

Sentinel-1 Toolbox

TOPS 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 Interferometric Wide Swath products.

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. In the case of differential interferometry (DInSAR), this topographic phase contribution is removed using a digital elevation model (DEM). 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.

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

Sentinel-1 Interferometric Wide Swath Products

The Interferometric Wide (IW) swath mode is the main acquisition mode over land for Sentinel-1. It acquires data with a 250 km swath at 5 m by 20 m spatial resolution (single look). IW mode captures three sub-swaths using Terrain Observation with Progressive Scans SAR (TOPSAR). With the TOPSAR technique, in addition to steering the beam in range as in ScanSAR, the beam is also electronically steered from backward to forward in the azimuth direction for each burst, avoiding scalloping and resulting in homogeneous image quality throughout the swath.

TOPSAR mode replaces the conventional ScanSAR mode, achieving the same coverage and resolution as ScanSAR, but with a nearly uniform SNR (Signal-to-Noise Ratio) and DTAR (Distributed Target Ambiguity Ratio).

IW SLC products consist of three sub-swaths (Figure 1, red labels) image per polarization channel, for a total of three (single polarizations) or six (dual polarization) images in an IW product. Each sub-swath image consists of a series of bursts (Figure 1, white labels), where each burst has been processed as a separate SLC image. The individually focused complex burst images are included, in azimuth-time order, into a single sub-swath image with black-fill demarcation in between, similar to ENVISAT ASAR Wide ScanSAR SLC products.

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

The data used in this tutorial includes the metropolitan area around Katowice, Poland. It is part of the Upper Silesian Coal Basin where [surface subsidence is reported](#) for a considerable number of small depressions as a result of the long-year coal mining and the subsequent flooding of the mines. Figure 2 shows the extent of the Sentinel-1 data (red) and of the subset used in this tutorial (blue).

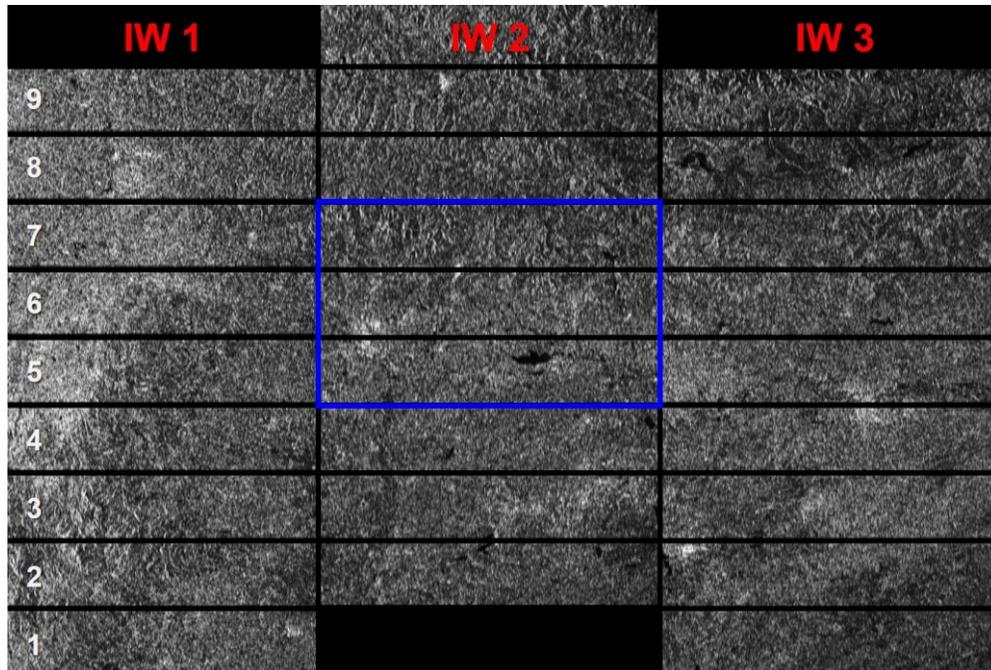


Figure 1: Sub-swaths (red) and bursts (white) of S1 IW products (blue area is used in this tutorial)



Legend

- ▭ extent Sentinel-1 SLC data
- ▭ area of interest

Top: Extent of Sentinel-1 SLC product and the area of interest within central Europe.
Background © OpenTopoMap (CC-BY-SA) as retrieved from opentopomap.org

Left: Landscape elements of the area of interest
Background © Wikimedia (CC-BY 3.0) as retrieved from wikimedia.org

Author: Andreas Braun
Date: 26.12.2019
Projection: WGS 84 / Pseudo-Mercator (EPSG:3857)
Created for the ESA SNAP S1 TOPS InSAR tutorial

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 and download them:

S1B_IW_SLC__1SDV_20191208T163422_20191208T163449_019276_024651_E2F6
S1B_IW_SLC__1SDV_20191220T163421_20191220T163448_019451_024BE6_79C7

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\`.

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**.

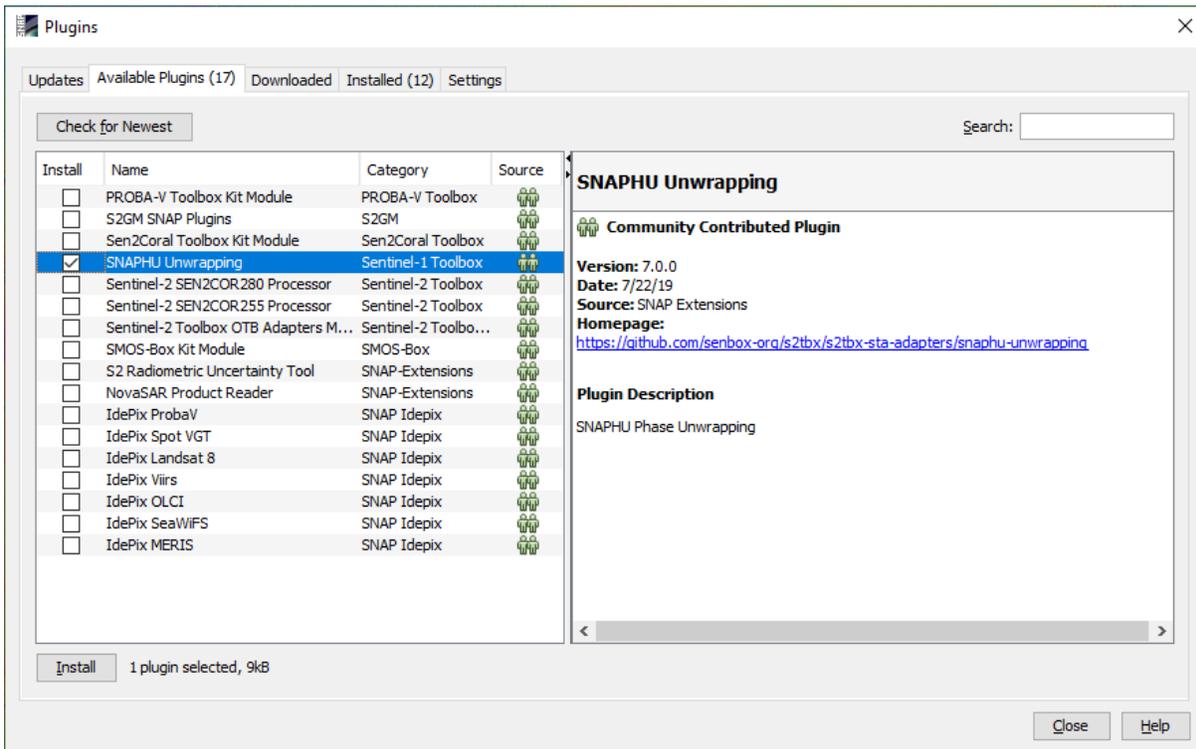


Figure 3: The Plugins interface

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.

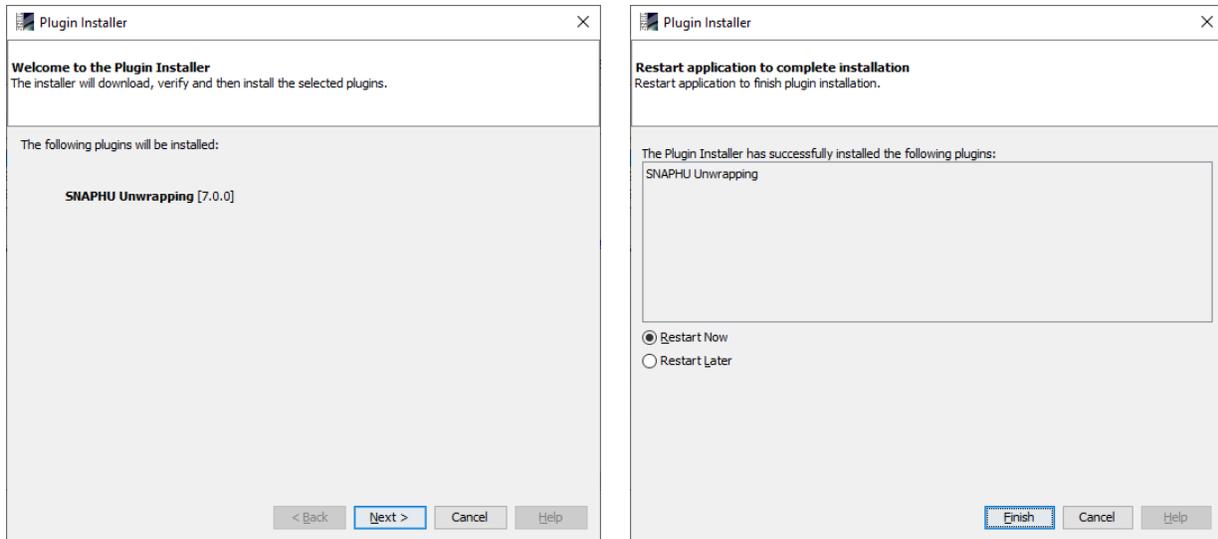


Figure 4: Installation of the snaphu plugin

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).

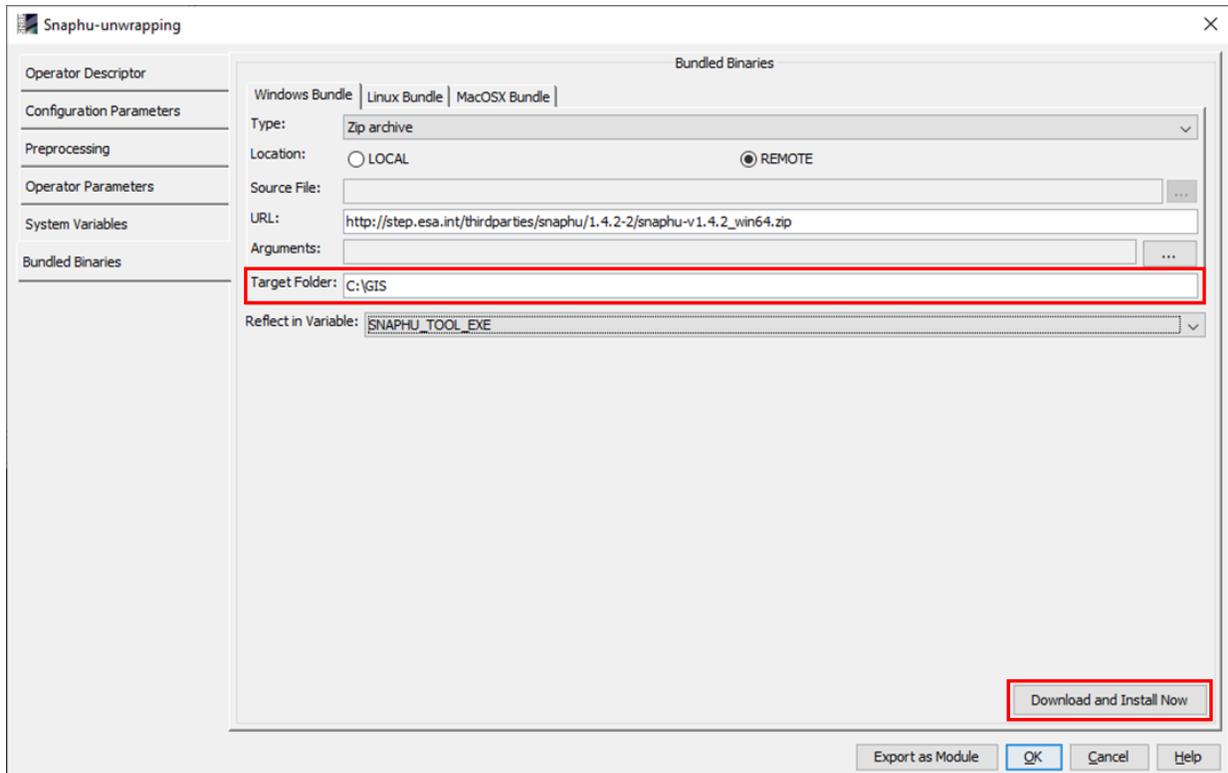


Figure 5: Installation of the snaphu bundles

Open the Products

Use the  *Open Product* button in the top toolbar and browse for the location of the downloaded data. Select the two zip files 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, organized by polarization and sub-swath as demonstrated in Figure 1).

As the data is still compressed in the zip file and each sub-swath covers a large area, it is not advised to open the bands in their current state, because it takes a considerable time until SNAP loads the raster. If you still want to check the data before proceeding double-click on the **Intensity_IW1_VV** band to view the raster data.

Another way to identify the location of your study area within the 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 in an RGB color representation.

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

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) and if they are shifted along-track. The latter is allowed for interferometry but needs to be taken into account in the next step (TOPS Split).

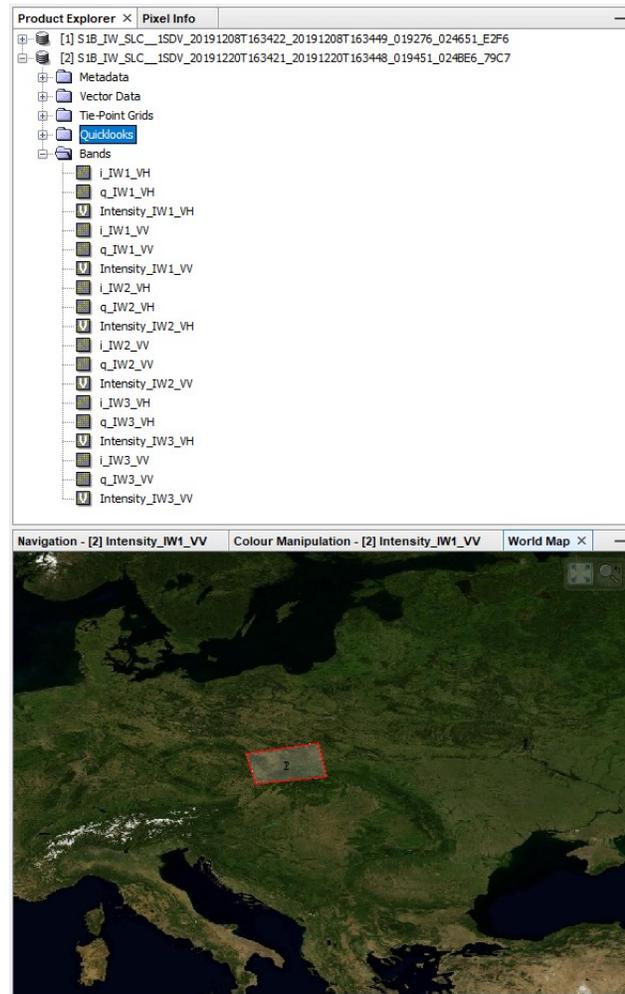


Figure 6: Product Explorer and World Map

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. While conventional Stripmap radar products can be coregistered within one step, S1 TOPSAR products require a series of steps, because of their special form of acquisition (Figure 1).

SNAP offers to combine all these steps within the *S-1 TOPS Coregistration with ESD* operator, but this processing chain consumes a lot of memory. In this tutorial, the single steps to correctly coregister the products are performed individually and successively.

TOPS Split

S-1 TOPS Split is applied to the data to select only those bursts which are required for the analysis. They are marked in blue in Figure 1. Currently, each Sub-Swath is processed separately. Note: If the area of interest covers several Sub-Swaths, they have to be merged with the *S-1 TOPS Merge* operator after the Sub-Swaths were debursted.

To reduce the loaded data to the area of interest, open the *S-1 TOPS Split operator* (under *Radar > Sentinel-1 TOPS*) and select sub-swath **IW2** and **VV** polarization in the *Processing Parameters*. Then reduce the bursts to **6 to 7** by dragging the grey triangles towards the middle. Use the preview to check the location of the selected area (Figure 7). Confirm with **Run** and repeat the step for the second S1 image.

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.

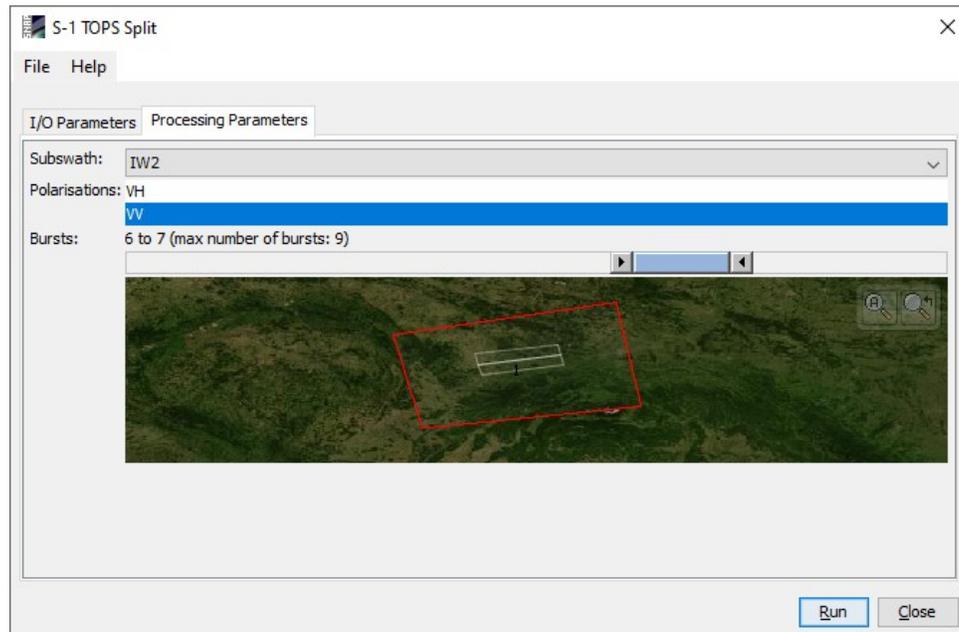


Figure 7: TOPS Split

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.

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 8).

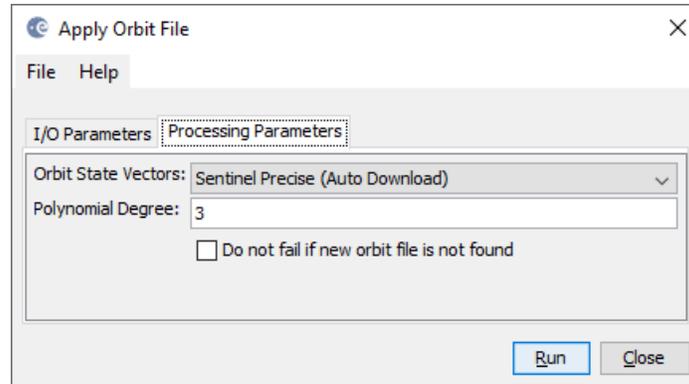


Figure 8: Apply Orbit File

Back Geocoding and Enhanced Spectral Diversity

The *S-1 Back Geocoding* operator (under *Radar > Coregistration > Sentinel-1 TOPS Coregistration*) coregisters the two split products based on the orbit information added in the previous step and information from a digital elevation model (DEM) which is downloaded by SNAP.

Add the products of the two dates (ending with “_split_Orb”) to the file list in the *ProductSet-Reader* tab and select **SRTM 1Sec HGT (AutoDownload)** in the *Back-Geocoding* tab (Figure 9).

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).

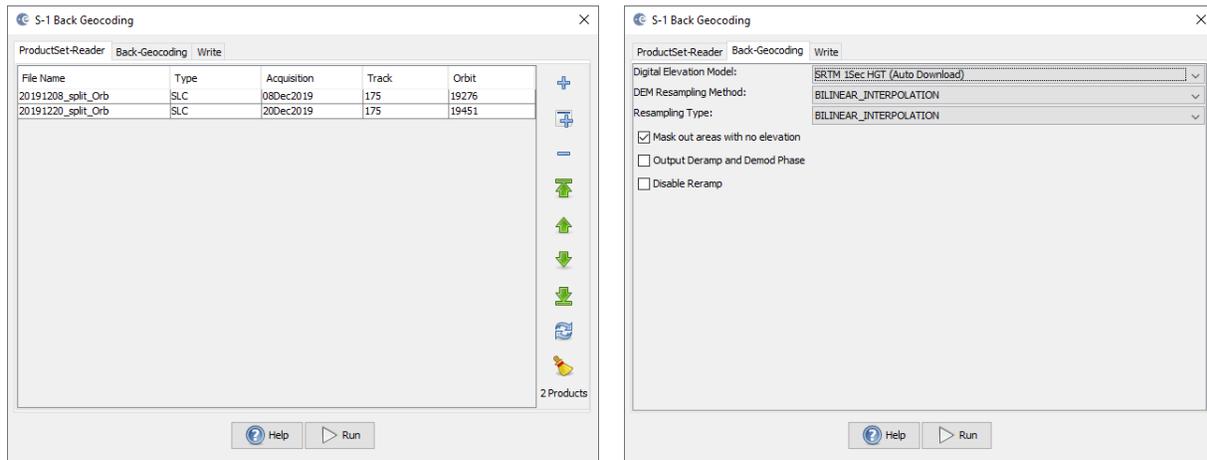


Figure 9: Back Geocoding

To increase the quality of the coregistration you apply the *S-1 Enhanced Spectral Diversity* (ESD) operator (under *Radar > Coregistration > Sentinel-1 TOPS Coregistration*) on the stack generated by the Back Geocoding. It applies range and azimuth shift corrections to the secondary image.

Note: This operator is only needed when you select more than one burst. If you only selected one burst in the TOPS Split step, you do not need the ESD operator.

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 10)².

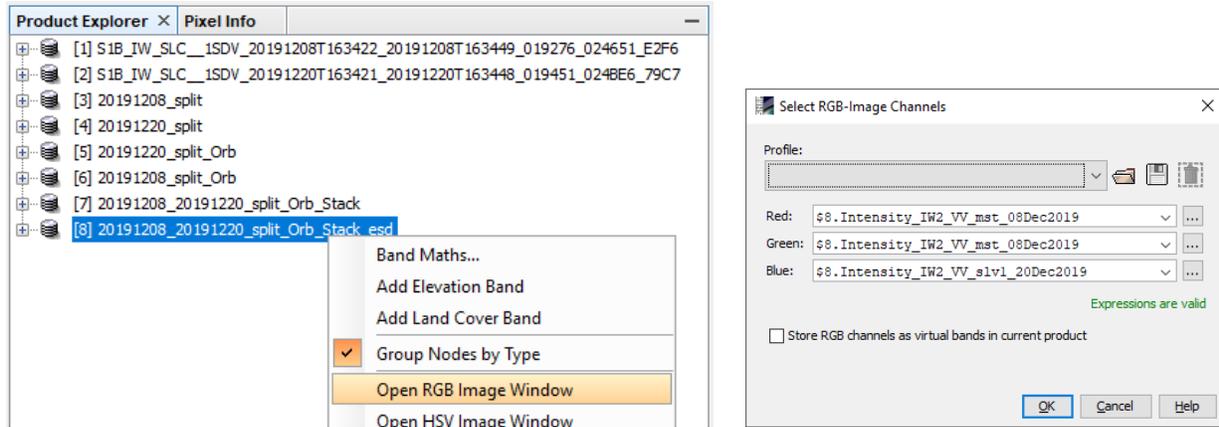


Figure 10: Generation of an RGB image

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 11).

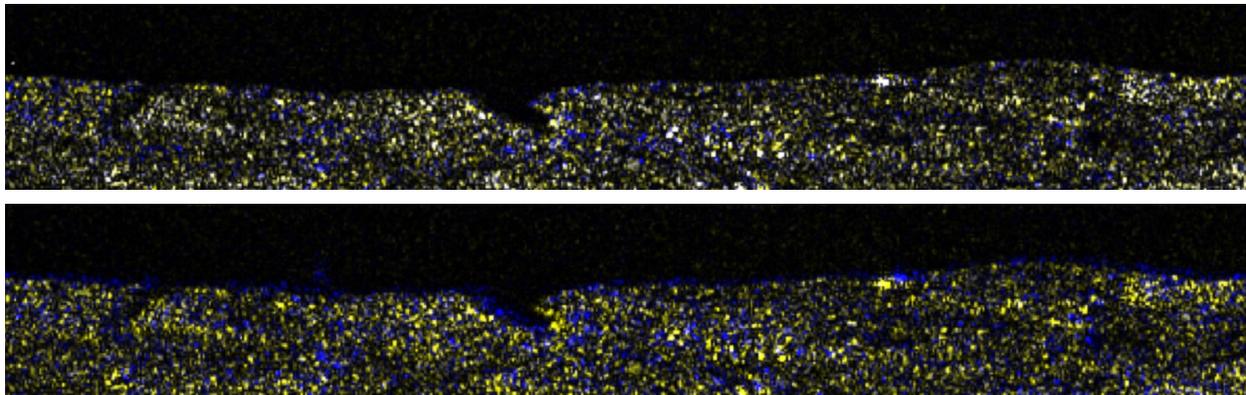


Figure 11: Successful (top) vs. failed (bottom) coregistration in an RGB image

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/>

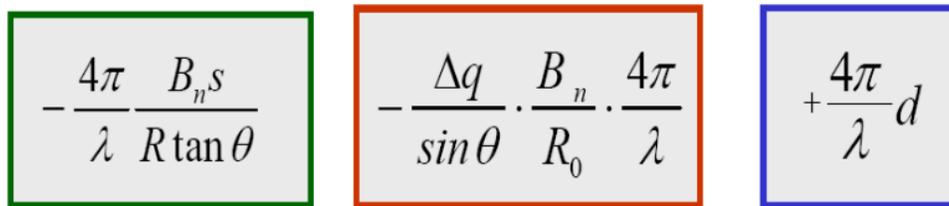
Interferogram Formation and Coherence Estimation

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 ϕ_{disp} which occurred between the two acquisitions (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 12: Contributors to SAR interferometric phase

Differential 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 remove them from the interferogram so that the remaining phase variation can be attributed to surface elevation changes between both image acquisitions (Equation 2; [ESA TM-19A](#), chapter 2.3). This works best if atmospheric contributions and other noise is kept as small as possible because they are hard to model. It is therefore advisable to use images from the dry season and with small perpendicular baseline. More hints on the selection of suitable image pairs are given in [ESA TM-19B](#), chapter 1.4)

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

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).

Accordingly, repeat-pass interferometry (phase difference of images of two different acquisition dates) will rarely lead to usable results over dense vegetation, especially with C-band SAR data of Sentinel-1 which has a wavelength of around 5.5 cm).

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 stack you generated after Back Geocoding and ESD 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.
- **Subtract topographic phase:** Flat terrain should produce a series of regularly spaced, parallel fringes. Any deviation from a parallel fringe pattern can be interpreted as topographic variation. If you want this topographic variation (e.g. for the derivation of a digital elevation model), you do not subtract the topographic phase. As this workflow is interested in the surface displacement (Equation 2), topographic phase removal is applied by selecting the **SRTM 1Sec HGT (Auto Download)**.
- **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](#).

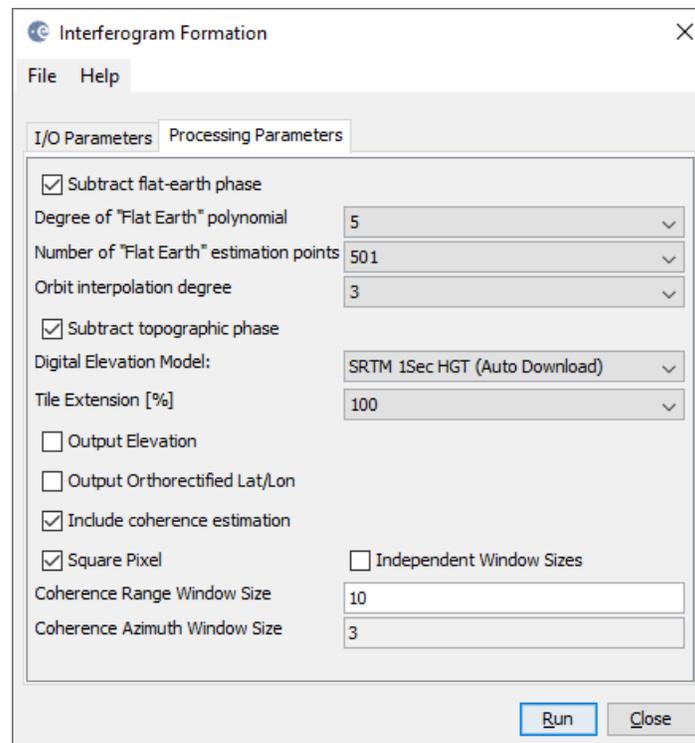


Figure 13: Interferogram Formation

The resulting product will contain the interferogram (*Phase_ifg_IW...*) and the coherence (*coh_IW...*) as separate bands (Figure 14). Double click them to check for their quality. Both products still contain the black seamlines separating the single bursts. They will be removed in the following step.

As topographic phase removal was applied, the interferogram should now only contain variations from displacement, atmosphere and noise. It is displayed in a rainbow color scale ranging from $-\pi$ to $+\pi$. 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. Relative ground movement between two points is later derived by counting the fringes and multiplying by half of the wavelength. The closer the fringes are together, the greater the strain on the ground.

The coherence shows the areas where the phase information is coherent, which means that it can be used to measure deformation (as in this tutorial) or topography (without removing the topographic phase). While urban areas and agricultural land are displayed in white and show high coherence values (above 0.6), forest areas are dark and have low coherence (below 0.3). Accordingly, phase information over forest areas 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.

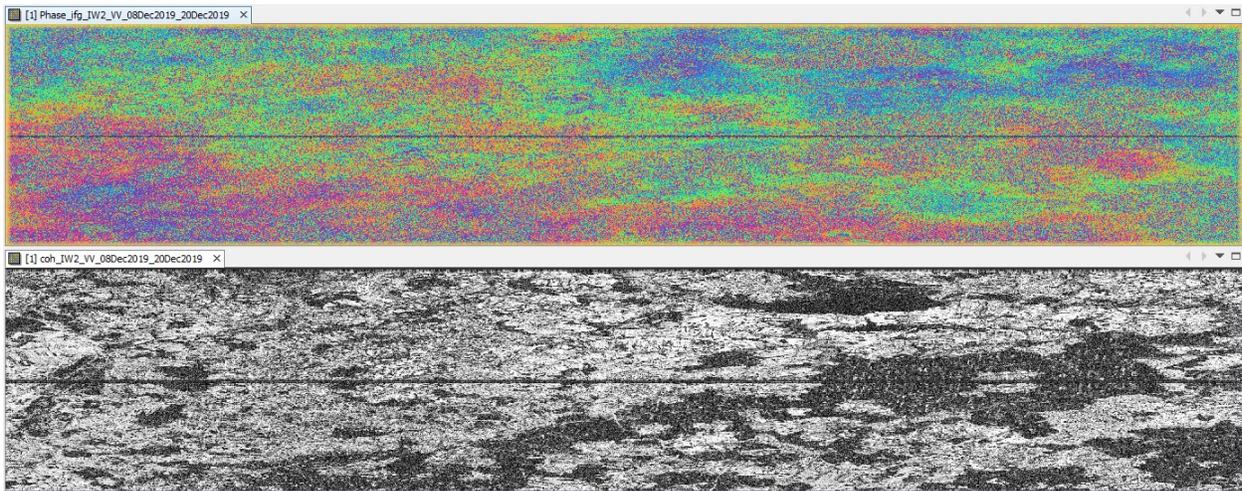


Figure 14: Interferogram (top) and coherence (bottom)

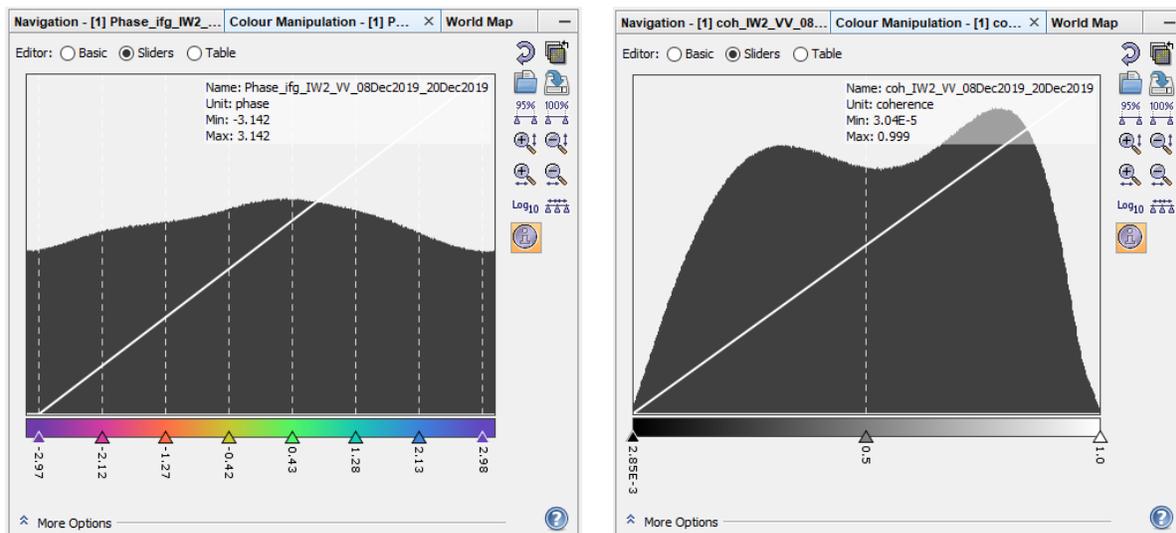


Figure 15: Histogram of interferogram (left) and coherence (right)

TOPS Deburst

To remove the seamlines between the single bursts, the *S-1 TOPS Deburst operator* (under *Radar > Sentinel-1 TOPS*) is applied to the interferogram product. It does not require any user input (Figure 16). The output contains the same bands as the input, but with merged bursts according to their zero Doppler time. More information on this step is provided in the [Sentinel-1 User Guide](#).

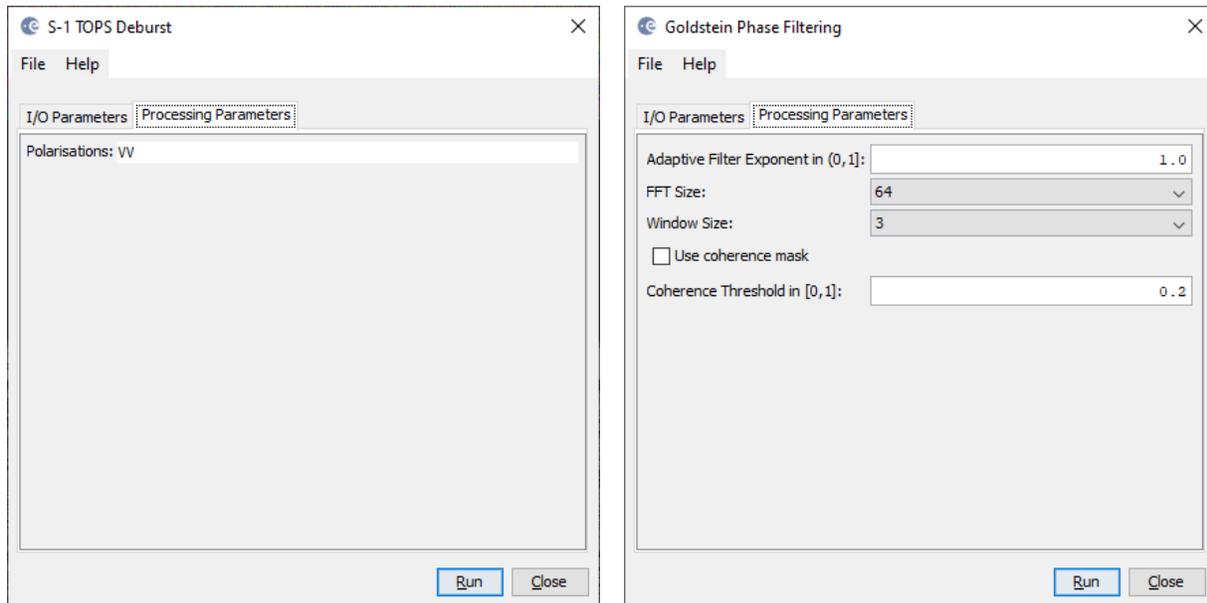


Figure 16: TOPS Deburst (left) and Goldstein phase filtering (right)

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 \(1998\)](#).

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

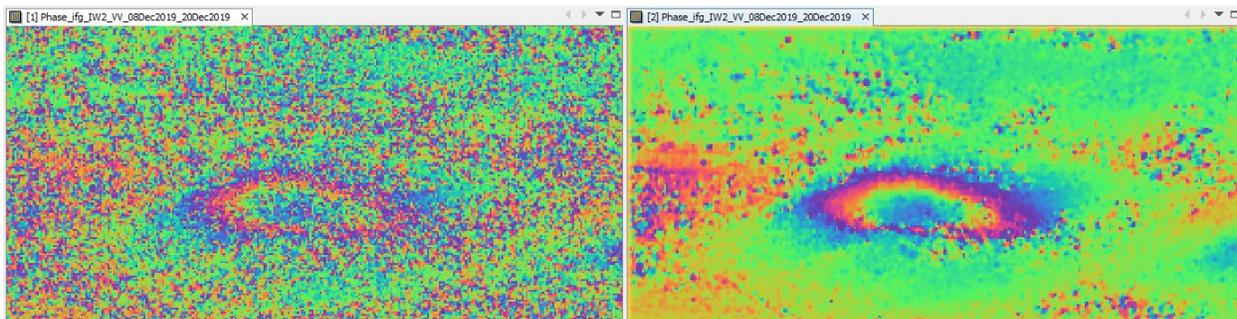


Figure 17: Interferogram before (left) and after (right) Goldstein phase filtering

(50° 03' 28" N, 18° 34' 19" E)

Subset

As the selected bursts cover a larger area than required for this analysis, a subset can be generated. Please note that the subset should only be applied on a S1 SLC product after *TOPS Deburst*. Technically, the subset could have been applied before the phase filtering, but sometimes patterns become visible after applying the filter and it is good to have a look at the filtered result before selecting the area of interest. Furthermore, the subset allows to get rid of the green areas at the edges of the image which were introduced during the processing.

To create a subset, select the filtered product in the *Product Explorer* and select *Subset* (under *Raster*). Enter the following Pixel coordinates

- Scene start X: 8958
- Scene start Y: 50
- Scene end X: 17250
- Scene end Y: 2800

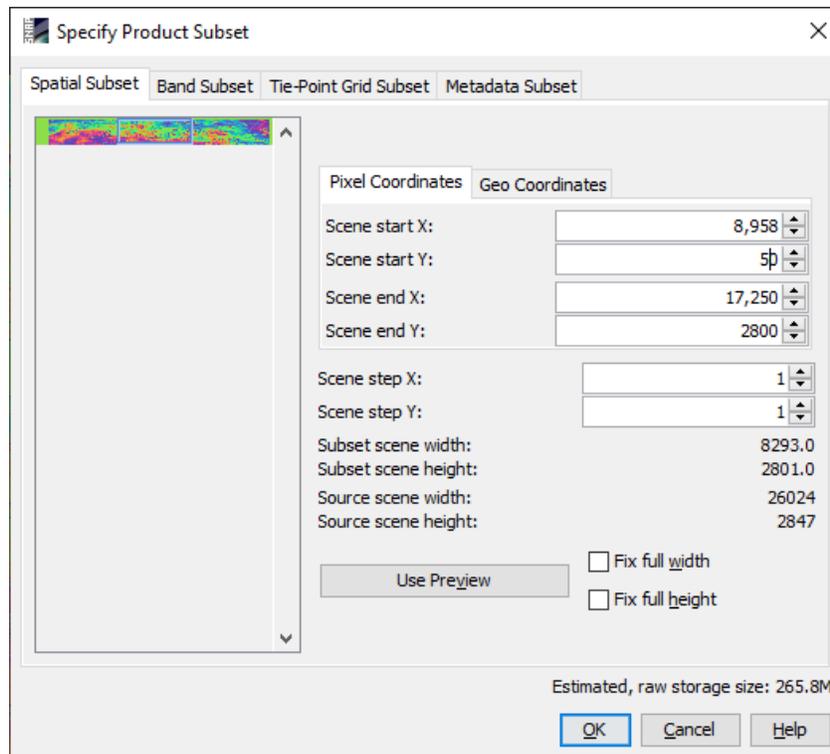


Figure 18: Subset

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_`. This product is only of temporary nature and lost if SNAP is closed. To permanently store it, right-click on the product and select **Save Product As...** and save it in BEAM DIMAP format under the name

```
20191208_20191220_split_Orb_Stack_esd_ifg_debflt_subset.dim
```

Note: for reasons of consistency, the suffix `subset` is placed at the end of the filename.

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.

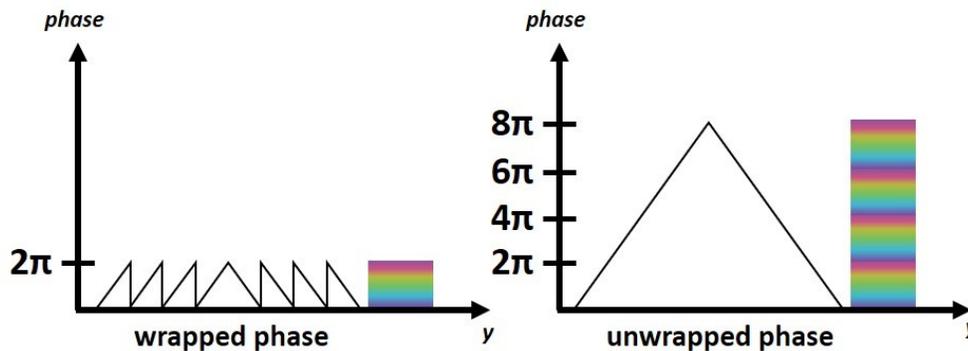


Figure 19: Principle of phase unwrapping

For optimal unwrapping results it is recommended to filter the interferogram as done in the previous step and eventually apply multi-looking (under *Raster > SAR Utilities*). As the fringe patterns of the surface displacement are quite fine scaled (Figure 17), no multi-looking is applied in this case. For the derivation of large-scale displacement maps, multi-looking to a spatial resolution of 20 meters or lower should be considered.

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 the section “Install *snaphu*” at the beginning of this document), 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`). If the selection of the directory does not work, simply copy and paste the path of your working directory into the text field. Select **DEFO** as *Statistical-cost mode* and select **200** pixels for *Row Overlap* and *Column Overlap*. 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](#).

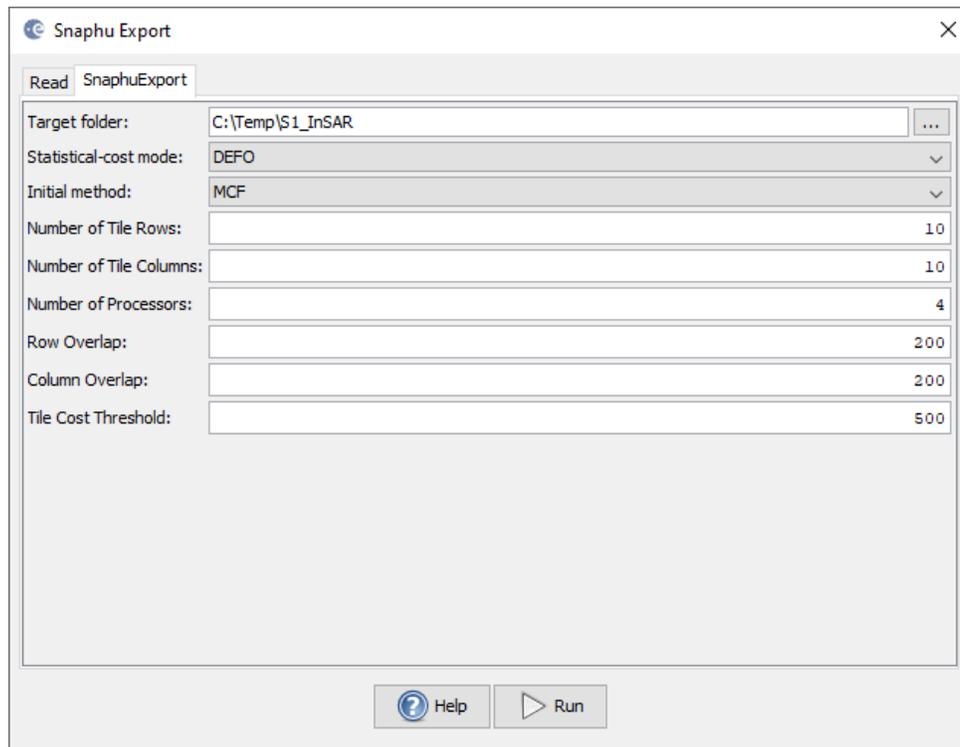


Figure 20: Snaphu export

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: `20191208_20191220_split_Orb_Stack_esd_ifg_debflt_subset`). 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: `20191208_20191220_split_Orb_Stack_esd_ifg_debflt_subset`). 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.

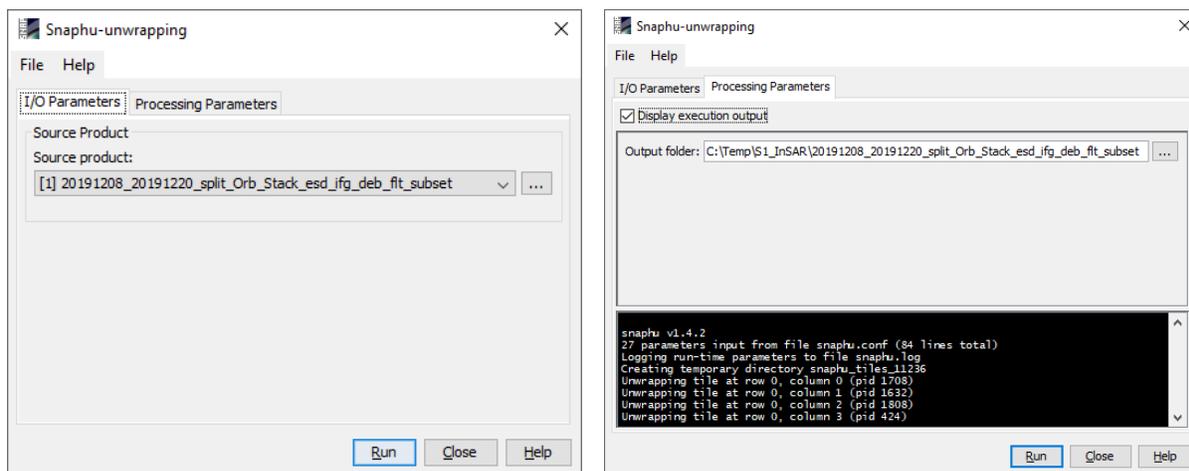


Figure 21: Unwrapping with the snaphu plugin

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.

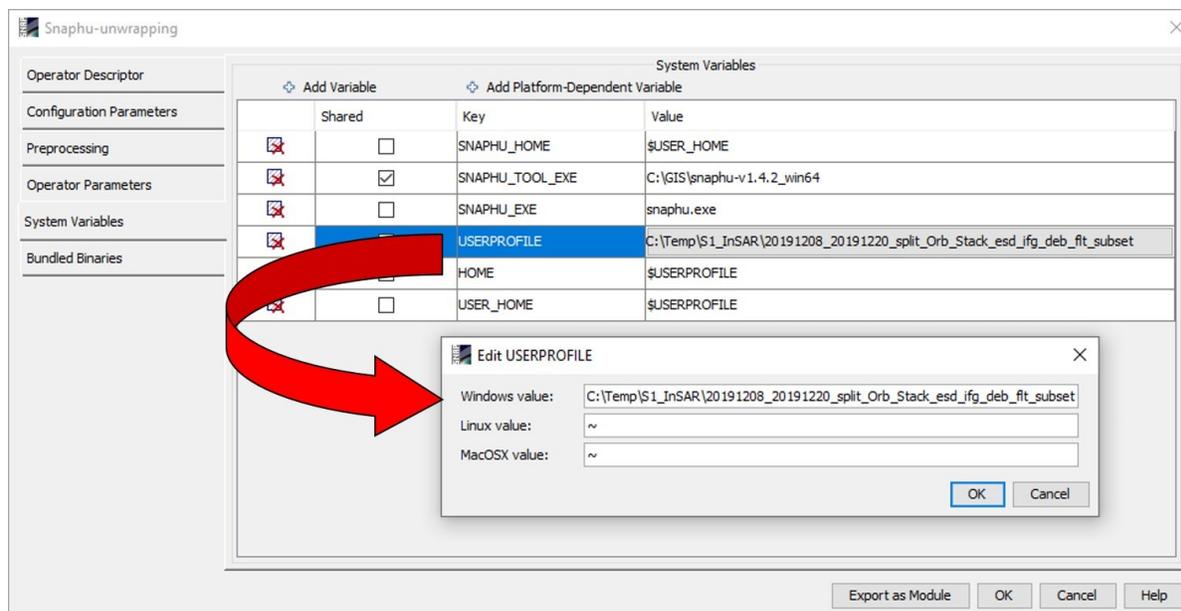


Figure 22: System variables of the snaphu plugin

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.

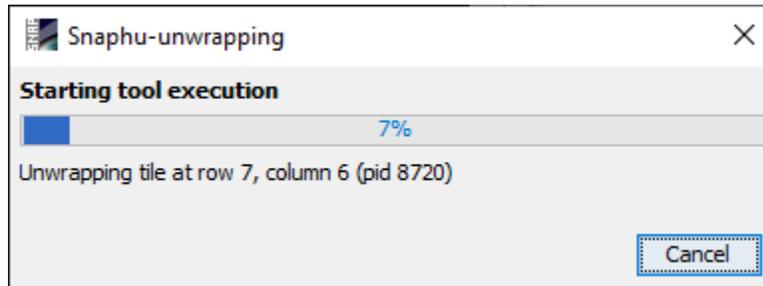


Figure 23: Progress of the unwrapping

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: `20191208_20191220_split_Orb_Stack_esd_ifg_debflt_subset_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: `Unw_Phase_ifg_08Dec2019_20Dec2019`)

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.

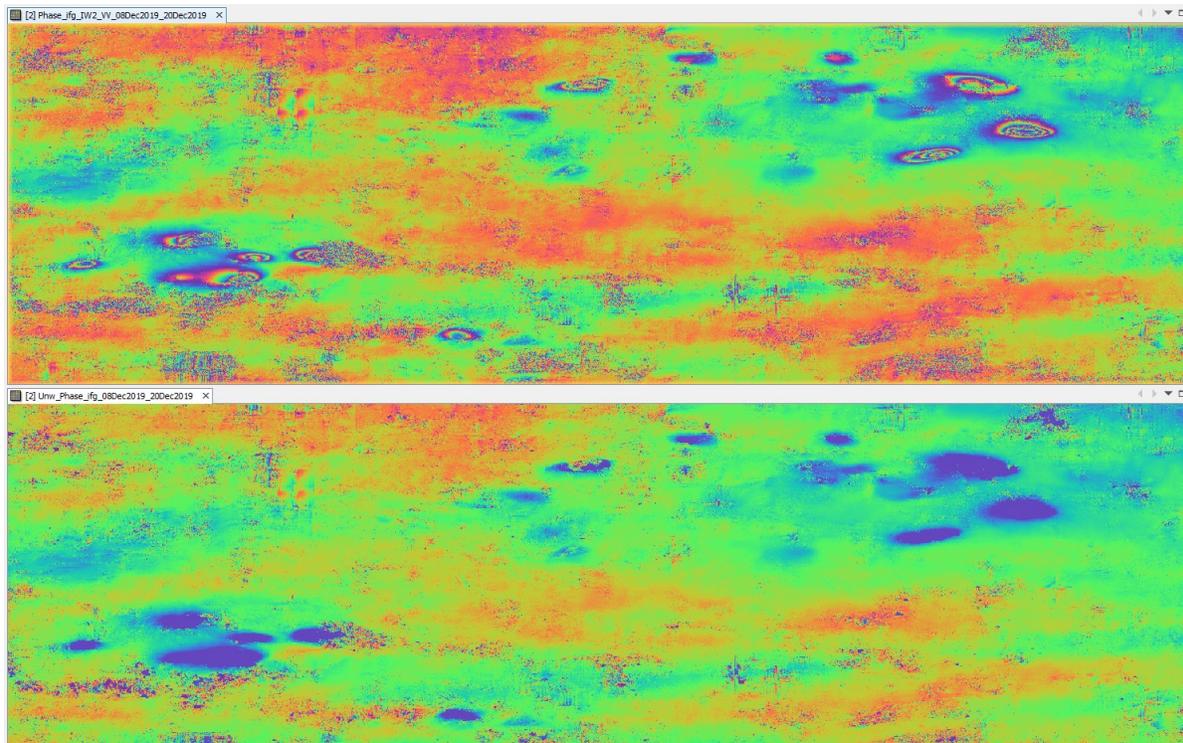


Figure 24: Phase before (top) and after (bottom) unwrapping

Phase to Displacement

The unwrapped phase is now a continuous raster but not yet a metric measure. To convert the radian units into absolute displacements, the *Phase to Displacement* operator (under *Radar > Interferometric > Products*) is applied. It translates the phase into surface changes along the line-of-sight (LOS) in meters. The LOS is the line between the sensor and a pixel. Accordingly, positive values mean uplift and negative values mean subsidence of the surface (if the reference image has the earlier acquisition date).

The *Phase to Displacement* operator has no parameters and 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 displacement

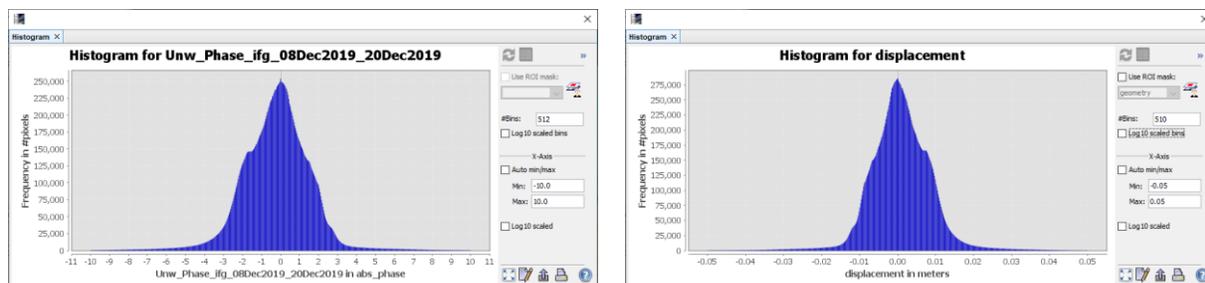


Figure 25: Histogram of unwrapped phase (left) and LOS displacement (right)

You can digitize a line and use the *Profile Plot* tool  to visualize single displacement patterns and their ranges (Figure 26). This is also a good way to check also the amount of noise in the lower coherence areas. In this case, local craters with diameters of up to 100 meters become visible in the unwrapped phase which indicate subsidence of up to 8 cm (-0.08 m), but this has to be validated by field measurements or external data. A suggestion on how to make the values more stable by multi-temporal averaging is given at the end of the document.

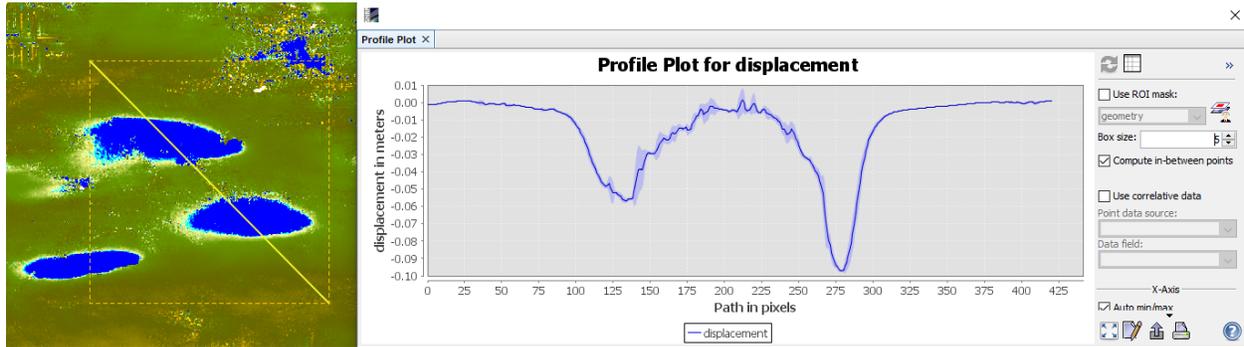


Figure 26: Profile plot for the displacement band across two subsidence craters

Note: The original phase and coherence bands are not automatically copied into the resulting raster of the *Phase to Displacement* operator. If they are needed in the final product, they can be added via the *Band Maths* operator (right-click on the displacement 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. Confirm with **OK** (twice) to apply the calculation.

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

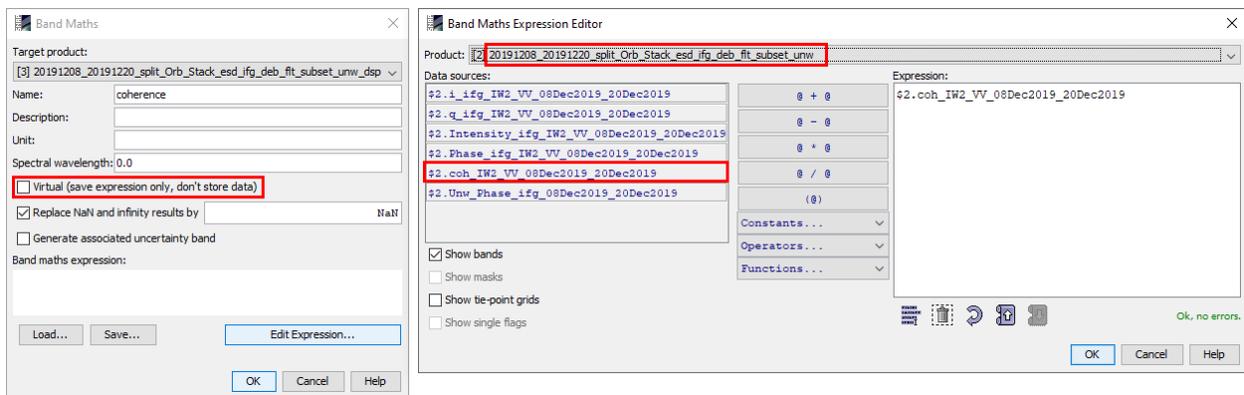


Figure 27: Transfer of bands between products

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](#).

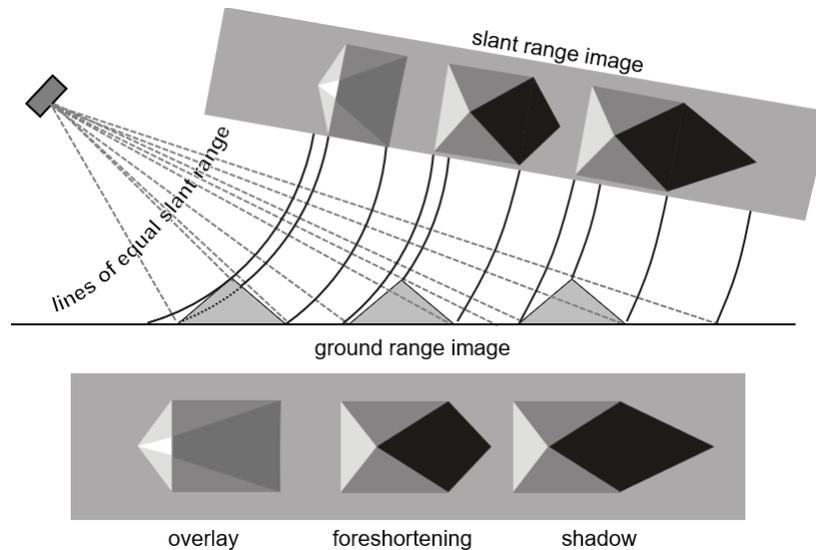


Figure 28: Geometric distortions in radar images ([Braun 2019](#))

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

In the Processing Parameters tab, select **SRTM 1Sec HGT (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. 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.

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.

Double click on the output to view the geocoded displacement raster (Figure 30).

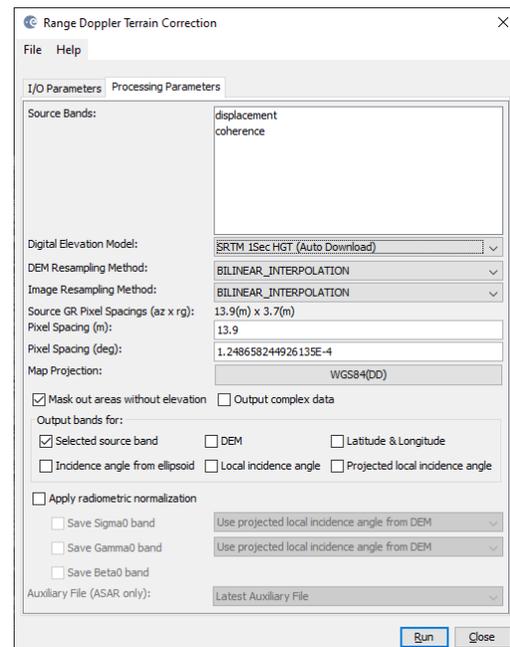


Figure 29: Range Doppler Terrain Correction

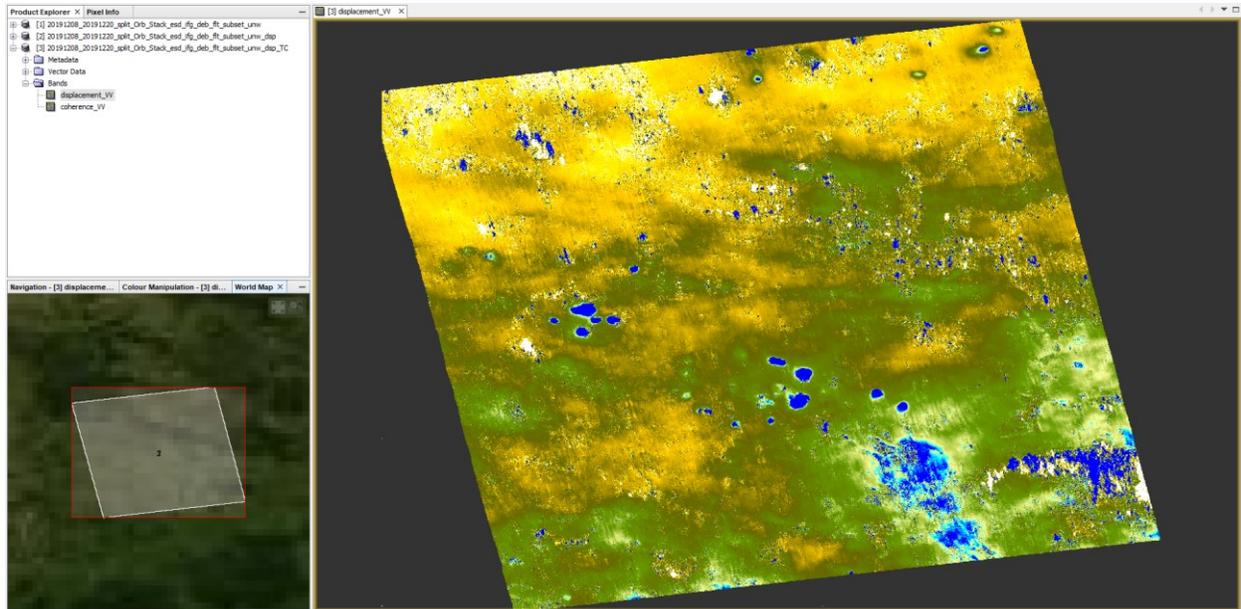


Figure 30: Terrain corrected and geocoded displacement raster

Mask out low coherence pixels

Sometimes it is good to mask out image parts with low coherence to prevent misinterpretation of patterns which resulted from phase decorrelation. This is why the coherence was transferred into the displacement product in the previous step. To mask them out, right-click on the geocoded displacement band and select **Properties**.

In the *Valid-Pixel Expression*, enter the term `coherence_VV > 0.6` (Figure 31).

All pixels with a coherence value below 0.6 are now made transparent in SNAP.

Export to Google Earth

All geocoded products (projected to WGS84) can be exported as a KMZ file to view them in [Google Earth](https://www.google.com/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 **Safe**. Open the kmz file in Google Earth to view the location of the displacement patterns on the satellite image base map (Figure 32).

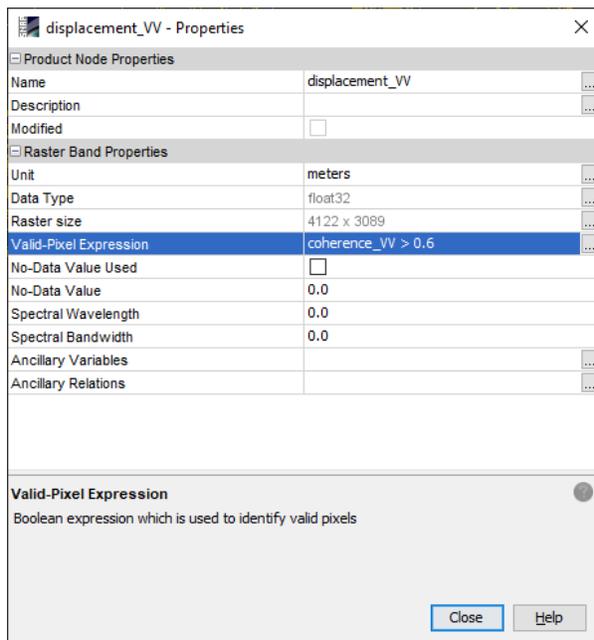


Figure 31: Masking out areas of low coherence

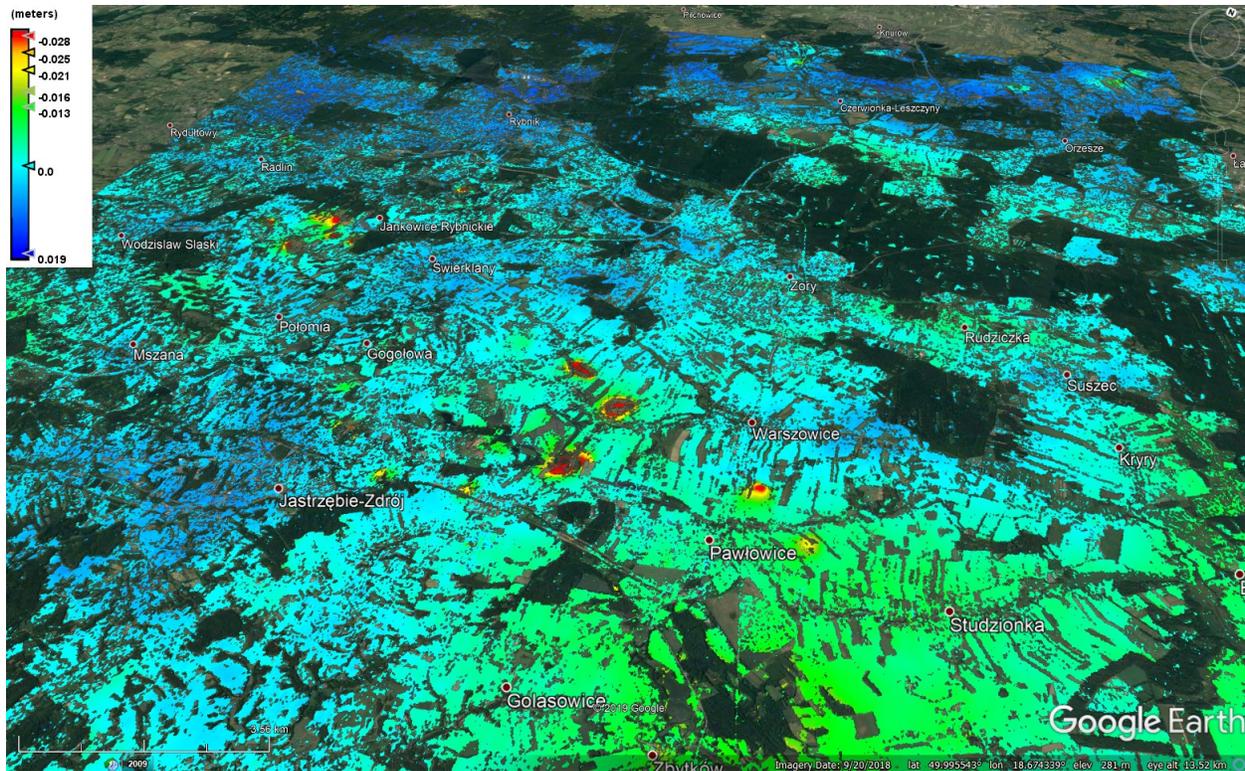


Figure 32: Result exported to Google Earth

Suggestions for further analyses

This tutorial showed how to derive surface displacement from a single image pair of SLC radar data. However, it remains unclear how well the result represents the real conditions. This can only be achieved by external reference data.

However, to minimize the impact of atmospheric phase disturbances and unwrapping errors, a series of images can be analyzed to get a more reliable result. For this, the following products were downloaded, all belonging to the same relative orbit (175) at a temporal interval of 12 days:

1. S1B_IW_SLC__1SDV_20191009T163423_20191009T163449_018401_022AA1_F8D3
2. S1B_IW_SLC__1SDV_20191021T163423_20191021T163450_018576_022FFE_581D
3. S1B_IW_SLC__1SDV_20191102T163423_20191102T163449_018751_02357D_5396
4. S1B_IW_SLC__1SDV_20191114T163423_20191114T163450_018926_023B27_3BDF
5. S1B_IW_SLC__1SDV_20191126T163422_20191126T163449_019101_0240C7_98AB
6. S1B_IW_SLC__1SDV_20191208T163422_20191208T163449_019276_024651_E2F6
7. S1B_IW_SLC__1SDV_20191220T163421_20191220T163448_019451_024BE6_79C7
8. S1B_IW_SLC__1SDV_20200101T163421_20200101T163448_019626_02517E_73AC

All steps in this tutorial were repeated for each consecutive image pair, for instance 1+2, 2+3, 3+4, and so on, resulting in a total of 7 geocoded displacement products between 09.10.2019 and 01.01.2020 (Figure 33).

The single products were stacked in chronological order (*Radar > Coregistration > Stack Tools > Create Stack*, using **Geolocation** as *initial offset method*).

One average displacement was then calculated in the *Band Maths* by adding raster of all dates and dividing the result by 7:

```
(displacement_VV_mst +
displacement_VV_slv1_21Oct2019 +
displacement_VV_slv3_02Nov2019 +
displacement_VV_slv5_14Nov2019 +
displacement_VV_slv7_26Nov2019 +
displacement_VV_slv9_08Dec2019 +
displacement_VV_slv11_20Dec2019) / 7
```

The same was calculated for the coherence. A new valid pixel expression can be entered in the properties of the averaged displacement band (for instance `coherence_avg > 0.4`). By averaging displacements of several dates, the impact of atmospheric disturbances and unwrapping errors is reduced, and actual displacement patterns become more evident (Figure 33). However, this assumes that deformation trend is linear between the first and the last image pair.

The *Profile Plot* tool  can then be used to plot the average LOS displacement rates between October and December 2019. As shown in the image, the rate is about 4 to 5 cm per 12 days.

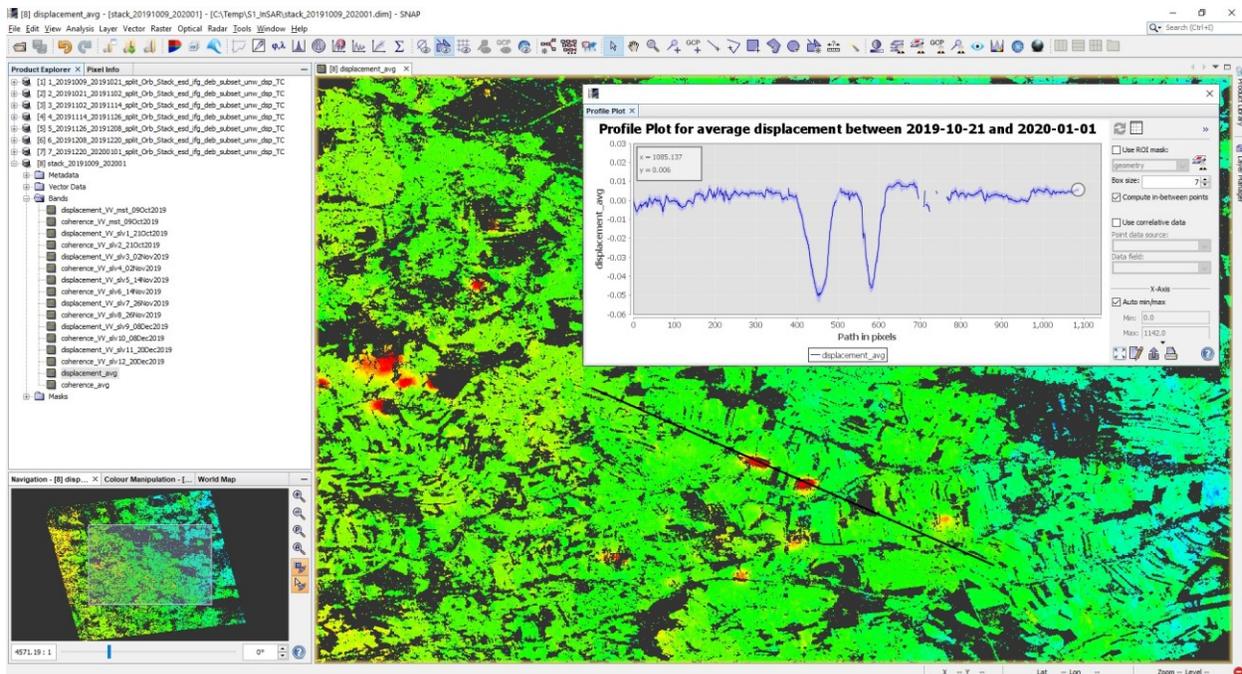


Figure 33: Multi-temporal averaging of displacement



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/>