Advanced Remote Sensing

1. Overview of the study data

Understanding and monitoring geohazards is crucial for reducing the risks to human life and infrastructure. Sentinel-1 SAR data is an excellent tool for detecting ground displacement over wide areas with high temporal and spatial resolution. The main goal of this assignment is to generate a displacement map using SAR data, processed in ESA's SNAP software.

The study area will be La Palma, Canary Islands, where the Cumbre Vieja volcano erupted from September 19 to December 13, 2021. This event was one of the most significant eruptions in recent European history, displacing thousands of residents and causing extensive ground deformation, lava flows, and property damage. It provides a compelling case for analyzing volcanic deformation patterns and highlights the value of InSAR technology for geohazard monitoring.

Mapping pre- and post-eruption deformation will be conducted using Sentinel-1 SAR images. The proposed dates are as follows:

- **Before the eruption**: September 5 to September 15, 2021
- **After the eruption**: December 14 to December 24, 2021

These dates were selected to capture changes before and after the eruption. The analysis will focus on the region surrounding the volcano, approximately located at 28.573° N, -17.840° W. The SAR data was downloaded over the ASF Data Search Vertex website, using the settings described above. The images below show the settings for the downloaded images.

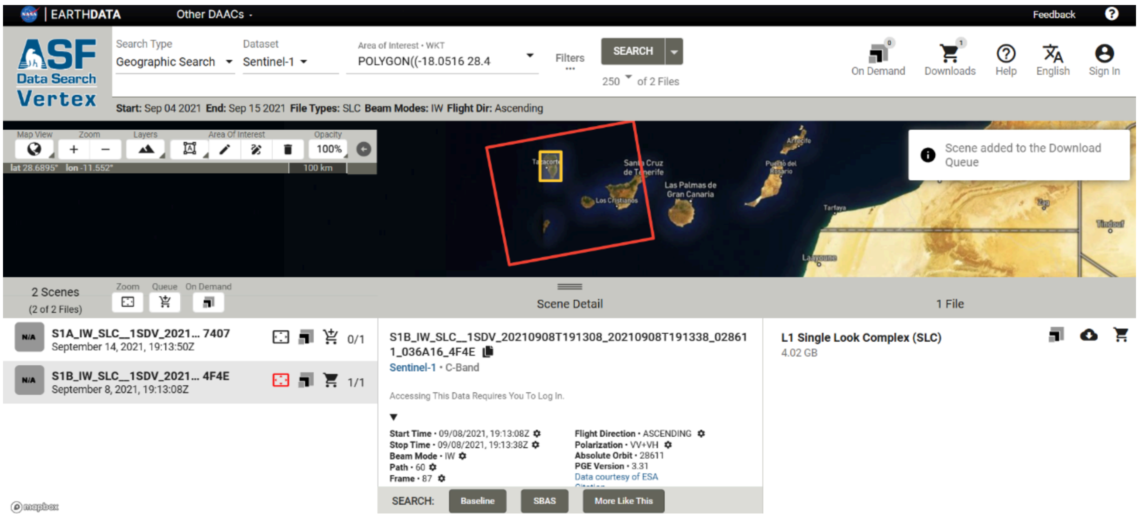
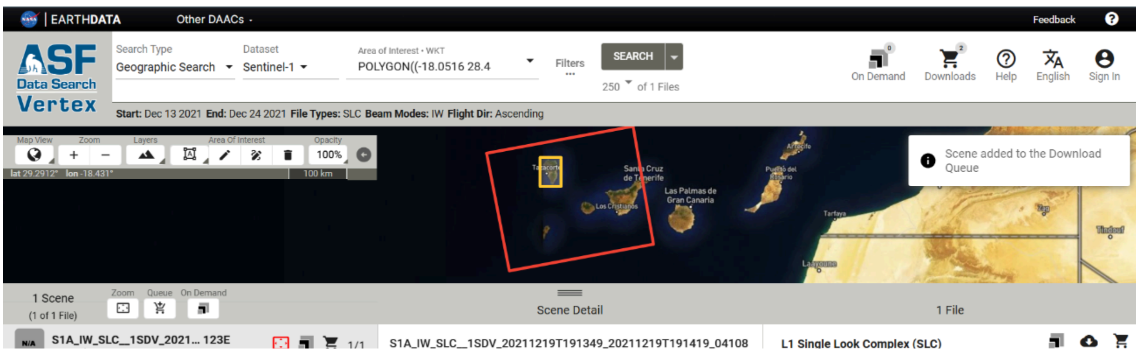


Image 1 – Settings for the SAR data concerning the dates before the eruption.



2. Importing the data into SNAP

The downloaded data should be imported into SNAP software without unzipping it. Before any processing, the original radar images are essentially meaningless, impossible to interpret, just like seen on image 3. This is why we must perform certain processing methods over the images in order to create the final displacement map.

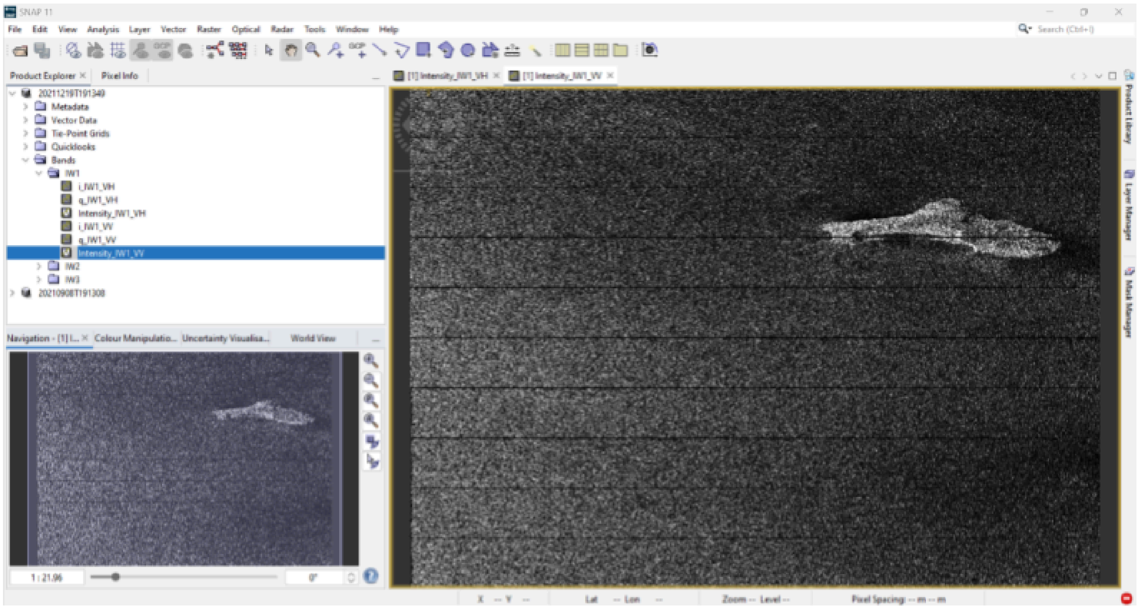


Image 3 – Visualization of the image after the eruption.

3. Split the data

To improve performance, we should crop the data, to run the analysis just in the area of interest. We will use the S-1 TOPS Split tool (Radar > Sentinel-1 TOPS > S-1 TOPS Split) and select the desired, as seen in image 4. Choosing the polarization is important (in this case, we chose VV) but also the sub swath (we chose IW2 to match our study area) and the burst, which looking closely to the image, are the black horizontal lines dividing it. Since we chose to reduce the burst to just 6 (we didn't need more considering the study area), the created images have less horizontal lines than the original imported one, as seen on image 5. This procedure should be done for both images. After that, the original images can be removed from the software, they are no longer needed.

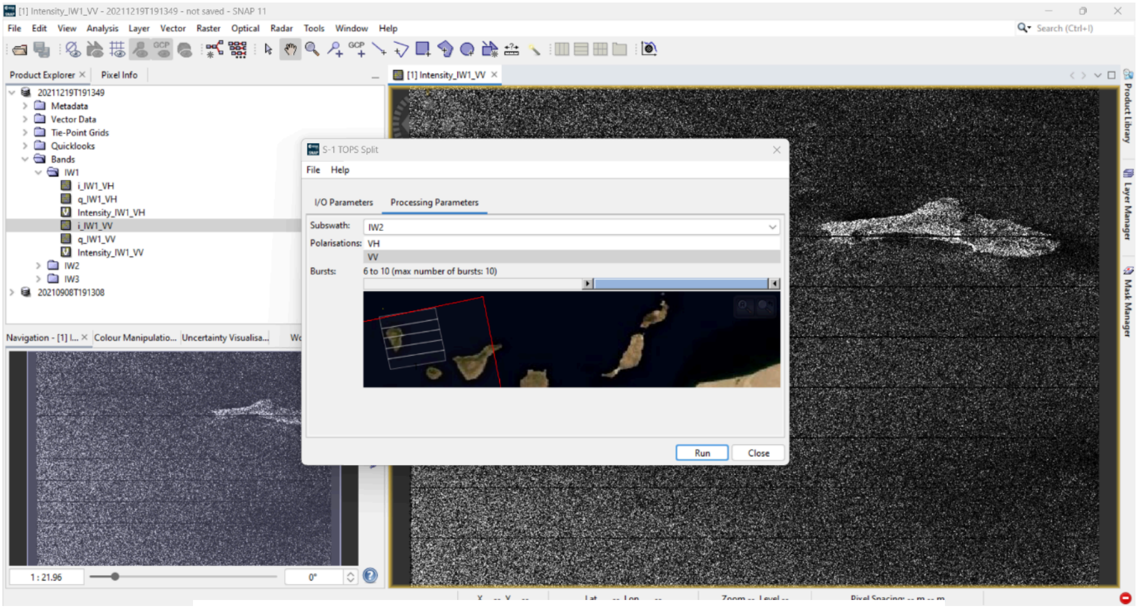


Image 4 – Spliting the data.

Image 5 – Less burst lines after reducing them.

4. Apply orbit correction

The next step is to correct satellite positioning errors, using the Apply Orbit File tool (Radar > Apply Orbit File). The saving directory is by default the last one used and we chose only to check the box "Do not fail if a new orbit file is not found", just like seen in image 6. This is because the orbit files are being automatically downloaded from the platform and, in case there is an internet connection failure or there is no file to download, an error message will not appear. This procedure should be done for both images.

When we open the new processed images, we will not see any differences in comparison with the previous ones. This happens because the calibration was applied at a pixel level, concerning its radiometry, we can't see any differences.

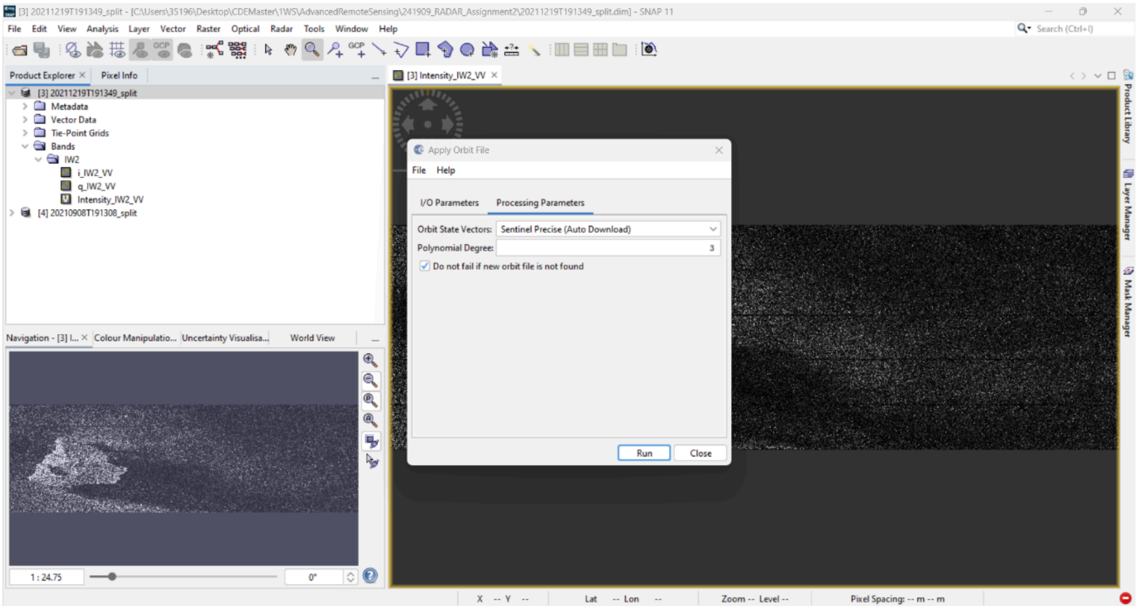


Image 6 – Applying orbit files to images.

5. Co-registration

To generate the interferogram we need to coregister the images, which means an image alignment. This is done using the S-1 Back-Geocoding tool (Radar > Coregistration > S-1 TOPS Coregistration > S-1 Back-Geocoding). The latest generated images are opened and, by default, the first image in the list is the master image and the second one is the slave one. For this exercise, the master image is the image taken before the eruption, as shown in image 7. All the

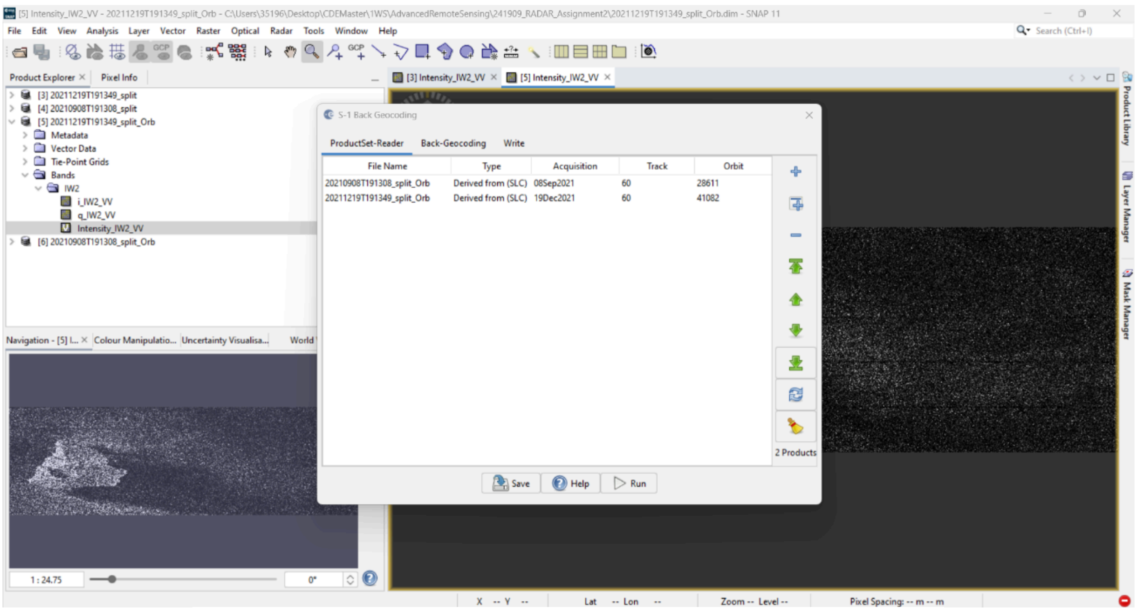


Image 7 – Master and slave image on S-1 Back-Geocoding tool.

necessary input settings are displayed in image 8. This processing method will merge the two images in one.

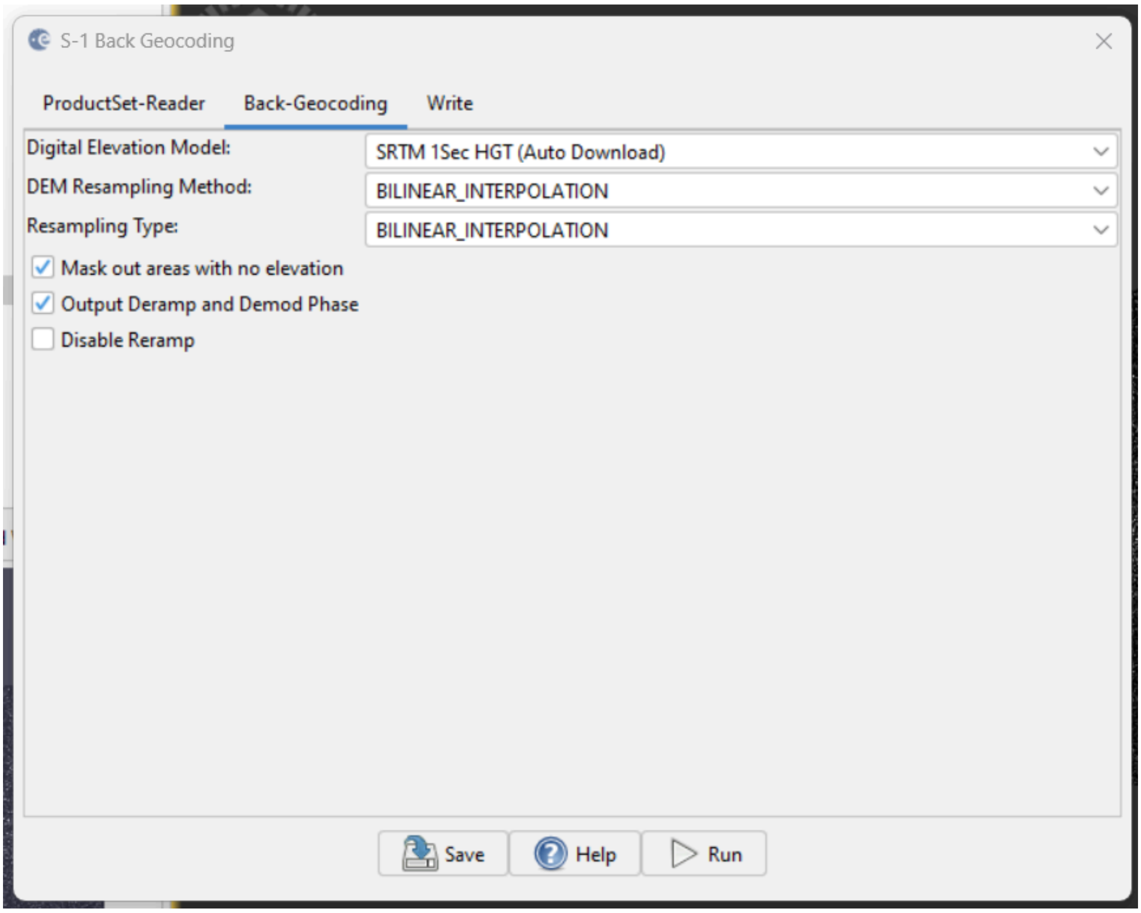


Image 8 – Input settings for S-1 Back Geocoding tool.

6. Second co-registration

We should perform a second co-registration method, which is optional but provides a finer registration compared to the initial rough registration. The first co-registration simply removes areas that are not common to both images. In contrast, this second method ensures that each pixel in the slave image precisely aligns with its corresponding pixel in the master image. To achieve this, we use the S-1 Enhanced Spectral Diversity tool (Radar > Coregistration > S1 TOPS Coregistration > S-1 Enhanced Spectral Diversity). The tool can be run with the default setting. However, it is important to note that no visible difference will be observed after running this tool.

7. Interferogram generation

Finally, we have gone through all the necessary steps to generate the interferogram. At this point, we will use the Interferogram Formation tool (Radar > Interferometric > Products > Interferogram Formation) using the settings shown on image 9. The interferogram, displayed as the phase image, can be seen in image 10. Additional images were also generated, including interferometric products with the real and imaginary parts, as well as the amplitude image.

Even though we already have the interferogram, it is still not enough for a good interpretation, considering it's hard to distinguish the different fringes, as seen on image 11.

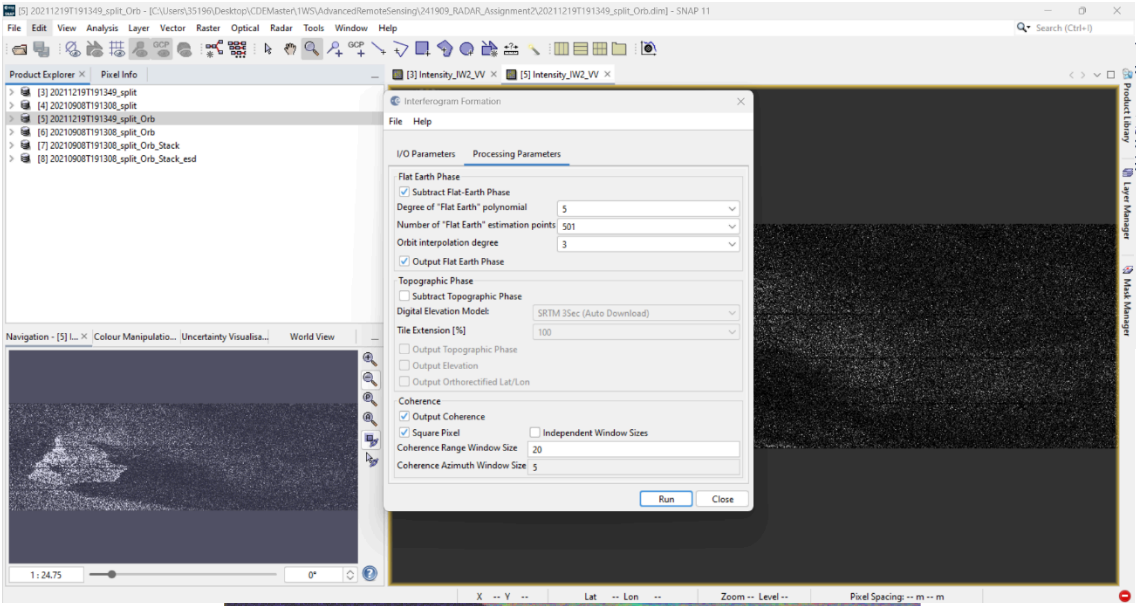


Image 9 – Interferogram Formation settings.

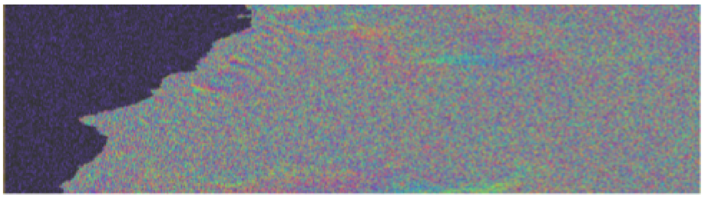
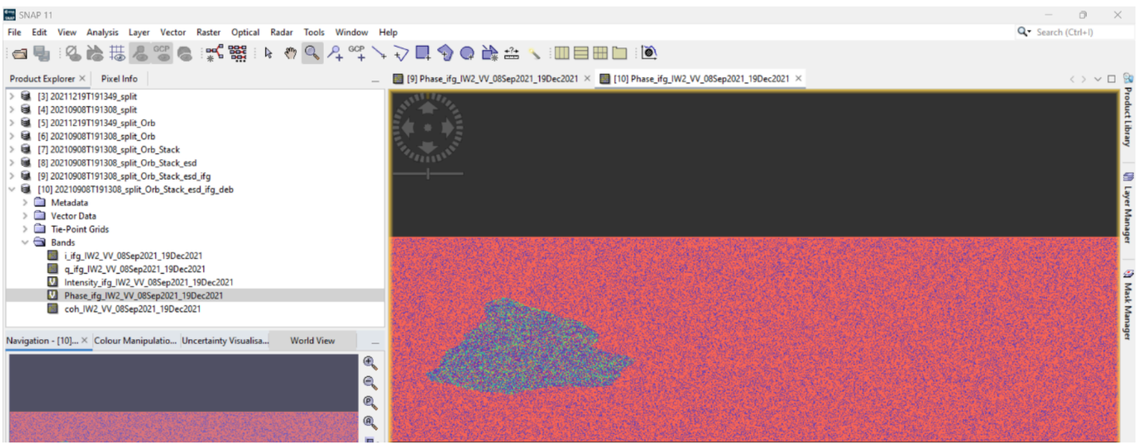


Image 11 – Detail of the interferogram created.

8. Remove the burst boundaries

Since burst boundaries make visualization more difficult, it is important to eliminate them. This can be done using the S-1 TOPS-Deburst tool (Radar > Sentinel-1 TOPS > S-1 TOPS-Deburst) with the default input settings. The result image, without the burst line, can be seen on image 12, as our topographic interferogram.



9. Topographical phase removal

In order to create a differential interferogram we need to eliminate the topographic effects out of the topographic interferogram. For doing this, we will use the Topographic Phase Removal tool (Radar > Interferometric > Products > Topographic Phase Removal) and we will "remove" the same digital elevation model specified on the previous steps. The correct input settings can be seen on image 13.

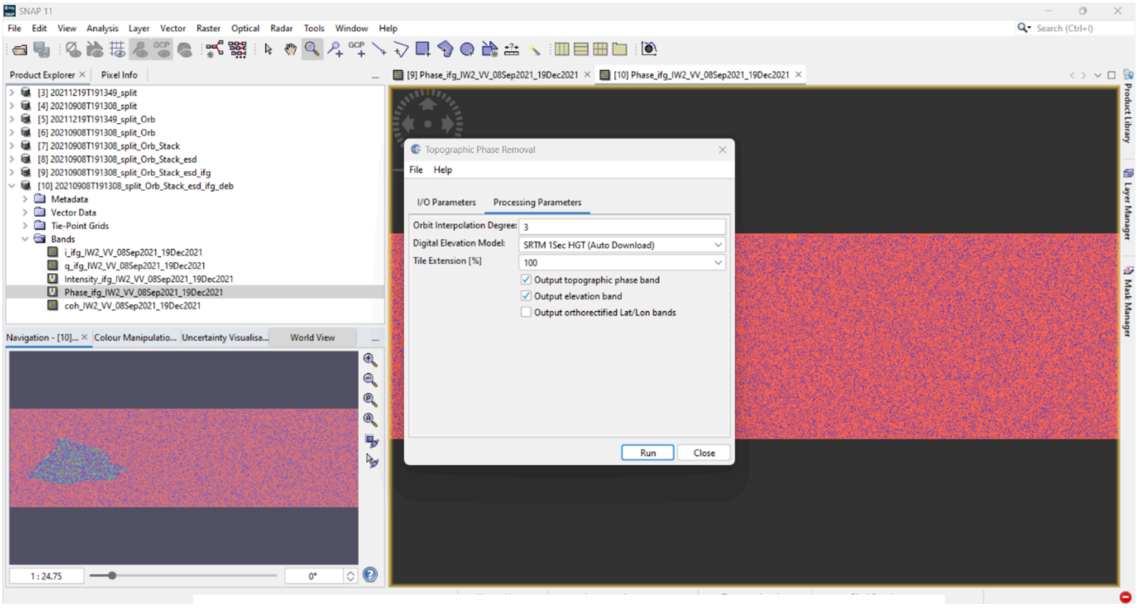


Image 13 – Topographic Phase Removal settings.

Some interestin the area, which is basically the DEM removed from the topographic interferogram. The differential interferogram can be seen on image 14.

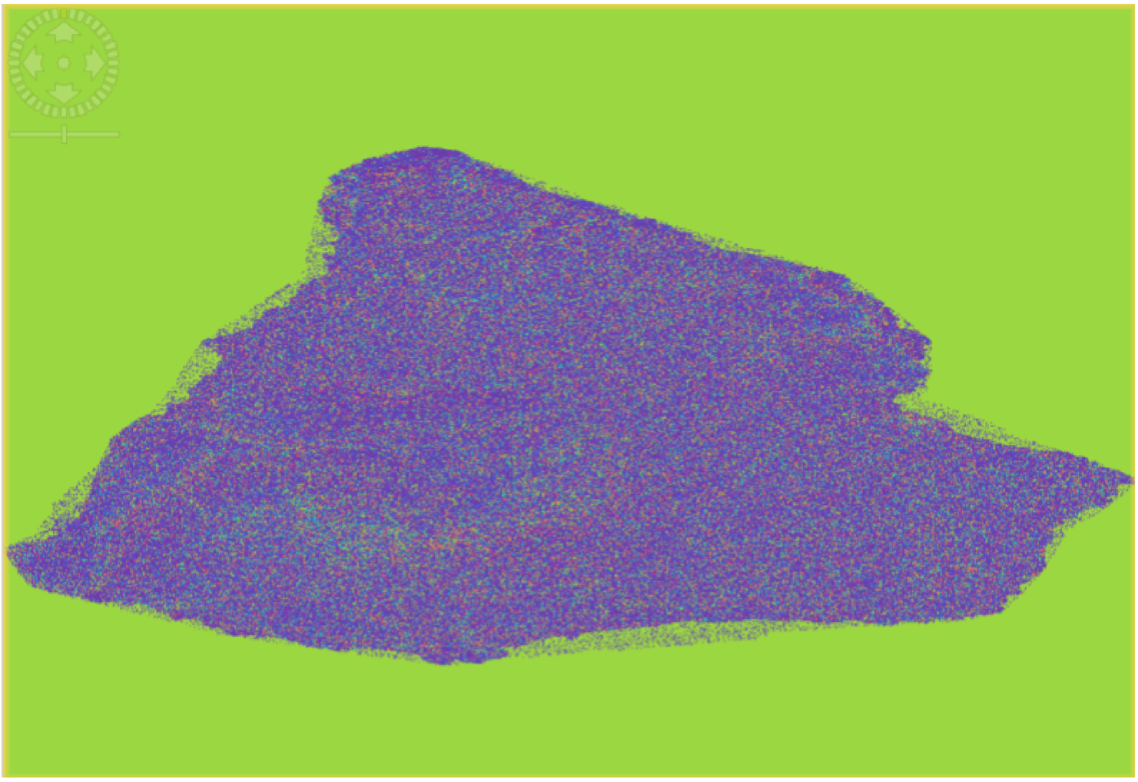


Image 14 – Differential interferogram.

10. Multilooking

Because the interferogram has different resolutions in each axis we need to perform an action to solve this problem. We will use the Multilooking tool (Radar > SAR Utilities > Multilooking) with the input settings as shown on image 15. After this step, the resulting image will have reduced noise, and the pixels will be resquared, enhancing the overall visual interpretability of the differential interferogram.

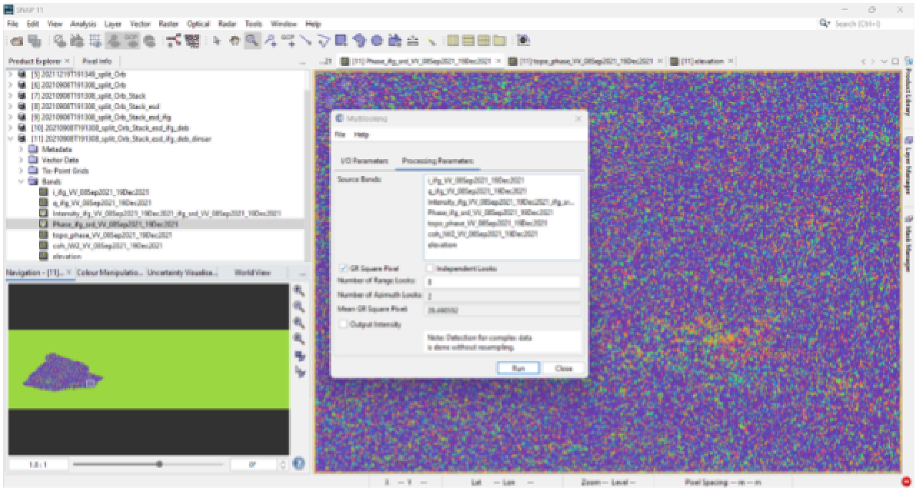


Image 15 – Multilooking input settings.

11. Goldstein Phase Filtering

We need to further reduce image noise and improve phase quality to ensure accurate unwrapping and displacement calculation. This is achieved using the Goldstein Phase Filtering tool (Radar > Interferometric > Filtering > Goldstein Phase Filtering), with the default input settings. The result of this operation is shown in image 16, where there is significantly less noise, and the fringes appear much clearer.

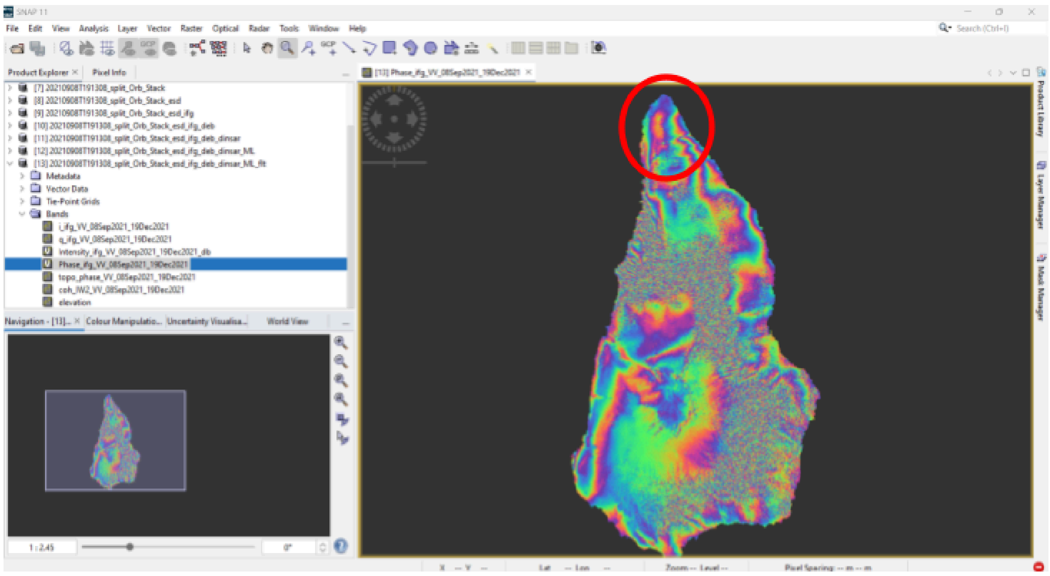


Image 16 - Displacement map after goldstein phase filtering and the volcano eruption highlighted

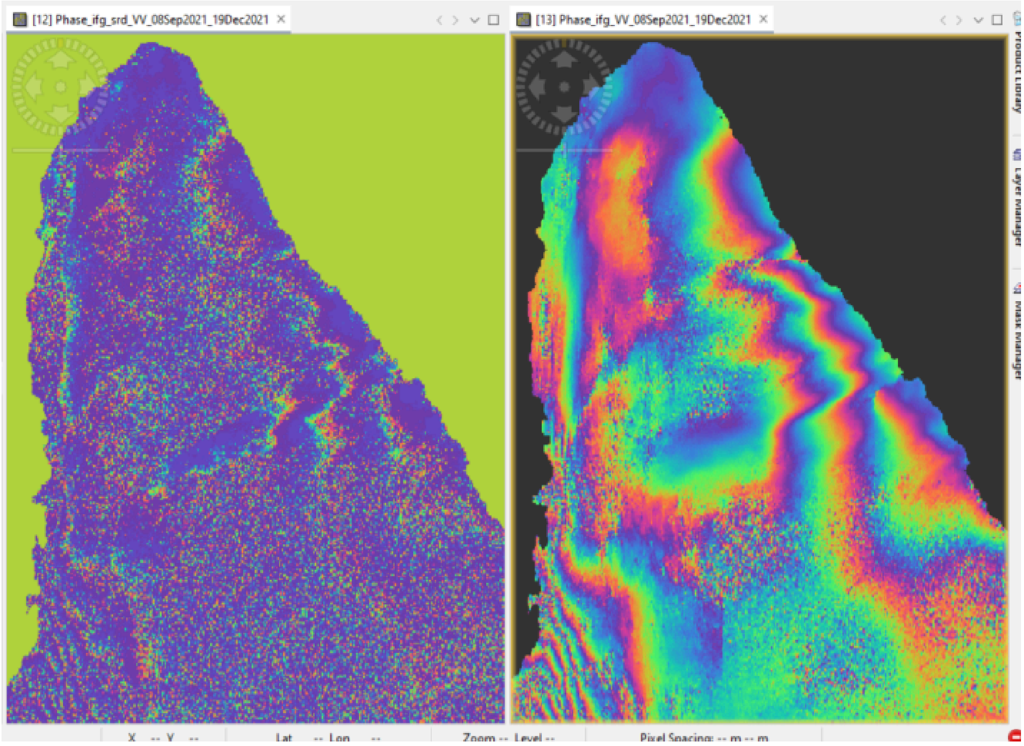


Image 17 - differences between pre and after goldstein phase filtering

12. SNAPHU plugin

At this point interferogram values vary between minus pi and pi and it is necessary to reconstruct the interferometric phase of the interferogram. In order to reconstruct it, we need to use the SNAPHU plugin (Radar > Interferometric > Phase Unwrapping > SNAPHU Export) and use the input settings as shown on image 18.

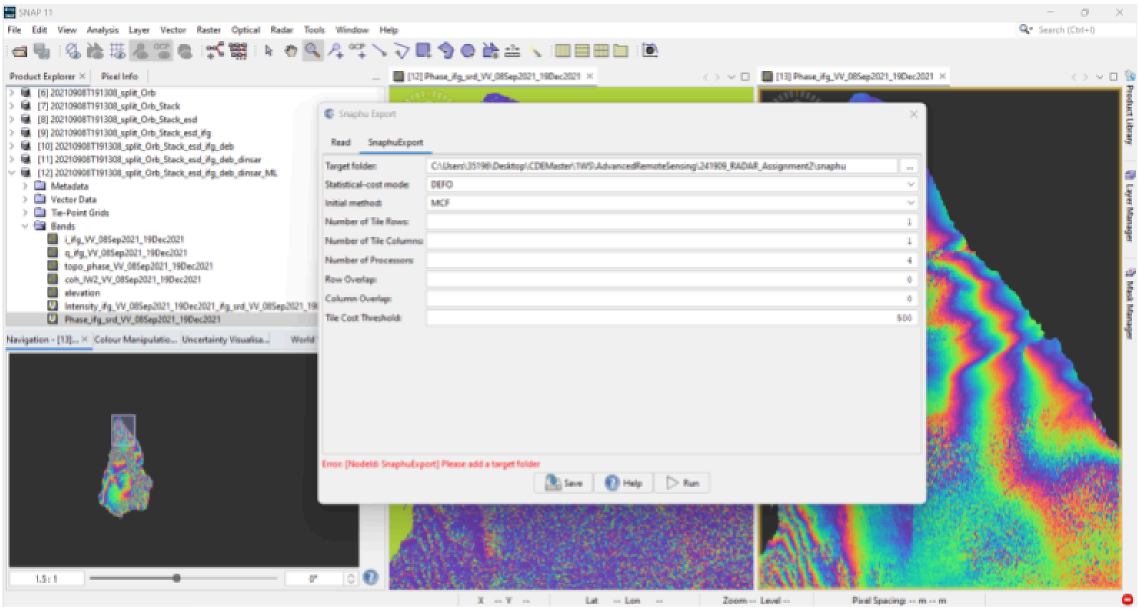


Image 18 - SNAPHU Export input setting

Once the exporting is done, we open the created document, comment the “LOGFILE snaphu.log” line and copy the following command line “snaphu -f snaphu.conf Phase_ifg_VV_08Sep2021_19Dec2021.snaphu.img 3062”. On the created folder we open a GIT Bash terminal, copy the command line and execute it. To succeed on this step it is important to already have installed the SNAPHU Unwrapping plugin. After the procedure is done, it should look like the message on the image 19.

After unwrapping the phase using the SNAPHU plugin, the data must be imported back into the SNAP software (Radar > Interferometric > Phase Unwrapping > SNAPHU Import). It is crucial to select the correct input file generated by the SNAPHU plugin and rename the output product to distinguish it from others. The resulting image is shown in image 20. Unlike the original phase values, which ranged from $-\pi$ to π, the unwrapped values now range from -0.108149 to 8.7706517.

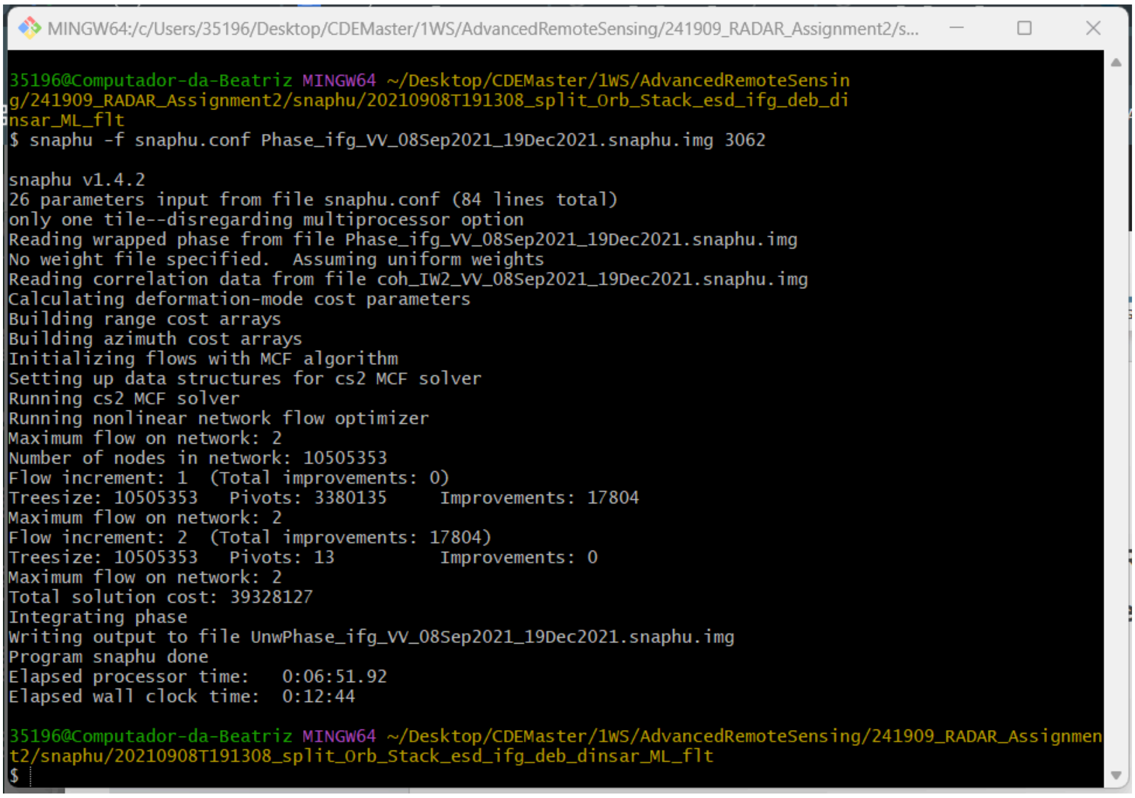


Image 19 - Result message after running SNAPHU

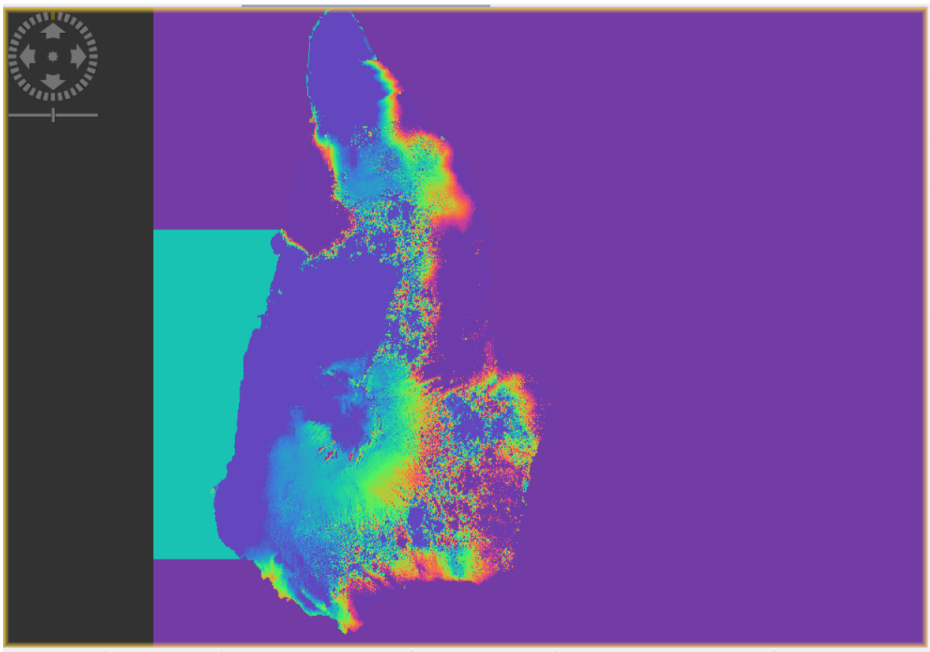


Image 20 - result image after unwrapping the phase

13. Displacement map generation

One of the final steps is to convert the unwrapped image to an actual displacement image, in order to enable the analysis of the ground movement. To perform this, we will use the Phase to Displacement tool (Radar > Interferometric > Products > Phase to Displacement). After running the tool we will get the final displacement map, as shown on image 21, representing a displacement that goes from -0.112 to 0.171 meters, meaning that we have ground movement with a range of around 0.28 meters.

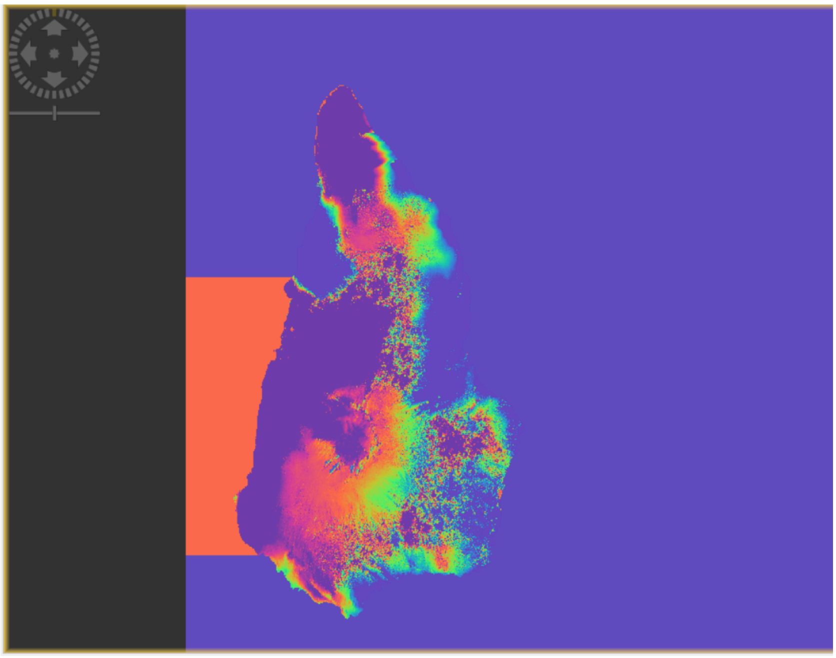


Image 21 - Final displacement map

13. Geo referencing the map

The final step in generating the displacement map is terrain correction, which aligns the map to a coordinate system and eliminates distortions caused by topography. This final procedure will ensure that the displacement map can be compared with other geo referenced images since it will be back in place with the original coordinates. For that, we will use the Range-Doppler Terrain Correction tool (Radar > Geometric > Terrain Correction > Range-Doppler Terrain Correction) with the input settings as seen on image 22.

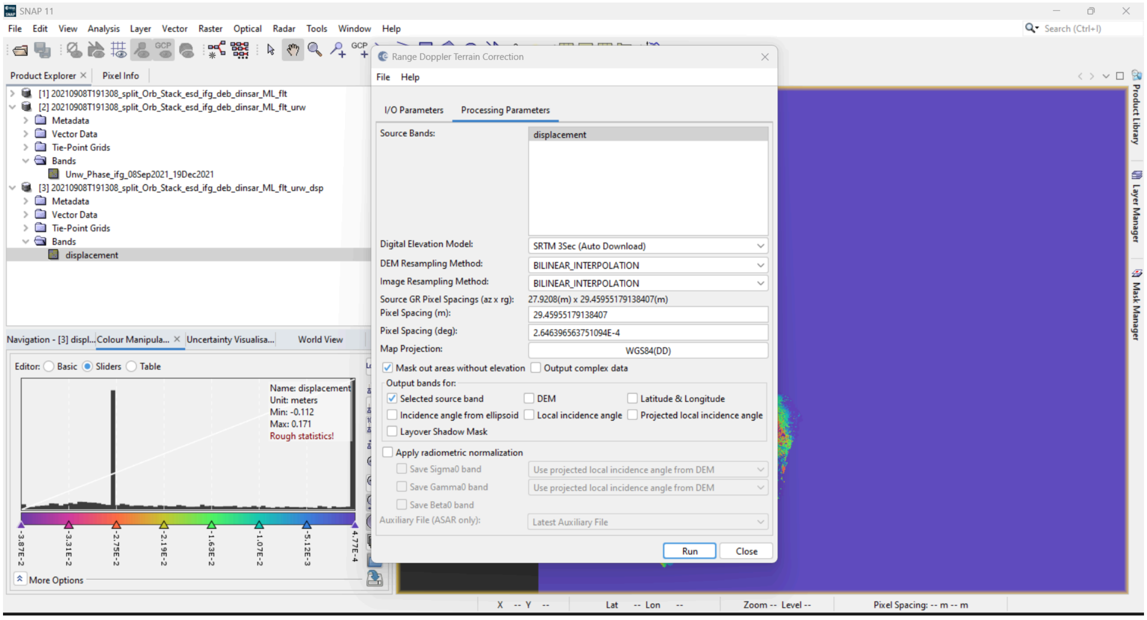


Image 22 - Input settings for Range-Doppler Terrain Correction tool

This last procedure not only changed the coordinate and referencing system but also the displacement range, which now is placed from a range of -0.106 to 0.159 meters. You can see the displacement map below.

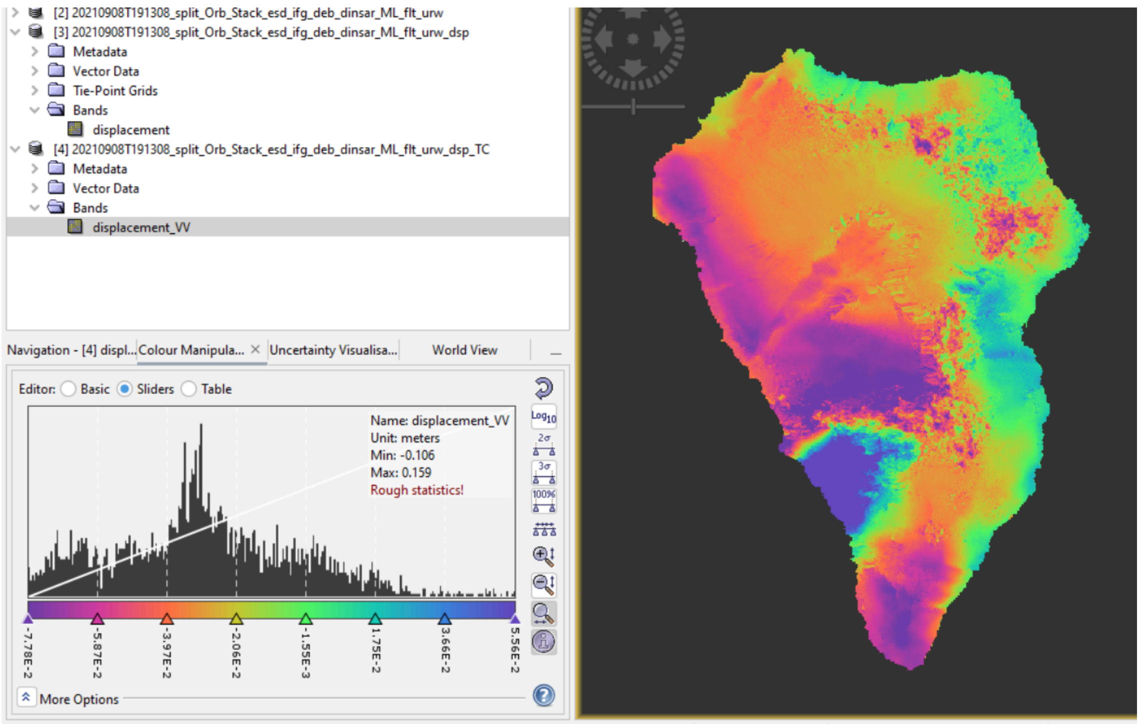


Image 23 - Final displacement map with the correct geo referencing

14. Analysis of the results

The displacement values range from -0.106 meters to 0.159 meters, as shown in the histogram and metadata in Image 23. The negative values correspond to ground subsidence (areas where the ground moved downward), while the positive values indicate uplift (areas where the ground moved upward). This range confirms the presence of significant ground deformation caused by the volcanic activity.

The displacement map shows clear regions of deformation: areas with warm colors (orange, red) represent uplift, and areas with cool colors (purple, blue) represent subsidence. The central region, where the volcanic activity occurred, displays significant displacement patterns, suggesting localized uplift and subsidence due to lava intrusion and surface deformation.

The histogram presents the distribution of displacement values, with most values clustering around zero, indicating minor displacement over large portions of the area. However, extreme values near -0.106 and 0.159 meters are less frequent and highlight regions with notable deformation.

In summary, the displacement map confirms the volcanic deformation caused by the Cumbre Vieja eruption.