

Sentinel-1 Toolbox

Stripmap Interferometry Tutorial

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Interferometry Tutorial

The goal of this tutorial is to provide novice and experienced remote sensing users with step-by-step instructions on interferometric processing with Sentinel-1 Stripmap (SM) products to generate a digital elevation model (DEM).

Background

What is Interferometry?

Interferometric synthetic aperture radar (InSAR) exploits the phase difference between two complex radar SAR observations taken from slightly different sensor positions and extracts information about the earth's surface.

A SAR signal contains amplitude and phase information. The amplitude is the strength of the radar response and the phase is the fraction of one complete sine wave cycle (a single SAR wavelength). The phase of the SAR image is determined primarily by the distance between the satellite antenna and the ground targets.

By combining the phase of these two images after coregistration, an interferogram can be generated whose phase is highly correlated to the terrain topography. The remaining variation in the interferogram can be attributed to surface changes which occurred between the two image acquisition dates, as well as unwanted atmospheric effects. In this tutorial, surface heights and landforms are derived from an image pair of two Sentinel-1 Stripmap products.

For an introduction to interferometric concepts, please see ESA's [InSAR Principles: Guidelines for SAR Interferometry Processing and Interpretation \(ESA TM-19\)](#).

Sentinel-1 Stripmap Products

While the Interferometric Wide (IW) swath mode is the standard configuration of the Sentinel-1 mission, Stripmap products are only acquired over selected parts of the earth, according to the [observation scenario](#). Until January 2020, a total number of 8189 products was made available through the [Copernicus Open Access Hub](#) (according to a search for `Product Type = SLC` and `Sensor Mode = SM`).

The Stripmap (SM) mode of Sentinel-1 acquires six overlapping swaths images ([S1 - S6](#)) at a width of 80 km and each swath range of 60 km to form a seamless image with a footprint of 80 x 375 km (Figure 1). Its spatial resolution ranges between 1.7x 4.9 m and 3.6 x 4.9 m (single look), depending on the swath, so that a final ground range resolution of 5 x 5 m can be achieved.

Depending on its configuration, the SM acquisitions consist of single (HH or VV) or dual polarization (HH+HV or VV+VH).

More information on Sentinel-1 SM products is provided here: <https://sentinel.esa.int/web/sentinel/user-guides/sentinel-1-sar/acquisition-modes/stripmap>.

The data used in this tutorial is a part of a Sentinel-1 SM acquisition in Western Africa and covers an area of ca. 50 x 75 km (Figure 2, blue line). It belongs to the Sahara Desert and has very little vegetation cover, which is a favorable precondition for radar interferometry.

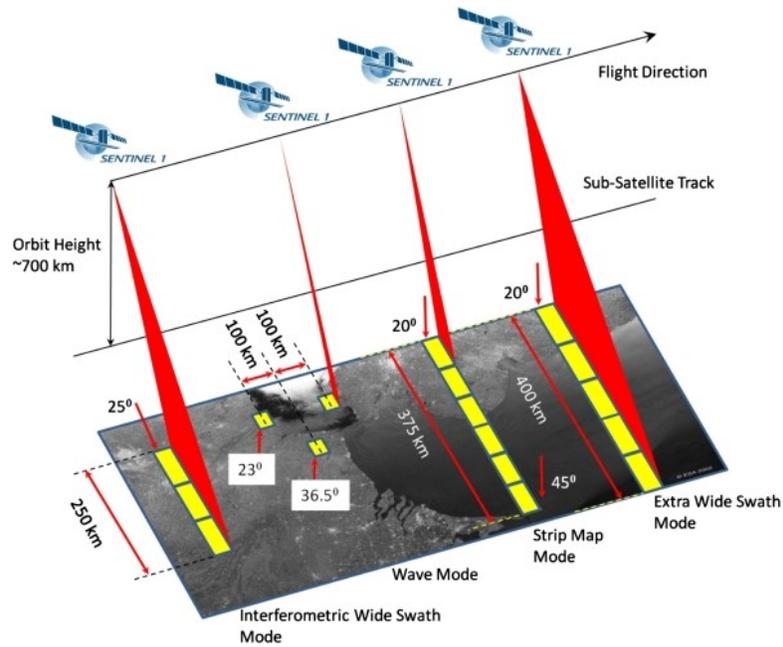


Figure 1: Sentinel-1 acquisition modes (© 2020 ESA)

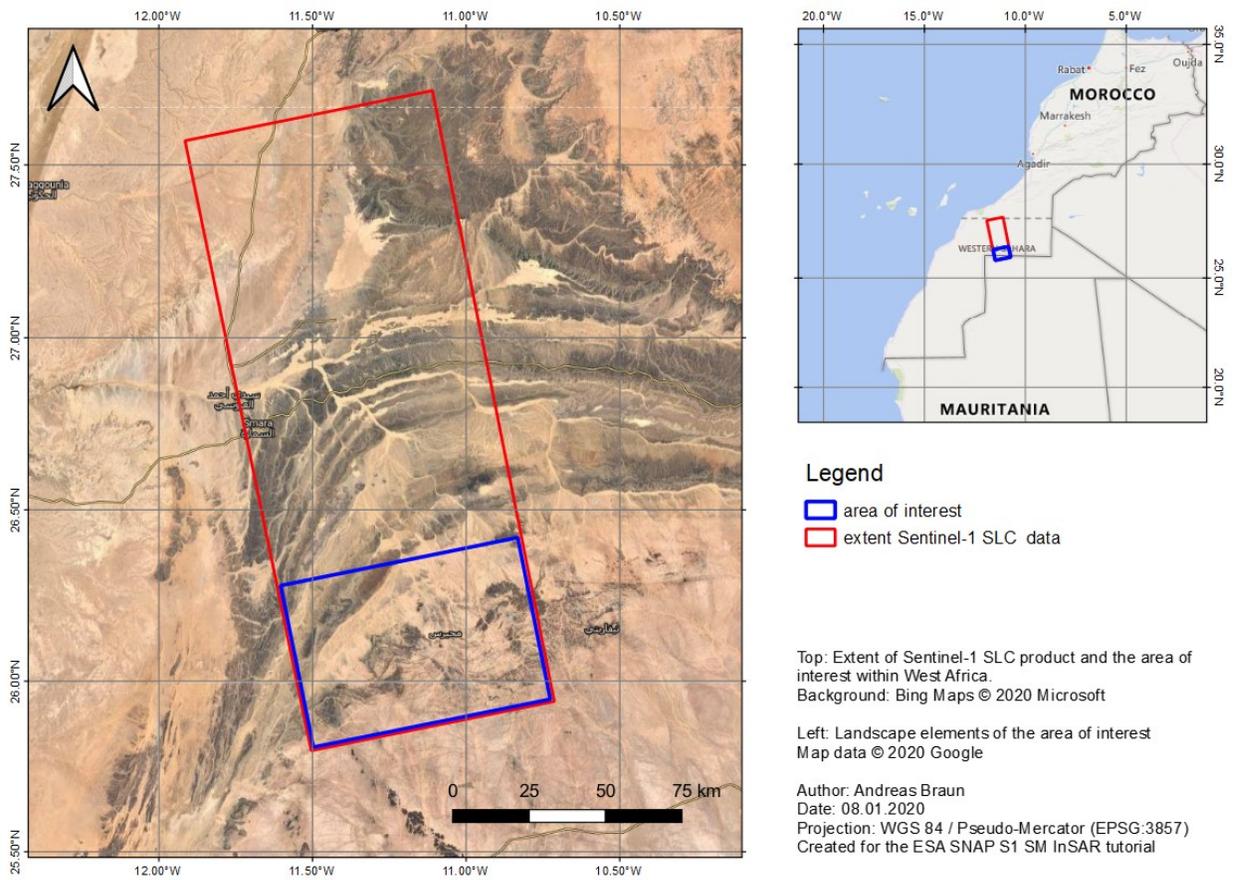


Figure 2: Extent and location of the data

Preparation

Download the Data

The data used in this tutorial can be downloaded from the Copernicus Open Access Hub at: <https://scihub.copernicus.eu/dhus> (login required, registration is free)

Search for the two product IDs, download them and extract the downloaded zip files to a suitable location:
 S1A_S1_SLC__1SSV_20181227T184017_20181227T184047_025215_02C983_C8A6
 S1A_S1_SLC__1SSV_20190108T184017_20190108T184046_025390_02CFD5_FCEB

As some of the required steps are computationally intensive, it is good to store the data at a location which 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. In this tutorial, the data is stored under `C:\Temp\S1_InSAR_SM\`.

Install *snaphu*

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 <https://web.stanford.edu/group/radar/softwareandlinks/sw/snaphu/>.

To install the plugin in SNAP, go to *Plugins* (under the *Tools* menu, Figure 3) and search for “SNAPHU Unwrapping” in the *Available Plugins* tab. Select it and click **Install**.

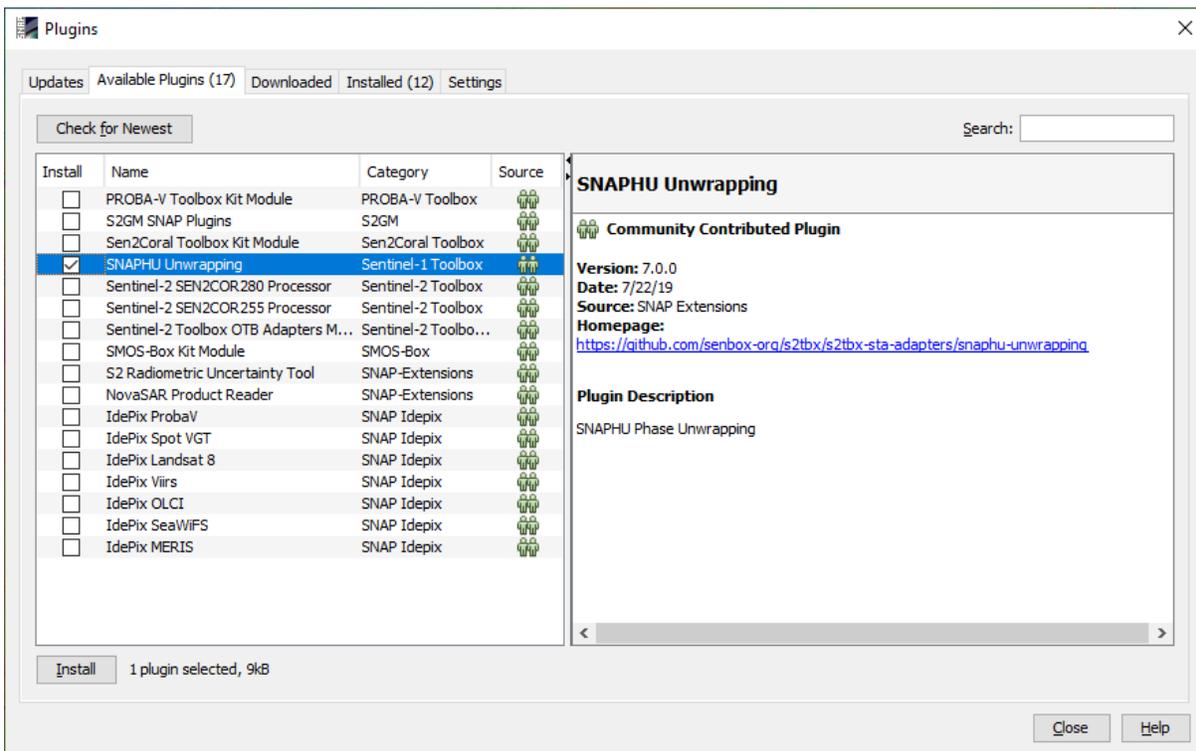


Figure 3: The Plugins interface

You will be asked to proceed with “Next” and restart SNAP (Figure 4). This creates a menu entry for *snaphu* unwrapping in the Interferometry menu.

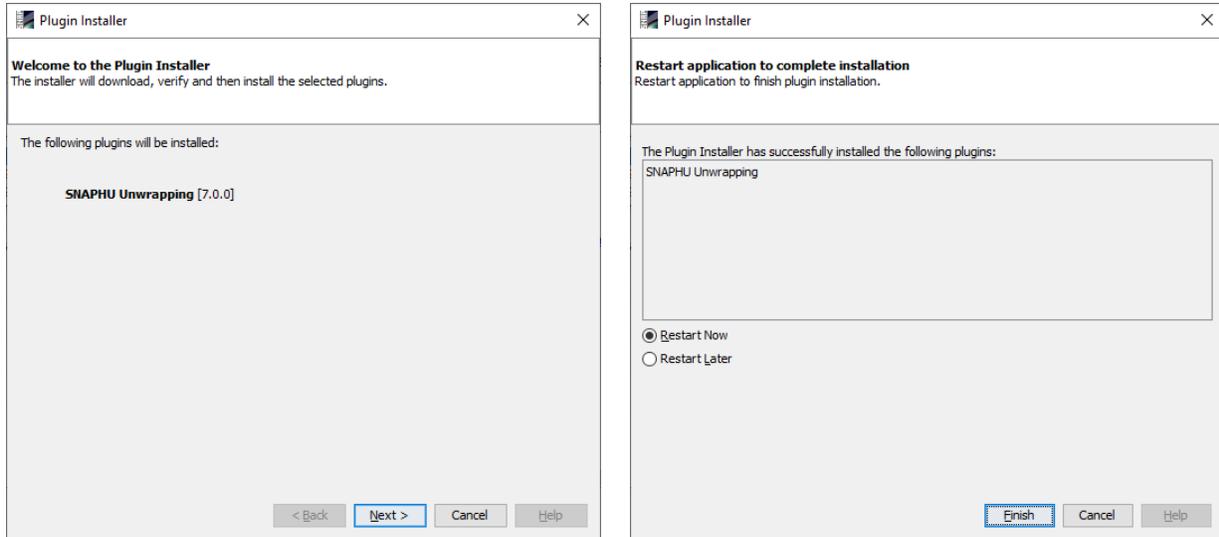


Figure 4: Installation of the snaphu plugin

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 5). Select a suitable Target Folder (here C:\GIS) where snaphu will be installed and proceed with **Download and Install Now**. You will then get a confirmation “Bundle was installed in location C:\GIS\snaphu-v1.4.2_win64” (this may differ according to version, path and operating system).

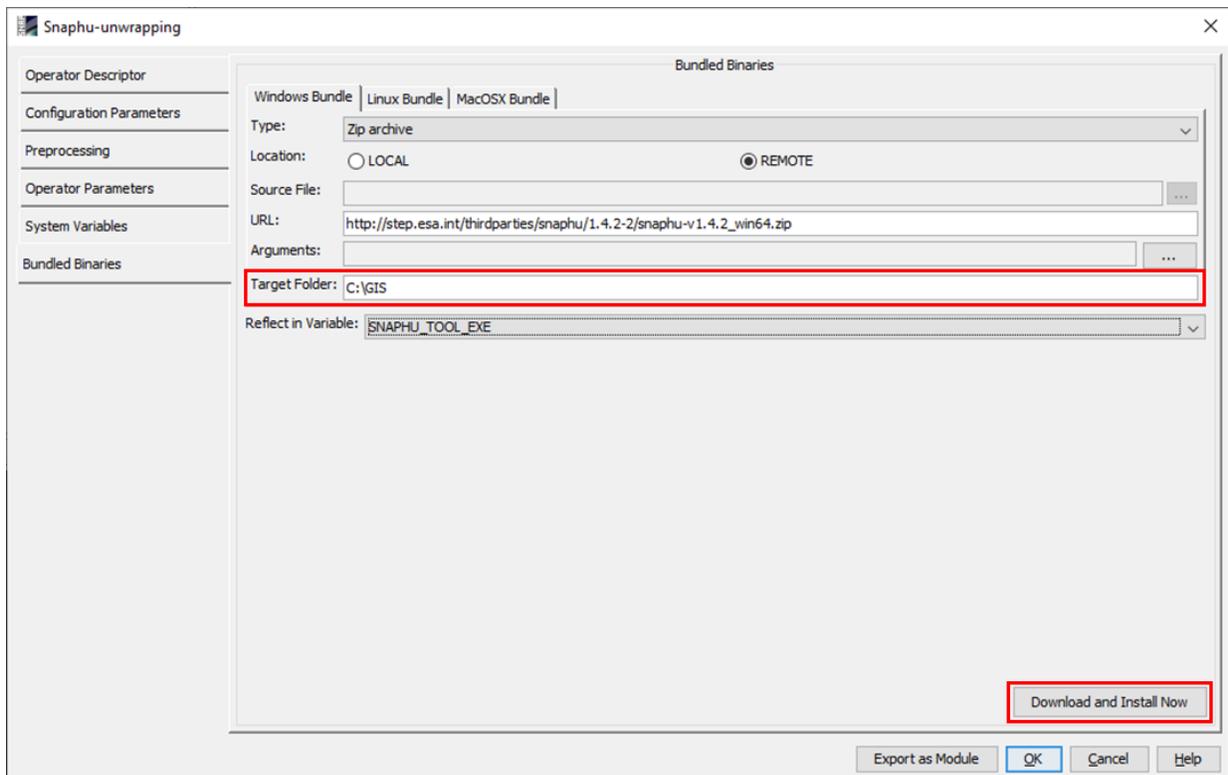


Figure 5: Installation of the snaphu bundles

Open the Products

Use the *Open Product* button in the top toolbar and browse for the location of the downloaded data. Select the `manifest.safe` file located in each of the two extracted folders and press **Open Product**.

In the *Products View* you will see the opened products. Each Sentinel-1 product consists of *Metadata*, *Vector Data*, *Tie-Point Grids*, *Quicklooks* and *Bands* (which contains the actual raster data, represented by `i_VV`, `q_VV` as the real and imaginary parts of the complex radar product and the resulting intensity as demonstrated in Figure 6).

Double-click on the `Intensity_VV` band to view the raster data (Figure 7). Depending on the capabilities of your computer, this might take a while. To reduce the amount of data, a subset is created in the next step which covers only a part of the dataset.

To identify the location of the area of interest within the entire product (required for the next step), you can use the *World View* or *World Map* (to see its full extent on a base map or open the *Quicklook* for a preview of the dataset).

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).

Note: If you miss any items in your user interface you can activate them in the menu under *View* and *Tool Windows*.

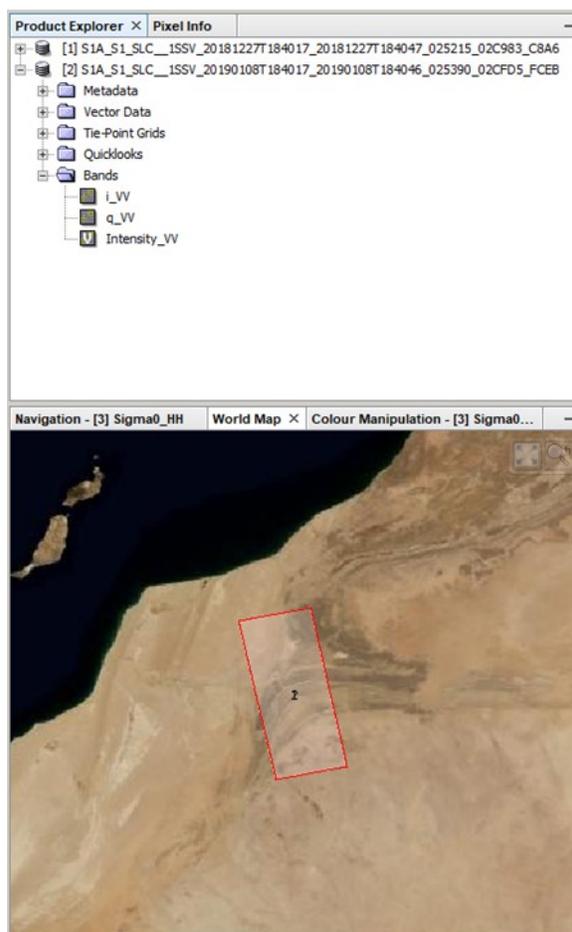


Figure 6: Product Explorer and World Map

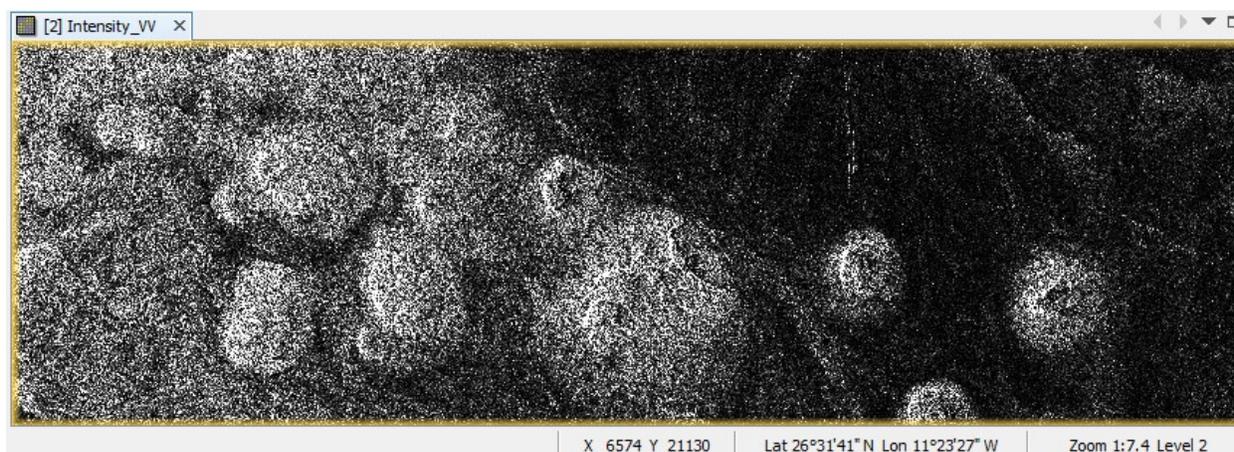


Figure 7: Preview of the S1 SM product

Create a Subset

To reduce the loaded data to the area of interest, select each of the two products and open the open the *Subset* operator (under *Raster*). A separate window might open (“Creating thumbnail image”), but this takes quite a long time, so it is ok to **Cancel** this window.

Check **Fix full width** at the bottom of the operator and enter the following pixel coordinates (Figure 8):

- Scene start X: 0
- Scene start Y: 0
- Scene end X: 21,301
- Scene end Y: 15,000

Confirm with **Run** and repeat the step for the second S1 image.

It is also possible to enter geographic coordinates, but as the product is still stored in slant range geometry, these are not very precise. Furthermore, it is possible to draw a rectangle in the image preview.

A new product is shown in the *Product Explorer*, starting with `subset_0_of_` for each subset. These products are only of temporary nature and lost after SNAP is closed. To permanently store them, right-click on the products, select **Save Product As...** and save them in BEAM DIMAP format under the names

- 20181227.dim
- 20190108.dim

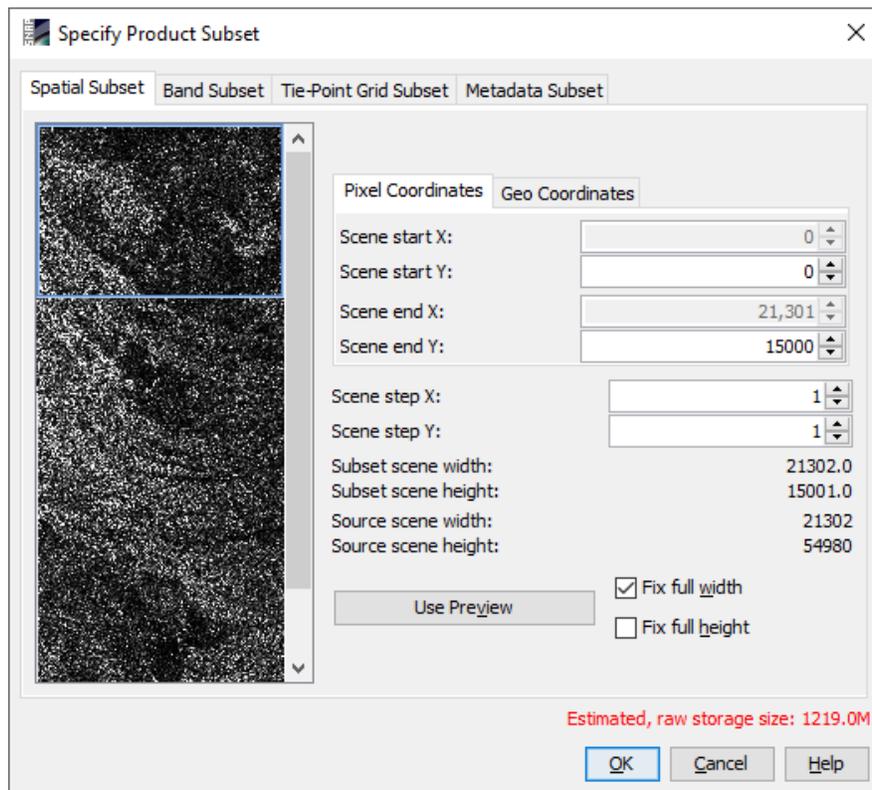


Figure 8: Creating a subset

Applying Orbit Information

Orbit auxiliary data contain information about the position of the satellite during the acquisition of SAR data. They are automatically downloaded for Sentinel-1 products by SNAP and added to its metadata with the *Apply Orbit File* (under the menu point *Radar*) operator.

The Precise Orbit Determination (POD) service for Sentinel-1 provides restituted orbit files and precise Orbit Ephemerides (POE) orbit files. POE files cover ca. 28 hours and contain orbit state vectors at intervals of 10 seconds intervals. Files are generated one file per day and are delivered within 20 days after data acquisition.

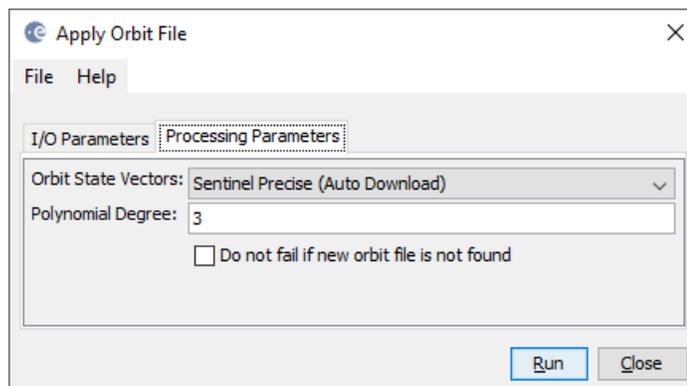


Figure 9: Apply Orbit File

If precise orbits are not yet available for your product, restituted orbits can be selected which may not be as accurate as the Precise orbits but will be better than the predicted orbits available within the product.

Execute the operator for both split products as generated in the previous step (Figure 9).

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. Conventional Stripmap radar products can be coregistered the *Coregistration* operator (under *Radar > Coregistration*).

Note: If you want to combine images Sentinel-1A and Sentinel-1B be aware that the extents of the products can be shifted along-track and different bursts must be selected for the same area.

Load the two subset products (with orbit files applied) to the *ProductSet-Reader* tab (Figure 10, left) and increase the *Number of GCPs* to **6000** in the *Cross-Correlation* tab (Figure 10, right). Furthermore, check **Estimate Initial Coarse Offset**. Lastly, select **Show Residuals** in the *Warp* tab and click Run to start the coregistration. Depending on the size of the products and the number of GCPs, this can take a while.

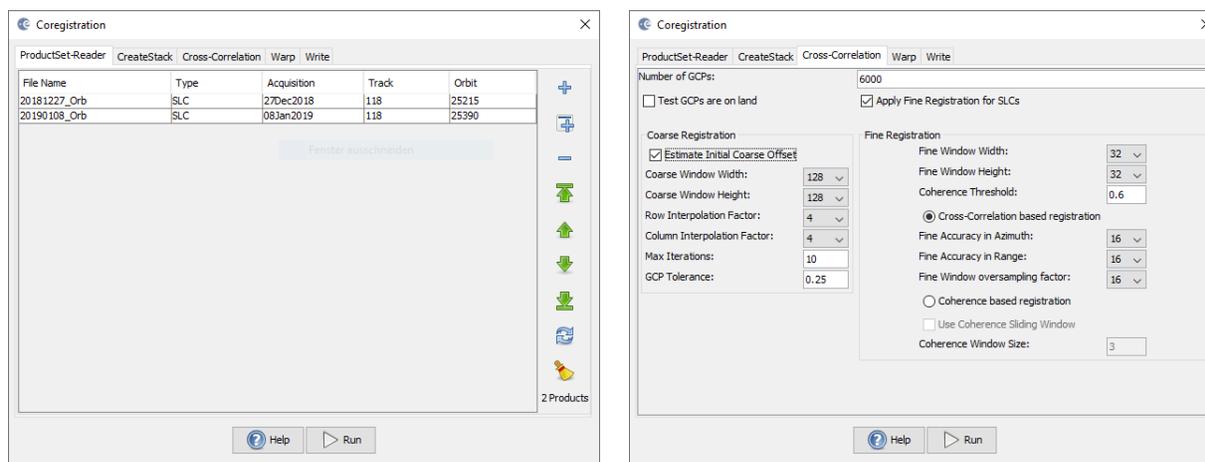


Figure 10: Coregistration of Sentinel-1 Stripmap products

After the coregistration is completed, it is advisable to visually check the quality of the stack. This can be done by an RGB representation of the reference and secondary¹ product which shows if the images are correctly aligned. Select the reference for red and green and the secondary for blue (Figure 11)².

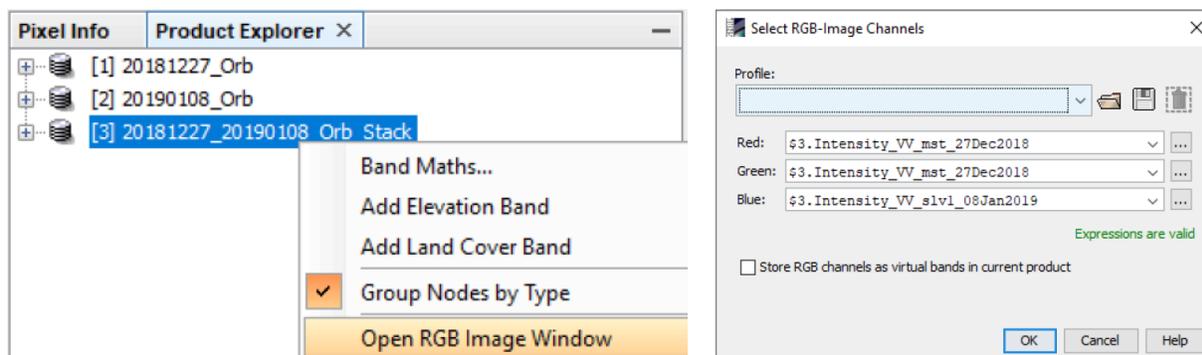


Figure 11: Generation of an RGB image

Zoom in to an area with distinct surfaces, for example the border between land and water. The RGB image should be clear and sharp and not be dominated by one of the images (yellow [red+green] for the reference or blue for the secondary image). The only exception are changes in landcover or scattering mechanisms which occurred in the time between the first and the second image acquisition (Figure 12).

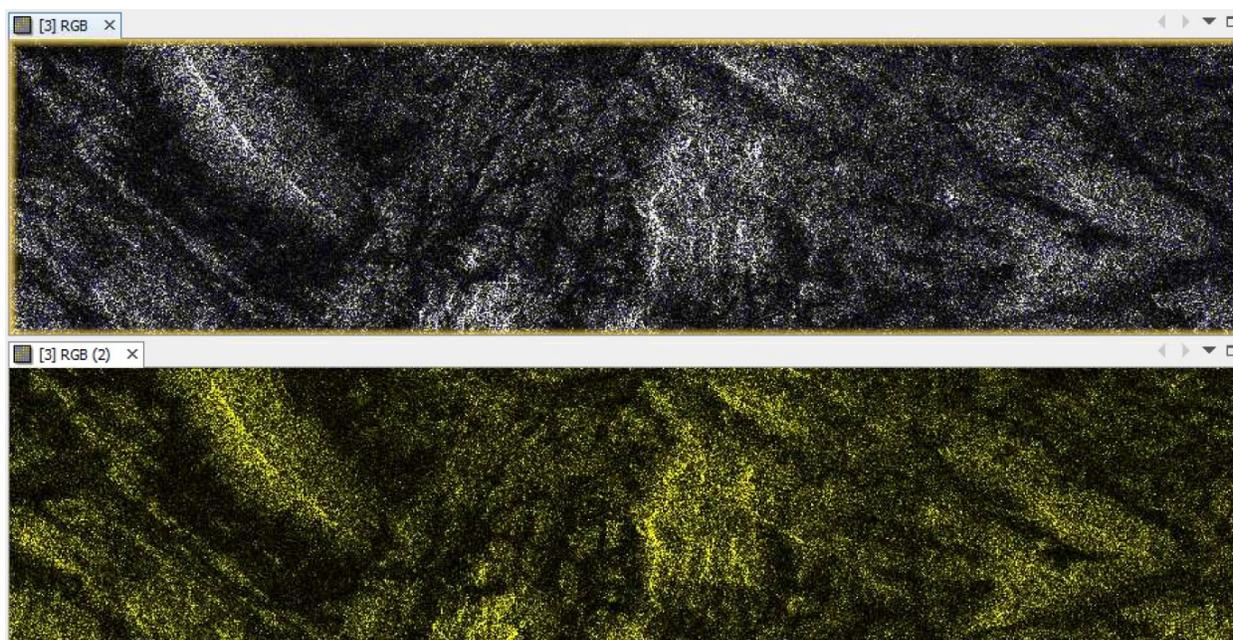


Figure 12: Successful (top) vs. failed (bottom, empty slave image) coregistration in an RGB image

¹ We support the [statement of the executive committees of WInSAR and COMET](#) to exchange the inappropriate terminology in all InSAR-related fields. Accordingly, the former "master/slave" will be replaced by "reference/secondary" in future versions of SNAP.

² <https://www.scientificamerican.com/article/end-of-the-rainbow-new-map-scale-is-more-readable-by-people-who-are-color-blind/>

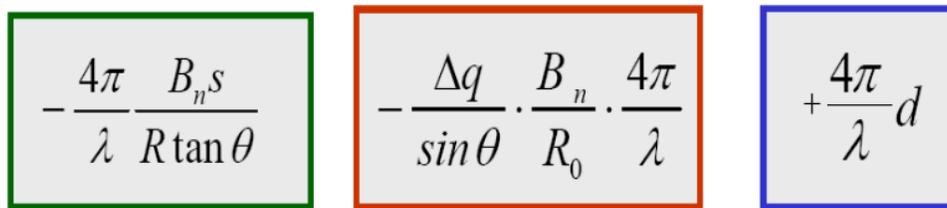
Interferogram Formation and Coherence Estimation

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. Accordingly, the computed interferogram contains phase variation ϕ from several contributing factors, most importantly the flat-earth phase ϕ_{flat} (earth curvature), the topographic phase ϕ_{DEM} (topographic surface of the earth), atmospheric conditions ϕ_{atm} (humidity, temperature and pressure change between the two acquisitions), and other noise ϕ_{noise} (change of the scatterers, different look angle, and volume scattering), and lastly the eventual surface deformation occurred between the two acquisitions ϕ_{disp} (Equation 1).

A more detailed explanation is given by [Roca et al. \(1997\)](#), and in the documents compiled by ESA: [InSAR Principles: Guidelines for SAR Interferometry Processing and Interpretation](#) (ESA TM-19).

$$\phi = \phi_{\text{DEM}} + \phi_{\text{flat}} + \phi_{\text{disp}} + \phi_{\text{atm}} + \phi_{\text{noise}} \quad (1)$$



$$-\frac{4\pi}{\lambda} \frac{B_n s}{R \tan \theta}$$

$$-\frac{\Delta q}{\sin \theta} \cdot \frac{B_n}{R_0} \cdot \frac{4\pi}{\lambda}$$

$$+\frac{4\pi}{\lambda} d$$

Figure 13: Contributors to SAR interferometric phase

Traditional SAR interferometry tries to estimate the contribution from the earth's surface (ϕ_{flat} and ϕ_{DEM}) which is considered equal for both image acquisitions and derive the heights of the topography (Equation 2; [ESA TM-19A](#), chapter 2.2; [ESA TM-19B](#), chapter 3).

$$\phi_{\text{DEM}} = \phi - \phi_{\text{flat}} - \phi_{\text{disp}} + \phi_{\text{atm}} + \phi_{\text{noise}} \quad (2)$$

This works best if atmospheric contributions and other noise is kept as small as possible because they are hard to estimate and if there is no elevation change ϕ_{disp} between the two image acquisitions. It is therefore advisable to use images from the dry season and with a suitable perpendicular baseline. More hints on the selection of suitable image pairs for InSAR DEM generation are given in [ESA TM-19B](#), chapter 1.3). This source names an **optimum perpendicular baseline of 150 - 300 m**, but Sentinel-1 was mainly designed for differential interferometry (DInSAR, [ref1](#), [ref2](#)), so image pairs with short temporal baselines (6 - 12 days at best) and perpendicular baselines above 100 meters are hard to find.

Besides the interferometric phase, the coherence between the reference and the secondary image is estimated as an indicator for the quality of the phase information. Basically, it shows if the images have strong similarities and are therefore usable for interferometric processing. Loss of coherence can produce poor interferometric results and is caused by temporal (over vegetation and water bodies), geometric (errors

or inaccuracies in the orbit metadata) and volumetric **decorrelation** (potential scattering mechanisms of voluminous structures, such as complex vegetation or dry surfaces).

Because of the predominantly short perpendicular baselines and the comparably quick decorrelation of C-band SAR data, repeat-pass interferometry for DEM generation is challenging, especially over vegetated areas. So please be aware that, despite the higher spatial resolution, phase decorrelation will lead to errors and the resulting elevation data is not of better quality than of freely available DEMs, such as [SRTM](#) or [AW3D30](#), in most cases.

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 the image, vegetation is shown as having poor coherence and buildings have very high coherence.

To compute the interferogram and the coherence bands, apply the *Interferogram Formation* operator (under *Radar > Interferometric > Products*). Select the coregistered stack you generated in the previous step as an input and make sure to check the boxes:

- **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 based on equation 1.13 in [ESA TM-19C](#).

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

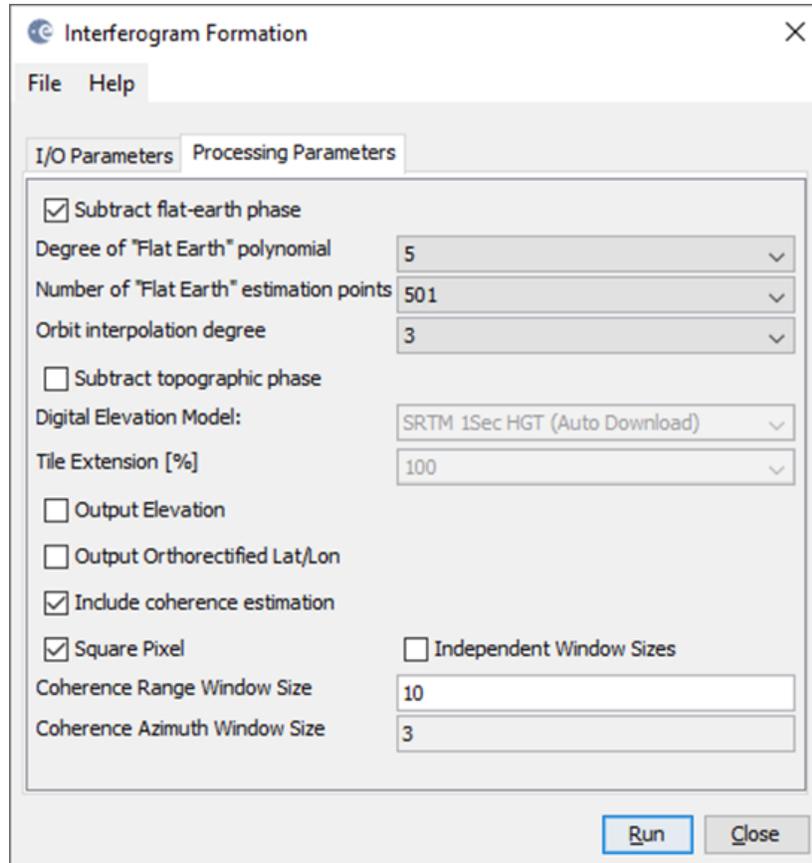


Figure 14: Interferogram Formation

The resulting product will contain the interferogram (Phase_ifg_IW...) and the coherence (coh_IW...) as separate bands (Figure 15). Double click them to check for their quality.

The interferogram is displayed in a rainbow color scale ranging from $-\pi$ to $+\pi$ and contains variations from topography, atmosphere and potential surface deformation (considered zero). The patterns, also called “fringes” represent a full 2π cycle and appear in an interferogram as cycles of arbitrary colors, with each cycle representing half the sensor’s wavelength.

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), wadi areas are dark and have low coherence (below 0.3). Accordingly, phase information over wadis is not usable here. If low coherence areas are too dominant in the image, the later unwrapping will fail and produce faulty or random results.

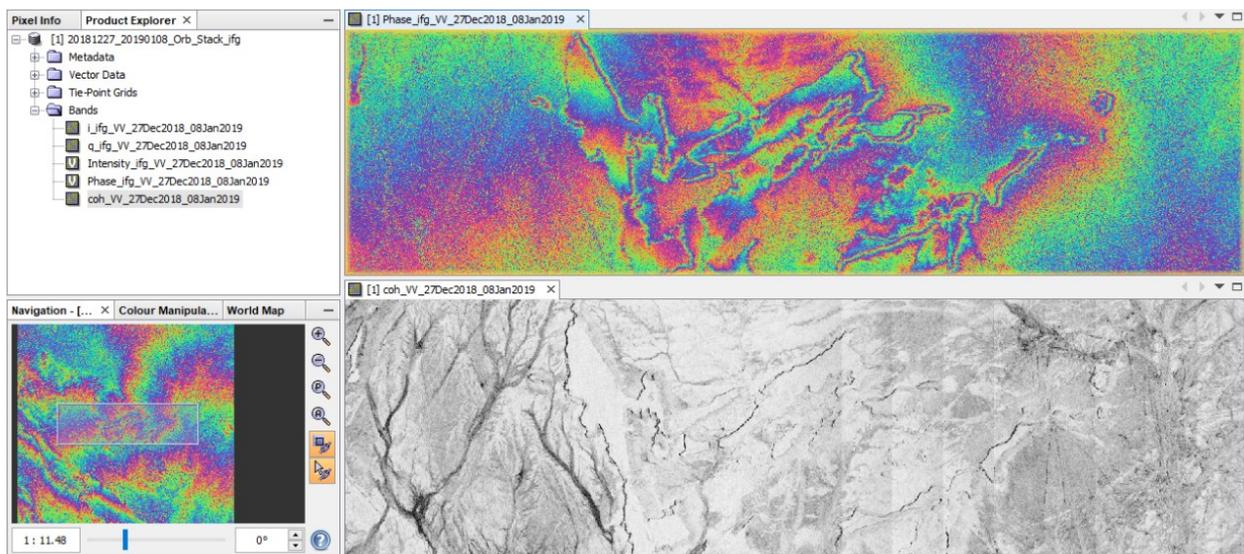


Figure 15: Interferogram (top) and coherence (bottom)

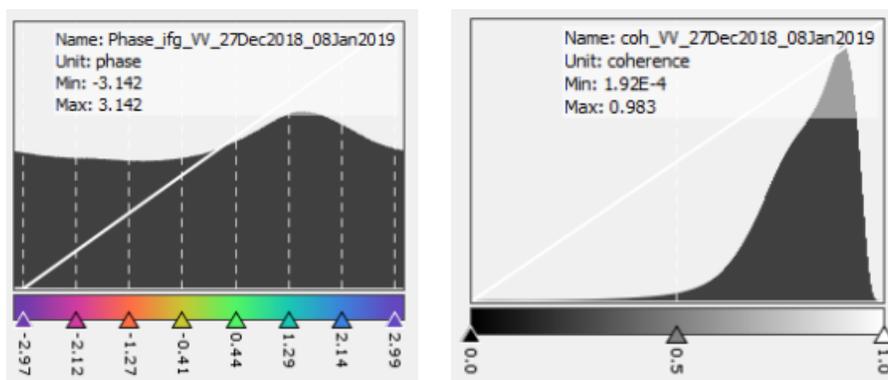


Figure 16: Histogram of interferogram (left) and coherence (right)

Multilooking

Multilooking allows to decrease the spatial resolution of SAR data without losing the complex information contained in the interferogram. It is not a mandatory step, but helps to reduce the size of the processed data while increasing the quality of the data because noise is reduced. The number of looks has to be decided according to the level of noise, the extent of the dataset and the scale of the patterns of interest.

Select the interferogram product and open the *Multilooking* operator (under *Radar > Utilities*). The only thing to adjust is the *Number of Range Looks* to **2**. The *Number of Azimuth Looks* will automatically be updated accordingly (as long as *GR Square Pixel* is checked, both numbers are equally increased). The resulting ground range resolution will be 7.4 meters in the bottom field (Figure 17).

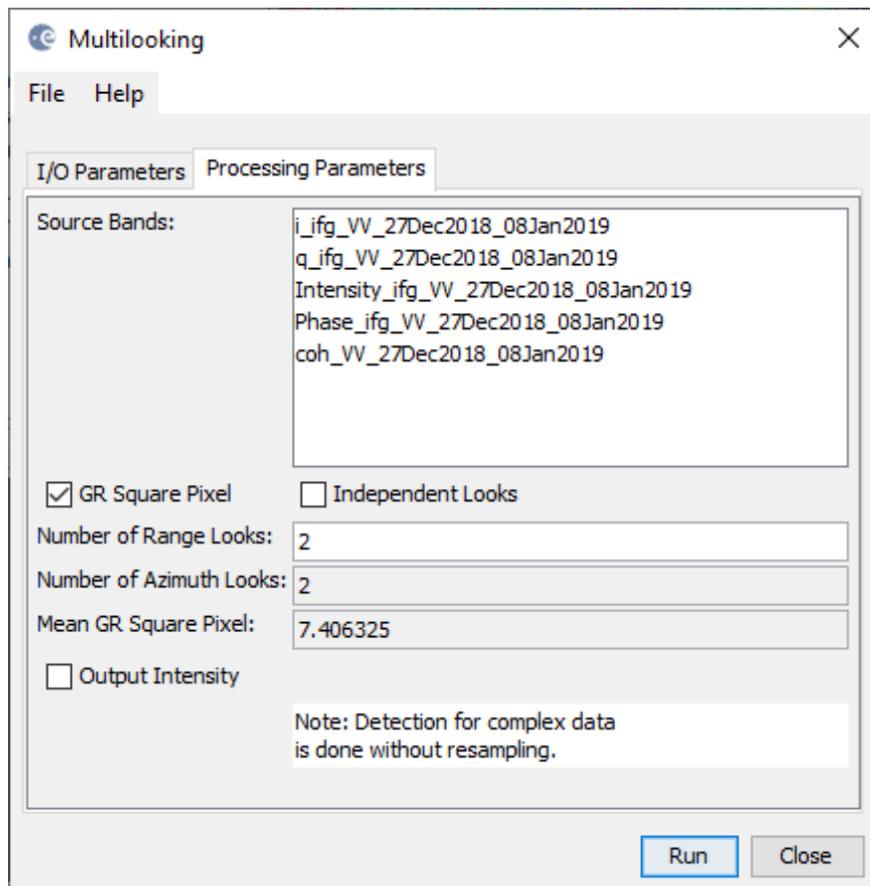


Figure 17: Multilooking of the interferogram

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.

A filtered phase image 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 \(1998\)](#).

Apply the *Goldstein Phase Filtering* (under *Radar > Interferometric > Filtering*) to the multilooked image. The output is a filtered phase image (Figure 18), the coherence is not affected.

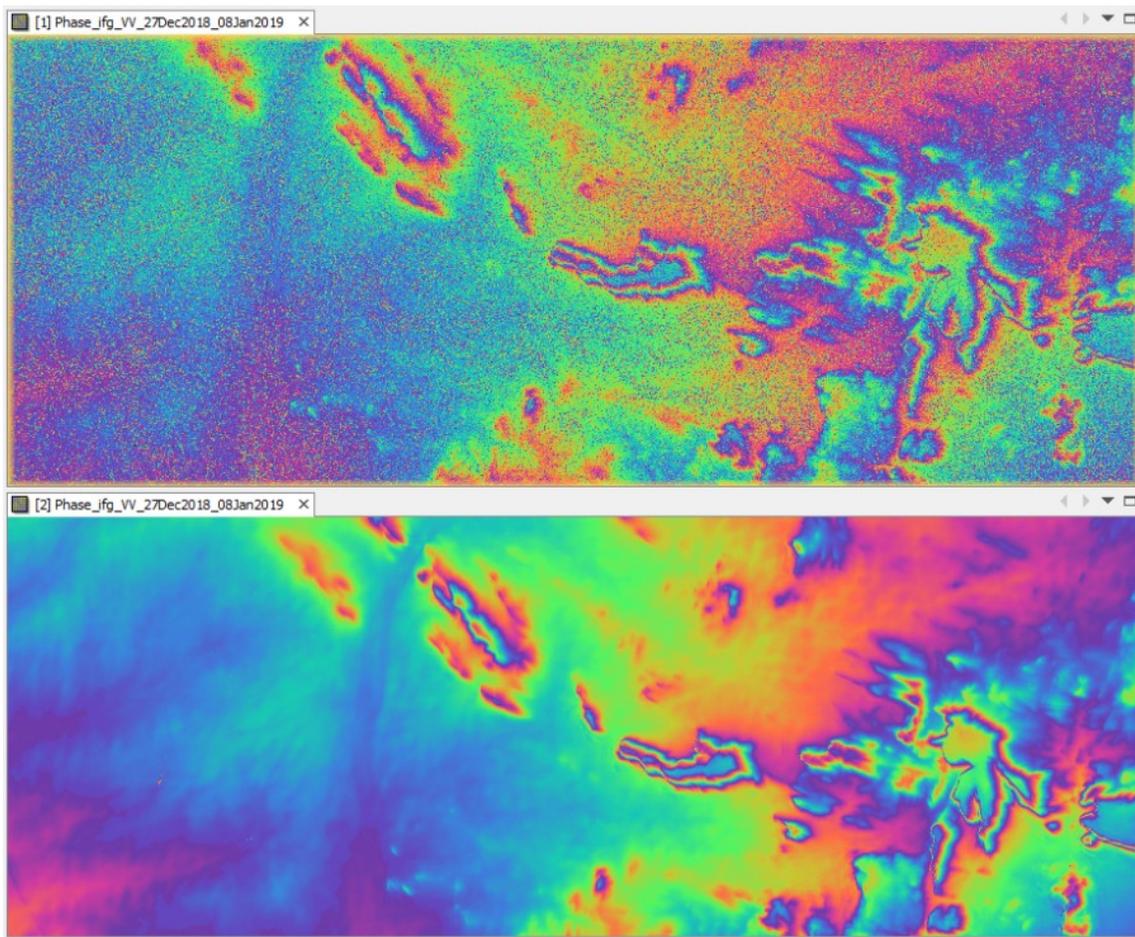


Figure 18: Interferogram before (left) and after (right) Multilooking and Goldstein phase filtering

(26° 13' 30" N, 10° 50' 00" W)

Phase Unwrapping

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 neighboring pixels. After deleting any integer number of altitudes of ambiguity (equivalent to an integer number of 2π phase cycles), the phase variation between two points on the flattened interferogram provides a measurement of the actual altitude variation (Figure 19). Accordingly, unwrapped results should be interpreted as a relative height/displacement between pixels of two images.

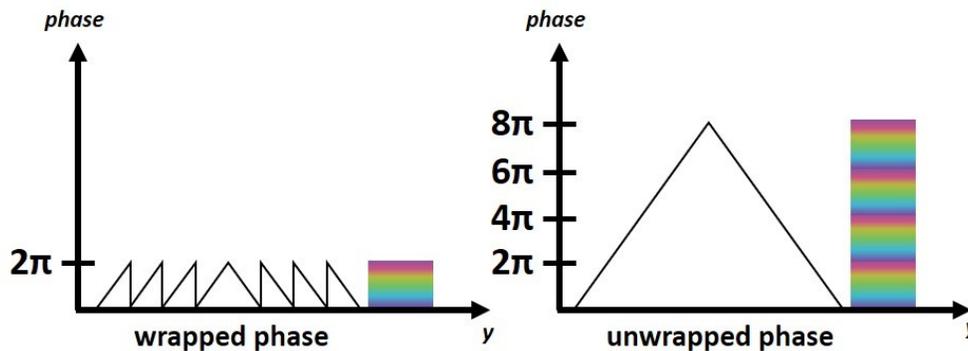


Figure 19: Principle of phase unwrapping

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. Although no definite threshold exists, a minimum coherence of 0.3 is suggested.

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 (see under “Preparation” > “Install snaphu”), the unwrapping is executed outside SNAP, but the plugin allows to call this execution, so no command line processing is required any longer.

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.

Export

The Export operator (under *Radar > Interferometric > Unwrapping*) converts the interferogram (as the wrapped phase) into a format which can be read by snaphu. Furthermore, a couple of parameters can be selected which affect the unwrapping process and stored in a configuration file which is accessed by snaphu.

The source product is the subset created in the previous step. In the *SnaphuExport* tab, select your working directory as the target folder (here: `C:\Temp\S1_InSAR_SM`). 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 **200** pixels for *Row Overlap* and *Column Overlap* (Figure 20). Depending on the number of processors of your computer, you can also increase the *Number of Processors* variable.

Note: You can neglect the eventual error message (`Error: [NodeId: SnaphuExport Please add a target folder]`). It will go away once you switch tabs or hit **Run**, as long as you have entered a valid target folder.

To learn about the meaning and impact of all parameters, please consult the [official documentation](#).

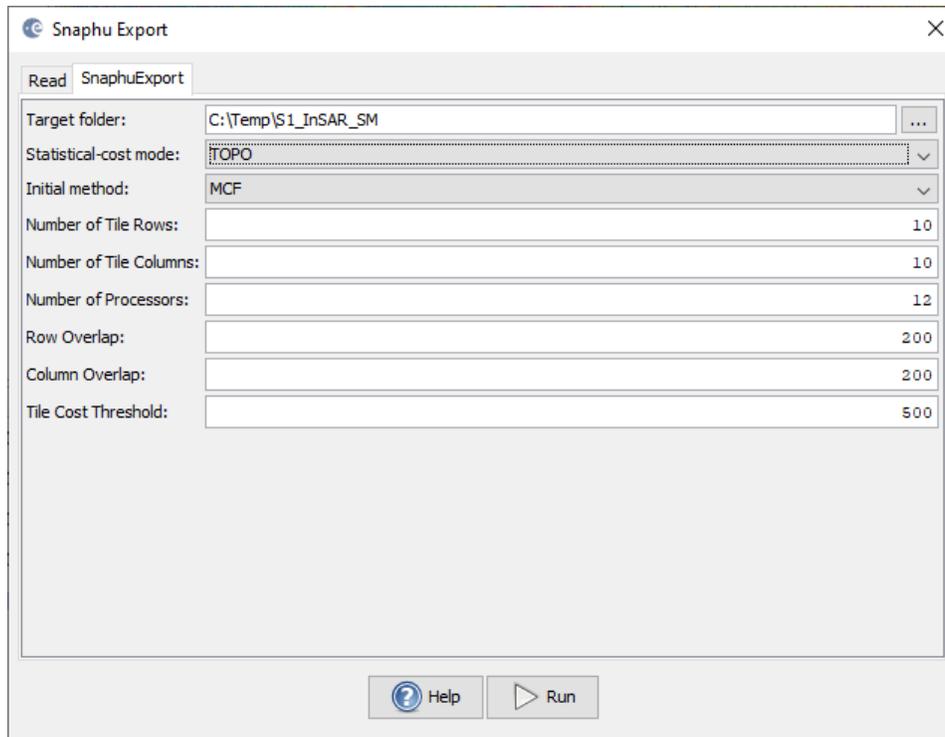


Figure 20: Snaphu export

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 (here: `20181227_20190108_Orb_Stack_ifg_MLflt`). 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

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 subset which was created before the export from the drop-down menu. For the output folder in the

Processing Parameters tab you can activate **Display execution output** and select the folder which was created during the export (here: 20181227_20190108_Orb_Stack_ifg_ML_fit). 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.

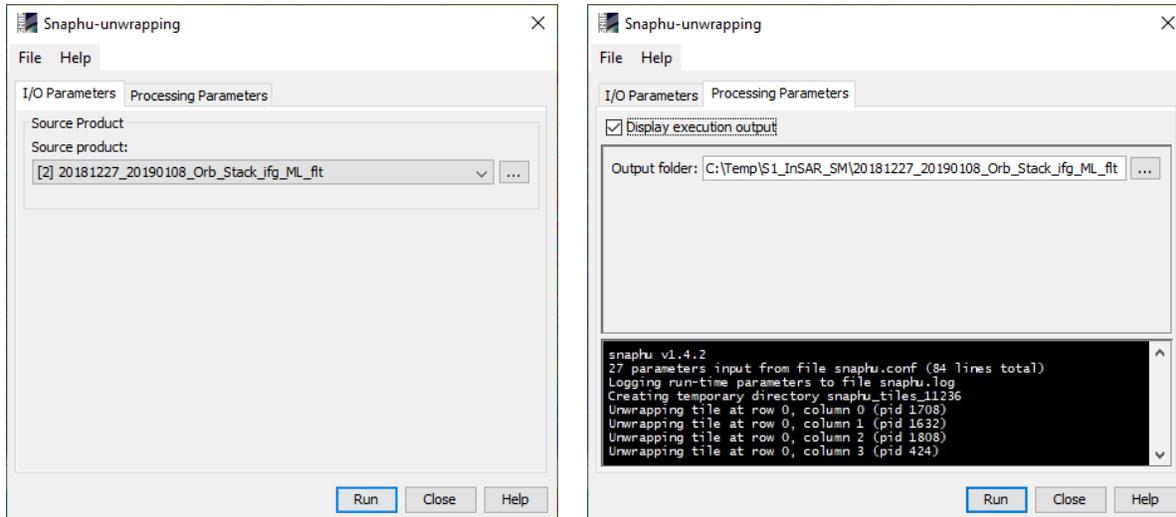


Figure 21: Unwrapping with the snaphu plugin

Note: If the tool is not executed by clicking Run, go to *Manage External Tools* in the *Tools* menu. Select “Snaphu-unwrapping” and click **Edit the selected operator** to open the configuration and enter the export directory in the variable **USERPROFILE** under the *System Variables* tab. Confirm with OK and start the *Snaphu-unwrapping* operator again.

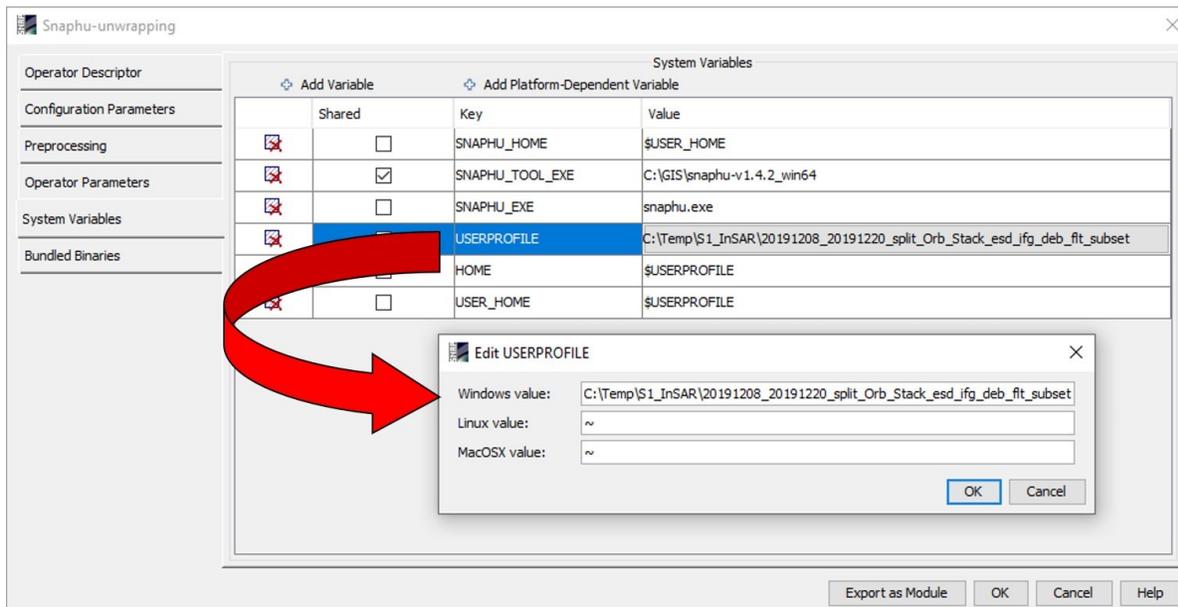


Figure 22: System variables of the snaphu plugin

Note that unwrapping can take a considerable amount of time. To break the raster into smaller chunks, snaphu divides it by standard into 10 rows and 10 columns, leading to a total of 100 tiles to be unwrapped. These tiles are merged afterwards based on the selected pixel overlap (here 200 pixels). A progress bar will inform you about the remaining time (Figure 23). The calculation is completed when the progress reaches 100% and the output states “Finished tool execution in ... seconds”. You can then close the operator.

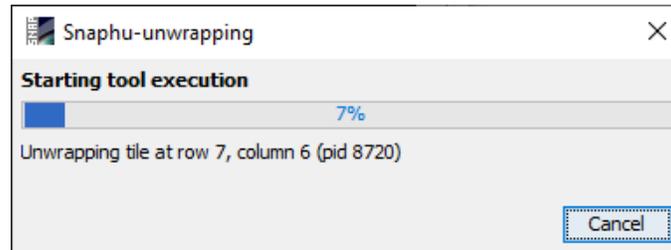


Figure 23: Progress of the unwrapping

Alternative option: If the unwrapping does not work with the plugin from within SNAP, snaphu can also be started from the command line. It can be downloaded from the following page which also contains instruction for its manual execution: <https://step.esa.int/main/third-party-plugins-2/snaphu/>

Import

The opened unwrapped phase does not have any metadata or geocoding. The *Snaphu import* (under *Radar > Interferometric > Unwrapping*) converts the it back into the BEAM DIMAP format 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 subset of the interferogram (before the export) from the drop-down menu.
- **2-Read-Unwrapped-Phase:** Select the  icon to open a file menu and 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 (here: `20181227_20190108_Orb_Stack_ifg_MLflt_unw`) and click **Run**.

A new product is added to the Product Explorer which contains the wrapped interferogram (`Phase_ifg_IW...`), the coherence (`coh_IW...`) and the unwrapped phase generated with snaphu (here: `20181227_20190108_Orb_Stack_ifg_MLflt`).

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 24). All fringe patterns are summarized to absolute changes (Figure 19). 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. Sometimes it is also favorable to switch the statistical cost-mode from **DEFO** to **SMOOTH** or the initial method from **MCF** to **MST** and compare the outputs.

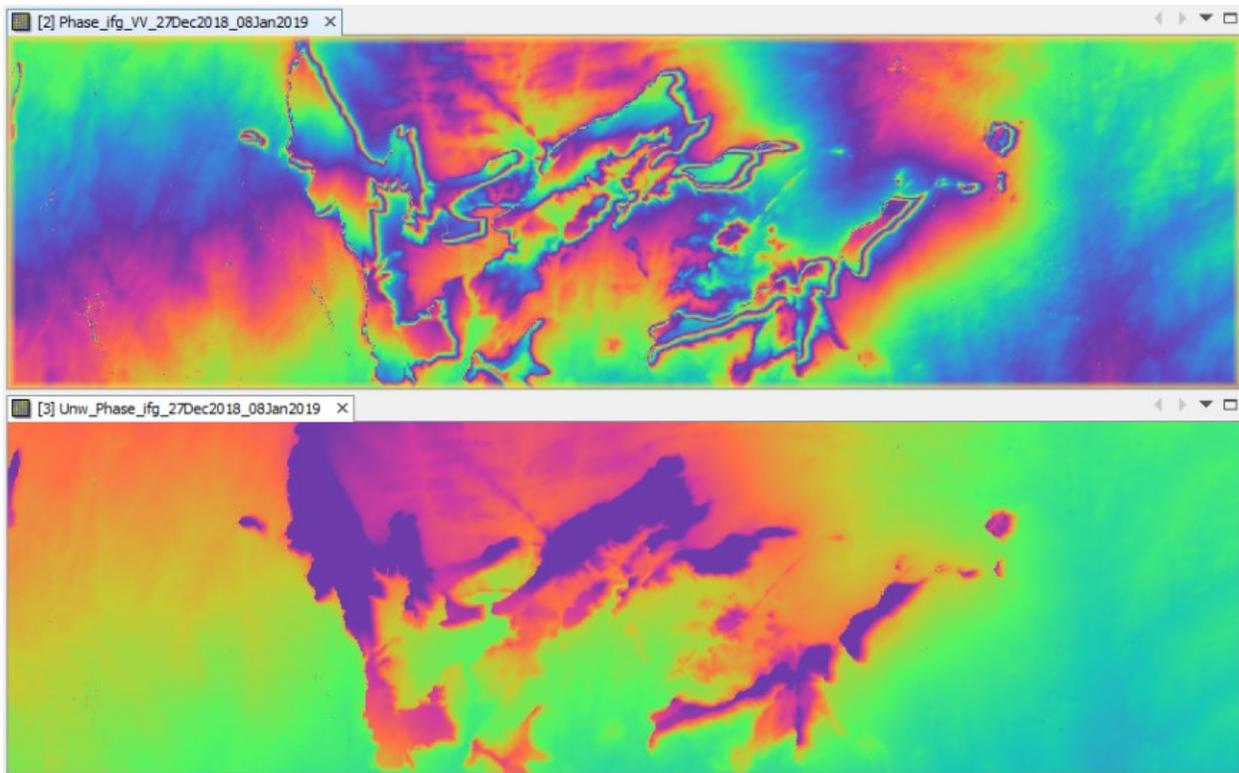


Figure 24: Phase before (top) and after (bottom) unwrapping

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 **SRTM 1Sec HGT (AutoDownload)** as input DEM.

The operator 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 height above sea level.

You can plot a *Histogram*  to check the frequency distribution of the values (Figure 26).

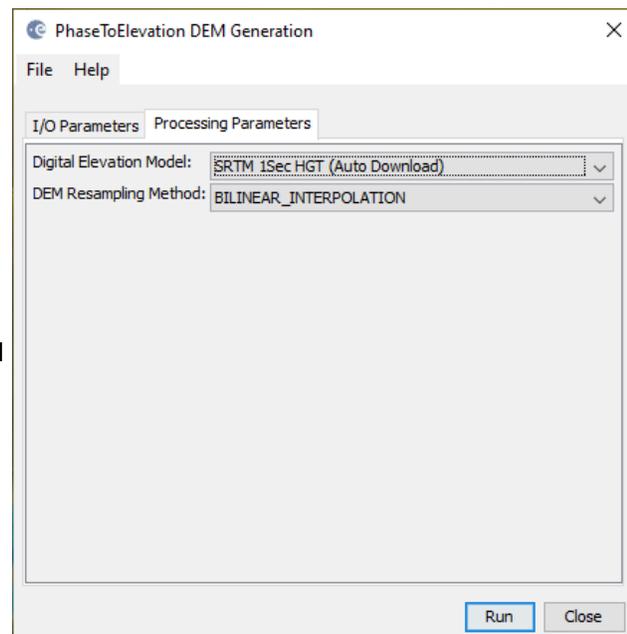


Figure 25: Phase to Elevation

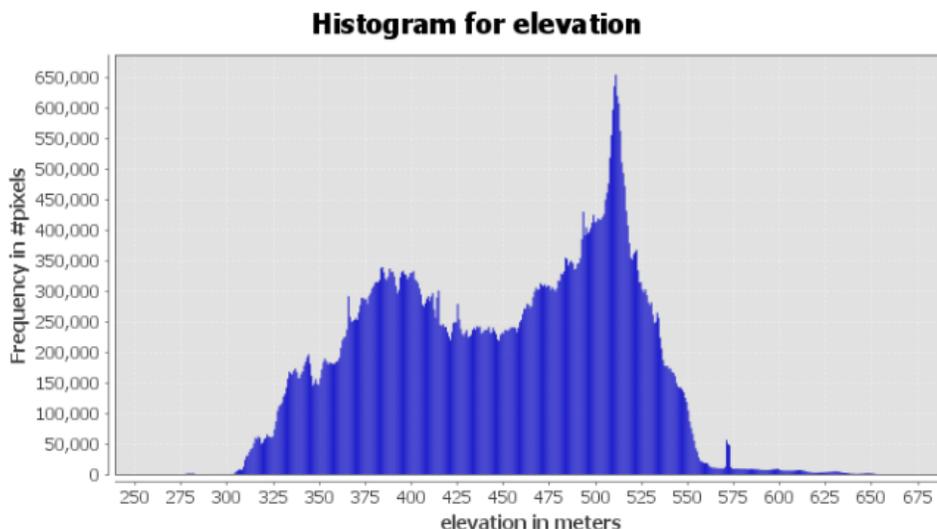


Figure 26: Histogram of the elevation raster

Note: The original phase and coherence bands are not automatically copied into the resulting raster of the *Phase to Elevation* operator. If they are needed in the final product, they can be added via the *Band Maths* operator (right-click on the elevation product and select **Band Maths**).

Call the new raster which is to be generated `coherence` and uncheck the “Virtual” option (Figure 27, left). Open the *Band Maths Expression Editor* by clicking **Edit Expression**. You can now switch between products which have the same dimensions (rows and columns) in the Band Maths Expression Editor and double-clicking the coherence band of a previous product to add it to the expression window (Figure 27, right). Confirm with **OK** (twice) to apply the calculation.

The coherence band is now part of the elevation product. Save it by selecting *File > Save Product* in the menu.

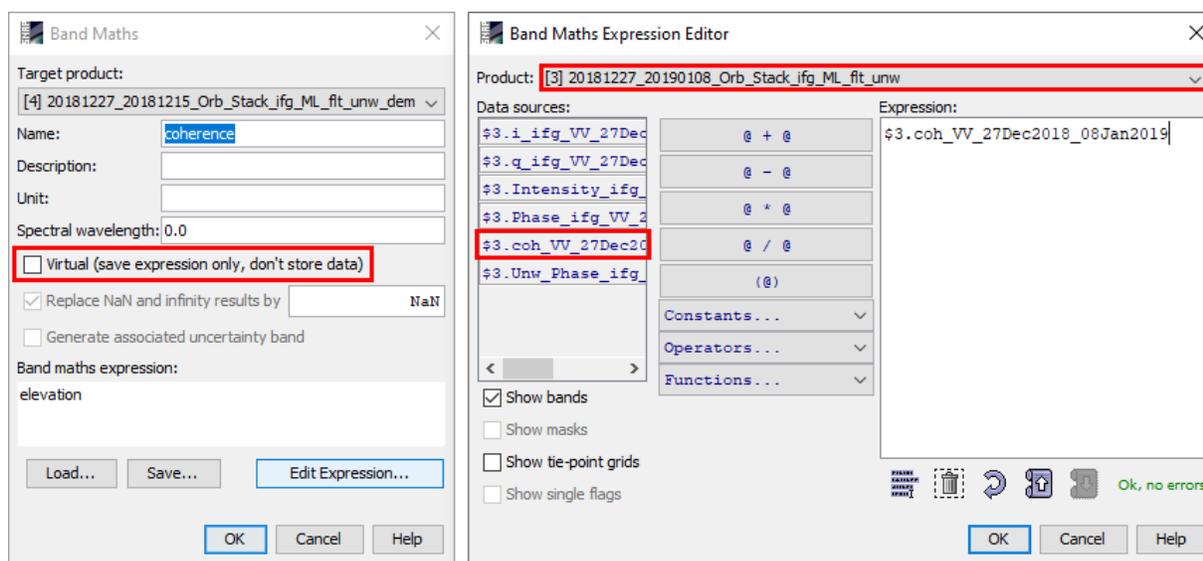


Figure 27: Transfer of bands between products

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.

Geocoding converts an image from slant range or ground range geometry into a map coordinate system. Terrain geocoding involves using a Digital Elevation Model (DEM) to correct for inherent geometric distortions, such as foreshortening, layover and shadow (Figure 28). More information on these effects is given in the [ESA radar course materials](#).

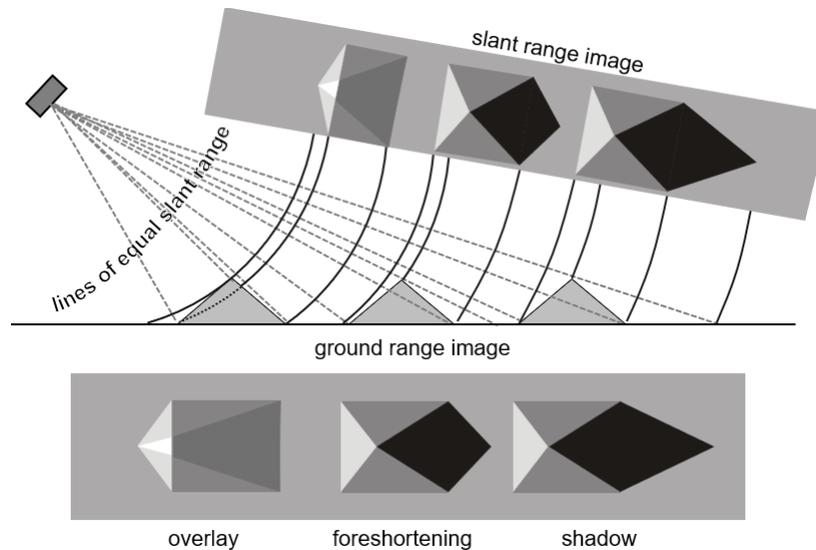


Figure 28: Geometric distortions in radar images ([Braun 2019](#))

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 **SRTM 1Sec HGT (AutoDownload)** as input DEM.

Please be aware that SRTM is only available between 60° North and 54° South. If your area lies outside this coverage (<https://www2.jpl.nasa.gov/srtm/coverage.html>), you can use one of the other DEMs with AutoDownload option or use an external DEM (just make sure it stored as a GeoTiff and projected in geographic coordinates / WGS84).

If you want to export the data as a KMZ file to view it in Google Earth **WGS84** must be selected as Map Projection. It is based on geographic coordinates (latitude and longitude). For the later use in a geographic information system (GIS) a metric map projection, such as UTM (Automatic) could be selected as well.

If no **Source Band** is selected, all bands of the input product are geometrically corrected.

If you want to compare the quality of the InSAR DEM, you can select **DEM** as a further output. This writes the SRTM data used for Terrain Correction to a separate elevation band. The S1 DEM will then be named `elevation_VV` and the SRTM data is named `elevation`. This option is, however, just for comparison and not mandatory.

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.

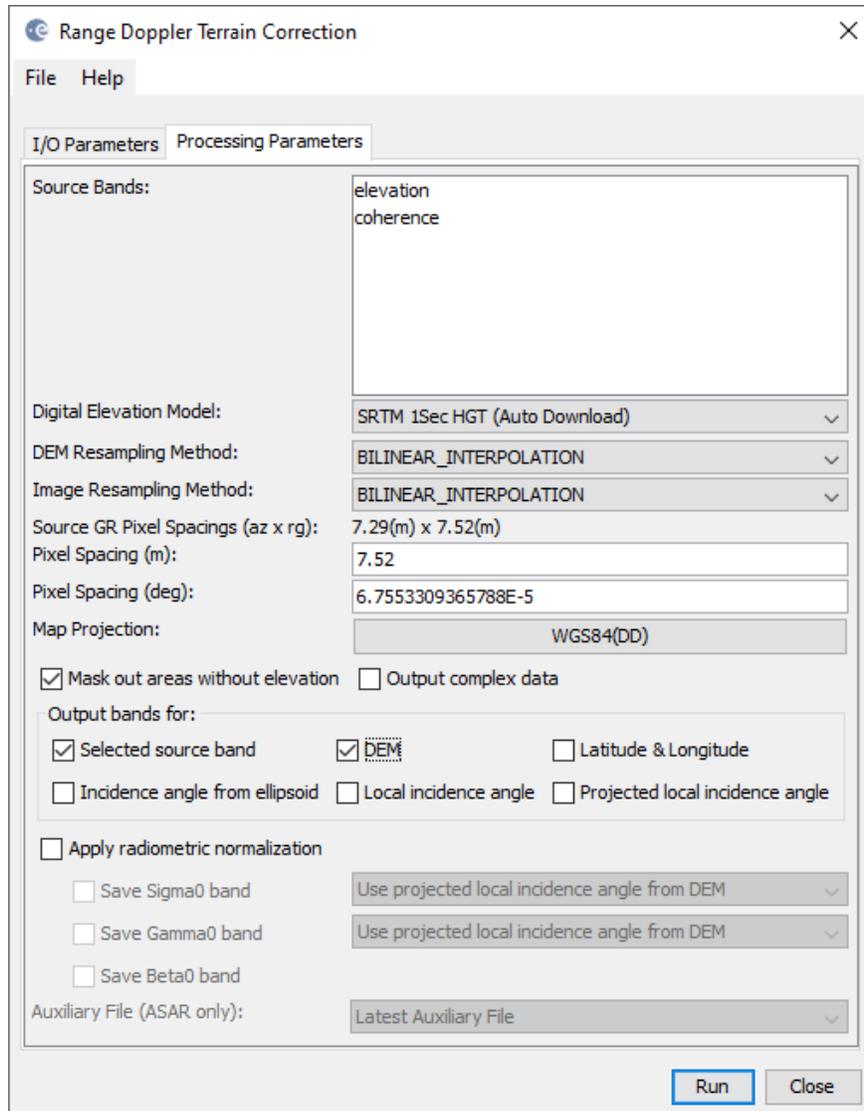


Figure 29: Range Doppler Terrain Correction

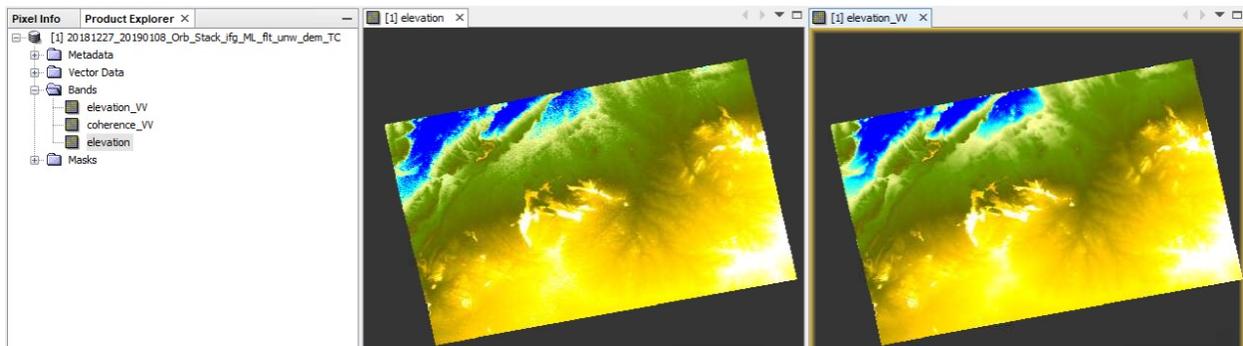


Figure 30: Geocoded elevation of SRTM (left) and Sentinel-1 (right)

Suggestions for further analyses

Profile lines

To assess the quality of your DEM, you can digitize a line and use the *Profile Plot* tool  to visualize selected landforms (Figure 31). This is also a good way to check also the amount of noise in the lower coherence areas.

Once the profile line is displayed you can select different bands from the same product and update the plot, for example to check how well SRTM and S1 DEM are aligned.

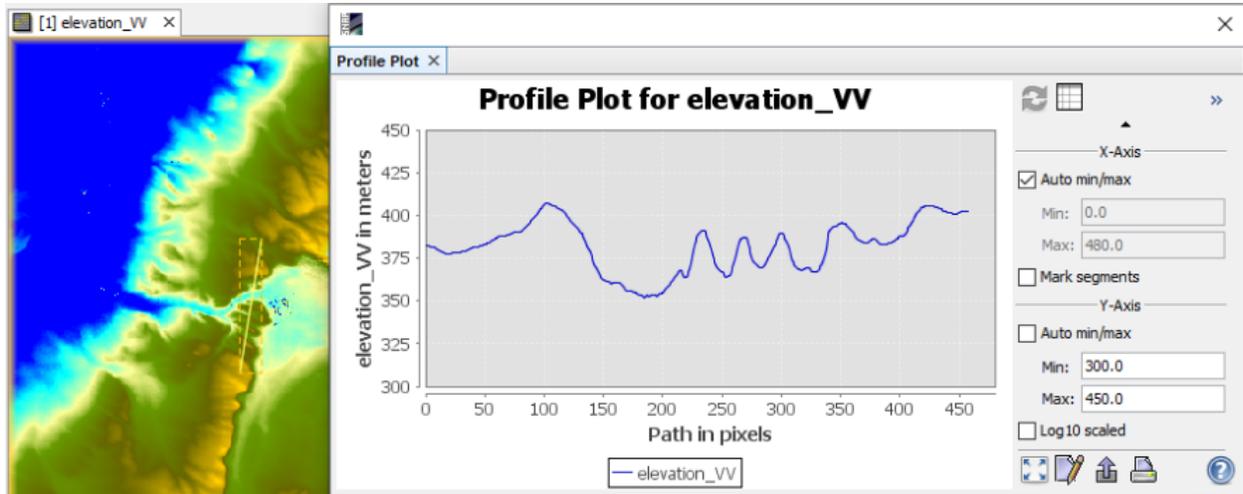


Figure 31: Profile plot for the S1 elevation

The data behind the plot (elevations along the profile line) can be exported via the *Table View*  by right-clicking > **Copy Data To Clipboard**. By doing this, elevations of both rasters can be extracted and compared, for example in MS Excel.

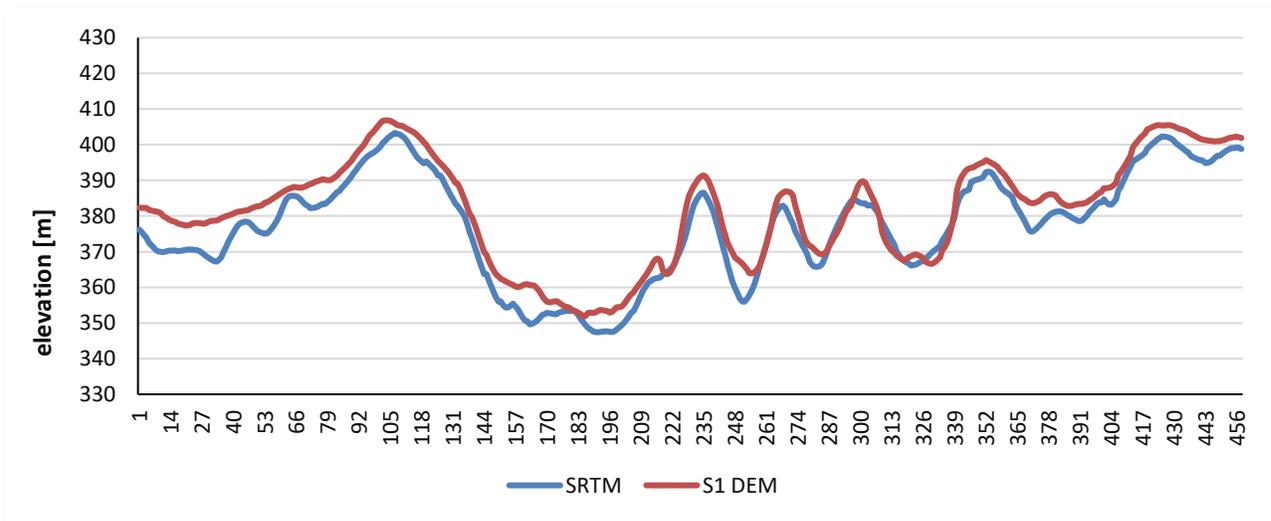


Figure 32: Comparison between SRTM and S1 DEM elevations along the digitized profile

Compare Hillshades

Open the file `elevation_VV.img` (inside the `.data` folder) into a GIS (e.g. [QGIS](#)) and compute a hillshade representation. You might need to set the z-value to 0.0005 (because data projected in WGS84 is based on degrees and the height is given in meters). The coherence layer will give you an indication on where your data is of good quality and where there can be phase errors (mainly along the wadis) and in areas of radar shadow (Figure 28, mainly slopes facing southwest).

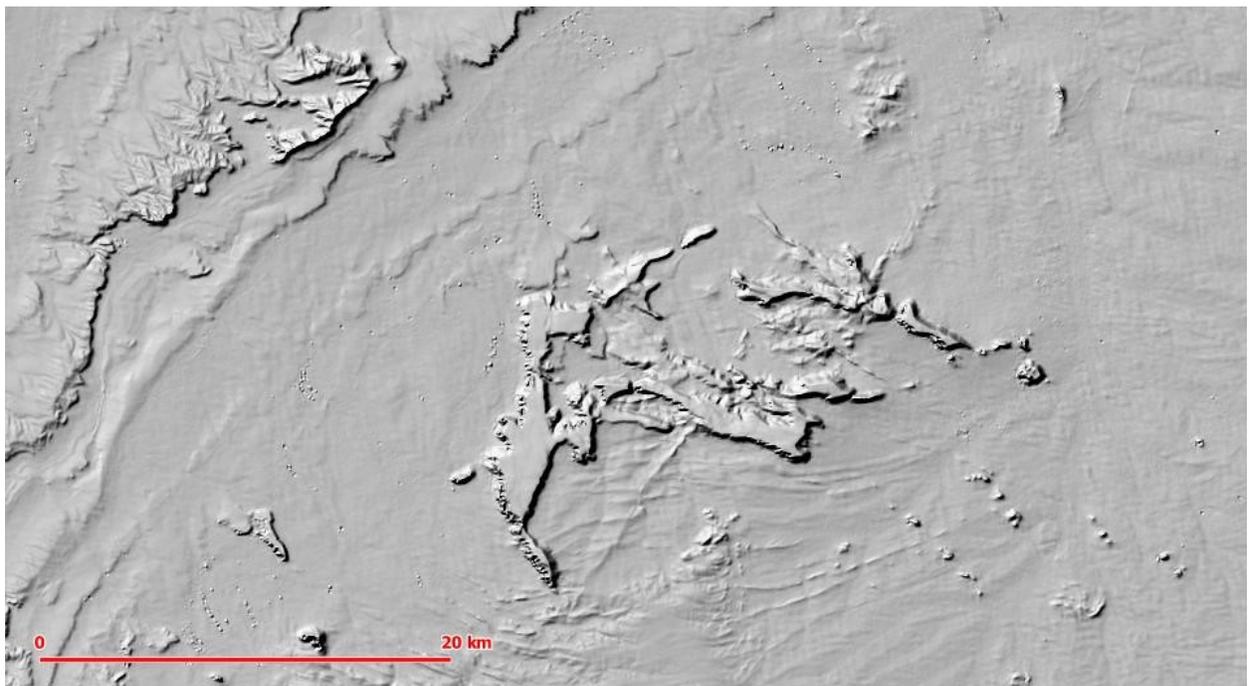
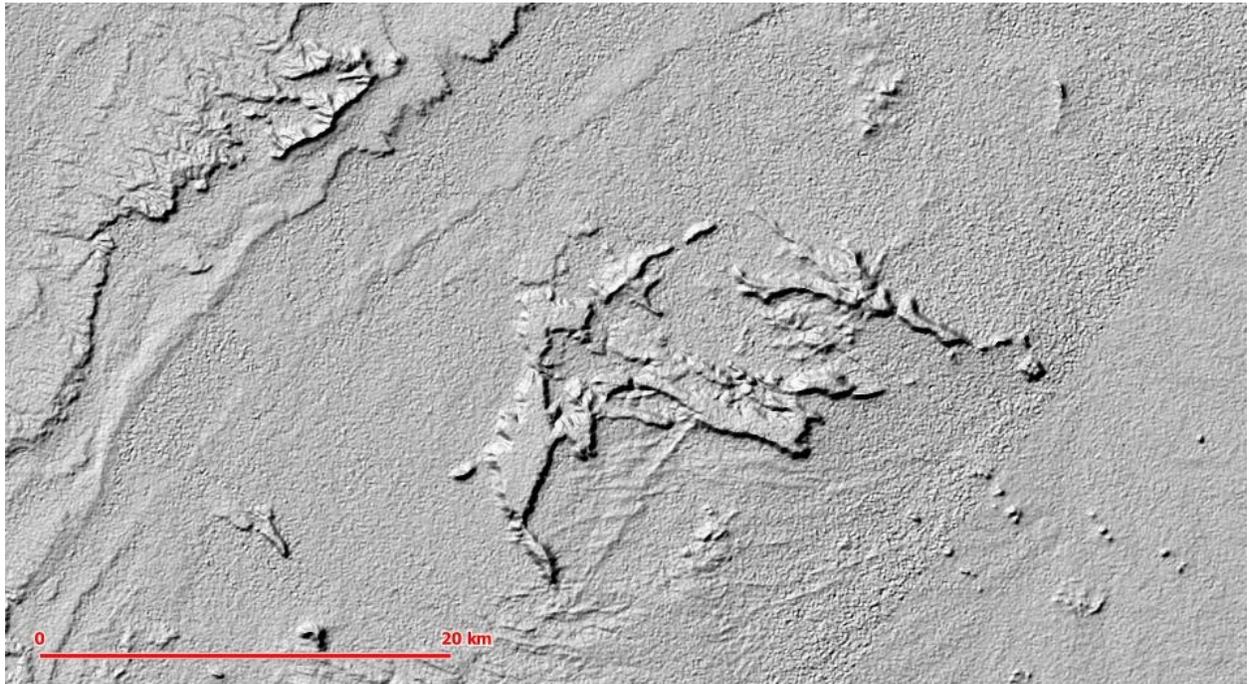


Figure 33: Hillshade of SRTM (top) and S1 DEM (bottom) elevation models

Export to Google Earth

All geocoded products (projected to WGS84) can be exported as a KMZ file to view them in [Google Earth](#).

Select a suitable color scale and color ramp in the *Color Manipulation* tab and then chose *File > Export > Other > View As Google Earth KMZ*.

Select an output directory and a suitable filename and confirm with **Save**. Open the kmz file in Google Earth to view the location of the elevation raster on the satellite image base map (Figure 34).

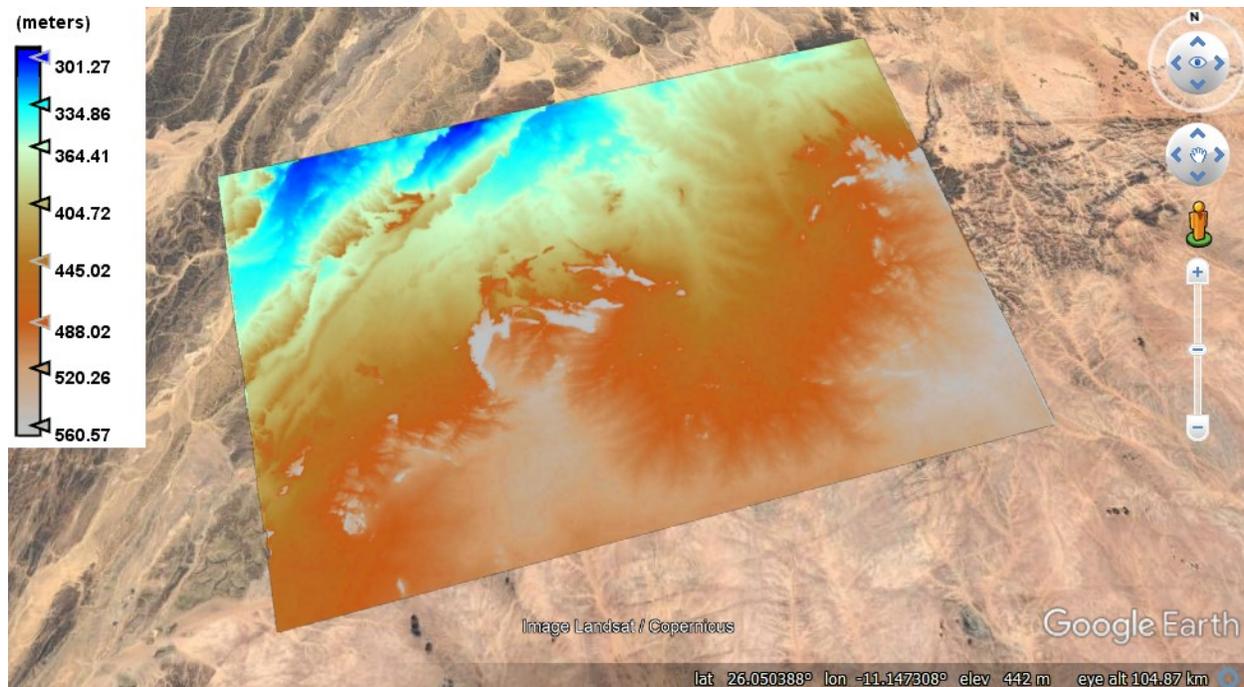


Figure 34: Result exported to Google Earth



For more tutorials visit the Sentinel Toolboxes website

<http://step.esa.int/main/doc/tutorials/>



Send comments to the SNAP Forum

<http://forum.step.esa.int/>