SUPPLEMENTAL MATERIALS

A. Exploratory Study Supplemental Materials

i. Distractor Study research questions

Important questions we hoped to address in this study include; 1) Are students able to recognize the same types of features in both aerial photographs and lidar images?, 2) Do land use patterns, vegetation and infrastructure (which we call "distractors") keep the student from being able to clearly visualize the landscape/topography?, 3) Do high resolution topographic images aid in the correct interpretation of geologic features as compared to aerial photos?

ii. Participants and process

The participants (n=46) in this study were non-major geology students taking an introductory Geology class lecture coupled with a lab course at Arizona State University in the fall of 2010. Two separate lab classes were surveyed; both classes were taught by the same Teaching Assistant and both began at the same time. The students had previously attended four weeks of lecture during which they covered plate boundaries and plate tectonics but had not yet been introduced to faulting or landform development. The lab class had discussed topographic maps and practiced naming types of landforms like (mesas, valleys, mountains, ridges, canyons, buttes and depressions). Approximately 1/3 of the students in the landscape exploratory study said they had some experience with maps, while 2/3 said they had very little to no experience. None of the students considered themselves to be proficient with maps or aerial photographs, although some mentioned using Google Earth occasionally and several said they often used road maps or Google maps.

Each class was broken into two groups, and each student received an image to analyze, an image on which to annotate, and a question sheet. They had 10 minutes in which to answer 6 questions about the image (Section iii). Class 1 (n=21) looked at lidar-derived hillshades. Part of the class (n=12) was given a lidar hillshade of the Wallace Creek area of the San Andreas Fault in central California (Figure 2b) and the others (n=9) were given a lidar hillshade of the fault in the San Bernardino area of southern California (Figure 2d). Class 2 (n=25) was given Google Earth images. Part of the class (n=10) was given a Google Earth image of the Wallace Creek area (Figure 2a) while the other part (n=15) received the Google Earth image of the San Bernardino area (Figure 2c). Each class was told that this was part of a study to learn more about what people see when they look at different types of images. They were given no instructions on what to look for or focus on, and they were given no information about faulting or fault-related landforms.

iii. Questionnaire for Study

Below is the questionnaire that students filled out as part of the study.

1. To what are your eyes first drawn?
2. What things in the image do you recognize? List them here and label them on the image.
3. What geologic features do you see? List them here and label them on the image.
4. What features might indicate a fault? Draw arrows to them on the image (if you see any).
5. How much experience do you have with maps or aerial photographs?
6. Additional observations or comments

iv. Study Results

Question 1: Most prominent feature, or “to what are your eyes drawn?” (Figure 5; Table 1).

In the visually complex San Bernardino Google Earth image, the most common answer was that a landscape feature drew the student’s attention. However, many students (up to 40%) were distracted by other elements of the image such as land use or infrastructure. Compare this to the lidar image of the San Bernardino area, in which 100% of the students listed a landscape or topographic feature as initially drawing the eye, rather land use or infrastructure.

In the Wallace Creek Google Earth image students listed land use or vegetation as the most prominent feature 80% of the time, and features of the landscape (mountains, valley, streams, etc.) as most prominent 20% of the time. However, when viewing the lidar image of Wallace Creek, 90% of the students listed the landscape or a landscape feature as being the most prominent feature in the image. 20% of those listed the fault as the most dominating feature. However, only one student actually identified that landscape feature as a fault. Several other students identified it as “the slash through the landscape separating the higher area from the lower area” or “the vertical line running from the NW corner to the SE corner of the picture”.

Noted features (Figure 6)

Questions 2 and 3

Almost all students identified mountains (or hills or higher areas), valleys (or streams, or lower areas) and flat regions. While many students (48%) identified and labeled structures/infrastructure in the San Bernardino Google Earth image, far fewer listed or labeled the same anthropogenic features in the lidar image of the same area (12%). In the Google Earth image of Wallace Creek, 30% of participants identified the road, but no one identified any infrastructure (like the road or fence lines) in the lidar image. This shows a 30-40% decrease in the recognition and identification of non-landscape features such as roads and houses when looking at the lidar images versus the Google Earth images.

Fault Identification

When asked to mark the fault or fault-related features on the image with arrows, all of the introductory geology students looking at the SB Google Earth image marked it incorrectly, most often marking a valley/ridge (60%) or a road (40%) (Figure S1). When given the lidar image of the same area, their identification improved, with 11% correctly marking the fault, and 89% marking a valley/ridge. In the Google Earth image of Wallace Creek, 20% correctly marked the fault, while 60% marked a valley/ridge and 20% marked the road. However, students given the lidar image of the WC area show significant improvement in the correct evaluation of the fault related landscape features, with 58% of the students correctly marking the fault. One student even marked the direction of fault movement, and several students drew arrows to offset stream channels to show evidence for the fault, rather than just drawing a line down the fault, or marking it along its length with arrows.

B. San Andreas fault Earthquake Cycle Exercise Supplemental Materials

i. Science Motivation for SAF EQ Cycle Exercise

The concept of elastic rebound is often difficult to teach to introductory students because the scale at which strain accumulation and release across a strike-slip fault occurs is difficult to display. Simple illustrations often cause the misconception that deformation and elastic rebound occurs within a few meters of the fault when in reality, deformation is on the scale of tens to hundreds of kilometers. The length scale of the displacement gradients in both phases of a simply defined earthquake cycle (interseismic and coseismic) is controlled by the 10-20 km locking depth of a strike-slip fault fault; e.g., Thatcher, 1990. Along the southern San Andreas Fault in California, displacement gradients can be computed by plotting the relative motion of GPS stations (Figure 3); now mostly part of the Plate Boundary Observatory of EarthScope. The stations record benchmark movement relative to stable North America and allow for the measurement of interseismic strain accumulation across the SAF. In a simple model of the earthquake cycle (e.g., Thatcher, 1990), the strain accumulation across the SAF during interseismic times is balanced by the coseismic strain release along the fault. Using lidar topography and GPS station velocities in the SAF earthquake Cycle enables students to appreciate the geographic scale at which strain accumulation occurs relative to the scale of displacement along the fault, as well as how the two roughly balance along a major plate boundary fault zone.

ii. *SAF EQ Cycle activity discussion*

For the San Andreas Fault EQ Cycle activity, students were asked 6 multiple-choice questions on the assessment. The question in the study which showed key conceptual understanding was: *How was the landscape at Wallace Creek formed?*

a. It is a creek that formed by flooding events. It has a significant and strange bend in it that geologists have studied and continue to not understand.

b. It is a creek that formed after an earthquake on the San Andreas Fault. The creek was deflected by the crack in the ground from the fault.
c. It is a creek that formed before a large earthquake on the San Andreas Fault. This earthquake offset the creek in one major ground-rupturing event.
d. It is a creek that formed and has been repeatedly offset by numerous earthquakes on the San Andreas Fault.

The answer to this question is option d. Correctly answering this inquiry shows that the students have a basic understanding of the earthquake cycle; that is that faults have a cycle of strain accumulation and release. Students showed a 37.5% raw gain increase in correct responses to this question from pretest to posttest in the experimental group.Thus, the example of Wallace Creek helps students visualize that the San Andreas Fault has repeatedly offset Wallace Creek over time by several ground-rupturing earthquakes, which improves their overall understanding of the earthquake cycle..

C. Lidar Video Discussion

For the lidar video assessment, students improved in the experimental group from pretest to posttest with an overall average raw gain of 2.8 points out of a possible 10 points. The control group had a zero gain from pretest to posttest, which is ideal as the control group was not shown the lidar video or given any material in-class to increase their understanding of lidar and its applications to studying earthquakes. These results indicate that overall the lidar video is effective in increasing the viewer's understanding of lidar and the role of lidar for studying earthquake hazards.

Some of the assessment questions on the lidar assessment test a student's understanding of the terminology introduced in the video (i.e., point cloud, lidar). Other questions target the student's understanding of how lidar is used for research in the Earth sciences. One of the key questions asked in the lidar video assessment is question 6:

Which of the following is the BEST reason to use lidar for the study of earthquakes?

a. The data can be used to image the Earth's surface at a resolution of a meter or smaller.
b. The data can create 3D models of the earth's surface in real color with hillshading
c. The data can create 3D models of the earth's surface with exaggerated topography
d. The data can be used to image the earth's surface at a resolution of millimeters or smaller

The correct response to the question is response a. The response shows that the student understands the appropriate scale to study faulting and earthquakes. Although distractor d might seem a more suitable selection, aerial lidar topography is not typically capable of these fine resolutions. The results from this question in the experimental group show an increase from 18 correct responses to 57 correct responses out of n=88 from pretest to posttest, or a 45% raw gain increase. These results indicate that students understand one of the more important reasons lidar topography is used for the study of earthquakes and that they understand both the scale at which aerial lidar is collected along with the correct scale to study earthquakes and faulting.

D. Educational Assessment Tools

This section shows the assessment tools used for assessing the "*Lidar: Illuminating Earthquake Hazards*" video and the San Andreas fault Earthquake Cycle Activity. Each were given twice, once as a pre-test and once as a posttest. Control and experimental groups both took each assessment twice.

i. LiDAR: Illuminating Earthquakes Assessment

http://www.youtube.com/watch?v=dwGT9B4s6Iw

1. What does LiDAR stand for?
    a. Light Detection and Radar
    b. Light Detailing and Radar
    c. Light Detection and Ranging
    d. Light Detailing and Ranging

2. What is LiDAR as it is used for the study of earthquakes?
    a. high-resolution aerial photography that produces very detailed topographic maps.
    b. a remote-sensing technology that produces very detailed topographic maps.
    c. a remote-sensing technology that uses both satellites and radar.
    d. high-resolution aerial photography that uses both satellites and radar.

3. What is the **BEST** definition of a point cloud?
    a. The collection of individual bounces of the laser during collection via aircraft
    b. The collection of data that shows topography with artificial sun shading
    c. The collection of data that shows satellite imagery and topography
    d. The collection of photographs at high resolution which represents topography in 3D

4. How is LiDAR data collected for the study of earthquakes?

a. High-resolution photographs are taken via aircraft and GPS is used for positioning.
b. High-resolution photographs are taken via satellite and GPS is used for positioning.
c. Laser technology collects laser bounce returns via aircraft.
d. Laser technology collects laser bounce returns via satellite.

5. How is LiDAR different from photography?

a. the data use GPS which can recreate a 3D environment
b. the data are individual points which can recreate a 3D environment
c. the data are shaded artificially by the sun which can recreate a 3D environment
d. the data are photographs taken in stereo which can recreate a 3D environment

6. Which of the following is the **BEST** reason to use LiDAR for the study of earthquakes?

a. The data can be used to image the earth’s surface at a resolution of a meter or smaller
b. The data can create 3D models of the earth’s surface in real color with hillshading
c. The data can create 3D models of the earth’s surface with exaggerated topography
d. The data can be used to image the earth’s surface at a resolution of millimeters or smaller

7. Which of the following is **NOT** true about LiDAR topography data?

a. LiDAR can be used to virtually remove trees and other objects.
b. LiDAR can represent the earth’s surface in 3D at a high resolution
c. LiDAR can represent the earth’s surface as a photograph in color

d. LiDAR can be used to virtually back-slip faults to see how the landscape looked before an earthquake

e. LiDAR can be used to virtually forward-slip faults to see how the landscape could look after an earthquake

8. Match the images below with the appropriate letter. Write your choice underneath the image. Not all choices will be used.

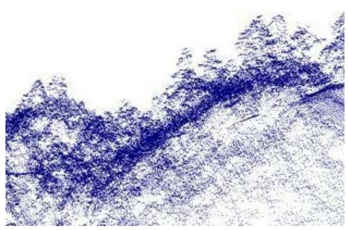
a. hillshaded digital elevation model (DEM)

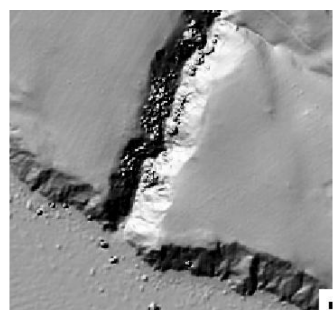
b. photograph

c. point cloud

d. geologic map

e. topographic contour map





_______ _______ _______

ii. San Andreas fault Earthquake Cycle Activity Assessment

1. What is a fault?

a. A lithospheric plate which moves with respect to any other tectonic plate
b. A displaced topographic feature along a plate boundary
c. A crack, fracture, or hole in the earth's crust
d. The point on the surface of the earth directly above where an earthquake originates
e. The break in a rock along which one side of the rock has moved with respect to the other side

2. How was the landscape at Wallace Creek formed?

a. It is a creek that formed by flooding events. It has a significant and strange bend in it that geologists have studied and continue to not understand.
b. It is a creek that formed after an earthquake on the San Andreas Fault. The creek was deflected by the crack in the ground from the fault.
c. It is a creek that formed before a large earthquake on the San Andreas Fault. This earthquake offset the creek in one major ground-rupturing event.
d. It is a creek that formed and has been repeatedly offset by numerous earthquakes on the San Andreas Fault.

3. Choose the **BEST** statement describing landscape evolution:

a. The landscape changes by magmatic fluctuations and radioactivity
b. The landscape changes by erosion via water and air which breaks it down
c. The landscape changes by tectonic processes which uplift and form new crust

d. a and b
e. b and c
f. a and c
g. a, b, and c

4. What does a GPS station record?

a. The movement of the earth at the station's location
b. Earthquakes at the station's location
c. Long-term slip rate on faults over many years
d. a and b
e. b and c
f. a and c
g. a, b, and c

5. Which statement is **NOT** true about the San Andreas fault and how it relates to plate boundaries?

a. The San Andreas is a fault that is related to plate motion
b. The San Andreas is a fault that has resulted from stress and movement at the Pacific Plate and North American Plate boundary.
c. The San Andreas is part of the plate boundary between the Pacific and North American plates
d. The San Andreas fault is moving at the surface at the current strain accumulation rate
e. The San Andreas fault is located in California

6. The earthquake cycle is

a. steady strain accumulation due to plate tectonics and episodic strain release in the earthquake

b. repeating earthquakes

c. the offset of stream channels along faults by earthquakes

d. the offset of geomorphologic features along faults by earthquakes

e. a and b

f. a, b, and c

g. a, b, and d

h. a, b, c, and d

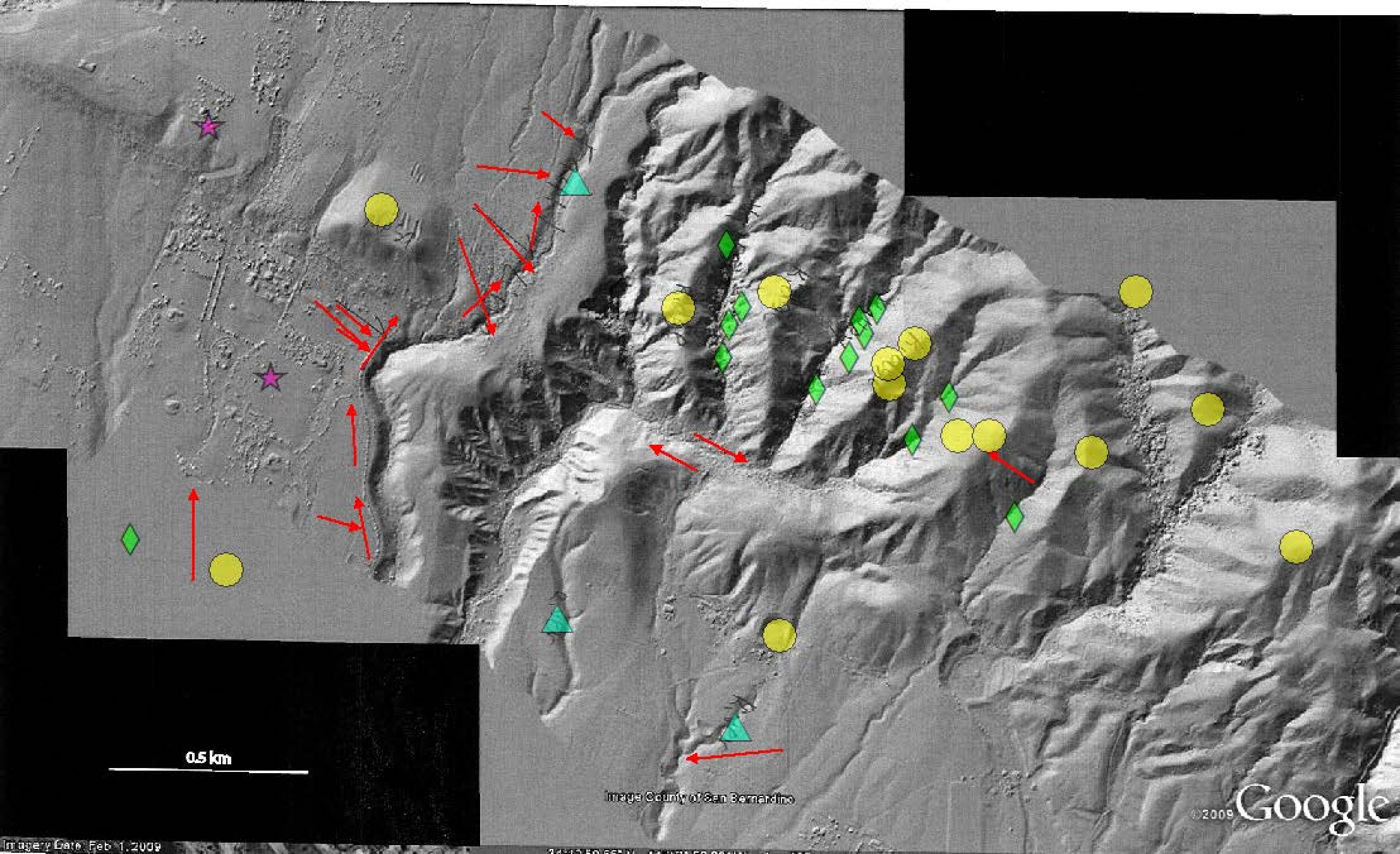
E. Open Landform Catalog

An educational resource developed using lidar data is the OpenLandform catalog (http://www.opentopography.org/lidarlandforms). It is designed to illustrate different types of landforms in high resolution topography (Kleber, et al., 2012). The OpenLandform Catalog uses the freely available lidar data on OpenTopography to highlight classic geologic landforms including features formed by wind, landslides, water, faulting, and volcanic activity. This resource brings digital topographic data to an accessible level that can be interrogated and explored using free tools, such as Google Earth. The catalog complements advanced high school and introductory college level earth science courses where the study and analysis of landscapes and their characteristic landforms is essential to students understanding of fundamental earth system processes. As of May 2016, the catalog has six landform types: geologic landforms created by (1) wind action, (2) impacts and landslides, (3) water, (4) ice, (5) faulting, folding, and earthquakes, and (6) volcanic activity.

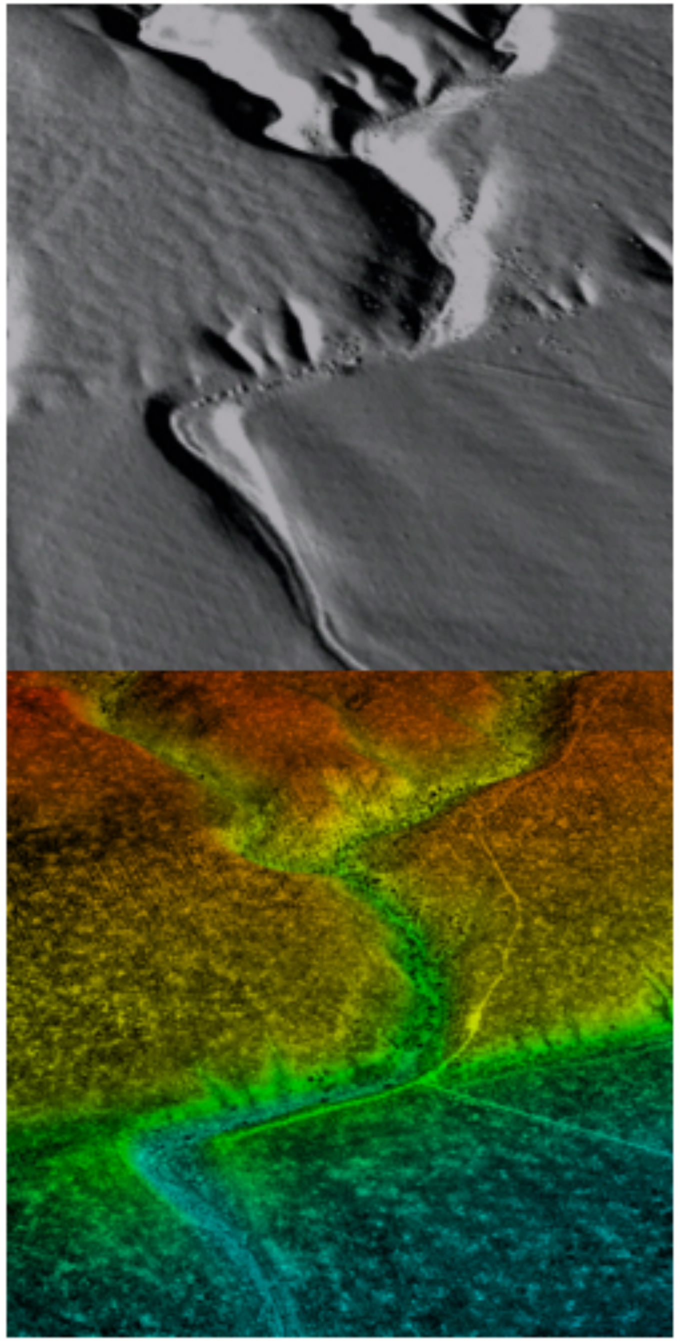
Supplemental Materials Figure Captions

Figure S1) Results from distractor study showing student's observations from Google Earh and hillshade imagery of the San Andreas Fault in San Bernadino, California. Yellow circles indicate landscape features (hills, rivers, valleys) identified by students, blue circules indicate infrastructure (roads, buildings) identified by students, and red lines are where students identified the fault, which was required by the activity. Figure 1A shows Google Earth imagery of northern San Bernadino, CA and student observations from the distractor study. Figure 1B shows the lidar derived hillshade image used by students to identify features.

Figure S2- Screen shot of an entry in the OpenTopography OpenLandform Catalog (http://www.opentopography.org/lidarlandforms#OffsetDrainage; Accessed May, 2016). Each entry consists of an image and brief description of the pictured landform, any associated exercise that has been developed in conjunction with the point cloud data, the original dataset, and pre-generated data products. These products include images of the hillshade/point cloud of the landform pictured on the page, Google Earth KMZ files, Digital Elevation Models (DEMs) with derived hillshades and slope products, and the point cloud data in the standard LAS format. These pre-generated products, especially point cloud files, are selected from larger datasets and aim to be a reasonable size (<1 GB) for use on a personal or classroom computer.


0.5 km
Image County of San Bernardino
©2009 Google
Imagery Date: Feb 1, 2009

Offset Drainage



Wallace Creek, Carrizo Plain National Monument
Wallace creek is an example of a drainage area that has been physically altered by active faulting. An offset channel occurs when a channel that would normally be somewhat straight, crosses an active transform fault and is physically"beheaded" by the strike-slip movement of the downstream plate in one or numerous earthquakes. For more information about the geologic history of Wallace Creek, please read The San Andreas fault at Wallace Creek, San Luis Obispo County, California field guide by Kerry Sieh and Robert Wallace.

Exercise: Wallace Creek Student Field Trip Guide: The goal of this exercise is to give a better understanding to students about the earthquake cycle, strike-slip faulting, plate boundaries, and plate motion using Wallace Creek on the San Andreas Fault in California as an example.

B4 Project - Southern San Andreas and San Jacinto Faults

- Images
- Google Earth KMZs
- DEM's, Hillshades and Slope Grids
- Point cloud