

# Sentinel-1 Toolbox

## InSAR Displacement Mapping with ERS data

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## ERS Interferometry Tutorial

The goal of this tutorial is to provide novice and experienced remote sensing users with step-by-step instructions on interferometric processing of ERS products to estimate surface deformation.

### **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 changes which occurred between two image acquisitions are estimated using radar interferometry.

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

#### *ERS Stripmap Products*

The European Remote Sensing Satellites (ERS) are two spaceborne radar sensors which were launched in July 1991 (ERS-1) and April 1995 (ERS-2) by the European Space Agency (ESA).

Besides other instruments, such as radar altimeters or wind scatterometers, both systems operate a C-band wavelength (5.3 GHz) synthetic aperture radar (SAR) for the formation of images at an azimuth resolution of 6 to 30 meters and a range resolution of 36 meters. Each image covers a footprint of approximately 100 x 100 kilometers.

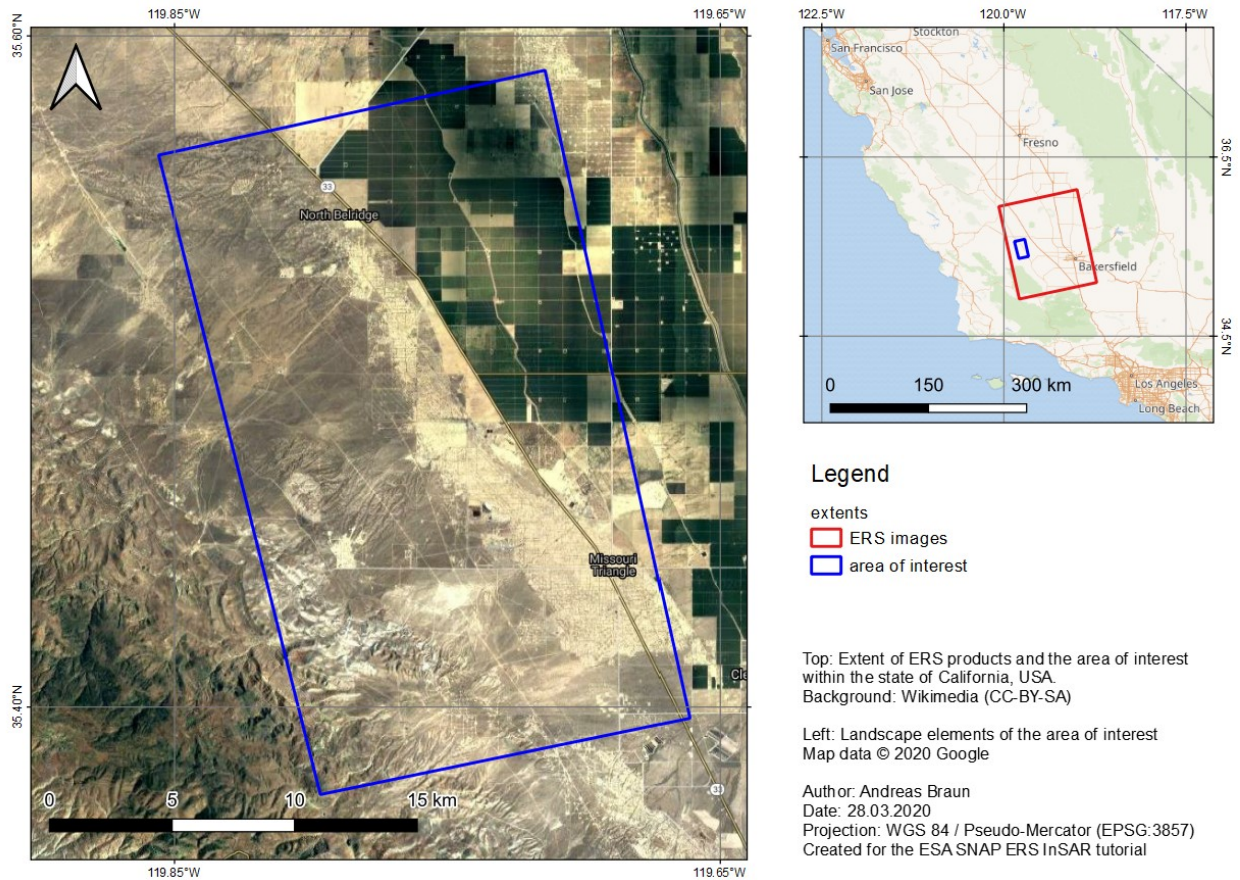
The repeat cycle, defined as the interval at which the satellite is able to acquire another image from the exact same position (same track) is 35 days. Between March 1995 and June 1996 both sensors were operating in a tandem phase, allowing same track temporal baselines of one day to reduce temporal decorrelation and increase the interferometric potential of the missions ([Duchossois & Martin 1995](#)).

ERS-1 and ERS-2 operated at VV polarization until March 2000 and June 2003 respectively, clearly exceeding their initially expected lifetimes. Together with [ENVISAT ASAR](#) (2002-2012) which was flying in the same orbital plane, they achieved over 20 years of consistent and global coverage of radar imagery.

More information on ERS products is provided here: <https://directory.eoportal.org/web/eoportal/satellite-missions/e/ers-1> and here <https://directory.eoportal.org/web/eoportal/satellite-missions/e/ers-2>.

### Study area

The data used in this tutorial is a part of a ERS acquisition in the US state of California and covers a footprint of around 16 x 27 km (Figure 1, blue line). It belongs to Kern county and covers parts of the [Lost Hills Oil Field](#), one of many oil fields in California. Two ERS images from April and May 1995 are used in this tutorial to estimate deformation rates in this area.



**Figure 1: Extent and location of the data**

This tutorial is based on a study of Fielding, Blom and Goldstein:

Fielding, E.J.; Blom, R.G.; Goldstein, R.M. (1998): Rapid subsidence over oil fields measured by SAR interferometry. *Geophysical Research Letters* **25**(17), 3215-3218. <https://doi.org/10.1029/98GL52260>.

The reference study makes use of more than one image pair to analyze the sensitivity of image combinations on the observed deformation: They use temporal baselines between one day and 26 months to assess surface subsidence at different temporal scales and to get the maximum deformation rate.

In this tutorial, only one image pair is used with a temporal baseline of 35 days and a perpendicular baseline of 20 meters, but all results could be replicated with the additional images listed in Table 1 of the study.

## Preparation

### Download the Data

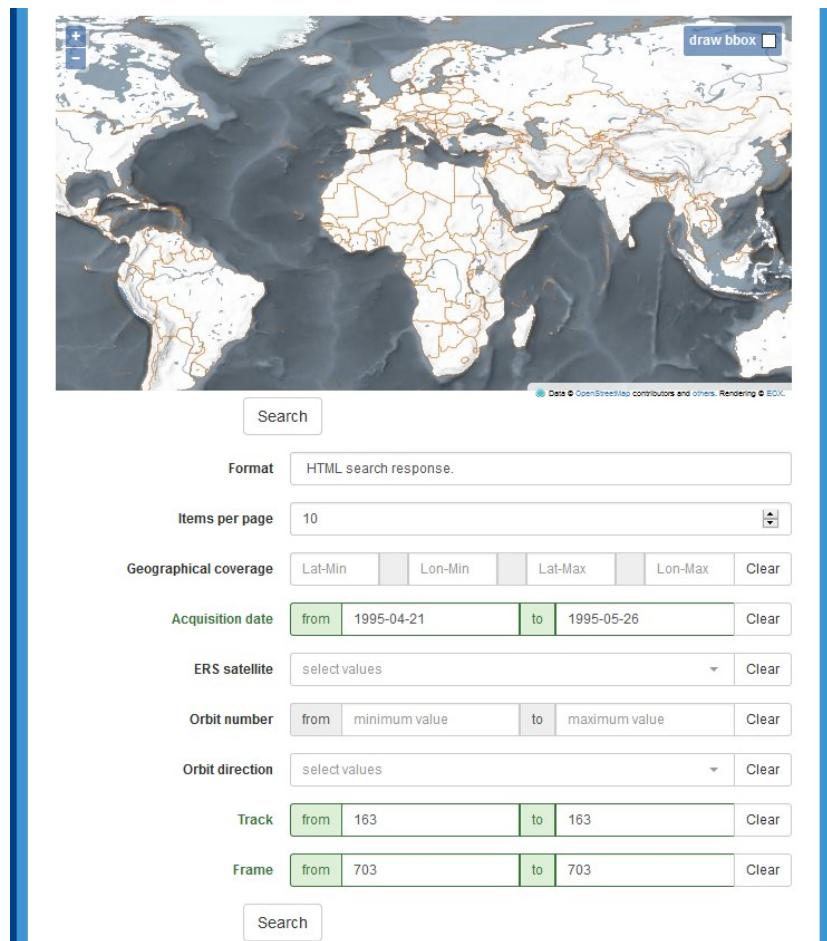
The data used in this tutorial can be downloaded from the ESA Online Dissemination Service:  
<https://esar-ds.eo.esa.int/oads/access/>

An ESA Earth Observation Users' Single Sign On (EO-SSO) login is required, but it can be freely registered here: <https://earth.esa.int/web/guest/general-registration>

Once you are logged in, navigate to [Collections](#) and select [SAR IMS 1P - Level 1 product for ERS SAR](#). **IMS** represents the Single Look Complex product which contains the real and imaginary part of the complex radar signal. This is required for SAR interferometry. Accordingly, it is important **not** to select **IMP** which is a Precision Image product, only containing backscatter intensity (more information on product specifications is given [here](#)).

Although there are many ways to find the products, the easiest is via the [Catalogue search](#). Enter the parameters as specified below and displayed in Figure 2:

- Acquisition date: from **1995-04-21** to **1995-05-26**
- Track: from **163** to **163**
- Frame: from **703** to **703**



Search

Format HTML search response.

Items per page 10

Geographical coverage Lat-Min Lon-Min Lat-Max Lon-Max Clear

Acquisition date from 1995-04-21 to 1995-05-26 Clear

ERS satellite select values Clear

Orbit number from minimum value to maximum value Clear

Orbit direction select values Clear

Track from 163 to 163 Clear

Frame from 703 to 703 Clear

Search

Figure 2: Search for suitable ERS images

Execute the query by clicking “Search”. it yields exactly two products which are located in the study area (Figure 3).

- #1 SAR\_IMS\_1PNESA19950421\_061616\_00000015G145\_00163\_19690\_0000.E1
- #2 SAR\_IMS\_1PNESA19950526\_061620\_00000015G146\_00163\_20191\_0000.E1

[back to search form](#) | [bulk download lists](#)

### Collection SAR\_IMS\_1P

Level 1 products for ERS SAR Single-Look Complex

More information can be found in this [page](#).

Search result page 1 of 1 pages (2 of 2 records found in 0.002 seconds).



**Figure 3: Result of the query**

Download them by clicking on the corresponding download link in the results list below the map. Note that a separate window opens, and it can take some minutes until the download starts. It is therefore important not to close this page before.

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\ERS\Fielding\`.

Note: The ESA Online Dissemination Service also allows to search for specific interferometric configurations using the [Interferometric search](#). It allows to define the maximum temporal baseline (e.g. to find image pairs of ERS-1 and ERS-2 acquired during the tandem phase) or to identify pairs with ideal perpendicular baselines. Recommendations on the selection of suitable image pairs are given in [ESA TM-19B](#), chapter 1.4).

## 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 4) and search for “SNAPHU Unwrapping” in the *Available Plugins* tab. Select it and click **Install**.

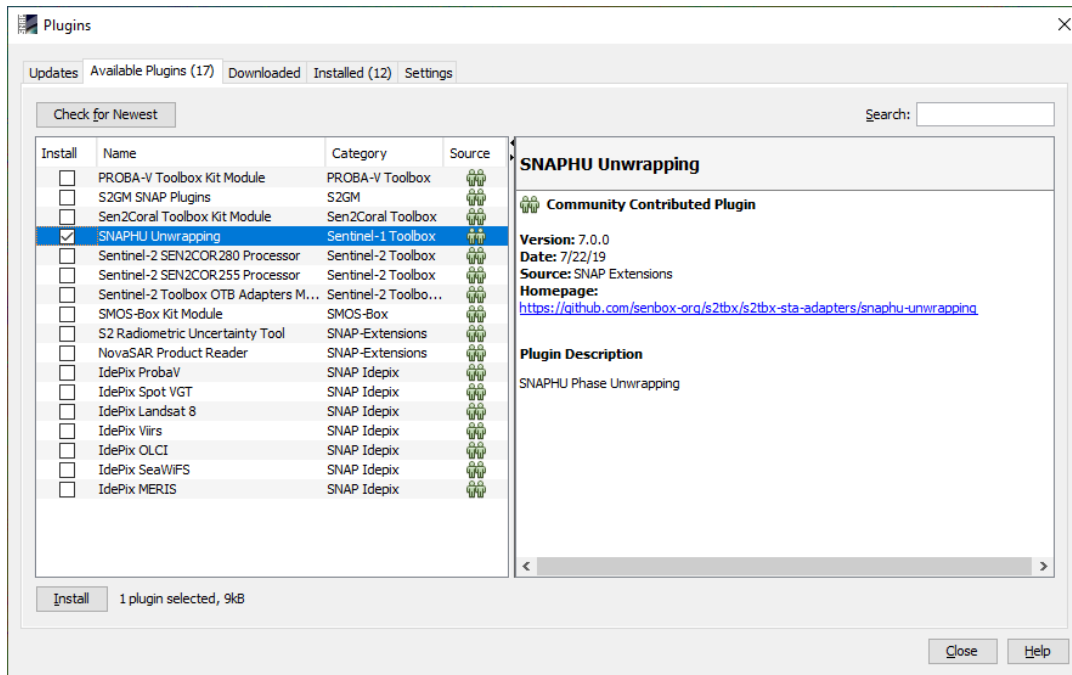


Figure 4: The Plugins interface

You will be asked to proceed with “Next” and restart SNAP (Figure 5). This creates a menu entry for *snaphu* unwrapping in the Interferometry menu.

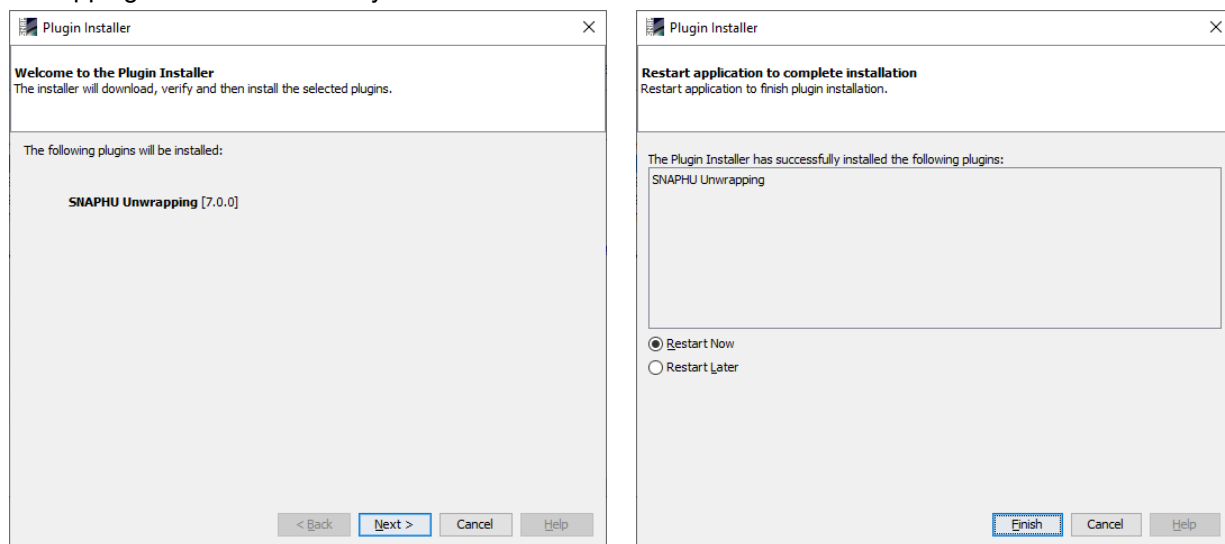



Figure 5: Installation of the *snaphu* plugin

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 6). 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).

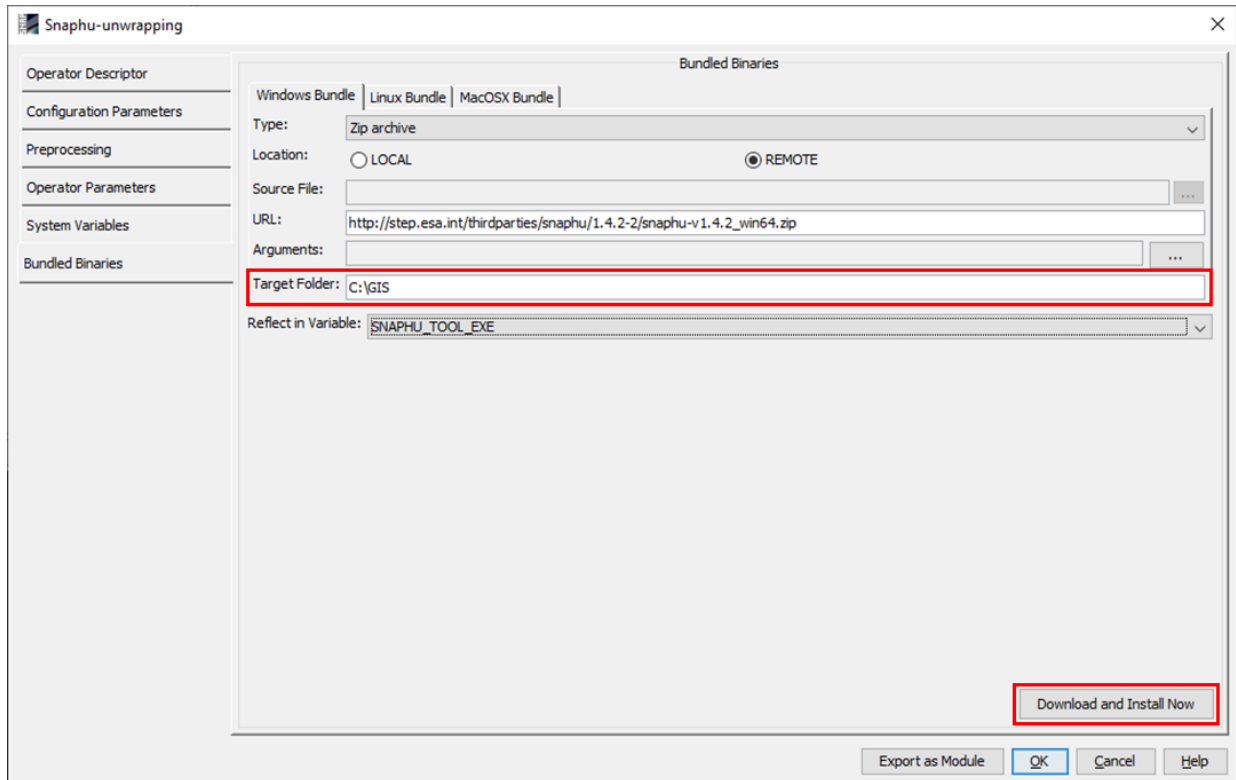


Figure 6: Installation of the snaphu bundles

## Open the Products

Use the *Open Product* button in the top toolbar and browse for the location of the downloaded data. Select the two files ending with \*.E1 file located in your working directory and press **Open Product**.

In the *Products View* you will see the opened products. Each ERS product consists of a number of metadata , tie-point grids and raster entries. The radar information is stored in the *i* and *q* raster as the real and imaginary parts of the complex signal and the resulting backscatter intensity as demonstrated in Figure 6.

Double-click on “Abstracted Metadata” to view the most important parameters of the imaging system. For example, the native resolution of the raster is given by

- range\_spacing (7.9 m) and
- azimuth\_spacing (3.98 m)

as shown in Figure 8.

Double-click on the *Intensity* band to view the raster data (Figure 9). Depending on the capabilities of your computer, this might take a while.

The footprint of the radar image is displayed in the *World View* or *World Map*. It shows that both images cover the same track (required for interferometry) and frame.

Because of the side looking geometry of the SAR system and the smaller resolution in azimuth direction, the squared footprint of the image is displayed rectangular in the image view

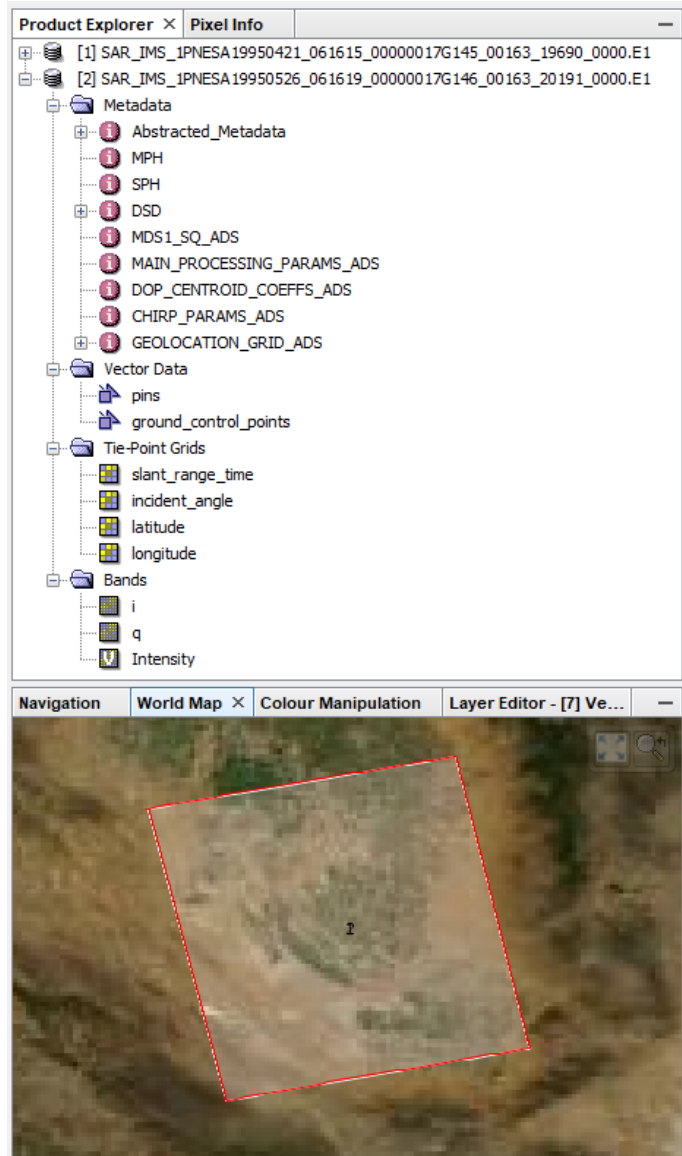
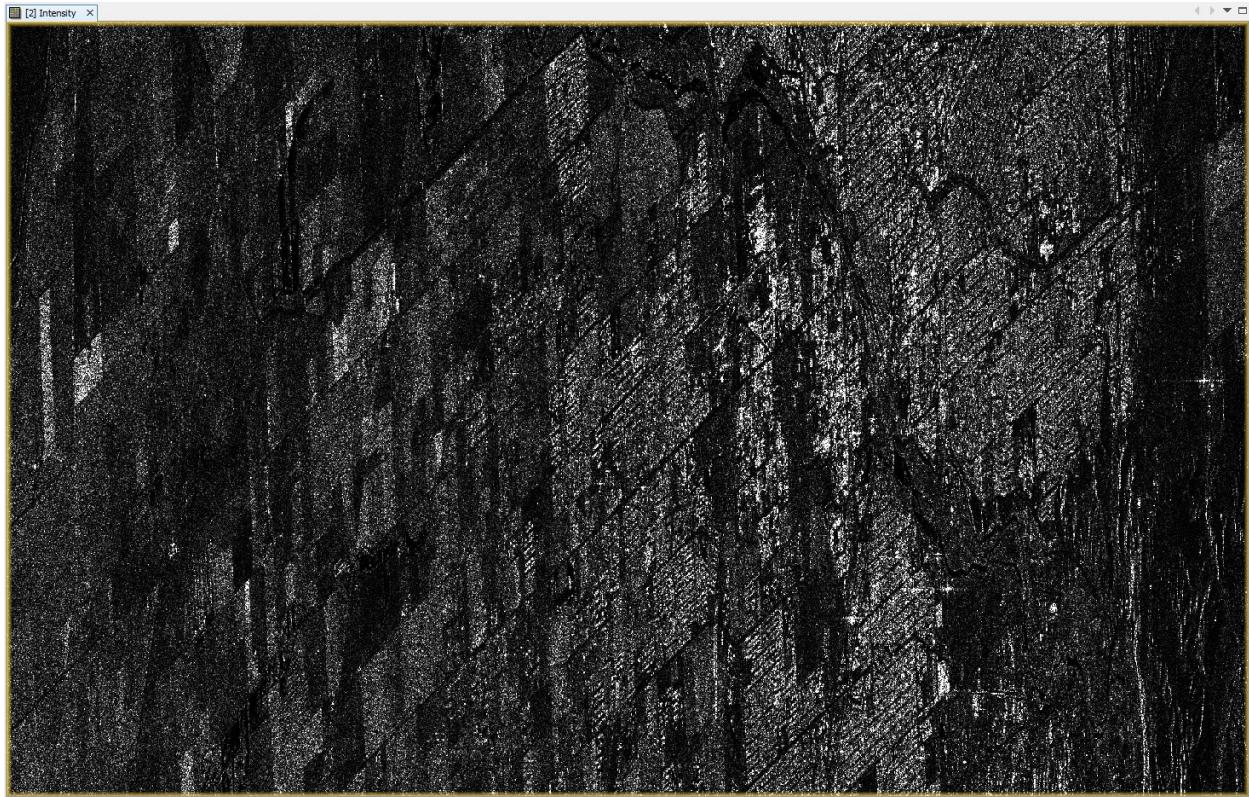


Figure 7: Product Explorer and World Map

Name	Value	Unit	Type
range_spacing	7.90489006	m	float64
azimuth_spacing	3.98126841	m	float64

Figure 8: Metadata of the imported product





**Figure 9: Preview of the ERS-1 product**

### **Applying Orbit Information**

Orbit auxiliary data contain information about the position of the satellite during the acquisition of SAR data.

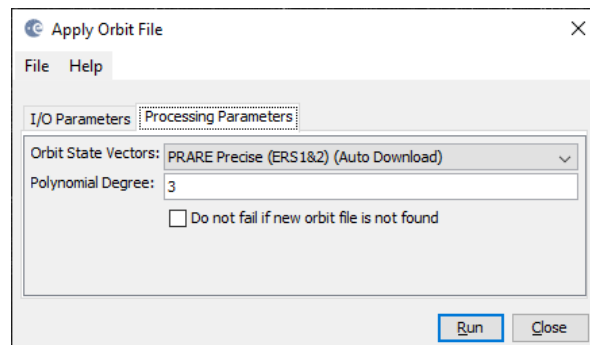
They are automatically downloaded for ERS products by SNAP and added to its metadata with the *Apply Orbit File* (under the menu point *Radar*) operator. More information on the orbit files provided for ERS products is given here: <https://earth.esa.int/web/guest/-/prare-precise-orbit-product>

Execute the operator for both split products as generated in the previous step (Figure 10).

Use suitable output names for the target products. In this tutorial, the products are named:

- 19950421\_Orb.dim
- 19950526\_Orb.dim

The output products are written in the BEAM DIMAP format which conserves all metadata required for the later processing steps.



**Figure 10: Apply Orbit File**

## 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*).

Load the two products (with orbit files applied) to the *ProductSet-Reader* tab (Figure 11, left). Depending on the quality of the orbit files, the difference in Doppler centroid, and the image content of the radar image, it might be necessary to increase the *Number of GCPs* in the *Cross-Correlation* tab. In this case, the standard parameters are sufficient.

To increase the chances to find many usable ground control points, it is advisable to coregister the full images and make a subset later.

Enter `ERS_Orb_Stack` as target name and click **Run** to start the coregistration. Depending on the size of the products and the number of GCPs, this can take a while.

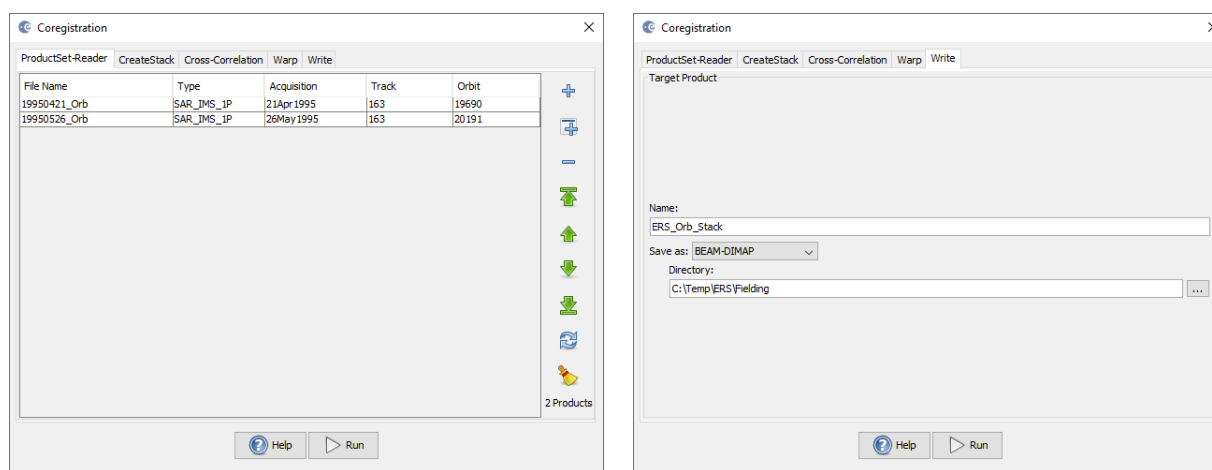


Figure 11: Coregistration of ERS products

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 secondary<sup>1</sup> product which shows if the images are correctly aligned. Select red and green for the reference and blue for the secondary image (Figure 12)<sup>2</sup>.

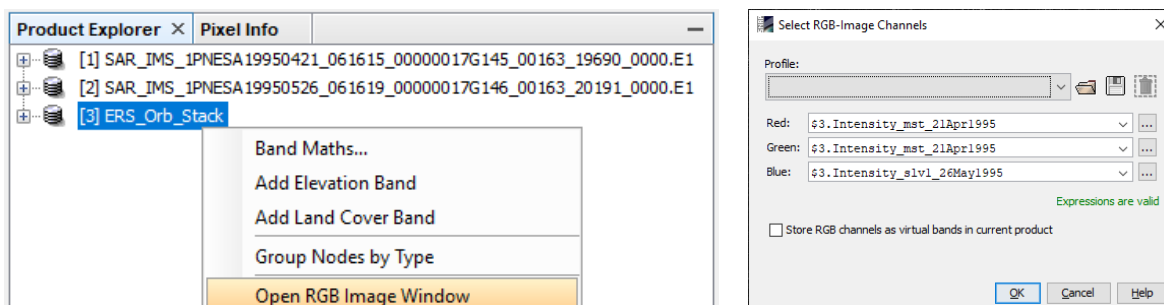
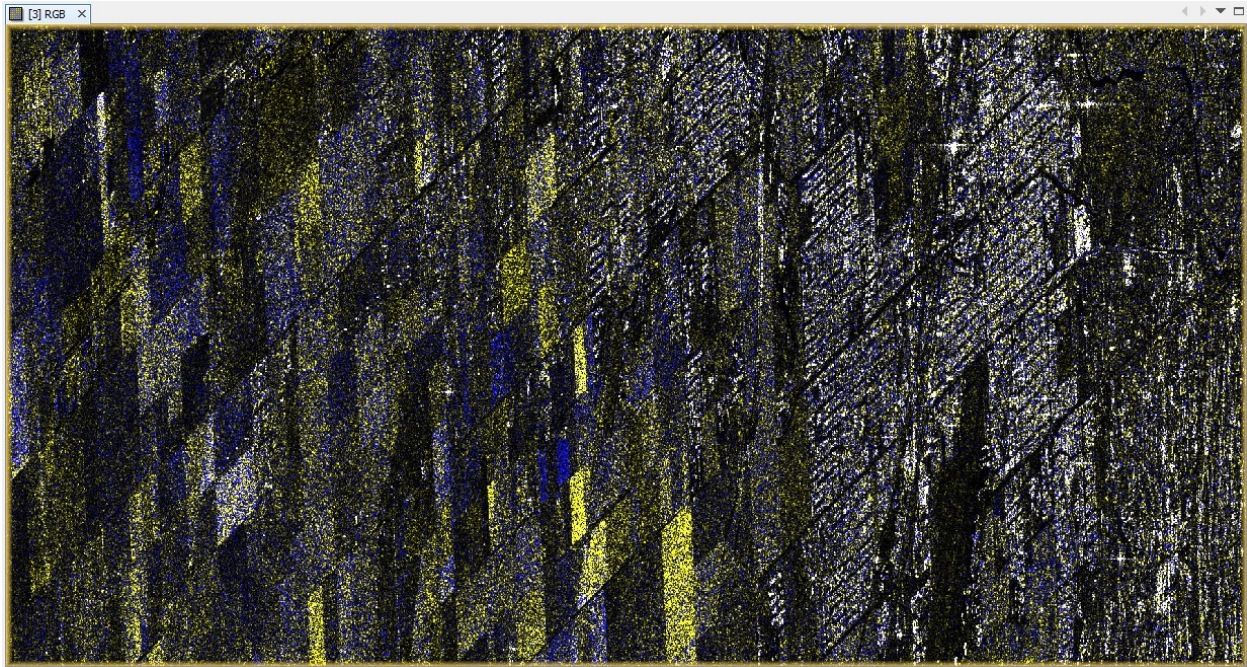


Figure 12: Generation of an RGB image

<sup>1</sup> 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.

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

Zoom in to an area with distinct surfaces, for example the tree plantations and almond orchards in the middle of the scene. The borders of the fields, as well as the roads should be sharply separable by the human eye. In the example below black lines indicate successful coregistration. Areas which have not changed between the first and the second image are displayed in black or white. These are mostly urban areas or bare land. Changes in backscatter intensity are indicated by yellow (red + green; decrease of backscatter intensity) or blue (decrease of backscatter intensity).



**Figure 13: Successful coregistration in an RGB image**

To furthermore check the accuracy of the coregistration, the InSAR Stack tool can be selected from the menu. A new window opens on the right side with the tab “Coregistration Residuals”. As the initial distribution of GCPs is random, these results can differ with every run. In this case, 130 ground control points remained which had the required tolerance (defined in the Cross-Correlation tab of the coregistration module). In the summary, rms stands for “root mean square” determining the average difference of the ground control point to the selected polynomial. The average rms of 0.26 meters confirms coregistration accuracy at the sub-pixel level.

InSAR Stack					
Stack Information	Coregistration Residuals	ESD Measure	ESD Histogram	Baselines	Baseline Chart
GCP119	408.0000	25171.0000	408.0000	25167.3750	0.0354
GCP120	3401.0000	25171.0000	3400.9375	25167.4375	0.2983
GCP121	408.0000	25443.0000	408.0000	25439.2500	0.1407
GCP122	408.0000	26259.0000	408.0000	26255.3125	0.0704
GCP123	3401.0000	26259.0000	3400.8750	26255.3750	0.3391
GCP124	680.0000	26532.0000	680.0000	26528.2500	0.1568
GCP125	4762.0000	27076.0000	4761.8750	27072.4375	0.4198
GCP126	4217.0000	27892.0000	4216.8750	27888.3125	0.4694
GCP127	4762.0000	27892.0000	4761.8125	27888.4375	0.4066
GCP128	3401.0000	28981.0000	3400.8750	28977.3750	0.2972
GCP129	4762.0000	29253.0000	4761.8125	29249.2500	0.5729
GCP130	3945.0000	29253.0000	3944.8750	29249.3125	0.4175
rmsStd	1.0334				
rmsMean	0.2698				
rowResidualStd	1.0673				
rowResidualMean	-0.0000				
colResidualStd	0.0382				
colResidualMean	0.0000				

**Figure 14: Coregistration quality**

## Create a Subset

To reduce the coregistered stack 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. Enter the pixel coordinates as shown in Figure 15 and confirm with **OK**.

- Scene start X: 500
- Scene start Y: 12500
- Scene end X: 1100
- Scene end Y: 18000

A new product occurs in the *Product Explorer*, starting with `subset_0_of_`. This product is only of temporary nature and lost after SNAP is closed.

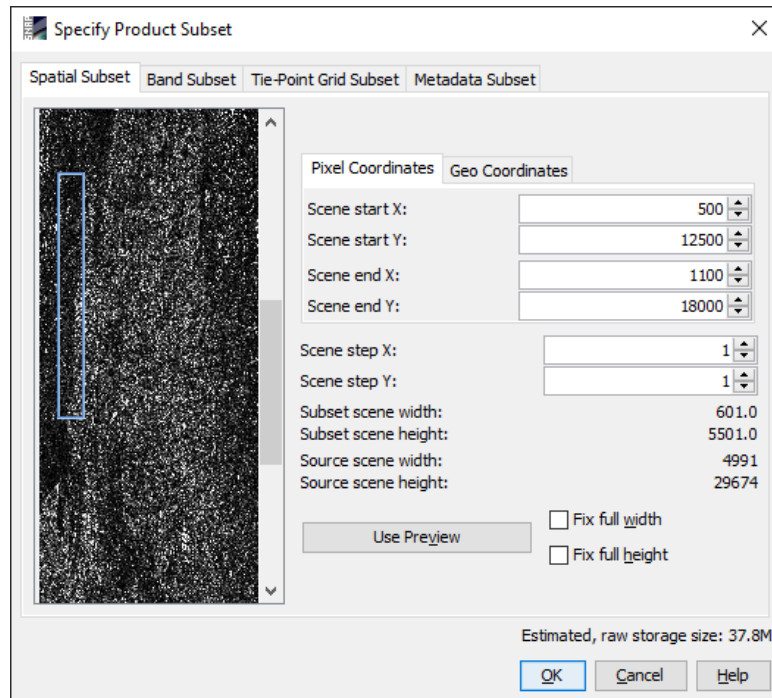


Figure 15: Creating a subset

To permanently store this subset, right-click on the product, select **Save Product As...** and save it in BEAM DIMAP format under `ERS_Orb_Stack_subset.dim`.

Again, because of the different spatial pixel widths in azimuth and range direction, the subset appears as a rectangle but will have a more quadratic shape when it is converted to ground range after proper geocoding. This is also shown in the *World Map* tab when comparing the original product with the subset (Figure 16).

Generally, it is advisable for InSAR analyses to work in the slant range domain as long as possible to preserve the phase information. Conversion to ground range is done after computation of the final results as the last step.

Creating a subset has several advantages: Firstly, the dimensions of the raster can be reduced to accelerate the later processing steps. Secondly, cropping the image to a smaller extent is advisable to reduce the risk of unwrapping errors which occur in areas of low coherence and potentially introduce faulty patterns in the interferogram. The smaller the area of interest, the lower is the risk of unwrapping errors propagating over the image.

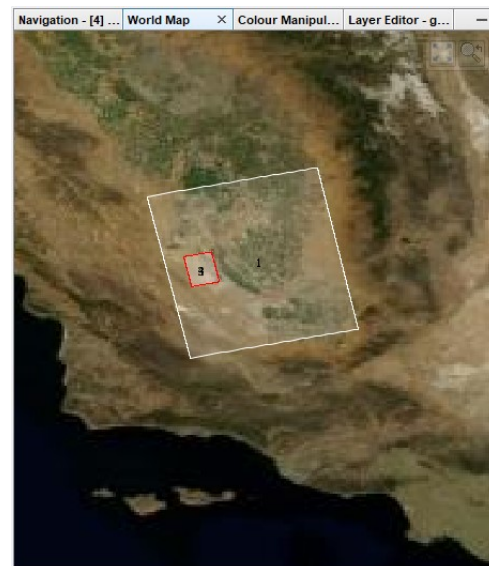


Figure 16: Extent of the full image (white) and the subset (red)

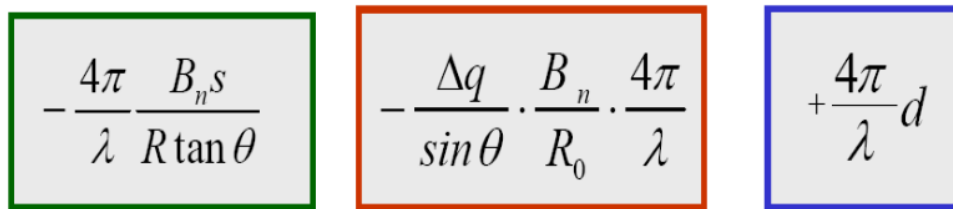
## Interferogram Formation and Coherence Estimation

An interferogram is formed by cross multiplying the reference image with the complex conjugate of the secondary. 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  $\phi$  from several contributing factors, most importantly the flat-earth phase  $\phi_{\text{flat}}$  (earth curvature), the topographic phase  $\phi_{\text{DEM}}$  (topographic surface of the earth), atmospheric conditions  $\phi_{\text{atm}}$  (humidity, temperature and pressure change between the two acquisitions), and other noise  $\phi_{\text{noise}}$  (change of the scatterers, different look angle, and volume scattering), and lastly the eventual surface deformation  $\phi_{\text{disp}}$  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 17: Contributors to SAR interferometric phase

Differential SAR interferometry tries to estimate the contribution from the earth's surface ( $\phi_{\text{flat}}$  and  $\phi_{\text{DEM}}$ ) 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 ERS which has a wavelength of around 5.5 cm).

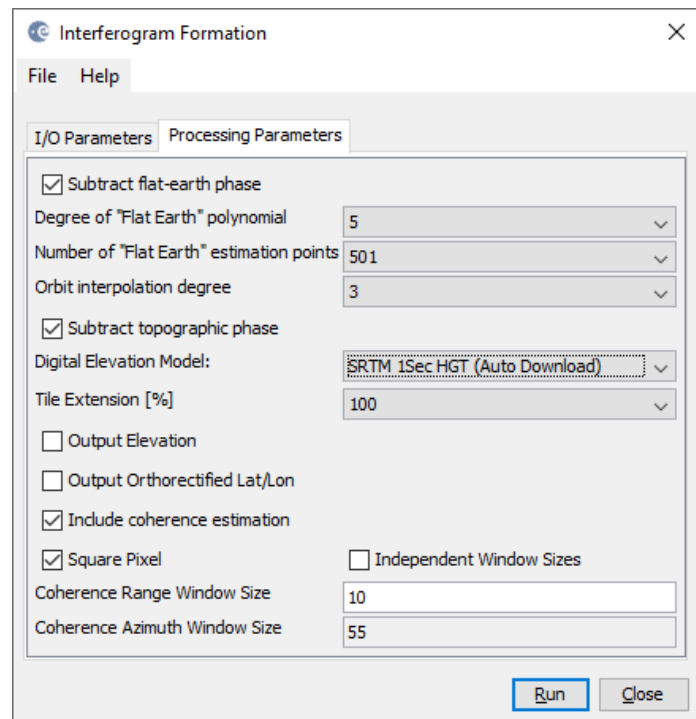
Coherence is calculated as a separate raster band and shows how similar each pixel is between the secondary and reference images in a scale from 0 to 1. Areas of high coherence will appear bright. Areas with poor coherence will be dark. In the image, vegetation is shown as having poor coherence and buildings have very high coherence.

To compute the interferogram and the coherence bands, apply the *Interferogram Formation* operator (under *Radar > Interferometric > Products*). Select the subset created 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.
- **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 10x55 pixels in range/azimuth direction based on equation 1.13 in [ESA TM-19C](#).

The resulting product will contain the interferogram (`Phase_ifg_`) and the coherence (`coh_`) as separate bands (Figure 19). 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  $2\pi$  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.

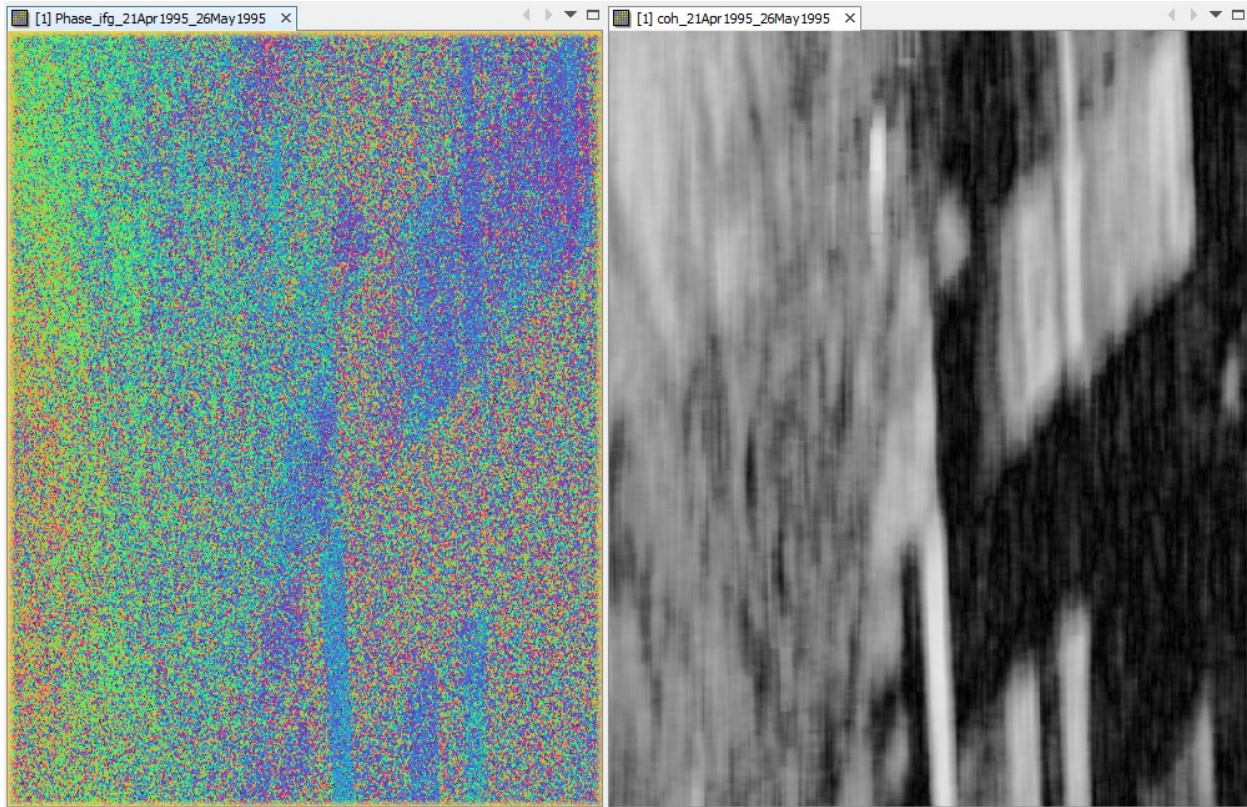


**Figure 18: Interferogram Formation**

Areas of high coherence (bright) indicate 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). In this case, these are mostly urban areas and bare lands without much vegetation cover.

In turn, low coherence is observed over the orchard fields which are covered by trees during the time of acquisition. Growth and movement of the trees between the first and the second image causes a change

in surface scattering mechanisms, leading to low coherence and phase decorrelation. If low coherence areas are too dominant in the image, the later unwrapping will fail and produce faulty or random results. As shown in Figure 19, areas of high coherence have clear patterns in the interferogram while areas of low coherence have random phase. The overall distribution of coherence is shown in the histogram (Figure 21).



**Figure 19: Interferogram (left) and coherence (right)**

As shown in Figure 20, the oil fields are mostly bare areas or covered by metal objects. These surfaces produce a stable phase return for reliable analyses. In turn, the almond orchards are dominated by volume scattering. Interferometric phase cannot be exploited here because of temporal and volume decorrelation.



**Figure 20: Photograph from the oil fields (left, credit to Eric Fielding, JPL) and the orchards (right, image From Google Street View)**

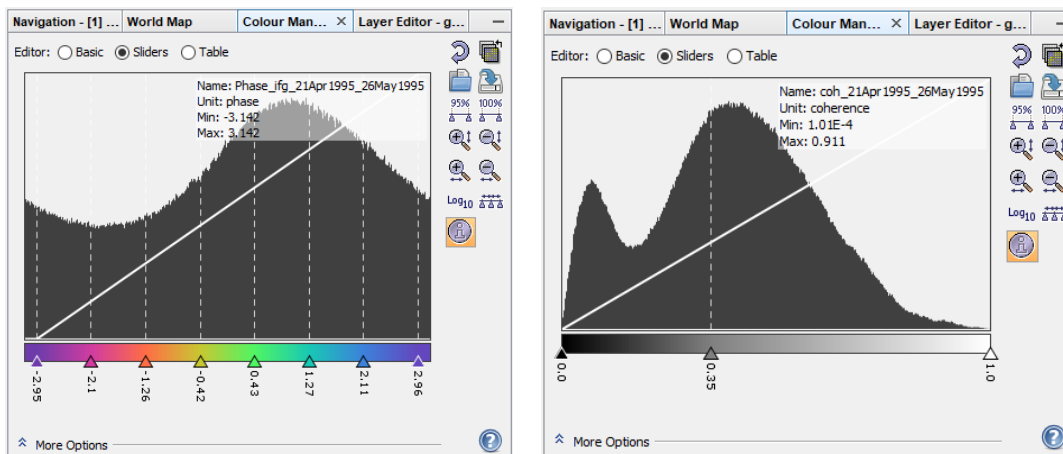


Figure 21: Histogram of interferogram (left) and coherence (right)

### 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.

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 interferogram image. The output is a filtered phase image (Figure 22) with a clearly reduced amount of noise. But it is also shown in the image that filtering can only improve the interferogram quality in areas of good coherence. It cannot restore fringes of completely decorrelated areas. Furthermore, coherence is not affected by the filtering and cannot be increased accordingly.

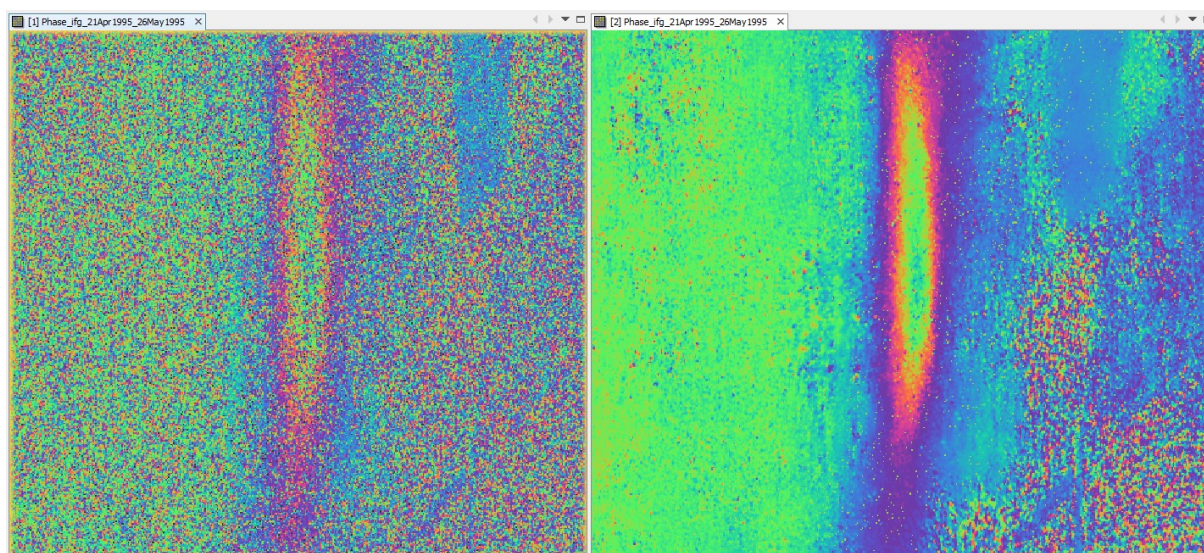


Figure 22: Interferogram before (left) and after (right) Goldstein phase filtering



## Phase Unwrapping

In the interferogram, the interferometric phase is ambiguous and only known within the scale of  $2\pi$ . 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  $2\pi$  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  $2\pi$  phase cycles), the phase variation between two points on the flattened interferogram provides a measurement of the actual altitude variation (Figure 23). Accordingly, unwrapped results should be interpreted as a relative height/displacement between pixels of two images.

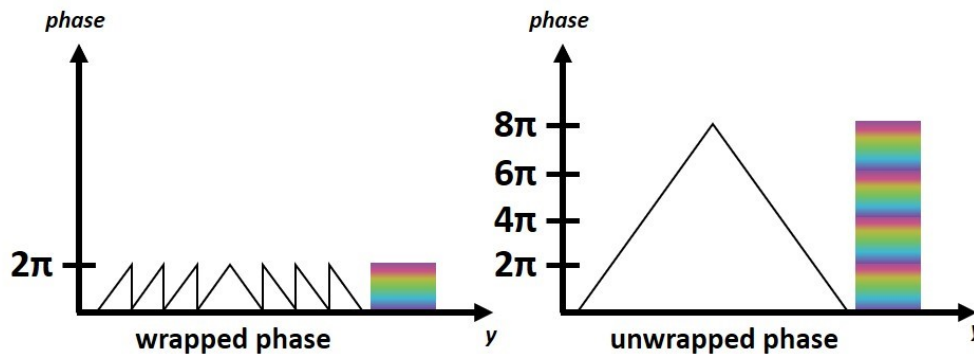


Figure 23: Principle of phase unwrapping

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.

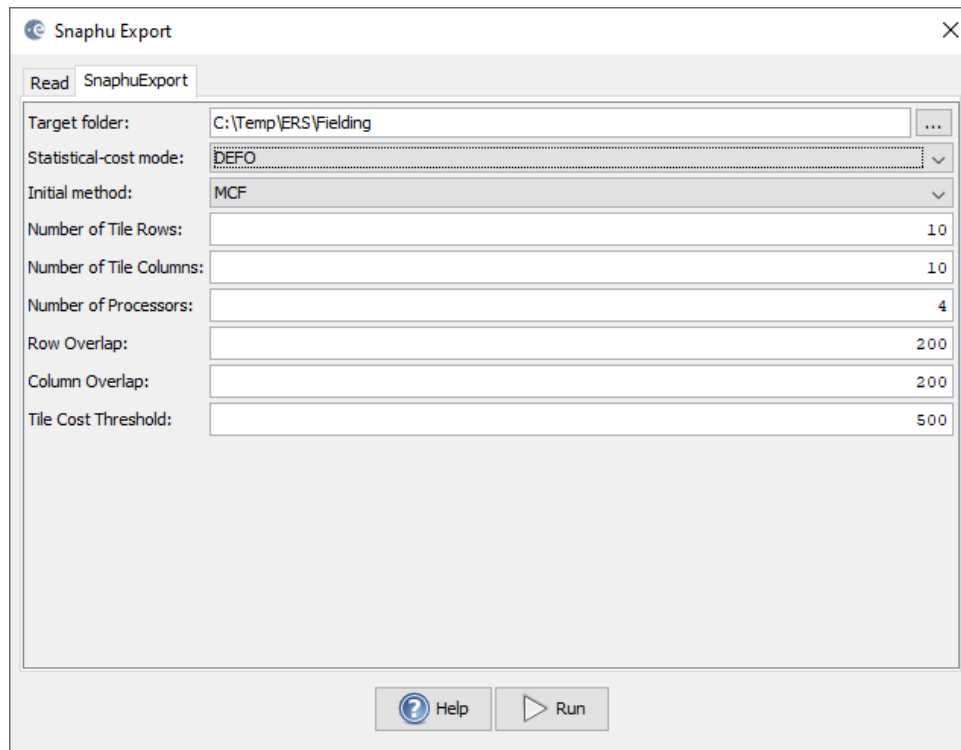
## Export

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\ERS\Fielding`). 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 24). 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 24: 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: `ERS_Orb_Stack_subset_ifgflt`). 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\_MLflt). 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.

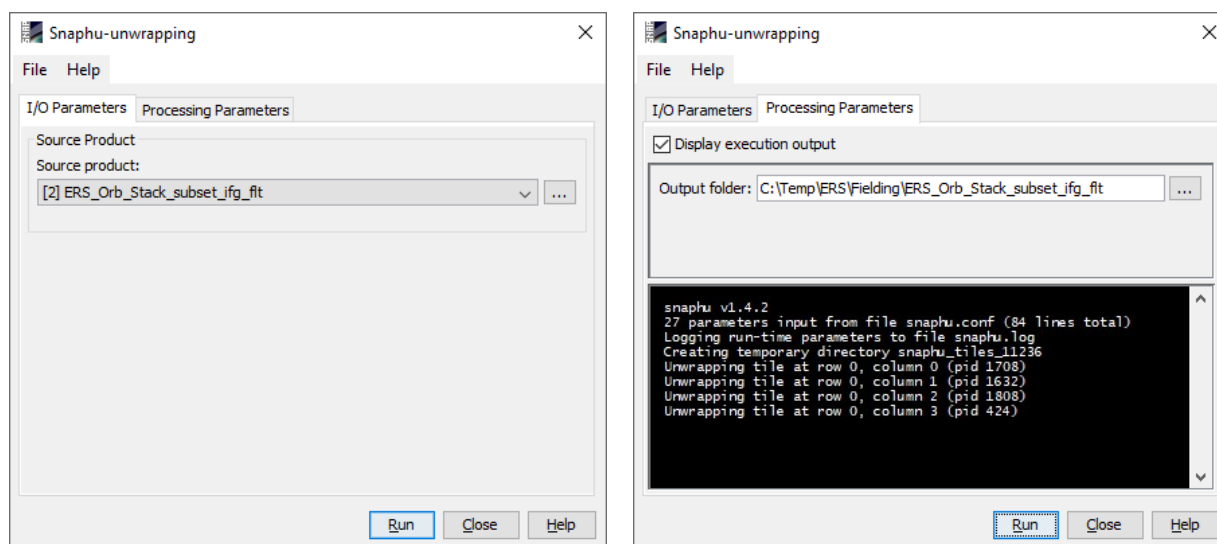


Figure 25: Unwrapping with the snaphu plugin

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.

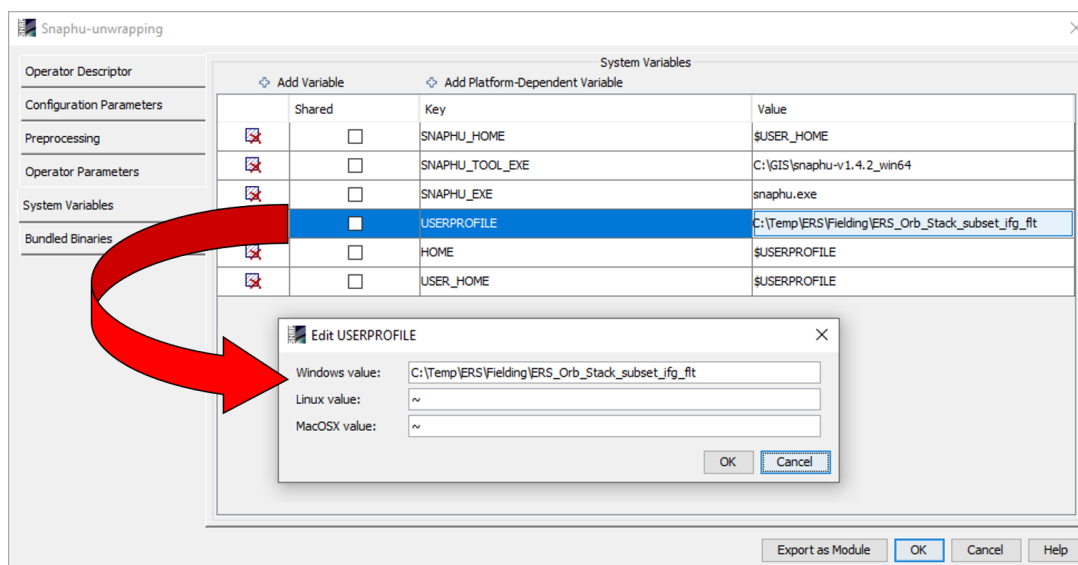
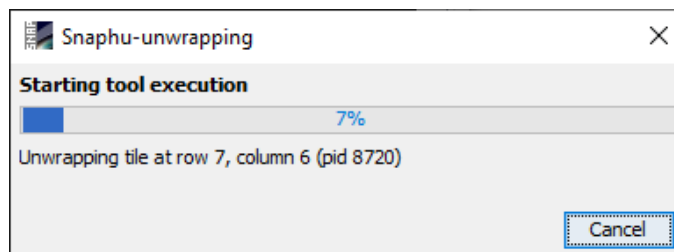


Figure 26: System variables of the snaphu plugin

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 27). 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 27: 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 (in this study it is called `UnwPhase_ifg_21Apr1995_26May1995.snaphu.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: `ERS_Orb_Stack_subset_ifgflt_unw`) and click **Run**.

A new product is added to the Product Explorer which contains the wrapped interferogram (`Phase_ifg_`), the coherence (`coh_`) and the unwrapped phase generated with snaphu (here: `Unw_Phase_ifg_21Apr1995_26May1995`).

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). All fringe patterns are summarized to absolute changes (Figure 23). 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.

As shown in Figure 28, the unwrapped phase no longer shows recurring colors but only a general trend from purple (low values) to blue (high values). At areas of noisy phase (bottom right) smaller unwrapping errors can be observed as purple patches with values outside the common trend.

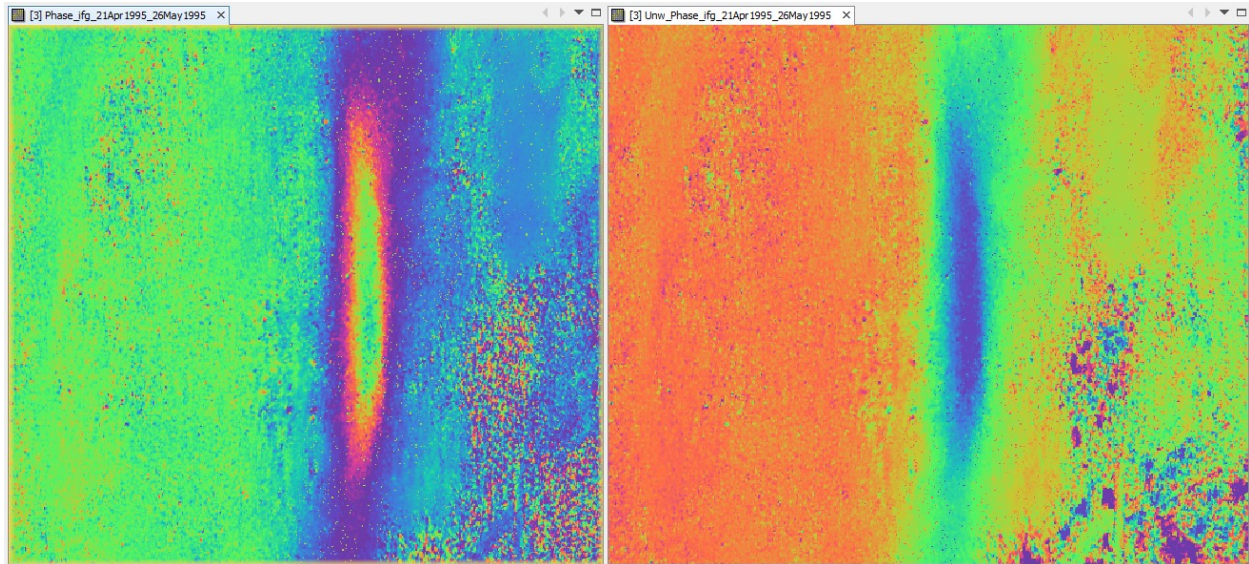


Figure 28: Phase before (left) and after (right) unwrapping

### 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 is 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 29). The spikes in the histogram result from constant values introduced at the right margin of the product.

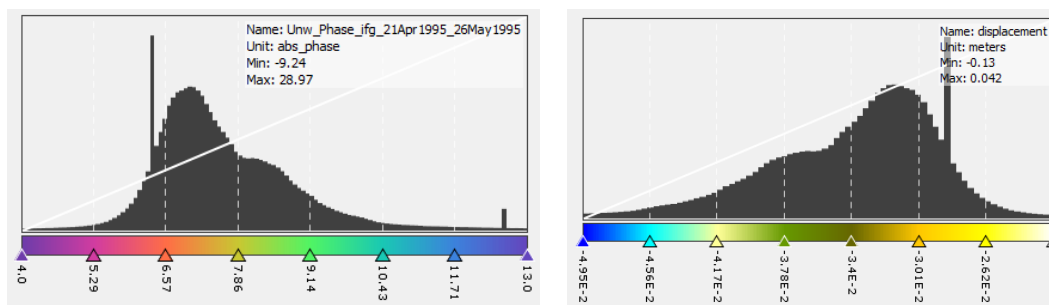


Figure 29: Histogram of unwrapped phase (left) and LOS displacement (right)

## Include coherence

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 imported from a previous product 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 30, 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.

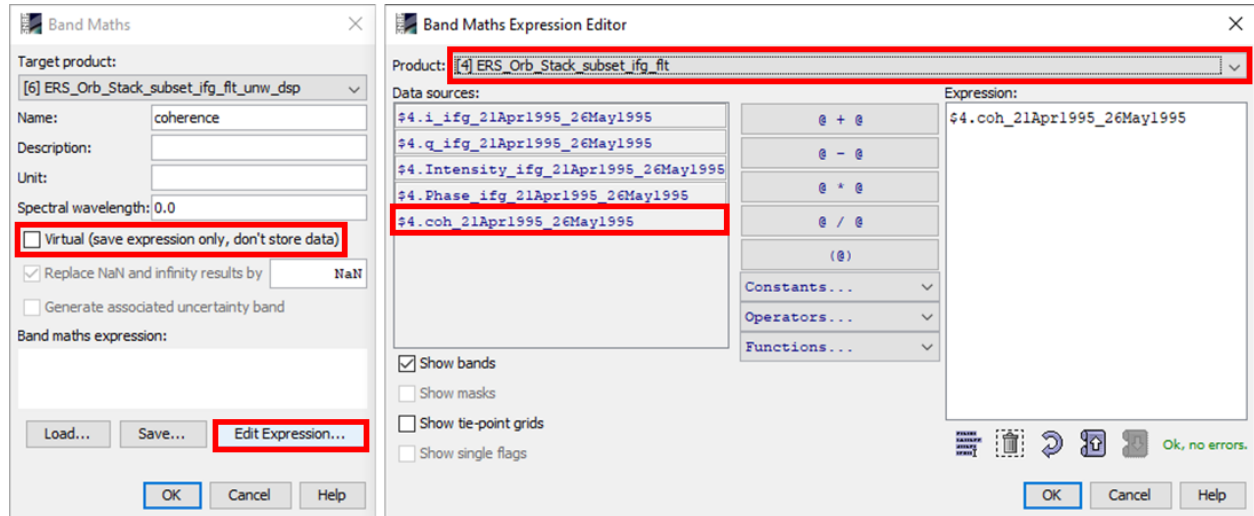


Figure 30: Transfer of bands between products

The coherence band is now part of the displacement product as shown in Figure 31. Save the made changes by selecting *File > Save Product* in the menu.

This allows to geocode both the displacement and coherence rasters in the next step. This makes sense whenever there are larger areas of low coherence which should be masked out in the final result for reasons of transparency.

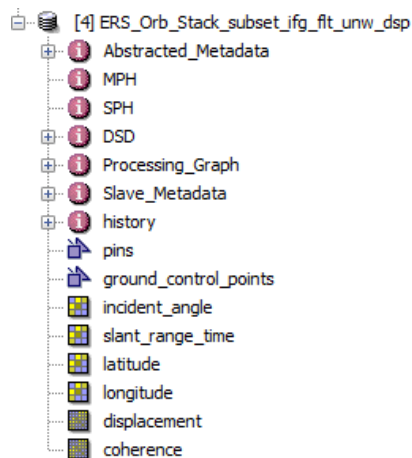


Figure 31: Displacement and Coherence in one product

## 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 32). More information on these effects is given in the [ESA radar course materials](#).

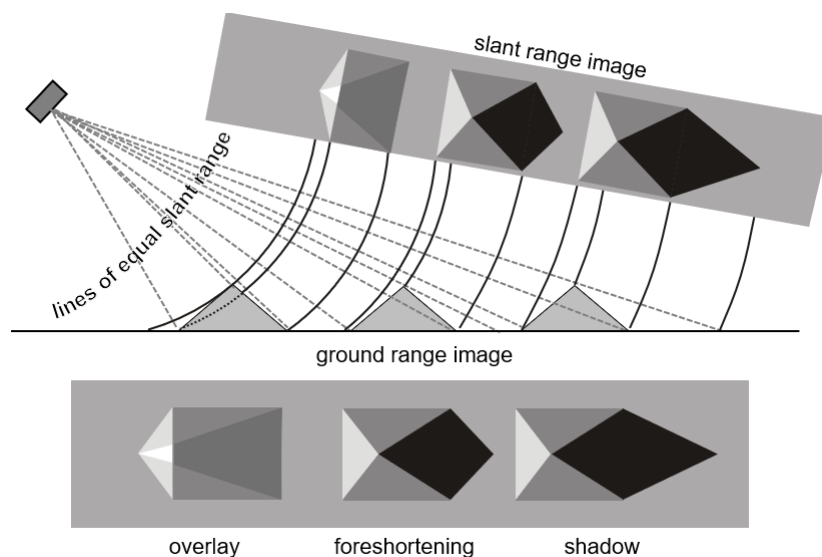


Figure 32: Geometric distortions in radar images ([Braun 2019](#))

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.

As shown in the dialogue, the resolution of 3.98 meters in range direction and 22 meters in azimuth direction is finally resampled to an output resolution of 22 x 22 m using bilinear interpolation.

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 and open the resulting geocoded displacement raster (Figure 34).

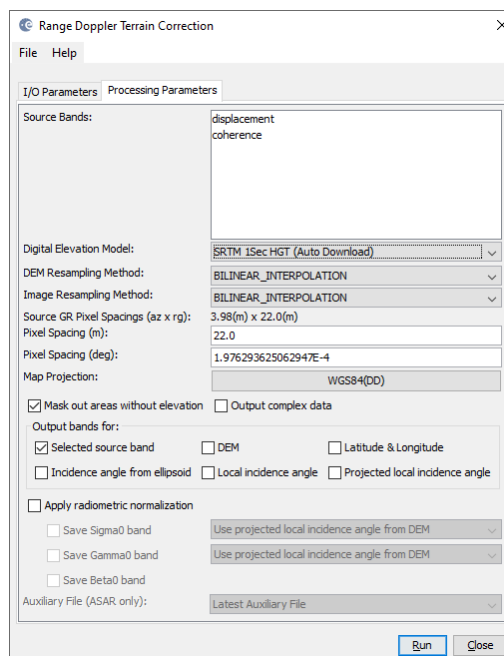
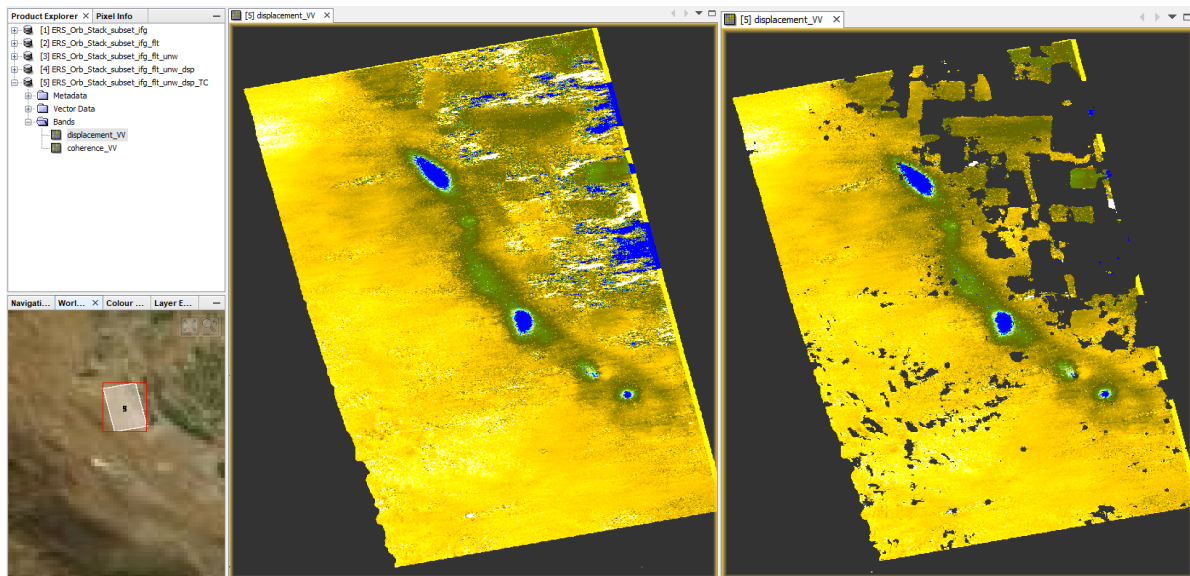


Figure 33: Range Doppler Terrain Correction

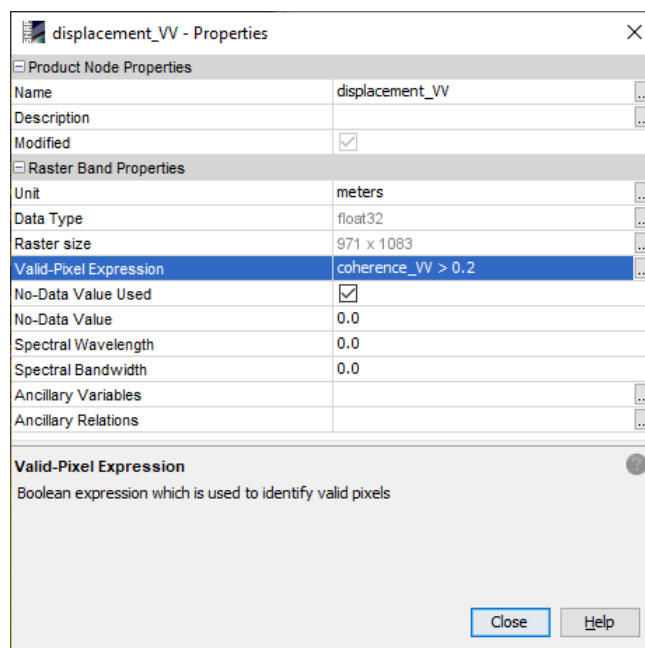


**Figure 34: Terrain corrected and geocoded displacement raster before (left) and after (right) masking of low coherence areas**

### *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. Therefore 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 > 0.2` (Figure 35). All pixels with a coherence value below 0.2 are now made transparent in SNAP.

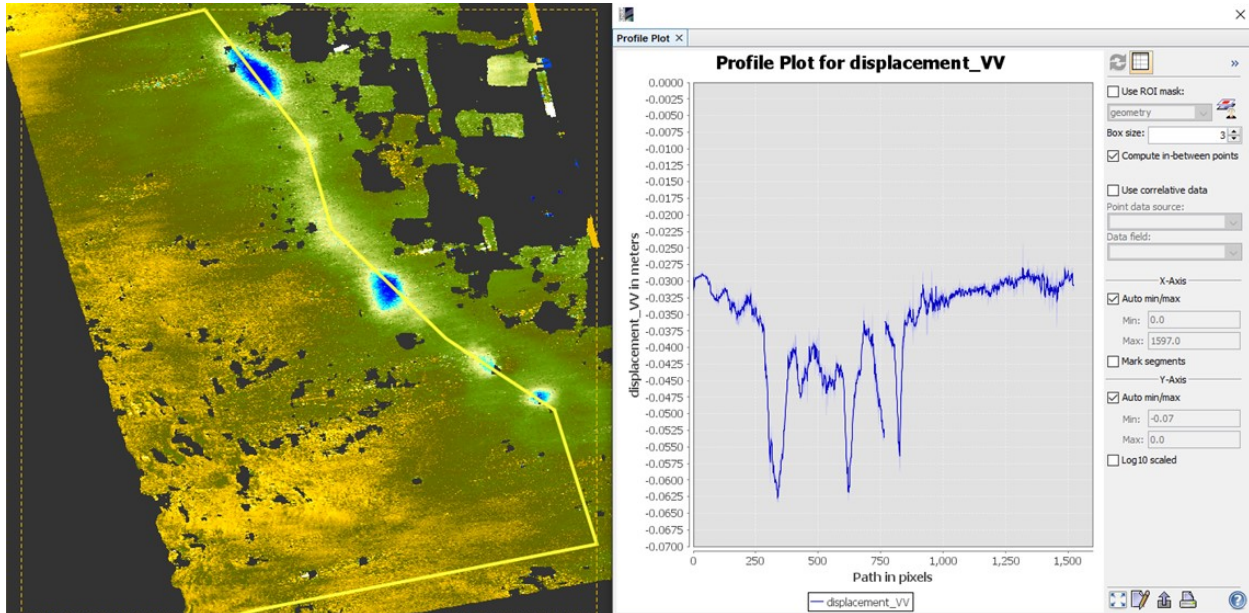


**Figure 35: Masking of low coherence pixels**



### Check and correct for offsets

You can digitize a line  and use the *Profile Plot* tool  to visualize single displacement patterns and their ranges (Figure 36). This is also a good way to check also the amount of noise in the data and test for a general offset.



**Figure 36: Profile plot for the displacement band across the subsidence craters**

In this case, the line shows a clear decrease through the observed craters. However, areas with zero subsidence currently range around a value of  $-0.03$  ( $\pm 3$  cm per year). As this is very unlikely for the entire image, this offset has to be corrected.

Note: Depending on your unwrapping, this offset can be slightly different.

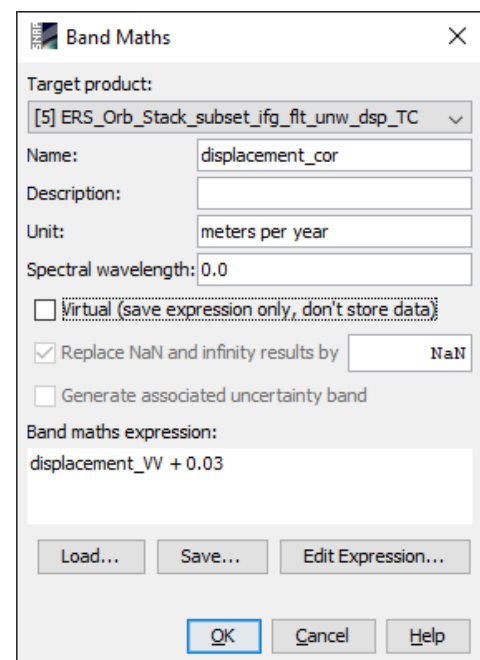
Right-click on the terrain corrected displacement product and open the **Band Maths**. Enter `displacement_cor` as name for the target raster. You can optionally enter a unit which will later be displayed in the legend of the raster when it is exported to Google Earth.

Uncheck the “Virtual” option and enter the following expression:

`displacement_VV + 0.03`

Confirm with **Run** and make the changes permanent by selecting *File > Save Product* in the menu.

The created product is 0.03 meters higher so that the areas of no expected change have zero displacement and the actual LOS displacement values of the craters are more reliable.



**Figure 37: Adjustment of the offset**

### 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 **Safe**. Open the kmz file in Google Earth to view the location of the displacement patterns on the satellite image base map (Figure 38).

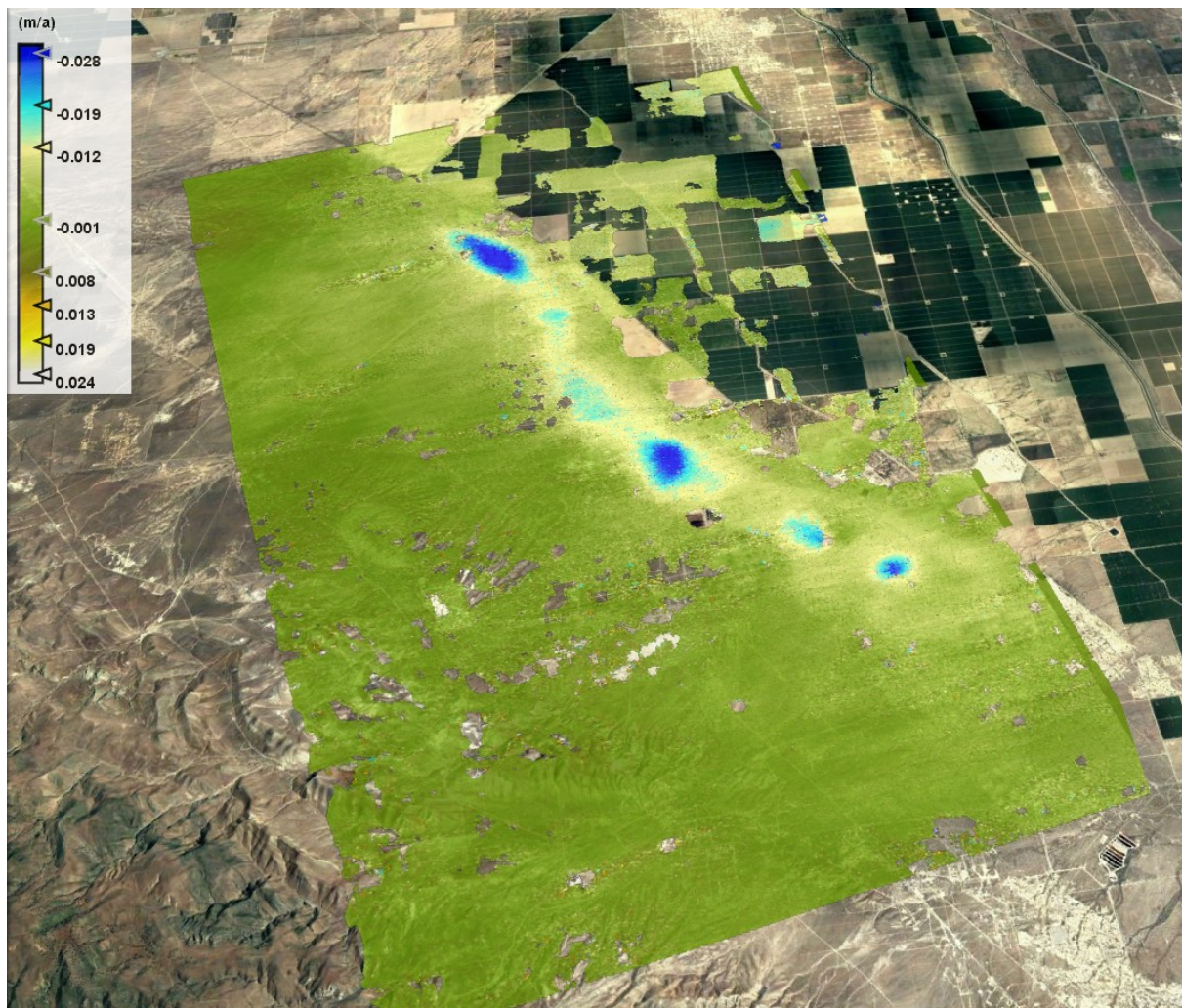
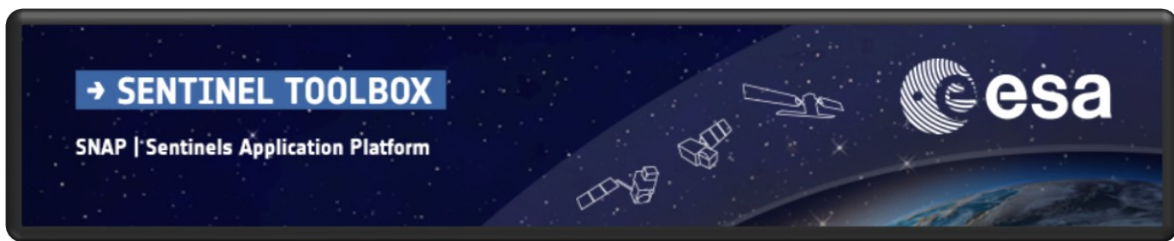
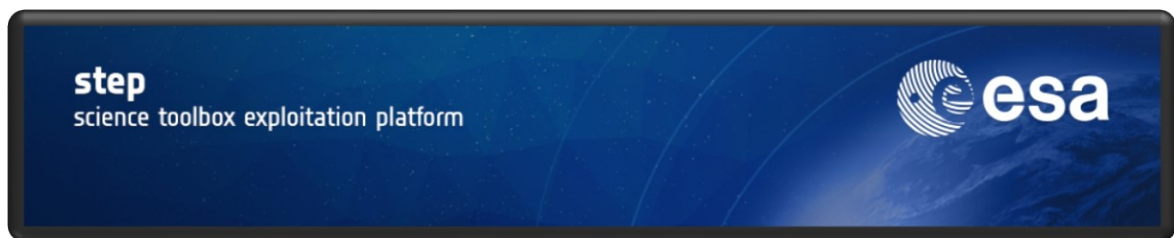


Figure 38: Result exported to Google Earth



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/>