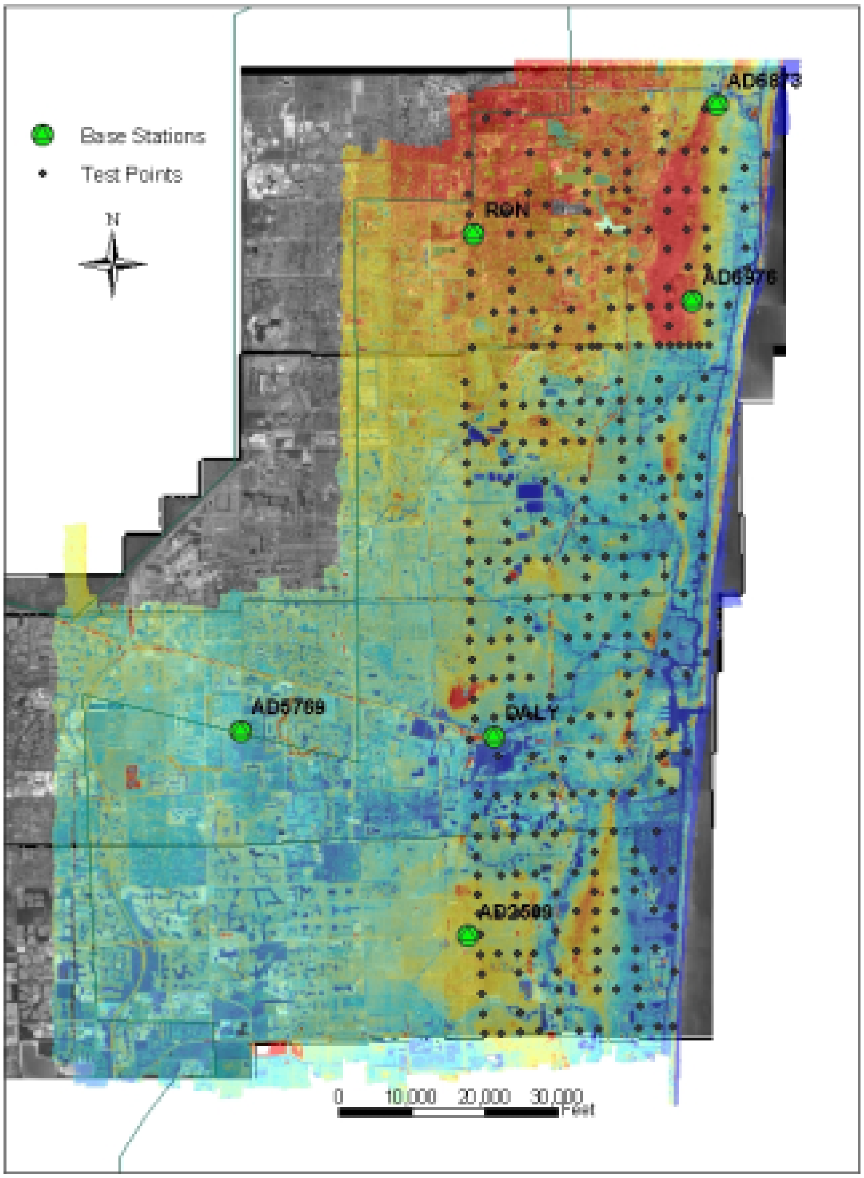
Visualization and Analysis of Gridded LIDAR Digital Elevation Data with ArcView Spatial and 3-D Analyst



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Introduction

In 2000- 2001, the International Hurricane Center (IHC) of Florida International University (FIU) was awarded grant funding by Federal Emergency Management Division (FEMA) and the Florida Department of Community Affairs (FLDCA), for a program entitled the Windstorm Simulation and Modeling project. Four tasks under this three year project included 1) the re-evaluation of existing storm surge; 2) data acquisition of high-resolution elevation data via LIDAR technology for participating South Florida counties; 3) computer simulation of findings for researchers and the general public; and 4) development of public awareness and education programs in regards to human vulnerabilities to hurricanes and the means to mitigate the risks. This project was also supported partially from matching funds provided from participating counties.

In 2000-2002, Florida International University (FIU) collected LIDAR measurements in eastern Broward and Palm Beach Counties. These data were processed and delivered to the Counties in the form of ASCII text point (x,y,z) files and gridded digital elevation models (DEMs). These datasets are also now available on the Internet at URL, http://gis.ihc.fiu.edu/website/lidar.

This workshop will explore applications of digital elevation models (DEMs) derived from airborne LIDAR measurements. The following exercises will demonstrate techniques for reading, visualizing, and analyzing gridded LIDAR data collected for these studies. The exercises will use ArcView GIS software and requires both the Spatial Analyst and 3-D Analyst extensions. It is assumed that the user will have some familiarity with both ArcView and its Spatial Analyst Extension. Sample datasets, scripts, and documentation required for these exercises are included on a CDROM.

Background

Airborne LIDAR (an acronym for Light Detection And Ranging) is an active remote sensing technology, which sends pulses of laser light toward the ground and detects the return times of back-scattered energy in order to determine ranges to the surface. Most LIDAR systems consist of three basic components (Figure 1): the laser scanner, the Inertial Measurement Unit (IMU), and a kinematic Global Position System (GPS). The laser scanner measures ranges to targets on a zig-zag shaped pattern beneath the flight path. Meanwhile, GPS and IMU measurements allow a continuous and precise determination of the aircraft's position and orientation. Data are recorded in flight and are later post processed to return X, Y, Z coordinates of the ground surface. Additional data analysis and filtering allows separation of non-surface features from the terrain surface. Finally, irregularly spaced points are usually interpolated onto a regularly spaced grid to produce a DEM.

In 2000-2002, Florida International University (FIU) collected LIDAR measurements in eastern Broward and Palm Beach Counties to assist emergency management personnel in revising their hurricane evacuation maps. Elevations were collected with an Optech ALTM 1210 LIDAR mapping system jointly owned and operated by FIU and the University of Florida. Data were collected as a series 600-meter-wide swaths consisting of points spaced approximately every 2.5 m (8 ft). beneath the flight path. Flight lines were spaced 500 m apart to allow sufficient overlap in order to avoid data gaps and to assess measurement repeatability. Each deployment typically took 4-5 hours during which GPS data were continuously recorded on both the aircraft and on the ground. In total 160 separate swaths consisting of over 700 million measurements were collected.

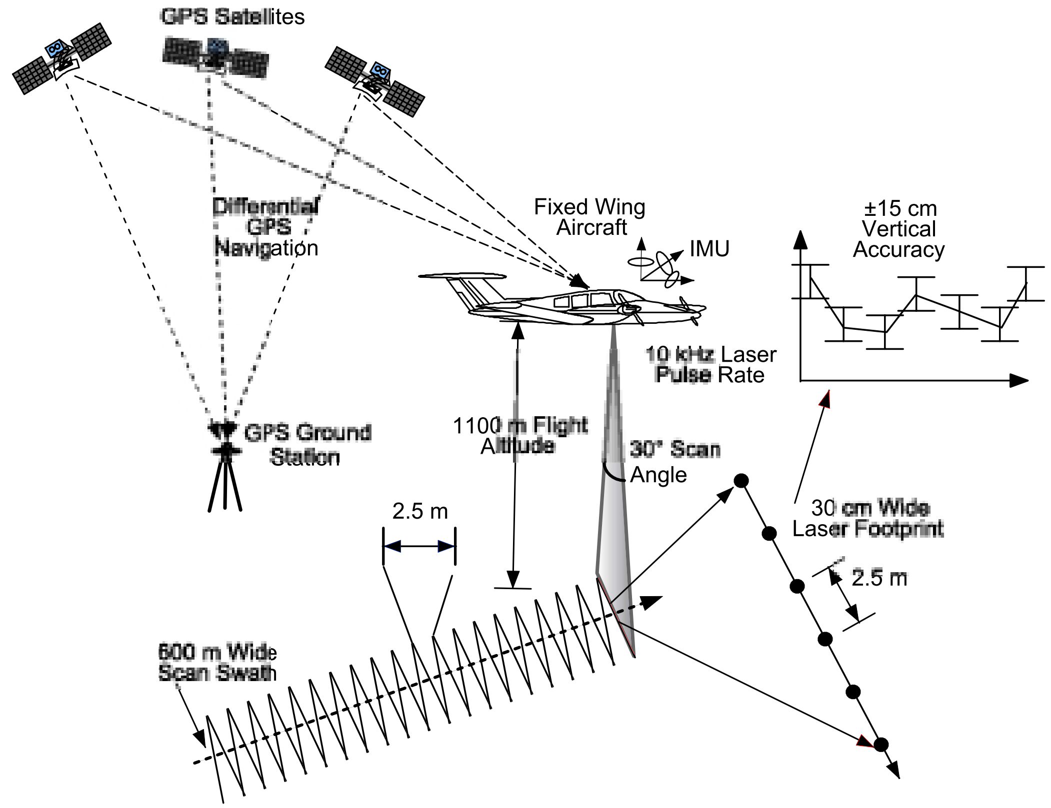


Figure 1. Schematic diagram showing the components of a typical airborne LIDAR system and the acquisition parameters used in the FIU data collection in 2000-2002.

The processing of the LIDAR measurements consisted of several steps and resulted in a variety of different datasets (Figure 2). Initially, measurements from individual swaths were output as 9 column ASCII text files containing the pulse time, the first pulse return (x,y,z coordinates and intensities) and the last pulse return. Then, the first and last return data were separated into two different data streams. Since the first returns often correspond to features such as buildings and trees, this stream was used to produce an unfiltered “top surface” dataset. In contrast, since the last return can correspond to the ground return beneath the canopy in vegetated areas, the last stop returns were used to produce the “bare earth” elevation data. For both data streams, horizontal coordinates were transformed from UTM coordinates to NAD83, State Plane, FL East zone feet and elevations were converted from GPS ellipsoidal heights to NAVD88 orthometric heights with the NGS GEOID99 model.

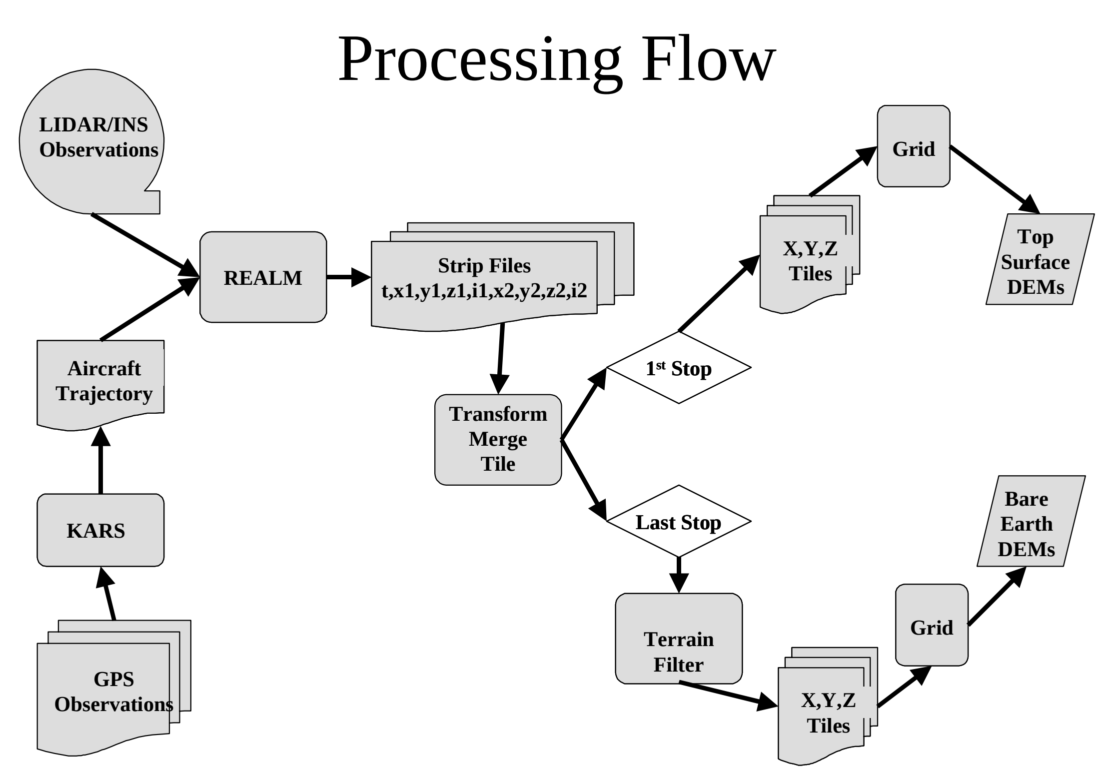


Figure 2. Diagram showing the processing flow ant the end product datasets.

Data from overlapping swaths were checked for internal consistency, combined and subdivided into smaller and more manageable sized portions. These "tiles" consisted of 5000 by 5000 ft blocks, each containing from 1 – 2 million points. The first return data for each tile was gridded using kriging interpolation with a linear variogram model and a 50 ft search radius to produce a set of 5 ft resolution, (1000x1000), DEMs. This DEM resolution was selected to be consistent with the 8 ft nominal point spacing.

The 2^{nd} return data consists of a 3-dimensional cloud of points corresponding to laser reflections off various objects. In order to model and visualize variations in the ground surface, reflections from non-ground features such as buildings, vegetation, and vehicles must be classified and removed. Since a given DEM pixel can often contain both ground and non-ground surface reflections, terrain classification is best performed on the raw, irregularly spaced laser points rather than on gridded data. After classification, the remaining ground surface points were gridded to produce a set of 5 ft resolution "bare earth" DEMs for each tile. As with the top surface data, kriging interpolation was used, except that a 150 ft search radius was used to interpolate over gaps left by removing vegetation and buildings.

For modeling and display purposes, a lower resolution dataset was produced by subaveraging the bare earth 5 ft pixels to 100 ft resolution. First a 21x21 focal mean filter was applied to each of the bare earth 5 ft resolution DEM tiles. Then the tiles were resampled by a factor of 20. Finally the tiles were mosaiced to form the 100 ft DEM

These subaveraged grids are comparable in horizontal resolution to the familiar USGS 30 m DEMs.

Exercises

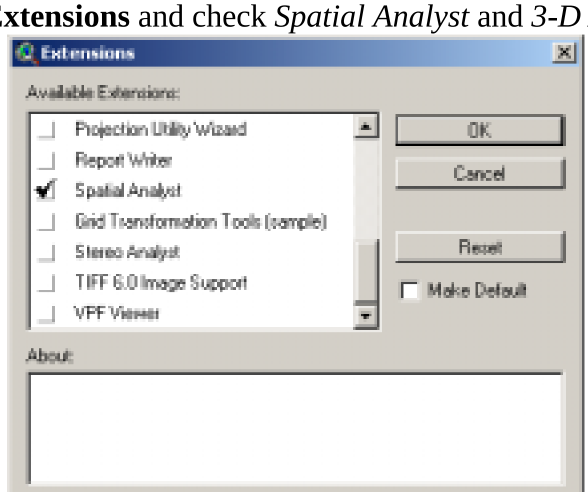
The exercises below require the ArcView *Spatial Analyst* and *3-D Analyst* extensions. Materials for the exercises are provided on the CD. Before starting the exercises, create a workspace directory on your hard disk named *arcws*. Copy all the files in the *sourcedata* directory on the CD to your *arcws* directory. Make sure that the full path name to *arcws* does not contain any spaces. For example, the path, *C:\exercises\arcws* is correct whereas the path *C:\My Documents\exercises\arcws* will cause an error.

Exercise 1: Data Import and Visualization

The gridded LIDAR datasets are distributed as ESRI Binary Raster format. The binary raster file format is a simple format that can be used to transfer raster data between various applications. It consists of two files, the IEEE floating-point file and a supporting ASCII header file. The header file must have the same name as the data file, but with a *.hdr* file extension. The data file will be a matrix of 32 bit signed IEEE floating-point values. The file will have a line of binary numbers for each row in the data set. The first line of data is the top row of the data set, moving from left to right. The binary raster file format can only be imported or exported using the Spatial or 3D Analysts. A description of this format can be found in the on-line help under *importing*. In this exercise, we will learn to import data from a tile into an ESRI GRID.

Step 1: Start ArcView, and load the extensions.

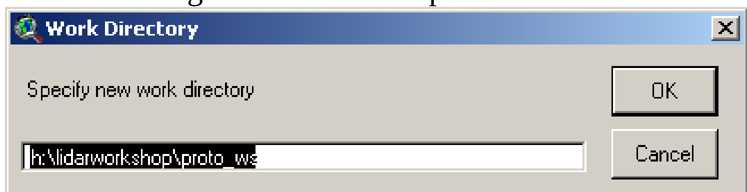
Start ArcView and create a new view. Make the View active. From the **File** menu → choose **Extensions** and check *Spatial Analyst* and *3-D Analyst*.



Click **OK**

Step 2: Set the Working Directory

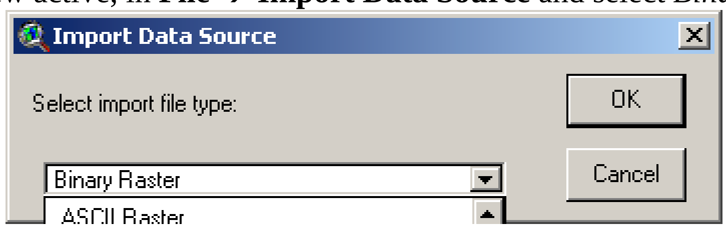
The Spatial Analysis extension is notorious for generating lots of files. In the Windows Explorer, create a sub-directory named *arcws*. Save your files and datasets in this directory. Make the View active and change the Work Directory (**File** menu→ choose **Set Working Directory**) to this directory in order to prevent datasets from being written to C:\temp.



Make sure to use the full path to this directory including the drive letter.

Step 3: Import the "bare earth" and "top surface" LIDAR grids.

Make the view active, in **File** → **Import Data Source** and select *Binary Raster.*



Navigate to the *arcws* directory and select the file, *940000_695000_z.flt*. This file contains the top surface DEM for the tile with lower left coordinates, 940000, 695000.

Click **OK.** Name the grid *940_695t*. Click **OK**. Add the grid as a theme to the View.

In a similar manner, import and name the 3 remaining grids:

945000_695000_z.flt → 945_695t
940000_695000_zf.flt → 940_695b
945000_695000_zf.flt → 945_695b

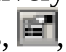
The latter 2 grids correspond to the "bare earth" DEMs for each tile.

Note: The Binary raster file format can also be imported using other methods

1. In ARC/INFO with the command line FLOATGRID command or GRID function.
2. In ArcToolbox: with **Import to Raster** →**Floating Point Data to Grid**
3. In another GIS/ Image Processing package with a generic binary float read and using the appropriate information in the *.hdr* file

For more information of the ESRI Binary Raster Format, see the help under: *Importing data from generic raster files*

Compare the Grid Theme Properties to the lines in the *.hdr* file. Make the Grid Theme, *945_695t*, active and zoom to the theme extents. Then, go to the Project (.apr) window and open a New script. In the **Script** menu, select **Load Text File**

,, and load the file *940000_695000_z.hdr* (alternatively, you can open this file in a text editor). Now examine the Theme Properties, , for *945_695t.* Understand the relationship between the theme corner coordinates (Left, Right, Bottom, Top) and the keywords in the .hdr file.

Q1a: Calculate the coordinates of the NE corner of the grid in terms of NCOLS, NROWS, XLLCENTER, YLLCENTER, and CELLSIZE.

Step 4: Visualizing the Elevation Grids

Color-coding is a common method for visualizing topographic surfaces . In color-coding, each elevation pixel is assigned a color on the basis of a *lookup table* (LUT, sometimes referred to as a colormap).

By default, ArcView assigns a monochromatic colormap which is stretched between the minimum and maximum grid values. Note how the color ranges of the top surface and bare earth DEMs differ, making it difficult to compare the two surfaces.

The default colormaps can be altered by editing the legends for each grid theme. Make the theme, *945_695t*, active and double click on the legend to open the legend editor. At this point, you may choose to edit the legend by manual or automatic classification and by selecting a different color ramp. We have saved you some time by creating a legend file. Click Load and select the legend file, *0-50topo.avl* and click OK. Click Apply in the Legend Editor.

Repeat this process for the other surfaces. Compare the top surface grids with the bare earth grids. Are you able to identify buildings and vegetation?

Shaded relief images are also useful for visualizing and interpreting surfaces. To create a relief image, make the grid theme active and select **Compute Hillshade** from the **Surface** menu. Complete this operation for the grid themes 945_695_t and 945_695_b.

Note: Compute Hillshade creates a *temporary* grid that is given an arbitrary name such as *hlshd2*. Temporary grids are deleted when you exit ArcView unless they are made *permanent*. To make a grid permanent, either save the project, in which case the grid will retain its original name, or select **Save Data Set** in the **Theme** Menu, at which time you will be prompted for a new name.

Color mapped grids my be combined with a shaded relief image to produce a *color shaded relief image*. To make a color shaded relief image, edit the grid theme legend and select **Advanced**. Select the appropriate hillshade layer as the Brightness theme. Click **OK** and **Apply**.

Step 5: Create 1 foot contours

Contours also provide a useful means for visualizing surfaces. Spatial Analyst provides a useful tool for generating contours from grids. Contouring involves the weaving of isolines between the pixels of the grid to give the illusion of terrain.

Contour the bare earth elevations for tile 945000_695000. First, make the grid theme, *945_695_b* active. Then select Create Contours from the Surface menu. Enter a Contour interval of 1, base contour of 0. Click OK.

The contour shapefile will be added to the view. Turn the contour theme on. Compare the contours to the grid theme. Which one do you feel is more useful for understanding the ground surface?

Step 6: Overlay orthophotos on the elevation grids

Digital orthophotos are created from aerial photographs and are a common source of geospatial information. LIDAR elevation grids can provide a useful tool in the interpretation and use of this imagery. Similarly, orthophotos can be extremely useful in interpreting LIDAR elevations.

One foot resolution digital orthophotos of each tile, *940_695.tif* and *945_695.tif* are located in the *arcws* directory. Make the view active and add these orthophotos as image themes, . Turn the image themes on and then move them below the grid themes in the View legend.

Zoom to the extent of *945_695.tif*. Compare the bare earth and top surface grids with the orthophotos. Consider the following questions:

1. Examine the top surface grid theme, 945_695t. Identify the parts of the grid that have the value of NODATA. Compare this NODATA region on the orthophoto. To what feature does this NODATA region correspond? Why might there be no LIDAR elevations over this type of feature?
2. Examine the bare earth grid theme, 945_695b, at the same location. Is there any NODATA here? If not, why (Consider the different search radii used for gridding each of these layers)?
3. Zoom to the forested area in the NW quadrant of the tile. By comparing the bare earth and top surface grids, the contours, and the orthophoto, determine how effective the filtering process is in heavily wooded areas.

Zoom to the extent of *940_695.tif*. Zoom into the residential area in the SW quadrant of the tile. Compare the bare earth and top surface grids with the orthophotos. Note how using LIDAR elevations with the orthophotos is more effective in identifying ground features than orthophotos alone.

Save your project as Ex1.apr. We will use the same grid and image themes in the next exercise.

Exercise 2: Information Extraction

LIDAR elevation data is a potentially rich source of information that can be applied to a variety of disciplines. ArcView Spatial Analyst provides several tools for querying and extracting elevation data. Some of these tools are available from the default menus and buttons such as the **Identify** tool, , on the **View** button bar. Others are accessible from Avenue scripts. In this exercise, we will learn to extract elevation information at points, along lines or profiles, and within polygons.

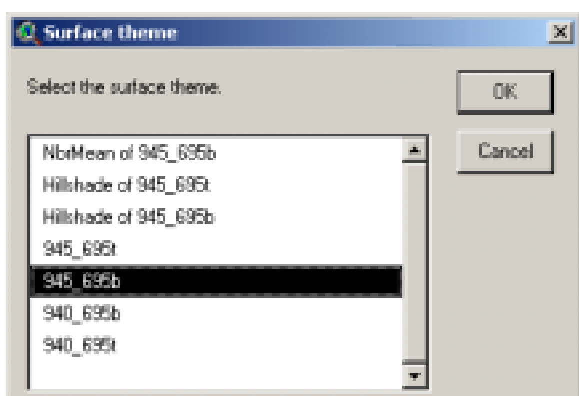
Step 1: Point query and extraction.

One common practice is to compare the values of lidar elevations with elevation data determined by a method of higher accuracy such as conventional surveying. This procedure is known as "ground truthing", and is necessary in order to evaluate the accuracy of a given dataset. In this step, we will interpolate the elevations of the LIDAR grids to the locations of points in a shapefile. An Avenue script, *gridspot.ave*, located in the *arcws* directory, will interpolate the values of the elevation grid to each point and write the results to a field in the point attribute file. Gridspot is modeled after the ARC command, LATTICESPOT and uses the *Avenue* function pointvalue which interpolates the value at a point from the values of the 4 nearest grid cell centers.

Zoom to the extents of tile *945_695*. Click the Add Theme button, , and load the shapefile *Pba_profile.shp*. This theme contains the x,y,z coordinates of a ground survey profile collected on the taxiway of the airport. Turn the theme on. Open and examine the theme table, .

Create a new script and make the script window active. Select the Load Text File icon, , and load the file, *gridspot.ave*. Edit the script properties and name the script *gridspot*. Compile the script by clicking on the icon.

Go back to the View window and make the *Pba_profile.shp* theme active. Then, select the *gridspot* script window and click the Run icon, . You will be prompted to select a surface theme.



Select the bare earth grid, *945_695b*. Use the default name, *945_695b* for the spot field. Click **OK**.

Go back to the View window and make the *Pba_profile.shp* theme active. Open the theme attribute table. Notice how a new field, *945_695b*, containing the spot elevations has been added to the table. Repeat the above procedure with the top surface grid, *945_695t*, adding a similarly named field.

The ground truth data may be compared with the interpolated surface values by means of a scatter plot. ArcView has some capability for plotting scatter plots, however, it is very poor. In order to view our extracted data, we will export it to a text file and graph it in M.S. Excel.

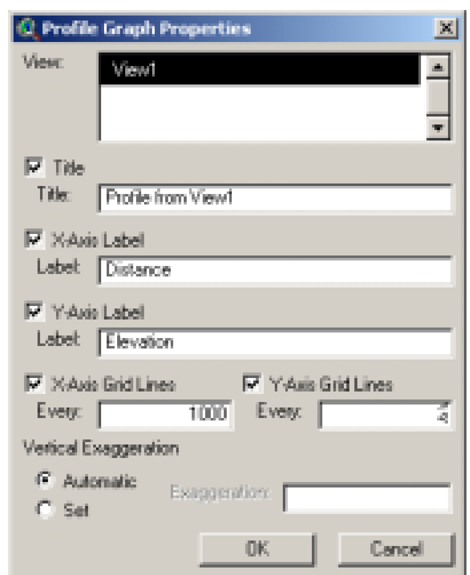
First, make the attribute table active. Then from the **File** menu, select **Export**. Export to a Delimited text file named *pba_profile.txt*. Now, start Excel. Open the file as comma delimited text. Then using the chart wizard, graph the 3 elevation values.

Step 2: Extracting elevations along a profile

Extracting elevations from a surface along a line is known as profiling. Profiles are often used to visualize elevation changes along linear features such as streams or road centerlines. In order to construct a profile, surface values are interpolated to points located at specified intervals between vertices of a line or polyline. In this step, we will use some of the built-in functions in *3-D Analyst* to extract and graph profiles from surfaces. This function allows profiles to be extracted from either 3-D line graphics or from 3-D shape files. The surface providing the heights may be either a grid or a TIN.

To extract a profile from a 3-D line graphic, make the View window active and zoom to the extent of *945_695.tif*, the image of the airport. Make only the TIF image visible by moving it to the top of the legend; this theme will serve as a reference for drawing your profile line. Then, make the grid theme *945_695b* active; this theme will provide the heights for the profile line.

Choose the **Interpolate Line** tool, , from the toolbar. Bring the cursor into the view window over the NW end of Runway14 (the NW-SE trending runway) and click the mouse. Move the cursor to the SE end of the runway and double click (you may add intermediate vertices by single clicking). This will create a 3-D graphic.



Move to the **Project** window, select Layouts and create a new Layout. Select the Profile Graph tool, . Using the cursor, define the area on the page where you want the graph. In the **Profile Graph Properties** dialog, choose the view containing the selected 3D lines that you want to graph. Choose appropriate numbers for the X and Y axis Grid lines.

Profiles may also be extracted from line themes. Load the shapefile, *pomp_r5.shp*. In order to extract a profile from this shape, it first needs to be converted to a 3-D shapefile. First, activate the theme and select **Convert to 3D Shapefile** from the **Theme** menu. Get the Z values from **Surface**, selecting *945_695b*, as the height source. Use the default sample distance. Click **OK**. Name the theme *pompr5_3d* and add the theme to the View. Make the view active. Finally, open a Layout and in a manner similar to the previous example, create a profile graph.

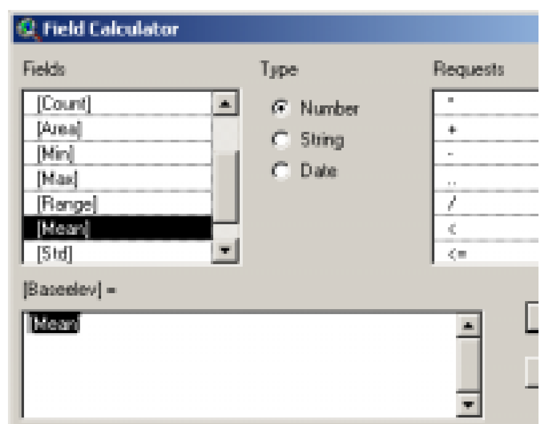
More elegant options for extracting profiles can be found in ARCPLOT, ArcMap, or in user submitted Avenue scripts available at the ESRI website.

Step 3: Polygon Zonal stats: height and base

Load the polygon theme houses.shp. Open the attribute table. The attribute table contains fields corresponding to a unique id for each house as well as empty fields for the base elevation, top elevation, and height. The Summerize Zones function will be used to calculate the mean base and top elevation for each house.

In the **Analysis** menu, select **Summarize Zones**. Select the Id field to define the zones. Then, select the grid theme *940_695b* to define the base elevation of each house. Click **OK**. Next, choose the *Mean*, for the statistic to chart.

This procedure will create a theme table (named: *Stats of 940_695b Within Zones of Houses.shp*) containing various statistics for each house. In order to assign the mean elevation for each house to the *Baseelev* field in the attribute table, we will have to *join* the tables. First, make the stats table active. Select the Id field. Next, open the theme attribute table for *houses.shp* and select the Id field. Finally, select **Join** from the **Table** menu. This operation will append the statistics to each record in the attribute table.



In order to assign a value to the *Baseelev* field, select **Start Editing** from the **Table** menu table. Then select the *Baseelev* field. Next, select **Calculate** from the **Field** Menu. The field Calculator will open. Double click on the *Mean* field and click OK. Finally, select **Remove All Joins** from the table menu.

Repeat the above procedure using Summarize Zones for the grid theme, 940_695t. Similarly, join the statistics to the attribute table and assign the Mean to the *Topelev* field with the field calculator. Again, select **Remove All Joins** from the table menu.

Finally, calculate the height of each house by subtracting *Baseelev* from *Topelev* in the Field Calculator. When you are done, select **Stop Editing** from the **Table** menu and save your edits.
Save your project as Ex2.apr.

Contents of the CD

The CD included with this manual contains materials used in the exercises as well as other data of interest.

LIDARworkshop.pdf Adobe PDF file of this manual

sourcedata Materials used the exercises. All coordinates are in State Plane, FL East zone, NAD83 Feet

Top Surface 5 ft LIDAR DEMs
940000_695000_Z.flt, 940000_695000_Z.hdr
945000_695000_Z.flt, 945000_695000_Z.hdr

Bare Earth Surface 5 ft LIDAR DEMs
940000_695000_Zf.flt, 940000_695000_Zf.hdr
945000_695000_Zf.flt, 945000_695000_Zf.hdr

1 ft resolution orthophotographs provided by Broward Co.
940_695.tif, 945_695.tif

Scripts and Legends

0-50topo.avl	Legend file at 5 ft categories for displaying elevations 0 - 50 ft
gridspot.ave	Avenue Script for interpolating spot elevations from a grid to points in a shapefile.

Shapefiles

pba_profile.shp	Points surveyed at Pompano Beach Airport
pomp_r5.shp	Runway 5
houses.shp	

samples Sample datasets and scripts. All coordinates are in State Plane, FL East zone, NAD83 Feet unless otherwise specified

strip_a1.asc.gz	Compressed 9 column (t,x1,y1,z1,x2,y2,z2,i1,i2) strip file. Horiz coordinates are in UTM17 NAD83 meters, heights are ellipsoidal meters
940000_695000_150.asc.gz 945000_695000_150.asc.gz	Compressed Top Surface x,y,z Point files
940000_695000_150f.asc.gz 940000_695000_150f.asc.gz	Compressed Bare Earth x,y,z Point files

Broward_sub100.flt, Broward_sub100.hdr Subaveraged 100 f LIDAR DEMs
Pbeach_sub100.flt, Pbeach_sub100.hdr

vertcon94e.asc Vertcon Grid (ASCII raster import format) for SE United States (Decimal Degrees, 0.05 deg interval)

br_pb_tileindex_dd.shp Tile index

altm_scatter.ave

Contact Information

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