



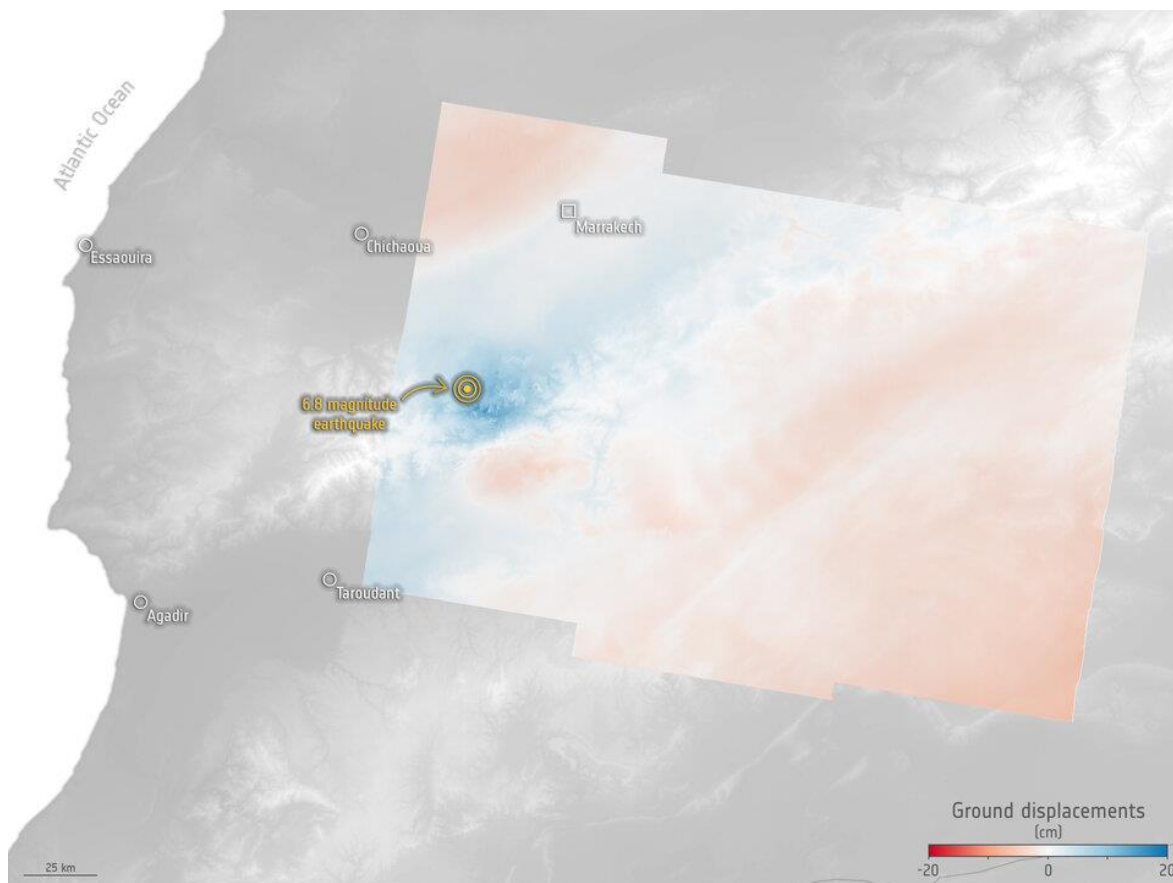
EXERCISE 13 – TUTORIAL

Earthquake deformation with Sentinel-1 using the SNAP software

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



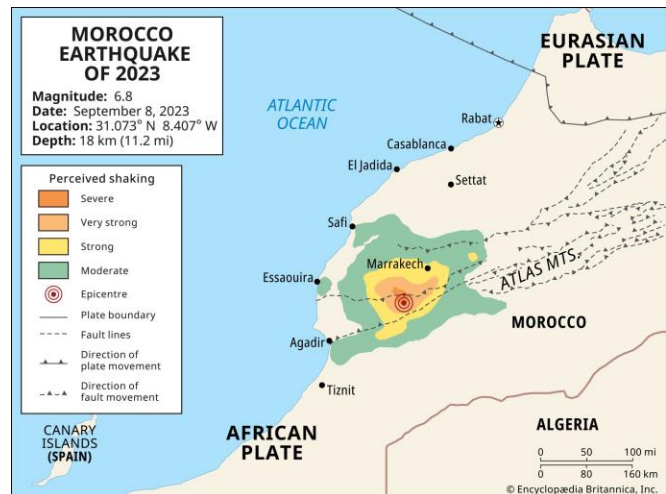
Morocco earthquake deformation

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/](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

The figure displays three sequential screenshots of the 'S-1 TOPS Coregistration' software interface, showing the configuration steps for image coregistration.

First Screenshot (Read Tab): The 'Read' tab is active. The 'Source Product Name' dropdown is set to '[2] S1A_IW_SLC__1SDV_20230911T062920_20230911T062947_050276_060D5E_D10D'. The 'Data Format' is set to 'Any Format'. An 'Advanced options' button is visible.

Second Screenshot (TOPSAR-Split Tab): The 'TOPSAR-Split' tab is active. The 'Subswath' is set to 'IW1'. The 'Polarisations' dropdown is set to 'VV'. The 'Bursts' are set to '1 to 9 (max number of bursts: 9)'. A satellite image preview is shown at the bottom with a red rectangular region of interest marked.

Third Screenshot (Apply Orbit File Tab): The 'Apply Orbit File' tab is active. The 'Orbit State Vectors' dropdown is set to 'Sentinel Precise (Auto Download)'. The 'Polynomial Degree' is set to '3'. The checkbox 'Do not fail if new orbit file is not found' is checked.

3.3 Forming a Raw Interferogram

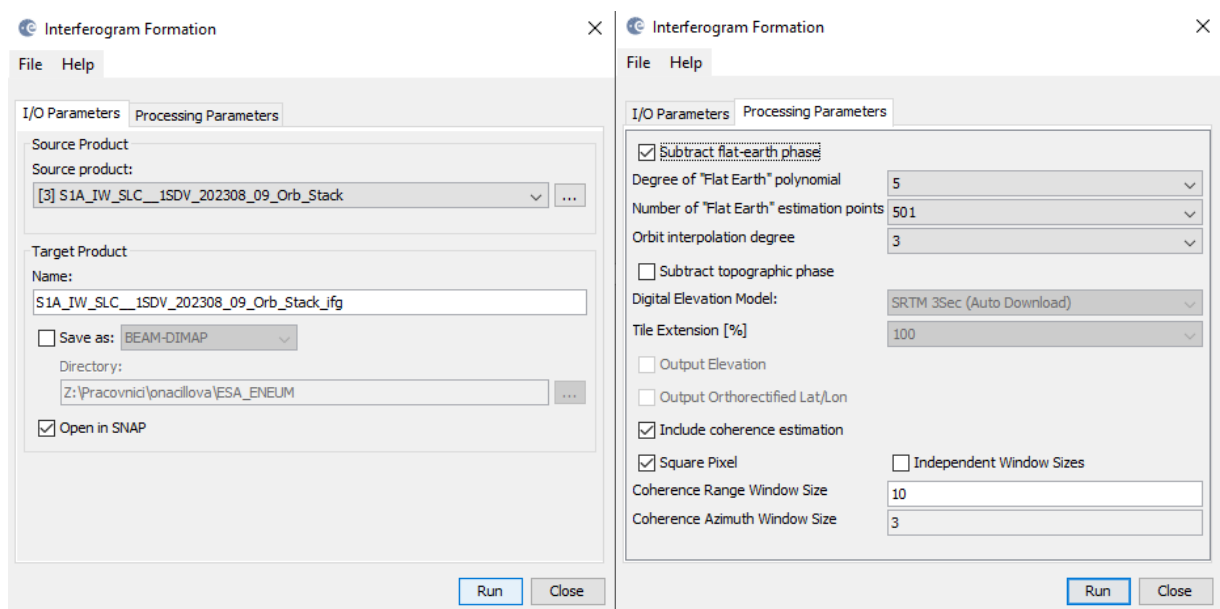
The next phase of interferometry involves generating an interferogram using the coregistered SLC images. To do this, follow these steps:

From the main menu bar, go to Radar – Interferometric - Products and finally select Interferogram Formation.

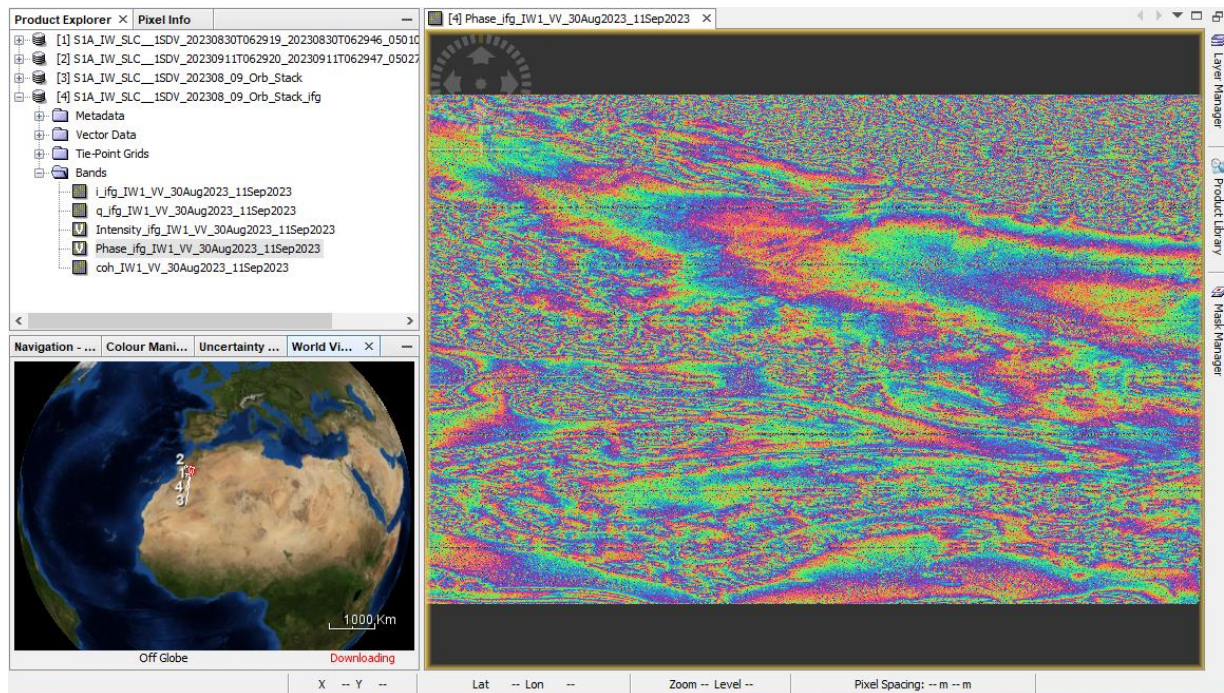
In the I/O Parameters tab, choose the "Orb_Stack" product that was generated during the coregistration process.

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 in the View tab.



3.4 TOPS Debursting and Topographic Phase Removal

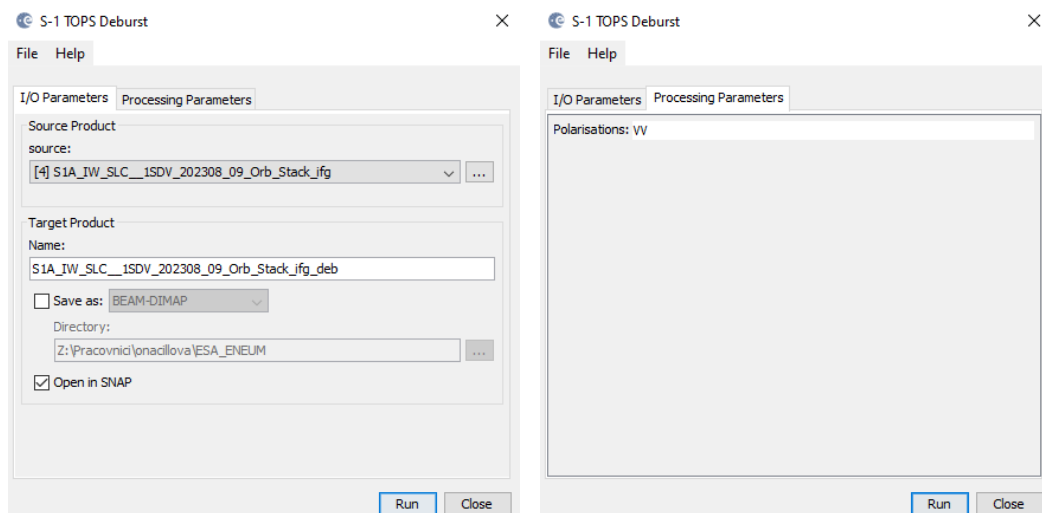
The next stage in interferometry using Sentinel-1 TOPS mode (IWS) data involves "debursting" or merging the bursts, a step not required with Sentinel-1 or other stripmap SAR data.

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).

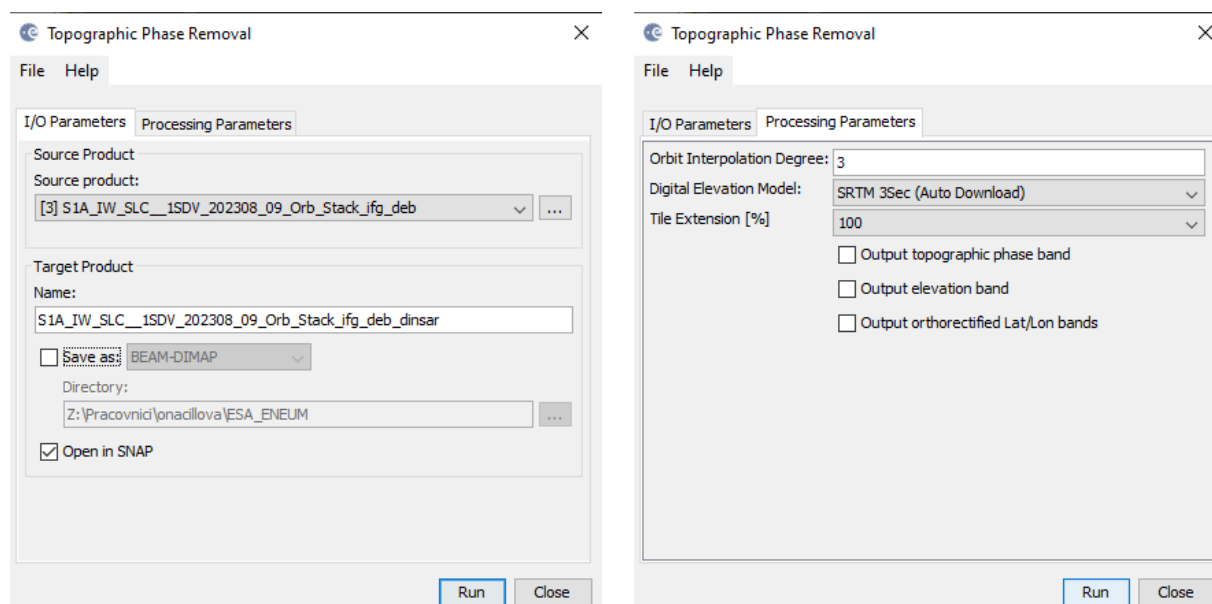
To proceed with topographic phase removal, follow these steps:

From the main menu bar, navigate to Radar, then Interferometric, then Products, and finally Topographic Phase Removal.

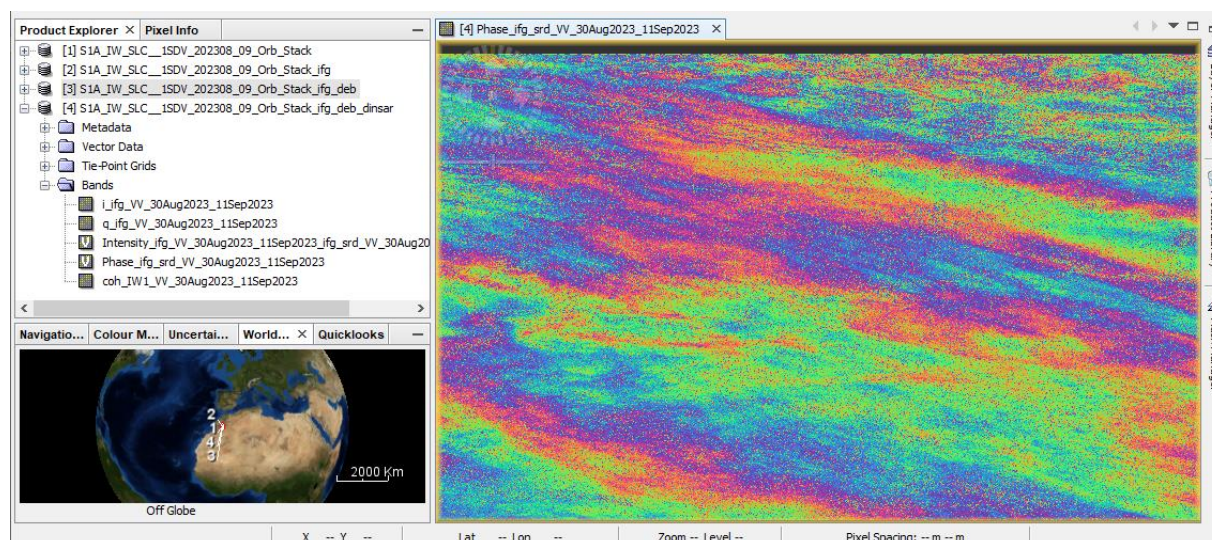
In the I/O Parameters tab, choose the "Orb_Stack_ifg_deb" product generated during the deburst step. If not using TOPS mode, select "Stack_ifg" instead.

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.

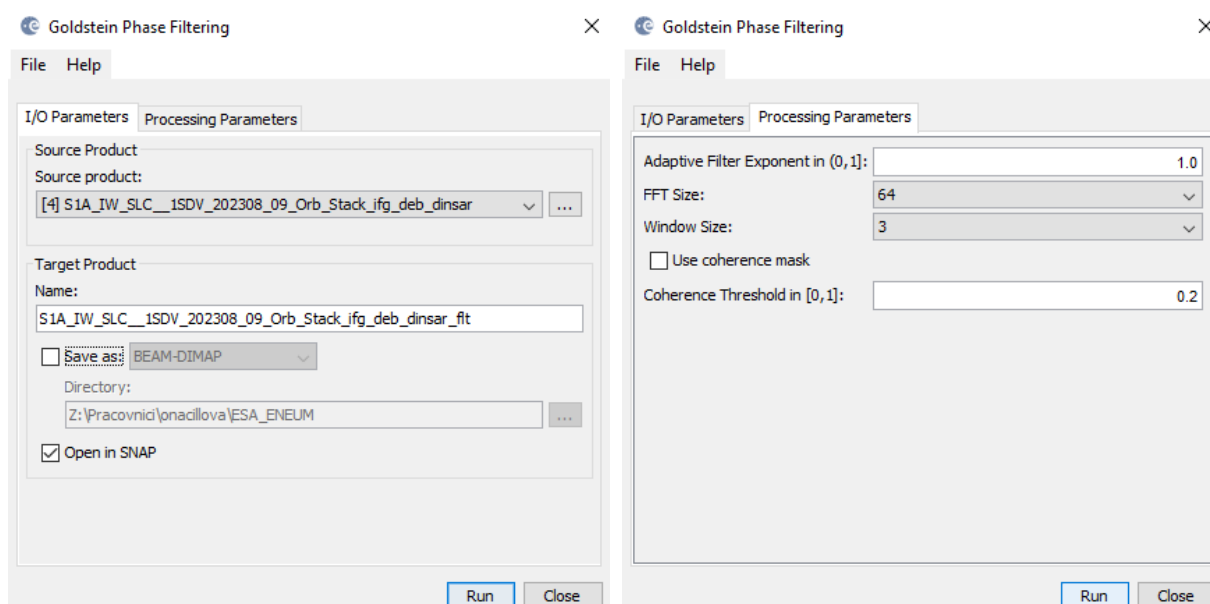
To begin filtering:

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.

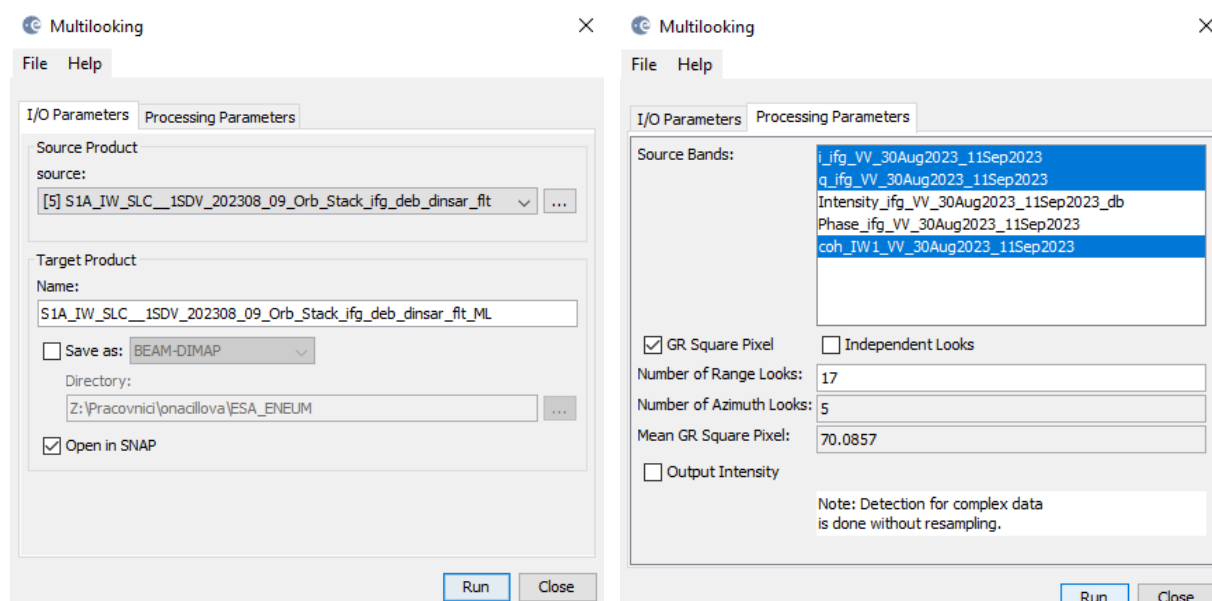
To initiate multi-looking:

From the top main menu bar, select Radar, then SAR Utilities, and finally Multilooking.

In the I/O Parameters tab, choose the "dinsar_fit" 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

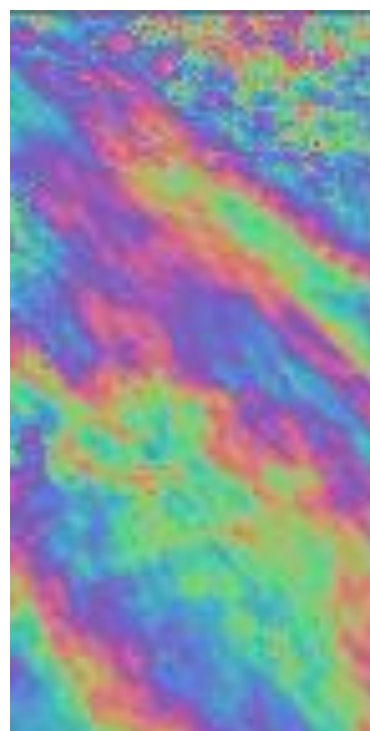
Initially, we must generate a new virtual phase band after multi-looking the complex interferogram.

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:

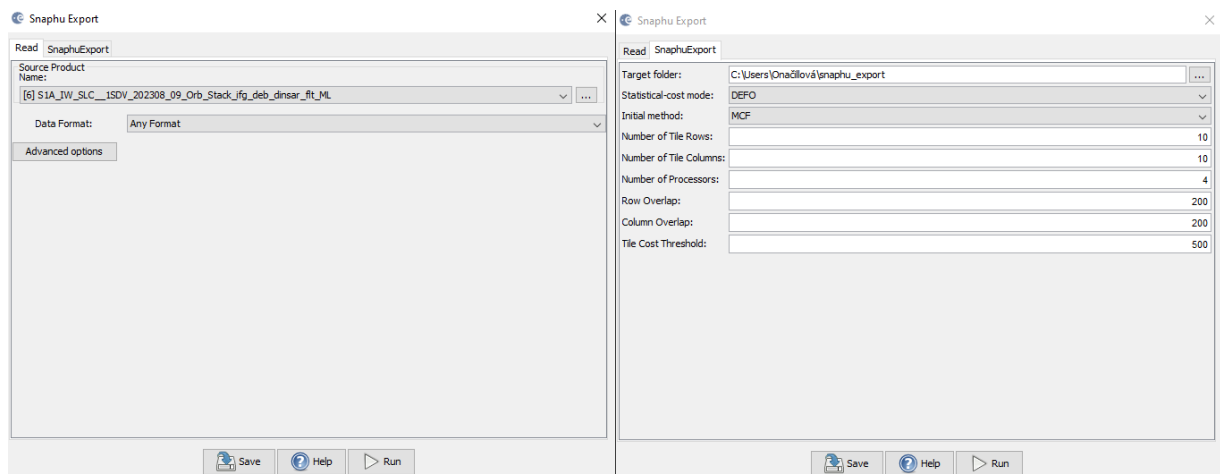
In Read tab, select the "ML" product created by the multilooking step

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:

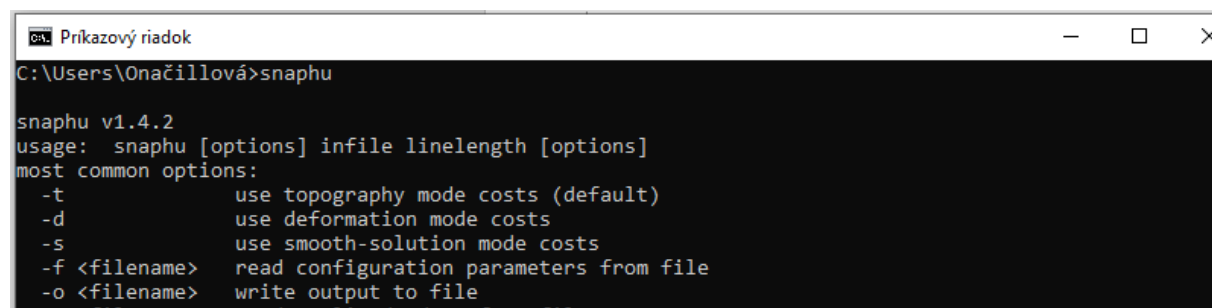
- the coherence: image (*.img) and metadata (*.hdr)
- the wrapped phase: image (*.img) and metadata (*.hdr)
- the unwrapped phase: only the metadata (*.hdr), because the image (*.img) is first to be created by snaphu in the next step.
- a configuration file (snaphu.conf) containing the parameters defined 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

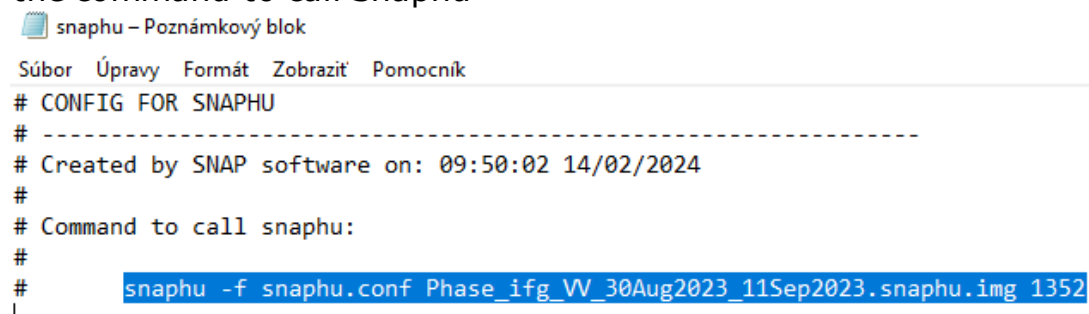
To start unwrapping, check the location of the interferogram exported from SNAP. If snaphu.exe is not in your system's PATH variable: Copy it in there as well. It is recommended to store the data and snaphu on the same disk. Open Command Window Here.



```
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
```

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: 09:50:02 14/02/2024
#
# Command to call snaphu:
#
# snaphu -f snaphu.conf Phase_ifg_WW_30Aug2023_11Sep2023.snaphu.img 1352
```

```
Príkazový riadok
C:\Users\Oňačilová>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)

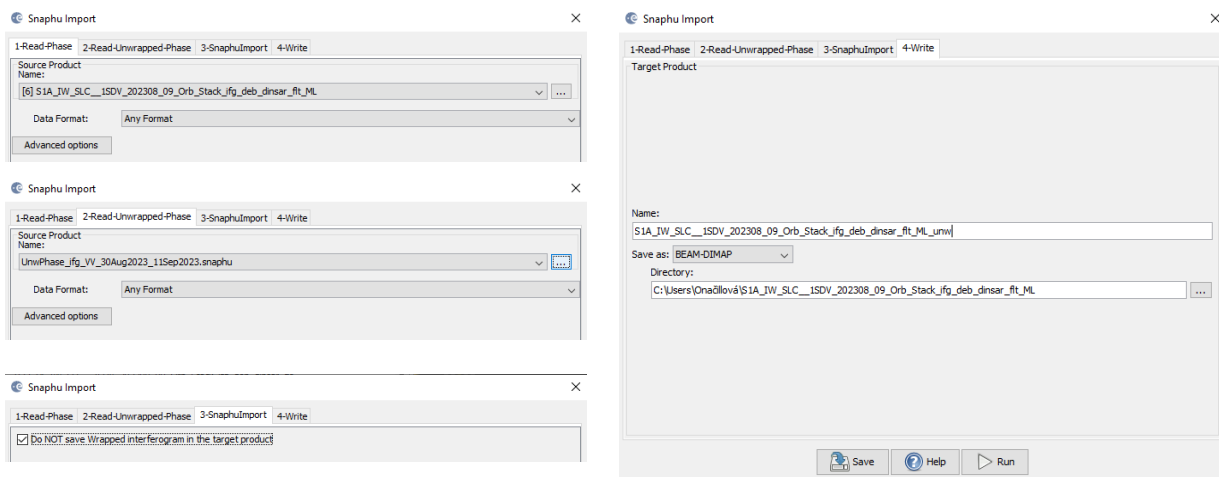
Read-Unwrapped-Phase: select the unwrapped phase product: Navigate to folder where you exported for Snaphu. Select the "UnwPhase_ifg*.snaphu.hdr" file. Note: The error message will then vanish if you proceed to the next tab.

SnaphuImport: Leave the option "Do NOT save Wrapped interferogram in the target product"

unchecked, because it is required in the later step.

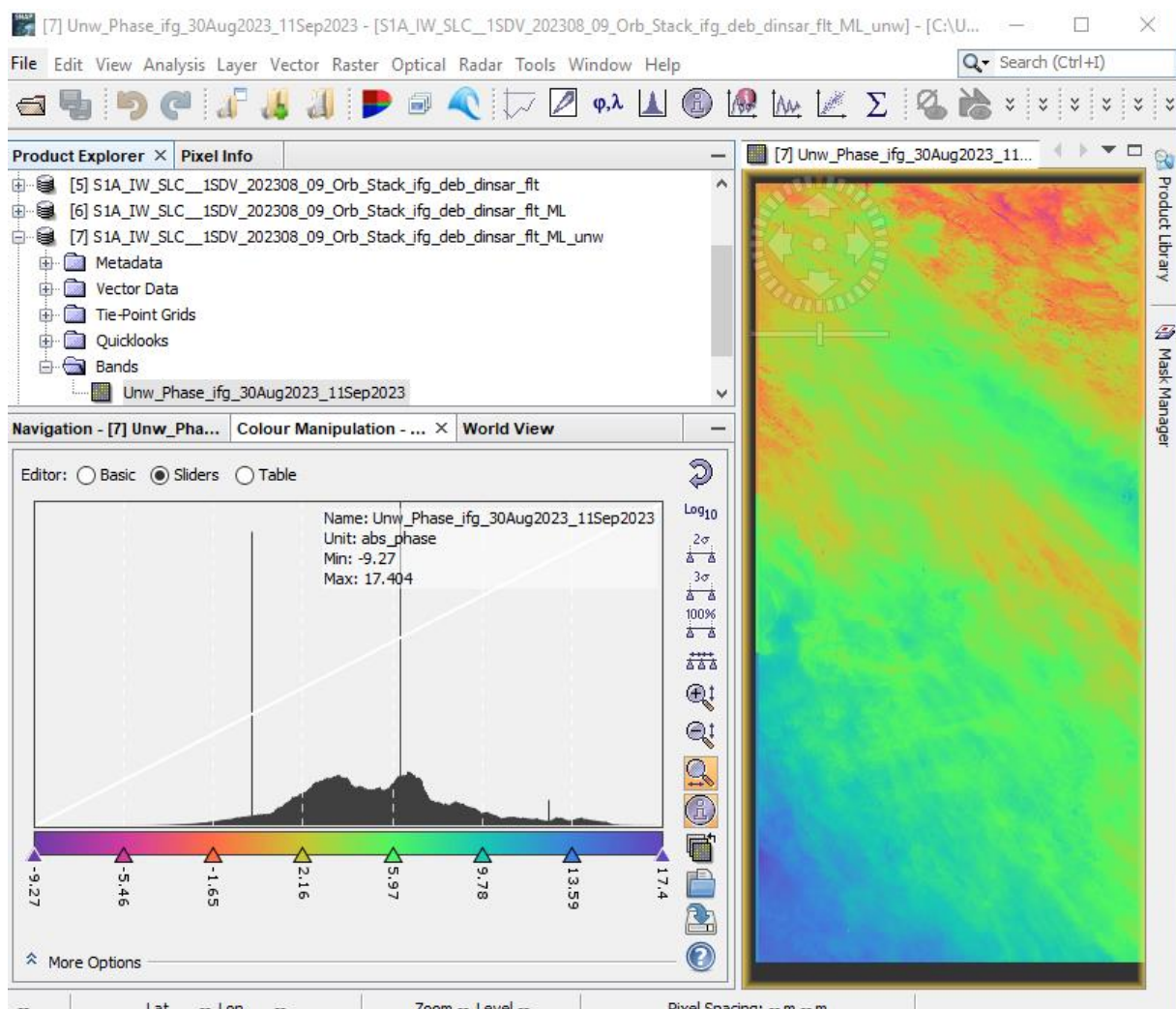
Write: To store the imported unwrapped band in a separate product (recommended), add '_unw' to the end of the output name and click Run.

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)



3.8 Phase to displacement

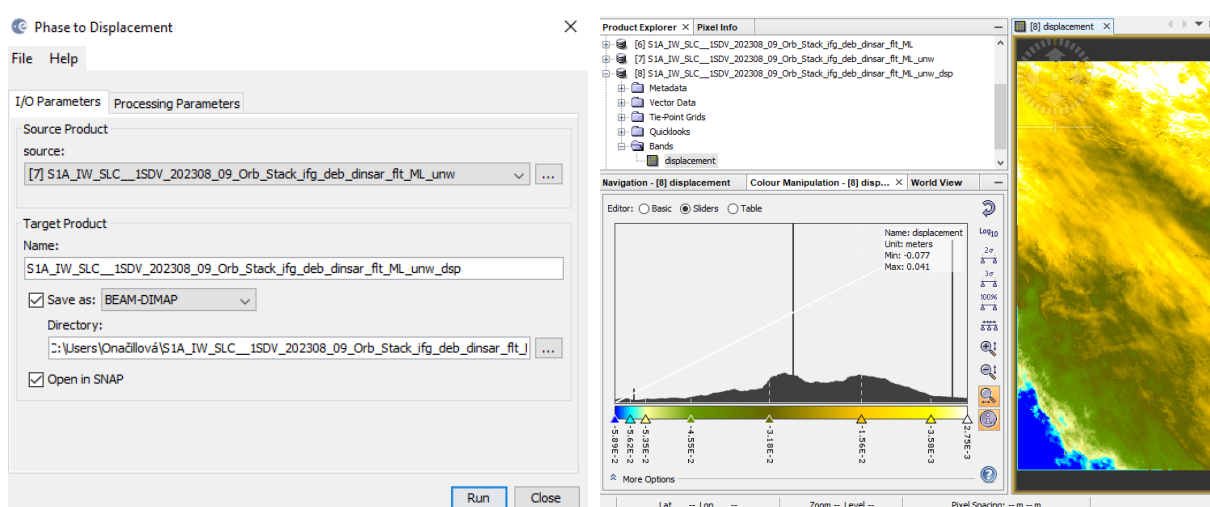
We can convert the unwrapped phase to displacements. From the top main menu bar, select Radar, then Interferometric, then Products, and then Phase to Displacement.

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).

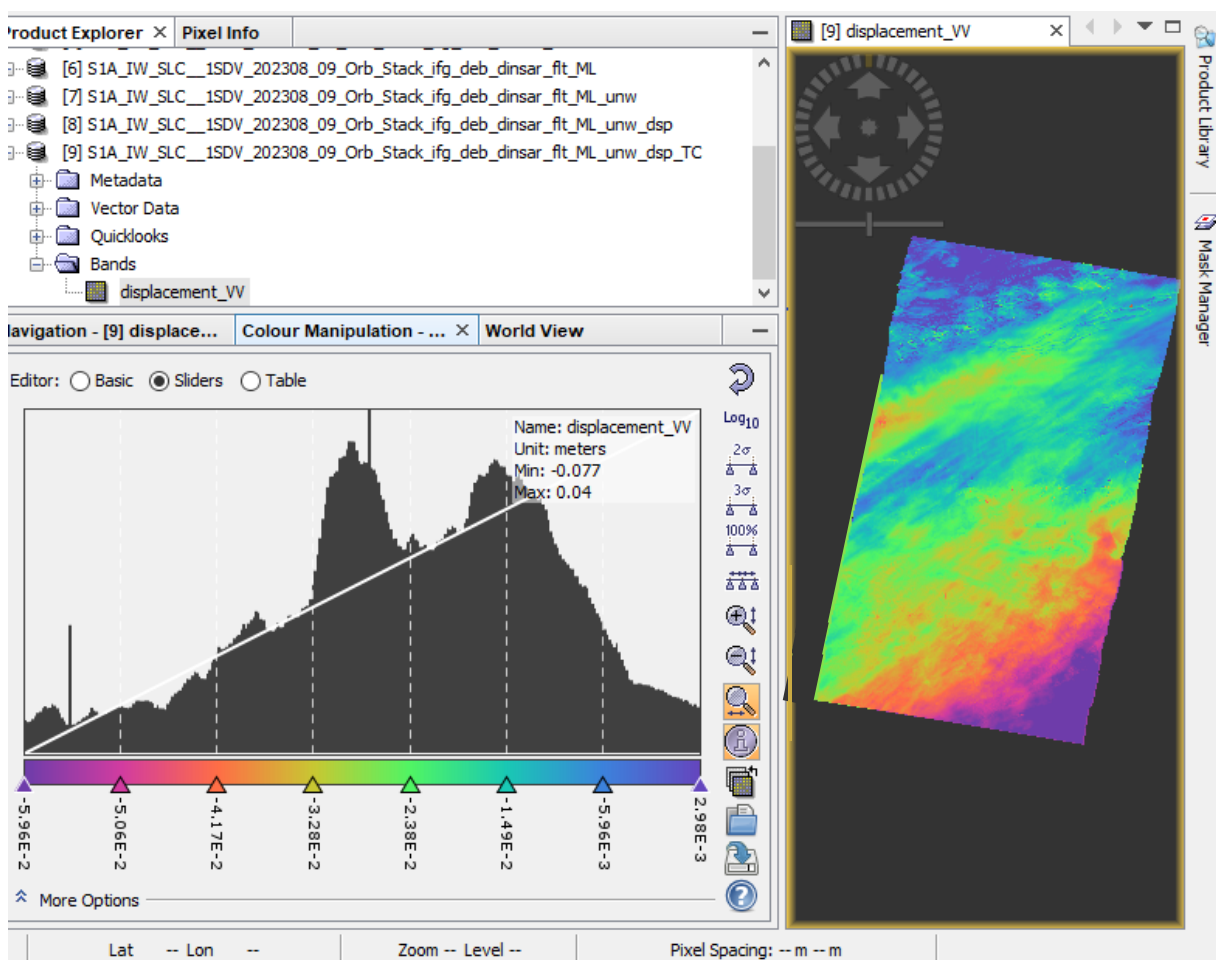
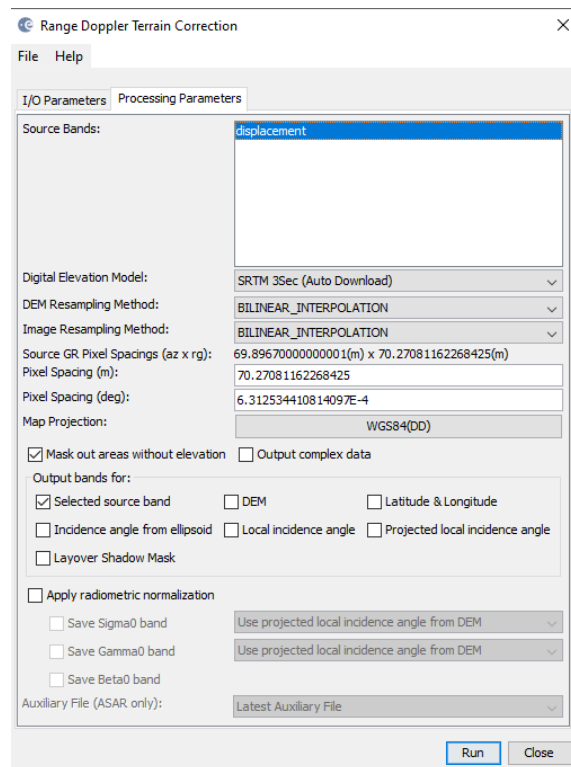
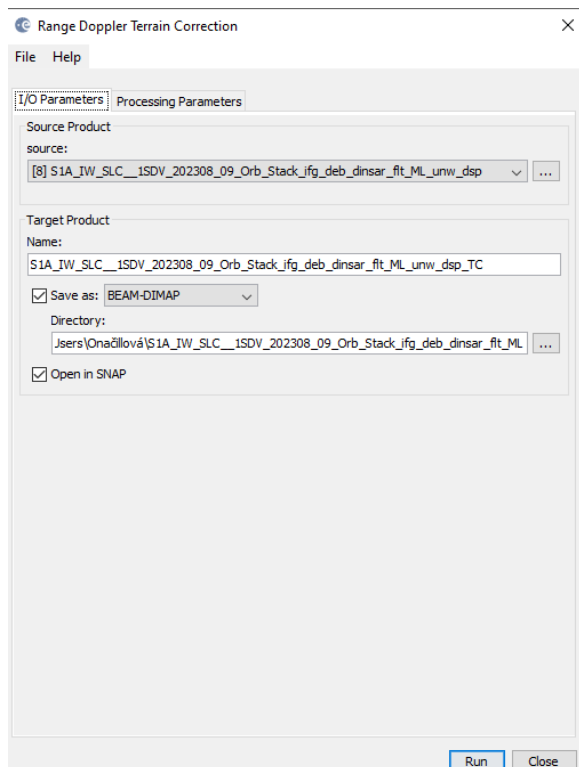
default for target product name is to add “_TC” to the name

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.



3.10 Displacement Profiles

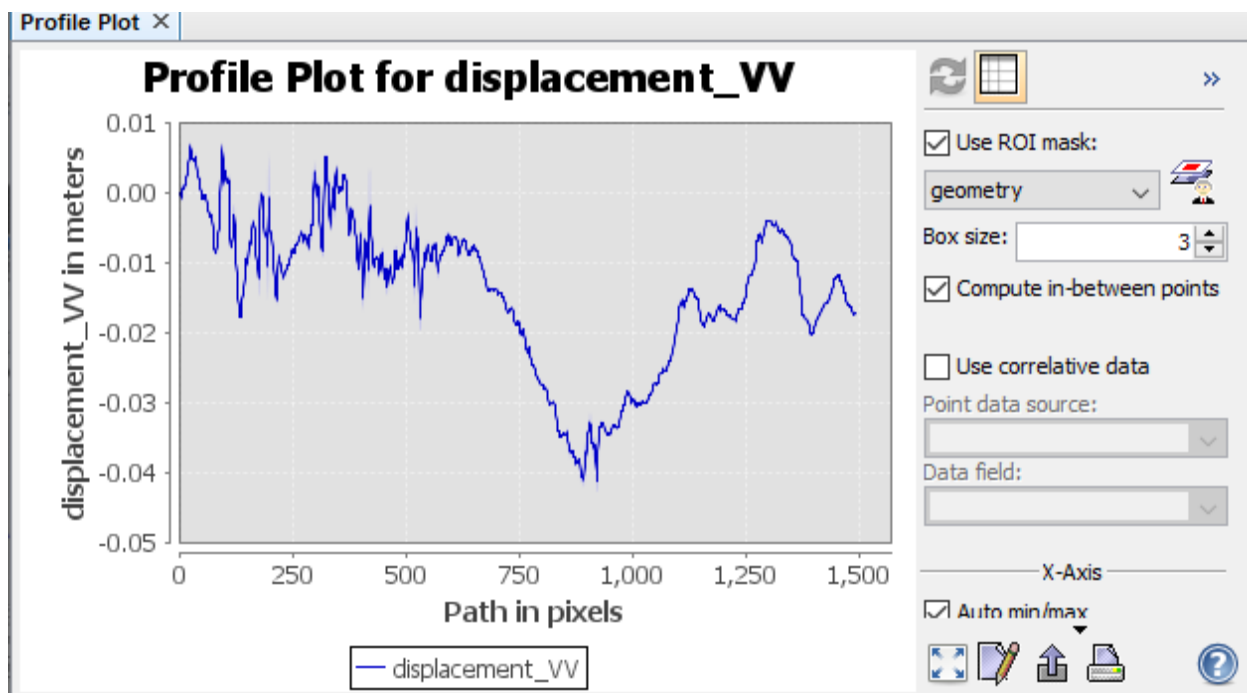
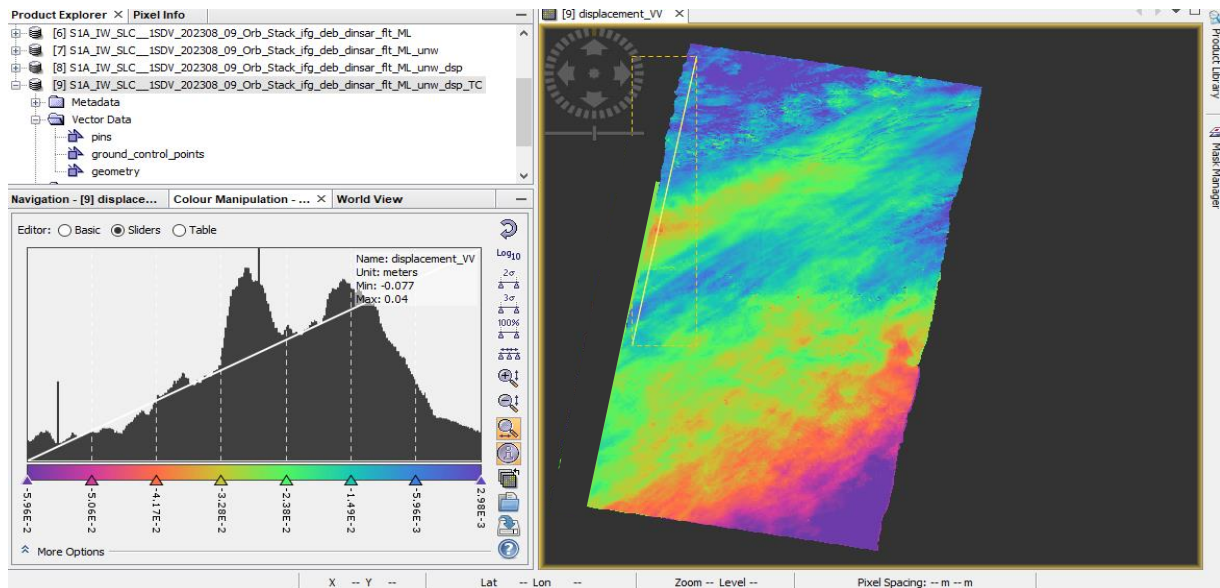
Use the line drawing tool (top bar of SNAP window) to draw a line across the signal.

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!