UNIVERSITY COURSE EARTH OBSERVATION WITH ESA MISSIONS

TUTORIAL FOR EXERCISE 6

InSAR for detect, map, and monitor natural hazards

esa FBERG

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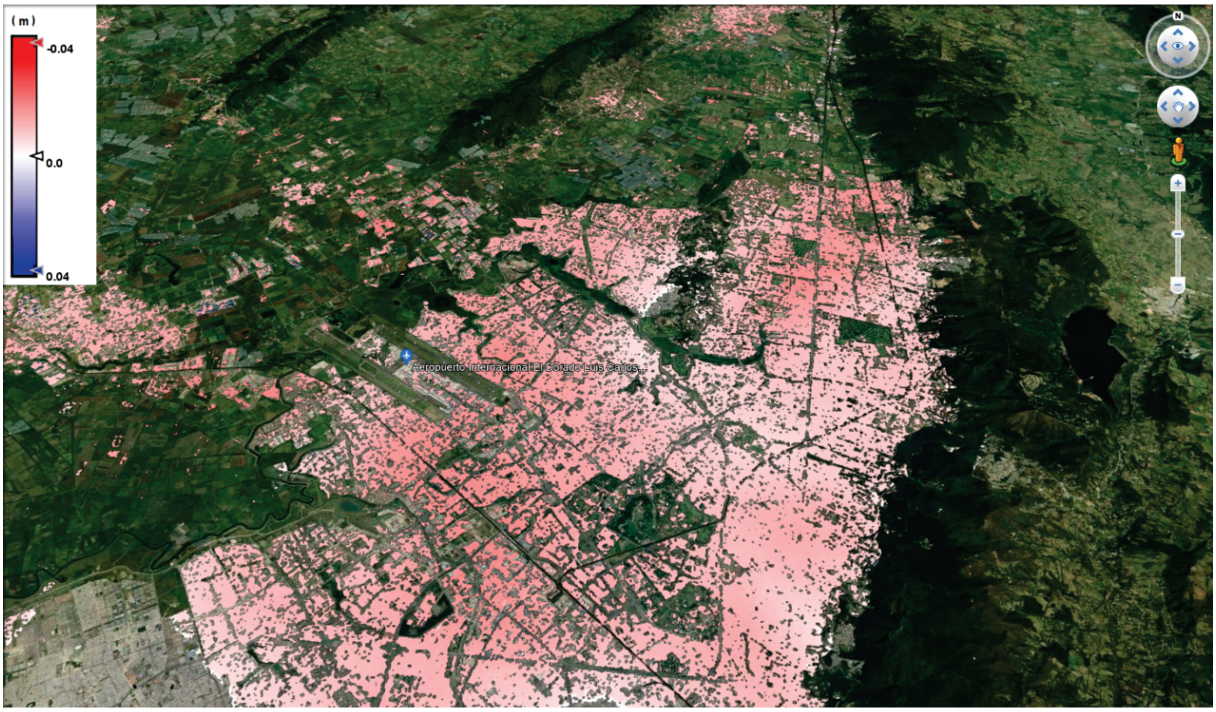
(PLAN FOR EUROPEAN COOPERATING STATES)

Table of Content

1 Exercise outline

In this exercise, we will:

- learn how to preprocess Sentinel-1 SCL IW products for InSAR mapping
- download Sentinel-1 data from another data portal (ASF Vertex)
- learn how to generate interferogram in SNAP
- work with phase in DInSAR processing
- learn how to install and use SNAPHU plugin
- learn SAR unwrapping phase process
- learn how to detect displacement by means of band Math expression
- visualize results of displacement in Google Earth



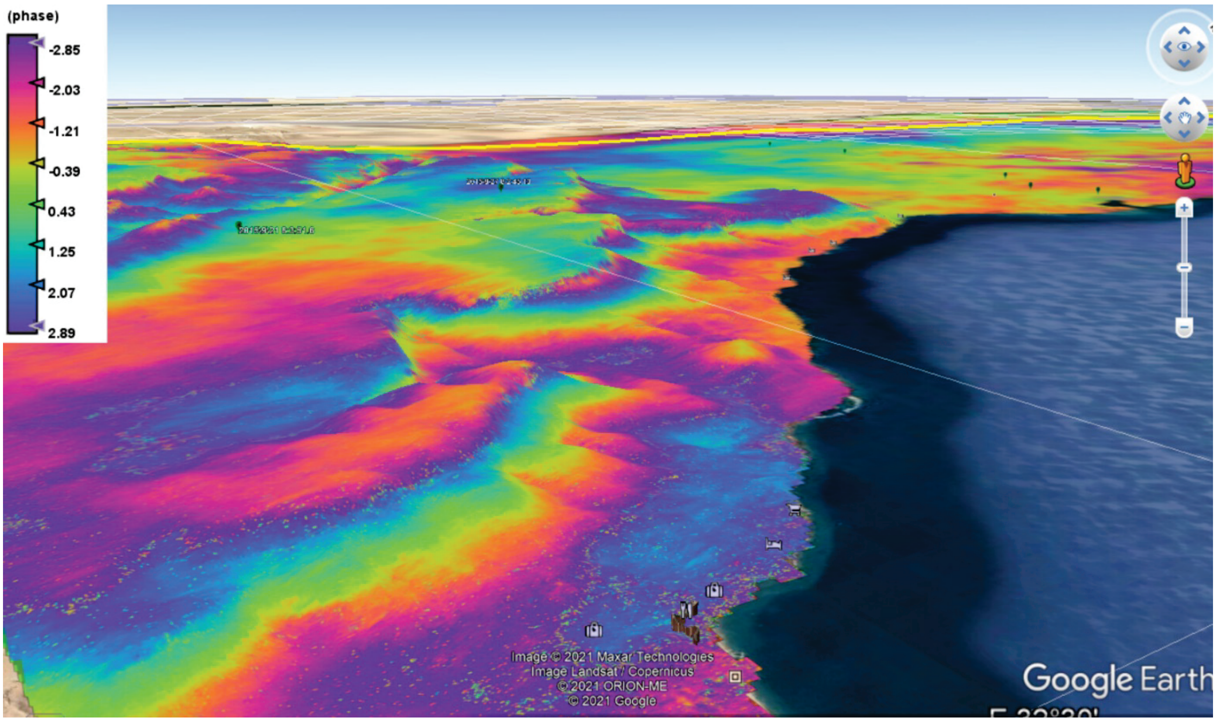
2 SAR interferometry

SAR interferometry, also known as InSAR (Interferometric Synthetic Aperture Radar), is a method that can be used to measure displacements and elevation changes of reliefs using the phase difference between two radar acquisitions.

DInSAR (Differential Interferometric Synthetic Aperture Radar) method consists in processing a pair of SAR images into the form of interferograms . Application in determining deformations of the Earth's surface and objects on it. The processing of SAR images using the DInSAR method uses, similarly to InSAR, one main (so-called Master) and the other sub-so-called (so-called Slave) image. This means that the image before the monitored change is considered the main one and the secondary one after the change (or even if the change persists). The result of this method is a representation of the phase difference of the radar waves $\Delta\ \phi$. The phase difference of the radar waves is determined as follows:

$$\Delta\varphi = \Delta\varphi_f + \Delta\varphi_{el} + \Delta\varphi_d + \Delta\varphi_a + \Delta\varphi_n$$

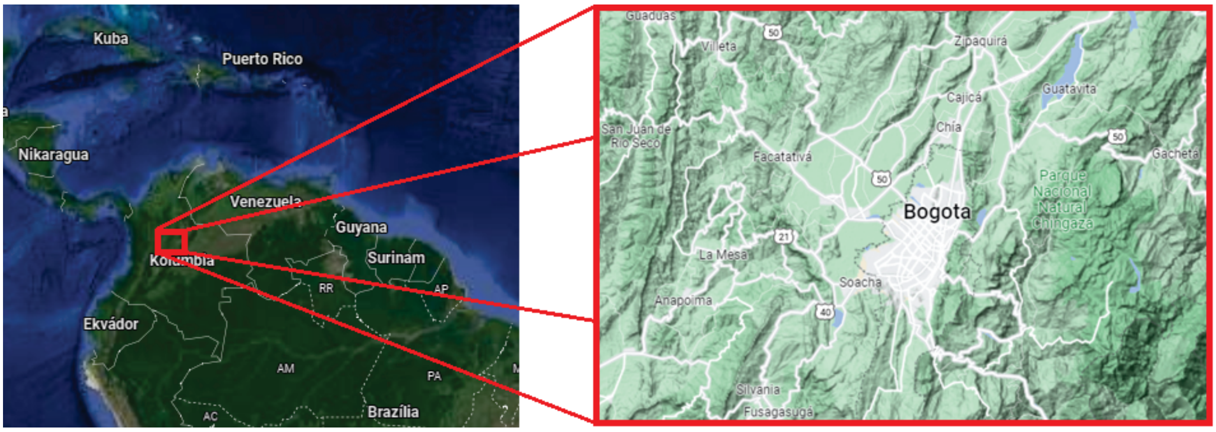
if $\Delta\varphi_f$ is a component of the curvature of the earth, $\Delta\varphi_{el}$ is a topographic component, $\Delta\varphi_d$ symbolizes the movements of pixels in the direction of direct visibility called Line of Sight (LOS), $\Delta\varphi_a$ is the atmospheric phase delay component between transitions, and $\Delta\varphi_n$ is the phase noise caused by scattering variability.



Source: https://forum.step.esa.int/t/interpreting-results-from-s1-a-dinsar/1324/41?page=3

2.1. Study area and image download

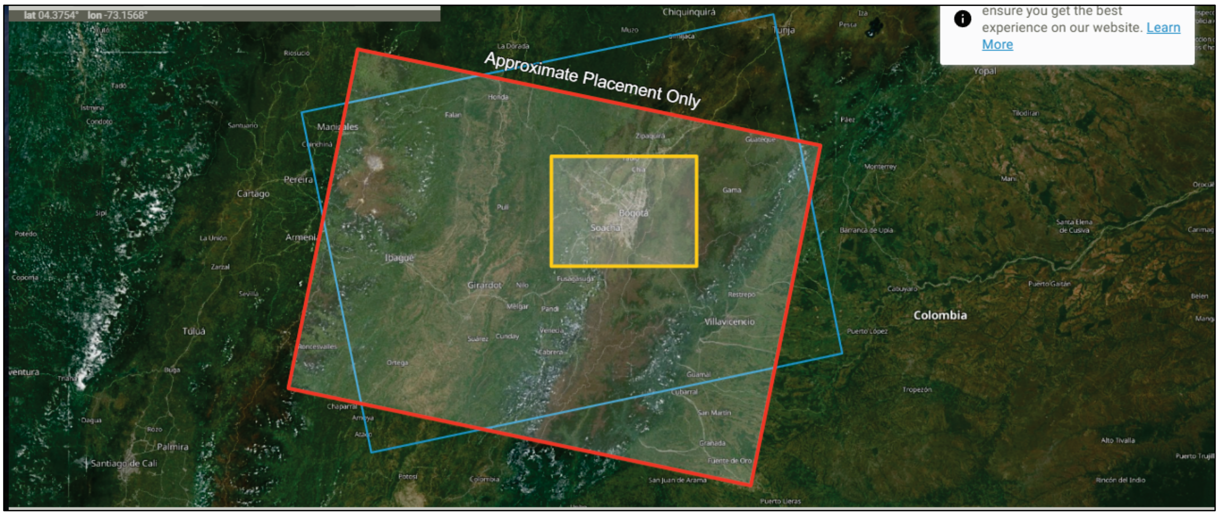
The study area is Bogota city, the capital of Columbia.

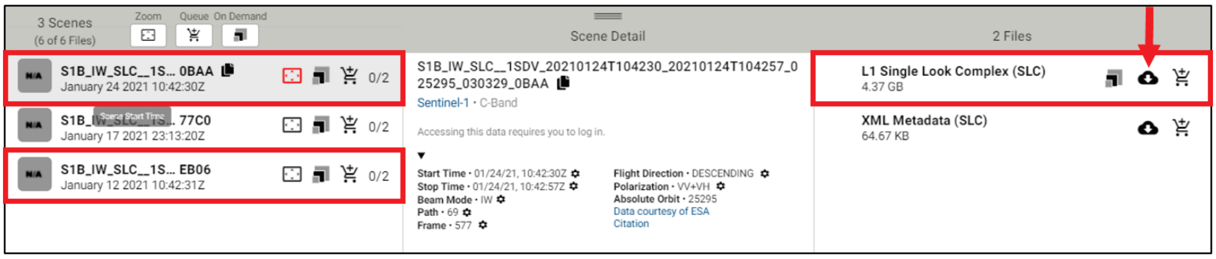


Download images:

S1B_IW_SLC__1SDV_20210112T104231_20210112T104258_025120_02FD9A_EB06 from 12th January 2021

S1B_IW_SLC__1SDV_20210124T104230_20210124T104257_025295_03032_0BAA from 24th January 2021

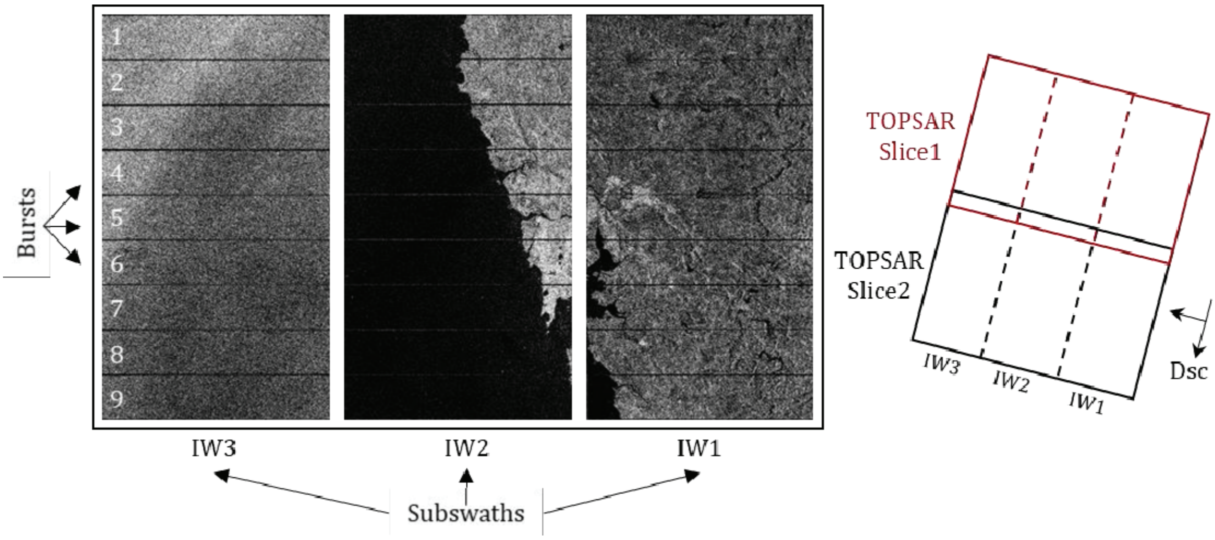




from Alaska Satellite Facility Vertex portal

[https://search.asf.alaska.edu/]

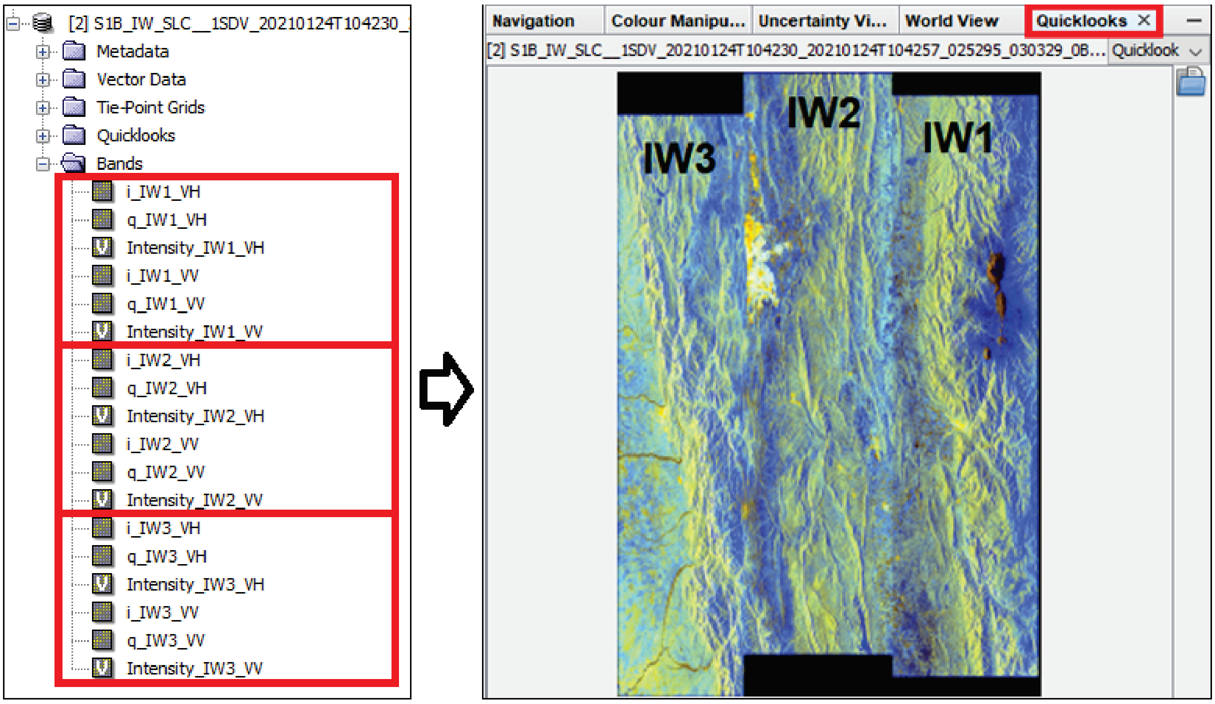
We use Selecting the product level type (SLC) and acquisition mode (IW). IW (Interferometric Wide Swath). This data type consists of three sub-rows or "sub-lines" called "Subswaths" (TOPSAR). The IW product contains three images in single polarisation and six images with dual polarisation. Each "subswath" consists of a series of images or bursts in azimuth.



Source: https://www.semanticscholar.org/paper/Sentinel-1-SLC-Preprocessing-Workflow-for-A-Generic-Mandal-Vaka/29b43304e3b14c2f6896b330373312c878b33bcc/figure/0

Export of 2 data products (necessary for interferogram creation)

No file extraction required (import into SNAP)



2.2. InSAR pre-processing

The first part of for InSAR data processing is pre-processing step in SNAP software. To simplify data processing, we will use the Graph Builder function to compile the processing steps. It is an intuitive way to add data processing features. We can export the created graphs after completion and use them for further processing. After completing the graph, we will connect the functions to each other using the Connect Graph option.

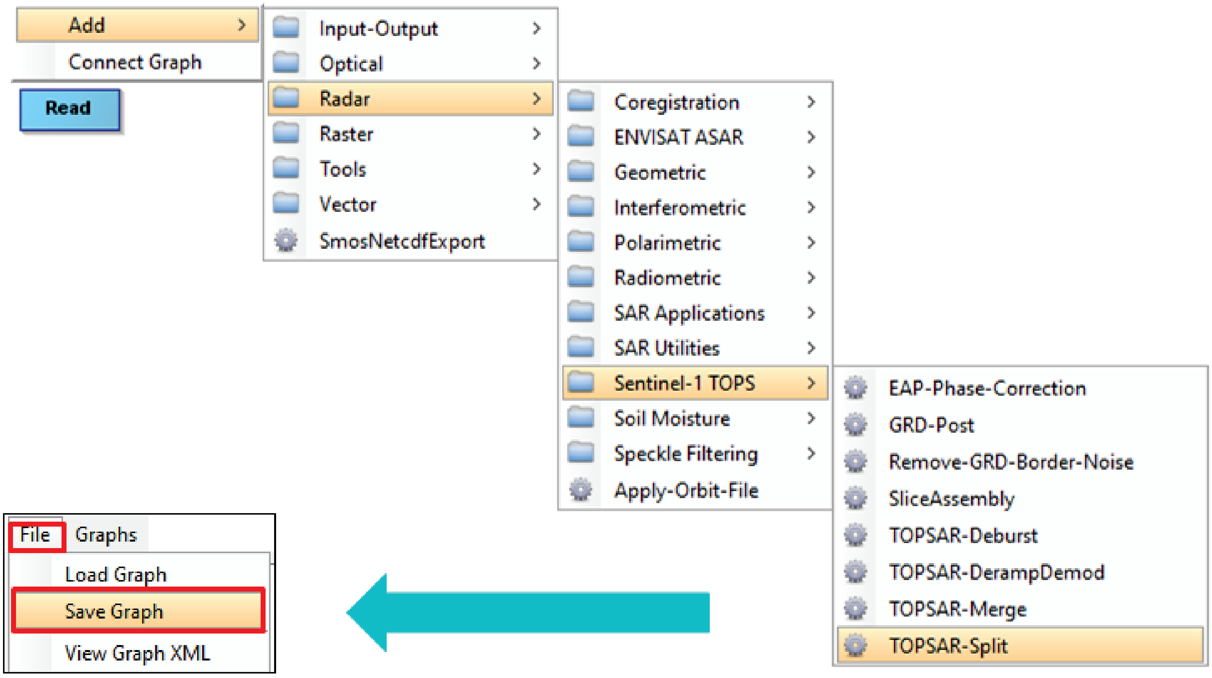
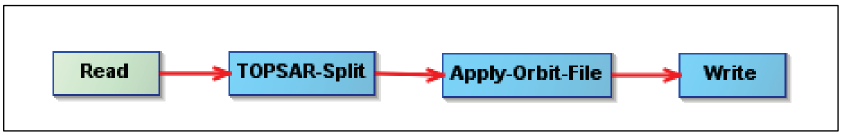
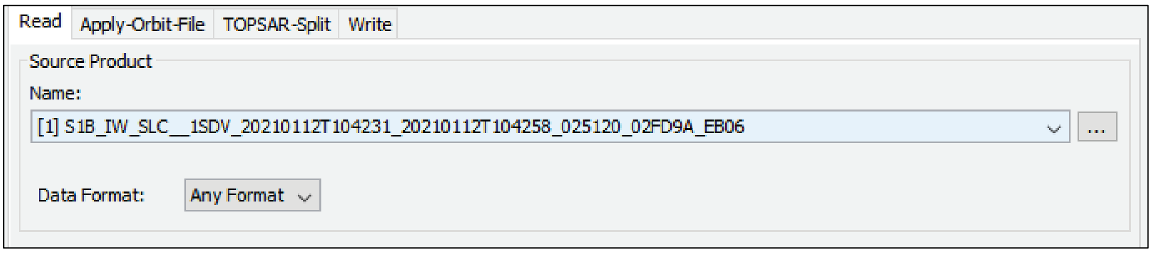


Image import

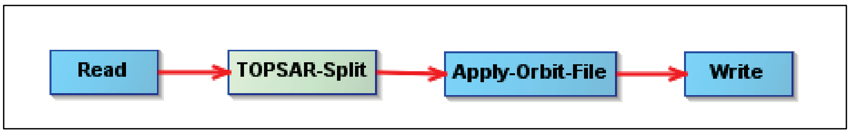
Firstly, At the beginning of the pre-processing it is necessary to read images (already imported in SNAP. It is important to add both images sequentially, as pre-processing is required for both images. If you use Batch Processing function, we need to import the already created processing graph.





TOPSAR Split

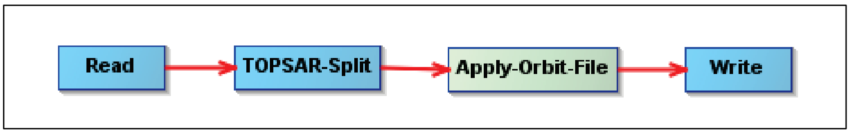
The second important step of pre-processing is TOPSAR Split function. This step involves splitting the individual "subswaths" of an image into a separate product. In this step it is necessary to select the required type of "subswath" taking into account the area of interest.



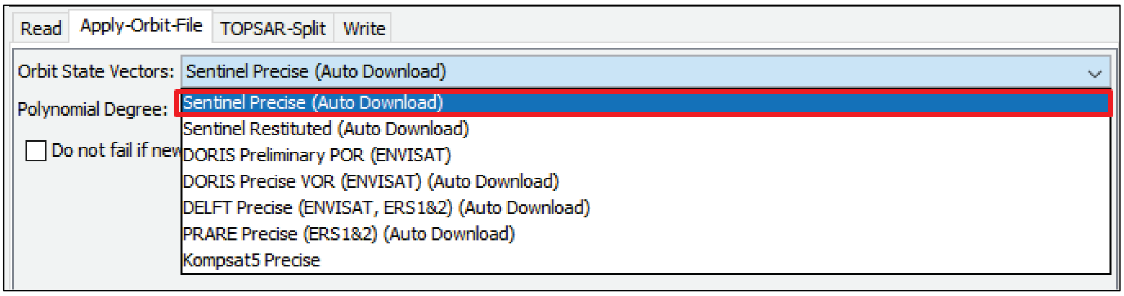
It is also advisable to choose the desired number of „bursts" in a given "subswath" (using the cursors). In this case „bursts" from 2 to 5. At the same time, we select the VV polarization configuration that is necessary for InSAR processing. In this way, the desired extent of the area required for processing is obtained.

Apply Orbit File

It is known that multiple sensors detect the satellite's orbit. Using the Apply Orbit File function we obtain precise orbit information, (position and velocity of the satellite).

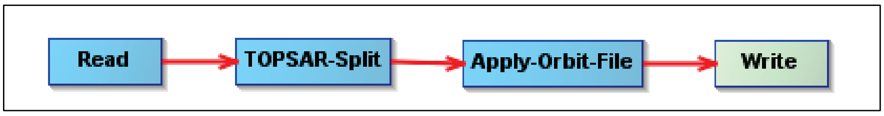


This process updates the data in the metadata file (aux files). Also it can improve geocoding (obtaining more accurate processing results). The parameters used for this step are Sentinel Precise, which are automatically downloaded (precise ephemerides, predicted orbit, etc.)

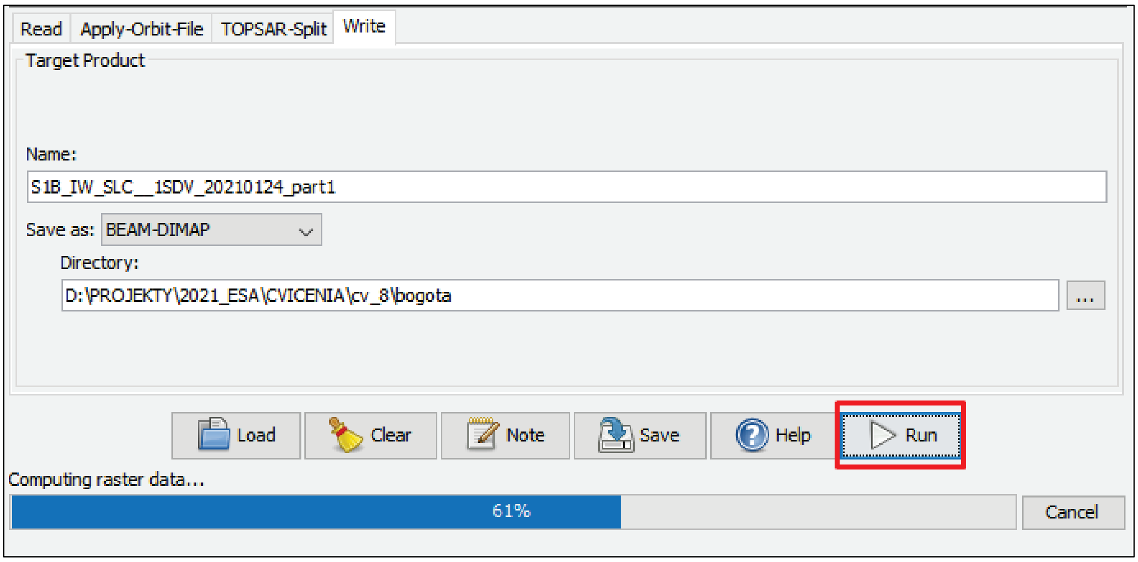


Define output parameters and results

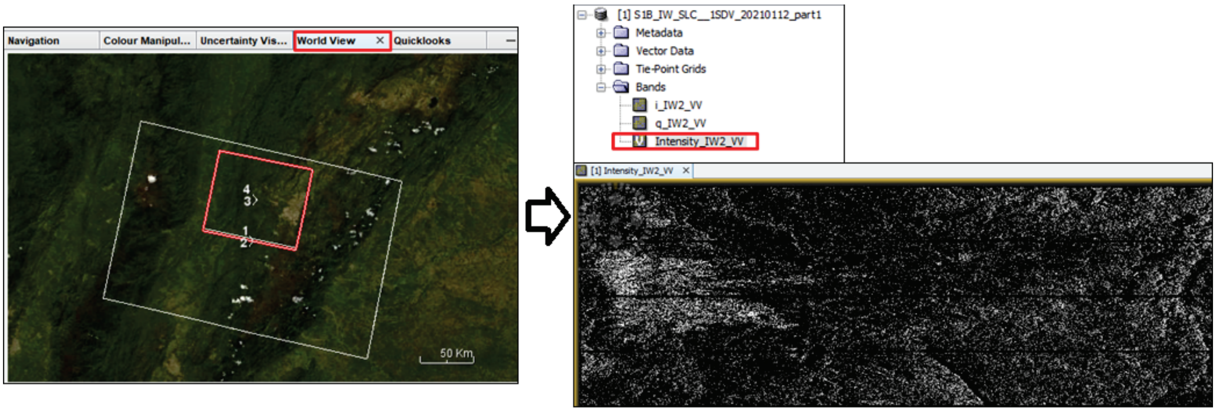
The last step is to define the name and set the location of the InSAR pre-processing output files (2 images = 2 files). The name of the output files can be modified (for better clarity).



The format of the output files will remain in BEAM-DIMAP format (further processing in SNAP). Finally, it is necessary to start the whole process with Run (possibility to use batch processing).



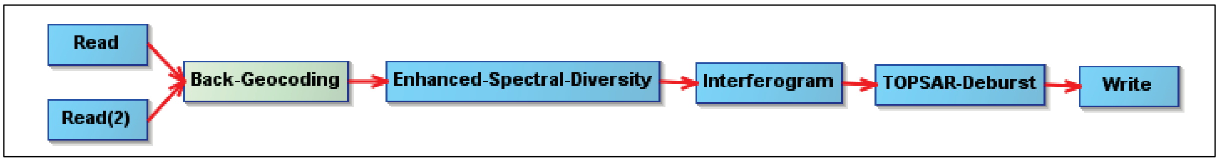
The result is the product after importing the orbit parameters and defining the extent of the territory. In this way, only files for "subswath" IW2 and VV polarization will remain in the bands tab.



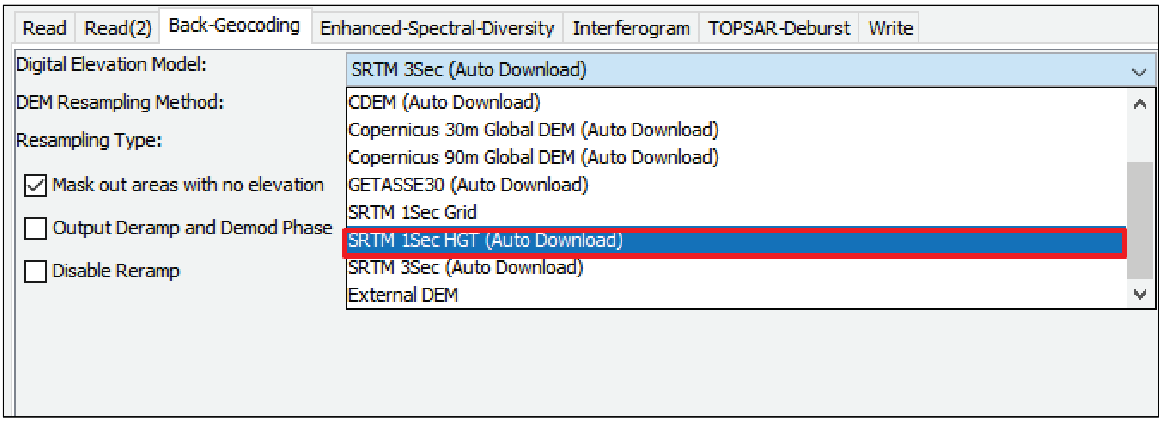
2.3. Interferogram generation

Import data and image geocoding

In this part of the processing we will show how to generate an interferogram from SAR images. The first step is to import the created graph for this processing. Initially, you need to load the output files from InSAR preprocessing.

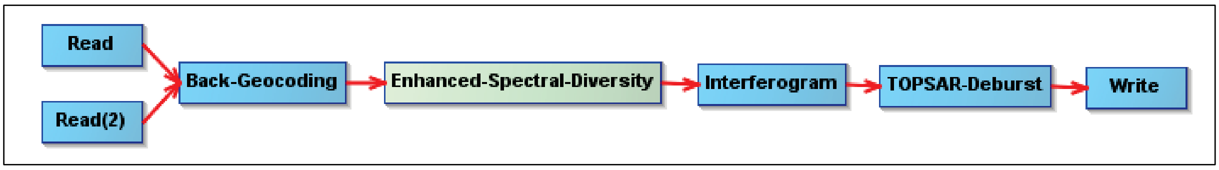


In order to make the outputs useful, the interferometric phase image needs to be projected into a geographic coordinate system. This is done by geocoding the image using a digital elevation model (DEM). We will use the SRTM 1 Sec HGT model for this purpose. Regarding the DEM resampling method, we choose Bicubic Interpolation. Also we set type of resampling as 5-point interpolation.

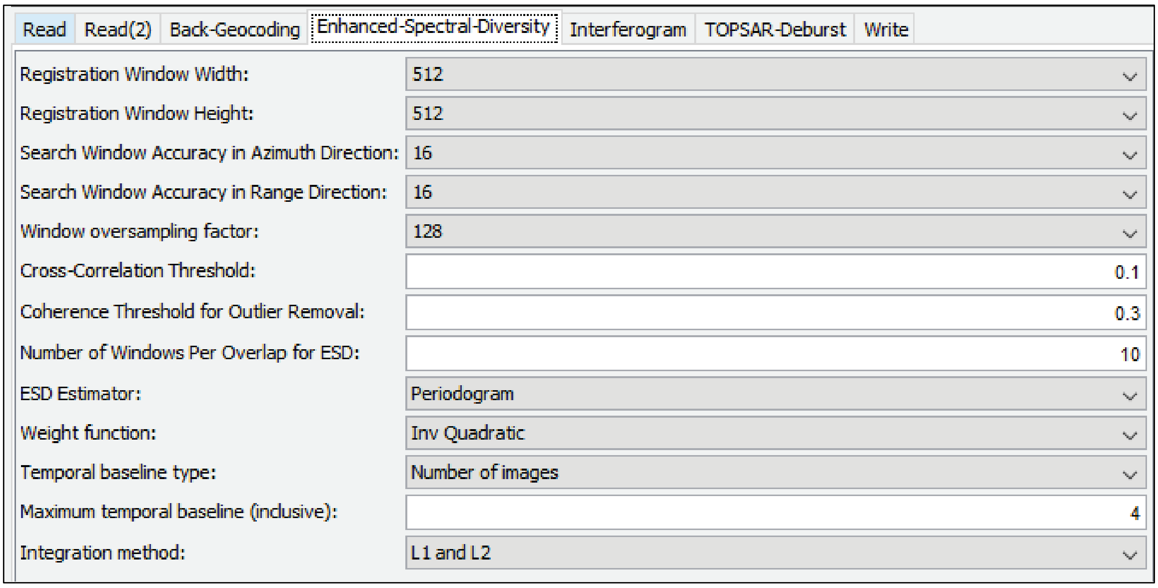


Enhancing of spectral diversity

The next step is enhancing of spectral diversity. This step is performed in order to increase the quality of image co-registration after geocoding.

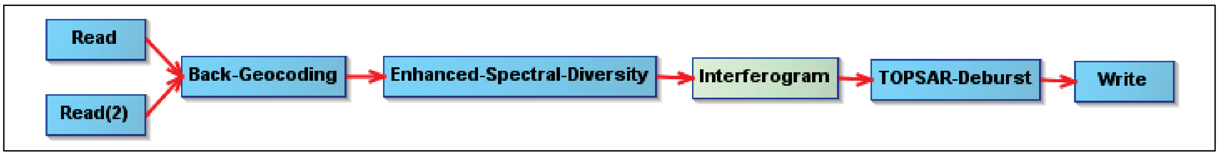


Range and azimuth shift correction is then applied to the secondary image. In this process, it is sufficient to keep the preset parameters.

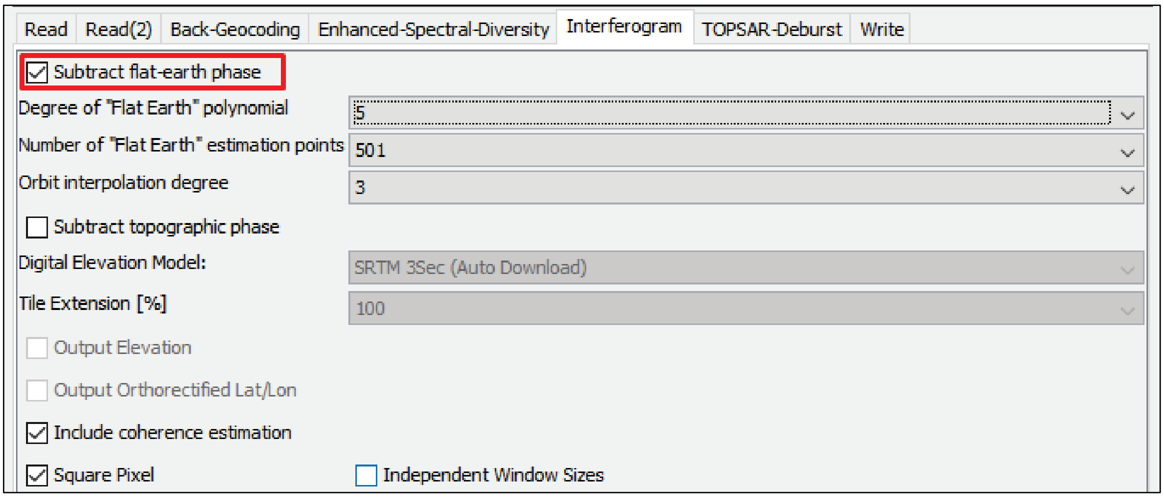


Interferogram creation and coherence estimation

In the next step, an interferogram is generated by cross-multiplying the reference image by the complex conjugate of the secondary image. The name of this step function is Interferogram.

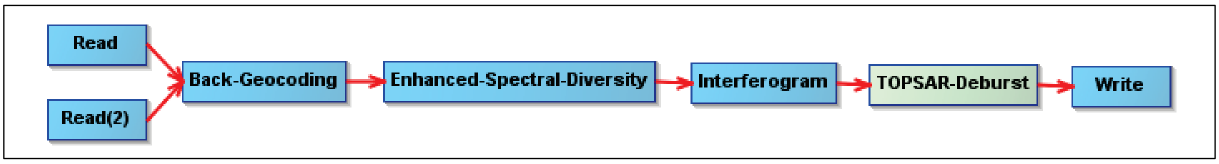


The amplitude of both images is multiplied. The phase represents the phase difference between the two images. In the calculation, we take into account the subtraction of the flat Earth phase. The latter is present in the interferometric signal due to the curvature of the Earth.

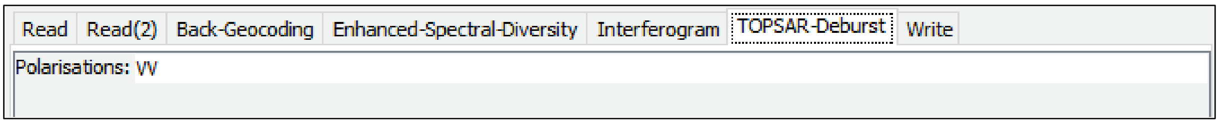


TOPSAR Deburst

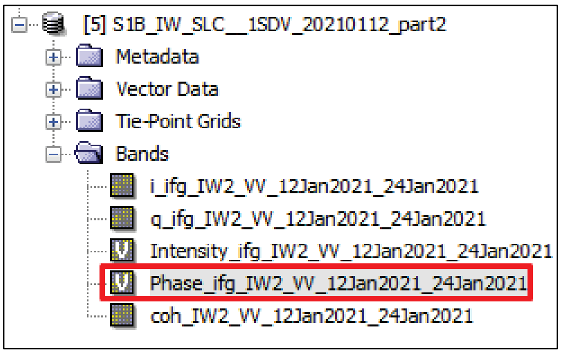
The nest step of processing is TOPSAR Deburst. It is aimed at removing of demarcation zones in the generated interferogram. The purpose of this operator is to seamlessly merge all frames (bursts) in a line into a single image.



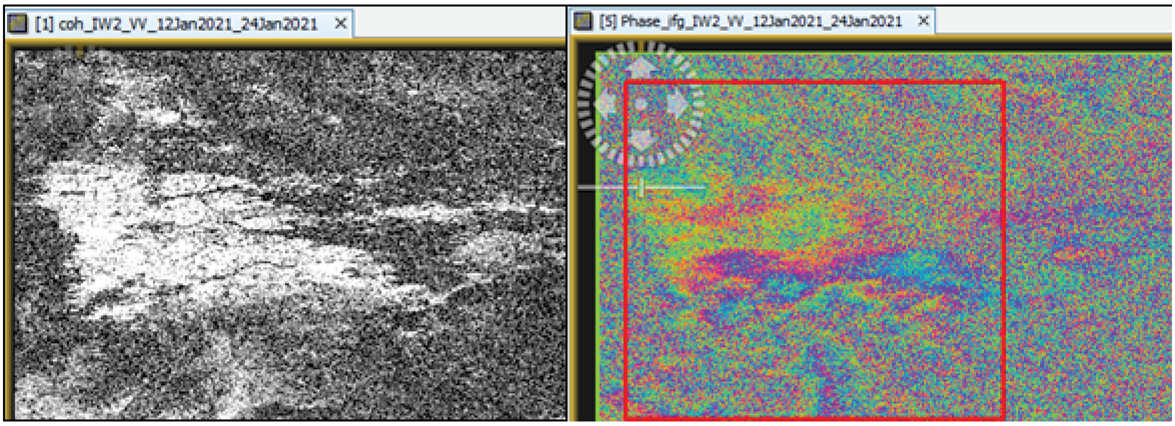
During processing, we consider only the VV polarization (used in the previous steps).



The result is an image product containing the interferogram (Phase) and coherence (coh) already as separate bands.



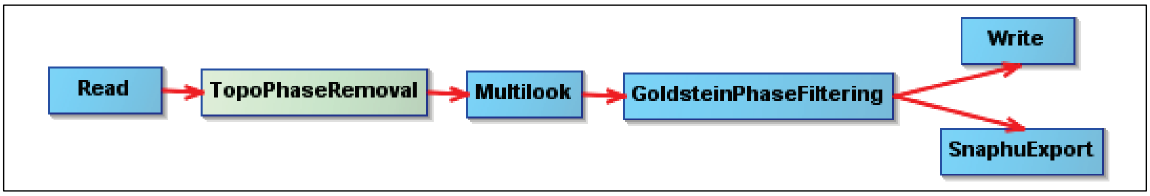
After opening them, it can be seen that both products still contain black connecting lines separating the individual frames and bursts. In DInSAR processing this phenomenon is eliminated.



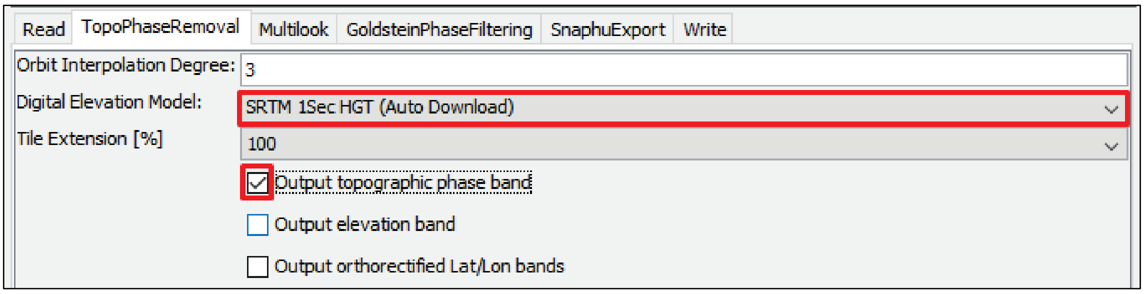
2.4. DInSAR processing

Removing of topographic phase

The first step in DinSAR processing is to remove the topographic phase component by TopoPhaseRemoval button. This principle is based on "simulating" the interferogram based on the reference DEM.

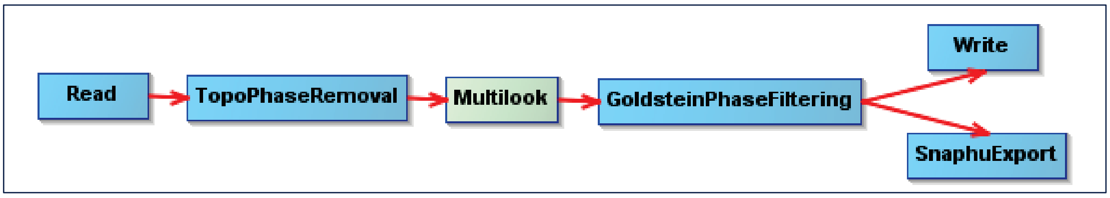


Subsequently, this component is subtracted from the processed interferogram. The reference DEM used is the same as in geocoding (SRTM 1Sec HGT). It is also important to keep the Output topographic phase band option checked.

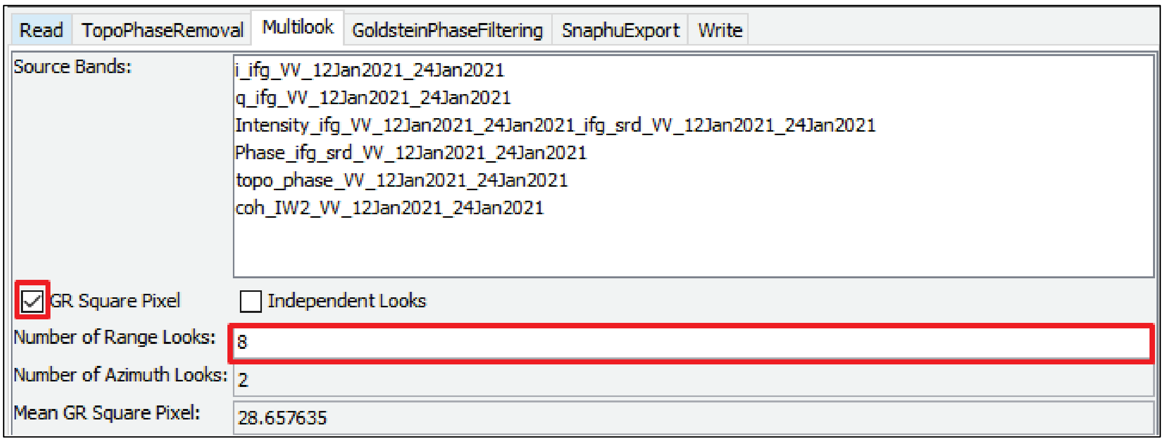


Multilook processing

The main task of multilayer processing called Multilooking is to obtain an image with a nominal pixel size. This appearance improves radiometric resolution but reduces spatial resolution. The result of this processing step is an image containing less noise.

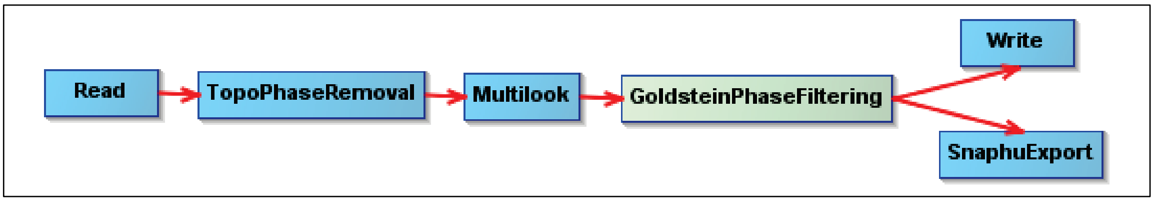


Approximate square pixel spacing after converting the slant range to the ground range is necessary to retain by means of the GR Square Pixel option.

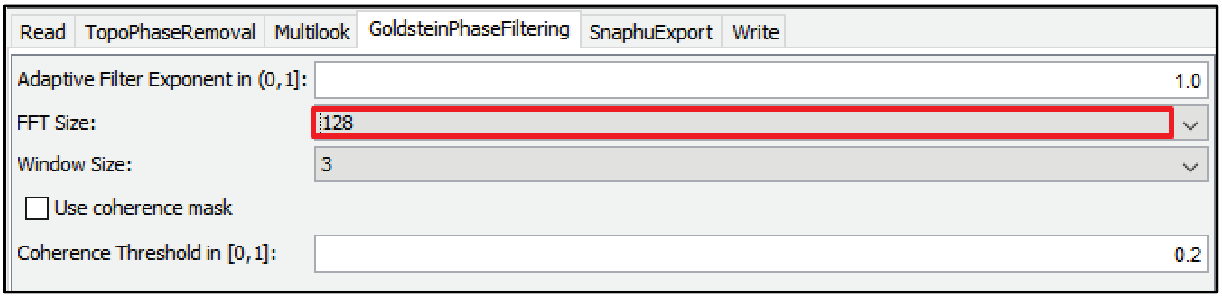


Application of phase filter

The next step of DInSAR processing is application of Goldstein interferometric phase filter. The principle of the tool is the use of fast Fourier transforms (FFT).

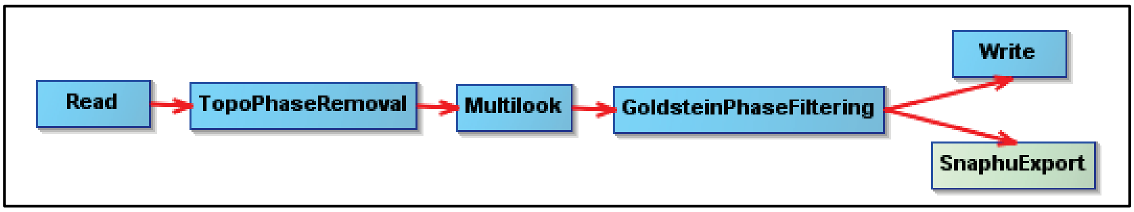


The FFT Size parameter thus defines the window size of the transform. Its values range from 8 to 256 (default value 64). The use of larger windows reduces interferometric noise, on the other hand deteriorate phase continuity. In this processing we use window size 128.

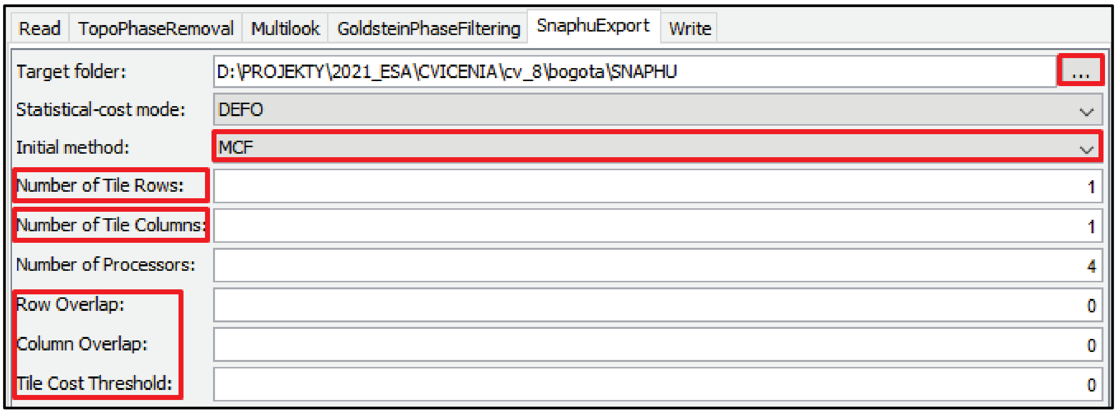


Export data for SNAPHU processing and results

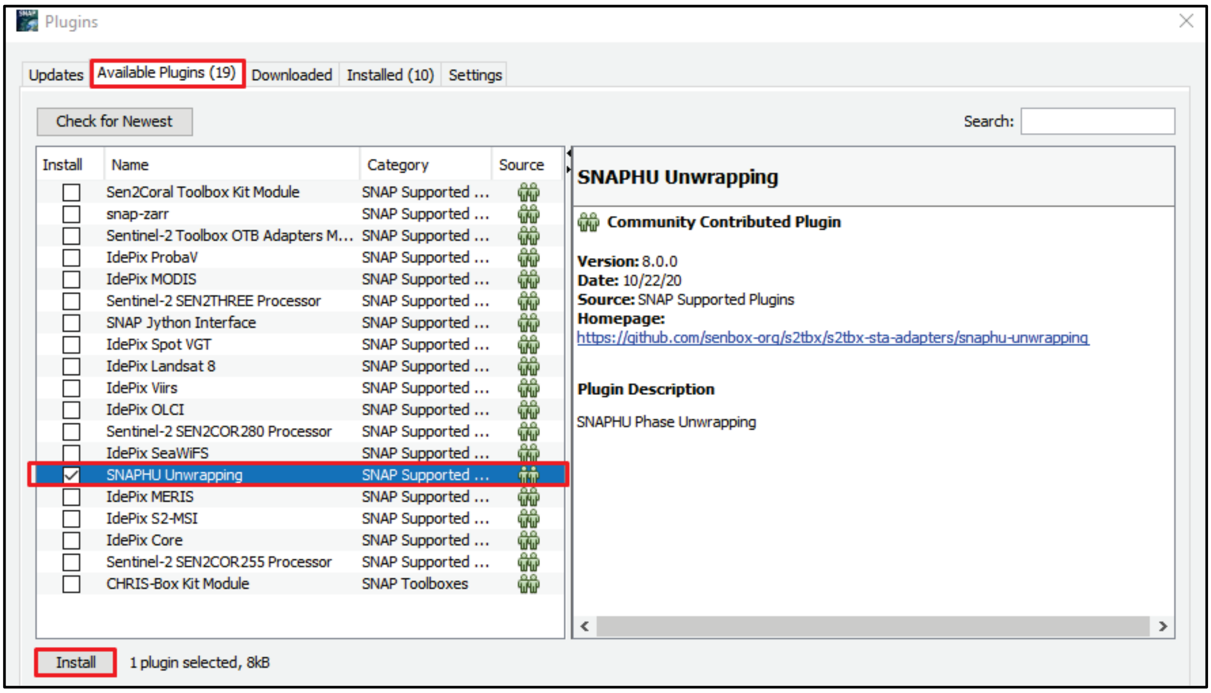
In the last step, we use SNAPHU plugin. SNAPHU process is an implementation of the Statistical-cost, Network-flow Algorithm for Phase Unwrapping proposed by Chen and Zebkerin.



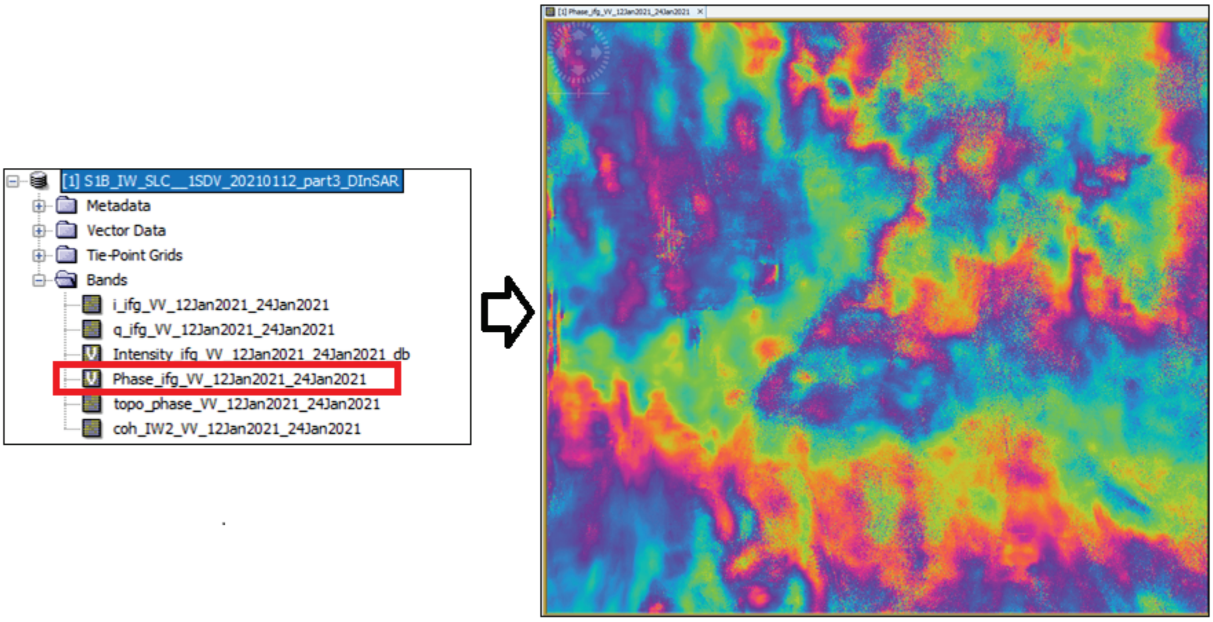
In this step in addition to setting the parameters of the output file, we also export files for SNAPHU. We create an output directory for export and also we select the initial MCF processing method.



An important part of DInSAR processing is the installation of the SNAPHU plugin in SNAP for phase expansion. It is recommended to perform this step before running the processing process.



The result of the processing is a filtered phase with the topographic influence removed with the nominal pixel value of the image. Other bands including coherence have a nominal pixel size value. This product is further processed using the SNAPHU plugin.



2.5. Phase unwrapping

As we mentioned in the previous chapter SNAPHU presents the algorithm for two-dimensional phase unwrapping. This algorithm includes three built-in statistical models for topographic data, deformation data and smooth generic data.

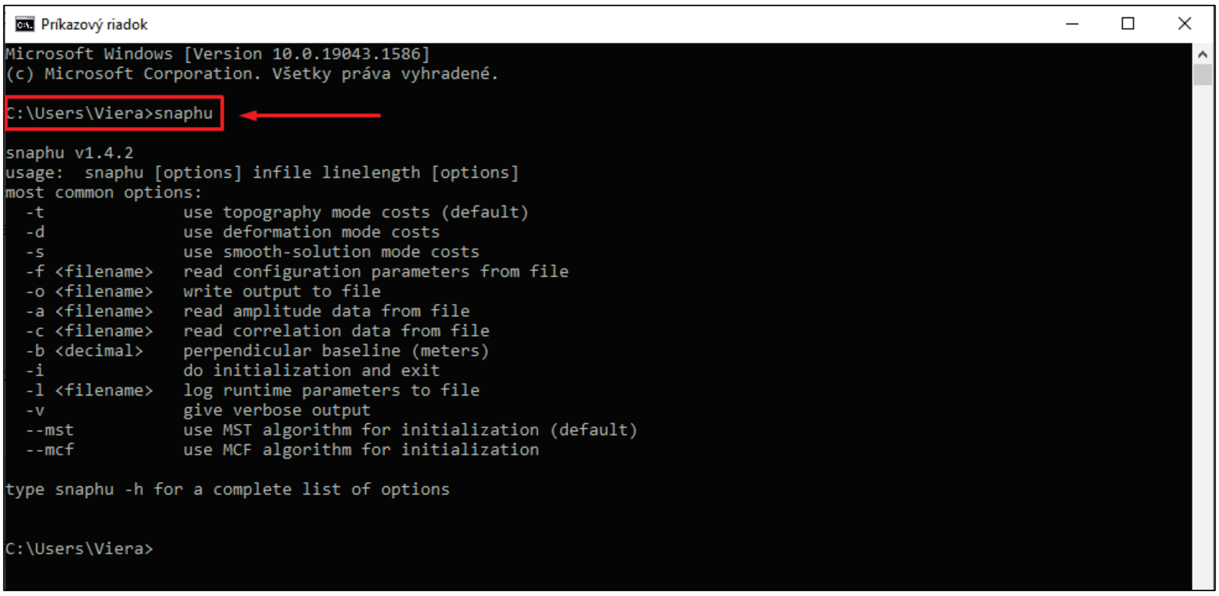
SNAPHU installation files are available on URL:

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

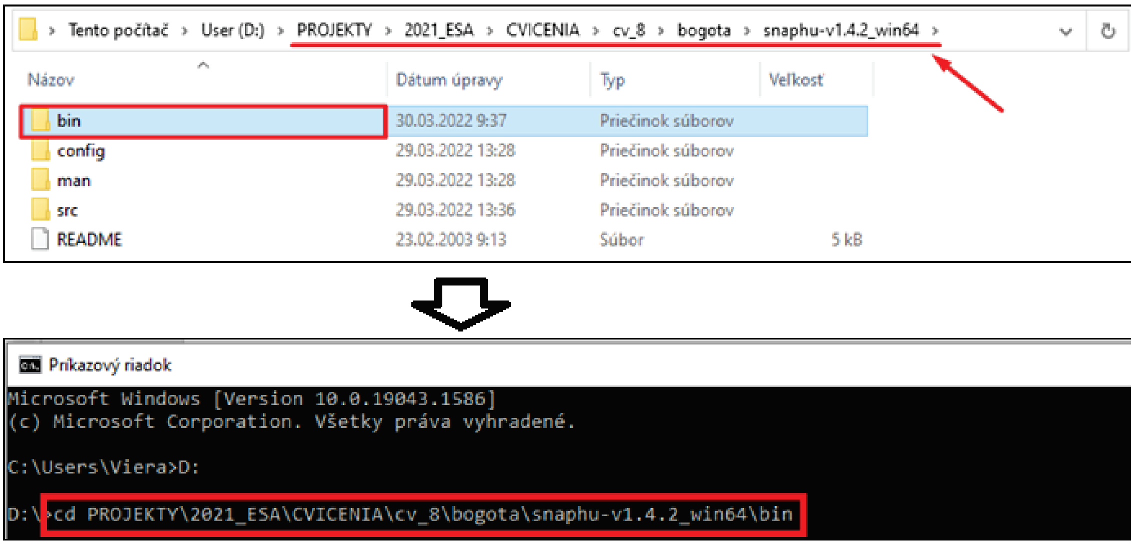
Information about SNAPHU plugin:

https://step.esa.int/main/snap-supported-plugins/snaphu

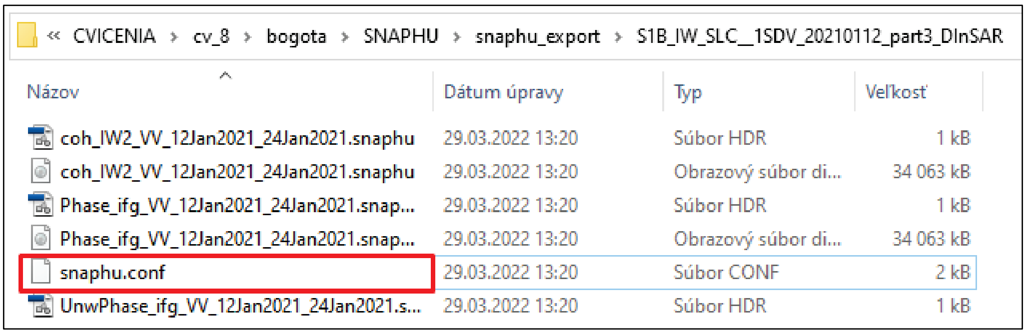
At the beginning of the phase unwrapping process it is necessary to run the command line (cmd - ComandLine). After downloading, the SNAPHU v1.4.2 installation folder is first moved to the disk with the other file. In the next step, the individual compressed files will be extracted. Thus, the text "snaphu" is entered into the command line.

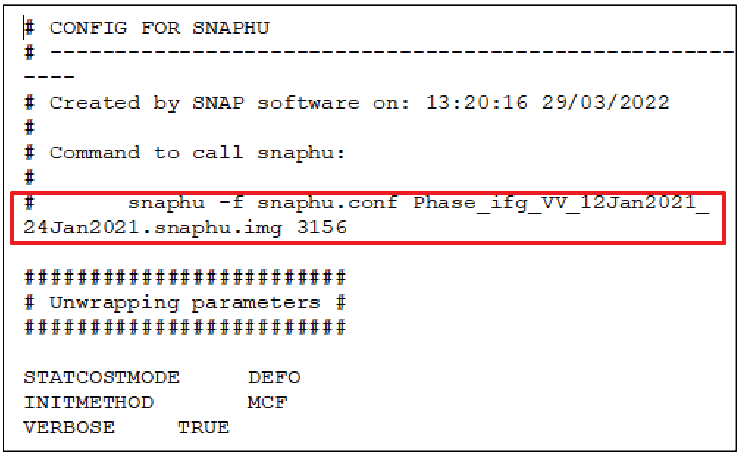


Subsequently, in the command line, we define the path to the required "bin" folder. The connection with the D drive is ensured by placing the shortcut cd (change directory).

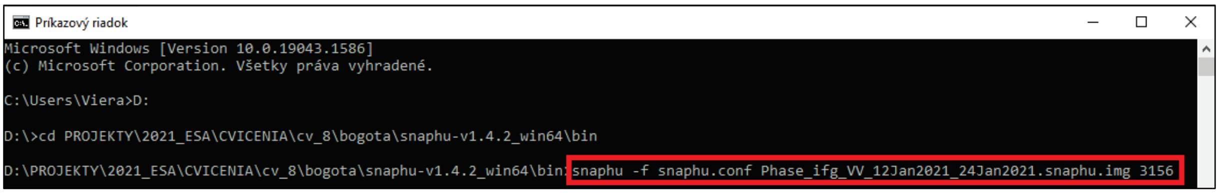


After the SNAPHU export, there are several files available in the folder. We copy these files to the bin folder located in the downloaded SNAPHU directory (e.g. snaphu-v1.4.2_win64). These files we will open snaphu.conf which contain the parameters of the exported phase from SNAP.

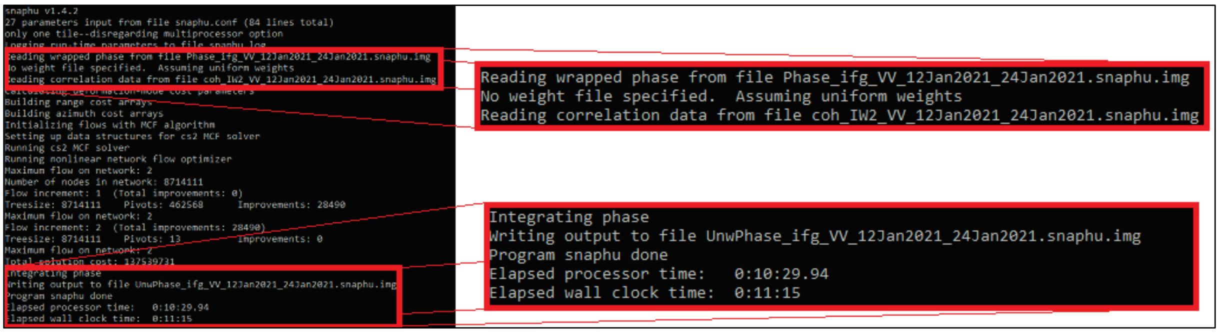




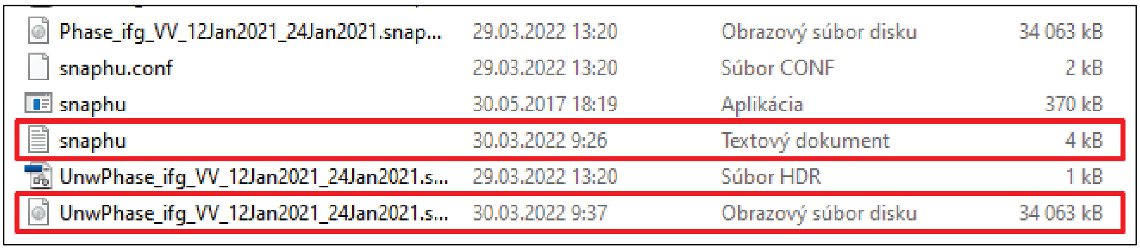
After that, we copy and paste the information about the unpacked phase from the configuration file and the Enter option starts the process. You can also use other command tools to unpack the phase (e.g. Cygwin64 Terminal and other tools - WARNING! For Cygwin you need to check the availability of the gcc-core package).



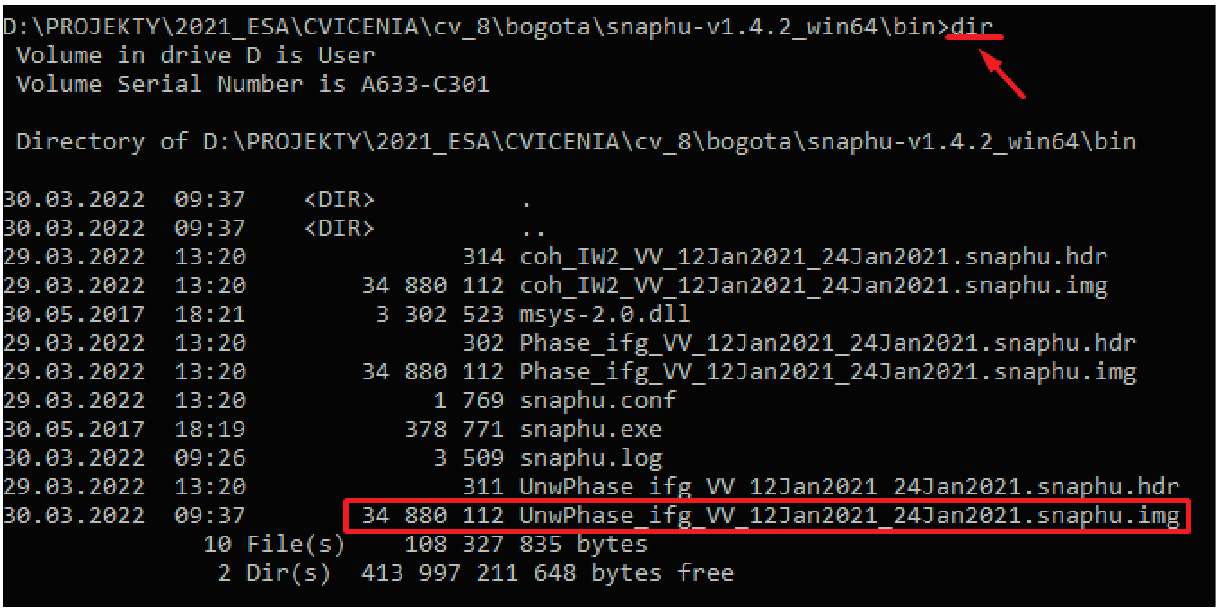
The progress of the process can be continuously monitored. Estimated duration for this image is about 10 minutes.



Once the process is complete, an image file (UnwPhase_ifg_VV12Jan2021_24Jan2021.snaphu.img) of the unwrapped phase is available in the bin folder, as well as information (snaphu.txt) about the unwrapped phase.



We can be check the location and size of newly created files at the command line by typing dir (Directory). Then, in the next part of the processing, we return to SNAP to determine the displacement values.

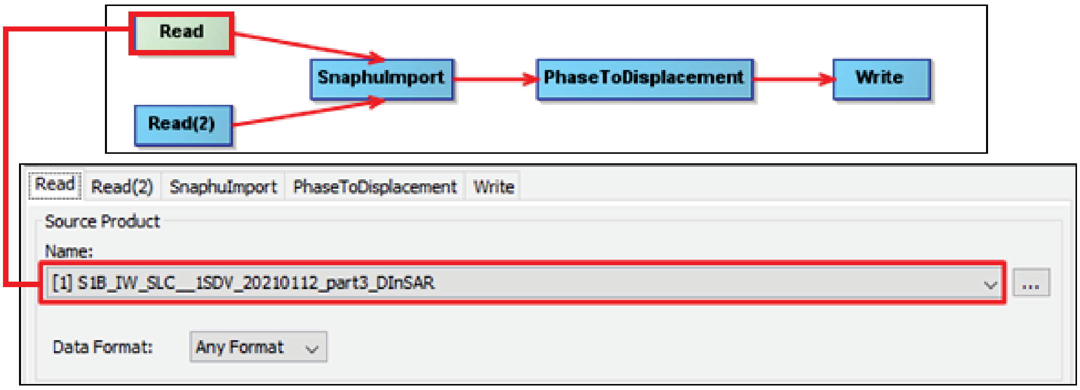


```
D:\PROJEKTY\2021_ESA\CVICENIA\cv_8\bogota\snaphu-v1.4.2_win64\bin>dir
 Volume in drive D is User
 Volume Serial Number is A633-C301

 Directory of D:\PROJEKTY\2021_ESA\CVICENIA\cv_8\bogota\snaphu-v1.4.2_win64\bin

30.03.2022  09:37    <DIR>          .
30.03.2022  09:37    <DIR>          ..
29.03.2022  13:20               314 coh_IW2_VV_12Jan2021_24Jan2021.snaphu.hdr
29.03.2022  13:20        34 880 112 coh_IW2_VV_12Jan2021_24Jan2021.snaphu.img
30.05.2017  18:21         3 302 523 msys-2.0.dll
29.03.2022  13:20               302 Phase_ifg_VV_12Jan2021_24Jan2021.snaphu.hdr
29.03.2022  13:20        34 880 112 Phase_ifg_VV_12Jan2021_24Jan2021.snaphu.img
29.03.2022  13:20             1 769 snaphu.conf
30.05.2017  18:19           378 771 snaphu.exe
30.03.2022  09:26             3 509 snaphu.log
29.03.2022  13:20               311 UnwPhase_ifg_VV_12Jan2021_24Jan2021.snaphu.hdr
30.03.2022  09:37        34 880 112 UnwPhase_ifg_VV_12Jan2021_24Jan2021.snaphu.img
              10 File(s)    108 327 835 bytes
               2 Dir(s)  413 997 211 648 bytes free
```

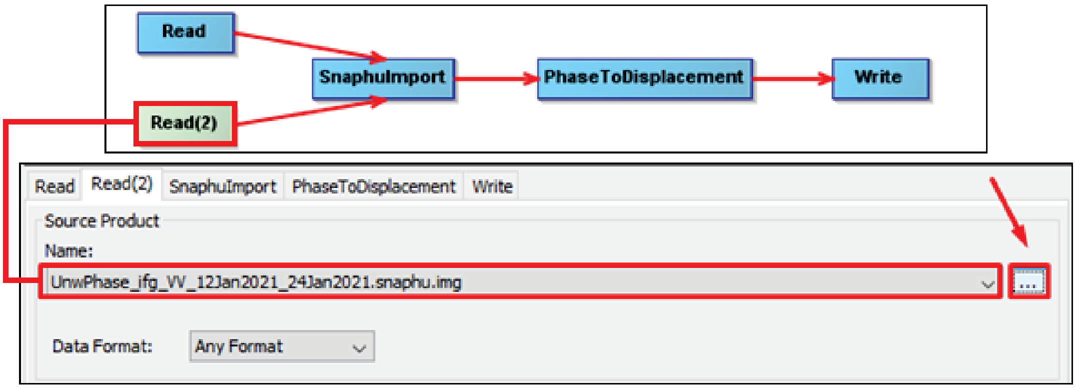
2.6. Displacement detection

In this part of the processing, we return to the SNAP. The few remaining operations will be implemented by data processing using the Graph Builder. In the first step we need to import 2 file types:

- The first one is the image after DInSAR processing (previous part of this exercise)

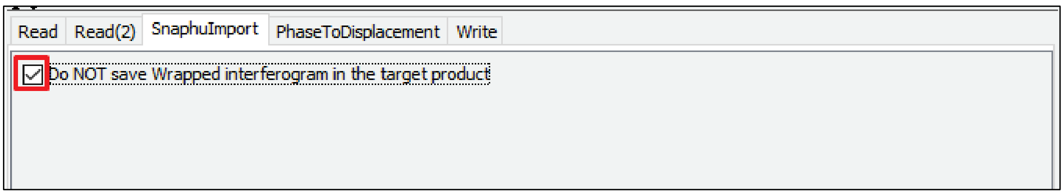


- The second is the image file of the expanded phase with the extension .img, obtained using the SNAPHU algorithm

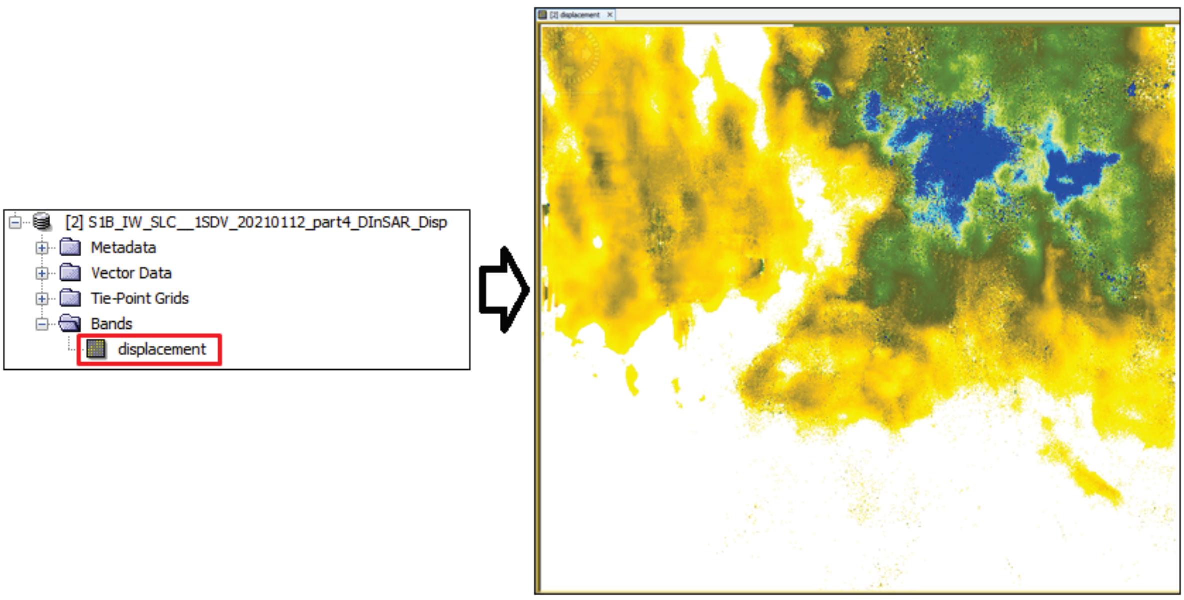


Import SNAPHU processing files and displacement determination

In the next step, we import the unwrapped phase from the previous processing step. It is important to keep checked the option: do NOT save Wrapped interferogram in the target product. PhaseToDisplacement operator is also important in the processing. This step is necessary to determine the displacement of the Earth's surface in the LOS (Line of Sight) direction. Finally, the location of the target file representing the displacements is set.

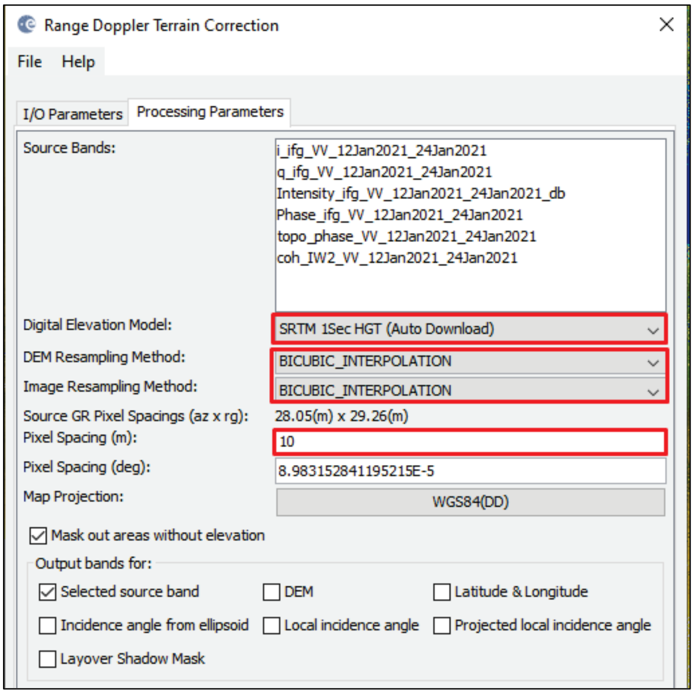


The resulting image thus consists of a single band expressing the displacements. In the next stage, it is necessary to change the orientation of the final displacement image.



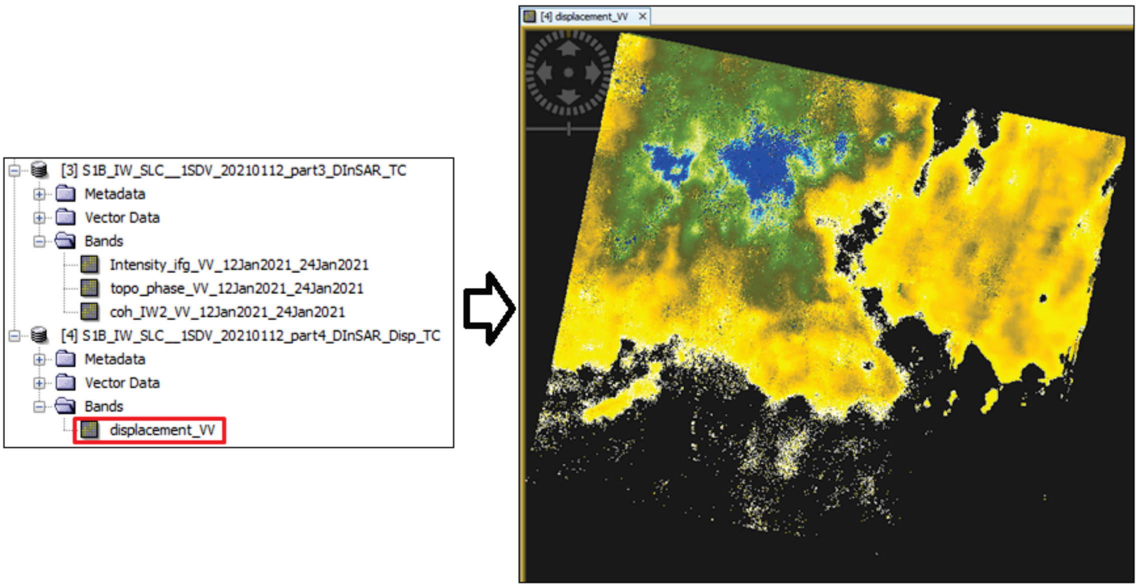
Applying terrain correction

It is essential that the resulting image contains a terrain correction, so we must apply it in this step by means of Radar - Geometric - Terrain Correction - Range-Doppler Terrain Correction. Important processing parameters are DEM selection (SRTM 1Sec HGT) and resampling parameters of the DEM and image (bicubic interpolation).



Results

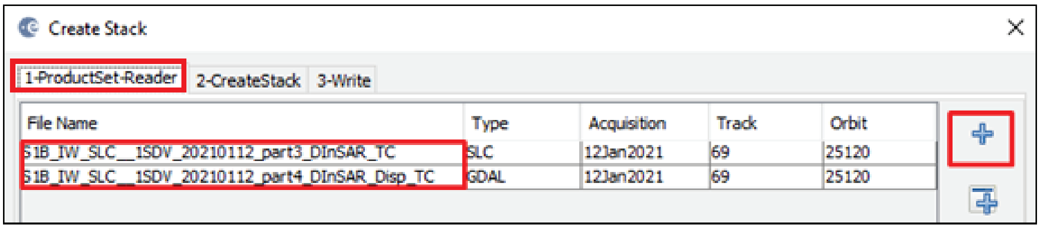
The resulting image is rotated according to the preset WGS84 map projection after Range Doppler Terrain Correction. Its position is thus identified with the Earth's surface.

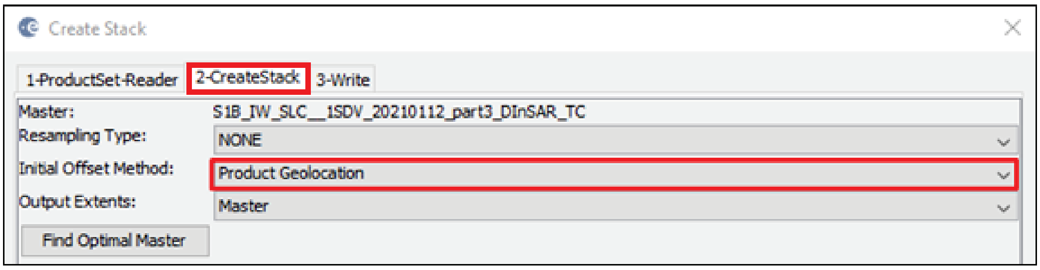


2.7. Evaluation of results

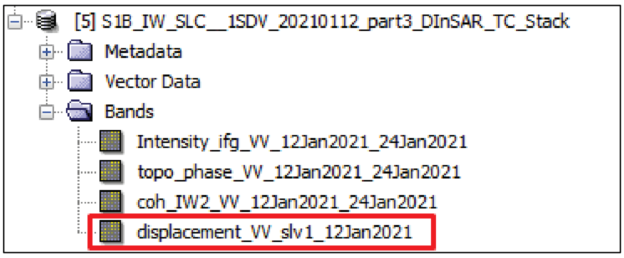
Creating image stack

In order to assess the results against each other, it is necessary to compare the coherence in the context of the displacement. Thus, a merging of the layers into one image called Stack is created, i.e. merging the DInSAR output (SLC) with the resulting displacements (GDAL). Stack step is available by Radar – Coregistration – Stack Tools – Create Stack.

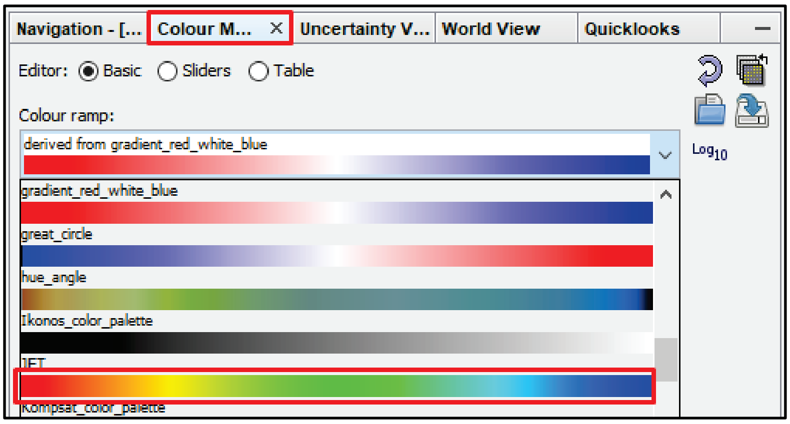




The result is an image that already contains a displacement layer in the bands tab of the image.

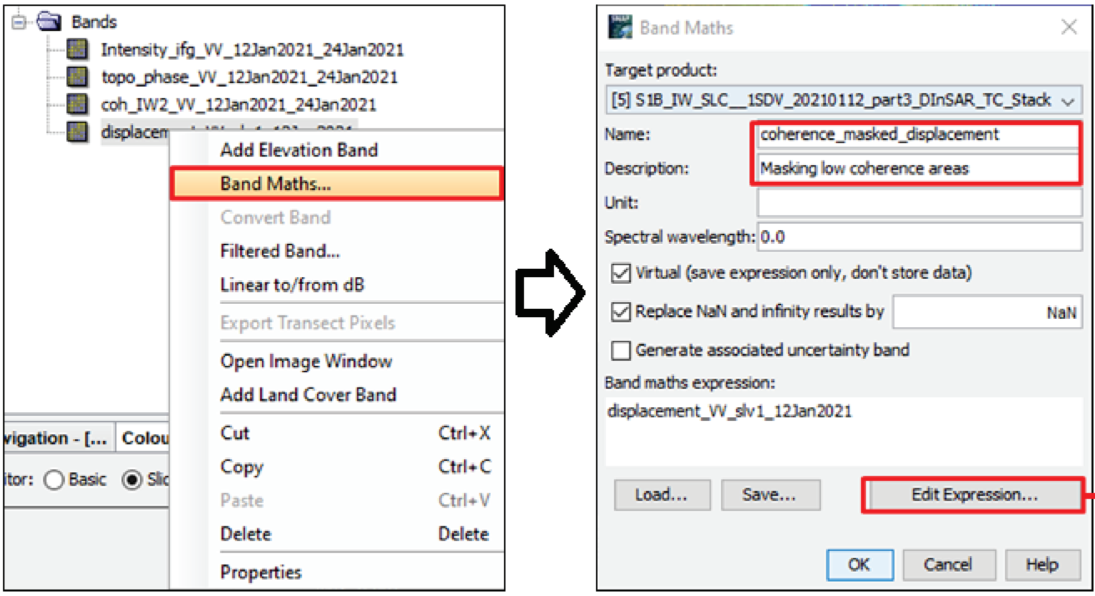


The final image can be assigned a colour palette according to the processing requirements and in relation to the minimum and maximum values.



Mathematical operations

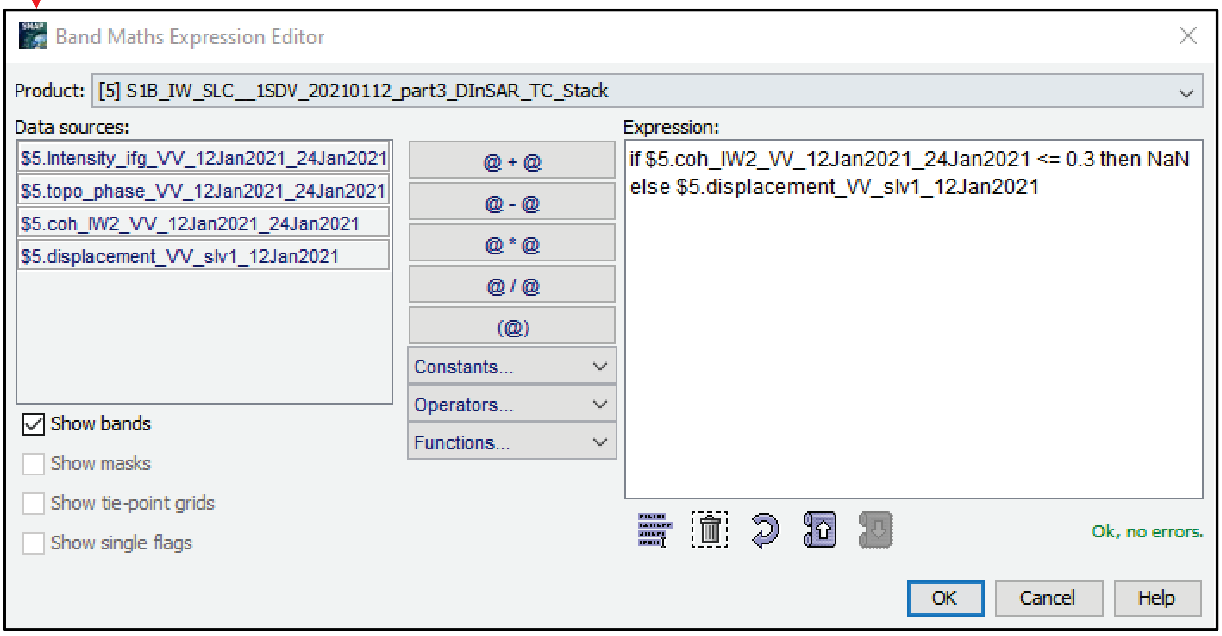
For better interpretation of the results, we create a new "band" using the Band Maths editor (the Earth's surface displacement taking into account the coherence), and is also defined mathematically using the Edit Expression option.



Then we define the following condition:

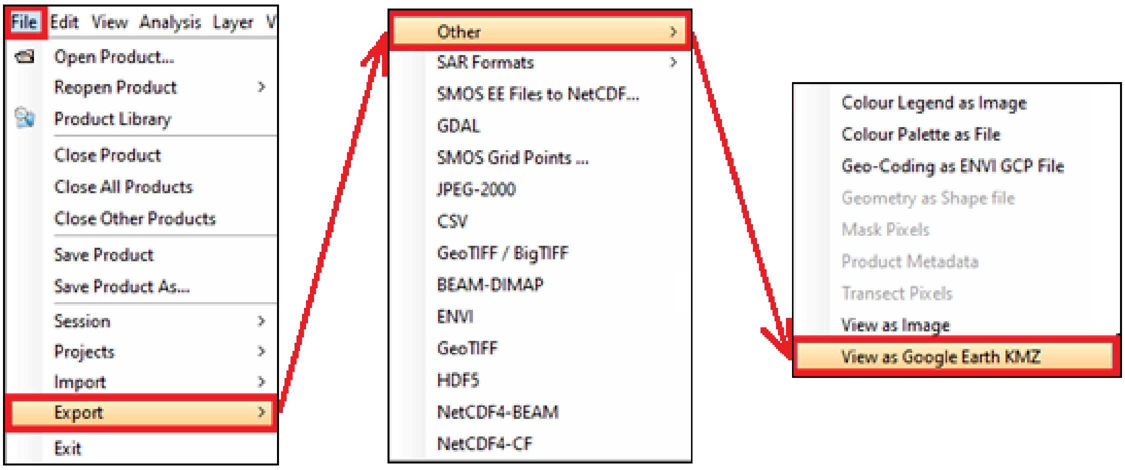
If coherence <= 0.3 then NaN else displacement

Thus, if the coherence is less than and equal to 0.3 then the result is not a numerical value. If the reverse is the case, the result is a display of displacement.



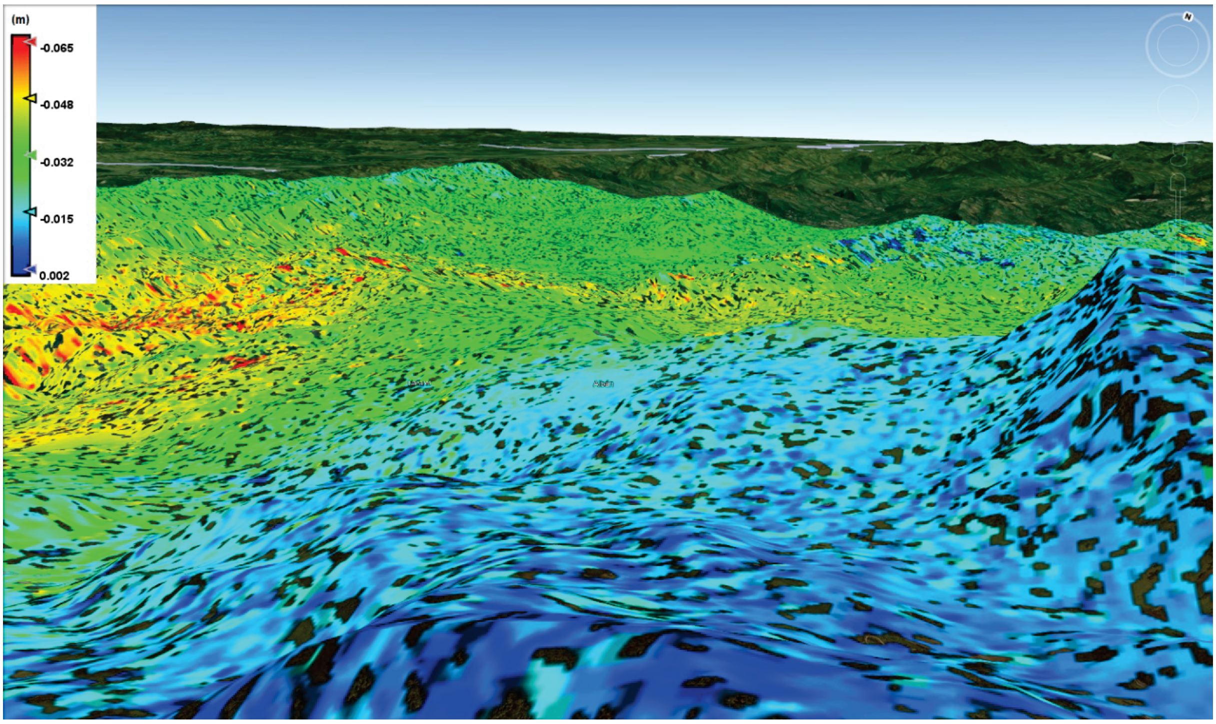
2.8. Results interpretation

Finally, we export the final displacement image to a file supported by Google Earth (extension .kmz)by Export – Other- View as Google Earth KMZ. For export, it is advisable to set minimum and maximum offset values in the Colour Manipulation panel (rounded numbers to a maximum of 3 decimal places).



Displaying the results of displacements

- Export for coherence greater than 0.3
- Actual range of values from 0.002 m to -0.065 m
- Largest values - surrounding terrain
- Post-processing can achieve more accurate determination of displacements (e.g. masking of incoherent values)



Resulting displacement map of Bogotá

- Export for coherence greater than 0.7 (urbanised areas)
- Values of vertical displacements of the Earth's surface in the interval 0,001 m to -0,020 m
- To obtain absolute values of displacements - it is preferable to use the PS persistent scatterer method

THANK YOU FOR FOLLOWING THE EXERCISE!