Operating Instructions

3DEM Software for Terrain Visualization and Flyby Animation
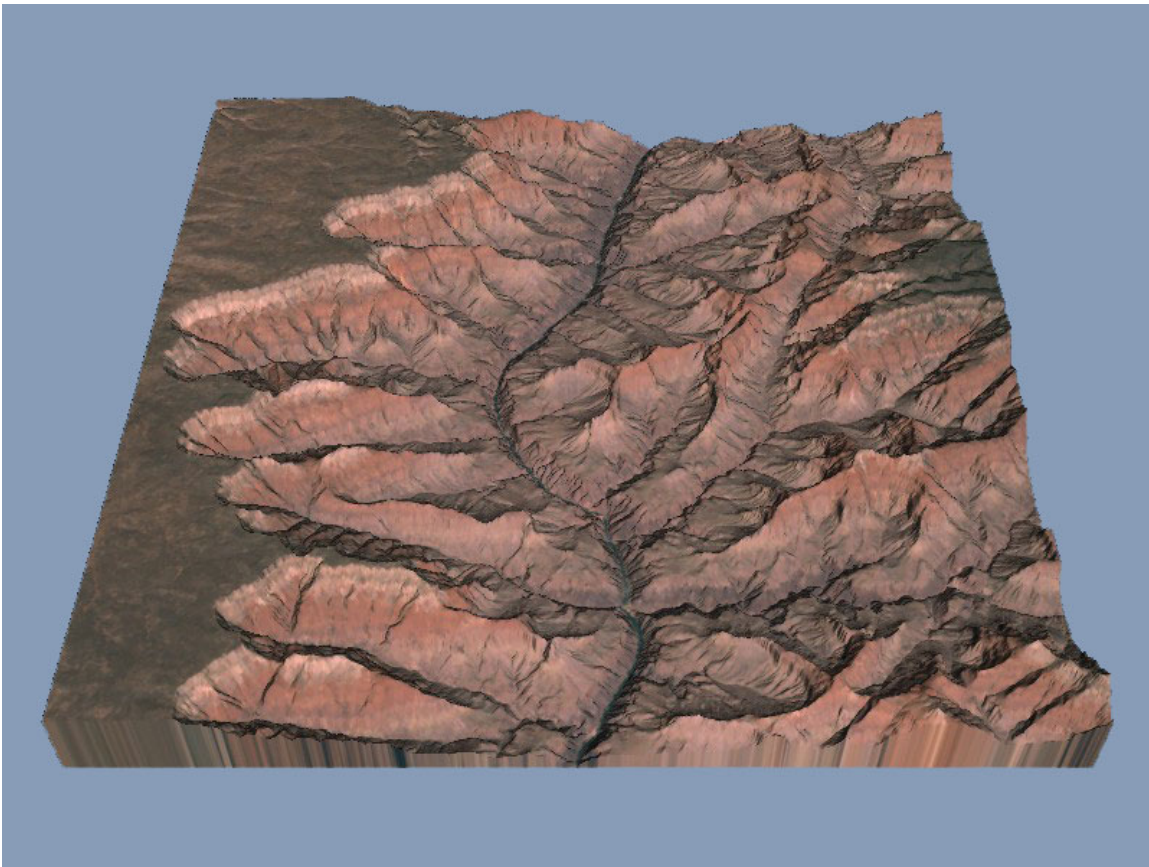
Version 20

Table of Contents

CONCEPT OF OPERATION

3DEM can render 3D terrain scenes and MPEG flyby animations from the following data sources:

> USGS Digital Elevation Model (DEM) files
> USGS Spatial Data Transfer Standard (SDTS DEM) files
> USGS National Elevation Dataset (NED) files
> LIDAR Point Cloud (LAS) files
> XYZ Point Cloud files (ASCII or floating point binary)
> USGS Global 30 Arc Second Elevation Data Set (GTOPO30 DEM) files
> NOAA Global Land One-km Base Elevation (GLOBE) files
> GEOTIFF Digital Elevation Models
> NASA Mars Orbiter Laser Altimeter (MOLA) files
> NASA Mars Orbiter Laser Altimeter (MOLA POLAR) files
> Any topographic data file organized by rows and columns of elevation data

3DEM uses the SGI/Microsoft OpenGL libraries for high-speed 3D rendering. 3DEM will render 24 bit color 3D projections, red-blue projections requiring red-blue 3D glasses for viewing, or color side-by-side stereo 3D projections. 3DEM scenes can be saved in the following formats.

> Windows Bitmap (*.bmp, *.dib)
> Joint Photograhic Experts Group (*.jpg,, *.jpeg)
> Tagged Image File (*.tif, *.tiff)

> Flyby animation AVI (*.avi)
> Flyby animation MPEG (*.mpg, *.mpeg)

> USGS ASCII Digital Elevation Model (.dem)
> GEOTIFF Digital Elevation Model (*.tif)

> Binary terrain matrix (*.bin)
> VRML world (*.wrl)
> Terragen terrain (*.ter)

Maps, three-dimensional terrain images and animations, and GPS waypoints and routes produced by the 3DEM computer program are for general visualization purposes only. 3DEM is not intended for precise backcountry navigation, GPS referencing, mountaineering, or other specialized uses requiring high positional accuracy.   No warranty is expressed or implied regarding the use or the results of the use of the 3DEM computer programs in terms of correctness, accuracy, reliability, currency, fitness for a particular purpose, or otherwise. The user assumes the entire risk as to the results and performance of the 3DEM computer program.

EQUIPMENT AND SOFTWARE REQUIRED

3DEM is designed to run under Win95/98//NT/ME/2K/XP or Windows Vista with 24 bit color graphics. A one GHz Pentium or better microprocessor and fast graphics card are recommended.

A minimum of 512 MBytes of memory is also required. Less than 512 MBytes of memory will limit the usefulness of the high-resolution modes of OpenGL rendering.

 For Win95 you will need the Microsoft OpenGL dynamic link libraries (opengl32.dll and glu32.dll) These file can also be downloaded from the 3DEM home page at http://www.visualizationsoftware.com/3dem.html. Opengl32.dll and glu32.dll should reside in your Windows/System directory.

3DEM will display GPS tracks on both the Overhead View and the 3D Scene generated from a Digital Elevation Model. This will allow you to view the track of any journey across a high-resolution 3D image of the terrain. GPS data can be read directly from Garmin and Magellan handheld GPS receivers via a serial data connection to your computer. Text files of GPS points can also be read and displayed.

CONTACTING THE AUTHOR

Programs are only improved by the incorporation of new ideas. Your ideas are welcome. Please report any bugs or send any questions, comments, or ideas to Richard Horne at r.horne@verizon.net, or visit the 3DEM web page at http://www.visualizationsoftware.com/3dem.html for the latest program update.

DISCLAIMER

Maps, three-dimensional terrain images and animations, and GPS tracks produced by the 3DEM computer program are for general visualization purposes only. 3DEM is not intended for precise backcountry navigation, GPS referencing, mountaineering, or other specialized uses requiring high positional accuracy. No warranty is expressed or implied regarding the use or the results of the use of the 3DEM computer programs in terms of correctness, accuracy, reliability, currency, fitness for a particular purpose, or otherwise. The user assumes the entire risk as to the results and performance of the 3DEM computer program.

Comments, questions, or problem reports are always welcome and should be sent to r.horne@verizon.net.

DIGITAL ELEVATION MODEL FILE SELECTION

Choose "File - Load Terrain Model" from the Overhead View menu to bring up a dialog box for selection of the type of input data to be used. Each of these selections represents DEM data that are freely available on the Internet.
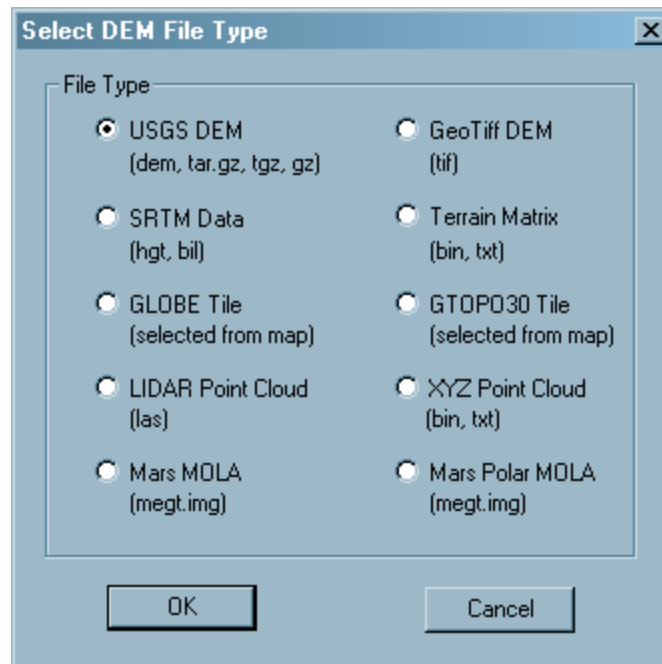
Select the File Type that corresponds to the terrain data file that you wish to view. See the description of file types in the section entitled "Digital Elevation Models Available on the Internet".

LARGE SCALE SHADED RELIEF OVERHEAD VIEW

The first view of any Digital Elevation Model produced by 3DEM is a large-scale shaded relief view of the terrain from directly overhead. Just load a new DEM, SDTS DEM, GEOTIFF DEM, GLOBE DEM, GTOPO30 DEM, Mars MOLA file, or Terrain Matrix file, and 3DEM will automatically produce an Overhead View. A terrain map overlay may also be applied to the shaded relief Overhead View. See the instructions under Graphics Overlay Procedure that follow.

The lighting angle and depth of shade for the Overhead View can be adjusted by choosing "Color Scale - Shaded Relief "from the Overhead View menu. This will bring up the Lighting Parameters dialog box that allows adjustment of the angle and elevation of lighting in degrees and the depth of shade in percent

The Overhead View can be resized to larger or smaller scale. Choose "Operation - Resize Overhead View" from the program menu (or use Function Key F6). Enlarge the Overhead View as necessary to see the desired details in the shaded relief image.

Once a large scale shaded relief image has been created, it may be saved as a GeoTiff file that can be used with other Geographic Information Systems applications. The GeoTiff file contains coordinate information that will allow other GIS applications to accurately position the image in latitude and longitude. This function is only available for shaded relief maps that have been created using the UTM map projection. Choose "Operation - Show DEM Specs" to determine the map projection in use. Change the map projection to UTM if necessary with the "File - Convert to UTM" menu item.

Saved GeoTiff images will be sized to match the Overhead View screen display. To obtain high-resolution GeoTiff images, resize the Overhead View to higher magnifications.

If an overlay has been applied to the surface, it is recommended that you resize the map image to a magnification of 2 or more and carefully examine the match between the overlay and the underlying Digital Elevation Model before saving a GeoTiff. The application of the overlay is complex mathematically, and small errors in position may be visible at high magnification. If errors are present, use Adjust Map Overlay Position to make corrections.

RESIZING THE OVERHEAD VIEW
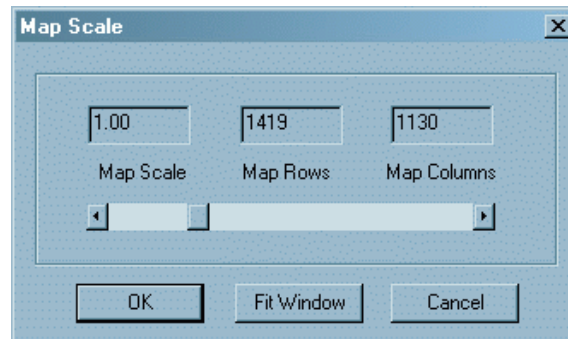
Upon loading a DEM or group of merged DEMs, the Overhead View is automatically scaled to fit the entire terrain surface into the available 3DEM window area. This allows creation of 3D scenes or flyby animation using very large terrain areas. The Overhead View can be rescaled to a larger or smaller size by choosing "Operation - Resize Overhead View" (or Function Key F6) from the Overhead View menu. This will bring up the Map Scale dialog box with controls for selecting the scale of the Overhead View. To focus on a small area of terrain, rescale the Overhead View to a larger size. To move away and use larger areas of terrain, rescale the Overhead View to a smaller size.

Resizing of the Overhead View is useful when a large-scale shaded view of the surface for export to other mapping programs is needed. The Overhead View can be enlarged to maximum size and then saved as an RGB geotiff graphics file format that will be readable by other mapping programs.

Once Overhead View resizing has been started, it may be interrupted and cancelled using the "Esc" key.

Adjust the terrain color scale of the Overhead View by choosing "Operation - Modify Colors" (or Function Key F3) from the Overhead View menu. Adjust the terrain color scale of the 3D Scene by choosing "Operation - Modify Colors" (or Function Key F3) from the 3D Scene window menu.

3D Scene Colors

Terrain Colors

| 1223 m |
| 1143 m |
| 1062 m |
| 981 m |
| 901 m |
| 820 m |
| 739 m |
| 659 m |
| 578 m |
| 497 m |
| 417 m |
| 336 m |
| 255 m |
| 175 m |

Copy To   Spread To

Cancel Operation

Other Colors

Sky
Ocean
Waypoint
Text

Color Controls

Red   215

Green   179

Blue   104

Forest   Snow   Store 1   Store 2

Reset   Recall 1   Recall 2

Altitude Range

Reset   Modify   175   Min (meters)   1224   Max (meters)

Terrrain Type

Mountain/Plain   Island/Ocean   Lowlands   Sea Level (meters)

OK   Cancel

TERRAIN COLORS - These controls allow selection of terrain color at each of fourteen altitude steps. The objective is to choose a range of colors to be spread from the lowest to the highest elevation on the surface. Select an altitude using its button in Terrain Colors, and adjust its color using the Color Controls RGB sliders.

You can also copy a color from one altitude to another, or create a smooth transition (or Spread) between colors at different altitudes. To copy a color, choose its altitude button in Terrain Colors, press the "Copy To" button, and then select the altitude button at the point you wish to copy the color. To spread colors, choose a starting point from the altitude buttons in Terrain Colors, press the "Spread To" button, and then select the desired end point from the altitude buttons to create a smooth transition of colors. To cancel the operation to copy or spread colors, click the "Cancel Operation" button.

The complete color scale can be saved to a file for future use. Once you have defined terrain colors, click the "Save Color File" button to save a colors data file. Colors from this data file can be recalled and applied to the terrain by clicking the "Load Color File" button.

OTHER COLORS - You also have the option of adjusting the colors of the sky, the ocean, the edge of a projection, or the text of the scene legend using the Other Colors buttons.

COLOR CONTROLS - The Color Controls include horizontal sliders that allow adjustment of the red, green, and blue components of any individual terrain color. Click a Terrain Colors button at an appropriate altitude step, and use the color control sliders to adjust that individual color. You can also modify Other Colors using these sliders.

The Color Controls also provide for storage and recall of working color scales as an aide in making fine color adjustments. Use the "Store 1, Store 2, Recall 1, and Recall 2" buttons to save and recall working color scales to memory while making fine adjustments.

ALTITUDE RANGE - It is also possible to modify the low and high elevation limits of the color scale. This allows choosing a color scale that is precisely matched to the selected terrain area. Click the "Modify" button under "Altitude Range" and enter revised values for the minimum and maximum altitude limits of the color scale.   Then click the "Apply" button to apply these new low and high elevation limits. Clicking the "Reset" button will set the altitude limits to the minimum and maximum values found in the entire DEM.

TERRAIN TYPE - And finally, you can select the Terrain Type for the 3D Scene from the Terrain Colors Dialog Box. Normally, terrain is a combination of mountains and plains with lighting determined by the azimuth and elevation of the illumination source. However, if you are developing a scene containing the ocean's surface you may want the sea to appear as a uniform ocean color rather than appear as a brightly lighted plane. Choose Mountain/Plain for normal scenery, or Island/Ocean for scenery including the ocean's surface. You can also use the Island/Ocean setting for scenes in which there are rivers or lakes.

GRAYSCALE HEIGHTFIELD BITMAPS

3DEM can produce high resolution, large area grayscale heightfield bitmaps for use by other 3D terrain modeling programs. These are Overhead View images in which height is scaled to shades of gray from black at the lowest elevation to white at the highest elevation.

To create a grayscale heightfield bitmap, load any new DEM, SDTS DEM, GEOTIFF DEM, GLOBE DEM, GTOPO30 DEM, Mars MOLA file, or Terrain Matrix file, and 3DEM will automatically produce an Overhead View.   Rescale the Overhead View to a large size giving high surface resolution.

Then choose "Color Scale - Shaded Relief " from the Overhead View menu, and set "Shade Depth" to zero. This will remove all shadows from the image.

Then choose "Color Scale - Modify Scale" from the Overhead View menu to bring up the "Terrain Colors" dialog box. This control will be used to set the color scale from black at the lowest elevation to white at the highest elevation as shown below.
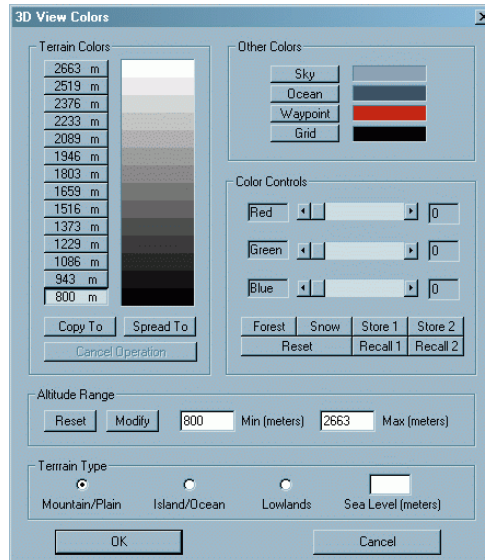
SELECTING SMALLER GEOGRAPHIC AREA

3DEM allows selection of a smaller geographic area from a large digital elevation model. After loading a large DEM, choose "Operation - Select Smaller Area" (or function key F8) from the Overhead View menu. Then drag and expand the red outline rectangle around the smaller area that you wish to use and press "Enter." 3DEM will then extract this smaller area and display a new Overhead View using the same geographic projection (latitude-longitude or UTM) as the original DEM.


This smaller selected area can subsequently be saved as a USGS ASCII format DEM, GeoTiff DEM, or terrain matrix.   By merging DEMs and then saving a smaller selected area, custom DEMs can be created that show features that are inconveniently located on the boundaries of published DEMs.

TERRAIN PATCHING PROCEDURE

Occasionally it will be necessary to patch missing elevation data points in the digital elevation model. This is particularly true with the SRTM data, which may be sprinkled with obvious holes where elevation values are missing from the terrain grid. These holes can disfigure the 3D images of the terrain, and must be patched.

Choose "Operation - Patch Missing Data" from the program menu (or Function Key F7). Then drag and expand the red outline rectangle to enclose the area that you wish to patch and press "Enter." 3DEM will then fill the missing elevation points with values derived from the surrounding area by linear interpolation.
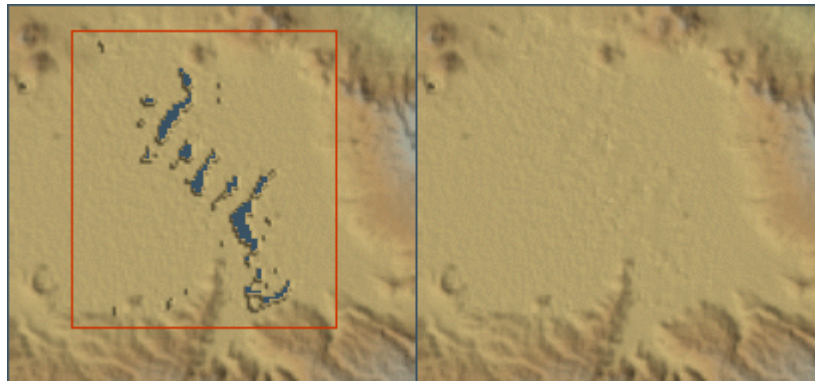
Terrain Before and After Patching Missing Data

This patching procedure is suitable for repair of small closed areas of missing elevation data. It will not be suitable for repair of large open-ended areas of missing data such as entire missing valleys or mountain ranges that are sometimes encountered in the SRTM digital elevation models.

Also, if conversion of the terrain to UTM projection is necessary, patching should be conducted before this conversion for most accurate results.

MAP PROJECTION CONVERSION

3DEM provides the capability to convert any terrain using Geodetic (latitude-longitude) projection into a Universal Transverse Mercator (UTM) projection. Terrain data sources such as the NASA SRTM data and the National Elevation Dataset are provided in a geodetic latitude-longitude projection. The disadvantage of the geodetic projection is that it introduces an east-west distortion at high latitudes. The UTM projection corrects this distortion, providing a more realistic map view and 3D scene. An example of this correction is shown in the two overhead (map views) of Mount Saint Helens, below.
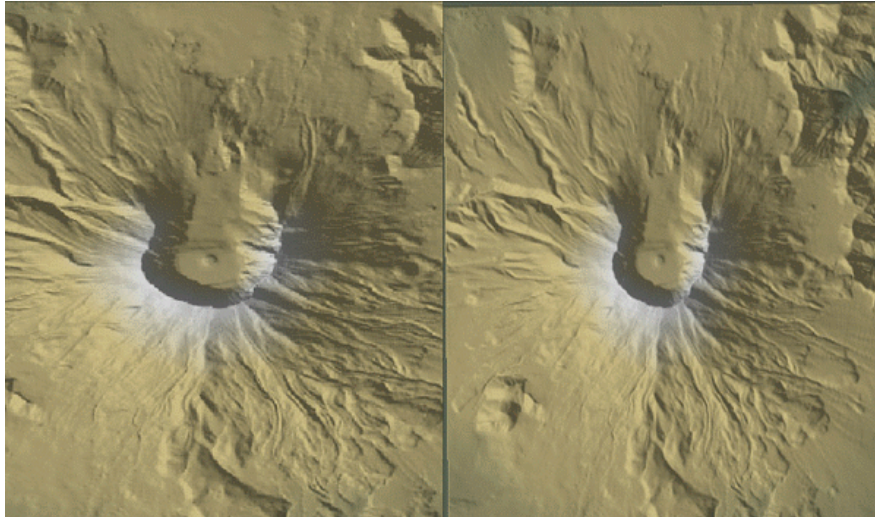
On the left is a map of Mount Saint Helens in geodetic projection from the National Elevation Dataset. The map appears stretched in the east-west direction due to the smaller physical distance between longitude points at this high latitude. On the right is a UTM projection of the same NED data. The east-west distortion has been removed giving a map of the terrain that will match the physical appearance of the surface.

To convert from geodetic to UTM projections, choose "Operation - Change Projection - Convert to UTM Projection" from the Overhead View menu. 3DEM will convert then convert the current terrain to UTM projection.   You will have a choice of ellipsoids to be used for representation of the globe. The available ellipsoids are

WGS84   NAD83   NAD27

There are some restrictions to this conversion. Areas to be converted must be contained within a single UTM zone. UTM zones are North-South strips of 6 degrees longitude in width around the circumference of the globe. UTM conversions cannot be made for areas that cross zone boundaries or that cross the equator. Areas to be converted must also be contained between 84 degrees North latitude and 80 degrees South latitude.

Also note that conversion to UTM projection can be helpful in application of terrain overlays. Most DRG and DOQ overlays are available in UTM projection using the NAD27 ellipsoid. Converting the terrain to UTM will facilitate matching the terrain and overlay to one another.

Once the map projection conversion has been started, it may be interrupted and cancelled using the "Esc" key.

CHANGING UNIVERSAL TRANSVERSE MERCATOR (UTM) ELLIPSOID

The UTM ellipsoid defines the shape of the globe used to create those DEMs and GeoTiff overlay files that use UTM projection. Dozens of different ellipsoids have been defined for mapping purposes over the years. The importance of the ellipsoid here is that all DEMs to be merged must use the same ellipsoid definition. Likewise, the ellipsoid of a GeoTiff overlay must match the ellipsoid of the Digital Elevation Model to which is will be applied.

To change the UTM ellipsoid, choose "Operation - Change Projection - Change UTM Ellipsoid" from the Overhead View menu. Any one of the ellipsoids in the table below may be used in common for all DEMs being merged.

WGS84   NAD83   NAD27

If you attempt to apply a GeoTiff overlay that uses a UTM ellipsoid not matching the Digital Elevation Model, you will see an error message "DEM Must First Be Converted to XX Ellipsoid" where "XX" will be one of the ellipsoid choices above.   Choose "OK" and 3DEM will proceed to transform the DEM to the UTM ellipsoid required by the overlay.

3D TERRAIN RENDERING PROCEDURE

In addition to the Large Scale Shaded Relief images described previously, 3DEM can also produce oblique angle 3D scenes from any observer position and altitude over the terrain. These 3D scenes can be used to examine a small section of the terrain or to produce landscape views from the surface of the terrain. To produce a three dimensional scene you must perform four operations in sequence with the 3DEM software as follows:

STEP 1 - Load a new terrain file and draw an Overhead View of scaled altitude data. Choose "File - Load Terrain Model" from the Overhead View menu to bring up the DEM File Type dialog box for selection of the desired file type. Select the file type, and then locate and open the desired DEM file. 3DEM will then load the selected terrain model and draw an Overhead View of the entire geographic area with color scaled to the altitude at each point on the map.

STEP 2 - Define an area within the Overhead View for conversion into a three dimensional scene. Click the left mouse button at a location on the Overhead View that interests you. The area to be viewed will be outlined by a black rectangle. The observer's location and direction of view are indicated by a notch in one side of the outline rectangle. Rotate or change the size of the outline rectangle by clicking and holding down the left mouse button at any corner of the rectangle. Reposition the outline rectangle by clicking the left mouse button at any point of interest on the terrain. You can also make fine adjustments to the rotation of the outline rectangle using the left and right arrow keys.

STEP 3 - Once you are satisfied with the selected area, compute and display a three-dimensional landscape scene. Choose "Operation - View Scene" and 3DEM will give you a choice of terrain projection parameters as explained in the following paragraphs. Initially, you can just accept the default values and 3DEM will proceed to render the selected projection using OpenGL. The 3D image will be displayed in a separate window as the "3D Scene." Once the scene is complete, you can save the image as a graphics file by choosing "File - Save Scene Image" from the 3D Scene menu.

STEP 4 - To reposition the observer or to tilt, rotate, or shift the position of the landscape relative to the observer, choose "Operation - Change Position" from the 3D Scene menu (or function key F6). Depending on the selected Terrain Position, this will bring up either the Rotate or Shift Scene Dialog Box, or the Reposition Observer Dialog Box. These controls allow you to tilt, rotate, or move the scene to obtain the best view of the terrain.

ADJUSTING OBSERVER POSITION

Once a terrain scene has been created, its position in space or the observer's position can be modified using fine adjustment controls. After rendering a terrain scene, choose "Operation - Change Position" from the 3D Scene menu (or function key F6).

If the Terrain Position is "Background," the Reposition Observer Dialog Box will appear, giving a choice of observer movement as follows:
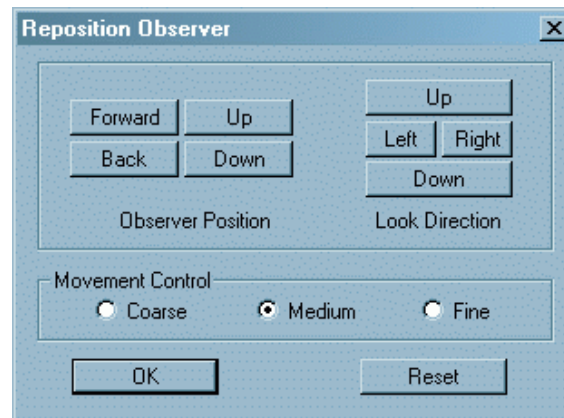
- Controls can be selected to have a Course, Medium, or Fine effect on the observer's position.
- The observer can be moved forward or back, up or down relative to the terrain by use of the "Observer Position" buttons
- The observer's look direction can be directed up or down, left or right by use of the "Look Direction" buttons.
- The "Reset" button returns the observer to the initial position used in creating the scene.

If the Terrain Position is "Foreground" the Rotate or Shift Scene Dialog Box will appear, giving a choice of scene adjustment as follows:
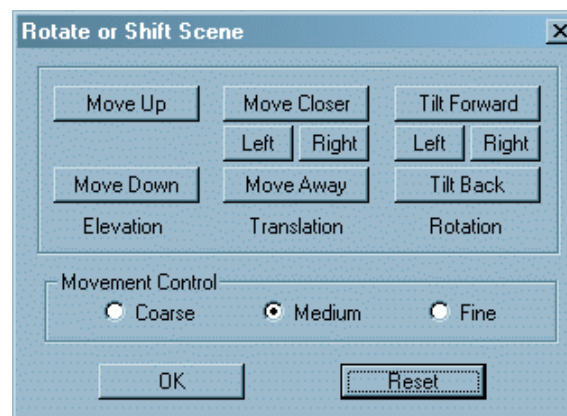
- Controls can be selected to have a Course, Medium, or Fine effect on the terrain scene.
- The Elevation of the terrain scene, relative to the observer, can be adjusted up or down using the "Elevation" buttons.
- Translation of the terrain scene, relative to the observer, is possible by use of the "Translation" buttons.
- Rotation of the terrain scene, relative to the observer, is possible by use of the "Rotation" buttons.
- The "Reset" button returns the terrain to its original orientation used in creating the scene.

TERRAIN PROJECTION PARAMETERS

Terrain projection parameters are selected using this dialog box. See the descriptions of each parameter which follow.

Terrain Projection Parameters ✕

Legend
[OLD RAG MOUNTAIN, VA-24000]

Projection Type
◉ Color   ○ S/S   ○ R/B

Projection Size
○   ◉   ○   ○
480x360   640 x 480   800 x 600   1024 x 768

Observer's Altitude
◀ [▮   ] ▶   [2048]   Meters

Terrain Illumination
[240] Deg Azimuth   [60] Deg Elevation

Terrain Vert Mag
[100] Percent

Terrain Position
○ Foreground ◉ Background

Terrain Resolution
◉ Min   ○ Max

Terrrain Type
◉ Mountain/Plain   ○ Lowlands   ○ Island/Ocean
Sea Level [   ] Meters

[OK]   [Cancel]

LEGEND

The Legend is text which will appear at the top of your finished three dimensional scene. Initially, this legend is read from the DEM file header. Legends in Flyby are printed at the bottom of the screen and are only displayed for the first 50 frames of the animation. Adjust the legend words to your own preference.

PROJECTION TYPE

This control is available from the dialog boxes for Terrain Projection Parameters and Flyby Projection Parameters and is used to adjust the appearance of the final 3D rendering.

The type of 3D projection for either single scenes or for flyby projections is determined here. The "Color" selection provides a color 3D projection with surface colors determined by terrain height and the direction of illumination. The "R/B" or "Red Blue" selection provides a 3D projection for viewing with red-blue lens 3D glasses. The "S/S" selection provides a side-by-side color stereo 3D projection.. See the illustrations of projection type below.
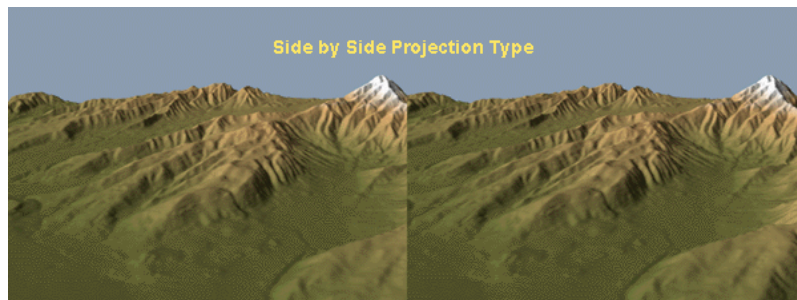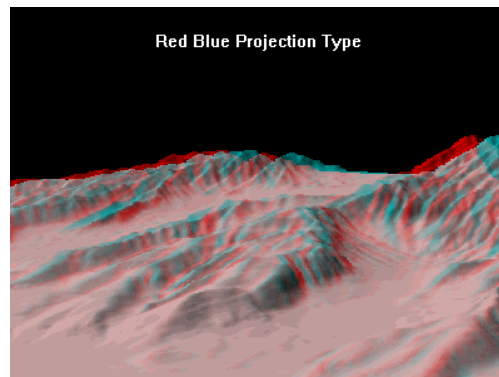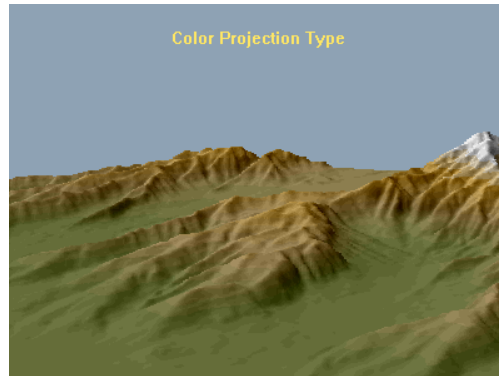
PROJECTION SIZE

For 3D terrain rendering and flyby animation, you have a choice of projection sizes of 640 by 480, 800 by 600, and 1024 by 768 pixels.

OBSERVER'S ALTITUDE

The observer's height above the surface in meters can be set to any value from a high altitude to zero altitude (standing on the surface). It is usually best to create an initial scene using a moderate altitude, and then make fine adjustments using the Reposition Observer controls.

TERRAIN VERT MAGNIFICATION

Large scale DEMs and DTM's often show very low relief features. Vertical magnification increases the height of surface features to make them more visible in the three dimensional projection. Don't hesitate to use magnifications of 200% to 300% to improve the appearance of your scene. The default value of vertical magnification is 100%, but you should change this value if you are not satisfied with the appearance of the 3D projection.

TERRAIN RESOLUTION

Terrain image resolution of both the 3D scene and flyby animation can be set to either "Max" or "Min." Using minimum resolution gives the fastest rendering speed while maximum resolution gives the most detailed images possible. It is usually a good idea to compose a scene using minimum resolution and then create the final scene using maximum resolution.

CAUTION – Use of the maximum resolution setting produces the very best 3D images, but can require long time periods (sometimes 10 minutes or more) to complete a single scene or animation frame. Use the maximum resolution setting with caution.

Note that low resolution is always used during real-time View Flyby. Maximum resolution during flyby is only available during Animate Flyby.

TERRAIN ILLUMINATION

OpenGL rendering uses one source of illumination at the azimuth and elevation angles chosen here. These directions are relative to the geographic north at all times. Zero degrees azimuth indicates a source directly from the north, while 180 degrees azimuth indicates a source directly from the south. Zero degrees elevation indicates a source on the horizon, while 90 degrees elevation indicates a source directly overhead. Thus the default values of 240 degrees azimuth and 60 degrees elevation indicate an illumination source from the southwest. Experiment with these values if you find a need to change the appearance of light and shadow in your three dimensional projection.

TERRAIN POSITION

The position of the terrain model can be chosen to be "Foreground" or "Background" relative to the observer. A Foreground terrain position will produce a miniature view of the entire selected area projected into the foreground of the display window. A Background terrain position will fill the entire display window with a large-scale view of the selected area. Examples of the Foreground and Background terrain positions are shown below.
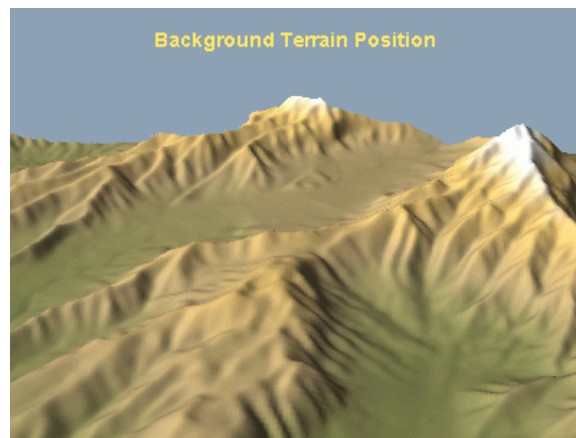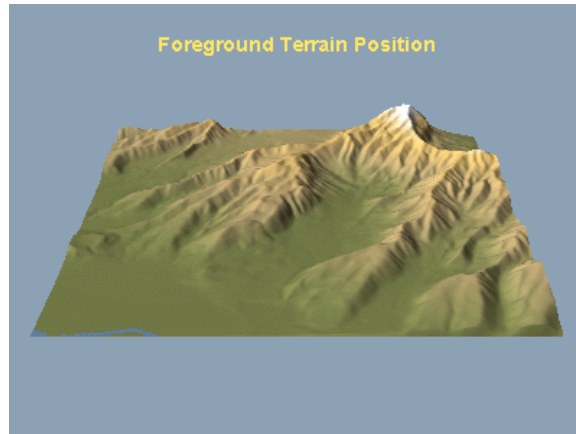
Normally, terrain is a combination of mountains and plains with lighting determined by the azimuth and elevation of the illumination source. However, if you are developing a scene containing the ocean's surface you may want the sea to appear as a uniform ocean color rather than appear as a brightly lighted plane. Choose "Mountain/Plain" for normal scenery, or "Island/Ocean" for scenery including the ocean's surface. You can also use the "Island/Ocean" setting for scenes in which there are rivers or lakes.

If you are developing an island and ocean scene, the shape of the shoreline may be adjusted by selection of a "Sea Level" value. You may need to experiment by raising or lowering the sea level to achieve the proper shoreline or riverbank. See the illustrations of Terrain Type below.

A variation of the Island/Ocean terrain type called Lowlands is also provided. The Lowlands terrain type provides the best results where large areas of the terrain are very close to sea level. This situation can result in streaking of the ocean surface or inaccurate rendering of the shoreline when using the Island/Ocean terrain type. If the shoreline is observed to be incorrect, or if the shoreline or ocean surface shows rapid flickering during flyby animation, use the Lowlands instead of Islands/Ocean terrain type.

3D FLYBY ANIMATION PROCEDURE - FREE FLIGHT

A flyby animation is a stored series of 3D scenes (or frames) which are played back rapidly in sequence to produce the appearance of a flyby. 3DEM compresses these frames into either an AVI or MPEG file that can be played back with most any commercial or freeware mpeg animation player. To produce a flyby animation you must perform four operations in sequence with the 3DEM software as follows:

STEP 1 - Load a new terrain file and draw an Overhead View of scaled altitude data. Choose "File - Load Terrain Model" from the Overhead View menu to bring up the dialog box for selection of the desired file type. Select the file type, and then locate and open the desired DEM file. 3DEM will then load the selected terrain model and draw an Overhead View of the entire geographic area with color scaled to the altitude at each point on the map.

STEP 2 - Define an area within the Overhead View for conversion into a three dimensional scene. Click the left mouse button at a location on the Overhead View that interests you. The area to be viewed will be outlined by a black rectangle. The observer's location and direction of view are indicated by a notch in one side of the outline rectangle. Rotate or change the size of the outline rectangle by clicking and holding down the left mouse button at any corner of the rectangle. Reposition the outline rectangle by clicking the left mouse button at any point of interest on the terrain. You can also make fine adjustments to the rotation of the outline rectangle using the left and right arrow keys. Note that the horizon distance during flyby is determined by the size of the selected area. The horizon can be no farther away than the outer edge of the selected area. So in order to have a far horizon, rather than a narrow view looking downward, choose as large an area as possible. It is often advisable to merge several DEMS together to create a very large area that will allow selection of a far horizon in flyby.

STEP 3 - Select "Operation - View Flyby" and 3DEM will give you a choice of flyby projection parameters. Select "Flyby Type - Free Flight," and accept the default values of the remaining flyby projection parameters. 3DEM will then render a real-time animated view of a flyby of the DEM landscape. The speed of this animation will depend on the speed of your computer and graphics card, and memory available. A fast machine will allow a frame rate of up to 30 frames per second. The primary purpose of this operation is to record a flight path through space over the DEM surface for subsequent conversion into a full resolution AVI or MPEG animation. Use the keyboard arrow keys to turn, climb, and dive. A cross mark cursor at the center of the view indicates your current flyby attitude, whether turning left or right, climbing, or diving.

STEP 4 - Once you are satisfied with the flight path through space, you can record a high-resolution flyby animation as either an AVI or MPEG file that can be played back using the Windows Media Player. Select "Operation - Animate Flyby" to create the flyby animation along the flight path previously defined. Animations can be created in the following formats.

- Conventional color 3D animation
- Red-blue animation for viewing with red-blue 3D glasses
- Color side-by-side stereo 3D animation

It is important to select an appropriate projection size for the animation. Projection sizes of 480 by 360, 640 by 480, 800 by 600, and 1024 by 768 pixels are available. Animations with smaller projection sizes can be created more quickly, and can be played back at high speed on most any computer. The larger sized animations are more impressive to see. However, they will take much longer to create and may not play back at full speed on machines without the very best graphics hardware.

If you choose AVI animation, you may be given a choice of AVI Video Format depending on the capabilities of your machine. If you are given a choice, the Indeo Video Compressor is capable of producing good animations with large projection size and relatively small file size.

3D FLYBY ANIMATION PROCEDURE - GPS TRACKS

Flyby animations can also be created to follow GPS waypoints or tracks in position and altitude. These GPS points may be waypoints or tracks downloaded from a handheld GPS receiver, points read from GPS Waypoint or Track Files or IGC Flight Path files, or they may be manually entered on the DEM Overhead View using the mouse.   To produce a flyby animation using GPS points, you must perform five operations in sequence with the 3DEM software as follows:

STEP 1 - Load a new terrain file and draw an Overhead View of scaled altitude data. Choose "File - Load Terrain Model" from the Overhead View menu to bring up the DEM File Type dialog box for selection of the desired file type. Select the file type, and then locate and open the desired DEM file. 3DEM will then load the selected terrain model and draw an Overhead View of the entire geographic area with color scaled to the altitude at each point on the map.

STEP 2 - Enter GPS waypoints or tracks. To load GPS track files, choose "GPS - Transfer GPS Points - File to Screen" from the Overhead View menu. Either Waypoint Files or IGC Flight Path Files may be selected. To read GPS waypoints or tracks from a handheld GPS receiver, choose "GPS - Transfer GPS Points - Receiver to Screen" from the Overhead View menu and follow the directions given under GPS Interface. To enter points manually, choose "GPS - Enter GPS Points By Mouse" and then click the left mouse button at each desired point on the DEM Overhead View.

 STEP 3 - Define the surface area to be included in each frame of the flyby animation. Rotate or change the size of the outline rectangle by clicking and holding down the left mouse button at any corner of the rectangle. Reposition the outline rectangle by clicking the left mouse button at any point of interest on the terrain. This defines the surface area that will be included in the rendering of each animation frame.   Note that the horizon distance during flyby is determined by the size of the selected area. The horizon can be no farther away than the outer edge of the selected area. So in order to have a far horizon, rather than a narrow view looking downward, choose as large an area as possible. It is often advisable to merge several DEMs together to create a very large area that will allow selection of a far horizon in flyby.

STEP 4 - Select "Operation - Animate Flyby" and 3DEM will give you a choice of flyby projection parameters. Select a Flyby Speed that is appropriate for the GPS track being used.   High altitude flights over a large terrain area require high flyby speed (50 meters per frame or more). IGC Flight Path Files usually require lower flyby speed (10 meters per second or less). Accept the default values of the remaining flyby projection parameters, and 3DEM will render a real-time animated view of a flyby of the DEM landscape. The speed of this animation will depend on the speed of your computer and graphics card, and memory available. A fast machine will allow a frame rate of up to 30 frames per second. The primary purpose of this operation is to record a flight path through space over the DEM surface for subsequent conversion into a full resolution AVI or MPEG animation.

Note that the creation of the animation file does not take place at actual flight speed. Depending on the complexity of the terrain and the use of graphics overlays, each animation frame might take a second or two to complete. This means that it may take many times the actual flight time to create an animation.   An hour or more may be required to create an animation of a few minutes in length.

When using IGC Flight Path Files or other GPS flight recordings, it is generally not practical to view or to create an animation of the entire flight path, which could require hundreds of thousands of frames of animation. Each second of animation (30 frames) will require at much as 800 Kbytes of space, depending on the complexity of the terrain. So an animation of a 20 minute flight could require a gigabyte of file space or more. To solve this problem, 3DEM provides the capability to select a smaller section of the flight path for viewing or animation. You will be prompted to select the beginning point and ending point of the flight along the recorded track. Look for further details under IGC Flight Recording.

Animations can be created in the following formats

- Conventional color 3D animation
- Red-blue animation for viewing with red-blue 3D glasses
- Color side-by-side stereo 3D animation

It is important to select an appropriate projection size for the animation. Projection sizes of 480 by 360, 640 by 480, 800 by 600, and 1024 by 768 pixels are available. Animations with smaller projection sizes can be created more quickly, and can be played back at high speed on most any computer. The larger sized animations are more impressive to see. However, they will take much longer to create and may not play back at full speed on machines without the very best graphics hardware.

If you choose AVI animation, you may be given a choice of AVI Video Format depending on the capabilities of your machine. If you are given a choice, the Indeo Video Compressor is capable of producing good animations with large projection size and relatively small file size.

You may also choose to create an MPEG-1 animation. However please note that MPEG-1 is limited to a maximum animation size of 640 x 480. MPEG-1 full screen animation is not possible. Use AVI if full screen animation is required.

3D ROTATION ANIMATION PROCEDURE

3DEM can be used to create a 3D animation of rotation about a fixed point on the terrain surface.

STEP 1 - Load a new terrain file and draw an Overhead View of scaled altitude data. Choose "File - Load Terrain Model" from the Overhead View menu to bring up the DEM File Type dialog box for selection of the desired file type. Select the file type, and then locate and open the desired DEM file. 3DEM will then load the selected terrain model and draw an Overhead View of the entire geographic area with color scaled to the altitude at each point on the map.

STEP 2 - Define an area within the Overhead View for conversion into a three dimensional scene. Click the left mouse button at a location on the Overhead View that interests you. The area to be viewed will be outlined by a black rectangle. The observer's location and direction of view are indicated by a notch in one side of the outline rectangle. Rotate or change the size of the outline rectangle by clicking and holding down the left mouse button at any corner of the rectangle. Reposition the outline rectangle by clicking the left mouse button at any point of interest on the terrain. You can also make fine adjustments to the rotation of the outline rectangle using the left and right arrow keys.

STEP 3 - Once you are satisfied with the selected area, compute and display a three-dimensional landscape scene. Choose "Operation - View Scene" and 3DEM will give you a choice of terrain projection parameters as explained in the following paragraphs. Initially, you can just accept the default values and 3DEM will proceed to render the selected projection using OpenGL. The 3D image will be displayed in a separate window as the "3D Scene." Once the scene is complete, you can save the image as a graphics file by choosing "File - Save Scene Image" from the 3D Scene menu.

STEP 4 - Now choose "File - Save Rotation Animation" from the menu of the 3D Scene menu. Select a file name and AVI animation format as requested, and 3DEM will then create and save an animation rotation consisting of 360 degree rotation in 180 animation frames.

It is important to select an appropriate projection size for the animation. Projection sizes of 480 by 360, 640 by 480, 800 by 600, and 1024 by 768 pixels are available. Animations with smaller projection sizes can be created more quickly, and can be played back at high speed on most any computer. The larger sized animations are more impressive to see. However, they will take much longer to create and may not play back at full speed on machines without the very best graphics hardware.
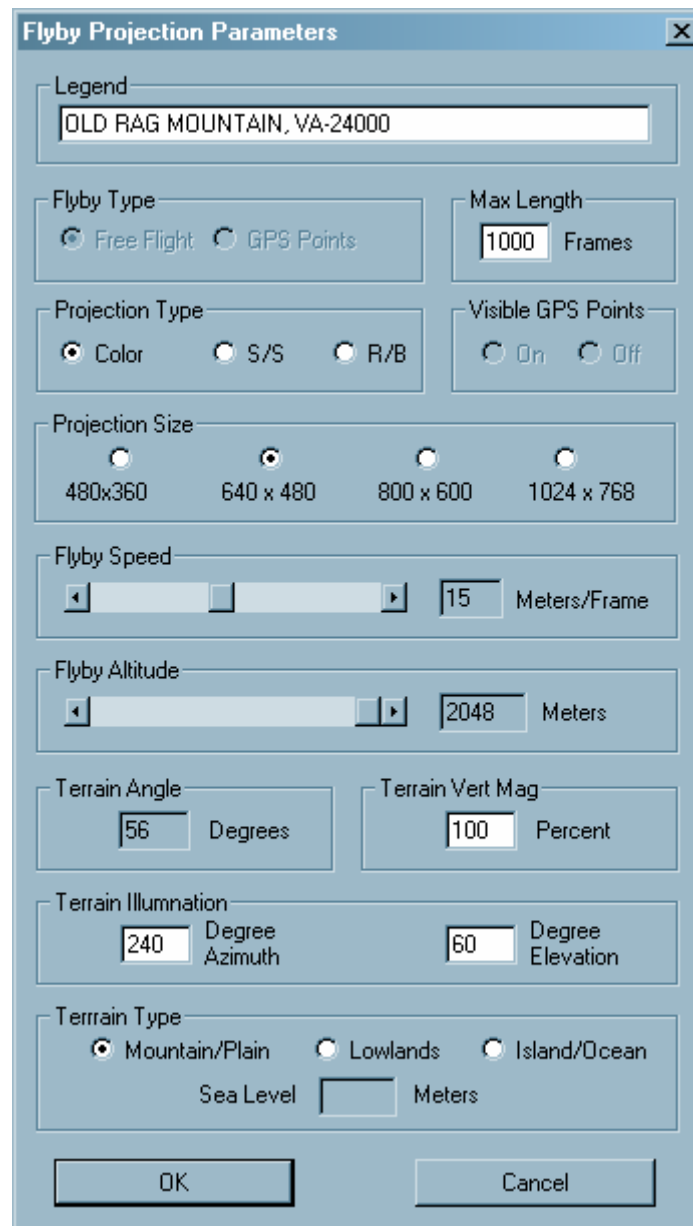
If you choose AVI animation, you may be given a choice of AVI Video Format depending on the capabilities of your machine. If you are given a choice, the Indeo Video Compressor is capable of producing good animations with large projection size and relatively small file size.

You may also choose to create an MPEG-1 animation. However please note that MPEG-1 is limited to a maximum animation size of 640 x 480. MPEG-1 full screen animation is not possible. Use AVI if full screen animation is required.

FLYBY PROJECTION PARAMETERS

Flyby projection parameters are selected using this dialog box. See the descriptions of each parameter which follow.

FLYBY TYPE

Flyby animation can be created either by free flight over the DEM surface, or by following GPS waypoints or tracks. These may be waypoints or tracks downloaded from a handheld GPS receiver, points read from GPS Waypoint or Track Files or IGC Flight Path files, or they may be manually entered on the DEM Overhead View using the mouse.

VISIBLE GPS POINTS

When creating a flyby using GPS waypoints or tracks, choose here to make these points visible or invisible in the final animation.

MAX LENGTH

Select here the maximum number of frames to be included in your flyby animation. Animation playback will ordinarily run at 30 frames per second for AVI and MPEG animation. When creating a flyby using GPS waypoints or tracks, the number of frames will be automatically set by the flyby speed (below) and the length of the flight path.

FLYBY SPEED

Flyby speed is the distance in meters over the terrain between each animation frame. You will probably need large flyby speeds for very high altitude flybys and low speeds for flybys close to the terrain surface. Experiment with flyby speed during real-time flyby to choose a speed that is matched to the altitude and scale of the terrain below. Animations created by 3DEM run at 30 frames per second. So, for example, if you choose a flyby speed of 5 meters between each animation frame, the apparent flight speed for the corresponding animation will be 150 meters per second.

When viewing a real-time flyby with 3DEM, the time between each frame update will be determined by the speed of your graphics card, the amount of RAM memory available, and the complexity of the 3D scene. It will not be possible in all situations to directly view a 3D flyby at full flight speed. In these cases, the best solution is to create a flyby animation that can be subsequently viewed at a rate of 30 frames per second, thus allowing for full flight speed.

Note that the creation of an animation file does not take place at actual flight speed. Depending on the complexity of the terrain and the use of graphics overlays, each animation frame might take a second or two to complete. This means that it may take many times the actual flight time to create an animation. An hour or more may be required to create an animation of a few minutes in length.

FLYBY ALTITUDE

Viewpoint altitude can be adjusted to improve the field of view during a flyby. The initial value will be a high above the landscape surface. Lower values can be chosen depending on the terrain. When following IGC Flight Path recordings or GPS tracks above the surface of the terrain, altitude is set automatically as dictated by the GPS data.

TERRAIN ANGLE

Terrain Angle is the angle at which the observer views the terrain. Zero degrees terrain angle corresponds to a view parallel to the surface. Ninety degrees terrain angle corresponds to a view looking straight down at the surface. During Flyby, terrain angle is automatically adjusted based on altitude above the surface. The Flyby Projection Parameters show the value of terrain angle for the altitude at the start of the flyby. Lower flyby altitude results in a smaller automatic value of terrain angle.

3DEM allows you to overlay surface maps showing roads, cities, lakes and rivers, and other features over the 3D terrain image. These overlays can be Digital Raster Graphic (DRG) or Digital Orthophoto Quad (DOQ) files. Overlay files can be very large (50 to 100 Mbytes), and processing of overlays can be a very lengthy process. Processing of map overlays is not recommended if you have less than 256 Mbytes of RAM or less than a 1 gHz processor.

Overlay maps must be fixed to the geographic coordinates of the underlying DEM. To apply a map overlay using the Map Overlay Dialog Box, take the following steps in sequence.

STEP 1 - Locate a source of DEMs and corresponding surface maps that cover the same geographic area at about the same scale. For the United States, good matches are the 7.5 Minute SDTS DEMs and matching DRGs provided by the USGS at http://www.gisdatadepot.com/dem/. The following instructions will illustrate overlay of Digital Raster Graphics on a Digital Elevation Model using the Snowshoe Peak, Montana, DEM and matching DRG available at this location.

STEP 2 - Download the Showshoe Peak SDTS DEM and matching DRG from http://www.gisdatadepot.com/dem/. These files can be found under Lincoln County, Montana. The DEM will be downloaded as a tar.gz file from "Digital Elevation Models (DEM) 24 k." The DRG will be downloaded as a zip file from "Digital Raster Graphics (DRG) - 24k."

STEP 3 - Decompress and extract the DRG graphics file from the downloaded zip file. Winzip can be used for this operation. The result will be a DRG geotiff graphics file (*.tif).

STEP 4 - Start the 3DEM program and Load the Digital Elevation Model. Choose "File - Load Terrain Model" from the Overhead View menu, and choose "USGS DEM" as the File Type. Then locate and load the DEM tar.gz file from Step 2 above.

STEP 5 - Load the DRG as a map overlay from the Overhead View before creating the 3D Scene. Choose "Operation - Apply/Remove Map Overlay" (or Function Key F4) to bring up the Map Overlay Dialog Box. Click the "Load" button and select the DRG file from Step 3 above. 3DEM will read the coordinates of the DRG geotiff file, convert it into a geo-referenced overlay, and apply it to the surface of the Digital Elevation Model. The result will be previewed in the Map Overlay Dialog Box as shown below.
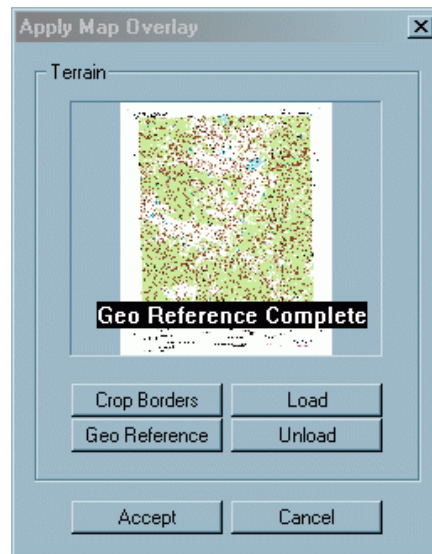
STEP 6 - If the overlay preview is acceptable, and if the words "Geo Reference Complete" appear in Map Overlay Dialog Box, click the "Accept" button and 3DEM will return to the Overhead View of the terrain showing the applied map overlay. This completes application of the map overlay, and you can proceed to Step 8 to create a 3D terrain view.

However, if the words "Geo Reference Complete" do not appear in the Map Overlay Dialog Box, Step 7 below will be required.

STEP 7 - Occasionally you will encounter DRGs that are not true geotiff files and do not include the necessary geographic coordinates. In these cases the overlay cannot be automatically geo-referenced by 3DEM, and manual geo-referencing will be required. You can manually geo-reference the DRG image either by cropping the map borders so that the DRG image exactly matches the underlying DEM (click "Crop Borders"), or by manually entering the latitude and longitude coordinates of known points on the map (click "Geo Reference"). For most DRGs, cropping the borders is the easiest method of geo-referencing.

To crop the DRG borders, click the "Crop Borders" button on the Map Overlay Dialog Box to bring up a magnified map view. Be sure that your Windows task bar does not cover either the horizontal or vertical scroll bars in this full screen window. The cropping tool consists of an outline rectangle with red colored cross marks at each corner. Clicking on a corner cross mark with the mouse designates it as the active (green) corner which can then be moved with either the mouse or the keyboard arrow keys. Go to each corner in sequence and adjust the outline rectangle so that it encloses the entire map area. Because of the UTM coordinate system, the map will appear tilted within the outline rectangle. Be sure to enclose the entire area of the map, even if small areas of the collar remain. Then click "Enter" to crop the map borders.

STEP 8 - Choose "Operation - 3D Scene" (or function key F2) to create a 3D Scene of the terrain. Examine the resulting image to see that there is a good match between the map overlay and the underlying DEM features. It may be necessary to adjust the map overlay coordinates or dimensions slightly to obtain a perfect match. See Adjusting Overlay Position that follows.

GRAPHICS OVERLAY PARAMETERS

The parameters of the graphics overlay process are selected using the dialog boxes shown below. See the parameter descriptions that follow.
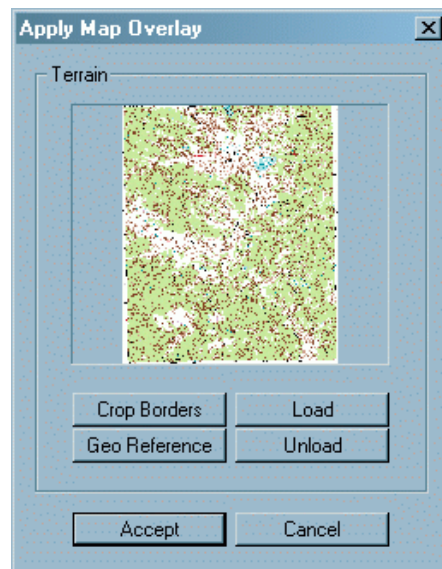
The Apply Map Overlay Dialog Box is used to load, resize, crop, and geo-reference surface maps, and to accurately position them relative to the underlying DEM and will apply a map overlay to both the Overhead View and the 3D Scene of the terrain.
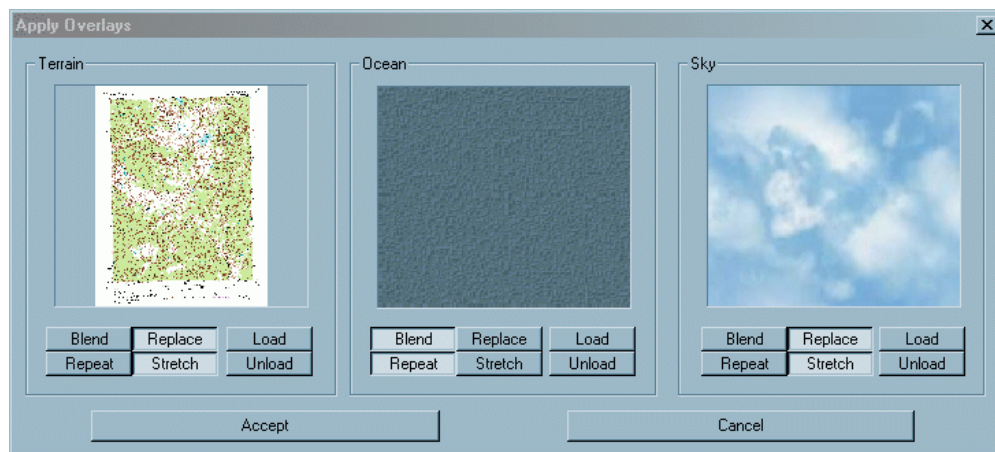
Once a 3D Scene has been created, the Apply Overlays Dialog Box is used to add, remove, or modify overlays to the terrain surface, the ocean surface, and the sky.

LOAD AND UNLOAD

Use the "Load" and "Unload" buttons to choose an overlay or discard an overlay for either the terrain, ocean, or sky. The overlay you choose will be previewed in the small window above the selection buttons. Overlays used by 3DEM can be any of nine different graphics file formats of any dimension. However, it is best not to use overlays of more than about 10000 pixels in width in order to keep processing time to a reasonable limit.

BLEND OR REPLACE

Overlays can be applied so that their colors either blend with the underlying terrain, or replace the colors of the underlying terrain. The "Blend" and "Replace" buttons are used to make this selection. In either case, the resulting surface is deformed and shaded to match the peaks and valleys of the underlying terrain.

When blending, the color white is treated as transparent. This can be useful for the situation in which you wish the overlay to only apply certain features (such as bodies of water, roads, boundaries, etc.) to the 3D scene. In this case, you can modify the overlay image using most any graphics image manipulation program to recolor all areas of the overlay as white, except for the features that you wish to be visible. Then apply the modified overlay image using 3DEM.

REPEAT OR STRETCH

Overlays can either repeat many times across a surface, or stretch so that the overlay exactly matches the surface and is only repeated once. The "Repeat" and "Stretch" buttons are used to make this selection. Choose "Repeat" where you wish to apply a very fine pattern across an entire surface. Choose "Stretch" where you have a large overlay image that you wish to apply as a fixed background (such as clouds for the sky or a surface map overlay for the terrain). Note that if you plan to use overlays in generating a flyby animation that you must use the stretch option to fix the overlay to the underlying terrain surface. Otherwise, the overlay image will move and flicker from frame to frame during the animation.

CROP BORDERS BUTTON

Clicking the "Crop Borders" button will initiate tools for cropping an overlay image to remove unneeded borders or other areas. Cropping is particularly useful when using Digital Raster Graphics (DRG) files as map overlays. DRG's are usually scanned images of paper maps that have a wide border around the useful map area. Cropping of DRG's is also necessary in order for the overlay map to exactly match the dimensions of the underlying DEM. Click the"Crop Borders" button to bring up a magnified map view and cropping tool. The cropping tool consists of an outline rectangle with a red colored cross mark at each corner. Clicking on a corner cross mark with the mouse designates it as the active (green) corner which can then be moved with either the mouse or the keyboard arrow keys. Move to each corner in sequence and adjust the outline rectangle so that it encloses the entire map area. Because of the UTM coordinate system of the map, it will appear tilted within the outline rectangle. Be sure to enclose the entire area of the map, even if small areas of the collar remain. Press the "Enter" key to complete the cropping process.

GEO-REFERENCE BUTTON

Clicking the "Geo-Reference" button will bring up a magnified map view and initiate tools for accurate referencing of the overlay map to the coordinates of the underlying DEM.   See the sections on Automatic and Manual Geo-Reference Procedure that follow for more complete instructions.

AUTOMATIC GEO-REFERENCING PROCEDURE

Geo-referencing is the process of precisely matching a terrain overlay to the geographic coordinates of the underlying digital elevation model. This process is completed automatically during application of a terrain overlay, provided that the overlay consists of a GeoTiff file (*.tif) containing the needed coordinate information, or a that a separate World File (*.jgw) containing coordinate information is present. Most of the DRGs available from the USGS are provided as GeoTiff files. Automatic geo-referencing will normally apply for all USGS 7.5' DEMs and associated DRGs. Digital Orthophoto Quads (DOQs) from the Microsoft Terraserver at http://terraserver.microsoft.com/ or USAPhotoMaps from http://jdmcox.com/ include *.jgw coordinate files and can be automatically geo-referenced by 3DEM.

Choose "Operation - Apply/Remove Map Overlay" (or function key F4) from the Overhead View menu to load the selected overlay using the Apply Map Overlay Dialog Box. Click the "Load" button and select the appropriate GeoTiff overlay file. If the needed coordinate information is available in the GeoTiff overlay file, geo-referencing will be completed automatically, and the message "Geo Reference Complete" will appear in the map window. Then click the "Accept" button to apply the overlay to the surface of the digital elevation model.

If the "Geo Reference Complete" message does not appear, then Manual Geo-Reference will be required as described below. For successful automatic geo-referencing, the following conditions must be met.

- The terrain overlay must be a GeoTiff graphics file containing the required geographic coordinates, or a separate World File (*.jgw) must be present containing the required geographic coordinates.

- The Digital Elevation Model and terrain overlay must both be UTM projections contained in the same UTM zone and hemisphere. Note that NED data, SRTM data, GTOPO30 and GLOBE DEMs will require conversion to UTM.

- The DEM and the terrain overlay must use the same UTM reference ellipsoid. Most USGS 7.5' DEMs and DRGs use the NAD27 ellipsoid. Most DOQs and other satellite photographs use the WGS 84 ellipsoid.
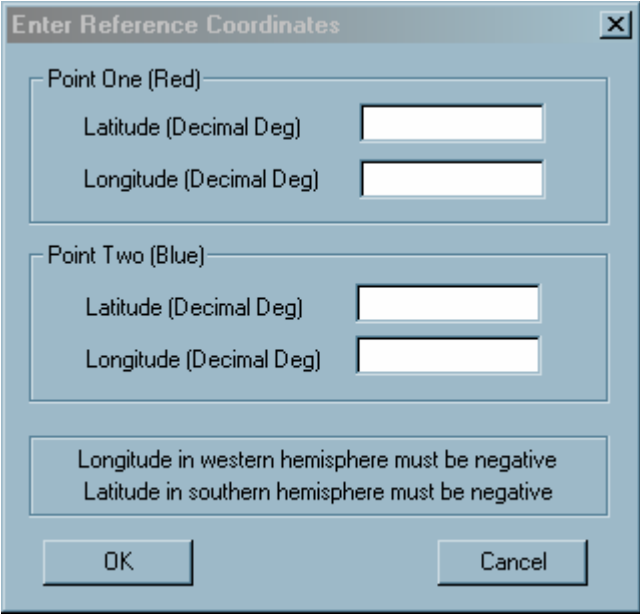
Warning Regarding Use of World Files (*.jgw).

Unfortunately, World Files do not contain a complete definition of map projection or coordinates. They include only the corner UTM coordinates of the terrain and spacing between terrain points. Missing is any indication of the UTM zone in use or the UTM ellipsoid in use. So in order to properly apply an overlay using a World File for geo-reference, you must be certain that the overlay UTM zone and UTM ellipsoid match the underlying Digital Elevation Model. If you observe an obvious mismatch between the overlay and the underlying DEM, it is most likely due to differences in UTM zone or UTM ellipsoid.

MANUAL GEO-REFERENCING PROCEDURE

After you have loaded a Digital Elevation Model and applied a map overlay, the geo-referencing tools in 3DEM can be used to accurately match the position of the map overlay to the underlying DEM. Geo-referencing requires that you know the coordinates (latitude and longitude) of at least two points on the map overlay. The tools provided by 3DEM allow you to designate these two points on a magnified map image and will then automatically adjust the position of the map overlay as necessary for an accurate match.

Choose "Operation - Apply/Remove Map Overlay" (or function key F4) from the Overhead View menu to load the selected map using the Apply Map Overlay Dialog Box. Then click the "Geo-Reference" button. The geo-referencing tools consist of two moveable cross-mark pointers that can be positioned on the magnified map.

Position the red marker at any position on the left (west) side of the map, and the blue marker at any position on the right (east) side of the map. These two points must be separated vertically and horizontally to the greatest extent possible. Ideally these two points would then be located in diagonally opposite corners of the map. Enter the known decimal values of latitude and longitude of the two points in the text entry box provided and click the "OK" button. 3DEM will then apply these corrections to the map overlay. Please remember, LONGITUDE IN THE WESTERN HEMISPHERE IS NEGATIVE in value.

When you exit from the geo-referencing function, the coordinates that you have entered are saved to a file in the same directory as the chosen overlay file. The coordinate file name is the same as the overlay file name (less extension) with an added "_ref.txt". For example, if the overlay file is named "overlay.tif" the saved coordinate file will be named "overlay_ref.txt". Thereafter, each time you choose to geo-reference this particular overlay file, you will be given the option of using the stored coordinates again rather than going through the entire laborious geo-referencing procedure.

ALTERNATIVE GEO-REFERENCING PROCEDURE

If you are working with a terrain matrix file in X-Y coordinates, an alternative procedure is available that allows you to match the overlay relative to the underlying digital elevation model. The surface map and the DEM are aligned by specifying the relative coordinates of the southwest corner and the width and height of the map overlay relative to the underlying DEM. These values are defined as follows:

West Coord = (Distance, west edge of DEM to west edge of map overlay)/(Total DEM Width)
South Coord = (Distance, south edge of DEM to south edge of map overlay)/(Total DEM Height)
Width = (Width of map overlay)/(Total DEM Width)
Height = (Height of map overlay)/(Total DEM Height)

By definition, if the underlying DEM and the map overlay are perfectly matched, then

West Coord = 0.0   Width = 1.0   South Coord = 0.0   Height = 1.0

These relative coordinates are ratios that can be computed using any unit of measure (feet, meters, pixels) that is common to both the DEM and the overlay map.

ADJUSTING OVERLAY POSITION

Often, a map overlay will require fine position adjustment so that it precisely matches the features of the underlying Digital Elevation Model. Choose "Operation - Adjust Overlay" from the 3D Scene menu (or function Key F5) to bring up the "Adjust Overlay Position" dialog box as shown below.
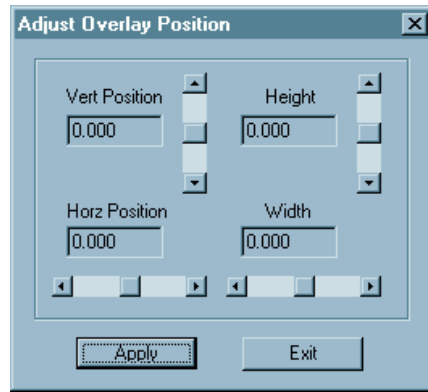
- Vert Position - Moves the overlay vertically (North-South) with respect to the underlying DEM.
- Horz Position - Moves the overlay horizontally (East-West) with respect to the underlying DEM
- Height - Increases or decreases the height of the overlay (North-South) with respect to the underlying DEM
- Width - Increases or decreases the width of the overlay (East-West) with respect to the underlying DEM.

First choose a scene area near the southwest corner of the DEM with the observer is looking directly north. Choose a scene that includes a prominent and identifiable surface feature that can be used for matching the position of the map overlay. Adjust the Vert Position and Horz Position controls to match the map overlay to the position of the chosen surface feature. Click "OK" to apply the correction to the 3D Scene.

Then choose a scene area near the northeast corner of the DEM with the observer looking directly north. Choose a scene that includes a prominent and identifiable surface feature that can be used for matching the position of the map overlay. Adjust the Height and Width controls to match the map overlay to the position of the chosen surface feature. Click "OK" to apply the correction to the 3D Scene.

Because of interaction between these controls, it may be necessary to repeat this procedure several times, making small adjustments each time. These fine controls make it possible to achieve a very precise match between the map overlay and the underlying digital elevation model.

GLOBAL POSITIONING SYSTEM (GPS) INTERFACE

3DEM can transfer position data (waypoints, routes, or tracks) to and from Garmin and Magellan handheld GPS receivers via a serial data connection. 3DEM will connect these points with a solid line in the order in which they appear in the GPS point file. This allows you to record GPS points during a trek through the wilderness, and then visualize the traveled path on the Overhead View and 3D projection of the terrain. Choose "GPS - Transfer GPS Points" to bring up the GPS interface dialog box as shown below.

Either a Garmin or Magellan receiver may be selected. 3DEM has been tested with Garmin GPS II+, Garmin GPS III+, Garmin eMap, Garmin eTrex Summit, and Magellan GPS 315 handheld receivers. Generic interfaces are also provided for other models from these manufacturers.

Garmin receivers must be set up for GRMN/GRMN interface using the internal system menu and always operate at 9600 baud. Magellan receivers must be set up for either 4800 or 9600 baud both at the receiver and at 3DEM. Then serial data transfer can be established using either COM1 or COM2 serial ports on your computer. The interface operates with full duplex data transfer using 8 data bits, no parity, and 1 stop bit. A complete range of GPS point transfers is possible including:

| • Receiver to Screen | • Screen to Receiver | • File to Screen |
| • Receiver to File | • Screen to File | • File to Receiver |

3DEM will display waypoints, routes, or tracks stored in the GPS receiver using the "Receiver to Screen" option. Waypoints and routes are made up of individual points that have been entered by the user to mark position along a trail. Routes consist of a sequence of selected waypoints between a starting and ending position. Tracks consist of the internal track log of the GPS receiver used to plot a smooth track curve on the GPS display. Routes (and often tracks) may be stored in your receiver with a designation or name. If so, you must enter the designation or name exactly as recorded in the GPS receiver into the "Name" text box in the GPS interface dialog box to allow 3DEM to locate the desired route or track.

The magnified map display available in 3DEM allows plotting of GPS points to a few meters accuracy on an overlay map, and then transferring these points to the GPS receiver using the "Screen to Receiver" option. This also allows planning a course or trail with high accuracy, and then visualizing it with the 3D Scene, 3D flyby animation, or VRML worlds created by 3DEM. Choose "Operation - Map Overlay View" from the Overhead View menu to see the magnified map display.

Points transferred to the GPS receiver (Screen to Receiver or File to Receiver) are loaded into the receiver memory as waypoints. The maximum number of waypoints that can be loaded into the receiver is 500.

3DEM also provides the option of entering GPS points manually. Choose "GPS - Enter GPS Points by Mouse," and then click the left mouse button to enter GPS points in sequence.

GLOBAL POSITIONING SYSTEM (GPS) TRACK FILES

3DEM stores GPS points as a series of latitude - longitude - altitude values in an ASCII text file as shown below. Values are in decimal degrees (latitude and longitude) and meters above sea level (altitude). Files of this type can be saved from the GPS receiver and from the 3DEM screen display. Recorded files can be transferred as waypoints back to either the GPS receiver or to the 3D display generated by 3DEM. Please note that longitude values are negative in the western hemisphere.

```
38.54794  -78.32410  896.0
38.54847  -78.32408  904.0
38.54888  -78.32332  891.0
38.54889  -78.32264  879.0
38.54953  -78.32195  871.0
38.55012  -78.32083  881.0
38.55079  -78.31915  890.0
38.55074  -78.31773  902.0
38.55095  -78.31750  920.0
38.55147  -78.31754  942.0
38.55159  -78.31712  955.0
38.55141  -78.31617  972.0
38.55140  -78.31562  983.0
38.55111  -78.31500  984.0
38.55122  -78.31449  988.0
38.55055  -78.31251  955.0
```

Files of GPS points from other mapping programs can be converted into this format using any good spreadsheet program. However, please note that if your GPS data does not include altitude, you must still include an altitude column in the 3DEM track file. In this case, set altitude equal to "0" for each point, and 3DEM will place the GPS track on the terrain surface.

IGC FLIGHT RECORDING

The Federation Aeronautique International (FAI) Gliding Commission, also known as the IGC, has developed a specification for flight path recording using GPS for measurement of latitude and longitude, and an altimeter for measurement of altitude. 3DEM can read and display files of IGC flight paths and thus show the 3D track of a flight over the terrain surface. The IGC flight path file format is specified on page 36 of the "Technical Specification for IGC Approved GNSS Flight Recorders" that can be found at http://www.fai.org/gliding/gnss/tech_spec_gnss.asp.

Choose "GPS - Transfer GPS Points - File To Screen" and select an *.igc file of the proper format to read and display a 3D flight path over the terrain.
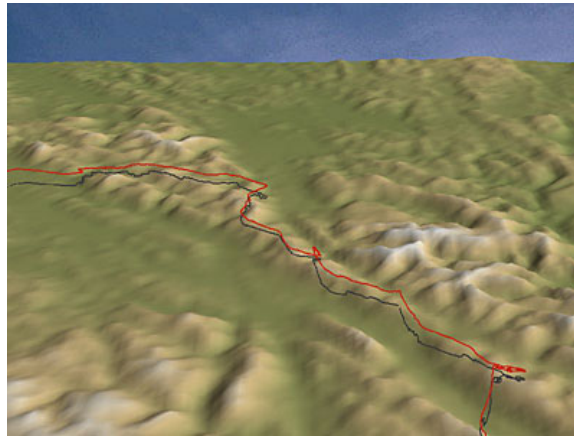
Flyby animations can also be created which follow the IGC flight recording as described under 3D Flyby Animation, giving a view out of the cockpit window. Because these flight paths can be very long, controls are provided to select the beginning and ending points for flyby. Choose "GPS - Transfer GPS Points - File to Screen" to load an IGC track file. Then choose "Operation - View Flyby" and select "GPS Flight" from the Flyby Projection Parameters. You will then be presented with controls for moving the starting point (marked with a black cross) and the ending point (marked with a red cross) as shown below. This allows selection of the most interesting section of the flight path for animation.
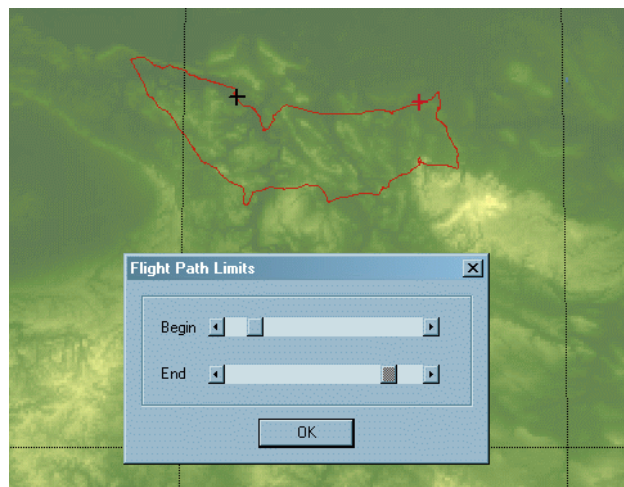
TERRAIN ELEVATION PROFILES

Two kinds of elevation profile plots can be produced by 3DEM. These can be either an elevation profile between two points, or an elevation profile along a GPS track.

ELEVATION PROFILE BETWEEN TWO POINTS

After loading a digital elevation model and creating an Overhead View, click and drag with the right mouse button to define a line between two points on the surface.   When you release the right mouse button, an elevation profile will be displayed as shown below.
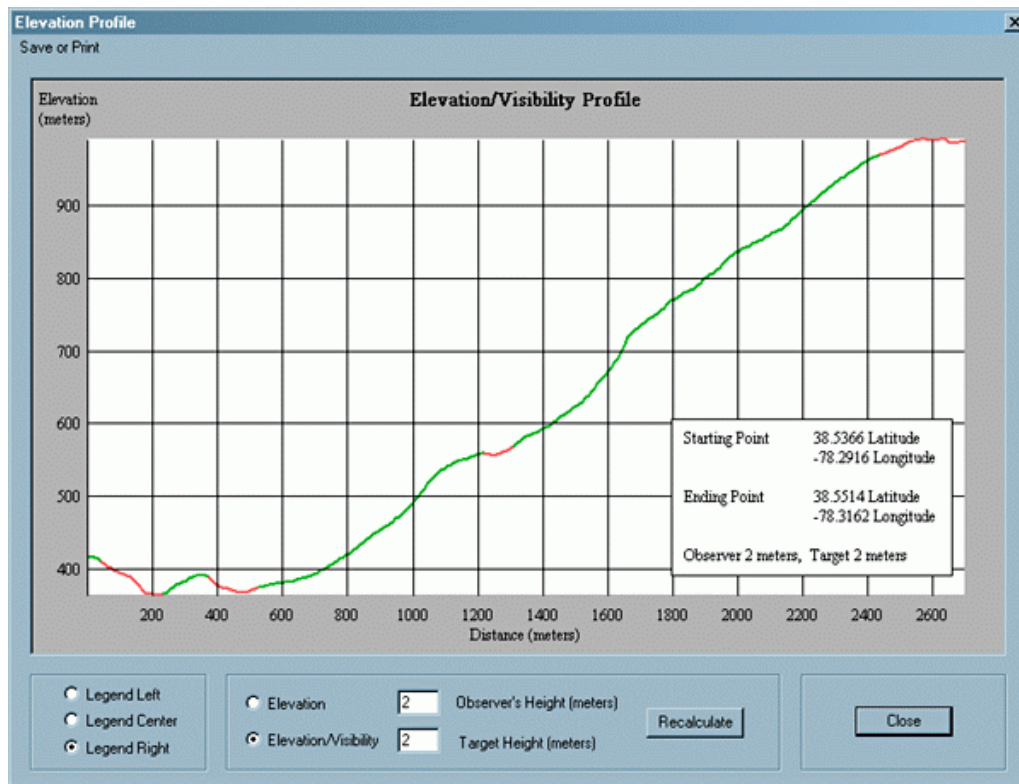
The elevation profile plot shows terrain elevation as a function of distance between the two selected points. Either an "Elevation Profile" or an "Elevation/Visibility" profile may be selected.   An Elevation profile is plotted as a continuous green line.   An Elevation/Visibility profile shows points of line-of-sight visibility in green and points of invisibility in red.

The Elevation/Visibility profile is interpreted as follows.   An observer is placed at the left edge or starting point of the profile, and a target is placed at the right edge or ending point of the profile. The observer and target heights above the terrain surface are independently adjustable. As the target moves toward the observer, it is visible or invisible to the observer depending on the peaks and valleys of the terrain. Points of visibility are plotted in green, and points of invisibility are plotted in red. Setting target height equal to zero creates a plot of the surface visibility along the line from the observer's position to the target ending position.

ELEVATION PROFILE ALONG A GPS TRACK

After loading a digital elevation model and defining a GPS track, choose "GPS - Profile GPS Track" from the Overhead View menu. An elevation profile along the GPS track will be displayed as shown below.
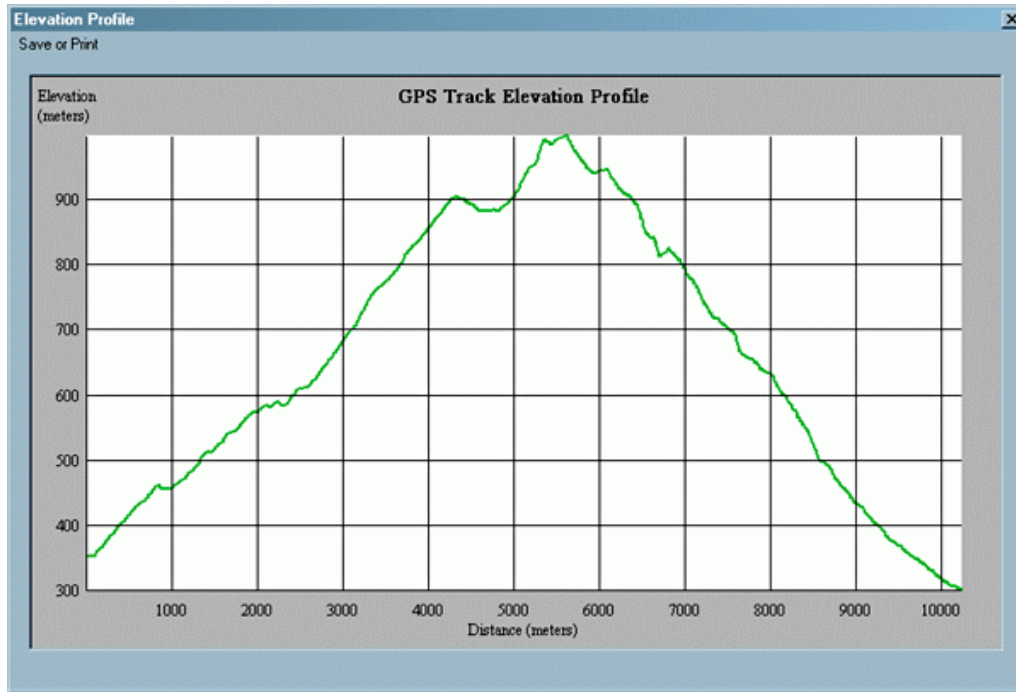
The horizontal axis of this plot is distance traveled in the horizontal plane, which can be considerably longer than the horizontal distance between the starting and ending points of the GPS track. The vertical axis of this plot is terrain elevation along the GPS track.

Note on Profile Accuracy

Elevation profiles will be most accurate with high resolution DEMs based on Universal Transverse Mercator (UTM) projection. Examples of these DEMs are the USGS 7.5' SDTS Digital Elevation Models. UTM DEMs preserve the geometry of straight lines on the surface of the terrain, which is important to the accuracy of the terrain profile. Elevation profiles produced using DEMs based on geodetic (latitude-longitude) projection such as the USGS one-degree DEMs, the NED DEMs, and the SRTM DEMs will be less accurate.

SAVING DIGITAL ELEVATION MODELS

SAVING ASCII FORMAT DEMS

Any terrain with latitude and longitude coordinates or UTM coordinates and equal grid spacing between points can be saved by 3DEM as a USGS ASCII format DEM file. Choose "File - Save USGS ASCII DEM" from the Overhead View menu to save a DEM file in this format.

This provides the capability to load and merge multiple DEMs and save the result as a single USGS ASCII format DEM. It also provides the capability to save GeoTiff,GLOBE, GTOPO30,and MOLA terrain data as USGS ASCII format DEMs for possible use in other mapping applications.

Note that GLOBE DEMs, GTOPO30 DEMs, and MOLA data must have been loaded as a "Lat/Lon Projection" in order to be saved as a USGS ASCII format DEM. Sinusoidal projected GLOBE, GTOPO30, or MOLA data cannot be saved in USGS format.

SAVING GEOTIFF FORMAT DEMS

Any terrain with geographic coordinates (Latitude-Longitude or UTM) and equal grid spacing between points can be saved by 3DEM as a GeoTiff DEM file. Choose "File - GeoTiff DEM" from the Overhead View menu to save a DEM file in this format. GeoTiff DEMs are similar to Tiff (*.tif) graphics files except that instead of color pixel values, the file contains a grid of 16 bit or 32 bit elevation measurements. Both GeoTiff and Tiff graphics files use the (*.tif) file extension. However GeoTiff DEMs cannot be read as a graphics file by paint programs. They can only be read by programs such as 3DEM that are designed for their use.

GeoTiff DEMs are a fairly efficient way to save large merged DEMs. For example, a merged DEM made up of 16 USGS 7.5' DEMs will require approximately 165 Mbytes when saved as a USGS ASCII DEM. Saving the same area as a GeoTiff DEM will require approximately 50 Mbytes. However, GeoTiff DEMs have the disadvantage of not being widely supported by other terrain visualization software.

SAVING TERRAIN DATA FILES

Terrain data can be also be saved as terrain matrix files for future use with 3DEM or other applications. Choose "File - Save Terrain Matrix - Entire Terrain" to save the entire terrain area. Choose "File - Save Terrain Matrix - Selected Area" to save only the area enclosed by the black outline rectangle on the 3DEM Overhead View. Then select the format of data to be saved as either binary 16 bit integer, binary 32 bit floating point, or ASCII text.
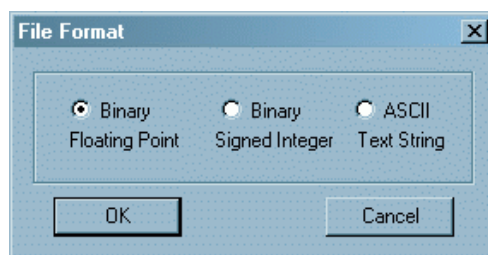
Ordinarily, the binary 16 bit integer format is the most compact and useful. However, when saving data that is known to require fractional accuracy (such as the USGS 7.5' SDTS DEMs that are accurate to 0.1 meter) the binary 32 bit floating point format should be used. Data may also be saved as ASCII text for use in special circumstances. However, the ASCII files can be enormous in size and are not recommended unless needed in special circumstances.

Each terrain matrix file will be saved with an accompanying text header file that specifies the terrain matrix size, coordinate system, and data format. Below is an example of such a header file.

```
file_title              = OLD RAG MOUNTAIN, VA-24000
data_format             = float32
map_projection          = UTM Zone 17N
ellipsoid               = NAD27
left_map_x              = 728530
lower_map_y             = 4264360
right_map_x             = 739820
upper_map_y             = 4278540
number_of_rows          = 1419
number_of_columns       = 1130
elev_m_unit             = meters
elev_m_minimum          = 174
elev_m_maximum          = 1224
elev_m_missing_flag     = -9999
```

Keep these header files (*.hdr) in the same file directory with their matching terrain matrix files (*.bin). 3DEM can then automatically open and read the terrain matrix files without manual entry of any terrain parameters. Choose "File - Load Terrain Model" and select "Terrain Matrix" file type. 3DEM will then read both the terrain matrix file and the associated header file and create the terrain with appropriate map projection and terrain dimensions.

SAVING TERRAGEN TERRAIN FILES

3DEM can export data files for use by the Terragen terrain-rendering program. Terragen can produce spectacular clouds and atmospheric effects and also provides advanced surface texturing capability. Terragen can be found at http://www.planetside.co.uk/terragen/ on the Internet.

To create Terragen terrain files, load a terrain digital model into 3DEM. Then choose "File - Save Terragen Terrain - Entire Area" from the Overhead View menu. 3DEM will then save a terrain *.ter file which can be opened and displayed by Terragen. This terrain will include the entire area of the DEM as seen in the 3DEM Overhead View.

Choose "File - Save Terragen Terrain - Selected Area" to save only the area enclosed by the black outline rectangle on the 3DEM Overhead View as a Terragen terrain file.

3DEM will export Terragen terrain in widths up to 4096 by 4096 in support of Terragen version 0.8 and higher. 3DEM attempts to find the best match between the terrain matrix width chosen in 3DEM and the fixed widths allowed by Terragen (256, 512, 1024, etc). The rules for dimension matching are as follows:

> DEM width less than 383 results in Terragen width of 256;
> DEM width from 384 to 767 results in Terragen width of 512;
> DEM width from 768 to 1535 results in Terragen width of 1024;
> DEM width from 1536 to 3071 results in Terragen width of 2048;
> DEM width greater than 3072 results in Terragen width of 4096.

To ensure the best reproduction of the terrain surface, it is advisable to select an area in 3DEM that matches the allowable Terragen widths. Press the "Ctrl and F8" keys to activate readout of Matrix Width. Then as the size of the 3DEM outline rectangle is changed, the width of the terrain matrix to be converted to Terragen terrain is shown as "Matrix Width" at the bottom right of the Overhead View window. If possible, this value should be matched to one of the allowable Terragen widths of 256, 512, 1024, 2048, or 4096.

SAVING VRML WORLDS

3DEM can save a 3D scene as a Virtual Reality Modeling Language (VRML) world file (*.wrl) which can then be viewed and explored in real time over the Internet using a VRML plug-in to your web browser. The GLView player available at http://home.snafu.de/hg/ is highly recommended.

Once you have generated a 3D scene choose "File - Save VRML World" from the 3D Scene menu. Then you will be presented with the VRML dialog box for selection of the level of detail in the VRML world.
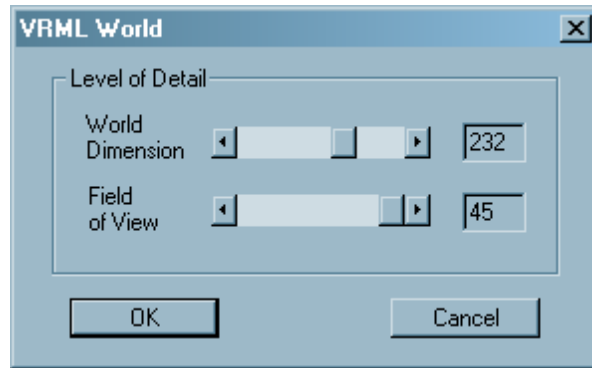
World Dimension is the number of points per side which make up the VRML terrain grid. If N is the world dimension chosen, the number of individual triangular faces making up the VRML world is 2*(N-1)*(N-1). So a VRML world with a dimension of 200 will be made up of almost 80000 faces. Obviously, World Dimension requires a trade-off between level of detail and the size of the resulting world file.

Field of view is the angular field of view, which will be used by the VRML player. A value of 45 degrees is normal, but you can choose narrower fields if necessary to improve the appearance of the scene. Note that this field of view is independent of the field of view that you have selected within 3DEM for the 3D scene rendering.

3DEM creates the VRML world by first constructing a terrain grid of elevation values and then by rendering a JPEG overhead image of the selected terrain. The terrain grid is saved in the *.wrl file, and the JPEG image is saved separately as a *.jpg file. Both of these files are then used by the VRML player to display the world. The terrain grid defines the surface elevation at each point in the world, and the JPEG image is applied as a overlay to define the colors at each point in the world. If you plan to use the VRML on a web page, be sure that the associated JPEG file is also available and can be located by the VRML player.

SAVING AND PRINTING SCENE IMAGES

3DEM can save graphics images in the following file formats.

Windows Bitmap (*.bmp, *.dib)
Tagged Image File (*.tif, *.tiff)

Both the Overhead View and the 3D Scene can be saved as graphics files. To save the Overhead View, choose "File - Save Map Image" from the Overhead View menu. To save the 3D Scene, choose "File - Save Scene Image" from the 3D Scene menu. Image magnification is provided as an option where the image is to be printed or displayed in another application. Often an image printed at a high value of dots per inch will appear much smaller than on your computer screen. Use the "Size When Printed" controls to predict the final printed size of your image as determined by magnification and the dots per inch of your printer.

SAVING LARGE FORMAT 3D SCENES
FOR PUBLISHING

Once a 3D scene has been created, it may be saved as a large format image file of up to 6000 pixels width. Such large images are often needed for publishing purposes. Choose "File - Save Large Format Image" from the 3D Scene menu and choose image size from the Image Parameters Dialog Box that appears. The 3D image will then be rendered to this scale and saved to the filename that you select.

Saving large jpeg scenes will sometimes fail if sufficient graphics memory is not available. In this case, try saving the large format scene as a windows bitmap.

SAVING LARGE FORMAT 2D SCENES
FOR PUBLISHING

To save the shaded Overhead View as a large format image for publishing, resize the Overhead View to maximum and save the resulting image as a bitmap, jpeg, or RGB geotiff image. See Resizing the Overhead View.

PRINTING IMAGES

Once you have created a 3D image, you can send it directly to a printer by selecting "File - Print Scene Image" from the 3D Scene window menu. This will bring up a standard Windows Print Dialog Box for selection of the printer and page setup. The size of the printed image will be automatically adjusted to match the size the paper being used.

DIGITAL ELEVATION MODELS AVAILABLE ON THE INTERNET

Digital Elevation Models can be downloaded at no cost from several locations on the Internet. Each download site has its own advantages and disadvantages that are summarized below:

USGS SEAMLESS DATA DISTRIBUTION SYSTEM

The USGS maintains a Seamless Data Distribution System at http://seamless.usgs.gov.   This site is a convenient source of National Elevation Dataset (NED) and Shuttle Radar Topography Mission (SRTM) terrain data for the United States and other limited areas of the world. Area selection is seamless and is not constrained by latitude or longitude boundaries, and data can be downloaded immediately. Currently downloads are free, with some size limitations. Click the "View and Download United States Data" to bring up the map for area selection as shown below.
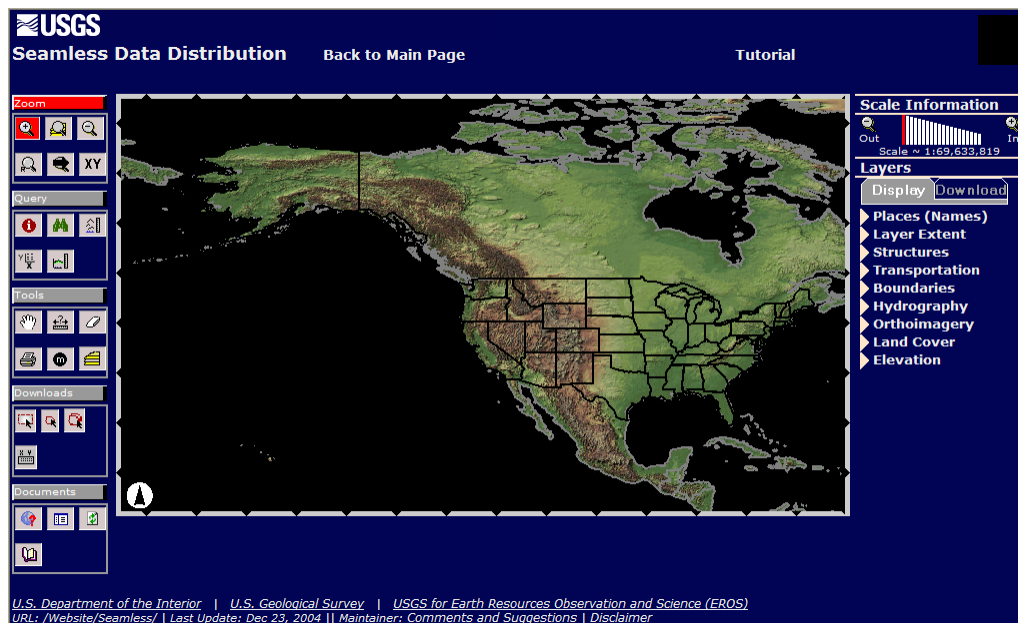
Use the mouse and the coordinate readouts at the lower left of the map window to select a location and zoom in to the desired area. Once you have found the desired area, choose the "Download - Select by Rectangle" function and outline the area of interest using the mouse. You will then see a "Request Summary Page" that indicates the data available for download for this area. The data that can be used by 3DEM will be the National Elevation Dataset (NED) and the Shuttle Radar Topography Mission (SRTM) data. Usually these are both initially offered as ArcGrid format for download. 3DEM requires the TIF (GeoTiff) data format instead of the ArcGrid format, so click the "Modify Data Request" button and change the requested format to TIF. If you are downloading SRTM data, you may also request the BIL format. Then click "Save Changes and Return to Summary." Now you can click "Download" to retrieve each data set as a TIF file. 3DEM will be able to read these files as GeoTiff DEMs.

The advantage of this site is that high-resolution (30 meter and 10 meter) terrain data can be easily located and downloaded for any area of the United States and many other areas of the world. These data are suitable for high resolution, low altitude 3D terrain scenes.

The disadvantage of this site is that all data are available only in geodetic (latitude-longitude) projection and generally must be converted by 3DEM to UTM projection before graphic overlays can be applied. However this is easily accomplished by 3DEM and usually will take only a few seconds of time.

Using Seamless Data Distribution Files - GeoTiff DEMs are similar to (*.tif) graphics files except that instead of color pixel values, the file contains a grid of 16 bit or 32 bit elevation measurements. Both GeoTiff and Tiff graphics files use the (*.tif) file extension. However GeoTiff DEMs cannot be read as a graphics file by paint programs. They can only be read by mapping programs designed for their use, such as 3DEM.

Choose "File - Load Terrain Model" from the Overhead View menu to bring up the "DEM File Type" dialog box. Then select "GeoTiff DEM" as the DEM File Type and click OK. Now select the appropriate *.tif file and 3DEM will read the DEM file and create the terrain Overhead View.

<center>USGS 7.5 MINUTE DIGITAL ELEVATION MODELS</center>

The USGS has designated GeoCommunity as a repository for 10 meter and 30 meter resolution, 7.5 minute, SDTS format DEMs for the entire United States at http://www.gisdatadepot.com/dem/demdownload.html. DEMs are cataloged here by State, County, and Map Name.
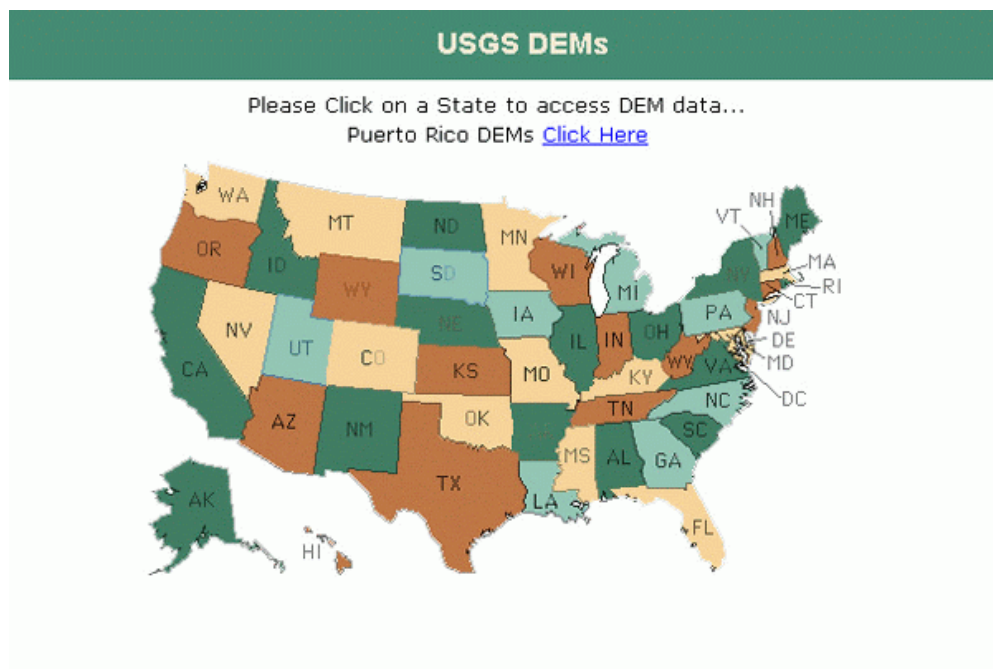
The DEMs found here are approximately 13.5 km (8.4 miles) square. These DEMs are not seamless, but are constrained to 1/8 degree latitude and longitude boundaries. Multiple DEMs can be merged by 3DEM to cover larger areas.

After selecting the appropriate state and county, you will see a list of available downloads including

Digital Elevation Model (DEM) - 24k
Digital Raster Graphics (DRG) - 24k

These are the 7.5 minute digital elevation models and topographic maps for the selected county. Select either DEM or DRG, and then click the green download button.

Often, the DEM selection will result in a choice of two downloads which are the 10 meter resolution and the 30 meter resolution versions of the same terrain. The 10 meter DEM is usually about 3 Mbytes in size while the 30 meter DEM is usually less than 300 Kbytes in size. The 10 meter DEM is the best choice for high resolution terrain scenes.

The DRG is a matching topographic map for the selected area. This map can be quickly applied as an overlay to the 3D terrain using the procedure described in Apply Map Overlay.

The advantage of this site is that the very highest resolution (10 meter) DEMs can be downloaded free of charge. These provide the very best high-resolution 3D terrain scenes and animation. It is also very convenient to be able to download a matching DRG for the same terrain area.

The disadvantage of this site is that DEMs must be located by State, County, and Map name. This requires that you have an external index for each state that will allow you to find County and Map names for your area of interest. An inexpensive map index named MapFinder covering all states is available from Digital Data Services.

Also, download speeds are limited to about 5 KB/sec for free downloads. This means that it will take at least 10 minutes to download the typical 10-meter DEM (3 MBytes) even with the very fastest Internet connection. DRGs will take longer. A fast download service is available for a fee.

Using SDTS DEM Files - Choose "File - Load Terrain Model" from the Overhead View menu to bring up the "DEM File Type" dialog box. Select "USGS DEM" as the DEM File Type and click OK. Then select the DEM *tar.gz file. 3DEM will proceed to decompress and read the file and create the terrain Overhead View.

Multiple adjacent 7.5 minute SDTS DEM files can be loaded and automatically merged by 3DEM. See Merging DEMs.

SHUTTLE RADAR TOPOGRAPHY MISSION (SRTM) DATA

Shuttle Radar Topography Mission data files for many parts of the world are available in selected sample data sets from NASA and the USGS at ftp://e0srp01u.ecs.nasa.gov/srtm/version2/.

SRTM data are distributed in two levels: SRTM-1 with data sampled at one arc-second intervals in latitude and longitude, and SRTM-3 sampled at three arc-seconds.

Data are divided into one by one degree latitude and longitude tiles in geographic projection. File names refer to the latitude and longitude of the lower left corner of the tile - e.g. N37W105 has its lower left corner at 37 degrees north latitude and 105 degrees west longitude. Digital elevation model data files are designated by a HGT file extension.

SRTM data are also available in the BIL and TIF format from the USGS Seamless Data Distribution System at http://seamless.usgs.gov.

Using SRTM Data Files - If you have obtained data in either the BIL or HGT format, choose "File - Load Terrain Model" from the Overhead View menu to bring up the "DEM File Type" dialog box. Then select "SRTM Data" as the DEM File Type and click OK. Now select the *.bil or *.hgt digital elevation model and 3DEM will read the SRTM data and create the terrain Overhead View. If you have obtained data in the TIF format, choose GeoTiff DEM as the DEM File Type.

Multiple adjacent SRTM files can be loaded and automatically merged by 3DEM. See Merging DEMs.

Note that SRTM files frequently contain areas of missing data that appear as holes in the surface of the terrain. Small defects of this type can be corrected using the Terrain Patching Procedure.

USGS GTOPO30 DEM FILES

Global 30 Arc Second Elevation Data Sets consisting of elevation measurements at intervals of 30 by 30 arc seconds (about 1KM) are available for the entire globe from

http://edc.usgs.gov/products/elevation/gtopo30/gtopo30.html

GTOPO30 DEMs are downloaded in compressed ".tar.gz" format. 3DEM can read these files directly without the need for file decompression.

Using GTOP30 DEM Files - 3DEM is designed to merge together multiple GTOPO30 DEM files to provide continuous surface coverage of the entire globe. Choose "File - Load Terrain Model" from the Overhead View menu to bring up the "DEM File Type" dialog box. Then select "GTOPO30 Tile" and you will be presented with the "Area Selection" dialog box for selection of the geographic position and width (in degrees) of the area to be mapped.
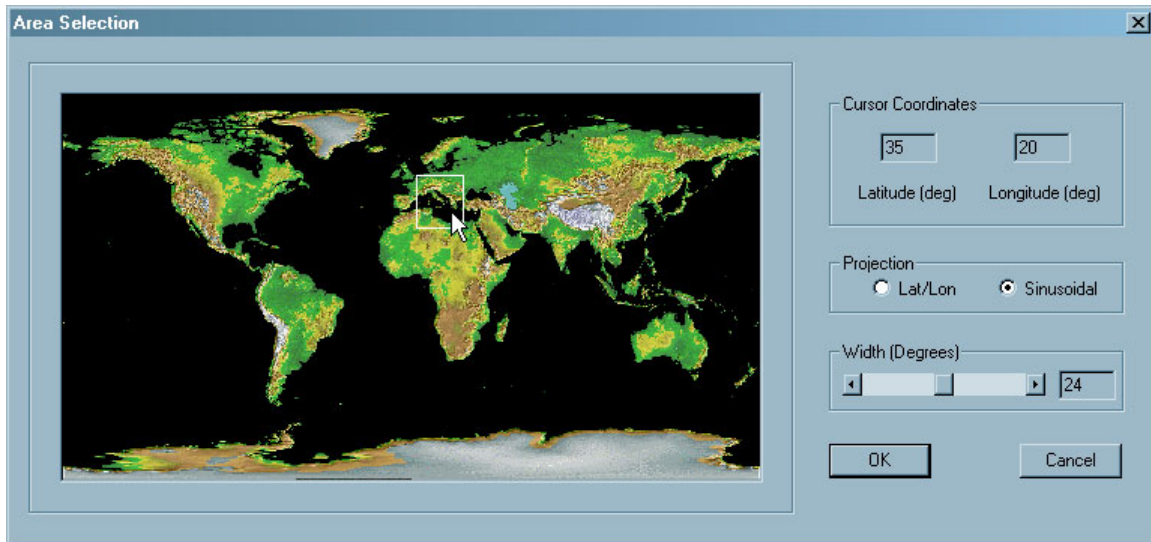
Select a geographic location by clicking and dragging the white outline rectangle on the map of world. Adjust the width of the selected area in degrees using the horizontal slider control provided. Once you have selected a geographic area, click "OK" and 3DEM will prompt you in sequence to locate and load the GTOPO30 DEM files that are needed to construct the desired map. A file dialog, with the name of the file to be located contained in the title bar, will appear for each file in sequence. You must locate and load each file that is named in the title bar of the file dialog. Once all files have been loaded, 3DEM will proceed to draw an Overhead View of the selected area.

3DEM provides a choice of either "Lat/Long" or "Sinusoidal" map projection when loading GTOPO30 DEMs. The Lat/Long projection produces a rectangular surface grid with equal extension in latitude and longitude. The disadvantage of the Lat/Long projection is distortion at high latitudes. If you are creating images at high latitudes, try the Sinusoidal projection, which produces a surface grid corrected for latitude and a more realistic Overhead View and 3D projection.

NOAA GLOBE DEM FILES

Global Land One-km Base Elevation (GLOBE) files consisting of elevation measurements at intervals of 30 by 30 arc seconds (about 1KM) are available from

http://www.ngdc.noaa.gov/mgg/topo/globe.html

There are two ways to obtain GLOBE terrain data. You can either download complete GLOBE tiles (*.tgz) with dimensions of approximately 40 degrees in latitude and 90 degrees in longitude, or you can interactively select a smaller area to be downloaded as a binary terrain matrix (*.bin) and a corresponding file header (*.hdr).

Using GLOBE Terrain Matrix Files - When you select a subset or smaller area from a complete GLOBE tile to be downloaded, you will receive a terrain matrix file (*.bin) and a header file (*.hdr). These files can be read directly by 3DEM. See the description of Terrain Matrix Files under Other Matrix File Formats.

Using GLOBE Tiles - If you are able to download complete GLOBE tiles, 3DEM can be used to merge these tiles together to provide continuous surface coverage of any area on the globe. Choose "File - Load Terrain Model" from the Overhead View menu to bring up the "DEM File Type" dialog box. Then select "GLOBE Tile" and you will be presented with the "Area Selection" dialog box for selection of the geographic position and width (in degrees) of the area to be mapped.
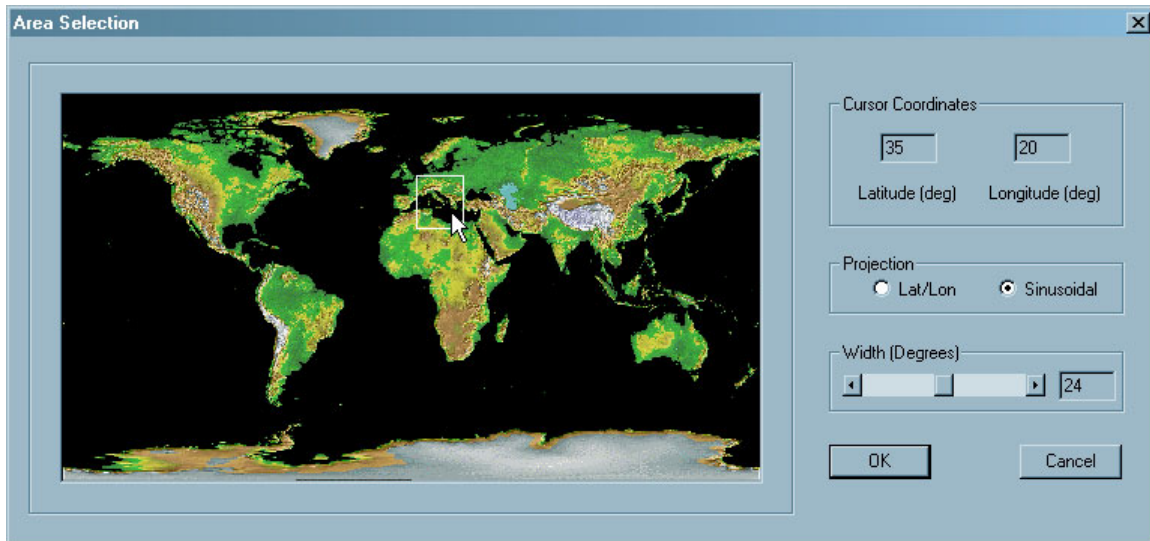
Select a geographic location by clicking and dragging the white outline rectangle on the map of world. Adjust the width of the selected area in degrees using the horizontal slider control provided. Once you have selected a geographic area, click "OK" and 3DEM will prompt you in sequence to locate and load the GLOBE tiles that are needed to construct the desired map. A file dialog, with the name of the file to be located contained in the title bar, will appear for each file in sequence. You must locate and load each file that is named in the title bar of the file dialog. Once all files have been loaded, 3DEM will proceed to draw an Overhead View of the selected area.

3DEM provides a choice of either "Lat/Long" or "Sinusoidal" map projection when loading GLOBE DEMs. The Lat/Long projection produces a rectangular surface grid with equal extension in latitude and longitude. The disadvantage of the Lat/Long projection is distortion at high latitudes. If you are creating images at high latitudes, try the Sinusoidal projection, which produces a surface grid corrected for latitude and a more realistic Overhead View and 3D projection.

3DEM can process high-resolution LIDAR point cloud files to produce Digital Elevation Models and 3D terrain views. LIDAR data are generally not free, although there are a few sample files available on the Internet. LIDAR data create such wonderful Digital Elevation Models that the cost involved may be justified.


Digital Elevation Model Created from LIDAR Data
(one-half meter grid resolution)

3DEM can process LIDAR data in LAS file format 1.0 or 1.1. LAS is a public file format for the interchange of LIDAR data, which has become a nearly universal standard. Choose "File - Load Terrain Model" from the Overhead View menu to bring up the "DEM File Type" dialog box. Then select "LIDAR" and use the LAS file selection box to choose one or more LAS files for processing. 3DEM will examine the list of selected files and determine the types of returns that are available and calculate point densities for each.

You will then be presented with the "LIDAR Terrain Specification" dialog box for selection of the LIDAR returns to be processed and selection of the desired grid resolution for the resulting Digital Elevation Model.
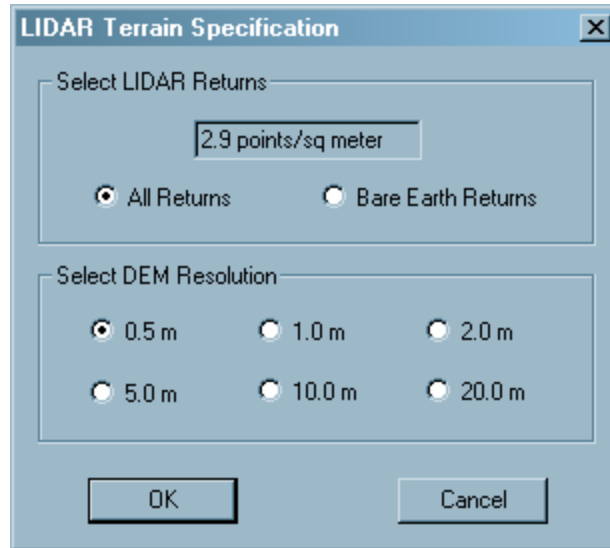
Each LIDAR pulse can produce several distinct returns from vegetation, structures, or the bare earth. Although all LAS files do not do so, the LAS file format has provision to identify each return as to its sequence number and probable source. 3DEM will give you the choice of using All Returns, or Bare Earth Returns if this classification information is available in the LAS files.

You are also given a choice of the grid resolution of the DEM that will be created from the LAS files. The choices range from 0.5 meter to 20 meter grid resolution.   Smaller values result in a higher resolution Digital Elevation Model, but at the cost of increased processing time.   The LIDAR point density (points/sq meter) is given for each LIDAR return type. In general, the 0.5 meter grid resolution should not be attempted for point densities less than about 3 points/sq meter, and the 1.0 meter grid resolution should not be attempted for point densities less than 1 about point/sq meter.

LAS files can be enormous in size, and processing time can be several minutes. A good strategy for very large LAS files (or groups of files) is to first view the entire area at 5 meter resolution. Then choose "Operation - Select Smaller Area" (or function key F8) from the Overhead View menu and move in to a smaller area that can be viewed at very high grid resolution. A 1600 x 1200 computer screen has less than 2 million pixels, so it is impossible to see all the detail on the screen in a 1 km square DEM at 0.5 meter grid resolution without moving in to a smaller area of interest.

XYZ COORDINATE POINT FILES

3DEM will read files containing groups of XYZ points recorded as either ASCII floating point values (*.txt) or as double precision binary floating point values (*.bin or *.dat). X, Y, and Z values must all be in units of meters. ASCII values must be organized as X, Y, and Z floating point numbers separated by spaces. Binary values must be double precision (64 bit) floating point XYZ values in sequence. These files are assumed to contain a cloud of ungridded scattered points. An example of groups of ASCII points in this format is as follows.

<div align="center">

359936.13 4348805.50 17.74
359935.60 4348805.50 17.80
359935.07 4348806.00 18.27
359934.28 4348802.00 -25.74
359933.75 4348802.00 -25.78

</div>

3DEM will sort through all of the points and create a terrain grid by extrapolation. Choose "File - Load Terrain Model" from the Overhead View menu to bring up the "DEM File Type" dialog box. Then select "XYZ Point Cloud" and use the file selection box to find the appropriate file.

You will then be presented with the "Terrain Specification" dialog box for selection of the desired grid resolution for the resulting Digital Elevation Model.
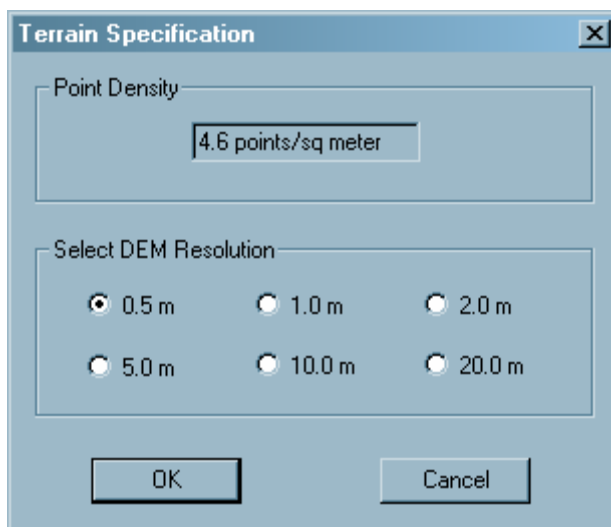
You are also given a choice of the grid resolution of the DEM that will be created from the XYZ file. The choices range from 0.5 meter to 20 meter grid resolution. Smaller values result in a higher resolution Digital Elevation Model, but at the cost of increased processing time. The XYZ point density (points/sq meter) is given for the selected file. In general, the 0.5 meter grid resolution should not be attempted for point densities less than about 3 points/sq meter, and the 1.0 meter grid resolution should not be attempted for point densities less than 1 about point/sq meter.

NASA MARS OBITER LASER ALTIMETER (MOLA) FILES

The MOLA Mission Experiment Gridded Data Records (MEGDRs) are global topographic map of Mars. MEGDRs have been produced at resolutions of 4, 16, 32, 64, and 128 pixels per degree. 3DEM will read and display MEGDR data of 64 and 128 pixels per degree.

MEGDR 128 Pixels Per Degree

The best resolution Mars data are contained in the 128 pixel per degree data set available from NASA at http://pds-geosciences.wustl.edu/missions/mgs/megdr.html in the MEG128 directory. There are 16 of these image files (*.img), each beginning with the letters "megt." Each file covers an area of 90 degrees width in longitude and 44 degrees height in latitude. The filenames specify the latitude and longitude of the NW corner of the included area. Each file is approximately 127 Mbytes in size.

It is highly recommend that all 16 files be downloaded and copied into a single directory on your hard drive. 3DEM will automatically merge the needed files as necessary to create a seamless digital elevation model.

MEGDR 64 Pixels Per Degree

The 64 pixel per degree data set is available at http://pds-geosciences.wustl.edu/missions/mgs/megdr.html in the MEG64 directory. There are 4 of these image files (*.img), each beginning with the letters "megt." Each file covers an area of 180 degrees width in longitude and 90 degrees height in latitude. The filenames specify the latitude and longitude of the NW corner of the included area. Each file is approximately 130 Mbytes in size.

 It is highly recommend that all 4 files be downloaded and copied into a single directory on your hard drive. 3DEM will automatically merge the needed files as necessary to create a seamless digital elevation model.

Using Mars MOLA Files

To use MEGDR files with 3DEM, choose "File - Load Terrain Model" from the Overhead View menu to bring up the "DEM File Type" dialog box. Choose "Mars MOLA" as the DEM file type, and you will be presented with a "Mars Area Selection" dialog box as shown below. Choose the "MEG 128" or "MEG 64" Topography Data Set and then select a geographic location by clicking and dragging the white outline rectangle on the map of Mars. Then click "OK."
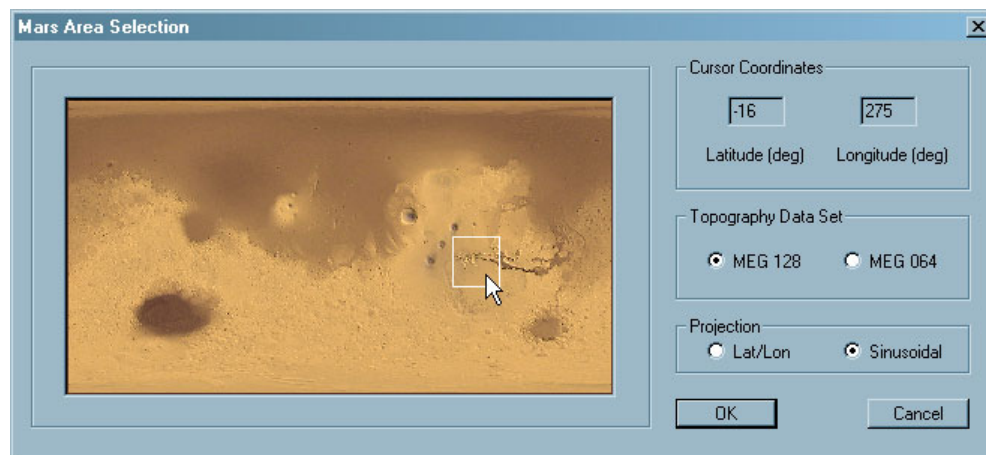
3DEM will then determine which MEGDR files are required and will present you with a file selection dialog box for locating these files. The first file to be located will be specified in the title bar of the file selection dialog box. The title bar will read something like "Locate MOLA MEGDR File megt44n180hb.img." Select this named file and click "Open." 3DEM will then proceed to read and merge all of the files needed to produce a digital elevation model and draw an Overhead View centered on the coordinates you have chosen. Usually two or three MEGDR files are required, and as long as they are located in the same file directory you will only have to locate the initial requested file.

3DEM provides a choice of either "Lat/Long" or "Sinusoidal" map projection when loading MOLA files. The Lat/Long projection produces a rectangular surface grid with equal extension in latitude and longitude. The disadvantage of the Lat/Long projection is distortion at high latitudes. If you are creating images at high latitudes, try the Sinusoidal projection, which produces a surface grid corrected for latitude and a more realistic Overhead View and 3D projection.

NASA MARS OBITER LASER ALTIMETER (MOLA) POLAR FILES

MOLA MEGDR data is also available separately for the north and south poles of Mars at http://pds-geosciences.wustl.edu/missions/mgs/megdr.html in the POLAR directory. Three data sets consisting of 128 pixels per degree, 256 pixels per degree, and 512 pixels per degree are available for each pole. There are thus 6 of these image files (*.img), each beginning with the letters "megt." Each file is 200 megabytes in size or larger. It is highly recommend that all 6 files be downloaded and copied into a single directory on your hard drive. 3DEM will automatically merge the needed files as necessary to create a seamless digital elevation model.

Using MOLA POLAR Files

To use MOLA POLAR files with 3DEM, choose "File - Load Terrain Model" from the Overhead View menu to bring up the "DEM File Type" dialog box. Choose "Mars Polar MOLA" as the DEM file type, and you will be presented with a "Mars Area Selection" dialog box as shown below.   Choose the 128, 256, or 512 pixel/degree Topography Data Set, and then select a geographic location by clicking and dragging the white outline rectangle on the map of Mars.   The green boundary rectangle indicates the geographic limits of data in the selected POLAR file.
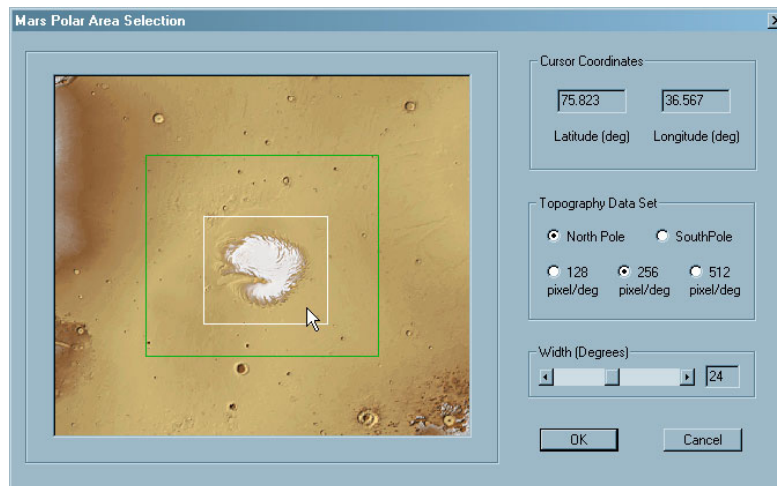
Adjust the width of the selected area in degrees using the horizontal slider control provided. Click "OK", and 3DEM will then determine which POLAR file is required and will present you with a file selection dialog box for locating this file.

The Mars POLAR files are very large and use a corresponding large amount of computer memory. At least 3 gigabytes of RAM is required to process an entire POLAR file at 512 pixels per degree. If you encounter a "Not enough memory" error when loading a POLAR file, try reducing the width of the selected area (as indicated by the white outline rectangle) using the horizontal slider control.

<p style="text-align:center">OTHER MATRIX FILE FORMATS</p>

3DEM can also read and display other matrix data files that are organized as rows and columns of elevation values. Elevation values can be read as ASCII, binary 16 bit integers, or binary 32 bit floating point numbers. Elevation values in the file must have been stored sequentially row by row (that is, row one followed by row two, etc) where each row is made up of sequential columns. Choose "File - Load Terrain Model" from the Overhead View menu, and select "Terrain Matrix" to bring up the "Matrix Data Format" dialog box. Choose "Files of Type - All Files" and then select the desired matrix data file. Note that if 3DEM finds a header file *.hdr of the same name as the matrix data file, it will assume that you are loading a terrain matrix file as described above. Otherwise, you will be presented with the "Matrix Data Format" dialog box for entry of the number of rows and columns, data format, grid spacing, etc. as described below.

DATA FORMAT AND OFFSET - Elevation data must be defined as signed 16 bit integers (INT 16), 32 bit floating point values (FLOAT 32), or as text values (ASCII). Also, if the matrix data file has a header section prior to the start of the elevation data, specify the header size here as "Offset" in bytes.

DATA BYTE ORDER - Specifies the byte order of the elevation data. Most data files produced by machines with Intel processors will contain "Little Endian" data in which the least significant byte is first in the data word. Other computers (such as the Macintosh) will produce files of "Big Endian" data in which the most significant data byte is first in the data word. You will find topographic data of both types on the Internet, and this selection gives you the option of processing both.

MISSING DATA - Some matrix data files will fill in missing data points with a fixed value other than zero. Sometimes a large negative number such as -9999 is used to distinguish missing data points. If you know this value, enter it here. Otherwise enter zero.

MATRIX DIMENSIONS - Specifies the matrix size as number of columns (width) and number of rows (height). Column order may be specified as West to East, or East to West. Row order may be specified as North to South, or South to North.

COORDINATE SYSTEM - 3DEM can display matrix data organized as Universal Transverse Mercator grids (UTM), rectangular Latitude-Longitude grids, or rectangular X/Y grids.

If UTM is selected, the UTM zone number and reference ellipsoid must also be specified. The UTM zone number can range from 1 to 60 and must be followed by the letter "N" or "S" to specify the northern or southern hemisphere (for example 17N).

The reference ellipsoid must be one of the following designations

<div align="center">

WGS84   NAD83   NAD27

</div>

If reference ellipsoid is not entered, a default selection of WGS84 will be utilized.

HORIZONTAL UNITS - Specifies the units of measure for grid coordinates. Horizontal units will automatically be set to meters for the UTM coordinate system, and to degrees for the Latitude-Longitude coordinate system. For the X/Y coordinate system, horizontal units can be either meters or feet.

VERTICAL UNITS - Specifies the unit of measure of elevation data stored in the data matrix (meters or feet). Either "Height" measurements or "Depth" measurements may be selected. Height measurements are normally used for surface terrain and imply that values increase with greater height above the surface. Depth measurements are normally used for bathymetry and imply that values increase with greater depth below the surface.

SW AND NE CORNER COORDINATES - Specifies the coordinates of the southwest and northeast corner of the matrix. These values must be in the same units of measure identified under Horizontal Units defined above.

MERGING DEMS

3DEM provides the capability to merge multiple DEMs to cover a large surface area at high resolution.

USGS 7.5 Minute SDTS DEMs in tar-gzip (*tar.gz or *.tgz) format can be directly merged by 3DEM. Choose "File - Load Terrain Model" and select "USGS DEM." Then you can select multiple DEM files from a common directory to be merged into one Overhead View. That is, all of the DEMs to be merged must be contained in the same file directory. To select multiple files, highlight each file required using the mouse, and then click OK to load all files into 3DEM. The only limit to the number of DEMs that can be merged is memory in your computer.

DEMs to be merged must be adjacent to each other. Note that merged DEMs do not always match perfectly at their boundaries since the quality and accuracy of each DEM can vary widely. 3DEM makes the best match possible with the selected DEMs.

Please note that 7.5' DEMs to be merged must be all of the same resolution. That is, 10-meter and 30-meter resolution DEMs cannot be mixed. Mixing DEMs of different resolution will result in an error message "DEMs Have Different Grid Resolutions."

Please note that 7.5' DEMs cannot be merged across UTM zone boundaries. You can check the UTM zone of each DEM by selecting "Operation - Show DEM Specs" from the Overhead View menu. Attempting to merge DEMs across UTM boundaries will also result in the error message "DEMs Are From Different UTM Zones."

Adjacent NASA Shuttle Radar Topography Mission (SRTM) digital elevation models can be directly merged by 3DEM. Place all files to be merged into a common file directory. Choose "File - Load Terrain Model" and select "SRTM Data." Then you can select multiple SRTM files from the common directory to be merged into one Overhead View. To select multiple files, highlight each file required using the mouse, and then click OK to load all files into 3DEM. The only limit to the number of DEMs that can be merged is memory in your computer.

Adjacent 3DEM Terrain Matrix Files can also be directly merged by 3DEM. Place all files to be merged into a common file directory. Choose "File - Load Terrain Model" and select "Terrain Matrix." Then you can select multiple terrain matrix files from the common directory to be merged into one Overhead View. To select multiple files, highlight each file required using the mouse, and then click OK to load all files into 3DEM. The only limit to the number of DEMs that can be merged is memory in your computer.

For GTOPO30 and GLOBE DEMs, 3DEM will automatically determine which DEM tiles must be merged to cover the surface area selected. See the previous description of GTOPO30 DEMs and GLOBE DEMs.

USING LANDSAT 7 IMAGES AS OVERLAYS

Landsat 7 images of the earth are available for free download from University of Maryland Global Land Cover Faclity (GLCF) at http://glcf.umiacs.umd.edu/data/. Landsat images can be easily located and downloaded from this site using a map of the world showing all available images. Images can also be selected by latitude and longitude limits.

Landsat 7 images have a resolution of 30 meters, which makes them suitable as overlays for large-area 3D terrain views with 3DEM.
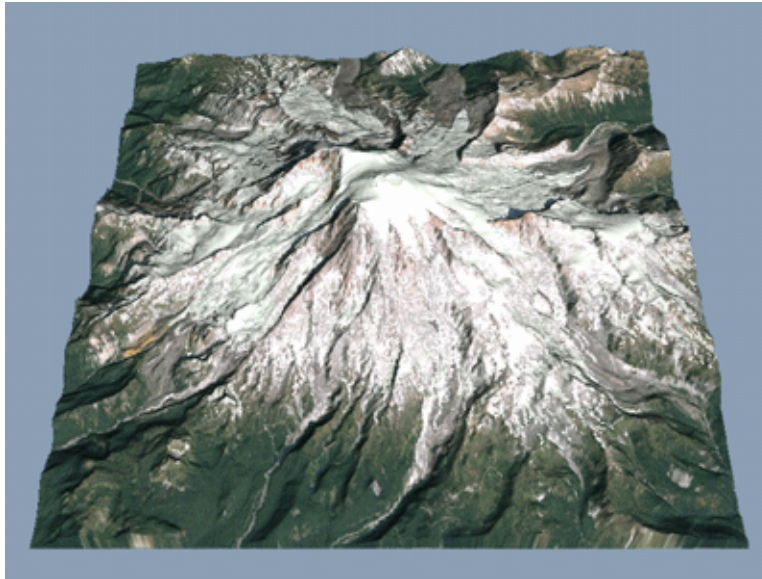
The best images to use with 3DEM are the orthorectified Landsat 7 Enhanced Thematic Mapper (ETM+) data.

Select "Landsat 7 ETM Data" from the GLCF web page, and then select "Map Search." Next check the "ETM +" box under "Landsat Imagery" and mark "Orthorectified" in the "Require" column.

Then click on the world map to locate the area of interest. Continue to click on the world map to zoom in to a level at which only four or five adjacent photographs covering the area of interest are shown. Click the "Select Window" icon (at top of the small map window) and then click "Preview and Download."

You will then be presented with a listing of the selected photographs from which you may choose to preview and/or download the associated files.

USING LANDSAT 7 IMAGES - Landsat 7 ETM images consist of grayscale geotiff images recorded in different color bands. Bands 3, 2, and 1 are a reasonable match to red, green, and blue visible light. So the concept is to combine these three separate grayscale images into a single RGB bitmap that can then be used as a terrain overlay in 3DEM. A graphics editing program such as Photoshop or its equivalent will be required to create the overlay bitmap.

First download the bands 3, 2, and 1 geotiff files. These are gzip-compressed files (*.gz) that usually end with the letters "nn30.tif.gz, nn20.tif.gz, and nn10.tif.gz". These are large files of about 30 megabytes each that can be decompressed using Winzip to about 60 megabytes each. It is also important to download the small metadata file (*.met), which contains information about the geographic coordinates of the image.

After decompression of the three geotiff files, combine them in Photoshop (or equivalent) into a single RGB color image. Usually some color adjustment is needed after combining. Typically it is necessary to add yellow to the color balance and to increase the image brightness and contrast. Every image will be a bit different, so some trial and error will be required here to obtain the most realistic looking terrain. Then save the combined image as a Windows bitmap file. This will be a very large image of perhaps 200 megabytes in size.

Now load the appropriate digital elevation models into 3DEM to create the 3D terrain surface. Then apply the merged RGB bitmap as a terrain overlay.   Manual georeferencing will be required since the RGB image contains no geographic coordinate information. You can use the latitude and longitude coordinates of the lower left and upper right corners of the image as given in the metadata file for manual georeferencing. 3DEM will trim the large bitmap file and save a small geotiff overlay file that can be used subsequently without going through the georeferencing procedure again and again.

It is also advisable to set the sun azimuth angle in 3DEM to match that of the original Landsat 7 image. You can read the original sun azimuth angle from the metadata file. Choose "Color Scale - Shaded Relief" from the Overhead View window and set the sun azimuth angle to the appropriate value.

Use of Landsat 7 images as overlays in 3DEM is not for the faint of heart. The overlay images are extremely large, and the memory utilization and processing time required are a severe test of 3DEM and of your computer. However, the beautiful results can be worth the time and trouble.

COMMON PROBLEMS

FAILURE OF 3D SCENE,
FAILURE OF TERRAIN OVERLAY

If 3DEM cannot generate a 3D scene, or if a 3D scene can be generated but terrain overlays cannot be applied, it is likely that the graphics card is not properly handling OpenGL rendering. Symptoms of this problem can include a program crash when attempting to create a 3D scene, a 3D scene that consists of a blank or completely black window, or entirely white or grey terrain after application of an overlay.

First determine if updated display drivers supporting OpenGL are available for your graphics card. Installing updated drivers will usually solve these problems.

If updated display drivers are not available, then go to the Windows Control Panel and select the Display controls. Disable all hardware acceleration or OpenGL acceleration in the display controls. This will bypass the graphics card hardware and allow OpenGL rendering to be performed in software. You might experiment with different levels of hardware acceleration to determine which settings are causing the OpenGL rendering failure.

MISSING Opengl32.dll

If your system does not have Opengl32.dll installed, you will receive an error message upon program startup. You can download the missing files from the 3DEM home page at

http://www.visualizationsoftware.com/3dem.html

FILES NOT RECOGNIZED BY 3DEM

File extensions must be of the proper type before files will load correctly.

3DEM expects that USGS 7.5 minute SDTS DEMs will be compressed files named *.tar.gz.

Uncompressed USGS ASCII format DEMs must be named as *.dem to be recognized by 3DEM.

3DEM expects that GTOPO30 DEMs will be compressed files named with SW corner longitude and latitude and a *.tar.gz file extension (example e020n40.tar.gz).

3DEM expects that GLOBE DEMS will be files named alphabetically as a10g through p10g.

3DEM expects that LIDAR files be named as *.las and follow the published LAS Format Specification (version 1.0 or 1.1).

3DEM expects that XYZ point cloud files be either ASCII (*.txt) or binary floating point (*.dat or *.bin). ASCII values must be organized as X, Y, and Z floating point numbers separated by spaces. Binary values must be double precision (64 bit) floating point XYZ values in sequence

Terrain matrix files must be named *.bin or *.txt and have an associated header file named *.hdr.

COMMON PROBLEMS (Continued)

STREAKED OR INACCURATE OCEAN SURFACE OR
OR INACCURATE SHORELINE

Rendering a 3D scene or flyby from high altitude where areas of terrain are near sea level can result in streaks in the ocean surface or inaccuracies in the shoreline.   This can be particularly annoying in flyby where the ocean surface or shoreline may flicker from frame to frame. First, try raising the sea level a few meters. Often this will remove the streaks or flickering. If raising the sea level isn't sufficient, use the Lowlands Terrain Type rather than the Island/Ocean Terrain Type to overcome this problem.

LOADING OVERLAYS TAKES A VERY LONG TIME

The time to load and resize large overlays (such as cropped DRG TIF files) may be lengthy (5 minutes or more) depending on the speed of your computer, and this is normal for 3DEM. Resizing must only be done once for each overlay file, and the resulting resized bitmap will be saved for subsequent use.

DIGITAL RASTER GRAPHIC OVERLAYS DON'T MATCH

To use DRG's as overlays, you must have a DRG created with the same coordinate system as the underlying DEM. You can read the characteristics of the DEM by selecting "Operation - Show DEM Specs" from the Overhead View menu. The DRG map chosen as an overlay should match the coordinate system information shown here. DEM and DRG maps that obviously tilt in different directions are an indication of a mismatch due to different coordinate systems.

Note that this restriction means that you cannot ordinarily overlay a DRG topographic map (UTM projection) directly on to a National Elevation Dataset DEM (Lat/Lon Projection). However, if you first convert the NED DEM to UTM projection, then a DRG overlay can be accurately applied. See Map Projection Conversion.

DIGITAL ORTHOPHOTO QUAD OVERLAYS DON'T MATCH

The Digital Orthophoto Quads (DOQs) from the Microsoft Terraserver at http://terraserver.microsoft.com/ or USAPhotoMaps from http://jdmcox.com/ generally use the WGS84 UTM ellipsoid as specified in an attached World File (*.jgw). For a proper match, you must be certain that the underlying DEM and DOQ overlay are actually from the same geographic area (or UTM zone) and that the underlying DEM also uses the WGS84 ellipsoid.

MEMORY USAGE

3DEM requires a large amount of memory, particularly if you are working with large overlay overlays. The program will run with only 512 Mbytes of memory, but will require a great deal of patience. 512 Mbytes is a practical lower limit, but 1 Gigabyte is recommended.

The Mars POLAR files are very large and use a corresponding large amount of computer memory. At least 3 gigabytes of RAM is required to process an entire POLAR file at 512 pixels per degree. If you encounter a "Not enough memory" error when loading a POLAR file, try reducing the width of the selected area (as indicated by the white outline rectangle) using the horizontal slider control.

When memory is in short supply, Windows programs will attempt to use the hard drive as virtual memory. When this happens to 3DEM, speed of operation becomes very slow. The best remedy for this situation is to take action to reduce the memory shortfall. This includes closing other running programs, choosing smaller sized maps, and of course installing more memory.

CREDITS

The following organizations or persons have provided free software via the Internet which has greatly contributed to the capabilities of the 3DEM program.

The late Mr. Sol Katz provided the SDTS to DEM conversion code and contributed the large library of useful GIS utilities at ftp://ftp.blm.gov/pub/gis/sdts/dem.

The code for all map projection conversion is derived from GeoTrans v 2.0.3 provided by the National Imagery and Mapping Agency (NIMA). GeoTrans can be downloaded from http://www.remotesensing.org/download/NIMA.php3.

The code for gz and tar.gz file decompression is derived from Steve Kirkendall's public domain source code for "untar.c".

Graphics format conversion and animation are provided by the Multimedia Conversion Library by Robert Tibljas and Zeljko Nikolic, available at http://www.gromada.com/index.html.

The global terrain image used in the Coordinate Selection dialog box for GTOPO30 and GLOBE DEMs was derived from GLOBE Documentation (ver 1.0).

Hastings, David A., and Paula K. Dunbar, 1999. Global Land One-kilometer Base Elevation (GLOBE) Digital Elevation Model, Documentation, Version 1.0. Key to Geophysical Records Documentation (KGRD) 34. National Oceanic and Atmospheric Administration, National Geophysical Data Center, 325 Broadway, Boulder, Colorado 80303, U.S.A.