

Measuring earthquake-generated surface offsets from high-resolution digital topography

July 19, 2011

David E. Haddad
david.e.haddad@asu.edu

Active Tectonics, Quantitative Structural Geology, and Geomorphology
Arizona State University
<http://activetectonics.asu.edu>

Table of Contents

INTRODUCTION	2
COMPUTING CONSIDERATIONS	2
WORKFLOW OVERVIEW	2
DETAILED WORKFLOW	4
Step 1: Generate a DEM in OpenTopography	4
Step 2: Download the DEM from OpenTopography	7
Step 3: DEM visualization	7
Step 4: Map fault traces	8
Step 5: Mark offset locations	9
Step 6: Calculate lateral offsets	9
Step 6a: Download the software	9
Step 6b: Prepare the DEM using LiDARimager	10
Step 6c: Calculate lateral offsets using LaDiCaoz	11
REFERENCES CITED	11

INTRODUCTION

High-resolution digital topographic data products such as LiDAR-derived digital elevation models (DEMs) provide unprecedented insights into the geomorphic response of earthquake-induced surface deformation. By measuring m-scale offsets of geologic and geomorphic markers, we can understand the surface slip history associated with recent earthquake ruptures, their spatiotemporal distributions, magnitudes, and recurrences. Surface offsets also facilitate physical constraints for surface slip distributions, thus providing physical guides to earthquake forecast models such as the Working Group on California Earthquake Probabilities' (WGCEP) Uniform California Earthquake Rupture Forecasts (UCERF; <http://www.wgcep.org/goals>).

The goal of this document is to provide an overview of the workflow involved in calculating surface slip offsets using LiDAR-derived DEMs. The workflow is comprised of modules that use different software suites, and so it is not intended to replace the already comprehensive documentation available for each software suite. Where appropriate, we provide information on how to access the documentation that typically accompanies each software.

COMPUTING CONSIDERATIONS

The workflow presented herein requires the following computing considerations and software:

1. High-speed Internet access and a Web browser.
2. Access to the ArcGIS suite (ArcMap, ArcToolbox, and ArcCatalog), or alternatively...
3. ...access to the paid version of Global Mapper.
4. MATLAB numerical computing environment.
5. LaDiCaoz lateral displacement calculator and LiDARimager from Zielke *et al.* (2010).
6. Access to a spreadsheet software (e.g., MS Excel).
7. Google Earth (optional).

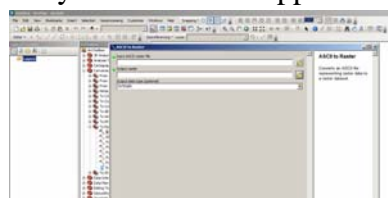
WORKFLOW OVERVIEW

The following is a brief overview of the workflow that goes through the steps of generating DEMs and computing surface offsets. Each screenshot is representative of the software/website application. A more detailed graphical workflow is presented in the following section of this document.

1. Generate and download DEMs from OpenTopography.



2. Convert the DEMs from Arc ASCII to Arc raster formats in ArcMap. Alternatively, load the DEMs directly into Global Mapper.

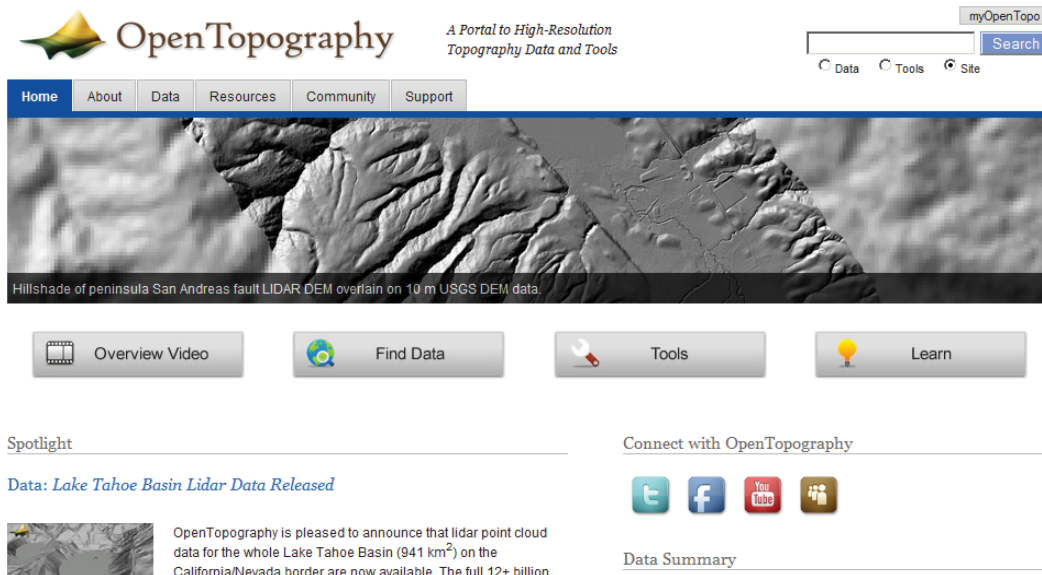


DETAILED WORKFLOW

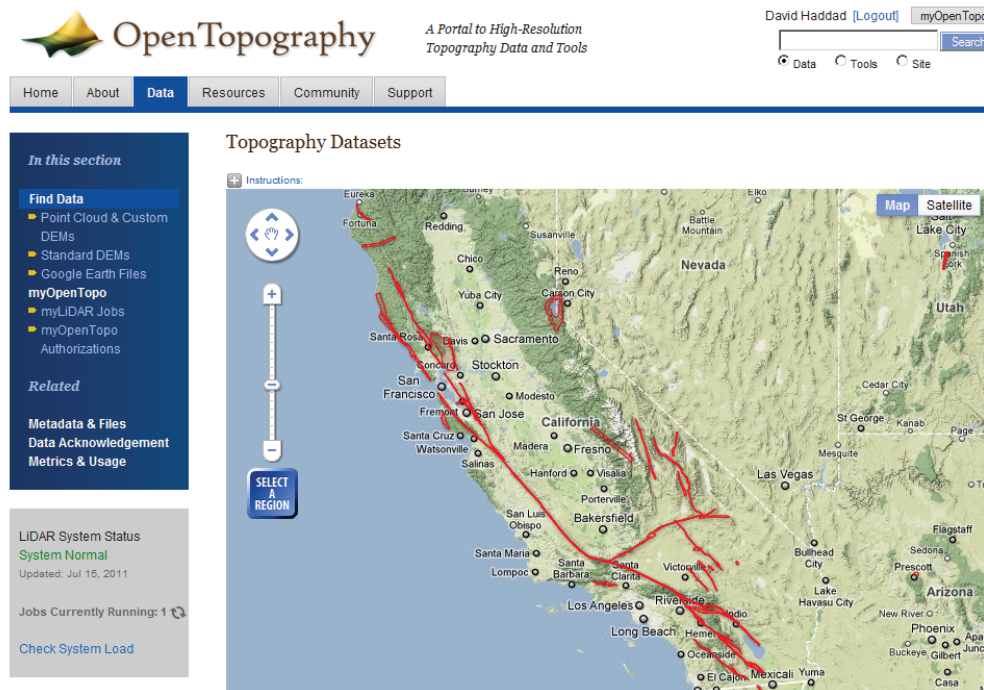
This section describes, in detail, the workflow associated with calculating an offset measurement.

Step 1: Generate a DEM in OpenTopography

Go to <http://opentopography.org>. If you are a new user to OpenTopography, click the “myOpenTopo” button and request a new account. This will allow you to process larger DEMs and have a custom interface from which you can access previously submitted DEM jobs. Registration is free. New account requests are typically granted in less than a day. Once your request has been granted, sign into your account and click the “Find Data” button.



Click “Point Cloud & Custom DEMs” from the left-hand menu. OpenTopography uses the Google Maps navigation interface.



Select a dataset from the list and navigate to the area from which you want to create a DEM. Click the “Select a region” button and draw a polygon that defines the extent of the DEM you wish to create. The DEM’s processing time depends on the size of this polygon. The user is advised to select small regions of which to create DEMs as opposed to selecting one large region to facilitate the subsequent processing of DEMs on the user’s local machine in “bite-sized” pieces versus large DEM tiles.



Set the DEM parameters. These parameters depend on the quality of the original LiDAR dataset. Measures such as shot density (the number of laser returns per area) and point cloud classification schemes are factors that control the quality of the final DEM. In general, airborne LiDAR data hosted on OpenTopography can produce DEMs of resolutions as high as 0.25 m per pixel. For more information on these factors and the science (and sometimes art) of finding the best DEM parameters, see the OpenTopography resource pages and <http://lidar.asu.edu>.

For the purposes of this document, set the DEM parameters to the following:

- *DEM Generation:* select the “**Calculate Zidw grid**” option. Set the “**Grid Resolution**” to 0.25 (meters) and the “**Radius**” to 2 (meters).
- *Derivative Products:* uncheck this option if you prefer to create your own hillshades and slope maps in ArcMap. Checking this option increases the DEM processing time. Note that Global Mapper automatically creates slope maps and hillshades of DEMs from the ASCII files that OpenTopography generates.
- *Visualization:* optional if you wish to visualize the DEM in Google Earth.
- *Job Description:* Enter a Job title (e.g., dem_1) and a brief description (optional). The user is highly advised to provide each DEM with a unique job title. This will greatly facilitate management of the DEMs in the future.
- *Email address:* If you are signed into your OpenTopography account, your email address should automatically appear in this field. If not, then you are visiting OpenTopography as a guest (with limited access). The user is highly advised to use OpenTopography as a registered user so as to keep track of the submitted DEM jobs and have access to larger

LiDAR dataset processing power. Once you are satisfied with the parameters and signed into your OpenTopography account, hit the “Submit” button.

Horizontal Coordinates: UTM Zone 11 N WGS84 Meters - Vertical Coordinates: Ellipsoid
Data Selection Coordinates: ☐ Manually enter selection coordinates

$X_{min} = 427409.521$ $Y_{min} = 3917238.438$ $X_{max} = 427904.501$ $Y_{max} = 3917731.246$

The selection area contains approximately 190,000 points.

1b. Choose return classification: [?](#) ☒ Ground ☐ Unclassified (Vegetation & Structures) ☐ All

2. Point Cloud Data Download:

[?](#) ☐ Download point cloud data in ASCII format
[?](#) ☐ Download point cloud data in LAS format

3a. DEM Generation (Local Gridding): [?](#)

Gridding Method

[?](#) ☐ Calculate Zmin grid
[?](#) ☐ Calculate Zmax grid
[?](#) ☐ Calculate Zmean grid
[?](#) ☒ Calculate Zidw grid
[?](#) ☐ Calculate point count grid

Gridding Parameters

[?](#) Grid Resolution (Default = 1 meter):
[?](#) Radius value (Default = 1 meter):

Grid Format [?](#) Null Filling [?](#)

3b. DEM Generation (TIN): [?](#)

Gridding Method

[?](#) ☐ Calculate TIN

Gridding Parameters

[?](#) Grid Resolution (Default = 1 meter):
[?](#) Max. triangle size (Default 50 units):

Grid Format [?](#)

Gridding Method

[?](#) ☐ Calculate TIN

Gridding Parameters

[?](#) Grid Resolution (Default = 1 meter):
[?](#) Max. triangle size (Default 50 units):

Grid Format [?](#)

4. Derivative Products: [?](#)

☐ Generate Hillshade & Slope

Job Description

These options allow users to describe and keep track of their jobs. Information entered below is recorded along with other job parameters in your personal LiDAR Job archive accessed via [myOpenTopo](#) (available only to [registered](#) OpenTopography users).

Job title: (up to 100 characters)

Job description: (up to 500 characters)

Email Address: Enter your e-mail address for notification upon completion of processing *

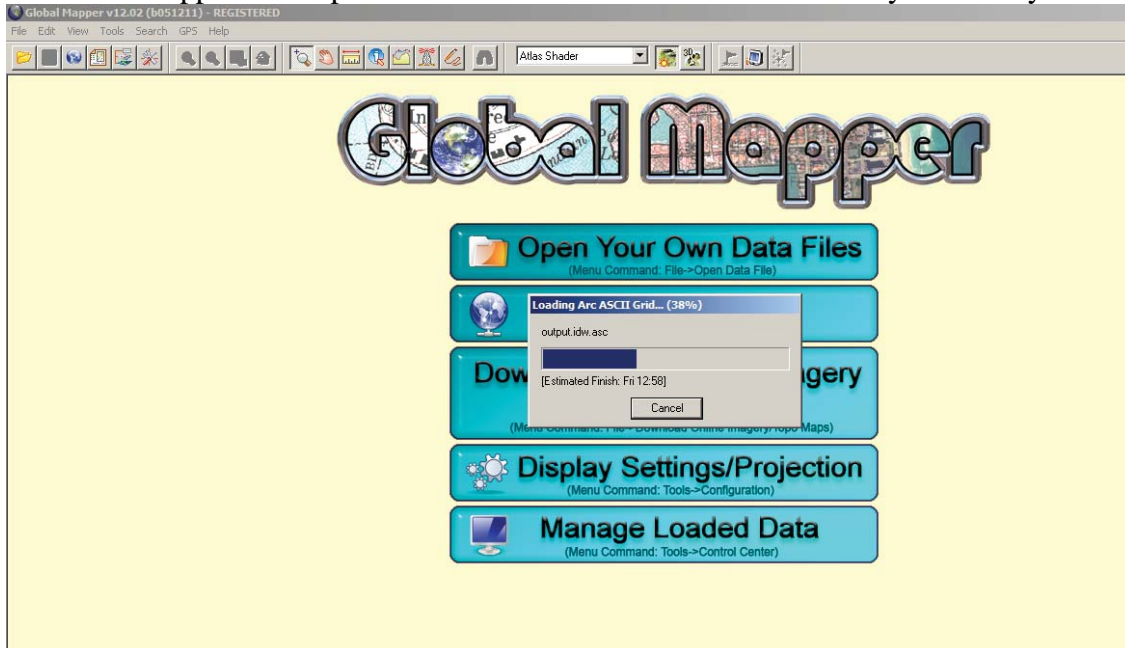
By submitting an OpenTopography point cloud processing job you agree to acknowledge OpenTopography and the dataset source as specified [here](#) in publications, presentations, and other materials produced using these data.

Step 2: Download the DEM from OpenTopography

OpenTopography creates several products that accompany the DEM. For the purposes of this document, we are only interested in the DEM. Click the “dems.tar.gz” link (exact link name may vary) to download the DEM in zipped form. Extract the DEM once the download is complete. The extension of the extracted DEM file is .asc. This is the raw DEM file in ASCII format.

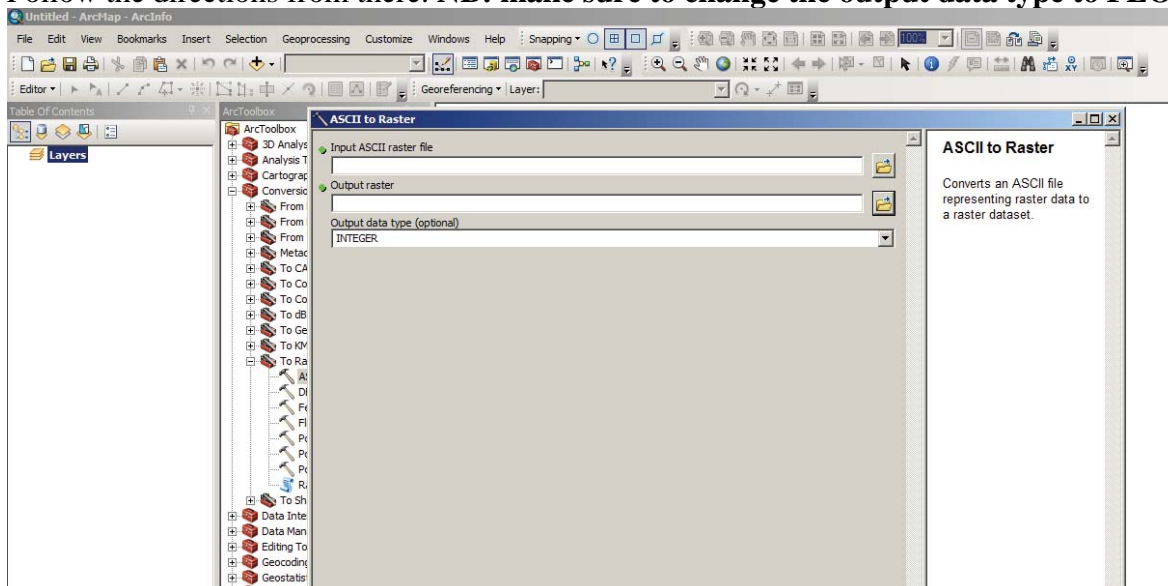
Step 3: DEM visualization

Global Mapper can import the .asc file and visualize the DEM very efficiently:



Global Mapper automatically creates a hillshade and slope map from the .asc file.

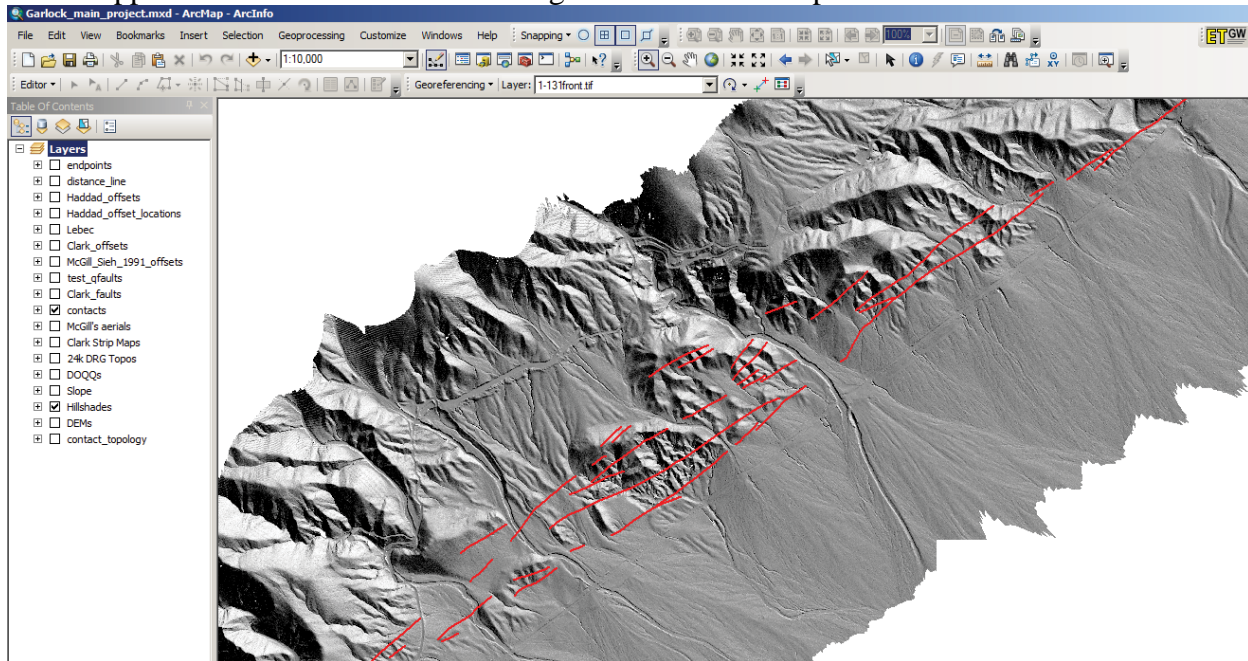
If using ArcMap, the .asc file needs to be converted to an Arc raster using ArcToolbox. In ArcMap, start ArcToolbox and go to Conversion Tools >> To Raster >> ASCII to Raster. Follow the directions from there. **NB: make sure to change the output data type to FLOAT.**



Step 4: Map fault traces

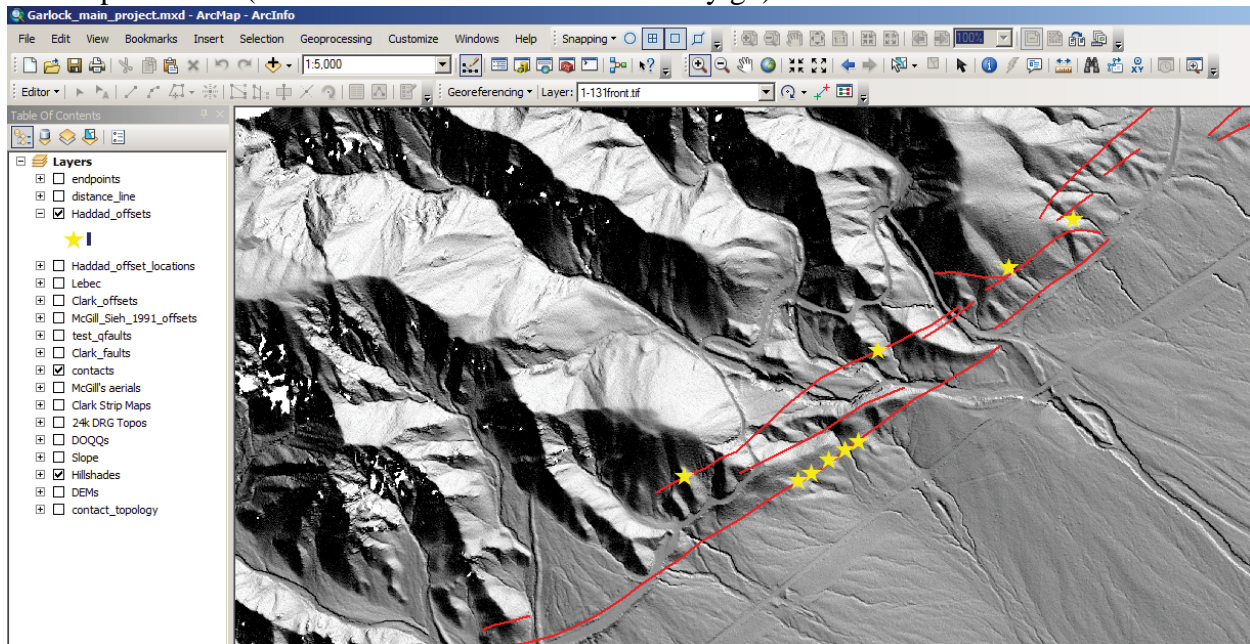
For Global Mapper and ArcMap users: create a line shapefile (polyline) and begin digitizing fault traces. This should be done at a scale of 1:2,000 or larger. Use aerial imagery (DOQQs/Google Earth/aerial photographs) to aid your mapping (and to make sure you are actually mapping faults). Slope maps can be very handy in illuminating subtle tectonogeomorphic features such as very low-relief fault scarps or offset channels. In general, for scarps that exhibit vertical displacement, the user has three placement options for the linework: (1) at the top of the scarp, (2) at the bottom of the scarp, or (3) in the middle of the scarp. For the purposes of this document, we place our linework in the middle of the fault scarp.

The user is advised to go over their linework at least twice to ensure all fault traces have been mapped and double check the existing linework indeed represents fault traces.



Step 5: Mark offset locations

For Global Mapper and ArcMap users, create a point shapefile and digitize the locations of offset geologic/geomorphic features. Depending on the resolution and quality of the DEM, this should be done at a scale between 1:500 and 1:1,000. The user is advised to perform this procedure at least twice to ensure that all offsets have been marked. Assign a unique offset name (e.g. “GF_1”) to the offset marker and enter it into the attributes table of the shapefile and your Excel spreadsheet (where the offset data will eventually go).



Step 6: Calculate lateral offsets

The user is highly advised to review the following comprehensive videos and instructions that go through preparing DEMs using LiDARimager and calculating lateral offsets using LaDiCaoz here: http://stockdale.sese.asu.edu/Geosphere_SOM/. The following section provides a very brief overview of the workflow.

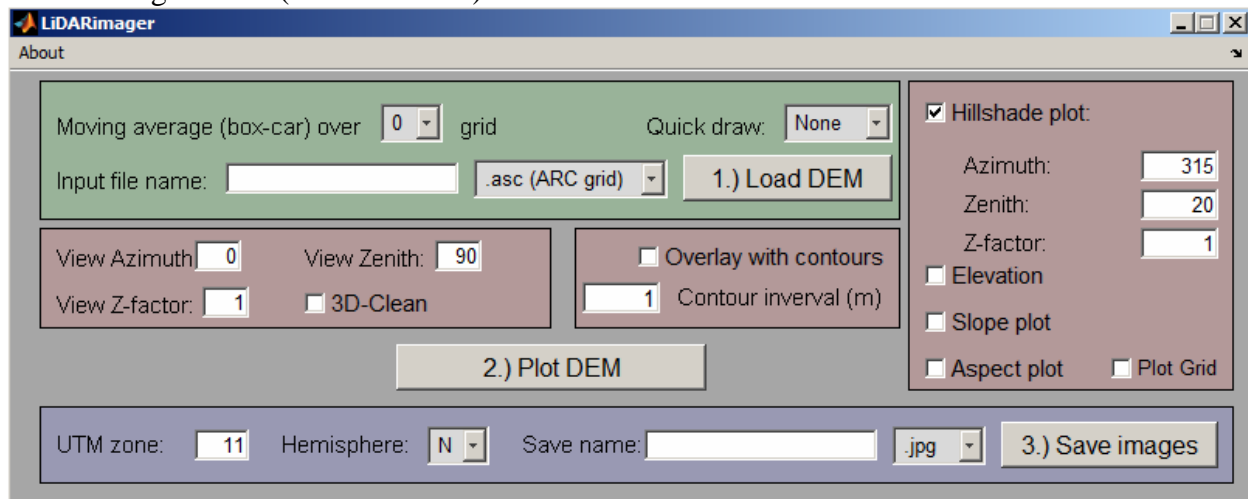
Step 6a: Download the software

Go to http://stockdale.sese.asu.edu/Geosphere_SOM/ and download the LiDARview.p and LaDiCaoz.p files into the directory that contains the .asc DEM files. **NB: these files must all be in the same directory!**

Step 6b: Prepare the DEM using LiDARimager

To improve processing efficiency in LaDiCaoz, the user will need to crop the DEM file to the extent that displays the offset feature(s). LiDARimager is a MATLAB-based GUI that loads the .asc file, creates a hillshade of the DEM using user-defined illumination parameters, and allows the user to create smaller .asc files at user-defined spatial extents (Zielke et al., 2010)

Start MATLAB and navigate to the directory that contains LiDARimager and the .asc files. In the Current Folder list to the left of the Command Window, right click on LiDARimager and select “Run File”. This will load the LiDARimager GUI. Follow the instructions in the LiDARimager video (see above link).



Step 6c: Calculate lateral offsets using LaDiCaoz

LaDiCaoz is a MATLAB-based GUI that calculates lateral displacements from high-resolution digital topography using a goodness-of-fit approach (Zielke et al., 2010). Start MATLAB and navigate to the directory that contains the .asc and LaDiCaoz files. In the Current Folder list to the left of the Command Window, right click on LaDiCaoz and select “Run File”. This will load the LaDiCaoz GUI. Follow the instructions in the LaDiCaoz video (see above link).

The screenshot shows the LaDiCaoz GUI with the following sections and controls:

- Top Bar:** Figures - LaDiCaoz, About, Debug, Desktop, Window.
- Input Section:** Moving average (box-car) over 0 grid points, 0.5) Load Previous run, Input file name: [text box], .asc (ARC grid), 1.) Load DEM file.
- Blue/Red Line Distances:** Blue line distance from fault (m): 10, Red line distance from fault (m): 10.
- Adjust blue profile:** Stretch factor range: min 1, increment 0.1, max 1; Vertical back slip (m): min NaN, increment 0.1, max NaN; Horizontal back slip (m): min NaN, increment 0.1, max NaN; left-lateral (dropdown); Number of iterations: [text box].
- Plot DEM:** 1.5) Plot DEM, 2.) Define Fault Line.
- Shift fault by:** Up 0 m, Left, Right, Down.
- Rotate fault:** Rotate fault Clock-Wise 0 deg, Counter-Clock-Wise.
- Define trend of line A/B:** 2.5) Define trend of line A, 2.5) Define trend of line B.
- Backslip Model:** Backslip surface by (m): 0, 4.) Backslip Model.
- Save All:** 5.) Save All.
- Hillshade plot:** ☒ Hillshade plot: Azimuth: 315, Zenith: 20, Z-factor: 1.
- Contour plot:** ☐ Contour plot: Min. Elevation NaN, Max. Elevation NaN, Contour 20.
- Information for saved Profile:** Distance to Start Point: 0, Offset Rating: high, Optimal Slip: NaN, Minimum Slip: NaN.
- Visual Display:** A grayscale image showing a fault line and two lines, Line A and Line B, with arrows indicating movement.

REFERENCES CITED

Zielke, O., Arrowsmith, J R., Grant-Ludwig, L. B., Akciz, S. O., 2010. Slip in the 1857 and earlier large earthquakes along the Carrizo Plain, San Andreas fault, *Science*, v. 327, p. 1119-1121.