Fault Zone Mapping with Differential Lidar
By Mike Oskin – Revised September 19, 2013

INTRODUCTION: This tutorial is designed to teach you to map well-expressed, fresh fault scarps on lidar topography and differential topography, using data from a portion of the 2010 El Mayor-Cucapah earthquake rupture. The area we will be working in is a complex stepover from the Borrego fault across the Paso Inferior Accommodation Zone in the northern Sierra Cucapah. The post-event data were collected by NCALM in August 2010 in response to the earthquake. The pre-event data are part of a regional survey of the Colorado River delta collected in 2006 and provided to us by INEGI.

There are several stages to setting up a GIS mapping project. For this exercise we will be keeping things simple. First we will generate a difference map from the two lidar data sets, then we will visualize and take cross-sections of the data. Lastly we will practice mapping fault scarps into a line feature class.

PART 1. Using Raster Calculator to Difference DEM data

Important! Many functions in ArcMAP are based on antiquated unix-style subprograms. These subprograms fail when given filenames that violate the rules (below). Pathetically, the default directory "My Documents" violates three of the four rules! You may not encounter problems right now, but following the rules now saves you from mysterious crashes later.
The 'Rules of Names'
   1. **Filenames must be 12 characters or less**
   2. **No spaces in the filename or path**
   3. **No capital letters in the filename or path**
   4. **You must use a letter as the first character of a filename**

1. Start an ArcMAP project and load in all of the data in the exercise 3 directory. You will want to build pyramids, if asked. The directory should contain the following grids of data (note the short names that obey the rules, above):

postdem	0.5 m-pixel DEM generated from post-even lidar
postdem5m	5m-pixel DEM generated be smoothing and resampling postdem*
posths4545	0.5m-pixel hillshade of postdem with 045° sun azimuth and sun angle of 45°.
postslope	0.5m-pixel slope map (in dimensionless units) derived from postdem.
predem	5m-pixel DEM provided by INEGI.
geoid	5m-geoid correction model, smoothed from a much coarser geoid model.

*smoothing was performed using focalmean function with 10 pixel (5m) radius. This step takes too long to repeat in class so we have provided the smoothed and resampled DEM for you to work with.

2. Use raster calculator to generate a difference map between pre- and post-event DEMs. The raster calculator is found in the Arc Toolbox->Spatial Analyst Tools->Map Algebra->Raster Calculator. You need to check out the spatial analyst license under tools->extensions to use this tool.

First, we need to remove the geoid correction from the pre-event DEM. Most research lidar data sets are delivered in ellipsoid height, without correction for the geoid. The difference between ellipsoid and geoid height can be significant (about 34m in our study area). Because there is no one right 'answer' for the geoid it is often better to work with ellipsoid heights when differencing DEMs. To remove the geoid correction from the pre-event data, add the geoid correction and predem grids in raster calculator:

predemgc = [predem] + [geoid]

The next step is to produce a difference map. This is just as easy as the previous step. Go to the Raster Calculator again and enter the following:

diffdem = [postdem5m] - [predemgc]

For each of these calculation steps the resulting DEM will show up in the table of contents. Now you can go ahead and visualize the results! Using the 5m diffdem as a transparent overlay on the hillshade or slope map works very well. Try one of the bi-color color ramps, with a custom scale from -3 to +3m.

PART 2. Topographic cross-sections

3D Analyst: The 3D analyst toolbar provides several useful functions. For this part of the exercise you will learn to generate topographic profiles. Find the 3D analyst toolbar the same way you did for Spatial Analyst. Once again, you may need to check out the extension for the toolbar to operate.

1. Use the cross-section tool to examine fault scarps. Select the line button on the 3D analyst toolbar (it looks like a line hovering over a square patch). Under the 'Layer' drop-down toolbox, make sure that the 'postdem' is selected. Now choose an interesting area of faulting (there are many) and click once to start a cross-section line. Double click at the other end to finish the line. There will be a long pause while ArcMAP finds and samples the DEM. Once this is processing is complete, the cross-section button should be visible on the 3D analyst toolbar (this button looks like a tiny graph). Click this button (while the cross-section line you just made is selected) and a graph of the topographic profile will appear. You may reshape the plot window to rescale the graph. Bonus feature: right clicking the top of the plot window will provide access to a properties menu, from which you may change the plot or even more usefully, export the data to a spreadsheet.

2. Use the cross-section tool again, only this time to look at the difference map. To do this, switch the layer in 3D analyst to 'diffdem' then define a new cross-section line. Cross-sections of the difference layer show the apparent elevation change of the surface (it apparent because horizontal motions are not corrected). Because of coseismic horizontal motion, areas of steep slopes show strong uplift or subsidence correlated with slope-aspect (facing direction). It is especially interesting to take very long cross-sections around faults in low-slope areas to capture subtle fault-related folding. You may also search for smaller fault-controlled features, such as subsidence or uplift in stepovers between faults.

PART 3. Setup of ArcGIS mapping project

ArcCatalog: ArcCatalog is a general-purpose data management utility that comes as a part of the ESRI ArcGIS package. In ArcGIS 10 ArcCatalog is available as a tab on the right side of the screen.

1. Create a new workspace folder in a location that is safe for the rules of names. For example, the common default working directory for ArcMAP is C:\workspace. Navigate to this folder in ArcCatalog using the tree view on the left side of the screen. Then right click in a blank area on the right side of the screen and select New->Folder. Name this folder for your project (*follow the rules!*) and then double click this new folder to navigate to your new workspace.

2. Create a shapefile to contain your fault map. Right click in the blank space on the right side of ArcCatalog and select New->Shapefile. Name the shapefile 'faults'. On the down-drop box, change the shapefile type from 'points' to 'polylines'. Assign a spatial reference to your shapefile by clicking the 'edit' button. Select Projected Coordinate Systems->UTM->WGS 1984->Northern Hemisphere->WGS 1984 Zone 11N. Don't check any of the checkboxes. Hit 'OK' to complete the shapefile. Note that it is automatically added in to your map project.

3. Create a custom attribute in your shapefile to denote the type of faults you are mapping. Double click the 'faults' shapefile. In the pop-up box that appears, click on the 'Fields' tab. Type 'linetype' on the blank line beneath 'Id'. Next click the adjacent blank box under 'data-type' and select 'Short Interger'. Click OK at the bottom of the screen to commit your changes to the shapefile.

4. Create subclasses for your fault types using the 'linetype' attribute. Double click on the 'faults' shapefile in the table of contents of your map project (left side of screen). In the window that pops up, click on the 'Symbology' tab. On the right side, change the 'Show:' menu from 'Single symbol' to 'Categories.' Under 'Categories,' select 'Unique values.' Next to this, change the 'Value field' from 'Id' to 'linetype'. Now go to the bottom of the pop-up box and click 'Add Values'. Another pop-window will appear. At the bottom, enter 0 and hit 'Add to List.' Do this again for 1 and 2. You should now see these listed under the 'Value' column. Under the 'Label' column, ender the following linetypes:

<Heading>	linetype
0	undefined
1	certain
2	uncertain

You might think of other useful linetypes. Feel free to add codes for as many line types as you like. Once complete, hit 'OK' to finish this step.

5. Create custom line symbols in ArcMAP so you can keep track of your mapping. Double-click the line next to 'certain' in the table of contents on the left side of the screen. This will bring up a 'Symbol Selector' pop-up box. There are a lot of options for symbols under the 'Style References' menu. We will make our own scarp symbol for this exercise. This is a complicated, multi-step process that is worthwhile to learn:

- Click on 'edit symbol' to bring up the 'Symbol Property Editor' pop-up box. Change the type (top of the box) from 'Simple Line Symbol' to 'Cartographic Line Symbol'. It will default to a black line. Change it to red to make it easier to see against your grayscale DEM.
- Add a second line to this symbol to make tics on the line. Click the + in the lower left to add another black line layer. Change this to red color as well.
- Offset this second line from the first. Click on line properties. Click the up arrow twice next to offset so that it reads 2. Look in the 'Preview' window to see that you now have two parallel, offset lines.
- Make this second line dashed. Click on the 'Template' tab. On the ruler below, click and hold on the little gray square. Drag it to the right by seven tics. Click once near the beginning of the line to turn one of the tics black. Now the 'Preview window should show one of the lines as a row of dots.
- Lets make these dots into tics. Go back to the 'Cartographic Line' tab (next to 'Template') and click the up arrow next to Width until it reads 4. Now the 'Preview' window should look like a red line with tics on one side.
- Click OK on the 'Symbol Property Editor' box, and then click OK on the 'Symbol Selector' box.

Now take a few minutes on your own to try to make a dashed line with tics for your 'uncertain' linetype. Ask the instructors if you need assistance. You can leave the 'undefined' line type alone or change it to something more visible (a simple yellow line, for example).

PART 4. Mapping of faults in ArcMAP

Now is a good time to save your work. Do it now, and do it often. ArcMAP will crash. I guarantee it.

Step 1. Start Editing. Find the editor toolbar. If its not visible, the pencil icon with three points will make it appear. On this toolbar, hit the 'Edit' button and select 'start editing.' A pop-up box will appear to ask what features you wish to edit. Highlight your 'faults' shapefile and hit OK. A 'Create Features' menu will appear on the right side of the screen where the ArcCatalog was. In it you will see buttons for each of your line types (undefined, certain, uncertain).

Step 2. Draw a line. To draw a certain fault, click the 'certain' button. Find the end of a fault scarp on your map. Click on the trace to start making a line. Keep clicking to add points (vertices in arc-speak) to the line. Try to locate the line precisely within the steepest part of the scarp. Keep clicking along the fault scarp until you have reached the other side. Its OK to grab the zoom or hand tools to move the map around as you edit. Just choose the pencil icon again to keep working on your line. Once its complete, hit F2 to 'Finish Sketch.' Don't worry if you made a mistake somewhere along the line. After you have finished the sketch you can go back, double-click the line, and move around each point or right-click to add or subtract points. Once you are satisfied with the line just hit F2 again.

Some useful tips:

Moving while editing: Holding down the 'C' key will temporarily bring up the hand tool, allowing you to grab and pan the map. Let go of 'C' to return to editing your line. Similarly, 'Z' will bring up the zoom-in tool, and 'X' will bring up the zoom out tool. These are very useful keyboard shortcuts.

Snapping: Snapping is used to ensure that lines meet up correctly. This is especially important if you are making a complete geologic map of an area and need to build polygons from your lines. While adding a line, you can find the snapping options by right-clicking and selecting 'Snap to Feature' from the options. You may also use these shortcut keys useful to aid with snapping:

Snap to End Point: Ctrl F5   *line ends or junctions*
Snap to Edge: Ctrl F8   *very useful for T intersections*

Editing lines: If you want to change a line, or add points to it, all you need to do is double click it with the editing arrow (the arrow on the editing toolbar). The individual points will show up as green boxes that you can grab and move. You can also right click on the line to add a point, or right click on a point and delete it. Click off of the line to finish editing.

Flipping lines: Lines in ArcGIS have a direction (a beginning and end). You always add points to the end. Asymmetric line symbols, such as a line with tics on one side, will be oriented one way or the other depending on the line direction. 'Flipping' a line changes this direction. This is useful for adding points to the other end of the line, or for flipping the orientation of the line symbol. To flip a line, double-click it with the editing arrow show that the points are editable. Then right click on the line and select 'flip'.

Notes on saving your work: Just in case ArcMAP crashes you should periodically save your editing work. It is important to understand that ArcMAP acts as an interface to your data. Your project file does not contain your data. The data (lines, etc.) are stored in your 'Personal Geodatabase.' Periodically you should 'commit' the changes you have made to your database. To do this, click the 'Edit' button and select 'Save Edits.' This is not the same as saving your ArcMAP project. Saving your project will not save changes to your data and vice-versa!