Rigorous Orthorectification Tutorial

This tutorial demonstrates how to create an orthorectified mosaic from two QuickBird multispectral images and a DEM of Phoenix, Arizona, USA. You will learn how to properly open the images and DEM in ENVI Classic, restore a ground control point (GCP) file, add new GCPs, add tie points, and define the parameters of the orthorectified product.

You must have a license for the ENVI Photogrammetry Module to run this tutorial.

Files Used in This Tutorial

Download data files from the website.

Click the "ENVI Tutorial Data" hyperlink to download data for all ENVI tutorials. Files for this tutorial are in the `rigorous_ortho` folder. You should save a copy of the entire `rigorous_ortho` directory to your local drive, to speed up performance and to simplify editing the GCP file.

File	Description
`005606990010_01_P008_MUL\05JUL*.TIF`	QuickBird Level-1 multispectral imagery for Phoenix, AZ from 11 July 2005
`005606990010_01_P011_MUL\05OCT*.TIF`	QuickBird Level-1 multispectral imagery for Phoenix, AZ from 09 October 2005
`phoenix_DEM_subset.tif`	DEM subset of Phoenix, AZ, in GeoTIFF format
`phoenixGCPs.pts`	Ground control points (GCPs) for the 05JUL* QuickBird image (in the 005606990010_01_P008_MUL directory)

QuickBird files are courtesy of DigitalGlobe and may not be reproduced without explicit permission from DigitalGlobe.

Background

An orthorectified image (or orthophoto) is one where each pixel represents a true ground location and all geometric, terrain, and sensor distortions have been removed to within a specified accuracy. Scale is constant throughout the orthophoto, regardless of elevation, thus providing accurate measurements of distance and direction. Geospatial professionals can easily combine orthophotos with other spatial data in a geographic information system (GIS) for city planning, resource management, and other related fields.

ENVI Classic's existing orthorectification tools (accessed through **Map > Orthorectification** in the main menu bar) allow you to orthorectify images using rational polynomial coefficients (RPCs), elevation and geoid information, and optional ground control points (GCPs). However, RPCs and elevation information do not provide enough details to build a rigorous model representing the path of light rays from a ground object to the sensor.

Rigorous Orthorectification is included when you purchase a separate license for the ENVI Photogrammetry Module. Rigorous Orthorectification allows you to build highly accurate orthorectified images by rigorously modeling the object-to-image transformation. The details of this transformation are mostly transparent to the user, which means you can quickly create orthorectified images without defining detailed model parameters.

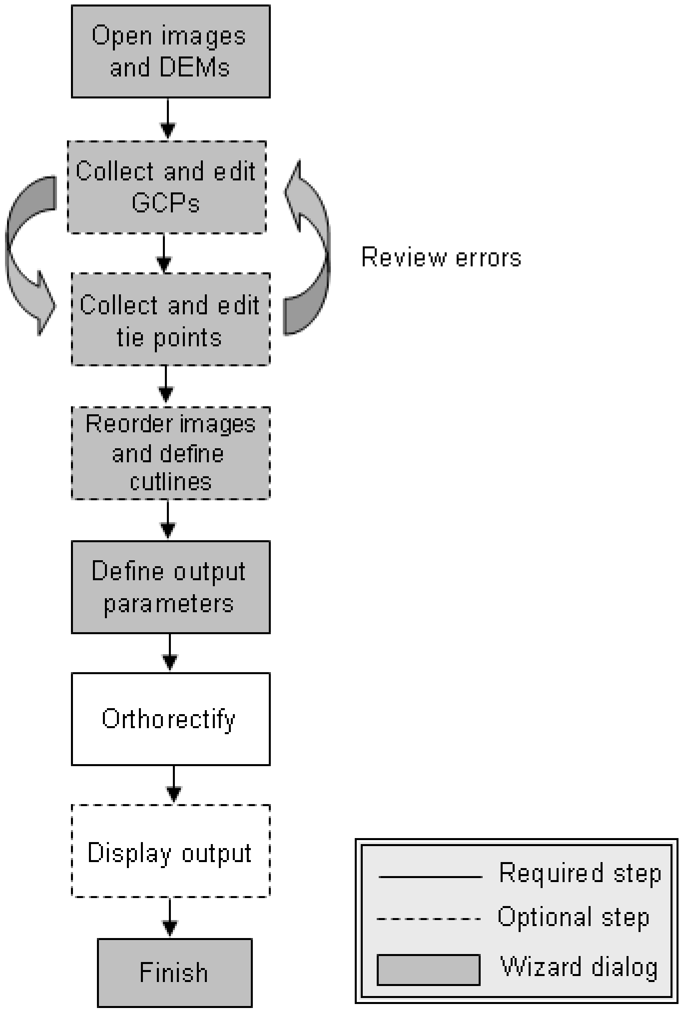
With the ENVI Orthorectification Layout Manager, you can easily see the spatial coverage of images, DEMs, GCPs, and tie points, along with residual error vectors for each GCP. You can adjust your GCPs and tie points to improve the overall residual error for the orthorectified output. Automatic color balancing is available during the final output step.

The ENVI Photogrammetry Module is a joint collaboration between Harris Geospatial Solutions and Spacemetric AB of Stockholm, Sweden. Spacemetric designed the underlying block-adjustment model, which provides a precision orthorectification solution for various sensors. For more technical information on Spacemetric's orthorectification models, see their website at http://www.spacemetric.com.

Workflow

The figure below shows a typical orthorectification workflow. The only required steps are (1) select input images and DEMs, (2) build an adjustment model, (3) select output parameters, and (4) rectify the input image(s) to produce the output image. However, you will achieve the most accurate results by incorporating optional ground control points (GCPs) and tie points into the model, while iteratively reviewing the overall model error and editing points as needed to reduce the error. You can also optionally create and edit cutlines and set some basic parameters for the final output.

The shaded boxes represent workflow steps that have an associated wizard dialog to guide you through the process.



Select Input Images and DEM

Input images must be in their native format and directory structure, exactly as they are delivered by the data provider. The imagery must include all associated metadata and ephemeris data.

You must first open the image files using ENVI Classic's **File > Open External File** menu option, before loading the images into the Orthorectification Wizard. Use the following steps to open two QuickBird images for input. Both are in a Geographic Lat/Lon projection with a WGS-84 datum.

1. From the ENVI Classic main menu bar, select **File > Open External File > QuickBird > GeoTIFF**. The Enter TIFF/GeoTIFF Filenames dialog appears.
2. Navigate to `rigorous_ortho/005606990010_01_P008_MUL`, and open `05JUL11182931-M1BS-005606990010_01_P008.TIF`. The file appears in the

Available Bands List. This is a multispectral image of Phoenix, Arizona, captured on 11 July 2005.

Note: This file will be referred to as the 05JUL* image throughout the rest of the tutorial.

3. From the ENVI Classic main menu bar, select **File > Open External File > QuickBird > GeoTIFF**. The Enter TIFF/GeoTIFF Filenames dialog appears.
4. Navigate to rigorous_ortho/005606990010_01_P011_MUL, and open 05OCT09183407-M1BS-005606990010_01_P011.TIF. The file appears in the Available Bands List. This is a multispectral image of Phoenix, Arizona, captured on 09 October 2005.

Note: This file will be referred to as the 05OCT* image throughout the rest of the tutorial.

Next, you will open a DEM into ENVI Classic. You do not need to use the **File > Open External File** menu option for DEMs, when using Rigorous Orthorectification.

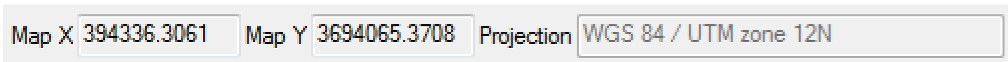
5. From the ENVI Classic main menu bar, select **File > Open Image File**. The Enter Data Filenames dialog appears. Navigate to rigorous_ortho, and select the file phoenix_DEM_subset.tif. Click **Open**. This is a subset of a U.S. Geological Survey DEM from the Phoenix area. It is in a Geographic Lat/Lon projection with a WGS-84 datum.
6. From the ENVI Classic main menu bar, select **Map > Rigorous Orthorectification**. The ENVI Orthorectification Layout Manager (hereafter referred to as the *Layout Manager*) and ENVI Orthorectification Wizard (hereafter referred to as the *Wizard*) appear.

Load Images and DEM into the ENVI Orthorectification Wizard

1. In the Wizard (Step 1 of 5), click the + button next to the Input Images section. The Select Input Files dialog appears.
2. Use the **Ctrl** key to select both GeoTIFF images (05OCT* and 05JUL*). Click **OK**. The Select Sensor Type dialog appears.
3. Select **QuickBird**, then click **OK**. The image filenames are listed in the Input Images section of the Wizard.
4. Click the + button next to the Input DEMs section. The Select Input Files dialog appears.
5. Select **Band 1** under phoenix_DEM_subset.tif, and click **OK**. The DEM filename is listed in the Input DEMs section of the Wizard.
6. Click **Next** in the Wizard. After the images and DEMs load, their boundaries are shown in the Layout Manager.

Using the Layout Manager

The top of the Layout Manager shows the projection of the input images. The Map X/Y coordinates update as you move the cursor around the draw area (the black area that shows the different layers of data):

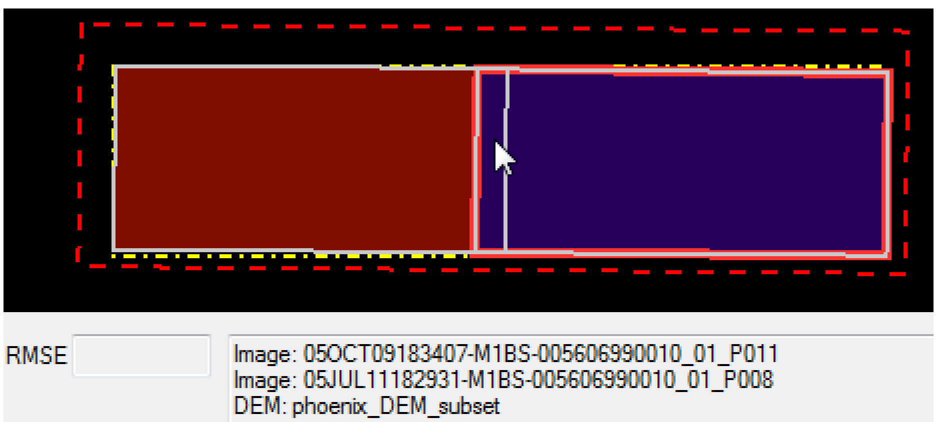


The DEM (shown with a red dashed box) surrounds the two QuickBird images. Use the **DEM** checkbox in the Layout Manager to turn on/off the DEM boundary.

The two QuickBird images overlap. The image boundaries are shown with solid grey boxes, and their interiors are filled with different colors. Use the **Image** checkbox in the Layout Manager to turn on/off the grey image boundaries in the Draw Area.

The yellow dashed box represents the default output area for the orthorectified product, which is currently selected to be the image boundaries. Use the **Output Area** checkbox in the Layout Manager to turn on/off the yellow boundary in the Draw Area.

As you move the cursor over an image boundary, the underlying image and DEM filename appear. In the area where both images overlap, both image filenames appear:

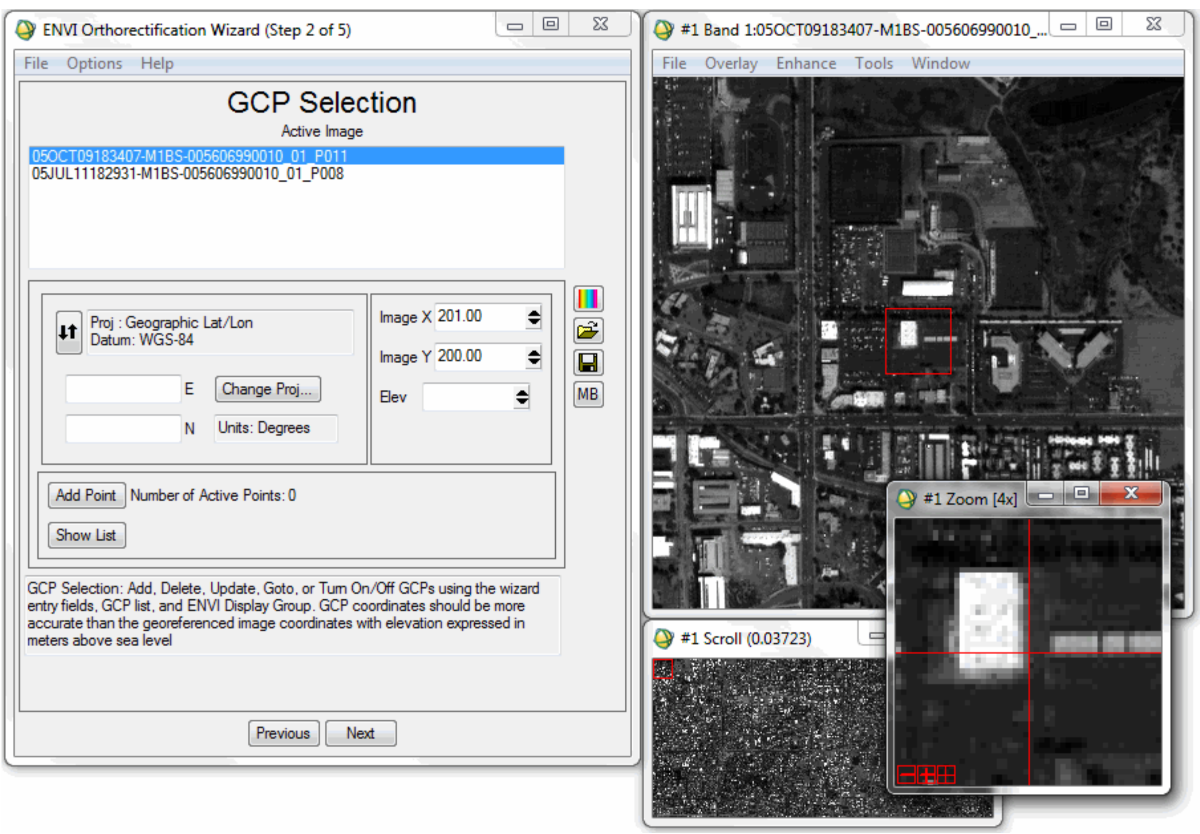


Use the scroll wheel on your mouse to zoom in or out. Or, right-click inside the draw area to select different zoom options. Click and drag the mouse to pan around.

Working with Ground Control Points

After you loaded the QuickBird images and DEM into the Wizard and clicked Next, the Wizard proceeded to the GCP Selection panel (Step 2 of 5), and a display group opened for the `05OCT*` image. In the GCP Selection step, you will associate image pixels to points on the ground whose locations are known through a horizontal coordinate system and vertical datum. These points are called *ground control points* (GCPs).

The controls in this step of the wizard allow you to optionally restore GCP files, to add new GCPs, and to edit existing GCPs. Although selecting GCPs is an optional step in the overall workflow, you will achieve the most accurate orthorectified results by using GCPs and iteratively reviewing the overall RMS error.



Restore GCPs

For this tutorial, you will restore a set of GCPs that lie within the `05JUL*` QuickBird image boundary (the left image as shown in the Layout Manager). DigitalGlobe, who provided the QuickBird images, also produced a set of GCPs for the entire Phoenix area, in Microsoft Excel format. However, Rigorous Orthorectification requires GCPs to be in a “Rigorous Orthorectification GCP” format. For more information, see the ENVI Classic Help.

The GCP file you are about to restore (phoenixGCPs.pts) was created by identifying those GCPs that fell within the 05JUL* QuickBird image boundary, then entering them one-by-one into the ENVI Orthorectification Wizard using map coordinates provided by DigitalGlobe. The GCPs were already in a Geographic Lat/Lon projection with WGS-84 datum (the same projection as the QuickBird images and DEM). The GCP file was then saved to ENVI format, using the **Save GCPs** button in the Wizard.

The first few lines in the GCP file (phoenixGCPs.pts) are the header lines, and they are preceded by semicolons. They list the input images you selected earlier. They currently only list the filenames, but the Rigorous Orthorectification GCP file format requires a full path to the image filenames. You will need to edit phoenixGCPs.pts to include the full path to the 05JUL* QuickBird image filename on your computer. As mentioned in the introduction, you should save a copy of the entire rigorous_ortho directory to your local drive, so that you can save your changes to the GCP file.

1. Navigate to rigorous_ortho and open the file phoenixGCPs.pts in a text editor.
2. Edit the third line that begins with FileName1 to include the full path to the 05JUL* image; for example:

   ; FileName1=**C:\MyData\rigorous_ortho\005606990010_01_P008_MUL**05JUL11182931-M1BS-005606990010_01_P008.TIF

   Note: You don't need to edit the FileName0 line, since the GCP locations in phoenixGCPs.pts only pertain to the 05JUL* image (FileName1).
3. Save the file phoenixGCPs.pts.
4. When working with multiple input images, you need to specify which image corresponds to the GCPs you are about to restore or add. In the Wizard, select the **05JUL*** image filename from the **Active Image** drop-down list:

   The display group updates to show the 05JUL* image.
5. Click the **Load a New GCP File** button in the Wizard. The Select GCP File dialog appears.
6. Select the file phoenixGCPs.pts that you just edited and saved, and click **Open**. The GCP Selection panel shows "Number of Active Points: 14." The GCPs also appear in the display group and the Layout Manager.

Add New GCPs

The GCPs you just restored are all within the 05JUL* image, so now you should add some GCPs to the 05OCT* image (the right-most image as shown in the Layout Manager). Unfortunately, there are only two available GCPs for this area. But this is a realistic scenario in orthorectification: you may not always have adequate GCP coverage throughout your area of interest, or the GCPs may be unevenly distributed.

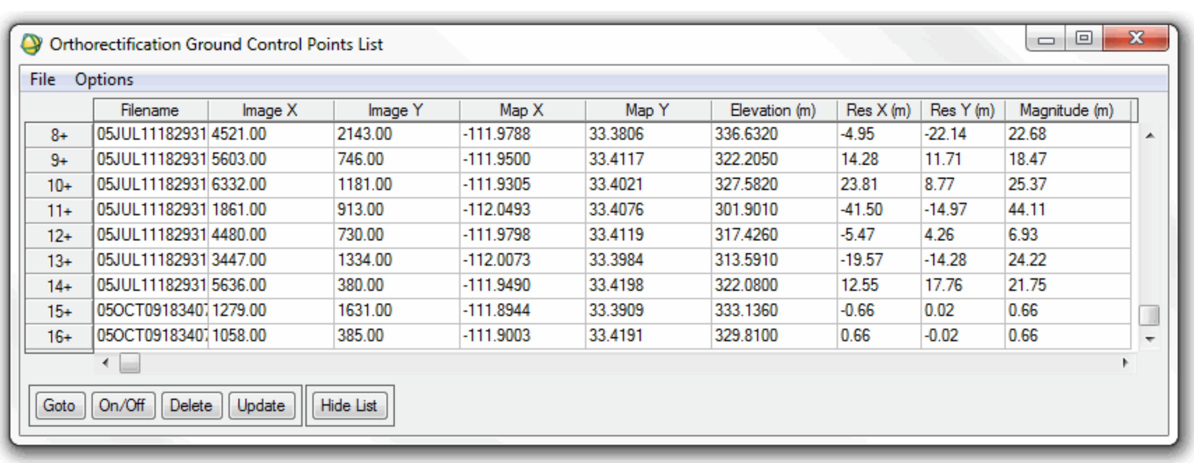
1. In the GCP Selection panel, click the `05OCT*` image filename:
2. Click the **Projection** toggle button .
3. Click **DDEG**. The **Lat** and **Lon** fields change so that you can enter map coordinates in decimal degrees.
4. Enter the following values in their respective fields in the GCP Selection panel, then click the **Add Point** button:

   Lat: 33.39088287
   Lon: -111.89436526
   Image X: 1279
   Image Y: 1631
   Elevation: 333.136

   After a few seconds, the new GCP appears in the display group and Layout Manager.
5. Enter the following values, then click the **Add Point** button:

   Lat: 33.41914515
   Lon: -111.90030564
   Image X: 1058
   Image Y: 385
   Elevation: 329.81
6. Click the **Show List** button in the GCP Selection panel.

   The table in the GCP Selection panel should look as follows. The new GCP locations that you added are shown in rows 15 and 16. The Geographic Lat/Lon coordinates are converted into eastings and northings for this table.



	Filename	Image X	Image Y	Map X	Map Y	Elevation (m)	Res X (m)	Res Y (m)	Magnitude (m)
8+	05JUL11182931	4521.00	2143.00	-111.9788	33.3806	336.6320	-4.95	-22.14	22.68
9+	05JUL11182931	5603.00	746.00	-111.9500	33.4117	322.2050	14.28	11.71	18.47
10+	05JUL11182931	6332.00	1181.00	-111.9305	33.4021	327.5820	23.81	8.77	25.37
11+	05JUL11182931	1861.00	913.00	-112.0493	33.4076	301.9010	-41.50	-14.97	44.11
12+	05JUL11182931	4480.00	730.00	-111.9798	33.4119	317.4260	-5.47	4.26	6.93
13+	05JUL11182931	3447.00	1334.00	-112.0073	33.3984	313.5910	-19.57	-14.28	24.22
14+	05JUL11182931	5636.00	380.00	-111.9490	33.4198	322.0800	12.55	17.76	21.75
15+	05OCT09183407	1279.00	1631.00	-111.8944	33.3909	333.1360	-0.66	0.02	0.66
16+	05OCT09183407	1058.00	385.00	-111.9003	33.4191	329.8100	0.66	-0.02	0.66

Evaluate Residual Errors

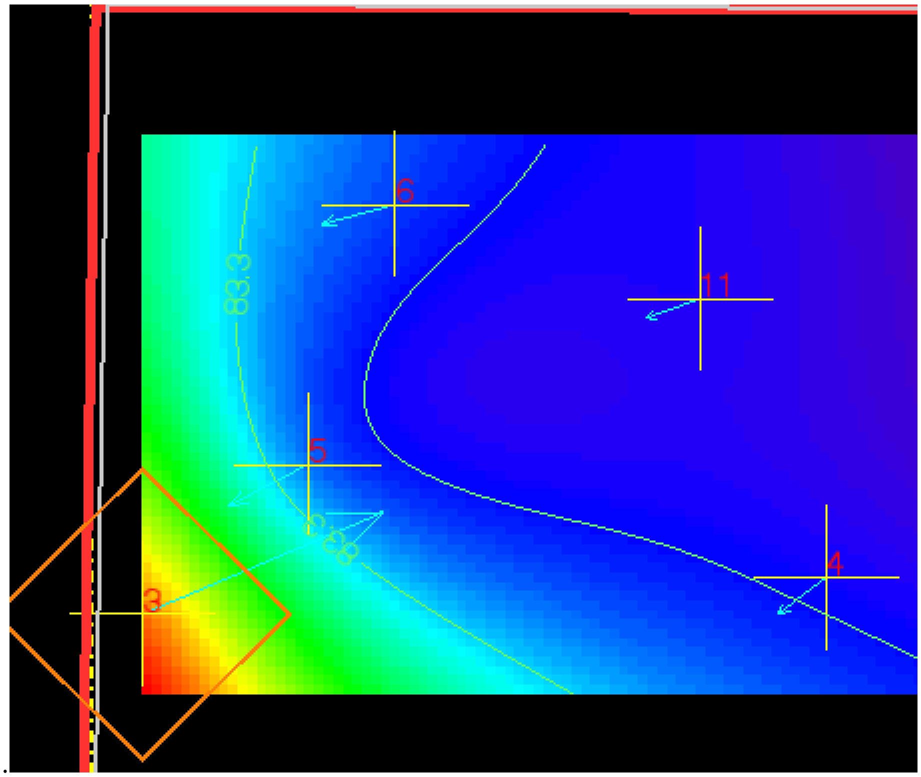
The controls in the Layout Manager to evaluate the overall model error are a powerful feature of Rigorous Orthorectification. As you interactively add, edit, or remove GCPs and tie points, the entire model is recomputed on-the-fly and your results are immediately visible in the Layout Manager. Note the **RMSE** (root mean square error) field that lists the overall model error. The current value should be 58.873389.

1. Enable the **Residual Image** option in the Layout Manager. A contour map is added to the Draw Area, showing the residual error throughout the area based on your GCP data. Purple-to-blue areas indicate the lowest residual errors, and red-to-white areas indicate the highest errors.
2. Right-click inside the draw area, and select **Zoom In** until you can see the contour labels more closely. Click-and-drag the mouse to pan around. From looking at this contour view, you can see that GCP #3 (in the far lower-left corner of the contour map) has a relatively high residual error.
3. Scroll to the right of the GCP list until you see the **Magnitude (m)** field. The contour view of residual error is based on these relative magnitude values. You must have four or more GCPs for this column to appear.
4. Click on the **3+** button to select the entire row for GCP #3:

1+	05JUL11182931	4366.00
2+	05JUL11182931	3569.00
3+	05JUL11182931	245.00
4+	05JUL11182931	2263.00
5+	05JUL11182931	651.00

   A diamond marker appears over the GCP. Its magnitude value is 200.33. This value is relatively high, compared to the magnitude values of other GCPs.

5. Enable the **Residual Vectors** option in the Layout Manager.
6. Increase the **Residual Exaggeration** value to **10**.
7. Disable the **Residual Image** option. Cyan-colored arrows originate from each GCP location, showing their error magnitudes and directions. The left side of the scene has the highest errors and, as expected, the GCP corresponding to ID #3 has the largest residual error vector.



.

In the next step, you will remove this GCP and see if the overall model improves.

8. With Row **3+** still selected in the GCP list, click the **Delete**button. The entire model is recomputed, and the updated residual errors are shown in the Layout Manager. The row numbers are updated accordingly.
   - What is the overall RMSE value now?
   - Did the overall model improve after removing this GCP?
9. Use the GCP list to look for other GCPs with relatively high magnitude values. In addition to removing GCPs, you can also interactively update their geographic location as follows:
   - Select any GCP with a relatively high magnitude value.
   - Open the Zoom window of the display group, which is centered over that GCP.
   - Click the + button in the Zoom window to zoom in further.
   - Click on a nearby pixel to move the crosshairs over that pixel.
   - Click the **Update** button in the GCP list. This moves the GCP to the new pixel location and recalculates the overall model error.
   - If the magnitude value for the GCP did not decrease, try a different pixel location and click **Update**.

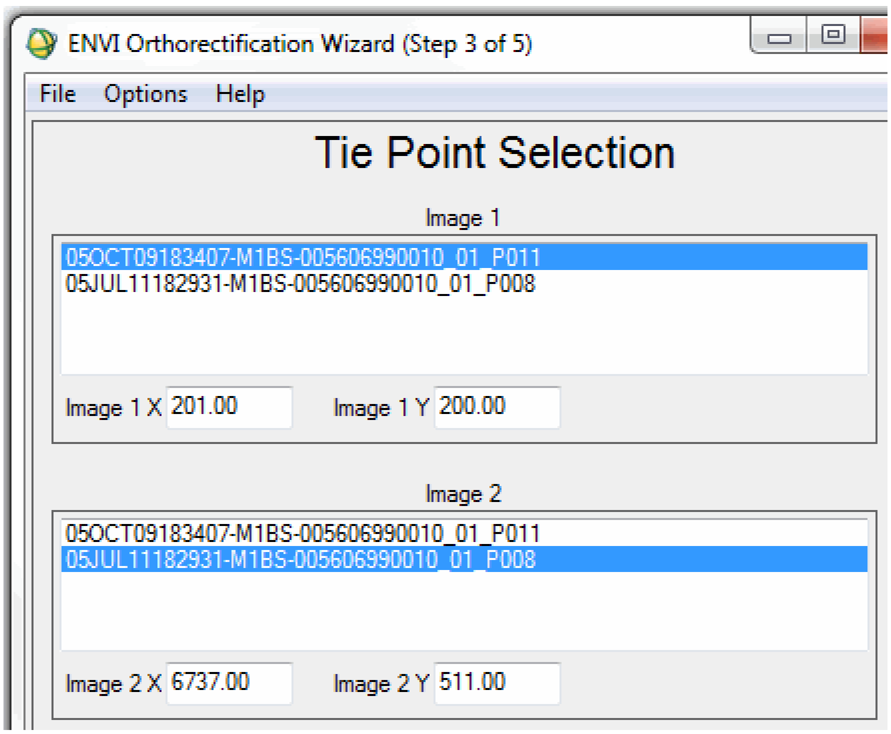
- Repeat these steps with other GCPs as needed. The goal is to decrease individual GCP magnitude values and the overall RMSE value. This is an interactive process that involves much trial-and-error to produce the best results.

10. Click **Next** in the Wizard to proceed to the Tie Point Selection panel.

Working with Tie Points

In this step, you can select pixels from both images that represent the same location on the ground. These pixels are called *tie points*. Although computing tie points is an optional step, tie points are an important component for computing the orthorectified model and account for most of the accuracy in the orthorectified product. In this exercise, you will add three tie points.

A display group appears with the `05OCT*` image, while another display group contains the `05JUL*` image. The Tie Point Selection panel shows the `05OCT*` image as **Image 1** and the the `05JUL*` image as **Image 2**.



To save some time, the pixel coordinates for each tie point were already determined for you. This process involved identifying an object in the `05JUL*` image (such as an intersection or building corner), zooming in, and using the Cursor Location/Value tool to record the image coordinates for that pixel. The same object was then identified in the `05OCT*` image, and the fractional image coordinates for the corresponding pixel were recorded.

1. Enter the following pixel coordinates that represent the first tie point, then click the **Add Point** button.

   Image 1
   Image X: 363, Image Y: 480

   Image 2
   Image X: 6736, Image Y: 512

2. Enter the following pixel coordinates that represent the second tie point, then click the **Add Point** button.

   Image 1
   Image X: 490, Image Y: 1928

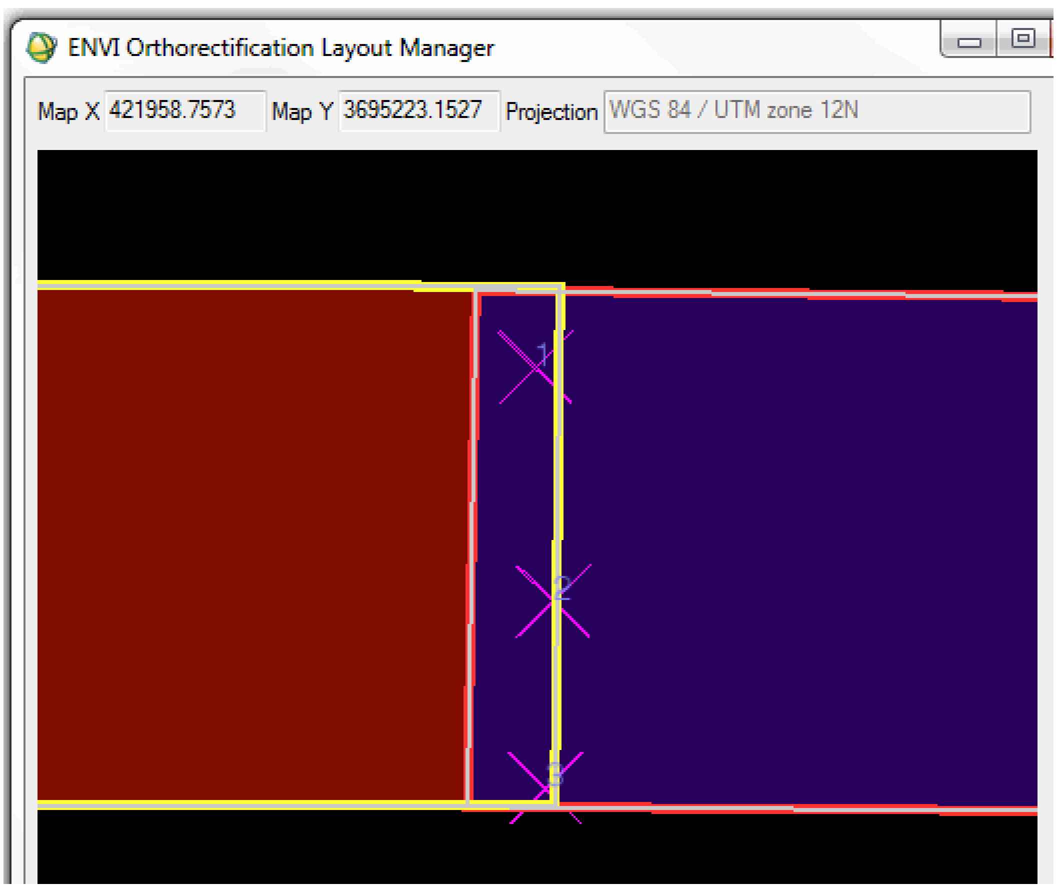
   Image 2
   Image X: 6860, Image Y: 1998

3. Enter the following pixel coordinates that represent the third (and final) tie point, then click the **Add Point** button.

   Image 1
   Image X: 461, Image Y: 3086

   Image 2
   Image X: 6824, Image Y: 3186

   The tie points are shown in the Layout Manager with magenta-colored "X" symbols:



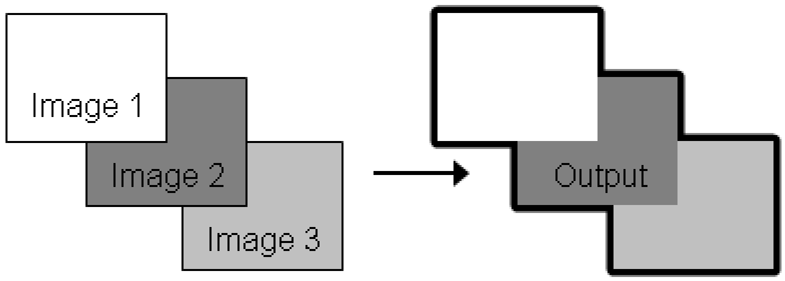
4. Click **Show List** in the Tie Point Selection panel to see the list of tie points.

5. Before proceeding to the next step in the workflow, you should save your project. From the Wizard menu bar (Tie Point Selection panel), select **File > Save Project**. The Select Project File dialog appears.
6. Enter a filename and location for the project state, and click **Save**. ENVI Classic saves the project state in XML format. If you need to restore your project later, select **Map > Rigorous Orthorectification** from the ENVI Classic main menu bar, then select **File > Restore Project** from the Wizard menu bar to select the XML file for your project. ENVI Classic automatically opens all input files, DEMs, GCPs, and tie points, so that you don't need to open them prior to restoring the project.
7. Click **Next** in the Wizard to proceed to the Image Order & Cutline Selection panel.

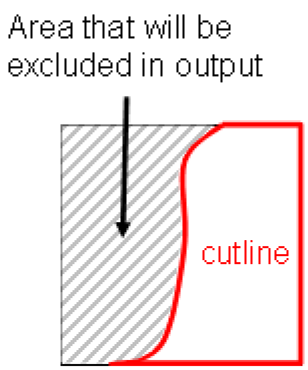
Ordering Images and Defining Cutlines

In this optional step, you can define any areas between two or more overlapping images that you want to appear in the final output. With each input image, you perform two steps: (1) define the hierarchy of the image relative to the others, and (2) define an optional cutline for the image.

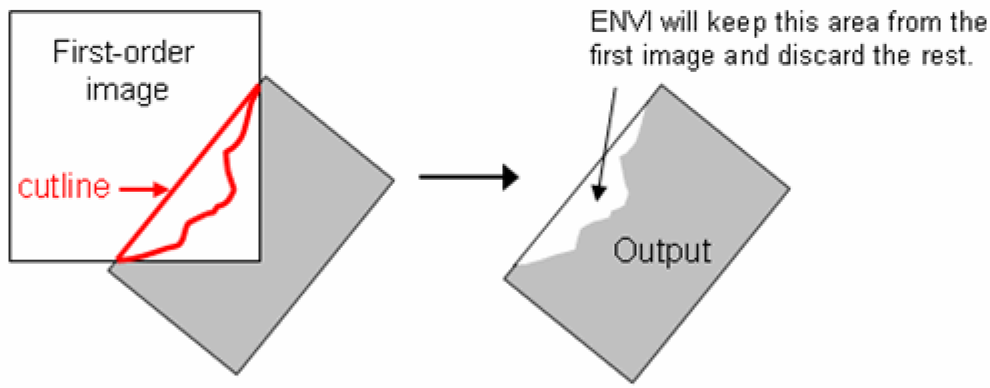
Use the **Image Order** list to define how multiple images are ordered in the final output. This list is populated with the image filenames you added to the workflow earlier. The image at the top of the list will be ordered first, followed by the second image, and so forth. Image ordering only pertains to areas of overlap between two or more images:



Cutlines are polygons that are used in combination with image ordering to define areas that you want to keep in the final output. A cutline is essentially an inclusion polygon, similar to a cookie cutter applied to one or more images. The following example shows a cutline for a single image:



Following is an example of applying a cutline to the first-order (top-most) image when you have multiple images.

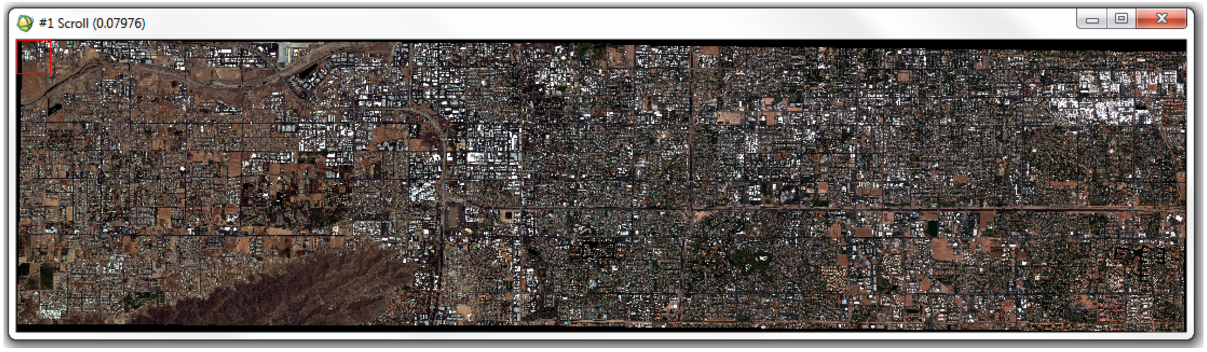


For this tutorial, you will skip the process of ordering images and defining cutlines, by clicking **Next**. ENVI Classic will use the image frame as a cutline by default. The image frame is the area of usable image data, excluding any background pixels.

Define Output Parameters

Follow these steps:

1. Enter an output filename and location for the orthorectified image. From the **File Format** drop-down list, select **ENVI**.
2. Select the **Auto Color Adjust** option to perform automatic color balancing.
3. Leave the default Pixel Size as 2.47400 m.
4. In the Post Processing Reprojection section, leave the default projection of UTM Zone 12, WGS-84. ENVI Classic will use the pixel sizes of the input QuickBird images, to determine the X and Y pixel size of the orthorectified image.
5. Click the **Preview** button to see a preview of the orthorectified image.
6. Select the **Display Result** option to display the image after it has been created.
7. Click **Finish** to create the orthorectified image. This process will take a long time, as the two QuickBird images are very large. Following is a true-color version of the output mosaic as it appears in the Scroll window:



Optional Step

If you have some extra time, you may want to experiment with skipping the steps of adding GCPs and tie points altogether, then re-running the orthorectification process. Compare the RMSE value of the overall model with no GCPs or tie points.

GCPs and tie points should have a quality that is consistently better than the initial accuracy of the sensor model; this varies with data type and vendor. For example, mid-latitude QuickBird scenes of a relatively flat area may provide an accurate orthorectification without the use of GCPs or tie points.