

Modeling Tutorial

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Introduction

This tutorial goes through a set of modeling tasks to get an overview of the main functionalities. The tutorial starts from the output of an InSAR processing, carried out with SARscape, of the M_w 6.6 earthquake occurred near Bam (Iran) on December 26th, 2003. After obtaining from the raster InSAR map the shapefile of sampled points to model, the coseismic signal is modeled via Non-Linear and Linear inversions, to infer fault geometry, kinematic rupture mechanism and slip distribution. A stress-transfer is then calculated, simulating the presence of another fault close to the modeled one. The modeled fault is also used with forward modeling to generate the raster map of the predicted displacement, eventually projected into the original Line-Of-Sight, unwrapped and wrapped.

Though this tutorial shows the main modeling features, it is not exhaustive of all the software potentialities and flexibility. We strongly suggest to refer also to the SARscape online help to know all the options not involved in this tutorial.

We highlight that good modeling results cannot be obtained by only tuning algorithm parameters: strategies and approaches could be very different according to problem complexity and their effectiveness strongly increase only with experience.

Tips and **notes** are also provided to improve modeling strategies and functionalities not exploited in this tutorial.

The Bam event data

This tutorial is based on the displacement map generated with a pair of SAR images acquired by the Envisat satellite (European Space Agency). This map has been obtained with an interferometric processing carried out with the SARscape interferometric module; the images have been acquired on December 3rd, 2003 and February 11th, 2004 and have a spatial baseline of about 4 m. In this tutorial the displacement is modeled with a single fault with distributed slip.

Refer to the cited literature (Wang et al., 2004; Funning et al, 2005) for a review of the event.

REFER TO YOUR LOCAL DISTRIBUTOR TO GET THE DATA FOR THIS TUTORIAL.

To run the tutorial, you need the following files:

- **Bam_envisat_dsc_disp**: displacement map (m) obtained from a descending Envisat image pair;
- **Bam_envisat_dsc_ALOS**: map of the Line-Of-Sight azimuth angle;
- **Bam_envisat_dsc_ILOS**: map of the Line-Of-Sight incident angle;
- **Bam_SRTM_dem**: SRTM digital elevation model with 90 m resolution.

Data are UTM-WGS84, Zone 40 North.

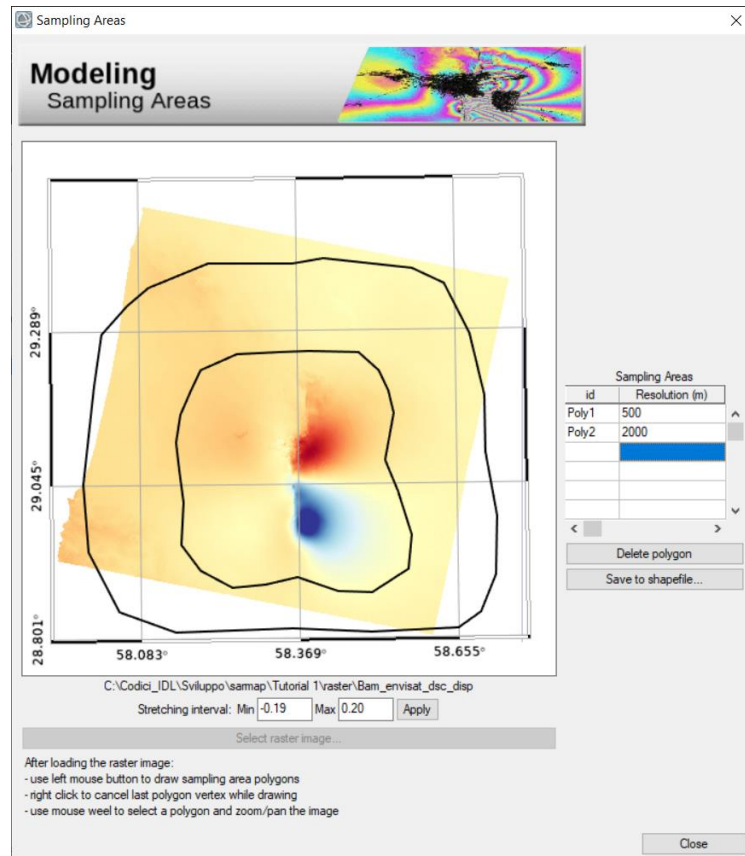
The XML Project File

All the main modeling panels are based on the XML Project File. This file allows to save and restore the configuration of any processing. Read more about the XML Project File in the SARscape online help. The XML Project File for this tutorial will be **ModelingProject.xml**.

Sampling Areas

MENU: SARSCAPE – INTERFEROMETRY - DISPLACEMENT MODELING - SAMPLING AREAS

Image sampling is required, in the case of InSAR data, to reduce the number of points to model. This panel allows to load a raster image (**Bam_envisat_dsc_disp**) and to draw polygons defining the areas where points must be sampled with a given resolution: 500 m for the inner polygon, containing most of the signal, and 2000 m for the outer polygon. Use the left mouse button to draw two polygons like those in figure and set the resolutions in the table.



Then, click on "Save to shapefile..." to save your polygons to the **SamplingAreas.shp** output shapefile.

Note: along this tutorial, negligible source parameter differences will derive from the way you define the polygons.

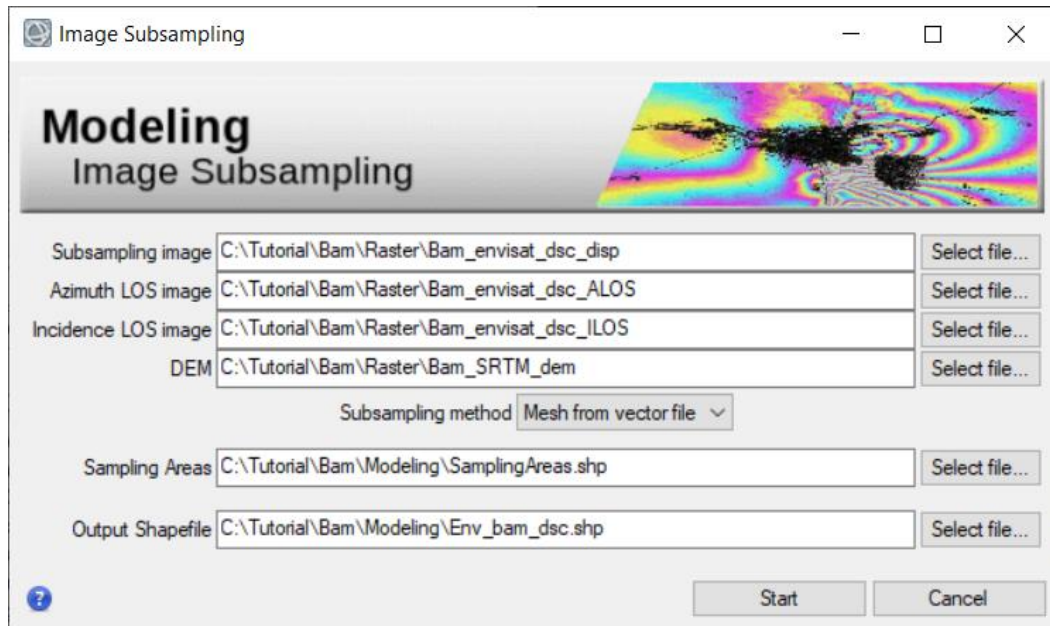
Output files: **SamplingAreas.shp** (shapefile of polygons defining the sampling areas and spatial rate)

Image sampling

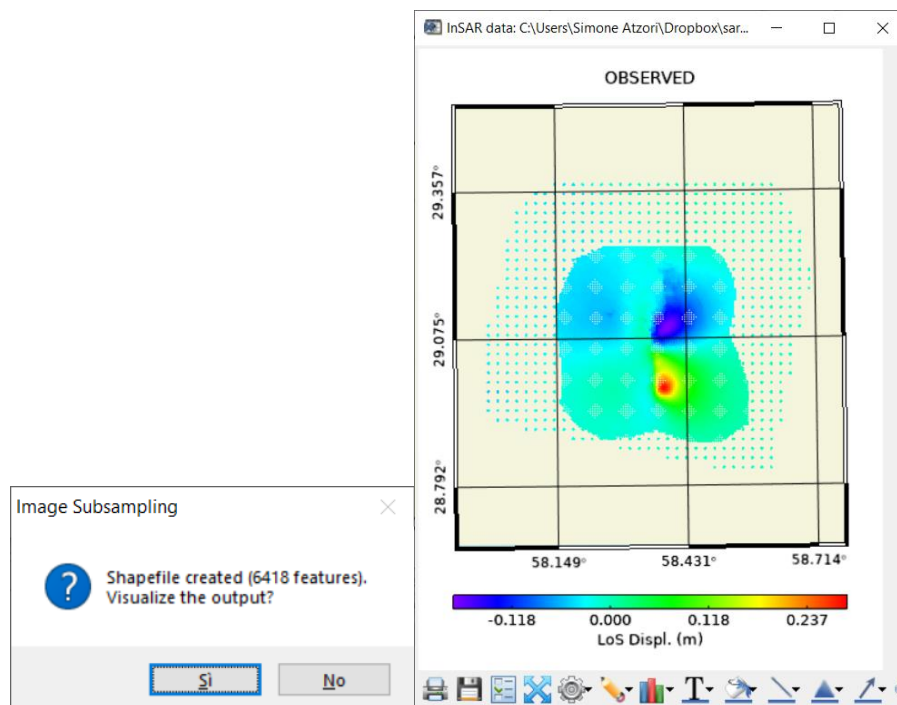
MENU: SARSCAPE – INTERFEROMETRY - DISPLACEMENT MODELING – TOOLS - IMAGE SUBSAMPLING"

Image subsampling can be carried out with two different approaches: with regular meshes of points over specific areas or with the Quadtree algorithm. In this tutorial we use the first approach, using the **SamplingAreas.shp** file created above.

The panel must be filled with the raster output of the InSAR processing (**Bam_envisat_dsc_disp**, **Bam_envisat_dsc_ALOS**, **Bam_envisat_dsc_ILOS**, **Bam_SRTM_dem**, as in figure) setting also the name of the output point shapefile (**Env_bam_dsc.shp**)



After the sampling is completed, check the number of sampled points and the output



Note: for overlapping areas (the inner polygon is completely contained in the outer) the sampling algorithm picks points with the finer resolution, 500 m in this case.

Tip: in general, an arbitrary number of datasets can be simultaneously inverted: keep a reasonable number of points for every dataset to avoid a computational excess load.

Tip: always check the shapefile attribute table (with ENVI or any GIS software) to check the content (see the "InSAR_dataset" online help for further details)

Attribute Viewer: Env_bam_dsc.shp

File Options Help

	East	North	Observed	Coef_east	Coef_north	Coef_up	Elev	Sigma
1	639712.190000	3195285.000000	0.004040	0.389600	-0.029740	0.920500	922.690000	0.020000
2	640212.190000	3195285.000000	0.004140	0.389040	-0.029670	0.920740	912.520000	0.020000
3	640712.190000	3195285.000000	0.003790	0.388480	-0.029590	0.920980	903.960000	0.020000
4	641212.190000	3195285.000000	0.003610	0.387910	-0.029490	0.921220	896.340000	0.020000
5	641712.190000	3195285.000000	0.004370	0.387350	-0.029420	0.921460	888.830000	0.020000
6	642212.190000	3195285.000000	0.004200	0.386790	-0.029330	0.921700	882.360000	0.020000
7	642712.190000	3195285.000000	0.004110	0.386230	-0.029230	0.921940	874.680000	0.020000
8	643212.190000	3195285.000000	0.004930	0.385660	-0.029150	0.922180	867.700000	0.020000
9	643712.190000	3195285.000000	0.002810	0.385100	-0.029080	0.922420	864.910000	0.020000
10	644212.190000	3195285.000000	0.004980	0.384540	-0.028990	0.922650	856.990000	0.020000
11	644712.190000	3195285.000000	0.004700	0.383980	-0.028890	0.922890	853.500000	0.020000
12	645212.190000	3195285.000000	0.003950	0.383410	-0.028810	0.923130	848.680000	0.020000
13	645712.190000	3195285.000000	0.003010	0.382850	-0.028740	0.923360	847.820000	0.020000
14	646212.190000	3195285.000000	0.002950	0.382290	-0.028650	0.923600	850.330000	0.020000
15	646712.190000	3195285.000000	0.001750	0.381730	-0.028550	0.923830	851.720000	0.020000
16	621212.190000	3195785.000000	-0.010700	0.410340	-0.032990	0.911330	1560.440000	0.020000
17	621712.190000	3195785.000000	-0.010130	0.409790	-0.032920	0.911590	1547.160000	0.020000

0 of 6,418 records selected

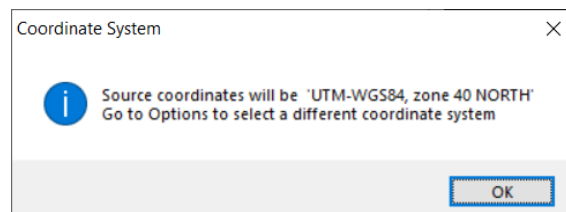
Output files: Env_bam_dsc.shp (shapefile of observed points to invert)

Non-Linear Inversion

MENU: SARSCAPE – INTERFEROMETRY - DISPLACEMENT MODELING - NON-LINEAR INVERSION

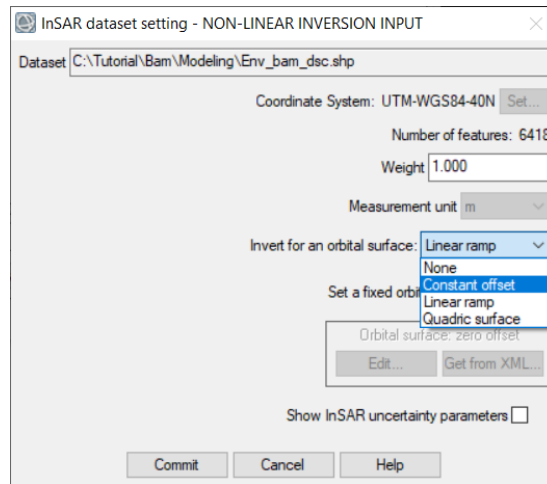
The Non-Linear Inversion is used to find the best-fit source parameters, i.e. those that better predict observed data. As for the main modeling panels, to enable any editing it must be set an XML Project File (see the online help for details). Through the "New..." button, create the **ModelingProject.xml** in an *ad hoc* folder, where all the modeling products will be also placed.

In the "INPUT Datasets" tab add the **Env_bam_dsc.shp** InSAR dataset ("ADD DATASETS – Add from file..."). The first dataset defines the output coordinate system.



Tip: you can select a different coordinate system, for the output sources, in the "Options" tab.

For an InSAR dataset, default option is to assess also parameters of a linear ramp. In this tutorial we assess only a constant shift. Double click on the dataset name or select it and go to "EDIT DATASET – Edit parameters..." and change the "Invert or an orbital surface" choice.



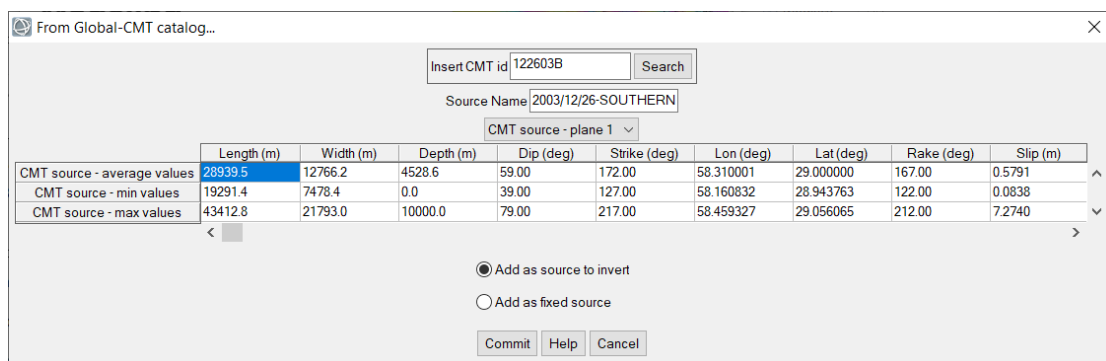
To set the source to invert there are several alternatives. In this tutorial we initialize the source parameters using the Global CMT catalog (<https://www.globalcmt.org/>). You only need the GCMT identifier, that can be retrieved at the page <https://www.globalcmt.org/CMTsearch.html> with the event occurring date (December, 26, 2003, M_w 6.6). The search will find the following result: just copy the identifier (**122603B**).

122603B SOUTHERN IRAN

```
Date: 2003/12/26   Centroid Time: 1:56:58.1 GMT
Lat= 29.10   Lon= 58.24
Depth= 15.0   Half duration= 4.8
Centroid time minus hypocenter time: 5.7
Moment Tensor: Expo=25   0.980 -1.410 0.433 -4.760 -2.550 7.590
Mw = 6.6   mb = 6.0   Ms = 6.8   Scalar Moment = 9.31e+25
Fault plane: strike=172   dip=59   slip=167
Fault plane: strike=269   dip=79   slip=31
```



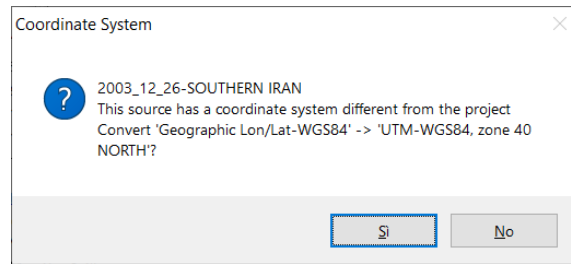
In the "INPUT Sources" tab, go to "ADD SOURCES – Import – From Global-CMT catalog...", set the identifier in the panel and click "Search" (an internet connection is required).



The "CMT source-plane 1" (fault oriented N-S) is the one to be selected in the pulldown menu. According to this choice, average, minimum and maximum values of all the source parameters are proposed. By clicking on "Commit", the source is added in the "INPUT Sources" list.

Note: though the CMT solution contains point-source parameters (strike, dip and rake angles, source location and depth, seismic moment), length, width and slip are automatically derived from Wells & Coppersmith (1994) rules.

The coordinate system for the source is automatically converted to the destination one.



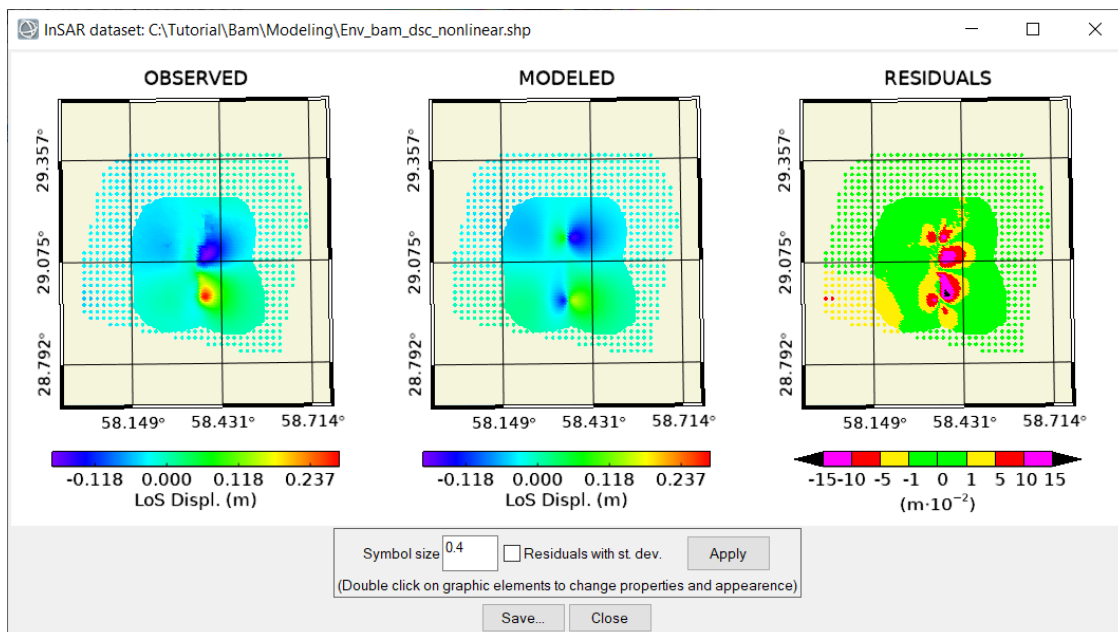
Edit the source (“EDIT SOURCES – Edit parameters...”) to change the source name to *Bam_fault*.

Now that datasets and sources are set, “Save” the XML project file and “Start” to run the inversion.

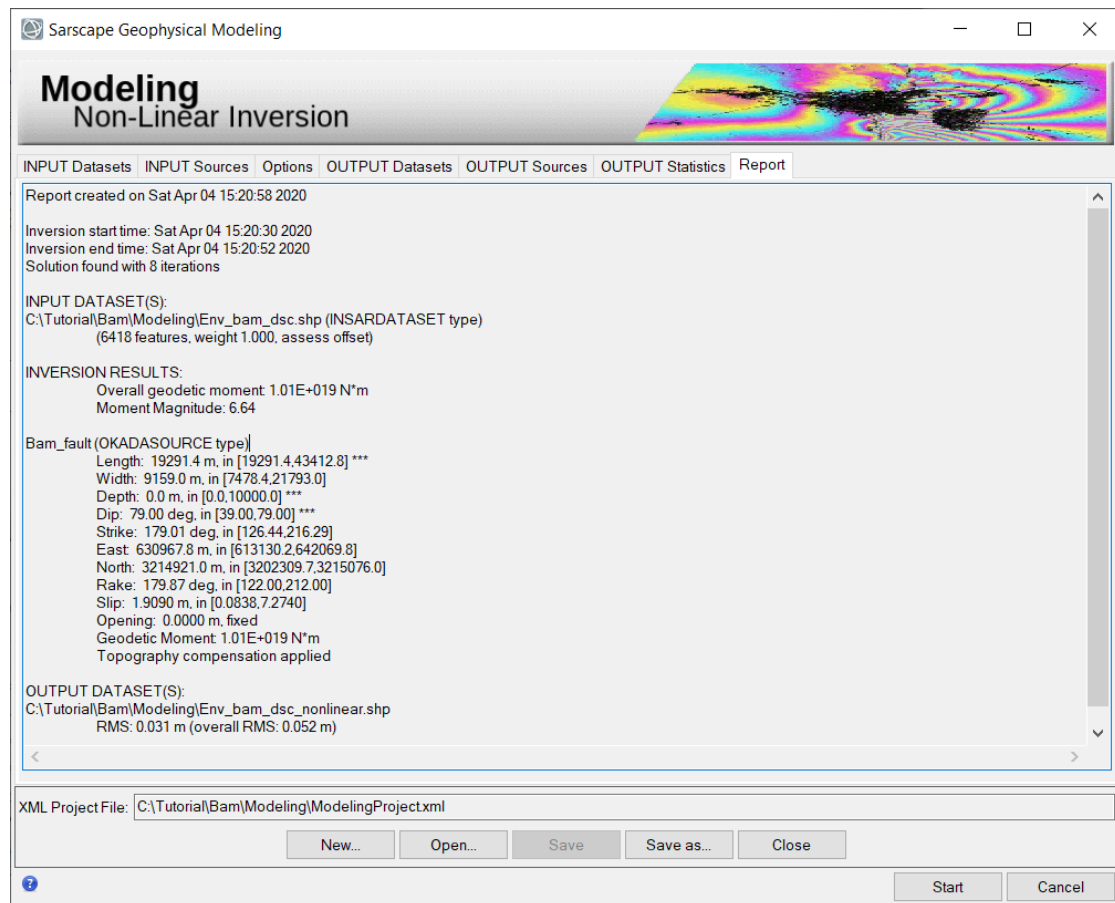
Note: in the Non-Linear inversion the time required to get the best-fit solution is strongly problem dependent. Read the online help for detail about the non-linear inversion algorithm.

After the inversion you’ll be asked to run the Focal Mechanism calculation: answer “No”, it will be done later in this tutorial.

After the processing end, new tabs are added to the panel: “OUTPUT Datasets”, “OUTPUT Sources”, “OUTPUT Statistics” and “Report”. In the “OUTPUT Datasets”, select *Env_bam_dsc_nonlinear.shp* and click on “VIEW DATASETS – Plot 2D” to see a comparison between observed, modeled data, with the residuals.



Select then the “Report” tab to have a synthetic and quantitative overview of the results.



It's important checking if all source parameters fall in the given minimum/maximum ranges or some of them reached an upper or lower limit. This is highlighted through the "****" string; when this occurs, that range parameter must be extended to allow that parameter to reach its best-fit value.

Note: the minimum/maximum range extension strongly affects the time to find a solution: wider ranges (or the largest possible, as 0-360 for strike) are more likely to contain the best fit value, but make the search more time consuming.

Go to "INPUT Sources", and double click *Bam_fault* source (or select it and go to "EDIT SOURCES – Edit Parameters..."). Change the minimum or maximum values as follows:

Elastic dislocation (Okada)

Source Name: Bam_fault

LENGTH (m)	Min 19291.4	Max 43412.8
WIDTH (m)	Min 7478.4	Max 21793.0
DIP (deg)	Min 39.00	Max 79.00
STRIKE (deg)	Min 126.44	Max 216.29
RAKE (deg)	Min 122.00	Max 212.00
SLIP (m)	Min 0.0838	Max 7.2740
OPENING (m)	Min 0.0000	Max 0.0000

Fault reference point

DEPTH (m)	Min 0.0	Max 10000.0
EAST (m)	Min 613130.2	Max 642069.8
NORTH (m)	Min 3202309.7	Max 3215076.0

(1) Fault center - Vertical top edge

Pick from map

ANCILLARY PARAMETERS

'mu' Lamé's constant (Pa) 3.00E+010

'lambda' Lamé's constant (Pa) 3.00E+010

Compensate for topography Yes

Draw Source in ENVI display

Coordinate System: UTM-WGS84-40N

Commit Cancel

Elastic dislocation (Okada)

Source Name: Bam_fault

LENGTH (m)	Min 10000.0	Max 43412.8
WIDTH (m)	Min 5000.0	Max 21793.0
DIP (deg)	Min 39.00	Max 90.00
STRIKE (deg)	Min 0.00	Max 360.00
RAKE (deg)	Min 122.00	Max 212.00
SLIP (m)	Min 0.0838	Max 7.2740
OPENING (m)	Min 0.0000	Max 0.0000

Fault reference point

DEPTH (m)	Min -1000.0	Max 10000.0
EAST (m)	Min 613130.2	Max 642069.8
NORTH (m)	Min 3202309.7	Max 3215076.0

(1) Fault center - Vertical top edge

Pick from map

ANCILLARY PARAMETERS

'mu' Lamé's constant (Pa) 3.00E+010

'lambda' Lamé's constant (Pa) 3.00E+010

Compensate for topography Yes

Draw Source in ENVI display

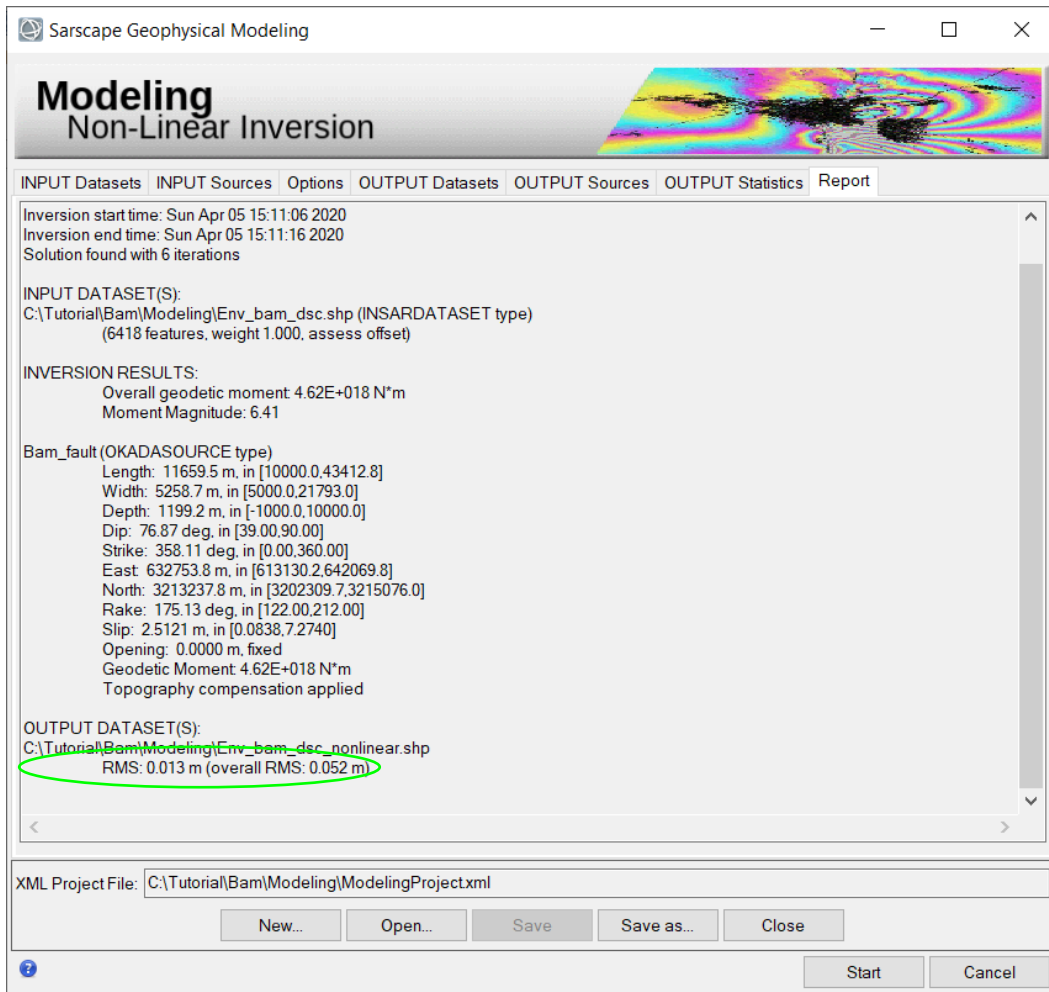
Coordinate System: UTM-WGS84-40N

Commit Cancel

Note: a negative depth value means top fault above the sea level. This condition applies when the "Compensate for topography" option is set (this is true by default).

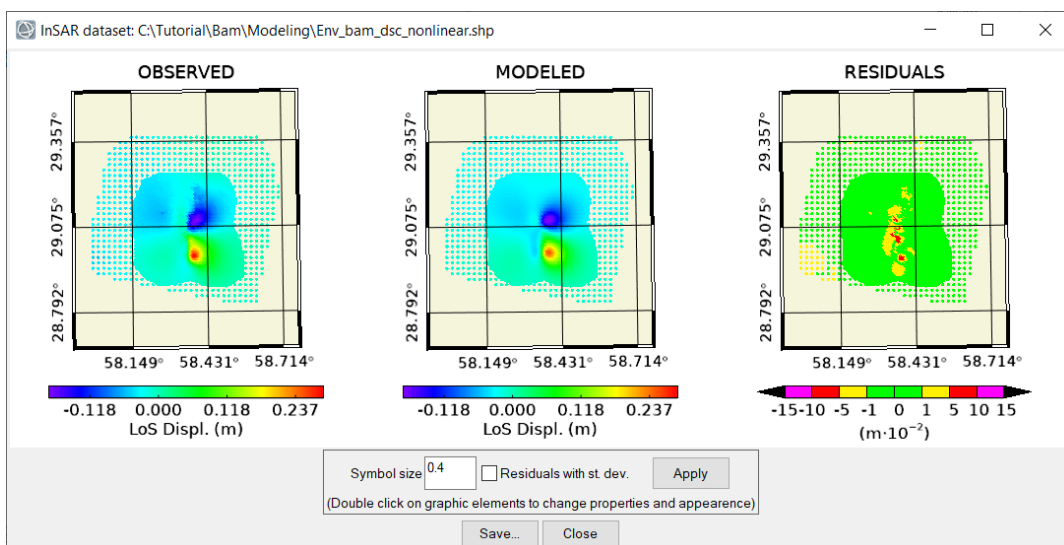
Tip: several inversion runs could be needed, each time adjusting parameters ranges, before getting a solution without "*" close to any parameter.

With the above parameters changes, a stable solution like this one should be obtained



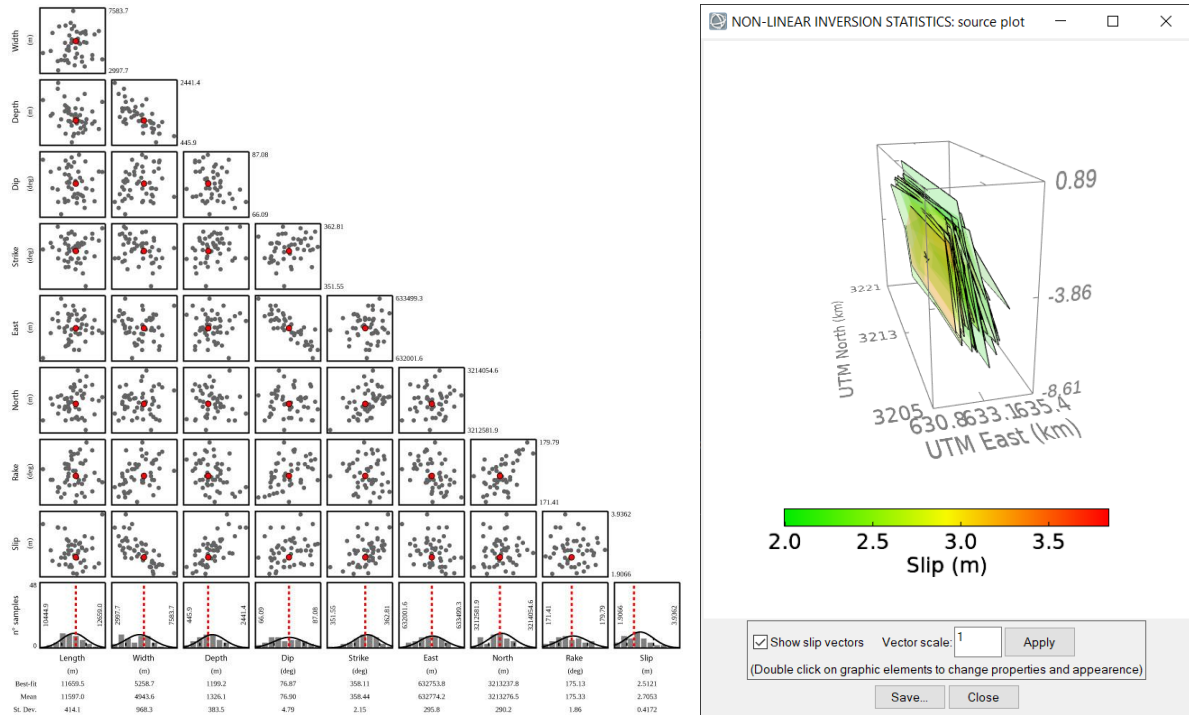
Note: you should get slightly different results because the InSAR dataset has been created with different sampling polygons.

The RMS of the residual, in the "Report" tab, shows a great improvement compared to the previous inversion. This improvement can be visualized also in the "OUTPUT Datasets" tab ("VIEW DATASETS – Plot 2D")

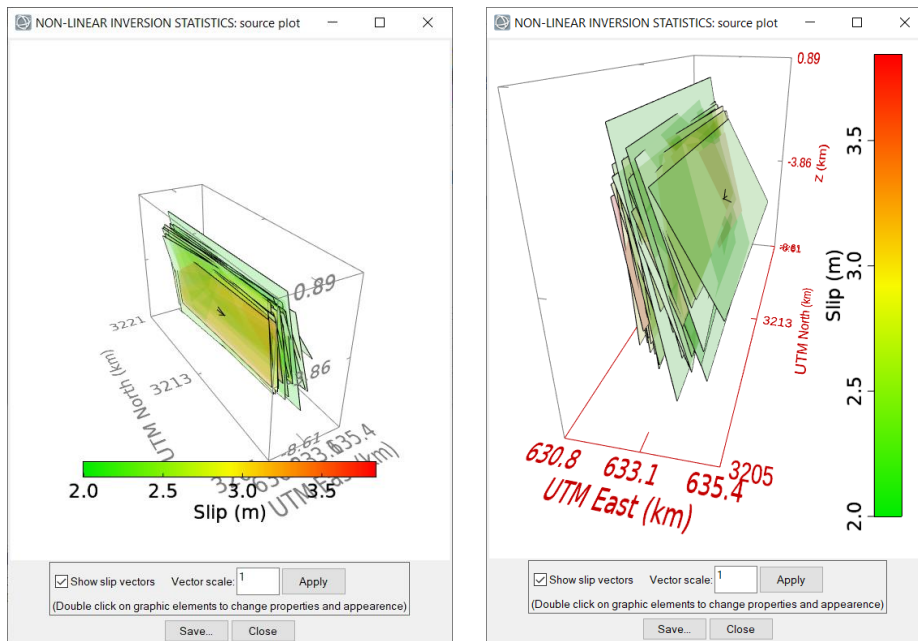


After finding the best-fit solution, we investigate the parameter uncertainty and the existence of possible trade-offs between them. In the "OUTPUT Sources" tab, click on "EDIT SOURCES – Calculate Statistics" and

wait for the end. 50 inversion runs are performed by adding, each time, a random noise, spatially correlated (the number of runs is in the "Options" tab). At the end you can see the results in the "OUTPUT Statistics" tab, with the "VIEW SOURCES – Plot parameters..." or with "VIEW SOURCES – Plot 3D" graphic tool



Tip: in all the graphic viewers (2D, 3D, for dataset and sources), the content can be rearranged by resizing the window, selecting and moving/zooming/rotating single elements, changing the element properties (double click to access the property panel), then saved to TIFF, PDF or JPG format. Here an example of editing from the starting view:



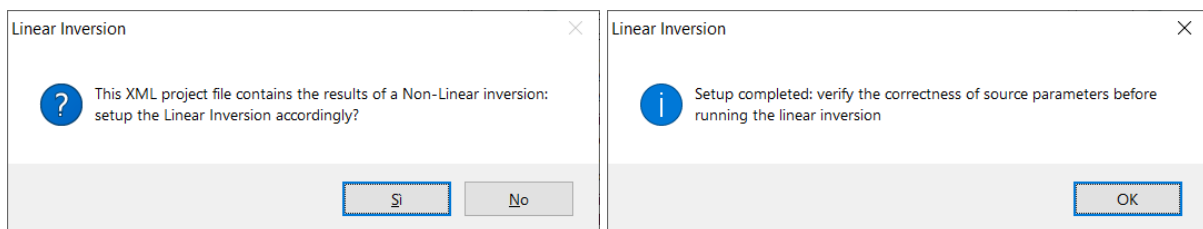
Output files: **Env_bam_dsc_linear.shp** (shapefile of point with the modeled displacement), **Bam_fault_nonlinear.shp** (polygon shapefile with the modeled source), **Bam_fault_statistics.shp** (polygon shapefile with all the sources coming from the statistic calculation).

Linear inversion

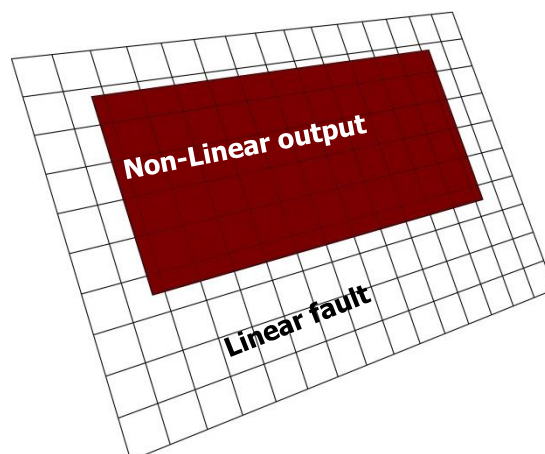
MENU: SARSCAPE – INTERFEROMETRY - DISPLACEMENT MODELING - LINEAR INVERSION

The linear inversion is carried out to find the slip distribution over the fault plane constrained via Non-Linear inversion. In this tutorial, a distributed positive slip with fixed rake is retrieved, but a complete set of alternatives is available (variable rake in a given interval, completely free rake, etc...).

To enable the panel, an XML Project File must be set: use the "Open..." button to set the **ModelingProject.xml** file. By setting the same XML Project File created with the Non-Linear inversion, the software checks the existence of a completed Non-Linear inversion allowing to automatically setup input datasets and sources (answer "Yes").



The "INPUT Datasets" is populated with the same input InSAR dataset, *Env_bam_dsc.shp*, of the Non-Linear inversion, with the assessment of a constant shift as well. Modifications are required in the "INPUT Sources" tab: *Bam_fault* source is set with Non-Linear output parameter; however, this source represents an average solution with uniform slip and it must be extended, in width and length, to completely contain the slip distribution.



Then a number of subdivisions in strike and dip directions must be set. All these modifications can be done in the "INPUT Sources" tab, clicking on "SOURCE EDIT – Edit parameters...", as follows

Elastic dislocation (Okada)

Source Name Bam_fault

Length (m)	11659.5
Width (m)	5258.7
Dip (deg)	76.87
Strike (deg)	358.11
Rake (deg)	175.13
Slip (m)	2.5121
Opening (m)	0.0000

Fault reference point

Depth (m)	1231.4
East (m)	631877.3
North (m)	3213208.9

(4) Fault trace center - Along dip top edge

Fixed source

LINEAR INVERSION INPUT OPTIONS

Variable size patches

Patches Along Strike 1

Patches Along Dip 1

Distributed and positive slip with fixed rake

Rake range width 0

ANCILLARY PARAMETERS

'mu' Lamé's constant (Pa) 3.00E+010

'lambda' Lamé's constant (Pa) 3.00E+010

Compensate for topography Yes

Draw Source in ENVI display

Coordinate System: UTM-WGS84-40N

Commit Cancel

Elastic dislocation (Okada)

Source Name Bam_fault

Length (m)	15000.0
Width (m)	10000.0
Dip (deg)	76.87
Strike (deg)	358.11
Rake (deg)	175.13
Slip (m)	2.5121
Opening (m)	0.0000

Fault reference point

Depth (m)	0.0
East (m)	631877.3
North (m)	3213208.9

(4) Fault trace center - Along dip top edge

Fixed source

LINEAR INVERSION INPUT OPTIONS

Variable size patches

Patches Along Strike 15

Patches Along Dip 10

Distributed and positive slip with fixed rake

Rake range width 0

ANCILLARY PARAMETERS

'mu' Lamé's constant (Pa) 3.00E+010

'lambda' Lamé's constant (Pa) 3.00E+010

Compensate for topography Yes

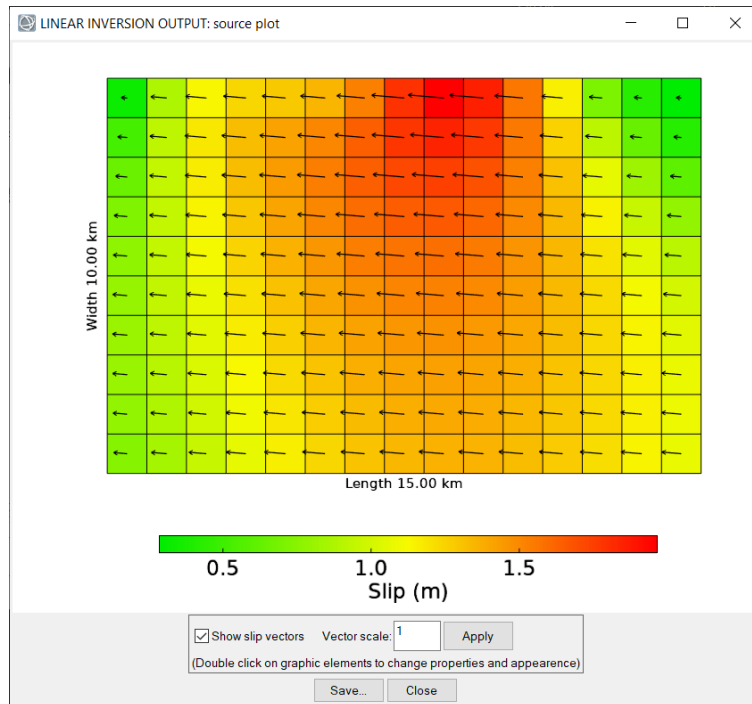
Draw Source in ENVI display

Coordinate System: UTM-WGS84-40N

Commit Cancel

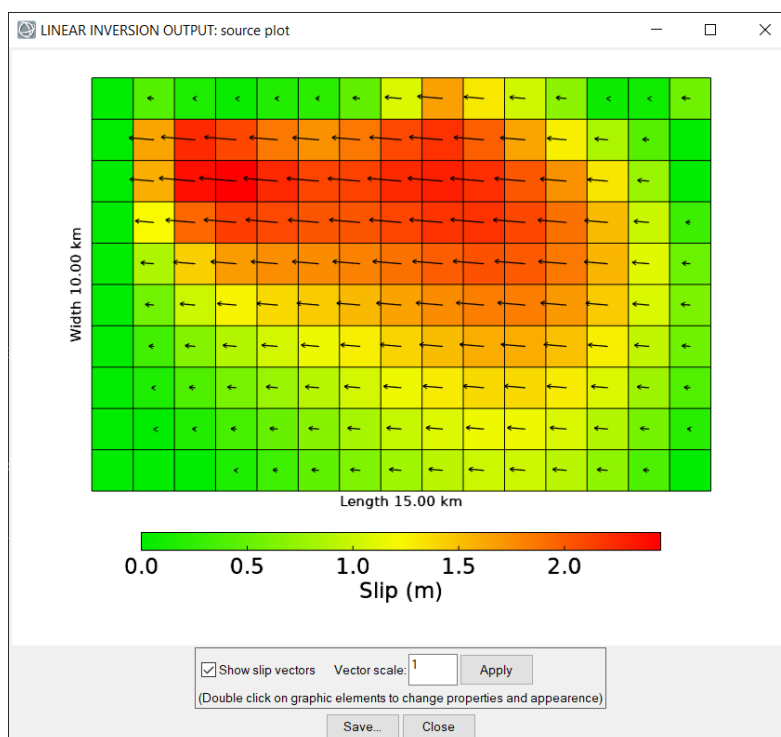
Tip: we apply the “Distributed and positive slip with fixed rake” constrain, but a wide range of alternatives are available in in the pulldown menu (see the online help).

After setting the input source, click on “Start” to run the inversion. At the end, new tabs are created: “OUTPUT Datasets”, “OUTPUT Sources” and “Report”, as for the Non-Linear inversion. Check the output source (“OUTPUT Sources”, any of the “SOURCE VIEW” plotting tools) and the comparison between observed and modeled (“OUTPUT Datasets”, “VIEW DATASET - Plot 2D”).

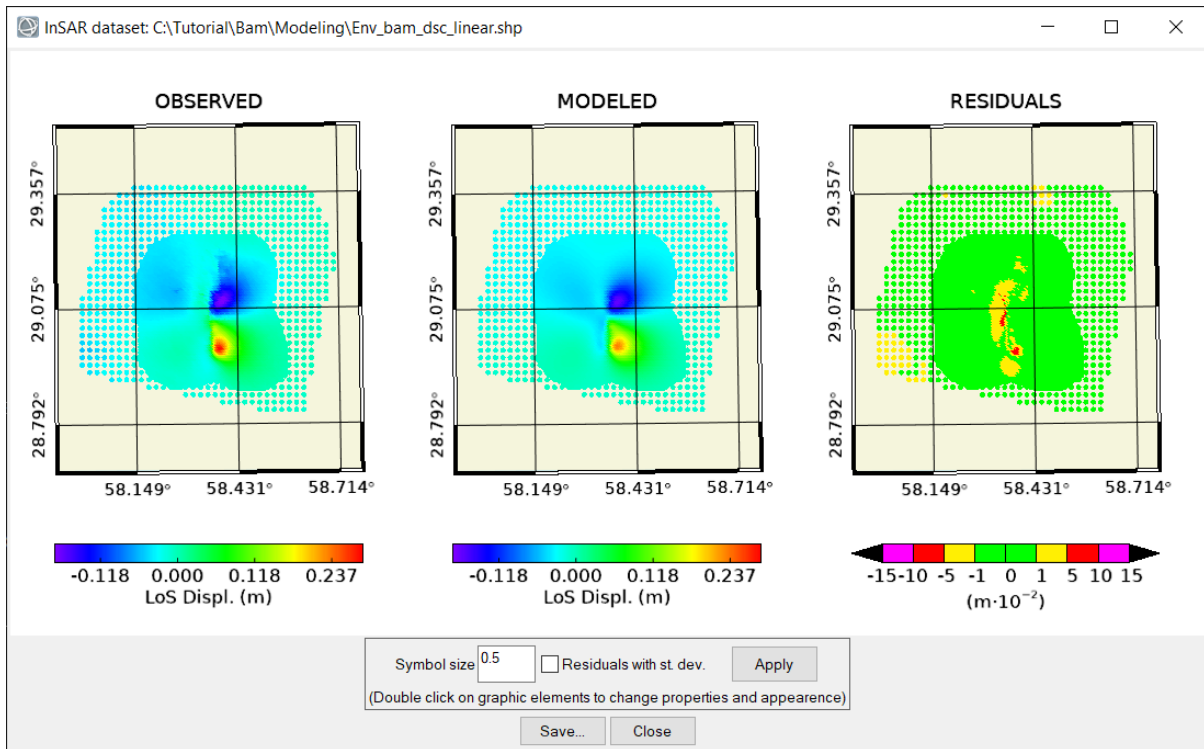


The slip distribution, after the run, appears too smooth.

This effect is controlled by the "Damping Factor", in the "Options" tab, set by default to 0.1. Reduce it to 0.02 and start again the inversion to get a more reliable solution.



Inspect also the comparison between observed and modeled ("OUTPUT Datasets", "VIEW DATASET - Plot 2D")



Tip: the damping factor is problem dependent; several automatic ways are proposed in literature to define it, but it's an empirical parameter whose definition is mostly related to the user experience.

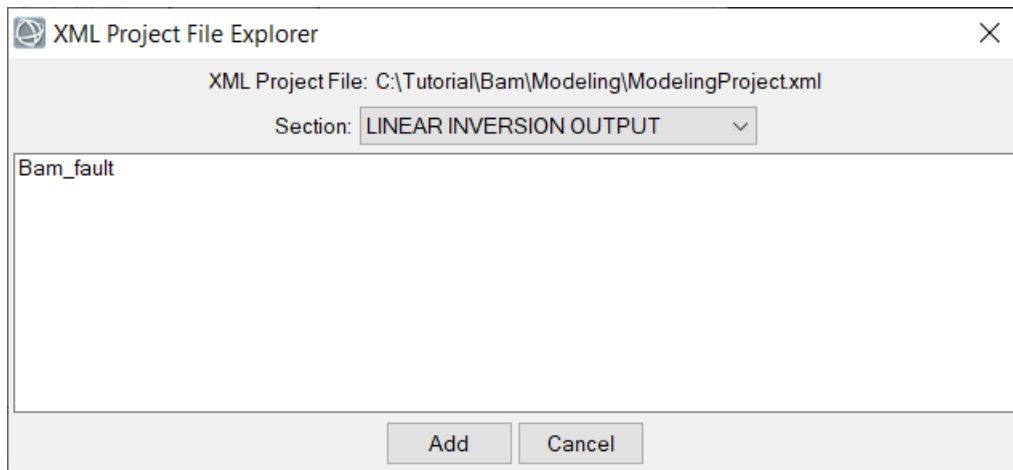
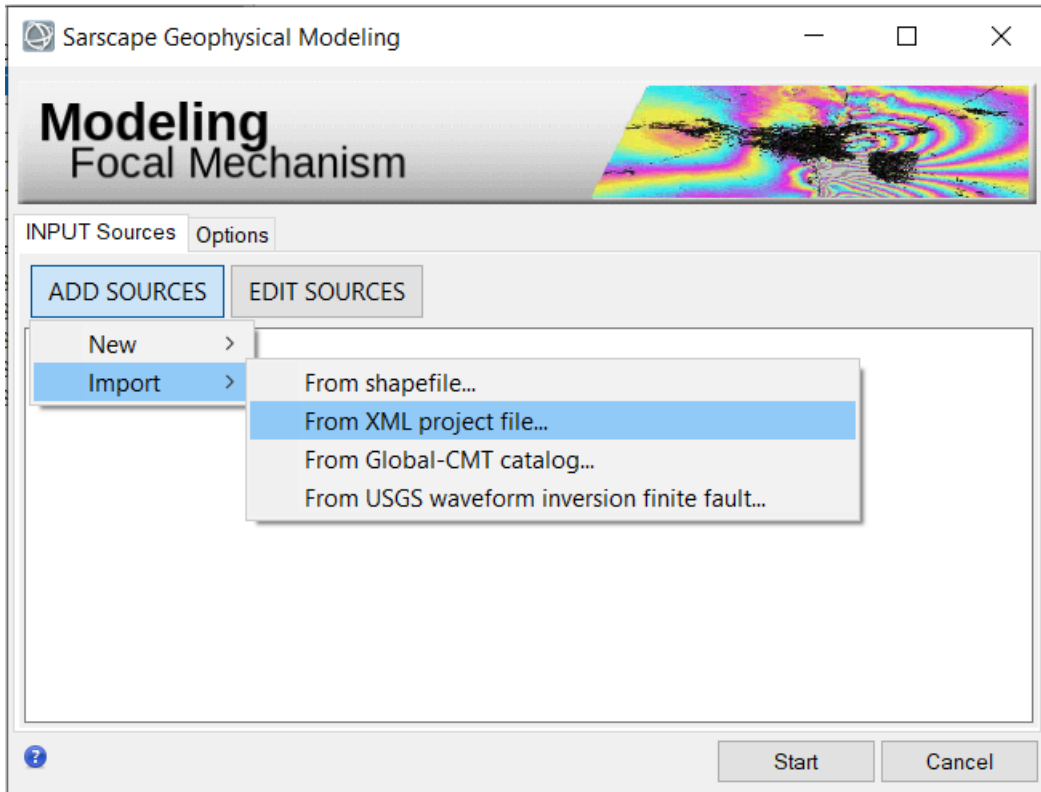
Output files: **Env_bam_dsc_linear.shp** (shapefile of points with the modeled displacement), **Bam_fault_linear.shp** (polygon shapefiles with the modeled slip distribution).

Calculate the moment tensor and draw the "beach ball"

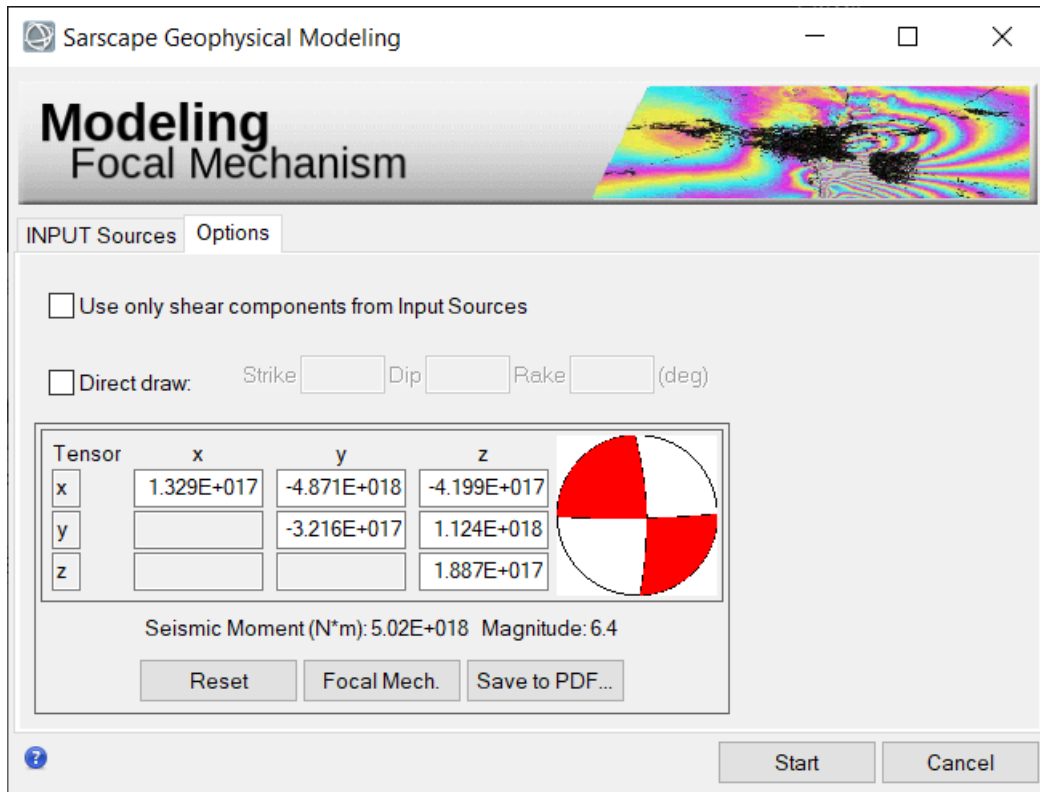
MENU: SARSCAPE – INTERFEROMETRY - DISPLACEMENT MODELING – MODELING TOOLS – CALCULATE AND DRAW FOCAL MECHANISM

This panel is automatically invoked after any Non-Linear and Linear inversion containing a seismic source, with the "INPUT Sources" tab automatically populated with the inversion results.

If invoked from scratch, we manually add the source in the "INPUT Sources" list. Goal of this task is calculating the focal mechanism, moment tensor, geodetic moment and magnitude corresponding to the slip distribution obtained via linear inversion. In order to get the Linear Inversion result, go to "ADD SOURCES – Import – Import from XML project file..."; this will open an XML explorer, through which you can access all the XML sections. In the pulldown menu, select the "LINEAR INVERSION OUTPUT" section, then select the *Bam_fault* item and click the "Add" button.



After that, click on "Start" and check the result on the "Options" tab.



Tip: a pdf file with the focal mechanism beach ball can be saved with the "Save to PDF..." button.

CFF Stress Transfer

MENU: SARSCAPE – INTERFEROMETRY - DISPLACEMENT MODELING – CFF STRESS TRANSFER

This panel can be used to calculate the stress change induced from a list of input sources to a list of receiver sources. To enable the panel, an XML Project File must be set: use the "Open..." button to set the **ModelingProject.xml**.

In this case, for simplicity, we simulate the existence of a fault 4 km east of the *Bam_fault* modeled, just duplicating and shifting it.

In the "INPUT Sources" panel, add the source with the slip distribution calculated via linear inversion: "ADD SOURCES – Import – Import from XML project file...", open the XML file and select "LINEAR INVERSION OUTPUT" from the pulldown menu; select *Bam_fault* and click "ADD".

Use the same procedure for the "Receiver Sources", but add the *Bam_fault* from the "LINEAR INVERSION INPUT". Edit this source (double click or "EDIT Sources – Edit parameters...") to shift it eastward by changing the East coordinate (change the name to *Bam_fault_shifted*, to avoid confusion).

Elastic dislocation (Okada)

Source Name

Length (m)

Width (m)

Dip (deg)

Strike (deg)

Rake (deg)

Fault reference point

Depth (m)

East (m)

North (m)

(4) Fault trace center - Along dip top edge

CFF RECEIVERS OPTIONS

Patches Along Strike

Patches Along Dip

CFF Type

ANCILLARY PARAMETERS

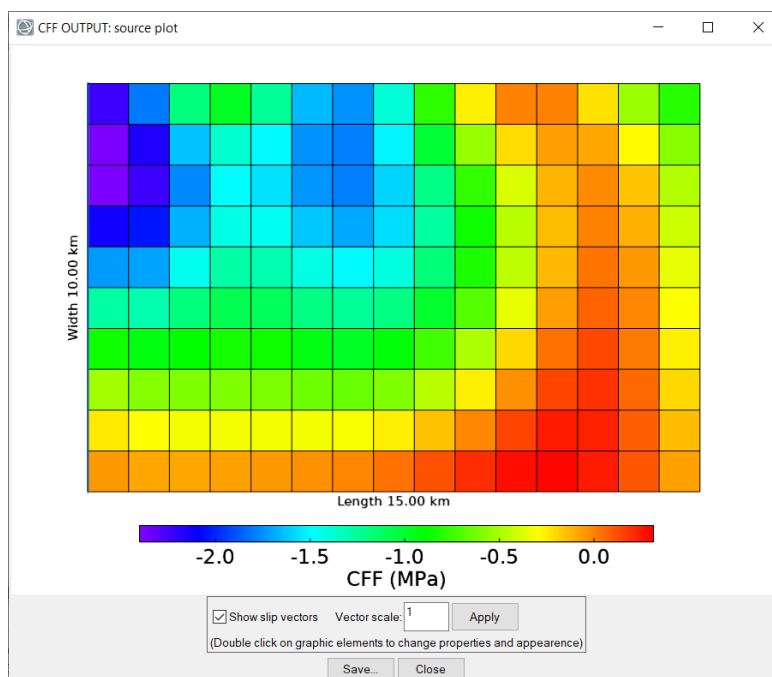
'mu' Lamé's constant (Pa)

'lambda' Lamé's constant (Pa)

Coordinate System: UTM-WGS84-40N

If you want, you can also specify a different number of patches along strike and dip, to get a finer CFF distribution. Check the online help for an explanation of available options.

After clicking "Start", the stress change over the receiver fault is calculated and placed in a new folder "OUTPUT Sources". Use the graphic tools in the "VIEW SOURCES" to check the result.



Output files: *Bam_fault_shifted_cff.shp* (polygon shapefile with the stress change distribution)

Forward Modeling

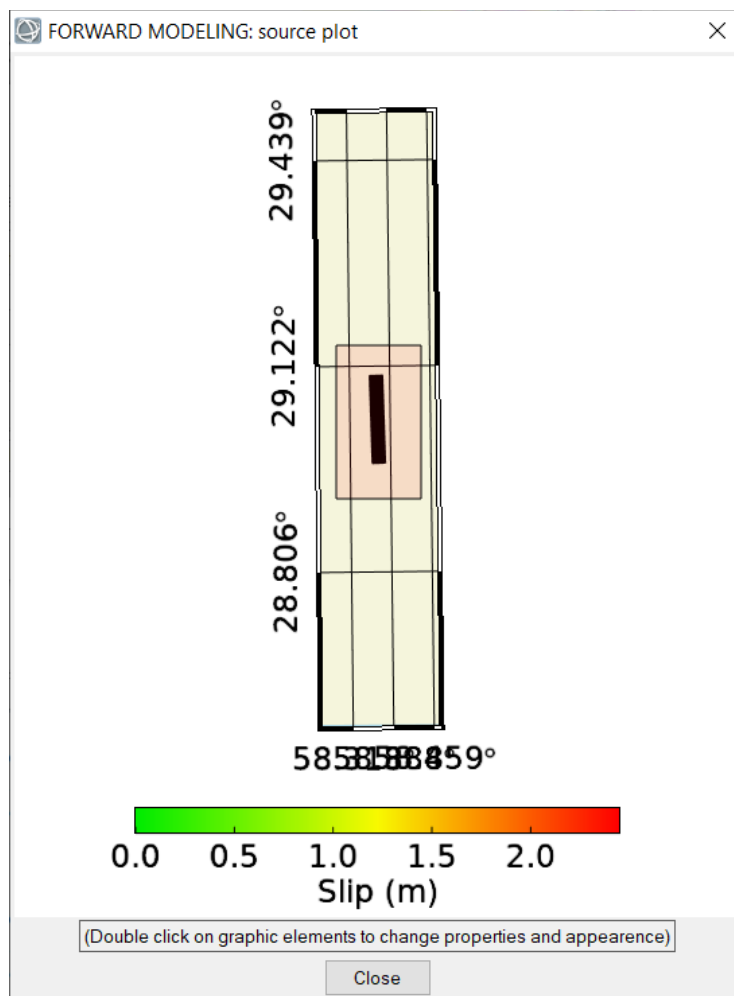
MENU: SARSCAPE – INTERFEROMETRY - DISPLACEMENT MODELING – FORWARD MODELING

This panel is used to calculate the predicted surface displacement due to one or more sources. The output can be raster or vector (point) type. In this tutorial, we use the source defined after the Linear Inversion to predict the surface displacement, in raster file format.

To enable the panel, an XML Project File must be set: use the "Open..." button to set the **ModelingProject.xml**.

As first step, set the *Bam_fault* in the "INPUT Sources", with the usual procedure: "ADD SOURCES – Import – Import from XML project file...", open the XML file and select "LINEAR INVERSION OUTPUT" from the pulldown menu, select *Bam_fault* and click "ADD".

To define the output, set "Raster" in the "Forward model output" pulldown menu in the "Options" tab. Click on "Set Raster Info..." button to set extent and resolution (the reference system is already set from the input source). About the raster extent, instead of writing the Left/Right/Top/Bottom coordinates, the "Get from map" button opens a graphic viewer to define them, as follow:

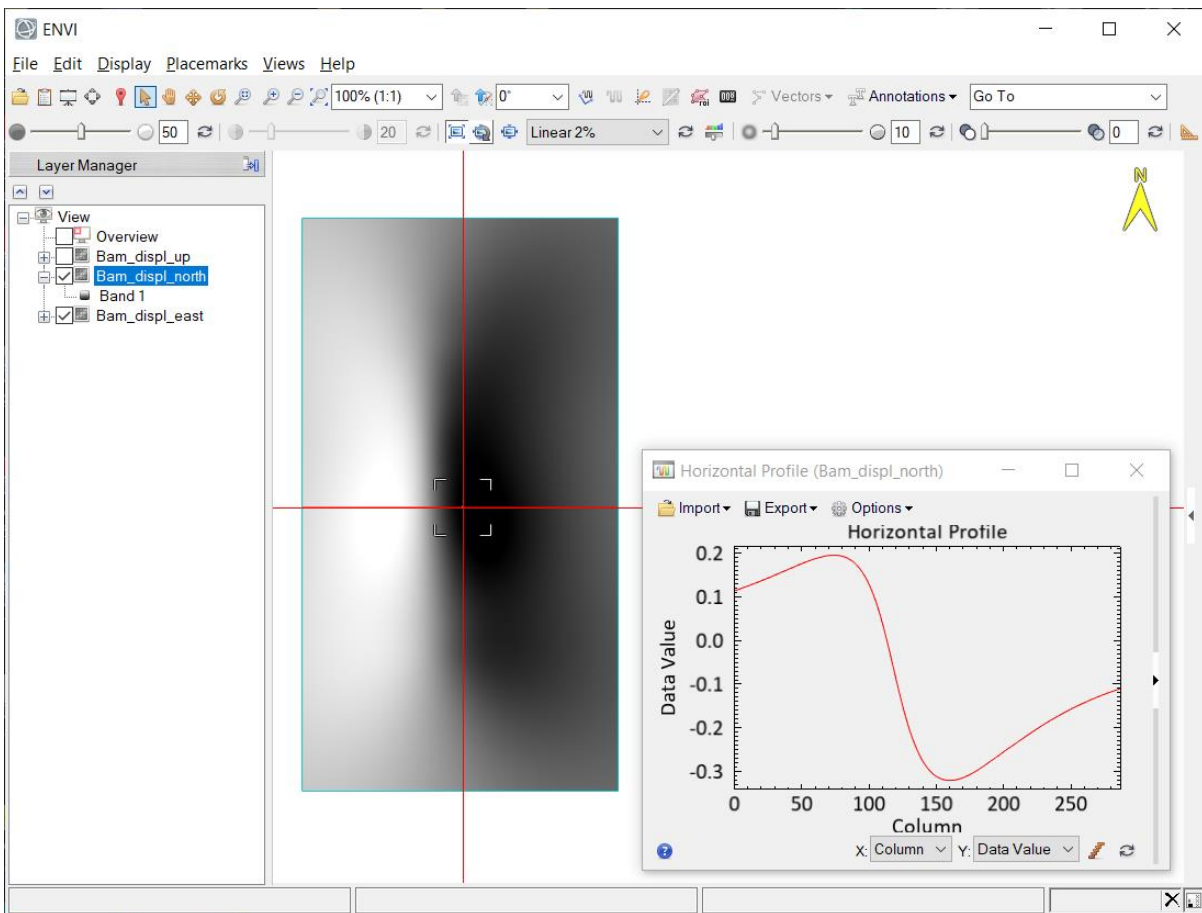


The rectangle coordinates are immediately transferred to the Left/Right/Top/Bottom text box. Click close on the graphic window and set the cell size to 50 m.

Set also the **Bam_SRTM_dem** file as DEM and the output filename **Bam_displ**.

Note: the DEM is required when a source, in the “INPUT Sources” list, has the “Compensate for topography” option set.

After running the calculation with the “Start” button, no additional tabs are created in the panel, but the output is produced with three raster files in ENVI format: **Bam_displ_east**, **Bam_displ_North** and **Bam_displ_up**, containing the three displacement components. Use ENVI (or other GIS softwares) to visualize them:



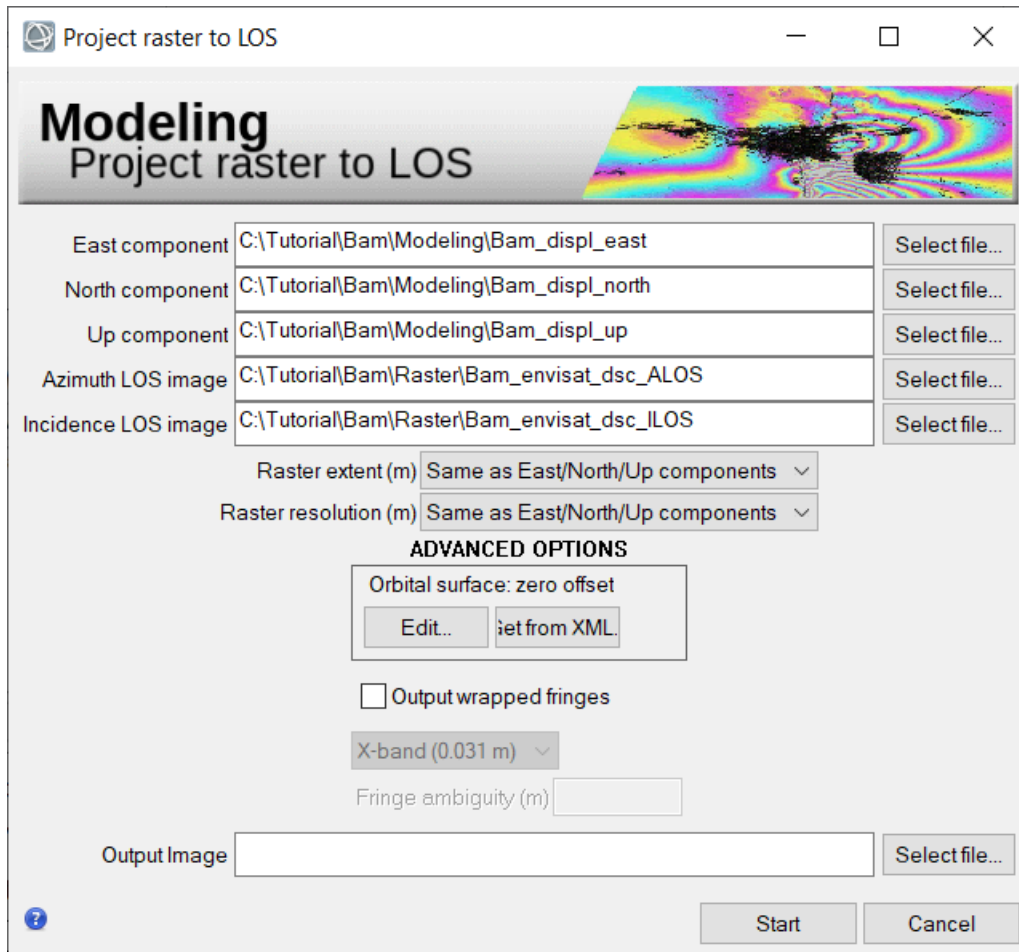
Output files: **Bam_displ_east**, **Bam_displ_North** and **Bam_displ_up** (raster file in ENVI format with the three components of the modelled displacement).

Project raster to LOS

MENU: SARSCAPE – INTERFEROMETRY - DISPLACEMENT MODELING – PROJECT RASTER TO LOS

This panel combine the East, North and Up components of the displacement to the satellite Line-of-Sight (LOS). The projection needs the sensor azimuth and looking angles, that are contained in the **_ALOS** and **_ILOS** files produced as output of interferometric process.

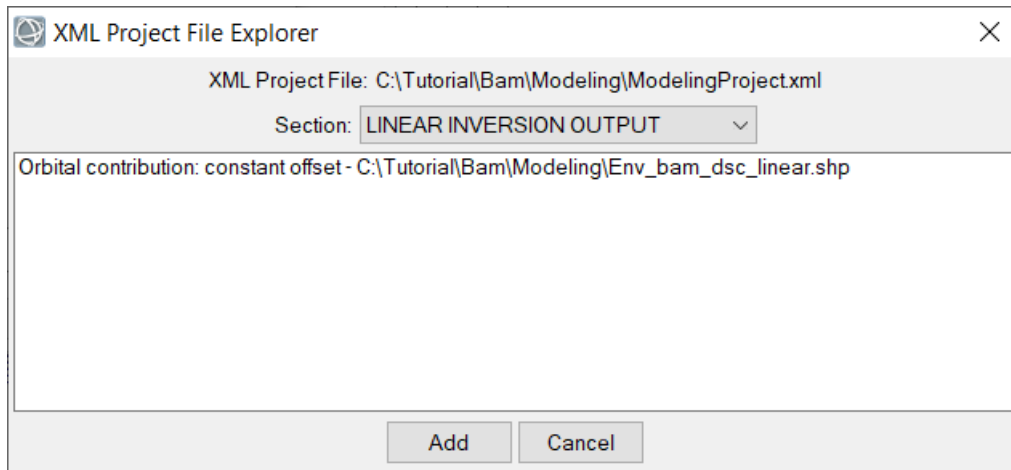
Set the input files as follows:



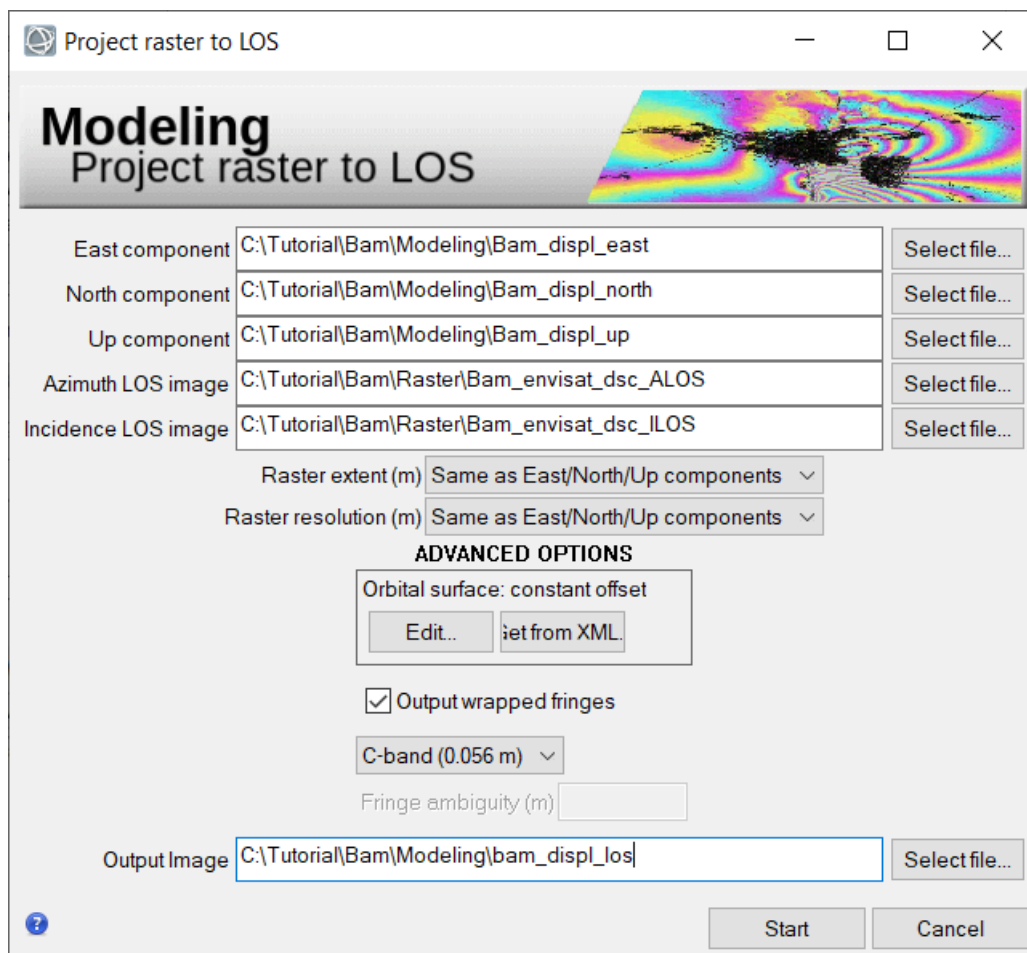
Since the East/North/Up displacement maps can have different extent and resolution of the *_ALOS/_ILOS* files, two pulldown menus allow to set the output extent and resolution.

Note: *_ALOS* and *_ILOS* files are available only if an InSAR processing was done for the area. If not available, in alternative two numbers can be supplied: see the online help for reliable values for ascending and descending orbits.

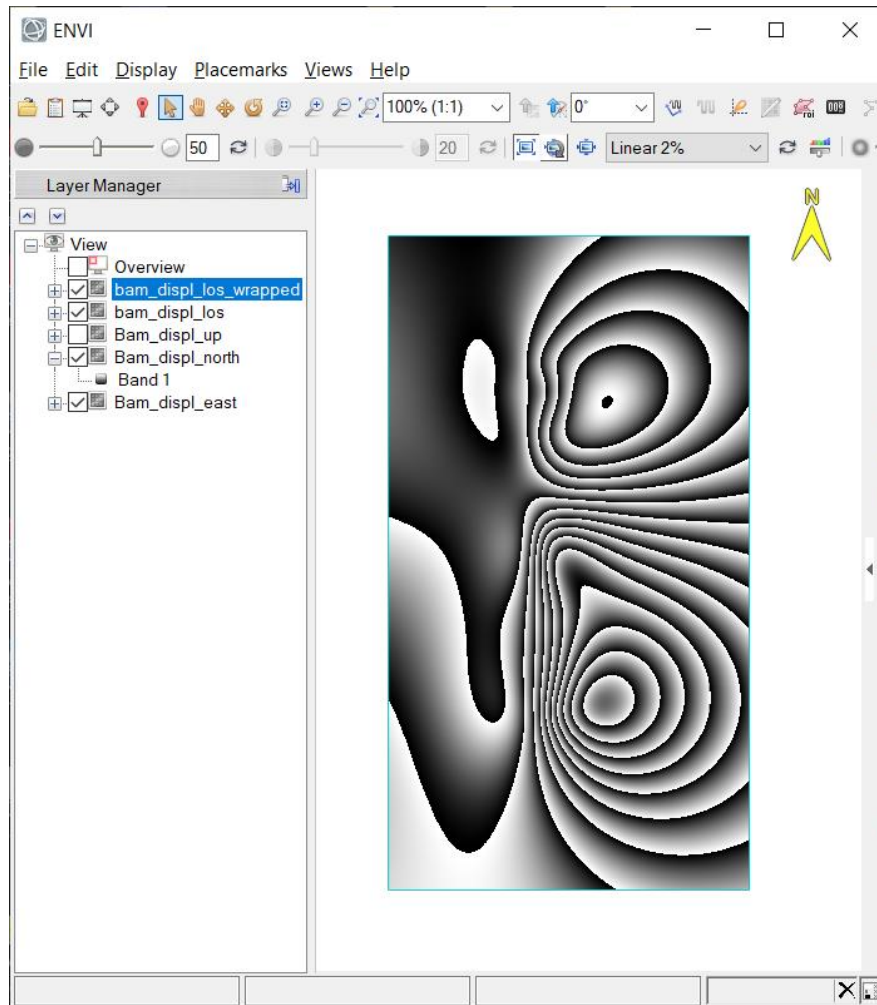
This panel also allows to add an orbital surface. This can be useful to better simulate the observed signal. In this tutorial a constant offset was assessed in the Non-Linear and Linear inversions. To retrieve the equation of the orbital surface (a simple offset, in this, case), use the XML Project File Explorer (with the "Get from XML..." button) and navigate to the "LINEAR INVERSION OUTPUT" section in the pulldown menu to retrieve the assessed orbital contribution:



After adding the orbital contribution, set the flag “Output wrapped fringes” to get also the wrapped version of the displacement, select “C-band” for the fringe ambiguity (as the Envisat original data) and set the output name, as follows:



Run the calculation with the “Start” button and wait for the end message. After that, two new raster files in ENVI format are created: **bam_displ_los** and **bam_displ_los_wrapped**. Use ENVI (or other GIS softwares) to visualize them:



Output files: **bam_displ_los** (raster file in ENVI format with the displacement projected into the line-of-sight) and **bam_displ_los_wrapped** (raster file in ENVI format with the interferometric fringes).

References

Funning, G.J., B. Parsons, T.J. Wright, J.A. Jackson and Fielding, E. J. (2005), Surface displacements and source parameters of the 2003 Bam (Iran) earthquake from Envisat advanced synthetic aperture radar imagery, *J. Geophys. Res.*, 110, B09406, doi:10.1029/2004JB003338.

Wang, R., Xia, Y., Grosser, H., Wetzels, H.-U., Kaufmann, H. and Zschau, J. (2004), The 2003 Bam (SE Iran) earthquake: precise source parameters from satellite radar interferometry, *Geophys. J. Int.*, 159: 917–922. doi: 10.1111/j.1365-246X.2004.02476.x

Wells, D. L. and K. J. Coppersmith (1994) New empirical relationships among magnitude, rupture length, rupture width, rupture area, and surface displacement, *Bull. Seism. Soc. Am.*; 84 (4): 974–1002.