



EXERCISE 12 – TUTORIAL

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

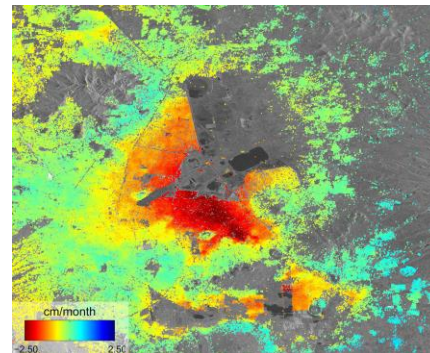
1 | Exercise outline

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.

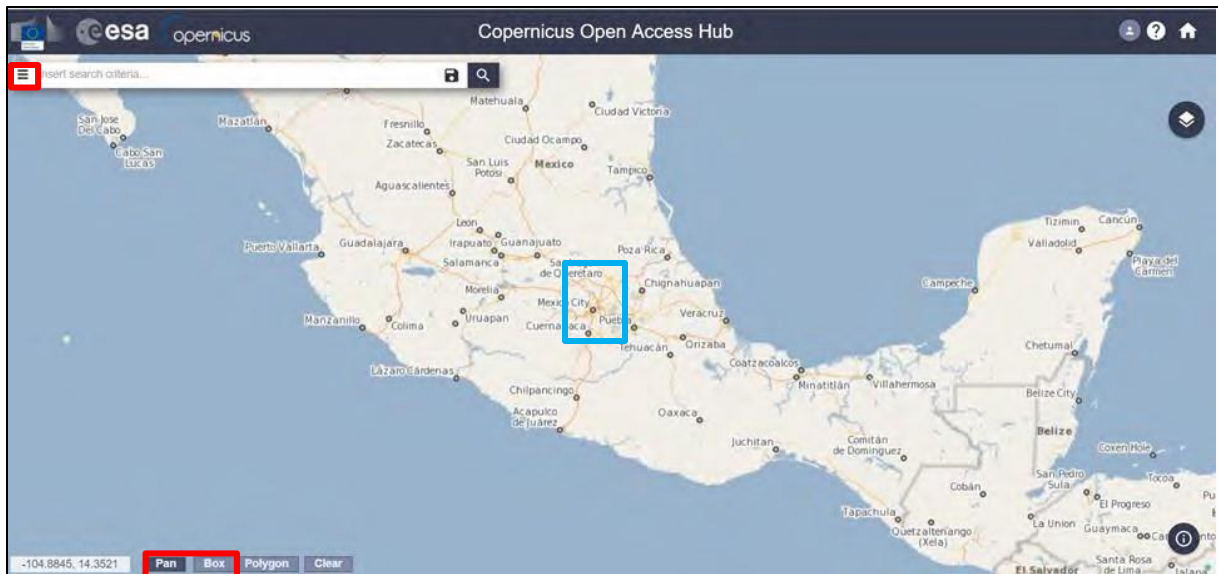
Sentinel-1 satellite data through radar interferometry techniques, can monitor subtle movements of the Earth's surface. With its frequent revisits and global coverage, Sentinel-1 enables continuous monitoring over large areas, aiding researchers and policymakers in assessing risks and implementing mitigation 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_Multi-media/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/](https://dataspace.copernicus.eu/)].

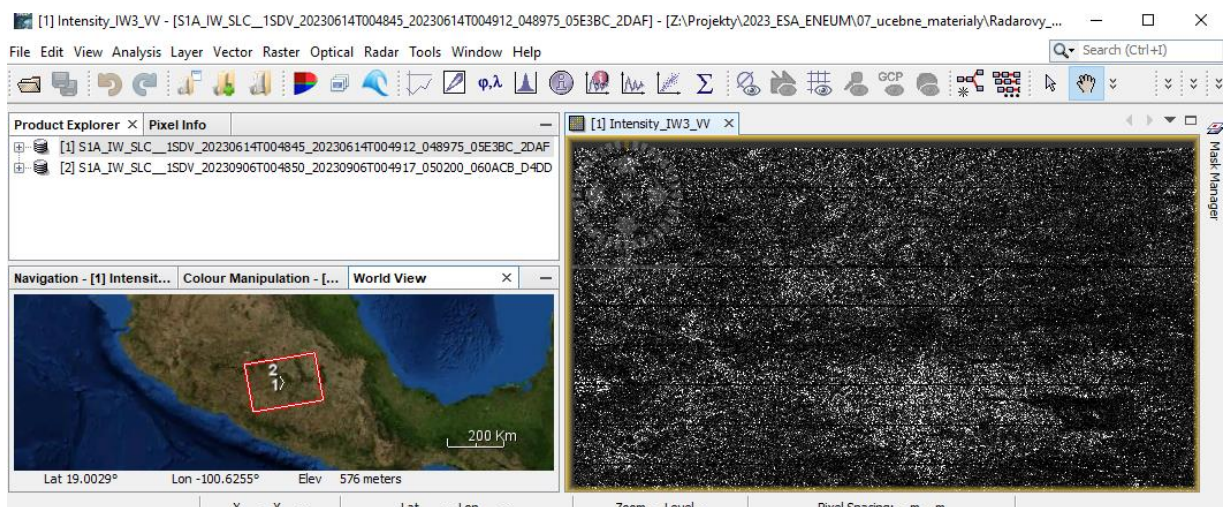


2.2. SNAP - Open and explore product

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.

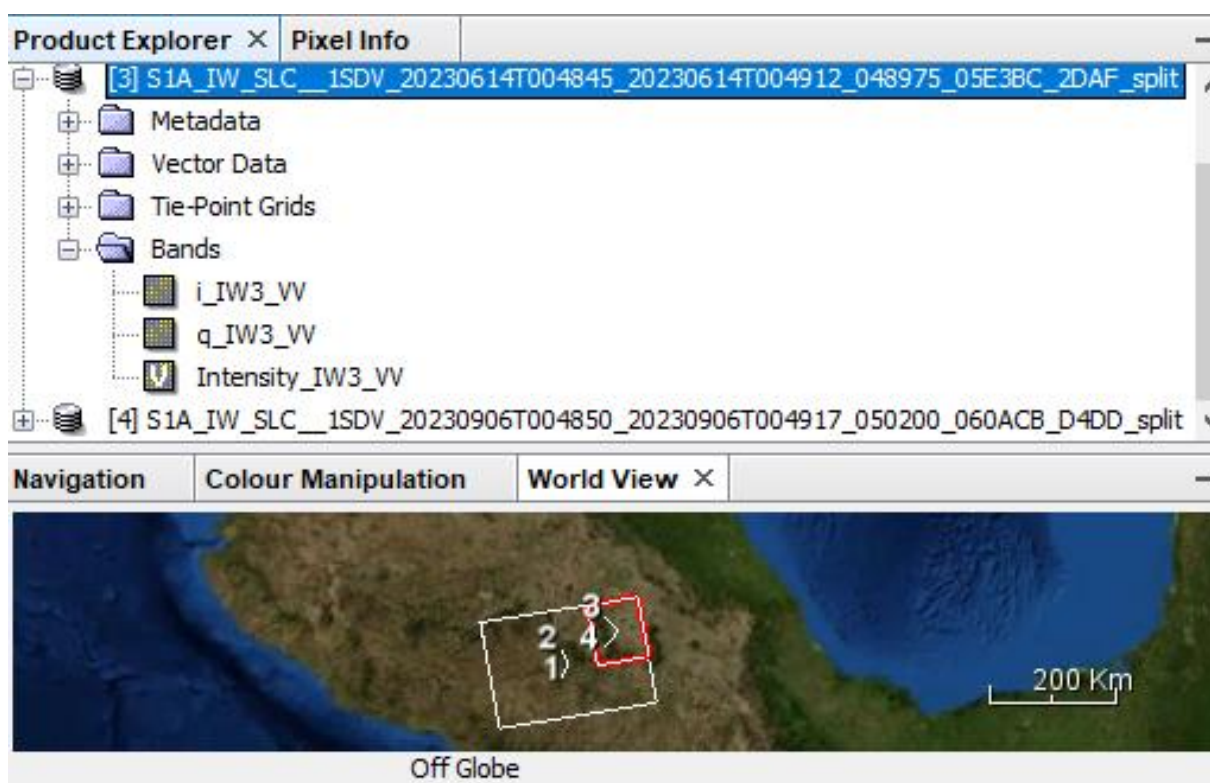
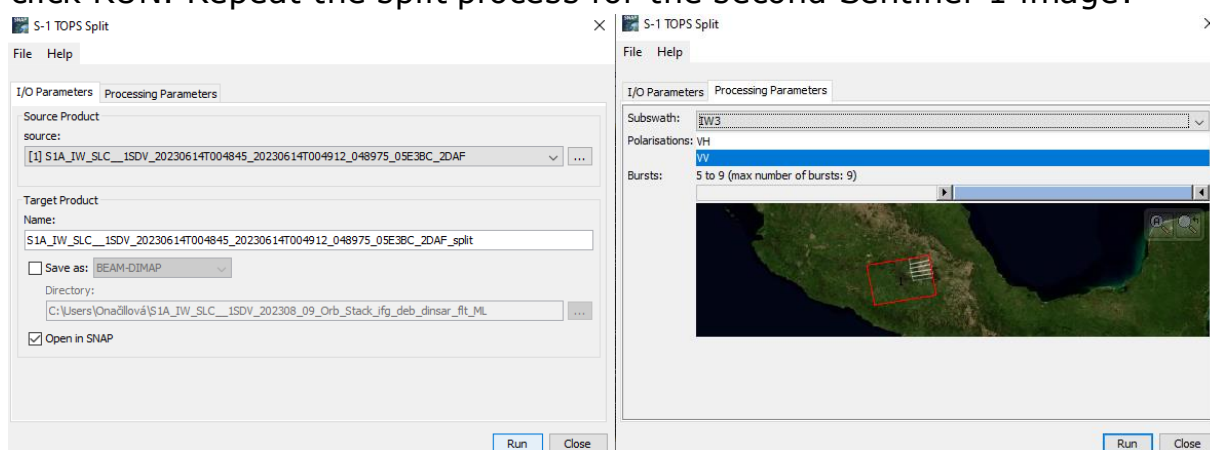
Navigate to Radar > Sentinel-1 TOPS > S-1 TOPS Split.

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

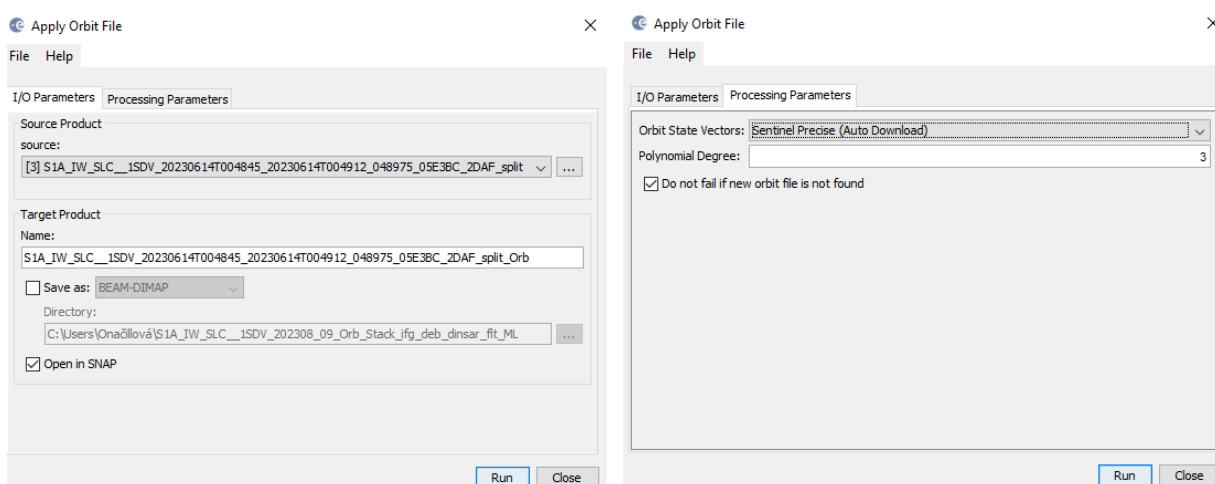
Navigate to Main Menu – Radar – Apply orbit file

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.

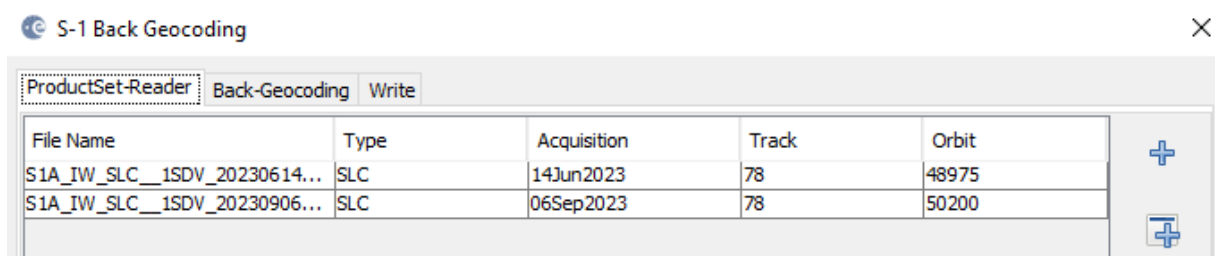


Back-Geocoding

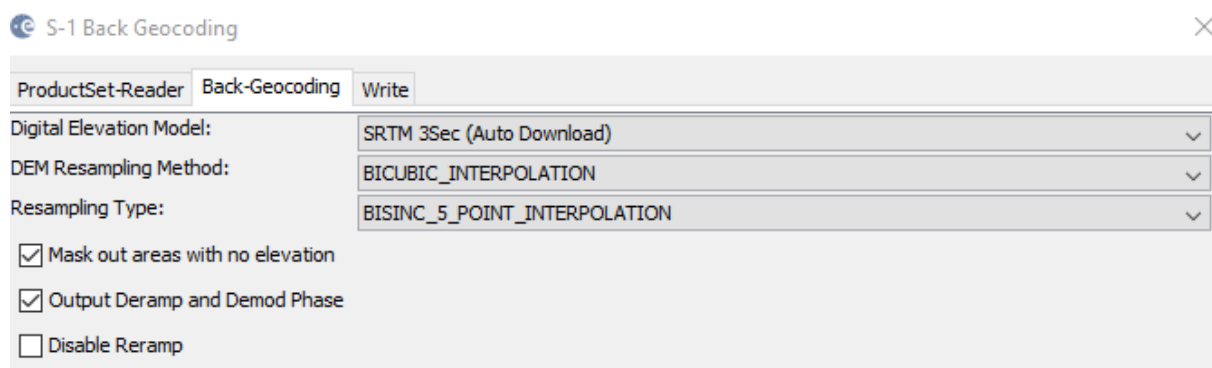
Next step will be to co-register the two Sentinel-1 images. For this reason the second image (slave) will be co-registered with respect to the first image (master). Sentinel-1 Back Geocoding operator co-registers two S-1 split products (master and slave) of the same sub-swath using the orbits of the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

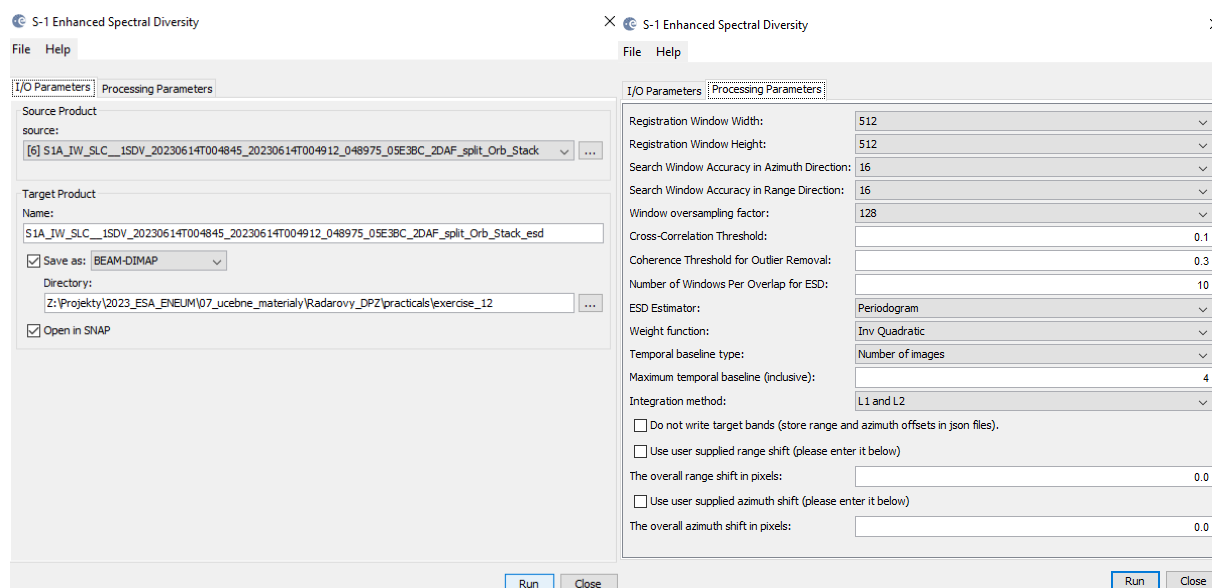
Enhanced Spectral Diversity

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.

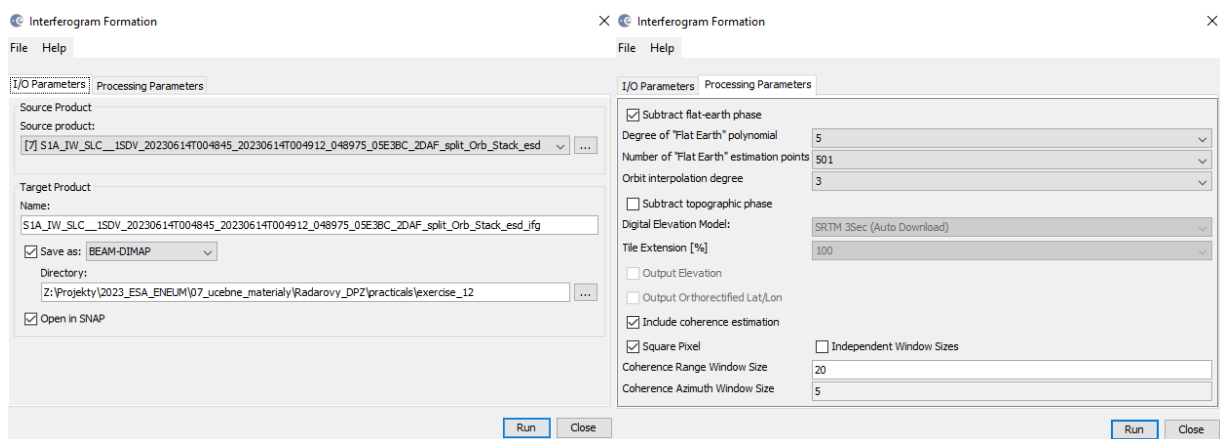
In the I/O Parameters tab, choose the „esd" product that was generated during the previous step.

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



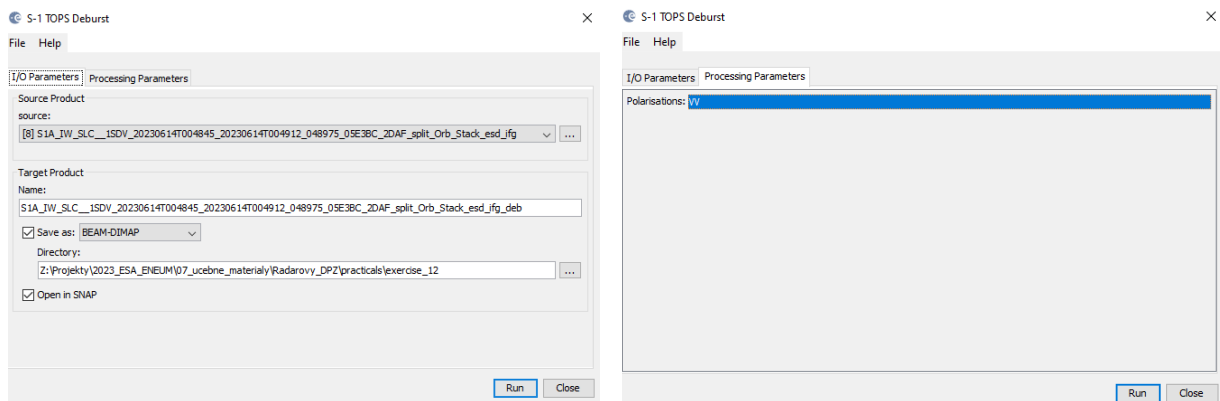
TOPS Debursting

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.

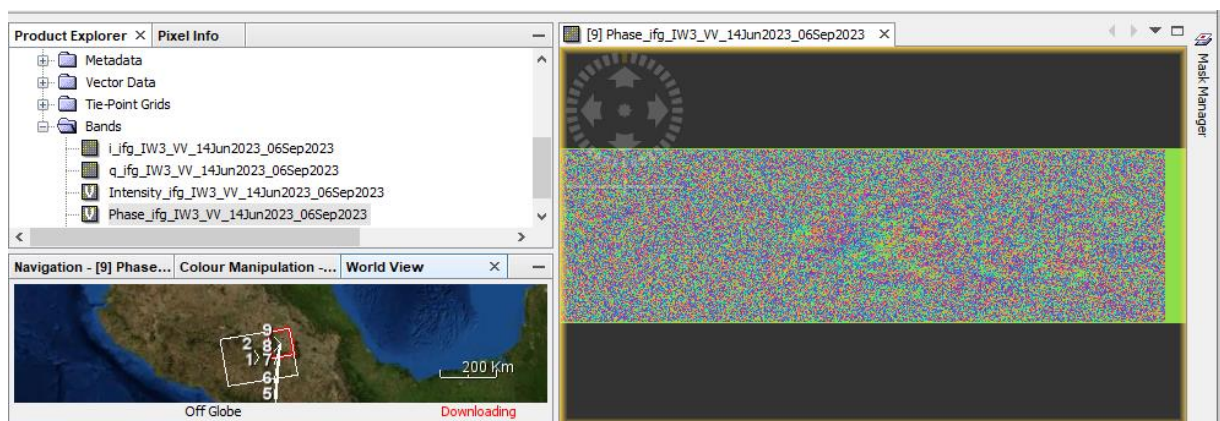
From the main menu bar, navigate to Radar > Sentinel-1 TOPS > S-1 TOPS deburst:

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“.

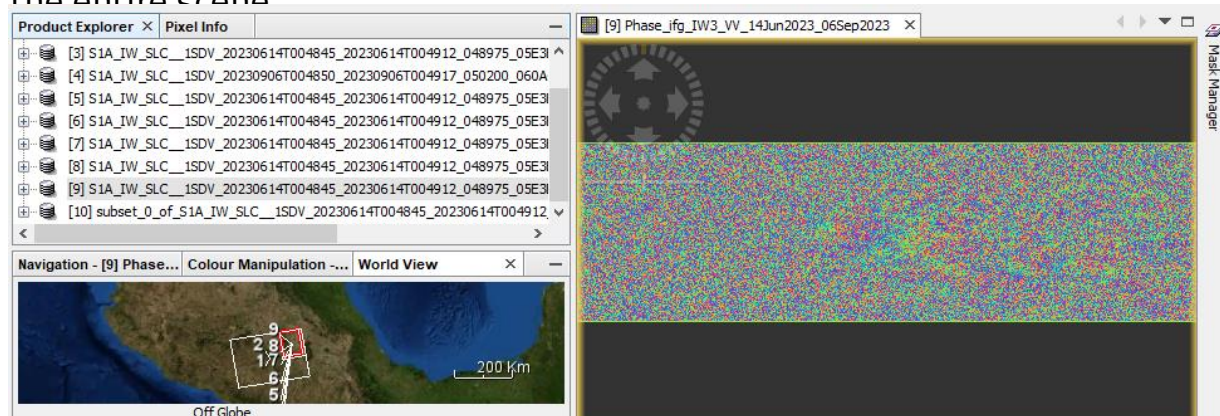


The new product will appear in the Product Explorer window. The processing might take some time depending on your machine.



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 deburst interferogram using a Digital Elevation Model (DEM).

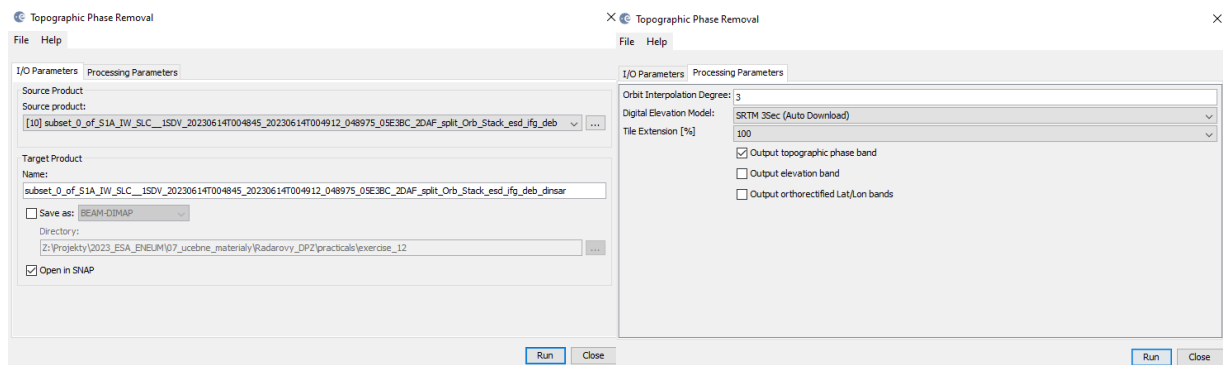
To proceed with topographic phase removal, follow these steps:

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:

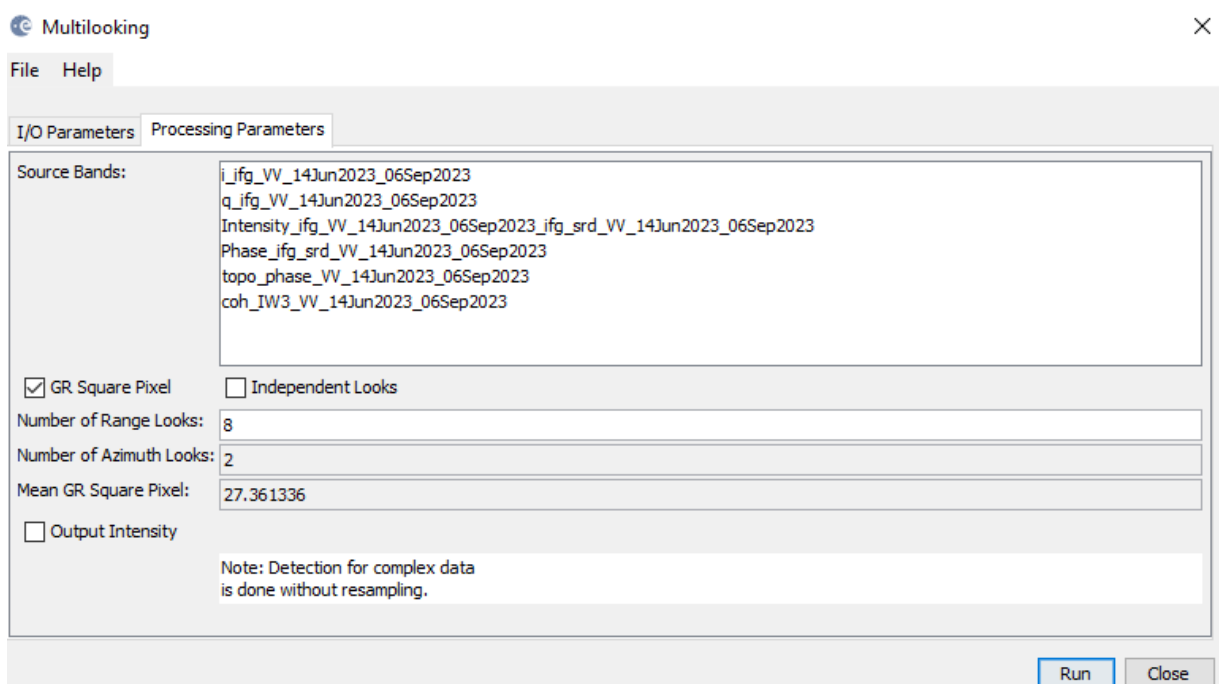
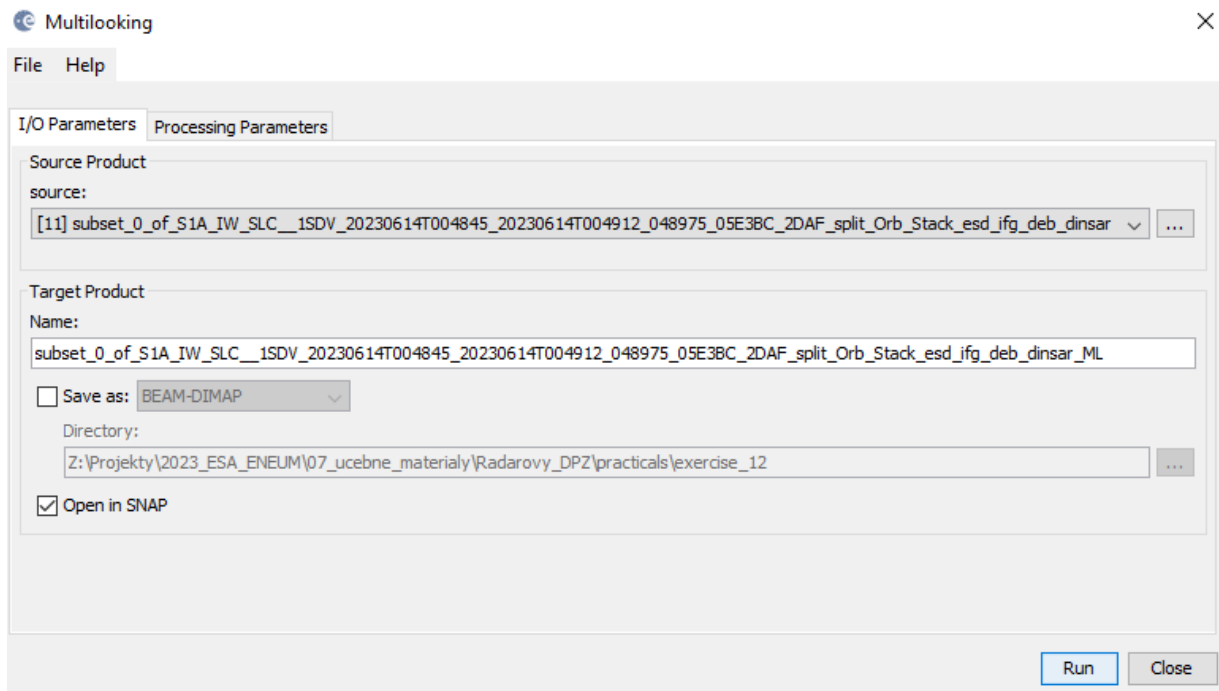
From the top main menu bar, select Radar > SAR Utilities > Multilooking.

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



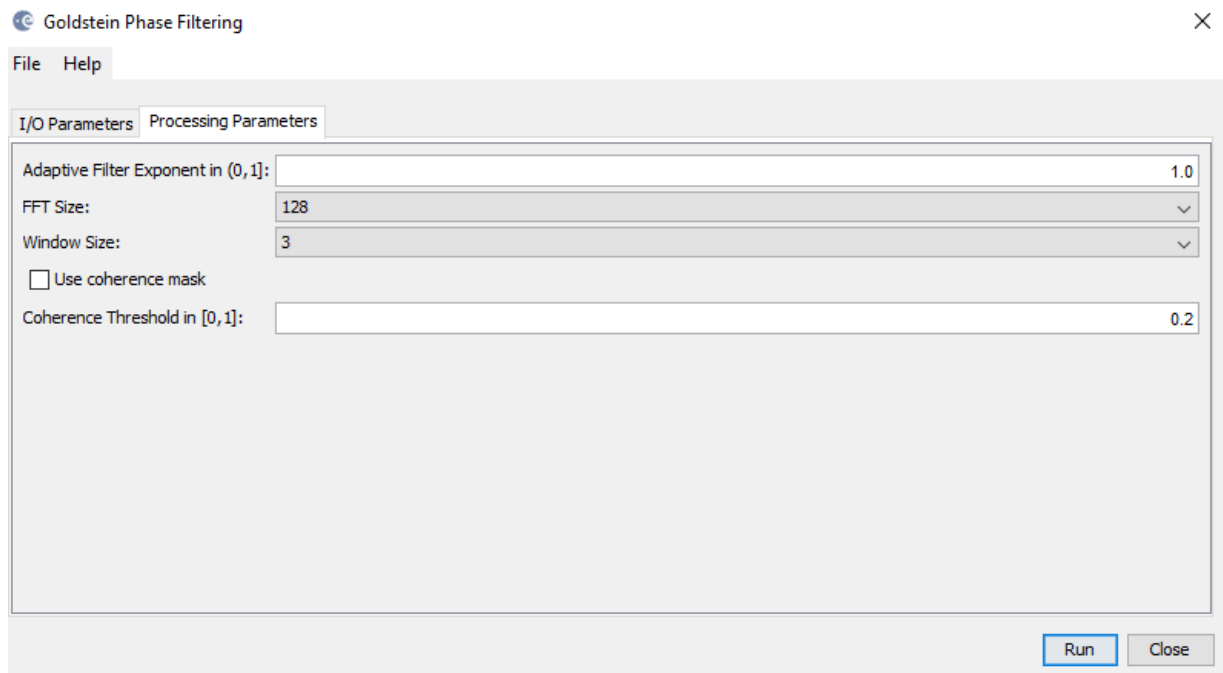
Filtering

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

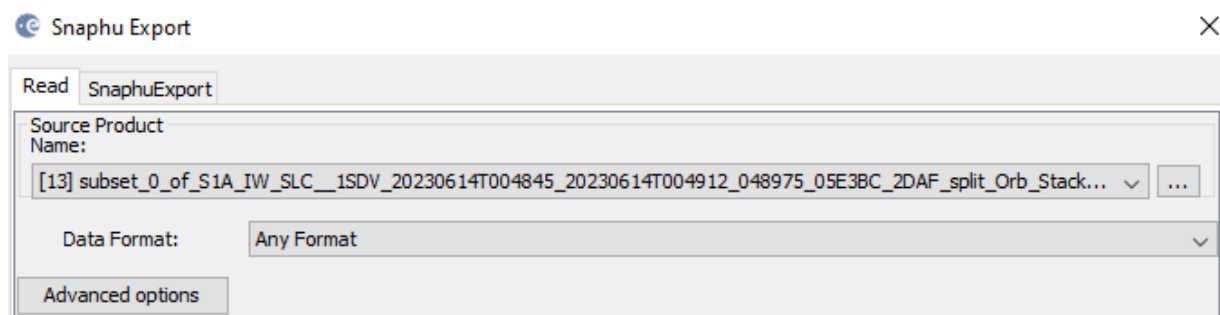
Export of the wrapped phase

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

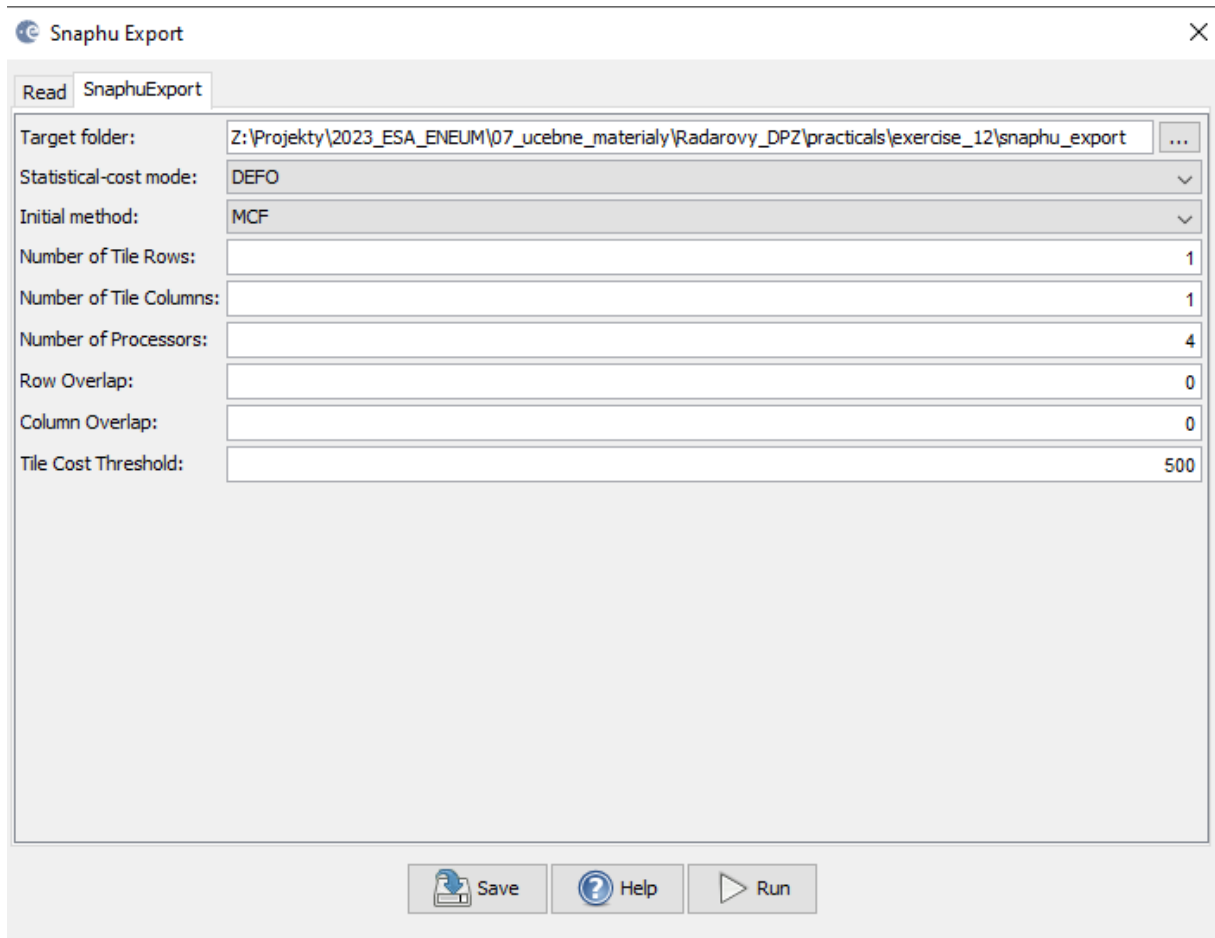
Number of Tile Rows: 1

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

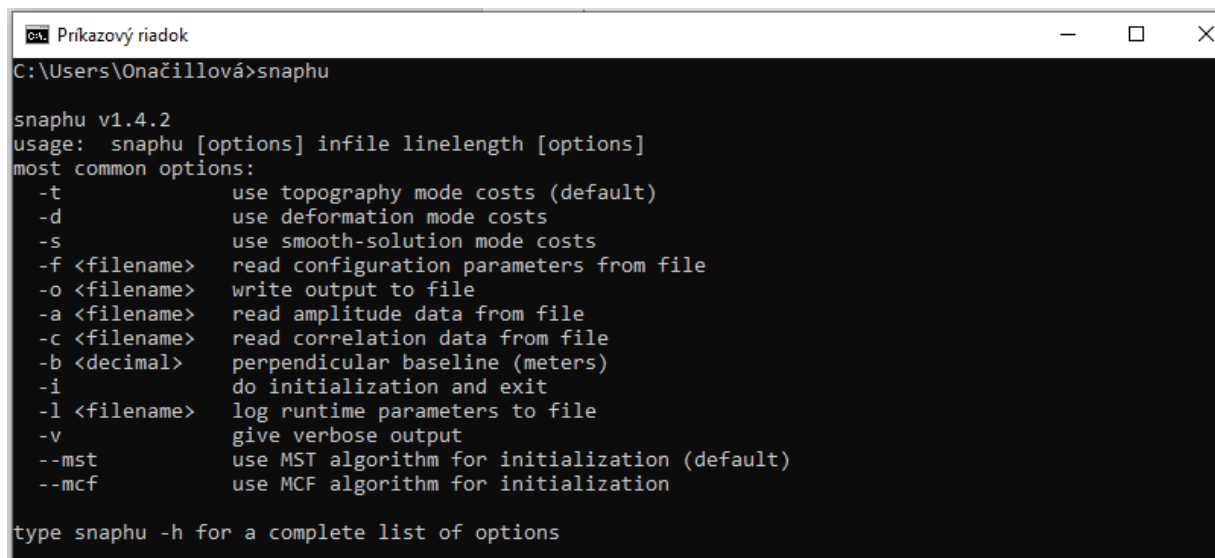
Unwrapping of the phase

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 Zobrazit 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_WW_14Jun2023_06Sep2023.snaphu.img 2552
```

```
Príkazový riadok
C:\Users\Oňačillová>snaphu -f snaphu.conf Phase_ifg_VV_30Aug2023_11Sep2023.snaphu.img 1352

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_9176
Unwrapping tile at row 0, column 0 (pid 17116)
Unwrapping tile at row 0, column 1 (pid 6756)
Unwrapping tile at row 0, column 2 (pid 17080)
Unwrapping tile at row 0, column 3 (pid 5492)
Unwrapping tile at row 0, column 4 (pid 8164)
Unwrapping tile at row 0, column 5 (pid 14144)
Unwrapping tile at row 0, column 6 (pid 4528)
Unwrapping tile at row 0, column 7 (pid 17300)
Unwrapping tile at row 0, column 8 (pid 16024)
Unwrapping tile at row 0, column 9 (pid 12940)
Unwrapping tile at row 1, column 0 (pid 13976)
Unwrapping tile at row 1, column 1 (pid 13484)
Unwrapping tile at row 1, column 2 (pid 15556)
Unwrapping tile at row 1, column 3 (pid 9680)
Unwrapping tile at row 1, column 4 (pid 8840)
Unwrapping tile at row 1, column 5 (pid 5068)
Unwrapping tile at row 1, column 6 (pid 11868)
Unwrapping tile at row 1, column 7 (pid 13908)
Unwrapping tile at row 1, column 8 (pid 13264)
Unwrapping tile at row 1, column 9 (pid 9124)
Unwrapping tile at row 2, column 0 (pid 5956)
Unwrapping tile at row 2, column 1 (pid 11740)
Unwrapping tile at row 2, column 2 (pid 10028)
```

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.

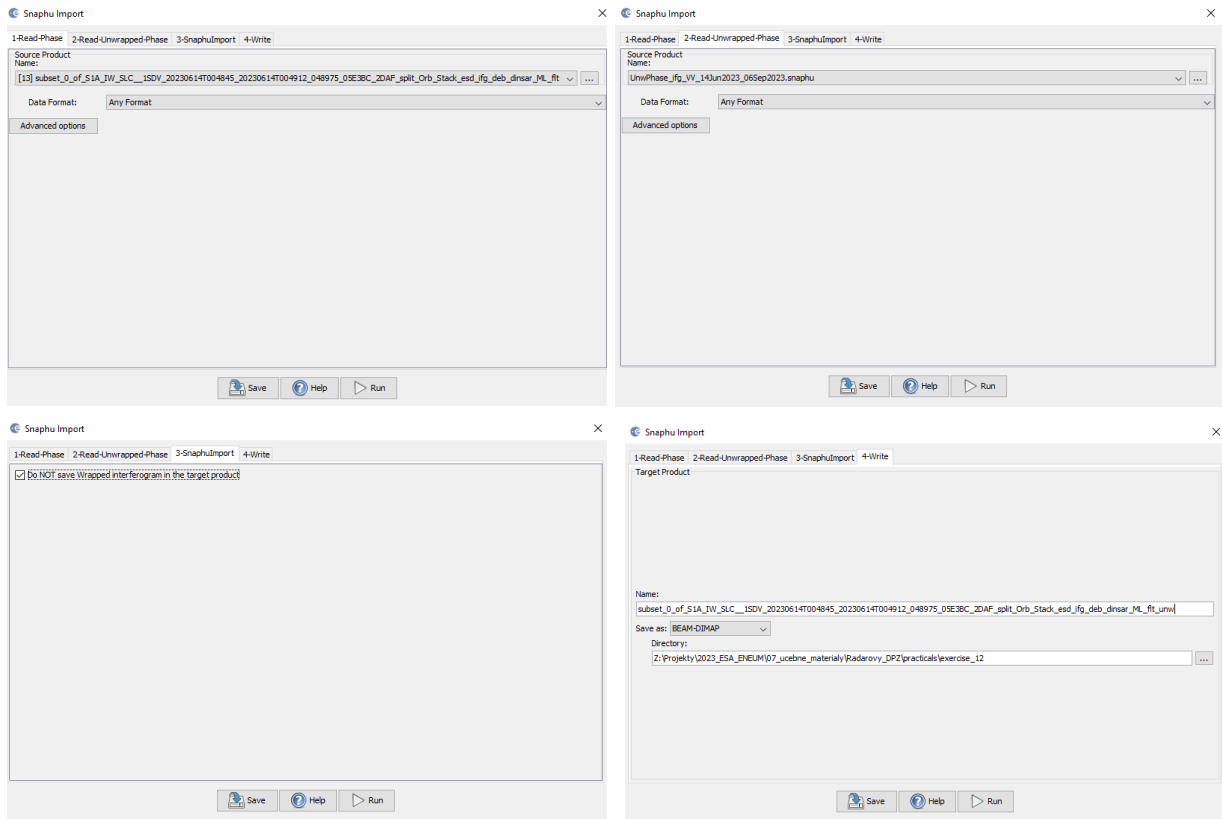
Read-Phase: should be set to the wrapped product that you exported(before the export)

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.

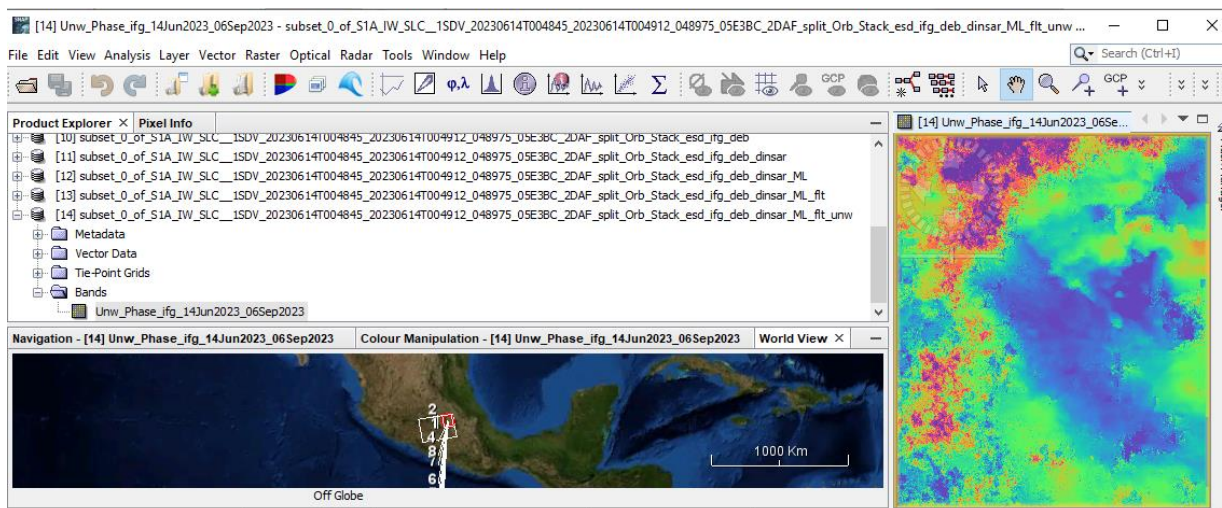
Write: To store the imported unwrapped band in a separate product (recommended), add `_unw` to the end of the output name and click Run.

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

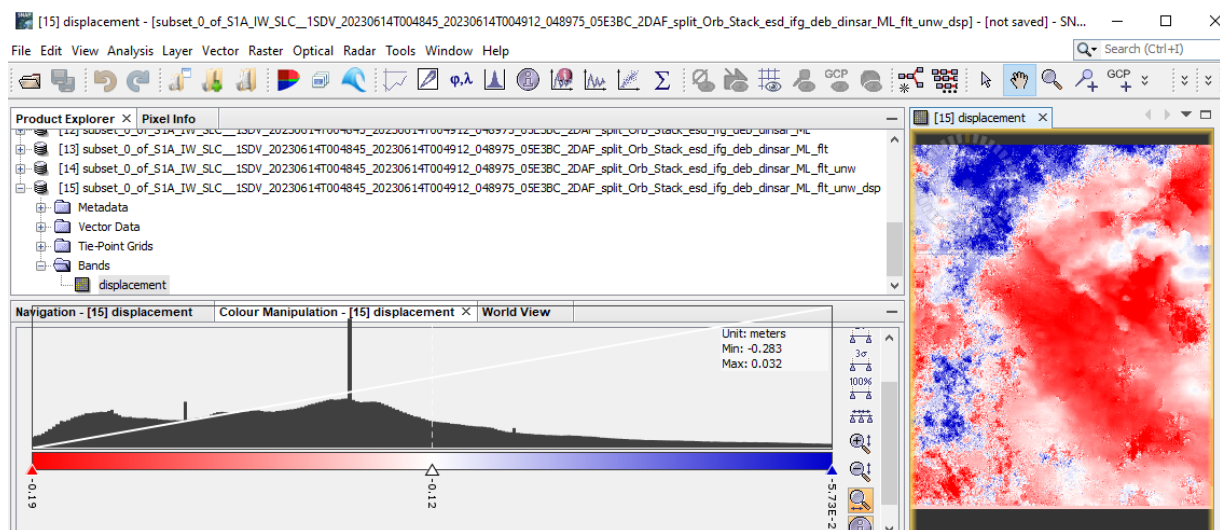
We can convert the unwrapped phase to displacements. From the top main menu bar, select Radar, then Interferometric, then Products, and then Phase to Displacement.

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:

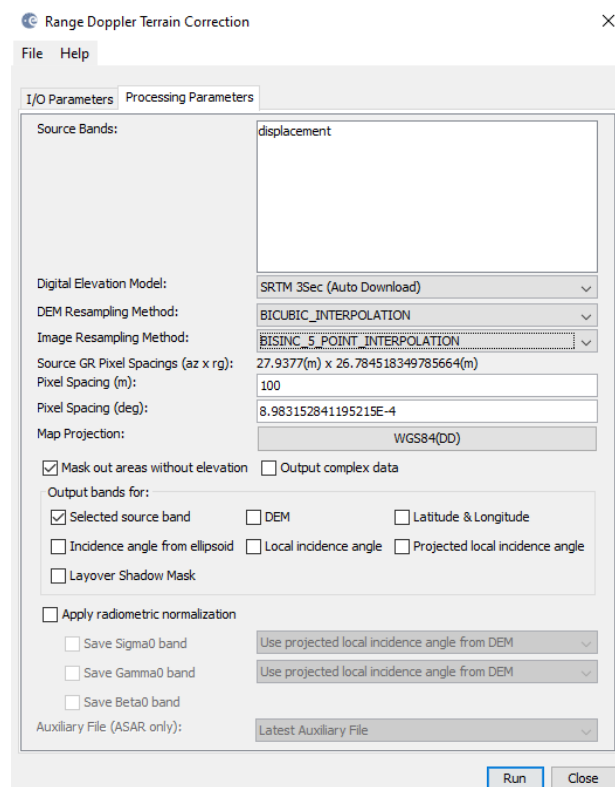
Pixel Spacing (m): 100

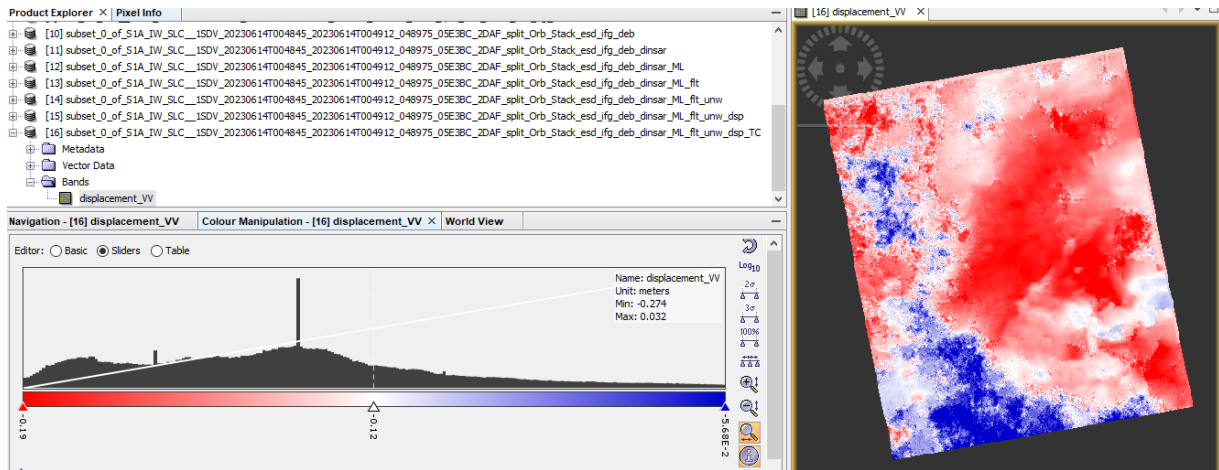
Map Projection: WGS84(DD)

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.

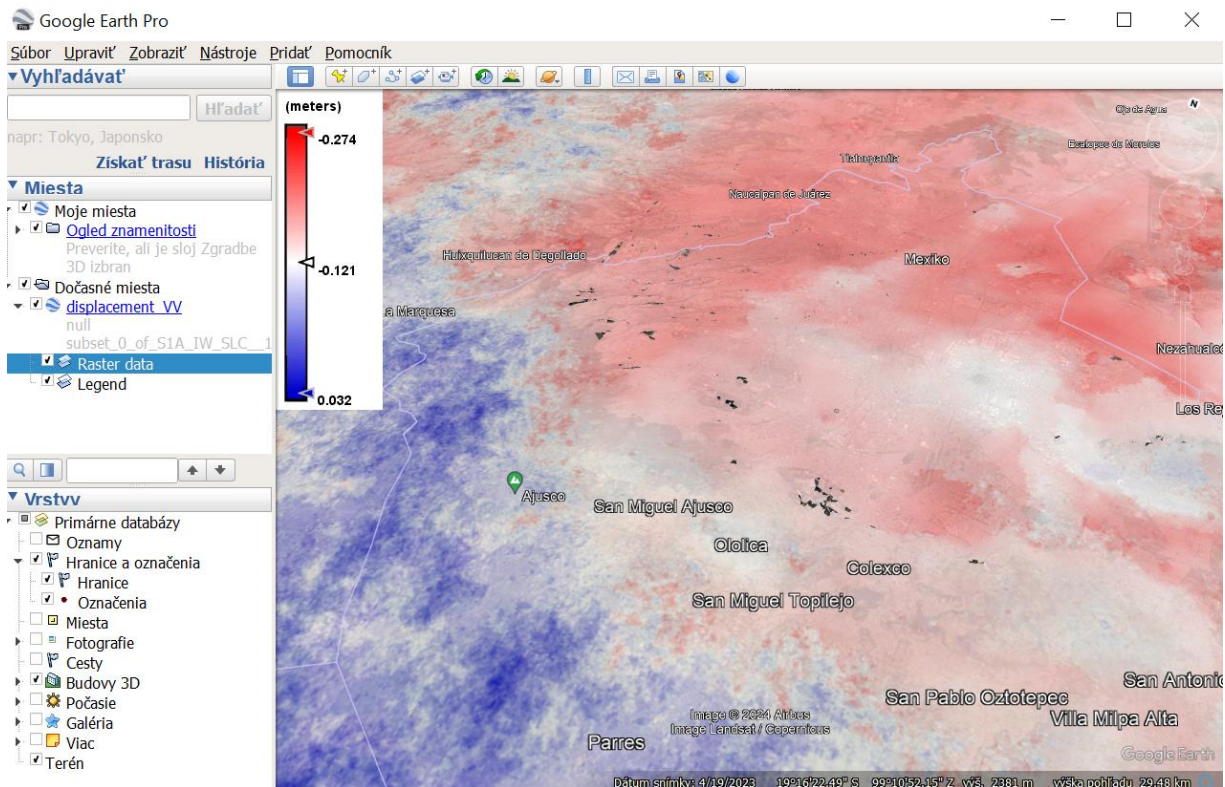
2.9 Export .kmz to Google Earth

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.



THANK YOU FOR FOLLOWING THE EXERCISE!