

Interferometry Tutorial

Digital Elevation Model creation

SARscape Version 5.7.0

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1. Introduction

The main goal of this tutorial is to give a basic description of the SARscape Differential Interferometric Synthetic Aperture Radar (DInSAR) processing chain to obtain a **Digital Elevation Model** from a pair of SAR images.

Interferometric synthetic aperture radar 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. Interferometry consists of combining the phase of two SAR images (Reference and Secondary images), by cross-multiplying, pixel by pixel, the first SAR image with the complex conjugate of the second. The result is a new complex number whose module is the product of the module of the two input SAR images, and whose phase is the difference between the phases of the two input images. The two input images must be aligned (coregistered).

The interferometric phase is the contribution of 4 components: the topographic component, the phase noise component, the displacement component, and the atmosphere component:

$$\varphi_{Int} = \varphi_{Topography} + \varphi_{Change} + \varphi_{Movement} + \varphi_{Atmosphere}$$

The terms φ_{Change} and $\varphi_{Atmosphere}$ are gathered in φ_{Noise} :

$$\phi_{Int} = \phi_{Topography} + \phi_{Movement} + \phi_{Noise}$$

There are two unknowns (φ_{Topo} and $\varphi_{Movement}$) and one measure (φ_{Int}); it is therefore necessary to make the assumption that the measure is totally topography or movement.

DEM generation:

$$\phi_{Int} = \phi_{Topography} + \phi_{Noise}$$

Displacement generation:

$$\phi_{Int} = \phi_{Movement} + \phi_{Noise}$$

For displacement measurement purposes it is necessary to make the assumption that the interferometric measure is totally relevant to displacement, thus no residual topography should be present between the two SAR acquisitions.

The displacement measurement through the DInSAR approach has the following main characteristics and requirements:

- The measurement accuracy is in the order of magnitude of centimeters or fraction of centimeters on the time span covered by the SAR data pair;
- It is mainly suited to measure displacement on wide areas and for intense event such as earthquakes;
- To run this tool the same sensor, the same geometry (Ascending/Ascending or Descending/Descending), the same incidence angle, the same data type and the co-polarized images (VV, HH) are mandatory;
- Displacement sensitivity depends on wavelength, which depends on sensors type. Data reliability depends on the object interaction. Moreover, the higher temporal changes, the lower reliability (i.e.

vegetation, snow, ice), above all for high frequency sensors. The reliability index is provided by the coherence product;

- The higher is the accuracy of the input DEM used to remove topographic phase contribution, the higher is the reliability of the estimated displacement;
- The selection of the temporal baseline should take into accounts the magnitude and the velocity of expected displacement. Slow displacement rates should be monitored with large temporal baseline, but a large baseline may lead to get low coherence over the analyzed area. At the same time a small baseline could not guarantee the sensitivity to detect the movement occurred between the two acquisitions;
- A small normal baseline is less sensitive to topographic variations; the Baseline estimation tool enables to obtain information about the baseline values and other orbital parameters related to the input pair (*Interferometry/Interferometric Tools/Baseline Estimation*);
- Sentinel-1 has been specifically designed to measure displacement thanks to his small orbit tube.

For Digital Elevation Model purposes it is necessary to make the assumption that the interferometric measure is totally relevant to topographic residuals, thus no displacement should have occurred between the two SAR acquisitions.

The DEM creation measurement through the DInSAR approach has the following main characteristics and requirements:

- To run this tool the same sensor, the same geometry (Ascending/Ascending or Descending/Descending), the same incidence angle, the same data type and co-polarized images (VV, HH) are mandatory.
- Low temporal baseline between is acquisition are strongly recommended in order to reduce as much as possible coherence drops.
- If the normal baseline is too small, these topographic effects on the differential phase are not pronounced enough. On the other hand too large baselines induce decorrelation effects; the critical baseline is the maximum value of baseline over which the interferometric correlation became zero. The Baseline estimation tool enables to obtain information about the baseline values and other orbital parameters related to the input pair (*Interferometry/Interferometric Tools/Baseline Estimation*). In any case, it is strongly suggested to use data pairs with a baseline value below half of the critical value.
- The Sentinel-1 mission was mainly designed for the retrieval of deformations (DInSAR) and not for DEM generation (*Geudtner et al. 2016*).

Processing steps overview

The DInSAR steps and sub-steps are described in the list below:

1. Interferogram Generation
2. Adaptive Filter and Coherence Generation
3. Phase Unwrapping
4. Refinement and Re-flattening
5. A - Phase to Height Conversion and Geocoding
5. B - Phase to Displacement conversion and Geocoding

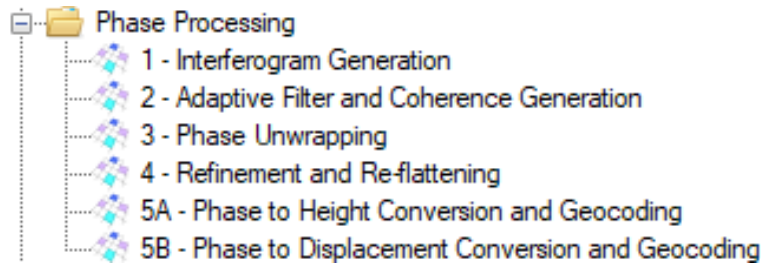


Figure 1 - Phase processing steps

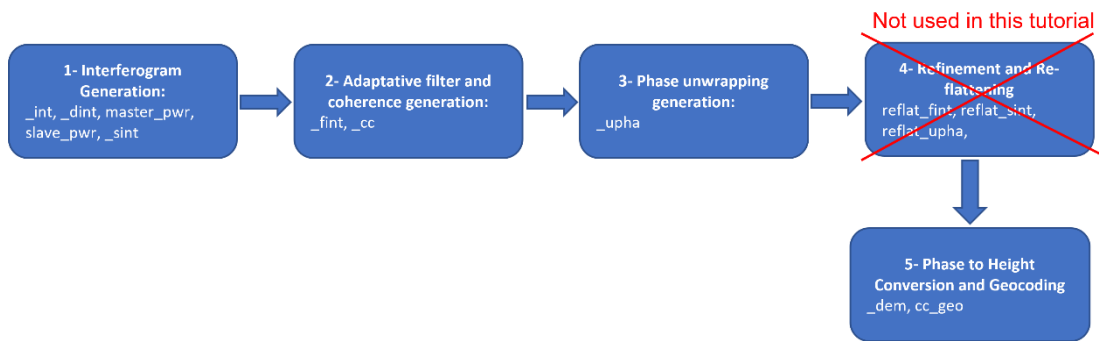


Figure 2 Phase processing workflow and files generated for each step

Co-registration of the SAR image pair is required. The co-registration is the process of superimposing, in the slant range geometry, two or more SAR images that have the same orbit and acquisition mode.

After image co-registration, an interferometric phase is generated by multiplying one image by the complex conjugate of the second one. A complex interferogram, module and phase, is generated, whose module is generated by multiplying the input SAR images modules and the phase is generated by performing the phase difference between the input SAR images.

Due to the slightly different antenna positions, a systematic phase difference over the whole scene can be observed related to **the flat terrain**, the presence of topography may introduce **geometrical distortions** over the flat terrain one.

The flat earth component and the known terrain contribution can be removed by knowing the acquisition parameters of the two images used to generate the interferogram. This operation is called **Flattening**. The topography contribution can be removed by **subtracting a low resolution DEM** from the interferogram.

The phase signal, intended as the interferometric phase difference, may be affected by a certain level of noise; a parameter that helps to evaluate the phase stability of each pixel is the Coherence; it ranges between 0 and 1, where 0 means completely random phase signal, classified as noise, while coherence close to 1 indicates a stable phase signal commonly associated to Permanent scatterers points.

Noise filtering is applied to the generated interferograms (once flattened and the topography is removed), in order to calibrate and increase the precision of those pixel that may provide unreliable results.

Once the **filtering** is performed, the unwrapping procedure allows to obtain the absolute phase for those pixels whose coherence overcomes a defined threshold value.

The next DInSAR steps require a **refinement and re-flattening** process, it allows both to refine the orbits (i.e. correcting possible inaccuracies shown as residual systematic phase trends) and to calculate the phase offset (i.e. getting the absolute phase values).

The final step is the Phase to displacement or height conversion, the absolute calibrated and unwrapped phase values are converted to displacement or height and directly geocoded into a map projection.

The current tutorial is focused on the DEM creation, a dedicated tutorial named 'Interferometry_Displ' covers the displacement mapping part.

SARscape version	5.7.0
ENVI version	5.6.3
SO	64-bit Windows 10 Pro
RAM	32 GB
Processor	Intel (R) Core (TM) i9-9980HK CPU @ 2.40GHz
OpenCL	NVIDIA Quadro RTX 3000
HD	SSD EVO 2TB (as working directory)

Prior to download this dataset it is necessary to carefully read and accepts the *Terms of use of products for technical evaluation of products* <https://www.intelligence-airbusds.com/en/9317-sample-imagery-detail?product=37995&keyword=&type=364>.

2. Training Data sets description

The area of interest covers an Iranian underground uranium enrichment facility located 20 miles (32 km) northeast of the Iranian city of Qom. The site is under the control of the Atomic Energy Organization of Iran (AEOI). It is the second Iranian uranium enrichment facility.

The site is characterized by the presence of a mountainous area with a poor vegetation coverage, ideal for interferometric purposes.



Figure 3 Area of Interest.

4. Before starting

Before starting to run the InSAR DEM processing chain, it is strongly recommended to:

- set the ENVI Preferences setting the proper root folders
- set the SARscape Preferences (Specific) based on the specific to *VHR (better than 3m)*
- read the Getting Started, Data Preparation and Basic Tutorial to become familiar with the basic processing chain that allows managing the dataset provided to run the InSAR processing.
- Send an email to the sarmap support team to get the access to the data stack.

The dataset contains:

- Two TerraSAR-X images
- Digital Elevation Model

It is worth to mention that to apply the DInSAR technique users have to consider suitable sensors and acquisition modes.

The necessary steps to run a displacement DInSAR analysis are the following:

- Interferogram Generation
- Adaptative filter and coherence generation
- Phase unwrapping
- Refinement and Re-flattening
- Phase to height conversion and geocoding

Note that all the parameters that need to be set or changed by the operator, different from the default values, are highlighted in this document using orange color of the text.

All the details related to the description of the parameters are shown in grey in this document. The same information can be found on the specific help page of each panel.

Baseline estimation

The *Baseline Estimation* tool (Interferometry/Interferometric Tools/Baseline Estimation) is designed to establish if a pair of SAR images can be used for interferometric purposes. This tool enables us to obtain information about the baseline values and other orbital parameters related to the input pair, the extracted parameters have to be intended as approximate measurements aimed at a preliminary data characterization and interferometric quality assessment.

When the normal baseline exceeds the critical baseline value, no phase information is preserved, coherence is lost, and it is not possible to compute interferometric processes.

The sensibility to detect height variations is inversely proportional to the "2n ambiguity height": the bigger the ambiguity height the worse the capability to detect small elevation changes. The sensibility to detect displacements depends, instead, on the observation wavelength.

Run the tool Baseline Estimation tool:

Input Files

Input Reference file

File name of the Reference data (`_pwr` for ScanSAR products; `_slc` or `_pwr` for all the others). This file is mandatory.

Use as Reference image the data `_TSX1_152_20111209_023746835_spot_062_D_HH_slc`

Input Secondary file

File name of the multi-looked coregistered Secondary Intensity data (`_pwr`). This file is mandatory.

Load the data `_TSX1_152_20111220_023745253_spot_062_D_HH_slc` as Secondary image.

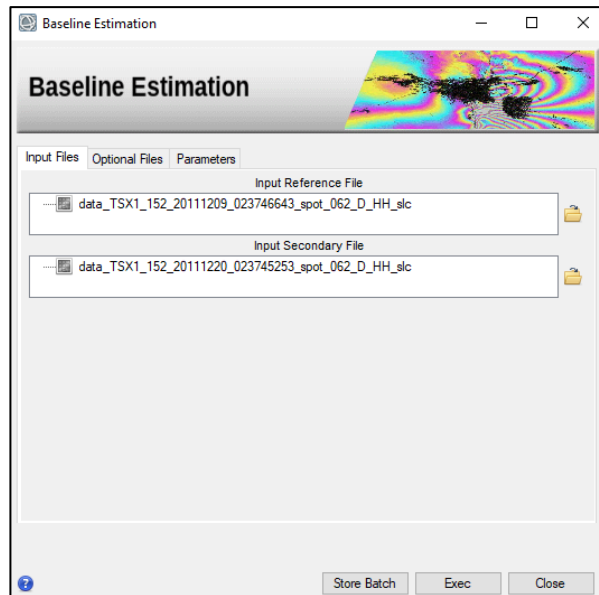


Figure 4 *Baseline Estimation* input panel.

Optional Files

Name of the output root. In addition to the results for the scene center that will shown up in the pop-up, this file includes the multilooked baseline, height of the ambiguity values and all other parameters for each pixel. This file is optional, if this field is empty, no output file will be created and only the values for the scene center are computed and shown up in the pop-up.

Set a customer output folder.

Click on the *Exec* button to run the tool.

A new window will appear, showing all the baseline details:

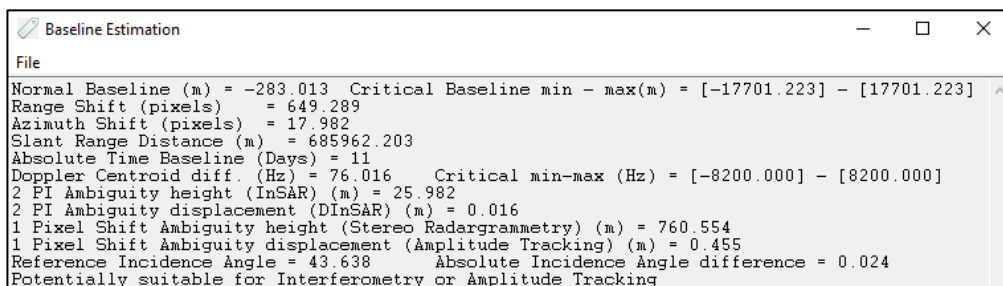


Figure 5 Baseline estimation output.

Normal Baseline (m) = -283.013 Critical Baseline min - max(m) = [-17701.223] - [17701.223]

Range Shift (pixels) = 649.289

Azimuth Shift (pixels) = 17.982

Slant Range Distance (m) = 685962.203

Absolute Time Baseline (Days) = 11

Doppler Centroid diff. (Hz) = 76.016 Critical min-max (Hz) = [-8200.000] - [8200.000]

2 PI Ambiguity height (InSAR) (m) = 25.982

2 PI Ambiguity displacement (DInSAR) (m) = 0.016

1 Pixel Shift Ambiguity height (Stereo Radargrammetry) (m) = 760.554

1 Pixel Shift Ambiguity displacement (Amplitude Tracking) (m) = 0.455

Reference Incidence Angle = 43.638 Absolute Incidence Angle difference = 0.024

Potentially suitable for Interferometry or Amplitude Tracking

The sentence "Potentially suitable for Interferometry or Amplitude Tracking" is printed in case the image pair can be used for interferometric purposes.

This specific pair has an *2 PI Ambiguity height* of around 25 meters, i.e. one fringe correspond to a variation of 25 meters; such high resolution can be achieved thanks to the high *Normal Baseline* value (below the critical baseline value).

It is recommended to use a pair of images with a baseline value lower than the 50% of the critical baseline one.

Workaround procedure for small 2 PI Ambiguity height values

In case the *2 PI Ambiguity height* is small (<10 meters) it is possible to apply the following procedure to increase the accuracy:

- The SRTM 3 V4 DEM is our reference DEM, and the goal is to improve the resolution and accuracy of the DEM and to update. Suppose that there are three pairs of SAR images available: AB, CD and EF with the following values of 2 PI ambiguity:

AB → 2 PI Ambiguity height (InSAR) (m) = 100

CD → 2 PI Ambiguity height (InSAR) (m) = 40

EF → 2 PI Ambiguity height (InSAR) (m) = 10

1. Perform the *InSAR DEM workflow* without GCP (Interferometry/Interferometry Without GCP Workflows/InSAR DEM Workflow) with the AB data pair as input and the SRTM DEM as input reference DEM.

In the *Phase to Height Conversion* step leave the default value of Spatial Wavelet Size (Figure 6); the wavelet filter is designed to remove the low frequency component of the topographic residual from the InSAR DEM, that may be due to orbital errors or atmospheric patterns, by keeping the low pass component of the reference input DEM, the finer details are obtained from the interferometric processing of the AB SAR data pair (Figure 7).

A new *InSAR DEM_{AB}* is created.

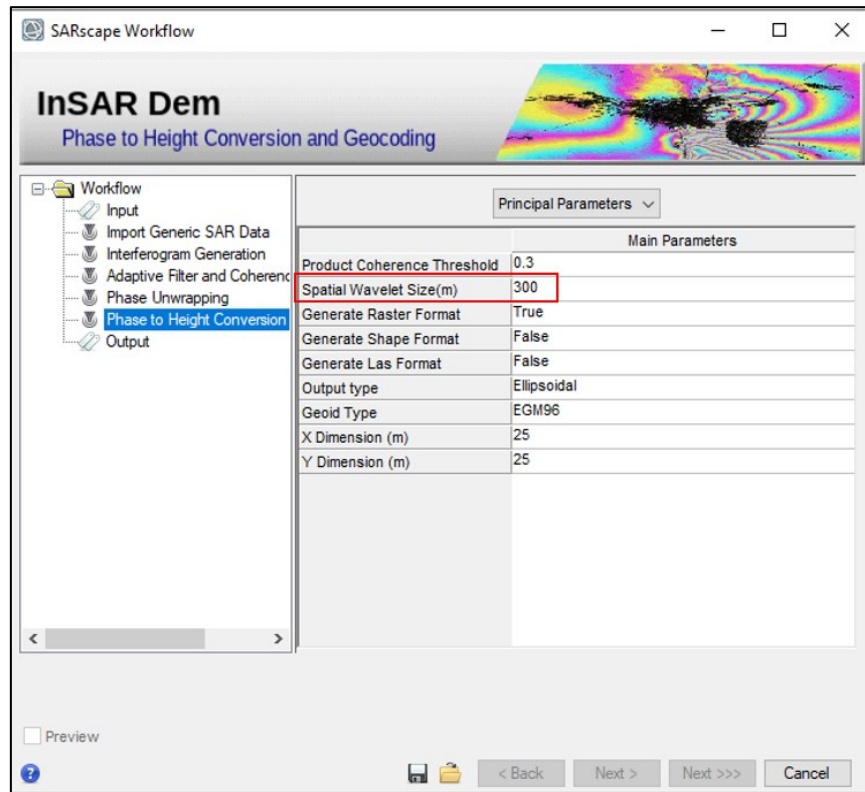


Figure 6 Phase to Height conversion panel.

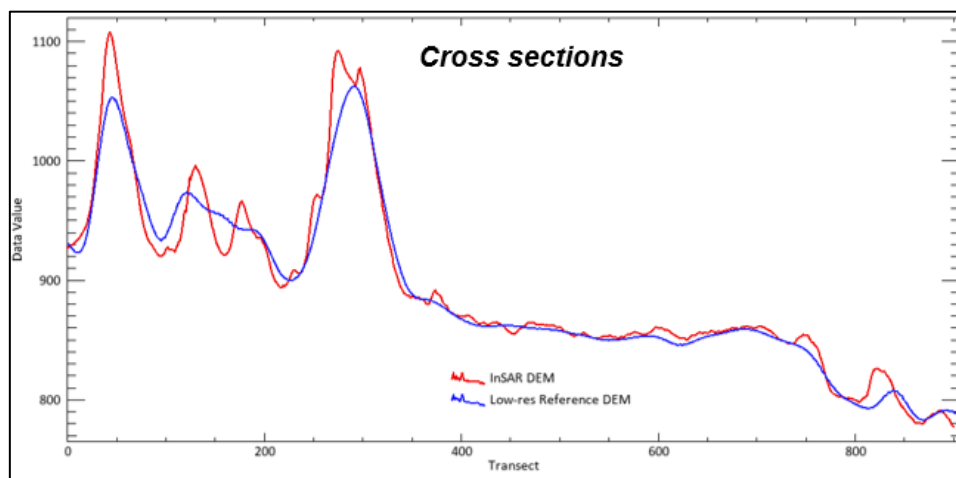


Figure 7 Profile comparison between the SRTM DEM and the InSAR one shows that, thanks to the wavelet filter, the low-frequency components of the low-resolution DEM are preserved in the InSAR DEM, while the finer details are obtained from the interferometric processing of the SAR data pair.

2. Perform a second *InSAR DEM workflow* (without GCP) with the CD data pair as input, use as input reference DEM the $InSAR DEM_{AB}$. The lower *2 PI Ambiguity height* value of the CD data pair allows to get a DEM with a finer resolution.

Keep the same wavelet value applied in the previous step or reduce it (the minimum size is the InSAR resolution obtained after the multilooking step).

The new output keeps the low frequency component of the $InSAR DEM_{AB}$ while the finer details are obtained from the interferometric processing of the CD SAR data pair.

A new finer *InSAR DEM_{CD}* is created.

3. Perform the third *InSAR DEM workflow* (without GCP) with the EF data pair as input, use as input reference DEM the *InSAR DEM_{CD}*. The lower *2 PI Ambiguity height* value of the EF data pair allows to get a DEM with a finer resolution.

Keep the same wavelet value applied in the previous step or reduce it (the minimum size is the InSAR resolution obtained after the multilooking step).

The new output keeps the low frequency component of the *InSAR DEM_{CD}* while the finer details are obtained from the interferometric processing of the EF SAR data pair.

The final high-resolution *InSAR DEM_{EF}* is created.

N.B: The same procedure can be followed by applying GCPs through the dedicated workflow (Interferometry/InSAR DEM Workflow). The same GCPs must be used for each different pair of images.

5. Interferogram Generation

The *Interferometric Generation* process step creates the multi-looked wrapped interferogram through a few sub-steps: *co-registration*, *differential interferogram generation*, optional *phase pattern removal* and *unwrapping*.

The *Interferometric Process* is performed running the *Interferometry/Phase Processing/1 - Interferogram Generation* panel (see Figure 8).

Input files

Select the Reference and Secondary images.

Use the as Reference image the `data_TSX1_152_20111209_023746835_spot_062_D_HH_slc` and the `data_TSX1_152_20111220_023745253_spot_062_D_HH_slc` as Secondary one.

Optional file

Leave the Geometry GCP File empty.

Leave Shift Parameters File empty.

Leave ScanSAR-TOPSAR Spectral Diversity Avoid Moving Area empty.

DEM/Cartographic System

Insert the `data_TSX1_152_20111128_023746835_spot_062_D_HH_slc_srtm3_demprovided` in the dataset.

Principal Parameters

Range Looks

Number of looks in range referred to the Reference.

Azimuth Looks

Number of looks in azimuth referred to the Reference.

Grid Size for Suggested Looks.

By setting this flag, the coregistration shifts between Reference and Secondary image are calculated and saved into the `_par` file.

Compute Shift Parameters

By setting this flag, the coregistration shifts between Reference and Secondary image are calculated and saved into the `_par` file.

Generate Coregistered SLC

By setting this flag, Reference and Secondary coregistered Single Look Complex data are generated among the output products. These files are over sampled of a factor 2 in range direction.

Coregistration with DEM

By setting this flag, the input Digital Elevation Model is used in the co-registration process. Pixels with coherence values smaller than this threshold are not unwrapped and set to NaN.

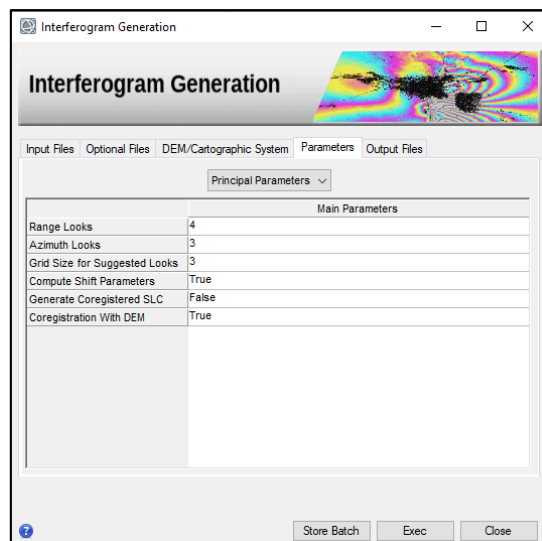
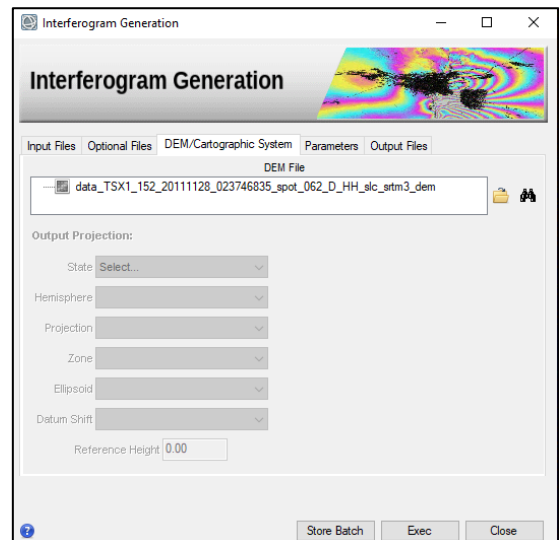
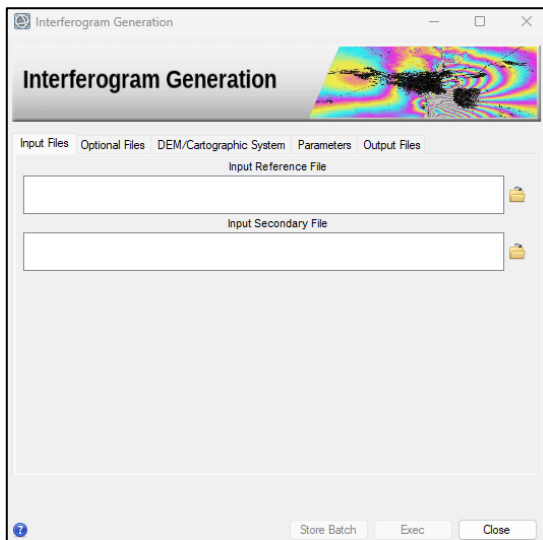


Figure 8 *Interferogram Generation* panels.

Output

The output folder contains the following products:

- *_int*
Interferogram with the associated header files (.sml, .hdr).
- *_dint*
Flattened interferogram with the associated header files (.sml, .hdr).
- *_dint_ql.tiff and/or _dint_qlt.tiff*
Tiff image of the flattened interferogram. The creation of these files depends on the selection of "quick look format" in the parameters.
- *_sint*
Synthetic phase with the associated header files (.sml, .hdr).
- *_srdem*
Digital Elevation Model, in slant range geometry, with the associated header files (.sml, .hdr).
- *_slc_rsp*
Coregistered Single Look Complex data. This file is generated only if the relevant flag is set.
- *_par*
ASCII file containing the coregistration shift parameters in range and azimuth. This file is generated only if the shift parameters are calculated.
- *_pwr*
Multi-looked Reference and Secondary image with the associated header files (.sml, .hdr).
- *_orb.sml*
Xml file containing the scene orbital parameters.
- *_orbit_off.shp*
Shape file with the points used to estimate the orbit based shift. This file contains the following information:
 - Pixel position in range direction (Range), in Single Look pixel units.
 - Pixel position in azimuth direction (Azimuth), in Single Look pixel units.
 - Shift measured in range direction (Dr), in Single Look pixel units.
 - Shift measured in azimuth direction (Da), in Single Look pixel units.
 - Pixel position in range direction (Range), in Single Look pixel units.
 - Pixel position in azimuth direction (Azimuth), in Single Look pixel units.
 - Calculated polynomial shift, to apply in range direction (Drfit), in Single Look pixel units.
 - Calculated polynomial shift, to apply in azimuth direction (Dafit), in Single Look pixel units.
- *_winCC_off.shp*
Shape file with the points used to estimate the cross correlation based shift from the Intensity data. In addition to the information provided by the "_orbit_off.shp" file, this file contains also the cross-correlation value (CC), which is dimensionless and it can vary from 0 to 1.
- *winCoh_off.shp*
Shape file with the points used to estimate the coherence based shift from the complex data (fine shift estimate). In addition to the information provided by the "_orbit_off.shp", this file contains also the following information:
 - Signal to Noise Ratio (SNR), which is a linear dimensionless value.
 - Coherence value. It is dimensionless and it can vary from 0 to 1.

The software automatically displays the flattened interferogram together with the power image of the Reference and Secondary data.

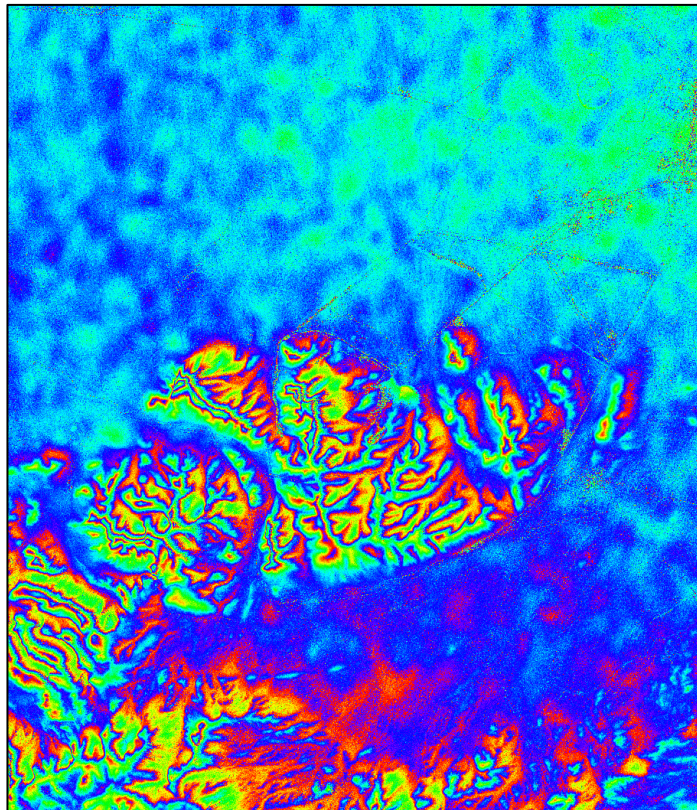


Figure 9 Flattened interferogram, in slant range geometry, colored with the ENVI Rainbow color scale (_fint).

Observing the above interferogram anomalous behavior, such as atmospheric artifacts (at low resolution) and residual topography effects (at high resolution) can be detected.

6. Adaptive Filter and Coherence Generation

Coherence is computed between a pair of SAR acquisitions, and refers to the phase stability on a certain pixel estimated through a complex cross correlation over the interferometric neighboring pixels; it ranges between 0 and 1, where 0 means completely random phase signal, classified as noise, while coherence close to 1 indicates a stable phase signal commonly associated to Permanent scatterers points.

Coherence data have two major applications:

- To determine the quality of the measurement (i.e. interferometric phase). Usually, interferograms generated from data with coherence lower than around 0.2 should not be considered for the further processing and will be considered as noise.
- To extract thematic information for land cover characterization. This analysis is typically performed by combining coherence and backscattering coefficient.

Noise filtering is applied to the generated interferogram (after flattening and topographic removal), in order to remove those pixel that may provide unreliable results. Several different types of filters can be applied, such as: Goldstein, Boxcar or the Adaptive Non Local filter. Further processing tools allow to apply atmospheric corrections through the usage of external data, such as GACOS data, or to remove polynomial

phase trend, low frequency phase components or height correlated phase distortions (*Interferometry/Interferometric Tools/Atmospheric Phase Delay Correction*); this tool will not be applied in this tutorial.

In this tutorial the filter applied is the Goldstein, see Annex 1. Filtering methods for more details.

The filtering of the flattened interferogram enables to generate an output product with reduced phase noise.

Input files

Interferogram file

File name of the previously generated interferogram (`_dint` or `_fint`). This file is mandatory.

Load the previously created `_corr_dint` file.

Input Reference file

File name of the multi-looked Reference Intensity data (`_pwr`). This file is mandatory.

Load the Reference_`_pwr` file.

Input Secondary file

File name of the multi-looked coregistered Secondary Intensity data (`_pwr`). This file is mandatory.

Load the Secondary_`_pwr` file.

Principal Parameters

Coherence Generation

By setting this flag, the coherence is generated.

Adaptive Filter

By setting this flag, the input interferogram is filtered. This flag is disabled when the "Local Frequency Removal (Range and Azimuth)" is set to a value higher than zero; indeed in this case the `_fint` file should have already been generated.

Filtering method

The choice is given between the following filtering methods according to the default values of the filtering section of the Preferences parameters:

- Adaptive window;
- Boxcar window;
- Goldstein.

Coherence from Fint

By setting this flag, the coherence is computed using the filtered interferogram (`_fint`) instead of the unfiltered one (`_dint`).

Output

The output folder contains the following products:

Output Root Name

Name of the output root. This file is mandatory.

`_fint`

Filtered interferogram with the associated header files (.sml, .hdr). This file is generated only if the Adaptive Filter flag is selected.

_fint_ql.tiff and/or *_fint_qlt.tiff*

Tiff image of the filtered interferogram. The creation of these files depends on the selection of "quick look format" in the parameters.

_pwr_fil

Filtered Intensity - from Reference and Secondary combination - with the associated header files (.sml, .hdr). This file is generated only if the "Adaptive" or "Non Local InSAR" filter is selected.

_cc

Estimated coherence with the associated header files (.sml, .hdr). This file is generated only if the Coherence Generation flag is selected.

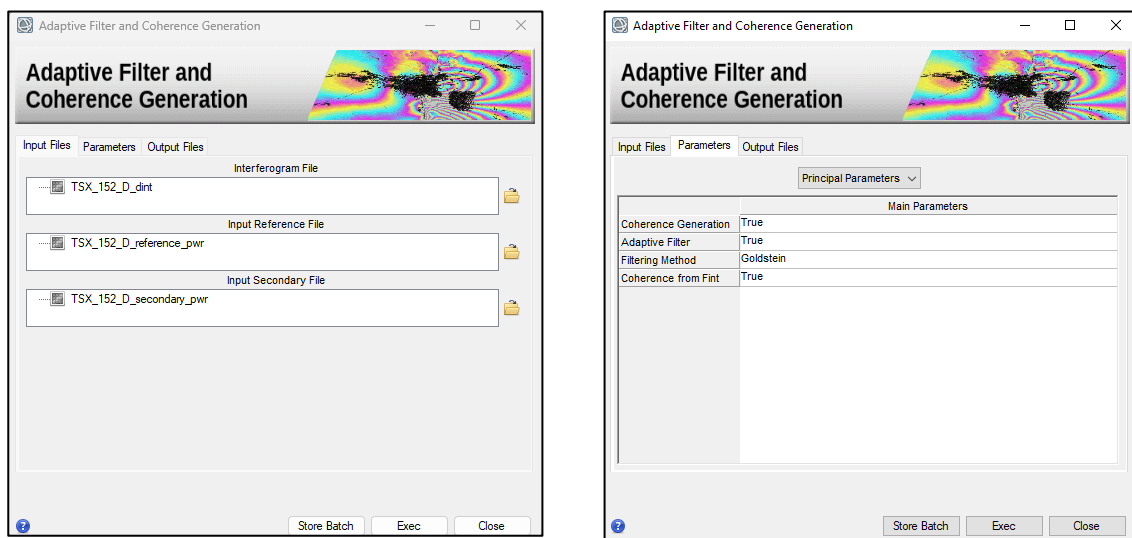


Figure 10 Adaptive Filter and Coherence Generation panels.

The area is characterized by an overall high coherence, the low coherence stripes (darker areas) are mainly related to roads and waterways (Figure 11).



Figure 11 Coherence image (_cc).

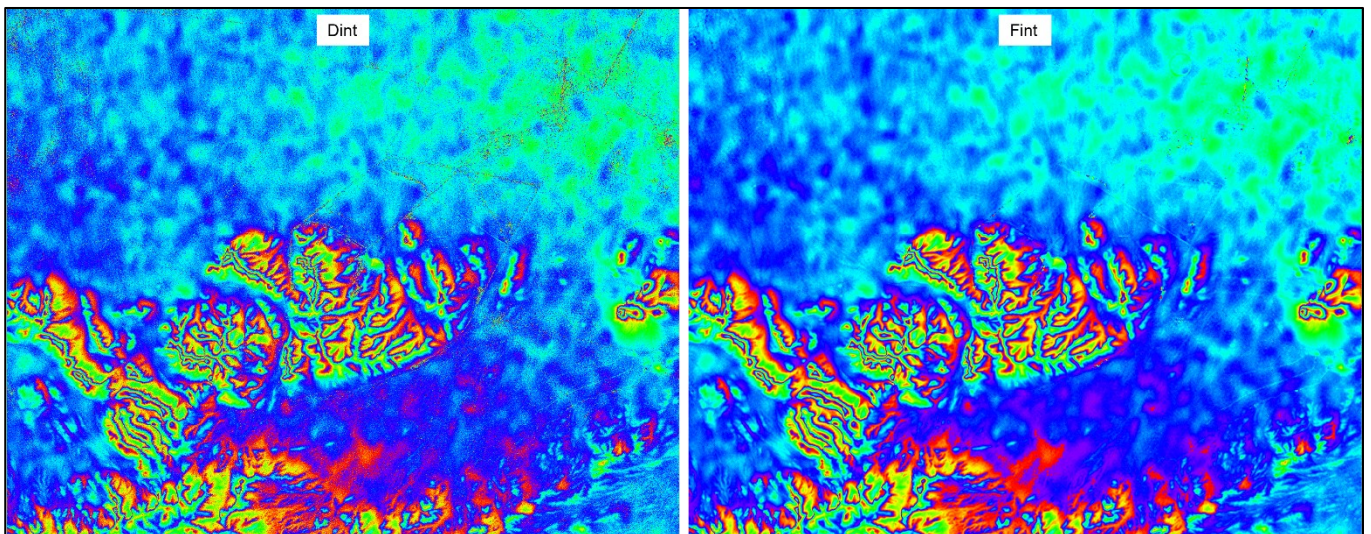


Figure 12 Flattened interferogram (_dint), on the left, and filtered interferogram on the right (_fint).

7. Phase Unwrapping

The phase of the interferogram can only be modulo 2π ; hence anytime the phase change becomes larger than 2π the phase starts again and the cycle repeats itself. Phase Unwrapping is the process that resolves this 2π ambiguity. Several algorithms (such as the branch-cuts, region growing, minimum cost flow, minimum least squares, multi-baseline, etc.) have been developed; in essence, none of these is perfect and different or combined approaches should be applied on a case by case basis to get optimal results.

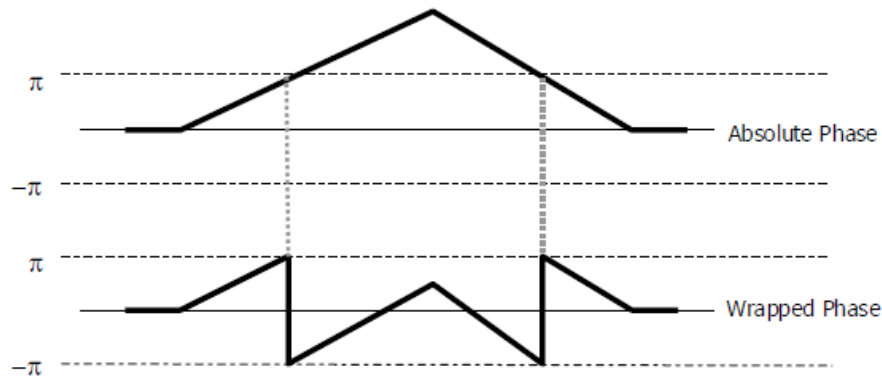


Figure 13 Wrapped Phase vs Absolute Phase sketch

Input files

Coherence file

File name of the coherence (`_cc`). This file is mandatory.

Interferogram file

File name of the flattened - and possibly filtered - interferogram (`_fint`). This file is mandatory.

Principal Parameters

Unwrapping Method Type

The choice is given between the following unwrapping methods:

- *Region Growing*, the Region Growing unwrapping method is used;
- *Minimum Cost Flow*, the Minimum Cost Flow (square grid) unwrapping method is used;
- *Delaunay MCF*, the Minimum Cost Flow (triangular grid) unwrapping method is used.

Unwrapping Decomposition Level

The number of under sampling levels to be applied to the complex interferogram before performing the phase unwrapping can be specified (refer to the Technical Note).

Unwrapping Coherence Threshold

Pixels with coherence values smaller than this threshold are not unwrapped.

Output

The output folder contains the following products:

Unwrapped Phase file

File name of the output unwrapped phase. This file is mandatory.

`_upha`

Unwrapped phase with the associated header files (`.sml`, `.hdr`).

`_reflat_upha`

Re-flattened unwrapped phase with the associated header files (`.sml`, `.hdr`). This file is generated only for Tandem-X bistatic Data.

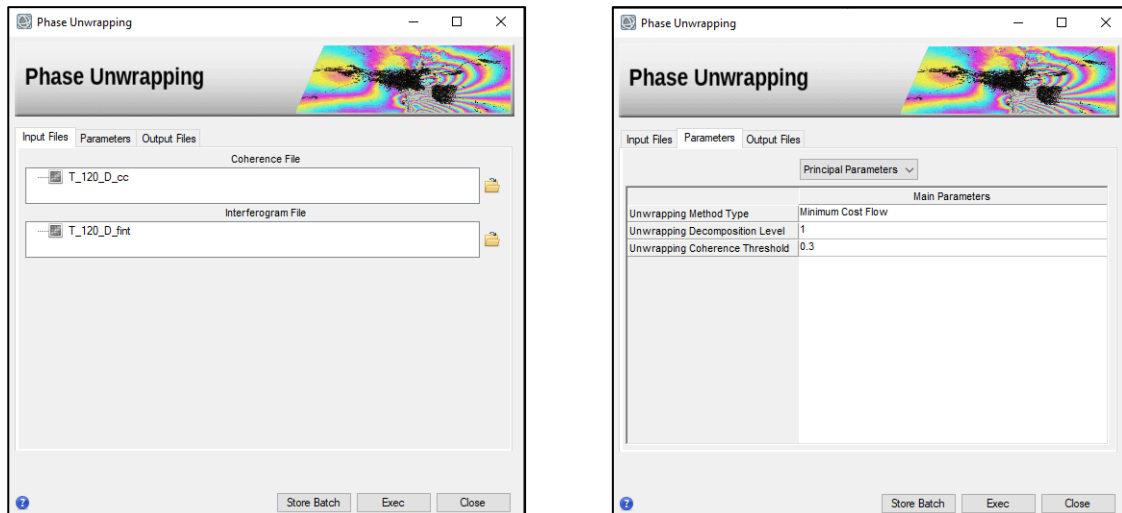


Figure 14 Phase Unwrapping panels.

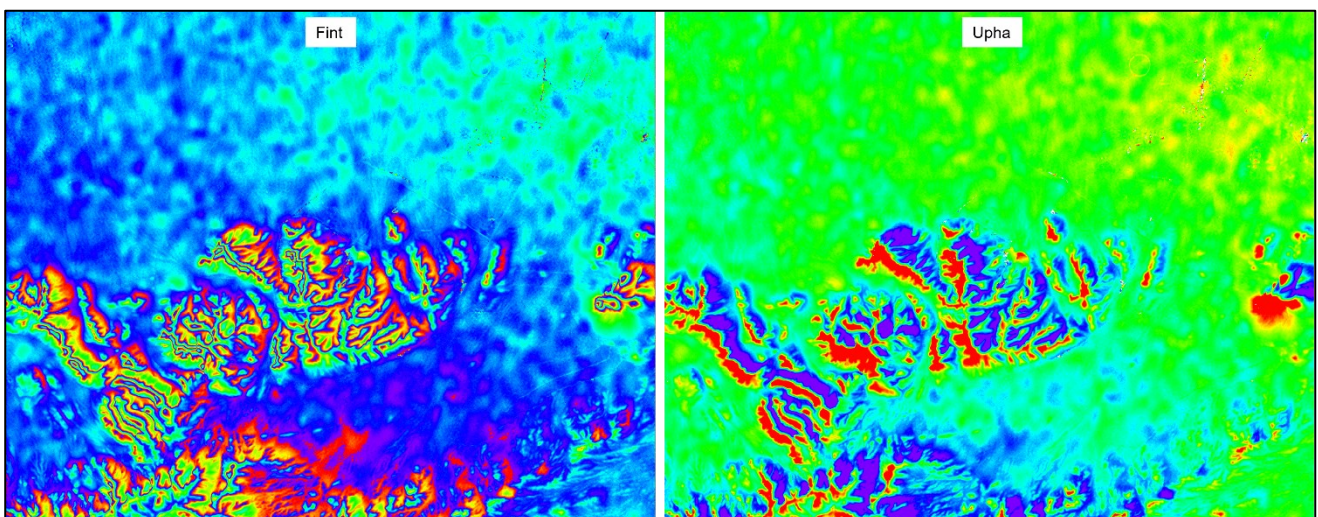


Figure 15 Corrected flattened and filtered interferogram (_dint), on the left, unwrapped dint on the right (_upha).

8. Refinement and Re-flattening

This step will not be performed since the refinement will be done during the Phase to Height Conversion and Geocoding step, through the application of the wavelet filter, which is ideal for DEM generation purposes. This refinement process does not need the creation of GCP, it is designed to remove the low frequency component of the topographic residual, that may be due to orbital errors or atmospherical patterns, by keeping the low pass component of the reference DEM. For more information please refer to the GCP manual available on the sarmap website: https://www.sarmap.ch/tutorials/GCP_Manual_V_1_1.pdf

9. Phase to Height Conversion and Geocoding

The unwrapped phase is re-combined with the synthetic phase and it is converted to height and geocoded into a map projection. This step is performed in a similar way as in the geocoding procedure (Basic module), by considering the Range-Doppler approach and the related geodetic and cartographic transforms. The fundamental difference with the geocoding step is that the Range-Doppler equations are applied simultaneously to the two antennae, making it possible to obtain the exact position of the scatterer point in three dimensions: Easting, Northing and Height.

The refinement is applied in this step with the application of the wavelet filter.

As result of this step also the coherence image is geocoded.

Two files are generated in this step, beside the Digital Elevation Model and the geocoded coherence image, for a further use in the data [mosaicking](#). They are:

- **Precision**, which is derived from parameters such as coherence, baseline and wavelength. It provides an estimate (i.e. standard deviation value) of the measurement precision. The higher this value the lower the measurement precision. The formula used for the precision calculation is:

$$\sqrt{\frac{1-\gamma^2}{2\gamma^2}} \frac{\lambda R \sin \vartheta}{4\pi B}$$

- **Resolution**, which represents the pixel resolution in ground range, that is:

$$\frac{\text{pixel spacing slant range}}{\sin \vartheta}$$

where γ is the interferometric coherence, λ is the wavelength, R is the slant range distance, ϑ is the local incidence angle.

Input Files

The software filter looks for the suffix `_reflat_cc/upha`, since the refinement has not been done, it is necessary to remove the filter and look for all the extensions.

Coherence file

File name of the coherence (`_cc`). This file is optional.

Unwrapped Phase file

The software filter looks for the suffix `_reflat_upha`, since the refinement has not been done, it is necessary to remove the filter and look for all the extensions.

File name of the reflattened unwrapped phase (`_upha`). This file is mandatory.

Synthetic Phase File

The software filter looks for the suffix `_reflat_sint`, since the refinement has not been done, it is necessary to remove the filter and look for all the extensions.

File name of the synthetic phase (`_sint`). This file is mandatory.

Reference File

File name of the Reference orbital data (`_pwr.sml`). This file is mandatory.

Secondary File

File name of the Secondary orbital data (_pwr.sml). This file is mandatory.

DEM/ Cartographic System

Digital Elevation Model file

Name of the Digital Elevation Model file. This should be referred to the ellipsoid. This file is optional. In case it is omitted, the ellipsoidal height and the relevant cartographic reference system, must be entered.

Output Projection

In case that the Digital Elevation Model is not used, the following parameters are compulsory to define the Cartographic System:

State

Definition of the country or general projection systems.

Projection

Definition of the projection system of the selected State. In case that a general projection system is selected in State, the Projection is automatically set.

Ellipsoid

Definition of the ellipsoid. This is chosen according to the selected State and Projection.

Hemisphere

Definition of the hemisphere. This is chosen according to the selected State and Projection.

Zone

Definition of the zone. This is chosen according to the selected State and Projection.

Datum Shift Parameters

Definition of the datum shift parameters. These are chosen according to the selected State and Projection.

Cartographic Parameters

The reference parameters for some projection systems (e.g. Stereographic, Polar Stereographic, Gnomonic, Mercator, Miller, Albers, etc.) can be set.

Parameters - Principal Parameters

Product Coherence Threshold

Pixels with coherence values smaller than this threshold will be set to dummy (NaN) in the final products.

Spatial Wavelet Size (m)

Insert 300.

The Height Wavelet size, expressed in meters, define what is kept of the residual topography estimated from processing data resolution till the specified resolution value. It removes the low pass distortion under the set resolution value by using wavelet decomposition.

Generate Raster format

By setting this flag the DEM is generated in raster format.

Generate Shape format

By setting this flag the DEM is generated in vector (.shp) format.

Generate Las format

By setting this flag the DEM is generated in Las format.

Output Type

Allows the use to choose between an output DEM with ellipsoidal heights (default) or heights over the geoid. The geoid type can be chosen in the next flag.

Geoid Type

By setting this flag it is possible to choose the geoid model (default: EGM96) used for geodetic heights in case "Ellipsoidal and Geoidal" is set in the previous flag.

Grid Size

The grid size of the output data must be defined; the default unit of measure is meters. Note that - for the Geographic projection - if values higher than 0.2 are entered they will be considered as metric units and then automatically, and roughly, converted from meters to degrees; if values lower than 0.2 are entered they will be considered as degree and used as such without any conversion. Different grid size, in Easting (X) and Northing (Y) direction, can be specified.

Mean Window Size

The mean filtering of the output height image is carried out. The window filter size must be specified. If zero is entered, the mean filtering is not applied. This filter is applied after the execution of the interpolation steps. The mean filtering is performed only on the Digital Elevation Model output.

Interpolation Window Size

The dummy values in the output file are interpolated. The interpolated value is the average of the valid values in a window of the size specified. If zero is entered, the interpolation is not applied; it is suggested to avoid setting this value to zero (see Technical Note).

Relax Interpolation

By setting this flag the relax interpolation is carried out. This interpolation is applied only to the Digital Elevation Model output.

Dummy Removal

By setting this flag the output geocoded files will be automatically resized in order to remove the dummy area exceeding the frame border.

Parameters – Other Parameters

Allow skip refinement

Set this field to True.

By setting this flag the Phase to height conversion and geocoding is permed even if the previous refinement and re-flattening step has not been performed.

Output Files

The output folder contains the following products:

Output Root Name

Name of the output root. It is mandatory.

_dem

Input Digital Elevation Model resampled onto the specified cartographic system and grid size, with the associated header files (.sml, .hdr). Its areal extent is the same as the output SAR products.

_cc_geo

Geocoded coherence with the associated header files (.sml, .hdr).

_precision

Estimate of the data quality with the associated header files (.sml, .hdr). This file is generated only if the coherence file is entered as input.

resolution

Spatial resolution based on the local incidence angle with the associated header files (.sml, .hdr). This file is used during the Digital Elevation Model mosaicking (Tools).

Details specific to the Units of Measure and Nomenclature of the output products can be found in the Data Format section.

Please Note: the annotations of the geocoded files are displayed in ENVI View according to Preferences Common.

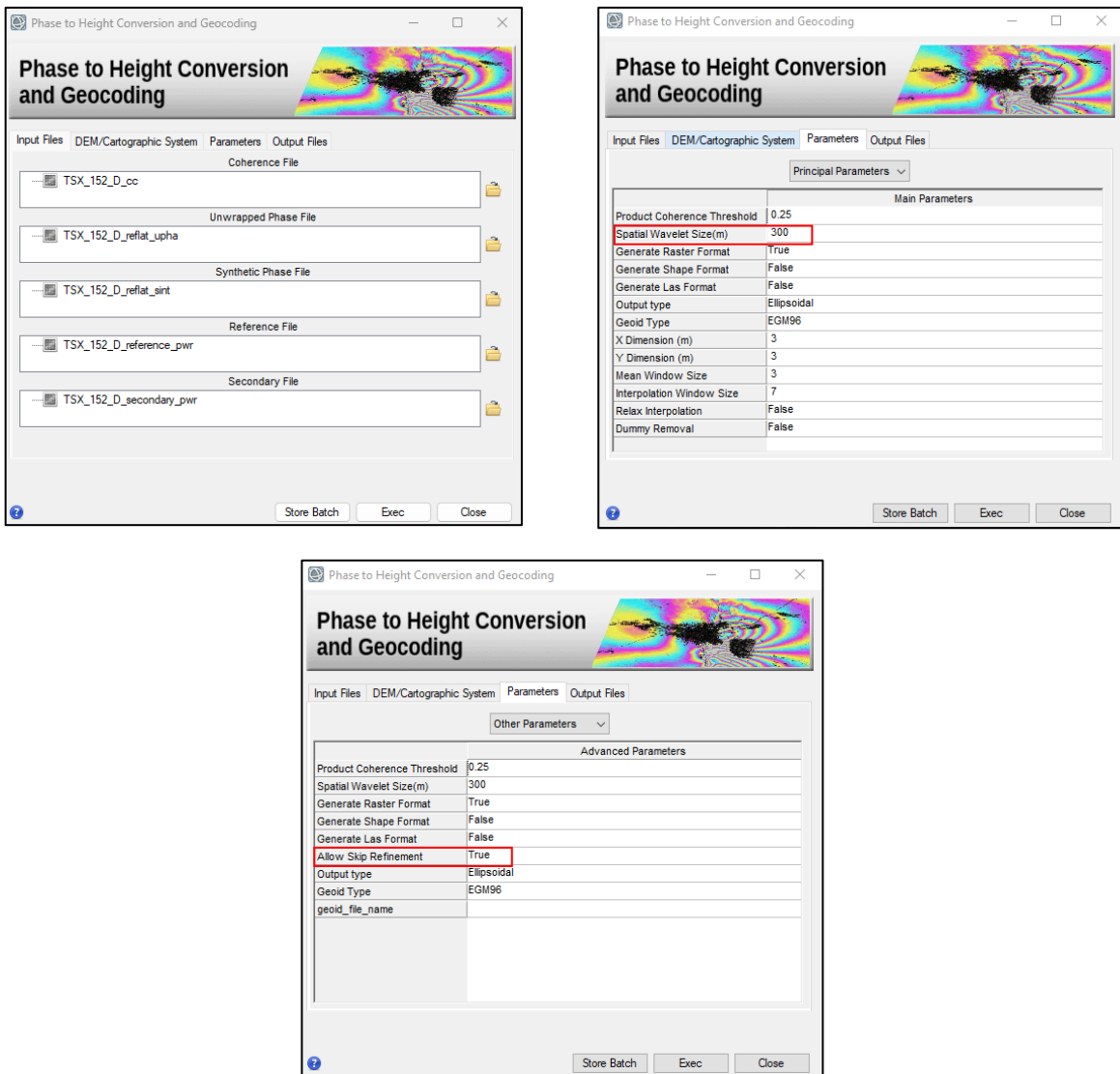


Figure 16 Phase to Height Conversion and Geocoding Panel.

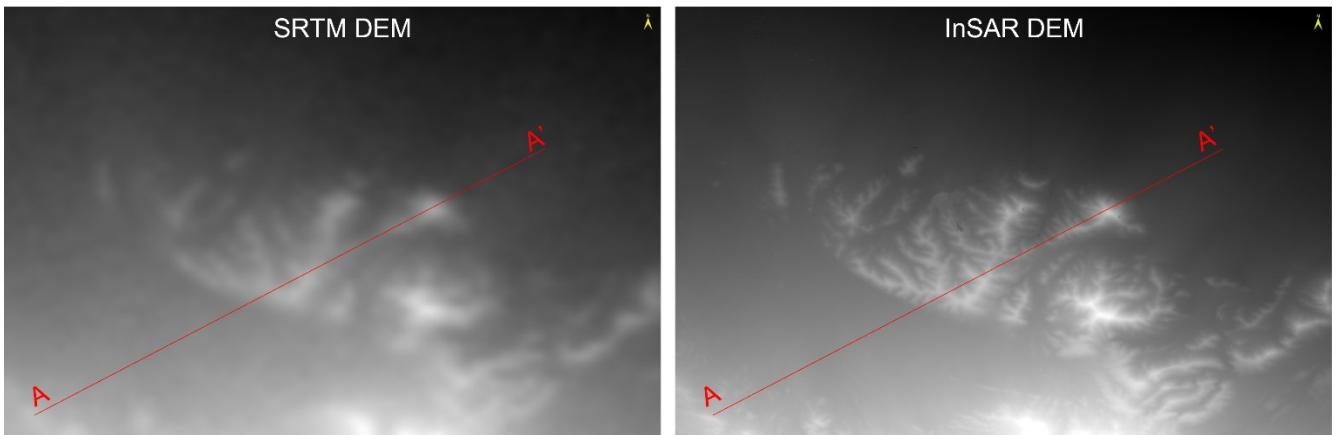


Figure 17 DEM comparison, TSX InSAR DEM versus SRTM3 v4 DEM.

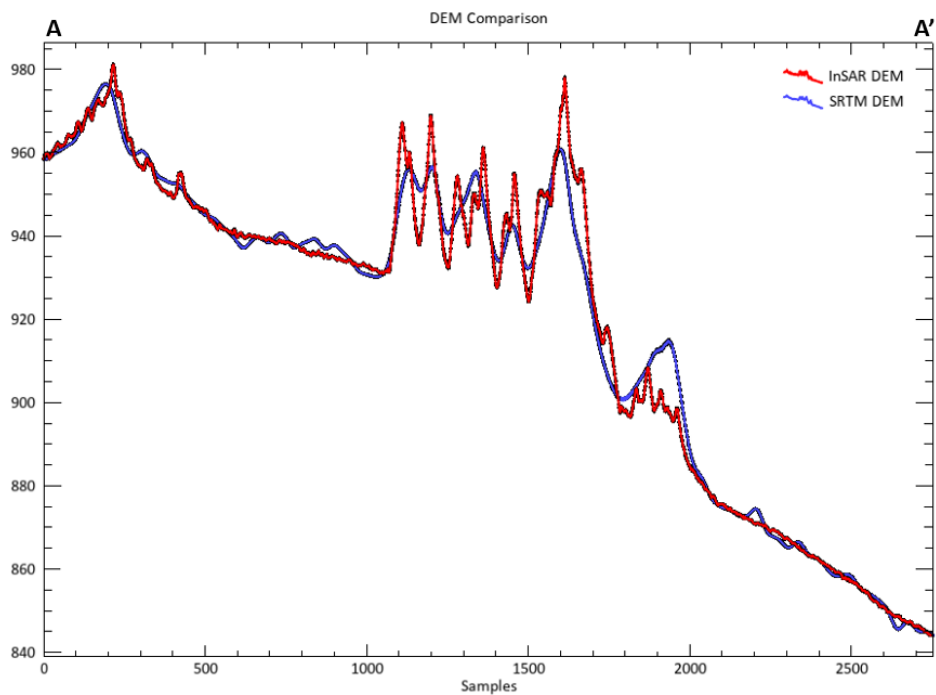


Figure 18 Cross-section comparison, TSX InSAR DEM versus SRTM3 v4 DEM.

Figure 17 and Figure 18 show the comparison between the InSAR DEM and the SRTM DEM; the first one add some details retrieved with the Interferometric processing of the two high resolution TSX image, the low frequency topographic features has been retrieved from the SRTM DEM.

10. InSAR DEM workflow (without GCP)

The operations described in the previous paragraphs can be executed in a single iteration through the InSAR DEM Workflow tool (*Interferometry/Interferometry Without GCP Workflows/InSAR DEM Workflow*). The same workflow with the usage of GCP is available at the following path: *Interferometry/InSAR DEM Workflow*

This functionality enables to execute, in a single iteration, the following processing sequence:

- Import Generic SAR Data
- Interferogram Generation
- Adaptive Filter and Coherence Generation
- Phase Unwrapping
- Phase to Height Conversion and Geocoding.

The final purpose of this processing chain is the generation of an Interferometric Digital Elevation Model.

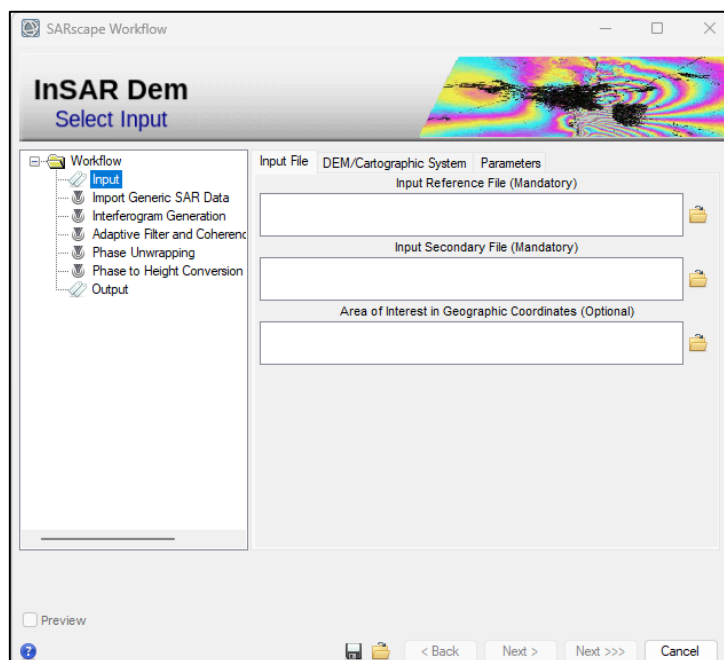


Figure 19 InSAR DEM workflow panel.

Annex 1. Filtering methods

Goldstein: The variable bandwidth of the filter, derived directly from the power spectrum of the fringes, smooths in a selective way the noise frequencies and the signal frequencies. In order to optimize the filter performance the "alpha" parameter, which characterizes the strength of the filter, is handled in an adaptive way on the basis of the local scene coherence: the lower the coherence the stronger the filter.

This filtering approach, which is an extension of the Goldstein method, significantly improves fringe visibility and reduces the noise introduced by temporal or baseline related decorrelation. In this implementation the alpha parameter is depending on the coherence: incoherent areas are filtered more than coherent zones. This implies a signal loss minimization, while strongly reducing the level of noise. The use of the coherence generated from the filtered interferogram (option enabled by setting the flag "Coherence from Fint"), must be carefully considered since the phase smoothing, which is produced by the filter itself, causes an over estimation of the coherence (the stronger the filter the higher the coherence values). If the objective is either not to unwrap areas which appear coherent but are actually very noisy or to use of the coherence data for other purposes (i.e. land cover classification or other qualitative/quantitative applications), the coherence shall be generated from the unfiltered interferogram or using the boxcar filtering approach.

Adaptive Non Local InSAR: In order to precisely estimate the coherence and filtering interferograms, a non-local filter, specifically designed for InSAR has been developed. This filter is based on the interferometric phase and amplitude similarity between the reference and secondary image in order to filter together pixels relevant to the same ground target, to avoid to mix the contribution of different scatterers.

This kernel used to measure the similarity is adaptive to overcome local distortions caused by strong backscattering variations (the so called "rare patches"), typical of the original filter design.

This algorithm implementation considers systematic phase ramp inside the similarity windows (estimated via FFT and removed before the process) to improve the similarity estimation itself and provide a better estimation of the underlying incoherent phase noise. Moreover, this algorithm overcome the extra smoothing over strong amplitude variations areas between Reference and Secondary acquisitions, typical of the original implementation, exploiting an innovative Central Pixel Modulation based on the previous coherence estimated value.

The number of iterations for the weighted denoising is set to 3 by default.

Non-local-based filtering is an intrinsically, computationally demanding feature, due to its many comparisons between different image areas. Therefore, this tool put the underlying hardware components under stress and requires a significant amount of time. For this reason, our implementation is entirely written in OpenCL to take advantage of the massive level of parallelization offered by modern graphical processing units. Hence, we warmly recommended to use this filter only in combination with a powerful GPU selected as the current OpenCL platform/device under the SARscape Common Preferences. It is always possible to select and rely to a CPU-only OpenCL platform/device, but in such a case performance will roughly be one order of magnitude lower than using a modern GPU.

The results of this tool are the following products:

- Filtered interferogram
- Coherence
- Reference filtered power
- Secondary filtered power

The strength points of this filter with respect to the other filters are the following:

- details preservation in the filtered interferogram, in the coherence and in the power layers, vs homogeneous area stronger filtering
- unbiased coherence estimation (evident mostly in low coherent areas) due to the large processing window size.
- spatial resolution preservation for all the output layers (coherence included) with respect to input resolution; moreover, the spatial resolution is the same for all the derived products differently from the other coherence estimators.
- The coherence is estimated directly from the input differential interferograms and not from the filtered one. For this reason, the coherence can be used for quantitative measurements for land use monitoring.

Annex 2. Unwrapping methods

Minimum Cost Flow: It is the default unwrapping method to compute interferometry, from a pair of SAR images; this works over areas characterized by the presence of large areas of low coherence or other spatial recursive growing limiting factors; in such cases the Minimum Cost Flow algorithm enables to obtain better results than using the Region Growing method. This approach considers a square grid all over the image pixels. All pixels whose coherence is lower than the "Unwrapping Coherence Threshold" are masked out.

Delaunay MCF: It is the same approach of the previous method, with the only difference that the grid does not necessarily covers all image pixels, but only those above the "Unwrapping Coherence Threshold"; moreover it adopts the Delaunay triangular grid instead of square one. As result only the points with good coherence are unwrapped, without any influence from the low coherence pixels. The exploitation of the Delaunay triangulation is especially useful when there are several areas of low coherence (water bodies, densely vegetated areas, etc.) distributed throughout the image; in such case the others unwrapping approaches would eventually produce phase islands/jumps, while the Delaunay approach is able to minimize these jumps.

Region Growing: If this method is selected, it is suggested to avoid setting a high coherence threshold (good values are typically between 0.15 and 0.2) in order to leave enough freedom during the growing process; this shall limit the possibility to introduce erroneous phase jumps - "unwrapping islands" - in the output unwrapped phase image.

Decomposition Level

Another important factor is the Decomposition level (DCL). The process is normally executed with the original pixel sampling (i.e. 0) or with the minimum decomposition level (i.e. 1). The use of the decomposition is intended to multilook and undersample the data in an iterative way: the interferogram is unwrapped at the lower resolution and then reconstructed back at the original resolution.

The use of the decomposition can help to reduce unwrapping errors (e.g. in case of distributed low coherence areas) and it reduces the processing time and it limits the use of computer resources.

The user can specify the number of iterations (decompositions) to be executed; each iteration corresponds to an undersampling factor of 3. We suggest to avoid setting this value higher than 2. In case of very large displacements or very steep topography (fast phase/dense fringe distribution) the use of the decomposition can cause aliasing effects. In this case the decomposition process should be avoided by setting its value to 0.

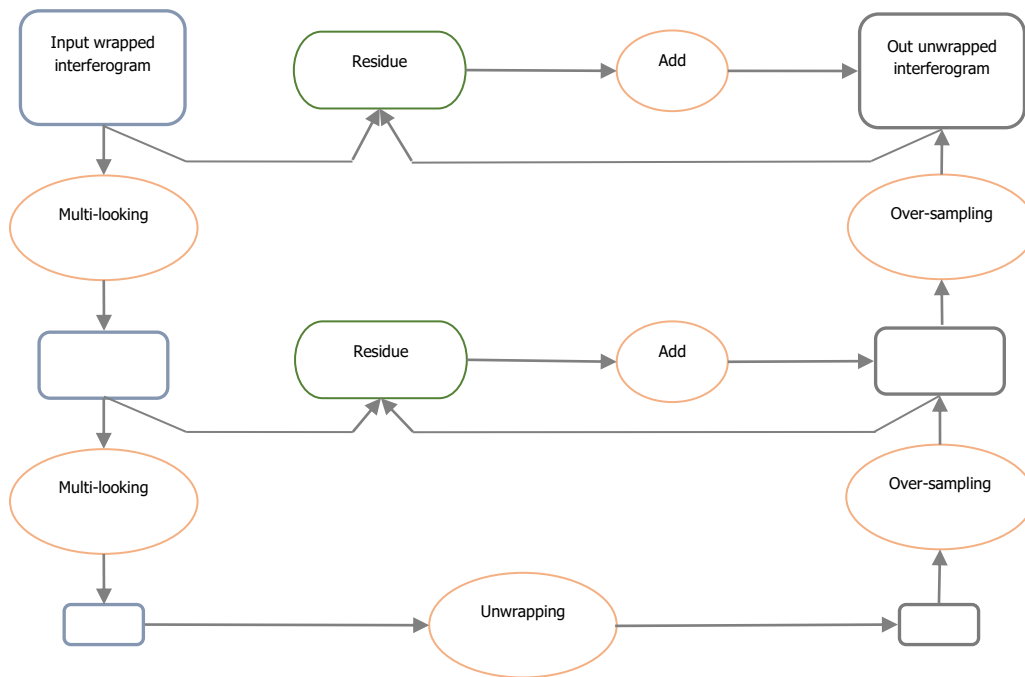
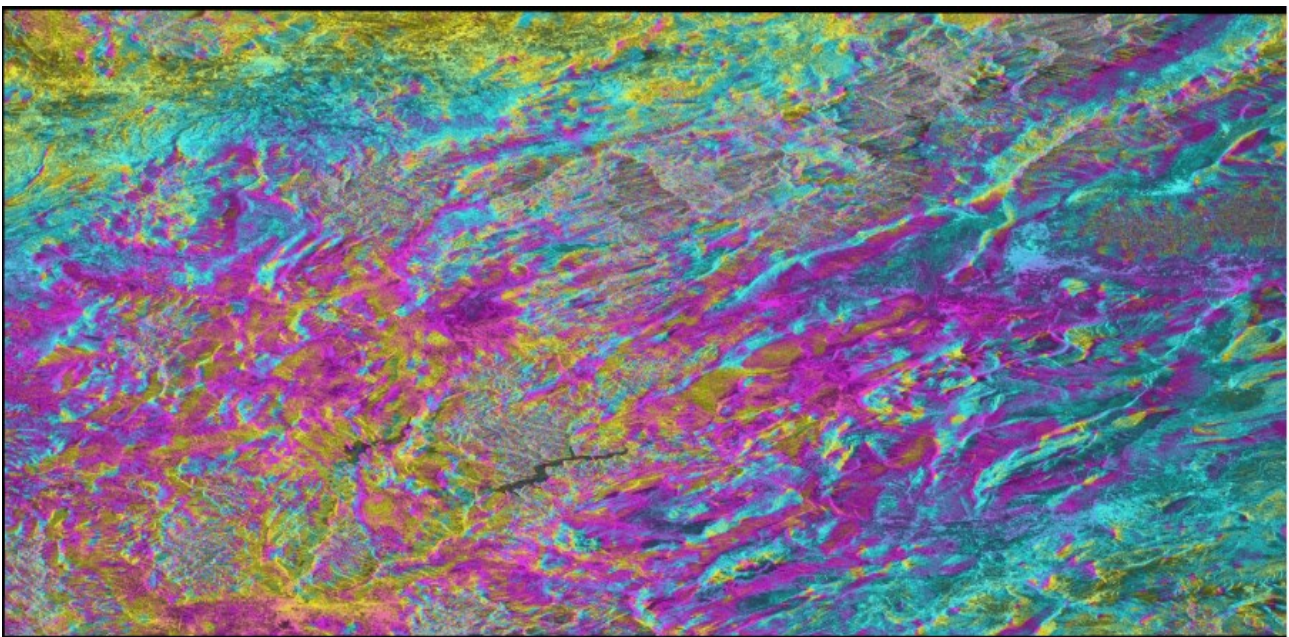


Figure 20 Decomposition Level 2. The under-sampling is performed at each step with a multi-looking 3X3



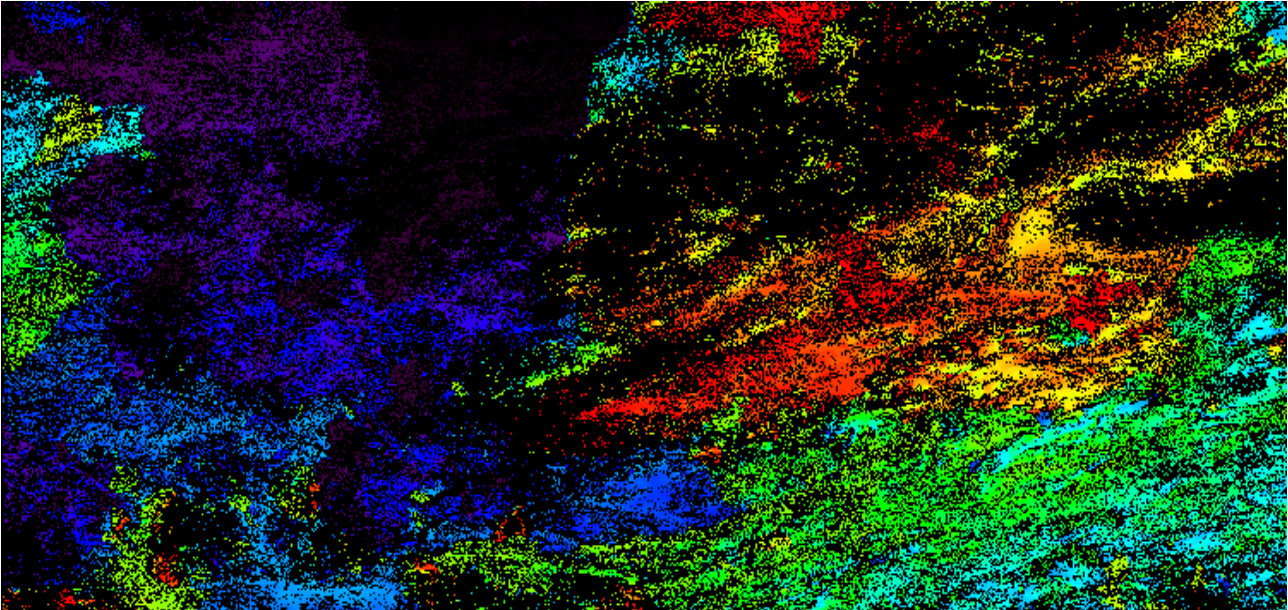


Figure 21 Unwrapping with Delaunay MCF with and Decomposition level 1. Macroscopic phase jumps are visible.

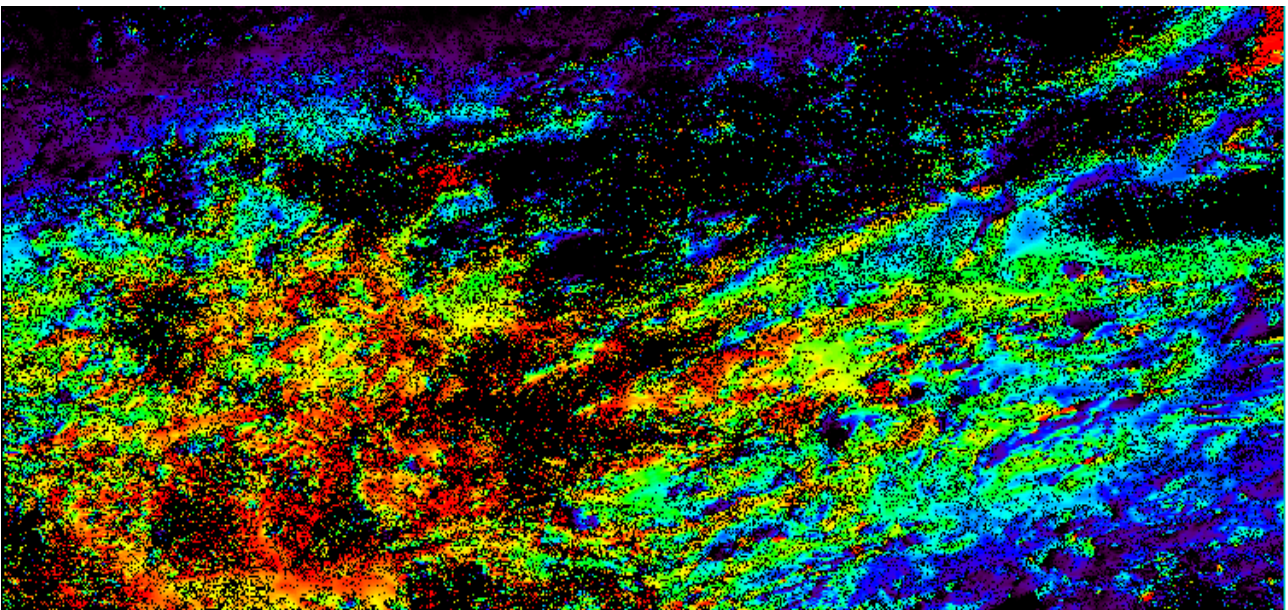


Figure 22 Unwrapping with Delaunay MCF and Decomposition level 2 has been used. The macroscopic phase jumps disappeared.

Be careful when increasing the Decomposition level number; macroscopically the improvement is meaningful and it significantly speeds up the software, but it can create localized discontinuities where the fringes to be unwrapped are too fast. The higher is the decomposition, the higher the probability to have aliasing problems.

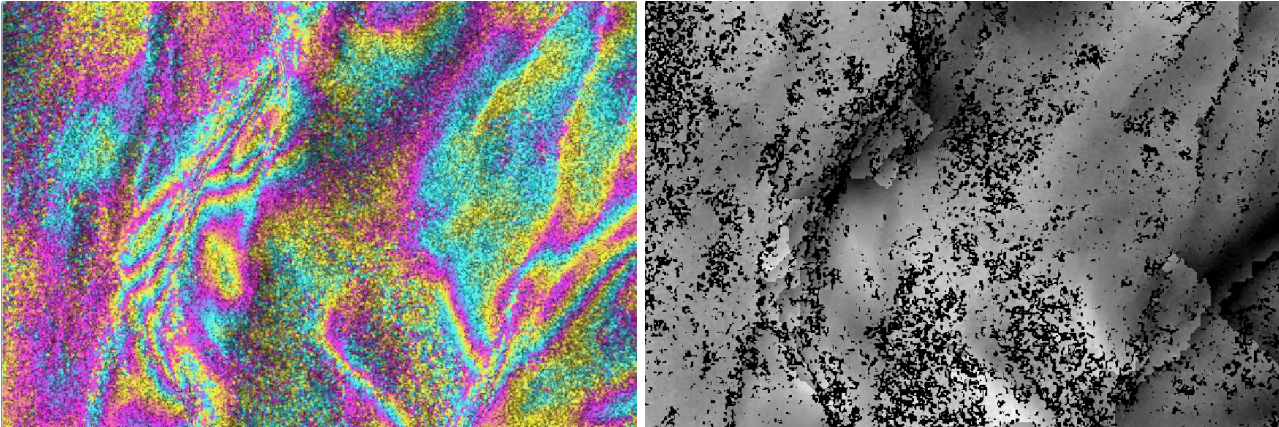


Figure 23 Zoom of the original (on the left) and unwrapped phase (on the right), obtained with Decomposition level 2. Many localized phase discontinuities appear where the fringes are too “fast” in the original interferogram.