Advanced Remote Sensing

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Assignment 2: Generation of a Displacement Map

Part 1 - An overview of the study area, where you describe the chosen site and the geohazard you are investigating. Explain why this particular site is relevant for analysis.

The study area for this assignment is **La Palma**, an island in the Canary Islands, Spain, which experienced a significant **volcanic eruption** from **September 19 to December 13, 2021**. The eruption occurred in the southern part of the island and was the most destructive in the recorded history of La Palma. It produced in total about 45 million m³ of pyroclastic products and gave way to heavy lava flows, remolding the outline by burying 1,237 hectares of farming land and forming two new lava deltas on the shoreline. During the eruption process, much destruction occurred; infrastructure was partially ruined or seriously damaged - more than 3,000 houses were destroyed, a part of highways for over 70 kilometers, and extensive farm fields.

This site is relevant to the analysis for both of its dual impacts on the geohazard: geologically, in how it illustrates the dynamical nature of the activity that a volcano goes through within an oceanic island; socially, it highlights the vulnerability in dense populations, where close to 8,000 residents had to be evacuated, while large losses were recorded in essential sectors such as agriculture and tourism. Understanding the pattern of displacement and the risks in this context is important for improving hazard mitigation strategies.

References: Troll, Valentin R., et al. "The 2021 La Palma eruption: social dilemmas resulting from life close to an active volcano." Geology Today 40.3 (2024): 96-111.

Part 2 - Workflow execution by documenting each step of the process, through screenshots.

To generate the displacement map of the volcanic eruption on La Palma, two Sentinel-1 SAR images were acquired via the *ASF Data Search Vertex*. The pre-event is represented by the Sentinel-1 SLC product from **September 14, 2021** and the post-event from **December 19, 2021**.

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1. Data Preparation

1.1 S1-TOPS Split

<u>Process:</u>

In order to separate the Sentinel-1 SLC images into the area of interest, a sub-swath of IW2 and the bursts from 7 to 9 were selected. This split reduces the size of the dataset and enhances the speed of further processing steps. At the same time, VV polarization was selected.

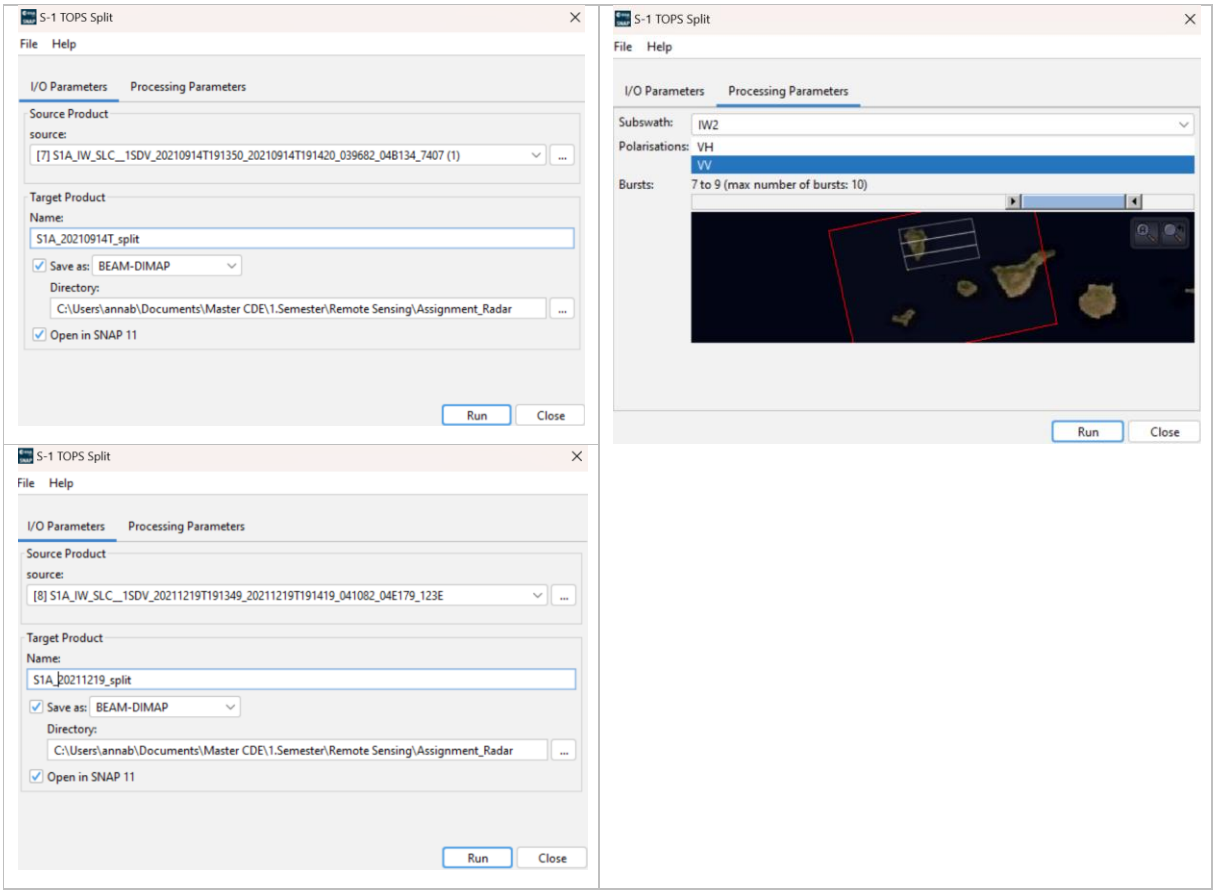

Figure 1. S-1 TOPS Split processing.

<u>Results:</u>

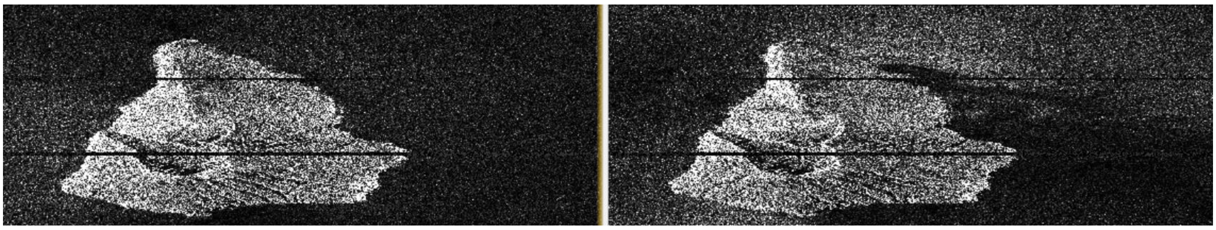

Figure 2. Separated Sentinel-1 SLC images (intensity) from the pre-event (*left*) and post-event (*right*).

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1.2 Apply Orbit File

<u>Process:</u>

The *Apply Orbit File* has been applied to correct satellite positioning errors.

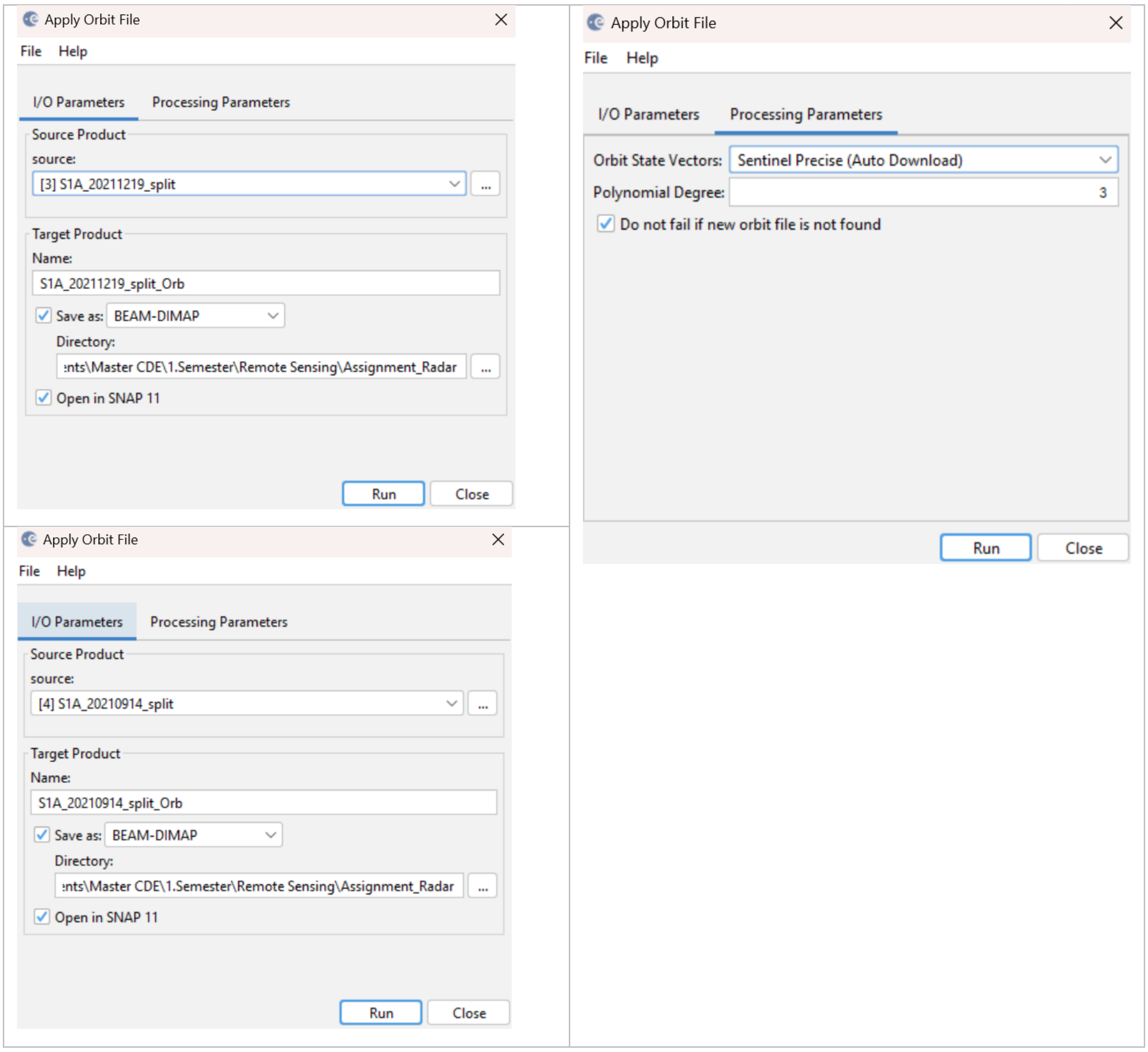

Figure 3. Apply Orbit File.

<u>Results:</u>

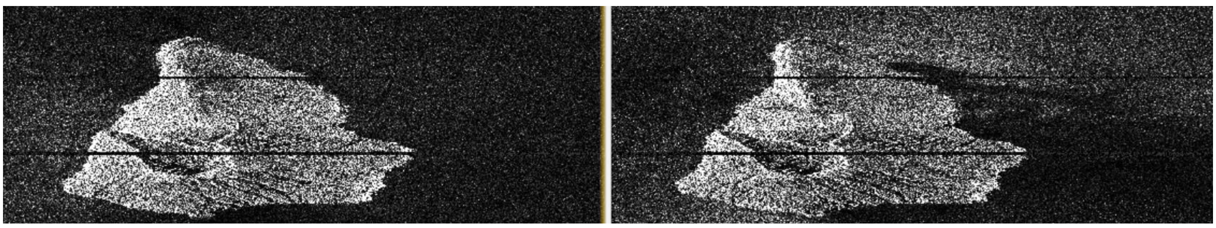

Figure 4. Corrected Sentinel-1 SLC images (intensity) from the pre-event (*right*) and post-event (*left*).

2. Generation of Topographic Interferogram

2.1 Co-registration (Back Geocoding)

Process:

To align the images from the pre- and post-event, the *Co-registration* tool was used. In this context, the **SRTM 1Sec HGT** was used as the DEM for the *Co-registration*.

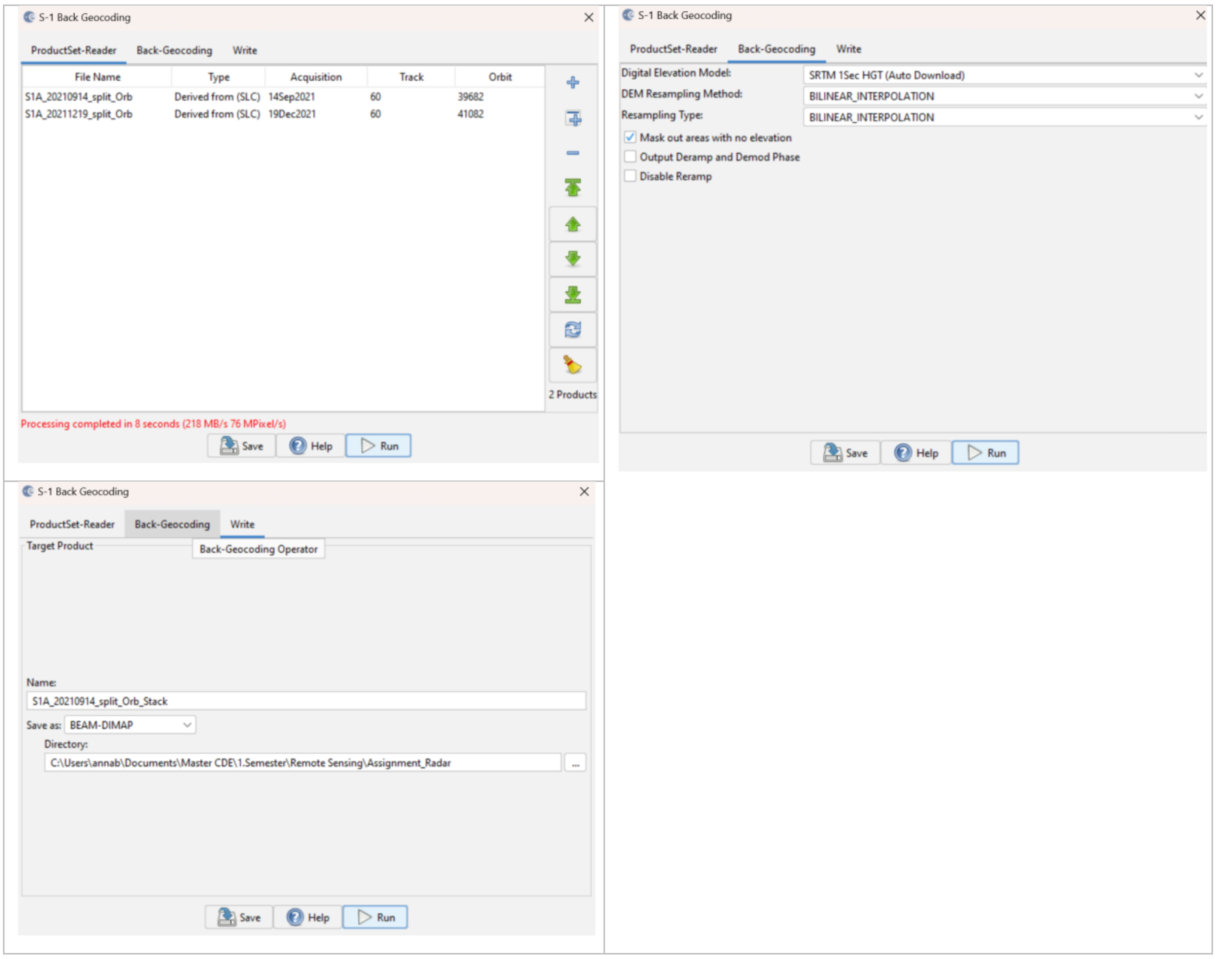

Figure 5. S-1 Back Geocoding for co-registration.

Results:

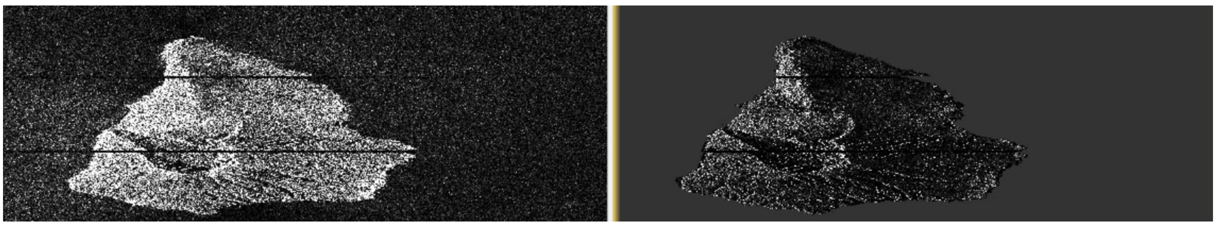

Figure 6. Co-registered Sentinel-1 SLC images (intensity) of the pre-event (*left*) and post-event (*right*).

2.2 Enhanced Spectral Diversity

Process:

The *Enhanced Spectral Diversity* tool is an optional step which removes ionospheric errors.

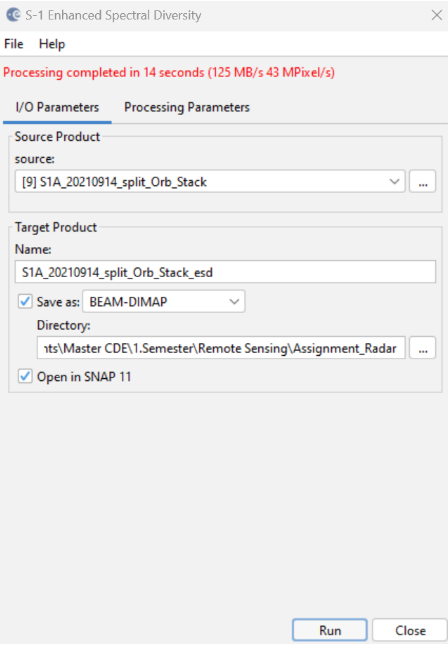

Figure 7. S-1 Enhanced Spectral Diversity tool.

Results:

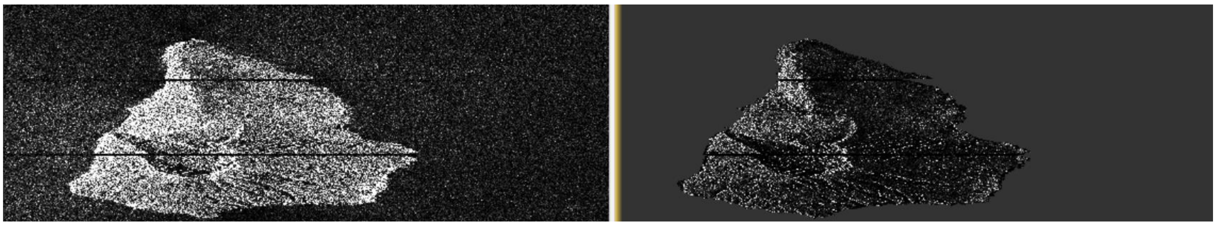

Figure 8. Sentinel-1 SLC images (intensity) of the pre-event (*left*) and post-event (*right*) after the application of the Enhanced Spectral Diversity tool.

2.3 Interferogram Generation

Process:

The *interferogram generation* tool creates a topographic interferogram which emphasizes the phase differences caused by terrain elevation. It corresponds to both topography and the displacement.

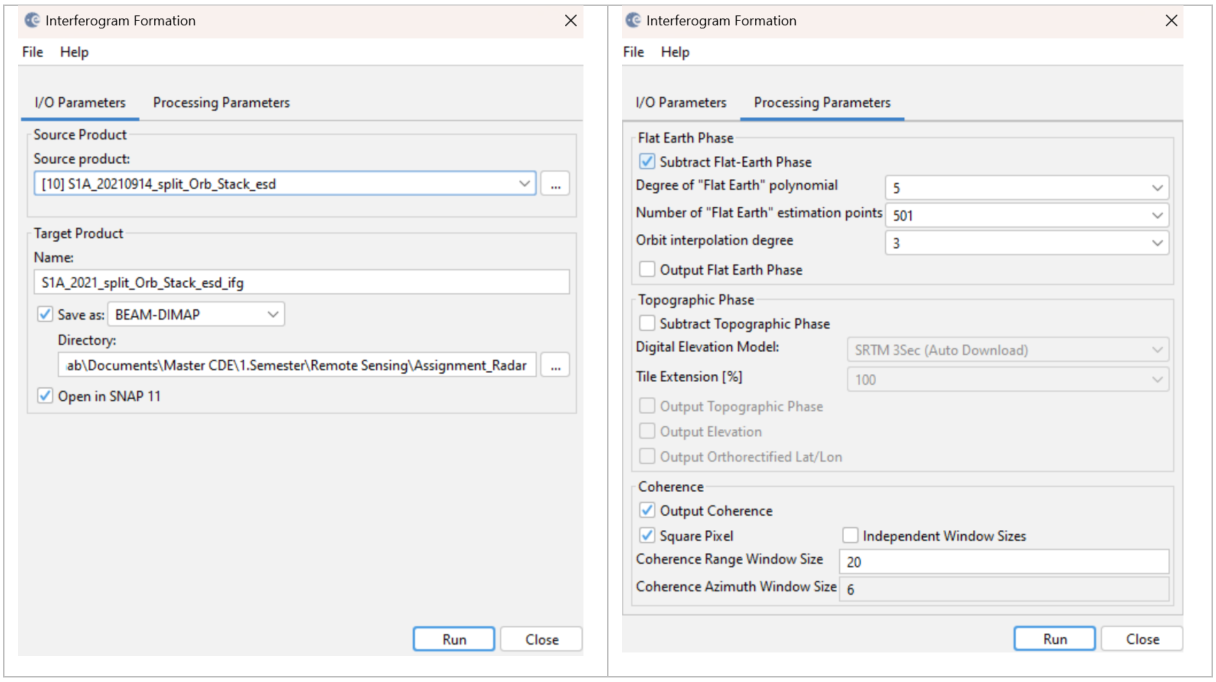

Figure 9. Interferogram Formation tool.

<u>Results:</u>

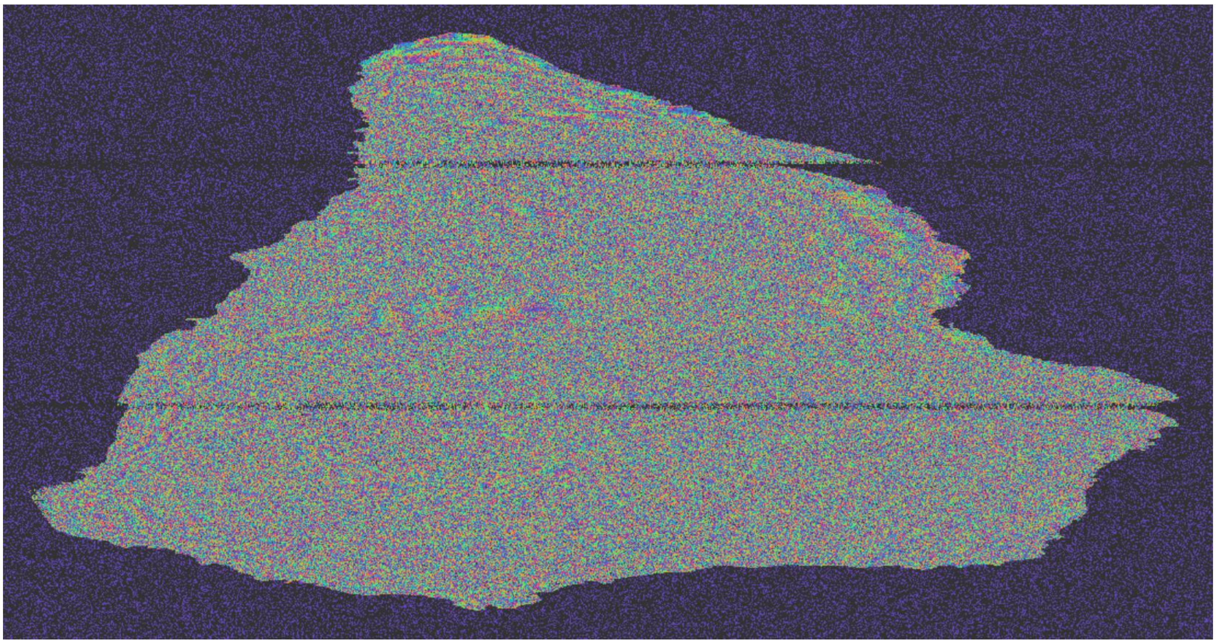

Figure 10. Topographic interferogram produced with the Sentinel-1 SLC images of the pre- and post-event.

The result shows the first fringes, which can be associated with surface elevation variations. At the same time, however, a lot of noise is visible, which indicates that further filtering is required. To show the real surface displacement, it is also necessary to remove the topographic phase contribution in the next steps.

2.4 TOPSAR Deburst

Process:

The *TOPSAR Deburst* ensures continuous images by removing the burst boundaries which otherwise impair the quality of the output.

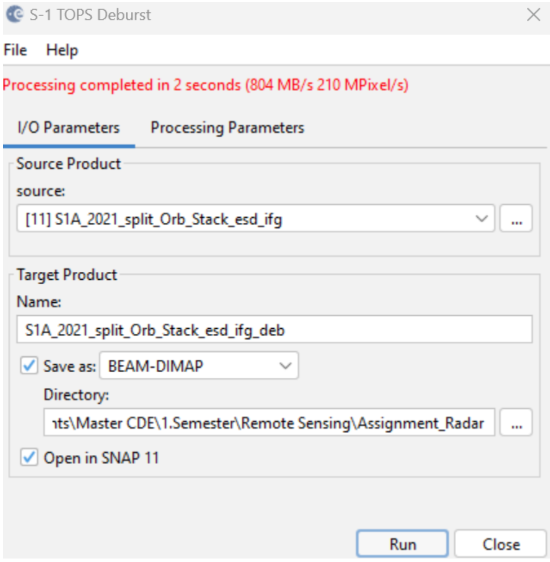

Figure 11. S-1 TOPS Deburst tool.

Results:

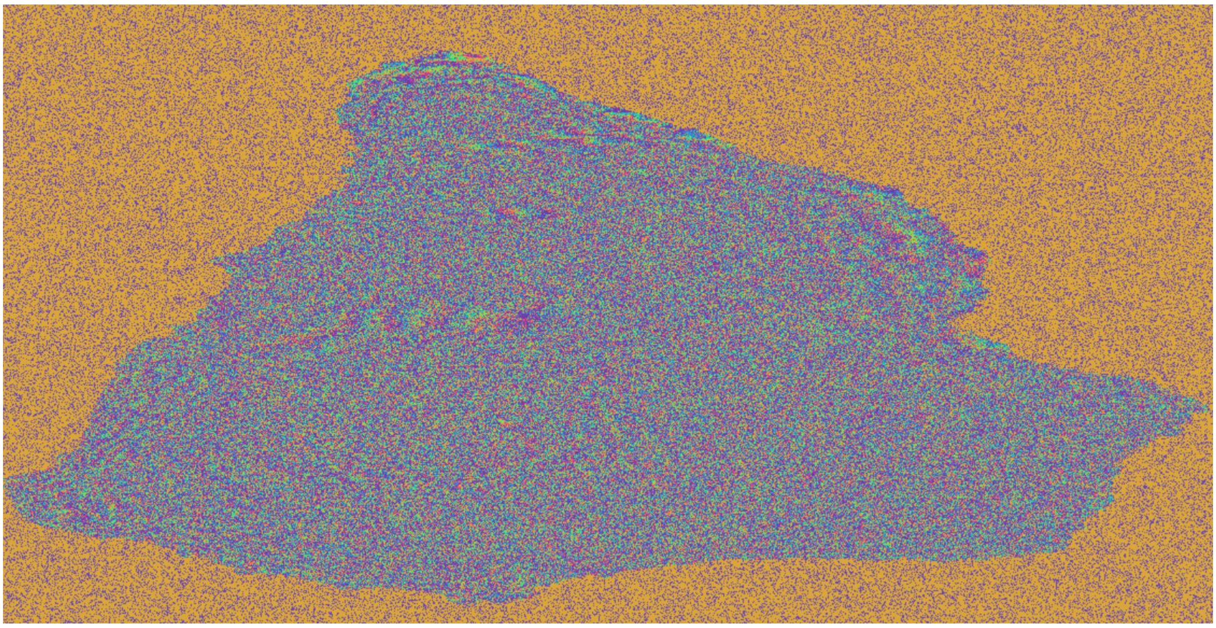

Figure 12. Topographic interferogram created with the Sentinel-1 SLC images of the pre-event and post-event after the deburst.

3. Generation of Differential Interferogram

3.1 Topographic Phase Removal (Interferogram formation)

Process:

The *Topographic Phase Removal* was used for the topographic correction by using a DEM, in this case the **SRTM 1Sec HGT**.

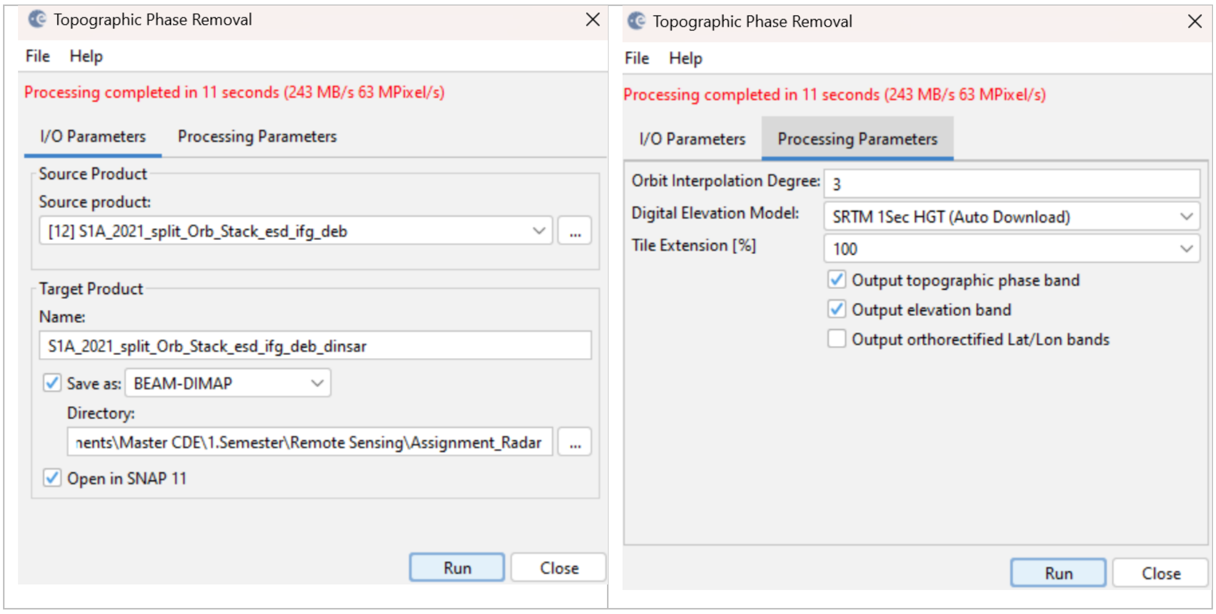

Figure 13. Topographic Phase Removal tool.

Results:

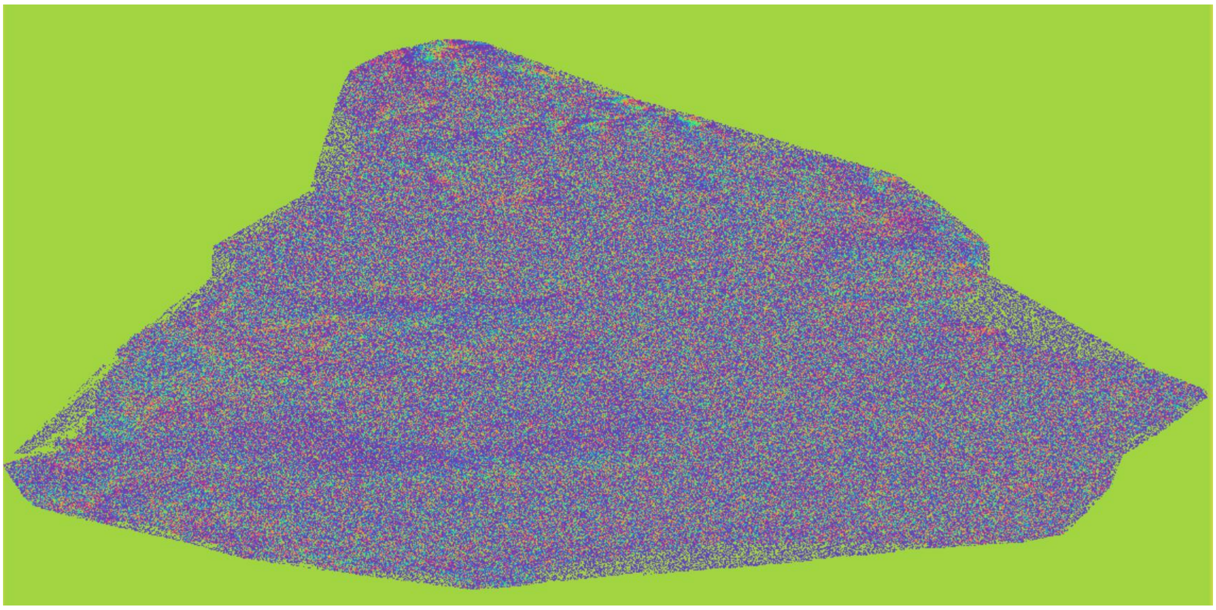

Figure 14. Differential interferogram after the Topographic Phase Removal.

3.2 Multilooking

<u>Process:</u>

The *Multilooking* tool is used to reduce noise and create square pixels. It is used to adjust the resolution by setting the *Number of Range looks* and *Number of Azimuth looks*. In this case, the *Number of **Range looks*** has been set to **8** and of ***Azimuth looks*** to **2** to ensure an acceptable resolution.

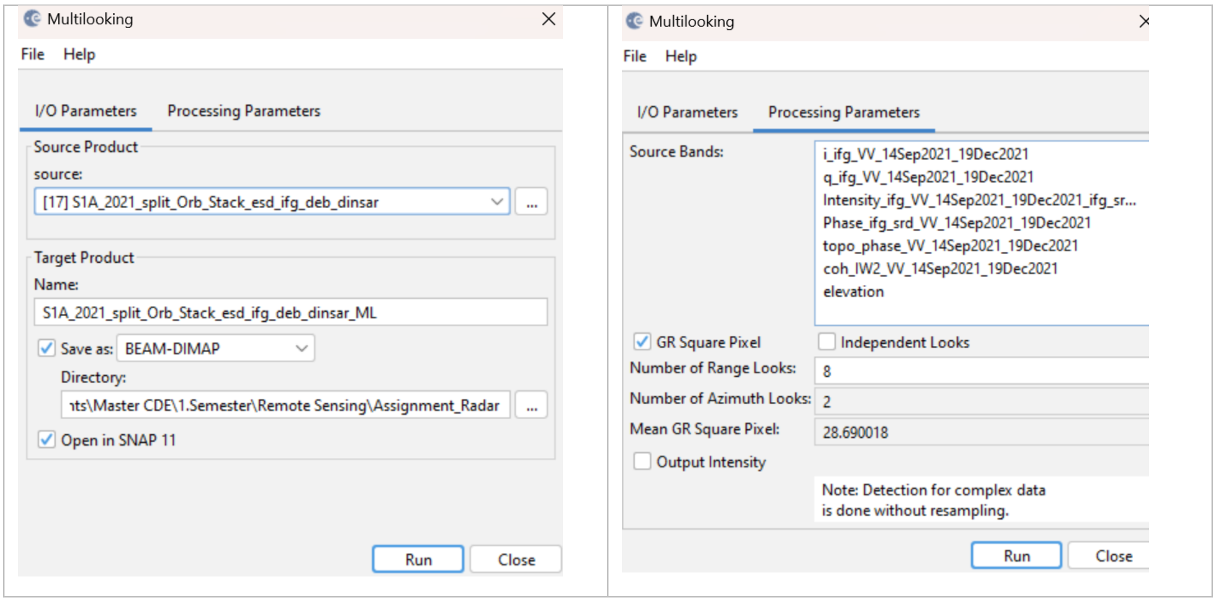

Figure 15. Multilooking tool.

<u>Results:</u>

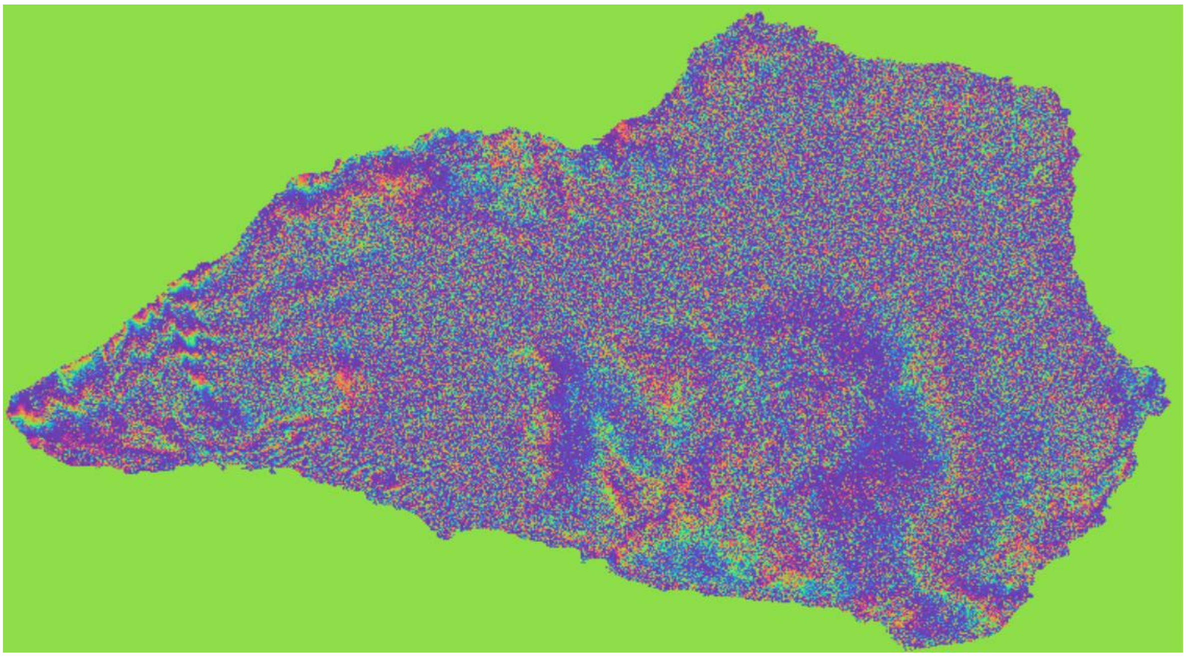

Figure 16. Differential interferogram with improved visual interpretability after using the Multilooking tool.

3.3 Goldstein Phase Filtering

<u>Process:</u>

The *Goldstein Phase Filtering* reduces noise and thus improves the phase quality. The ***Coherence Threshold***, which ranges from 0 to 1, can be set depending on the noise level. In this case, the presetting of **0.2** was used, but due to the high noise level in this example, it would also have been possible to select a higher threshold value.

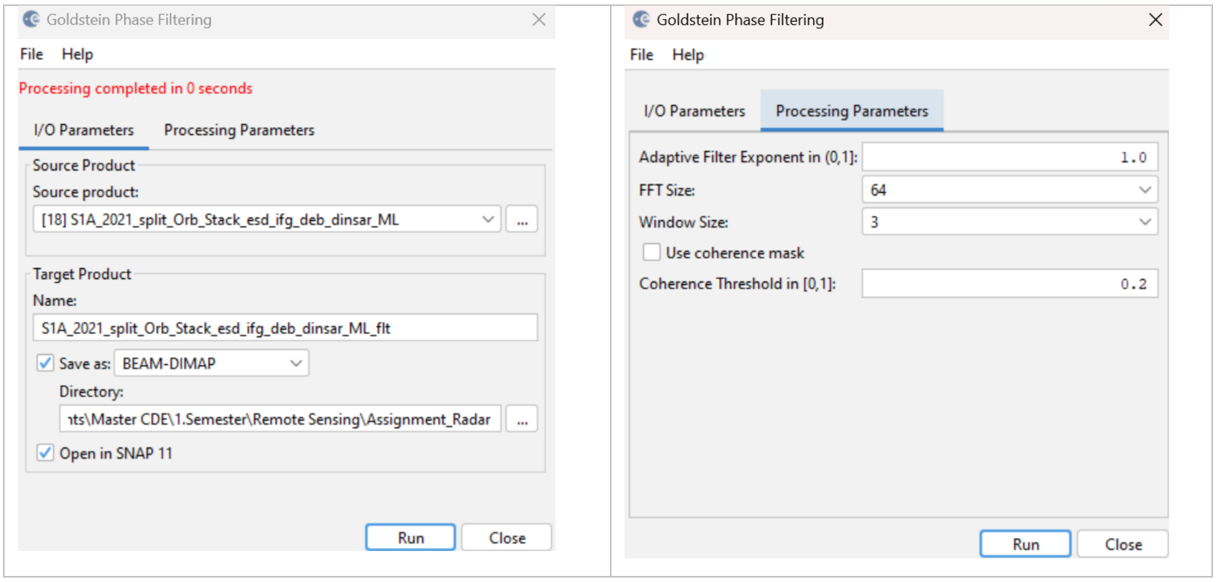

Figure 17. Goldstein Phase Filtering.

<u>Results:</u>

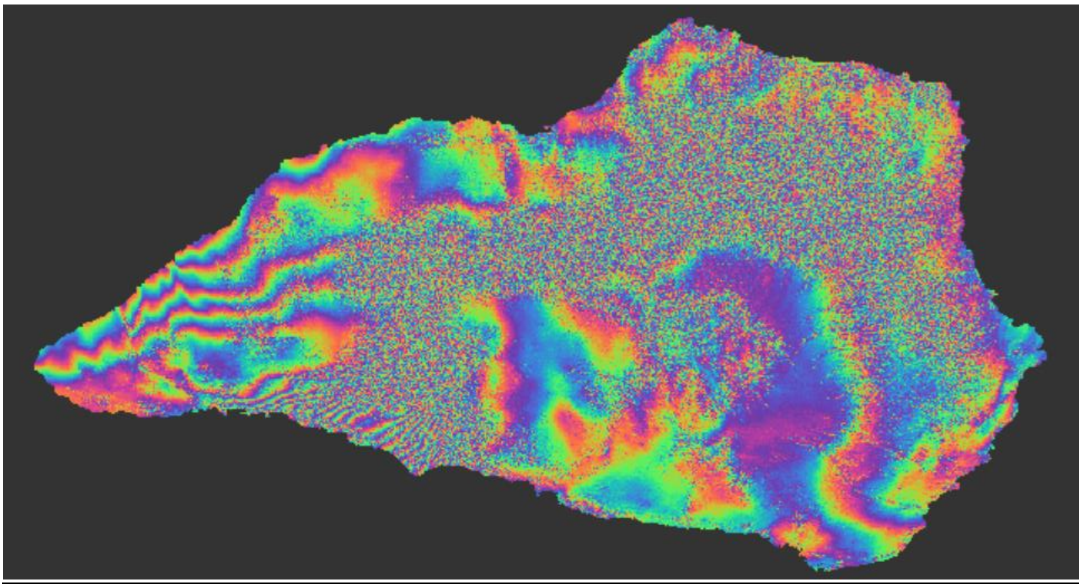

Figure 18. Differential interferogram after the Goldstein Phase Filtering (Coherence threshold: 0.2).

4. Generation of displacement map

4.1 SNAPHU Export

<u>Process:</u>

To generate a displacement map, it is important to unwrap the phase. This ensures continuous displacement measurements. To do this, we use a tool called *Snaphu* from ESA, which can be installed on the PC and then controlled via the console. In this context, we need to create a config file in Snap, which needs to be modified accordingly.

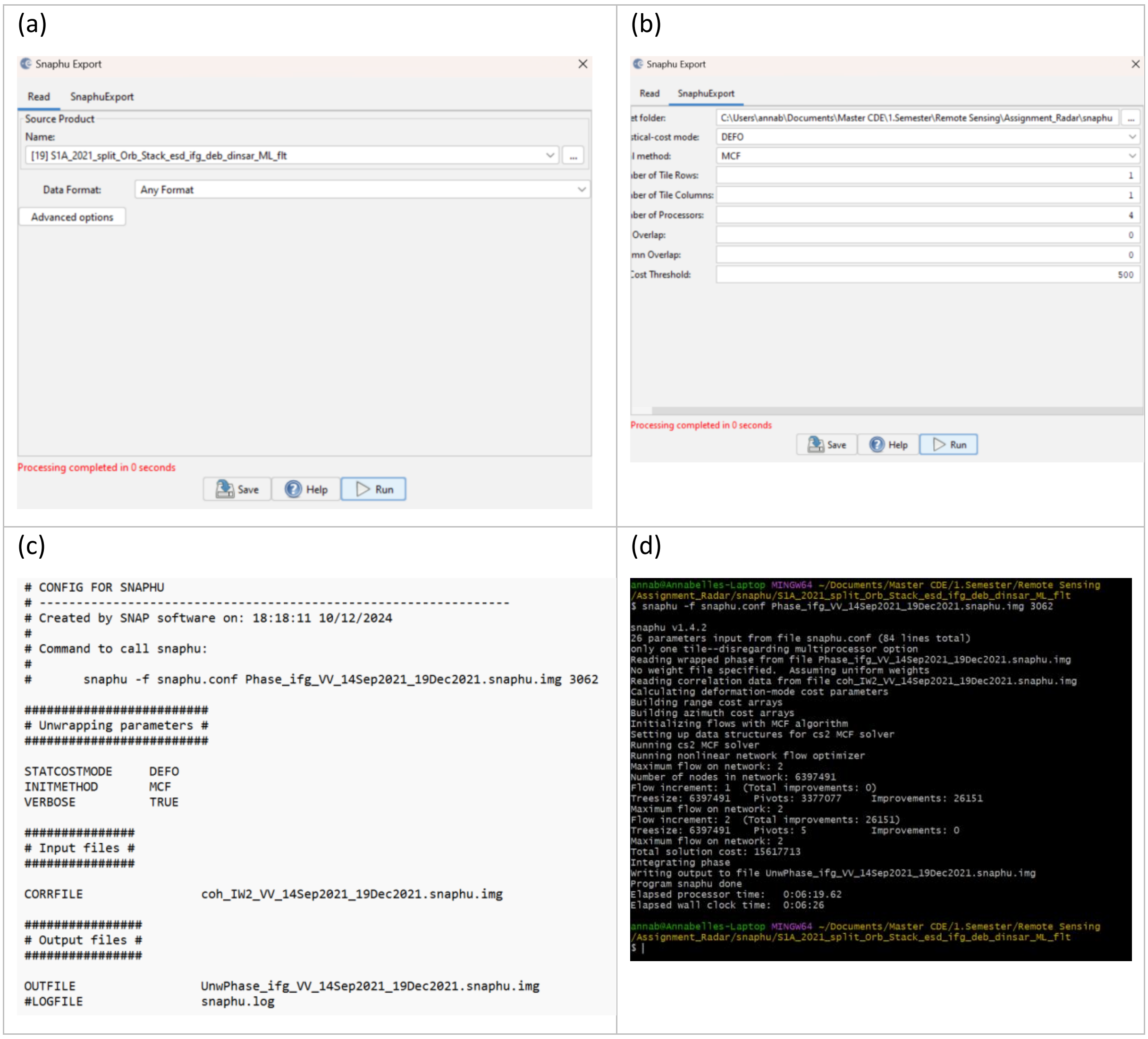

Figure 19. Snaphu Export in SNAP (a, b); Config file with the required modifications (c); Phase unwrapping by running Snaphu on the console (d).

4.2 SNAPHU Import

<u>Process:</u>

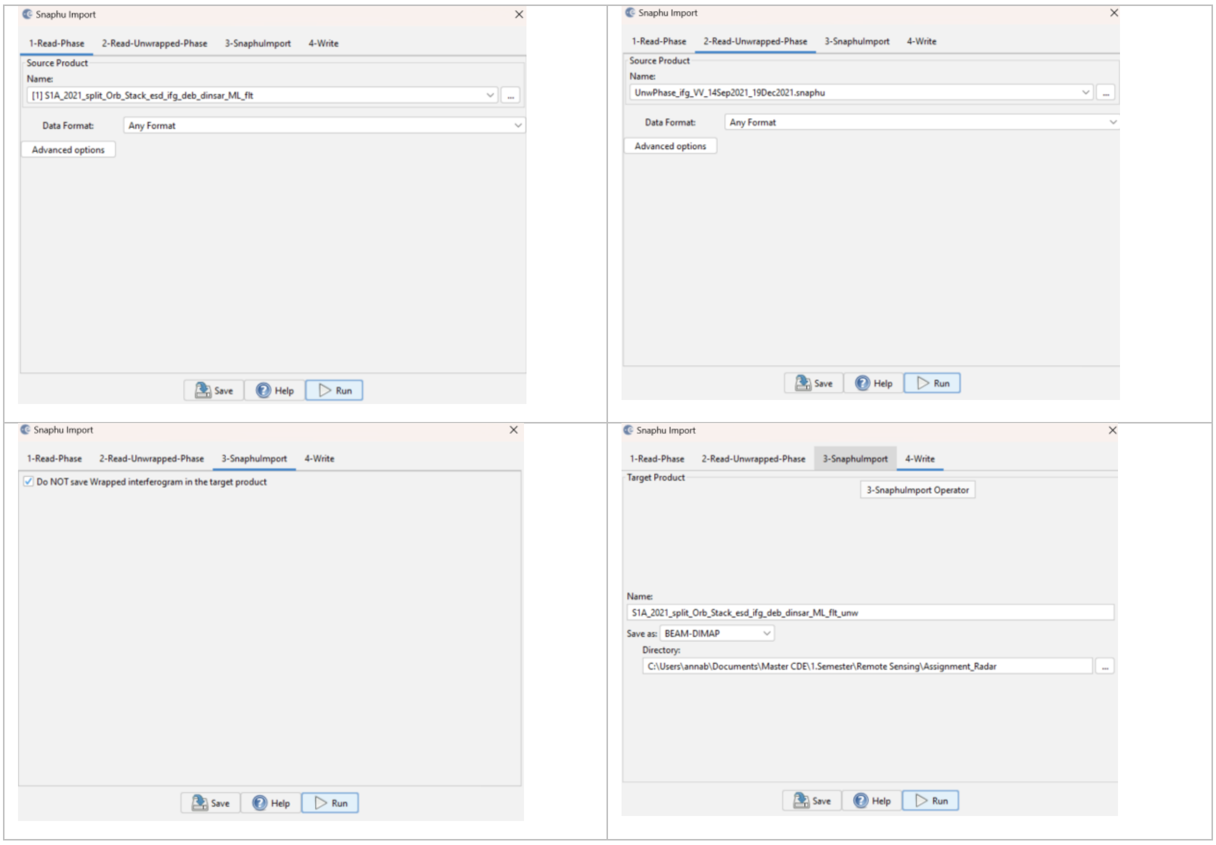

Figure 20. Importing the phase which was unwrapped with Snaphu in the console into SNAP.

<u>Results:</u>

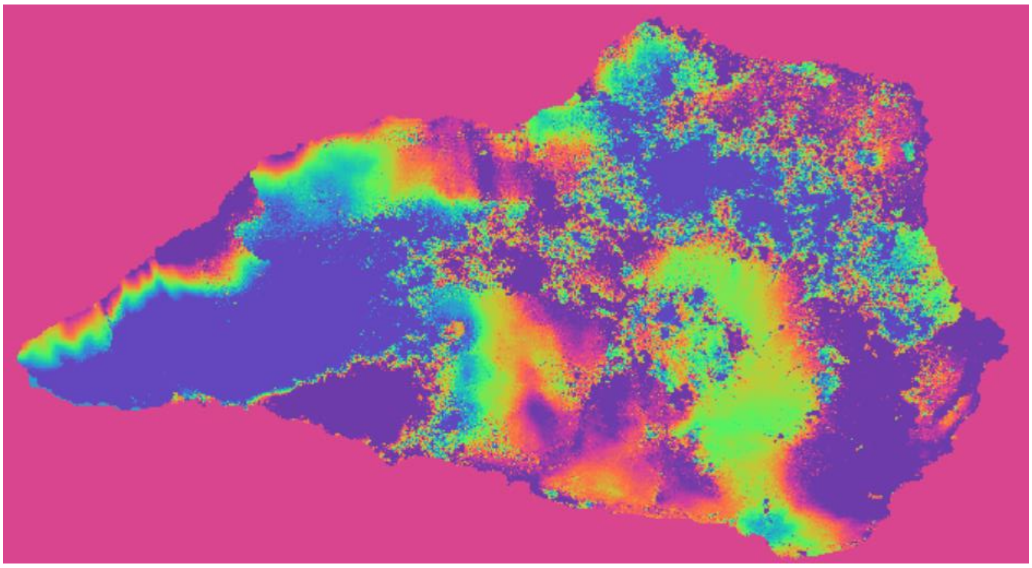

Figure 21. Unwrapped Phase of the study area.

4.3 Phase to Displacement (Generate a Displacement Map)

<u>Process:</u>

In this step, we generate displacement values from the unwrapped phase that allow us to analyze the ground movement in the study area.

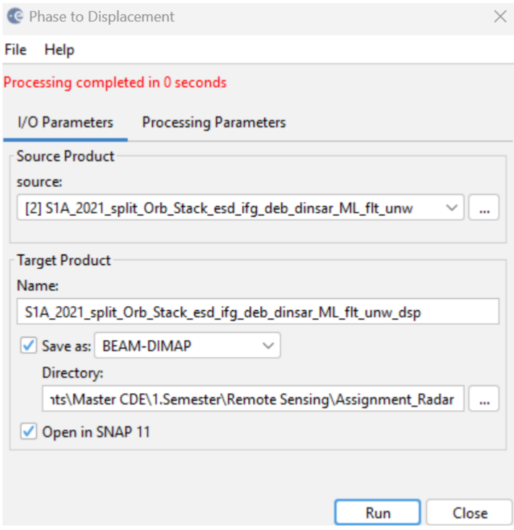

Figure 22. Phase to Displacement tool to generate a displacement map.

<u>Results:</u>

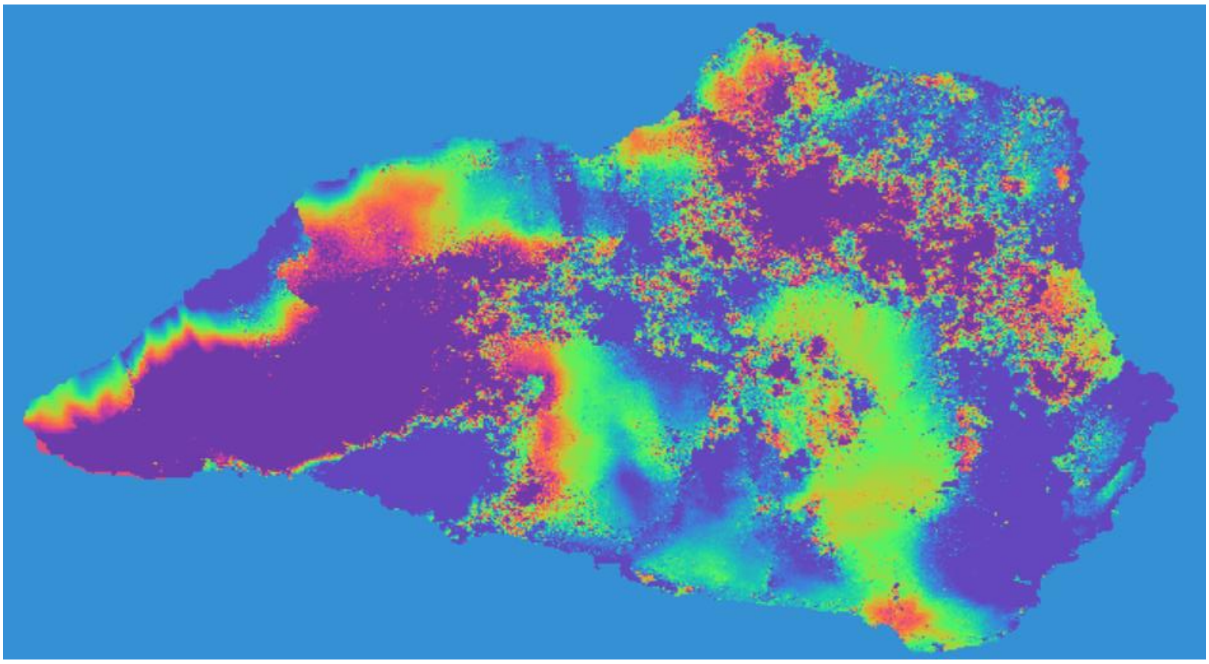

Figure 23. Displacement map of the study area showing displacement values.

4.4 Range-Doppler Terrain Correction

<u>Process:</u>

The *Range-Doppler Terrain Correction* is used to georeference the displacement map to a coordinate system, in this case **WGS84**. We also need to the define a DEM, here **SRTM 1Sec HGT**, to remove distortions caused by the topography.

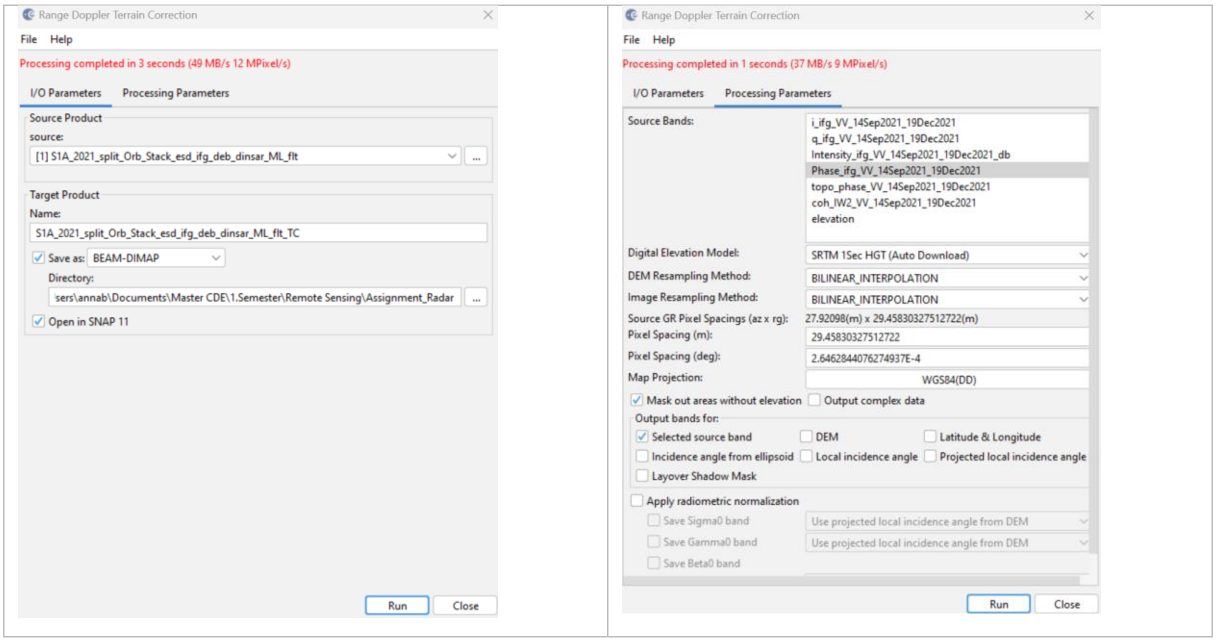

Figure 24. Range Doppler Correction.

<u>Results:</u>

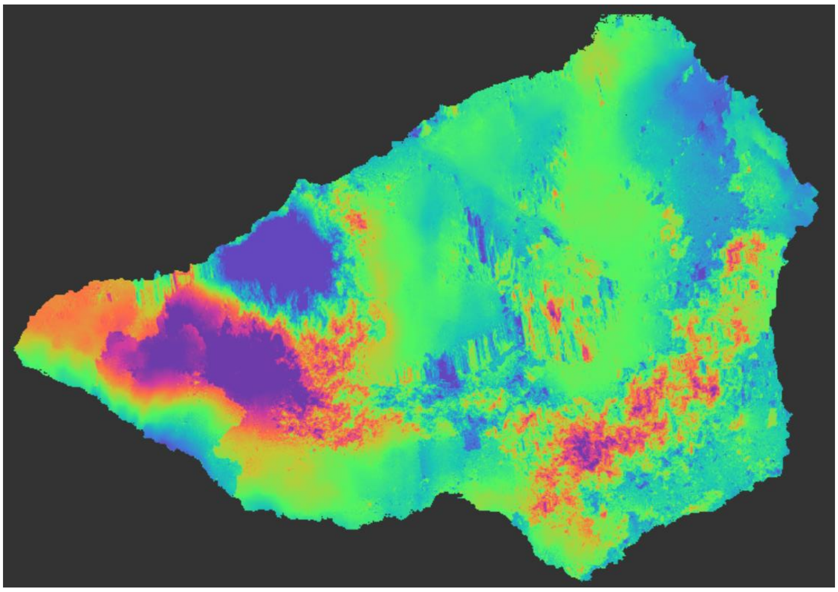

Figure 25. Georeferenced displacement map of the study area.

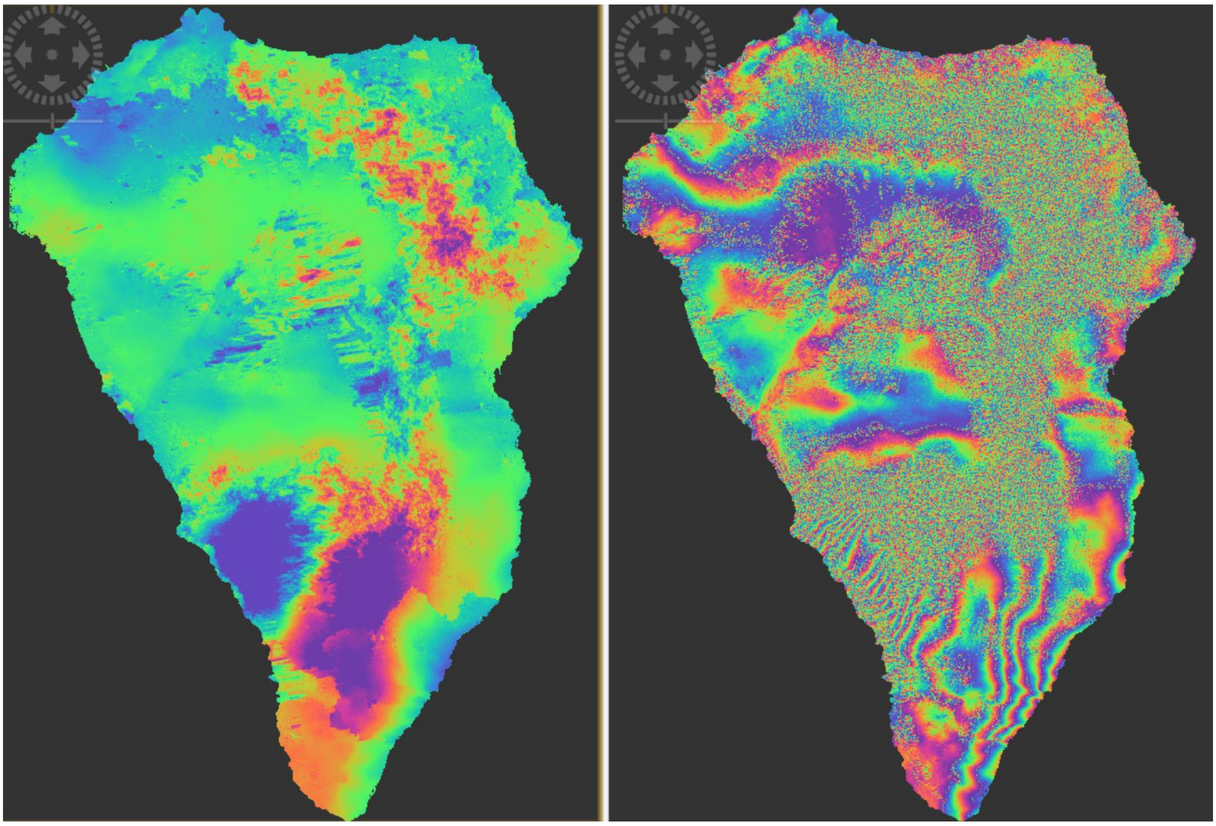

Figure 26. Comparison of the georeferenced displacement map (left) and the differential interferogram (right).

The main difference between the georeferenced differential interferogram and the displacement map is that the differential interferogram shows the phase changes caused by ground displacement, while the displacement map shows displacement values in meters. The latter thus allows analyzing the ground movement. Furthermore, it ensures accurate spatial analysis and can be used for emergency response and damage control.

Part 3 - Results Analysis of the observed deformation patterns. Discuss briefly the implications of your findings.

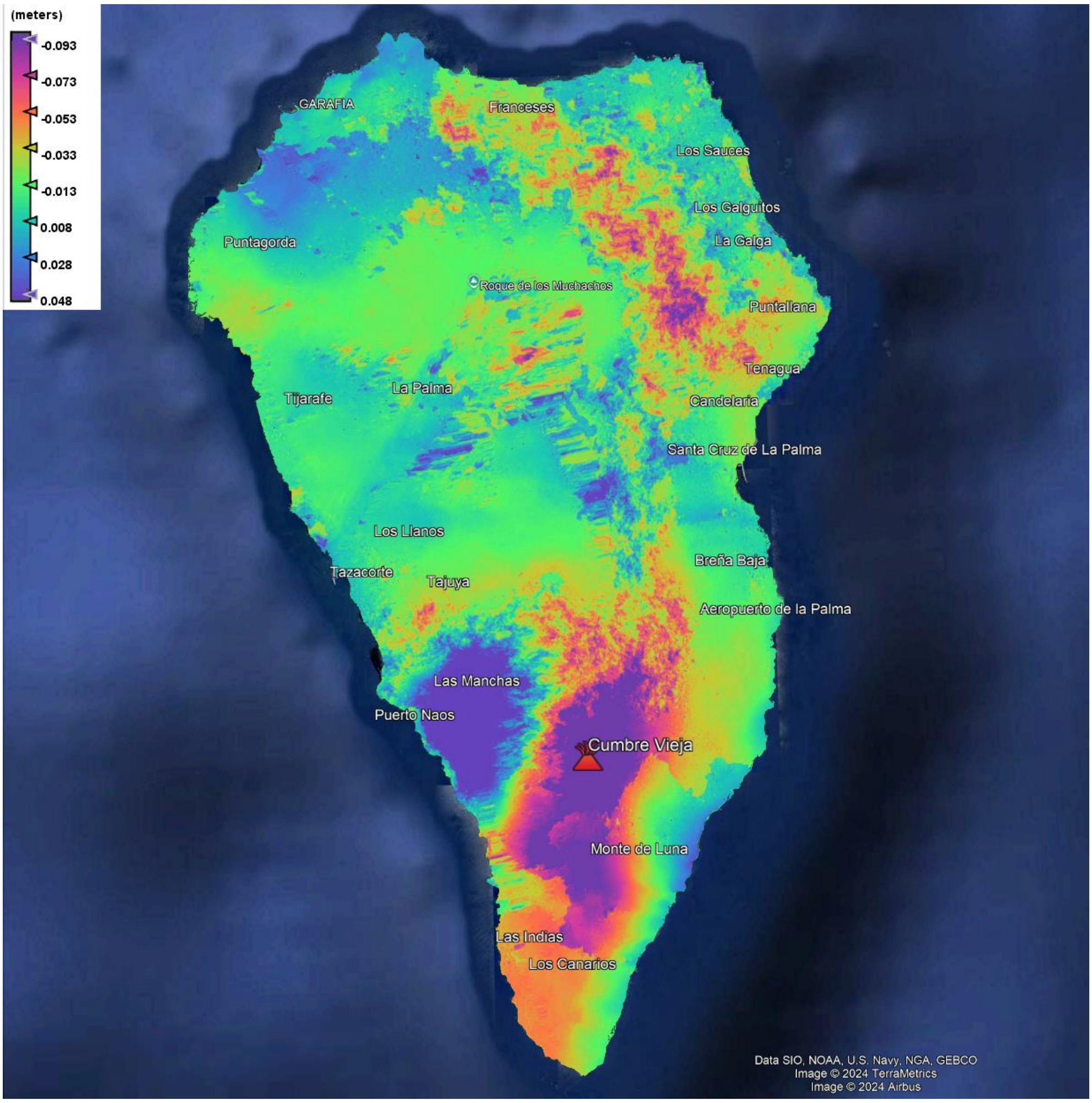

Figure 27. Displacement map of the study area, visualized in GoogleEarth Pro.

The displacement map shows significant ground deformation across La Palma, centered around the Cumbre Vieja volcano. Near the volcanic vent, the ground has lowered, likely due to the movement of magma underground. In contrast, the areas where lava flowed show an increase in elevation. Thick layers of lava built up during the eruption, creating new land and reshaping the landscape. These changes tell us how volcanic activity can dramatically alter the ground. Such information can tell us which areas need to be monitored for likely future hazards and how recovery efforts can be supported, as well as support emergency response, infrastructure planning, and further monitoring of volcanic activity.