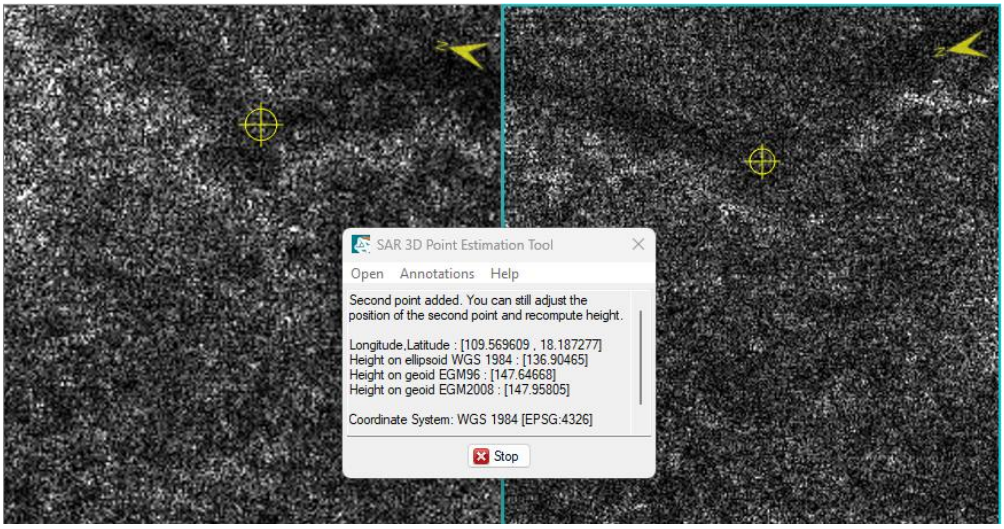
SAR ESSENTIALS TUTORIAL:
ESTIMATE FEATURE HEIGHTS – OBJECT HEIGHTS AND 3D POINT ESTIMATIONS



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1. INTRODUCTION

The ***SAR Essentials*** module gives the opportunity to estimate the height of vertical objects situated on the ground or to determine the 3-Dimentional (3D) coordinates of terrain points from Synthetic Aperture Radar (SAR) images.

In the first case, a single SAR image where both the top and base of the vertical object are clearly visible (Figure 1, left) is needed. While, in the second case, two SAR images taken from different satellite positions are needed to reconstruct the 3D coordinates of a selected point within the overlapping area between the two images (Figure 1, right).

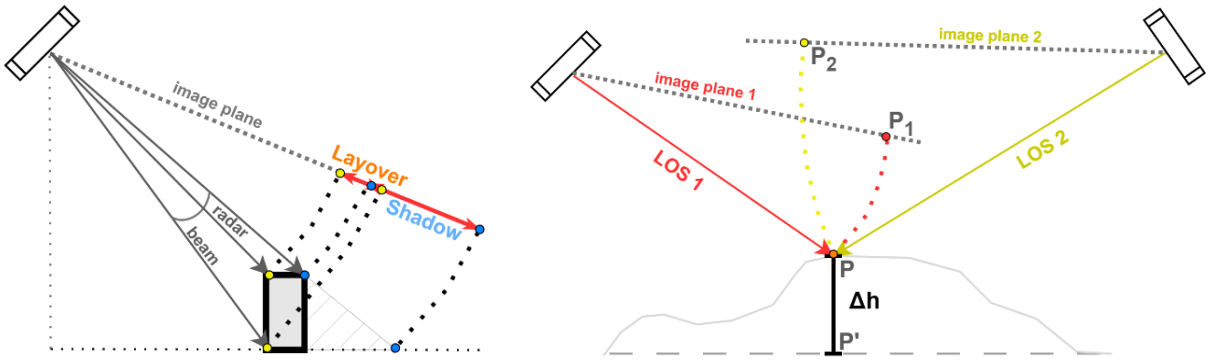


Figure 1. SAR Height Estimation (left) principle – it requires one SAR image and the selection of two points marking the layover (yellow) or shadow (blue) of the object. SAR 3D Point Estimation (right) principle using two SAR images with different geometries

COMPARISON		
SAR Essentials Tool	**Required number of input files**	**Measured feature**
SAR Height Estimation	1	Height of a vertical object
SAR 3D Point Estimation	2	3D coordinates of a terrain point

This tutorial guides the reader through the application of *SAR Height Estimation* and *SAR 3D Point Estimation* tools by two step-by-step examples. The reference software version used throughout the tutorial is SAR Essentials version 1.2.0, running under ENVI 6.3 with a standard (GIS-like) interface, installed on Windows 11, 64bit.

✍ Paragraphs with a hand on the left side indicate a practical step to be performed.

2. SAR HEIGHT ESTIMATION

The *SAR Essential Height Estimation* uses an interactive tool which guides the process step-by-step. The tool is located in the *SAR Essentials* folder in the ENVI toolbox (Figure 2).

✍ Go to the ENVI Toolbox, expand the *SAR Essentials* folder, and double-click the *SAR Height Estimation* tool.

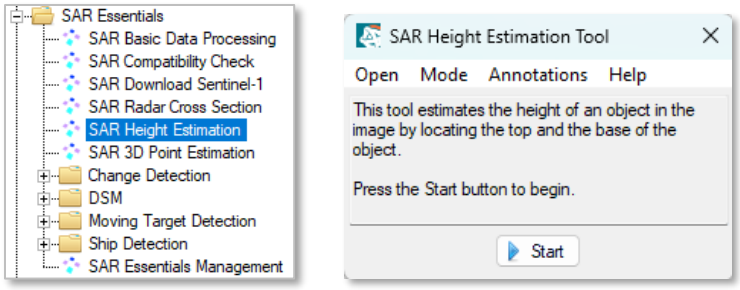


Figure 2. SAR Height Estimation tool window

2.1. DATA REQUIRMENTS

The *SAR Height Estimation* tool accepts SAR Single Look Complex (SCL) and power images in slant-range or ground-range geometry. The images can be in their native format such as manifest.safe, *.h5, *.xml, *.n1, *.e1, *.e2, IMG*, *.nitf, *.ntf. They also can be images (i.e. *_.sml) already imported by other SAR Essentials process.

The image should meet the requirements listed in the table below. The *Height Sensitivity* is the per-pixel measurement uncertainty of the layover length, and it depends on the *Incident angle*:

Data requirements for SAR Heigh Estimation		
Parameter	**Optimal Max**	**Max**
Incidence angle	60.0˚	75.0˚
Height sensitivity	10 m	20 m

These parameters are checked during the *Import* process included in the *Open Image Pair* step (Section **Error! Reference source not found.**).

2.2. LOADING THE DATA

The tool uses a **single** SAR image that can be previously loaded in the *ENVI Layer Manager* or can be opened through the tool. The *Open Image* option (Figure 3, left) transforms the original format into the *SAR Essentials* format, which consists of binary format, *.sml and *.hdr header files. The *SAR Select Image* window (Figure 3, right) allows the image to be loaded by browsing the machine … for the image file or from the ENVI *Data Manager*.

Select *Open -> Open Image* in the *SAR Height Estimation* window.

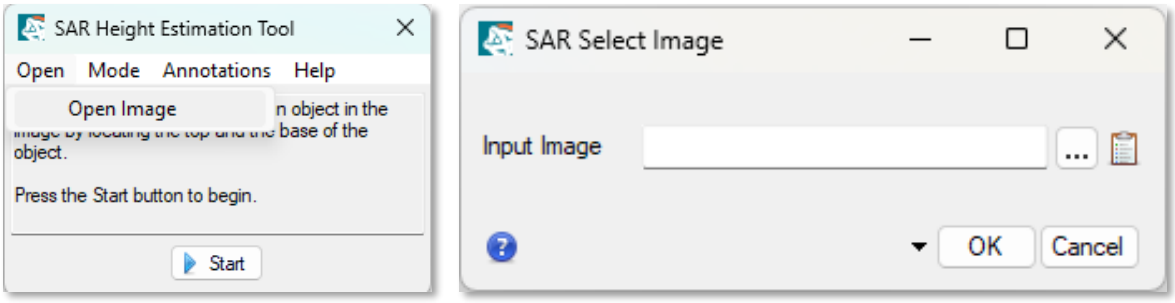


Figure 3. SAR Height Estimation tool and SAR Select Image window

2.2.1. Tutorial data

The functionality of the tool is demonstrated with an example based on the following image:

1. **buenos_aires_sicd_Umbra_2024-05-25.ntf** (footprint in red is shown in Figure 4). This dataset is a multilooked sample from a Sensor Independent Complex Data (SICD) file. The original file is 2024-05-25-13-01-21_UMBRA-04_SICD.nitf, provided with the courtesy of Umbra Synthetic Aperture Radar (SAR) Open Data, accessed on 11.06.2025 at https://registry.opendata.aws/umbra-open-data. The data are distributed under the Creative Commons License (CC by 4.0[1]).

The image has the following characteristics:

Date	Orbit	Observation direction	Azimuth resolution	Range resolution	ILOS*	ALOS*	Image format	Frequency Band
25.05.2024	descending	right	0.313 m	0.316 m	34.6°	-85.0°	SLC	X

* ILOS – incidence angle, measured between the Line-of-Sight (LOS) and the vertical to the ellipsoid; ALOS – azimuth of the projection of the LOS directions, measured clockwise from North.



Figure 4. Footprint of the UMBRA sample image (red polygon) used in this tutorial over Puerto Madero area in Buenos Aires (inset), Argentina (overlay in Google Earth Pro 7.3.6, Image © 2025 Airbus)

Click the … *Browse…* button in the *SAR Select Image* window (Figure 5) to navigate the *SAR Essentials* installation folder stored on the computer and the *SAR_Essentials_dataset* subfolder. Select the **buenos_aires_sicd_Umbra_2024-05-25.ntf** and click *OK*. The file will be imported, loaded in the *Layer Manager* and visualised in the *View* window.

[1] https://umbra.space/terms-of-use/

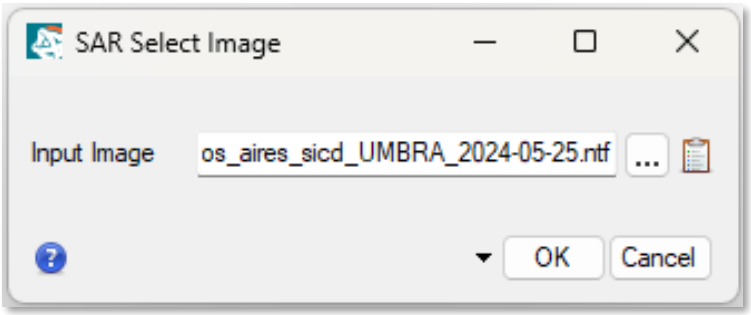


Figure 5. Selection of the tutorial image over Buenos Aires

2.2.2. Compatibility Check

Upon data import, a folder named *SAR_Select_Image_output_folder_XXX* is automatically created in the *Output Directory,* defined in the *Directories* panel of the *ENVI Preferences* menu (for more information consult *SAR Essentials: Getting Started tutorial*). The file *processing_report.txt* contains the report of the *Compatibility Check* for the imported data (Figure 7), also showing details about the data itself.

```
List of image names:
 image (1): [sicd_Umbra-04_20240525_130122000__VV_slc]

Summary:

 Height Estimation
        Compatible images: (1)
        Incompatible images: none



1) [Height Estimation]


 [Dataset spatial coverage]
  Union of image footprints dimensions: x = 0.763 km, y = 0.888 km.
  Union of image footprints area: 0.532 sq km.


 [Image parameters]
  Number of images: 1.

 Image (1):
  Image format is: SLC.
  Band X.
  Acquisition time: 2024-05-25 13:01:22.
  Range resolution: 0.316 m, azimuth resolution: 0.313 m.
  Range Looks: 1 (0.316 m), azimuth looks : 1 (0.313 m).
  Doppler value: 0.0 Hz.
  Slant range distance: 543.037 km.
  Footprint center coordinates: lon -58.3625, lat -34.6051.
  Suggested UTM 21S, Code: epsg:32721.
  Footprint center coordinates: E 375067.7714, N 6169902.9679.
  Image data units: SLC.
  Image is in slant-range geometry.
  Line-of-Sight Incidence angle (from vertical): 34.6 degrees.
  Line-of-Sight Azimuth angle (from North, clockwise): -85.0 degrees.
  Height sensitivity: 0.310 meters per pixel of uncertainty in layover length measurement
  Footprint dimensions: x = 0.763 km, y = 0.888 km.
  Footprint area: 0.532 sq km.
```

Figure 6. Report of the compatibility check for the data used in SAR Height Estimation (processing_report.txt)

2.3. MODE

The tool gives the possibility to choose between two modes based on the Layover or Shadow effects of the SAR images (Figure 7, left).

The layover effect characterises vertical objects whose inclination is steeper than the radar look angle. It occurs when the radar beam reaches the top of the object before it reaches the base (Figure 1, left). The returned signal from the top of the object will be received before the signal from the bottom. For this reason, the beginning of the layover area is before the base of the object, and its end is after the top of the object. The Shadow effect on the other hand, characterises the "blind" area behind the vertical object which is not illuminated by the radar signal.

The Layover and Shadow effects are influenced by the geometry in the SAR configuration. For this reason, the projection of individual points onto the slant range plane varies with respect to the incidence angle. The mode should be selected depending on which one of these two effects is more visible in the SAR image – the top and the base points of the vertical object of interest or its shadow (Figure 7, right).

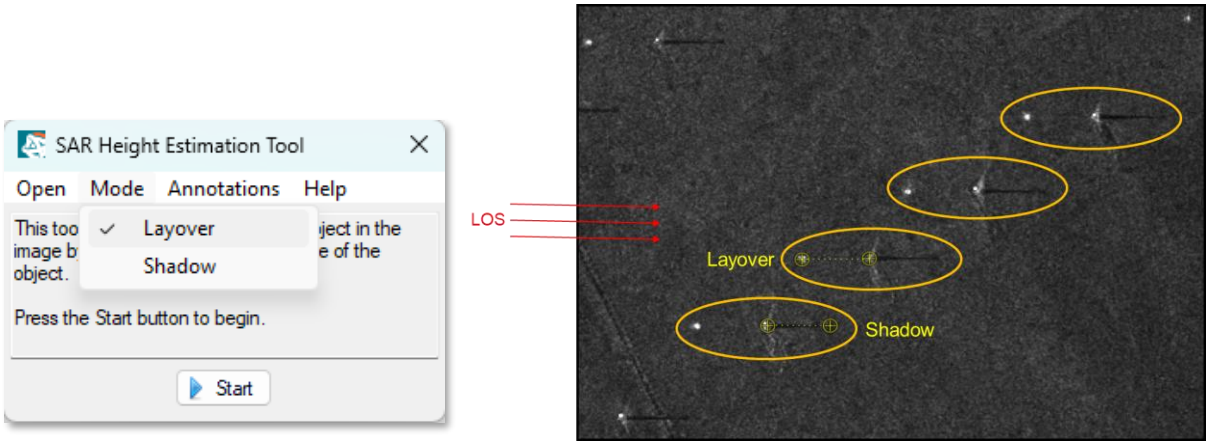


Figure 7. An example of Shadow and Layover effects with a wind turbine

For the data used in this tutorial, the *Layover* option must be selected.

2.4. ANNOTATIONS

There is a possibility to change the colour of the annotations related with the height estimations that will appear in the *View* window by opening the window *Color...* from the *Annotations* menu (Figure 8).

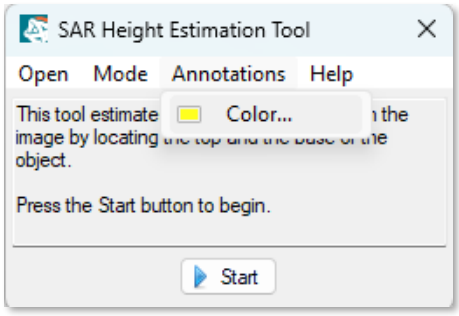


Figure 8. Annotations menu of the SAR Height Estimation tool

2.5. SAR HEIGHT ESTIMATION

As said before, two points from the vertical object must be selected – the first one on the base and the second one on the top of the layover or shadow of the object. The points must be carefully placed along the vertical façade to ensure accurate measurements.

Note: The height of only vertical objects, like wind turbines, antennas, building facades, can be measured. When estimating building height, avoid including the roof reflection along with the layover reflection.

Follow these steps to estimate the heigh of a building from the loaded SAR image:

1) Click the *Start* button (Figure 9, left). The mouse cursor changes to ⊹ crosshair and a prompt appears with instructions on how to define the first point of the observed object (Figure 9, right).

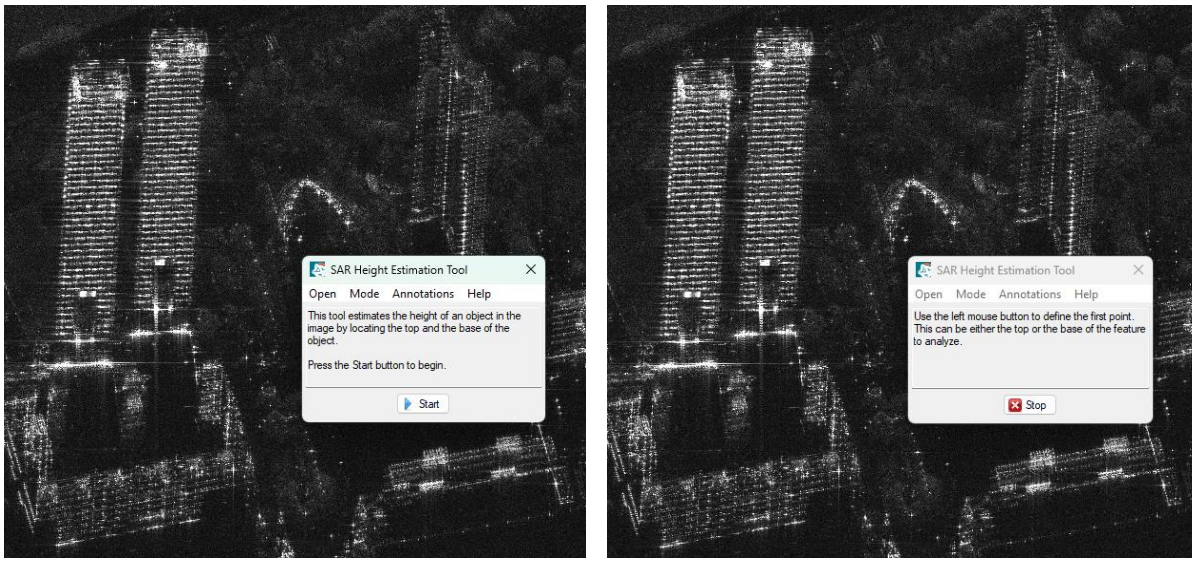


Figure 9. Start of the height estimation

2) Carefully select a point at the base of the vertical object to measure. Once placed, the first point appears as a target symbol in the colour selected for the annotation (Figure 10, left).

3) A dashed guideline in the same colour appears, passing through the first point aligned with the satellite's line-of-sight (LOS) direction (Figure 10, left).

4) Select the second point on the top of the object, along the dashed guideline (Figure 10, right).

   The *SAR Height Estimation* tool reports the height of the object, which is 124.84 m in this example (Figure 10, right).

5) Click the *Stop* button.

6) Repeat these steps with other buildings or vertical objects.

7) Close the *SAR Height Estimation Tool* when finished.

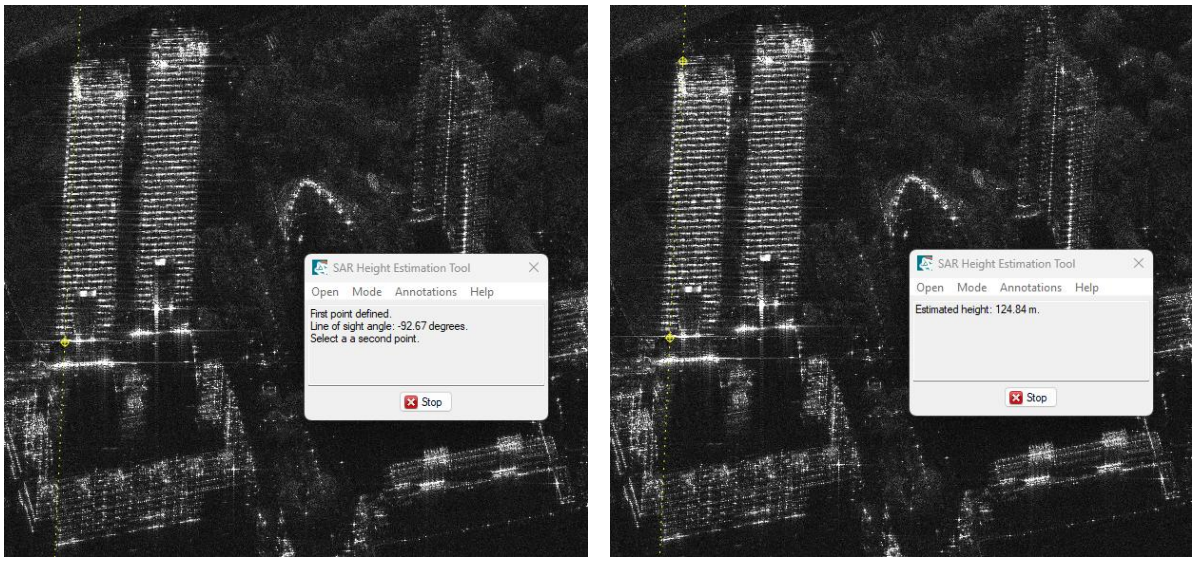


Figure 10. Selection of the bottommost and topmost points of the observed object

3. SAR 3D POINT ESTIMATION

The *SAR 3D Point Estimation* interactive tool can be found in the main menu of the *SAR Essentials* toolbox (Figure 11, left).

> Go to the ENVI Toolbox, expand the *SAR Essentials* folder, and double-click the *SAR 3D Point Estimation* tool.

This tool has similar interface (Figure 11, right) but it requires **two** SAR images over the same location to calculate the height of a point on the Earth's surface.

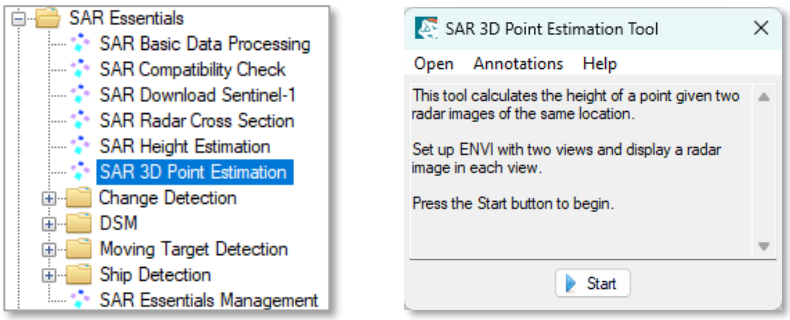


Figure 11. SAR 3D Point Estimation tool

3.1. DATA REQUIRMENTS

The *3D Point Estimation* tool can operate with the same data type and formats as the previously described tool of SAR Essentials (paragraph **Error! Reference source not found.**) – native SAR images or already imported by other SAR Essentials process. The input can be SLC or power images in slant-range or ground-range (or in some cases also mixed) format.

The two images should be acquired in the same (ascending-ascending or descending-descending pairs) but not identical geometries to form a stereo pair. Also, an ascending right-looking acquisition and a descending left-looking acquisition (or vice versa) can be considered as having the same

geometry, suitable for *3D Point Estimation*. The images could be acquired from different sensors and polarisations but using a pair generated by the same sensor type and/or same polarisation would ease identification of the common features in both images.

Both images should cover the same area of interest, and the common intersection must be at least 10 % of the area of the reference image. The pair must have an incidence angle difference of more than 4.5 degrees, measured between the Line-of-Sight (LOS) and the vertical to the ellipsoid – ILOS (Figure 12, left). Or a difference between the azimuths of the projection of the LOS directions (ALOS), measured clockwise from the North (Figure 12, right), of more than 9.0

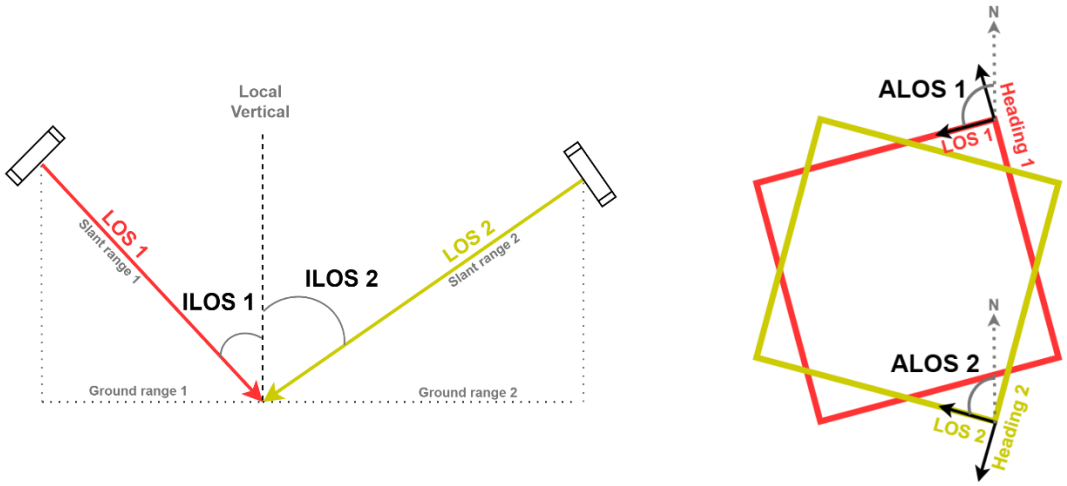


Figure 12. Schematic example showing two satellite positions and their ILOS angles with respect to the local vertical axis (left), and a pair of image footprints with ALOS angles measured to the LOS and satellite heading angles (right) – see also Figure 14

All the requirements to the imaging geometry are listed in the table below:

Data requirements for SAR 3D Point Estimation				
Parameter	**Min**	**Optimal Min**	**Optimal Max**	**Max**
Incidence angle difference	4.5˚	8.0˚	50.0˚	120˚
Azimuth angle difference	9.0˚	-	50.0˚	120˚

These parameters are checked during the *Import* process included in the *Open Image Pair* step (Section **Error! Reference source not found.**).

3.2. LOADING THE DATA

The two images must be loaded in two separate *ENVI View* windows.

Select the *Open* tab and the *Open Image Pair* menu of the *3D Point Estimation* tool (Figure 13, left). In case other images are already open in the *ENVI View*, the tool will forcefully close them to avoid wrong selection of the points (Figure 13, right). The previously opened images in the current session will be saved and reopened after the *3D Point Estimation* finishes. Choose *Yes* to open the new window *SAR Select Image* (Figure 15).

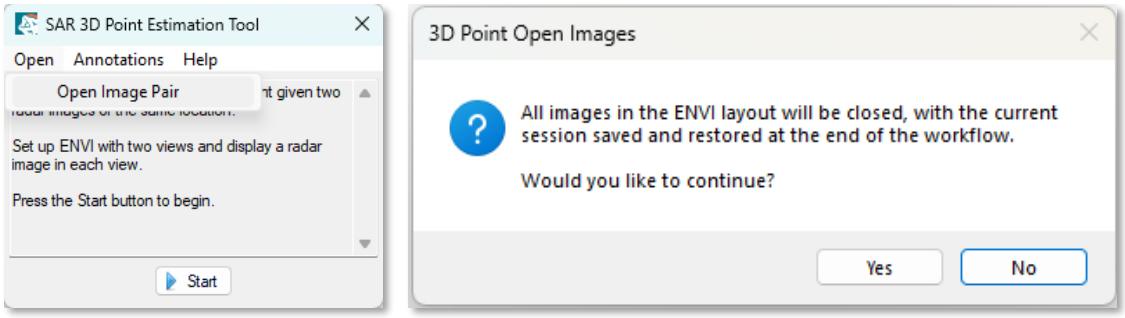


Figure 13. Open Image Pair menu and warning message of the SAR 3D Point Estimation tool

3.2.1. Tutorial data

The examples in this tutorial use the following images for demonstration:

1. **hainan_2023-01-23-13-46-55_UMBRA-04_SICD_sample.ntf:** the footprint of this image is shown in Figure 14 with a red polygon. The image is derived from a sample of a SICD file 2023-01-23-13-46-55_UMBRA-04_SICD.nitf, and
2. **hainan_2023-01-29-01-59-33_UMBRA-05_SICD_sample.ntf:** the footprint of this image is shown in Figure 14 with a yellow polygon. The dataset is based on a sample of a SICD file 2023-01-29-01-59-33_UMBRA-05_SICD.nitf

Both images are provided with courtesy by Umbra Synthetic Aperture Radar (SAR) Open Data, accessed on 23.07.2025 at https://registry.opendata.aws/umbra-open-data. The data are distributed under the Creative Commons License (CC by 4.0).

The images have the following characteristics:

Date	Orbit	Observ. direction	Azimuth res.	Range res.	ILOS	ALOS	Pol	Footprint area	Frequency Band
23.01.2023	Asc*	left	0.448 m	0.452 m	40.9˚	-120.8˚	VV	2.842 km2	X
29.01.2023	Desc	right	0.446 m	0.450 m	53.2˚	-79.2˚	VV	2.514 km2	X

* Asc – Ascending, Desc – Descending, res. – resolution, Inc. – Incidence, Pol – Polarisation

Use the … *Browse…* button in the *SAR Select Image* window to navigate to the *SAR Essentials* installation folder stored on your computer and the *SAR_Essentials_dataset* subfolder. For the field *Input Left Image* select **hainan_2023-01-23-13-46-55_UMBRA-04_SICD_sample.ntf** and for *Input Right Image* fields select **hainan_2023-01-29-01-59-33_UMBRA-05_SICD_sample.ntf**. Click *OK* (Figure 15).

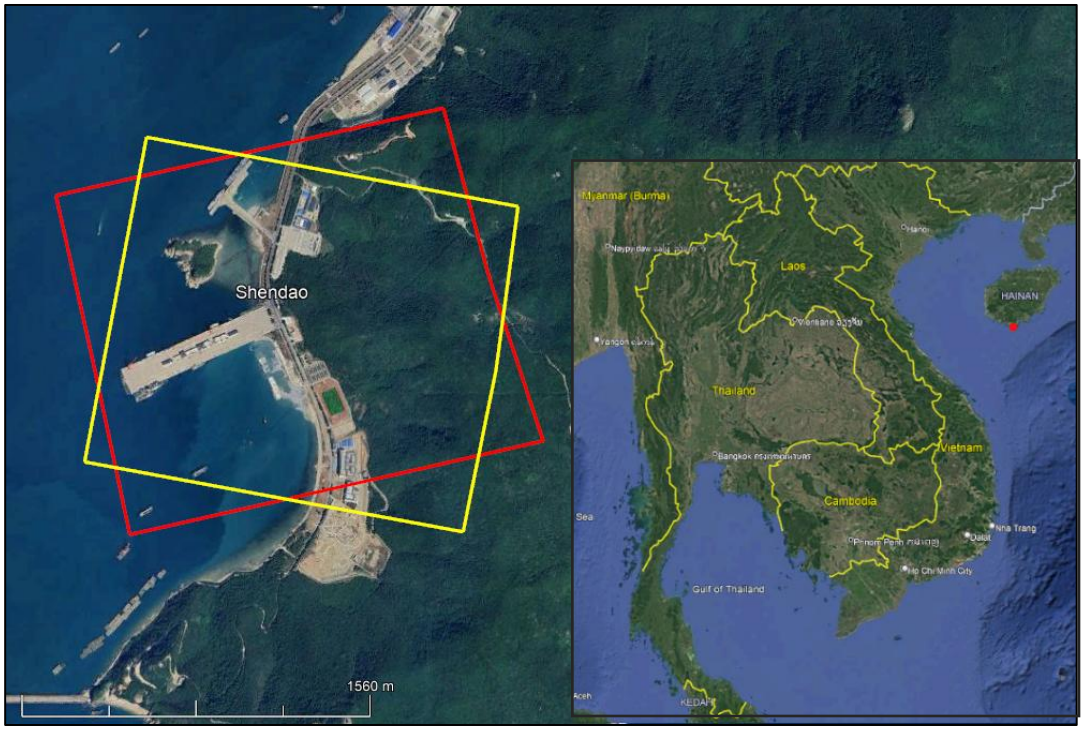


Figure 14. Footprint of the UMBRA sample images – ascending orbit from 23.01.2023 (red polygon) and descending orbit from 29.01.2025 (yellow polygon), over the island of Shen Dao and the near port on Hainan Island, China (overlay in Google Earth Pro 7.3.6, Image © 2025 Airbus)

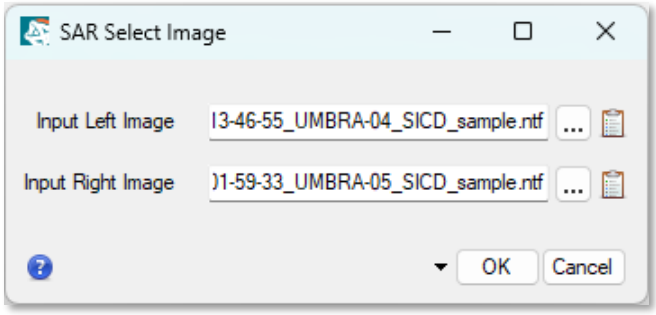


Figure 15. Selection of the tutorial images over Hainan port near Shen Dao Island

The tool imports the files, adds them to the *Layer Manager*, and displays them in **two** separate views (Figure 16). If the images do not have square pixels, the tool applies multilooking to correct them. This step may slow down the loading process. The process is finished when the two selected images are loaded in two parallel *ENVI views* (like the Views in Figure 16).

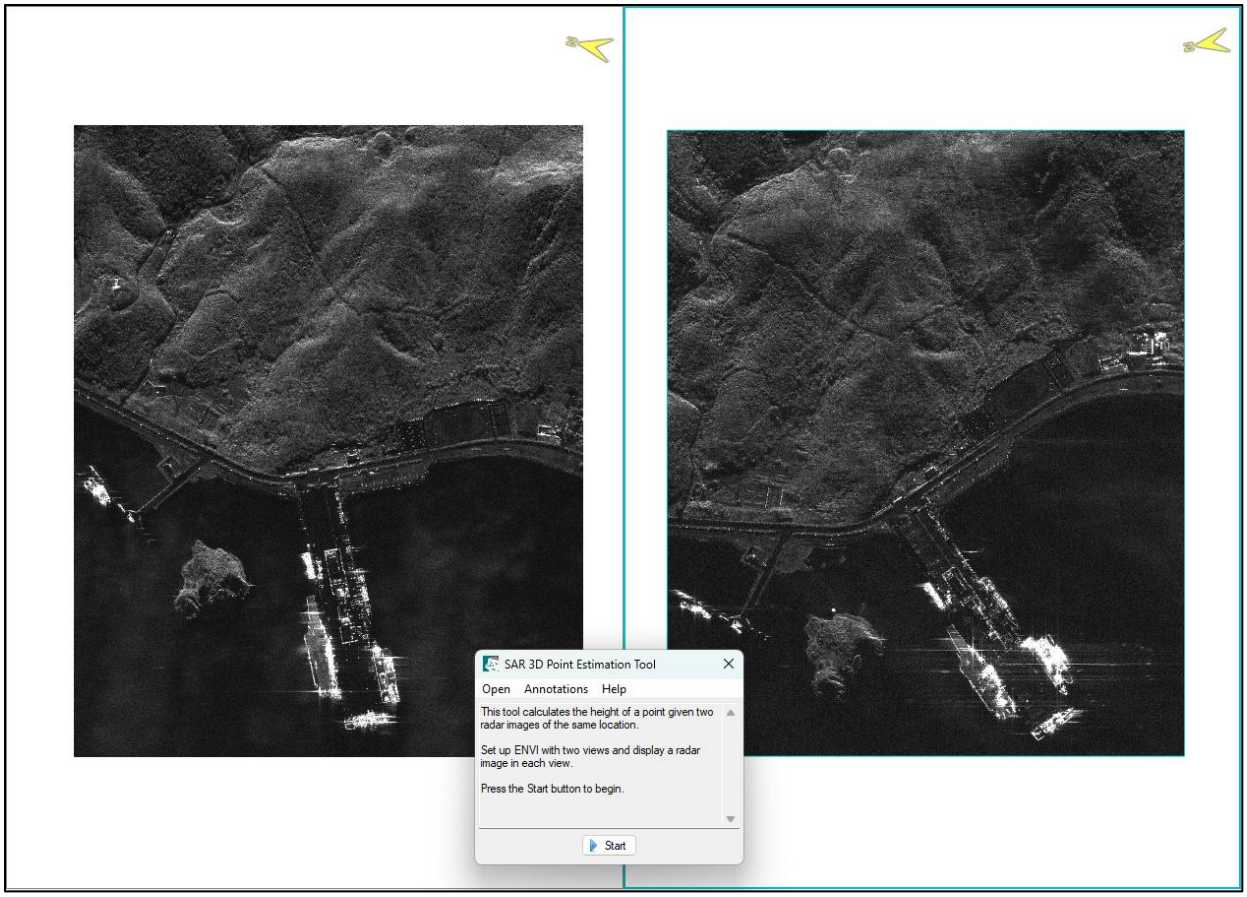


Figure 16. Two tutorial Umbra images loaded in two ENVI Views, together with the interactive window of the SAR 3D Point Estimation tool

3.2.2. Compatibility check

During the *Opening* of the data, *Import* process is applied, which

1) converts the images in the *SAR Essentials* format, and

2) checks the data for compatibility according to the requirements.

If the option to keep the imported and sampled data was enabled in the *SAR Essentials Management* tool, these files will be saved in the *Output Directory* set in the *ENVI Preferences*, within the folder *SAR_Select_Image_output_folder_xxx* (consult *SAR Essentials – Getting Started* tutorial for more details).

Review the compatibility analysis. It reports the following image characteristics, which fulfil the usage requirements of the tool (see the table in paragraph **Error! Reference source not found.**):

Pair temporal separation	Geometries	Sensor	ILOS difference	ALOS difference	Polarization	Common footprint area
5.5 days	Ascending / Descending	Umbra-04 / Umbra-05	12.3˚	23.6˚	VV / VV	2.269 km2

3.3. ANNOTATIONS

Similarly to the previous tool, this one also gives the opportunity to change the colour for the annotations (see paragraph **Error! Reference source not found.** for usage details).

3.4. SAR 3D POINT ESTIMATION

To calculate the 3D position of a point on the terrain, the location of the same point in both images loaded in the two ENVI views must be selected:

The interactive *SAR 3D Point Estimation* tool runs with the following steps:

1) Click the *Start* button of the interactive tool (Figure 16). The mouse cursor changes to a crosshair and an instruction to choose the point for height calculation appears (Figure 17). The point of interest must be carefully selected in the first (left) view (the active one at this stage).

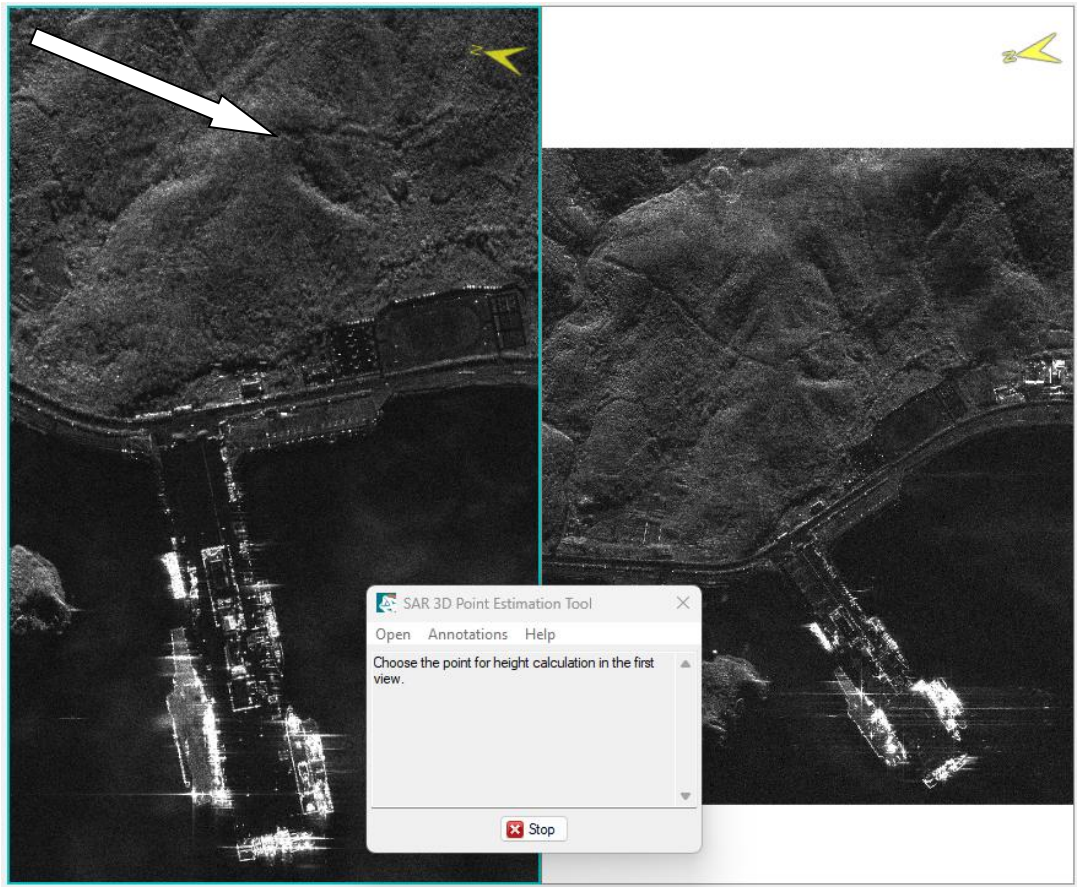


Figure 17. First step of the SAR 3D Point Estimation – selecting a point in the first view

2) Chose a point from a mountain road in the area marked with white arrow in Figure 17. Once selected, the point appears as a target circled marker in the colour selected for the annotations (*Figure 18*, left view). Consequently, the approximate location of the point is also suggested with the same symbol in the second image (*Figure 18*, right view).

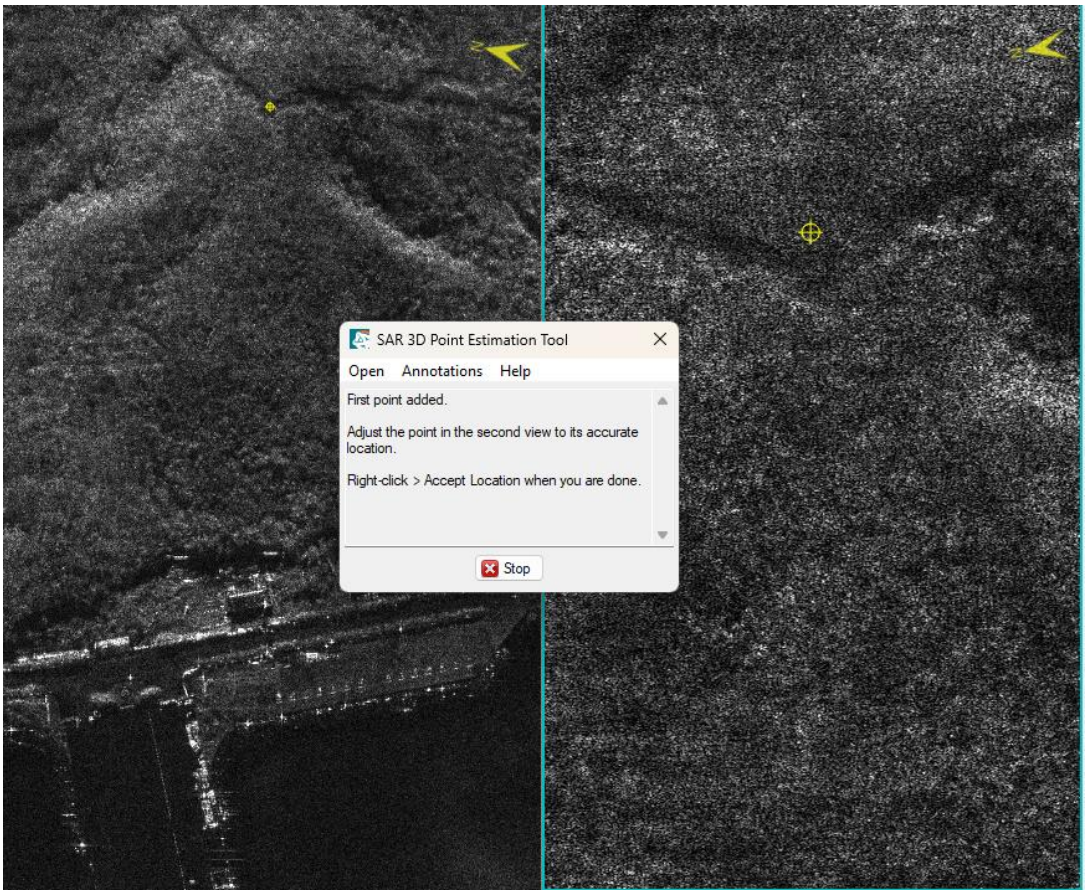


Figure 18. Second step of the SAR 3D Point Estimation – adjusting the location of the point in the second view

3) The second view window becomes active, as indicated by a cyan border. Drag and drop the point marker in the second view to refine its location. Confirm the final position by right-clicking in the view and choosing *Accept Location* (*Figure 19*). Another option is to select *Modify Initial Point*. By doing this, the position of the marker in the first view can be changed. A new point location is suggested in the second view. This location can be again adjusted by drag-and-drop. Continue this process as needed.

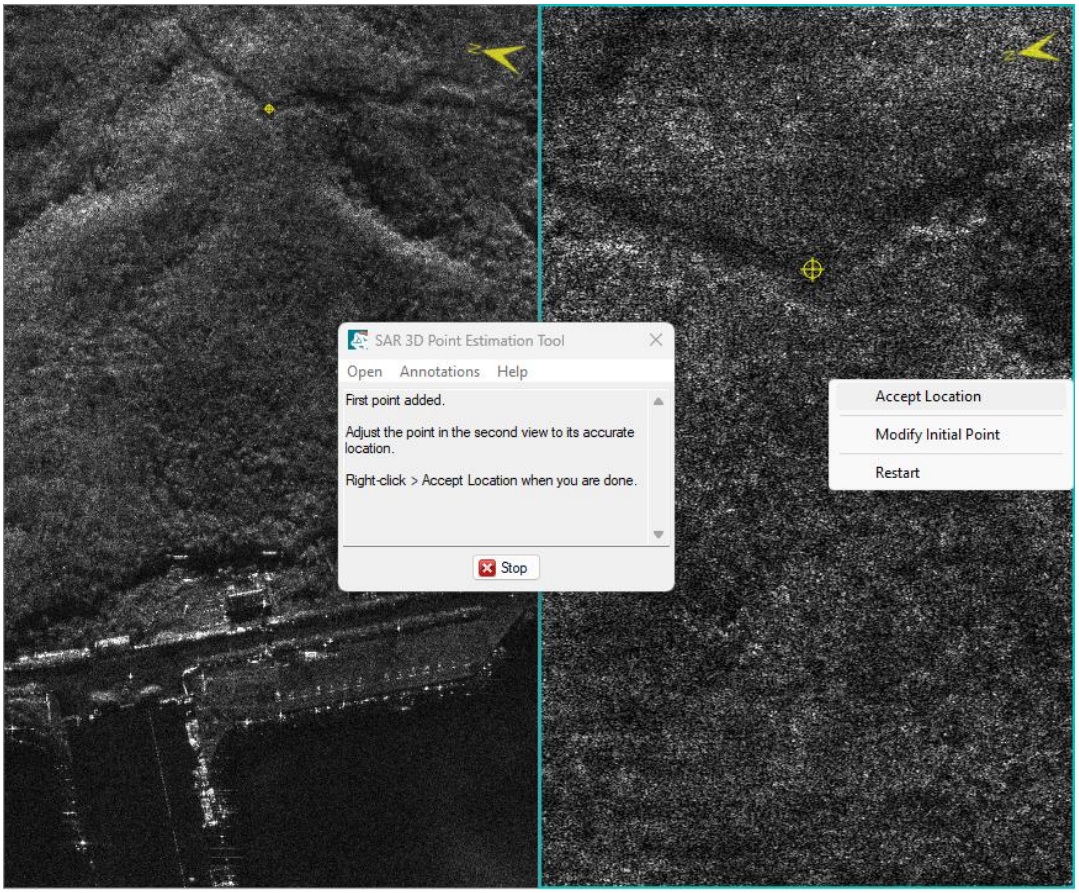


Figure 19. Third step of the SAR 3D Point Estimation – accepting the location of the point in the second view

4) Click *Accept Location* in the context menu, once the modification of the location of the point in the right *ENVI view* is satisfying. As a result, the 3D point estimations are listed in the window of the tool (*Figure 20*). The location of the point in the second view still can be adjusted and the hight recalculated.

   The *SAR 3D Point Estimation* tool lists the following calculation done in Coordinate system WGS 1984 (EPSG: 4326) about the point of interest:

   - Longitude, Latitude coordinates,
   - Height with respect to the ellipsoid WGS 1984,
   - Height with respect to geoid EGM96,
   - Height with respect to geoid EGM2008.

5) Select the *Stop* button to finish the operation. This clears the results from the window and is ready for new calculations. Repeat the previous steps with new point locations as desired.

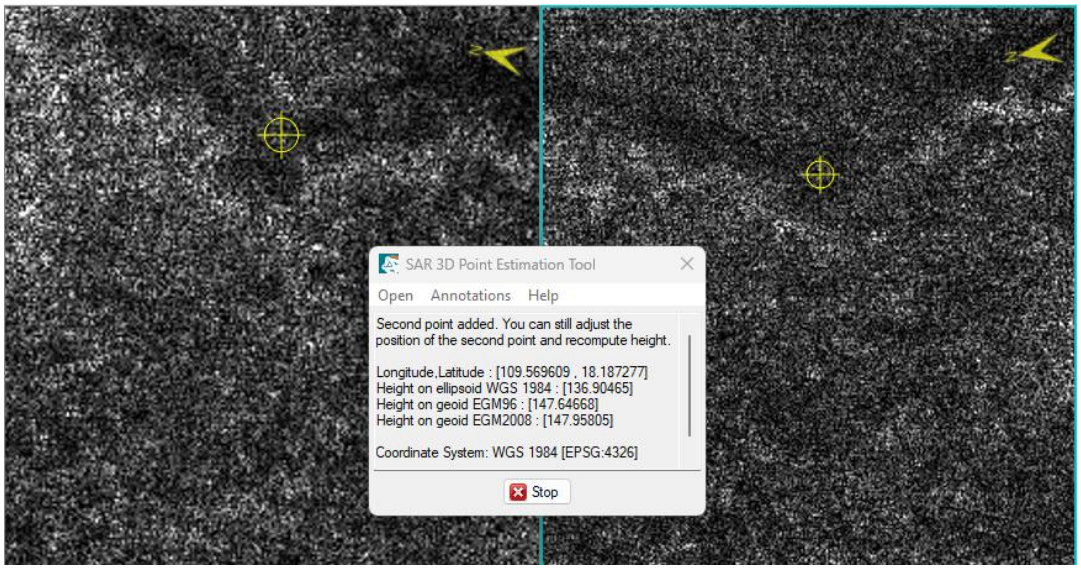


Figure 20. Results from the SAR 3D Point Estimation tool for the chosen point

The entire process can be finalised by closing the communication window with the × sign of the upper right corner of the window (*Figure 21*). If there was a previously opened images, their session can be reopened.

When completed, close the *SAR 3D Point Estimation* tool. If you previously displayed images before starting the tool, you can restore the previous layout by clicking *Yes* in the prompt (Figure 21). This will restore the previous ENVI session.

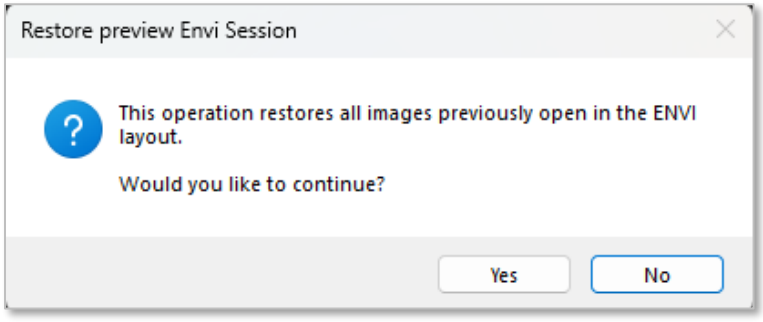


Figure 21. Results from the SAR 3D Point Estimation tool for the chosen point