

# ENVI Tutorial: Orthorectifying Aerial Photographs

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## Overview of This Tutorial

Orthorectification is the process by which the geometry of an image is made planimetric (map-accurate). This is done by modeling the nature and magnitude of geometric distortions in the imagery. Camera or satellite models in conjunction with limited ground control, allow construction of correction formulae that produce accurate, geometrically correct, map-oriented imagery.

ENVI provides the ability to rectify aerial photographs using a DEM (digital elevation model). This orthorectification process uses geometric projections to produce geometrically correct images for mapping and measurement.

Aerial photograph orthorectification corrects for distortions introduced by the camera geometry, look angles, and topography using a single photo resection.

This tutorial is designed to give you a working knowledge of ENVI's orthorectification capabilities for aerial photographs. It demonstrates ENVI's orthorectification capabilities for aerial photographs, but (because of the size of the required datasets) does not use any hands-on exercises. No data files are required. You should be able to produce similar results with your own scanned aerial photographs following the procedures outlined.

## Orthorectifying Aerial Photographs in ENVI

Orthorectification is done in three steps.

1. You build the interior orientation using the camera model, fiducial marks, and image tie points.
2. You build the exterior orientation. The exterior orientation is used to tie the image to the surface of the earth using ground control points, map coordinates, and elevations.
3. You perform the orthorectification from the interior and exterior orientations and a DEM file.

### Tip

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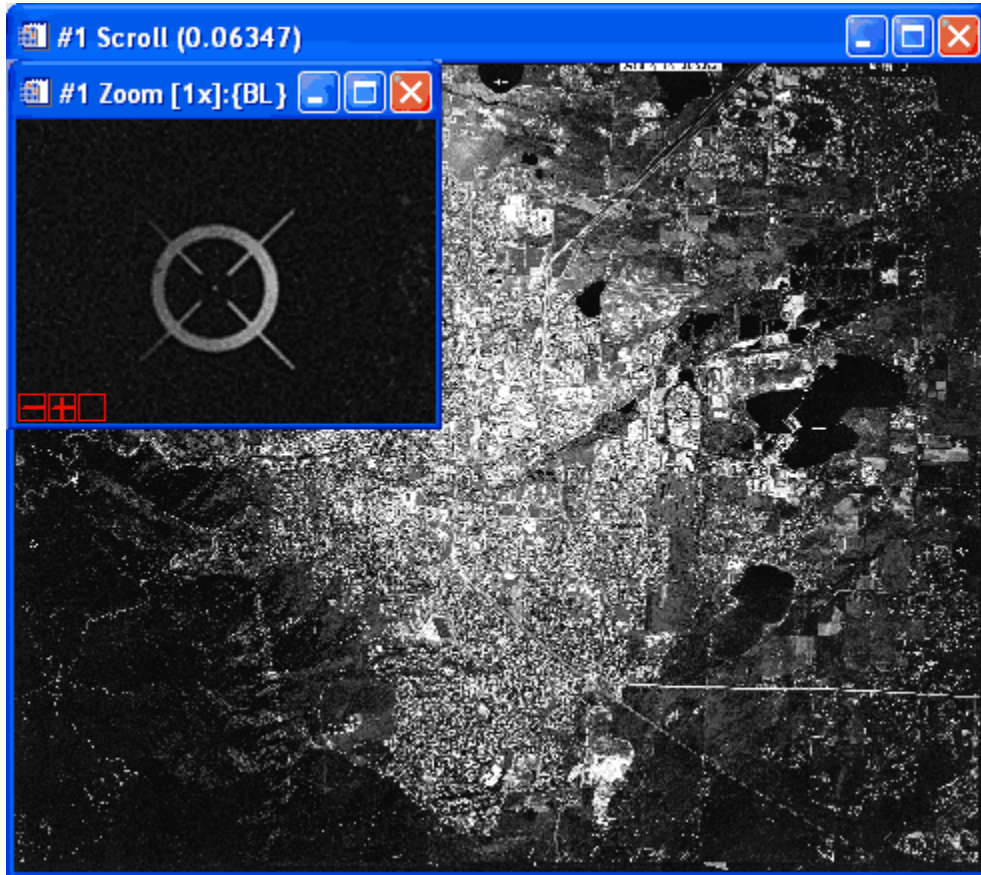
Because the orthorectification process is computationally intensive and time consuming, before beginning an orthorectification make sure you have sufficient disk space to save the resulting ortho image, as such images can be very large.

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The process of aerial photograph orthorectification using ENVI requires several steps that are the same regardless of the type of photograph used to collect the digital data. These include:

- **Build the Interior Orientation** — Building the interior orientation establishes the relationship between the camera and the aerial photograph. It uses tie points between the image and camera fiducial marks (at least three) and the camera focal length.
- **Build the Exterior Orientation** — The exterior orientation relates points in the aerial photograph or satellite image to their known ground locations (map coordinates) and elevations. It is built by selecting ground control points and entering the corresponding map coordinates similar to an image-to-map registration.
- **Orthorectify using a Digital Elevation Model** — This step does the actual orthorectification of the aerial photograph or satellite image using the orientation files or satellite location and collinearity equations generated using the above steps in conjunction with a digital elevation model (DEM).

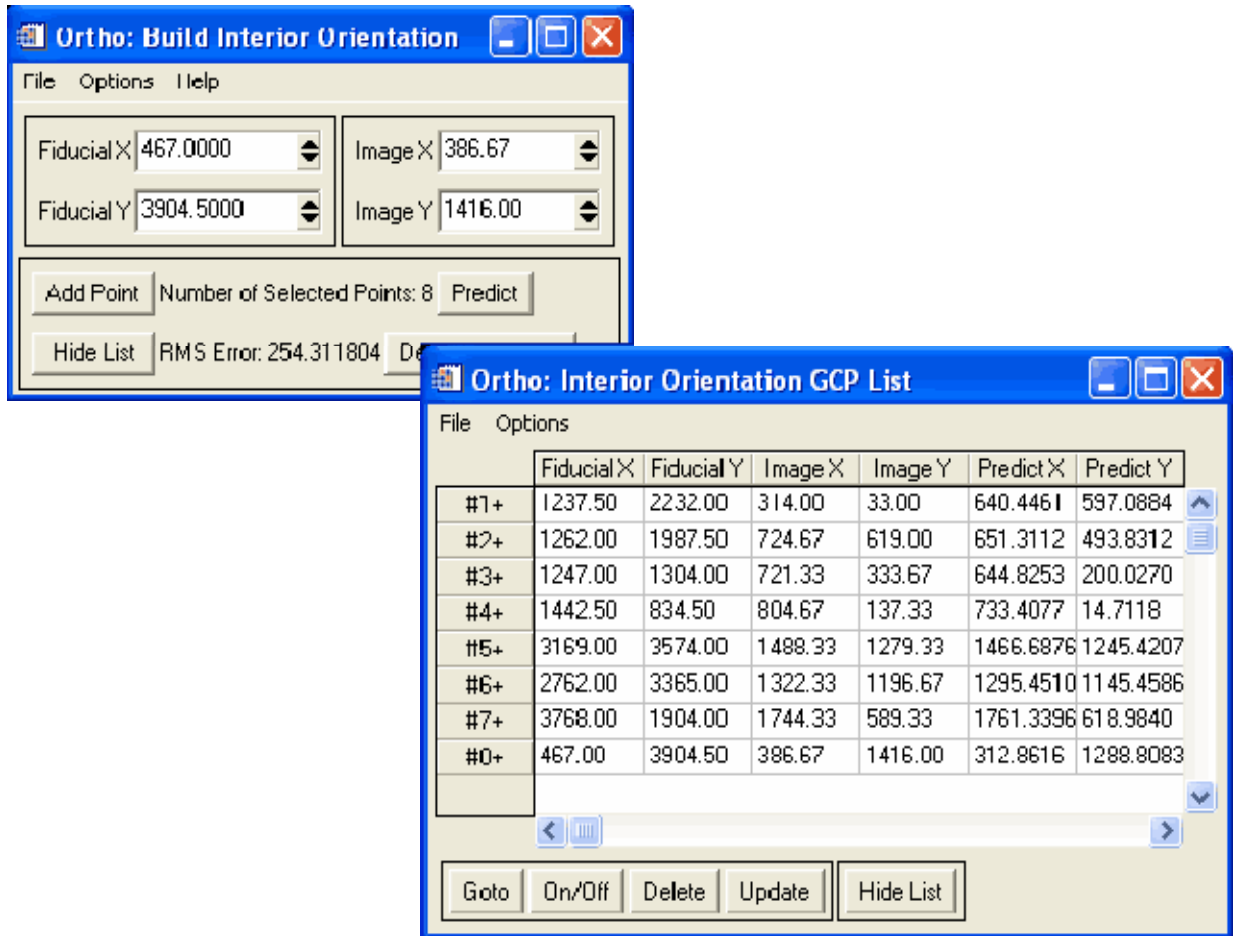
ENVI's aerial photograph orthorectification process corrects for distortions introduced by the camera geometry, look angles, and topography using a single photo. The orthorectification is done in three steps as described above. The figure below shows an original aerial photograph for Boulder, Colorado.



## Building the interior orientation

1. Display the aerial photograph image to allow interactive selection of fiducial marks. The image above shows a typical set of fiducial marks.
2. From the ENVI main menu bar, select **Map → Orthorectification → Air Photo → Build Air Photo Interior Orientation**. The Build Interior Orientation dialog appears.
3. Select a fiducial mark location by centering the Zoom window crosshair on the fiducial mark and entering the fiducial location in camera units (mm) in the **Fiducial X** and **Fiducial Y** text boxes (this information is obtained from the camera report).
4. Click **Add Point** on the Build Interior Orientation dialog to add the location to the list of tie points. Continue selecting fiducial mark locations until three or more have been entered.

- Click **Show List** at the bottom of the dialog to show the actual points and errors. Be sure to review the RMS error in the dialog to insure that the points were properly selected.



- From the Build Interior Orientation dialog menu bar, select **Options → Build Interior Orientation**. Enter the camera focal length in mm and enter an output filename with an `.ort` extension for consistency.

The output `.ort` file contains the fiducial tie point locations and the affine transformation coefficients for both the camera coordinates to image pixels and image pixels to camera coordinates. The following is an example of the `.ort` file after the interior orientation has been calculated.

```
ENVI Orthorectification Parameters File
Sensor Type = Air Photo
Focal Length= 304.67100
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
; Interior Orientation Information
; interior points = {fiducial (x,y) millimeters, image (x,y)}
Interior Points = {
-106.0230, -105.9940, 302.33, 251.44,
105.9780, 106.0140, 7315.45, 7359.55,
-106.0210, 106.0100, 7364.71, 303.57,
105.9790, -105.9940, 254.33, 7309.67,
-110.0200, 0.0100, 3834.00, 143.80,
109.9750, 0.0100, 3783.43, 7467.71,
-0.0220, 110.0040, 7473.14, 3832.43,
-0.0320, -109.9880, 146.00, 3779.57}
;Affine Transformation (Camera Coords to Image Pixels)
; a0 = 3808.86863414
; a1 = -0.22975948
; a2 = 33.30821680
; b0 = 3806.73931581
```

```

; b1 = 33.28923748
; b2 = 0.23988471
;Affine Transformation (Image Pixels to Camera Coords)
; a0 = -113.52361324
; a1 = -0.00021635
; a2 = 0.03003821
; b0 = -115.13524789
; b1 = 0.03002113
; b2 = 0.00020719

```

## Building the exterior orientation

1. Display the aerial photograph image.
2. From the ENVI main menu bar, select **Map → Orthorectification → Air Photo → Build Air Photo Exterior Orientation**. The Build Interior Orientation dialog appears.
3. Select the desired projection and enter a zone number if needed. The selected projection will be used as the orthorectified output projection and does not need to be the same projection as the DEM file.
4. Click **OK**. The Build Exterior Orientation dialog appears. This dialog is similar to the image-to-map registration Ground Control Points Selection dialog.
5. Select a ground control point (GCP) by centering the Zoom window crosshair over a pixel on the aerial photograph image and entering the corresponding map coordinates in the appropriate text boxes.
6. Enter an elevation for the selected pixel in the **Elev** text box and click **Add Point** to add the location to the list of GCPs.
7. Continue selecting GCPs until three or more have been entered. (Note: It is recommended that you use as many GCPs as possible spread over the image for best results). Be sure to review the RMS error in the dialog to insure that the points were properly selected.
8. From the Build Exterior Orientation menu bar, select **Options → Build Exterior Orientation** and enter the `.ort` parameters file created for the interior orientation. The GCPs from the exterior orientation are added to the selected `.ort` file. The following is an example of the exterior orientation parameters and points.

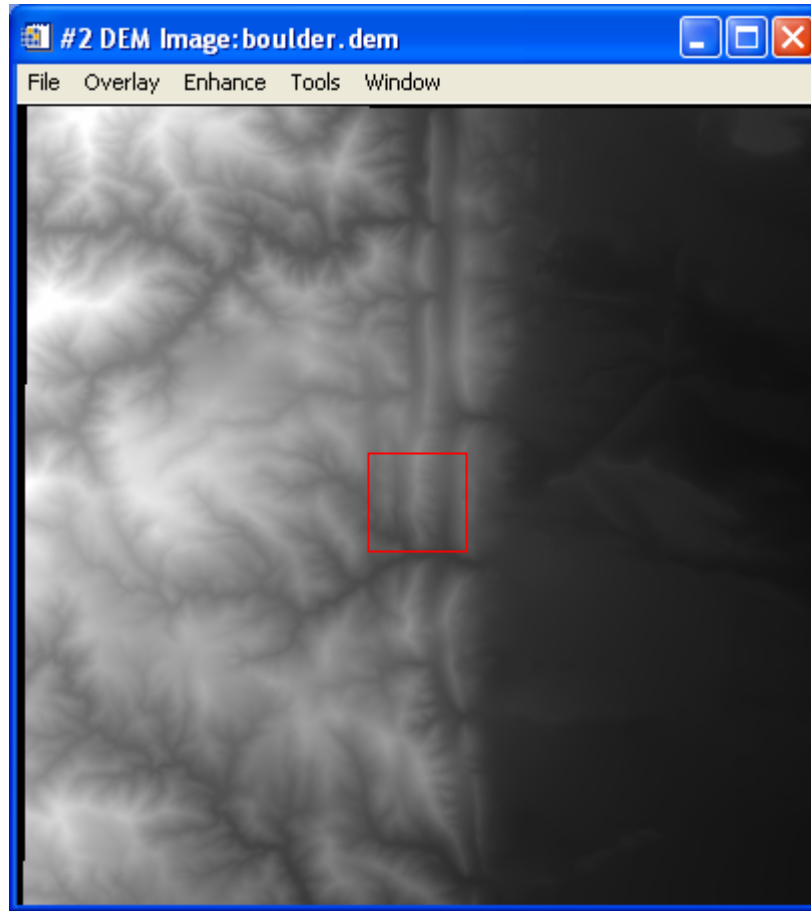
```

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
; Exterior Orientation Information
; projection info = {UTM, 13, North}
; exterior points = {map (x,y,z) meters, image (x,y)}
Exterior Points = {
476788.860, 4434052.500, 1702.040, 2993.00, 545.00,
475174.630, 4430823.600, 1705.600, 2037.50, 2192.50,
478404.380, 4430819.300, 1672.630, 3748.00, 2296.00,
478602.050, 4428903.900, 1635.940, 3799.00, 3314.00,
481632.990, 4430804.900, 1613.830, 5439.00, 2391.00,
480787.590, 4429184.200, 1627.220, 4965.00, 3212.00,
476789.250, 4427487.300, 1713.750, 2815.00, 3997.00,
477837.900, 4424410.800, 1750.380, 3279.00, 5646.00,
480272.650, 4422811.100, 1707.080, 4501.00, 6550.00,
483949.430, 4423904.600, 1762.360, 6487.33, 6086.33}
; PHI = 0.08065113
; OMEGA = -0.29078090
; KAPPA = -87.39367868
; Projection Center x = 478695.7071
; Projection Center y = 4428046.0844
; Projection Center z = 20962.4655

```

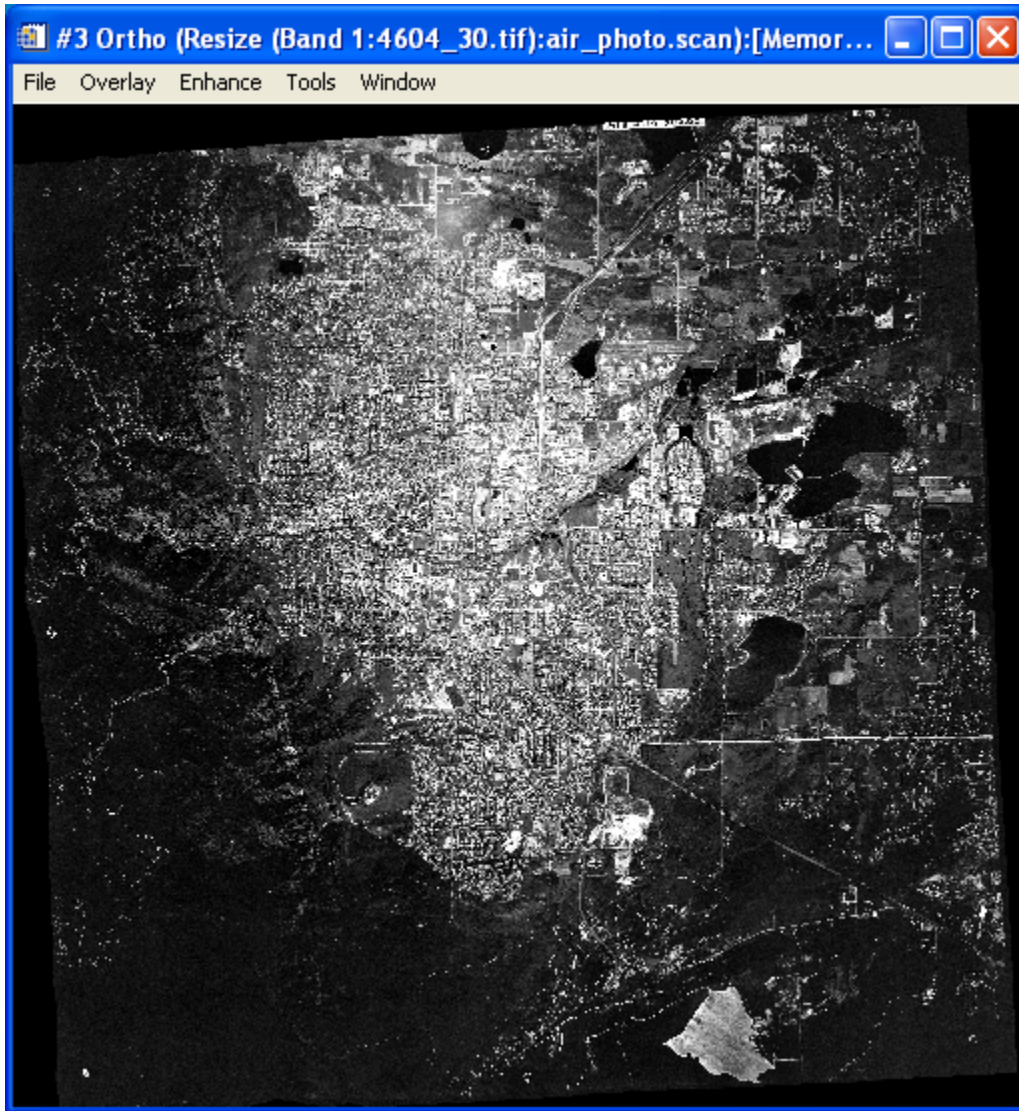
## Orthorectifying the air photo

1. From the ENVI main menu bar, select **Map → Orthorectification → Air Photo → Orthorectify Air Photo**.
2. Select the input aerial photograph filename and any subsetting if desired and click **OK**.
3. Select the input digital elevation model (DEM) filename. The DEM for the Boulder, Colorado, aerial photograph is shown below.



4. Select the orientation parameters (.ort) file you created using the steps described previously in the tutorial. The Orthorectification Bounds dialog appears.
5. Enter the approximate minimum value contained in the DEM file in the **Minimum DEM Value** field. You can also calculate a value from a file using the button provided.
6. Click **OK**. The Orthorectification Parameters dialog appears. Currently, only nearest neighbor resampling is available.
7. Enter the missing data in the **DEM Value to Ignore** field.
8. Type the DN value (used to fill areas where no image data appears in the warped image) in the **Background Value** field.
9. The output image dimensions are automatically set to the size of the bounding rectangle that contains the warped input image. Therefore, the output warp image size may not be the same size as the DEM image. The output size coordinates are determined in the exterior orientation projection coordinates.

10. Select output to **File** or **Memory** and click **OK** to start the orthorectification. The result of the orthorectification of the Boulder, Colorado, aerial photograph is shown below.



## Tips for successful aerial photograph orthorectification

ENVI's aerial photograph orthorectification routines were designed to be as flexible as possible, so there are very few restrictions on the parameters that you provide. While this flexibility makes the tools easy to use, it also makes it possible to set up an orthorectification incorrectly.

### Spatial resolution

Before beginning an orthorectification, it is important to consider the issue of spatial resolution, as it is handled very differently here than in ENVI's "warp" registrations. There are three key parameters:

- The pixel size of the DEM.
- The pixel size of the input image.
- The desired output pixel size for the resulting orthorectified image.

ENVI will let you proceed with any combination of pixel sizes, but these settings will have a profound effect on your results. Ideally, the pixel size of the DEM should be the same (or smaller) as that of the output ortho image you want to create. If the DEM resolution is significantly larger than the desired output resolution, you will often end up with artifacts in the ortho result that look like steps (or blocks) in the image. The steps will occur where there is a boundary between

groups of pixels in the output ortho image which map back to the same DEM elevation (i.e., the same DEM pixel). So, before doing an orthorectification in ENVI, use the [**Basic Tools** → **Resize Images (Spatial/Spectral)**] to resample the DEM to the desired output ortho image resolution. We recommend that you use bilinear interpolation for the resampling, as cubic convolution is more likely to create features that are unrealistic; the nearest neighbor technique will not smooth out the resampled DEM.

## Resampling during orthorectification

When producing the ortho image, the value for each pixel in the output image (i.e., the ortho image's DNs) is determined by figuring out which pixel in the input air photo "belongs" in this position. This is accomplished by using the 2 models to trace back which air photo DN occurs at a given map coordinate. Then, this air photo DN is placed in the correct location in the output ortho image. While the map coordinate of the center of each pixel in the output ortho image will map back to a single pixel in the input air photo, the value that is used for the output ortho image is typically adjusted by resampling it based on the values of the pixels in its immediate vicinity (in the air photo). This resampling produces a smoother, more realistic looking ortho image. Bilinear interpolation uses the values of the 4 nearest neighbors, while cubic convolution uses the 16 nearest neighbors. Currently only nearest neighbor resampling is offered. Nearest neighbor resampling does not provide any smoothing effects. When using nearest neighbor resampling, and the output pixel size of the ortho image is considerably larger than that of the input air photo, you may end up with an ortho image that does not have the spatial characteristics of a typical photograph.

Consider a case where the input air photo has 1x1 meter pixels but the output ortho image has been set up to have only 5x5 meter pixels. In the ortho result, each 5x5 meter pixel will have a DN based on a 1x1 meter area in the air photo. Further, because the map location of the centers of neighboring pixels in the 5 meter ortho result are separated by 5 pixels the air photo, neighboring pixels in the ortho result will have DNs represented by pixels in the air photo that are not continuous. If you wish for your ortho result to have a pixel size that is significantly larger than the air photo, you may want to first resample the air photo to the pixel size of the desired output ortho image.

## Accuracy of GCPs

Unlike the GCPs used in "warp" registrations, the accuracy of each GCP used for the exterior orientation is absolutely critical for locating the position of the air photo camera. If the exterior orientation is not accurate, then the orthorectified image will be in error, even if the interior orientation is perfect. It is not uncommon for GCPs to be based on survey results and be located to sub-millimeter accuracy, especially when orthorectifying air photos with a resolution of 1 meter or less. Also, in order to optimally recover the camera position, try to spread the GCPs across the entire image. It is better to have fewer GCPs that are well distributed than to have many GCPs clustered together. Once at least 4 GCPs are entered in the Exterior Orientation, an estimate of the (x, y) position error is reported as the RMS value. This error estimate is calculated with an RST warping algorithm which is quite different than the orthorectification procedure. The RMS error is provided to check for large errors, such as those that might occur with a typo or a misplaced decimal point when entering the GCPs. This error does not consider the Z-values of the GCPs and is not an accurate assessment of the true error in the orthorectification.

## Minimum DEM value

After you have built the .ort file by defining the interior and exterior orientations, and you are running the Orthorectify Air Photo procedure, you will be prompted to enter a **Minimum DEM Value**. For any given set of orthorectification parameters, the greater the distance between the camera and the ground, the bigger the ortho image must be. The value that is entered here is used to determine the size (in samples and lines) of the orthorectification output image. This value will not affect the DNs of the resulting ortho image, however, entering an accurate value will likely reduce the processing time and make a smaller resulting image file.

## Output pixel size

The output pixel size for the resulting ortho image defaults to the pixel size of the DEM. If this is not the pixel size you wish for your result, you can change the pixel size in the Orthorectification Parameters dialog by selecting the **Change Output Parameters** button. Generally speaking, it is always a good idea to check the values in the Output Image Parameters dialog before doing any kind of registration (orthorectification, warping, converting map projections, etc.), because a quick glance at these parameters can often identify problems with input parameters.