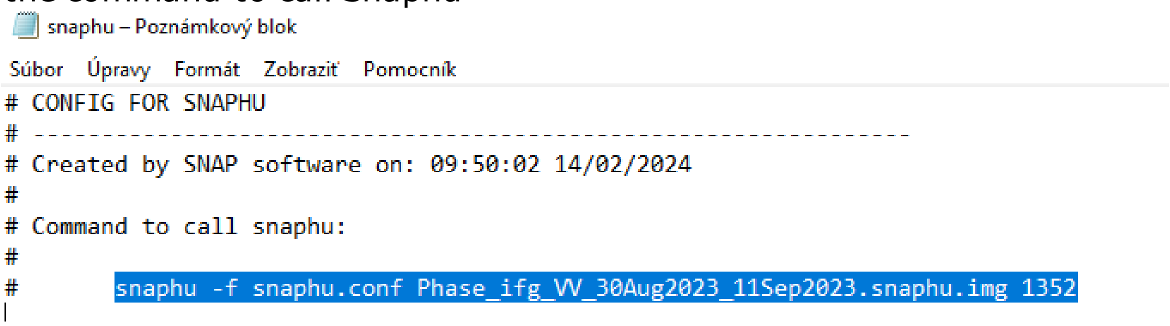
You should see the wrapped interferogram phase "Phase_ifg*.img", coherence "coh_*.img", and a "snaphu.conf" file.

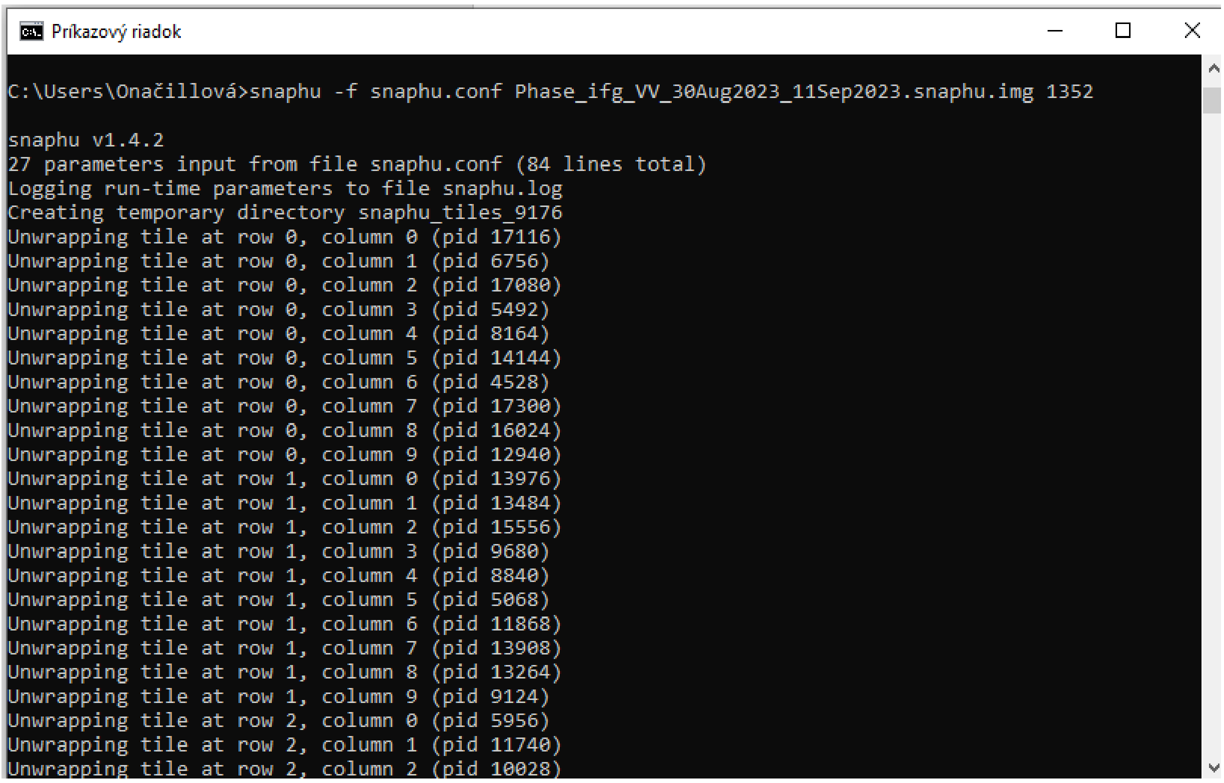
For the next step, you will need to instal SNAPHU in Windows. SNAPHU is a tool for phase unwrapping of interferometric information. To use it as an executable file (*.exe) in Windows it has to be compiled first so all required drivers (*.dll) are installed correctly. Follow the steps for installation here: file:///C:/Users/Ona%C4%8Dillov%C3%A1/Downloads/Installation_SNAPHU_English_ABraun.pdf

To start unwrapping, check the location of the interferogram exported from SNAP. If snaphu.exe is not in your system's PATH variable: Copy it in there as well. It is recommended to store the data and snaphu on the same disk. Open Command Window Here.



The command to start the unwrapping is shown in the file snaphu.conf. Open it with a text editor. The beginning of the "snaphu.conf" file shows the command to call Snaphu





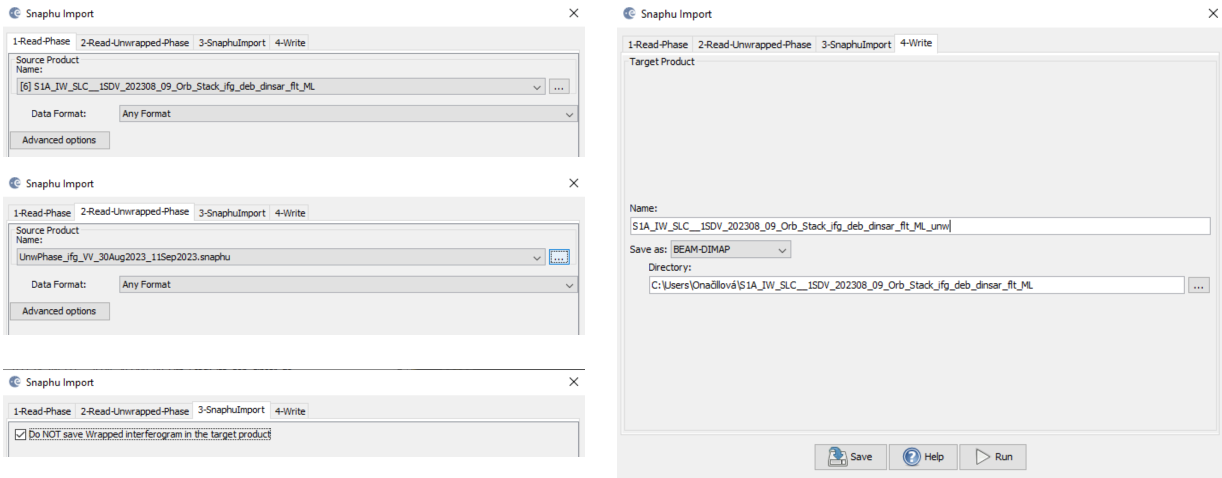
The Snaphu program can take a long time to run. At the end it writes **unwrapped phase to "Unw_ifg*.img" file**

Import of the unwrapped phase

Now, we import the unwrapped phase. From the top main menu bar, select Radar > Interferometric > Unwrapping, and then Snaphu Import that converts it back into the BEAM DIMAP format and adds the required.

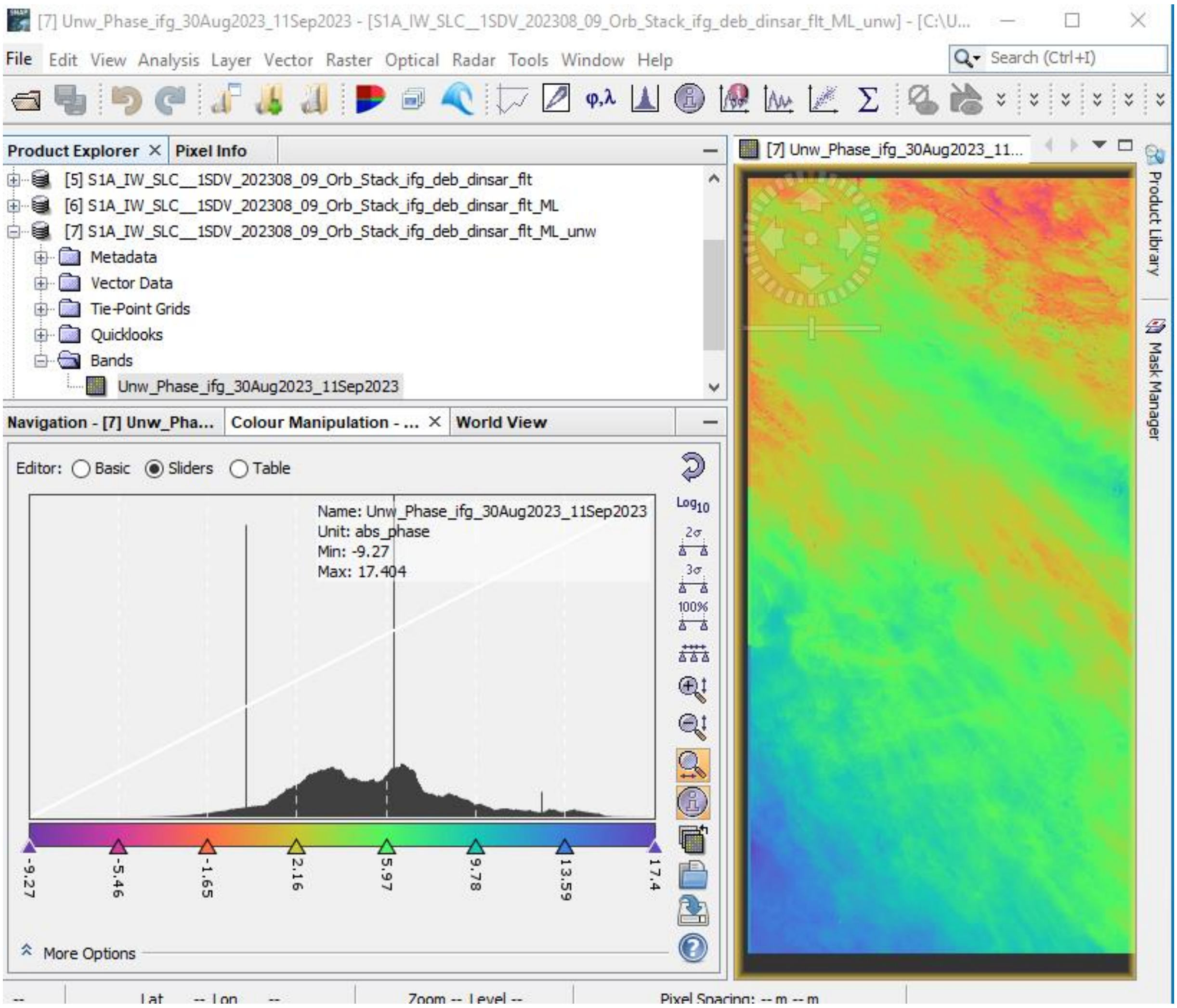
Read-Phase: should be set to the wrapped product that you exported(before the export)
Read-Unwrapped-Phase: select the unwrapped phase product: Navigate to folder where you exported for Snaphu. Select the "UnwPhase_ifg*.snaphu.hdr" file. Note: The error message will then vanish if you proceed to the next tab.
SnaphuImport: Leave the option "Do NOT save Wrapped interferogram in the target product"
unchecked, because it is required in the later step.
Write: To store the imported unwrapped band in a separate product (recommended), add '_unw' to the end of the output name and click Run.

Finally, a new product is added to the Product Explorer which contains the the unwrapped phase that we can display.



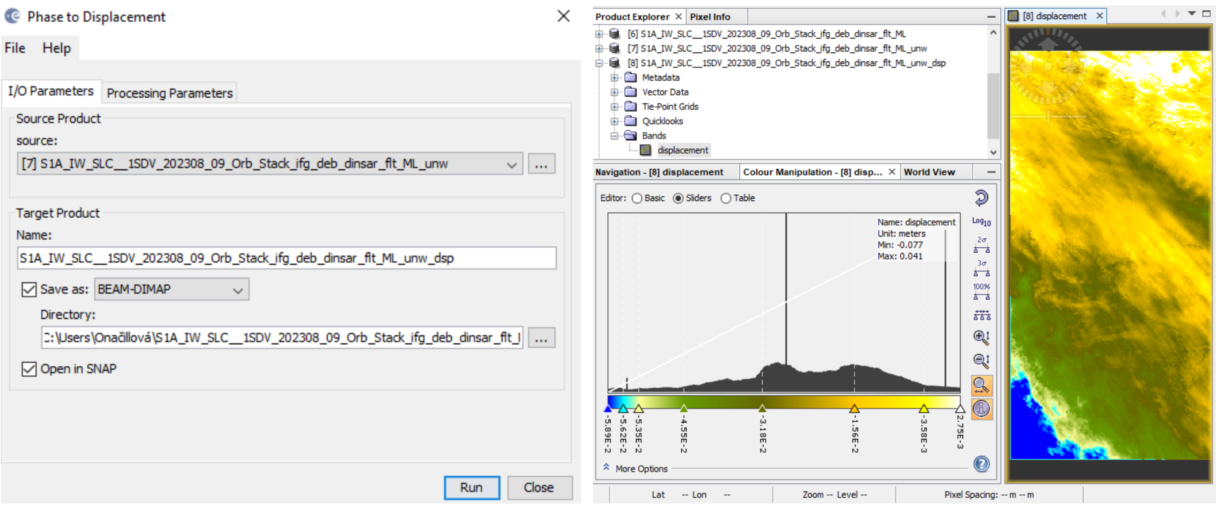
Select the Unw_Phase_ifg band. Double click on this unwrapped phase to see if the unwrapping was successful. It should be a smooth raster with little variation except for the areas of expected deformation.

All fringe patterns are summarized to absolute changes. Go to the Colour Manipulation tab and select "100%" to stretch color scale to full range of unwrapped data. Unwrapped phase is still in radians. Phase is reference image minus coregistered image. If reference image is earlier, then negative phase is land moving toward satellite (negative range change)



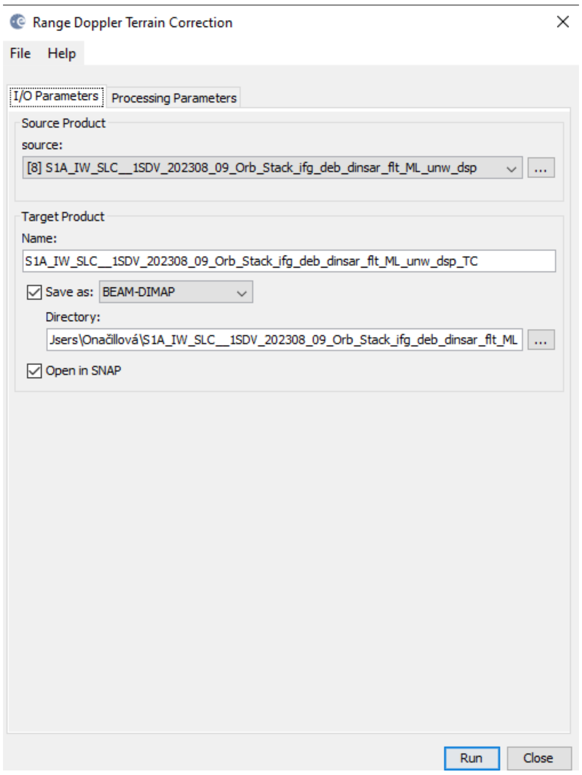
3.8 Phase to displacement

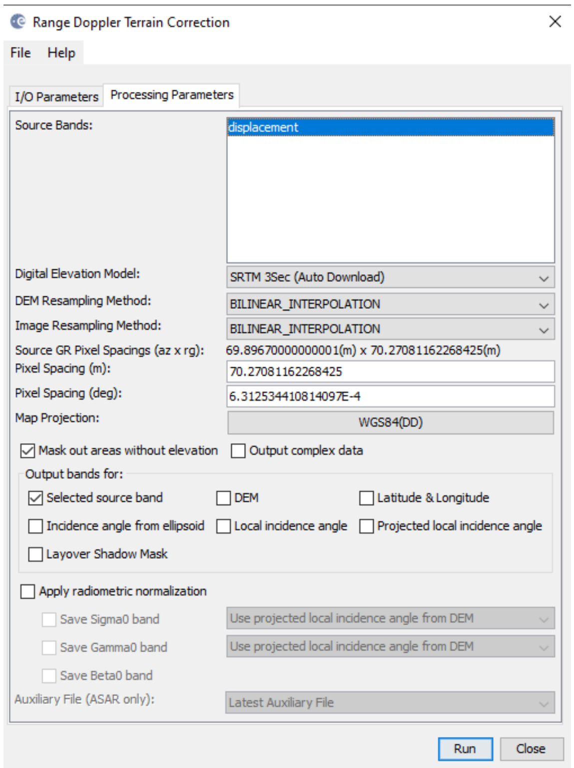
We can convert the unwrapped phase to displacements. From the top main menu bar, select Radar, then Interferometric, then Products, and then Phase to Displacement.
The I/O Parameters tab should be set to the unwrapped product that you imported.
Default for target product name is to add "_dsp" to the name
Now, we can display displacement band of result. Again, better to stretch colors. Displacements is now in meters.
Sign was changed so positive displacement is "up" towards satellite

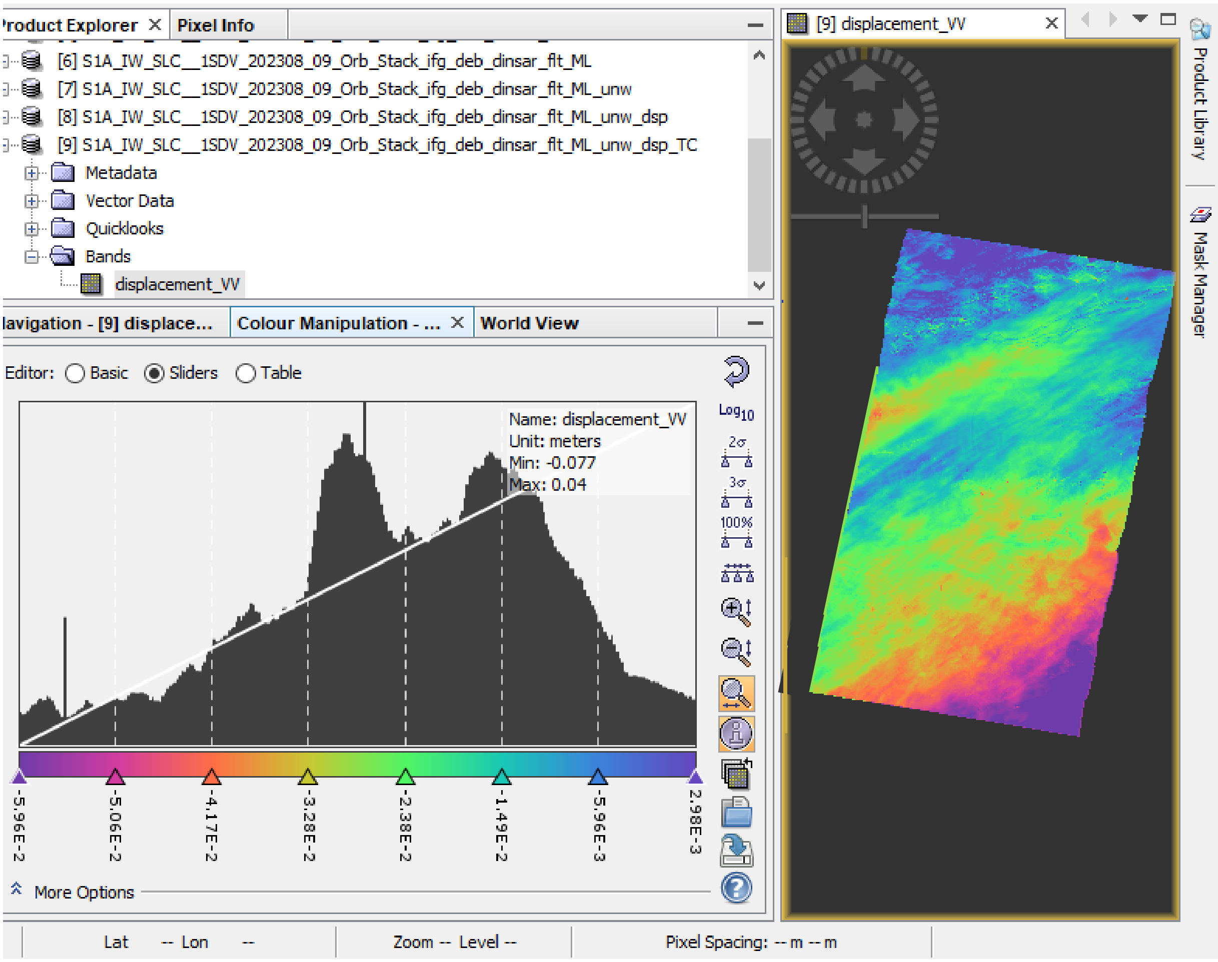


3.9 Geocoding results—Terrain Correction

SNAP calls geocoding with topography "Terrain Correction." From the top main menu bar, select Radar, then Geometric, then Terrain Correction, and then Range-Doppler Terrain Correction.
The I/O Parameters tab should be set to the displacement product that you imported (or one of the other ML products).
default for target product name is to add "_TC" to the name
Under Processing Parameters tab, select the Source Bands and any additional Output Bands. You can also choose what DEM to use, output spacing, and map projection.
Now, we can display displacement_vv band of geocoded result. Again, better to stretch colors.
Displacements in meters with positive values "up" towards satellite in Line-of-Sight direction.
Product is now evenly spaced in latitude and longitude.


Range Doppler Terrain Correction
File Help
I/O Parameters
Processing Parameters
Source Product
source:
[8] S1A_IW_SLC__1SDV_202308_09_Orb_Stack_ifg_deb_dinsar_flt_ML_unw_dsp
Target Product
Name:
S1A_IW_SLC__1SDV_202308_09_Orb_Stack_ifg_deb_dinsar_flt_ML_unw_dsp_TC
Save as: BEAM-DIMAP
Directory:
Jsers\Onačillová\S1A_IW_SLC__1SDV_202308_09_Orb_Stack_ifg_deb_dinsar_flt_ML
Open in SNAP
Run
Close


Range Doppler Terrain Correction
File Help
I/O Parameters
Processing Parameters
Source Bands:
displacement
Digital Elevation Model:
SRTM 3Sec (Auto Download)
DEM Resampling Method:
BILINEAR_INTERPOLATION
Image Resampling Method:
BILINEAR_INTERPOLATION
Source GR Pixel Spacings (az x rg):
69.89670000000001(m) x 70.27081162268425(m)
Pixel Spacing (m):
70.27081162268425
Pixel Spacing (deg):
6.312534410814097E-4
Map Projection:
WGS84(DD)
Mask out areas without elevation
Output complex data
Output bands for:
Selected source band
DEM
Latitude & Longitude
Incidence angle from ellipsoid
Local incidence angle
Projected local incidence angle
Layover Shadow Mask
Apply radiometric normalization
Save Sigma0 band
Use projected local incidence angle from DEM
Save Gamma0 band
Use projected local incidence angle from DEM
Save Beta0 band
Auxiliary File (ASAR only):
Latest Auxiliary File
Run
Close


Product Explorer
Pixel Info
[6] S1A_IW_SLC__1SDV_202308_09_Orb_Stack_ifg_deb_dinsar_flt_ML
[7] S1A_IW_SLC__1SDV_202308_09_Orb_Stack_ifg_deb_dinsar_flt_ML_unw
[8] S1A_IW_SLC__1SDV_202308_09_Orb_Stack_ifg_deb_dinsar_flt_ML_unw_dsp
[9] S1A_IW_SLC__1SDV_202308_09_Orb_Stack_ifg_deb_dinsar_flt_ML_unw_dsp_TC
Metadata
Vector Data
Quicklooks
Bands
displacement_VV
Colour Manipulation
World View
Editor: Basic Sliders Table
Name: displacement_VV
Unit: meters
Min: -0.077
Max: 0.04
-5.96E-2
-5.06E-2
-4.17E-2
-3.28E-2
-2.38E-2
-1.49E-2
-5.96E-3
2.98E-3
More Options
Lat -- Lon --
Zoom -- Level --
Pixel Spacing: -- m -- m
[9] displacement_VV
Product Library
Mask Manager

3.10 Displacement Profiles

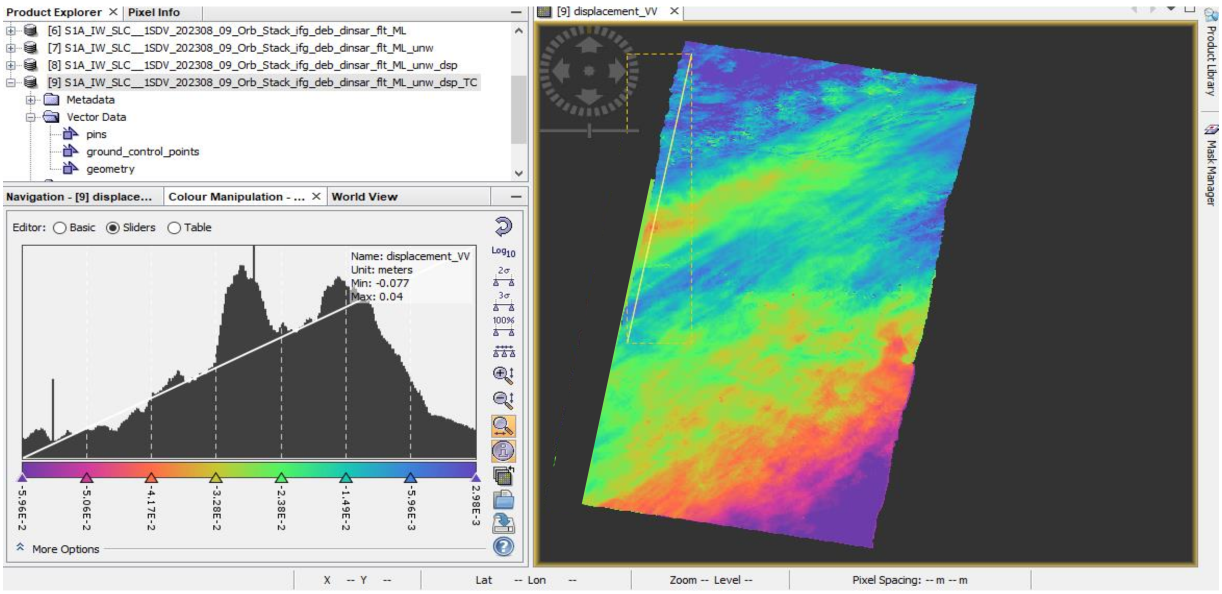
Use the line drawing tool (top bar of SNAP window) to draw a line across the signal.

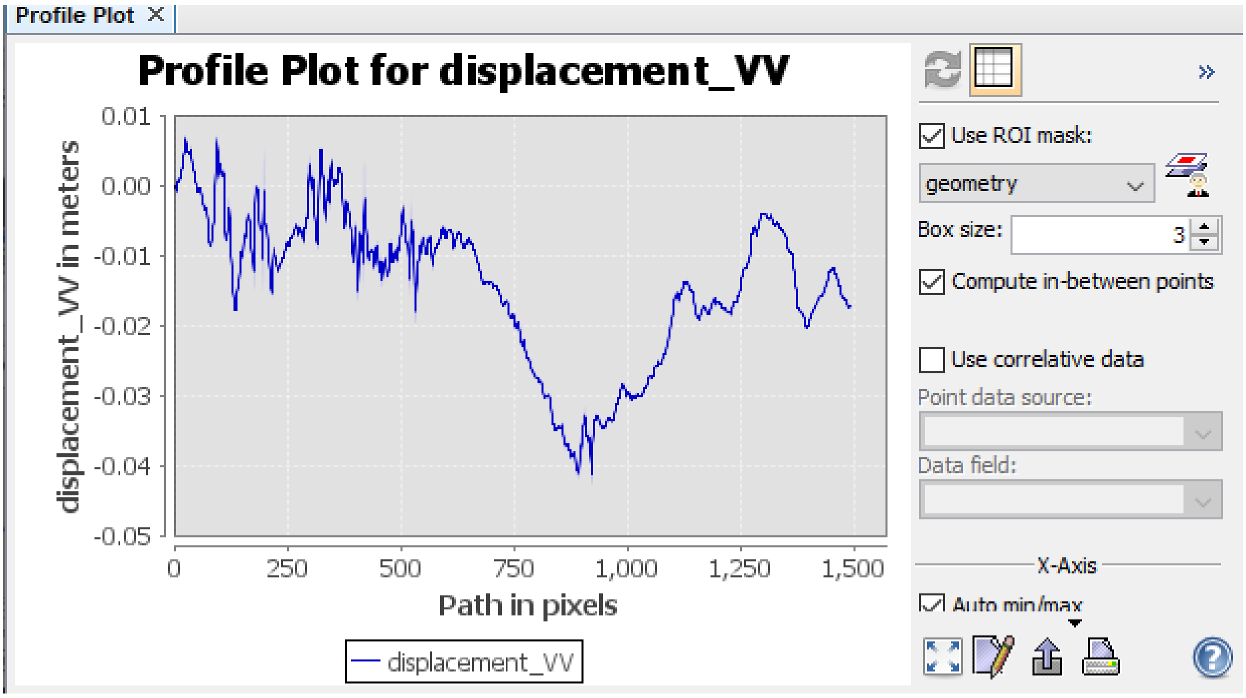
Run Analysis > Profile Tool to see displacement along the profile

Remember that InSAR displacements are relative

In this case, displacement far from the signal is about -0.1 m, so that is probably the "true zero" offset

Maximum is about 0.24 m, but we need to subtract zero offset to get total displacement of about 0.35 m





For more information, see the lecture: 13. SAR for earthquake monitoring

THANK YOU FOR FOLLOWING THE EXERCISE!

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PAVLA JOZEFA ŠAFÁRIKA
V KOŠICIACH

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