EXERCISE 3 – TUTORIAL

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

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.
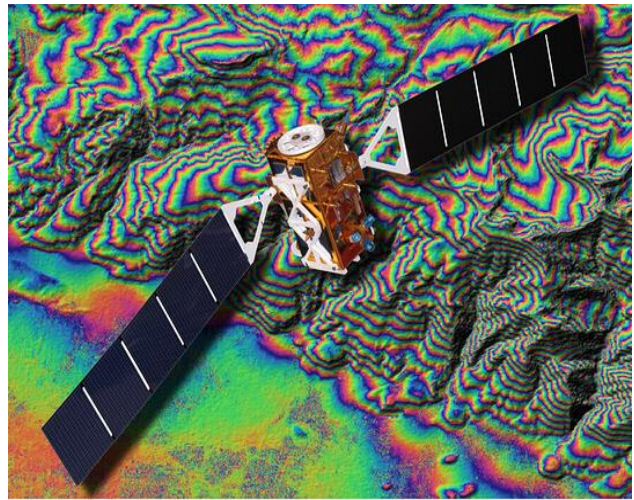

DEM generation with Sentinel-1 data offers a powerful method for deriving accurate and detailed elevation information over large areas, especially in regions with limited ground survey data or challenging terrain conditions.

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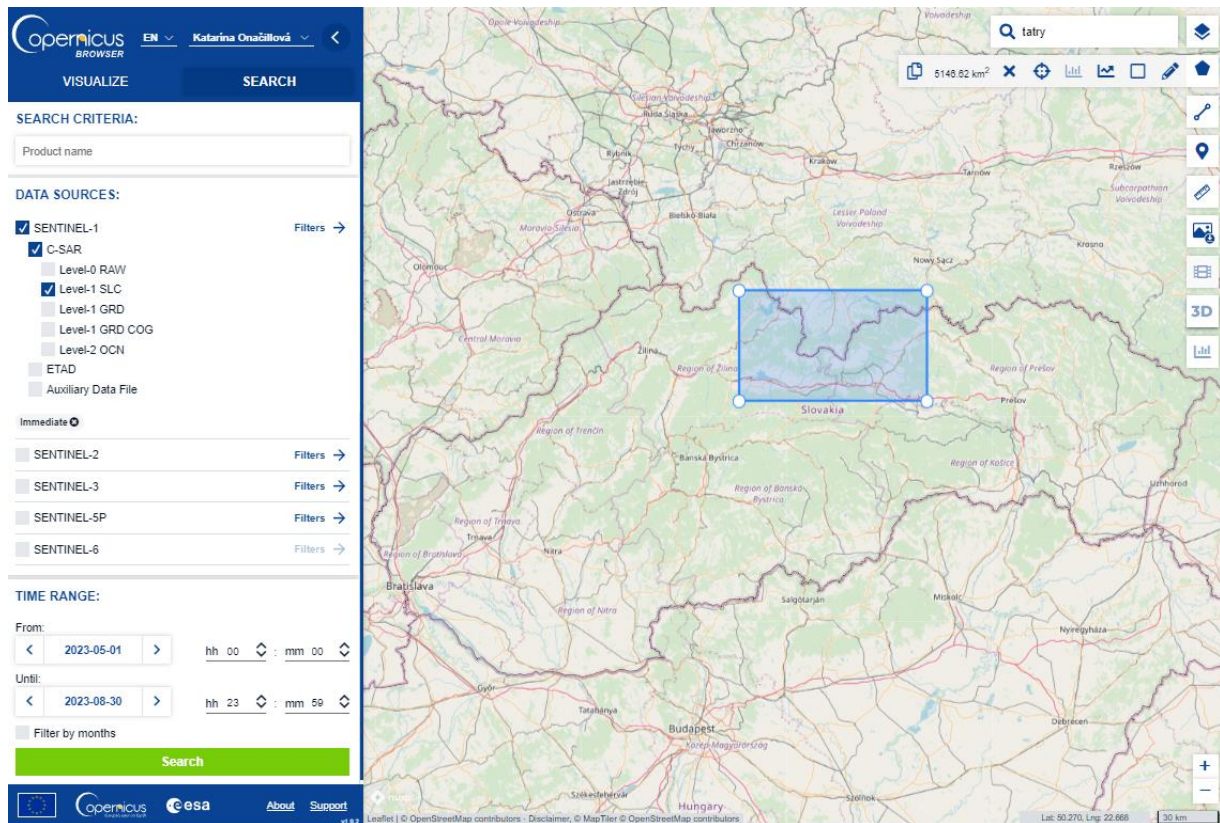
To ensure successful DEM generation, selecting image pairs with specific properties is crucial. These include:

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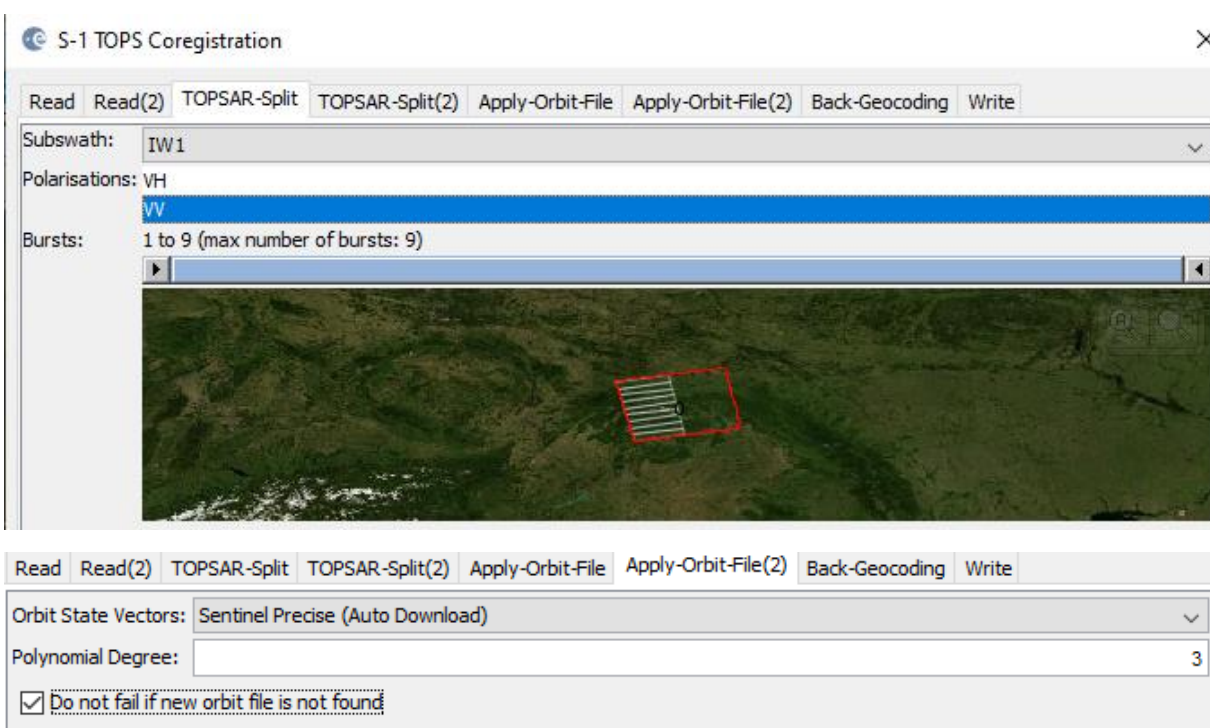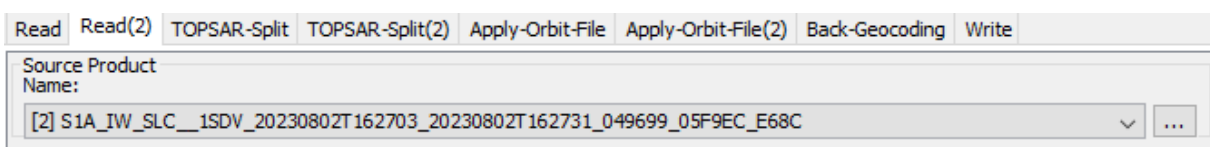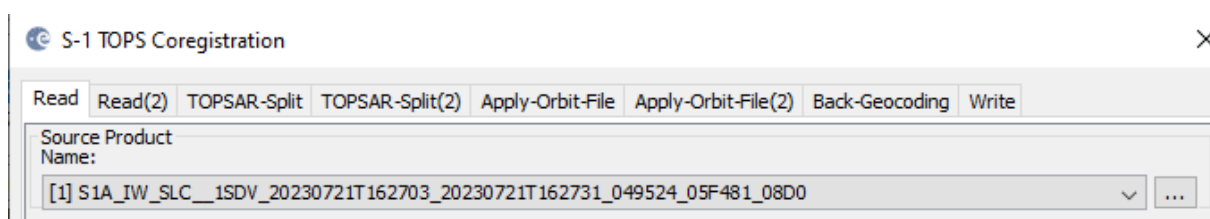
In the Back-Geocoding select SRTM 1Sec HGT (AutoDownload)
In the Write tab, select the directory to save your processing outputs

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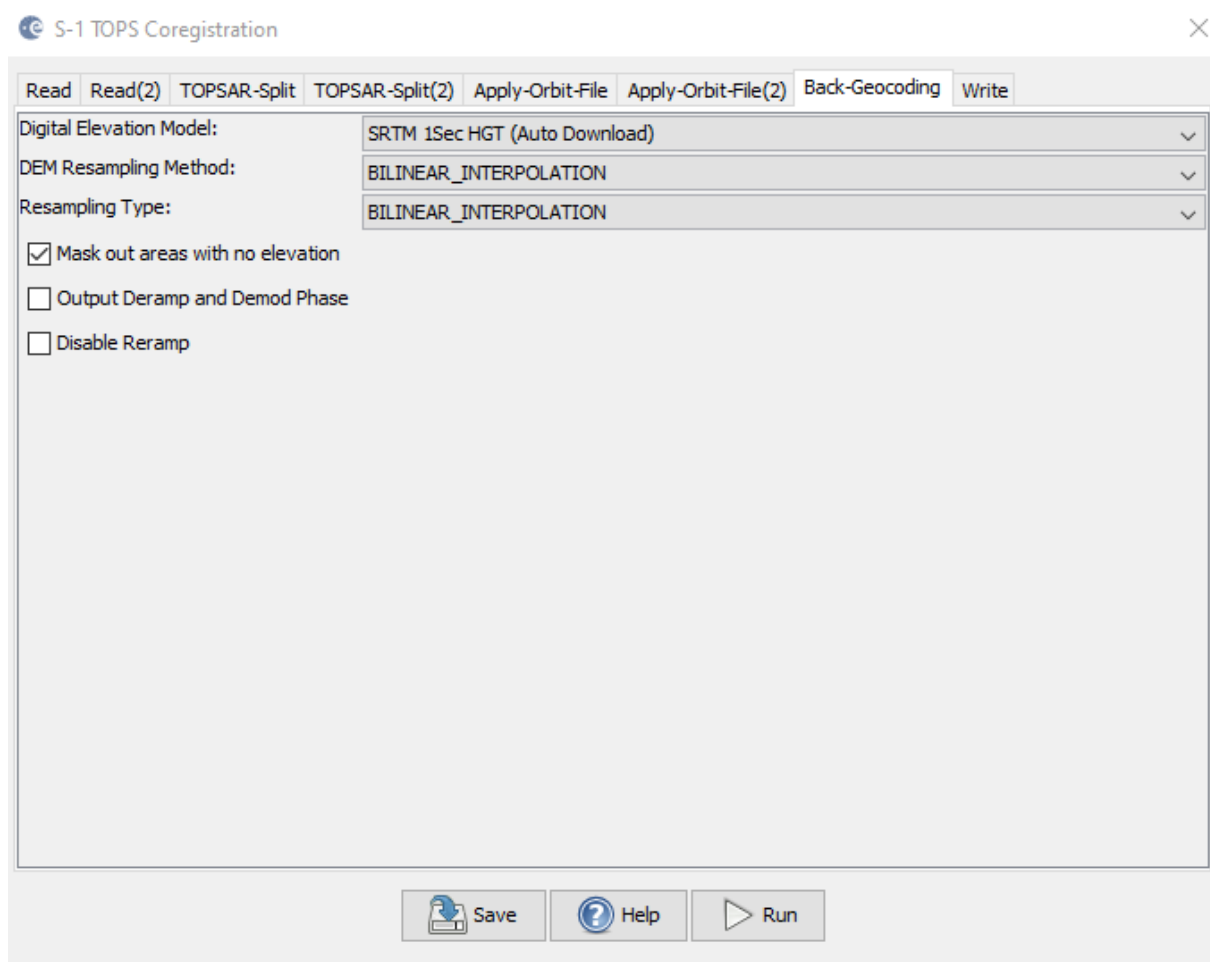
Once coregistration is finalized, it is recommended to visually inspect the stack's quality. This can be achieved through an RGB representation of the reference and secondary products, indicating if the images are appropriately aligned:

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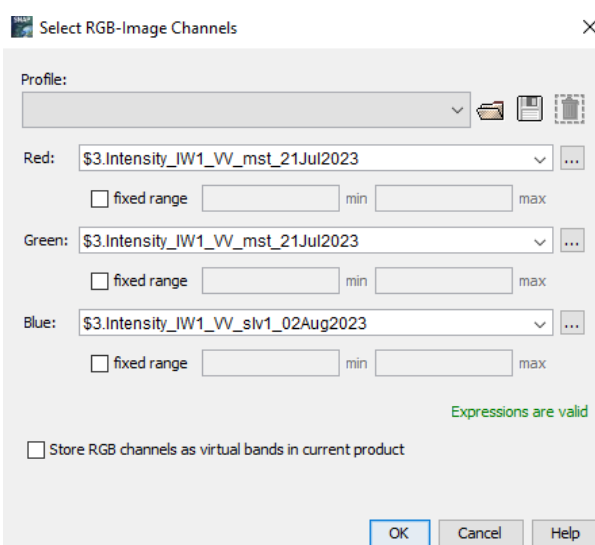
Zoom into a region with contrasting surfaces, such as the boundary between land and water. The RGB image should be clear and sharp, without being overly influenced by one of the images (e.g., appearing yellow for the reference or blue for the secondary image). The only acceptable exceptions are changes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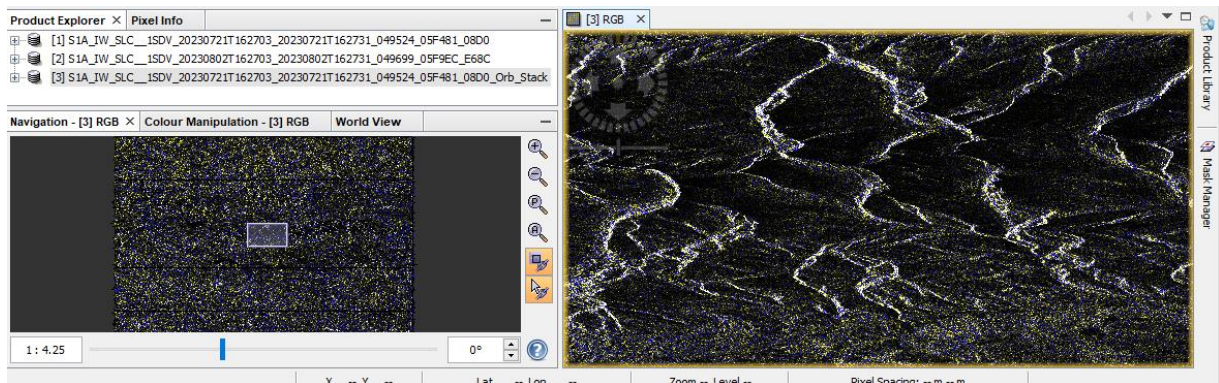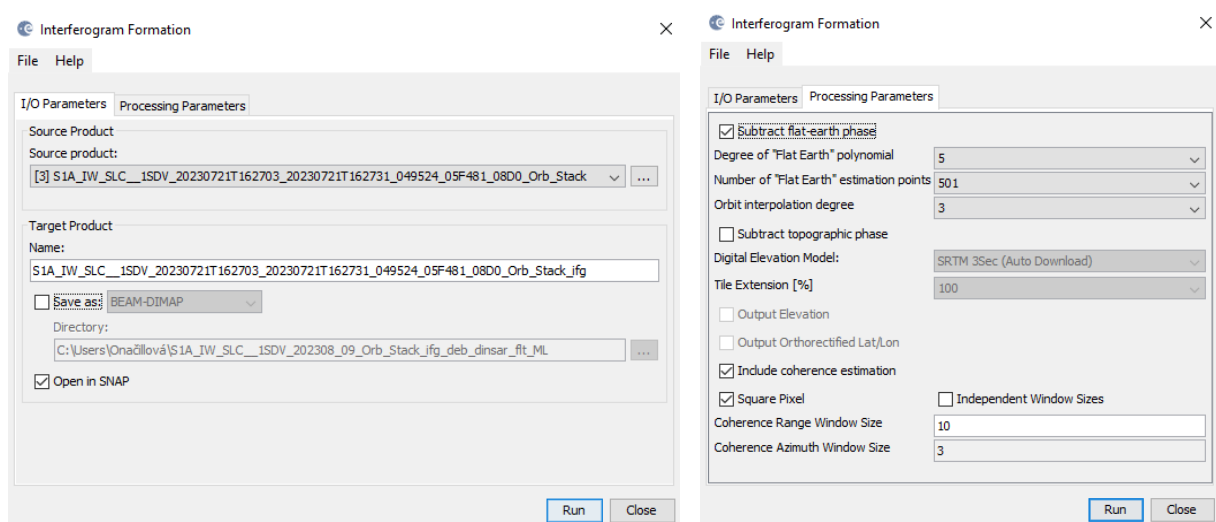

2.4 Forming a Raw Interferogram

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**.
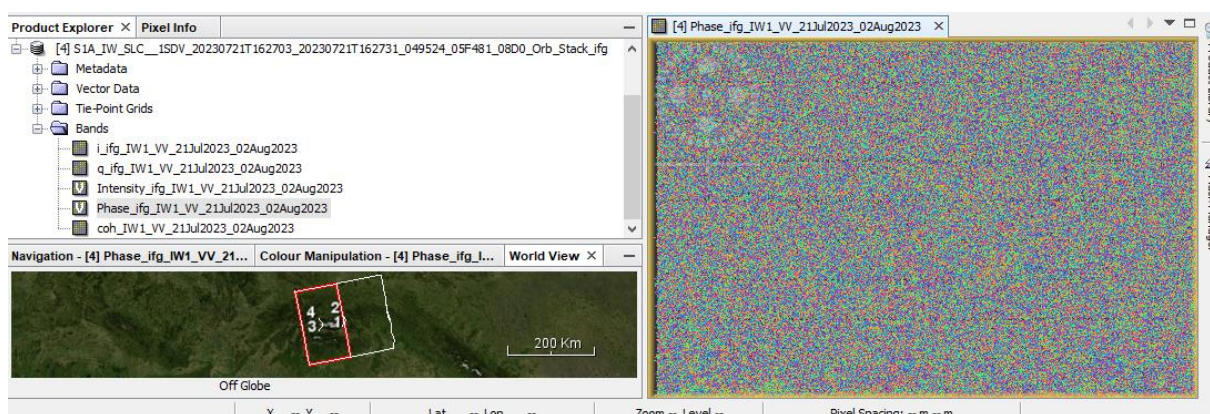In the I/O Parameters tab, choose the "Orb_Stack" product that was generated during the coregistration process.
By default, the output target is set to the same directory and appends "ifg" to the filename.
For standard processing, there's no need to modify the defaults in the Processing Parameters tab.

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.
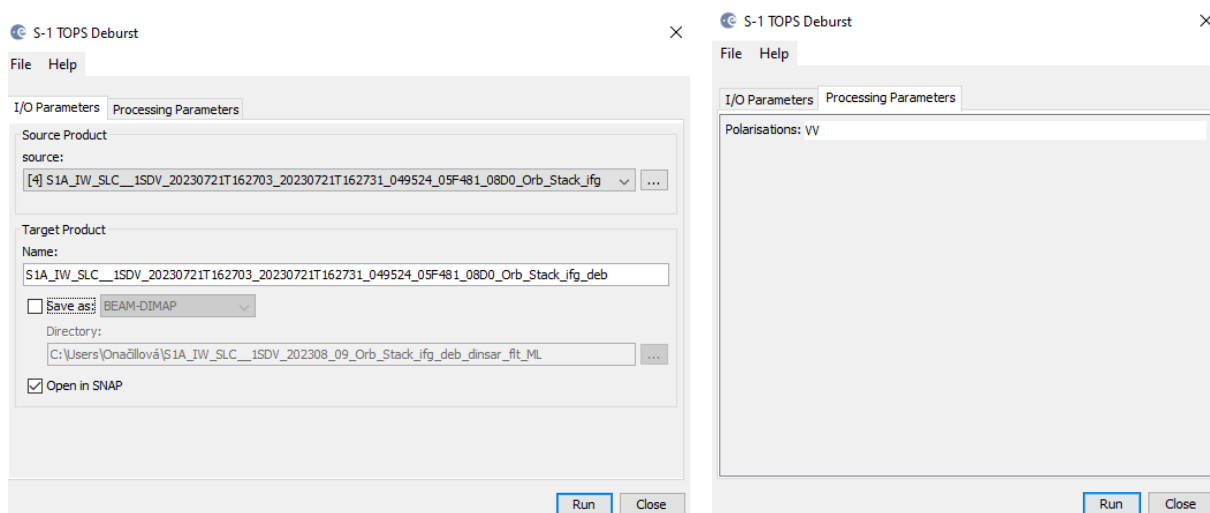
2.6 Goldstein Phase Filtering

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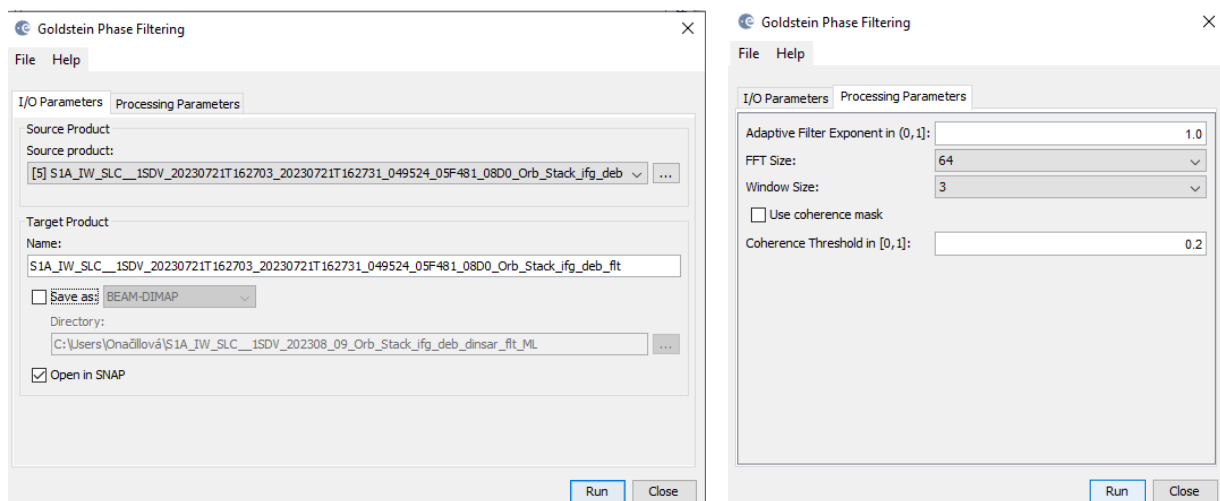
To begin filtering:
Go to Radar, then Interferometric, then Filtering, and select Goldstein Phase Filtering from the top main menu bar.
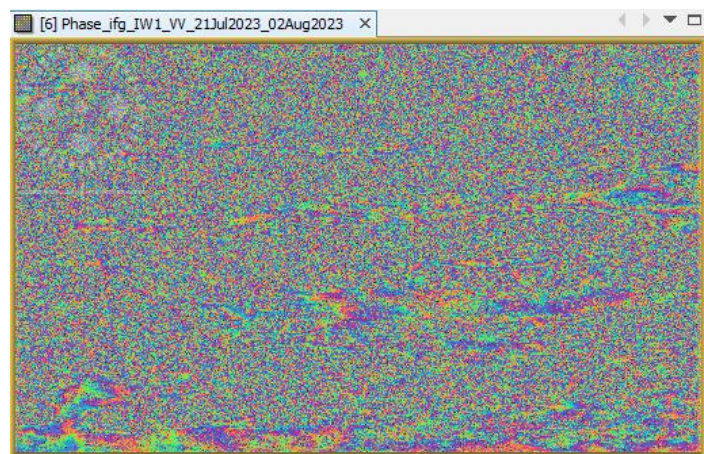In the I/O Parameters tab, choose the "deb" product generated in the previous step.
By default, the output name includes "flt."
There's no necessity to adjust the default settings in the Processing Parameters tab for basic processing.

Double-dick 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
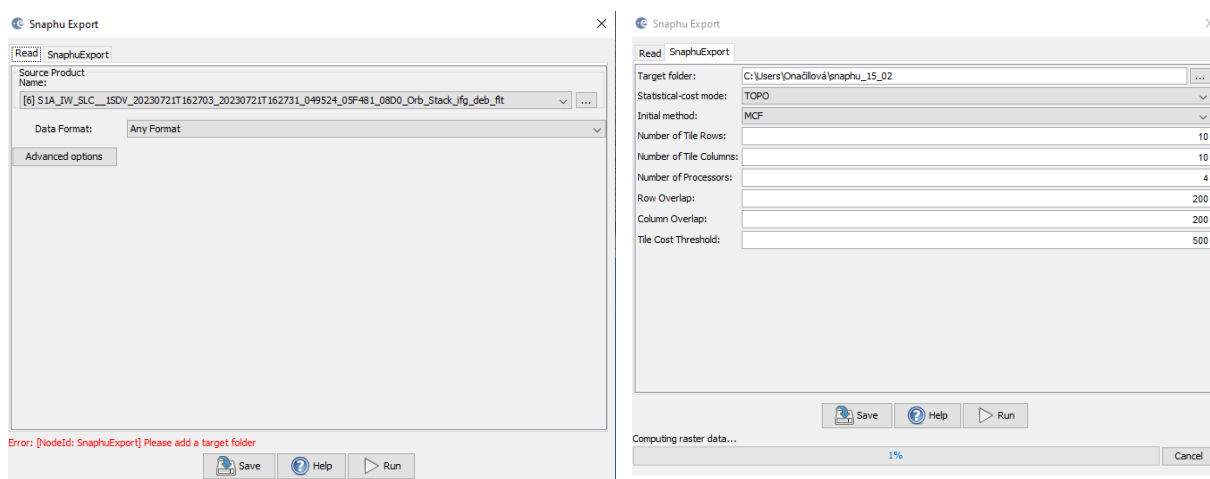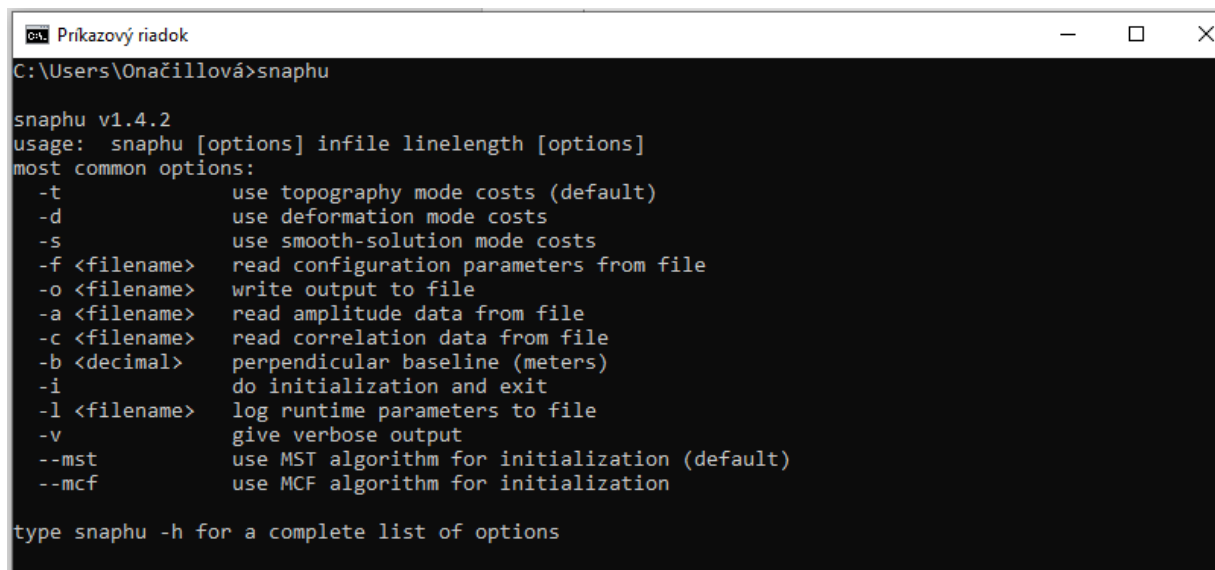
Unwrapping of the phase

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.

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

```
C:\Users\Onačillová>snaphu -f snaphu.conf Phase_ifg_IW1_VV_21Jul2023_02Aug2023.snaphu.img 22957

snaphu v1.4.2
27 parameters input from file snaphu.conf (84 lines total)
Logging run-time parameters to file snaphu.log
Creating temporary directory snaphu_tiles_6272
Unwrapping tile at row 0, column 0 (pid 4340)
Unwrapping tile at row 0, column 1 (pid 2800)
Unwrapping tile at row 0, column 2 (pid 6940)
Unwrapping tile at row 0, column 3 (pid 4268)
```

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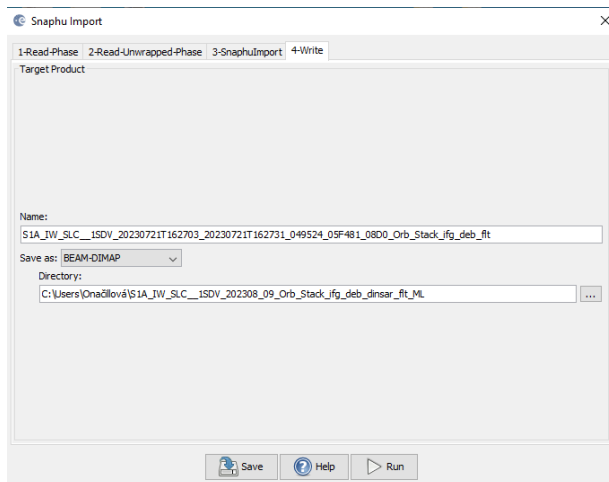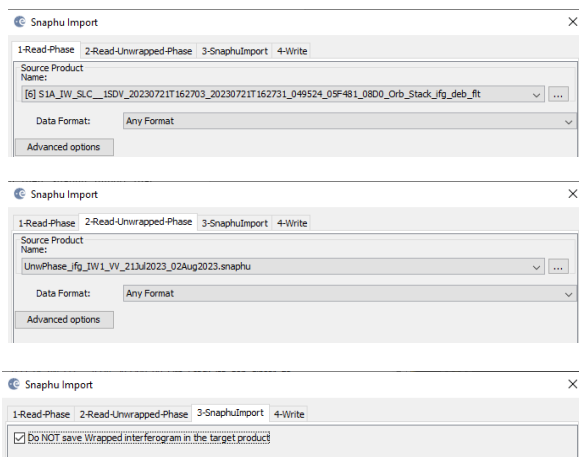
Finally, a new product is added to the Product Explorer which contains the the unwrapped phase that we can display.

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)
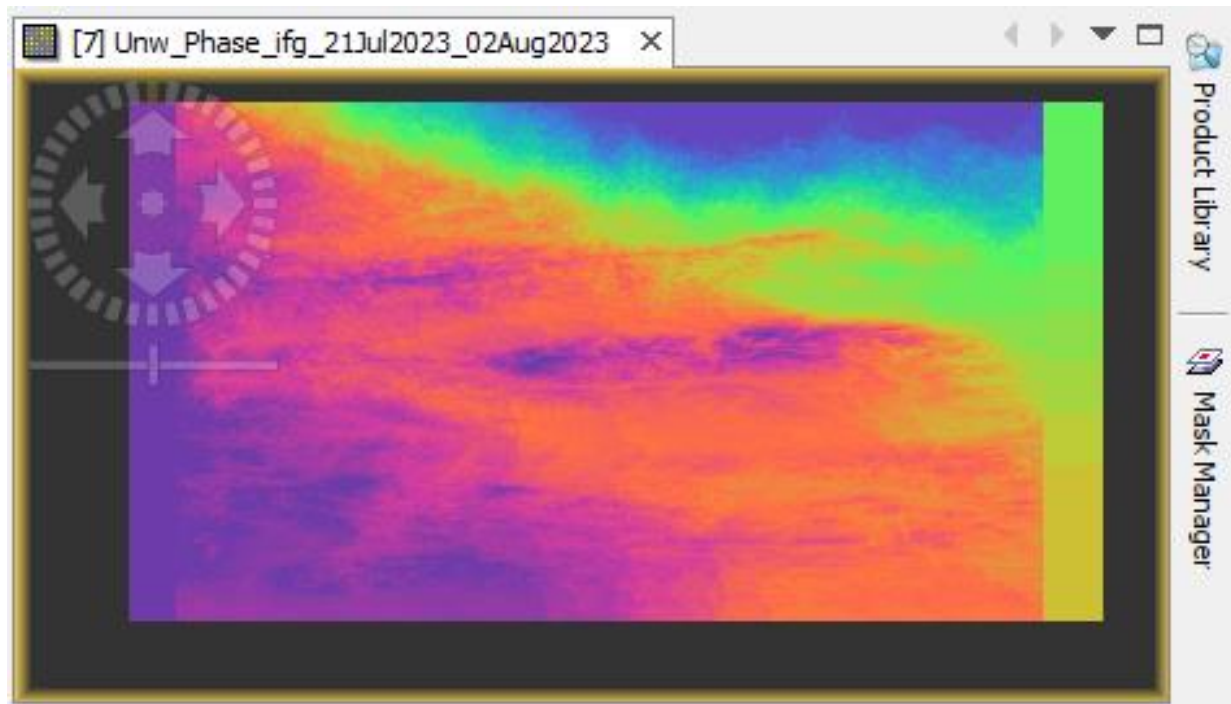
Create subset (optional)

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.
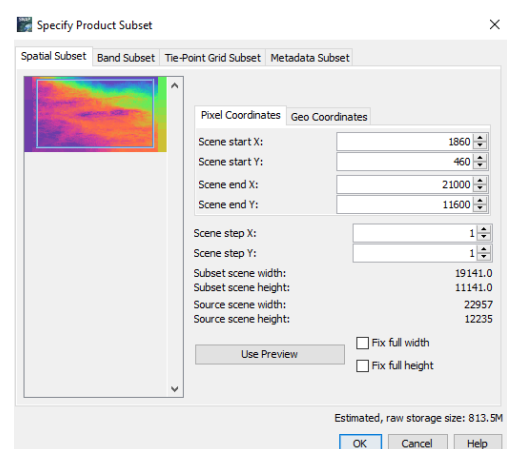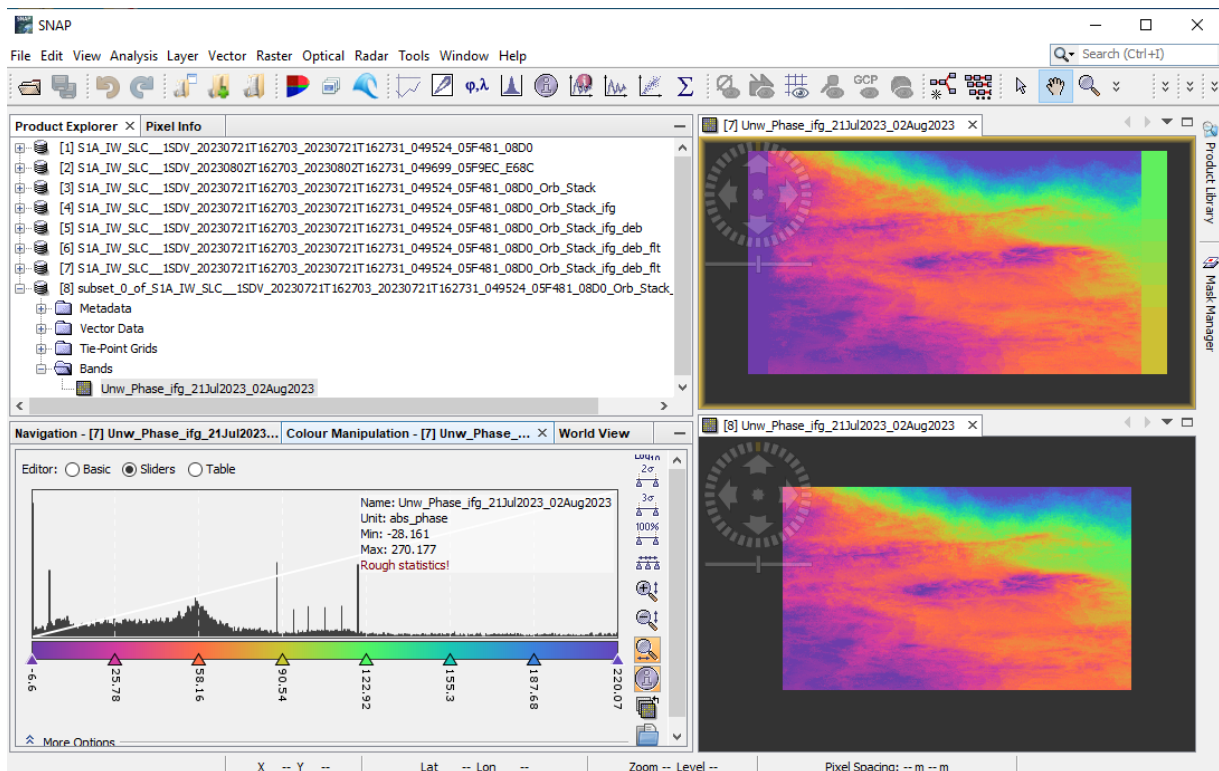
2.8 Phase to elevation

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.
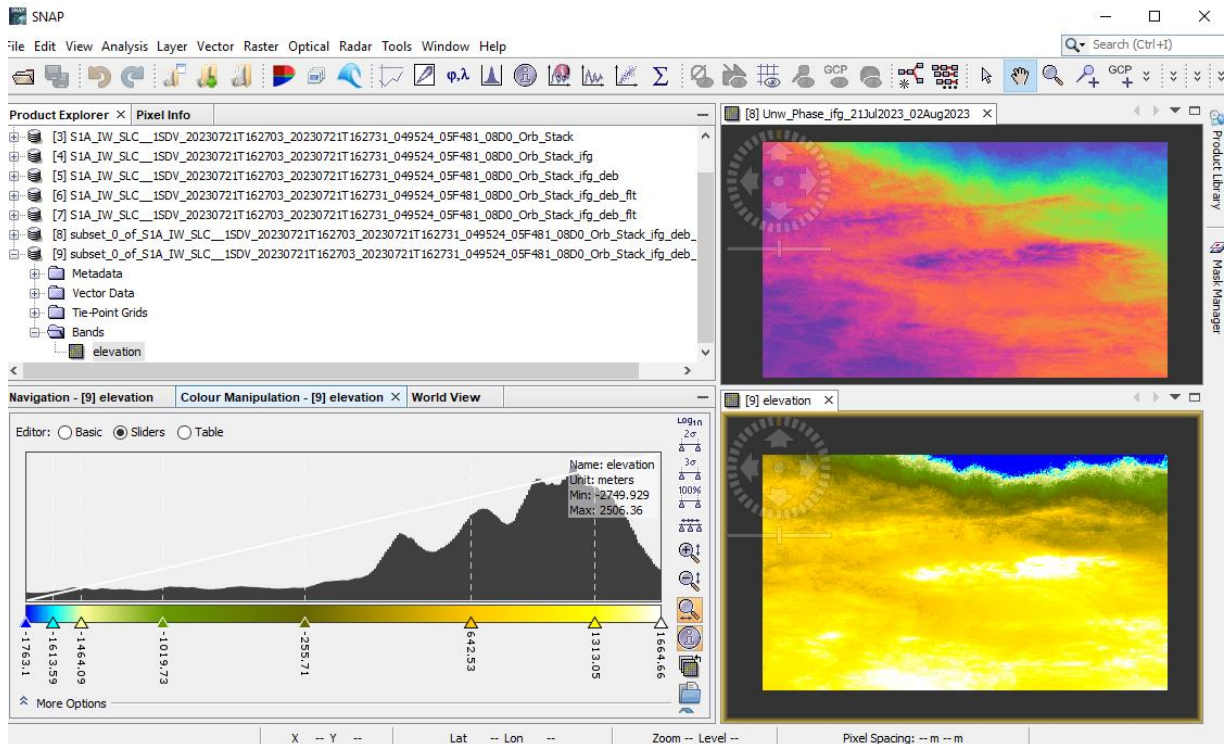
The I/O Parameters tab should be set to the last subset unwrapped product
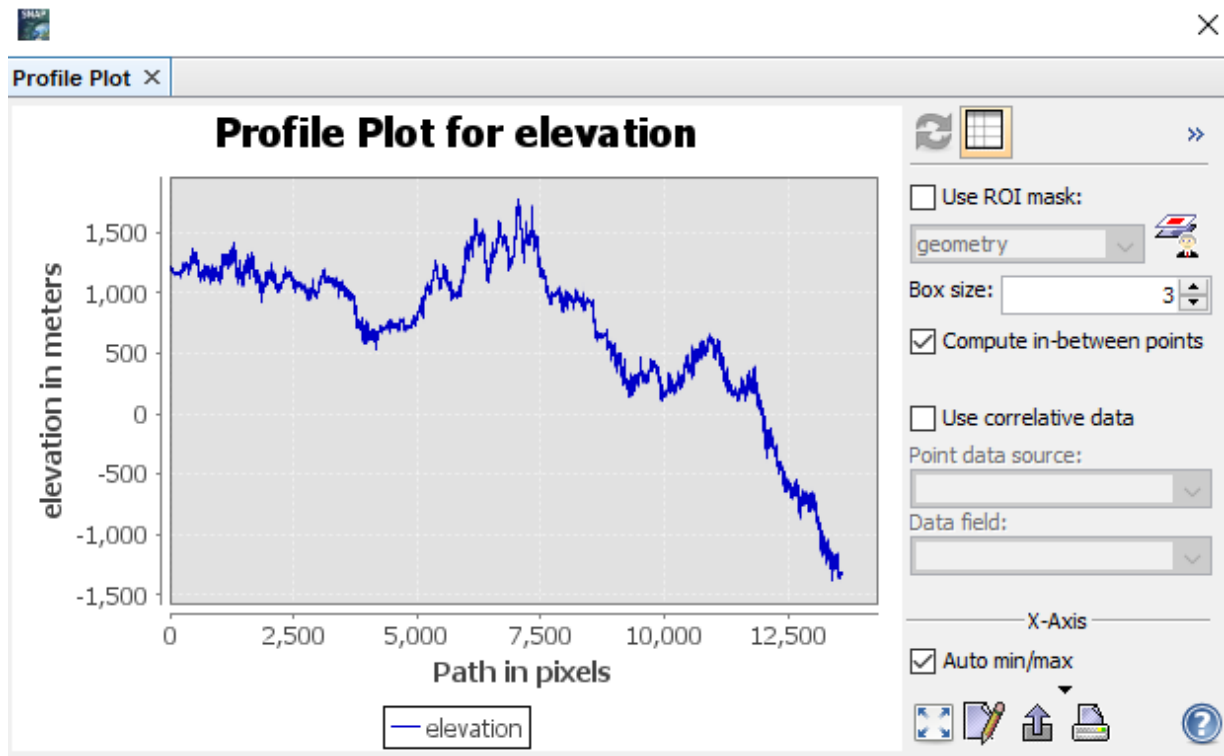Default for target product name is to add "_dem" to the name
Navigate to the Processing Parameters tab and select SRTM 1Sec HGT (AutoDownload) as the input DEM.
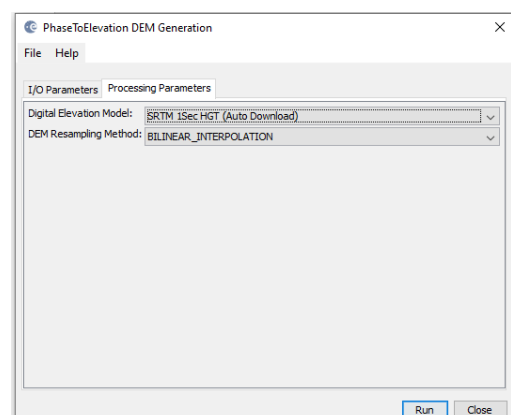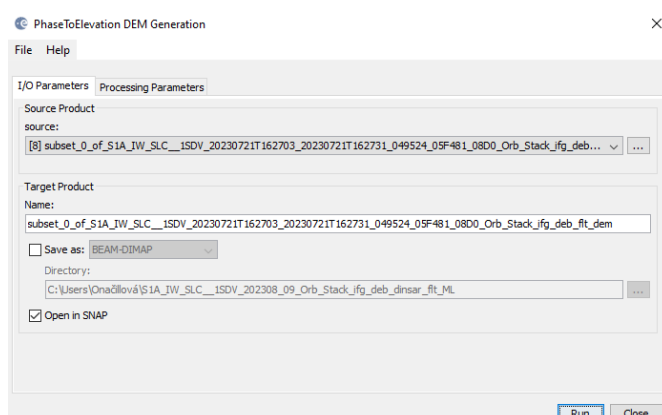
Now, we can display elevation result. Again, better to stretch colors. Displacements is now in meters.
Sign was changed so positive displacement is "up" towards satellite

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
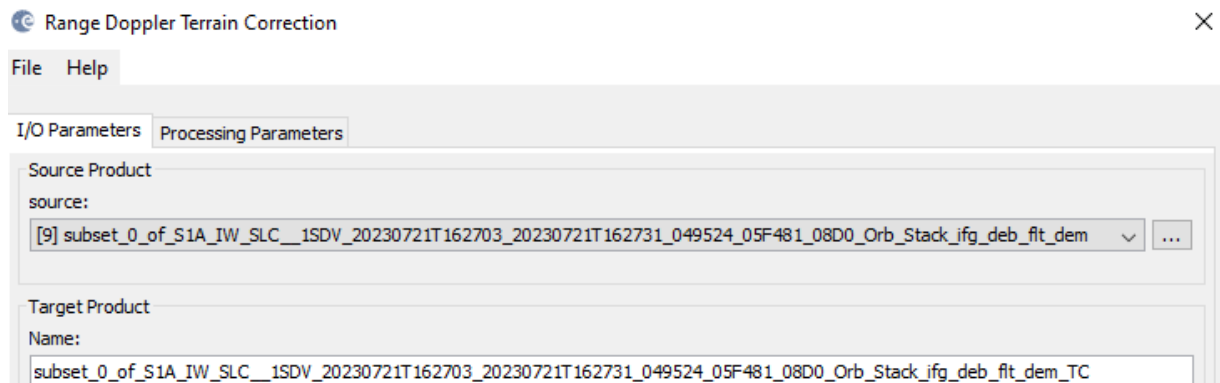
Under Processing Parameters tab, select the elevation band as the input
Select SRTM 1Sec HGT (AutoDownload) as input DEM.
If you want to export the data as a KMZ file to view it in Google Earth, WGS84 must be selected as Map Projection (latitude and longitude).
If you want to compare the quality of the InSAR DEM, you can select DEM as a further output.
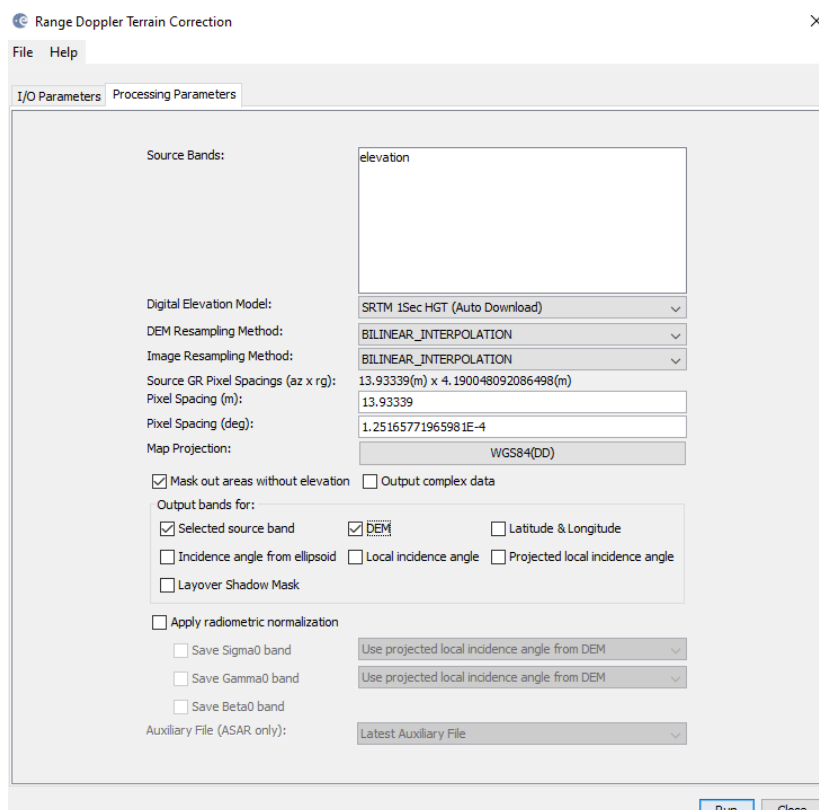
Now, double-click on the „elevation" raster to display the geocoded elevation raster output. Product is now evenly spaced in latitude and longitude and shows the elevation for the study area. You can create profile to see the elevation diversity.
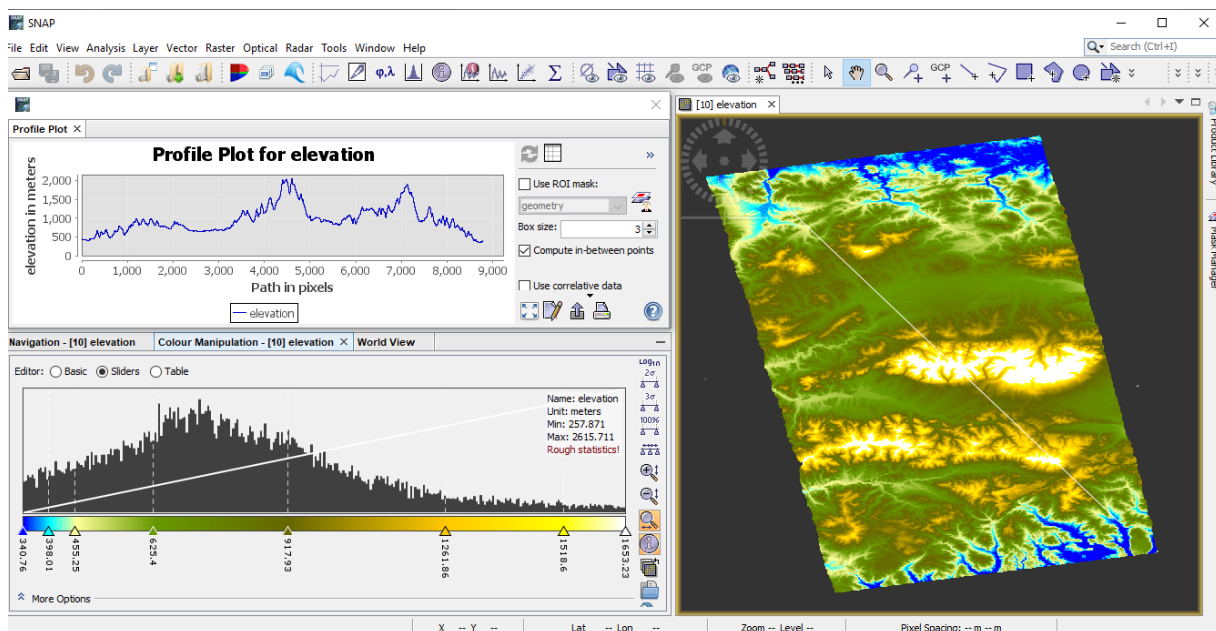

2.10 Export .kmz to Google Earth

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.
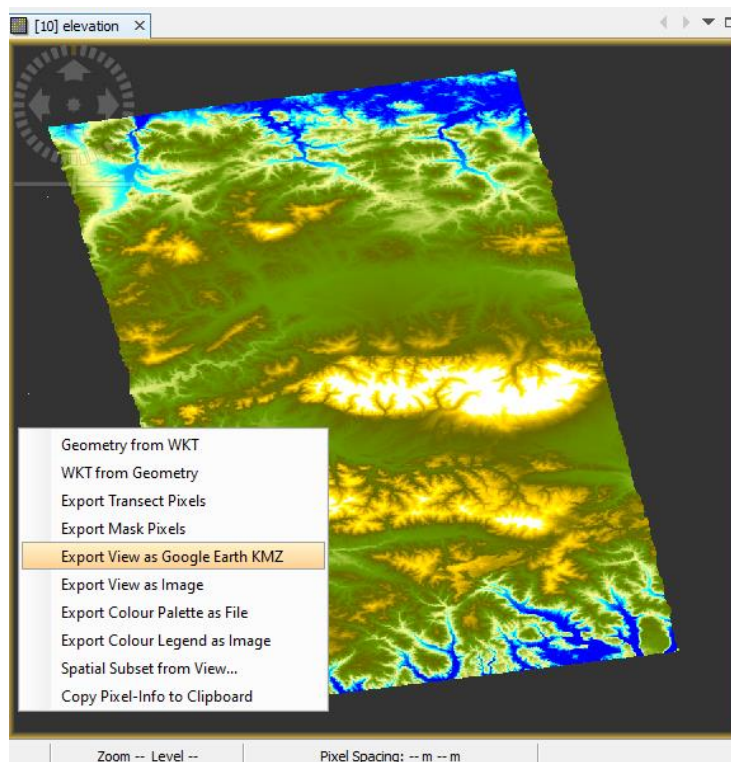
Open the resulting KMZ file in Google Earth to observe the elevation patterns overlaid on the satellite image base map.
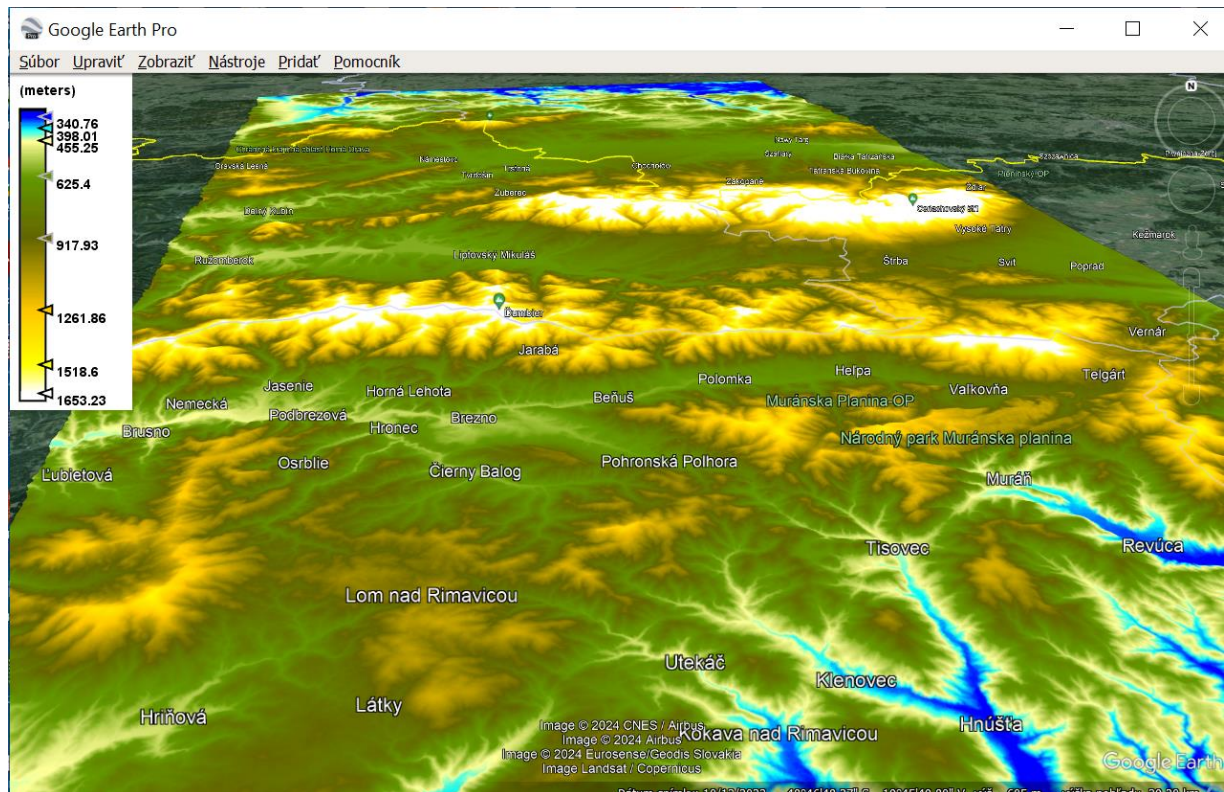
Compare with LiDAR-derived DEM

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.
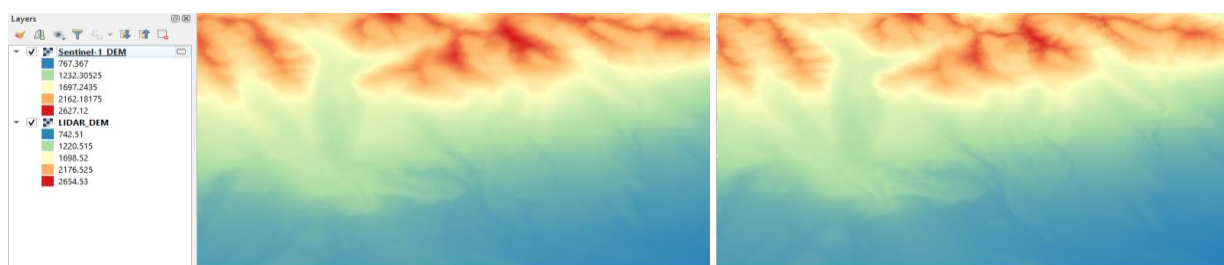
Comparing Sentinel-1 derived DEMs and LiDAR derived DEMs, LiDAR typically offers higher precision. This is because LiDAR directly measures the distance between the sensor and the Earth's surface using laser pulses, resulting in highly accurate elevation data. On the other hand, Sentinel-1 derived DEMs 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!