Fault Zone Mapping with Differential Lidar
By Mike Oskin – Revised Oct 20, 2011

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 under the spatial analyst toolbar (use view->toolbars to find the toolbar checkbox if it is not already visible). You may need to check out the spatial analyst license under tools->extensions to use the toolbar. Once you find the toolbar, click Spatial Analyst->Raster Calculator to get started.

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 for). 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 project in ArcCatalog

ArcCatalog: ArcCatalog is a general-purpose data management utility that comes as a part of the ESRI ArcGIS package. Start ArcCatalog by clicking on its icon (a file cabinet).

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 geodatabase to contain your mapping information. The geodatabase will contain a feature dataset, which is a container within the geodatabase. This is kind of confusing, but important because feature datasets permit relationships between layers. We will be using a simple relationship to define fault classes. Advanced topological relationships, useful for building polygons from lines, are also possible. Right click in the blank space on the right side of ArcCatalog and select New->Personal Geodatabase. Name the database for your project (*follow the rules!*).

3. Create a Feature Dataset to hold related map data. Feature datasets hold related geographic information, such as all of the features that comprise a single geologic map. This is sort of like a 'subdatabase' within the larger geodatabase. In ArcCatalog, double click on the geodatabase to get to its contents window. Next, right click in the contents window and select New->Feature Dataset. Name this data set 'qmapping' (i.e. Quaternary mapping). In the next window you will define the UTM projection of the feature data set. Select Projected Coordinate Systems->UTM->WGS 1984->WGS 1984 Zone 11N. The next window asks for a vertical coordinate system, which may be ignored for now (note: lidar data vertical datums often differ substantially from WGS84, so beware when using the absolute elevation values – see above discussion of geoid correction). The last window is for precision. Usually the defaults are more than adequate. Hit 'Finish' to complete this step.

4. Create line classes in your feature dataset. In ArcCatalog, double click the new feature data set to enter its 'folder' view (we are now two levels down from your directory!). You will now make features inside of this set. Next, right click in the blank area and select make a new feature. Make this first one a line feature class called 'faults'. Add a short integer field called 'linetype' by typing 'linetype' in the blank line under 'SHAPE' and changing the 'Data Type' to 'Short Integer.' We will assign numbers to various contact types shortly. For now, hit the 'finish' button.

Next we will use the type field under the 'faults' feature class to define our line types. In Arc Catalog, double click 'faults' to bring up its properties. Under the 'subtypes' heading, select 'linetype' as the subtype field. Next, fill out the table below with the following:

Code   Description
   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 adding subtypes.

PART 4. Mapping of faults in ArcMAP

Map fault scarps from interpretation of the lidar topography using hillshade or slope-shade maps together with the difference map.

Step 1: **Load your new feature class into your project**. Hit the yellow '+' button and then navigate to your geodatabase in the file window. Click once on the 'qmapping' feature dataset and then hit the 'add' button. This will load your faults feature class with all of its subclasses. These should show up in the table of contents on the left side of the ArcMAP project, including subdivisions for your different line types types. Double click each of these to change how these will be displayed. For fancy looking lines, try out the options under 'properties' when selecting the line style - 'cartographic line type' offers many options for creating dashed lines and multi-layer lines (e.g. lines with tics).

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

Step 2. Map a fault trace. 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.' The rest of the toolbar will now become highlighted. Select the 'faults – certain' feature class in the drop down box, and then select the pencil icon. Choose one end of the fault in the lidar data and 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 keys to aid with snapping:

Snap to End Point:	Ctrl F5	*line ends or junctions*
Snap to Vertex:	Ctrl F6	*good to target a particular bend*
Snap to Midpoint:	Ctrl F7	*not too useful for geology*
Snap to Edge:	Ctrl F8	*very useful*

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!