

Tutorial



Orthorectification Using Rational Polynomials



with
TNTmips[®]

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Before Getting Started

You can orthorectify images that have a mathematical model of the image geometry in the form of a set of rational polynomial coefficients supplied by the image vendor or computed in the Georeference process. This procedure also requires a digital elevation model. You can often improve the fit of a vendor's rational polynomial model to a particular image by regeoreferencing the image using accurate 3D ground control points. This booklet introduces the concepts and procedures involved in rational polynomial orthorectification in TNTmips, including the use of the rational polynomial model in georeferencing the image prior to rectification.

Prerequisite Skills This booklet assumes that you have completed the exercises in the *Getting Started* and *Introduction to the Display Interface* tutorial booklets. Those exercises introduce essential skills and basic techniques that are not covered again here. You should also be familiar with the topics covered in the *Georeferencing* and *Rectifying Images* tutorial booklets. Please consult those booklets for any review you need.

Sample Data The exercises in this booklet use sample data that is distributed with the TNT products. If you do not have access to a TNT products DVD, you can download the data from MicroImages' web site. In particular, this booklet uses sample files in the RECTIFY directory.

More Documentation This booklet is intended only as an introduction to orthorectifying satellite images. Details of the process can be found in a variety of tutorial booklets, color plates, and Quick Guides, which are all available from MicroImages' web site.

TNTmips® License Levels TNTmips (the Map and Image Processing System) comes in three versions: the professional version of TNTmips (TNTmips Pro), the low-cost TNTmips Basic version, and the TNTmips Free version. All versions run exactly the same code from the TNT products DVD and have nearly the same features. If you did not purchase the professional version (which requires a software license key) or TNTmips Basic, then TNTmips operates in TNTmips Free mode. All the exercises can be completed in TNTmips Free using the sample geodata provided.

Randall B. Smith, Ph.D., 24 February 2015

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You can print or read this booklet from MicroImages' Web site. The Web site is also your source for the newest Tutorial booklets on other topics. You can download an installation guide, sample data, and the latest version of TNTmips.

<http://www.microimages.com>

Welcome to RPC Orthorectification

Aerial and satellite images of land surfaces commonly contain spatial distortions due to terrain relief and off-vertical imaging geometry. Orthorectification is a procedure that removes these distortions, creating an *orthoimage* with features positioned as they would be in a planimetric map. Because an orthoimage has map-like geometry, map-derived thematic data layers register more accurately with an orthoimage than with an unrectified image, and the spatial information you extract from an orthoimage is more accurate.

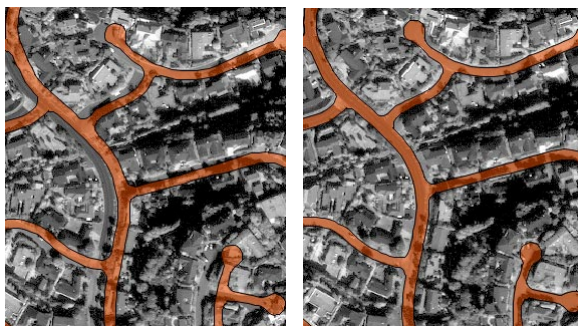
You can orthorectify images in the TNTmips Automatic Resampling process using the Rational Polynomial resampling model and an accurate elevation raster (DEM). Orthoready images from the QuickBird, WorldView, IKONOS, ALOS, and Pleiades satellites, among others, are supplied with auxiliary files containing the

orthorectification model in the form of rational polynomial coefficients (RPC). These images are also acquired from a high viewing angle to minimize terrain distortion.

You can also use the Georeference process to compute a Rational Polynomial orthorectification model for any aerial or satellite image for which you can provide a set of accurate 3D control points. See the Technical Guide entitled *Compute Rational Polynomial Model for Orthorectification* for more information.

STEPS

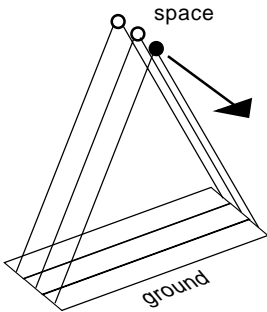
- start TNTmips
- select Image / Resample and Reproject / Automatic... from the TNTmips menu



Planimetric street vector (orange, traced from aerial orthophoto) overlaid on panchromatic IKONOS satellite image (1-meter cell size) of part of La Jolla, California. Left, georeferenced but unrectified image. Right, image after RPC orthorectification, resulting in excellent match with street vector. Area has about 60 meters of relief.

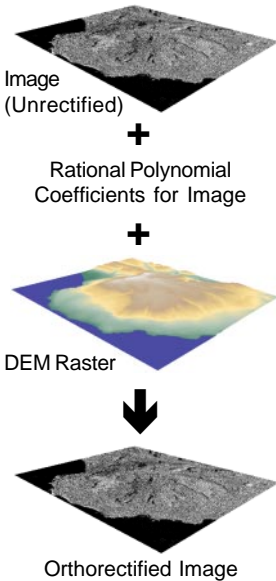
In the research literature the acronym RPC is derived either from "Rational Polynomial Coefficients" or "Rational Polynomial Camera model". Other authors use the term Rational Function Model (RFM) to refer to the same mathematical model.

About Rational Polynomial Models



A cross-track scanning imager such as IKONOS builds up an image from groups of scan lines acquired from different positions in space (circles) as the satellite moves forward in orbit (arrow).

Rational Polynomial Orthorectification



In a conventional aerial photograph made with a framing camera, each location in the image is captured at the same time from a single camera position. Because of this simple image geometry, the coordinate transformation from two-dimensional image coordinates to three-dimensional Earth-surface coordinates can be expressed mathematically using relatively simple expressions.

Most remote sensing satellite images, on the other hand, are built up of groups of scan lines acquired as the satellite moves forward in its orbit. As a result, different parts of the same image are acquired from different sensor positions. In order to rigorously describe the transformation from image coordinates to Earth surface coordinates, a mathematical sensor model that incorporates all of the physical elements of the imaging system can be exceedingly long and complex. For example, the IKONOS rigorous sensor model is 183 pages long!

Rational Polynomial satellite sensor models are simpler empirical mathematical models relating image coordinates (row and column position) to latitude and longitude using the terrain surface elevation. The name Rational Polynomial derives from the fact that the model is expressed as the ratio of two cubic polynomial expressions. Actually, a single image involves two such rational polynomial expressions, one for computing row position and one for the column position. The coefficients of these two rational polynomials are computed by the satellite company from the satellite's orbital position and orientation and the rigorous physical sensor model. Using the georeferenced satellite image, its rational polynomial coefficients, and a DEM to supply the elevation values, the TNTmips Automatic Resampling Process computes the proper geographic position for each image cell, producing an orthorectified image.

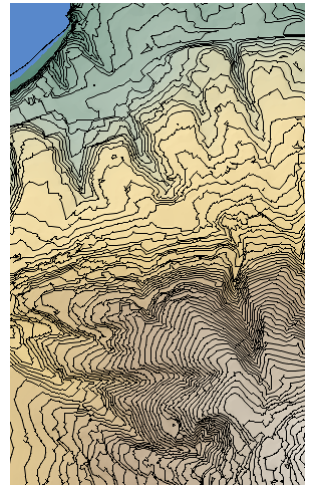
Acquiring a Digital Elevation Model

The digital elevation model you use to orthorectify an image need not match the image area or cell size (the common area of the two is orthorectified). To achieve the best results, however, the cell size of the DEM should be as close as possible to that of the image you are rectifying. DEMs with 30-meter resolution produced by the United States Geological Survey (USGS) are available for free download for any area in the United States, and 10-meter USGS DEMs are available in most areas. For other countries elevation data with similar resolution may be available for purchase from the relevant government agency. A global 90-m DEM produced from NASA's Shuttle Radar Topography Mission (SRTM V3) is also available for all of Earth's land areas from MicroImages. An enhanced 30-m SRTM DEM is also available from the USGS EROS Data Center for many areas.

If you cannot locate a DEM with sufficient spatial resolution for your image area, you may be able to create your own. Topographic contour data is available for some areas in digital form, or it can be produced from a scanned topographic map of the area. The resulting vector contour data can be surface-fit in the TNTmips Surface Modeling process to create a DEM. (See the tutorial booklet entitled *Surface Modeling* for more information.) For example, MicroImages wished to rectify a 1-m panchromatic IKONOS image of La Jolla, California, but a 30-m DEM was the best resolution available from the USGS. Instead we purchased low-cost vector contour data with 5-foot contour interval from the County of San Diego. After editing to remove contouring artifacts, we surface-fit the contours to create a DEM with 1-meter cell size and elevation values in decimal meters (floating-point raster), a resolution more appropriate to our image data.



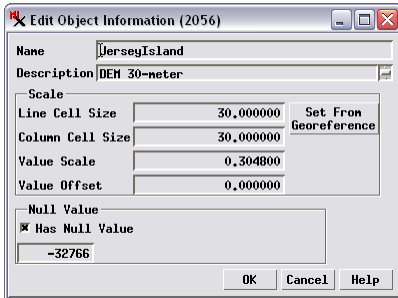
Portion of a 30-m DEM (displayed with color palette) for the La Jolla, California area, the best resolution available from the USGS.



Portion of DEM with 1-meter cell size created by surface-fitting vector contour lines with a 5-foot contour interval (black lines).

Elevation Units and Reference Surfaces

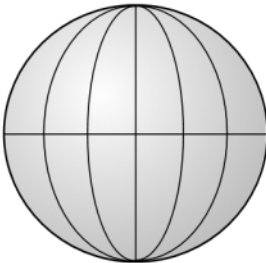
Topographic contour maps and digital elevation models may express elevation values in a variety of units. For example, DEMs available for the United States may have elevations in meters, decimeters, or feet, depending on the data source and the local relief. Before using a DEM for RPC orthorectification, check the metadata or other text information that accompanied the original data to verify the elevation units. The RPC orthorectification procedure requires elevations in meters. If your DEM uses other elevation units, don't panic. The simplest remedy is to



Edit Object Information window for a DEM in feet, with Cell Value Scale set to rescale DEM values to meters.

open the TNTmips File Manager (Tools / File Manager), navigate to the DEM raster, and press the Edit icon button, which opens the Edit Object Information window. The Scale panel on this window includes a Cell Value Scale field in which you can enter the conversion factor to rescale the raster cell values to meters (for example, 0.1 to rescale decimeters to meters and 0.3048 to convert feet to meters). Most TNTmips processes will then automatically use the rescaled value.

The rational polynomial coefficients for a particular satellite image are computed using data on the orbital position and orientation of the satellite sensor. The satellite position includes a height (elevation) component, but that raises the question, height above what? The physical surface of the Earth is irregular and its elevation is not known precisely everywhere, so it cannot be used as a reference surface. Satellite heights instead are referenced to an ideal, mathematically-defined

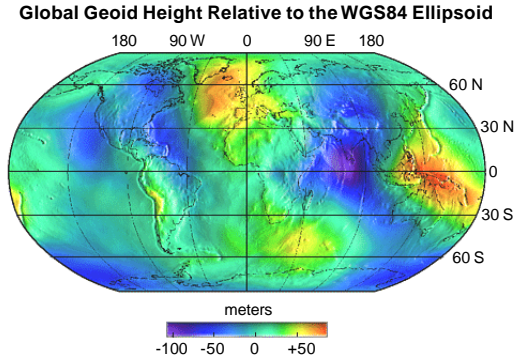


The global best-fit ellipsoid is nearly spherical, with a polar radius that is shorter than the equatorial radius by a factor of $1 / 298.257$.

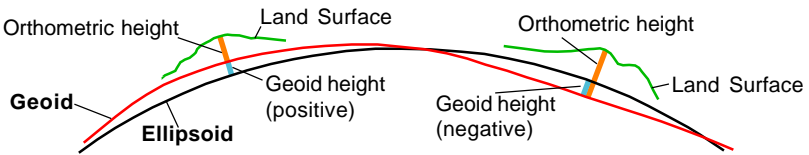
geometric shape, an earth-centered ellipsoid, that provides a global best fit to the overall shape of the earth. This ellipsoid is most commonly the World Geodetic System (WGS) 1984 ellipsoid that forms the basis for the WGS 1984 geodetic datum. Both remote sensing satellites (such as QuickBird and IKONOS) and the constellation of Global Positioning System (GPS) satellites reference elevations to this hypothetical ellipsoidal surface. Thus the elevation values built into the RPC model for an image are *ellipsoidal* elevations, as are the elevation values computed by GPS receivers from the GPS satellite information.

Obtaining the Geoid Height

On the other hand, the elevation values in most DEMs give the height of the ground surface relative to local mean sea level. This value is sometimes called *orthometric* height. Mean sea level on a global scale is a broadly undulating surface called the *geoid*, whose shape has been determined from studies of the Earth's gravity field supplemented by GPS survey data. The vertical separation between the geoid and ellipsoid at any location is called the *geoid height*, which may be either positive (geoid above ellipsoid) or negative (geoid below ellipsoid). Geoid heights vary gradually on a regional to continental scale within the range -100 to +100 meters.



Geoid height in vertical section (exaggerated)



Since rational polynomial image models use ellipsoidal elevations, georeference and rectification procedures that use this model must convert orthometric DEM elevations to ellipsoidal heights by adding the local geoid height. Therefore, when you select a DEM in the Georeference or Automatic Resampling processes, you are prompted to enter a geoid height. (Because of the regional scale of geoid height variations, a single geoid height value can suffice for an entire IKONOS or QuickBird scene.) You can find the appropriate geoid height for your image area by entering the latitude and longitude of the image center in one of several free geoid height calculators available on the World Wide Web:

<http://earth-info.nga.mil/GandG/wgs84/gravitymod/egm96/intpt.html>

<http://sps.unavco.org/geoid/>

http://www.ngs.noaa.gov/cgi-bin/GEOID_STUFF/geoid03_prompt1.pl

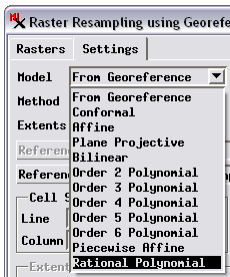
A Windows 9x/NT software program to compute geoid heights is also available (with supporting files) for free download at:

<http://earth-info.nga.mil/GandG/wgs84/gravitymod/egm96/egm96.htm>

Run the RPC Orthorectification

STEPS

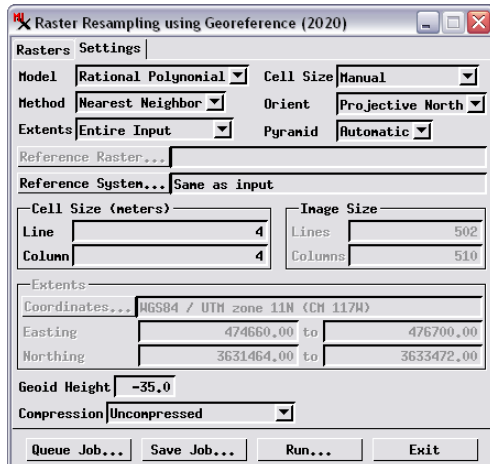
- in the Raster Resampling window, press [Select Rasters...]
- navigate into the LJMESA Project File in the RECTIFY sample data directory and select IKONLJM4
- on the Settings tabbed panel, set the Model menu to Rational Polynomial



- when prompted to select the Rational Polynomial model file, select RECTIFY / IKONLJM4_RPC.TXT
- when prompted to select the DEM raster, select DEM_4M from the LJMESA Project File
- set the Method menu to Nearest Neighbor and the Cell Size menu to Manual
- set the Orient menu to Projective North and the Extents menu to Entire Input
- enter -35.0 in the Geoid height field
- press [Run]
- use the standard Select Object window to select or create a destination Project File and to name the output raster object

Orthorectification using the Rational Polynomial model provided by an image vendor is carried out in the Automatic Resampling process using the Rational Polynomial selection on the Model menu. You can set the model before or after selecting the raster object (or set of raster objects) you wish to rectify. When you complete the second of these two actions, you are presented with a series of dialogs prompting you to select the elevation raster and to select the text file containing the rational polynomial coefficients. You must also provide a value for the local geoid height.

In this exercise you orthorectify a color image created from the red, green, and blue bands of a sample IKONOS multispectral image covering part of La Jolla, California. The image has a cell size of 4 meters and covers about 4 square kilometers. Topographically, the area is a plateau sloping southwest, cut by narrow canyons, and has a local relief of 200 meters. The image and associated elevation model are shown on the next page.

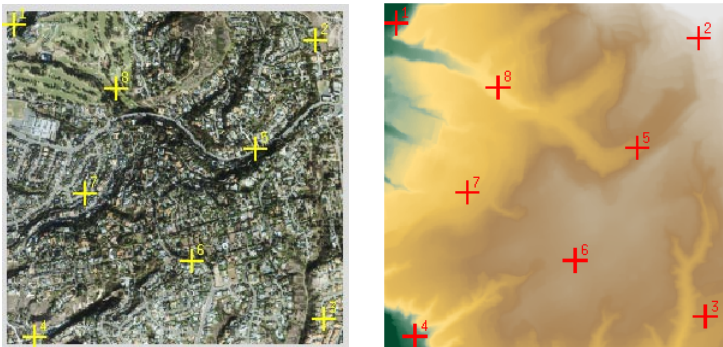


You can use the Display process to overlay the original and orthorectified images to see the geometric changes produced by the rectification.

Regeoreferencing the Image

The image you rectified in the previous exercise has georeference information obtained from the image provider. The satellite company determines the geographic “footprint” of the image using data on the position of the imaging satellite in its orbit, the direction the sensor was pointing, and an average elevation for the scene. These parameters are used to compute map coordinates for the four image corners. But small errors in the satellite parameters can translate into large errors in the image georeferencing. These errors can cause misregistration with the DEM you use for rectification, which in turn leads to errors in the position and internal geometry of the orthorectified image you produce.

You can improve the orthorectification results for most images by regeoreferencing the image (using the TNTmips Georeference process) with accurate, well-distributed ground control points (GCPs). This will ensure that accurate geographic extents are computed for the image and that it registers correctly with the DEM during orthorectification. (For best results, delete the corner control points provided with the image.) The new control points should be distributed relatively uniformly over the entire extent of the image, including the edges and corners.




A well-distributed set of ground control points for the IKONOS multispectral image of La Jolla Mesa (left) covers the image extents and also includes a range of elevations, as shown in the view of the DEM (right).

The georeference process can also use your control points to refine the rational polynomial orthorectification model provided with the image (see the following pages). As few as 4 to 6 accurate, well-distributed points may significantly improve the fit of the model and thus improve the registration and internal geometry of the orthorectified image you produce with it. A larger number of control points may improve the fit in some cases, in part by diluting or averaging out positional errors introduced by any less accurate control points. Placing additional control points in topographically significant locations (such as hill tops and valley bottoms) may further improve the fit of the RPC model.

Georeference with RPC Model

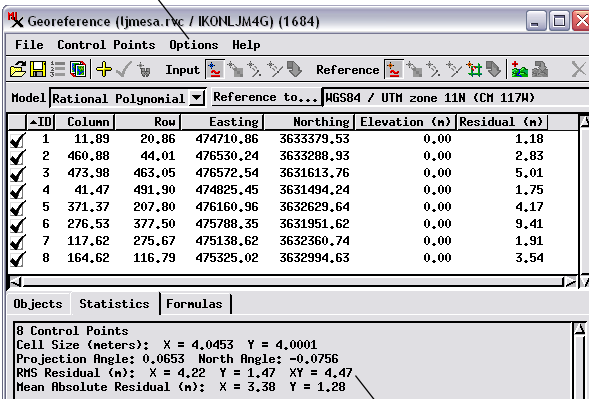
STEPS

- choose Main/Georeference from the TNTmips menu
- in the Georeference window, press the Open icon 
- use the standard Select Objects dialog to select raster object IKONLJM4G from the LJMESA Project File
- choose Rational Polynomial from the Model menu
- in the Select Rational Polynomial Model File window that appears, choose RECTIFY / IKONLJM4_RPC.TXT

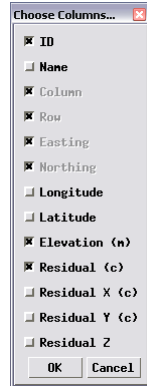
The version of the sample IKONOS image that you open in this exercise has been provided with 8 control points in a UTM coordinate system using the Affine model. To evaluate these and any added points in the context of RPC orthorectification we choose the Rational Polynomial option from the Model menu. You are then prompted to select the RPC text file to provide the rectification coefficients.

When you use the Rational Polynomial model in Georeference, control point residuals are computed by first projecting all control point positions through the rational polynomial transformation to remove terrain displacements, so that the residuals indicate departures from the rectification model. The process also makes adjustments to the transformation between image and geographic coordinates to minimize these residuals. This adjustment requires an accurate elevation value for each control point in addition to its horizontal coordinates. You can enter elevation values manually in the Elevation column in the control point list, or assign the elevation value from the corresponding cell in the DEM as shown in a later exercise.

Choose Options / Columns to open a window that lets you choose which columns of data to show in the control point list. Make sure that the Elevations column is toggled on.



a later exercise.



The bottom part of the Georeference window shows summary statistics for the current set of control points. The RMS (Root Mean Square) Residual and Mean Absolute Residual values provide measures of the fit of the entire set of control points to the adjusted rational polynomial model. These values are updated immediately with any change in the control points.

Control Points from GPS Survey



You can use several methods to acquire control points to georeference an image. If you have access to the area, you can use a Global Positioning System (GPS) receiver to acquire geographic position data. Since the routine use of Selective Availability (intentional degradation of position accuracy to non-military receivers) has been discontinued, even a single inexpensive handheld GPS unit can determine map coordinates accurately enough to provide adequate control points for multi-spectral (4-meter) IKONOS and QuickBird images. You can achieve even greater positional accuracy using a receiver designed to



accept real-time differential corrections, either from a surface broadcast source or from the Wide Area Augmentation System (WAAS) satellites. Alternatively, you can use a second stationary GPS unit to collect data to apply differential correction post-processing to the data from your roaming receiver.

Control point collected at a picnic table in a public park using an inexpensive hand-held GPS receiver. If you are using the GPS fix "Z" value for your control point elevation, be sure to subtract the unit's height above the ground.



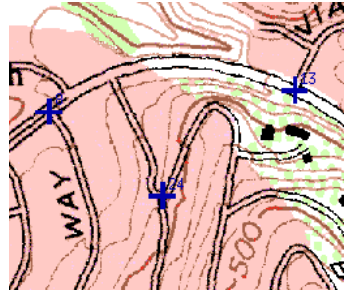
Your GPS stations should be in open areas free of obstructions that could block the GPS signal or the differential correction signal. In addition, the stations must be easily recognizable in the image.

GPS positions are normally expressed as latitude and longitude relative to the WGS 1984 datum. You may find it convenient to configure your GPS to report positions in the same coordinate reference system (CRS) used by your image. However, regardless of the image reference system, you can enter latitude/longitude coordinates directly in the control point list using the secondary CRS columns (see the Georeferencing tutorial). The elevation computed from the GPS satellites is the ellipsoidal elevation. This value is usually less accurate than the horizontal coordinates, so you may consider using the DEM elevation instead. In addition, some GPS receivers incorporate a barometer to report elevations. You typically calibrate the barometric elevation using a known elevation from a topographic map, which shows geoidal elevations. So you must add the geoid height to any barometric elevation before entering the elevation for the control point.

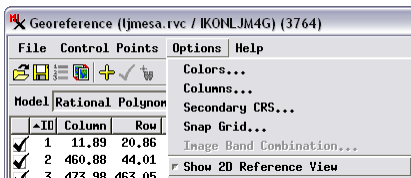


Control from Maps or Orthoimages

If you cannot travel to the image area or don't have access to a GPS, you can use a digital version of a topographic map, other planimetric map, or orthoimage of the area to provide control point locations. In the United States and some other developed countries, georeferenced bitmap (raster) images of topographic maps at various scales are available from government agencies. If only paper maps are available to you, you can have them scanned and then georeference the resulting map rasters. Digital orthoimages may be available from federal, state/provincial, or local government agencies.



When using a scanned map as a reference for georeferencing, you will need to find features that are readily recognizable in both the map and your image, such as road intersections and stream confluences. The accuracy of your control point positions on the reference map is more dependent on the spatial accuracy standard of the original map than on the cell size of the scanned version. A reference orthoimage typically provides more mutually-recognizable features as well as more detail and better spatial accuracy.



To use a reference object in the Georeference process, choose Show 2D Reference View from the Options menu. Then add the desired raster object to the Reference View. See the *Georeferencing* tutorial booklet for more information.



A topographic map has the advantage of including elevation information in the form of contour lines. You can compute the elevation for a control point by interpolating between adjacent contours. Remember that control point elevations must be ellipsoidal elevations in meters; before assigning your interpolated elevation to the point in the Georeference process, convert it to meters (if necessary) and add the local geoid height. If your DEM of the image area is sufficiently detailed, you may want to assign control point elevations from the DEM instead. If you are using an orthoimage to georeference your image, you will need to acquire control point elevations from the DEM or other source.

Control Point Elevations from DEM

Several tools in the Georeference process make it easy to assign control point elevations from a DEM. If you add a DEM as a terrain layer in the Georeference Input View, the process automatically turns on the Default Z from Surface icon button in the Georeference window's toolbar (see illustration below). This button sets a program mode in which each new control point you add is automatically supplied with an elevation value from the DEM cell corresponding to that location. (You can also turn this mode on and off manually, of course.)

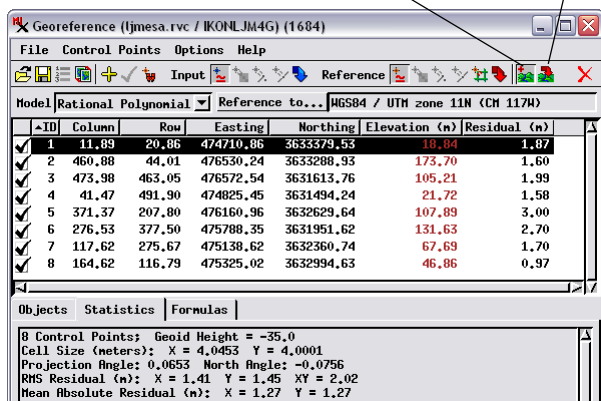
In addition, when you select one or more existing control points in the list, the Set Z from Surface icon button becomes active. Pushing this button assigns an elevation value to each selected control point from the corresponding cells in the surface layer DEM. (If no surface layer has been added yet, as in this exercise, you are automatically prompted to select one and set the geoid height). You can thus use the Set Z from Surface procedure to deal with existing control points and the Default Z from Surface mode to handle any new control points you add.

STEPS

- left-click on any field in the listing for control point 1 to select this point
- hold down the shift key and click on the listing for control point 8 to select all of the points
- press the Set Z from Surface icon button 
- when prompted, select raster object DEM_4M from the LJMESA Project File as the terrain layer
- enter -35 in the Prompt dialog for the local geoid height and press [OK]
- note that elevations have been assigned to each point from the DEM
- save the modified georeference 

When you save the georeference information using the Rational Polynomial model, the RPC coefficients are automatically saved with the georeference subobject. When you open such an image in the Automatic Resampling process, the RPC model is read automatically and you are prompted to select the DEM to use. You can keep the default option of From Georeference on the Model menu, and set the appropriate geoid height.

Default Z from Surface Set Z from Surface



The screenshot shows the Georeference window with the following data table:

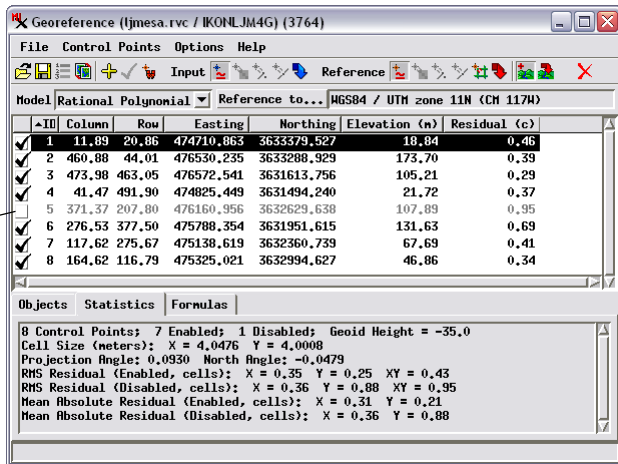
| ID | Column | Row | Easting | Northing | Elevation (m) | Residual (m) |
|----|--------|--------|-----------|------------|---------------|--------------|
| 1 | 11.89 | 20.86 | 474710.86 | 3633579.53 | 10.04 | 1.87 |
| 2 | 460.88 | 44.01 | 476530.24 | 3633288.93 | 173.70 | 1.60 |
| 3 | 473.98 | 463.05 | 476572.54 | 3631613.76 | 105.21 | 1.99 |
| 4 | 41.47 | 491.90 | 474825.45 | 3631494.24 | 21.72 | 1.58 |
| 5 | 371.37 | 207.80 | 476160.96 | 3632629.64 | 107.89 | 3.00 |
| 6 | 276.53 | 377.50 | 475788.35 | 3631951.62 | 131.63 | 2.70 |
| 7 | 117.62 | 275.67 | 475138.62 | 3632360.74 | 67.69 | 1.70 |
| 8 | 164.62 | 116.79 | 475325.02 | 3632994.63 | 46.86 | 0.97 |

Below the table, the software status shows: 8 Control Points; Geoid Height = -35.0; Cell Size (meters): X = 4.0653 Y = 4.0001; Projection Angle: 0.0653 North Angle: -0.0756; RMS Residual (m): X = 1.41 Y = 1.45 XY = 2.02; Mean Absolute Residual (m): X = 1.27 Y = 1.27

Evaluating Control Points

You can use the individual control point residuals and the RMS error statistics shown in the Georeference window to help judge the accuracy of your control points. However, this is a subjective procedure, and there are no rigid guidelines. Ideally, you would like the point residuals to be less than the cell size of the image, but you may only be able to approximate this level of accuracy. A large error residual for a particular point may indicate that you made a blunder of some sort. You may have incorrectly recorded a GPS map coordinate in the field, mistyped a value when entering point coordinates, or placed the point in the wrong location in the Input or Reference view. If you can't identify an obvious source of error or don't have the information to correct it, you can toggle off the checkbox to the left of the point's entry in the list to make the anomalous point Inactive. The residuals for the remaining active points (and the overall RMS error for the active points) are automatically recalculated. If you find there is dramatic improvement, you may want to delete the anomalous point.

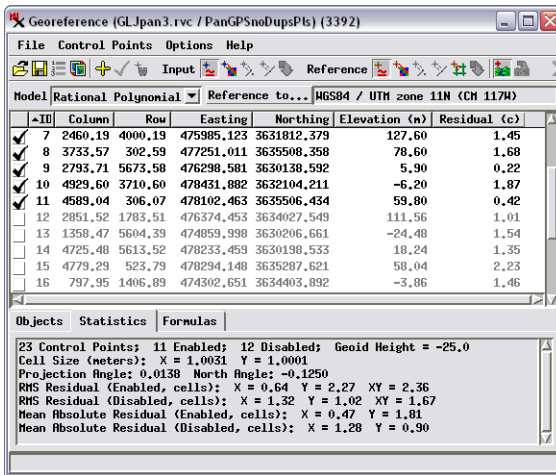
To inactivate a control point, left-click on the checkbox to the left of its entry in the list to uncheck it. The list values for an inactive control point are dimmed (shown in gray).



However, remember that residuals are computed from a global best fit to the entire set of active points. All points contribute equally to this procedure, so the result is influenced by the distribution of points. A control point may have a high residual error because it is isolated from other points that are more clustered together, and you usually need to retain such isolated points to provide adequate coverage of the image. Don't assume that the point with the highest residual is necessarily the "worst point" in the set. And residuals do not reveal systematic error that may affect all points equally, such as choosing the wrong datum.

Using Test Points

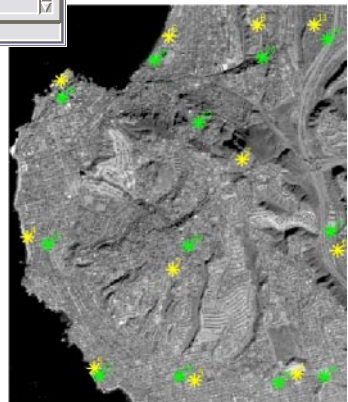
If you have a sufficient number of control points that you believe are accurate, you can reserve some of them to use as test points to check the quality of your control point set. First enter just the control points, check the residuals, and edit or delete any problem points. Then enter the test points and set each of them to be inactive. Residuals and overall RMS errors are computed separately for the active and inactive points, so they represent independent applications of the current RPC model. Since your “test” points were not used to develop the active point model, they represent an independent test of the accuracy of your control points. If the RMS error and individual point residuals for your test points are small (comparable in size to those for the active points), then you probably have a suitably accurate set of control points to perform the RPC orthorectification.



In this example, GPS control points for the 1-meter image below (yellow) are supplemented with inactive test points (green) placed from orthophotos with 0.15 meter resolution. The overall XY RMS error for the test points is comparable to (even less than) the error for the control points, indicating an accurate set of control points.

The status of control points (active or inactive) is saved when you save the georeference information for an object.

To see the effects of regeoreferencing, run the RPC orthorectification again (steps on page 8) using the regeoreferenced sample image (IKONLJM4G) and the 3D control points provided. You can use the Display process to overlay the two orthoimages you produced to see the geometric changes that result.



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