# User Manual

# SAR-TOOLS: A new open-source software for geospatial analysis in volcano-tectonic fields

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# Summary

# Introduction the SAR-TOOLS User Manual and Requirements

The open-source software SAR-TOOLS was born from the desire to want to group together a whole series of tools useful in geospatial field investigations. In particular, it represents the union of different functionalities, developed during its creation and/or implemented through the use of libraries already present on the network. One of these libraries is GDAL (Geospatial Data Abstraction Library), which allows efficient work on a great many data formats, whether raster and/or vector data. This user manual is intended for users who intend to use SAR-TOOLS for their data analysis.

A description of the main screen of the SAR-TOOLS will be given and all its functionalities will be described through a step-by-step method correlated with images that will help the user to understand more intuitively how to move within it. The source code has been developed and made public so that it can be used and modified by anyone who needs it. At the same repository, there is the SAR-TOOLS executable file.

The source code was written in Python language on Windows environment. Therefore, its functionality within that operating system is assured. Its operation in different operating systems is not guaranteed.

Within the source code, all the libraries necessary for its operation are present. Therefore, it is recommended to verify the installation of the libraries for the purpose of using SAR-TOOLS.

# License

# Main Screen

When SAR-TOOLS is started for the first time, the user will be confronted with the screen in Fig.1, which shows only the categories of tools with which it will be possible to work.

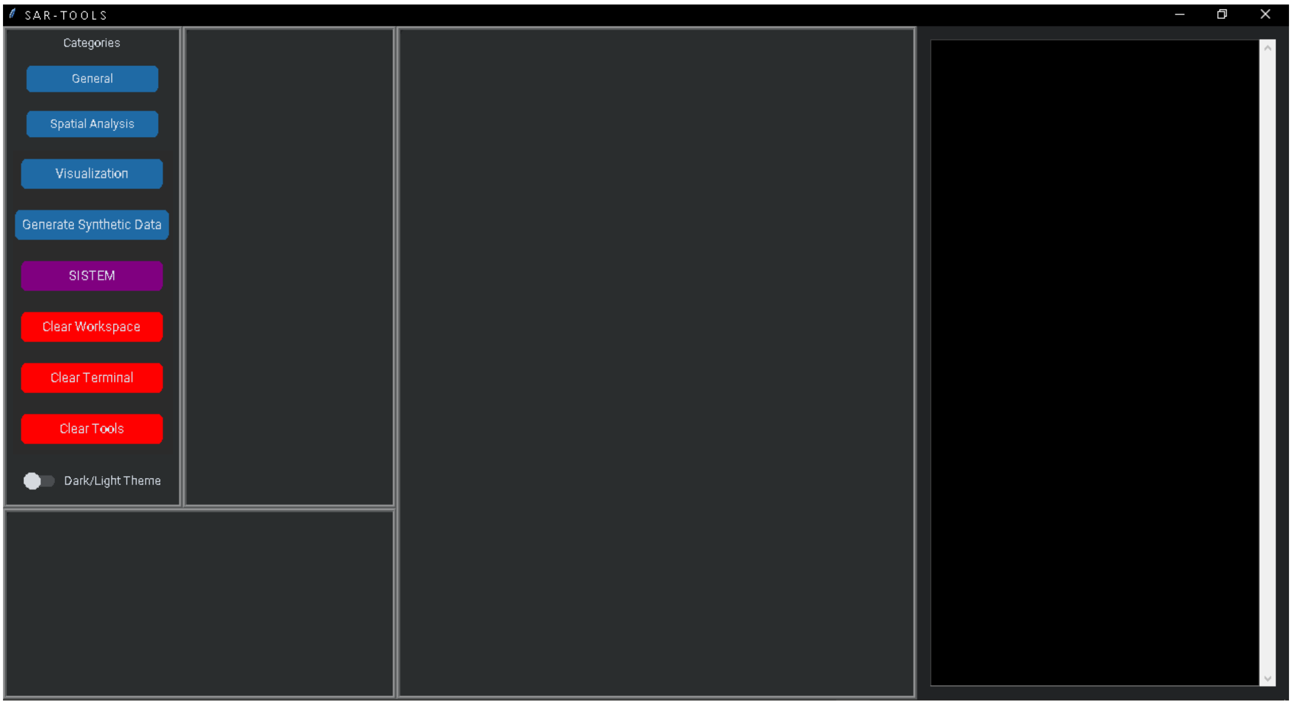



*Fig.1: Main screen of SAR-TOOLS at first startup.*

Below, however, is an example of the SAR-TOOLS working window.:

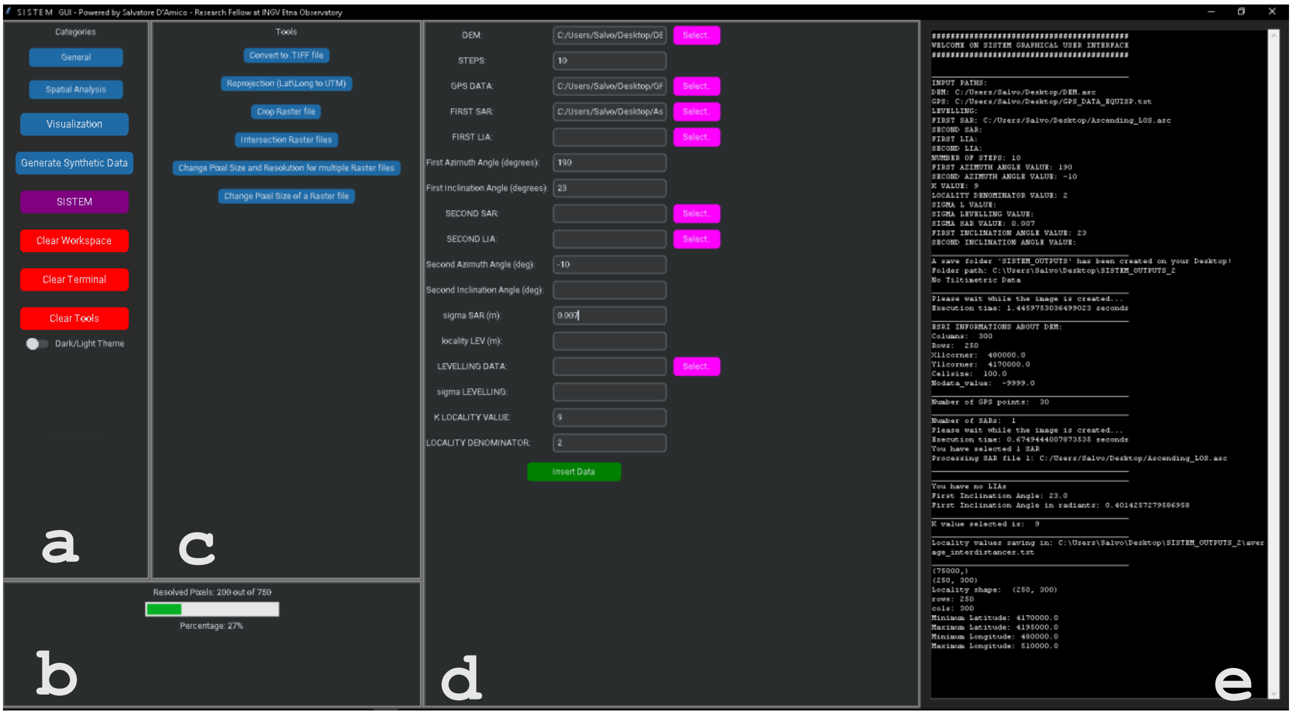



*Fig.2: Main working screen of the open-source SAR-TOOLS software. a: Frame named "Categories"; b: Frame hosting a progressbar to monitor the calculation status of the SISTEM algorithm; c: Frame named "Tools"; d: Frame named "Workspace"; e: Frame named "Terminal."*

The SAR-TOOLS GUI was developed to automatically adapt to the end user's screen resolution, ensuring an optimal experience on any desktop configuration.

Specifically, there are 5 frames (Figure 2a-e):

- **Categories**: this frame (Figure 2-a) is designed to encompass multiple functionalities in a few main sections (General, Spatial Analysis, Visualization, Generate Synthetic Data, GNSS Data Processing, SISTEM) that can be reached through interactive buttons. There are, in addition, three additional buttons (Clear Workspace, Clear Terminal, Clear Tools) that allow the various frames to be cleaned up after each work session. There is also a button that allows the user to be able to choose between a dark- or light-themed interface;

- **Progressbar**: in the SAR-TOOLS interface there is a progressbar (Figure 2-b) that shows, in real time, the calculation times of the SISTEM algorithm. In this way, the user can organize his work optimally while the algorithm performs the required operations.

- **Tools**: this frame (Figure 2-c) houses a set of category-specific tools that allow the user to perform multiple operations within SAR-TOOLS. Specifically, for each category, there are different buttons with a descriptive title indicating the purpose of the individual tool;

- **Workspace**: this frame (Figure 2-d) represents the workspace dedicated to the user for defining the inputs to be provided to the various tools. In this section, for example, the user can develop models and/or synthetic data to be provided later to the SISTEM algorithm to test its capabilities;

- **Terminal**: the frame (Figure 2-e) is represented by a terminal that prints out all the information entered as input by the user. In this way, the user is always in control of the computational operations performed by the various tools and can, if necessary, modify the input data if he needs different outputs;

# Categories and Associated Tools

## 4.1 General

The General category contains within it 3 tools (Gdal Info, Create an ENVI file, and Phase to Displacement Conversion).

### 4.1.1 Gdal Info

The gdalinfo tool, contained within the open-source GDAL library, lists various information about a raster dataset. It, like all GDAL functionality, is accessible only from the command line, but, within SAR-TOOLS, is easily queried via appropriate button.

To use Gdal info:

- Click on the General category ;
- Click on the Gdal info tool ;
- Select the geospatial file to query in the window that opens;
- Read the metadata associated with the selected geospatial file in the terminal to the right of the main screen;

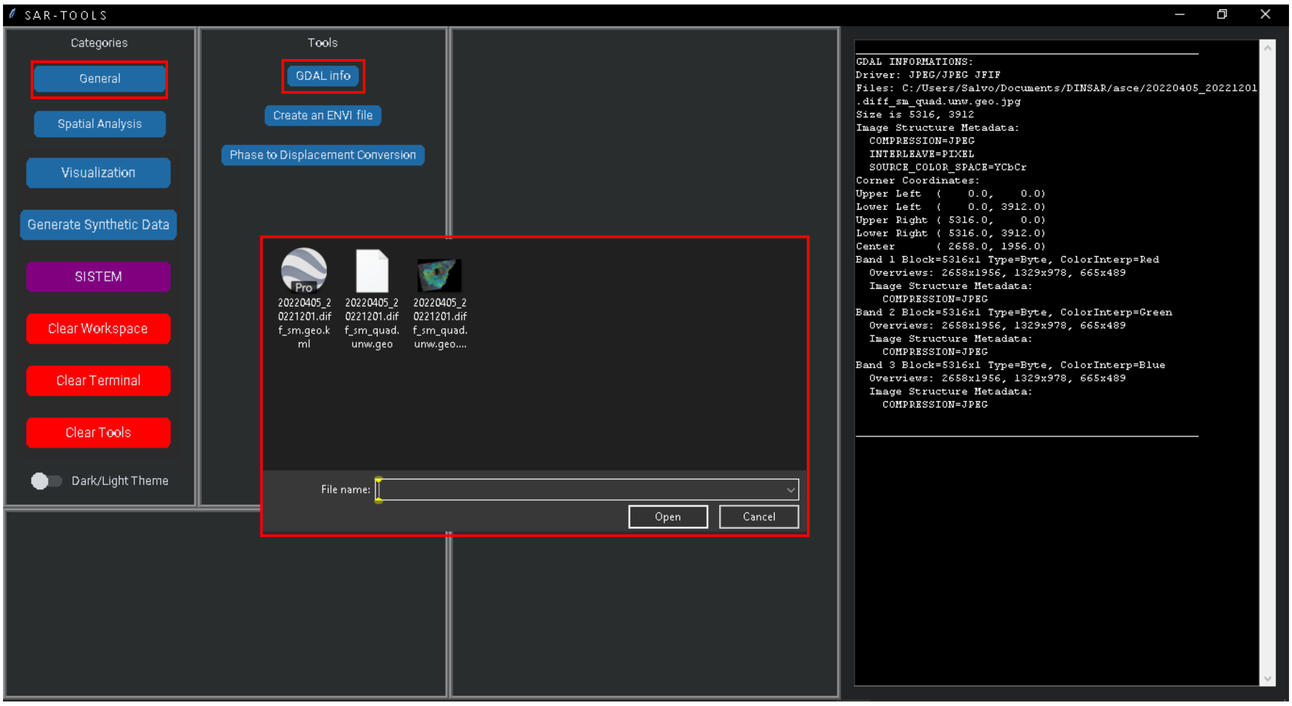
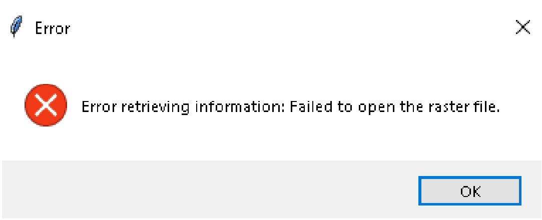



*Fig.3: Example of the screen (and Windows window) of SAR-TOOLS while using Gdal Info.*

If the selected geospatial file format was not queryable by GDAL, the user would get the following error:




### 4.1.2 Create an ENVI file

With this tool, the user can create ENVI (Environment for Visualizing Images) files through the input of various inputs. Specifically, ENVI files contain information about the structure and metadata (usually in .hdr format) associated with geospatial data;

Such inputs are:

- **Samples**: refers to the number of columns related to the raster file;
- **Lines**: refers to the number of rows related to the raster file;
- **Bands**: refers to the number of spectral bands contained in the raster file;
- **Interleave**: refers to the way the data is organized within the bands. For example, in the figure you can see the code 'bsq' which stands for 'BandSequential'. This format is relatively simple to manage and can be efficient in terms of data access if you are working with a single band at a time. Other formats may be: BIL (Band Interleave by Line), BIP (Band Interleave by Pixel);
- **Data Type**: refers to the type of data used to represent the pixels;
- **Byte Order**: Refers to the order in which Bytes are stored (e.g., in "big-endian" or "little-endian" format);
- **Minimum Longitude**: Refers to the minimum longitude coordinate of the geographic area covered by the raster. It must be given according to the WGS-84 (or EPSG: 4263) reference system.
- **Maximum Latitude**: refers to the maximum latitude coordinate of the geographical area covered by the raster. It must be provided according to the WGS-84 (or EPSG: 4263) reference system.
- **x size**: indicates the width of the area of interest in terms of a single pixel;
- **y size**: indicates the height of the area of interest in terms of a single pixel;

$$xsize = \frac{(Longitudemax - Longitudemin)}{lines}$$

$$ysize = \frac{(Latitudemax - Latitudemin)}{samples}$$

To create the ENVI file to be associated with the geospatial file:

- Click on General in Categories;
- Click on Create an ENVI file in Tools;
- Enter the parameters;
- Click on the "Save and export data to an ENVI file" button;

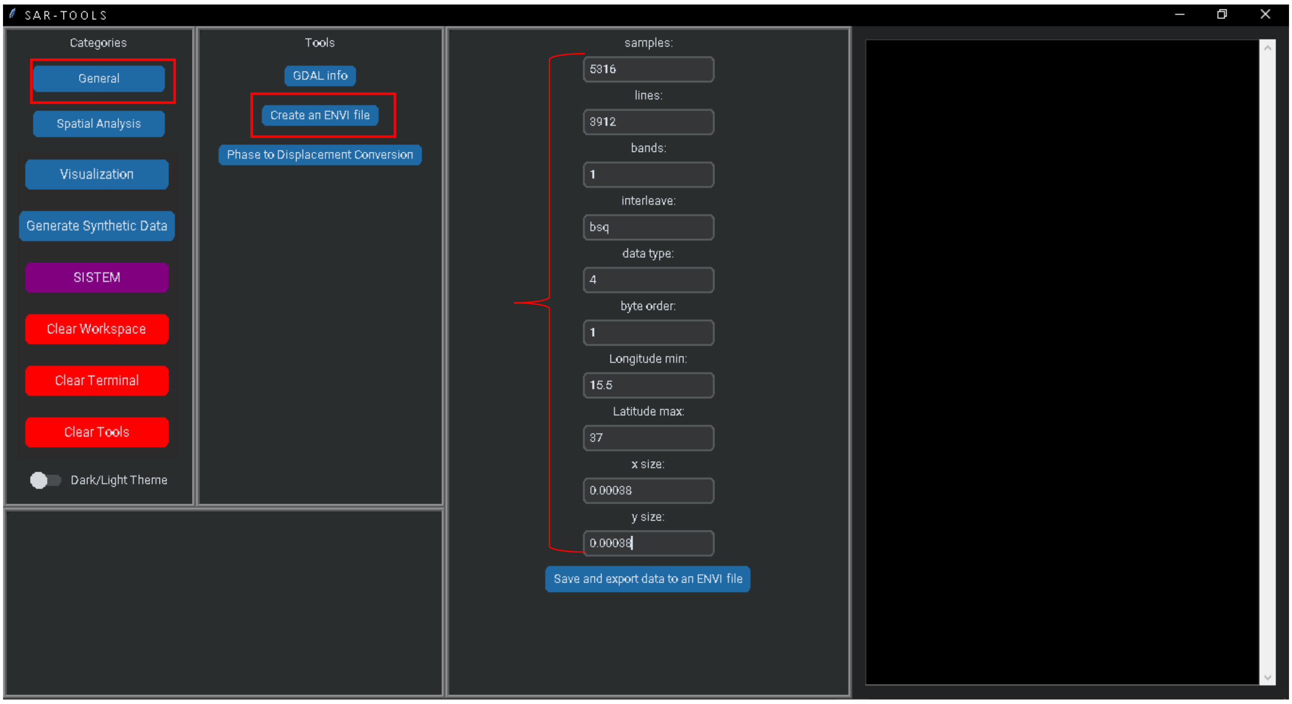
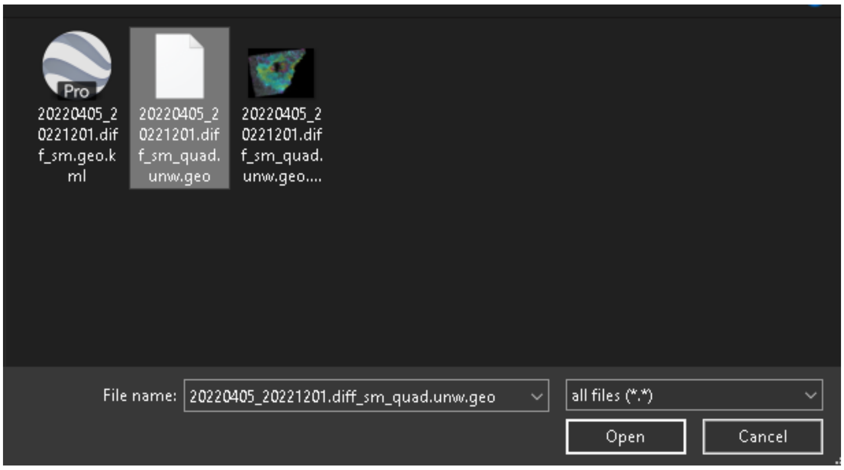



*Fig.4: Screen shot of SAR-TOOLS and workspace inherent in the Create an ENVI file tool.*

In the window that opens, select the geospatial file with which to associate the ENVI file you just created;

The new ENVI file will be located in the same folder as the geospatial file associated with it;



Below is an example of the contents of the ENVI file:*ENVI*

*samples = 5316*

*lines =  3912*

*bands =  1*

*interleave =  bsq*

*data type =  4*

*byte order =  1*

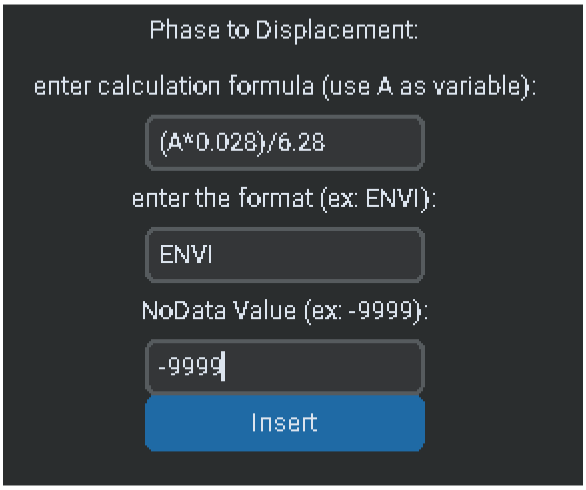
*map info =  {Geographic Lat/Lon, 0.5000, 0.5000, 15.5, 37, 0.00038, 0.00038, WGS-84, units=Degrees}*

### 4.1.3 Phase to Displacement Conversion

This tool allows efficient use of the GDAL functionality called gdal_calc. In particular, this functionality gives the possibility to create mathematical operations on the raster files held (which are identified with the letter A), such as, for example, intersection operations between different rasters. Within SAR-TOOLS, the ability to convert to convert the phase of an interferogram (expressed in radians) to displacement (expressed in meters) has been developed. To do this, the user only needs to specify λ (defined as half the wavelength of the chosen satellite) and the tool will return as output the new metric displacement map of the area under consideration;

- Enter the calculation formula: In the "Formula" section, enter the desired calculation formula using the variable "A" as a reference. For example, you can enter a mathematical formula such as "A * λ /2" to multiply all values in the input file by λ /2.

- Enter the format of the output data: In the "Format" section, enter the desired format for the output data. For example, you can enter "ENVI" if you want the output to be in ENVI format.
- Enter NoData Value: In the "NoData Value" section, enter the desired NoData value. This value will be used to identify missing data in the output.




- **Select the input file**: Click the "Insert" button to select the input file. A dialog box will open, allowing you to search and select the input file to be processed. Make sure the input file is compatible with the application (e.g., ENVI, GEO, or GeoTIFF file).
- **Select the output directory**: After selecting the input file, a dialog box will be displayed to select the directory where the output file will be saved. Select the desired directory.
- **Enter the name of the output file**: A third dialog box will be displayed to enter the name of the output file. Choose a name and specify the file extension (e.g., ".geo" or ".geotiff").

Once you have entered all the required information and selected the input file and output directory, the application will use the GDAL library to process the input file based on the specified formula, format, and NoData value. The save paths will be visible in the terminal within the main SAR-TOOLS screen.

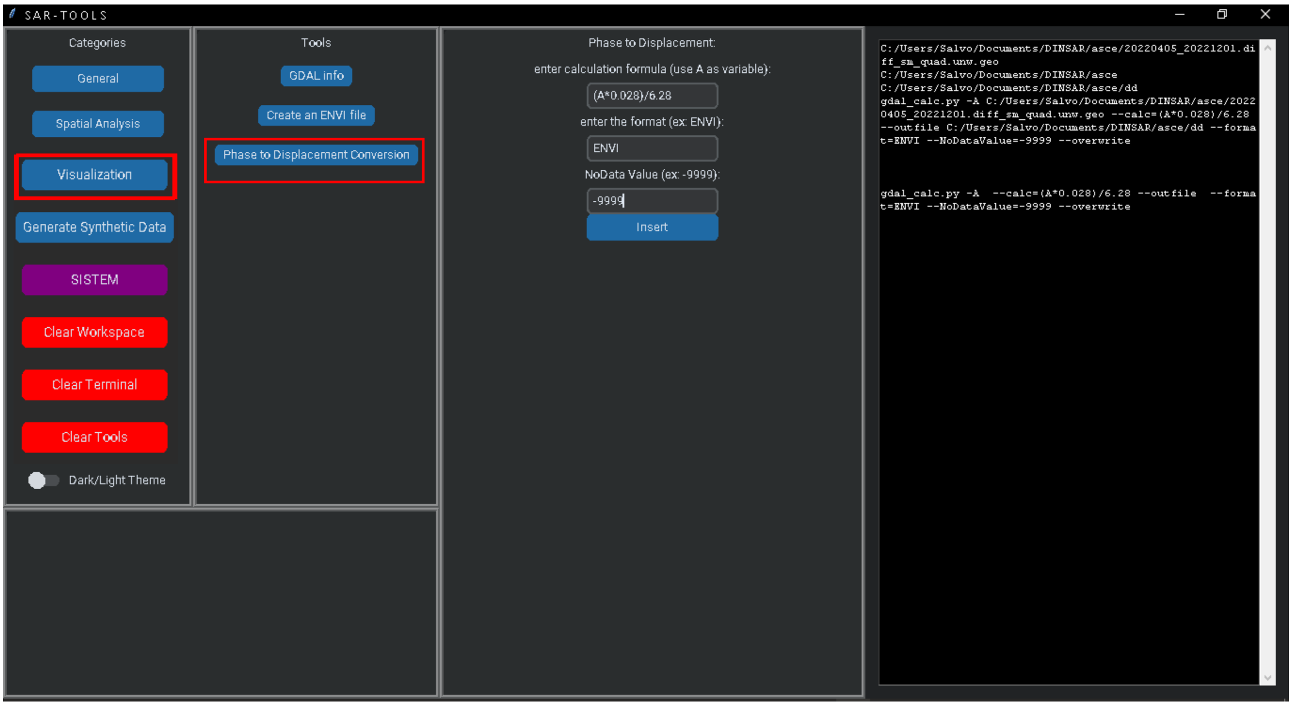



*Fig.5: Initial screen of SAR-TOOLS and workspace related to the Phase to Displacement tool.*

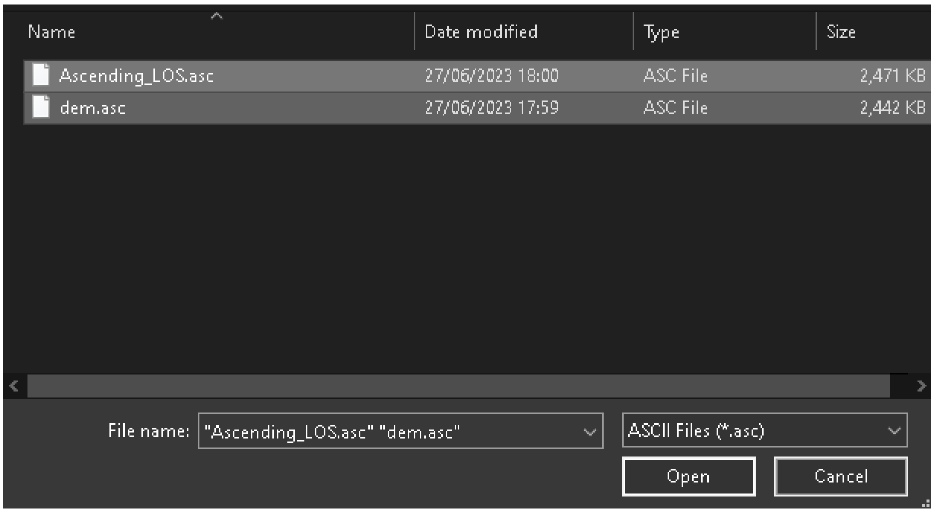
## 4.2 SPATIAL ANALYSIS

### 4.2.1 Convert to .TIFF file

With this tool you can convert geospatial files (for examples in ASCII or .TXT format) to images with .TIFF format.

At first, you will receive a message on the terminal to the right of the main screen explaining the use of the tool. It will indicate that you can use this tool to convert your data to raster images in the .tif format.

- **Selection of files to convert**: You will be prompted to select the files you wish to convert to images through a dialog box and select one or more files to convert to ASCII, JPEG or PNG format.




- **Save folder selection**: After selecting the files to be converted, you will be asked to select the folder where you want to save the converted images.
- **Convert files to TIFF images**: Once you have selected the files to be converted and the destination folder, the program will begin converting the files to TIFF images.
- **View the result**: After each file is converted, you will receive a message in the terminal indicating where the converted TIFF file was saved. You can find your converted images in the specified destination folder.

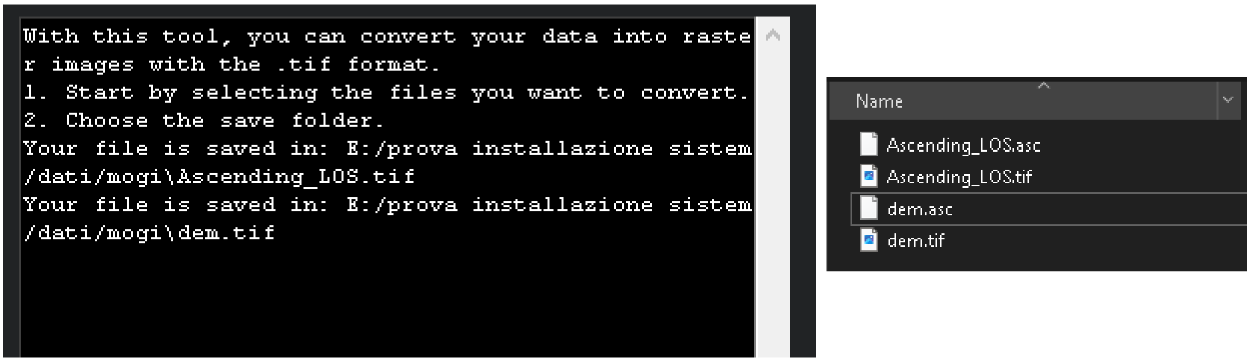


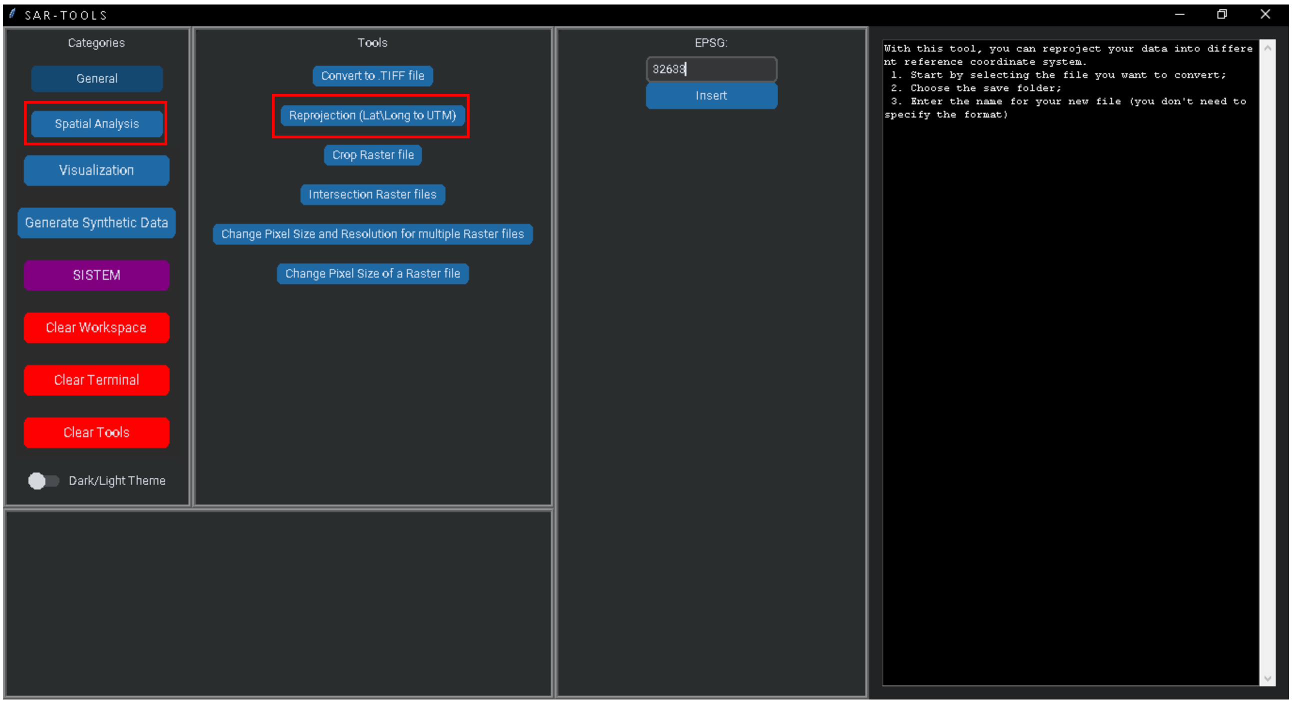

*Fig.6: Example of output in the SAR-TOOLS terminal with, on the right, the generated files.*

### 4.2.2 Reprojection (Lat\Long to UTM)

Through the GDAL library feature called gdal_translate, it is possible, among other things, to convert geospatial files to different reference systems. To do this, one needs the EPSG (European Petroleum Survey Group) code, a 4- to 6-digit number representing the parameters of a given reference system. To facilitate computational operations in terms of metric deformation in a volcanic context, a function was developed within SAR-TOOLS that allows conversion of the geospatial data available to the user from the WGS84 geographic reference system to UTM (Universal Transverse Mercator). The choice of the latter reference system, concerns the choice of a transverse cylindrical projection with rectangular zones and metric system, going to simplify calculations over linear distances and with relatively low distortions in small to medium-sized survey areas.

At the beginning, you will receive a message explaining how to use the Lat/Lon to UTM coordinate conversion tool. The explanation is broken down into three points:

- **Enter the EPSG code**: In the "EPSG" section, enter the EPSG code corresponding to the desired UTM coordinate system. For example, you can enter "32633" for UTM Zone 33N.




- **Coordinate conversion**: Click the "Insert" button to start the coordinate conversion process. The function will open a dialog box to select the input file containing the Lat/Lon coordinates to be converted.

- **Selection of output folder**: Next, you will be asked to select the folder where the converted files will be saved. This is the directory where the resulting UTM file will be stored.

- **Enter the name of the output file**: Finally, enter the name of the new converted UTM file, but it is not necessary to specify the extension (for example, you can enter "my_utm_file" instead of "my_utm_file.tif").

Once the selection operations are complete, the function will perform the Lat/Lon to UTM coordinate conversion using the entered EPSG code. A new file will be created in the specified output folder with the name provided by the user.

Below is an example of conversion from WGS84 to UTM Zone 33N.

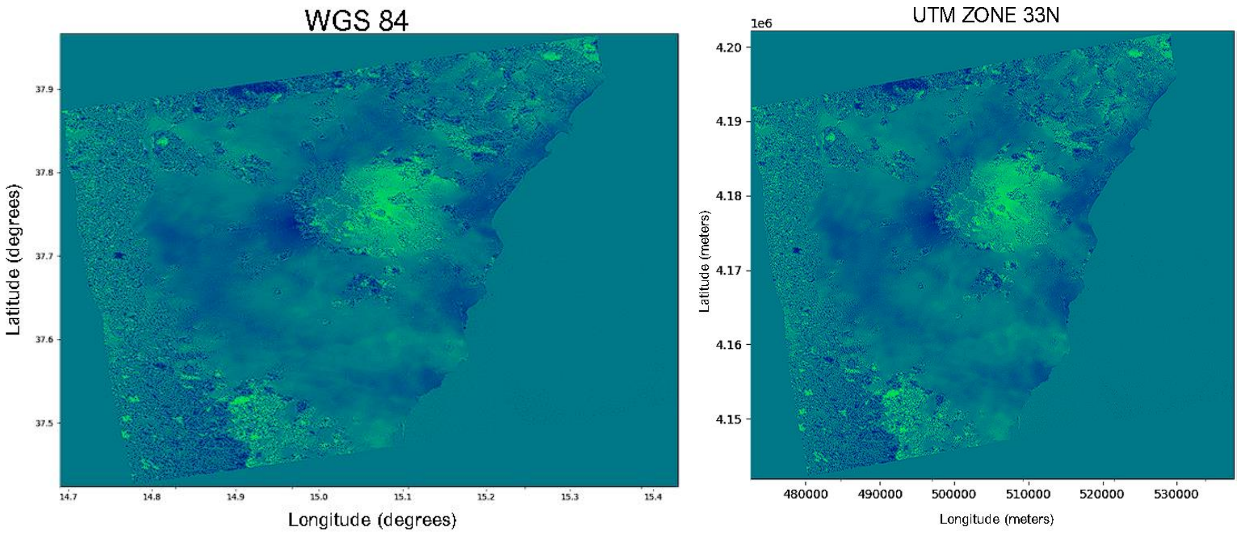



*Fig.7: Initial raster, left, with reference system in WGS84. On the right, the output of the same raster, with reference system in UTM (33N zones).*

### 4.2.3 Crop Raster file

With this tool it is possible to crop a georeferenced raster by going to select the extreme coordinates of the chosen cropping area. The tool will proceed to crop and save the new raster without losing quality and georeferencing information;

At first, you will receive a message explaining how to use the tool to crop an image. The explanation describes that you can crop an image by defining the values of the upper left and lower right corner coordinates of the crop area. These values should be obtained by looking at the image in an image viewer (for example, through the SAR-TOOLS feature called Show an image) and noting down the coordinate values (x, y) corresponding to the corners.

- Entering clipping coordinates: The screen contains four labels and four text boxes for entering the values of the corner coordinates of the clipping area.

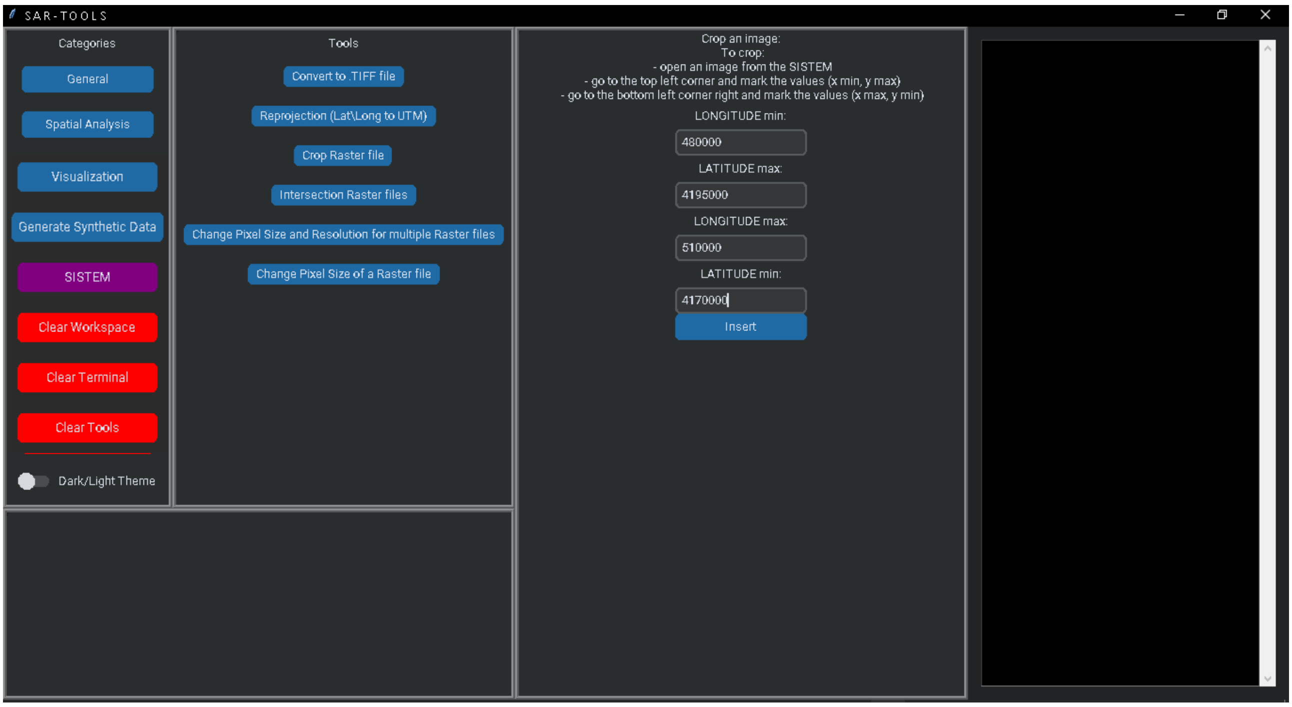
- Go to the Visualization category and click on the Show an Image tool;
- Select the raster to be cropped;
- Place the pointer at the four extreme clipping points and note the geographic coordinate values;
- Enter the following values:

"LONGITUDE min": The minimum x-coordinate of the upper left corner.

"LATITUDE man": The maximum y-coordinate of the upper left corner.

"LONGITUDE max": The maximum x-coordinate of the bottom right corner.

"LATITUDE min": The minimum y-coordinate of the bottom right corner.



- Perform clipping: Click the "Insert" button to start the clipping process. The function will open three dialog boxes:
- The first dialog box will allow you to select the image to be cropped. Choose the desired image.
- The second dialog box will ask you to select the directory where the cropped image will be saved. Choose the destination directory.
- The third dialog box will allow you to enter the name of the new cropped image file, without specifying the extension (for example, enter "my_cropped_image" instead of "my_cropped_image.tif").

After cropping, you will receive a message indicating that the image was successfully cropped and the location where it was saved.

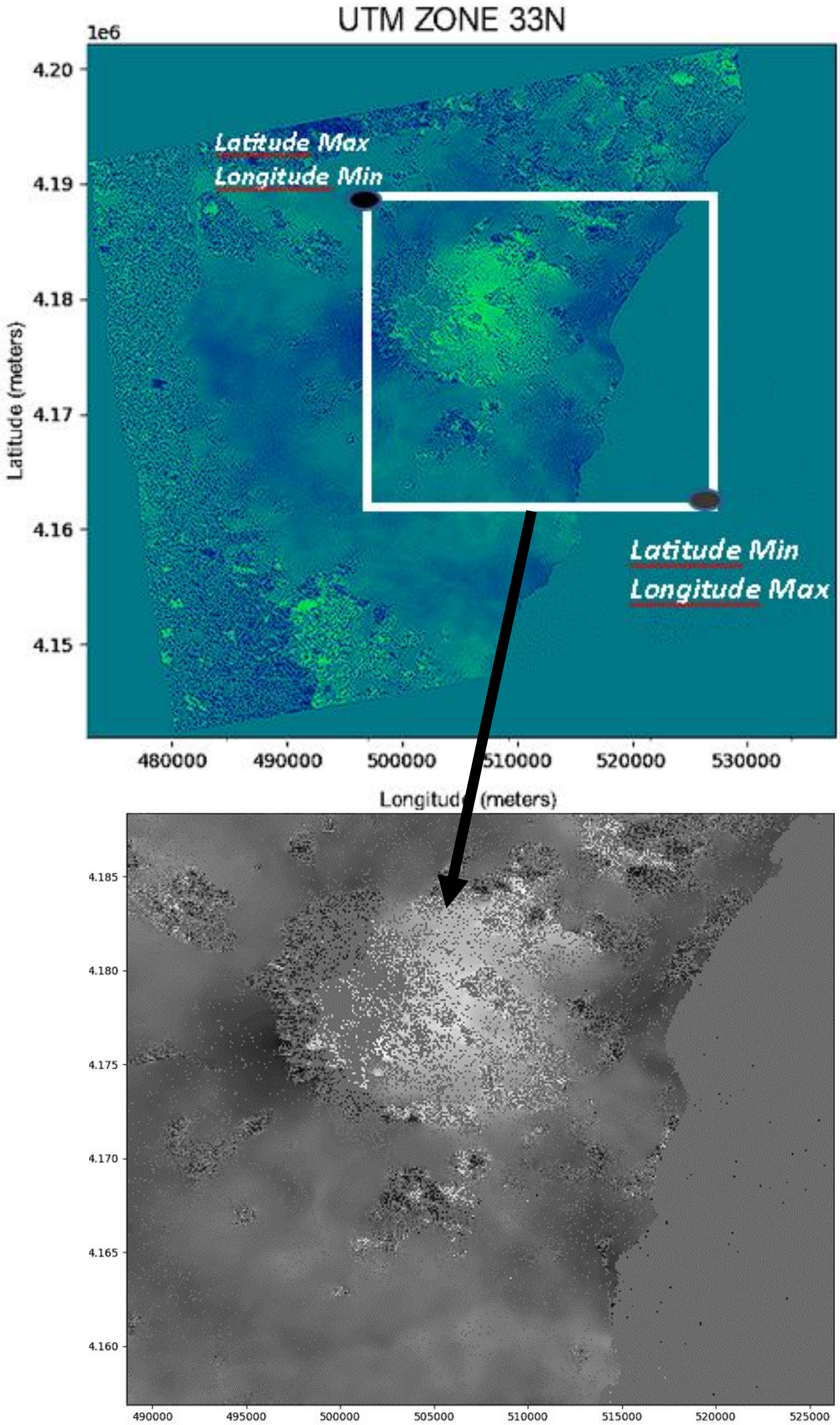
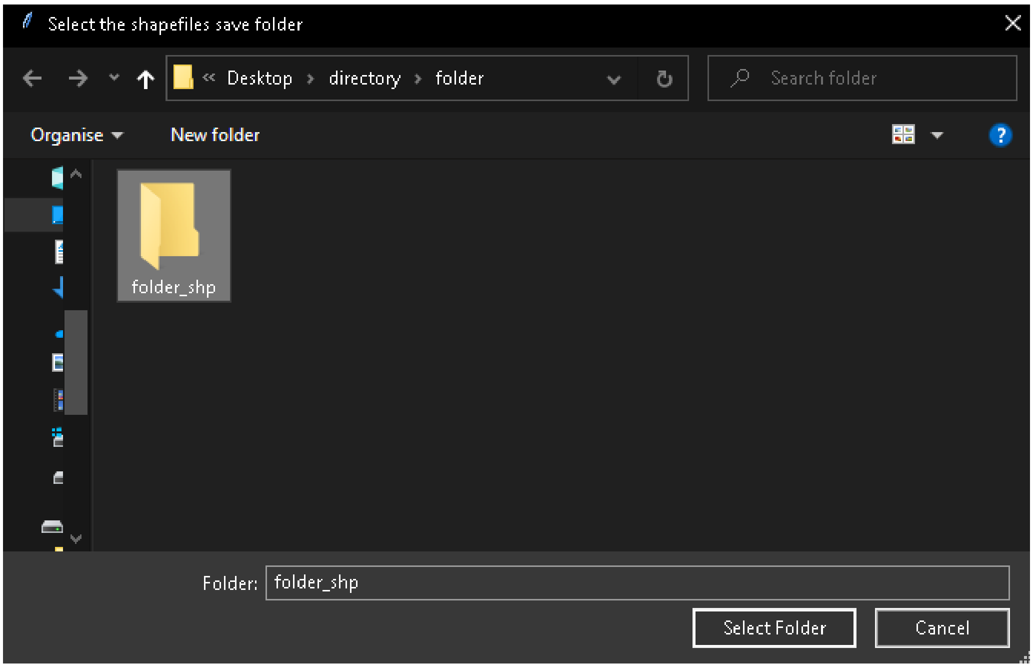



*Fig.8: Example of clipping operation through SAR-TOOLS. Above is the input raster with the quadrant for the clipping area chosen by the user. Note: The clipping area will not be visible, it was inserted here to give the user a clearer idea. Bottom, the output generated by SAR-TOOLS.*

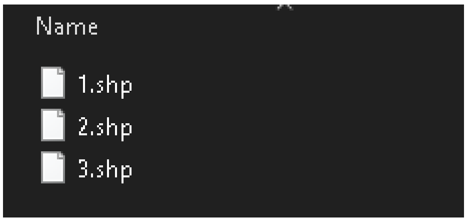
### 4.2.4 Intersection Raster files

If your rasters are in different folders, be sure to group them all in the same folder before you begin.

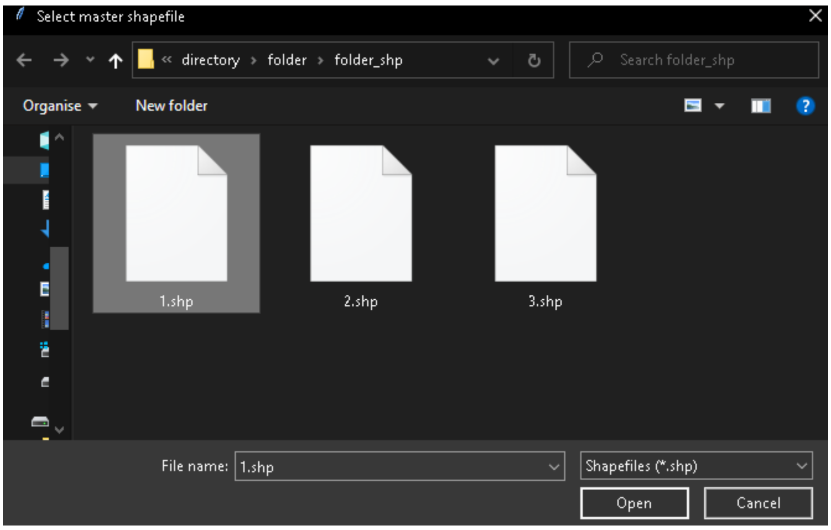
- Select the folder where you have grouped your rasters (they can be in ".tif",".jpg",".png" formats);
- Select the folder where you want to save the shapefiles associated with your rasters;




The function will create the shapefile for each raster in the folder selected in step 2;




- Selects the MASTER shapefile, which will be used as the main reference for the intersection;

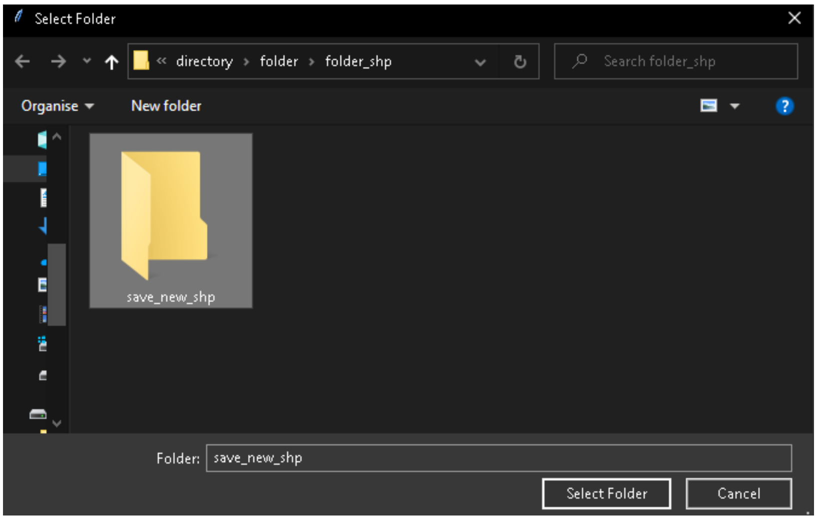


- Select the SLAVE shapefile you wish to intersect with the MASTER.

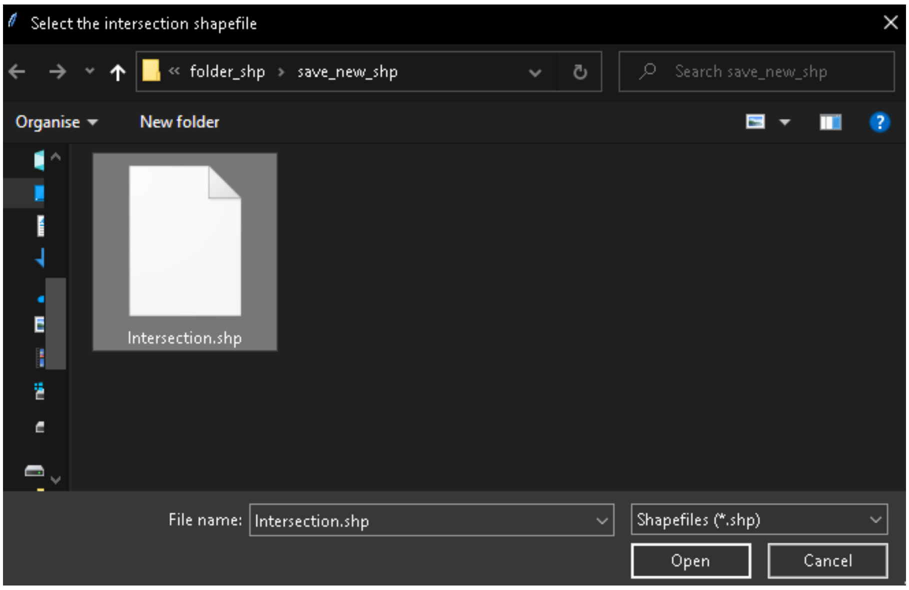
NOTE: The function is organized to handle a maximum number of slaves equal to 2 (for example, the ascending and descending phase of a SAR);

- Repeat the operation for the second SLAVE, being careful to select the new shapefile "intersection.shp" as MASTER;

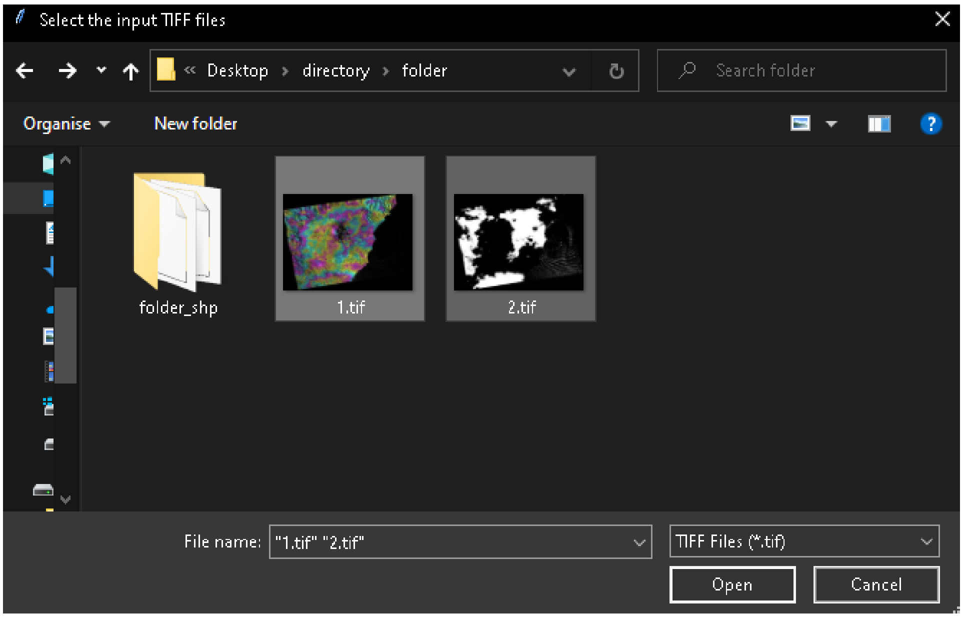
- Select the Save Folder where you wish to save the intersection output file. Such a file will be named "Intersection.shp";



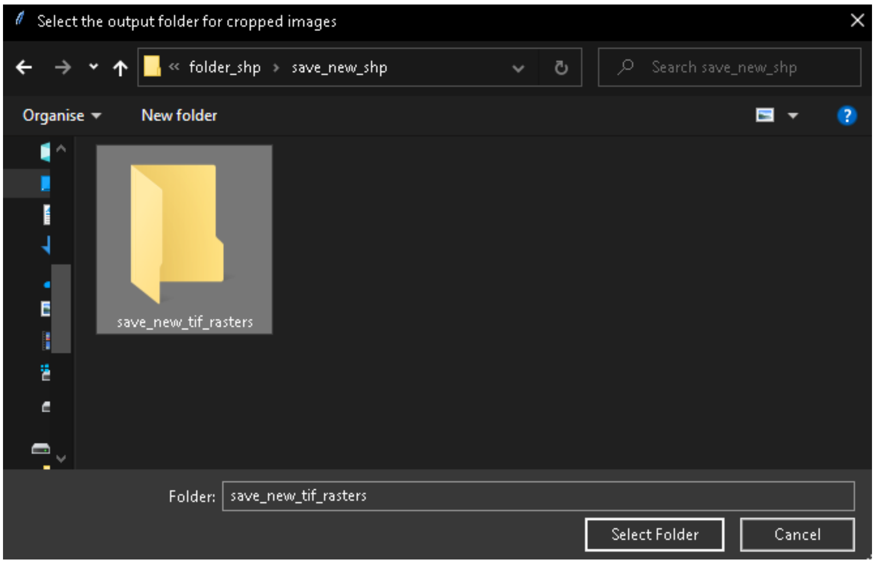

- Now select the "intersection.shp" file. It will be used to crop your initial rasters according to the geometry in "intersection.shp," so they will be homogenized.



- In the new window called "Select the input TIFF files," select the rasters you wish to crop based on the intersection area defined by "intersection.shp." The raster files can be in ".tif" format or in other formats by clicking on the bottom right and choosing the format you are interested in;




- Select the folder where the cropped rasters will be saved;




The new rasters will have the name of the initial rasters with the addition of "_cropped.tif".

### 4.2.5 Change Pixel Size and Resolution for multiple Raster files

- Enter the pixel resolution values you intend to associate with your rasters (for example: 100x100);
- Click Insert;
- In the window that opens, select the shapefile that will be used to crop the various rasters. Make sure the .shp file is in the same projection as the rasters you wish to crop;
- Select the folder where you want to save the cropped rasters;
- Select the rasters to which you want to associate the pixel resolution value you chose in step 1;
- Choose the name under which to save the new rasters and specify the format (for example: ".tif");

### 4.2.6 Change Pixel Size of a Raster file

This tools is similar to 4.2.5, but limited to changing pixel resolution value for a single raster.

## 4.3 VISUALIZATION

### 4.3.1 Show an image

In this function, The formats supported for display are as follows:

Here is a list of supported image formats:

- *VRT (Virtual Raster)*
- *TIF (TIFF - Tagged Image File Format)*
- *NTF (National Imagery Transmission Format)*
- *TOC (Table of Contents)*
- *XML (Extensible Markup Language)*
- *IMG (Erdas Imagine Image)*
- *GFF (Grid File Format)*
- *ASC (ASCII Grid)*
- *ISG (Image Storage and Retrieval System)*
- *DDF (Digital Distribution Format)*
- *PNG (Portable Network Graphics)*
- *DDS (DirectDraw Surface)*
- *JPG (JPEG - Joint Photographic Experts Group)*
- *MEM (In-Memory Dataset)*
- *GIF (Graphics Interchange Format)*
- *N1 (NITF 1.0)*
- *KAP (BSB/KAP Format)*
- *XPM (X PixMap)*
- *BMP (Windows Bitmap)*
- *PIX (Alias PIX)*
- *MAP (Maptech BSB Nautical Chart)*
- *RGB (Raw Red, Green, Blue Samples)*
- *HGT (SRTM Elevation Data)*
- *TER (Terragen Terrain File)*
- *NC (NetCDF - Network Common Data Form)*
- *HDF (Hierarchical Data Format)*
- *ERS (ENVI Header)*
- *JP2 (JPEG 2000)*
- *RSW (Raster ADRG)*
- *NAT (Natural Resources Canada)*
- *RST (Idrisi Raster Format)*
- *GRD (GMT Grid)*
- *HDR (Idrisi Raster Header)*
- *RDA (R Raster Data)*
- *WEBP (WebP Image Format)*
- *PDF (Portable Document Format)*
- *SQLITE (SQLite Database)*

- *MBTILES (MapBox Tileset)*
- *MRF (Meta Raster Format)*
- *BT (BIL - Band Interleaved by Line)*
- *LCP (Land Cover Prototype)*
- *GTX (Global Terrain Data)*
- *ACE2 (ACE2 Image)*
- *KRO (Kolor Raw Image)*
- *RIK (RikImage Format)*
- *DEM (Digital Elevation Model)*
- *GXF (GeoSoft Grid Exchange Format)*
- *BAG (Bathymetry Attributed Grid)*
- *GRC (Golden Software Grid)*
- *GEN (Golden Software ASCII Grid)*
- *BLX (Magellan Explorist Geocaching)*
- *XYZ (Plain Text XYZ)*
- *HF2 (HF2/HFZ Heightfield)*
- *JLS (JPEG-LS)*
- *DAT (ENVI DAT Format)*
- *BIN (Binary Data)*
- *PPI (SAR Complex Data)*
- *PRF (Pulse Repetition Frequency)*
- *DGRDA (DeltaGraph Data)*
- *SIGDEM (Signal Demodulation Data)*
- *EXR (OpenEXR)*
- *TGA (Targa Image)*
- *JSON (JavaScript Object Notation)*
- *GPKG (GeoPackage)*
- *DWG (AutoCAD Drawing Database)*
- *BIL (Band Interleaved by Line)*

Note that this list may not be exhaustive, but it covers a wide range of image formats supported in different applications and software libraries.

## 4.4 GENERATE SYNTHETIC DATA

### 4.4.1 Mogi Model

With this function, the user has the ability to develop a spherical Mogi source and observe its deformation field in a synthetic topographic surface (DEM) of a volcano whose shape follows a Gaussian normal distribution. In addition, a synthetic line-of-sight (LOS) can be developed for the ascending and descending orbital component.

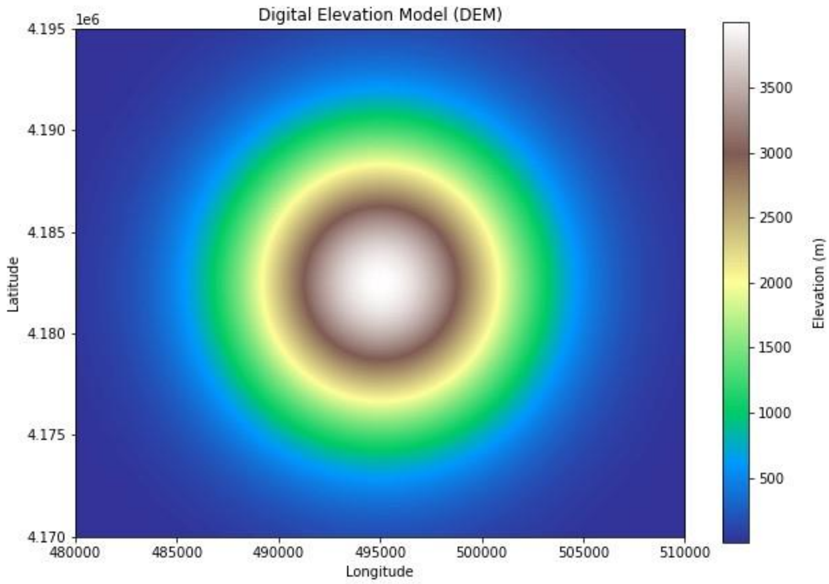
As input, the user must provide:

- Cellsize: represents the cell size in the synthetic DEM;
- Minimum latitude: represents the minimum latitude value (in the example in UTM);
- Maximum latitude: represents the maximum latitude value (in the example in UTM);
- Minimum longitude: represents the minimum longitude value (in the example in UTM);
- Maximum longitude: represents the maximum longitude value (in the example in UTM);
- Maximum elevation: represents the maximum value of the synthetic DEM (expressed in meters);
- Radius: represents the radius of the synthetic topographic surface (expressed in meters);
- Exponent: represents the influence in the shape of the attenuation function. Different values of exponent will determine how quickly the elevation will decrease moving away from the source. A higher value of exponent will cause the elevation to decrease more rapidly with distance, while a lower value of exponent will cause a more gradual decrease.
- Position of Mogi Source (rows/columns): represents the coordinates of the spherical Mogi source (must be from the same reference system as the latitude/longitude values);
- Depth of Mogi Source: represents the depth of the Mogi source (expressed in meters);
- Poisson Ratio: represents the Poisson modulus (dimensionless);
- Modulus of Rigidity: represents the modulus of Rigidity of the surrounding medium (expressed in Pascal);
- Pressure Variation of the source: represents the pressure variation that occurs within the source, which can cause the source to expand or contract (is expressed in Pascal);
- Radial Size of the source: represents the radius of the spherical Mogi source (expressed in meters);
- Inclination Angle: represents the angle of inclination from the vertical of the radar sensor (expressed in degrees);
- Azimuth Angle Value: represent the maximum and minimum value of the angle between the line of sight (LOS) of the radar sensor and a horizontal reference direction, often measured clockwise from geographic north (expressed in degrees);

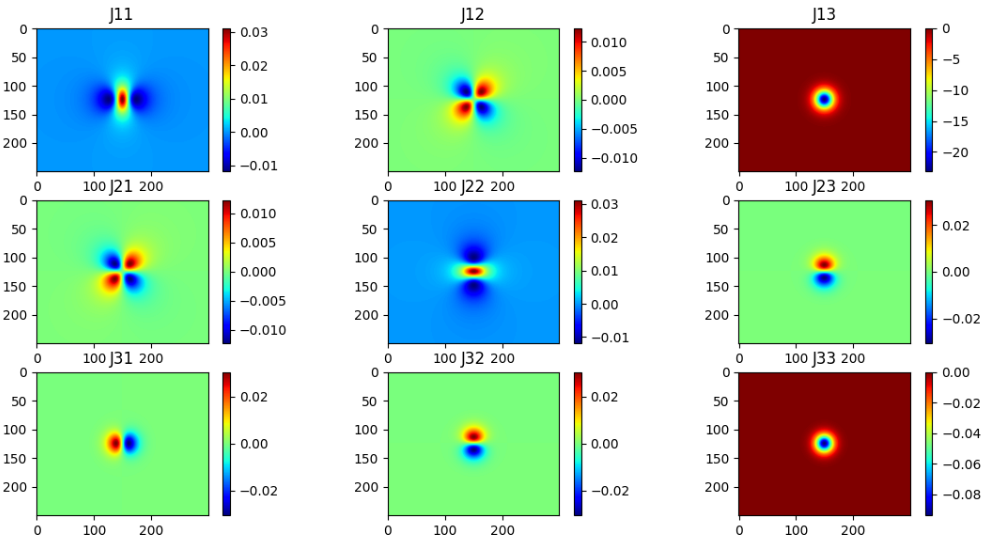
Once you have entered the parameters, you can click on the "Insert" button.

In the terminal of the main screen, a summary of the data entered will appear.

- Initially, the plot for the synthetic DEM will be displayed;




- The plot containing the partial derivatives of the Jacobian matrix, with respect to the spatial coordinates of the Mogi source, will then be displayed.



- The surface strain field caused by the spherical Mogi source (in the expanding example) along the x,y,z spatial components will then be displayed;
- The two synthetic LOSs will then be displayed;

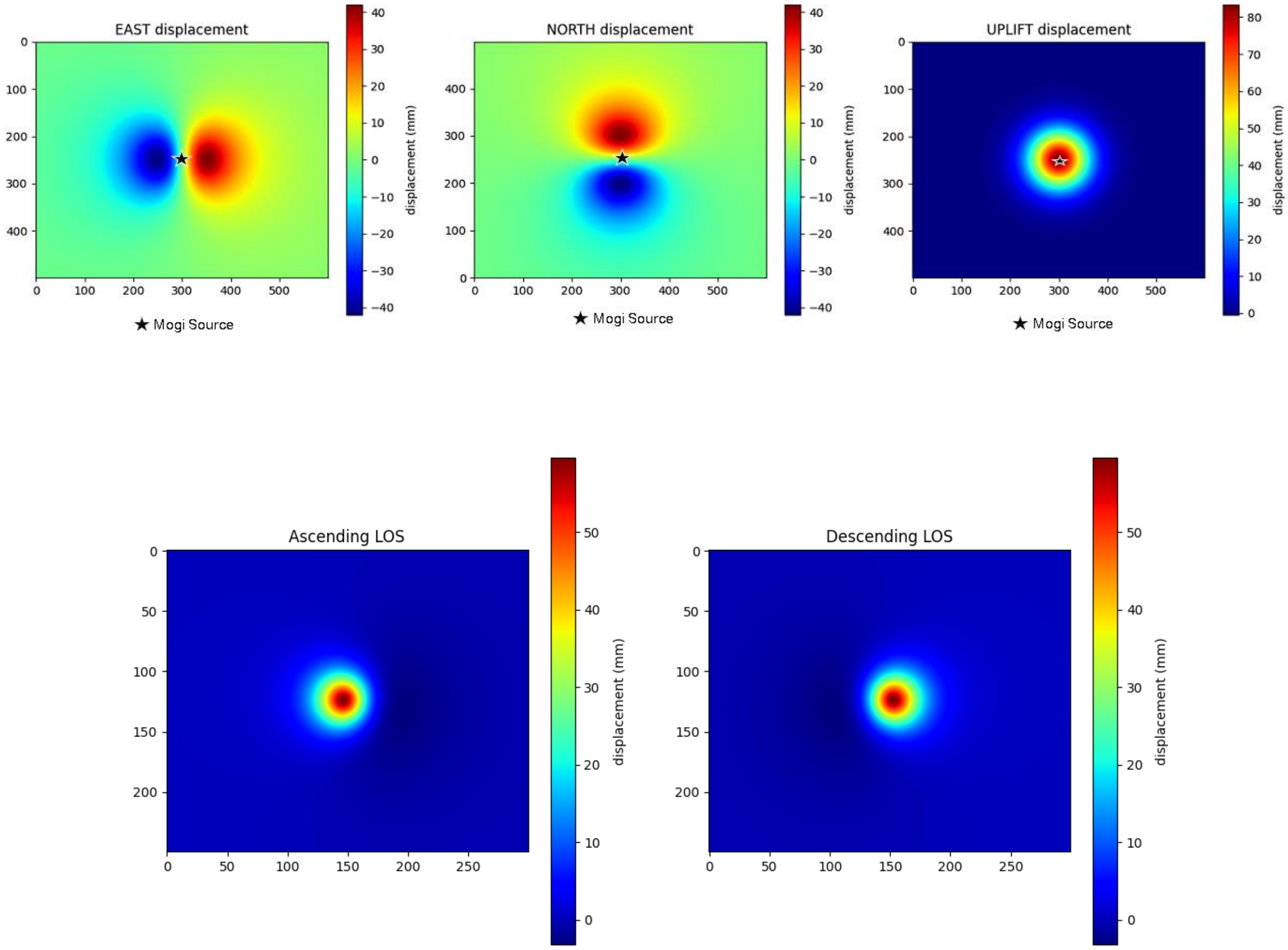



*Fig.9: Top: Synthetic soil deformation maps for the 3 components, generated from a Mogi point source (black star). Note that displacements are expressed in mm for ease of reading. The user will obtain the displacements in meters. Bottom: Maps of ascending and descending LOS (Line Of Sight) expressed in mm. Note that, again, the user will get the maps in meters.*

NOTE: All variables will be saved as ASCII files

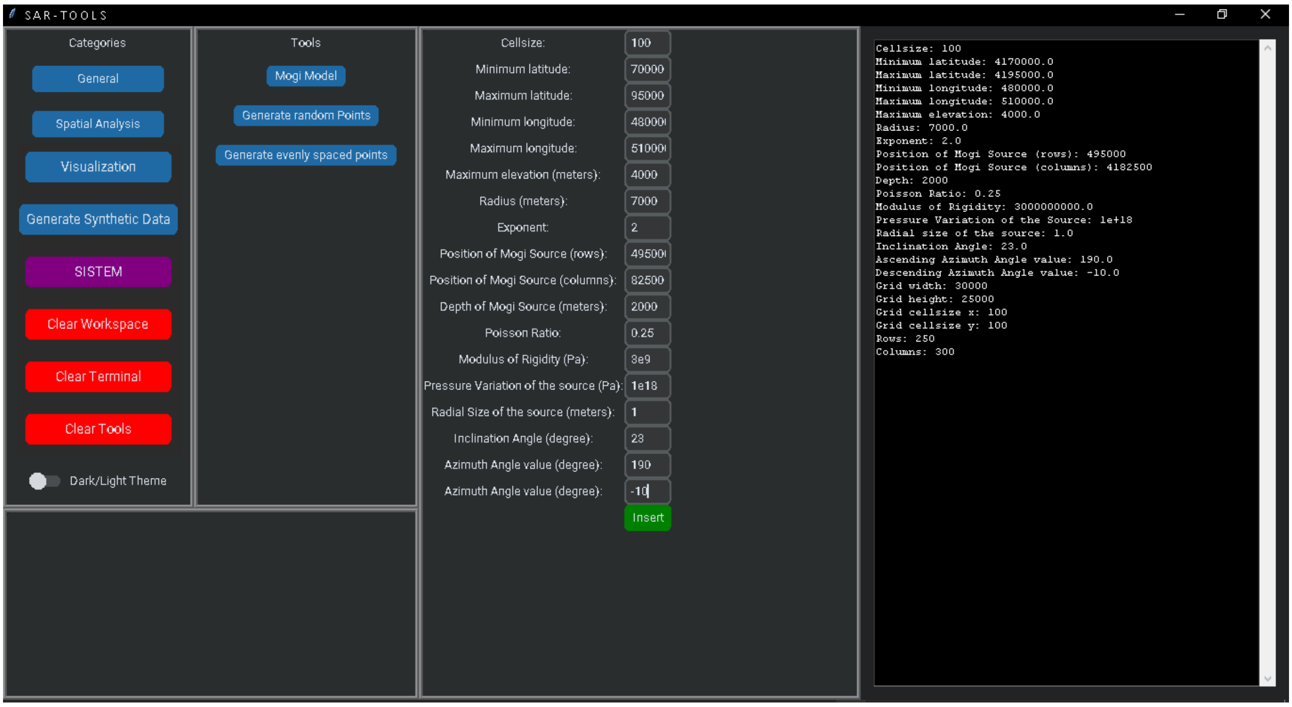



*Fig.10: SAR-TOOLS screen with workspace related to Mogi Model input parameters. On the far right of the screen you can view the output of the input data and other information useful in developing the Mogi model.*

### *4.4.2 GENERATE RANDOM POINTS*

This tool allows generating random synthetic GPS points based on Digital Elevation Model (DEM) data and displacement information in the East-West (x), North-South (y) and vertical (z) directions.

This represents an Excellent way to then test the functionality of the SISTEM algorithm from synthetic/real data, depending on the points within the DEM grid.

The interface consists of the following elements:

- **DEM File**: An input field to specify the DEM file (.asc format).
- **Displacement File E-W (x)**: An input field for the East-West displacement data file (.asc format).
- **Displacement File N-S (y)**: An input field for the North-South displacement data file (.asc format).
- **Vertical Displacement File (z)**: An input field for the vertical displacement data file (.asc format).
- **Number of GPS Points**: An input field to specify the number of random GPS points to be generated.
- **Error Value x**: An input field for the error value in the x direction (in meters).
- **Error Value y**: An input field for the error value in the y direction (in meters)
- **Error Value z**: An input field for the error value in the z direction (in meters).

Once all fields have been selected correctly, click on the green 'Insert' button.

If the operation was successful, you will get 'Your Random GPS points are created' on the GUI terminal.

NOTES: the file will be in '.txt' format; The number of synthetic GPS points you can generate will depend on the size of your DEM.

### 4.4.3 EVENLY SPACED POINTS

This tool has the functionality similar to the tool discussed earlier "Generate Random Points."

The difference lies in the choice of the number of synthetic GPS points to be generated.

Whereas in the "Generate Random Points" tool one must enter the number of points, in this case, in order to generate equidistant points within the grid, one will need to choose an appropriate "Sampling Rate Value s."

*Example: If we choose s=10, it means that a single point will be selected for every 10 points.*

The user will be informed of the number of points that the sampling rate step will generate and, if necessary, can change it to the number of points he or she prefers.

NOTE: Be careful, as the number of points that can be obtained always depends on the resolution of the DEM grid that sis ta using.

In Fig. 11 you can See an example of how the tool works, appropriately choosing a sampling step s=70 which, on a grid (DEM) with 250x300 resolution, is equivalent to 20 equispaced synthetic GPS points.

NOTE: The formatting in Fig. 12 will be the same for The points generated through the Generate random points tool.

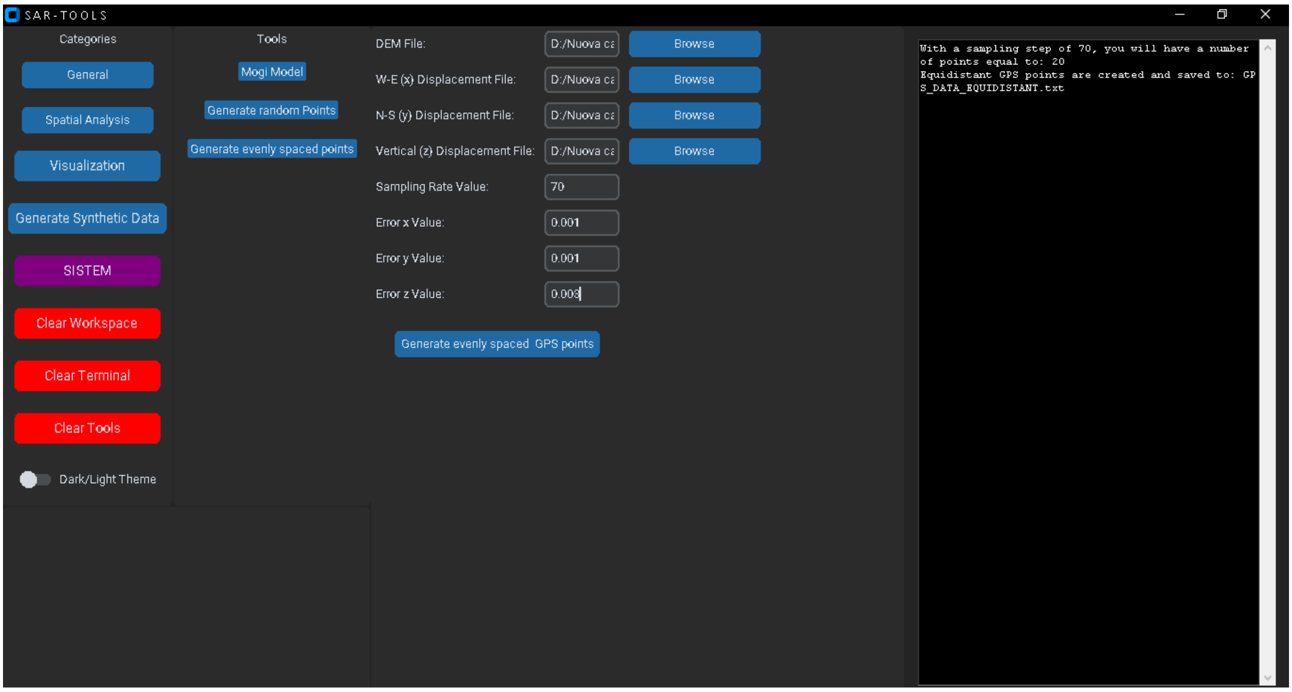



*Fig. 11: Screenshot of SAR-TOOLS with the workspace related to the Generate evenly spaced points tool. On the extreme right of the screen, it is possible to view the output information related to the sampling steps and the number of synthetic GPS points created, including the path of the .txt file.*

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 480000.000000 | 4170000.000000 | 2.379782 | -0.004770 | -0.003972 | 0.001276 | 0.003000 | 0.003000 | 0.009000 |
| 485000.000000 | 4170000.000000 | 30.199493 | -0.005607 | -0.007015 | 0.002254 | 0.003000 | 0.003000 | 0.009000 |
| 490000.000000 | 4170000.000000 | 138.135255 | -0.004527 | -0.011386 | 0.003658 | 0.003000 | 0.003000 | 0.009000 |
| 495000.000000 | 4170000.000000 | 227.746533 | 0.000056 | -0.013919 | 0.004472 | 0.003000 | 0.003000 | 0.009000 |
| 500000.000000 | 4170000.000000 | 135.344740 | 0.004583 | -0.011299 | 0.003630 | 0.003000 | 0.003000 | 0.009000 |
| 505000.000000 | 4170000.000000 | 28.991678 | 0.005601 | -0.006938 | 0.002229 | 0.003000 | 0.003000 | 0.009000 |
| 480000.000000 | 4175000.000000 | 16.041387 | -0.007376 | -0.003676 | 0.001974 | 0.003000 | 0.003000 | 0.009000 |
| 485000.000000 | 4175000.000000 | 203.565621 | -0.011173 | -0.008365 | 0.004492 | 0.003000 | 0.003000 | 0.009000 |
| 490000.000000 | 4175000.000000 | 931.127837 | -0.013155 | -0.019800 | 0.010631 | 0.003000 | 0.003000 | 0.009000 |
| 495000.000000 | 4175000.000000 | 1535.170270 | 0.000207 | -0.030803 | 0.016538 | 0.003000 | 0.003000 | 0.009000 |
| 500000.000000 | 4175000.000000 | 912.317819 | 0.013214 | -0.019494 | 0.010467 | 0.003000 | 0.003000 | 0.009000 |
| 505000.000000 | 4175000.000000 | 195.424104 | 0.011089 | -0.008220 | 0.004414 | 0.003000 | 0.003000 | 0.009000 |
| 480000.000000 | 4180000.000000 | 38.975264 | -0.009716 | -0.001592 | 0.002600 | 0.003000 | 0.003000 | 0.009000 |
| 485000.000000 | 4180000.000000 | 494.597113 | -0.018688 | -0.004602 | 0.007513 | 0.003000 | 0.003000 | 0.009000 |
| 490000.000000 | 4180000.000000 | 2262.332593 | -0.039021 | -0.019313 | 0.031532 | 0.003000 | 0.003000 | 0.009000 |
| 495000.000000 | 4180000.000000 | 3729.955868 | 0.001211 | -0.059337 | 0.096876 | 0.003000 | 0.003000 | 0.009000 |
| 500000.000000 | 4180000.000000 | 2216.630475 | 0.038559 | -0.018707 | 0.030542 | 0.003000 | 0.003000 | 0.009000 |
| 505000.000000 | 4180000.000000 | 474.815920 | 0.018417 | -0.004490 | 0.007330 | 0.003000 | 0.003000 | 0.009000 |
| 480000.000000 | 4185000.000000 | 34.133323 | -0.009686 | 0.001652 | 0.002592 | 0.003000 | 0.003000 | 0.009000 |
| 485000.000000 | 4185000.000000 | 433.152758 | -0.018573 | 0.004760 | 0.007466 | 0.003000 | 0.003000 | 0.009000 |
| 490000.000000 | 4185000.000000 | 1981.280476 | -0.038400 | 0.019782 | 0.031030 | 0.003000 | 0.003000 | 0.009000 |
| 495000.000000 | 4185000.000000 | 3266.579264 | 0.001171 | 0.059712 | 0.093666 | 0.003000 | 0.003000 | 0.009000 |
| 500000.000000 | 4185000.000000 | 1941.255983 | 0.037958 | 0.019167 | 0.030066 | 0.003000 | 0.003000 | 0.009000 |
| 505000.000000 | 4185000.000000 | 415.829005 | 0.018305 | 0.004645 | 0.007286 | 0.003000 | 0.003000 | 0.009000 |
| 480000.000000 | 4190000.000000 | 10.774831 | -0.007320 | 0.003697 | 0.001959 | 0.003000 | 0.003000 | 0.009000 |
| 485000.000000 | 4190000.000000 | 136.732879 | -0.011027 | 0.008367 | 0.004433 | 0.003000 | 0.003000 | 0.009000 |
| 490000.000000 | 4190000.000000 | 625.428738 | -0.012853 | 0.019604 | 0.010386 | 0.003000 | 0.003000 | 0.009000 |
| 495000.000000 | 4190000.000000 | 1031.157663 | 0.000200 | 0.030259 | 0.016031 | 0.003000 | 0.003000 | 0.009000 |
| 500000.000000 | 4190000.000000 | 612.794248 | 0.012913 | 0.019306 | 0.010229 | 0.003000 | 0.003000 | 0.009000 |
| 505000.000000 | 4190000.000000 | 131.264308 | 0.010946 | 0.008223 | 0.004357 | 0.003000 | 0.003000 | 0.009000 |

*Fig. 12: Content of the text file generated through the Generate evenly spaced points tool. From left: UTM Longitude (m), UTM Latitude (m), Elevation (m), West-East Displacement (WED) (m), North-South Displacement (NSD) (m), Vertical Displacement (VD) (m), Error (WED) (m), Error (NSD) (m), Error (VD) (m).*

## 4.5 SISTEM algorithm

In this section, we illustrate how to execute and use the SISTEM algorithm [Guglielmino et al., 2011] through the SAR TOOLS GUI.

By clicking on the 'SISTEM' button in the Categories section, a series of boxes for entering the input data useful for the SISTEM algorithm will appear in the Workspace.

The inputs are:

- **Select DEM Data**: Click on the "Select.." button and choose the DEM file (in .asc format);
- **Steps**: Select the sampling step with which the algorithm will subsample the output data. (Example: for a 100x100 grid, with steps=10, you will end up with a 10x10 grid). This way, the calculation will be faster (at the expense of lower resolution). If you wish to maintain the same resolution as the starting grid, select steps=1;
- **GPS data**: Select the file (in .txt format) containing the GPS data. Remember that the file must be formatted as in the figure (insert number).
- **First Sar**: Select the file (in .asc format) related to the SAR data you have (ascending or descending). Note that 'First' does not specifically refer to the ascending orbit (if you have both ascending and descending data). It is up to the user to decide which orbit to use;
- **First Lia**: Select the file (in .asc format) related to the LIA (Local Incidence Angle) data you have (ascending or descending). Note that, for the purposes of the SISTEM algorithm, the LIA data is optional. If the user does not have this data, it is necessary to specify the value of the inclination angle (in degrees);
- **First Azimuth Angle**: Enter the value of the azimuth angle (in degrees) related to the First Sar;
- **First Inclination Angle**: Enter the value of the inclination angle (in degrees) related to the First Lia. Note that, even if the user does not enter Lia data, it is necessary to enter an inclination angle to be associated with the Lia matrix of the SISTEM algorithm;
- **Second Sar**: Select the file (in .asc format) related to the SAR data you have (ascending or descending). Note that 'Second' does not specifically refer to the descending orbit (if you have both ascending and descending data). It is up to the user to decide which orbit to use;
- **Second Lia**: Select the file (in .asc format) related to the LIA (Local Incidence Angle) data you have (ascending or descending). Note that, for the purposes of the SISTEM algorithm, the LIA data is optional. In this case, only the 'First Inclination Angle' needs to be specified, which will be associated with the Lia data;
- **Sigma Sar**: Enter the error value (in meters) to be associated with the Sar data (First and/or Second Sar);
- **Locality LEV**: This parameter represents the standard deviation of errors (expressed in meters) in the line-of-sight angle of each SAR image. Within the SISTEM algorithm, this value is used to calculate the weights associated with the SAR observations used to minimize the effect of measurement errors when combining different observations to estimate ground deformations. Note that this parameter is optional, and the choice of whether to enter a value is left to the user;
- **Levelling Data**: Enter the file (in .asc format) related to the levelling data. This data is optional, and its absence does not affect the execution of the SISTEM algorithm;
- **Sigma Levelling**: This parameter represents the standard deviation of errors (expressed in meters) of the 'Levelling Data'. This parameter is optional and the box should be left empty if no data is entered in 'Levelling Data';
- **K locality value**: This parameter is used to calculate the locality matrix within the SISTEM algorithm. This matrix represents the average distances between each pixel of the DEM and the k-nearest points of the GPS point array. In particular, for each point of the DEM, the Euclidean distance between the points in the GPS array is calculated. The parameter k indicates how many nearest

points to consider. By default, 9 nearest points are considered, but the user can modify this parameter as desired.

- **Locality Denominator**: This parameter represents the scaling factor that normalizes the locality matrix. By default, a value of 2 is considered, which means that the locality matrix will be halved, thereby less influencing the weighting of GPS points in the calculation of ground deformation maps.

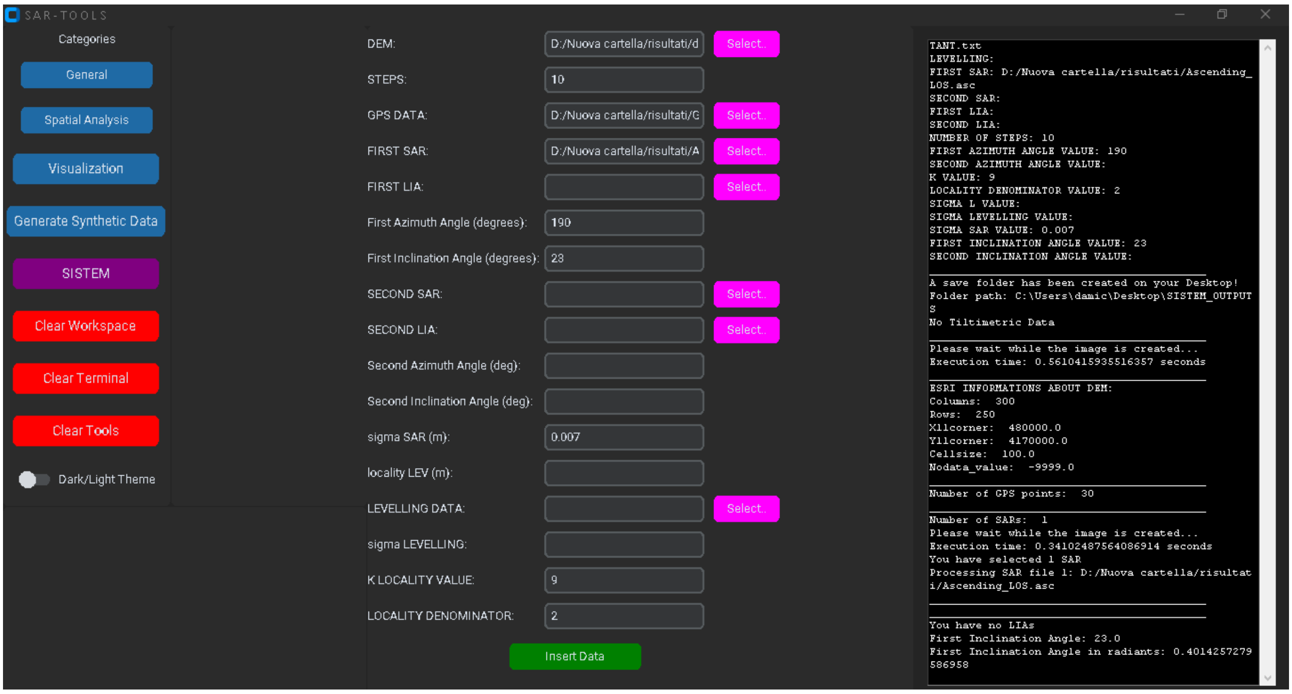
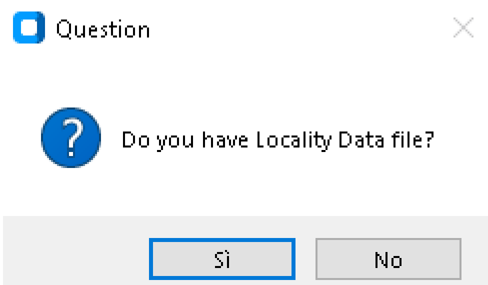
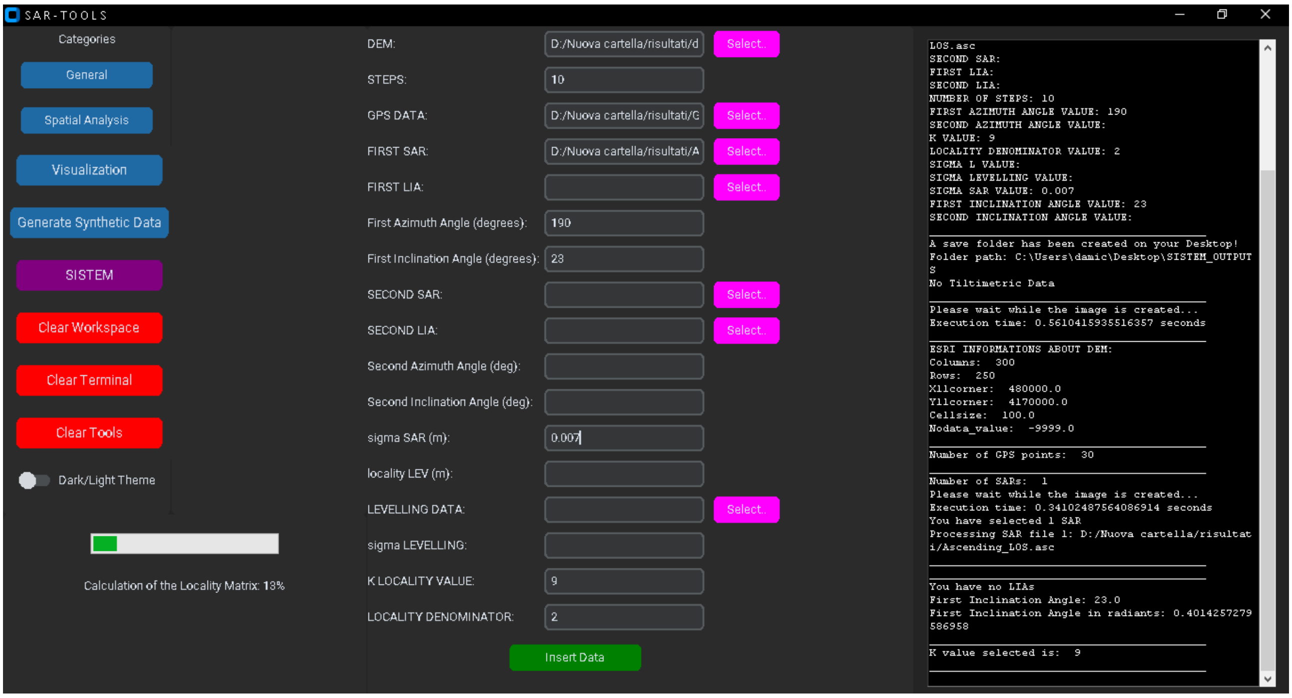


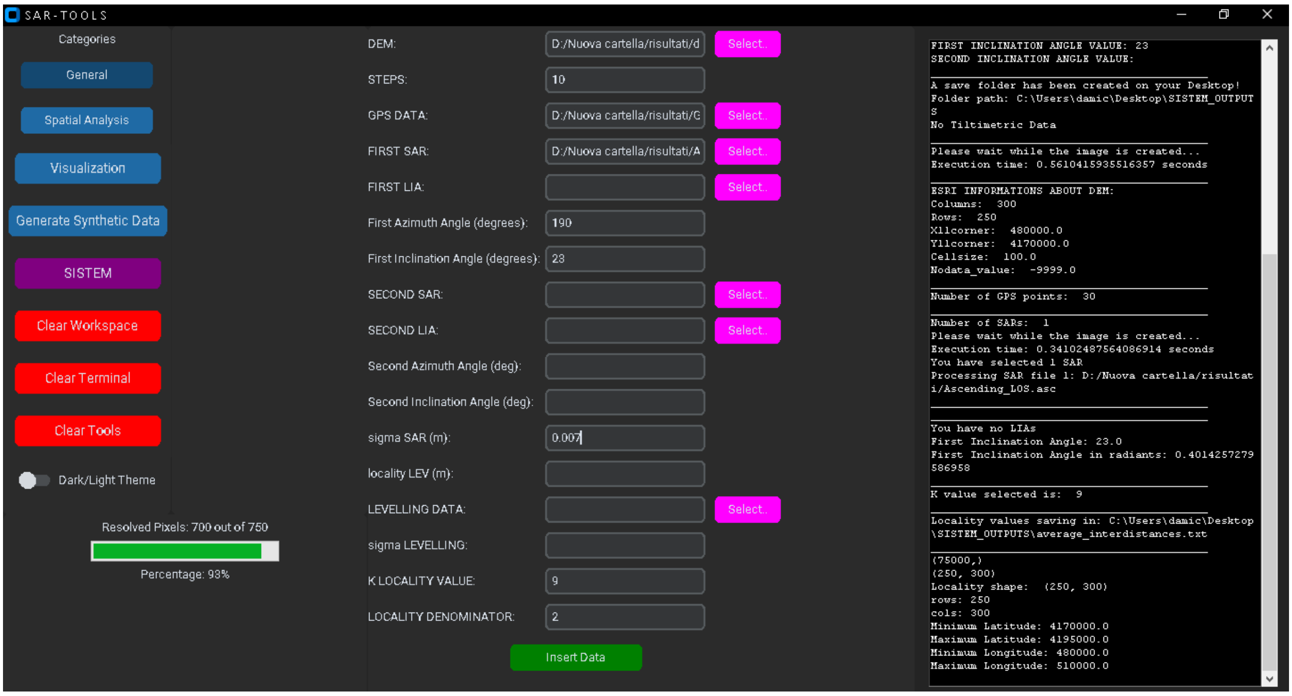

*Fig. 13: Screenshot of SAR-TOOLS and workspace related to the SISTEM tool. On the extreme right of the screen, inside the terminal, the information entered during the input phase is displayed.*

After entering the input parameters, click on 'Insert Data' and the algorithm will process the data. In the terminal to the right of the SAR TOOLS GUI, information related to all our input data can be observed. At a certain point, an informative window will appear asking the user if they have the locality matrix data (in .txt format). If not, click on 'No', and the progressive calculation of the locality matrix will begin, which can be observed within SAR TOOLS. Otherwise, click on 'Yes' and select the data.






After the calculation (or input) of the locality matrix, a new progress bar will appear in SAR TOOLS indicating the progress of the algorithm in solving the weighted least squares method for each pixel of our DEM, based on the value of steps decided by the user during the input phase.




At the end of the calculation, a folder named 'SISTEM_OUTPUTS' will be created directly on the user's desktop. This folder will contain all the outputs (in various formats) processed by the SISTEM algorithm within SAR TOOLS.

These outputs include:

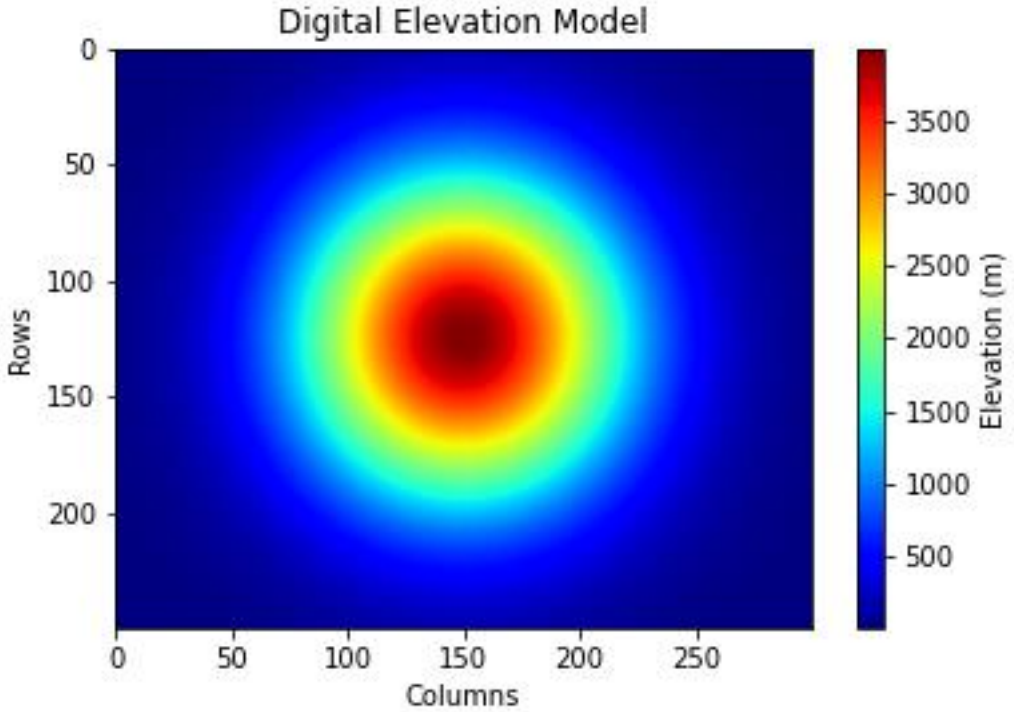
- **The DEM** (in .asc and .png formats);
- **The GPS data** (in .txt format and the map with the GPS points and associated displacement vectors in .png);
- **The SAR data** (in .png format);
- **The Lia data** (if entered, in .png format);
- **The locality matrix data** (in .txt format and the locality map in .png format);
- **The displacement data** (in .asc format and the displacement maps (and error) along the West-East, North-South, and Vertical components in .png format). The black stars in the various maps identify the individual GPS points;
- **The strain data** (in .asc format and the strain maps in 2D and 3D in .png format).

Please note that, if you wish to perform further analysis using the SISTEM algorithm, it is recommended, but not mandatory, to click on 'Clear Terminal' before starting a new analysis. Subsequently, a new folder, always on the user's desktop, named 'SISTEM_OUTPUTS' followed by a sequential number (e.g., SISTEM_OUTPUTS_2) will be created.

In Figs. 14, 15, 16, 17, an example of outputs obtained using:

- The synthetic DEM of a homogeneous volcano with a maximum altitude of 4000 meters.
- The map depicting 20 GPS points evenly spaced within the DEM grid with associated displacement vectors relative to a Mogi source placed at the center of the grid;
- The representation of the ascending LOS;
- The map of the locality matrix relative to the GPS points;
- The displacement maps along the 3 components and the errors associated with them;
- The strain maps in 2D (Left Column) and 3D (Right Column);

Note that all the input data used are synthetic data generated and processed within SAR-TOOLS, using its analysis tools.



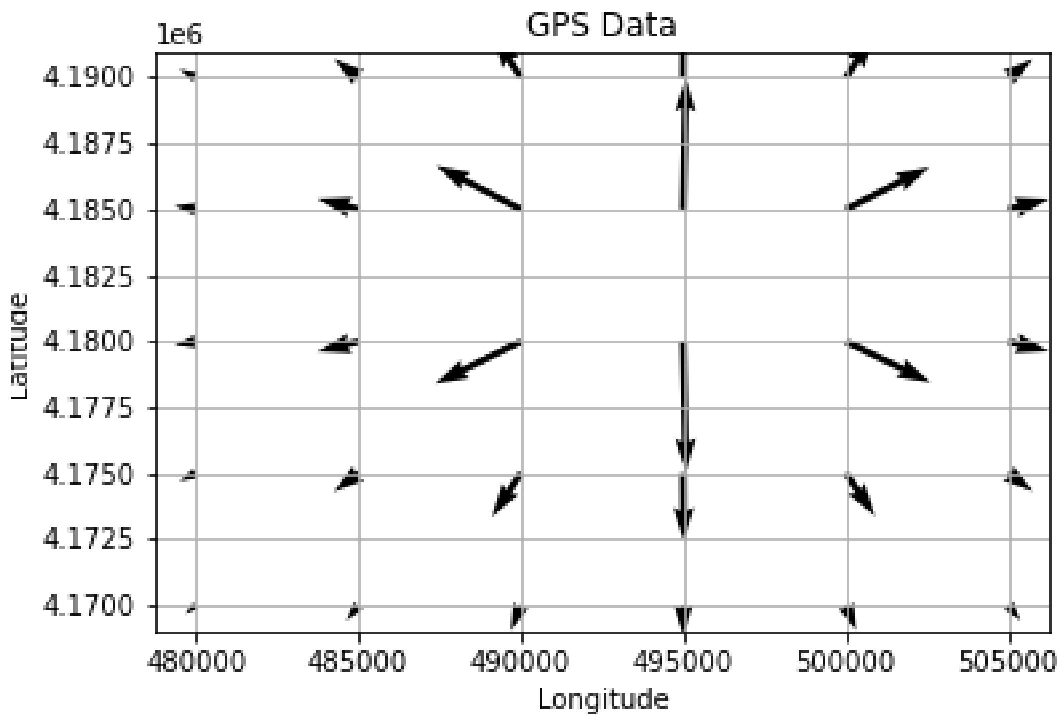
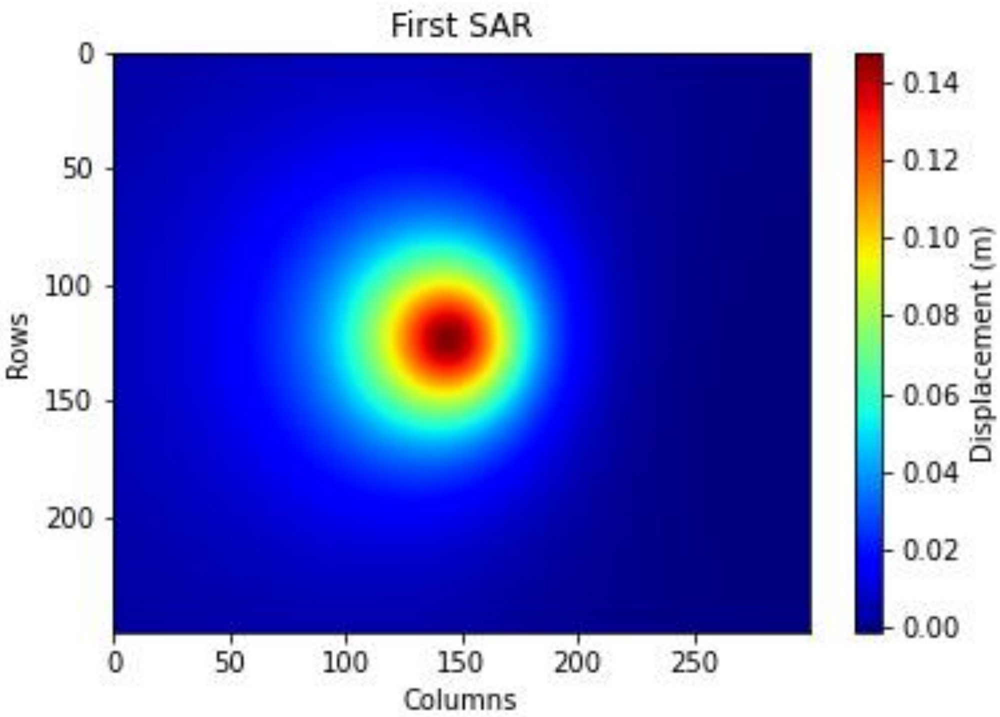




*Fig. 14: At the top: DEM defined during input phase. At the bottom: GPS vector displacement field. Each arrow is related to a GPS point.*



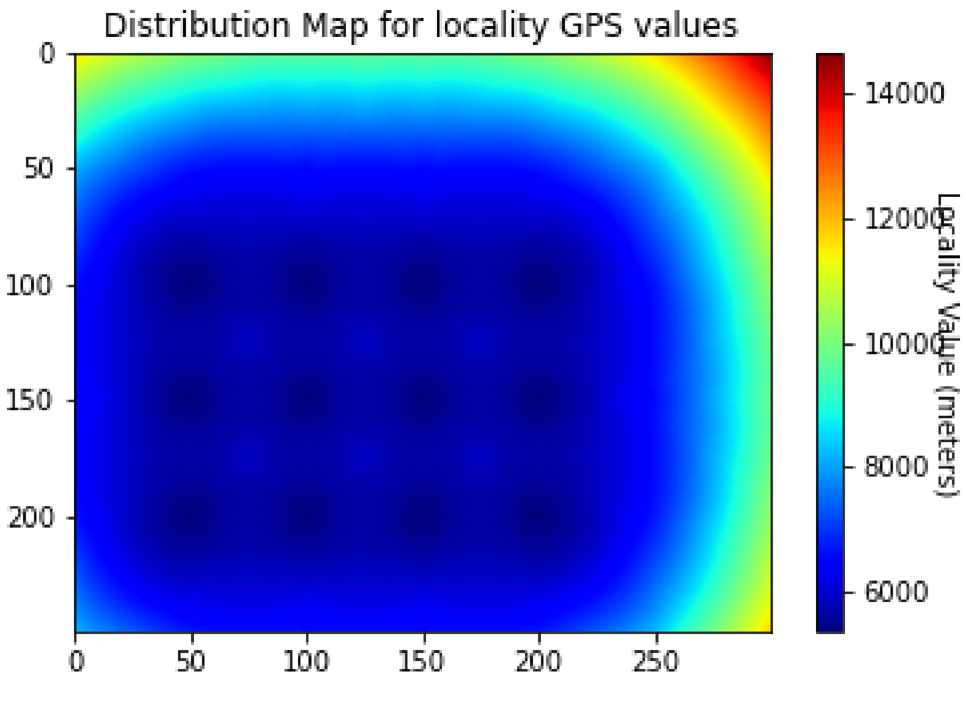




*Fig. 15: At the top: LOS (ascending) defined during the input phase. At the bottom: visual representation of the locality matrix, containing each single locality value (expressed in meters estimated based on the GPS points.*

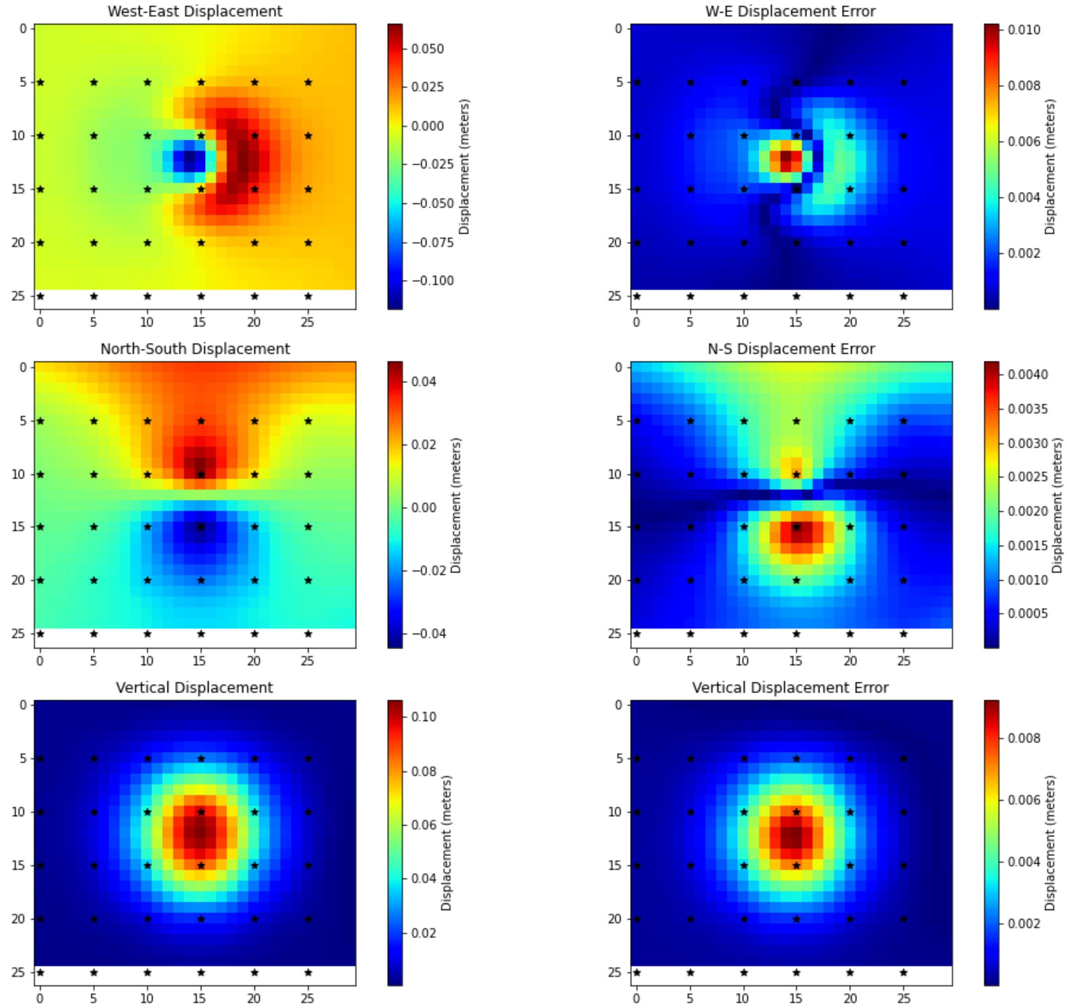



*Fig. 16: In the left column: ground deformation maps along the 3 components (West-East, North-South, Vertical). The unit of measurement is meters. In the right column: Error maps associated with the 3 components. The black stars represent the synthetic GPS points.*

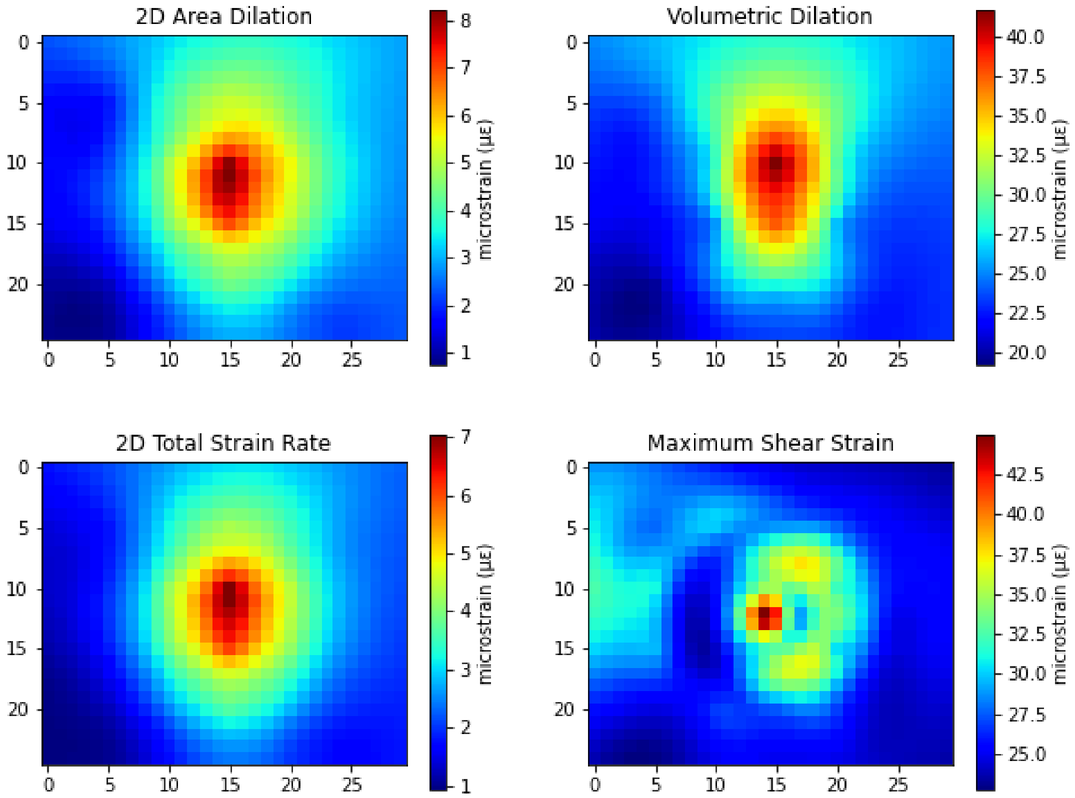



*Fig. 17: In the left column: two-dimensional strain maps. The unit of measurement is microstrain. In the right column: Three-dimensional strain maps.*

# CONCLUSION

We have walked the path together that guides you through the features, advice and best practices to get the most out of our product. We hope you have found this manual useful and intuitive, designed to make your experience with SAR-TOOL as simple and rewarding as possible.

The SAR-TOOL represents the culmination of a substantial commitment to providing advanced tools and accessible solutions to our users. To ensure effective use and give due recognition to the efforts of our team, we encourage you to use the Digital Object Identifier (DOI) when citing the SAR-TOOL in your research or in any publication.

For questions, support or feedback, please do not hesitate to contact us and thank you for choosing to use the SAR-TOOL.