

# ENVI Tutorial: The DEM Extraction Module

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## The DEM Extraction Module

This tutorial introduces the Digital Elevation Model (DEM) Extraction Module with functionality that enables you to extract elevation data from stereo imagery to create a DEM. A DEM is a raster grid of elevation values that represent a surface. DEMs are useful for many applications such as mapping, orthorectification, and land classification. They are often used to create contour maps and perspective maps and for various types of land use planning applications.

The DEM Extraction Module enables you to extract elevation data from scanned or digital aerial photographs, or from an along track or an across track *pushbroom* satellite acquisition, such as those from the ALOS PRISM, ASTER, CARTOSAT-1, FORMOSAT-2, GeoEye-1, IKONOS, KOMPSAT-2, OrbView-3, QuickBird, WorldView-1, or SPOT satellites. *Along track* stereo images are acquired on the same orbital pass by a satellite which usually has more than one sensor looking at the Earth from different angles. *Across track* stereo images are those taken by the same sensor on multiple orbits.

The DEM extraction process requires a stereo pair of images containing rational polynomial coefficients (RPC) positioning from aerial photography or pushbroom sensors. RPCs are used to generate tie points and to calculate the stereo image pair relationship. See "Building RPCs" in the *ENVI User's Guide* for details. DEM extraction does not currently support replacement sensor model (RSM) positioning.

The DEM Extraction Module is comprised of the DEM Extraction Wizard and three DEM tools: the DEM Editing Tool, Stereo Pair 3D Measurement Tool, and the Epipolar 3D Cursor Tool.

**Note:** The DEM Extraction Module requires an additional license in your installation; contact your ENVI sales representative to obtain a license. If you are not licensed for the DEM Extraction Module, the tool will be disabled.

### Files Used in this Tutorial

ENVI Resource DVD: /Data/aster

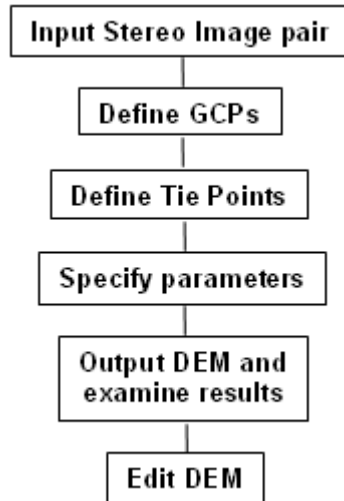
| File            | Description        |
|-----------------|--------------------|
| AST_L1A.hdf     | ASTER Level 1 data |
| AST_L1A.hdf.met | Metadata for above |

U. S. Geological Survey Data. This ASTER Level 1 dataset was processed by the Japanese Ground Data System (GDS) and archived by the Land Processes Distributed Active Archive Center (LP DAAC) at the USGS EROS Data Center (EDC). The data contains advanced spaceborne thermal emission and reflection radiometer (ASTER) data files in the hierarchical data format for earth observing system (HDF-EOS).

### Working with the DEM Extraction Wizard

DEM extraction is a multi-step decision making process involving the setting of many parameters used in different steps. These steps can be run individually, or from within the DEM Extraction Wizard. The Wizard guides you through nine steps, presenting you with objective parameters, such as minimum/maximum elevation of the area of interest, as well as other strategy parameters that depend upon the terrain relief, cultural content, image quality, shadowing, and the desired speed of operation.

Following is a diagram of the DEM Extraction Wizard workflow. The Wizard allows you to step forward, backwards, and to save the workflow at any step so that you can continue at a later time.

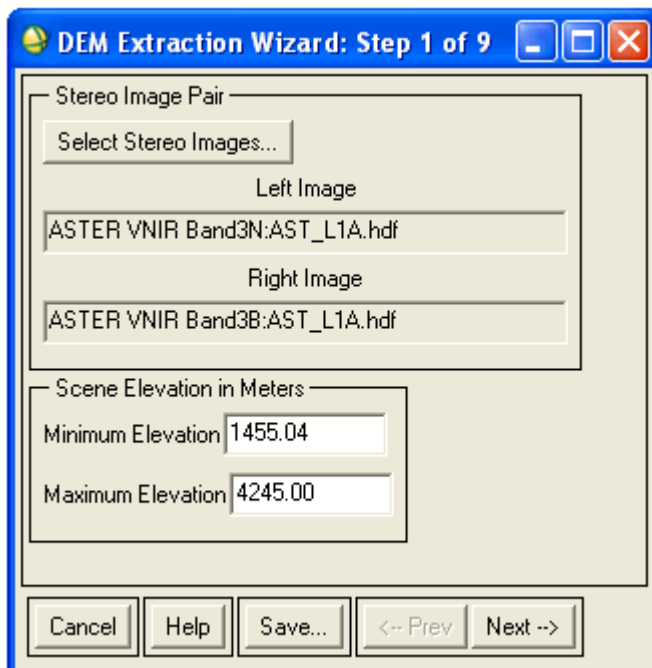


## Inputting a Stereo Image Pair

The DEM extraction process begins with input of a stereo image pair that contains or has associated RPCs. For this demonstration, we will extract a DEM from an ASTER L1A product using the DEM Extraction Wizard. ASTER uses the visible near infrared (VNIR) telescope's normal (3N) and backward (3B) viewing bands for along-track stereoscopic observation. In this example, we will use the 3B band for the left image and the 3N band for the right image.

In the following steps, you will select a stereo pair of images containing RPC positioning from either an along track or an across track satellite acquisition.

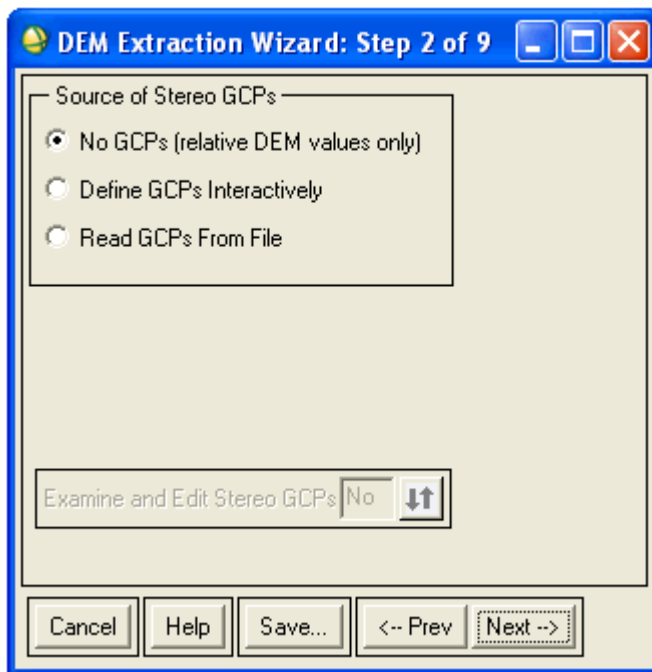
1. From the ENVI main menu bar, select **File > Open External File > EOS > ASTER**.
2. Navigate to the `Data\aster` directory, select the file `AST_L1A.hdf` from the list, and click **Open**. The Available Bands List is displayed.
3. From the ENVI main menu bar, select **Topographic > DEM Extraction > DEM Extraction Wizard > New**.
4. Click the **Select Stereo Images** button. The Select Left Stereo Pair Image dialog appears. The order of the data entry here should not matter. However, in tools such as the tie point generation, you will likely see different tie point selections and calculated errors because the solution will be different.
5. Select **ASTER VNIR Band3N** and click **OK**. The Select Right Stereo Pair Image dialog appears.
6. Select **ASTER VNIR Band3B** and click **OK**. ENVI estimates the scene minimum and maximum elevations using the associated RPC information and a World DEM file included in the ENVI sample datasets.
7. Click **Next** to continue.



## Defining Ground Control Points

In the second step of the Wizard, you will be provided with the option to define or use existing GCPs. When defining GCPs, you can choose any of the following options:

- **No GCPs.** Choosing this option would result in a relative DEM, which is a DEM with possible differences in position, scale and rotation from geodetic coordinates on the ground and mean sea level.
- **Define GCPs Interactively.** Choosing this option would require that you manually enter, load, and edit GCPs that will tie the DEM to a planar map projection. The result of which would be an absolute DEM. An absolute DEM uses ground control and has horizontal and vertical references systems tied to these geodetic coordinates.
- **Read GCPs From File.** Choosing this option would require that you select a GCP file from which to read GCPs.



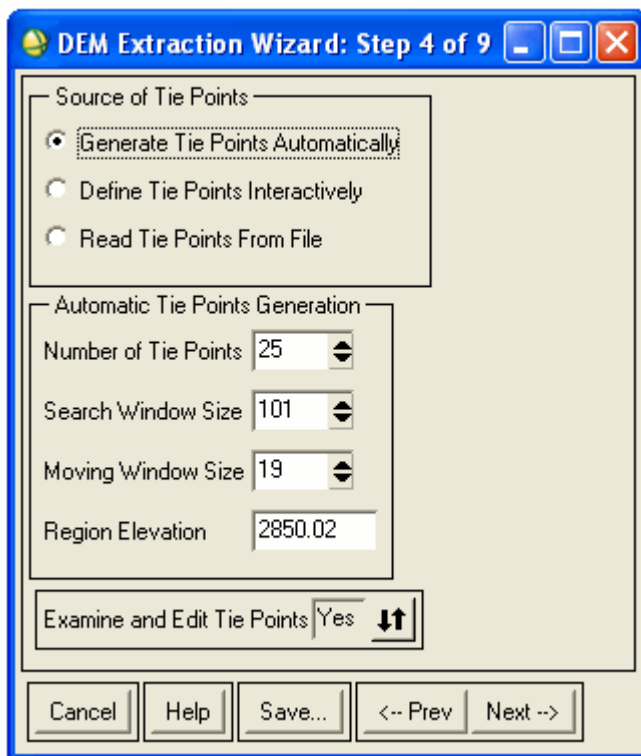
For this exercise, you will not use GCPs so the resulting DEM values will be relative elevations.

1. Click the **No GCPs** radio button. Note that the Examine and Edit Stereo GCPs option (step 3 of 9) is not available. It is only available if you have loaded a GCP file into the Wizard.
2. Click **Next** to continue. ENVI skips Step 3 and moves you to Step 4.

## Defining Tie Points

Next, the relationship between the stereo images must be defined by selecting or generating tie points. The tie points are used to define the epipolar geometry and create epipolar images, which are used to extract the DEM. When defining tie points, you can choose any of the following options:

- **Generate Tie Points Automatically.** ENVI can generate tie points automatically, based on terrain features within the image.
- **Define Tie Points Interactively.** Choosing this option would require that you manually define tie points between the two stereo images.
- **Read Tie Points From File.** Choosing this option would require that you select a tie point file from which to read the tie points.



For this exercise, you will generate tie points automatically.

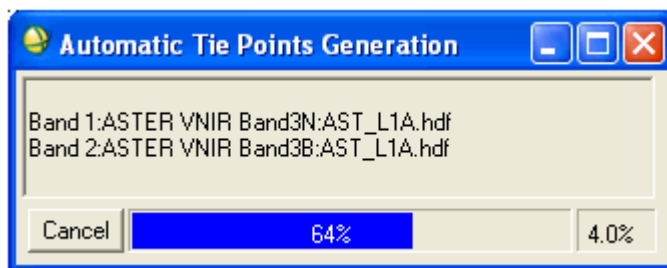
1. Click the **Generate Tie Points Automatically** radio button. Automatic tie point generation requires four parameters to be specified:
  - The **Number of Tie Points** you wish to generate.
  - The **Search Window Size** and the **Moving Window Size**. The Search Window is a defined subset of the image. The Moving Window defines an area within the Search Window that is used to scan and find a topographic feature match for a tie point placement. The size of these windows should be considered with respect to the spatial resolution of the data. For example, higher spatial resolution data, such as sub-meter

QuickBird imagery, should use larger window sizes in order to increase the reliability of finding similar features between the stereo image Moving Windows.

- The **Region Elevation** is the average elevation of the region based on the dominant elevation of the image. It is estimated based on the associated RPC information.

**Note:** Increasing the number of tie points, the **Search Window Size**, and/or the **Moving Window Size** will increase the processing time but should also increase the reliability of the matching.

2. Increase the number in the **Search Window Size** field to **101** (type and replace the current number in the field or use the increase/decrease buttons). Note that the **Search Window Size** is always an odd number in square pixels and must be larger than the **Moving Window Size**.
3. Increase the number in the **Moving Window Size** field to **19**, which is reasonable for 15 m ASTER data.
4. Ensure that the **Examine and Edit Tie Points** toggle is set to **Yes** so that you can review the tie points and edit those which are less than optimal, then click **Next** to continue. It may take a few minutes to generate the tie points.



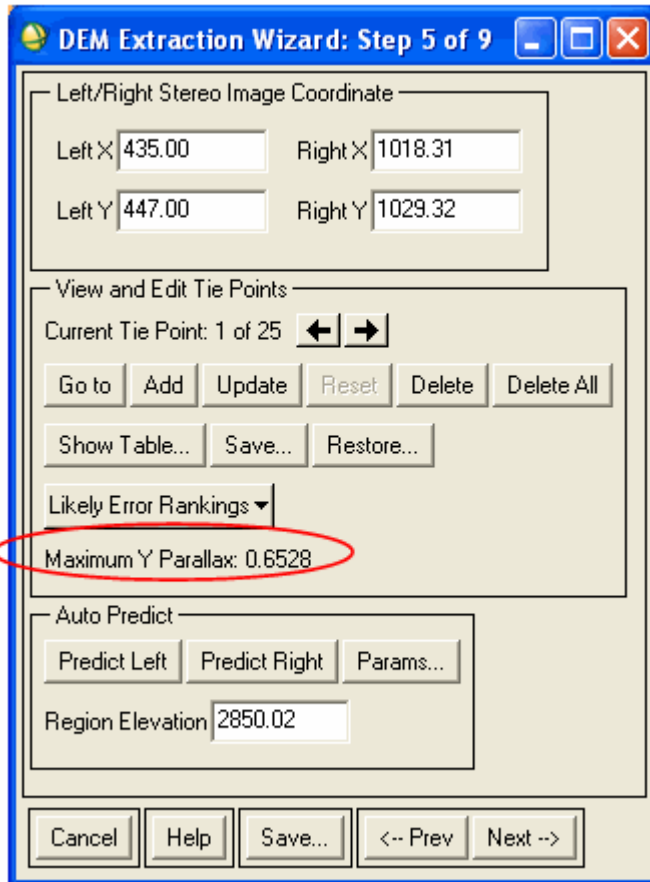
## Editing Tie Points

Once the tie points have been generated, step 5 of 9 of the DEM Extraction Wizard (View and Edit Tie Points) will display both images and tie points for examination. Explore and experiment with the options in this step. You can use the **Reset** button to undo the last change.

1. Try manually entering x and y locations for the left and right images.
2. Move the Zoom box to a new location in one of the images and click **Update** to update the tie point.
3. Use the **Current Tie Point** arrow buttons to examine each point.
4. Click the **Likely Error Rankings** drop-down button. This lists the tie points in order of relative likelihood of error. The first tie point listed is considered the “most likely” to have error. However, it is possible that the top ranking tie point has very little error since it is only an approximation. In this case, you should check through the list for pixels with obvious misalignment but with lower error.
5. Use the **Auto Predict** section to help estimate placement of the tie point in the image.
6. Examine the **Maximum Y Parallax** value displayed on the Wizard screen to see if you have improved the amount of error in the tie points. Any time you update a tie point, you should

examine the Y Parallax value. It provides an estimate, in pixels, of displacement between the images in the y direction. Tie points should be adjusted so that the Y Parallax is minimized. Ideally, it would display 0, indicating no offset in the y direction - all points are displaced in the x direction only. The maximum allowable Y Parallax value is 10 pixels. You must reduce the value to less than 10 in order to continue DEM extraction.

7. Once you have a Y Parallax under 10 pixels, click **Next** to continue.



## Calculating Epipolar Geometry and Images

Using the tie points, ENVI will calculate the epipolar geometry and epipolar images that are used to extract the DEM. These epipolar images describe the relationship between the pixels in the stereo pair and they can be viewed in 3D using anaglyph glasses. However, it should be noted that approximately 10% of the population cannot see in stereo, so the images may not appear in 3D for these individuals.

1. The epipolar parameters dialog allows you to enter the name for the left and right epipolar images and select how and where you wish to output the images.
2. You also have the option in this dialog to apply an **Epipolar Reduction Factor**, which will reduce the resolution of the extracted DEM. This is useful if you do not require a full resolution DEM for your application or demo as it will take less processing time to create the DEM. For example, this ASTER stereo pair has a resolution of 15m. If the requirement was for a 30m DEM, you could reduce the DEM by 2 using the **Epipolar Reduction Factor**.

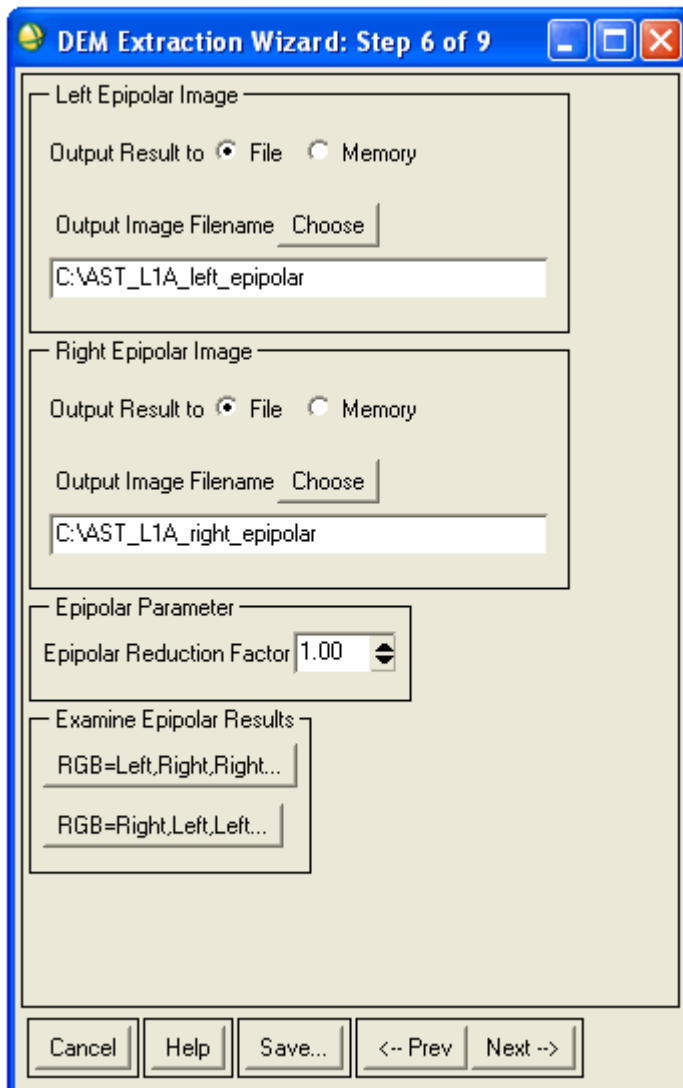
- Using the **Examine Epipolar Results** option, you can view the epipolar images prior to the DEM extraction. The images can be viewed in 3D using anaglyph glasses.

You can view the images using two different RGB triplets. The first option allows you to view the left epipolar image as red and the right epipolar image as green and blue. The second option allows you to view the right epipolar image as red and the left epipolar image as green and blue.

Click **RGB=Left,Right,Right**. The resulting epipolar image is displayed as an RGB triplet. If viewed through anaglyph glasses, the image will appear in 3D.

Depending on which image was initially entered as the right or left stereo image, the RGB triplets can be viewed as an inverse where peaks appear as valleys.

- Click **Next** to continue.



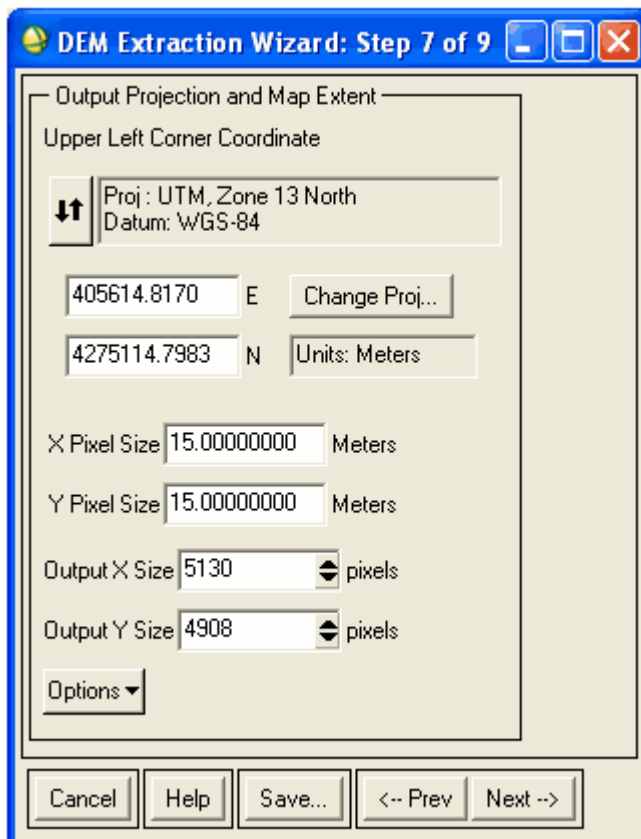
## Specifying Parameters

Now that you have created the epipolar images, you will need to specify the DEM output projection and extraction parameters.

### Specifying DEM Output Projection Parameters

Step 7 of the DEM Extraction Wizard allows you to set parameters for the DEM output projection and map extents. You have the option to change things such as the output projection type, pixel size, or output image size. Experiment with some of the following options.

- You can change the Eastings and Northings fields (**E** and **N** respectively) to Latitude and Longitude (**Lat** and **Lon**) by clicking the toggle button next to the map projection field.
- Click the **Change Proj** button to change the projection or projection units.
- You can type in values for **X Pixel Size** and **Y Pixel Size** in the fields provided.
- The **Output X Size** and **Output Y Size** values describe the output DEM size in pixels. This is the overlapping region of your output projection.
- The **Options** drop-down button allows you to set the output size units, choose options when pixel sizes change, restore initial values on this step of the Wizard, and use the map extent from an existing file.
- For this exercise, you will use the defaults provided for this screen. Click **Next** to continue.



## Specifying DEM Extraction Parameters

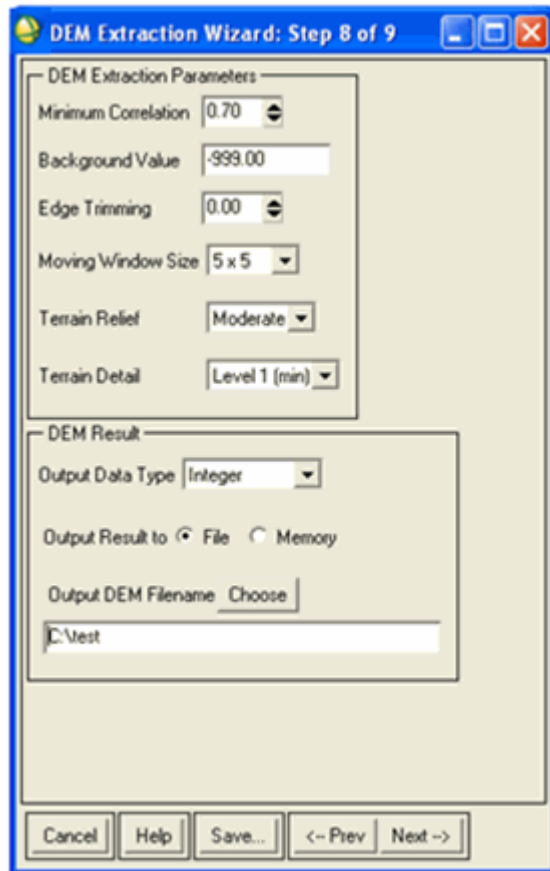
Step 8 of the DEM Extraction Wizard allows you to specify the parameters for the DEM extraction. Here you can define thresholds, set the size of the area in which you wish to perform image matching, determine the level of terrain detail, and specify where to save your DEM result.

- The **Minimum Correlation** value is the correlation coefficient threshold used to determine whether or not the points within the Moving Windows are a good match. If a correlation coefficient is smaller than this minimum, then the points are not considered to be a good match. In general, correlation values between 0.65 and 0.85 are reasonable, but for larger Moving Window sizes, a less strict correlation can be used.
- **Edge Trimming** indicates the normalized percentage of trimming to be applied to the outer edges of the output DEM.
- The **Moving Window Size** defines the area in which to compute the correlation coefficients between the two images. As with automatic tie point generation, a larger window size should be used with higher resolution imagery in order to increase the reliability of finding similar features within the Moving Window.
- From the **Terrain Relief** drop-down list, you can select the type of terrain your DEM best represents. Select **Low** if the terrain consists primarily of flat areas and low-terrain relief. The DEM will have a smoothed effect. **Moderate** is the default option, which is appropriate for most terrain types. Select **High** if the terrain consists primarily of mountainous and high-terrain relief. Topographic features with large relief displacement are not smoothed.
- DEM extraction uses image matching to find matching features on the left and right image of the stereo pair. The use of **Terrain Detail** determines how precisely you wish to represent the terrain in the DEM output. This option controls the number of image pyramid levels used during image matching. The levels range between **Level 1** (minimum) and  $N$  (maximum), where  $N$  is determined by the epipolar image resolution. **Level 1** terrain detail indicates that image matching stops after the coarsest level of image matching is finished. Level  $N$  indicates that image matching is performed on the highest image resolution possible (the epipolar image resolution). Higher levels of terrain detail will require a more rigorous level of image matching and will affect the processing time required to extract the DEM.
- You can set parameters for the DEM result. These parameters include the **Output Data Type** field, which allows you to choose between **Integer** (default) or **Floating Point**. You can also choose to save the output to **File** (default) or **Memory**, and you can select where you wish to save the DEM result.

For this exercise, you will use the defaults provided for this screen to produce a moderately detailed DEM.

1. Examine the options provided.
2. Type or choose a filename in **Output DEM Filename** field.
3. Click **Next** to start the DEM extraction process. The processing time required can be significant, depending on your choices for **Moving Window Size** and **Terrain Detail**. As the processing

completes, the various files created (Left Epipolar Image, Right Epipolar Image, and Elevation result) appear in the Available Bands List.



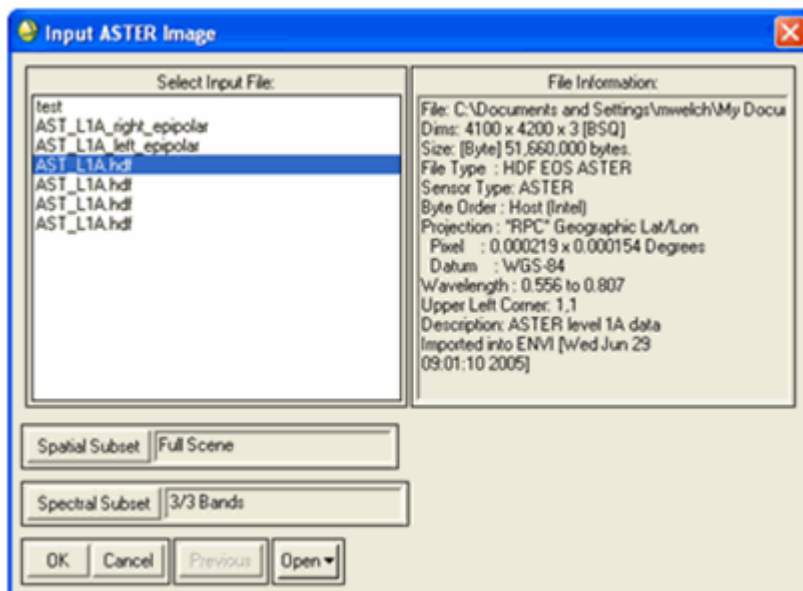
## Examining Results

Once your DEM extraction is complete, you can examine and/or edit the resulting DEM. The last screen of the Wizard provides two options; both options will load the DEM result to a display group, but one will also open the DEM Editing Tool so you can edit the DEM. You will explore each of the options in this step to examine and edit the resulting DEM.

## Loading the DEM Result to the Display and Performing 3D SurfaceView

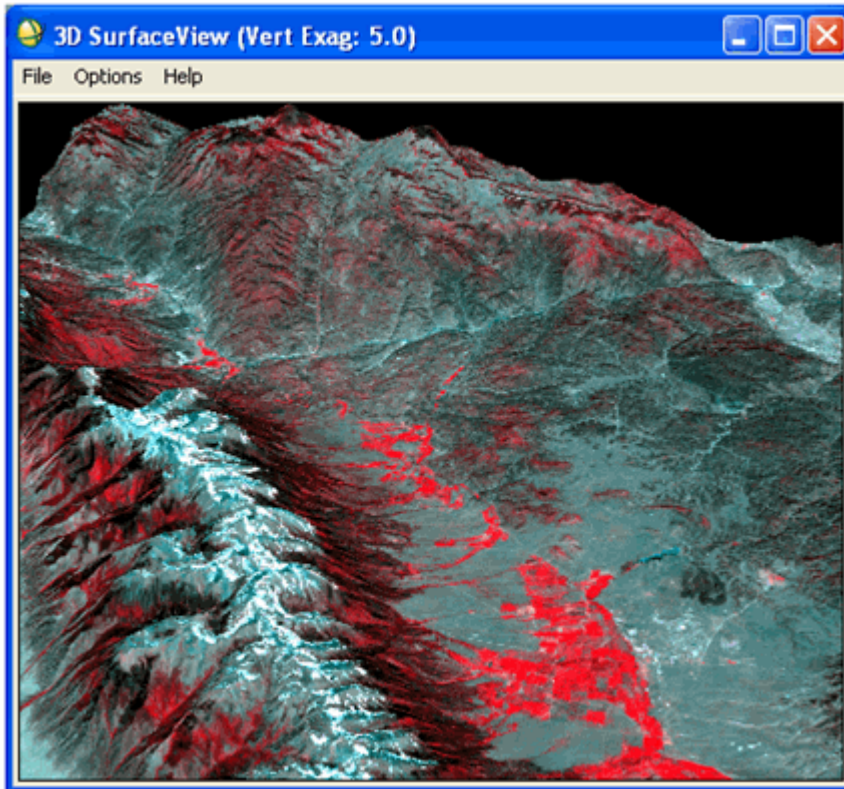
To begin, you will load the DEM result to display and perform a 3D surface view using the spectral bands from the original ASTER image to examine the DEM results.

1. Click the **Load DEM Results to Display** button (do not close the DEM Extraction Wizard). Since this extracted DEM has been projected using the UTM coordinate system, you will need to use a projected image to perform the overlay in order to have properly aligned image and DEM pixels.
2. From the ENVI main menu bar, select **Basic Tools > Preprocessing > Data-Specific Utilities > ASTER > Georeference Data**. This option will georeference the VNIR bands of the ASTER 1A data.
3. Select the `AST_L1A.hdf` file and click **OK**.



4. Select **UTM** and click **OK**.
5. In the **Output Result to** section, select **File**, type or choose a file name and location, and click **OK**.
6. Now you will load a color infrared (CIR) image. From the Available Bands List, right-click the file you just created and select **Load CIR to <current>**. Move the Image box in the Scroll window to an area in the image.

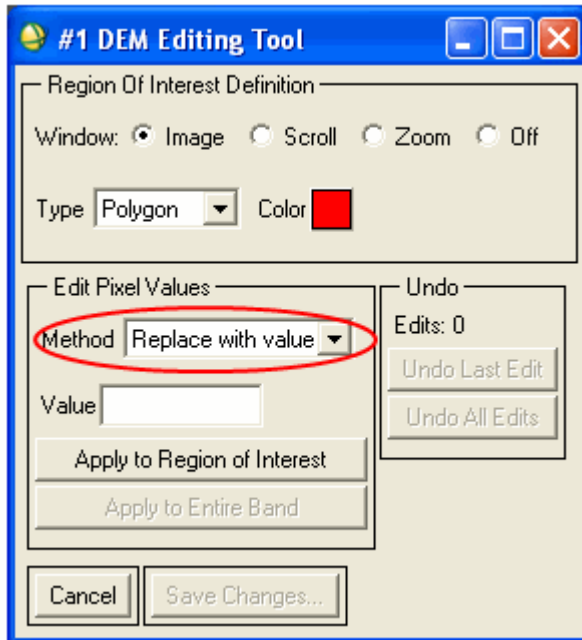
7. From the Display group menu bar, select **Tools > 3D SurfaceView**.
8. Select the newly created DEM Elevation input band and click **OK**.
9. Accept the default parameters to display the surface by clicking **OK**.
10. Look for unusual artifacts. Use the **Options** menu in the 3D SurfaceView window to set options for viewing the image. If you find areas that you wish to alter, you can use the DEM Editing Tool.



## Using the DEM Editing Tool

The DEM Editing Tool, which is a component of the DEM Extraction Module, allows you to interactively edit pixel values within a region of interest (ROI) using one of seven different methods.

1. From the DEM Extraction Wizard dialog, click **Load DEM Result to Display with Editing Tool** to open the DEM in a display group with the DEM Editing Tool available.
2. Move the Image box in the Scroll window to an area in the image.
3. Draw a polygon ROI by clicking the left mouse button in the Image window to establish the first point of the ROI polygon then selecting further border points in sequence by clicking the left button again. Close the polygon by clicking the right mouse button.
4. Using the DEM Editing Tool, you can replace the new ROI or the entire DEM with a single value, a smoothing filter, the mean of the area, and so on. Explore the options available in the **Method** drop-down list in the DEM Editing Tool dialog.



If you are satisfied with your edits, you can save the file with the new values. If you do not like the effect, you can choose to undo your edits to the DEM.

The DEM Editing Tool can also be used on spectral data to edit pixels in a single band.

5. For this exercise, you do not have to save your edits. Click **Cancel**.
6. Click **Finish**, then click **No** to close the DEM Extraction Wizard without saving your place in the Wizard.

## Working with the Stereo 3D Measurement Tool

The Stereo 3D Measurement Tool is another tool available with the DEM Extraction Module. This tool allows you to interactively calculate elevations from stereo images and associated RPC information given a single tie point.

1. From the ENVI main menu bar, select **Topographic > DEM Extraction > Stereo 3D Measurement**.
2. Select the **ASTER VNIR Band3N** option and click **OK**.
3. Select the **ASTER VNIR Band3B** option and click **OK**.
4. In either the left or right Image window, move the Zoom box over a feature whose 3D measurement you wish to collect. Using the buttons on the Stereo 3D Measurement Tool dialog, click **Predict Right** or **Predict Left** to have the Zoom box in the second image center on the conjugate point.
5. Click **Get Map Location** to compute the Lat/Lon and elevation based on the RPS and selected points. The regional elevation is estimated from the RPC information, but if you have a more accurate elevation for the region, then you can enter this value here.
6. You could choose to collect and save these points as an ENVI vector file or as a 3D shapefile using the **Export Location** button.
7. Click **Cancel** to close the Stereo 3D Measurement Tool.



## Working with the Epipolar 3D Cursor Tool

The Epipolar 3D Cursor Tool is another tool available with the DEM Extraction Module. This tool allows you to perform 3D measurements in a 3D stereo viewing environment based on an existing epipolar stereo pair of images. You can view an anaglyph of epipolar stereo imagery and adjust the height of the cursor to extract elevation data. As you view the surface, you can collect points then export them as points, lines, or polygons to an ASCII file, EVF file, or ArcView 3D Shapefile.

1. From the ENVI main menu bar, select **Topographic > DEM Extraction > Epipolar 3D Cursor**.
2. Select the **Left Epipolar Image** option and click **OK**.
3. Select the **Right Epipolar Image** option and click **OK**. The epipolar stereo image opens in a new display group, with left epipolar image as the red band, and the right epipolar image as the blue band.
4. The cursor in the Image window is now a double red and blue cursor which, when viewed using anaglyph red/blue stereo glasses, merges together into a single cursor. You can control the 3D cursor using specific mouse and keyboard controls.
  - Use the mouse to move the 3D cursor around the epipolar stereo image.
  - Click the left mouse button to snap the 3D cursor to the ground.
  - Click the middle mouse button to export the map and elevation for the point to an ENVI Point Collection table.
  - Use the right and left arrow keys on the keyboard to move the 3D cursor one pixel to the right or left.
  - Use the up or down arrow keys on the keyboard to move the 3D cursor one pixel toward the top or bottom of the image.
  - Use the + or - key on the keyboard number pad to raise or lower the apparent elevation of the 3D cursor.
5. Once you have explored some of the options available in the Epipolar 3D Cursor Tool, click **Cancel** to close the tool.