GEOS 639 – Geodetic Imaging

Lab 2 / Homework 2: Mapping Topography with InSAR using SNAP

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Homework 2 issue Date: Feb 13, 2024 **Homework 2 due date: Feb 22, 2024**

This Lab includes THREE assignments

1 Introduction

In this lab, we will generate a DEM for a pair of ALOS PALSAR L-band SAR acquisitions over Okmok Volcano, AK. ALOS PALSAR is chosen as this sensor provides sufficient spatial baselines for DEM generation. You can learn more about ALOS PALSAR on the websites of the **Alaska Satellite Facility (ASF)**. The lab will walk you through the InSAR processing workflow using the **SNAP toolbox**, a freely available remote sensing data analysis toolbox distributed by the European Space Agency.

2 Preparation

2.1 Selection of suitable images

A crucial step for a successful DEM generation is the selection of an image pair with suitable properties. Among others, favorable conditions include:

- **Short temporal baseline**: The time between the first and the second image should be kept as short as possible to reduce the risk of temporal decorrelation of the phase. This happens over vegetation and water areas, but also under changing moisture conditions, moving objects ect. To minimize temporal decorrelation we are working with an L-band data pair from ALOS PALSAR in this exercise. If you have strong seasonality, try to find image pairs at times of minimum vegetation cover.
- **Suitable perpendicular baseline**: The distance between the satellites' positions at the time of image acquisition should be long enough to warrant sufficient sensitivity to topography. In our example, the perpendicular baseline is close to 1000m. If the perpendicular is too small, these topographic effects on the differential phase are not pronounced enough. With too large baselines, the coherent phase is increasingly different, also leading to decorrelation.
- **Suitable atmospheric conditions**: Water vapor in the atmosphere causes phase delays and potentially decreases the quality of the measurement. It is therefore advisable to select images acquired during dry periods and to make sure that no rainfall occurred during both image acquisitions.

2.2 Download the Data

The data used in this tutorial can be downloaded from the Alaska Satellite Facility's (ASF) Vertex search client at **https://search.asf.alaska.edu/** (login required, registration is free)

Search for the following two products and download the Level 1.1 version (SLC) of the data:

- ALPSRP137311060
- ALPSRP144021060

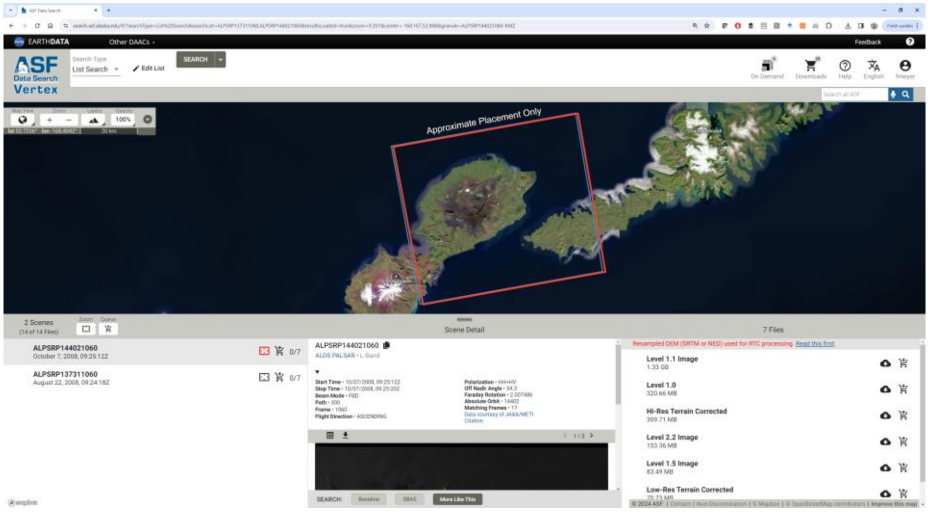


Figure 1: Screenshot of ASF's Vertex client showing the names and locations of the data we will be working with in this lab.

I created this search already for you. Click **[this link]** and you will see the data we need right away. **Figure 1** shows a screenshot of ASF's Vertex client showing the names and locations of the data we will be working with in this lab. Click on the download button on the bottom right pane of the interface to download each of the two images.

Unzip the files after you downloaded them to prepare them for further processing.

As some of the required steps are computationally intensive, it is good to store the data at a location that offers good reading and writing speed. If your computer has an internal SSD, processing should be done there to ensure best performance. Network drives or external storage devices are not recommended. Also, paths which include special characters should be avoided.

2.3 Install the SNAP snaphu Plugin

This tutorial can entirely be done within SNAP. Yet, as an external software package, snaphu (statistical cost network-flow algorithm for phase unwrapping) has to be installed separately. For more information on this tool, please visit this website. To install the plugin in SNAP, go to Plugins (under the Tools menu, **Figure 2**) and search for "SNAPHU Unwrapping" in the Available Plugins tab. Select it and click Install.

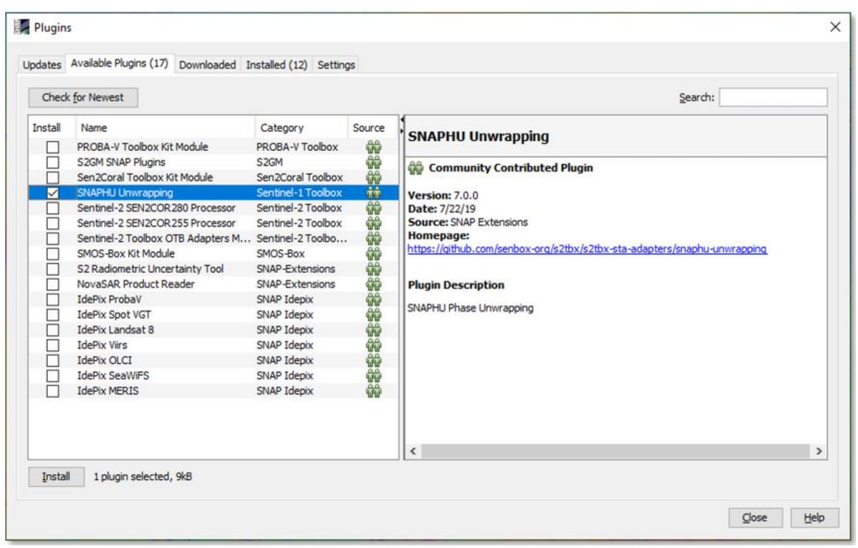


Figure 2: The Plugins interface.

You will be asked to proceed with "Next" and restart SNAP. This creates a menu entry for snaphu unwrapping in the Interferometry menu.

After you have restarted SNAP, you need to install the snaphu bundles as well. Go to *Manage External Tools* in the *Tools* menu. Select "Snaphu-unwrapping” and click **Edit the selected operator** to open the configuration (**Figure 3**). Select a suitable Target Folder where snaphu will be installed and proceed with **Download and Install Now**. You will then get a confirmation “Bundle was installed in location your location” (this may differ according to version, path and operating system).

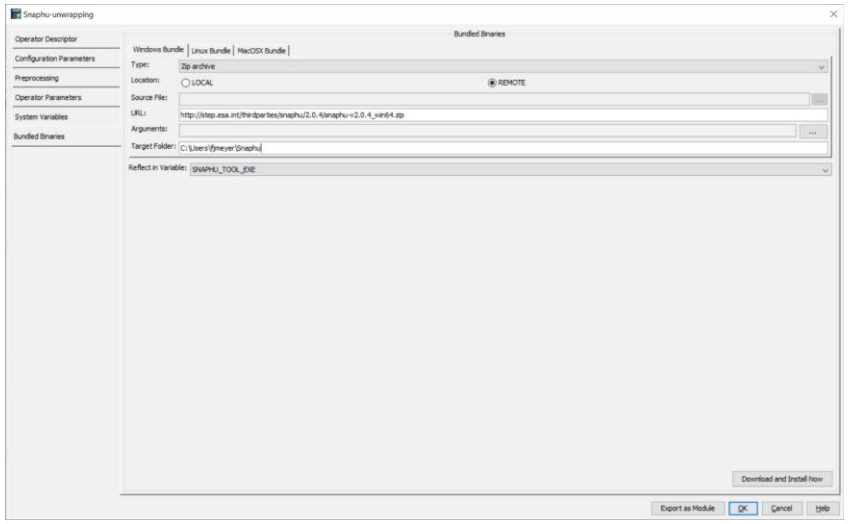


Figure 3: Installation of the snaphu bundles.

3 Open the Products

Use the *Import / SAR Sensors / ALOS PALSAR CEOS* option in the *File* menu (**Figure 4**) and browse for the location of the downloaded data. You will have to import the two products separately.

In the Products View you will see the opened products. Each ALOS PALSAR product consists of Metadata, Vector Data, Tie-Point Grids, and Bands (which contains the actual raster data, organized by polarization). If you still want to check the data before InSAR proceeding double-click on the Intensity_HH band to view the raster data.

Another way to identify the location of your study area within the product, you can use the World View or World Map (to see its full extent on a base map) The World View or World Map menus are also a good way to check if your image belong to the same relative orbit (required for interferometry).

4 Check baseline information

As already indicated in the introduction, the quality which can be expected from DEM generation strongly depends on the properties of the two images, most importantly the position of the satellites at the time of acquisition. Their relative distance is called the **perpendicular baseline**. The larger this difference, the more details will be contained in the computed interferogram with respect to elevation changes. As shown in Figure 5, a perpendicular baseline of 974.15 meters is found for our pair.

The time between the first and the second image is called the **temporal baseline**. The shorter this period the lower is the loss of interferogram quality due to phase decorrelation,

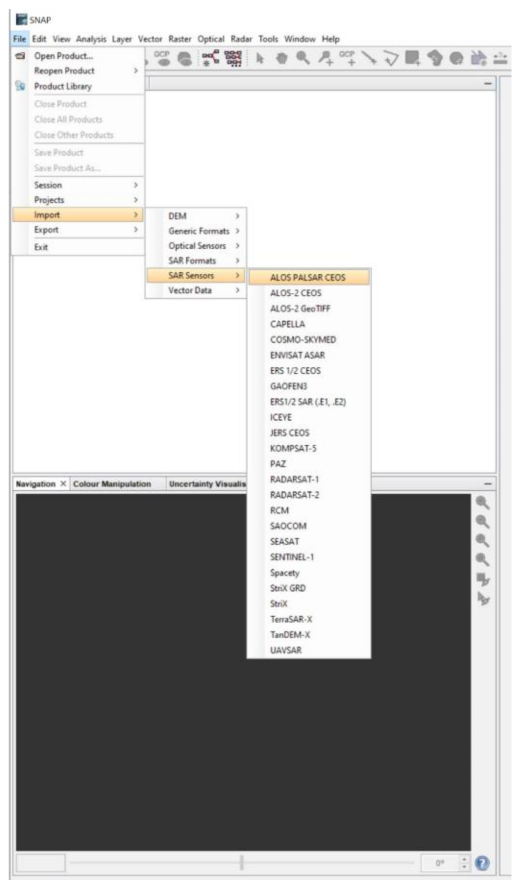


Figure 4: Importing the ALOS PALSAR data.

especially over natural surfaces. In our case the temporal baseline is 46 days.

To check the baseline information of your image pair, open *Radar / Interferometric / InSAR Stack Overview*. First, click on "Add Opened" to load the two Sentinel-1 products into the list at the top. Their acquisition date, track and orbit should now be displayed. Secondly, click "Overview" to load their metadata. The list at the bottom should then show information on (Figure 5):

- perpendicular baseline (Bperp) [meters]
- temporal baseline (Btemp) [days]
- the modelled cohererence [0-1]
- height ambiguity [meters] how many meters of height difference are represented by one color cycle in the interferogram
- the mean Doppler centroid frequency difference

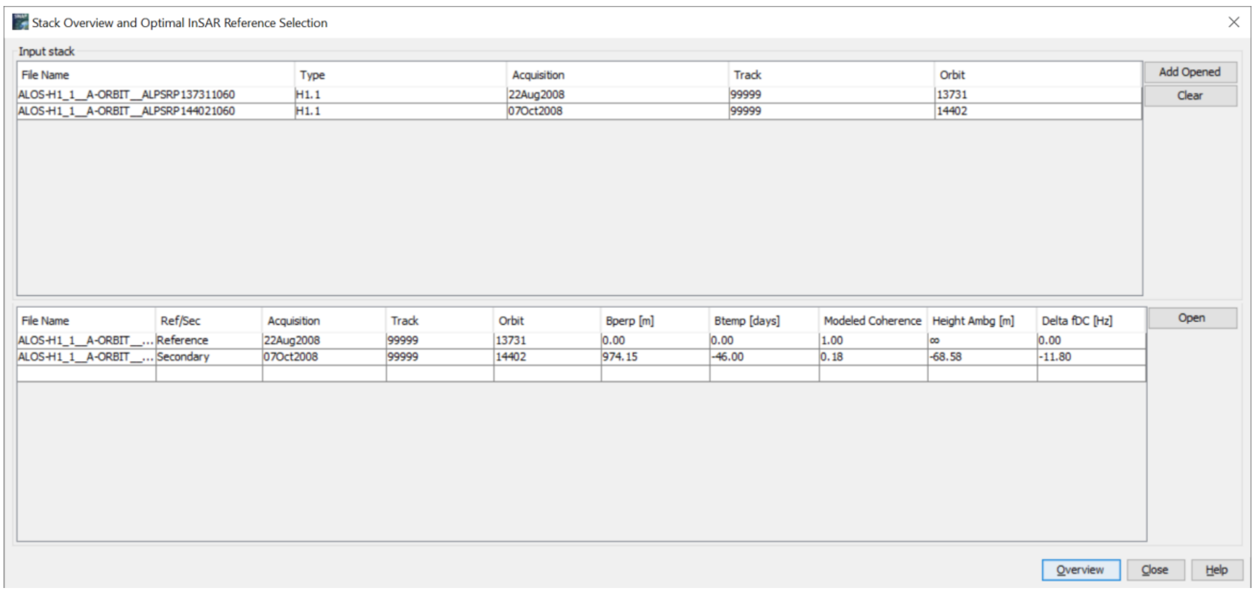


***Figure 5**: Importing the ALOS PALSAR data.*

Assignment #1: Sensitivity to Topography and Baseline Length – [5 points]

Based on the baseline information for your data, how much height difference $h_{2\pi}$ is needed to change the phase by 2π (one fringe). Use the equations from the class lectures to answer this question

5 Coregistration

To exploit the phase difference of the acquisitions, a stack containing both products must be created first. Coregistration makes use of image statistics to align both products at sub-pixel accuracy. For ALOS PALSAR, a conventional Stripmap radar product, coregistration can be completed in a single step. Note that for Sentinel-1, co-registration is a bit more complicated and requires several step to complete.

To perform coregistration, go to Radar / Coregistration / Coregistration. In the interface, click on the *Add Opened* icon.

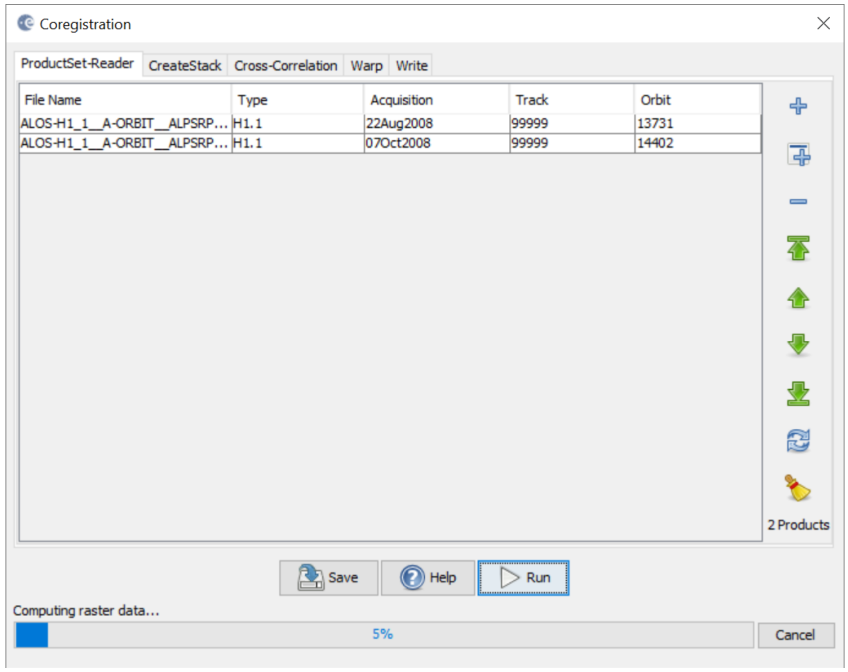


Figure 6*: Coregistration interface.*

Click on **Run** (**Figure 6**). This step will take a few minutes.

6 ALOS Deskewing

As ALOS PALSAR data are not acquired in a zero-doppler geometry, a deskewing operation on the co-registered stack needs to be performed before interferogram formation. To perform this step select *Radar / Geomettric / ALOS Deskewing*. Use the coregistered stack as input and click **Run**.

7 Interferogram Formation and Coherence Estimation

An interferogram is formed by cross multiplying the reference image with the complex conjugate of the secondary image. The amplitude of both images is multiplied while the phase represents the phase difference between the two images. The interferometric phase of each SAR image pixel would depend only on the difference in the travel paths from each of the two SARs to the considered resolution cell.

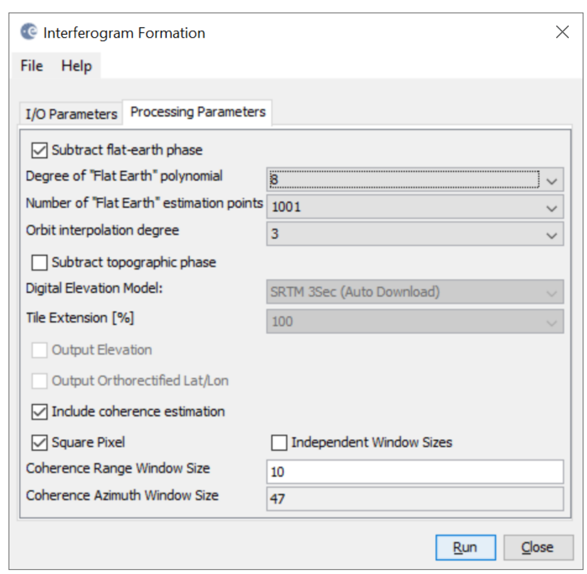


Figure 7*: Options for interferogram formation.*

Coherence is calculated as a separate raster band and shows how similar each pixel is between the secondary and reference images in a scale from 0 to 1. Areas of high coherence will appear bright. Areas with poor coherence will be dark. In our dataset, we observe

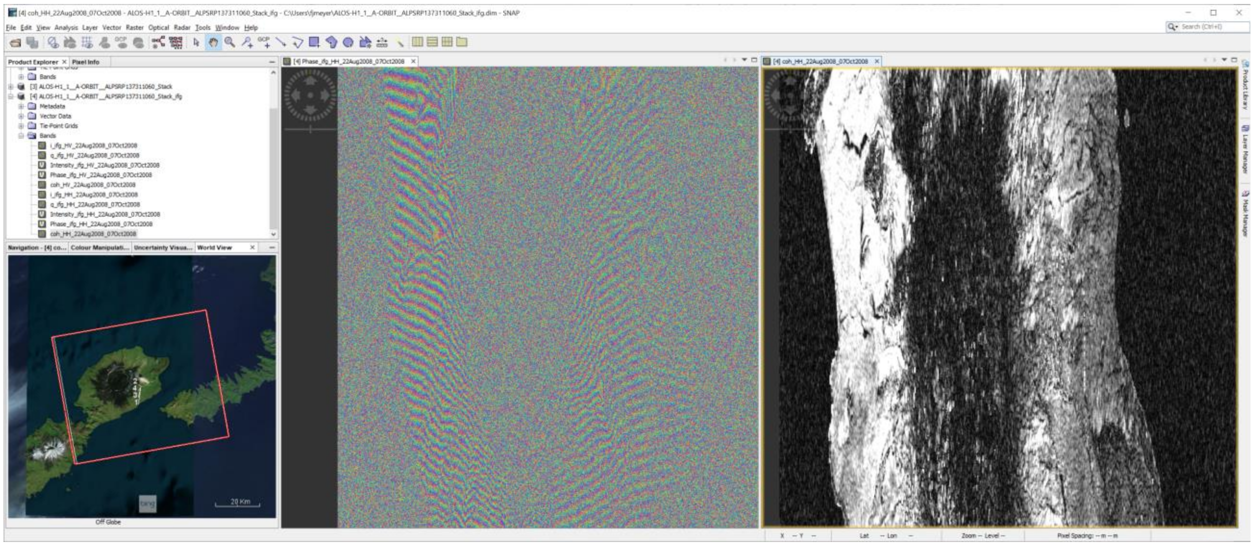


Figure 8: Phase and Coherence of our Okmok Scene.

decorrelation near the crater of Okmok. This is probably due to continued chances in the caldera after the 2008 eruption and due to potential snowfall that may have happened at high altitudes between the two acquisition times.

To compute the interferogram and the coherence bands go to *Radar / Interferometric / Products / Interferogram Formation*. Ensure that the output of the previous processing step is selected as input to the interferogram formation step. Make sure to check the boxes (**Figure 7**):

- **Subtract flat-earth phase**: The flat-earth phase is the phase present in the interferometric signal due to the curvature of the reference surface. The flat-earth phase is estimated using the orbital metadata information and subtracted from the complex interferogram.
- **Include coherence estimation**: This produces a coherence band in the output calculated based on a window of 10x3 pixels in range/azimuth direction.

Please do not check "Subtract topographic phase", because this is the information if interest.

In **Figure 8**, the interferogram is displayed in a rainbow color scale ranging from topography, atmosphere and potential surface deformation (considered zero). The patterns, also called fringes appear in an interferogram as cycles of arbitrary colors, with each cycle representing half the sensor's wavelength. To derive a DEM of sufficient quality, these fringes must be visible throughout the entire image. Areas of phase decorrelation appear as noise in the interferogram.

The coherence shows the areas where the phase information is coherent, which means that it can be used to measure topography (as in this tutorial) or deformation (includes removing the topographic phase). While large areas show high coherence (above 0.6), there is decorrelation near the summit of Okmok.

Assignment #2: Flat Earth Phase Correction -- [5 Points]

During Lectures 5 and 6 (InSAR), we saw that before flat earth correction, the interferogram contains many fringes. Here a couple of short questions related to that:

- **Question 2.1**: In addition to improve the visualization of InSAR data, one important reason why we remove the flat earth phase from interferograms is to make phase unwrapping easier. Explain in a few sentences why you think removing the flat earth phase makes phase unwrapping less complicated. To answer this question, please edit the markdown cell below. **-- [3 Points]**

- **Question 2.2**: It turns out SNAP would allow to reduce the unwrapping complexity even more. Instead of "just" removing the flat earth phase, it makes it possible to also subtract any already know topography from the interferogram by using an existing DEM. Once this is done, what would the residual information in an interferogram represent? **-- [2 Points]**

8 Goldstein Phase Filtering

Interferometric phase can be corrupted by noise from temporal and geometric decorrelation, volume scattering, and other processing errors. Phase information in decorrelated areas cannot be restored, but the quality of the fringes existing in the interferogram can be increased by applying specialized phase filters, such as the Goldstein filter, which uses a Fast Fourier Transformation (FFT) to enhance the signal-to-noise ratio of the image. This is required for a proper unwrapping in the subsequent step. A detailed description of this filter and its parameters is given in the publication of **[Goldstein & Werner (1998)](#)**.

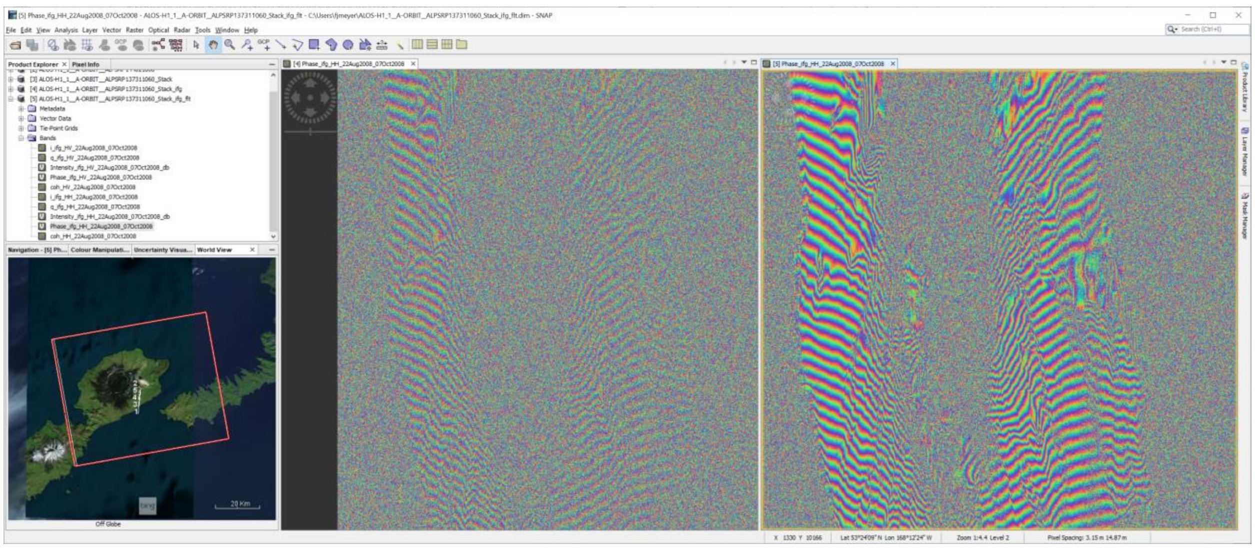


Figure 9*: Interferogram before and after phase filtering.*

Apply the Goldstein Phase Filtering by going to *Radar / Interferometric / Filtering* to the output of the interferogram formation step. The output is a filtered phase image, the coherence is not affected. **Figure 9** shows that the phase fidelity is significantly improved after filtering.

9 Multilooking

We will perform a multilooing step next to reduce the computational burden that we pass to the phase unwrapping step. We will perform multilooking in a way to achieve a square pixel of roughly 30m size on the ground.

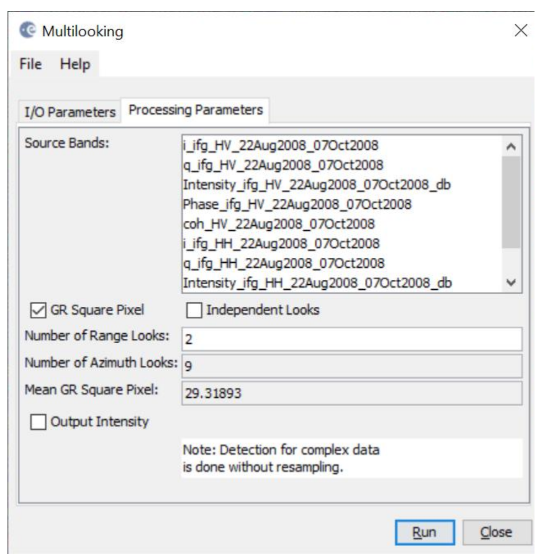


Figure 10*: Multilooking options.*

To perform multilooking go to *Radar / SAR Utilities / Multilooking*. Use the filtered phase product as input and set the mutllooking ratio to 2 x 19 pixels (**Figure 10**).

Interlude: Inspect your Multilooked Interferogram

Open the HH band of your multilooked interferogram. You may notice that there are a lot of fringes running across Unimak island, the island that houses Okmok volcano (**Figure 11**). These fringes can be caused by one of two issues:

1. An error in the baseline estimates (caused by poor orbit information) can cause these issues. Poor baseline info will cause the flat earth phase estimation to be incorrect and can result in the observed phase ramps.
2. Alternatively, these errors can be caused by ionospheric impacts. L-band data are sensitive to ionospheric phase delay and may show ramps caused by gradients in the ionospheric electron content.

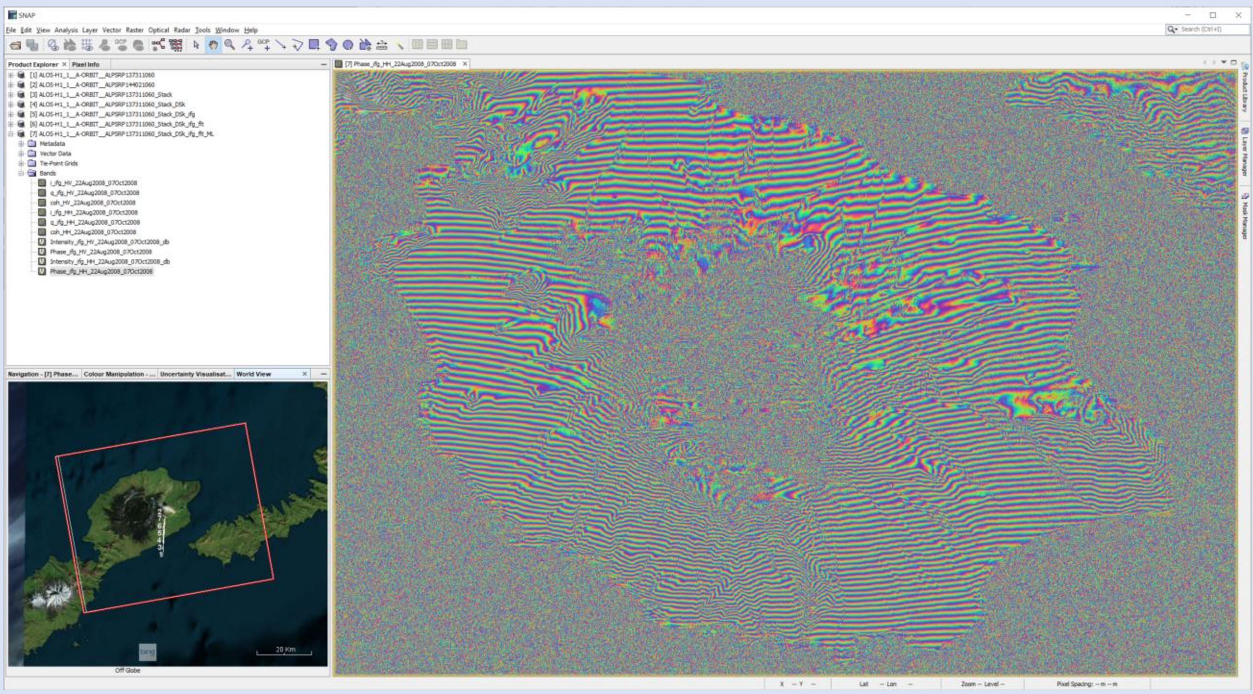


Figure 11: Your interferogram may show these phase ramps.

For now we will just accept these phase ramps as they are. Continue with the data as is to the next steps.

Note: Unwrapping may fail on you. The connection between SNAP and Snaphu in the latest versions of SNAP seems brittle. It worked for me off and on. If it fails on you, don't worry. Please proceed with Step 13.

10 Phase Unwrapping

To be able to relate the interferometric phase to the topographic height, the phase must first be unwrapped. Phase unwrapping solves this ambiguity by integrating phase difference between neighboring pixels. The unwrapped results should be interpreted as a relative height/displacement between pixels of two images.

For optimal unwrapping results it is recommended to filter the interferogram as done in the previous step. The quality and reliability of unwrapped results very much depends on the input coherence. Reliable results can only be expected in areas of high coherence.

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

Because snaphu is an independent software, the unwrapping is executed outside SNAP, but the plugin allows to call this execution, so no command line processing is required.

Depending on the capabilities of the system, the unwrapping can take a considerable amount of time. However, snaphu supports multi-threading which means that the computation can be distributed over multiple processor cores. This has to be defined during the export.

10.1 Export

The Export operator (under *Radar / Interferometric / Unwrapping*) converts the interferogram (as the wrapped phase) into a format that can be read by snaphu. A couple of parameters can be selected that affect the unwrapping process.

The source product is the filtered interferogram prom the previous step. In the SnaphuExport tab, select your working directory as the target folder (here: `C:\Users\fjmeyer`). If the selection of the directory does not work, simply copy and paste the path of your working directory into the text field. Select **TOPO** as *Statistical-cost* mode and select 500 pixels for *Row Overlap and Column Overlap*. Depending on the number of processors available on your computer, you can also increase the *Number of Processors* variable (**Figure 12**).

Note: You can neglect the eventual error message (`Error: [NodeId: SnaphuExport Please add a target folder`]. It will go away once you

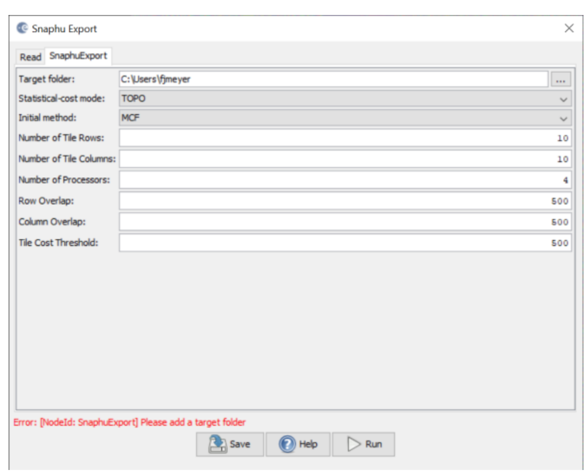


***Figure 12**: Snaphu Export.*

switch tabs or hit **Run**, as long as you have entered a valid target folder.

Hit Run to start the export. A directory is created in your working directory with the same name as the product you selected as an input. Inside this folder, you find:

- 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

10.2 Unwrapping with snaphu

Once the product is exported correctly, the unwrapping can be started from within SNAP, by calling the *Snaphu-unwrapping* operator under *Radar / Interferometric / Unwrapping*. As an input product, select the filtered phase product created before the export from the drop-down menu (**Figure 13**). For the output folder in the *Processing Parameters* tab you can activate **Display execution output** and select the folder that was created during the export (here: ALOS-H1_1__A-ORBIT__ALPSRP137311060_Stack_ifg_flt). To start the unwrapping, click **Run**. SNAP then sends the command stored in snaphu.conf to the snaphu.exe which creates the raster image belonging to the unwrapped phase metadata.

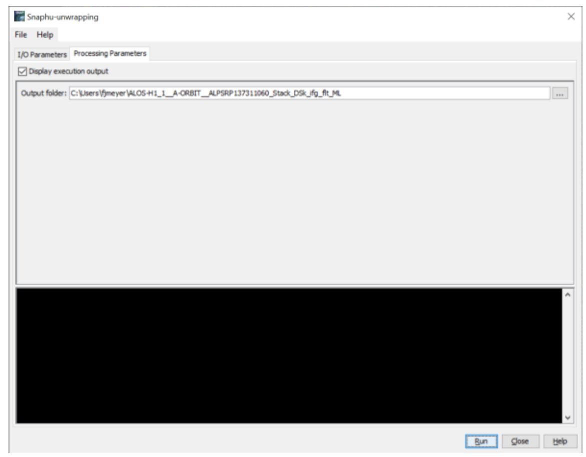


***Figure 13**: Snaphu unwrapping interface.*

10.3 Import

The *Snaphu import* (under *Radar / Interferometric / Unwrapping*) converts the unwrapping ouput back into a format SNAP understands and adds the required metadata from on the wrapped phase product as they have the same geometry. The Snaphu import needs the following tabs:

1. **Read-Phase**: Here, you select the multilooked interferogram (before the export) from the dropdown menu.
2. **Read-Unwrapped-Phase**: Navigate to the export directory. Select the *.hdr file of the unwrapped phase (here UnwPhase_ifg_[…].hdr). Note: The error message will then vanish if you proceed to the next tab.
3. **SnaphuImport**: Leave the option "Do NOT save Wrapped interferogram in the target product" unchecked, because it is required in the later step.
4. **Write**: To store the imported unwrapped band in a separate product (recommended), add '_unw' to the output name and click **Run**.

A new product is added to the Product Explorer which contains the wrapped interferogram, the coherence, and the unwrapped phase generated with snaphu.

Double click on the 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 (Figure 28). Unwrapping errors can occur in areas of low coherence and in urban areas with many vertical objects.

If you notice strange grid-like patterns in your unwrapped results, you can change the amount of tile columns and rows in the export (or directly in the snaphu.conf file) and run the unwrapping again. Just make sure you delete the unwrapped phase (UnwPhase_ifg_[…].img) and the temporary files in the export directory before you restart the unwrapping.

11 Phase to Elevation

The unwrapped phase is now a continuous raster but not yet a metric measure. To convert the radian units into absolute heights, the *Phase to Elevation* operator (under *Radar / Interferometric / Products*) is applied. It translates the phase into surface heights along the line-of-sight (LOS) in meters. The LOS is the line between the sensor and a pixel. A DEM is used to put the elevation values in the correct level.

In the Processing Parameters tab, select Copernicus 30m global DEM (AutoDownload) as input DEM. The operator is applied to the unwrapped phase that 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 height above sea level.

12 Terrain Correction

Terrain Correction will geocode the image by correcting SAR geometric distortions using a digital elevation model (DEM) and producing a map projected product.

Open the *Range Doppler Terrain Correction* operator (under *Radar / Geometric / Terrain Correction*). Select the elevation product as an input in the first tab.

In the Processing Parameters tab, select Copernicus 30m global DEM (AutoDownload) as input DEM. If you want to export the data as a KMZ file to view it in Google Earth WGS84 must be selected as Map Projection. If no Source Band is selected, all bands of the input product are geometrically corrected.

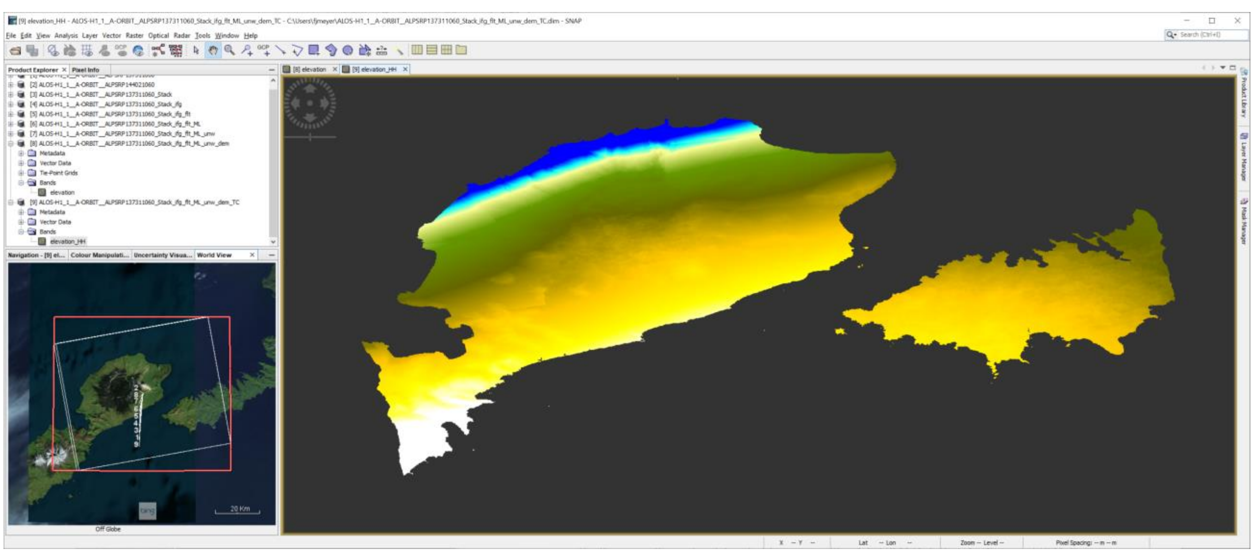


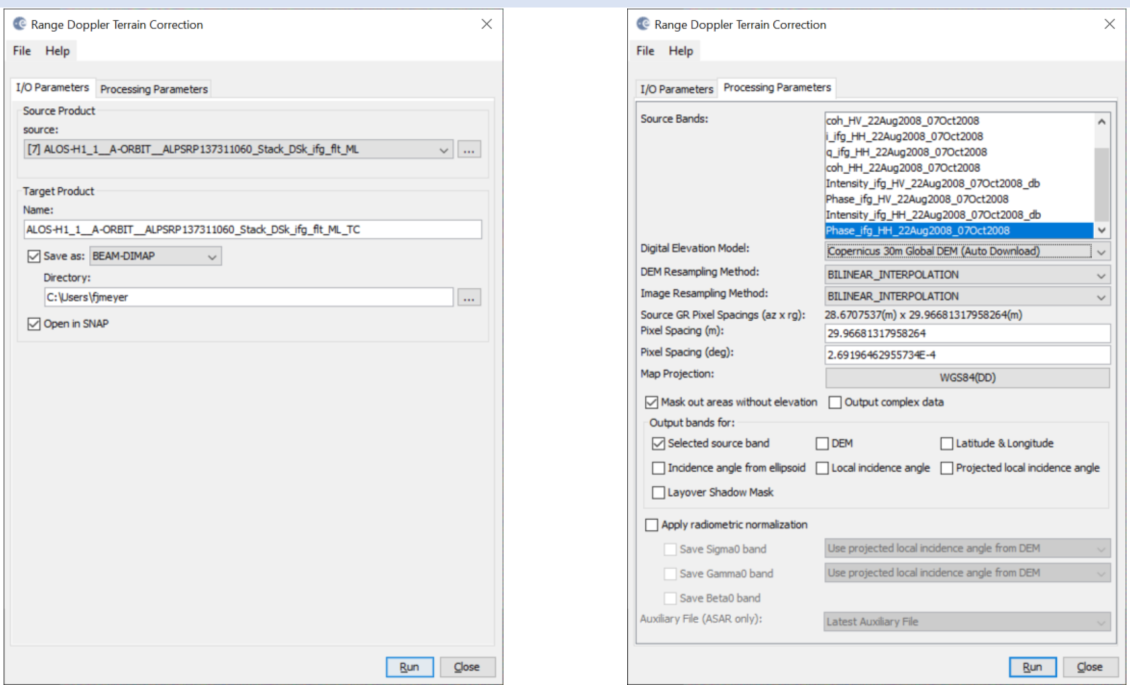
***Figure 14**: Terrain corrected and geocoded elevation raster.*

Click on Run to start the terrain correction. SNAP now establishes a connection to an external elevation database to download all SRTM tiles required to fully cover the input dataset. Once terrain correction is completed, you should see the image shown in Figure 14.

13 Alternative: Terrain Correct Wrapped Interferogram

If your unwrapping step does not succeed, geocode the wrapped interferogram instead. At the time of writing of this lab, the handoff between SNAP and the Snaphu unwrapping code is brittle and unwrapping only succeeds here and there. If your unwrapping fails, no worries. Please geocode the wrapped interferogram as your final project.

To terrain correct and geocode your wrapped interferogram, go to the *Range Doppler Terrain Correction* operator (under *Radar / Geometric / Terrain Correction*). Select the multilooked interferogram as input (**Figure 15a**). Make the following modifications to the *Processing Parameters* tab:



(a) (b)

Figure 15: Settings to be applied in the Terrain Correction Step to geocde the wrapped interferogram phase image.

- Select the **Phase_ifg_HH**… band for terrain correction (Figure 15b)
- Select the *Copernicus 30m Global DEM (Auto Download)* as your Digital Elevation Model.

My version of the terrain-corrected wrapped interferogram is shown in **Figure 16**.

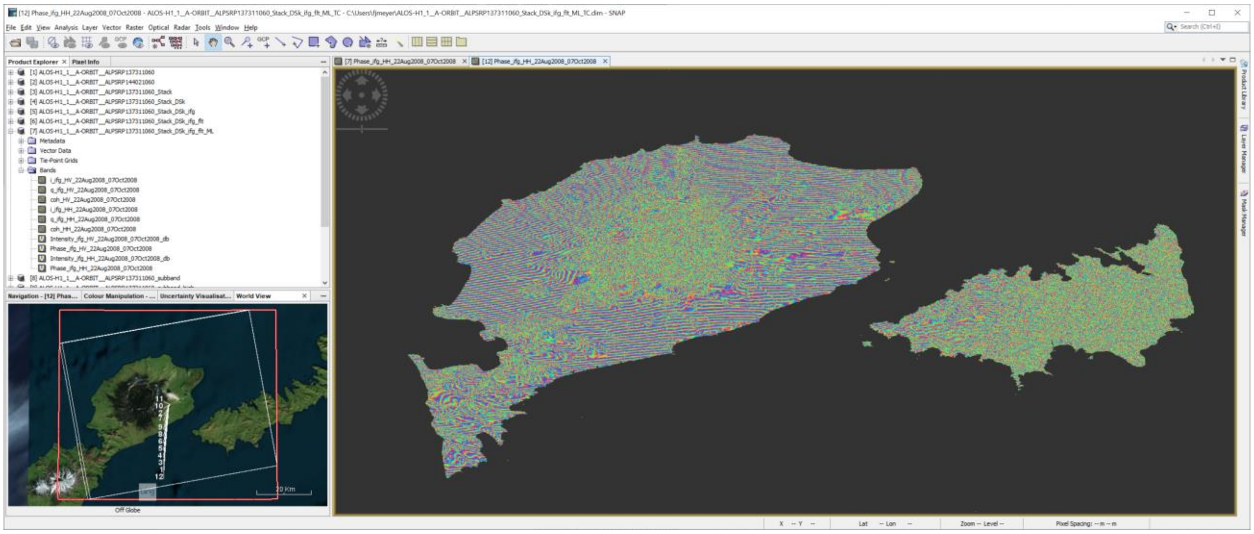


***Figure 16**: Terrain Corrected Wrapped Interferogram.*

Assignment #3: Show your Geocoded Product -- [10 Points]

Run the workflow all the way to this point and provide your result as a screenshot in your write-up. Provide eiher an image of your unwrapped and terrain corrected product or, if unwrapping failed, an image of your terrain corrected wrapped product. If your product looks very similar to either **Figure 14** or **Figure 16** then you succeeded with workflow.