Creating a Displacement Map

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December 5, 2025

> ***«It takes an earthquake to remind us that we walk on the crust of an unfinished planet.»***
> -Charles Kuralt

Abstract

The earthquake is still a mostly unpredictable natural catastrophe, with often disastrous consequences. Therefore, the more information one can acquire after such an event, the closer one comes to being capable of predicting them in the future.

This report explores the use of ESA's SNAP program to generate displacement maps by applying interferometry technics. The focus event was the earthquake that hit Myanmar in March of 2025, and the result was accomplished using Sentinel-1 imagery.

The outcome is questionable, as explained in the report, but the technic is theoretically solid.

Keywords: Interferometry, Displacement Maps

1 Introduction

The Sentinel Application Platform (SNAP) is a program developed by ESA to manipulate (mainly) Sentinel imagery. It is quite useful to produce elevation models, and, as I learned a few weeks ago, it can also be used to create "displacement maps".

This technic consists of using two different satellite images, presumably taken from (ever-so-slightly) different positions, to simulate an interferometer and assess the phase difference between the two, in this case with focus on physical displacement.

Copernicus releases Sentinel-1 Single Look Complex (SLC) products which, as the name implies, use a complex value representation, with the amplitude as the real (in-phase) component, and the phase as the imaginary (quadrature) component (1; 2). This makes them ideal for this kind of analysis!

2 Choice of Location

The easiest way to test the aforementioned technic is with earthquakes, and Portugal is no stranger to earthquakes. In fact, the Great Lisbon Earthquake of 1755 was the strongest earthquake ever recorded in Europe. Alas, that took place a few centuries before Sentinel-1A became operational, and thus one can't calculate a displacement map of that event in conventional ways. Hence why I initially picked the 2020 Earthquake that hit Madeira Island, where my cousin lives. I thought it was an interesting case, because the epicenter was in the ocean, unlike the example we saw in class. However, perhaps because it wasn't a very strong earthquake (5,3 in Richter's magnitude scale) or maybe precisely because the epicenter was underwater, I didn't get very satisfying results.

I've still decided to include my analysis of the 2020 earthquake on the appendix (Section 5.1), but, for the main report I decided I had to go big! And in-land!

The largest earthquake I've heard of in recent times was the Earthquake that hit Myanmar in March of this year, which had a magnitude of 7,7 in Richter's scale, i.e. more than 1000 times more powerful than Madeira's earthquake. Myanmar holds a special place in my heart, because I traveled there alone when I was 18 and I spent one month volunteering there. All of this, and the fact that the epicenter was in a continental plaque, made it seem like the perfect candidate!

The last step before starting was getting the images. For that, I used the Copernicus Browser and searched for images taken by Sentinel-1 satellites around the 28th of March of 2025 (the date of the incident). I ended up picking two images taken by Sentinel-1A: one from the 22nd of March and another from the 15th of April. The area covered by my images can be seen in Figure 1.

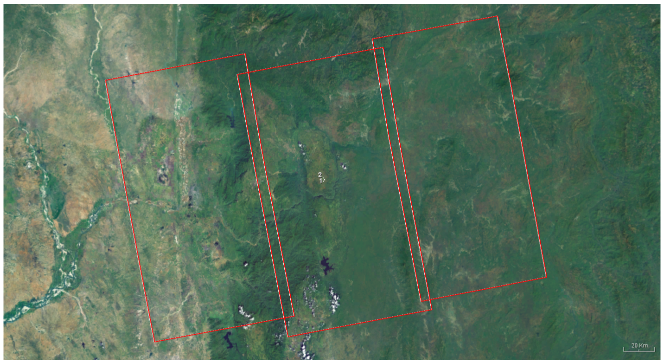

Figure 1: The limits of the three subswaths of my images (one trio marked in red and the other in white) can be seen here overlayed on a real-color image of the region.

3 Procedure

3.1 Data preparation

After opening both my images on SNAP, I began by running the "S-1 TOPS Split" tool on both images (as shown in Figure 8, in the appendix). My final study area can be seen in Figure 2.

After the split, I applied the "Apply-Orbit-File" tool with the default settings (as seen in Figure 8, in the appendix) to fix the vibrations in Sentinel-1A's movement. And then I could finally merge both files into one with the "S-1 Back-Geocoding" tool. I selected my two files (shown in Figure 8, in the appendix) and I changed the Digital Elevation Model (DEM) parameter to "SRTM 1Sec HGT", simply because the default setting is "SRTM 3Sec HGT" and 1 is more precise than 3 (I like preciseness).

3.2 Interferometry

With my stacked file, I ran the "Enhanced Spectral Diversity", "Interferogram Formation" and "S-1 TOPS-Deburst" tools all with the default settings (as seen in Figures 12, 13, and 14, respectively):

- The "Enhanced Spectral Diversity" is supposed to improve co-registration accuracy between the different bursts;

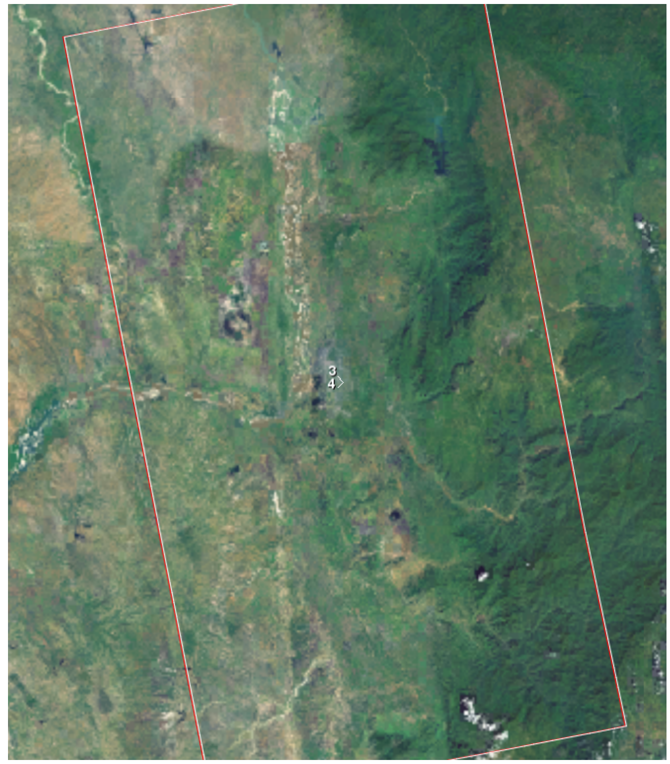

Figure 2: The selected area of both my images (one marked in red and the other in white) can be seen here overlayed on a real-color image of the region. It is also possible to see the landscape in more detail, namely the Irrawaddy River and the city of Mandalay, on the banks of the river close to the 90 degree turn. The earthquake and its replicas all happened in the vicinity of that

- The "Interferogram Formation" tool finally calculates the phase difference between layers;

- The "S-1 TOPS-Deburst" tool patches together the different bursts.

The next step is to remove the effects of topographic variance from the phase and thus I ran the "Topographic Phase Removal" (as seen in Figure 15), changing the DEM parameter to "SRTM 1Sec HGT" once more (as shown on Figure 16).

Afterwards, I ran the "Multilooking" tool with default settings (as shown in Figure 17) followed by the "Goldstein Phase Filtering" tool (as shown in Figures 18 and 19), with both being used to, hopefully, decrease the noise in the image.

After all theses steps, I finally got a visual result worth analyzing: fringes! As can be seen in Figure 3.

To be honest, I was expecting more fringes. The more fringes there are, the bigger the displacement is expected to be, hence why I was a bit disappointed, but I decided to go with what I'd gotten.

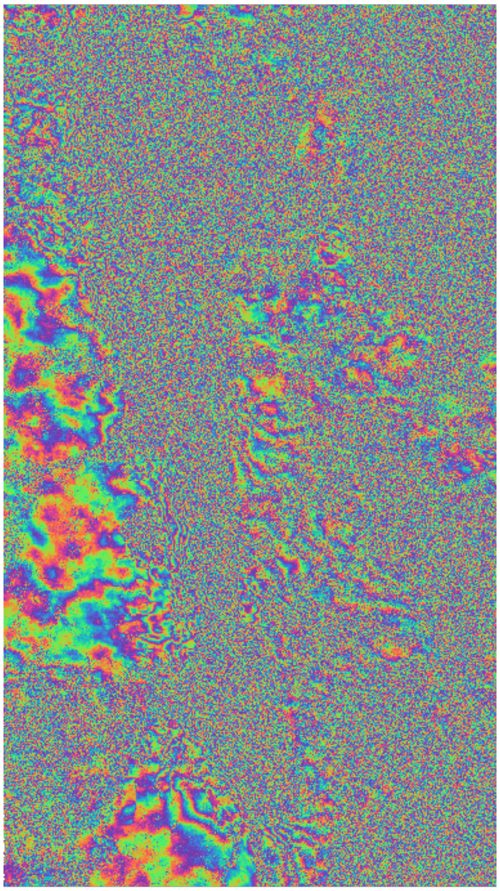

Figure 3: Phase Layer, created by the "Interferogram Formation" tool, after being deburst, having the topographic phase removed and being cleaned. With only 6 bursts (instead of all 9), the big fringes seen here in the bottom had been excluded.

3.3 SNAPHU

For the next step, I had to leave SNAP, so I exported my results using the "SNAPHU Export", as seen in Figure 20. This process creates several files, including one called "snaphu.conf", which includes the command to call SNAPHU (Statistical-Cost, Network-Flow Algorithm for Phase Unwrapping), which is able to “unwrap” the interferogram and help reveal the displacement once and for all.

Once it finished, I got the following message:

```
Treesize: 405888  Pivots: 2145812  Improvements: 10855
[...]
Elapsed processor time:   7:33:58.22
Elapsed wall clock time:  2:43:49
```

It would have been faster the less bursts I’d picked (in fact, it was much faster the previous times).

After this, I had to import the results back to SNAP. To accomplish this, I used the appropriately-named "Snaphu Import" tool: in the "Phase" field, I selected the Phase layer I had gotten at the end of Section 3.2 (and which can be seen in Figure 3); and in the "Unwrapped-Phase" field, I selected my newly created "UnwPhase_ifg_VV_22Mar2025_15Apr2025.snaphu.hdr" file (as seen in Figure 21).

3.4 Final steps

With my new "Unwrapped-Phase" layer, I could run the "Phase to Displacement" tool (seen in Figure 22) which converts the unwrapped phase into displacement values. Afterwards, I only had to run the "Range-Doppler Terrain Correction" tool (seen in Figures 22 and **??**) to get my final displacement file, which can be seen in Figure 4.

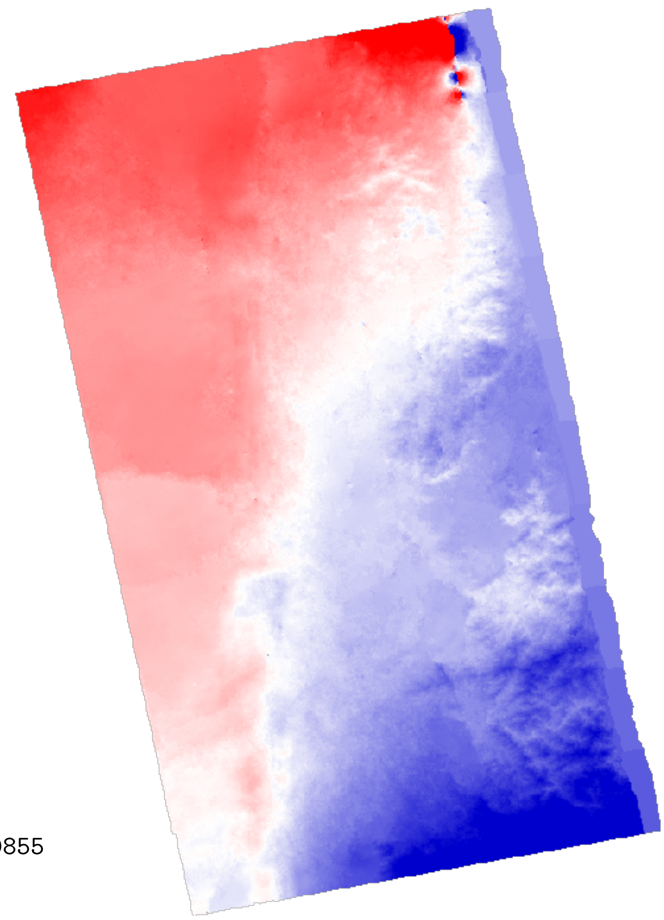

Figure 4: Displacement Map oriented with North in the vertical direction. The white areas represent zero displacement, the blue areas represent displacement away from the sensor, and the red areas represent displacement towards the sensor. The darkest, the largest the displacement.

4 Result Analysis

To better interpret the results, I exported the displacement layer as a kmz file to open it on Google Earth, and I have to say that, even after redoing things several times with different parameters, I'm not very happy.

For starters, I can see the "shadow" of the river's path on my displacement map (in the red area), as well as some of the surrounding mountains (in the blue area), which means the topographic effect was not removed well.

Furthermore, I would expect the white regions to represent the Sagaing Fault, the major fault that crosses Myanmar from North to South, and which is at the source of this earthquake (3), but, in reality, the fault passes to the west of the river (3), not east, as portrayed here; and it is more North-South oriented (3), while, here, it is very skewed.

With all this said, I'm forced to confess that I'm not sure if my result has any relevant meaning at all, and I think it's most likely because of the low coherence.

5 Appendix

5.1 The Madeira Case

As previously mentioned, I first decided to analyze the 2020 Madeira Earthquake, which happened on the 7th of March of that year, with an epicenter more than 20km off the southern coast of the island.

I got two Sentinel-1B's images: an image from the 1st of March and another from the 13th. Then, I ran the procedures similarly to what I described for the Myanmar case until I got my Phase Layer, seen in Figure 5.

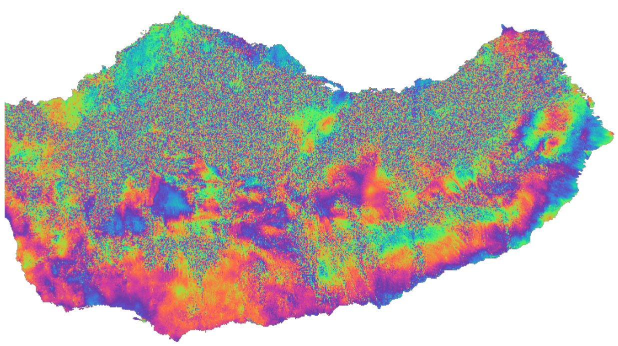

Figure 5: Phase Layer, created by the "Interferogram Formation" tool, after being deburst, having the topographic phase removed and being cleaned.

This was the first hint that things were probably not going to work out, as only a few fringes can be easily identifiable. But I still exported these features and completed the procedure. The result can be seen in Figure 6.

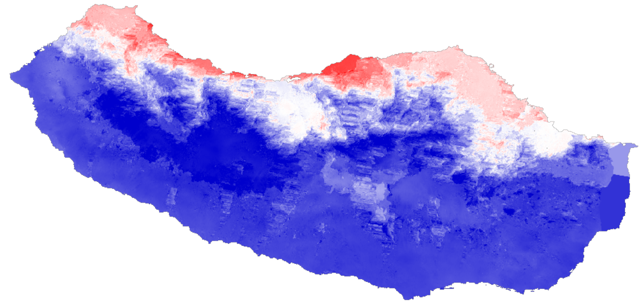

Figure 6: Displacement Map of Madeira. The white areas represent zero displacement, the blue areas represent displacement away from the sensor, and the red areas represent displacement towards the sensor. The darkest, the largest the displacement.

Once again, it seems like the topographic phase removal wasn't well executed, since it's possible to see the shadows of the mountains at the center of the island. In addition to that, I couldn't think of a single reason why the north of island (the furthest away from the epicenter) would move towards the sensor, while the rest would move away. To make things more interesting, I changed the color scale to match the one on the Myanmar Earthquake. The result can be seen on Figure 7.

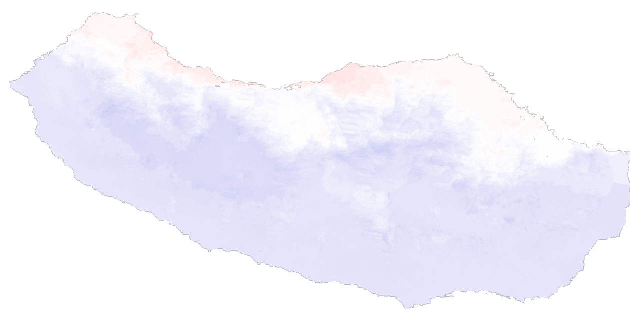

Figure 7: Displacement Map of Madeira using the Myanmar color scale. The white areas represent zero displacement, the blue areas represent displacement away from the sensor, and the red areas represent displacement towards the sensor. The darkest, the largest the displacement.

As expected, the colors are much fainter, but are they suspiciously fainter? Is the whole thing just noise? I'm not sure...

5.2 Procedure Screenshots

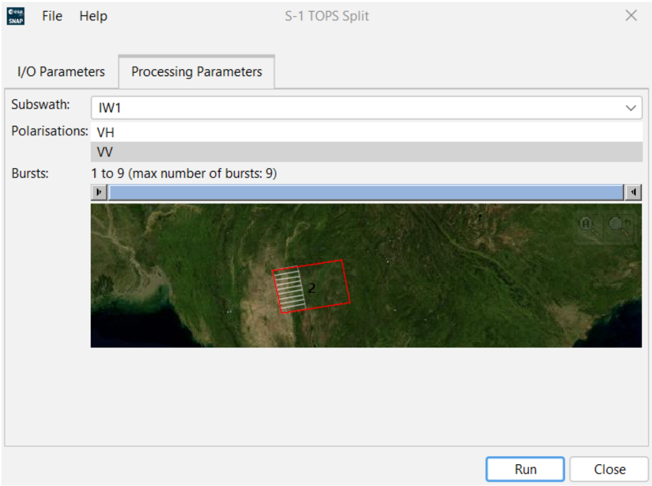

Figure 8: Selection of the first subswath, Vertical-Vertical (VV) polarization, and selection of all the bursts. I initially ran the tool with only 6 out of the 9 bursts, but decided to repeat the whole thing with the complete subswath.

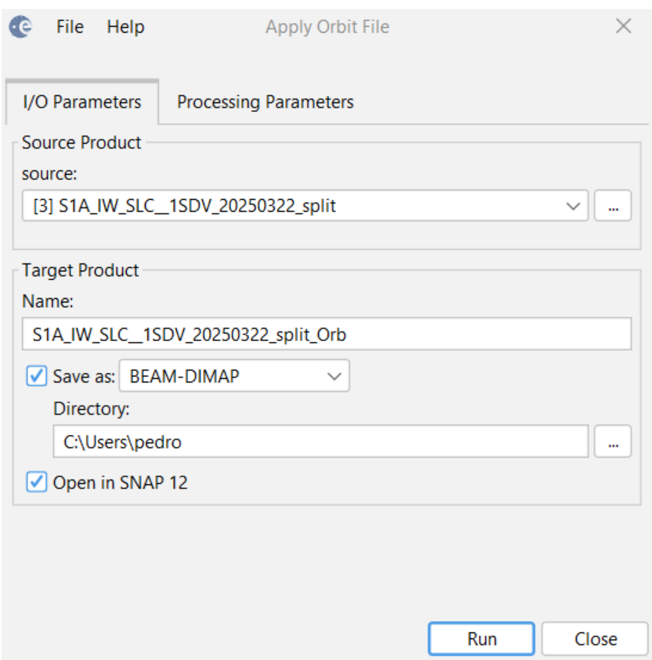

Figure 9: Application of the "Apply-Orbit-File" tool to one of my split layers.

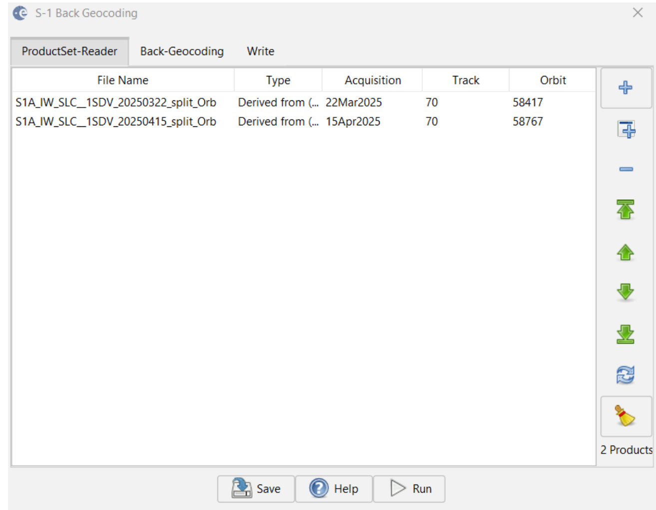

Figure 10: Selection of Layers in the "S-1 Back-Geocoding" tool.

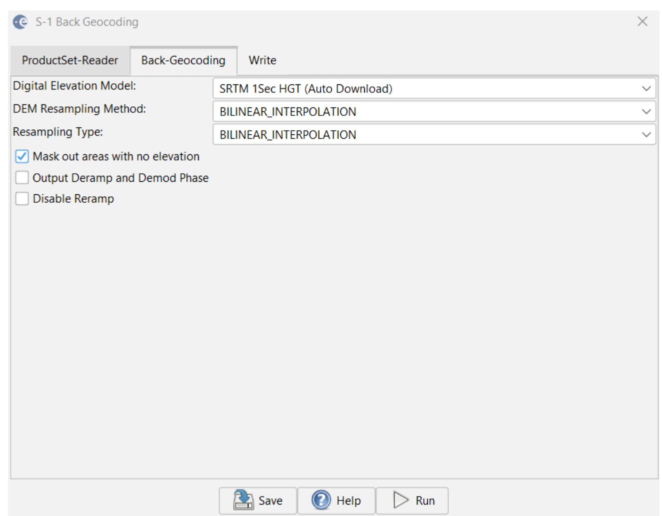

Figure 11: DEM selection on the "Apply-Orbit-File" tool.

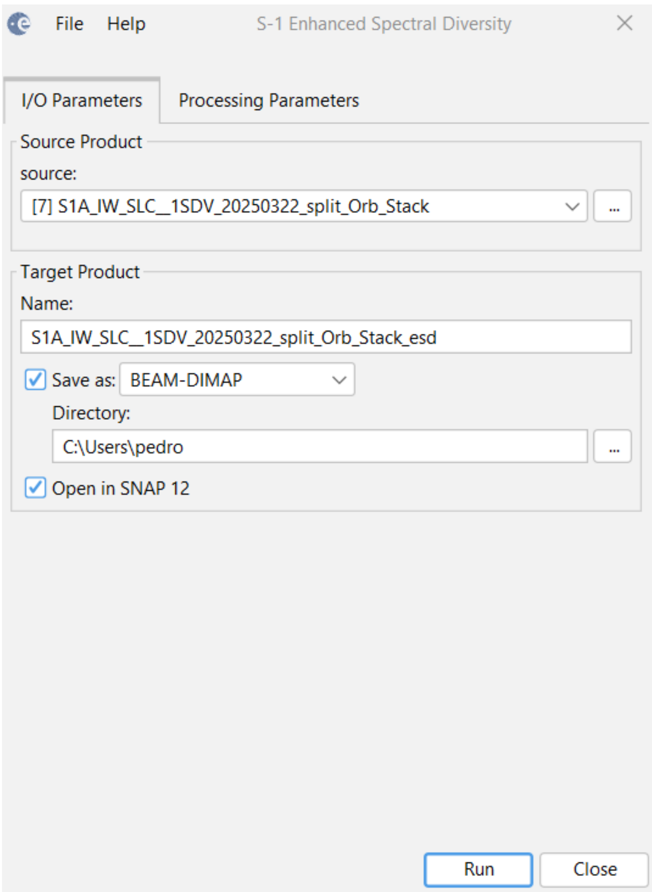

Figure 12: Application of the "Enhanced Spectral Diversity" tool to my stacked file.

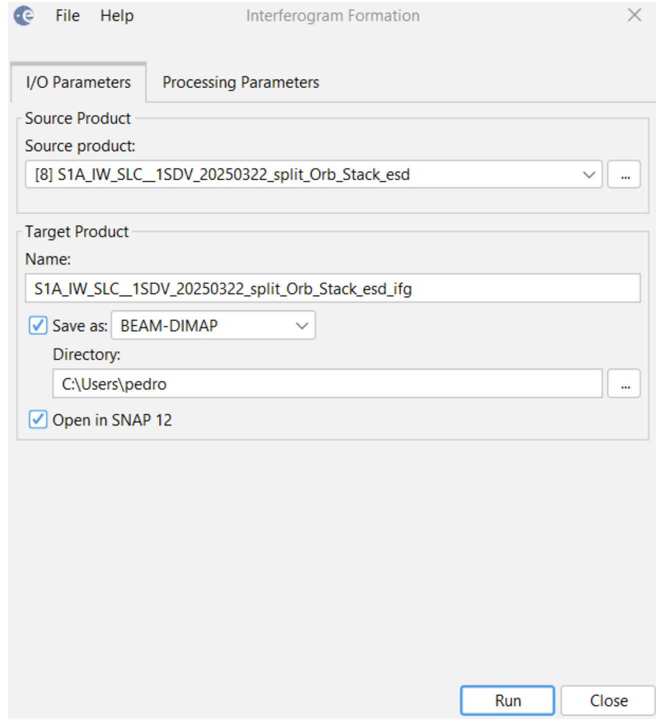

Figure 13: Application of the "Interferogram Formation" tool to my spectrally-enhanced file.

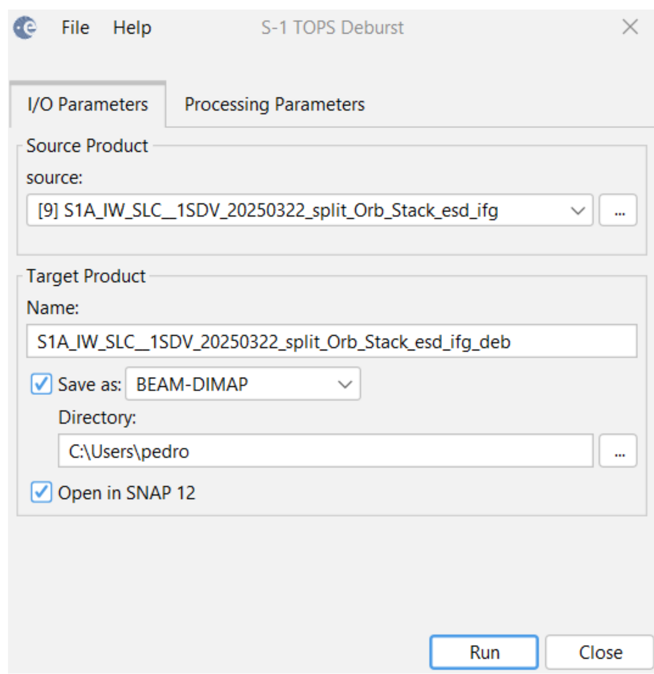

Figure 14: Application of the "S-1 TOPS-Deburst" tool to my interferogram product file.

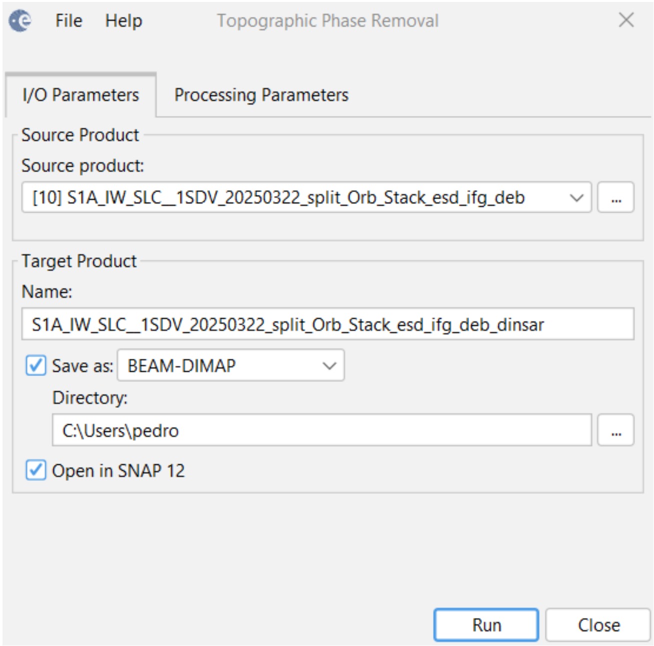

Figure 15: Application of the "Topographic Phase Removal" tool to my debursted file.

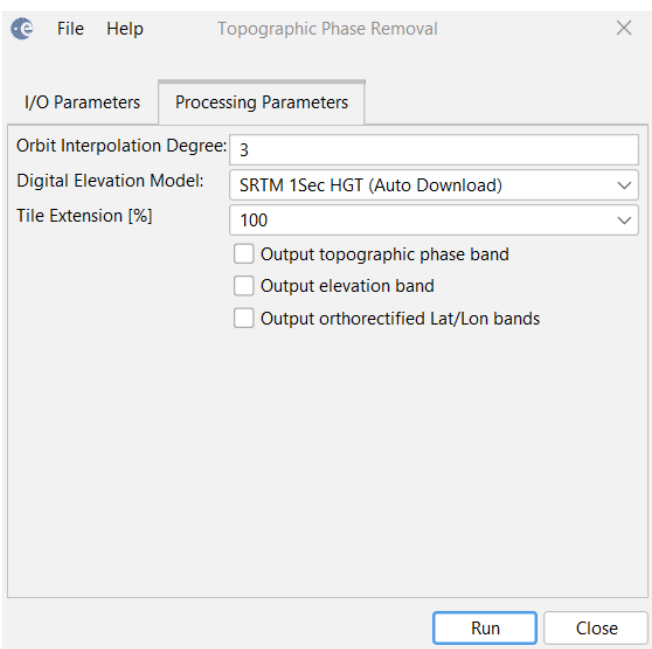

Figure 16: DEM selection on the "Topographic Phase Removal" tool.

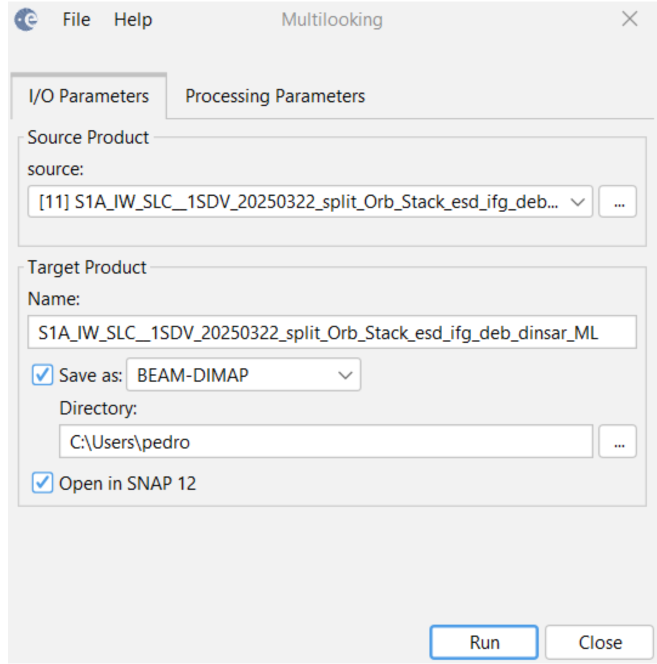

Figure 17: Application of the "Multilooking" tool on my topography-less file.

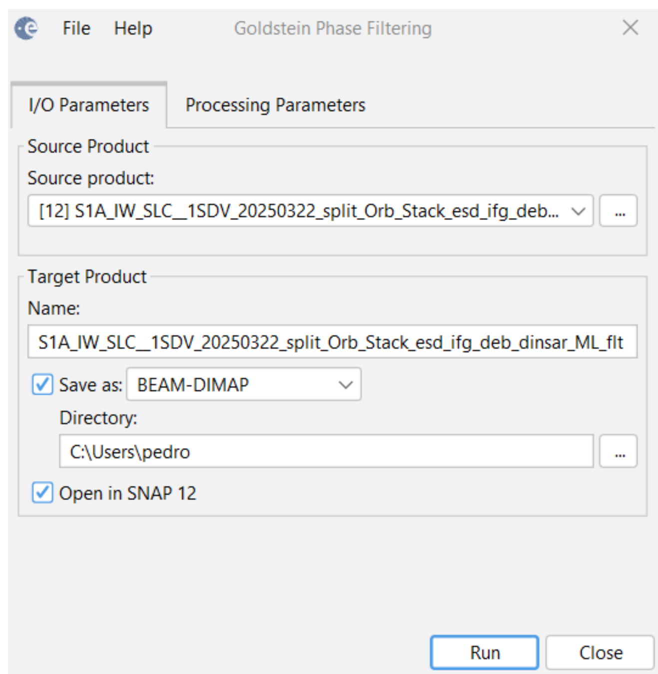

Figure 18: Application of the "Goldstein Phase Filtering" tool on my multilooking product file.

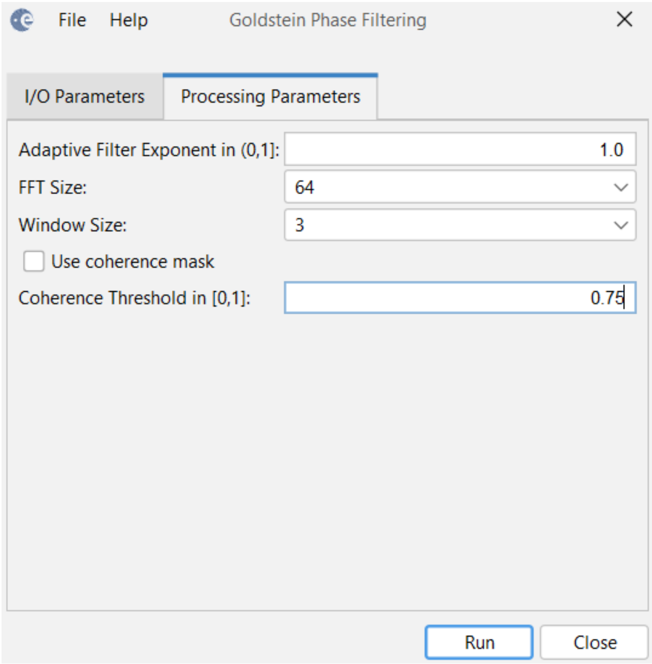

Figure 19: Coherence threshold selection on the "Goldstein Phase Filtering" tool. I tried 0,75, 0,8, 0,9 and 0,95 with no visible differences.

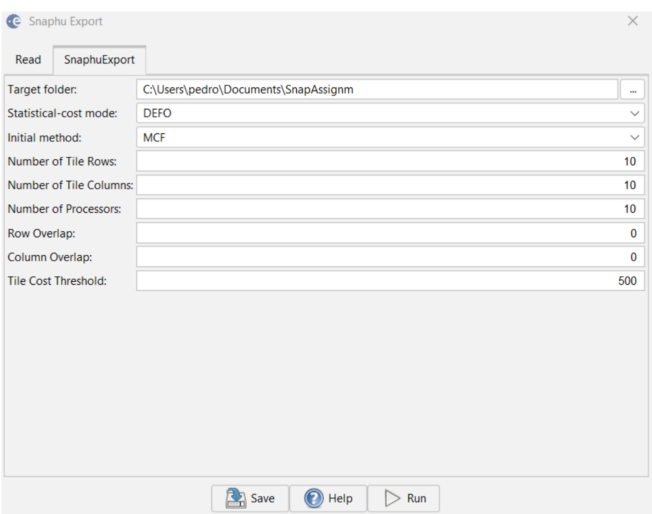

Figure 20: Settings of the "Snaphu Export" tool. I increased the Number of Processors from 4 to 10 (my computer's maximum) to increase the speed of the time-consuming calculations that followed.

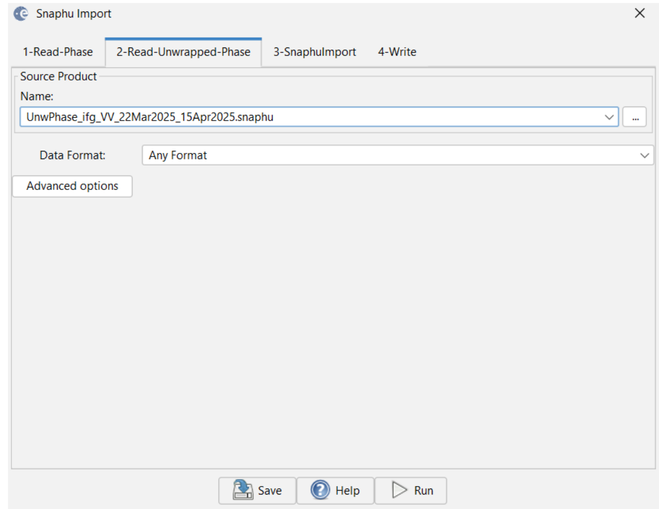

Figure 21: Selection of the "Unwrapped-Phase" file in the "Snaphu Import" tool.

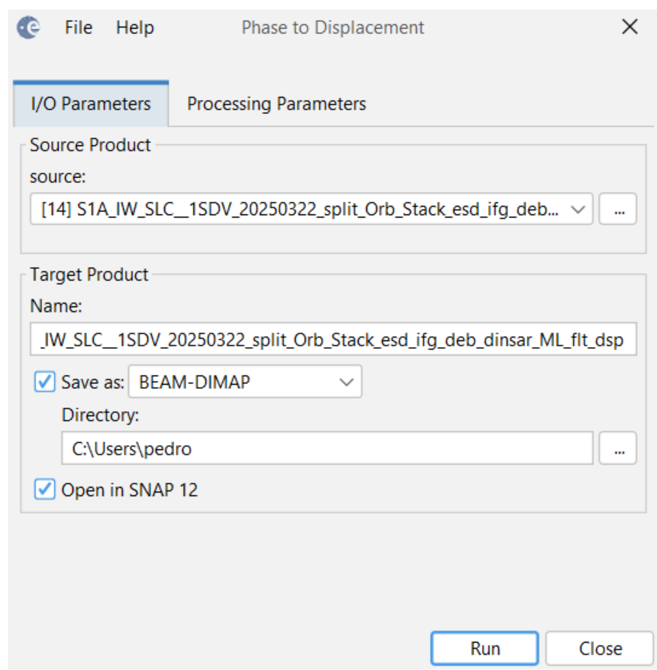

Figure 22: Application of the "Phase to Displacement" tool on my file with the new unwrapped phase layer.

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