

ENVI Tutorial: The ENVI Orthorectification Module

Table of Contents

OVERVIEW OF THIS TUTORIAL	2
<i>Files Used in This Tutorial</i>	2
BACKGROUND	2
<i>The ENVI Orthorectification Module Workflow</i>	3
<i>Installing the ENVI Orthorectification Module</i>	3
SELECTING INPUT IMAGES AND DEMS	4
<i>Loading the Images and DEM into ENVI</i>	4
<i>Loading the Images and DEM into the ENVI Orthorectification Wizard</i>	6
WORKING WITH GROUND CONTROL POINTS	7
<i>Restoring GCPs</i>	7
<i>Adding new GCPs</i>	8
<i>Evaluating Residual Errors</i>	10
WORKING WITH TIE POINTS	12
ORDERING IMAGES AND DEFINING CUTLINES	15
DEFINING OUTPUT PARAMETERS	16

Overview of This 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, restore a ground control point (GCP) file, add new GCPs, add tie points, and define the parameters of the orthorectified product.

Files Used in This Tutorial

ENVI Resource DVD: \envidata\rigorous_ortho

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)

Note: It is highly recommended that you save a copy of the entire `rigorous_ortho` directory to your local drive, in order to speed up performance and to simplify editing the GCP file (see “Restoring GCPs” on page 7).

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's existing orthorectification tools (accessed through **Map** → **Orthorectification** in the ENVI 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.

The ENVI Orthorectification Module 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. ENVI uses the latest innovative research methods to perform color balancing and mosaicking in the output product.

The ENVI Orthorectification Module is a joint collaboration between ITT Visual Information 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.se/technology>.

The ENVI Orthorectification Module Workflow

Figure 1 illustrates a typical orthorectification workflow. The only required steps in the ENVI Orthorectification Module workflow 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 in Figure 1 represent workflow steps that have an associated wizard dialog to guide you through the process.

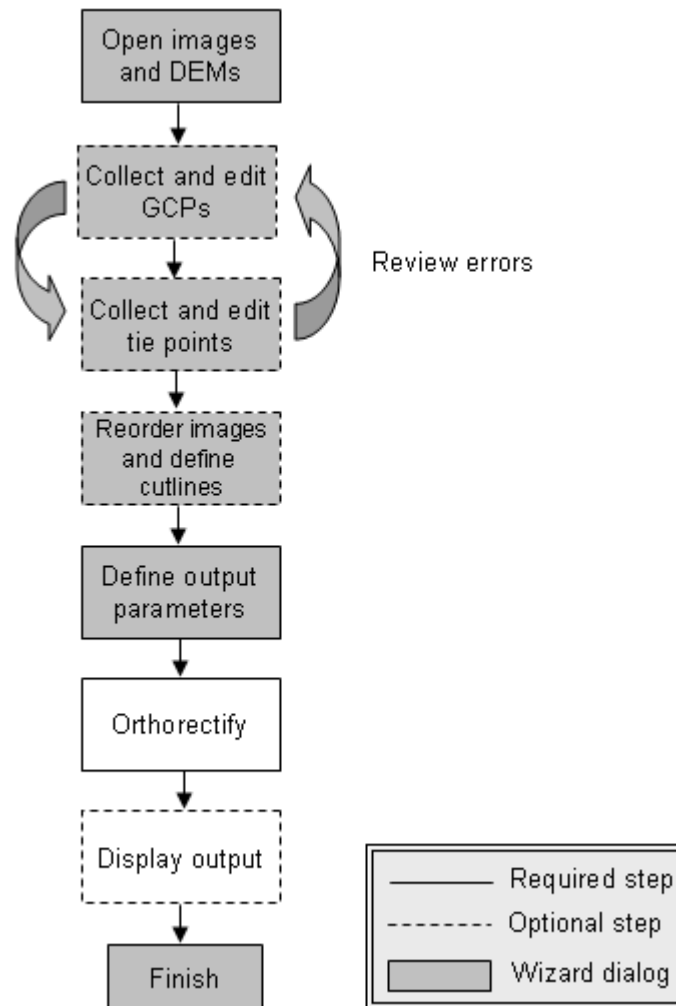


Figure 1: Orthorectification Module Workflow

Installing the ENVI Orthorectification Module

The ENVI Orthorectification Module requires a separate installer from the ENVI installer. When you purchase a license for the ENVI Orthorectification Module, you will have access to an installer for your Windows or UNIX platform. If you do not have an ENVI Orthorectification Module license, contact ITT Visual Information Solutions or your ENVI distributor.

For supported platforms and information about entering a new ENVI license, refer to the *Installation and Licensing Guide*, which is available on the ITT Visual Information Solutions website, on the ENVI installation DVD, or on the ENVI Resource DVD that shipped with your software.

Selecting Input Images and DEMs

The ENVI Orthorectification Module requires input images to 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. See the *ENVI Orthorectification Module User's Guide* for a list of supported image formats and required metadata.

You must first open the image files using ENVI'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.

Note: It is highly recommended that you save a copy of the entire `rigorous_ortho` directory to your local drive, in order to speed up performance.

Loading the Images and DEM into ENVI

1. From the ENVI 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 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. You do not need to use the **File** → **Open External File** menu option for DEMs, when using the ENVI Orthorectification Module.

5. From the ENVI 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 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.

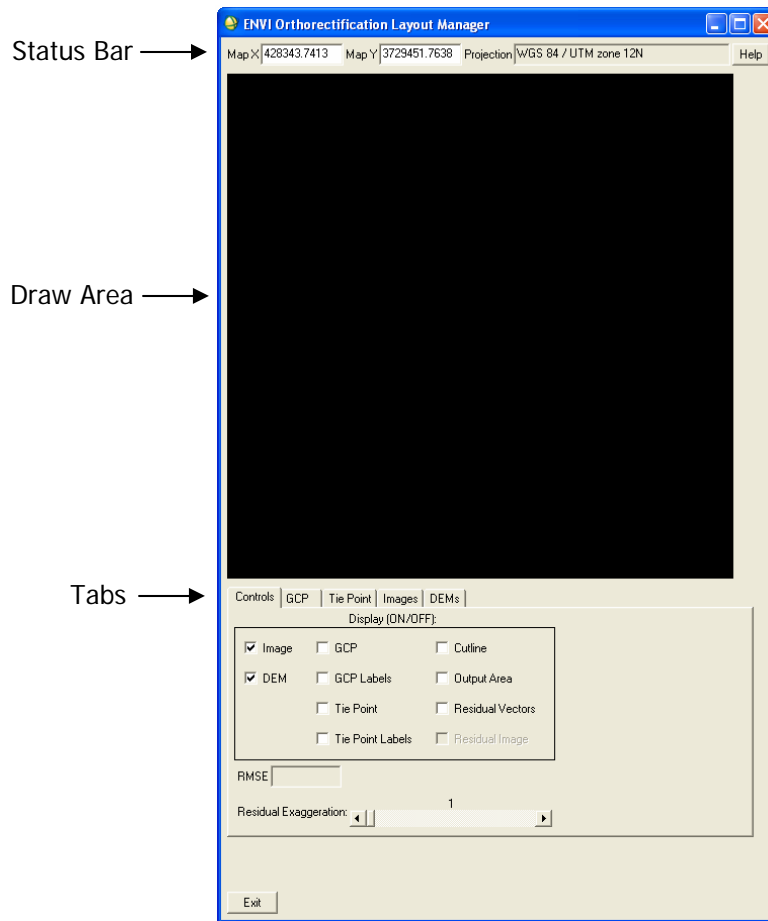


Figure 2: ENVI Orthorectification Layout Manager

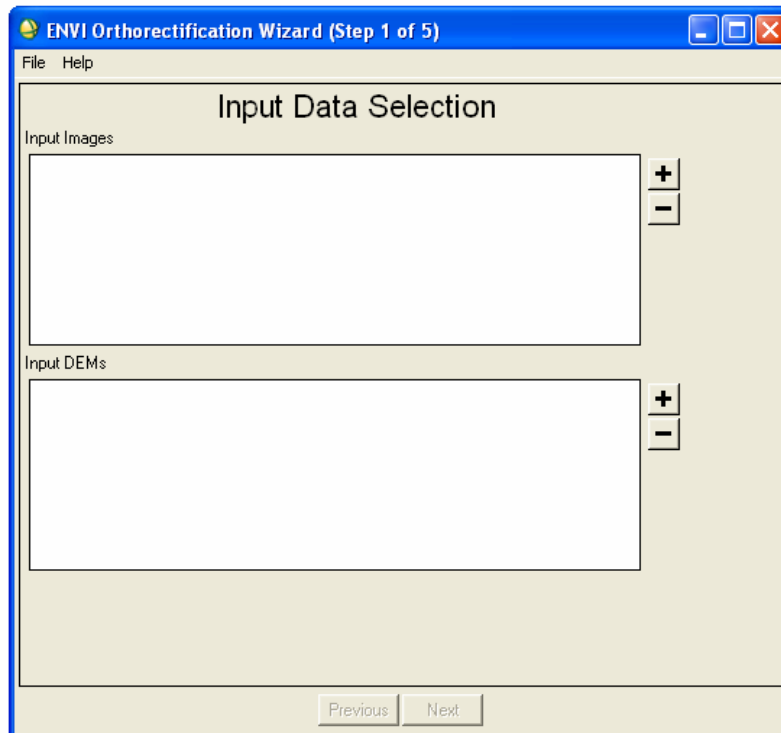




Figure 3: ENVI Orthorectification Wizard

Loading the 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 images appear in the Input Images list in the Wizard.
3. Click the  button next to the Input DEMs section. The Select Input Files dialog appears.
4. Select **Band 1** under `phoenix_DEM_subset.tif`, and click **OK**. The DEM filename appears in the Input DEMs list in the Wizard.
5. Click **Next** in the Wizard. After the images and DEMs load, their boundaries are shown in the Layout Manager. Depending on your system, this may take some time.

The DEM (shown with a red dashed box) surrounds the two QuickBird images. Use the **DEM** checkbox in the Layout Manager to control the display of the DEM boundary in the Draw Area.

Notice also that the two QuickBird images overlap. The image boundaries are shown with solid green boxes. Use the **Image** checkbox in the Layout Manager to control the display of the 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 control the display of the output area in the Draw Area.

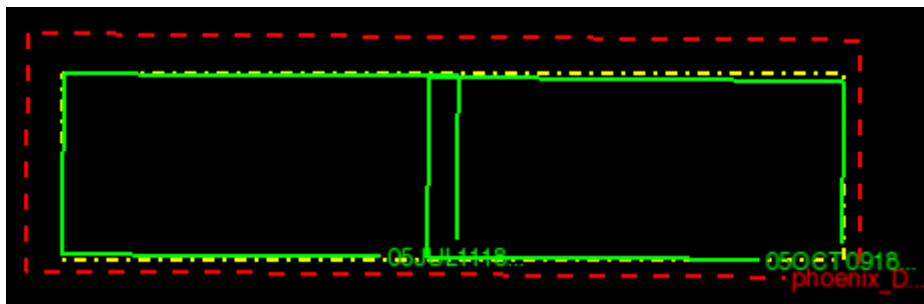


Figure 4: Image and DEM boundaries as shown in the Layout Manager

The names of the input images and DEM appear, respectively, under the **Images** and **DEMs** tabs of the Layout Manager:

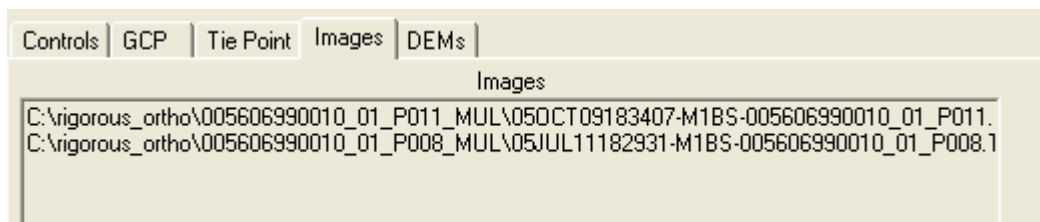


Figure 5: Images Tab in the Layout Manager

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.

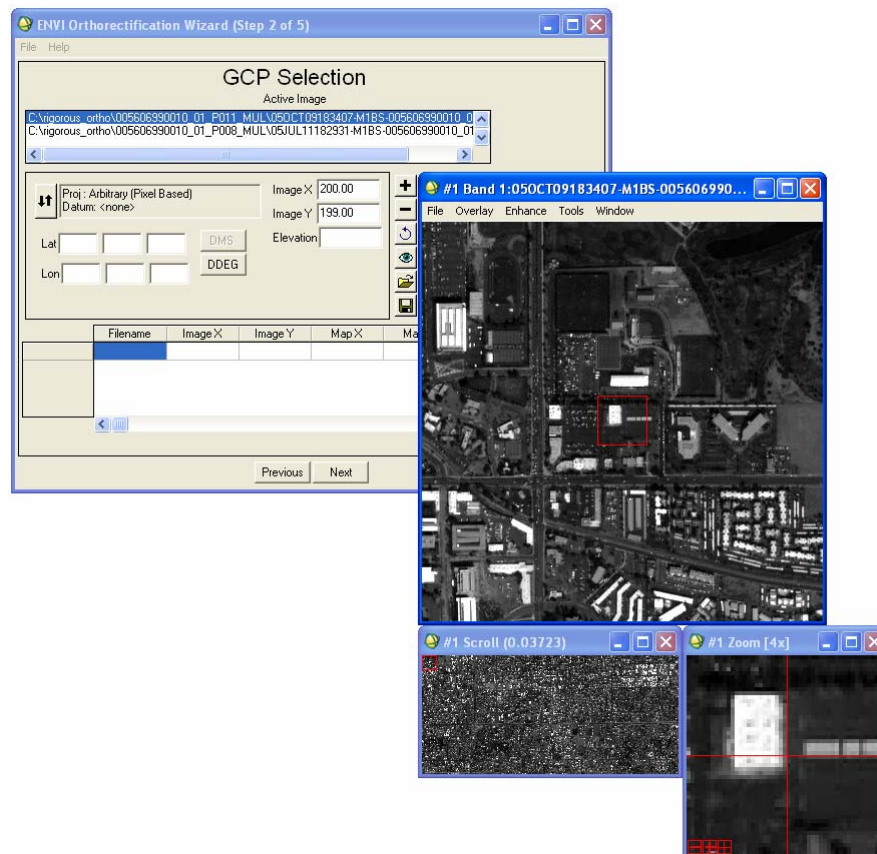


Figure 6: GCP Selection panel and display group

Restoring 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, the ENVI Orthorectification Module requires GCPs to be in a "Rigorous Orthorectification GCP" format, which is described in more detail in the *ENVI Orthorectification Module User's Guide*.

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 ENVI 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, it is highly recommended that you save a copy of the entire `rigorous_ortho` directory from the ENVI Resource DVD 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.

Following is an example of editing the line in Windows, assuming you copied the entire `rigorous_ortho` directory to your C: drive. The **bold** text indicates the part that you add:

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

Following is an example of editing this line in Unix, assuming you copied the entire `rigorous_ortho` directory to a directory named "usr1" on your local machine:

```
; FileName1=/usr1/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:



Figure 7: Selecting the 05JUL* image

The display group updates to show the 05JUL* image.

5. Click the **Load GCPs** 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**. After a brief moment, the GCPs are loaded in the GCP Selection panel of the Wizard and under the GCP tab of the Layout Manager. You may need to click the **GCP** and **GCP Labels** check boxes in the Controls tab of the Layout Manager to view the locations of the GCPs within the Draw Area of the Layout Manager.

Adding 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.

- In the Wizard, select the **05OCT*** image filename from the **Active Image** drop-down list:

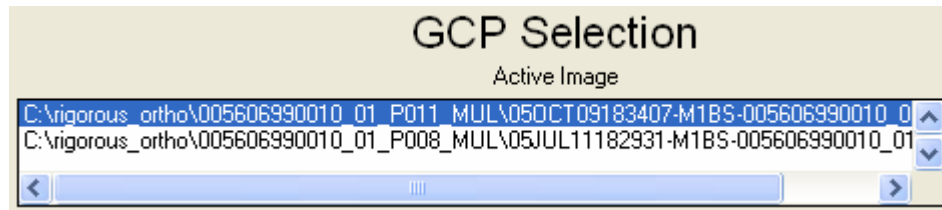




Figure 8: Selecting the 05OCT* image

- Click the **Projection** toggle button .
- Click **Change Proj.** The Projection Selection dialog appears.
- Select **Geographic Lat/Lon.**
- Ensure that the **Datum** is **WGS-84.**
- Click **OK** in the Projection Selection dialog.
- In the Wizard, click the **Projection** toggle button again.
- Click **DDEG.** The Lat and Lon fields change so that you can enter map coordinates in decimal degrees.
- Enter the following values in their respective fields in the Wizard, then click the **Add GCP** button .

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

- Enter the following values in their respective fields in the Wizard, then click the **Add GCP** button .

Lat: 33.41914515
Lon: -111.90030564
Image X: 1058
Image Y: 385
Elevation: 329.81

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. ENVI internally converts the geographic lat/lon coordinates into eastings and northings for this table. The locations of all 16 GCPs are shown in the Layout Manager.



	Filename	Image X	Image Y	Map X	Map Y	Elevation	
#13	05JUL1118...	3447.00	1334.00	406325.3484	3695911.7187	313.59	
#14	05JUL1118...	5636.00	380.00	411766.3376	3698229.2675	322.08	
#15	05OCT0918...	1279.00	1631.00	416821.1278	3694978.9045	333.14	
#16	05OCT0918...	1058.00	385.00	416295.7455	3698117.1838	329.81	

Figure 9: GCP values

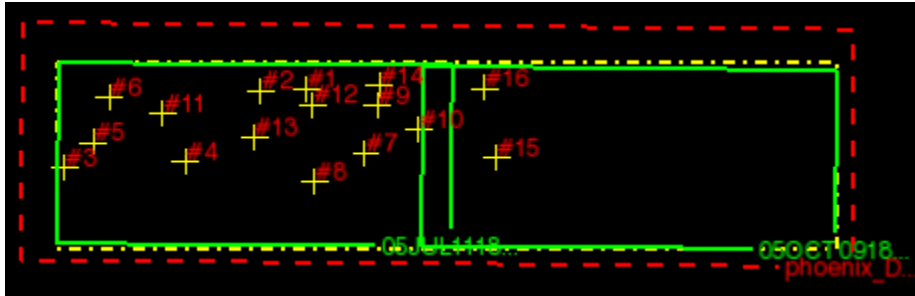


Figure 10: Layout Manager with "GCP" and "GCP Labels" options selected

Evaluating Residual Errors

The controls in the Layout Manager to evaluate the overall model error are a powerful feature of the ENVI Orthorectification Module. 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.

1. In the **Controls** tab of the Layout Manager, the **RMSE** (root mean square error) field lists the overall model error.
2. 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.
3. Right-click inside the Draw Area, and select **Zoom In** until you can see the contour labels more closely. Click-and-drag the left mouse button around the Draw Area to pan around. From looking at this contour view, you can see that ID #3 (in the far lower-left corner of the contour map) has a relatively high residual error. IDs #1 and #14 have a relatively low error.
4. Select the **GCP** tab in the Layout Manager, and scroll to the right until you see the **Mag** 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.
5. Select **Row #2**, which corresponds to GCP ID #3. A diamond marker appears over the GCP. This is the GCP associated with the large error you saw in Step 2. If you scroll to the **Mag** field for this point, you will see a value of 206.2582. This value is very high, compared to the **Mag** values of other GCPs.
6. Select the **Controls** tab in the Layout Manager, then enable the **Residual Vectors** option. Use the arrow button (to the right of the slider) to increase the **Residual Exaggeration** value to **10**. 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.

ID #3 has the highest residual error, as shown in the contour view. Its residual vector (cyan arrow) is also longer, compared to nearby GCPs.

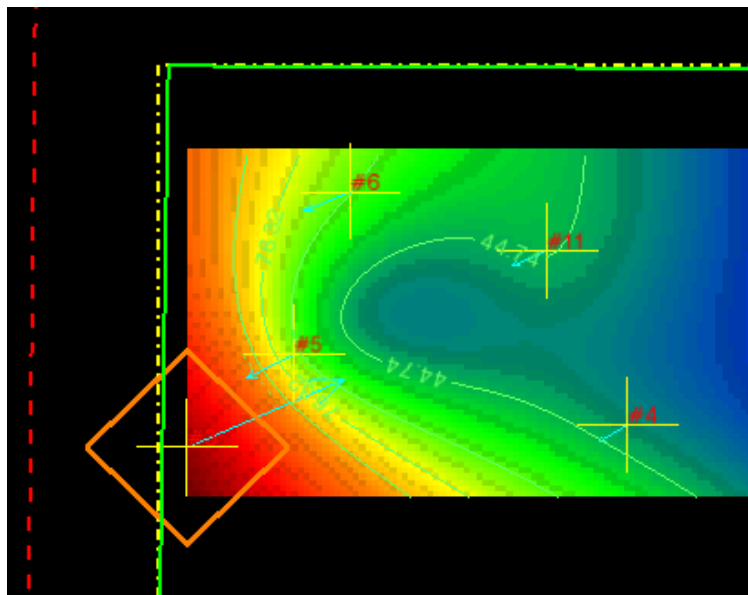



Figure 11: Residual image and vectors enabled in the Layout Manager

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

- In the Wizard, click **Row #3**.

	Filename	Image X	Image Y	Map X	Map Y	Elevation
#1	05JUL1118...	4366.00	447.00	408620.6531	3698080.9651	314.98
#2	05JUL1118...	3569.00	479.00	406652.0543	3698011.4858	311.08
#3	05JUL1118...	245.00	1861.00	398163.3694	3694523.4134	309.60
#4	05JUL1118...	2263.00	1788.00	403387.5195	3694806.4946	316.79

Figure 12: GCP table in the Wizard

- Click the **Remove GCP** button . The entire model is recomputed, and the updated residual errors are shown in the Layout Manager. What is the overall RMSE value now?
- Click the **GCP** tab in the Layout Manager, and evaluate the updated **Mag** values for each GCP. Did the overall model improve after deleting that GCP?
- You can experiment with removing GCPs or editing their values to improve the overall model error. For this tutorial, you can assume the results are reasonable and proceed to selecting tie points. 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.

Two display groups appear, which currently show the same image (05OCT*), You need to change one of them to show the 05JUL* image before adding tie points. You will do this in the first step.

1. In the Wizard, select the **05JUL*** image from the **Image 1** drop-down list. The 05OCT* image is selected by default for Image 2, so you don't need to select anything for Image 2. The dialog should look similar to the following:

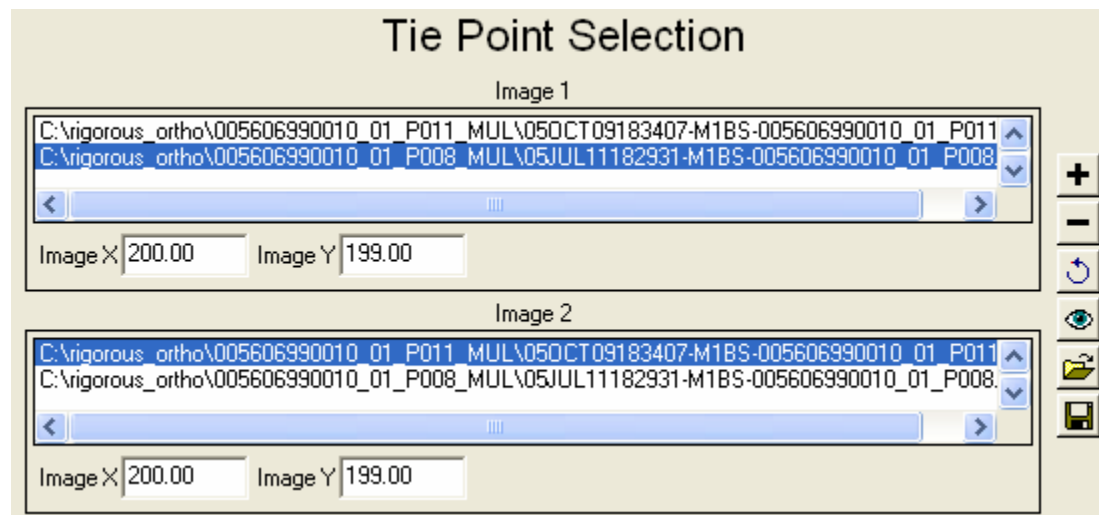


Figure 13: Selecting images for tie points

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 ENVI's Cursor Location/Value tool to record the fractional 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.


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

Image 1

Image X: 6737 Image Y: 511.75

Image 2

Image X: 363.75 Image Y: 480

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

Image 1

Image X: 6860.25 Image Y: 1997.75

Image 2

Image X: 489.75 Image Y: 1928

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

Image 1

Image X: 6835.5 Image Y: 3174

Image 2

Image X: 471.75 Image Y: 3073.5

The tie points are shown in the Layout Manager with magenta-colored "X" symbols, and their values are added to the Wizard and the Tie Points tab in the Layout Manager. These dialogs should look similar to the following.

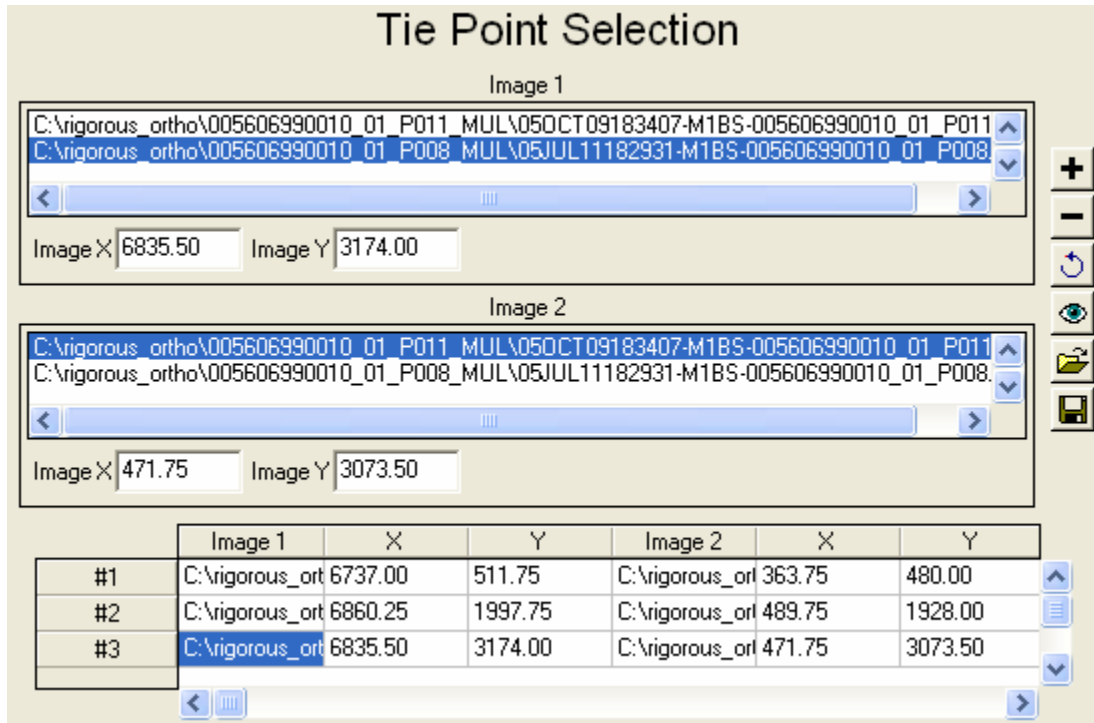


Figure 14: Three new tie points added

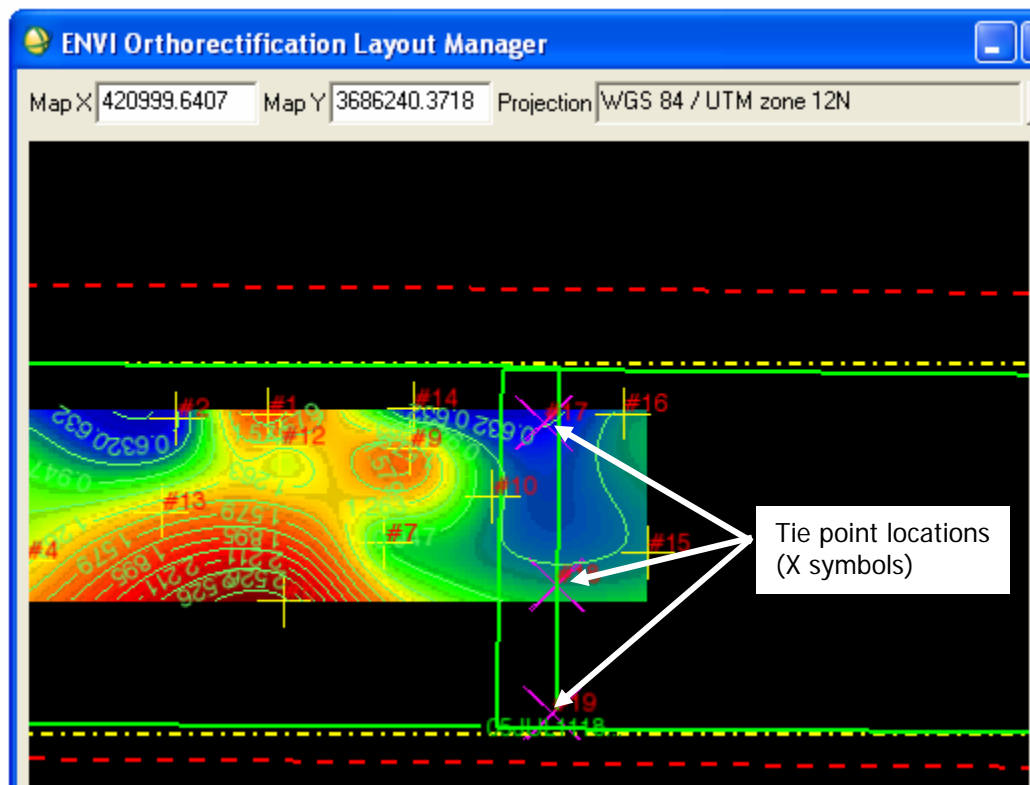


Figure 15: Locations of tie points in the Layout Manager

5. Before proceeding to the next step in the workflow, you should save your project. From the Wizard menu bar, select **File** → **Save Project**. The Select Project File dialog appears.
6. Enter a filename and location for the project state, and click **Save**. ENVI saves the project state in XML format. If you need to restore your project later, select Map → Rigorous Orthorectification from the ENVI main menu bar, then select File → Restore Project from the Wizard menu bar to select the XML file for your project. ENVI 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:

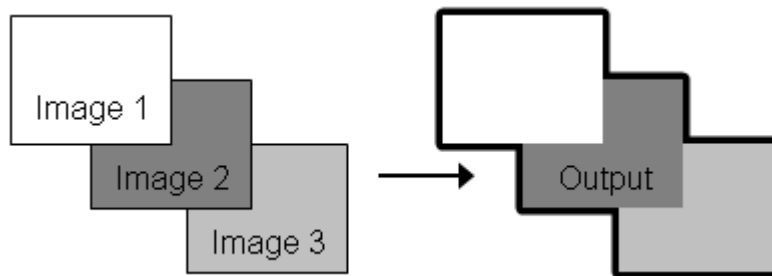


Figure 16: Image order

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:

Area that will be excluded in output

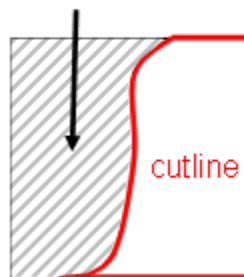


Figure 17: Cutline for a single image

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

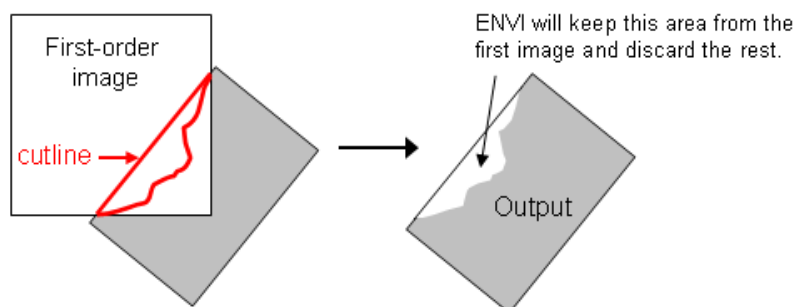


Figure 18: Using a cutline with multiple images

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

Defining Output Parameters

Follow these steps to select a projection, pixel size, and filename for the orthorectified product. These are required steps in the orthorectification workflow. ENVI raster format is the only available output format. ENVI performs mosaicking and color balancing automatically, using the latest innovative research methods.

1. In the **Select Output Projection** list, ensure that **UTM** is selected. Even though the QuickBird data and original GCPs were Geographic Lat/Lon, the Wizard will not allow you to select Geographic Lat/Lon in your output because it is considered a coordinate system, not a true map projection.
2. Ensure that the **Datum** is **WGS-84**, the **Units** are **Meters**, and the **Zone** is **12**.
3. Leave the **X/Y Pixel Size** fields as-is. ENVI will use the pixel sizes of the input QuickBird images.
4. Select an output filename and location for the orthorectified product.
5. Click **Finish**. ENVI builds the orthorectified image and adds it to the Available Bands List where you can choose to display it. 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:



Figure 19: Output mosaic

By default, the 05OCT* image (the eastern image) was at the top of the **Image Order** list back in the Image Order & Cutline Selection step. So in the area of overlap between the two images, the 05OCT* image is ordered above the 05JUL* image. You can see this in Figure 19.

6. Select **File** → **Exit** from the Wizard menu bar. You will be prompted to save the state of the orthorectification process in case you want to resume work later.

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.