LaDiCaoz:

A MATLAB Graphical User Interface to calculate the Lateral Displacement of offset geomorphic features

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Content

1 Introduction

Earthquakes along strike-slip faults such as the San Andreas Fault (SAF) can offset geomorphic markers. Measurements of offset amount and spatial distribution of these features are required to estimate the magnitude of prehistoric earthquakes and to better understand how slip recurs along a fault. Reconstructions of earthquake surface slip distributions were one of the main data sets, used to formulate mechanical models of fault behavior, such as the uniform slip model or the characteristic earthquake model (Sieh, 1984; Schwartz and Coppersmith, 1984).

LaDiCaoz is a MATLAB graphical user interface (GUI), build to allow fast and easy-to-reproduce measurements of lateral displacements of offset geomorphic features such as fluvial channels. It was written to determine the surface slip distribution along the southern-central SAF, due to the large 1857 Fort Tejon earthquake and preceding events along the 1857 rupture trace (Fig. 1).

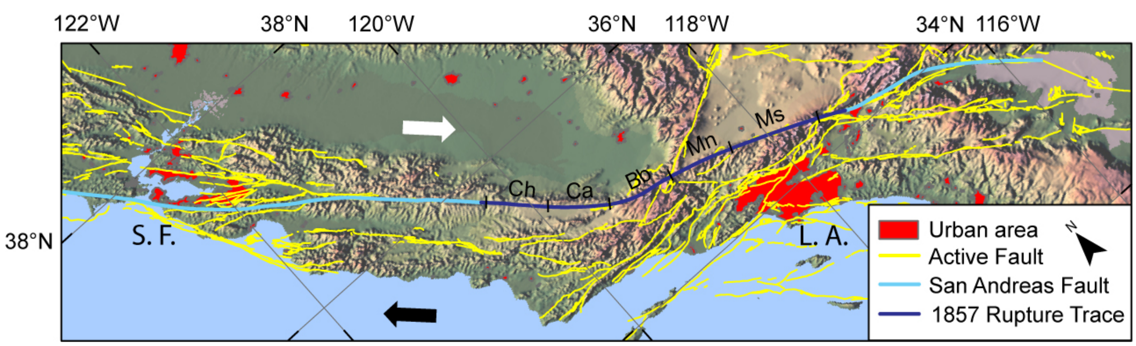


Figure 1. Overview of Quaternary active faults including the surface rupture of the great 1857 California earthquake along the SAF and their geographic relation to urban areas (S.F.–San Francisco, L.A.–Los Angeles). The southern SAF is divided into 5 major segments (Ch–Cholame, Ca–Carrizo, Bb–Big Bend, Mn–Mojave north, Ms–Mojave south) (WGCEP, 2007). Relative motion of North American and Pacific plate is indicated by block arrows.

Motivated was this work by a) the importance of this earthquake for fault behavior models and seismic risk, and b) the emergence of the high resolution "B4" LiDAR (Light Detection And Range) data set (Beavis et al., 2005; data freely available at http://www.opentopography.org). The airborne-acquired data set, with shot densities of 3-4m^{-2} allows production of digital elevation models (DEM) with grid sizes as small as

0.25m, allow identification of meter-scale tectonic landforms (Arrowsmith and Zielke, 2009). Unlike aerial photography, DEM are not limited by stereo depth resolution or fixed illumination angle, permitting identification and measurement of even subtle tectono-geomorphic expressions (Oskin et al., 2007).

LaDiCaoz was build for LiDAR-derived DEMs (ARC-grid format, downloadable from www.opentopgraphy.org). The current version should work with any ARC-grid format DEM. Upon interest, further versions of this tool may allow use of other data sets. Following, I will explain the methodology of offset reconstruction followed by the functionality of the LaDiCaoz GUI and then present a worked example.

I hope LaDiCaoz is of use for your work. I am aware that it may have glitches and certainly has room for improvement. So, please contact me under olaf.zielke@asu.edu if you have questions about its functionality i.e., on how to operate it or if you have suggestions of how to improve it.

2 Method

The following section is an excerpt from a draft by Zielke and Arrowsmith (in prep.).

2.1 Identification of offset features

We mapped primary and secondary fault traces along the south-central SAF (i.e., 1857 rupture trace, Fig. 1) in ESRI's ARCMAP, using hillshade plots (generated from 50cm grid size DEM) with NW and NE illumination (Fig. 2A). Distinction between primary and secondary traces was based on the number of sub-parallel fault strands and their relative geomorphic expression. Depending on the level of surface expression, individual sections of the fault trace were assigned ratings of certain, uncertain, inferred, and queried (Fig. 2B). Following, we searched the whole 1857 rupture trace for offset geomorphic markers (e.g., offsets and bends in stream channels as they cross the fault zone), usually on a scale of 1:2,000. First, we searched for offset geomorphic markers that have been identified in previous studies (Sieh, 1978; Lienkaemper 2001). After that, we searched for geomorphic markers that have not been reported before, capitalizing on the high resolution topographic LiDAR data set. This effort was repeated a few times. Offset features were assigned ratings of high, high-moderate, moderate, moderate-low, and low depending on their geomorphic complexity and estimated reliability as indicators of tectonic fault slip. Table 1 contains a list of criteria that guided us in assigning the rating. Deflected channels and offset features in locations with significant fault geometric and geomorphic complexity were not included in the record. To guide the identification of these unreliable sites we followed the criteria suggested by Sieh (1978): "The principal categories for unreliable sites are (1) stream channels deflected around uphill-facing scarps, (2) irregular channels displaced across several-meter-wide fault zones, and (3) possibly offset features at localities where the fault trace cannot be precisely located". For each potentially offset feature, we downloaded higher-resolution LiDAR-generated DEM from the www.opentopograhy.org website (e.g., 0.25m grid size DEM, with 0.8m search radius using inverse distance weighting (IDW) for sparsely vegetated places such as the Carrizo Plain and 0.5m grid size DEM, with 1.5m search radius using minimum elevation return for more densely vegetated places such as the Big Bend segment, Fig. 1). These DEM serve as a base map for further processing with LaDiCaoz.

Channel rating	Description
High	channel is at high angle to fault, only little degradation, long and straight channel at both sites of fault
High-moderate	channel at high-moderate angle or more degraded (abandoned channel?), parallel channels at both sites, but not very long (makes exact estimate of orientation difficult) or longer channel but with slight curvature
Moderate	channel at moderate angle and more degraded, channels may have slightly different angle (obliquity) on either site of the fault, or are not very long or may have distinct curvature when crossing the fault
Moderate-low	channel at oblique angle to fault trace, degraded, may have clear break in orientation (flow direction) at fault, curvature when crossing the fault, still relatively long upstream/downstream segments
Low	channel at oblique angle to fault trace, degraded, break in flow direction, curvature when crossing the fault only small upstream downstream extent, possible secondary fault trace that may have been activated in 1857 earthquake –possibility of distributed deformation

Table 1: Channel offsets were given a quality rating to identify their respective reliability as indicators for coseismic slip. Similar rating schemes have been used in other studies (e.g., Sieh, 1978; Lienkaemper, 2001).

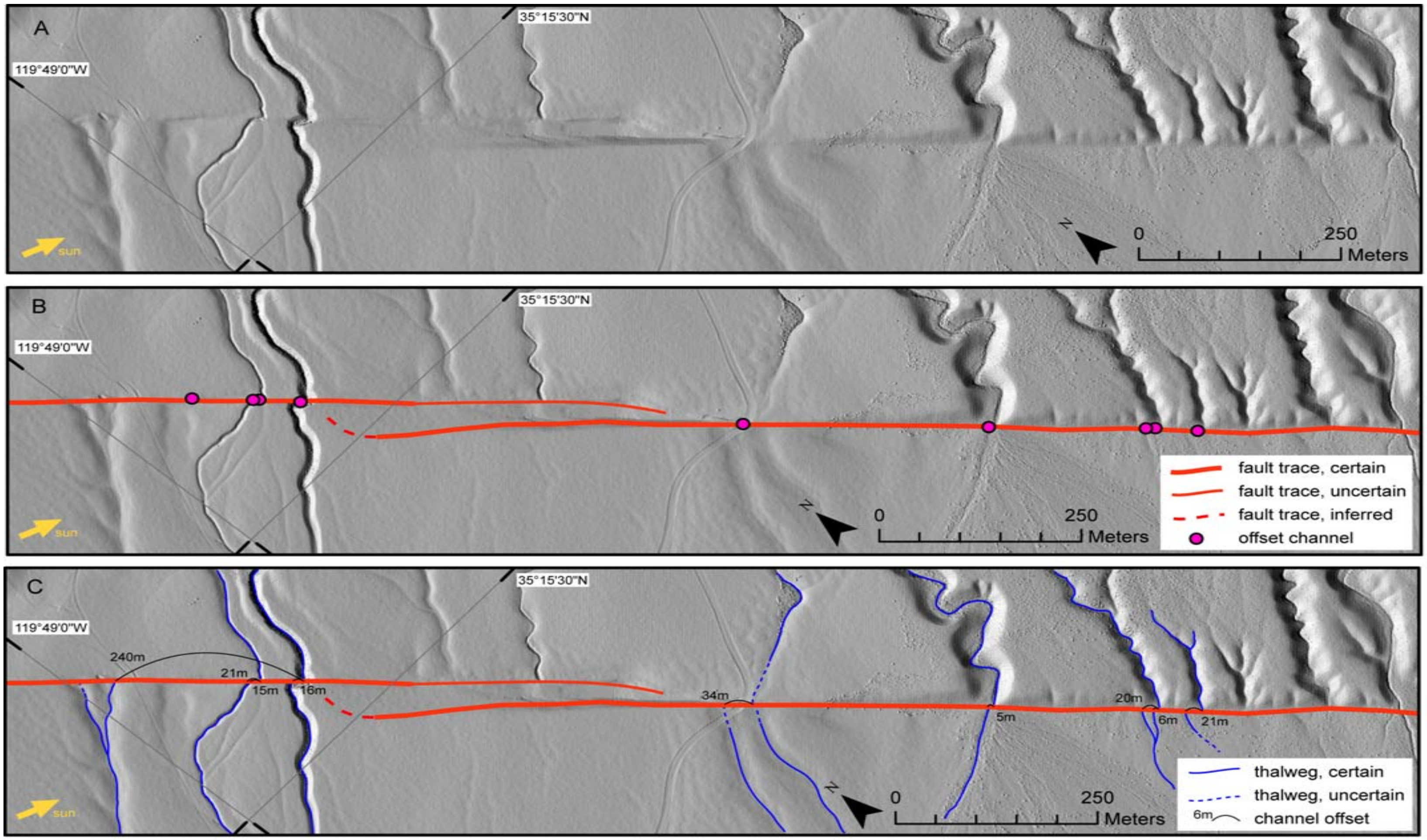


Figure 2. A) Hillshade map around Phelan Fan (Carrizo Plain) generated from 50cm grid size DEM with NW illumination angle. B) This and similar base maps were used in ARCMAP to map the main fault trace and identify offset geomorphic features. In this ~1.5km long stretch of the fault we found 9 offset channels. C) Channel thalweg and respective offset estimate are shown. Naturally, reliability as indicators for tectonic slip is different for each channel (see table 1 for an explanation of the rating scheme).

2.2 Fault tracing, profile location, and channel trend

For each offset feature we created multiple base maps (contour plots and hillshade plots with varying illumination angles) to gain a sound understanding of the site's morphology including the position of fault and channel trace (Fig. 3A-C). This approach guided us in separating out unreliable slip sites (see respective criteria in last section). If an offset feature was considered reliable, we mapped the fault trace and determined the location (i.e., normal distance to fault trace) of upstream and downstream topographic profile (Fig. 3D).

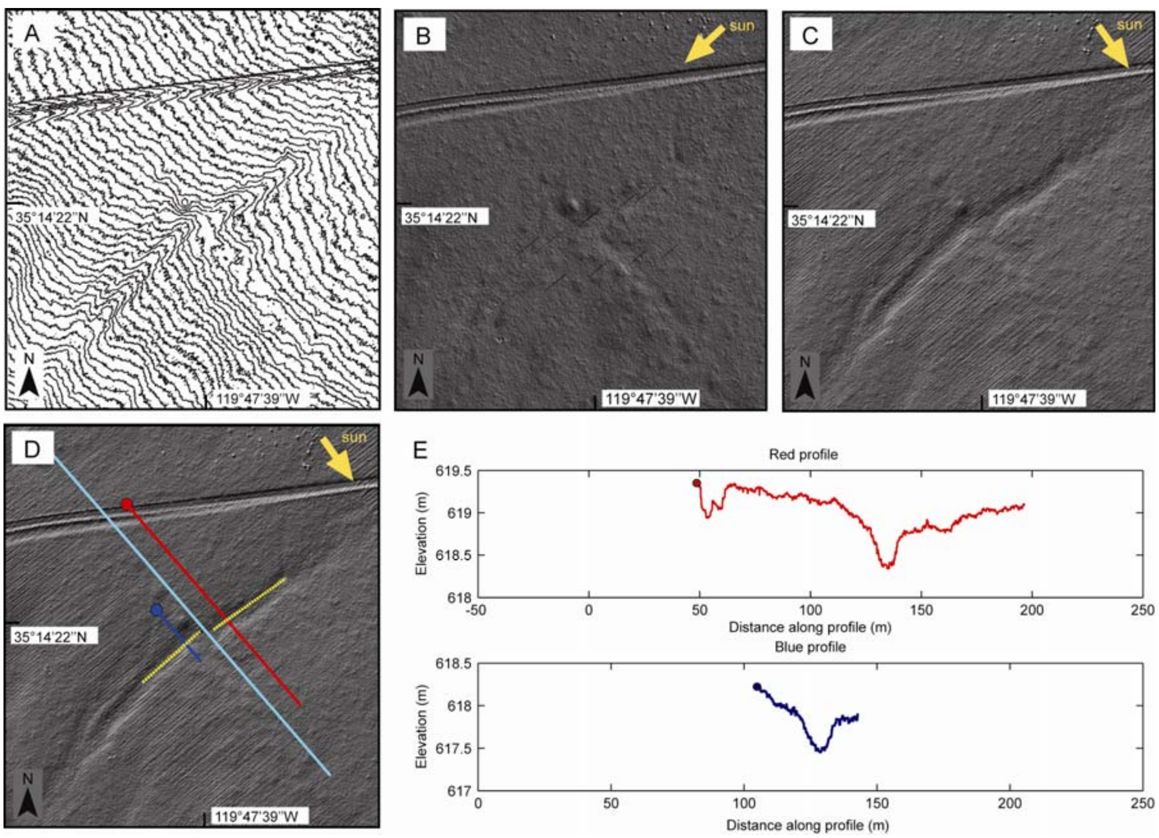


Figure 3. Base maps of a channel (#31 [Sieh, 1978]), in the Carrizo Plain. A) 0.1m contour plot. B) 0.25m grid size hillshade plot with NE illumination. C) 0.25m grid size hillshade plot with NW illumination. Identification of subtle geomorphic features like the fault trace and the small stream channel is difficult in A) and B). It requires multiple base maps to gain sufficient understanding of each site. D) Hillshade plot of Sieh (1978) channel #31 with fault trace (in turquoise), profile lines (in red and blue) and channel trend of upstream and downstream channel segment (in yellow). E) Projected (accounting for channel obliquity relative to the fault trace) topographic profiles. Both profiles have been cut on both ends.

The profile positions were chosen to lie outside of the geomorphically overprinted fault zone (Wallace, 1968; Sieh, 1978; Lienkaemper, 2001; Ouchi, 2004). We find that the preferred profile to fault-trace distance varies from approximately 3 to 15m, depending on specific geomorphic site conditions and total displacement of the offset feature. Figure 3E shows the topographic profiles along the red and blue lines in Figure 3D.We typically crop one profile (e.g., the blue profile) to the along-profile extent of the channel cross section. Cropping is justified because our goal is to determine the offset of the geomorphic feature--the stream channel cross section--and not the topography surrounding it. As a next step, we traced the orientation of upstream and downstream channel segment at the profile location (Fig. 3D). The goal is to capture the flow direction at this position to account for channel obliquity relative to the fault trace: Fluvial channels are typically not perpendicular to the fault trace (Fig. 4) so that the channel cross section at the profile location needs to be projected onto the fault plane which shifts the respective profile laterally into the correct position.

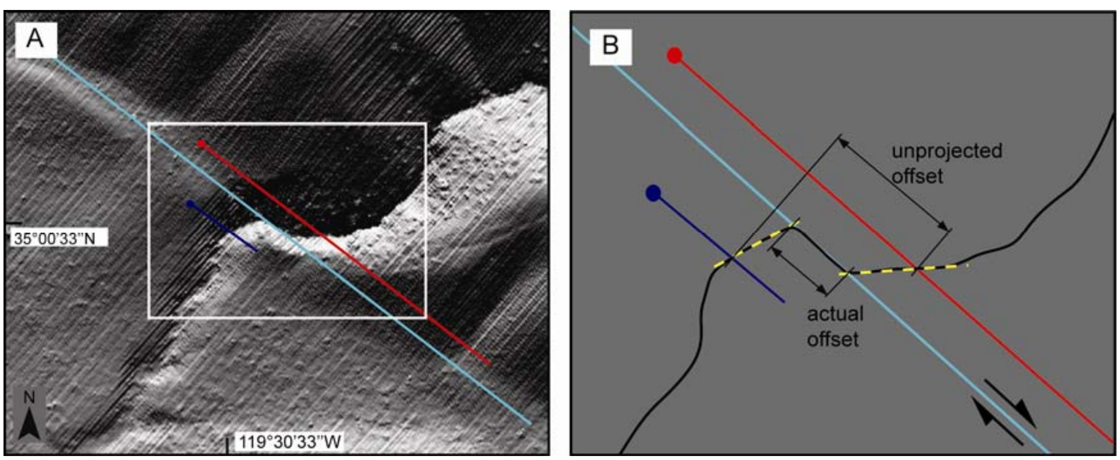


Figure 4. A) Hillshade map of channel ZA10792a (Zielke et al., 2009, submitted) with fault trace (turquoise) and profile locations (red and blue). B) Schematic plot of channel thalweg, fault trace, and profile locations. This channel is not parallel to the fault trace so that the upstream and downstream channel trend has to be determined (see yellow dashed line in B).

2.3 Channel morphology parameter

Then, LaDiCaoz iteratively determined the optimal offset, going over three dimensions: vertical shift and stretch of the blue profile and relative horizontal displacement. Note that it is not important which of the two profiles (red or blue) is adjusted. To decrease the number of input parameters we allow to only adjust one (i.e., blue) profile.

2.3.1 Vertical shift of blue profile

Naturally, the thalweg elevation at upstream and downstream profile location will be different (otherwise channel gradient would be zero and no flow would occur). To account for that, LaDiCaoz iteratively changed the elevation of the blue profile by shifting it upwards or downwards in 0.1m increments (depending on whether the blue profile crosses the upstream or downstream section of the channel).

2.3.2 Vertical stretch of blue profile

Upstream and downstream channel segment may evolve morphologically in a different way due to tectonic activity along the fault that separates them (e.g., downstream segment may be abandoned and start to degrade diffusively which lowers the profiles cross sectional relief) or other reasons we do not address here. To account for that, LaDiCaoz iteratively changes the z-factor to vertically stretch or un-stretch the blue profile (Fig. 5). For that, the minimum elevation of the blue profile is subtracted from the blue profile. The resulting profile is multiplied with the z-factor. After that, the minimum elevation of the original blue profile is added to the stretched profile.

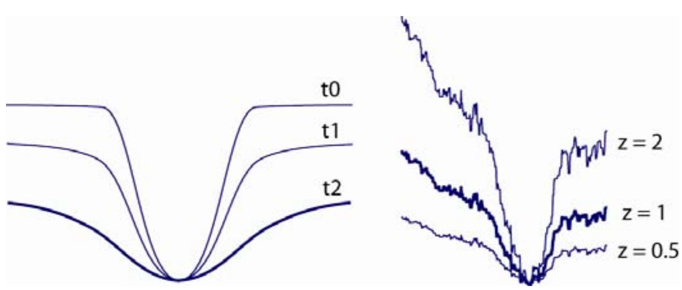


Figure 5. Left figure shows the diffusive evolution (from t0 to t2) of a simple channel profile, shifted to make the thalweg locations match. Right figure show an actual profile (blue profile in figure 3E) stretched by different z-factors. Qualitative comparison shows that using a stretch factor is to first order capable of recreating initial channel morphologies.

2.3.2 Relative horizontal displacement

The third iterative dimension is the relative horizontal displacement--the value of interest. LaDiCaoz iteratively changes the horizontal position of the blue profile, shifting it in 0.1m increments in a left-lateral sense (SAF is right-lateral fault and has to back-slipped left-laterally to reconstruct the pre-earthquake topography). The increment size for horizontal shift and spatial resolution of the topographic profiles are set to be equal to simplify computation.

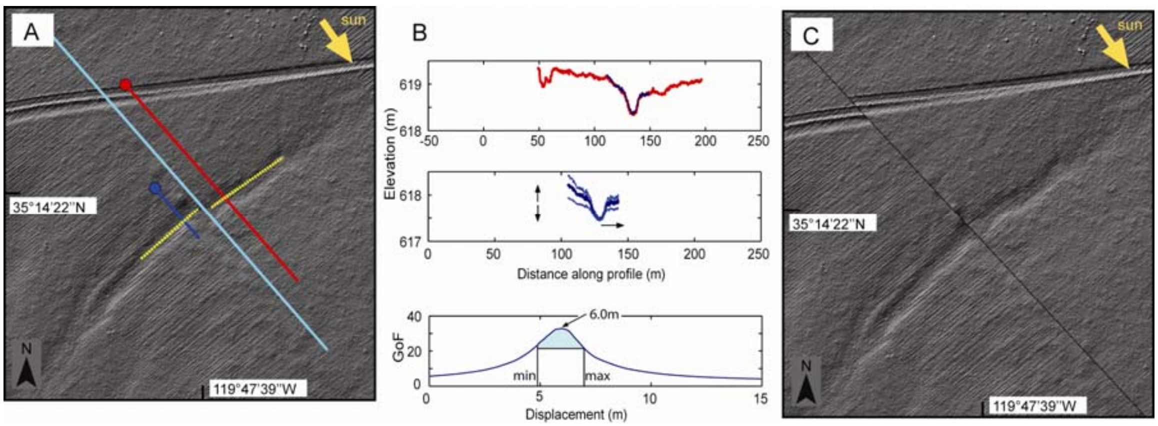


Figure 6. A) Position of fault trace, channel trace, and profile location. B) Top shows red profile with overlay of optimal back-slip (maximum GoF) blue profile. Middle shows initial position and shape of blue profile which is shifted and stretched vertically (indicated by arrows and light channel cross sections) and horizontally back-slipped during offset calculation. Bottom show the GoF as a function of back-slip. The line shown contains the maximum GoF within the data cube (see text) i.e., they use the optimal vertical shift and stretch for the blue profile. To create a PDF of slip values, we truncated the GoF line by minimum and maximum offset and normalized the area shown in turquoise. C) Hillshade plot, back-slipped by optimal displacement amount (here 6.0m) to visually assess reconstruction.

2.4 Offset calculation

LaDiCaoz iteratively determined the optimal offset, by incrementally changing a) vertical shift of the blue profile, b) vertical stretch (z-factor) of the blue profile, and c) horizontal position of the blue profile (Fig. 6B). The optimal offset is defined as the offset that results in the least mismatch between both profiles, in other words the offset for which the summed elevation difference of both profiles has its minimum. We introduce a Goodness of Fit parameter (GoF, =inverse of the summed elevation difference of both profiles) to measure how well a specific combination of vertical shift, and stretch and horizontal displacement is able to fit the two profiles (blue line in Fig. 6b, bottom). LaDiCaoz is calculating the GoF for all possible combinations of channel parameters, creating a data cube. From this data cube, the program picks the line of horizontal displacement (fixed vertical parameters) that contains the maximum GoF value (Fig. 6B, bottom) i.e., the optimal slip estimate. The blue profile, back-slipped by the optimal slip estimate, is overlain with red profile to assess the quality of the correlation (Fig. 6B, top).

2.5 Back-slip of hillshade and contour plots

We back-slip contour plots and hill shade plots of the topography by the optimal slip estimate for each offset feature to assess the quality of the slip reconstruction--closely inspecting the channel trace for potential bends (Fig. 6C). Successful back-slipping should have removed those bends as they indicate that not the right amount of back slip was used. Note the importance of having some general understanding of how the channel trace might have looked like prior to the earthquake.

2.6 Channel offset PDF

Aside from determining the optimal slip, we also estimated minimum and maximum offset, capable of reconstructing the pre-earthquake topography. This is done by trial and error. We back-slipped the topography by values bracketing the optimal slip amount and closely inspected how well these offset values reconstructed the initial topography. Minimum and maximum slip estimates are used to truncate the GoF (Fig. 6B, bottom) which is then normalized to create a probability density function (PDF). To account for different quality ratings assigned to individual channels (Tab. 1), the area is then scaled accordingly (high rating=1.0; high-moderate rating=0.75; moderate rating=0.5; moderate-low rating=0.25; low rating=0.0). This procedure emphasizes channels offset measurements with a high rating and vice versa.

3 LaDiCaoz GUI

Below is a screenshot of the GUI as of September 2009 (Fig. 7). LaDiCaoz is likely to develop over time, as it may be modified to allow other applications than measuring lateral displacements. Future versions of LaDiCaoz will be given successive numbers and corresponding tutorials will be provided along with it. Following is a list explaining how each of the 43 input parameters and buttons operate.

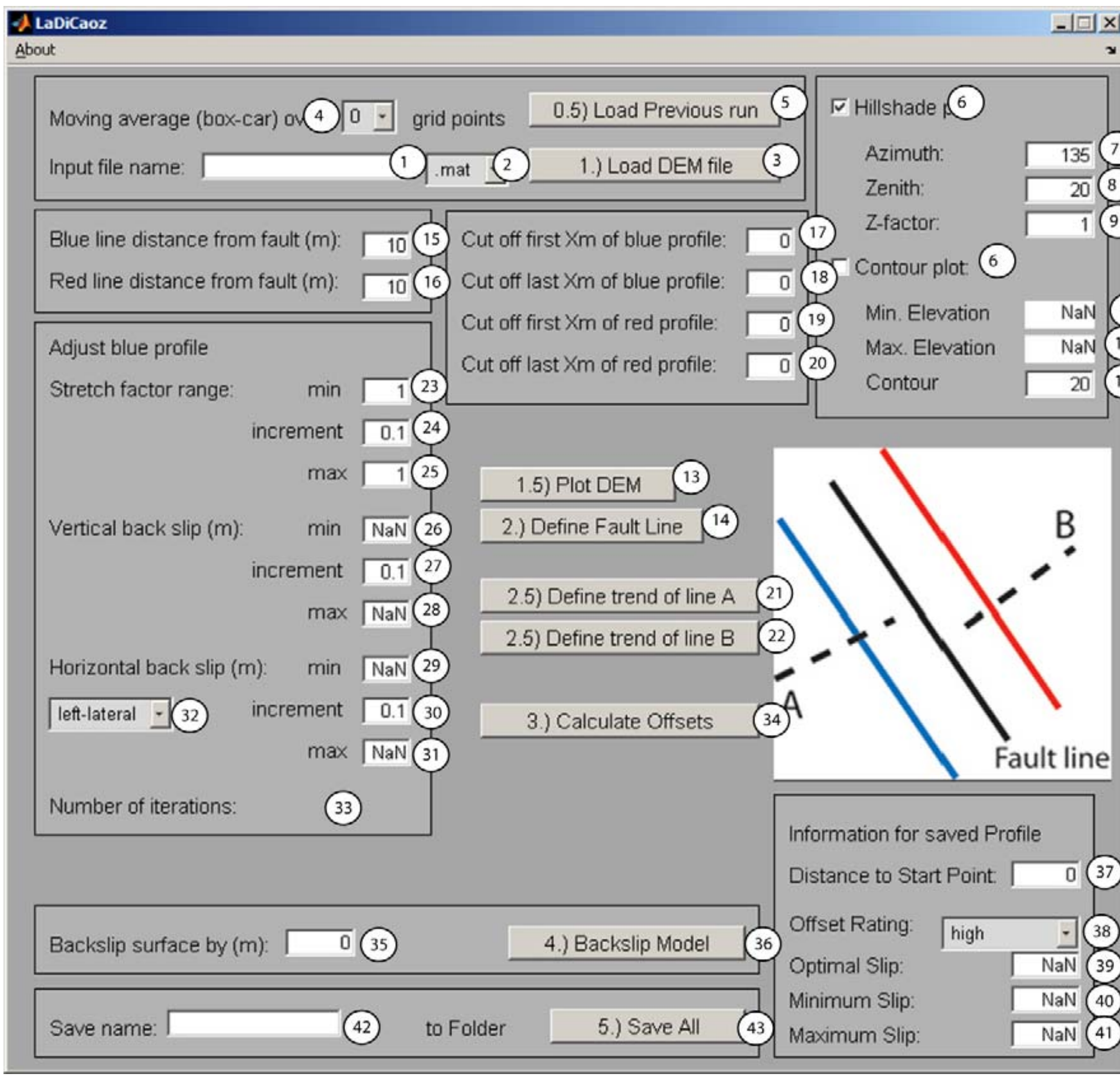


Figure 7. Screen shot of LaDiCaoz. Circled numbers on the different input options refer to the following explanation list.

1. Enter the file name of the digital elevation model (DEM) that you want to load without file extension.
2. Enter the file extension of the file you want to load. Three different types can be loaded: *.asc, and *.mat. The first type (*.asc) refers to DEM, saved in ESRI's ARCMAP ASCII-grid. This is the format I use most of the time. The "B4" LiDAR data from www.opentopography.org can be saved in this format. The second type (*.mat) refers to MATLAB generated binary grid files (the functionality of the latter data format has not been tested sufficiently at the point).
3. Push this button to load the input DEM. An error message will appear if opening the file was not successful. Check for typos in field (1) and make sure that you have chosen the correct file extension in field (2).
4. If you want to use a box-car moving average to filter out holes in the DEM and some high-frequency signal you can enter the number of grid points over which the average will be calculated. For example, if you choose "0" grid points, no moving average is used; for "3", the elevation within a 3x3-wide box around each grid point is averaged and assigned to the middle grid point. This step will be done when loading the DEM (after pushing button (3)). Averaging slows the loading of the DEM but is most of the time worth it.
5. Push this button if you want to look at i.e., re-run a previous channel reconstruction. The GUI is searching for an "XXXX_parameter.mat" file, where XXXX refers to the file name entered in field (1). Successful loading will open the DEM and plot fault and profile positions as well as channel trends as they have been defined in the previous run.
6. You have three options on how to plot the DEM base map. You can select "Hillshade" to produce a hillshade map of the topography, using the Azimuth, Zenith, and Z-factor, defined in field (7), (8), and (9). You can select "Contour" to produce a contour plot of the topography, using the number of contours defined in (12). The third option is to select both, hillshade and contour. In this case the hillshade map is overlain by a contour plot. Generally, I recommend to use

hillshade plots as base map only. I prefer to use the contour plots only for evaluation of the channel reconstruction (back-slipping).

7. Azimuth refers to the horizontal angle of illumination (Fig. 8). The angle is measured in degrees (0-360°) from south and in counter-clockwise direction. For example: illumination from south to north has an azimuth of zero. Illumination from east to west has an azimuth of 90degrees, illumination from north to south an azimuth of 180degrees. Note that, depending on the azimuth the topography may appear inverted (typically for azimuths below 90° and above 270°).

8. Zenith refers to the vertical angle of illumination (Fig. 8) measured in degrees (0-90°) from the horizon (=0°) to the zenith (=90°).

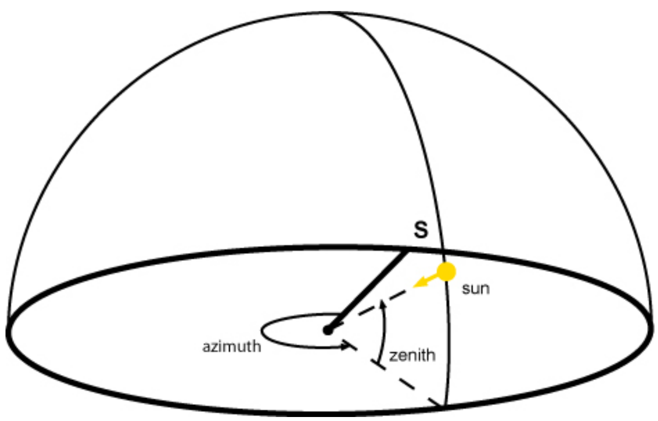


Figure 8. Schematic view of illumination angle, defined by azimuth and zenith. Azimuth is measured from south in counter-clockwise direction. Zenith is measured from horizon upward. The example illumination angle is: azimuth ≈215°, zenith ≈30° which corresponds to NW illumination, an early afternoon sun angle.

9. Z-factor allows to increase the contrast of the hillshade. This may be helpful if the region of interest has low relief.

10. When the DEM was successfully loaded by pushing button (3), the minimum elevation value of the input DEM is plotted here.

11. When the DEM was successfully loaded by pushing button (3), the maximum elevation value of the input DEM is plotted here.

12. Defines the number of contours plotted. If you make a contour plot of the base map (not the back-slip) by pressing button (13) the elevation difference is equal to the difference of fields (11) and (10) so that you can determine the contour interval that corresponds to the contour number. To decrease computation time and focus on the offset feature, a smaller section of the DEM is plotted i.e., contoured during back-slipping (see explanation for button (36)). Then

determination of the contour interval is not straight-forward but has to be found by trial and error (the actual contour interval used when pressing buttons (36) or (13)) is displayed in the MATLAB window).

13. Push this button to plot the base map. Depending on the selection of fields (6) to (12), different images will be produced (Fig. 9). You should adjust hillshade or contour parameters until you can identify fault zone and offset feature (play around…).

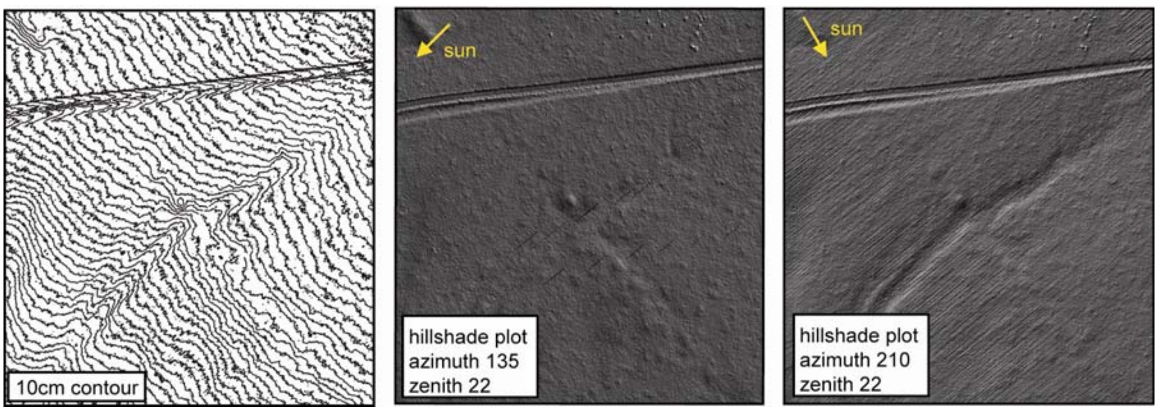


Figure 9. Examples for different base maps of Sieh's channel #31. Left figure shows a 10cm contour plot. Middle and right figure show a 0.25m grid size hillshade plot with different illumination angles (azimuth), z-factor is 2. Note that resolution of geomorphic features depends not only on features size and relief but also feature orientation relative to illumination angle.

14. Push this button to define the fault trend. When button (14) is pushed LaDiCaoz opens the base map plot and allows you to define start and end point of the fault trace via mouse click. Move the mouse to one end of the fault trace and left-click. Then move to the other end of the fault trace and left-click again. I usually put a ruler onto the screen along the fault trace when I trace the fault. Make sure that the fault trace covers a large enough area around the offset feature to show it in the local geomorphic context. Usually the extent from fault trace end point to fault trace end point is used during back-slipping (only the area covered by the fault trace will be back-slipped). Also make sure that the traced fault is at the proper position and has the proper orientation. If it doesn't, press button (14) again. If you have defined start and endpoint of the fault trace, LaDiCaoz draws a

turquoise line to show the fault trace on the base map. It also draws the red and blue profile line. Furthermore, LaDiCaoz opens the "Profiles" figure to plot the topographic profile along red and blue lines. The starting position of the profile (left end in profiles figure) is indicated by a dot in the base map. The number of profile points is defined by its final length and the increment size in field (30), so that dx = profile length/grid size. Each profile point is assigned the elevation of the nearest grid point (Fig. 10).

15. Enter the distance between fault trace and blue profile line (Fig. 10).
16. Enter the distance between fault trace and red profile line (Fig. 10).

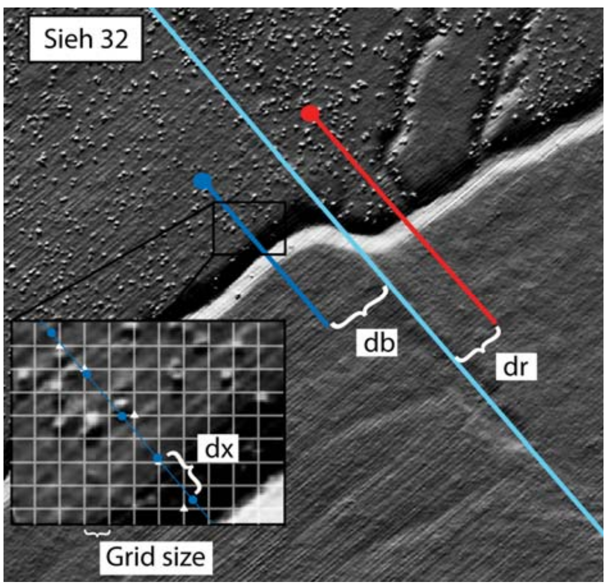


Figure 10. Fault trend (in turquoise) as well as red and blue channel profile lines across Sieh's channel #32 (Bidart fan site, Carrizo Plain). Profiles are parallel to the fault trace; db and dr (entered in field (15) and (16)) define the normal distance between fault trace line and respective profile. Field (30) allows to determine the increment size (dx) along the profile line. The elevation of each profile point is set equal to the elevation of it nearest neighbor grid point (indicated by triangles in inset image).

17. Blue and red profile can be cut on both ends. This is usually done with one profile (e.g., the blue profile) to improve fitting i.e., calculation of the optimal offset (the goal is to fit the channel profiles, not the topography surrounding it). Enter here the amount you want to **cut of the start of the blue profile** (Fig. 11). Once you have entered a value, the base map (profile line) and the Profiles figure will be updated accordingly.
18. Blue and red profile can be cut on both ends. This is usually done with one profile (e.g., the blue profile) to improve fitting i.e., calculation of the optimal offset (the goal is to fit the channel profiles, not the topography surrounding it). Enter here the amount you want to **cut of the end of the blue profile** (Fig. 11). Once you

have entered a value, the base map (profile line) and the Profiles figure will be updated accordingly.

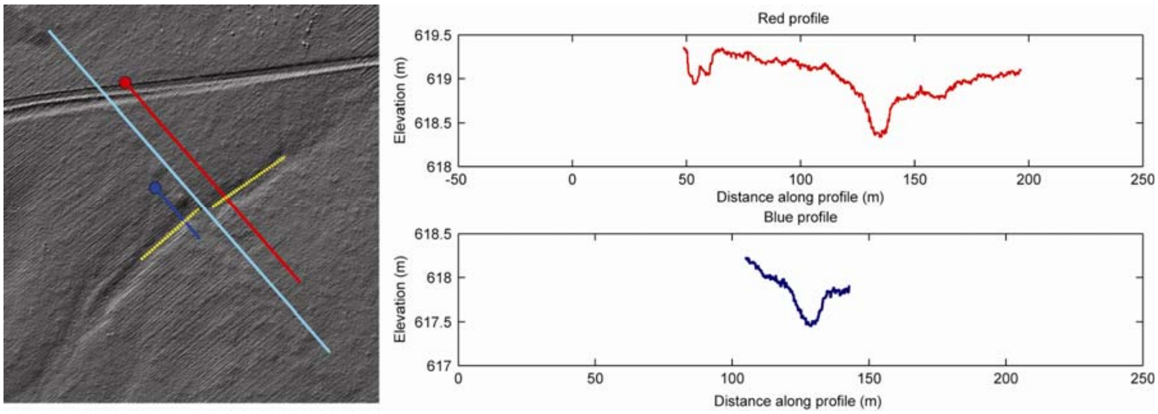


Figure 11. A) Hillshade plot of Sieh's channel 31 (a few hundred meter NW of the Bidart fan site) with fault trace (in turquoise), profile lines (in red and blue) and channel trend of upstream and downstream channel segment (in yellow). B) Projected (to account for channel obliquity relative to the fault trace) topographic profiles. Both profiles have been cut on both ends. Start point of the profile is indicated by a dot in the hillshade view and corresponds to the left side of the topographic profile.

19. Blue and red profile can be cut on both ends. This is usually done with one profile (e.g., the blue profile) to improve fitting i.e., calculation of the optimal offset (the goal is to fit the channel profiles, not the topography surrounding it). Enter here the amount you want to **cut of the start of the red profile** (Fig. 11). Once you have entered a value, the base map (profile line) and the Profiles figure will be updated accordingly.
20. Blue and red profile can be cut on both ends. This is usually done with one profile (e.g., the blue profile) to improve fitting i.e., calculation of the optimal offset (the goal is to fit the channel profiles, not the topography surrounding it). Enter here the amount you want to **cut of the end of the red profile** (Fig. 11). Once you have entered a value, the base map (profile line) and the Profiles figure will be updated accordingly.
21. Define the **trend of the channel section, cut by the blue profile**. Similar to button (13), pushing button (20) opens the base map figure. Here you can enter start and end point of the channel trend line via mouse click. After you entered

both points, a yellow dashed line is plotted in the base map plot outlining the channel trace. The profile in the profiles figure will also be shifted accordingly (accounting for channel obliquity relative to the fault trace).

22. Define the **trend of the channel section, cut by the red profile**. Similar to button (14), pushing button (22) opens the base map figure. Here you can enter start and end point of the channel trend line via mouse click. After you entered both points, a yellow dashed line is plotted in the base map plot outlining the channel trace. The profile in the profiles figure will also be shifted accordingly (accounting for channel obliquity relative to the fault trace).
23. Define the minimum vertical stretch factor. The blue profile can be adjusted by stretching it vertically (changing its z-factor) to account for different morphologic evolution of upstream and downstream channel segment. For example, a beheaded channel may degrade diffusively (lowering the channel profile relief) while the respective head water is still active (Fig. 5). Stretching one profile vertically is a simple way of creating an approximation of the initial channel morphology. When button (34) is pushed, the blue profile will be stretched systematically, ranging from values in field (23) to field (25) with the increment size of field (24).
24. Define the vertical stretch factor step size. See explanation for field (23) for further detail on the stretch factor.
25. Define the maximum vertical stretch factor. See explanation for field (23) for further detail on the stretch factor.
26. Define minimum vertical shift of blue profile. The tool was developed to match offset ephemeral stream channels. Naturally, the thalweg elevation at upstream and downstream profile location will be different (otherwise channel gradient would be zero –no flow would occur). To account for that and allow a better fit of the channel profiles, the GUI allows to shift the blue profile vertically. When button (34) is pushed, the blue profile will be shifted vertically, ranging from values in field (26) to field (28) with the increment size of field (27).
27. Define vertical shift step size of blue profile. See explanation for field (26) for further detail on the vertical shift.

28. Define maximum vertical shift of blue profile. See explanation for field (26) for further detail on the vertical shift.
29. Define the minimum horizontal slip of the blue profile.
30. Define the horizontal slip step size. This value is not only the increment size (precision) in which the displacement will be measured. It also defined the distance dx (Fig. 10). Once a new value is entered, the red and blue profile in the profile figure is redrawn, using the new step size.
31. Define the maximum horizontal slip of the blue profile.
32. Define back-slip direction. This direction should be the opposite direction of the actual fault slip. In other words, select left-lateral back-slip for the right-lateral San Andreas Fault.
33. This field is the product of increments in vertical stretch, vertical shift, and horizontal displacement. It was introduced to give the user a proxy for the computation time used for the offset determination.
34. Using this button starts calculation of the optimal offset. The GUI is going trough all possible combinations of vertical stretch, vertical shift, and horizontal displacement. From the resulting three-dimensional data cube the minimum cumulative elevation difference is determined, along with the corresponding values in vertical stretch, vertical shift, and horizontal displacement. Once the calculation is complete, the Goodness of Fit (GOF, inverse of cumulative elevation difference) as a function of horizontal displacement and the back-slipped blue profile are plotted, for the combination of vertical parameters that contains the optimal fit (Fig. 6B). Optimal horizontal displacement, vertical stretch and vertical displacement are displayed in the MATLAB window. Also plotted is the GOF (color-coded) with respect to vertical and horizontal displacement in an extra figure window (Fig. 12).

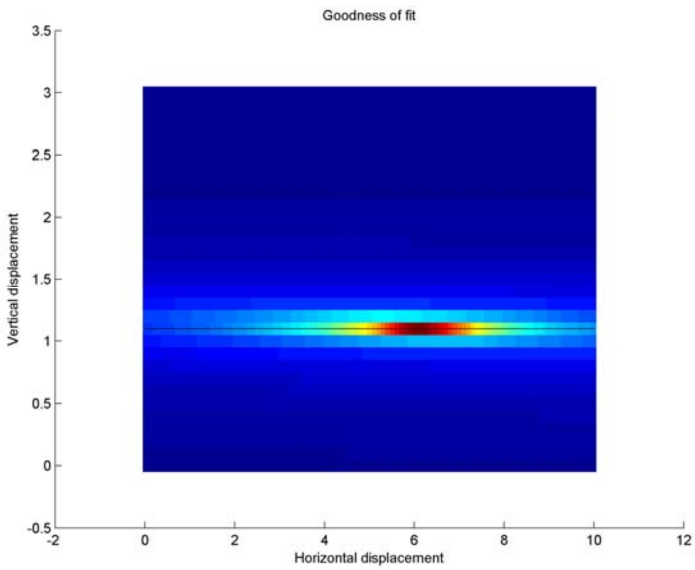


Figure 12. Color-coded GoF (reds = high correlation, blue = low correlation) as a function of horizontal and vertical shift of the blue profile, relative to red profile for reconstruction of channel Sieh #31 (Fig. 7, 9 11).

35. Enter the value by which the base map will be back-slipped.

36. Push this button to back-slip the base-map in the direction, defined in field (32) by the amount defined in field (35). Depending on the selection in fields (5-11) a hillshade plot or contour plot will be produced i.e., back-slipped. The back-slipped i.e., reconstructed surface is then inspected to visually assess the quality of the reconstruction. If reconstruction is not satisfying it is likely that channel trace, fault trace, or profile position may have been chosen unfavorably. Note the importance of having a general idea of what the initial topography might have looked like –the user has to make a conscious decision on what is considered the pre-earthquake topography, in other words what part of the profile should be correlated.

37. LaDiCaoz was written to reconstruct the 1857 surface slip distribution. To allow easy visualization of the along-fault slip distribution, you can enter in this field the along-fault-distance to a reference point. For the 1857 rupture trace we used the intersection of Hwy 46 and fault trace.

38. Enter the quality rating, assigned to the channel reconstruction. Because this is a subjective procedure, we present a guide to assign the rating (Table 1).

39. Enter the optimal offset estimate. This value and the values entered in field (40) and (40) will be stored in an output file that allows creation of the along fault surface slip distribution. Furthermore, pushing the button (43) saves the results: it

saves the current input parameters of LaDiCaoz, the channel profiles, the original base map, the base map with channel and fault trace, and the back-slipped topography. The values used for the back-slip plots are the ones entered in field (39)-(41).

40. Enter the minimum offset estimate. See explanation for (39) for further detail.
41. Enter the maximum offset estimate. See explanation for (39) for further detail.
42. Enter the name, used to store the saved data. I recommend to use a unique name that refers to the individual offset i.e., back-slipped feature (e.g., Sieh32 refers to Sieh's channel # 32 from his 1978 paper; ZA8355a refers to an offset channel at 83.55km along-fault-distance from Hwy46, measured by Zielke et al., 2009).
43. Push this button to save the channel reconstruction. Saving will create a number of files (see Table 2 for explanation) including parameter files, images of current and back-slipped topography, ascii files of the along profile PDF.

File name = Field (41) + ext.	Description
_Hshd.jpg	Base map plot of the topography. I generally use hillshade plots as base map (therefore the name). However you also may use contour plots. Whichever base map you have chosen will be saved under this name
_PrfLoc.jpg	Base map plot showing fault trace, profile lines, and channel trend.
_Prof.jpg	Image of both initial profiles (red and blue profile). Also show is the back-slipped blue profile (back-slipped by optimal slip estimate), plotted on top of initial red profile. This helps to visually assess the reliability of the determined offset amount (whether the fit is reasonably good). At the bottom is a plot of Goodness of fit (GOF, inverse of cumulative elevation difference) as a function of horizontal displacement for the optimal vertical shift and stretch of the blue profile.
_OptBackslip.jpg	Back-slipped image (back-slipped by amount, defined in field (38)) of the base map. Depending on the selections in field (5-11) either hillshade or contour plot are shown.
_MinBackslip.jpg	Back-slipped image (back-slipped by amount, defined in field (39)) of the base map. Depending on the selections in field (5-11) either hillshade or contour plot are shown.
_MaxBackslip.jpg	Back-slipped image (back-slipped by amount, defined in field (40)) of the base map. Depending on the selections in field (5-11) either hillshade or contour plot are shown.
_OffsMatrix.jpg	Color-coded GOF as a function of horizontal and vertical shift i.e., displacement of the blue profile (vertical stretch of blue profile is fixed –used is the slice of the data cube that contains the optimal fit (highest value of GOF)
_Parameters.mat	Parameters that populate the field of the LaDiCaoz GUI. In case the user wants to look at an earlier reconstruction, this file can be loaded by pressing button (4).
_Prof.txt	Contains two lines, the first containing the input of field (36), (39), (40), and (37). The second line contains the pdf values from min to max offset value (field (39) and (40).
_ProfLines.txt	Is a x by 4 table: the first column contains the distance along the profile (see profile figure "XXXX_Prof.jpg "–distance in upper and middle plot); the second column contains initial blue profile elevation; the third column contains initial red profile elevation; the fourth column contains shifted blue profile elevation (for optimal fit).

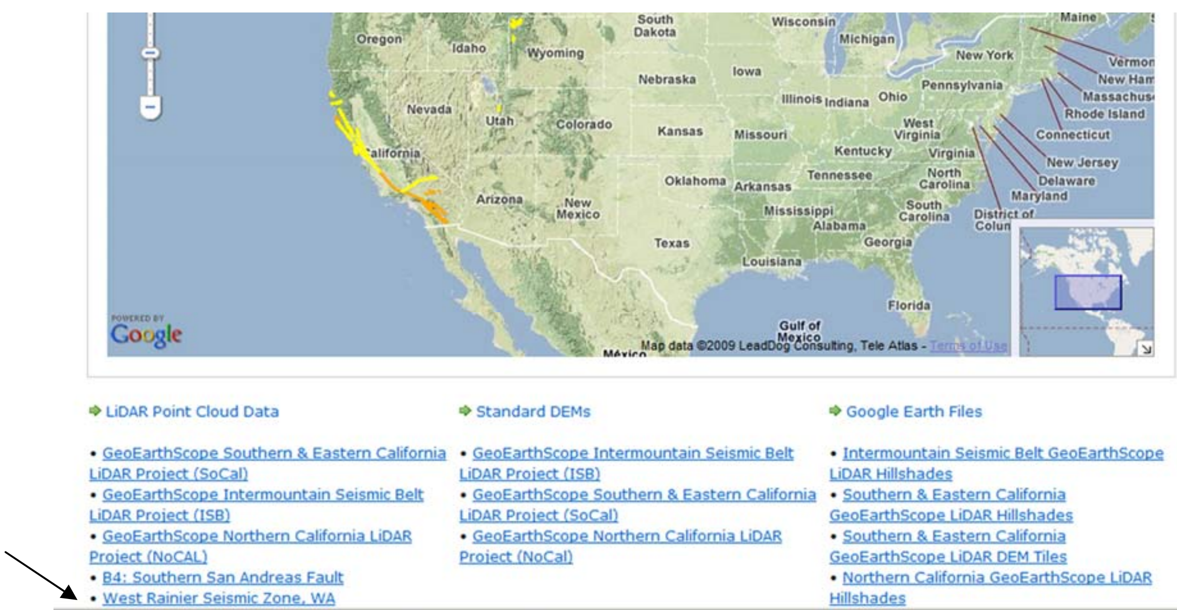
4 Worked example

Following I will go briefly through an example -the reconstruction of a small offset of channel Sieh #77. Also watch the demo files that will be contributed along with the tutorial.

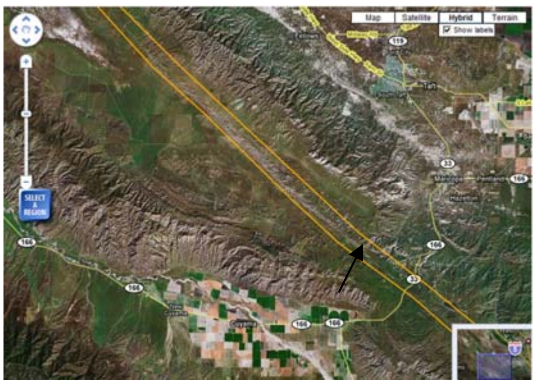
4.1 Download data

First, go to www.opentopography.org, the following page will appear, select the “Data” registry. In case you want to skip that step you will find the downloaded DEM attached to this tutorial.

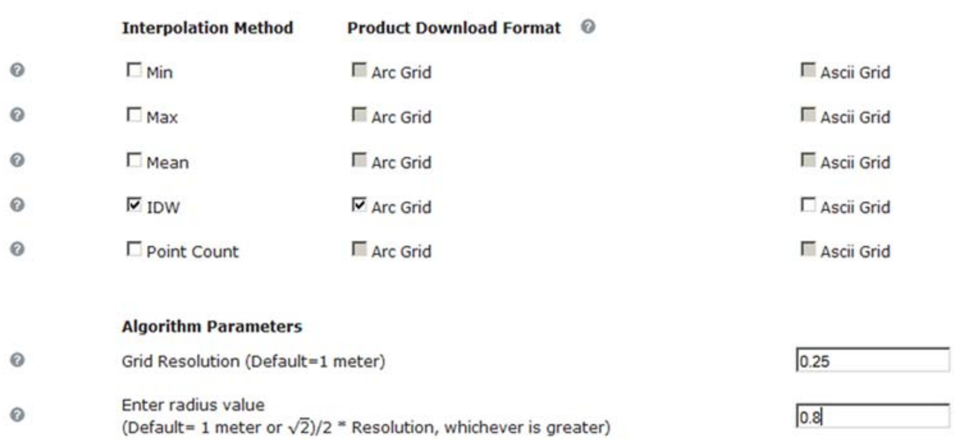
The following page shows a base map and the outline of the currently available data sets (shown in yellow and orange). Scroll down and select “B4: Southern San Andreas Fault”



Zoom into the location of interest, for this example it is the southern end of the Carrizo plain. Zoom further in at the location, indicated by the arrow. Once you are close enough you can use the “Select a Region” button to do just that. LiDAR data for the selected region can be downloaded. Make sure to download a region of reasonable size. Depending on whether you have registered as a user or not you may download different amounts of points. I highly recommend to register.

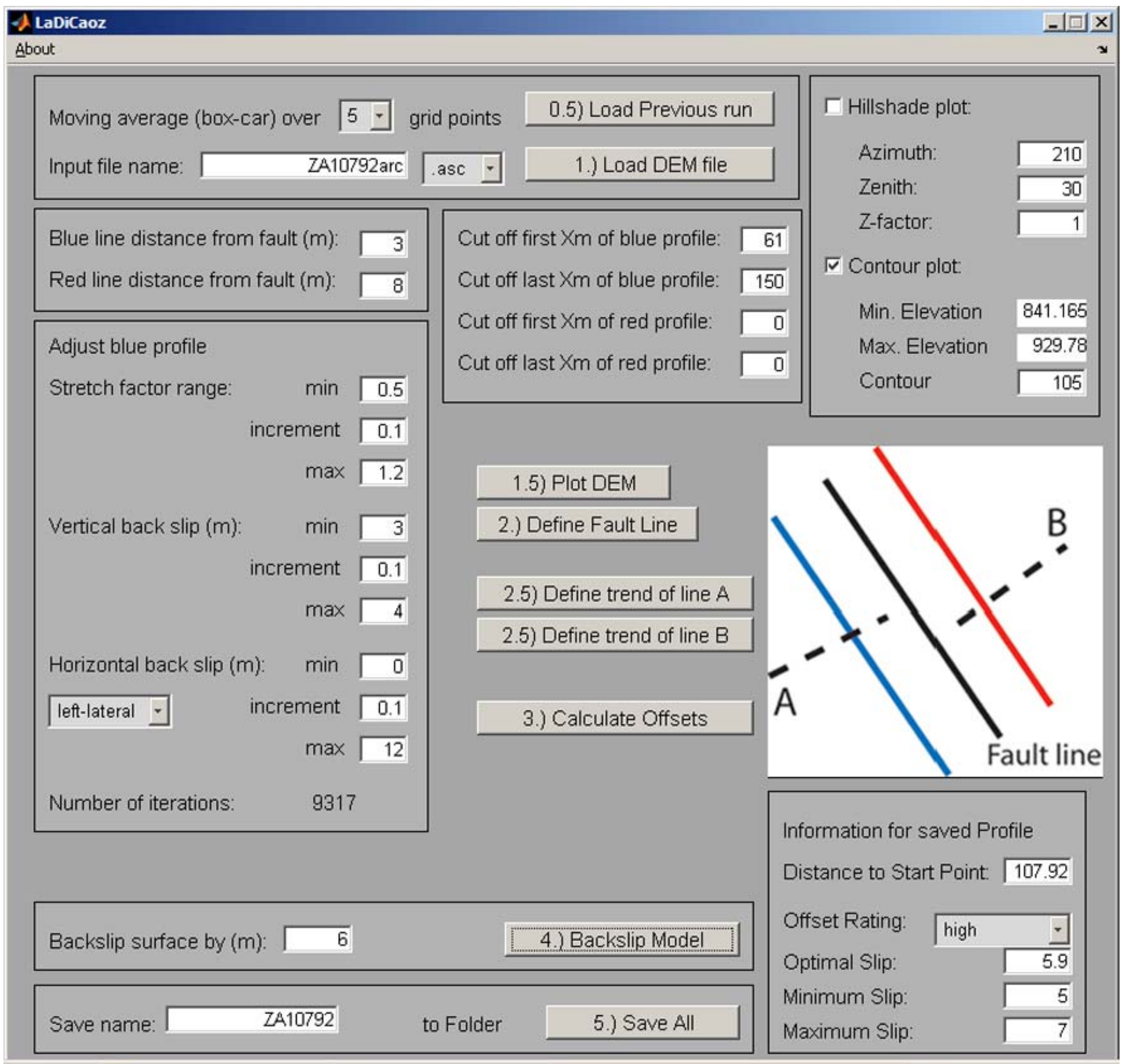


Now that the area of interest is outlined, you can define what data you want to download. For example, you can download the raw point clouds, or some pre-processed data. I typically use the IDW (inverse distance weighting) ARC-grid with a grid resolution of 0.25m and a search radius of 0.8m. If vegetation coverage is too high, I typically select the Min interpolation method (filtering out vegetation) and a lower grid resolution (0.5-1m) and higher search radius (1-2m).



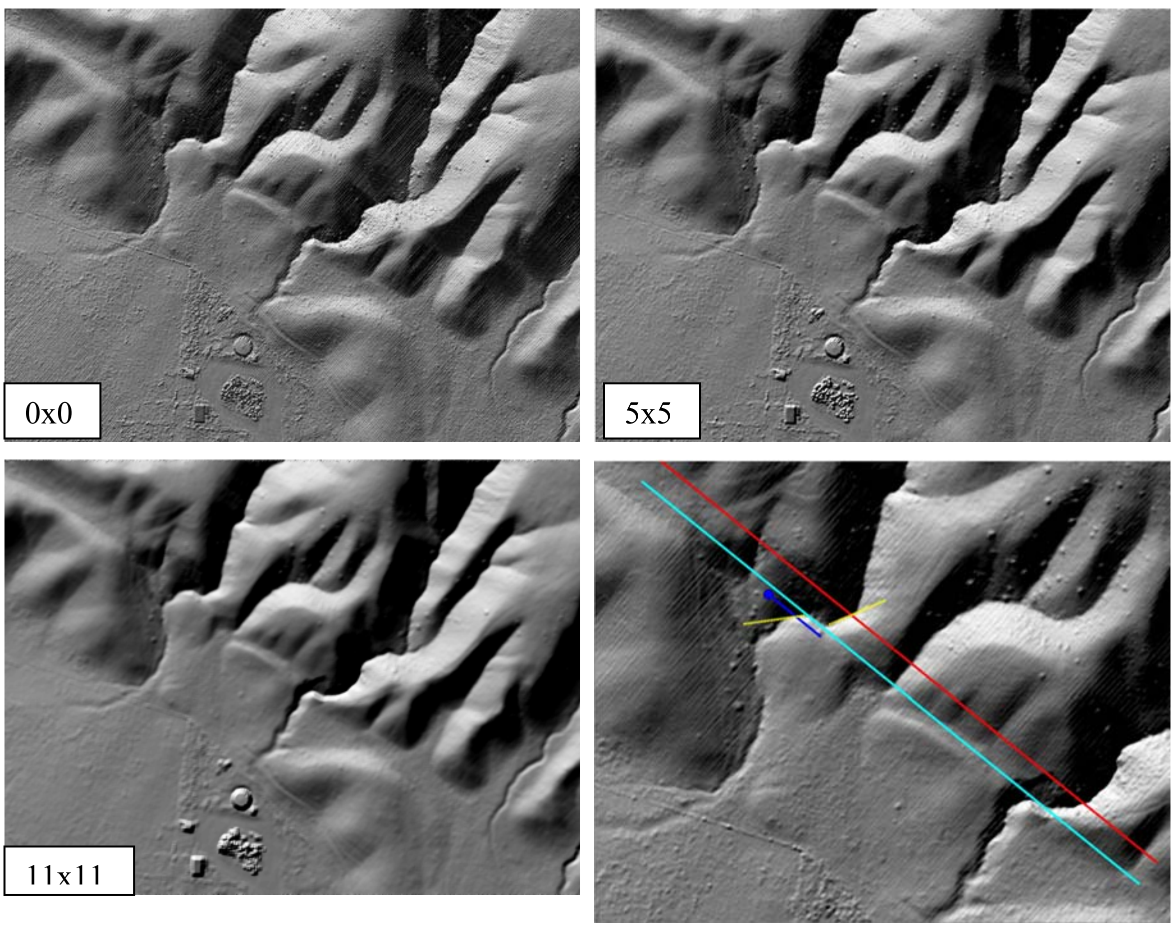
Enter your email address and submit the data request. You receive an email from opentopography.org when the data extraction and interpolation is complete. Download this file, unzip it and copy it into the folder that contains *LaDiCaoz*. I always rename the file due to the cryptic and non-descriptive naming of the original download. For this example I named the file ZA10792arc.asc –if you haven't downloaded it, you will find it together with this tutorial. This channel (ZA10792a) is within the same DEM, therefore the naming (I used this DEM to reconstruct both channels).

4.2 LaDiCaoz



Start MATLAB, change directory to the one that contains LaDiCaoz as well as the DEM (ZA10792arc.asc). Here, simply type “LaDiCaoz” to start the program. IMPORTANT: always have only one GUI at a time open. Due to the way GUIs in MATLAB are setup, multiple open GUIs of the same type will cause error messages and simply not work.

Enter the input file name, select the size of the moving average “box-car” and press the “1.) Load DEM file” button. A message box will open once the DEM was successfully imported. Loading the DEM will be faster if you skip the interpolation step i.e., use a 0x0 moving average. Now you can push the button “1.5) Plot DEM”. Depending on the averaging method you will get different results. The following figure shows the same DEM a) with no interpolation, b) 5x5 moving average, and c) 11x11 moving average. For this example we use a moving average of 5x5.



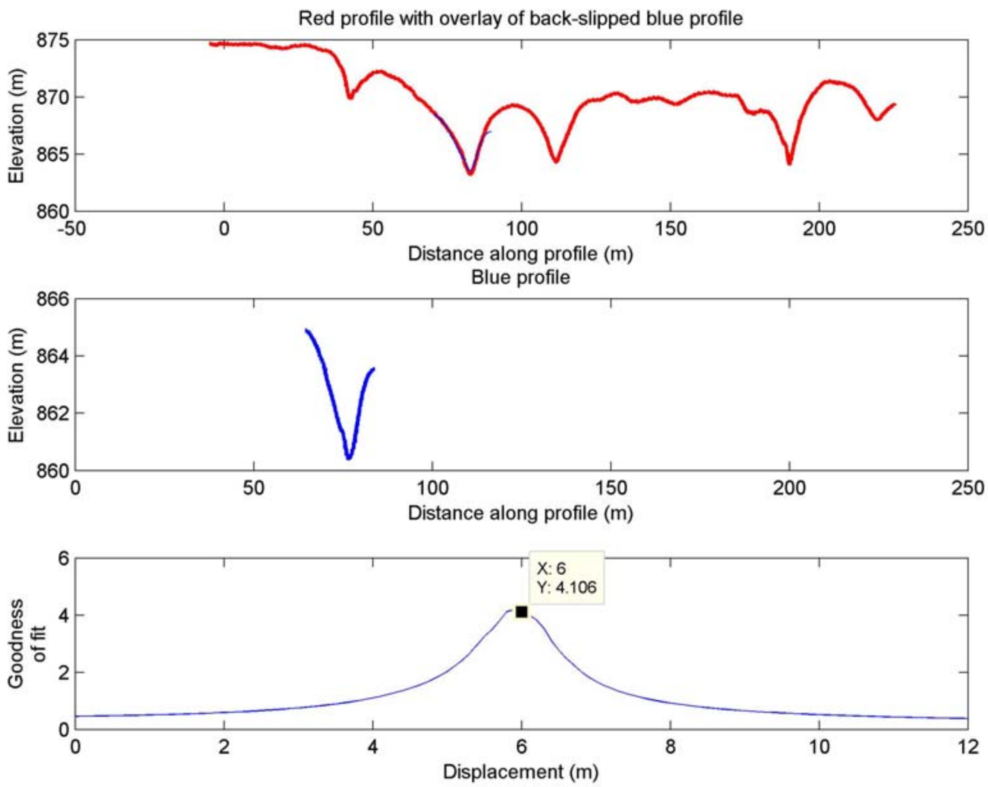
Play around with the illumination angle to find an orientation that shows fault trace as well as channel sufficiently well. After you change the illumination angle, press “1.5) Plot DEM” to update the figure.

Press button “2.) Define Fault Line” to define the fault line. I typically use a ruler or something alike that I put on the computer screen to guide me when clicking start and end point of the fault trace. Press the button again to repeat the tracing. Adjust at least one profile (preferably the blue one), i.e., crop everything that is not part of the channel that you want to reconstruct –use the respective fields [(17)-(20)] to clip start and/or end of the profiles. Also adjust the profiles distance normal to the fault trace [field (15) and (16)]. After entering a new value, profile location on the base map as well as topographic profile are updated.

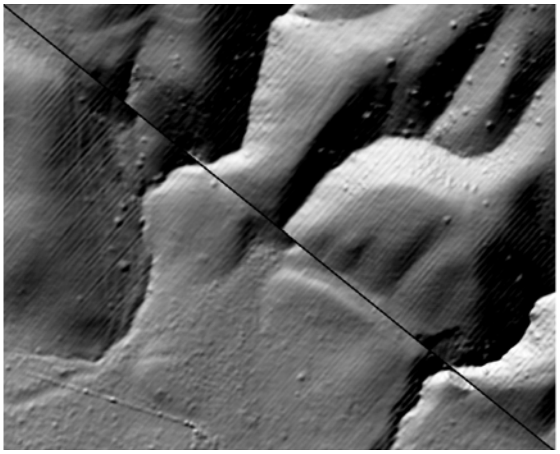
Next, define the orientation of upstream and downstream channel segment at the profile location (i.e., where channel and profile intersect). The profiles will be shifted laterally, according to channel segments trend relative to the fault trace. In other words, the profile is projected onto the fault plane and as a result red and blue profiles are now on the same plane (the fault plane). Click the respective button again to redo the tracing. When going through this example, you will find that the offset measurement results are quite sensitive to the input of upstream and downstream channel segment orientation. This becomes apparent during back-slipping i.e., during visual assessment of the reconstruction. I often trace the segments multiple times and rerun the offset calculation until the resulting reconstruction (back-slipping) becomes satisfying.

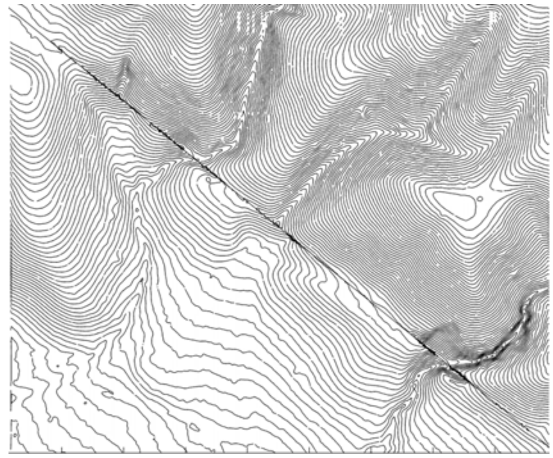
After I entered a range of vertical shift, vertical stretch and offset value that I consider a good bracket for the actual (best) value I start the offset calculation by pressing the corresponding button. The value in field (33) gives you some estimate on how long this calculation will take.

LaDiCaoz is now going through the iterations. After it is finished it will open the profile window and display the Goodness of Fit as a function of back-slip for the optimal vertical shift and stretch (optimal within the bracketing range: look into the MATLAB window, here you will find the output of optimal vertical shift, and stretch and optimal back-slip value, all three values should be within the bracket, if one of them is equal to a corresponding bracketing value you should adjust it). Besides the GoF plot you will also see and overlay of the shifted blue profile (back-slipped, vertically shifted and stretched by the optimal values--see MATLAB window again) with the original red profile in the top sub window of the Profiles figure. This overlay serves as a quality check. Is the fit of both profiles satisfying? If not you might want to change your bracketing values or crop the profiles in a different way, focusing on the channel you want to back-slip.



If the overlay of both profiles is good, enter the value of optimal horizontal displacement into field (35) and back-slip by pressing button (36). Does the reconstruction look reasonable? If the map view back-slip is not satisfying but the overlay of both profiles is good, then the tracing of at least one channel segment orientation was not correct (remember that the profiles are shifted, according to the relative angle of channel segment orientation and fault trace). In this case, simply trace the channel segment orientation again by pressing button (21) and/or (22). Then rerun the offset calculation by pressing the corresponding button, and enter the new offset value for back-slipping.





If both, overlay of both profiles and the back-slip look good you have defined the optimal offset and you can determine the minimum and maximum offset. This is done by trial and error. Simply enter offset values that bracket the optimal offset, back-slip the topography by this amount and visually assess the quality of the reconstruction.

The last step is to save the result. Enter the respective values in fields (37)-(42) and press button (43).

5 References

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