Opticks – Basic SAR Processing Tools
Geocoding and stereo measurement

Andrea Nascetti

August 17, 2012

Contents

List of Figures

1 Introduction

1.1 Project Introduction

Overall, this project concerns the development of the main tools necessary for Synthetic Aperture Radar (SAR) imagery georeferencing and orthorectification, exploiting the full capabilities of the sensor. In particular, the aim is to develop an Opticks' PlugIn that will allow robust rigorous orientation model for two SAR high resolution sensors: RADARSAT-2 and TerraSAR-X. Furthermore, the PlugIn will provide an handy tool to perform 3D stereo measurements.

1.2 Background

Both optical and SAR imagery are characterized by proper deformations due to the different acquisition geometries and processes. These deformations have to be duly taken into account during image processing in order to exploit their full potentialities. The correct orientation of remote sensing imagery is a fundamental task for orthoimagery and Digital Surface Models (DSMs) generation and 3D feature/object extraction.

At present, the interest in satellite SAR data is rapidly growing due to the new high resolution imagery (up to 1 m Ground Sampling Distance (GSD)) that can be acquired by COSMOSkyMed, TerraSAR-X and RADARSAT-2 sensors in Spotlight mode.

As regards the rigorous orientation model, it has to be underlined that, starting from the model proposed in the classical book of Leberl (F. Leberl, Radargrammetric image processing, Artech House, Norwood, USA, 1990), a refinement of satellite orbit is needed to comply with and to exploit the potentialities of the novel high resolution (both in azimuth and in range). Then, the defined and implemented model performs a 3D orientation, allowing for the least squares estimation of some calibration parameters, related to satellite position and velocity and global atmospheric refraction.
The model is based on two fundamental radargrammetric equations: the first equation represents the general case of zeroDoppler projection in which the target is acquired on a heading perpendicular to the flying direction; the second equation is the slant range constrain, which implies that the distance from satellite to ground point should be equal to the slant range on the image (see Fig. 1).

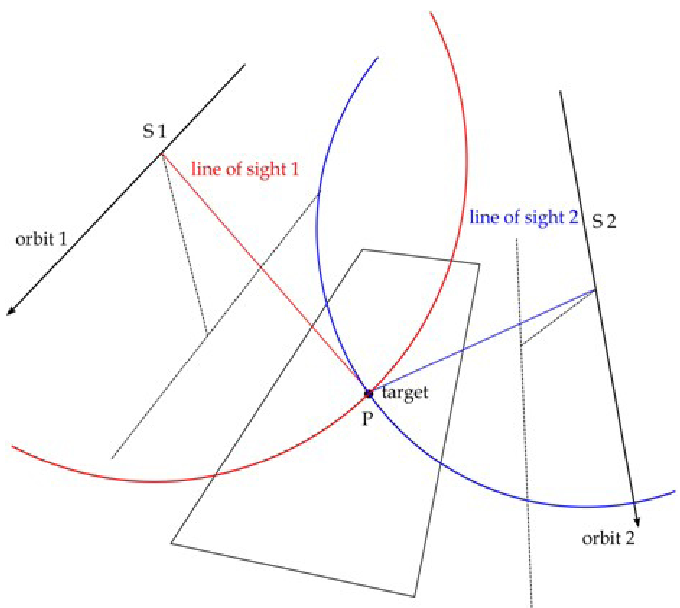


Figure 1: Principle of stereoscopy with zeroDoppler stereopairs

As regard the orbit reconstruction, the orbital arc related to the image acquisition in Spotlight mode is quite short (about 10 Km), it could be conveniently modeled interpolating the few orbital state vectors available in the metadata using the Lagrange polynomials.

2 PlugIn documentation

2.1 SAR Image Orientation Tool

This tool implements a classical orientation model for SAR images. At present, two SAR sensors are supported: TerraSAR-X and RADARSAT-2. Using this model it is possible to relate the image and the ground coordinates.

The model is based on two fundamental radargrammetric equations: the first equation represents the general case of zero-Doppler projection in which the target is acquired on a heading perpendicular to the flying direction; the second equation is the slant range constrain, which implies that the distance from satellite to ground point should be equal to the slant range on the image. For the sensor orbit interpolation, Lagrange polynomial have been used.

Orientating an image is the first step required in order to perform image orthorectification (which is the main objective of the present PlugIn). Consequently, it was decided to implement image orientation into a stand-alone tool. In such a way, before proceeding with the complete orthorectification for a single image, it will be possible to check the results of the orientation procedure.

2.1.1 Free dataset used for this tutorial

In order to test this tool, free SAR images for TerraSAR-X and RADARSAT-2 sensors can be downloaded at the following links:

- TerraSAR-X SpotLight SCC image of Toronto - Canada - Astrium website
- RADARSAT-2 FineQuad image of Vancouver - Canada - MDA website

2.1.2 Tool workflow

The user can load the image to be orientated using the standard *Import data* method available from Opticks main menu. After the data are loaded and displayed in the main Opticks window, the user can access the *Image Orientation tool* through the SAR PlugIn menu (i.e. SAR PlugIn->Orientation Model->check<sensor_name>, where <*sensor_name*>has to be replaced with the sensor used to collect the image). Fig. 2 shows how to launch the *Image Orientation* tool for the sample RADARSAT-2 image.

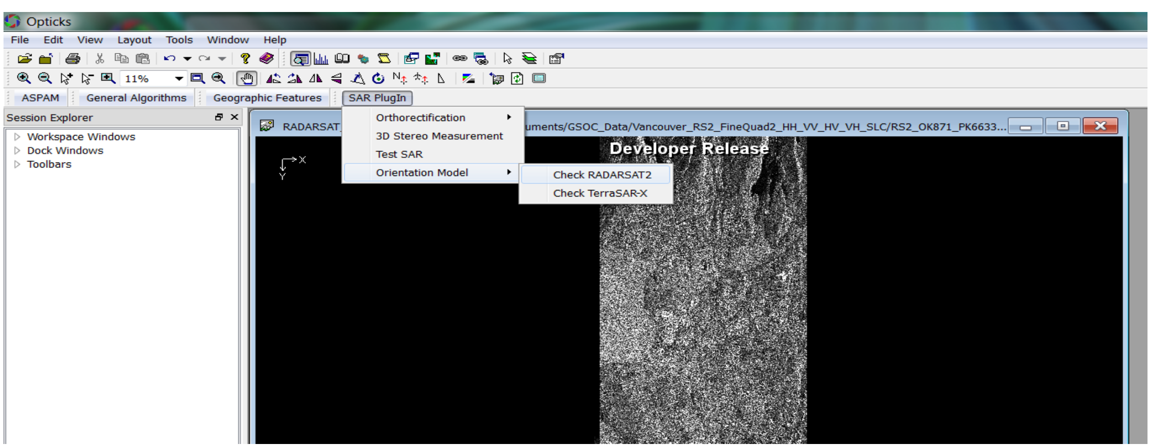


Figure 2: Launch the Image Orientation tool through the SAR PlugIn menu

The *Image Orientation* tool allows to test the efficacy of the orientation model using a list of ground points (GCPs) that is included in the sensor metadata. These points have both image and ground coordinates: the former are computed from the nodes of a regular grid built on the image; the latter are computed projecting the image coordinates on a reference Digital Surface Model according to the model defined by the image vendor. These GCPs, are used to assess the orientation model.
Now, as soon as the tool is launched, the user is asked to choose a list of GCPs using a sliding tag. Fig. 3 shows the procedure. The list of points included in the image metadata are most often referred to as *Corner coordinates*.

Figure 3: Select a list of GCPs to assess the orientation performed

After the list has been selected, the *Ok* button should be pressed and the tool is executed. Fig. 4 shows the results of the orientation model assessment performed with respect to the selected list of GCPs.

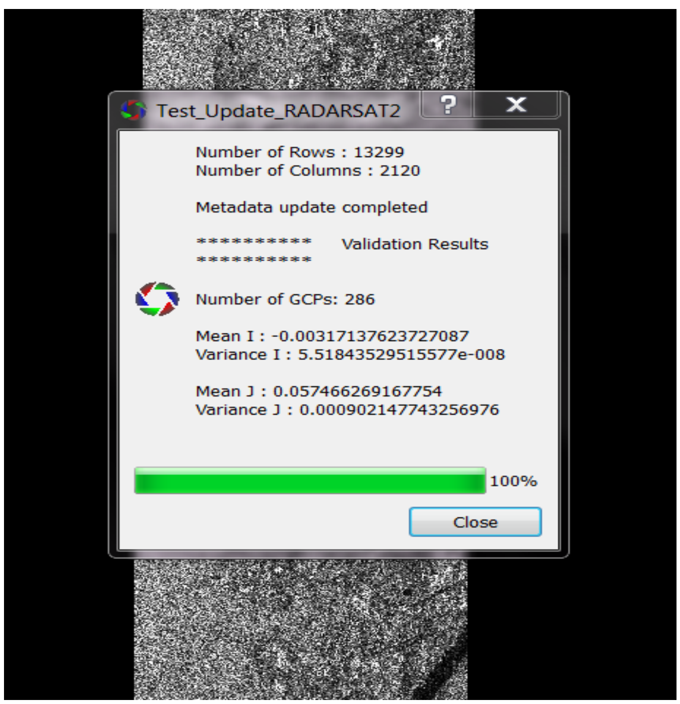
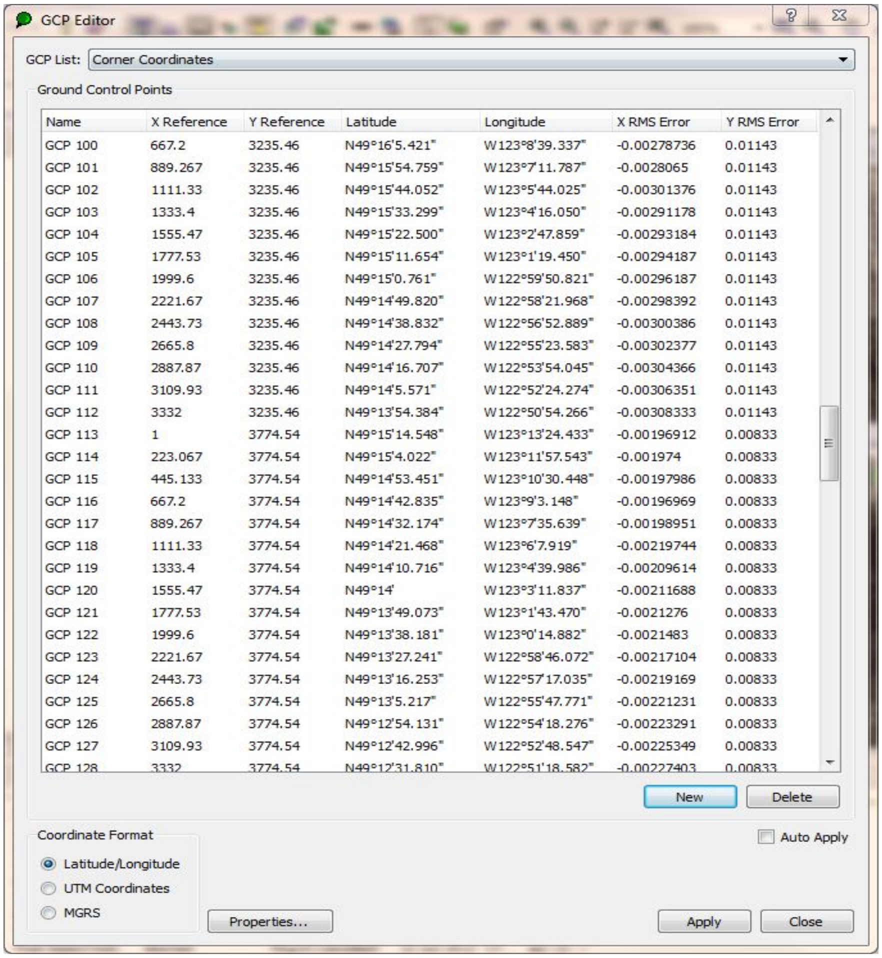


Figure 4: Statistics of the orientation residuals for the selected GCPs

The orientation tool has now been executed and the results were displayed to the user with the pop up window shown in Fig. 4. Furthermore, at the end of this step it is possible to check the orientation residuals computed with respect to the reference coordinates of the used GCPs. In fact, the *Image Orientation* tool updates the Opticks GCP list and inserts the image residuals computed with respect to the reference coordinates. In Fig. 5 the residuals for each of the GCPs are shown (if the residual is equal to -9999 the related GCP is out of the image).



Name	X Reference	Y Reference	Latitude	Longitude	X RMS Error	Y RMS Error
GCP 100	667.2	3235.46	N49°16'5.421"	W123°8'39.337"	-0.00278736	0.01143
GCP 101	889.267	3235.46	N49°15'54.759"	W123°7'11.787"	-0.0028065	0.01143
GCP 102	1111.33	3235.46	N49°15'44.052"	W123°5'44.025"	-0.00301376	0.01143
GCP 103	1333.4	3235.46	N49°15'33.299"	W123°4'16.050"	-0.00291178	0.01143
GCP 104	1555.47	3235.46	N49°15'22.500"	W123°2'47.859"	-0.00293184	0.01143
GCP 105	1777.53	3235.46	N49°15'11.654"	W123°1'19.450"	-0.00294187	0.01143
GCP 106	1999.6	3235.46	N49°15'0.761"	W122°59'50.821"	-0.00296187	0.01143
GCP 107	2221.67	3235.46	N49°14'49.820"	W122°58'21.968"	-0.00298392	0.01143
GCP 108	2443.73	3235.46	N49°14'38.832"	W122°56'52.889"	-0.00300386	0.01143
GCP 109	2665.8	3235.46	N49°14'27.794"	W122°55'23.583"	-0.00302377	0.01143
GCP 110	2887.87	3235.46	N49°14'16.707"	W122°53'54.045"	-0.00304366	0.01143
GCP 111	3109.93	3235.46	N49°14'5.571"	W122°52'24.274"	-0.00306351	0.01143
GCP 112	3332	3235.46	N49°13'54.384"	W122°50'54.266"	-0.00308333	0.01143
GCP 113	1	3774.54	N49°15'14.548"	W123°13'24.433"	-0.00196912	0.00833
GCP 114	223.067	3774.54	N49°15'4.022"	W123°11'57.543"	-0.001974	0.00833
GCP 115	445.133	3774.54	N49°14'53.451"	W123°10'30.448"	-0.00197986	0.00833
GCP 116	667.2	3774.54	N49°14'42.835"	W123°9'3.148"	-0.00196969	0.00833
GCP 117	889.267	3774.54	N49°14'32.174"	W123°7'35.639"	-0.00198951	0.00833
GCP 118	1111.33	3774.54	N49°14'21.468"	W123°6'7.919"	-0.00219744	0.00833
GCP 119	1333.4	3774.54	N49°14'10.716"	W123°4'39.986"	-0.00209614	0.00833
GCP 120	1555.47	3774.54	N49°14'	W123°3'11.837"	-0.00211688	0.00833
GCP 121	1777.53	3774.54	N49°13'49.073"	W123°1'43.470"	-0.0021276	0.00833
GCP 122	1999.6	3774.54	N49°13'38.181"	W123°0'14.882"	-0.0021483	0.00833
GCP 123	2221.67	3774.54	N49°13'27.241"	W122°58'46.072"	-0.00217104	0.00833
GCP 124	2443.73	3774.54	N49°13'16.253"	W122°57'17.035"	-0.00219169	0.00833
GCP 125	2665.8	3774.54	N49°13'5.217"	W122°55'47.771"	-0.00221231	0.00833
GCP 126	2887.87	3774.54	N49°12'54.131"	W122°54'18.276"	-0.00223291	0.00833
GCP 127	3109.93	3774.54	N49°12'42.996"	W122°52'48.547"	-0.00225349	0.00833
GCP 128	3332	3774.54	N49°12'31.810"	W122°51'18.582"	-0.00227403	0.00833

Figure 5: GCPs image residuals with respect to the reference coordinates

Finally, it has to be underlined that most of the necessary information to orientate the image were originally not available into Opticks using the standard *Import data* function. The SAR *Image Orientation* tool has been implemented in such a way that all the missing information are read from the image metadata. Afterwards, these information are used to enrich the Opticks metadata object that is associated with the image *raster element*. Eventually, it is possible to display these information following the next steps: select the *Elements* tab in the bottom left Opticks menu, then use the right mouse button to click on the image name and select *Properties* (see Fig. 6).
Now, selecting *Metadata* will display all the image metadata information retrieved by Opticks (see Fig. 7).
The *SAR Metadata* tag contains the information read in the *XML* image file and used to perform image orientation.

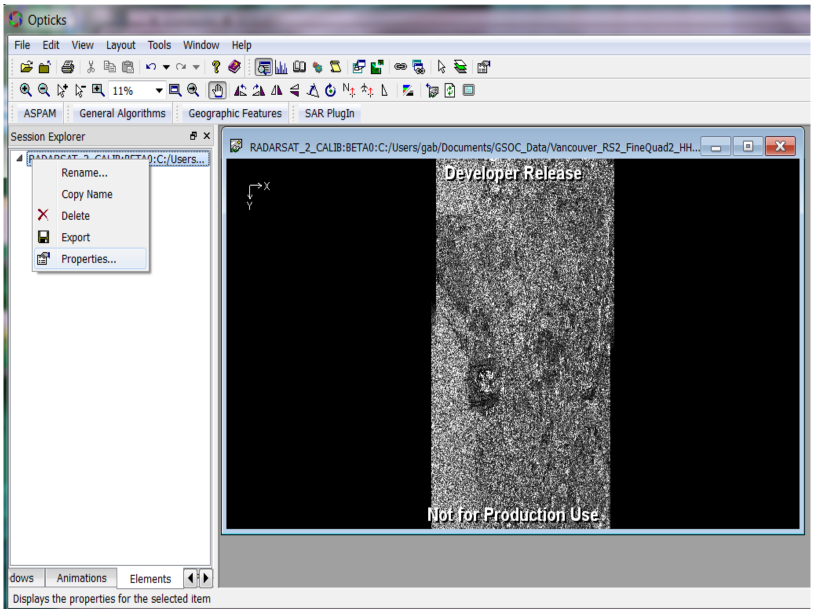


Figure 6: Access the metadata information useful for image orientation - Step 1

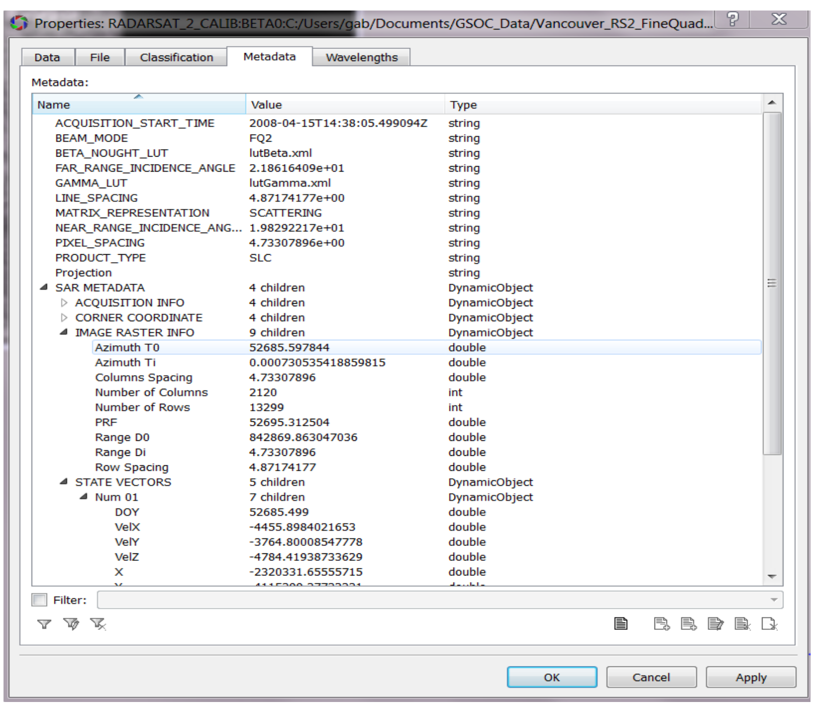


Figure 7: Access the metadata information useful for image orientation - Step 2

2.2 3D Stereo Measurement Tool

The 3D Stereo Measurement tool allows to select a common point from two stereo images and to calculate an elevation value for that point. This is a basic tool that can be used to retrieve some 3D local information. The two stereo images must be acquired from different look angles in order to obtain a good stereo geometry. This tool can currently handle the standard SLC (Single Look Complex) products of both TerraSAR-X and RADARSAT-2 sensors. Furthermore, this can be considered as a first step towards the DSM generation using a radargrammetric approach.

2.2.1 Free dataset used for this tutorial

The MDA Corporation provides free datasets for testing the RADARSAT-2 SAR imagery at the following link. The Vancouver dataset is the one that will be used for this tutorial, in particular the only stereopair available to test the 3D stereo measurement tool is formed by the two images contained in these zip files:

- Vancouver_R2_FineQuad15_Frame1_SLC.zip
- Vancouver_RS2_FineQuad2_HH_VV_HV_VH_SLC.zip

This stereopair has neither a good geometry nor a good ground resolution. However, it is the only one that can be downloaded for free. In case the user has access to another stereopair with better characteristics it is advisable to use that to test the tool. Download these files from the MDA ftp server before starting the tutorial.

2.2.2 Tool workflow

The user can load the stereo images using the standard *Import data* method available from Opticks main menu. After the stereo images are loaded and displayed in the main Opticks window, the user can access the *3D Stereo Measurement* tool through the *SAR PlugIn* menu (i.e. *SAR PlugIn->3D Stereo Measurement*). Fig. 8 shows how to launch the *3D Stereo Measurement* interface.

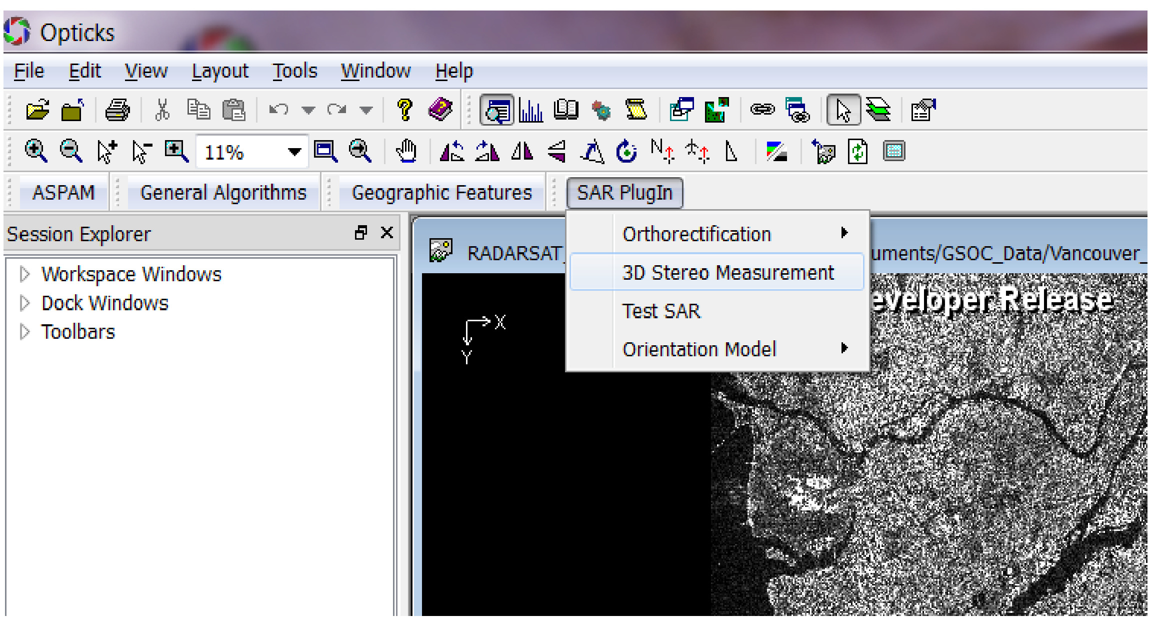


Figure 8: Launch the *3D Stereo Measurement* tool through the *SAR PlugIn* menu

The *3D Stereo Measurement* Graphical User Interface (GUI) is displayed in Fig. 9.

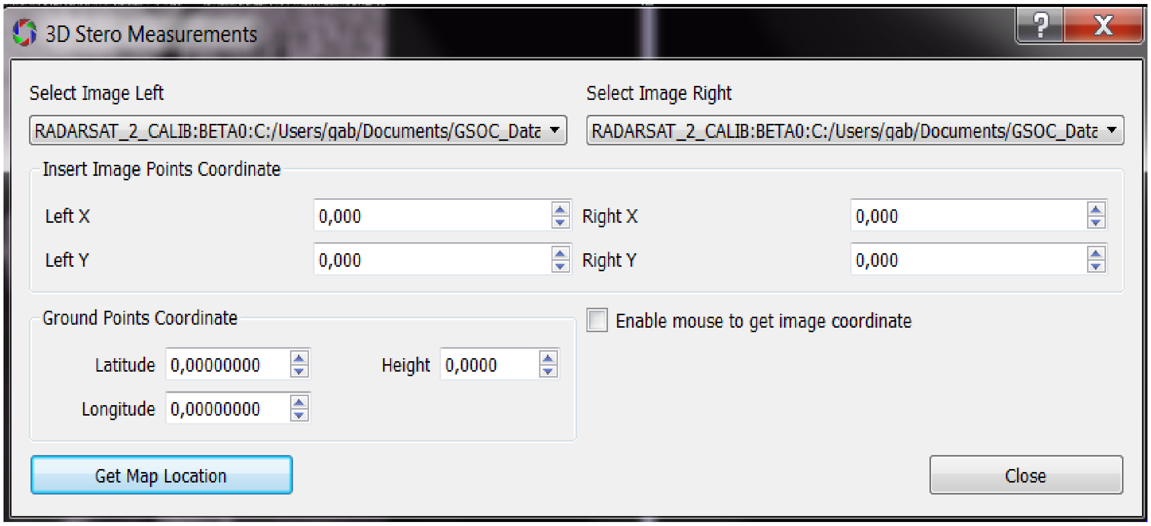


Figure 9: Graphical User Interface of the *3D Stereo Measurement* tool

Generally, the images that compose a stereopair can be referred to as *left* and *right* image. These images can be selected using the sliding tags *Select Image Left* and *Select Image Right*. These tags contain all the images previously loaded into Opticks Workspace. Now, images can be browsed to identify the target point whose 3D coordinates should be retrieved. Once the point is identified in both images, the pixel coordinates of the point should be inserted into the related boxes.
There are two alternative ways to proceed: the first is to manually copy pixel coordinates into the related boxes; the second is to flag the *Enable mouse to get image coordinate* button and to click on the selected point into the image. Thereby, pixel coordinates of the selected points will be copied directly into the appropriate box (i.e. Left/Right X/Y). This second way is a nice feature that proves to be handy and useful for at least two reasons:

1. it shortens the time required to retrieve the 3D coordinates executing the *3D Stereo Measurement* tool
2. it avoids gross errors that possibly occurs when typing the pixel coordinates manually

For the automatic pixel coordinates collection to work, the *Edit mode on* button for the mouse should be activated (i.e. the button is located in the main Opticks panel, see Fig. 10).

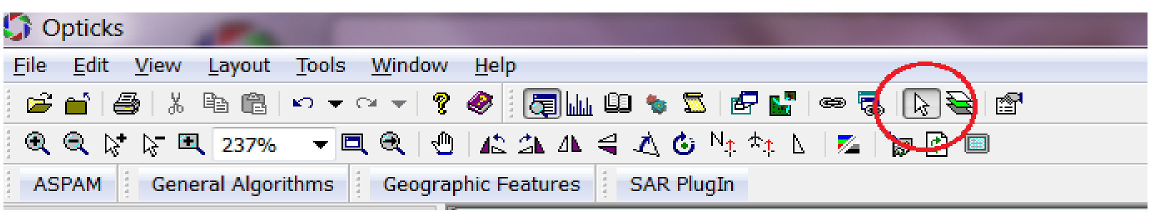


Figure 10: Enable *Edit mode on* for the mouse

Once pixel coordinates for the left and right images have been retrieved, *3D Stereo Measurement* tool can be run by pressing the *Get Map Location* button.
The results of *3D Stereo Measurement* tool are displayed in Fig. 11. The 3D coordinates (both the geocentric X, Y, Z and the geographic *Latitude*, *Longitude*, h) of the selected point are retrieved and displayed in the window that pops up when the tool is executed. Additionally, the geographic coordinates are copied in the related boxes in the

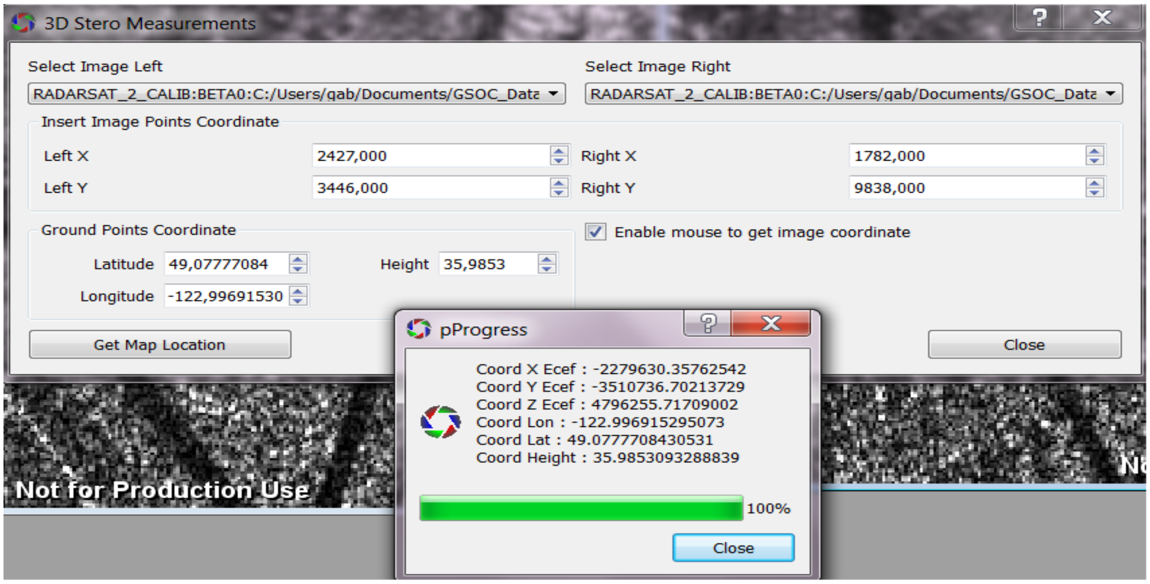


Figure 11: Results of the *3D Stereo Measurement* tool

3D Stereo Measurement graphical interface. At this point, *3D Stereo Measurement* finished its execution. To start it over again it is sufficient to close the pop up window (i.e. *pProgress*), to choose a new point to be processed, to select the pixel coordinates of the new point and to press the *Get Map Location* button.

3D Stereo Measurement tool can be terminated by pressing the *Close* button in the low-right side of the interface.

2.3 TerraSAR-X Orthorectification Tool

The TerraSAR-X Orhtorectification tool is capable of performing a rigorous orientation model on SSC (Single Look Slant Range Complex) TerraSAR-X data (the operational mode supported are: High resolution spotlight, Spotlight and Stripmap). Without any GCPs the model is calculated based on the metadata satellite's positional information. Then, image orthorectification is performed using a so called inverse model (i.e. starting from a regular ground grid, at first, for each pixel the height information is retrieved using the DSM. Then, the so achieved 3D information is associated with the image pixel. Finally, the radiometric value of the pixel is computed using a resampling method).

2.3.1 Free dataset used for this tutorial

The Astrium Company provides free datasets for testing the TerraSAR-X imagery at the following link.
The available SSC Spotlight Image of Toronto - Canada is the one that will be used for this tutorial, download this file before starting. Afterwards, the user can test the SAR PlugIn tool with the other SSC images available on the Astrium database.

2.3.2 Tool workflow

The user can load the TerraSAR-X image using the standard *Import data* method available from Opticks main menu (image can be accessed directly using *TSX1_*.xml* file). After the data are loaded and displayed in the main Opticks window, the user can access the *TerraSAR-X Orthorectification* tool through the *SAR PlugIn* menu (i.e. SAR PlugIn->Orthorectification->TerraSAR-X). Fig. 12 shows how to launch the TerraSAR-X orthorectification interface.
TerraSAR-X Orthorectification tool GUI is displayed in Fig. 13. The image to be processed can be selected using the sliding tag *Select Input Image*. This tag contains all the images previously loaded into Opticks Workspace. Once

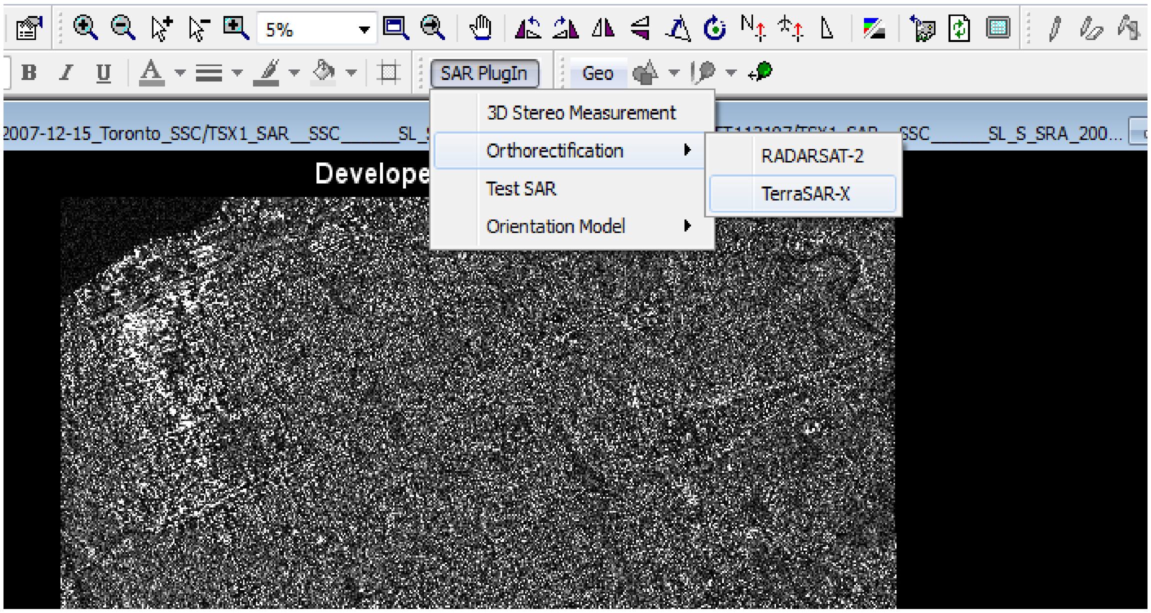


Figure 12: Launch the TerraSAR-X Orthorectification tool through the SAR PlugIn menu

image has been selected, *Check Image* button is the only one that can be pressed and it is used to verify that the selected image is suitable for orthorectification.

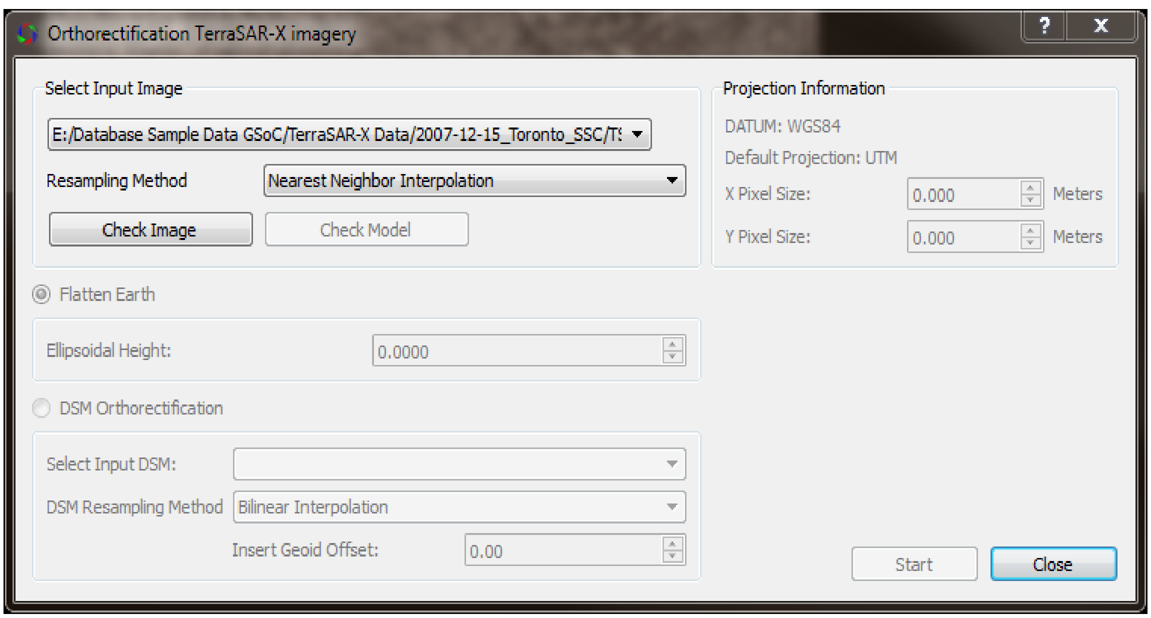


Figure 13: Graphical User Interface of the TerraSAR-X Orthorectification tool - Step1

At this point, all other functions are available, see Fig. 14.

Before starting the processing, the user must set all the input parameters. First of all, it is necessary to set the orthophoto pixel size in both X and Y directions (e.g. 3 meters) and consequently the image Resampling Method using the corresponding sliding tag (there are four interpolation methods available: Nearest Neighbor, average box with windows size of 3x3, 5x5 and 7x7).

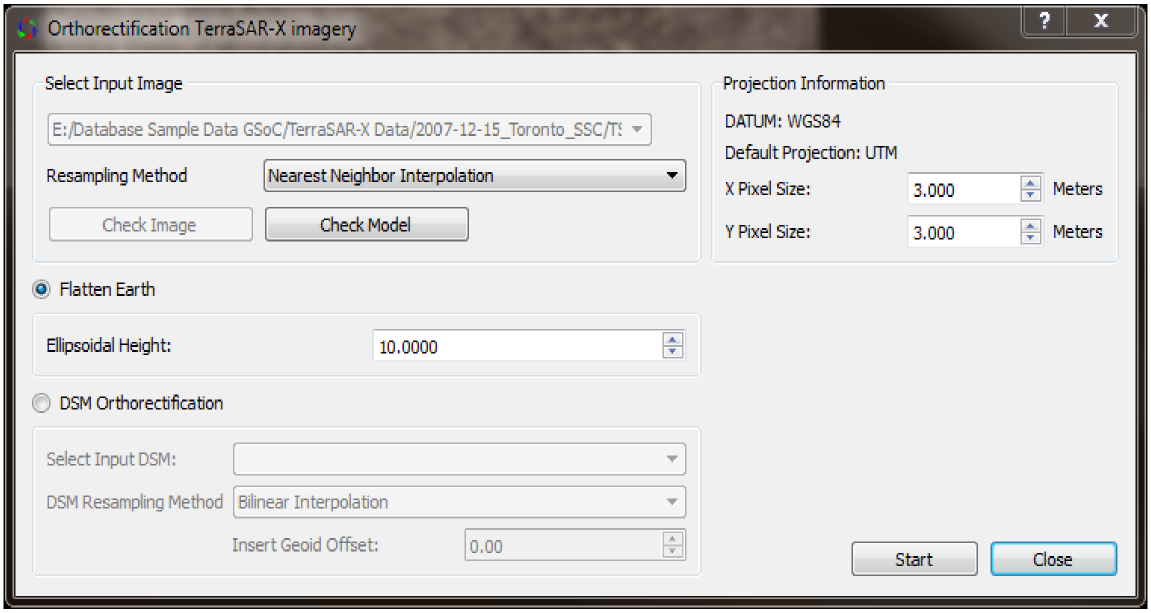


Figure 14: Graphical User Interface of the TerraSAR-X Orthorectification tool - Step2

Finally, the user should choose the surface to be used for image orthorectification: an ellipsoidal surface with constant height or a general standard ASCII Digital Surface Model (DSM). For the present tutorial, it has been decided to select the *Flatten Earth* option and to insert 10 meters as *Ellipsoidal Height* (the Toronto area is morphologically flat and it is therefore suitable to be processed using a constant height). For more information about using a DSM for the processing looking at section 2.4.

Once all input parameters have been selected, *TerraSAR-X Orthorectification* tool can be run by pressing the *Start* button. Fig. 15 and 16 show on the left the raw TerraSAR-X image and on the right the results of the Orthorectification PlugIn with the overlaid geographic layer (to add the geographical information layer into the image one can simply use the Opticks *Georeference* tool).
Finally, the image can be exported by using the Opticks *Export module* and can be saved in GeoTiff format.

2.4 RADARSAT-2 Orthorectification Tool

The *RADARSAT-2 Orhtorectification* tool is capable of performing a rigorous radar orientation model on SLC (Single Look Complex) RADARSAT-2 data (the operational mode supported are: Spotlight, Ultra Fine, Standard with all polarization type). Without any GCPs the model is calculated based on the metadata satellite's positional information. The image orthorectification will be performed using a so called inverse model (i.e. starting from a regular ground grid, at first, for each pixel the height information is retrieved using the DSM. Then, the so achieved 3D information is associated with the image pixel. Finally, the radiometric value of the pixel is computed using a resampling method).

2.4.1 Free dataset used for this tutorial

The MDA Corporation provides free datasets for testing the RADARSAT-2 SAR imagery at the following link. Vancouver dataset is the one that will be used for this tutorial, in particular download the *Vancouver_R2_FineQuad15_Frame1_SLC.zip* from the MDA ftp server before starting. Afterwards, the user can test the *SAR PlugIn* tool with the other SLC images available on the MDA database. Shuttle Radar Topography Mission (SRTM) DSM used in this tutorial can be downloaded at the following link.

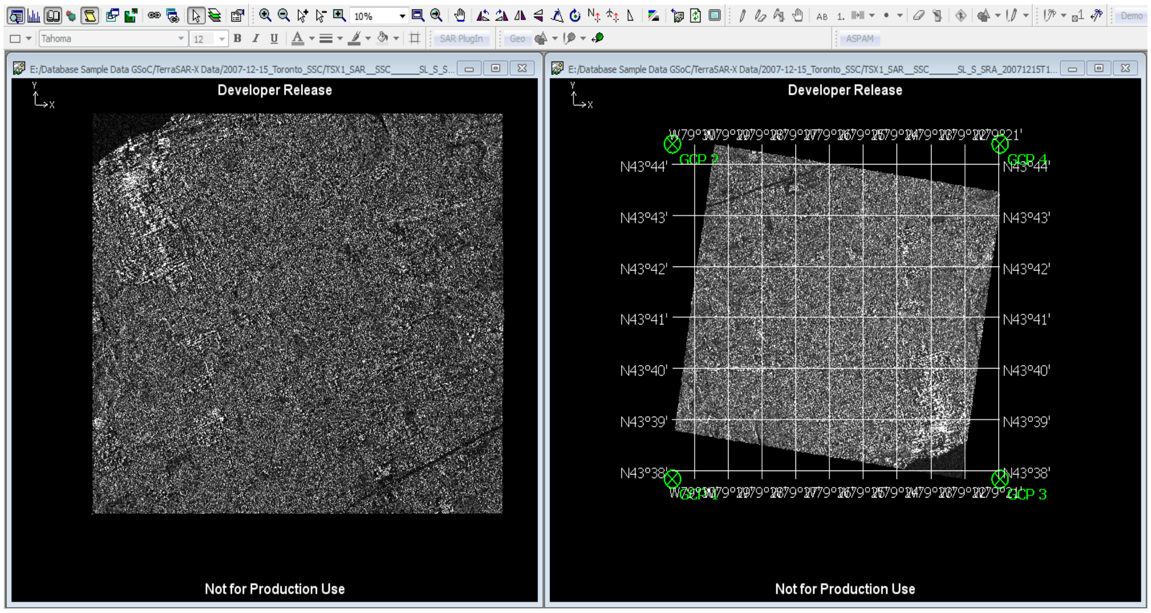


Figure 15: TerraSAR-X Orthorectification tool results

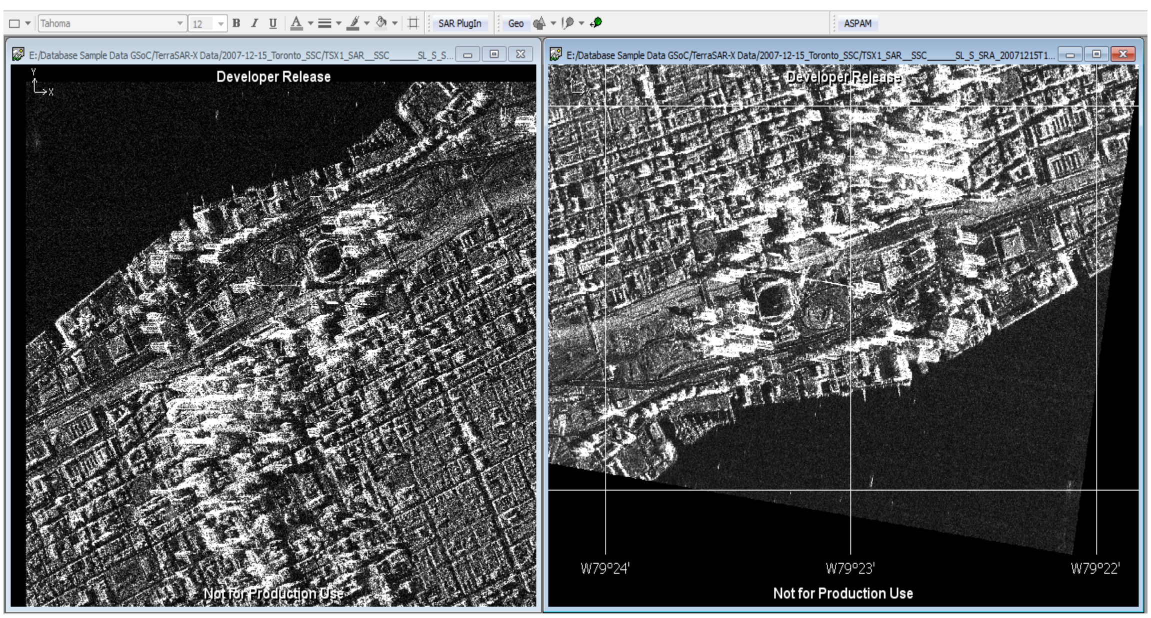


Figure 16: TerraSAR-X Orthorectification tool results zoom

2.4.2 Tool workflow

The user can load the RADARSAT-2 image and SRTM DSM using the standard *Import data* method available from Opticks main menu (image can be accessed directly unsing *product.xml* file). After the data are loaded and displayed in the main Opticks window, the user can access the RADARSAT-2 Orthorectification Tool through the *SAR PlugIn* menu (i.e. SAR PlugIn->Orthorectification->RADARSAT-2). Fig. 17 shows how to launch the RADARSAT-2 Orthorectification interface.
The RADARSAT-2 Orthorectification GUI is displayed in Fig. 18. The image to be processed can be selected using

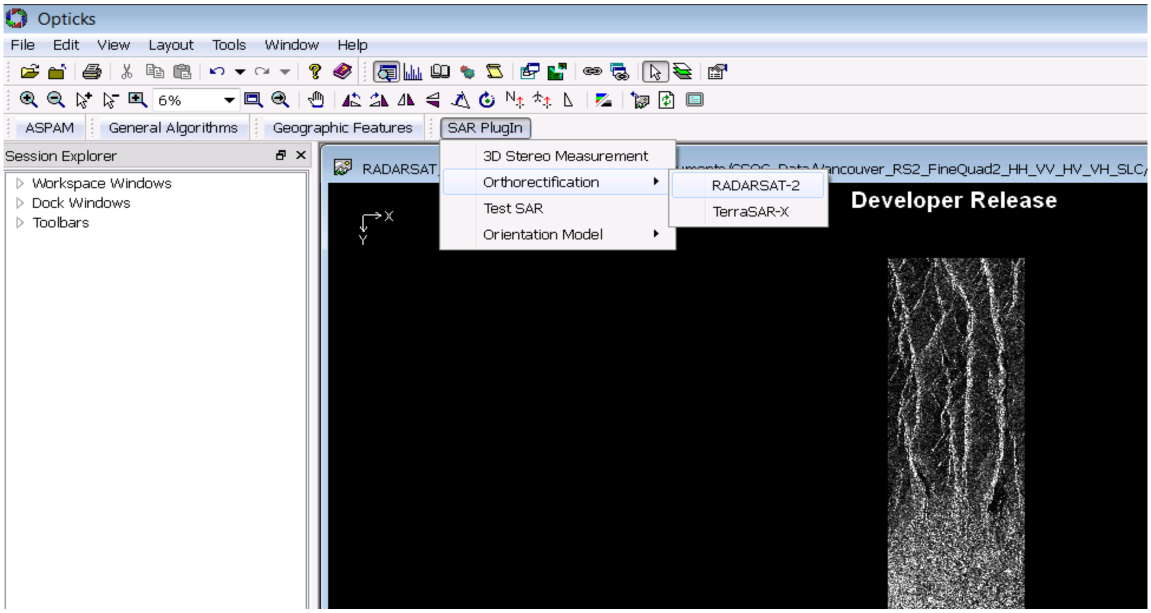


Figure 17: Launch the RADARSAT-2 Orthorectification tool through the *SAR PlugIn* menu

the sliding tag *Select Input Image*. This tag contains all the images previously loaded into Opticks Workspace. Once image has been selected, *Check Image* button is the only one that can be pressed and it is used to verify that the selected image is suitable for orthorectification.

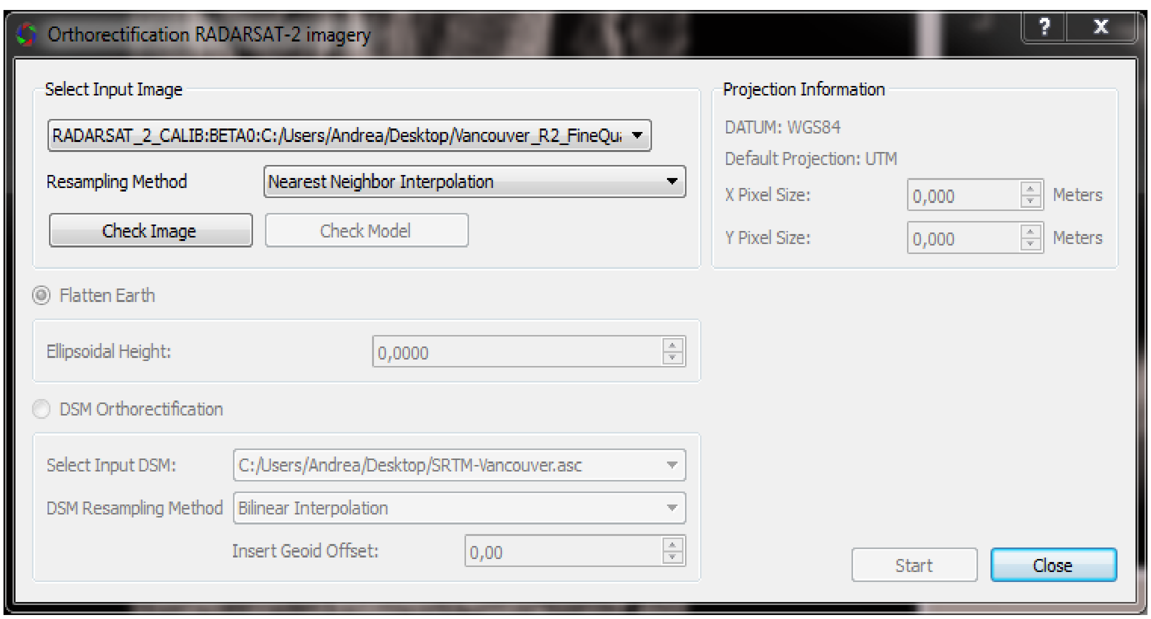


Figure 18: Graphical User Interface of the RADARSAT-2 Orthorectification tool - Step1

At this point, all other functions are available, see Fig. 19. Before starting the processing, the user must set all the input parameters. First of all set the orthophoto pixel size in both X and Y directions (e.g. 10 meters) and consequently the image Resampling Method using the corresponding sliding tag (there are four interpolation methods available: Nearest Neighbor, average box with windows size of 3x3, 5x5 and 7x7). *Check Model* button is used to assess the orientation model choosing a list of CP to compute the orientation residuals (to see how the model is checked, see section 2.1.

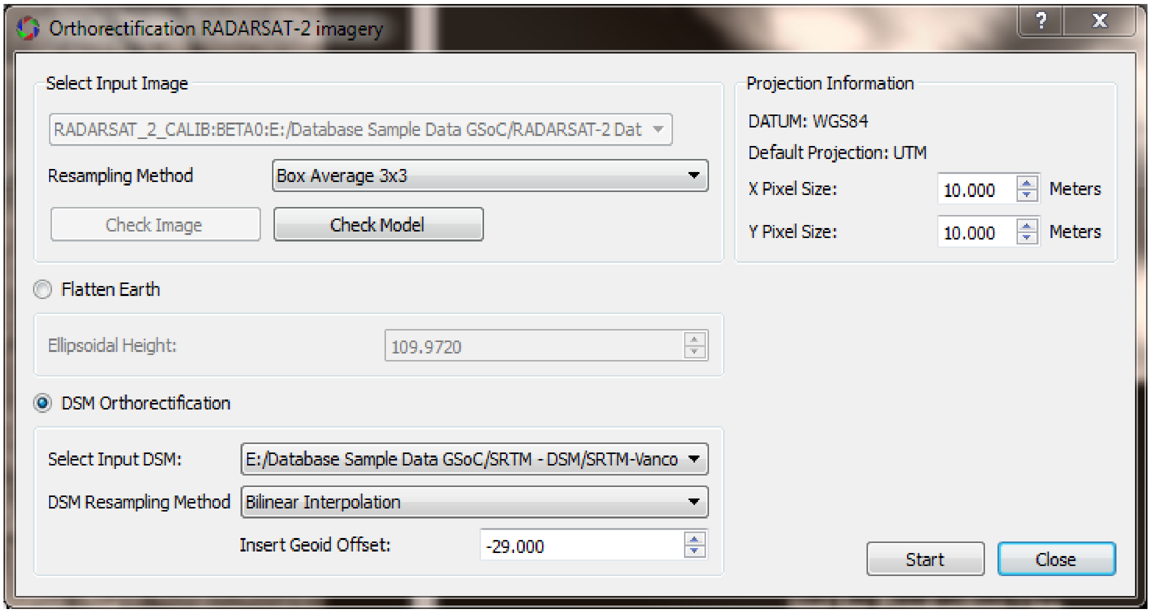


Figure 19: Graphical User Interface of the RADARSAT-2 Orthorectification tool - Step2

Finally, the user should choose the surface to be used for image orthorectification: an ellipsoidal surface with constant height or a general standard ASCII DSM. For the present tutorial, it has been decided to select the DSM Orthorectification option. The DSM to be used can be selected using the sliding tag *Select Input DSM*. Choose the bilinear Interpolation method from the corresponding sliding tag and for the *Geoid Offset* value type 29.00 meters (a free geoid undulation calculator is available online).

Now that all input parameters have been selected, RADARSAT-2 Orthorectification tool can be run by pressing the *Start* button. In Fig. 20 are shown the raw RADARSAT-2 image (Left), the input SRTM DSM (up right) and the orthorectified image (down right) with the overlaid geographic layer (to add the geographical information layer into the image one can simply use the Opticks *Georeference* tool).
Fig. 21 show a zoom area, on the left the raw RADARSAT-2 image and on the right the results of the *Orthorectification PlugIn*.
Finally, the image can be exported by using the Opticks *Export module* and can be saved in GeoTiff format.

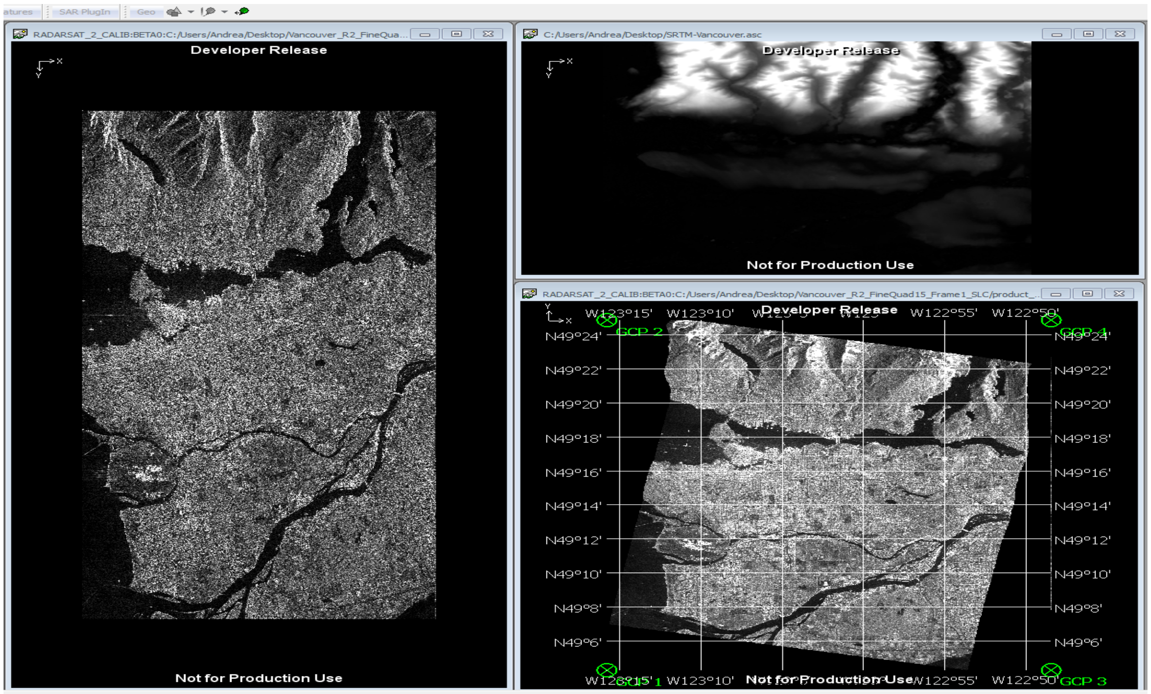


Figure 20: RADARSAT-2 Orthorectification tool results

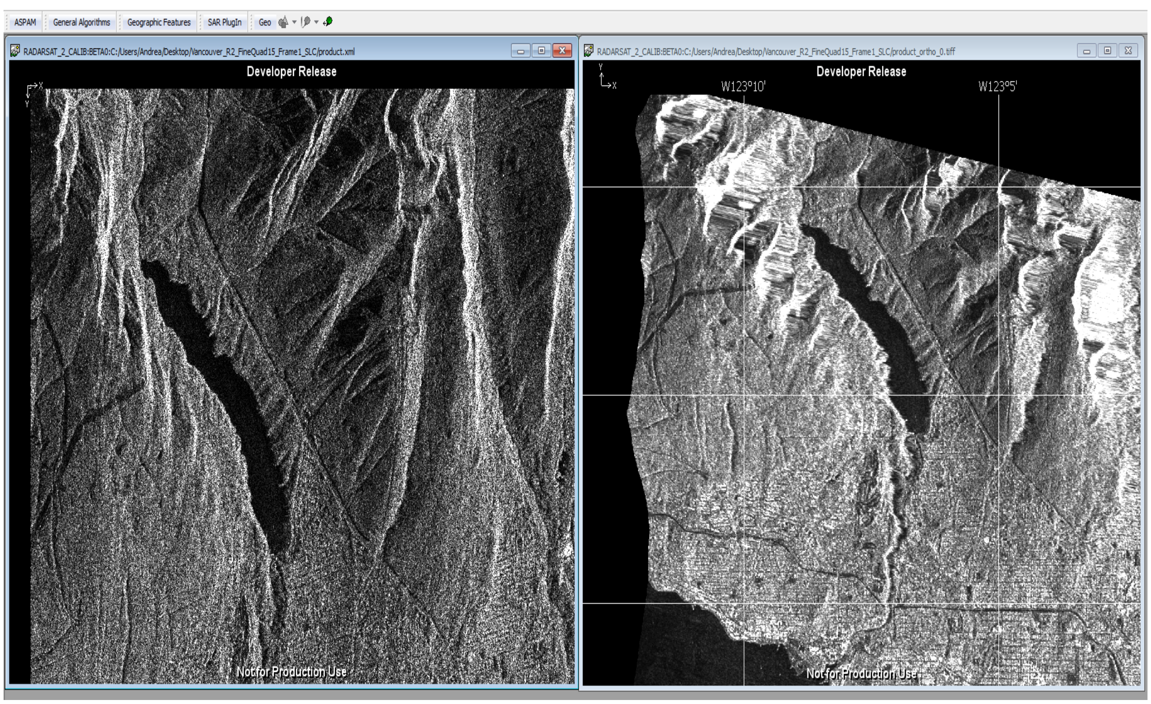


Figure 21: RADARSAT-2 Orthorectification tool results zoom