Copernicus Master in Digital Earth
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Advanced Remote Sensing
Assignment: Radio Detection and Ranging.

Generation of a Displacement Map

The aim of this study is to understand and measure the displacement of an earthquake using RADAR images acquired from Sentinel products, specifically the Sentinel-1 SLC Interferometric Wide Swath.

Area of Interest:

The earthquake was registered on 19 July 2024 at 1:50AM (GMT-3), by the USGS service and occurred in the Atacama's Desert located in Chile. The epicentre was located 41 kilometres southeast of the city San Pedro de Atacama. It had an incredible magnitude of 7.4 on the Richter scale and was recorded at a depth of 127.3 kilometres. According to the USGS, the earthquake resulted from normal faulting at an intermediate depth within the subducted Nazca plate, approximately 120 kilometers beneath the tri-country borders of Chile, Argentina, and Bolivia. The image below shows the location of the event.

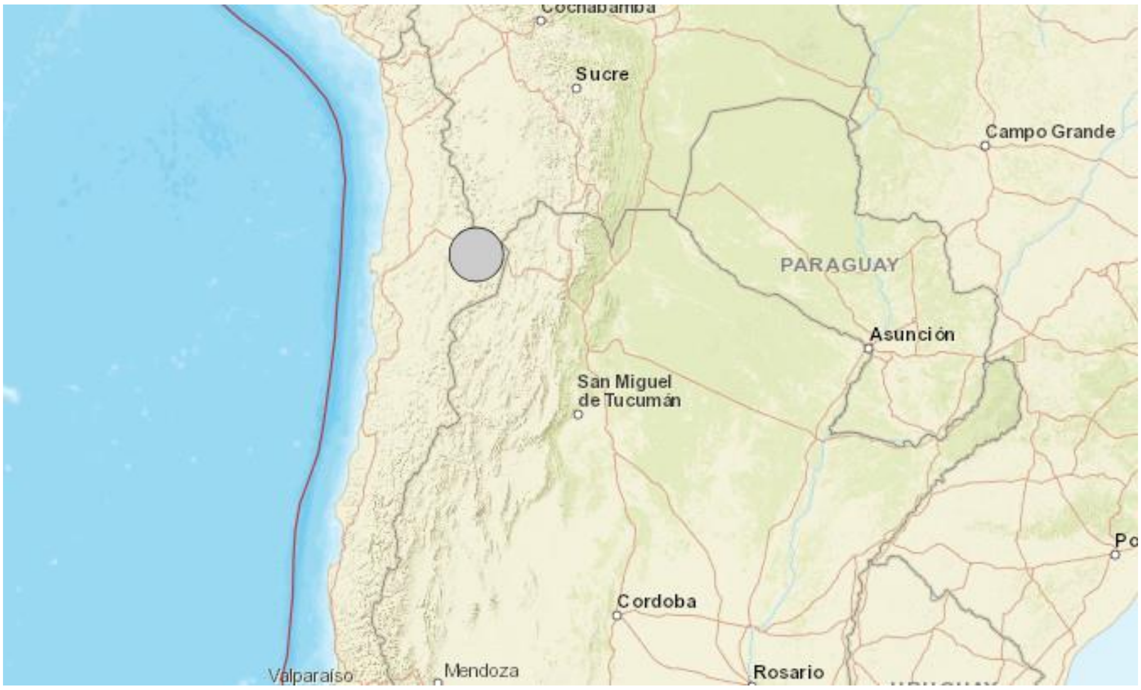


*Figure 1: **7.4 richer scale earthquake at Atacama's desert, Chile.***

On the local news, the earthquake was registered as: "***Large Earthquake Rocks Northern Chile"***, with no reports of damage or injuries from this episode.

Radar Image Acquisition:

The Sentinel-1 SLC images were acquired from the Copernicus Browser. An area of interest was delimited over the region of the earthquake. The first image was chosen before the earthquake on July 7, and the second image, after the earthquake, on July 30, to measure the displacement of the land due to the earthquake. The images acquired have the exact same window extension. The image below shows the region of interest, which is the earthquake epicentre, and the tiles of the Sentinel-1 images that were chosen for the analysis.

Figure 2: Area of interest and the image scene.

A quick look of the image in the *SNAP* shows the following:

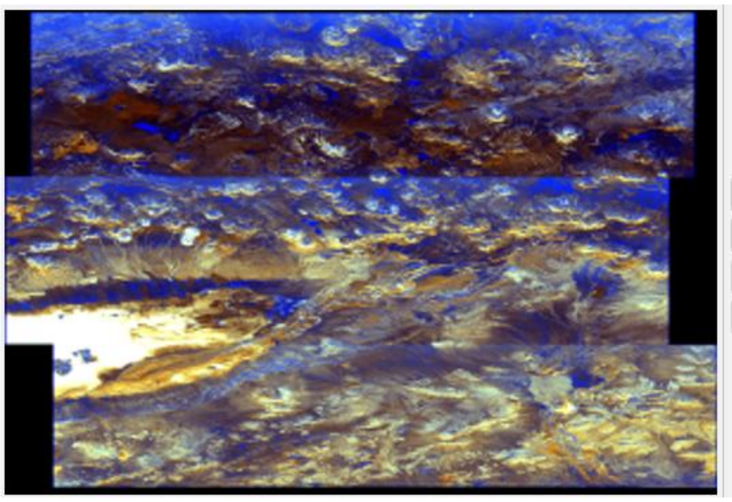


Figure 2: Quick look of the image.

Image Processing

Data Preparation.

- *Split*

S-1 TOPS Split was applied to the data to select only those bursts which are required for the analysis. Split is the first processing step in the TOPS InSAR processing chain. The image below show the sub swath choice due the comparison made at the exact location of the earthquake.

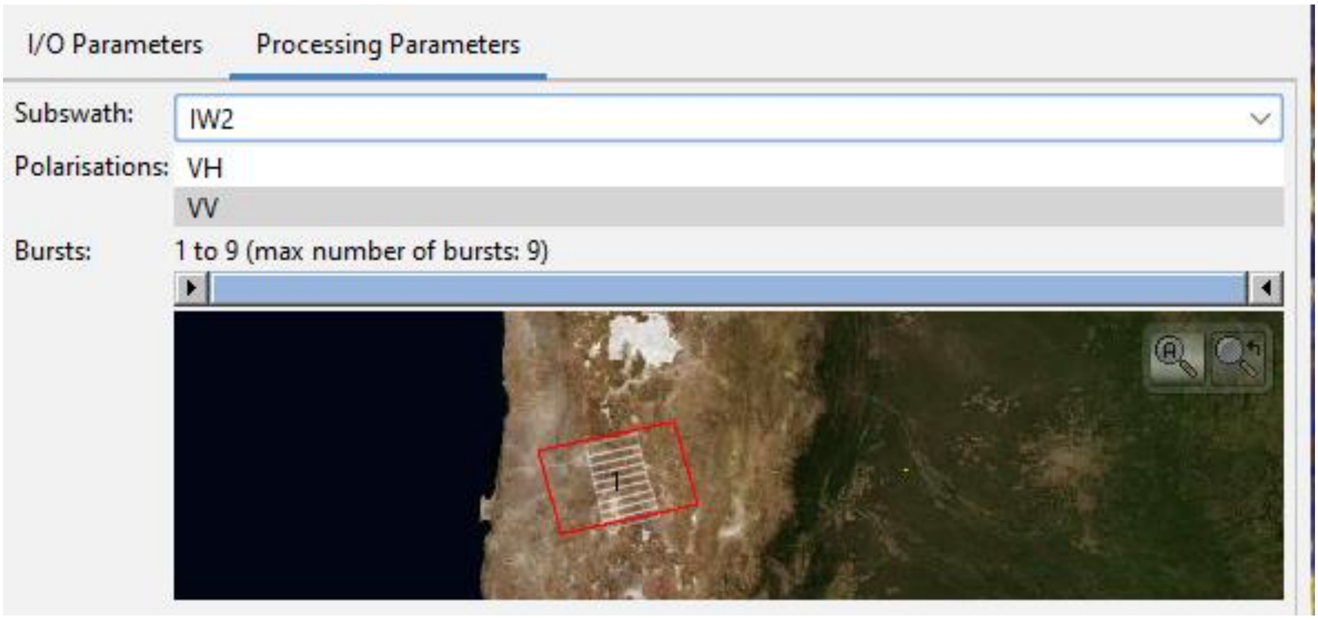


Figure 3- The burst chosen it.

- *Orbit-File:*

Orbit auxiliary data contain information about the position of the satellite during the acquisition of SAR data. They were automatically downloaded for Sentinel-1 products by SNAP and added to its metadata with the Apply Orbit File.

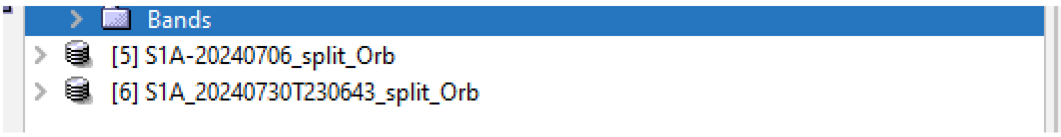


Figure 4- Orbit-file correction applied for the image.

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

- *Corregistration:*

To exploit the phase difference of the acquisitions, a stack containing both products must be created first. Applying *S1 TOPS Back Geocoding*, which makes the superposition of both images by georeferencing them. Now the bands are stacked and saved into the same SNAP product.

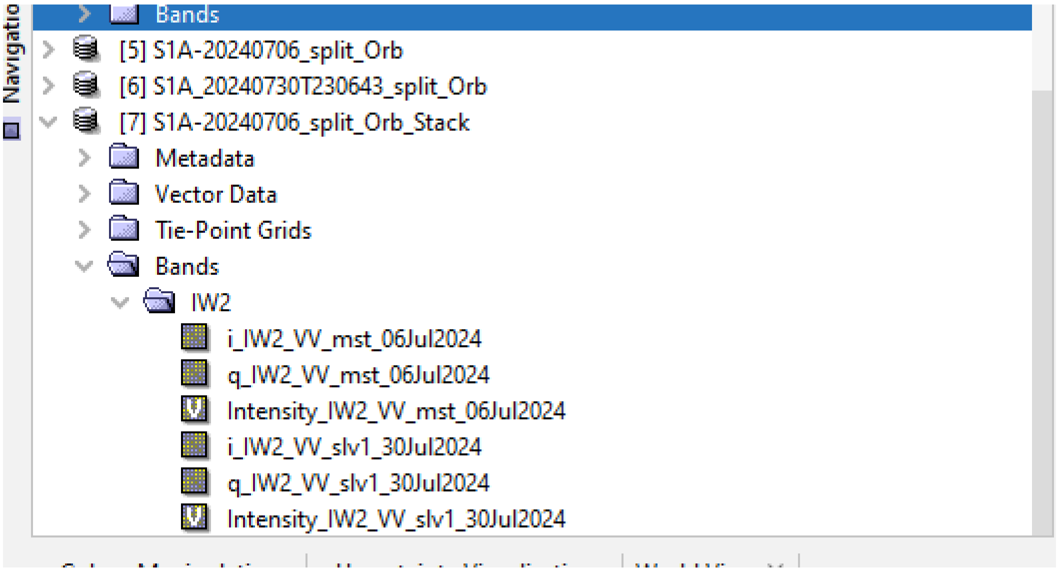


Figure 5- Coregistration applied.

- *Enhanced Spectral Diversity*

The coherence between the reference and the secondary image is estimated as an indicator for the quality of the phase information.

- *Interferogram:*

An interferogram is formed by cross multiplying the reference image with the complex conjugate of the secondary image (ESA, 2007). The amplitude of both images is multiplied while the phase represents the phase difference between the two images.

The interferogram was computed with subtraction of flat-earth (reference) phase. The flat earth phase is the phase present in the interferometric signal due to the curvature of the reference surface. And the topographic phase is removed using a DEM with 1 arcs. The following image represents the Interferogram in the phase band:

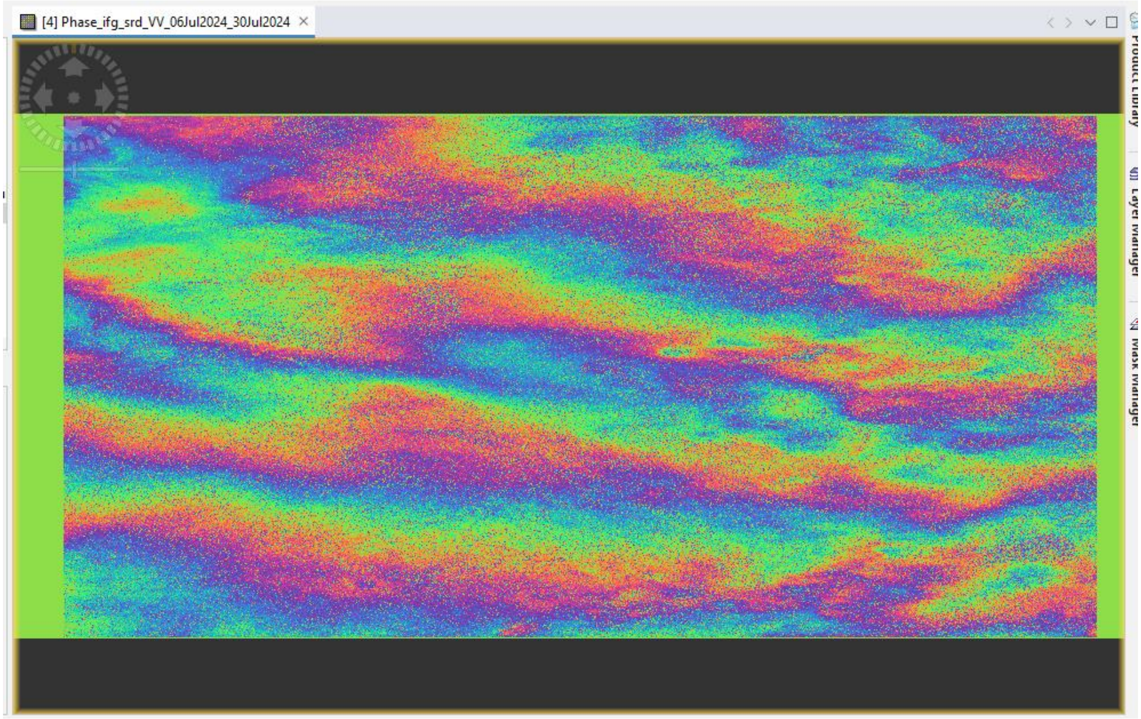
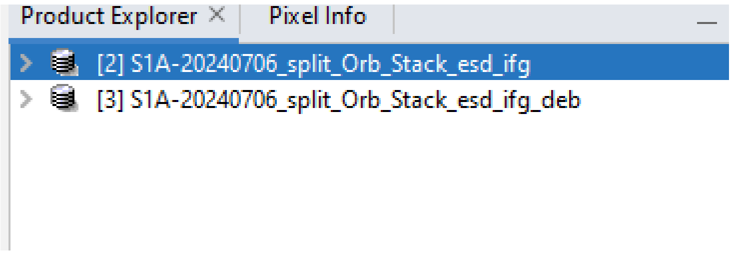


Figure 6 – Interferogram in the phase band.

The phase band of the interferogram shows the fringes for the whole image, the fringes correspond to the topographic and the displacement. The phase band does not show a high noise.

- *Deburst*

The deburst was used to remove the burst boundaries of the sub swath. The application can be visualized here:



- *Topographic Phase Removal.*

Topographic removal was applied in order to generate the differential interferogram. The input parameter is the result from the deburst. The phase band of the topographic removal can be seen below:

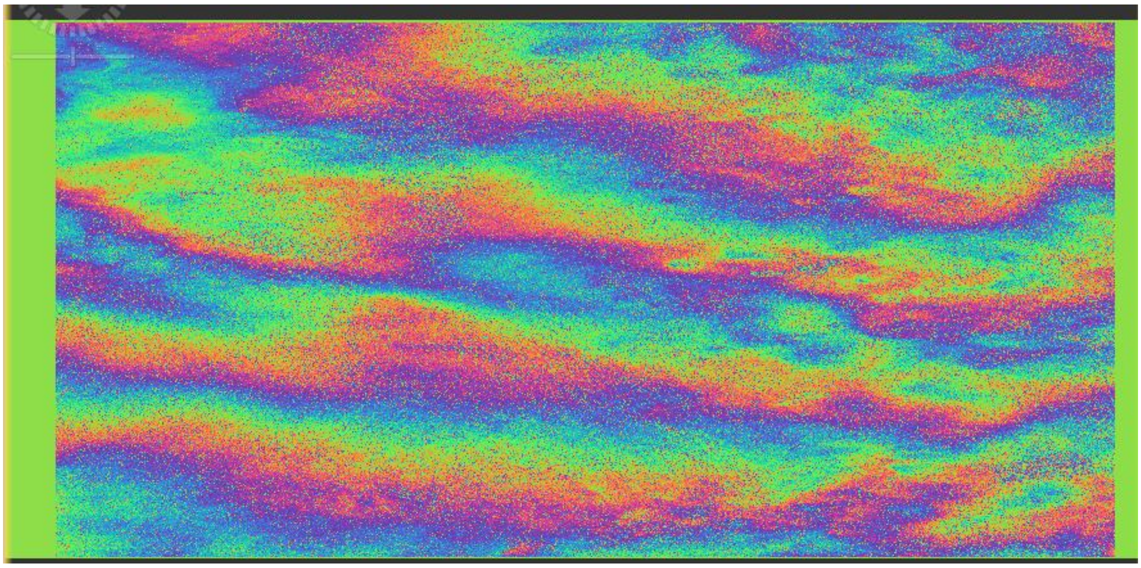


Figure 7- Phase band after topographical removal.

- ### *Multilooking*

The multilooking parameters were chosen based on the range of looks and the azimuth, generating a mean square pixel approximately of 28 meters. The image below shows the parameters:

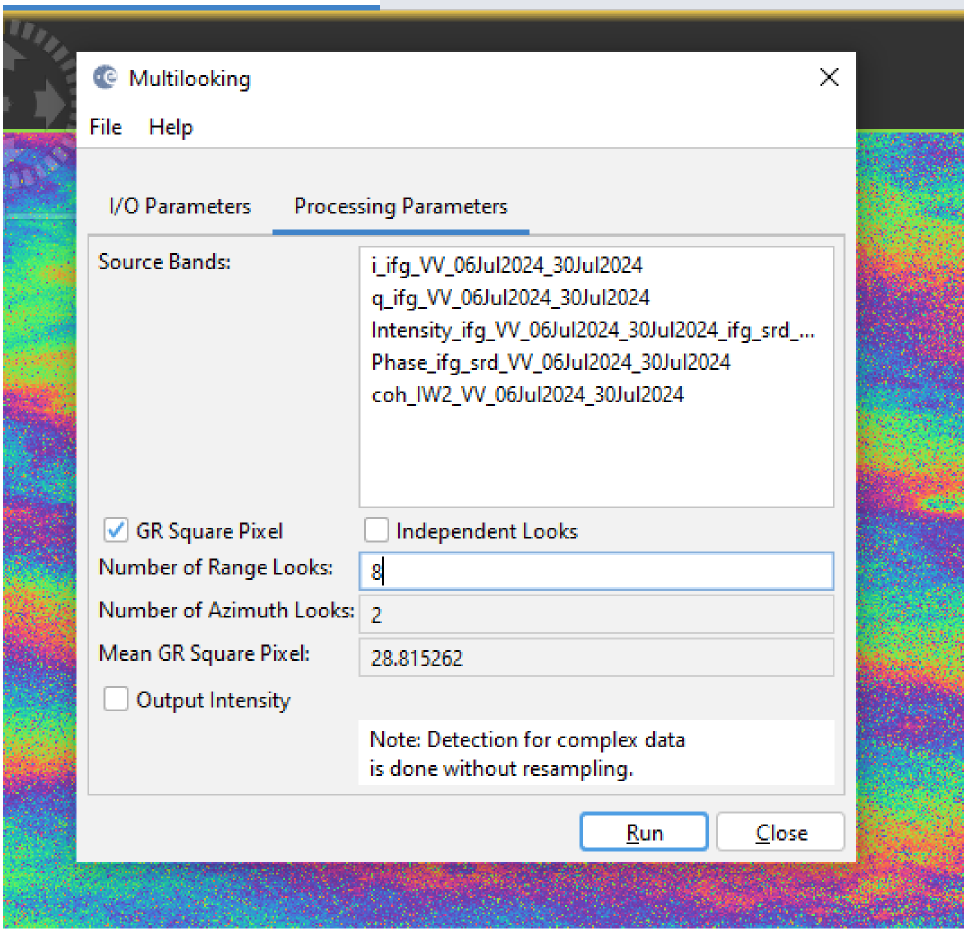


Figure 8- Multilooking parameters.

- *Goldstein Phase Filtering.*

With no alteration in the standards parameters, the following images show the Goldstein phase filtering in the phase band. It is very remarkable how the filters have smoothed the fringes. So our differential interferogram is finally filtered and the phase discontinuous.

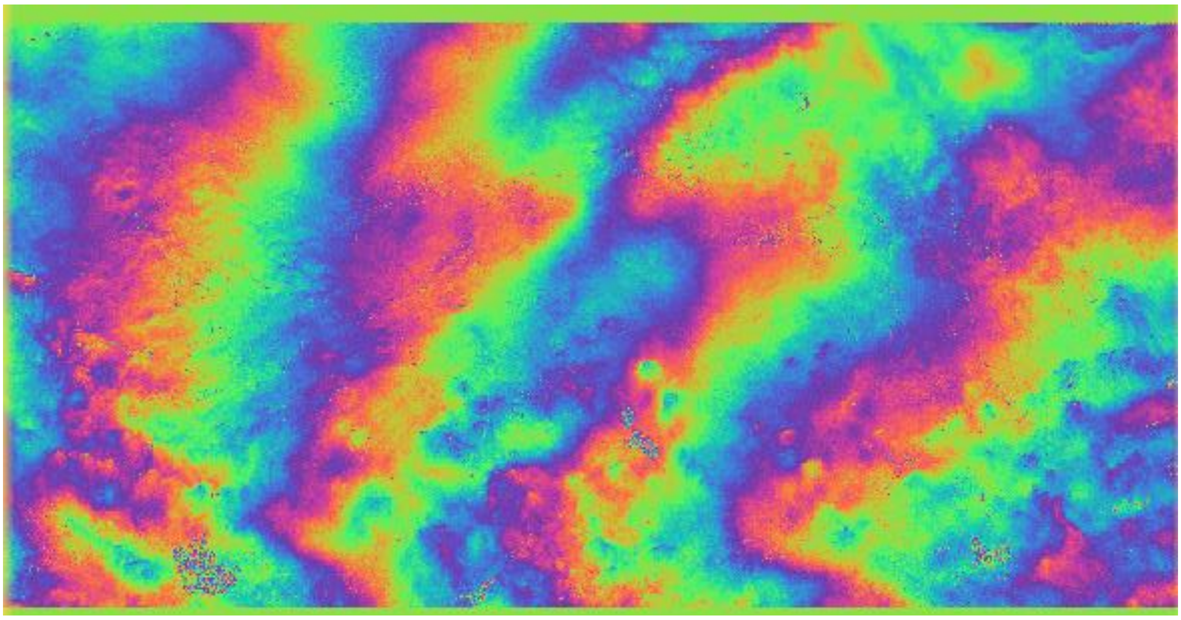


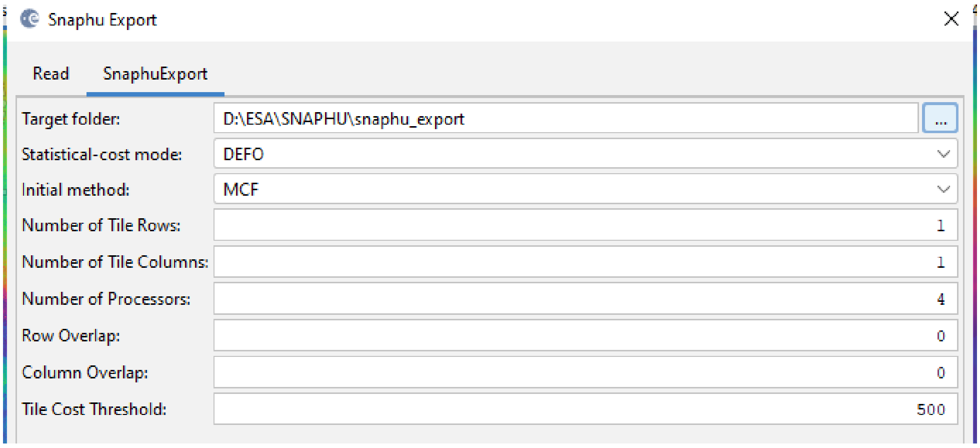
Figure 9- Goldstein filtering in the phase band.

- *Unwrapping Interferogram phase band*

In the interferogram, the interferometric phase is ambiguous and only known within the scale of 2π. To be able to relate the interferometric phase to the topographic height, the phase must first be unwrapped. The altitude of ambiguity is defined as the altitude difference that generates an interferometric phase change of 2π after interferogram flattening. Phase unwrapping solves this ambiguity by integrating phase difference between neighbouring pixels.

- *SNAPHU Export*

Using the SNAPHU Export and changing the parameters, the image below represents the parameters changes.



After the export, it is possible to see a document created with the documentation of the SNAPHU. It is important to make a few alterations in the file, so a few lines should be commented.

The LOGFILE line is commented, and the SNAPHU command line is copy : “snaphu -f snaphu.conf Phase_ifg_VV_06Jul2024_30Jul2024.snaphu.img 3244”.

For the SNAPHU Plugin to work, it is necessary to download the plugin. I downloaded the SNAPHU plugin, added it to the SNAP folder with a subfolder called SNAPHU, and also added the path to my local variables.

Opening a git bash, it is possible to add the files into the snaphu, where 26 parameters were added on to it. The SNAPHU output of the git bash took 30 minutes to process all the files.

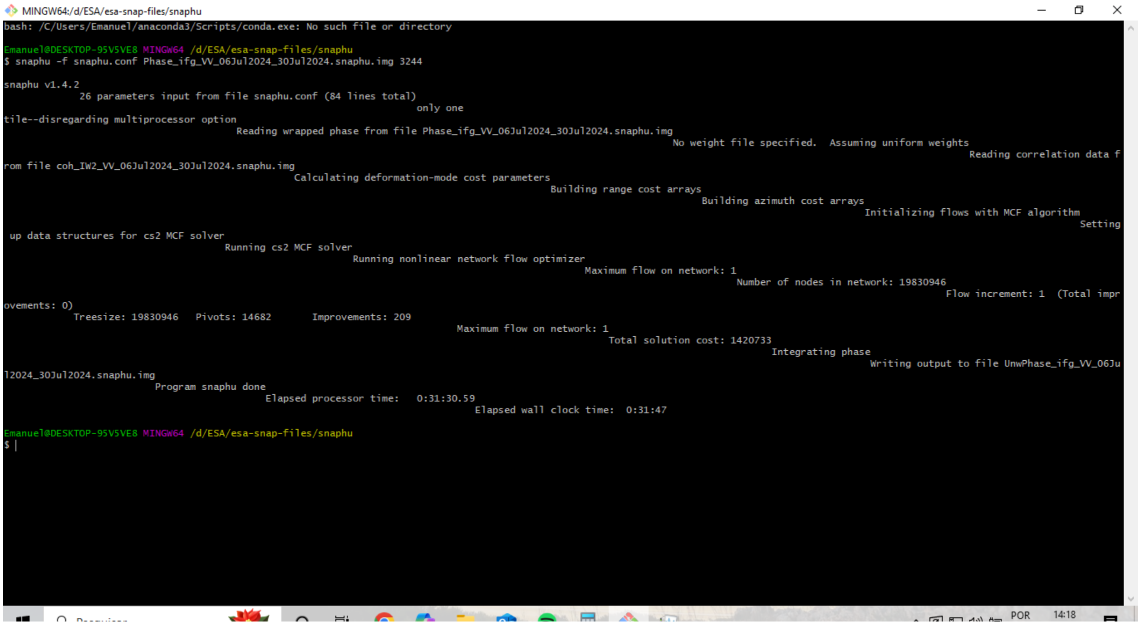


Figure 10- Gitbash SNAPHU processing.

- *Import SNAPHU*

. The Snaphu import (under Radar > Interferometric > Unwrapping) converts it back into the BEAM DIMAP format and adds the required metadata from the wrapped phase product as they have the same geometry.

After importing the unphased image, the result is followed below:

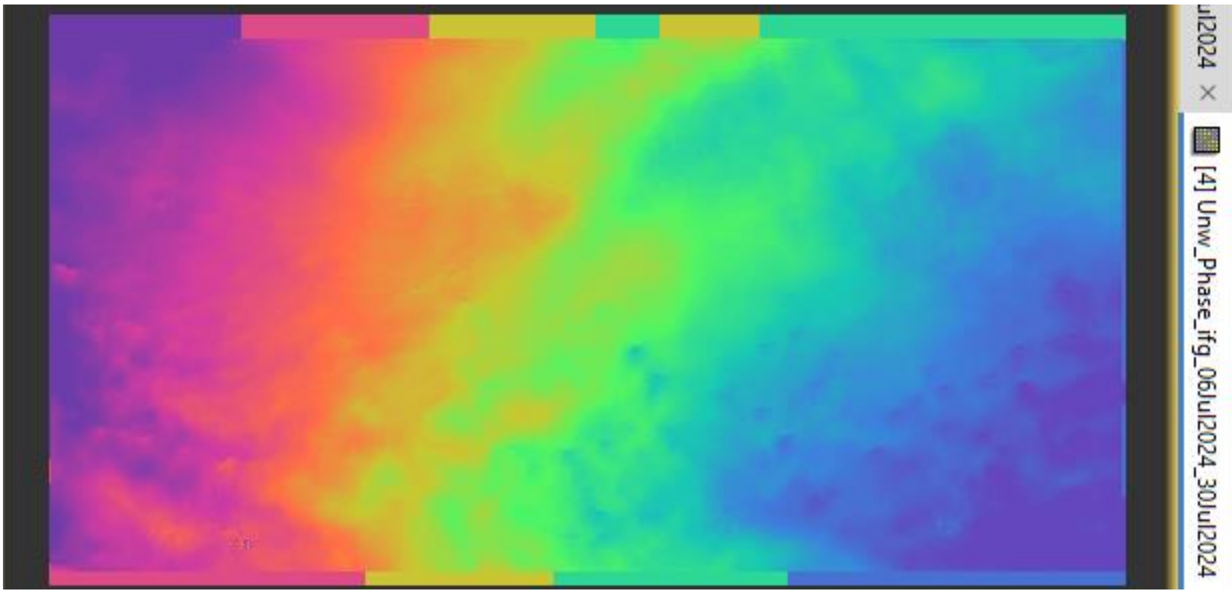


Figure 11- Unphased image processed by SNAPHU

- *Phase to Displacement.*

The unwrapped phase is now a continuous raster but not yet a metric measure. To convert the radian units into absolute displacements, the Phase to Displacement operator (under Radar > Interferometric > Products) is applied.

It translates the phase into surface changes along the line-of-sight (LOS) in meters. The LOS is the line between the sensor and a pixel. Accordingly, positive values mean uplift and negative values mean subsidence of the surface.

The Phase to Displacement operator has no parameters and is applied to the unwrapped phase which was imported in the last step. It produces an output which looks similar to the unwrapped phase (slightly different predefined color ramp), but now each pixel has a metric value indicating its displacement.

Histogram of the unwrapped phase from the displacement:

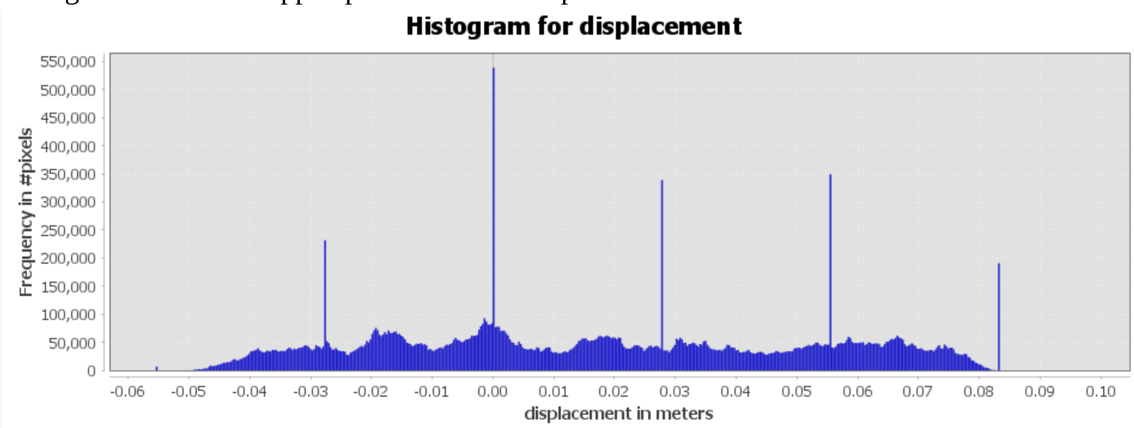


Figure 12- Histogram of the displacement

- *Range-Doppler Terrain Correction*

Terrain Correction will geocode the image by correcting SAR geometric distortions using a Digital Elevation Model (DEM) of 1 arc-sec and producing a map-projected product. Geocoding converts an image from slant range or ground range geometry into a map coordinate system. Terrain geocoding involves using a DEM to correct for inherent geometric distortions.

The image after applied Terrain Correction is shown below:

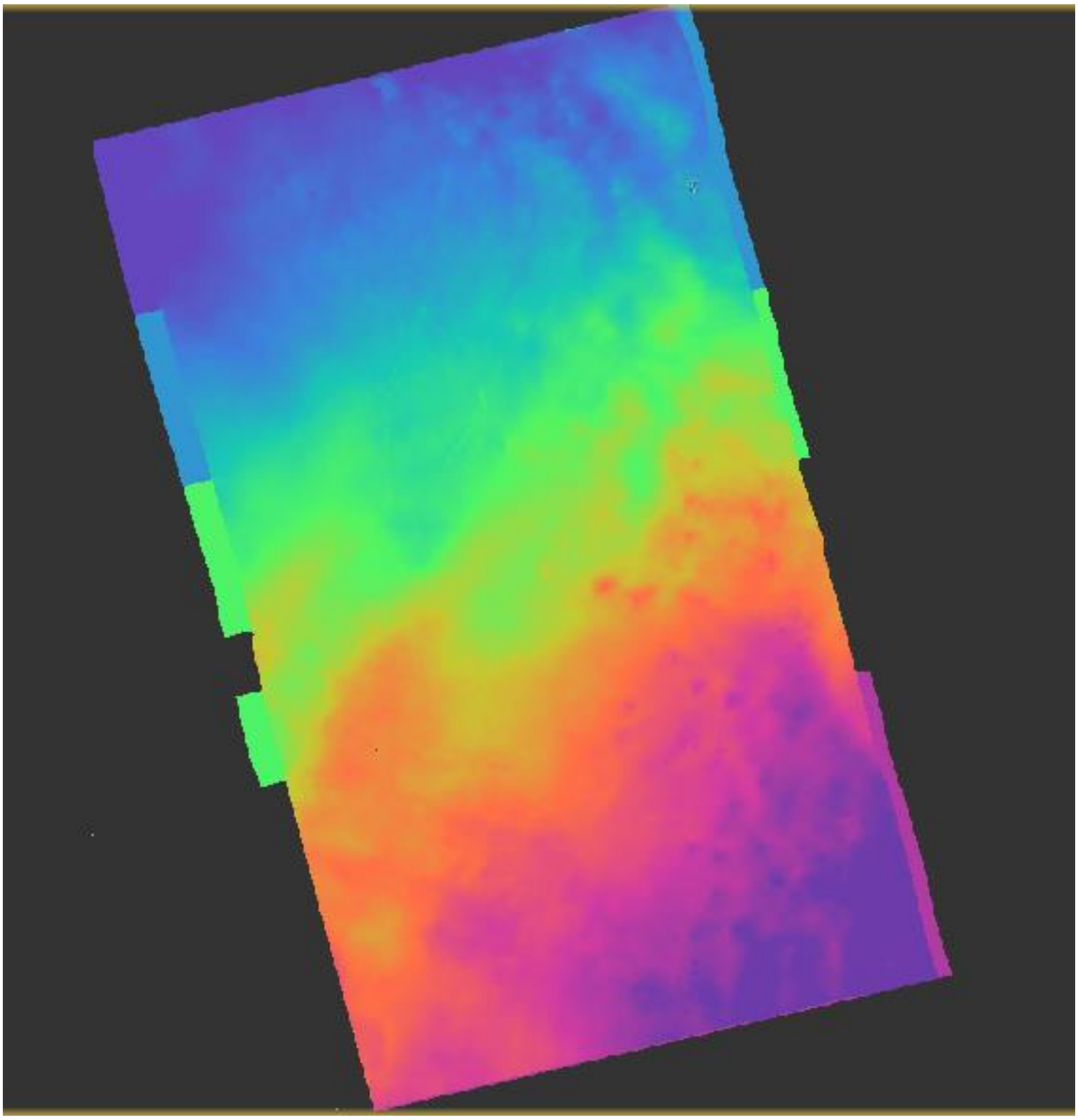


Figure 13 - Displacement image after terrain correction.

Displacement Analysis.

The image below shows the displacement histogram for the Sentinel-1 SLC image processed with SNAP tools.

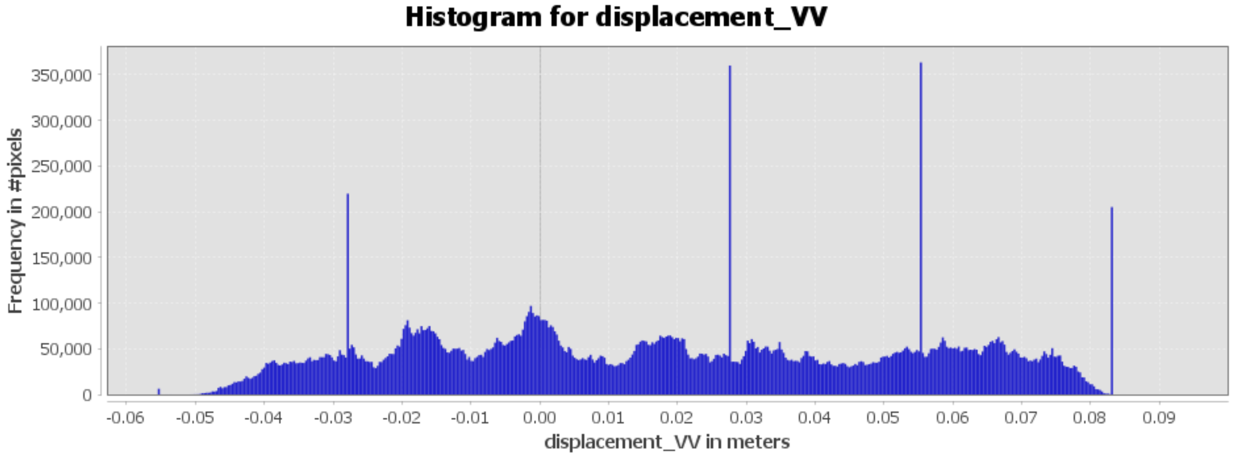


Figure 14 Histogram for displacement.

The range of displacement is between 6 centimeters and 8 centimeters.

The Statistics provided by SNAP tool, show the displacement:

displacement_VV

#Pixels total:	20727057
Minimum:	-0.0555
Maximum:	0.0925
Mean:	0.0182
Sigma:	0.0345
Median:	0.0171
Coef Variat...	1.8985
ENL:	0.7678
P75 thresh...	0.0497
P80 thresh...	0.0552
P85 thresh...	0.0601
P90 thresh...	0.0662
Max error:	2.8893E-4

Figure 15 – Statistics of the displacement.

Based on the statistics, the maximum displacement was 9 centimeters up, and the minimum was 5 centimeters down. Even though the earthquake was very deep and the depth influences on the surface measured displacement, due to the magnitude of the earthquake (7.5), it was possible to verify a displacement.

Using the profile tool, it is possible to understand how the displacement is distributed over the image acquired. The profile was drawn with a line that is diagonal and goes end-to-end in the image.

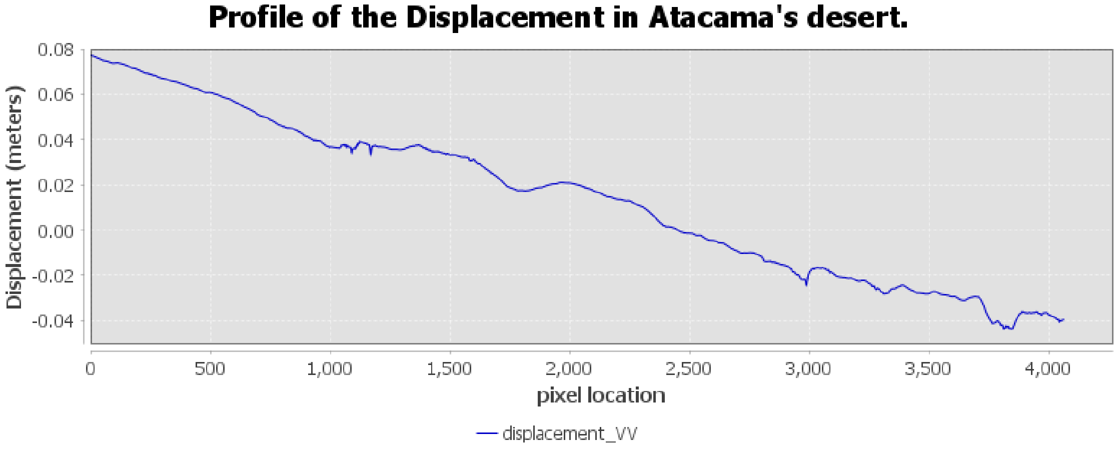


Figure 16 - Profile displacement of the image

Based on the profile displacement, and due to the line that tailor the profile was drawn diagonally north to south, the displacement registered was on the up direction in the north and down the south a downgrading of the surface area was perceived with a maximum of 4 centimeters.