Preprocessing AVIRIS Data Tutorial

This tutorial demonstrates how to calibrate an AVIRIS image to surface reflectance, while teaching the following concepts:

- Why you should preprocess hyperspectral data
- How to use FLAASH to correct for atmospheric effects
- How to plot radiance and reflectance spectra
- How to remove bad bands from reflectance data, which removes artifacts from the plotted spectra.

You must have a separate license for the Atmospheric Correction Module: QUAC and FLAASH to use this tutorial.

This is the first in a series of tutorials that demonstrate how to work with hyperspectral data. Here are the other tutorials:

- Basic Hyperspectral Analysis Tutorial
- Whole-Pixel Hyperspectral Analysis

Files Used in this Tutorial

Tutorial files are available from our ENVI Tutorials web page. Click the **Hyperspectral** link to download the .zip file to your machine, then unzip the files.

The image used in this exercise was collected by the Airborne Visible Infrared Imaging Spectrometer (AVIRIS) sensor. AVIRIS data files are courtesy of NASA/JPL-Caltech. The sample image covers the Cuprite Hills area of southern Nevada, an area with diverse mineral types. The scene was collected from an ER-2 aircraft on August 8, 2011. The full original scene is available from NASA/JPL.

File	Description
`CupriteAVIRISSubset.dat`	AVIRIS radiance image and header file, spatially subsetted and saved to ENVI image format.
`AVIRIS11_gain.txt`	Text file with multiplication factors used for calibration to spectral radiance

Background

Hyperspectral sensors, also called *imaging spectrometers*, should be spectrally and radiometrically calibrated before you analyze their data. NASA/JPL has already processed the AVIRIS data to remove geometric and radiometric errors associated with the motion of the aircraft used during data collection. However, the data should be further corrected for atmospheric effects and converted to surface reflectance prior to scientific analysis. Before

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you begin the tutorial, you should understand some basic concepts about the different types of information stored in the pixel values of your imagery.

Raw DN Data

Pixel values are also called *digital numbers*, or DN values. They have not yet been calibrated into physically meaningful units; they are 2-byte (16-bit) signed integer data that include the effects of surface reflectance, the solar irradiance curve, scattering, atmospheric gas absorptions, variation in illumination due to topography, and instrument response.

Radiance

Radiance is the amount of radiation coming from an area. It includes radiation reflected from the surface, from neighboring pixels, and from clouds. Calibration to radiance compensates for variations in detector sensitivity. To derive a radiance image from an uncalibrated image, you must multiply the raw data by a series of gain values, one for each band. Resulting pixel values are typically in units of $W/(m^2 * sr * \mu m)$.

Data vendors usually provide gains/offsets in the metadata that accompanies the imagery. NASA/JPL documented the gain values for 2011 AVIRIS data in the file `AVIRIS11_gain.txt`, which you will use later in this tutorial. By applying the gains from this file, the AVIRIS radiance image will be in units of $\mu W/(cm^2 * sr * nm)$. This image uses specialized gain values retrieved when the image was downloaded. FLAASH defaults to an input scale of 1, which is used by all AVIRIS-NG images.

Radiance images include the radiation effects of the sun; in fact, a spectrum of a radiance pixel closely matches that of the solar irradiance curve, also called the *solar spectrum*. For hyperspectral data analysis, you should remove the effects of solar irradiance by calibrating the data to reflectance.

Reflectance

Reflectance is the proportion of the radiation reflected off a surface to the radiation striking it. In hyperspectral data analysis, materials are identified by their reflectance spectra. So calibrating the data to reflectance is the first step toward identifying materials from an image. When analyzing imagery from multispectral sensors (such as Landsat or GeoEye), atmospheric effects are of lesser concern because the channels are designed to accommodate atmospheric gas absorption features. However, hyperspectral sensors cover all of the visible and near-infrared spectrum, including absorption features. So it is important to compensate for these effects in hyperspectral imagery.

Other advantages of using reflectance data include:

- Spectral features are more apparent in the imagery
- The shape of the image spectra are mostly influenced by chemical and physical properties of the surface materials, rather than by atmospheric and solar effects.

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An atmospheric correction tool such as FLAASH can remove the effects of atmospheric scattering and gas absorptions to produce reflectance data. With hyperspectral data analysis, calibrating imagery to *apparent surface reflectance* is sufficient; the imagery may still have variations in illumination due to topography. With reflectance data, pixel values typically range from 0 to 1 but are often scaled by some factor to yield integer data. FLAASH automatically scales reflectance values by 10,000.

We will demonstrate these concepts in the steps that follow.

Display the Uncorrected Data

1. Start ENVI.
2. From the menu bar, select **File > Open** and select the file `CupriteAVIRISSubset.dat`. ENVI displays the image with an approximate true-color representation.
3. Double-click the filename in the Layer Manager to open the Metadata Viewer. Here, you can see more information about the file. For example:
    - Select the **Map Info** category to see the pixel size and units.
    - Select the **Extents** category to see the geographic coordinates of the spatial extent.
    - Select the **Spectral** category to see the wavelengths defined for each of the 224 bands. The FWHM column lists the full-width-half-maximum values that NASA/JPL provided for the AVIRIS file.
4. Click the **Close** button to close the Metadata Viewer.
5. In the middle of the Status bar (at the bottom of the application), right-click and select **Raster Data Values**. When you move the cursor around the image, the Status Bar shows the pixel values for the red, green, and blue channels. These are 2-byte signed integer data.

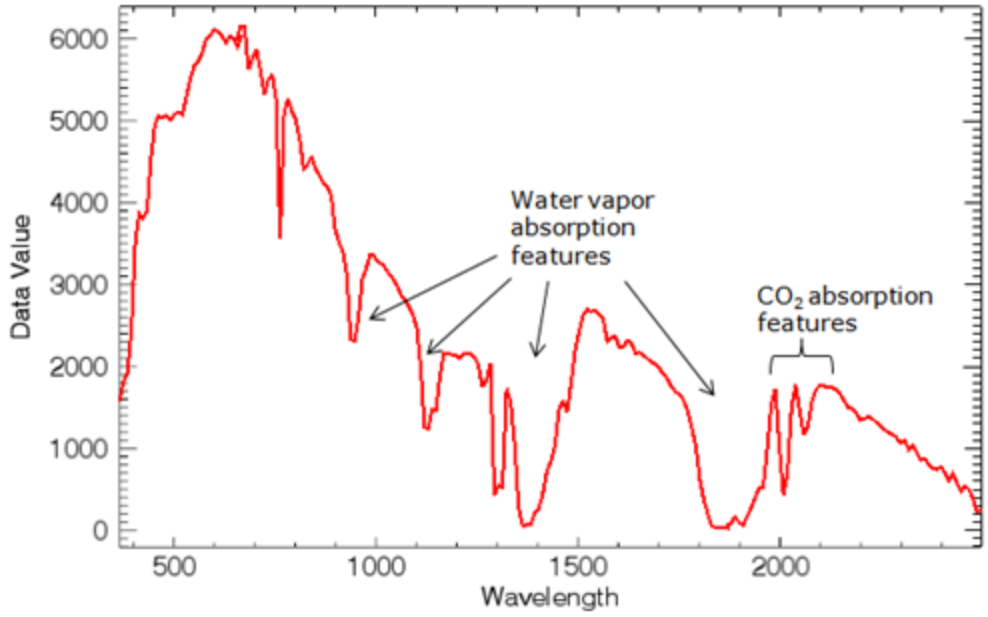
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6. In the Layer Manager, right-click on layer name and select **Profiles > Spectral**.
7. Click inside of the image to move the crosshairs to a different location. The Spectral Profile dialog updates with the spectrum of that pixel location. Notice how the shape of the radiance curve changes slightly as you move the crosshairs to different materials within the scene.

The spectral profile, in general, shows some of the common atmospheric features often seen in hyperspectral data:

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The FLAASH tool that you will use next will convert the radiance data to reflectance.

Start FLAASH

FLAASH is a model-based radiative transfer program to convert radiance data to reflectance.

This tool requires a separate installation and license for the FLAASH Module; contact your sales representative for more information.

1. In the Toolbox search field, type **flaash**. Double-click on the **FLAASH Atmospheric Correction** tool name. The Data Selection dialog appears.
2. Select the file `CupriteAVIRISSubset.dat`, and click **OK**. The FLAASH - Rigorous Atmospheric Correction dialog appears, with the Main tab selected.

Set Time and Output Options

1. In the Main tab, use the **Acquisition Date/Time** drop-down lists to set the date to **6 August 2011** and the flight time to **19:20:00**.
2. In the **Output Raster** field, specify the path and filename you want to write the output reflectance image to. Type `CupriteReflectance.dat`. Disable the **Display result** check box.

Select Sensor and Geometric Options

1. Select the Sensor tab in the FLAASH dialog.
2. From the **Sensor Type** drop-down button, select **AVIRIS**.

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3. For the **Input Scale**, import the values from `AVIRIS11_gain.txt` file. Click the **Load Values** button , navigate to the file, and click **Open**.

   The scale factors in this file boost the signal from each channel, especially in the shortwave-infrared spectrum where the solar irradiance signal is much lower. This results in higher levels of radiance. In this particular file, Bands 1-110 have a scale factor of 300, Bands 111-160 have a scale factor of 600, and Bands 161-224 have a scale factor of 1200. When each spectrum is divided by the factors in this file, the 16-bit integers will be converted to radiance in units of µW/(cm2 * sr * nm).
4. Select the Geometric tab. Set the **Sensor Altitude** to 20.
5. Set the **Ground Elevation** to 0.6

The Sensor Altitude field is typically 20 km for the ER-2 aircraft collecting AVIRIS data. The Ground Elevation value was estimated using Google Earth. (Another option is to view the GMTED2010 DEM file that is installed with ENVI.) The flight date and time were recorded in an `*.info` file that NASA/JPL provided with the AVIRIS imagery.

While more accurate values are best, none of the fields require precise data. They are only used to determine the approximate geographic location and solar elevation angle at the scene, for the atmospheric correction model.

Select Atmospheric Model, Water, and Arerosol Options

Hyperspectral images typically include enough spectral information needed to estimate water vapor and aerosols in the atmosphere. You will set parameters to retrieve water vapor and aerosols in the following steps.

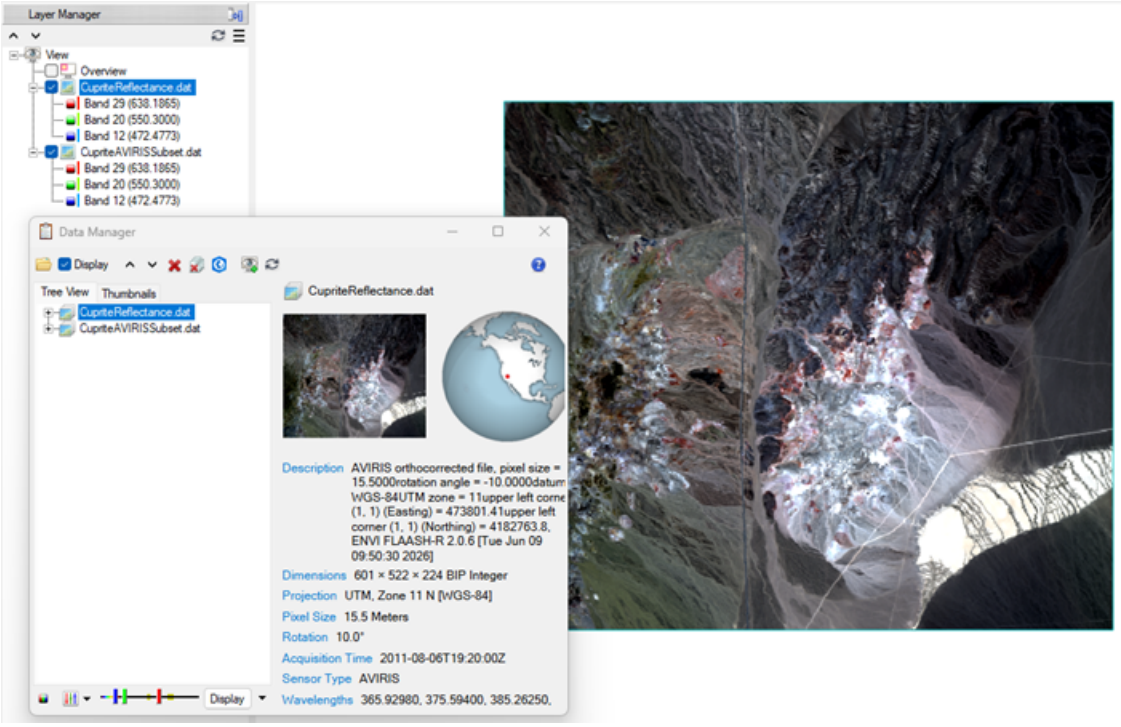
1. Select the Model tab.
2. From the **Atmospheric Model** drop-down list, select **1976 US Standard Atmposphere**.
3. Select the Water tab.
4. From the **Water Absorption Wavelength** drop-down list, select **1130**. If you select 1130 nm or 940 nm and the feature is saturated due to an extremely wet atmosphere (unlikely for summer in southern Nevada), then use the 820 nm setting instead.
5. Select the Aerosol tab.
6. Set the **Aerosol Model** parameter to **High-Visibility Rural**. This is a good option for the location of this scene in southern Nevada, where aerosols are not strongly affected by urban or industrial sources. The choice of model actually is not critical in this case, as the visibility is typically greater than 40 km.
7. Click **OK**.

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Display the Reflectance Image

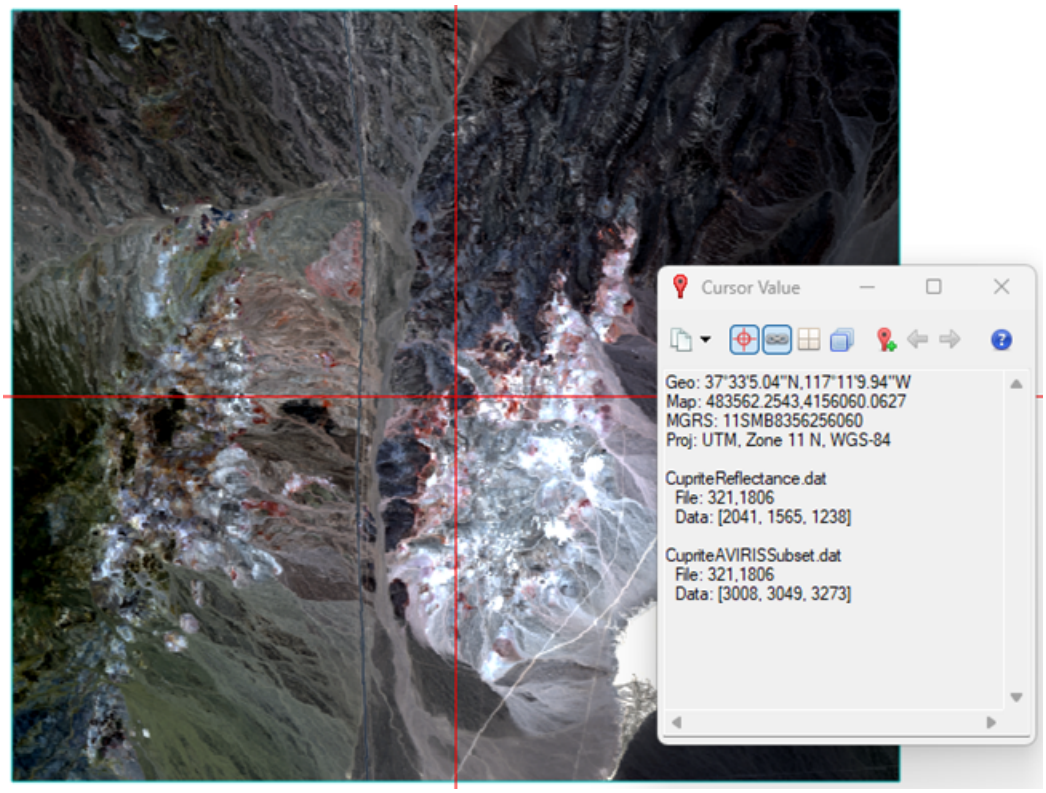
1. Click the **Data Manager** button  in the toolbar.
2. Select `CupriteReflectance.dat`.

   Click the **Predefined Band Combinations** button  and select **True Color**, then click the **Display** button. The true color reflectance image appears in the view.



3. With the radiance and reflectance images both selected in the Layer Manager, click the **Cursor Value** button  in the toolbar.
4. The **On demand updates** button  in the Cursor Value dialog is enabled by default. Click it to turn off the red probe.
5. Move the cursor around the display, and compare data values from both images. The following screen capture shows an example of a pixel location over a black area of the image. Look for the "Data" row in each image.

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6. Close the Cursor Value dialog.

FLAASH automatically scaled the reflectance values by 10,000. In this example, the pixel value for the red band of the reflectance image is 2031, or 0.2, if divided by 10,000. Reflectance values range from 0 to 1.0.

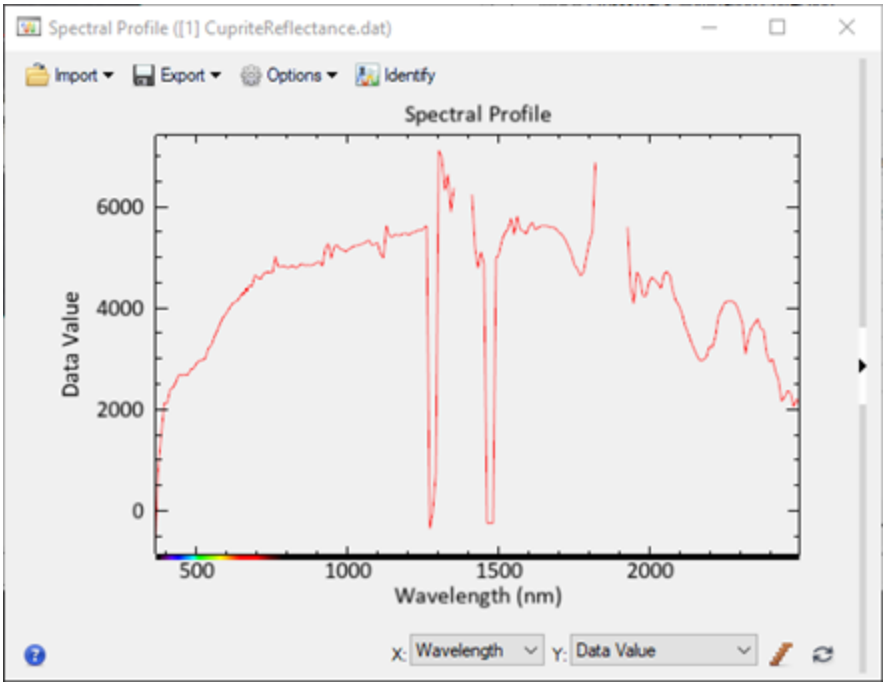
View Spectral Profile

1. In the Layer Manager, select the CupriteReflectance.dat layer.
2. Click the **Spectral Profile** button in the toolbar.
3. Click anywhere in the image. The Spectral Profile shows the spectrum for the selected pixel location.

   Note the shape of the reflectance curve and how it generally peaks near 1400 nanometers (nm). FLAASH determined that some bands were "bad" according to the strength of the reflectance signal, and the pixel values from these bands were omitted from the spectral profile. These appear as gaps in the reflectance curve. FLAASH wrote these bad bands to the ENVI header file that accompanies the reflectance image. In the header file, bad bands are indicated by a 0 under the `bbl` field. Reviewing the header file shows that Bands 108-112 and 155-166 were designated as bad.

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4. In the **Go To** field in the toolbar, enter pixel coordinates **412,1880** and press the **Enter** key. Note the reflectance curve for this pixel location: it has two spikes centered over 1300 nm and 1500 nm:

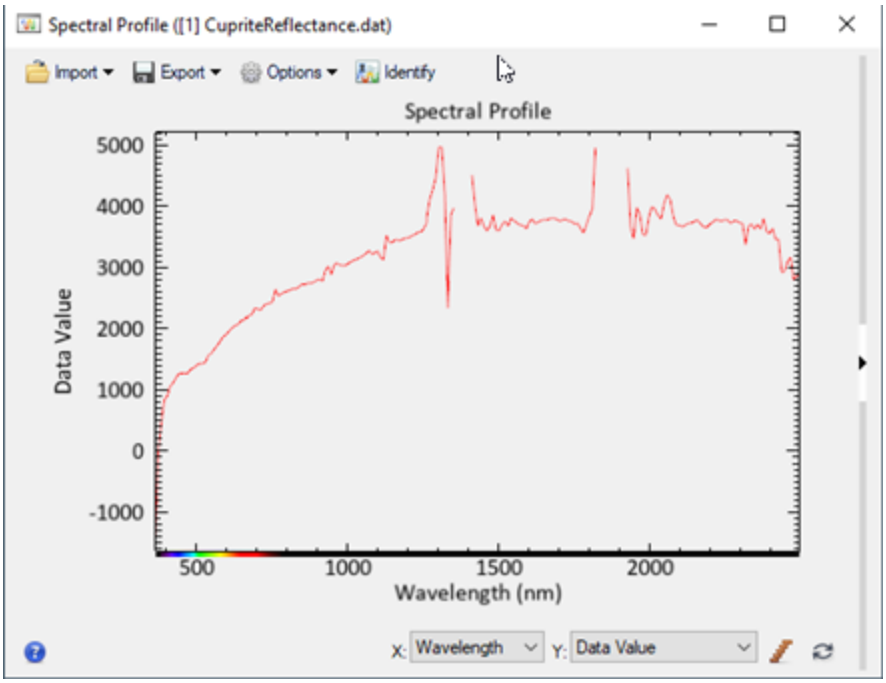


Conversion of radiance data to reflectance using a model-based program such as FLAASH can introduce artifacts into the spectra. These artifacts can result from any of the following factors:

- Mismatches in the spectral calibration of the hyperspectral data set and the spectral radiative transfer calculations
- Errors in the absolute radiometric calibration
- Errors in the radiative transfer calculations

In addition, the 1400 nm and 1900 nm water vapor bands typically give very noisy reflectance results. These noisy values result from the low radiance values in these portions of the spectrum and can cause undesirable spikes. The following plot shows an example of this:

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FLAASH attempts to correct for these artifacts by applying an EFFORT-based spectral polishing method on the data, if you set the **Spectral Polishing** toggle button to **Yes**. But it does not correct every artifact, especially with the noisy water vapor bands.

You can remove these artifacts by adding even more bands to the "bad bands" list in the header file for this AVIRIS scene.

Close the Spectral Profile.

Remove Bad Bands

1. In the Toolbox search field, type **Edit ENVI**. The Edit ENVI Header tool name appears.
2. Double-click the **Edit ENVI Header** tool name to open it.
3. In the Data Selection dialog, select `CupriteReflectance.dat` and click **OK**. The Edit ENVI Header dialog appears.
4. Select the Spectral tab. The **Bad Bands List** contains the bands that FLAASH already added from processing. Bands 108-112 and bands 155-166. You will overwrite that selection in the next step by expanding the range of bands to further exclude.
5. The **Wavelength** field shows the wavelength centers (in nanometers) for each band. You will move the following ranges from the **Wavelengths** list to the **Bad Bands List**. This should remove the artifacts around 1300, 1400, 1500, and 1900 nm.
    - Bands 98-128 (1263 to 1562 nm)
    - Bands 148-170 (1761 to 1958 nm)

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In the **Bad Bands List** field and click the **Add** button  next to the list. The Add dialog appears.

6. Scroll down the list in the Add dialog.
   - Click to select **Band 98**, then press the **Shift** key and scroll down to select **Band 128**. The selected bands will be blue. This will select Bands **98** to **107** and Bands **113** to **128**
   - Next, scroll down to **Band 148**, then press **Ctrl+click** to select it. Pressing the **Crtl** key when you click should select Band 148 while keeping the previous bands you chose selected. Continue holding the **Ctrl** key down so you can select the Bands **148** through **170**.

   The total number of selected bands to add should be 37.
7. Click **OK** to add the selected bands to the **Bad Bands List**, then click **OK** to close the Edit ENVI Header dialog.
8. The reflectance image is removed from the view and reloaded.
9. Click the **Spectral Profile** button  in the toolbar.
10. Click anywhere inside of the display, and notice how the spectral profile curve appears. The following is an example:



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Gaps in the curve correspond to the bands that you just removed. Out of the original 224 AVIRIS bands, you are now working with 170. This is still sufficient for hyperspectral image analysis and material identification. See the Basic Hyperspectral Analysis tutorial to learn more about these concepts.

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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.

This tutorial a separate license for the ENVI Photogrammetry Module; contact your sales representative for more information.

The ENVI Photogrammetry Module is a joint collaboration between NV5 Geospatial Solutions, Inc. 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 https://www.spacemetric.com/.

Files Used in This Tutorial

The files used in this example are available from our ENVI Tutorials web page. Click the **Rigorous Ortho** link to download the .zip file to your machine, then unzip the files to a directory named `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)

QuickBird files are courtesy of Maxar/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.

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RPC Orthorectification allows 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 **Rigorous Orthorectification** tool 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.

The tool includes the ENVI Orthorectification Layout Manager, which helps you 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.

Workflow

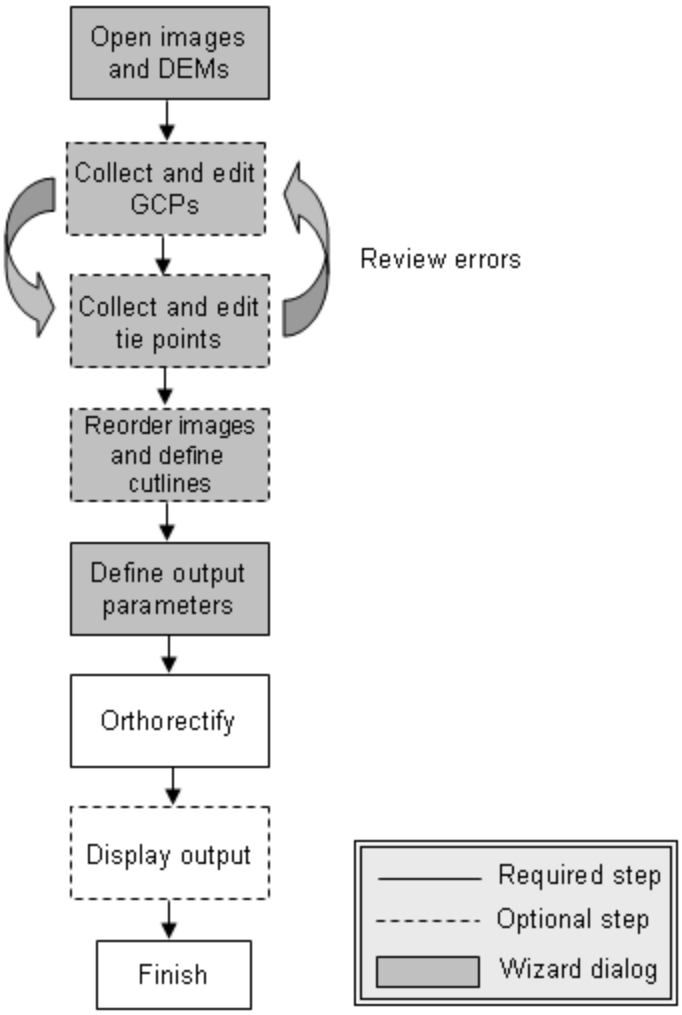
The figure below shows a typical orthorectification workflow. The required steps are:

1. Select input images and DEMs.
2. Build an adjustment model.
3. Select output parameters.
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.

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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.

Open the image files before loading the images into the Orthorectification Wizard. Use the following steps:

1. Start ENVI.
2. From the menu bar, select **File > Open**. The Open dialog appears.
3. 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. This file will be referred to as the `05JUL*` image throughout the rest of the tutorial.

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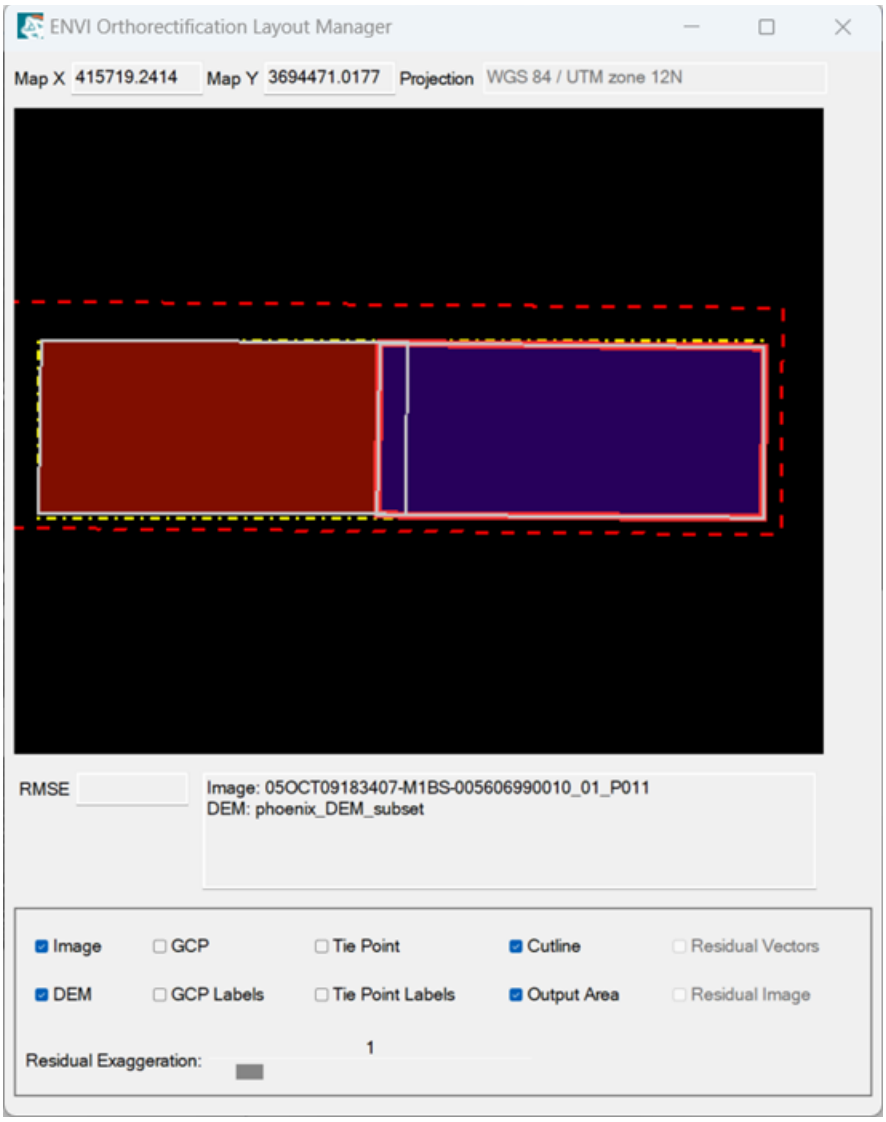
4. Select **File > Open**, navigate to `rigorous_ortho/005606990010_01_P011_MUL`, and open `05OCT09183407-M1BS-005606990010_01_P011.TIF`. The file appears in the Available Bands List. It is a multispectral image of Phoenix, Arizona, captured on 09 October 2005. This file will be referred to as the `05OCT*` image throughout the rest of the tutorial.
5. Last, open the DEM subset file that was included in the tutorial data. Select **File > Open**, 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.

Load Images and DEM into the ENVI Orthorectification Wizard

1. In the ENVI Toolbox, select **Geometric Correction > Orthorectification > Rigorous Orthorectification**. The ENVI Classic display group opens with the images loaded, and the ENVI Orthorectification Layout Manager and the ENVI Orthorectification Wizard appear.
2. In the Wizard (Step 1 of 5), click the  button next to the **Input Images** field. The Select Input Files dialog appears.
3. Use the **Ctrl** key to select both GeoTIFF images (`05OCT*` and `05JUL*`). Click **OK**. The Select Sensor Type dialog appears.
4. Select **QuickBird**, then click **OK**. The image filenames are listed in the **Input Images** field of the Wizard.
5. Click the  button next to the **Input DEMs** field. The Select Input Files dialog appears.
6. Select **Band 1** under `phoenix_DEM_subset.tif`, and click **OK**. The DEM filename is listed in the **Input DEMs** field of the Wizard.
7. Click **Next** in the Wizard. After the images and DEMs load, their boundaries are shown in 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):

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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 gray 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** check box 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.

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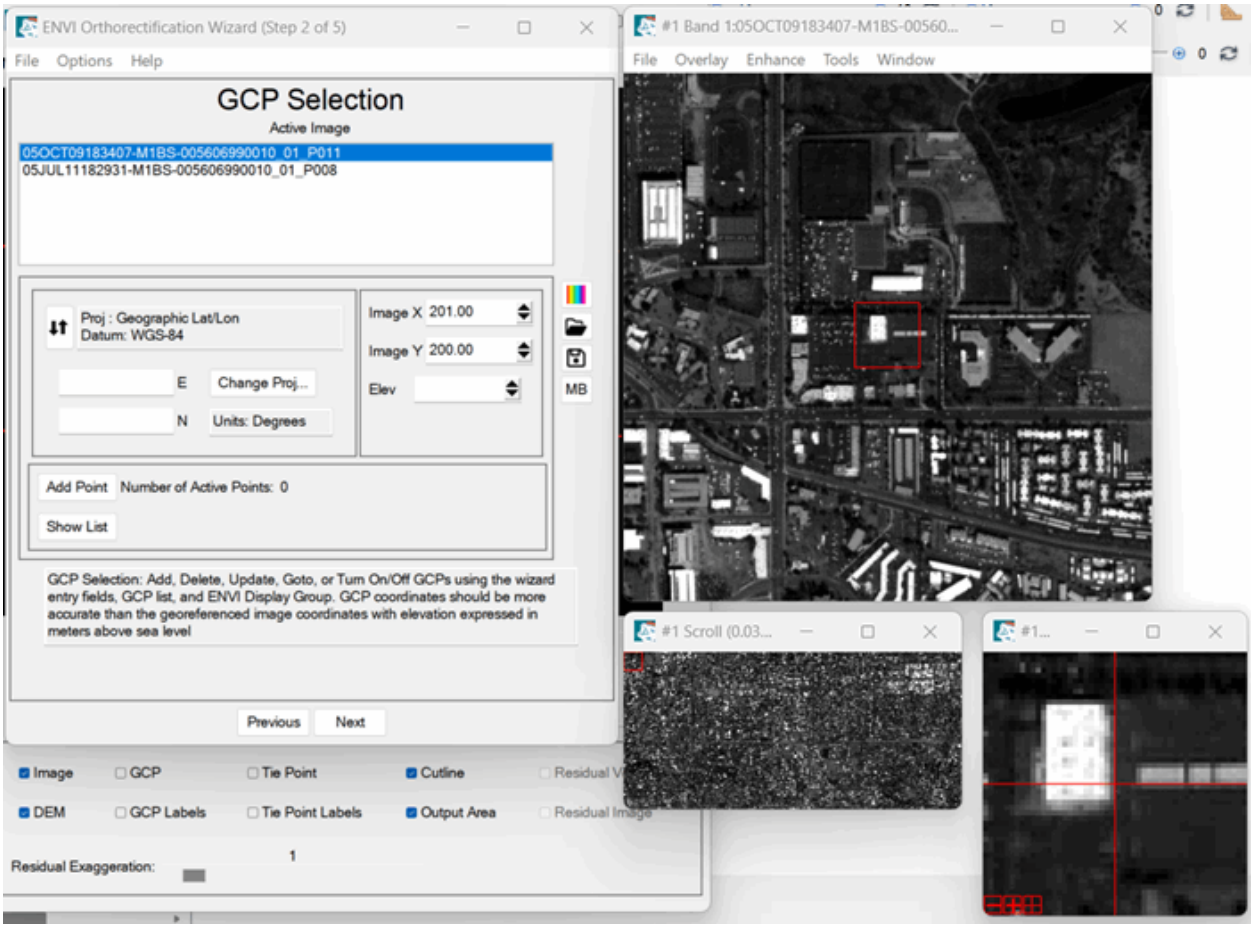
Use the scroll wheel on your mouse to zoom in or out. Or, right-click inside the draw area to select different zoom options. Click and drag the mouse to pan around.

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Working with Ground Control Points

After you load the QuickBird images and DEM into the Wizard and click **Next**, the Wizard proceeds to the GCP Selection panel (Step 2 of 5), and a display group opens 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, add new GCPs, and 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

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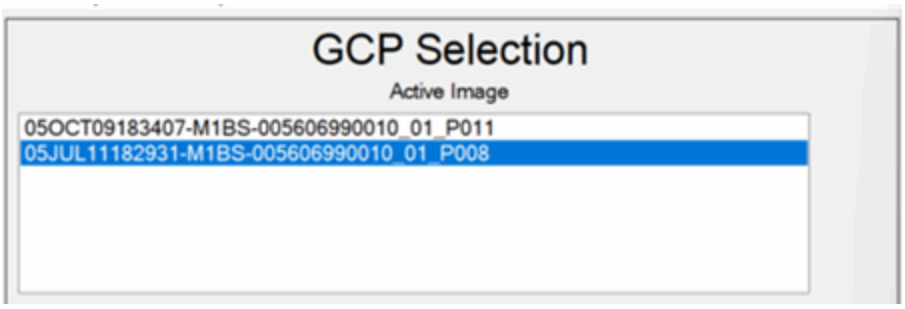
format. However, Rigorous Orthorectification requires GCPs to be in a "Rigorous Orthorectification GCP" format. For more information, see the ENVI Classic Help.

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 do not 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** 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.

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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: 33.41914515
   Lon: -111.90030564
   Image X: 1058
   Image Y: 385
   Elev: 329.81

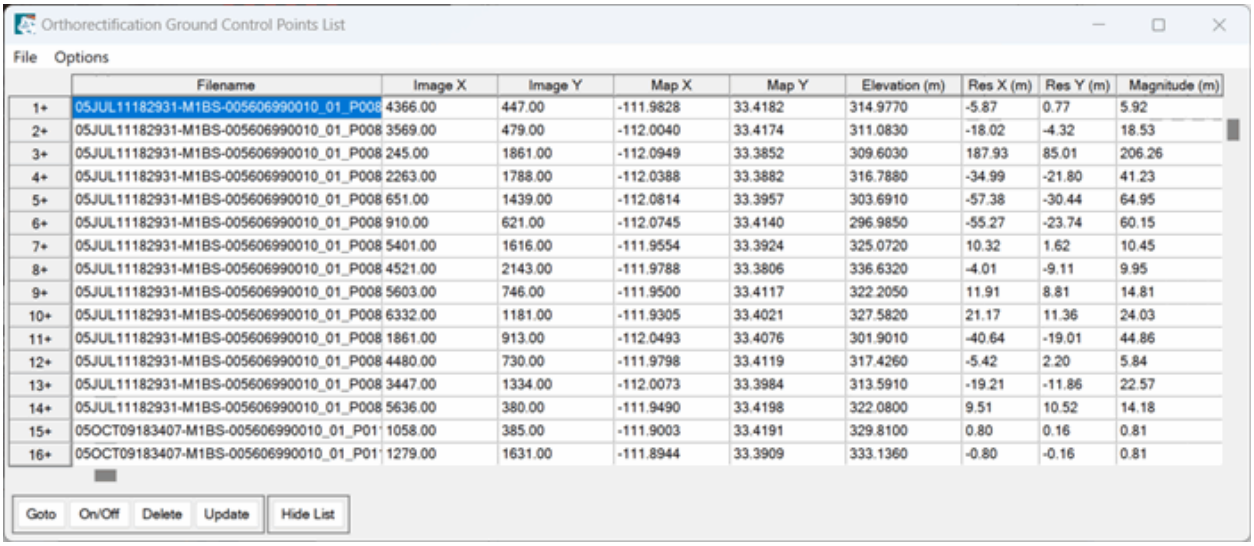
   After a few seconds, the new GCP appears in the display group and Layout Manager.
5. Enter the following values, then click the **Add Point** button:

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

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converted into eastings and northings for this table.

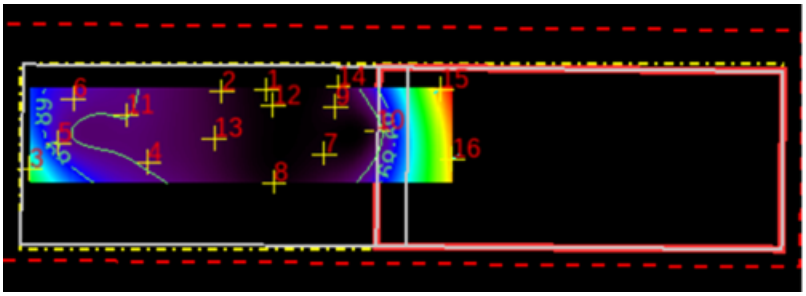


	Filename	Image X	Image Y	Map X	Map Y	Elevation (m)	Res X (m)	Res Y (m)	Magnitude (m)
1+	05JUL11182931-M1BS-005606990010_01_P008	4366.00	447.00	-111.9828	33.4182	314.9770	-5.87	0.77	5.92
2+	05JUL11182931-M1BS-005606990010_01_P008	3569.00	479.00	-112.0040	33.4174	311.0830	-18.02	-4.32	18.53
3+	05JUL11182931-M1BS-005606990010_01_P008	245.00	1861.00	-112.0949	33.3852	309.6030	187.93	85.01	206.26
4+	05JUL11182931-M1BS-005606990010_01_P008	2263.00	1788.00	-112.0388	33.3882	316.7880	-34.99	-21.80	41.23
5+	05JUL11182931-M1BS-005606990010_01_P008	651.00	1439.00	-112.0814	33.3957	303.6910	-57.38	-30.44	64.95
6+	05JUL11182931-M1BS-005606990010_01_P008	910.00	621.00	-112.0745	33.4140	296.9850	-55.27	-23.74	60.15
7+	05JUL11182931-M1BS-005606990010_01_P008	5401.00	1616.00	-111.9554	33.3924	325.0720	10.32	1.62	10.45
8+	05JUL11182931-M1BS-005606990010_01_P008	4521.00	2143.00	-111.9788	33.3806	336.6320	-4.01	-9.11	9.95
9+	05JUL11182931-M1BS-005606990010_01_P008	5603.00	746.00	-111.9500	33.4117	322.2050	11.91	8.81	14.81
10+	05JUL11182931-M1BS-005606990010_01_P008	6332.00	1181.00	-111.9305	33.4021	327.5820	21.17	11.36	24.03
11+	05JUL11182931-M1BS-005606990010_01_P008	1861.00	913.00	-112.0493	33.4076	301.9010	-40.64	-19.01	44.86
12+	05JUL11182931-M1BS-005606990010_01_P008	4480.00	730.00	-111.9798	33.4119	317.4260	-5.42	2.20	5.84
13+	05JUL11182931-M1BS-005606990010_01_P008	3447.00	1334.00	-112.0073	33.3984	313.5910	-19.21	-11.86	22.57
14+	05JUL11182931-M1BS-005606990010_01_P008	5636.00	380.00	-111.9490	33.4198	322.0800	9.51	10.52	14.18
15+	05OCT09183407-M1BS-005606990010_01_P01	1058.00	385.00	-111.9003	33.4191	329.8100	0.80	0.16	0.81
16+	05OCT09183407-M1BS-005606990010_01_P01	1279.00	1631.00	-111.8944	33.3909	333.1360	-0.80	-0.16	0.81

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.



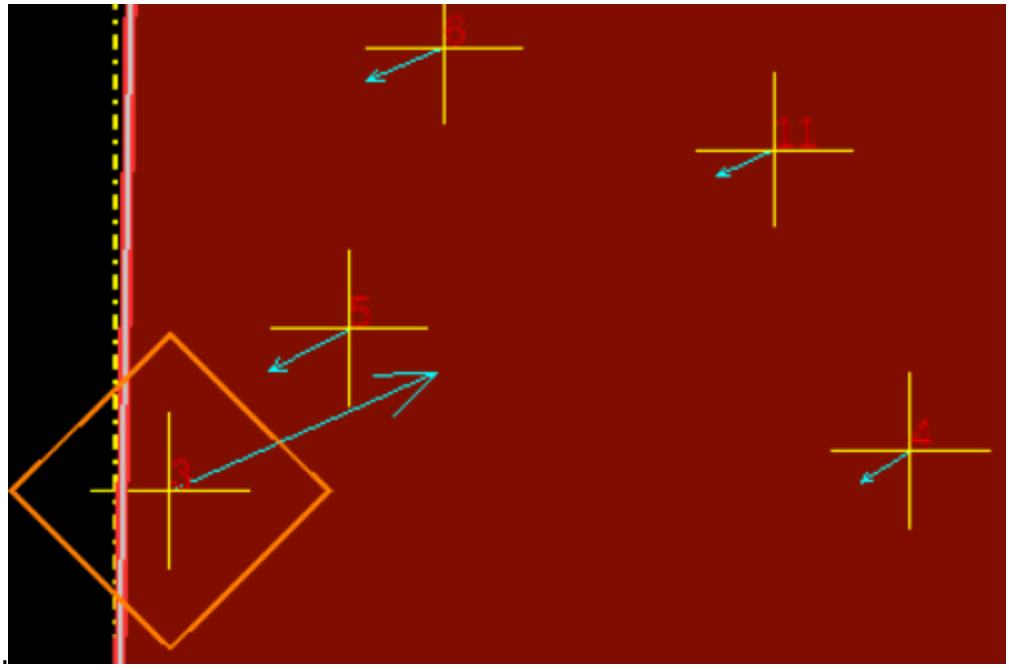
2. Right-click inside the draw area, and select **Zoom In** until you can see the contour labels more closely. Click and drag the mouse to pan. From looking at this contour view, you can see that GCP #3 (in the far lower-left corner of the contour map) has a relatively high residual error.

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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. There must be four or more GCPs in the list for this column to appear.
4. Click on **3+** to select the row:

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.

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- What is the overall RMSE value now?
- Did the overall model improve after removing this GCP?

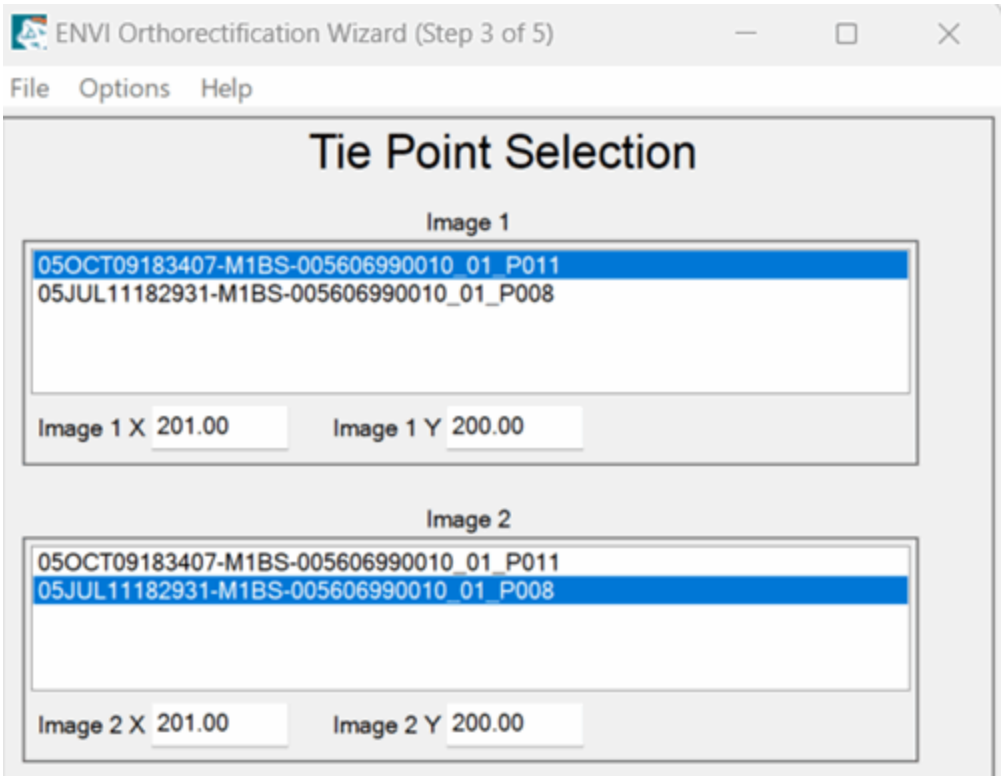
9. Use the GCP list to look for other GCPs with relatively high magnitude values. In addition to removing GCPs, you can also interactively update their geographic location as follows:
   - Select any GCP with a relatively high magnitude value.
   - Open the Zoom window of the display group, which is 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.

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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

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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

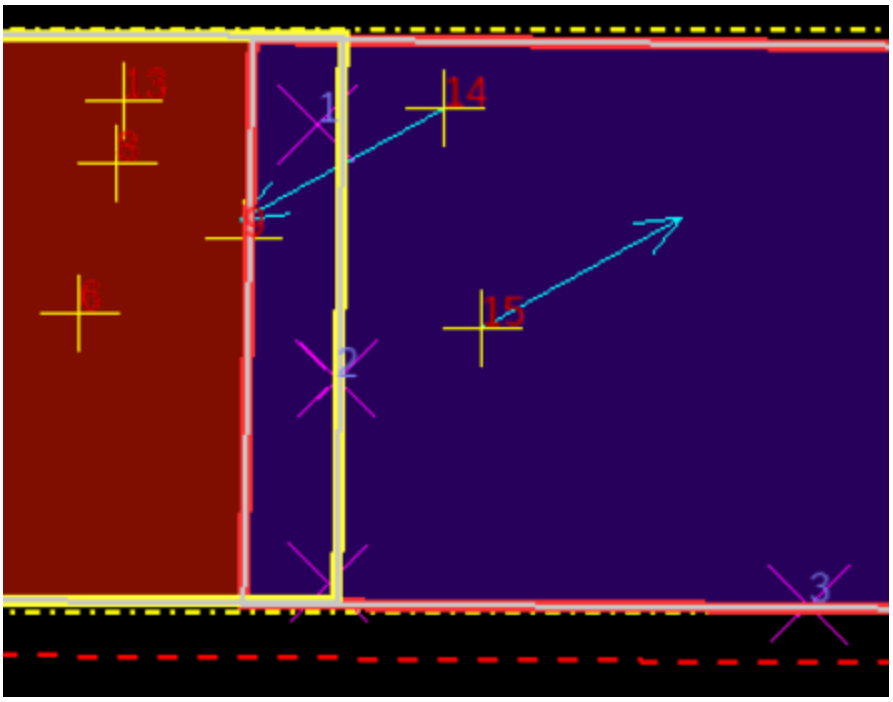
   Image 2
   Image X: 6860, Image Y: 1998

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 in the 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**. The project state is saved in XML format. To restore your project later, select select **File > Restore Project** from the Wizard menu bar and select the XML file for your project. ENVI

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automatically opens all input files, DEMs, GCPs, and tie points, so you do not need to open them before restoring the project.

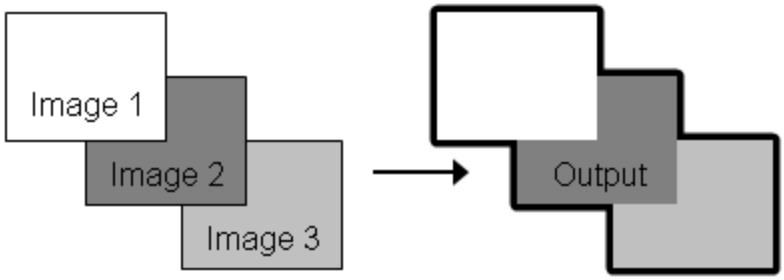
7. Click **Next** in the Wizard to proceed to the Image Order and Cutline Selection panel.

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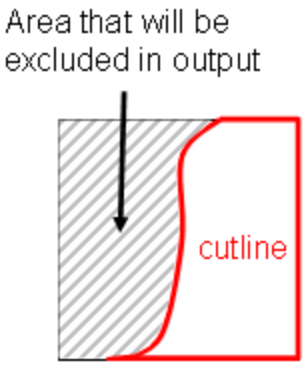
Ordering Images and Defining Cutlines

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:

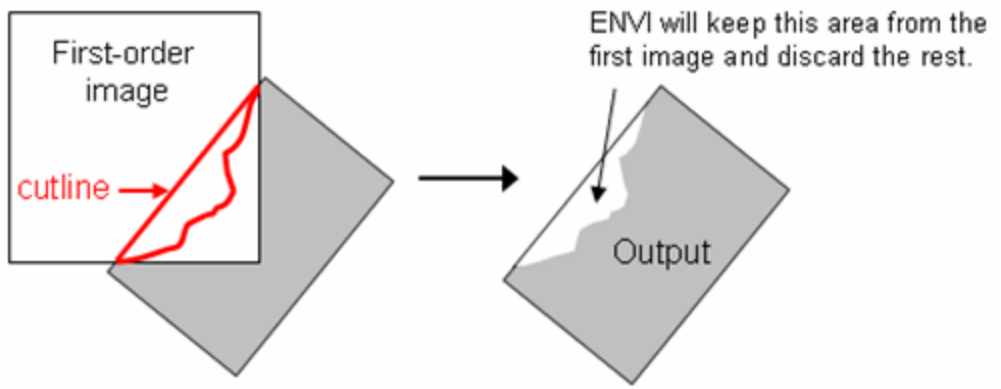


Cutlines are polygons that are used in combination with image ordering to define areas that you want to keep in the final output. A cutline is essentially an inclusion polygon, similar to a cookie cutter applied to one or more images. The following example shows a cutline for a single image:



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

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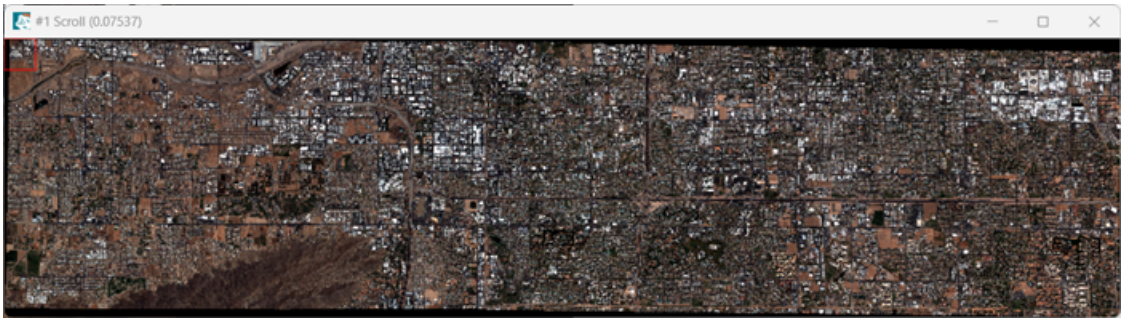
For this tutorial, you will skip the process of ordering images and defining cutlines, by clicking **Next**. ENVI Classic will use the image frame as a cutline by default. The image frame is the area of usable image data, excluding any background pixels.

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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.

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