ShakeAlert® activities for formal and informal learning settings

Kinesthetic Modeling & Interpreting & GPS Data Maps

Demonstrating Tectonic Motions in Earthquake Hazard Regions

Version 10/13/22

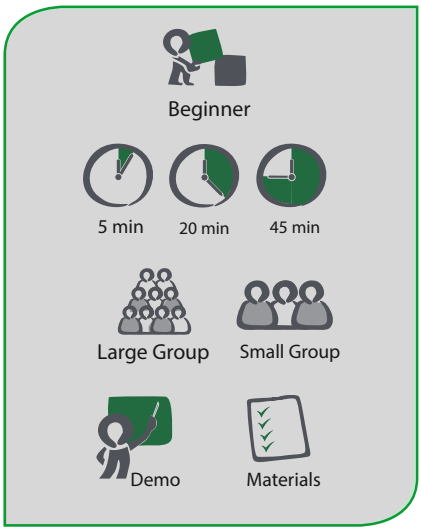
Activity by Roger Groom, Middle Grade Science TOSA-Instructional Coach, Portland Public Schools, Portland OR

OVERVIEW

The ground is always moving. Within a tectonic plate, some parts of the land move more quickly or in different directions from other regions nearby. This can cause the land to deform, stretch, compress, and twist, until it breaks along a fault, creating an earthquake. This motion can be measured and monitored using the Global Positioning System (GPS; Vocabulary Appendix A).

Using hand and body motions, data from GPS and maps, learners explore ground deformation at and near plate boundaries. Ground deformation is then related to seismic hazards and societal impacts. In the 5-minute activity, learners explore the concept of vectors by kinesthetically enacting ground movement using their body and hand movements (Figure 1). In the 20-minute activity, learners model GPS ground motion in different regions and connect deformation to earthquake hazards. In the 45-minute activity learners distinguish between different boundary types by measuring the vectors within tectonic plates. They identify regions with higher earthquake hazards and compare their findings to earthquake shaking potential maps.

Why is it important to learn about plate motions and ground deformation near plate boundaries? More than 143 million people are exposed to potential earthquake hazards in the U.S. that pose the risk of thousands of lives and billions of dollars in damage. Identifying regions with higher seismic hazards is fundamental to earthquake preparedness. The ShakeAlert Earthquake Early Warning System, which in part integrates GPS data, is an important tool used for hazard preparedness for the West Coast of the United States.



Time: 5-, 20-, and 45-minute guided activities that can be adapted for audience and venue.

Audience: Novice and experienced geoscience learning groups.

Subject: Natural Hazards: Earthquakes, Geoscience.



Figure 1: Learners demonstrating different velocities as represented by vectors.

OBJECTIVES

Learners should be able to:

- Explain that velocity has two components; the speed and direction of ground movement.
- Illustrate or describe two types of tectonic plate boundary motion using velocity vectors.
- Identify regions more likely to have higher earthquake hazards using relevant GPS evidence.

TABLE OF CONTENTS

Overview. 1
Materials & Relevant Media 2
Activities and Demonstrations 4
Appendices 13
NGSS Standards 39

MATERIALS

Materials for the 5-minute activity

- Appendix C—Vector Components for Kinesthetic Activity (printed)
- Appendix D—GPS Vector Maps (projected or printed)
- Optional: Computer with projection system
- Optional: Stretchy/elastic bands (3' - 4'), exercise-resistance band or tubing

Materials for the 20-minute activity

(In addition to materials listed for 5-minute activity)

- Large space to spread learners out to represent GPS station movement.
- Computer projection system
- Appendix D—GPS Vector Maps: Southern CA GPS Vector Map (projected)
- Appendix E—Generic GPS Station Signs for human-scale modeling of ground deformation
- Printed Generic GPS Station Signs
- Stretchy/elastic bands 3' - 4' for each segment.
  Material options: very long rubber bands, exercise-resistance bands/tubing, or sewing elastic.
  - For 6 learners in a 2 x 3 grid, 7 elastic bands are needed (ideally, 4 of one color, 3 of another).
  - For 9 learners in a 3 x 3 grid, 12 elastic bands are needed (6 of one color, 6 of another).
- Appendix G—20-minute Activity Summary Handout (printed) with enough copies for the # of learners
- Optional: Floor-sized map of California, such as National Geographic MapMaker's Table Top CA Map
- Optional: Masking tape on floor for outline of CA, with different color tape for the San Andreas Fault.
- Optional: Appendix F—GPS Station Info Placards (see note on Appendix for more information.)

Materials for the 45-minute activity

(In addition to materials listed for 5- and 20-minute activity)

- Appendix H—45-minute Activity Learner Outline (in lieu of 20-minute handout)
- Metric rulers
- Long measuring tape (up to 50m length)
- Calculators (optional)
- Colored pencils: 3 colors—enough for all learners
  - Adaptations for colorblind learners: use colored pencil, crayons, and small felt markers to differentiate between textures

RELEVANT RESOURCES

Videos / Animations

- Video Tutorial: How GPS Measures Ground Motion (3:05)
- Video: GPS Measures Deformation in Subduction Zone (0:58)

Publications as relevant background (optional)

- USGS: Understanding Plate Motions for plate tectonics
- USGS: Earthquake Hazards
- USGS: Intro to the National Seismic Hazard Maps

Videos and online tools as relevant background

- Animation: Measuring Plate Tectonic Motions with GPS (5:42)
- Video: NASA's Brief History of Geodesy (2:24)
- Tool: UNAVCO GPS Velocity Viewer

Appendices—Background info and handouts

Click links below to view appendices. Return to this page by clicking the "Page 2" arrow.

Page 2

Appendix A: Vocabulary
Appendix B: Background on GPS and Reference Frames
Appendix C: Printable Vector Components for Activity
Appendix D: GPS V Maps
Appendix E: Human-scale modeling of ground deformation with Generic GPS Station Signs
Appendix F: GPS Station Info Placards
Appendix G: 20-minute Activity Summary Handout
Appendix H: 45-minute Learner Outline
Appendix I: Answer Keys for the 20- and 45-min handouts
Appendix J: Full GPS Vector Map of the Western U.S.
Appendix K: Earthquake Shaking Potential Maps
Appendix L: NGSS Science Standards & 3-D Learning

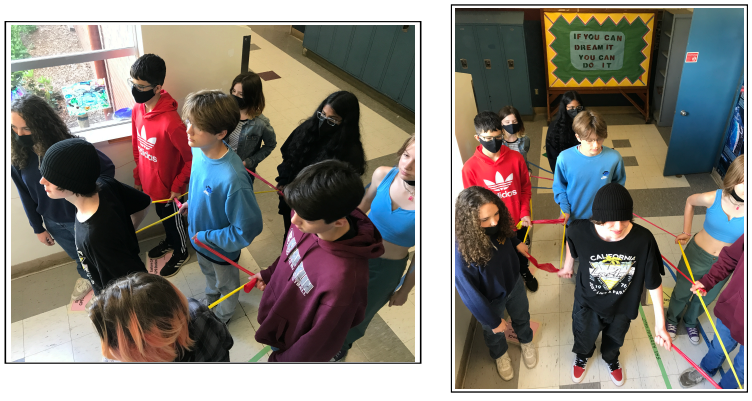


Figure 2. Before and after of the human-scale modeling of ground deformation from the 20- and 45-minute activities. See Appendix E for larger photo.

INSTRUCTOR PREPARATION

The movement of the land is measured very precisely by GPS or other Global Navigation Satellite Systems (GNSS) (Figure 3). GPS satellites send signals to GPS receiving stations permanently anchored into rock or deep into soil. If the ground moves, the GPS station moves with the ground. The change in position is collected every tenth of a second, every day, to precisely measure the movement in all three dimensions at the sub-millimeter level. The data are processed daily to determine a daily change of position (see Appendix B for more detail) with an average velocity of the ground calculated periodically.

On the maps (Figure 5 below), the vectors—which appear as arrows —indicate the location of a high-precision GPS station (at the tail of the vector), as well as the horizontal velocity of the GPS station and therefore the ground. The longer the arrow, the faster the ground and the GPS station move (Figure 4, to the right).

Note: Learners might confuse the length of a vector with total distance. Emphasize that the length is the speed the ground is moving in millimeters per year.

It is recommended that instructors familiarize themselves with the Media Resources and Appendices listed on the previous page.



Figure 3: GPS Station P411 in Forest Grove, OR. The GPS antenna on the left, is anchored to the ground. Solar panels, GPS receiver, and communication equipment is on the right. (Source: UNAVCO)

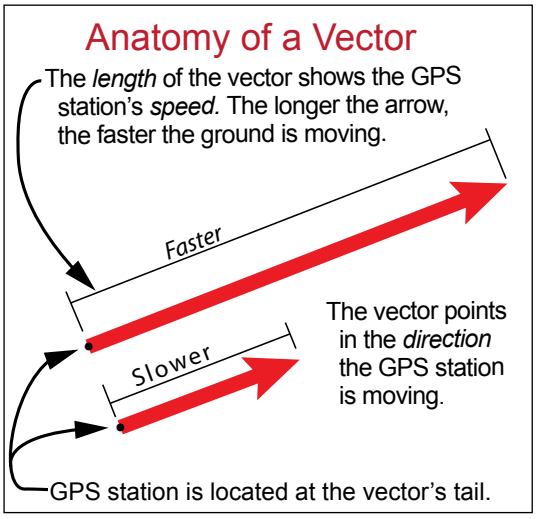


Figure 4: Anatomy of a vector. A vector represents the speed (vector length and the direction that a specific piece of ground is moving.

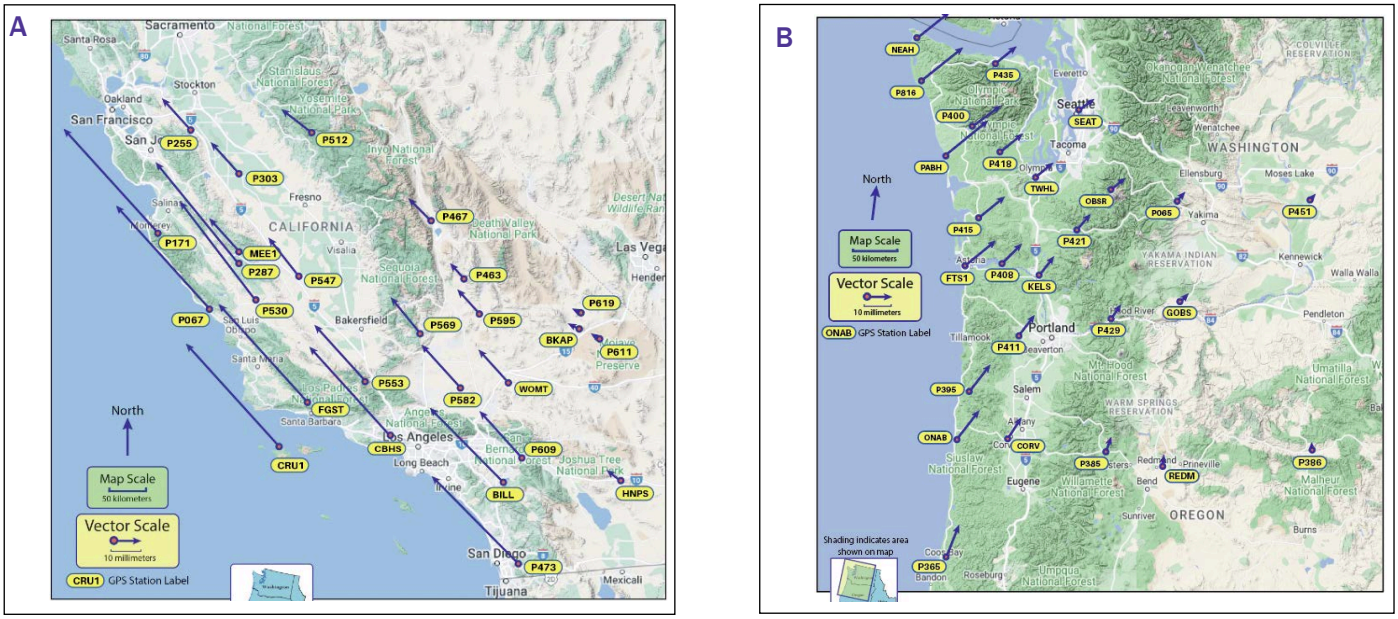


Figure 5: Ground Motion Vector Maps. A) Southern California; B) Oregon and Washington Ground Motion. For higher resolution versions of these maps to print or project, see Appendix D.

ACTIVITIES AND DEMONSTRATIONS

IF YOU HAVE 5 MINUTES

Did You Know?

- Did you know that the ground is moving beneath our feet right now?

Yes, the ground is moving! Most of the time, it's moving very, very slowly, so slowly that we normally can't feel it move. We only feel the earth move if it's a larger, sudden movement, such as an earthquake.

In this 5-minute activity, learners will become familiar with vectors and how vectors can be used to show ground movement as measured by GPS instruments. First, they will do a quick and easy activity to get the idea of vectors showing direction and speed of travel. Then, learners will use one (or both) of the GPS vector ground motions maps (Appendix D, Figures 5A and B) to explore ground motion near and at tectonic plate boundaries. Learners will discover that there are areas where the ground is moving at similar speeds and direction, and other areas where the speed and direction of the ground change across the region. By using their hands, learners will demonstrate the motion of the ground in areas with differences in speed and/or direction and interpret the basic tectonic motions represented by the vectors. In an optional extension, two learners hold a long elastic band between them. They will notice that the material stretches, modeling deformation of the ground over time)

Preparation

- Before beginning the activity, watch the relevant media resources on GPS data and plate motion:
  - Video Tutorial: How GPS Measures Ground Motion (3:05) to learn about vector maps and show hands illustrating plate motion
  - Video: GPS Measures Deformation in Subduction Zone (0:58)
  - Optional: view animation "Measuring Plate Tectonic Motions with GPS" (5:41) for more information.
- Print out copies of the vector components (Appendix C) and tape them on the floor.
  - Both vectors point in the same direction, spaced such that people can see them and then walk on them. If possible, laminate the arrows before taping.
  - One short vector should be approximately 3 feet (90 cm) long
  - One long vector should be approximately 6 feet (180 cm) long
  - Arrows need to be large enough to see from a distance and survive being walked on. Alternatively, arrows could be drawn on butcher paper, or laid out with tape.
- Print out or plan to project the GPS vector maps (Appendix D).
- Optional: prepare a projection system and have elastic bands readily available (for extension).
- Pose or post the "**Did You Know?**" question to your learners. Modify to fit your situation. For example, in an informal setting, the instructor could ask visitors if they felt the ground move? When they say no, use that to launch into the activity.

Directions

Note: Introduce new vocabulary (Appendix A) to meet your learner's needs.

1. Draw attention to the "Did You Know" question, then to the two large arrows taped on the ground.
2. Ask a learner to stand at the tail of the short arrow and move in the direction the arrow is pointing. Instruct learner to move the length of the arrow in two steps (three steps if younger learners).
3. Ask another learner to stand at the tail of the long arrow and move in the direction the arrow is pointing, and to cover the length of the long arrow with the same number of steps as the person in step number 2.
4. Now ask both learners, or another set of learners, to stand at the tails of the vectors. Tell learners that they will each have to reach the end of their vector in the same amount of time with a certain number of steps. Two steps are ideal but, again, could be three for younger learners.
5. At the pace of 1 clap per second, each learner should make it to the end of the vector with 2 or 3 steps. Have the learners practice the motions first. Those on the long arrow will be moving further with each step. The learner with the longer arrow will walk more quickly.
6. Meanwhile, the remaining learners are observing the process and noting the differences in speed of the people on the vectors.
7. Do a final run with observers all clapping together.

Questions for Discussion:

Ask learners what they noticed about their movements.

- *Expected response: Learners should observe that the arrow indicates the direction of movement.*

They have to move more quickly to travel the length of the longer arrow in a given amount of time, compared to the shorter arrow. They have demonstrated the speed of movement; the longer the arrow, the faster the speed.

8. Show one of the posters: GPS Vector Map of Southern California or GPS Vector Map of Oregon and Washington (Appendix D).
9. Point out the arrows on the map and explain that each arrow represents data collected about the motion of the ground. Relate the arrows that learners walked on to the vectors on the Tectonic Motion maps. Show the *Anatomy of a Vector* diagram (Appendix D/Figure 4) and point to the vector elements on the figure and the map.
10. Explain that a GPS station is a tool to measure ground movement. GPS works by very precise communication from a system of GPS satellites to GPS antennas permanently anchored to the ground so that if the ground moves, the GPS moves with the ground and records that movement. Explain:
    a. On the map, the tail (point to the tail of one vector) indicates the location of a GPS station.
    b. The vector arrowhead points in the direction that the station is moving. Emphasize that the vectors indicate the average speed over a period of time, not the total distance moved. These maps show the movement in millimeters/year.
    c. The length of the vector is proportional to the station's speed; the longer the arrow, the faster the ground and the GPS station are moving.
11. As you point out different vectors, use your hands (Figure 6) to demonstrate the motion depicted by vectors, particularly pairs of vectors that show the motions indicated in Figure 6.

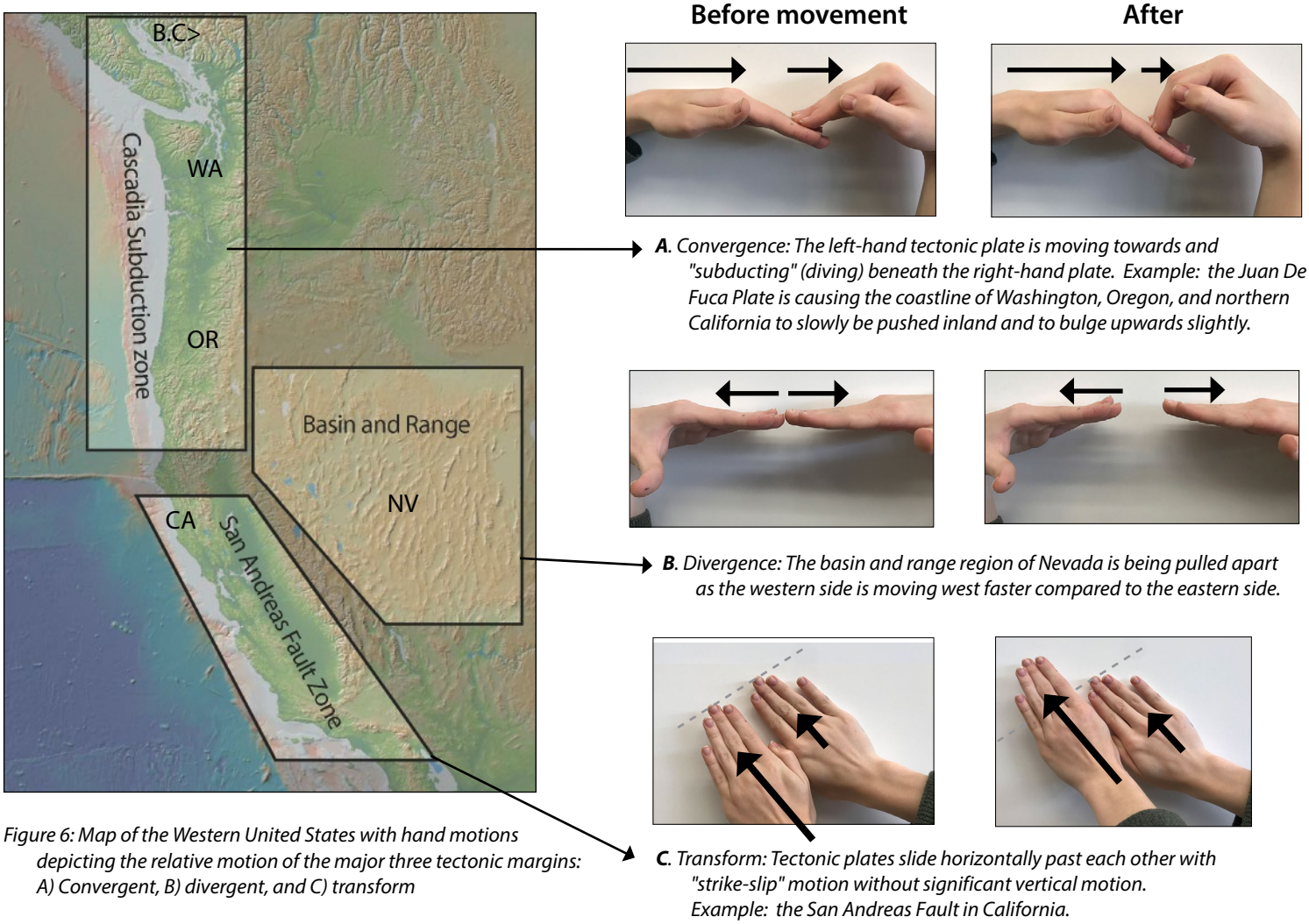


Figure 6: Map of the Western United States with hand motions depicting the relative motion of the major three tectonic margins: A) Convergent, B) divergent, and C) transform

Questions for Discussion by region:

Ask learners the following questions about the maps they are viewing. (Questions for **CA** = blue; **OR/WA** = green.)

1) Where are the longest and shortest vectors on the map, and what does that mean?
   - **Southern California:**
     Longest vectors: Closer to the coast, especially islands off the coast, meaning that those areas are moving the fastest. Shortest vectors: The farther inland you go, the shorter the vectors become, meaning less and less motion in the same amount of time. In fact, areas east of Death Valley are barely moving at all.
   - **Oregon/Washington:**
     Longest vectors: Closer to the coast, meaning those areas are moving the fastest. Shortest vectors: Farther north/inland vectors show less motion per year.
2) Describe the motion of the areas between the longest and shortest vectors.
   - **Southern California:**
     Vectors show the areas between the coast and inland are moving in the same direction but not as fast.
   - **Oregon/Washington:**
     Vectors show the areas in between the coast and inland are moving in the same direction, but not as fast. The land near the coast is compressing against further inland areas.
3) Based on the movements of different areas within this map, describe the overall forces acting over the entire area.
   - **Southern California:**
     The west coast is moving faster than the eastern part of CA, thus, stretching and pulling on the middle of the state. This could lead to earthquakes as the ground gives way.
   - **Oregon/Washington:**
     The west coast of OR and WA is being pushed northeast into the rest of the Pacific Northwest, crunching the area in the middle. This could lead to earthquakes. Note: the 'crunching' of the urban corridor not only leads to movement to the northeast but also vertical movement. Vertical motion is harder to interpret and so will not be discussed here.
4) GPS shows where areas are moving a lot compared to others. How might that affect earthquake hazards and preparedness?
   - *Answers will vary, but learners should be able to recognize a higher earthquake hazard for regions with faster ground movement next to a region with less or little ground movement.*

Extensions

1. When learners move at different speeds along the arrows, have them do it with a stretchy material between them. As they move, the material will deform by elongating. Ask learners what would happen if elastic material got stretched too far. It would break. This demonstration illustrates that the land between areas moving at different velocities will get deformed like the elastic band until, at some point, it will break, creating an earthquake. The discussion of deformation here, though, is secondary to the idea that GPS vectors indicate direction and speed of movement.
2. Review the 3 plate boundary types with learners as a transition to the 20-minute activity. The instructor could show the other tectonic motions map or the UNAVCO GPS Velocity Viewer if time permits.

IF YOU HAVE 20 MINUTES



Did You Know?

- Did you know that some parts of the land within a tectonic plate are moving faster than others? What do you think might happen as a result?

Learners experience what vectors mean by using their bodies to kinesthetically model not only ground movement from GPS data, but the deformation of the land due to tectonic forces. Learners then discuss personal and societal implications. This activity is written for a flexible instructional environment to fit either a classroom or a more open forum.

Preparation:

1. Content presented in the 5-minute demonstration should precede this activity.
2. Watch the video, How GPS measures Ground Motion (3:05).
   - This video uses 'gumdrop' GPS stations and printed directional arrows to model how GPS receivers move with different types of boundaries.
3. Print and ideally laminate vectors to tape on the floor. (Appendix C).
   - Short vector for Eastern California—less than a foot
   - Medium length vector for Central California—about 2 feet
   - Long length vector for Coastal California—about 5 feet
4. Southern CA GPS vector map printed as large as possible (Appendix D).

5. Setting up the model:
   - Decide how many learners to include in the model. Space permitting, a larger grid is better for this activity.
   - Print enough copies of generic GPS station signs (Appendix E) for the number of learners in the model. Give each GPS station sign a unique number or letter to account for the number of signs used in each region.
   - Mark and label the San Andreas Fault with tape.
   - Tape GPS station signs on the floor in their approximate locations while paying particular attention to spacing. To make what is happening visible, space out the signs so they are a couple feet apart, and make sure that the signs within a particular region are spaced equally.
   - Make enough elastic bands to connect all the learners as shown in Figure 7.
     - For 6 learners in a 3x2 grid, 7 elastic bands are needed (ideally 4 of one color, 3 of a different color).
     - For 9 learners in a 3x3 grid, 12 elastic bands are needed (ideally 6 of one color and 6 of another color to differentiate between learners in the same geologic region from those in different regions).
     - Elastic bands should be slightly longer than the distance between GPS station signs to enable learners to hold the elastic with minimal stretching in the initial setup.
   - Optional but recommended: use tape to make the CA borders and landmarks to help orient learners. See Appendix E (inset C) for an example of initial setup with CA border (blue tape) and San Andreas Fault (green tape).
   - **Other options:**
     a. Make specific GPS Station placards with station images and their GPS velocities (mm/year). See Appendix F—GPS Station Info Placards for a few examples and instructions.
     b. Want to go one step further? Get a big piece of stretchy cloth or cargo netting—or some other fabric that will stretch. Cut holes in the fabric where learners would stand and then have them move according to the GPS vector lengths. The fabric would stretch across the fault, showing areas of highest deformation.

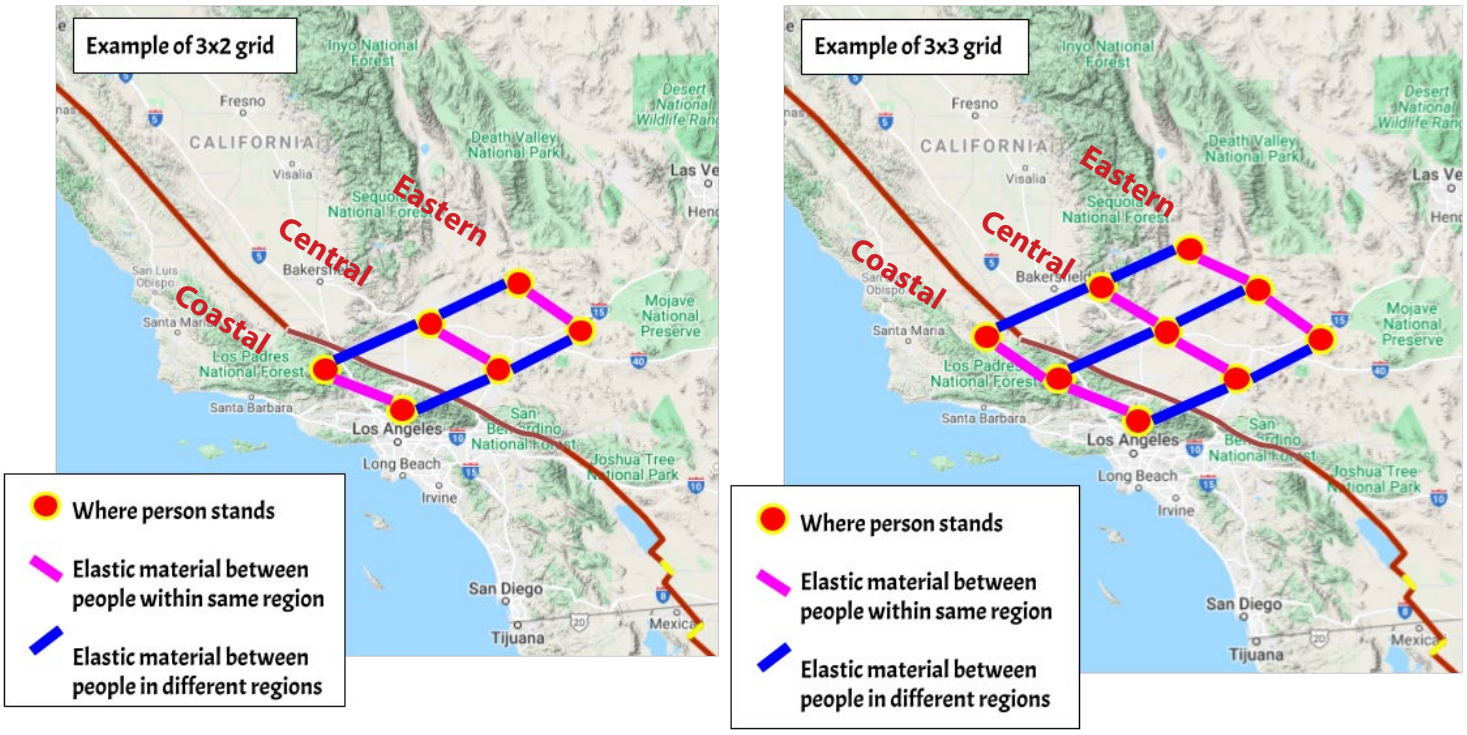


Figure 7: Map illustrating approximate locations where learners stand for human-scale modeling of ground deformation in California. See Figure 2 and Appendix E for photograph of learners doing the activity.

Directions

Note: Introduce new vocabulary (Appendix A) to meet your learner's needs.

1. Follow the directions related to learners moving along the vectors for the 5-min activity above. In this demonstration, instead of using 2 vectors, there are 3 vectors: a medium-length vector between the super-short and the long vectors. These vectors are examples compared to the CA GPS vectors explained below.
2. Spread out learners on generic GPS Station Signs to mirror the tectonic scenario in CA as shown in Figure 7.
3. Project California GPS Vector Map (Appendix D).
4. Some learners will be much further inland (east of the San Andreas fault), some just east of the San Andreas fault (Central California), while others will be on the coastal west side of the San Andreas fault.
   a. Have learners note the direction and annual distance of movement as noted on the GPS station signs.
5. Learners act out the movement to move along the vectors, with the instructor counting down and then clapping once to start the step and another clap to end the movement. To help visualize the overall motion, each step and clap will represent 10 years.
   a. Rather than have exact measurements, simplify the distance moved with each clap. Learners need to take a uniform stride length for their assigned vector. Practice with each region separately so the instructor can coach each region independently on correct stride length.
      - Learners assigned to a Coastal GPS station with 'long' vectors take large steps.
      - Learners assigned to a Central GPS station with 'short' vectors take small steps, approximately 6-8 inches each step.
      - Learners assigned to an Eastern California GPS station far inland with super-short vectors would take tiny steps, approximately 2 inches per step.
   b. Have learners practice moving their stride length. Coach learners to start their steps with the same foot, i.e. left foot first. Then, have them move simultaneously with the claps. Clap at least a couple of times to show movement over a longer period of time.

Discussion Question:

What did you observe while everyone was moving?

- *Expected Response: Learners should observe that everyone moves in approximately the same direction but at different speeds, so some people are getting farther away from others.*
- *Learners should also observe that those in the same group of locations (i.e., all the coastal stations) don't get farther apart from each other; they move as a block.*

6. Now, provide stretchy bands or material to learners.
   a. **SAFETY NOTE**: Depending on the strength of the elastic material, letting go of it will result in the material springing back which could potentially cause injury. Be proactive about your learners and provide the most appropriate safety discussions.
7. Have learners gently stretch the bands between each other on the same side of the fault and on opposite sides of the fault. See Figure 7 for a visual representation of where people could be standing and where elastic bands would be. As noted in the Materials above, the instructor could use different colored elastic bands. Learners should hold the elastic material at their hips.
8. When everyone is ready, tell them to move the same way they moved above for Step 5. Instructor should count down as before and say "Ready, set, step, step, step" to synchronize learner motions. If space and elastic material allow, take additional steps.

Discussion Questions:

a. What does the elastic material represent?

- *Expected Response: Learners must recognize that the elastic material represents the land that is connecting all the GPS stations and is actually deforming as the regions move.*

b. What did you observe this time while everyone was moving?

- *Learners should notice that the elastic between participants in the same group (coastal, central or eastern regions) will not change in length.*
- *They will also clearly notice that the elastic between regions is stretching, with the most stretching occurring on either side of the San Andreas fault.*

9. Remind learners that GPS stations are permanently anchored to the ground so that if the ground moves, the GPS moves with the ground and records that movement.
10. Hand out the 20-min Activity Summary Handout (Appendix G).
11. The instructor can use their discretion on the best way to have learners complete the outline (individually, with partners, one question at a time, review of all the answers at once, etc).
12. The instructor should have at least a couple of learners share their response to Question #3 on the 20-min Activity Summary handout about their explanation of what was happening in the diagram.
    a. Answer Key for the 20-min Activity Summary is included in Appendix I.

13. Refer to projected CA GPS Vector Map (Appendix D).
    a. Point out to learners that the vector scale on the maps is different from the map scale. The two maps used in this activity show the vectors at a 1:1 scale when printed on 8.5-inch x 11-inch paper, e.g., measuring a 10 mm vector on the printed map represents 10 mm/year of movement.
    b. Ask what the units of the vectors depicted on the map are (this reinforces that the legend shows the velocity in mm/year).
14. Learners may not appreciate the significance of millimeters (mm) of movement per year (similar to the rate that your fingernails grow). Emphasize that the movement can be significant over long periods, say 100 years.
    a. For 100 years, the movement of some of the coastal regions west of the San Andreas Fault (Pacific Plate) would be 4.5 meters or about 15 feet. The instructor should show that distance in their setting for a visual representation.

Discussion Questions:

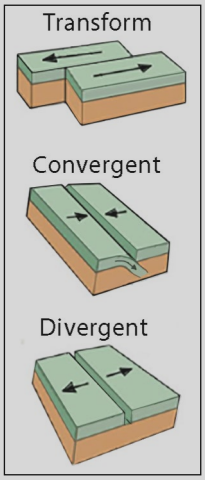
a) How does this activity relate to earthquake hazards?
- *Expected Response: Learners should recognize that where the land is stretched the greatest, there is a higher danger of the land breaking and producing an earthquake.*

b. How can GPS data showing areas of different velocities help inform earthquake preparedness, especially for scientists and emergency planners?
- *Learner responses will vary, and the instructor can point toward developing a warning system for higher risk areas, such as the USGS ShakeAlert Earthquake Early Warning System.*

Extensions to 20-minute Activity

1. Explain what a transform boundary is. Typically, this is where tectonic plates slide past one another in opposite directions. However, the motion represented in this activity indicates a transform boundary where both plates move in the same direction. In this case, the Pacific Plate is sliding past the North American Plate due to its higher velocity.
2. Ask learners what it might mean if two vectors were pointing in opposite directions away from a boundary? Instructor models the arrows with their fingers or draws them.
    a) Learners recognize that arrows moving in opposite directions (like at a divergent boundary) means that those parts of the ground are moving in opposite directions and that the land between is being stretched.

The Subtleties of Plate Boundary Motion

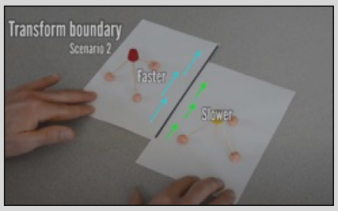


Typical diagrams of plate boundary motion indicate vectors moving as shown in the images at right.

However, there are subtleties of motion where the vectors are actually pointing in the *same* direction, yet are still transform, convergent, or divergent boundaries.

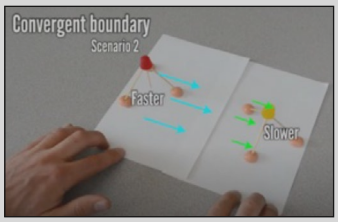
The alternative perspectives, illustrated in the photos below, can be seen in the UNAVCO video, "How GPS Measures Ground Motion." (3:05)

Transform Boundary



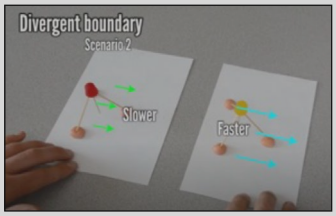
Not every transform boundary involves two plates moving in completely opposite directions. While that may be true for some, there are a variety of plate movements that make them a transform boundary, and it depends on the point of reference. If both plates are moving parallel to each other in the same direction, with one plate moving faster, it can still indicate a transform boundary. This is what we see in this Activity for Southern CA.

Convergent Boundary



Two plates moving in the same direction, with one plate moving faster than, and running into, the other, can also indicate a convergent boundary, like the Juan de Fuca plate moving towards the North American plate.

Divergent Boundary



Here, two plates could be moving in the same direction overall, but one of them is moving faster and is still diverging from the other one.

"*How GPS Measures Ground Motion" (link above) has* visual examples showing regions around the world and their respective plate motions. See Appendix B for an explanation of reference frames to help interpret plate motions.

IF YOU HAVE 45+ MINUTES

Did You Know?

- Did you know that being able to precisely measure the rate of tectonic motion enables geologists to identify earthquake hazards?

Within tectonic plates, or along plate boundaries, regions where there are different velocities, either in speed and/or direction, increase earthquake hazards. This 45-min activity addresses this important issue and is written for a flexible instructional environment to fit either a classroom or more open forum.

In Section A, learners will first kinesthetically model the movement of Southern CA as in the 20-min activity above, and then half the learners will focus on the details of Southern California motion while the other half focuses on Oregon/Washington. In Section B, each learner will get a laminated GPS Vector Map (or paper map if you have multiple copies) with a key indicating the scale of the vectors. Using a handout and metric ruler, learners will measure GPS vectors. They will determine the velocity (speed and direction) of regions within tectonic plates and along plate boundaries to determine the type of boundary the data suggest. Their exploration continues in Section C, with learners using GPS data to identify areas of higher earthquake hazards and compare with state and/or U.S. Geological Survey (federal) published seismic hazard maps. If time and space allow, learners can extend the kinesthetic modeling with specific GPS data to model the plate motions of the entire US west coast.

Preparation:

1. Print/make large arrows as in 5-minute activity (Appendix C).
2. Familiarize yourself with the 45-minute procedure.
3. Watch the video How GPS measures Ground Motion (3:05).
   - This video uses 'gumdrop' GPS stations and printed directional arrows to show how GPS receivers move with different types of tectonic boundaries.
4. Print CA and OR/WA GPS Vector Maps (Appendix D) on 8.5-inch x 11-inch paper. If possible, laminate the maps and have enough copies of each map available for pairs or groups, depending on how the instructor organizes their instructional space. Important note: print maps at 100% scale.
5. Print in color or prepare to display Earthquake Shaking Potential Maps for California, Oregon, Washington, and the USGS Seismic Hazard Map (Appendix K). To learn more about how the shaking potential maps are made, visit Introduction to the National Seismic Hazard Maps or visit the USGS site on Earthquake Hazards.
6. Printed full-size color copies (if possible) of CA and OR/WA maps showing GPS data vectors (Appendix J—Full GPS Vector Maps of the Western United States).
7. Print and copy 45-minute Activity Learner Outline (Appendix H). Answer Key is provided in Appendix I—Instructor Answer Keys for 20-min Summary Handout and 45-minute Learner Outline.
8. Provide colored pencils and a ruler to each learner.
   - Adaptations for colorblind learners: use colored pencils, crayons, and small felt markers to make it easier to distinguish between the lines.
9. Note: Introduce new vocabulary (Appendix A) to meet your learner's needs.

Directions for Section A:

1. If the 5-minute activity did not precede this activity, have learners act out movement along the two (or 3) large vectors as described in the 5-minute activity with the instructor clapping to synchronize the timing of movement.
2. Follow the instructions for the 20-minute activity for learners to experience ground motion and deformation derived from GPS data. Summarize what the learners noticed about the deformation of the land along the San Andreas fault through discussion; do not use the 20-minute handout.
3. Either assign or give learners an option of which map they want to use, CA or OR/WA.
   - With enough learners, divide into pairs or groups as desired.
4. Distribute the appropriate maps, rulers, colored pencils, and 45-minute Activity Learner Outline (Appendix H) and suggest that learners read over the questions before jumping in.
5. Have learners complete the Outline. The instructor can use their discretion on the best way to have learners complete the outline and to compare their findings (individually, with partners, one question at a time, review of all the answers at once, etc).
   - Part A involves students measuring the length of vectors. Because the scale is 1:1, the length of the vector is the length of the distance moved by that GPS station.

Questions for Discussion:

For Section A: Compare responses between CA and OR/WA.

a. Was there a different overall direction of movement of the ground?

- *Expected Response: Yes, the directions were different. In Southern CA all of the motion is towards the Northwest, while all motion in OR/WA is moving towards the Northeast.*

b. How did the relative speed of ground movement compare?

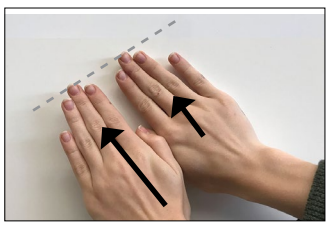
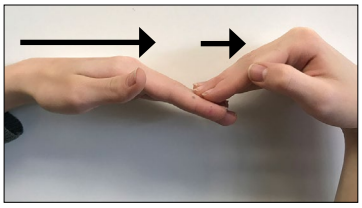
- *Answers here will vary depending on the vectors chosen. Areas on the Pacific Plate in Southern CA are moving upwards of 40 mm/year as compared to around 15 mm/year in OR/WA (again depending on which vector is used). On both maps there is a faster moving section of the plate and a slower moving section moving in the same direction.*

Directions for Section B:

6. Now that learners have an understanding of how to measure vector length, they will continue to Section B to explore what the GPS data show about crustal motion.
7. Both maps indicate an area closer to the coast with significantly longer vectors, an area inland with motion in the same direction and less velocity, and an area even farther inland that has relatively little motion.
8. Learners should clearly distinguish those different regions and be able to answer the questions on the outline.
9. Have learners quickly meet with someone who looked at a different region and have them compare what they learned.
10. Instruct learners about transform (southern CA) and convergent (OR/WA) boundaries. See Sidebar on page 9 to help guide the discussion about why both boundary types show vectors moving in the same direction even though they are different types of boundaries.

Questions for Discussion:

- For Section B: Compare responses between CA and OR/WA in the table below. Have learners look at the map in Section B of the Learner Outline.

For Southern California	For Oregon/Washington
a. Which type of boundary is indicated by the GPS data in Southern California? *Because both the coastal and inland areas are moving in the same direction, with the coast moving faster, that indicates a transform boundary. Remind learners that transform boundaries don't always have to be moving in opposite directions.*	a. Which type of boundary is indicated by the GPS data in Oregon and Washington? *Because both the coastal and inland areas are moving in the same direction, with the coast moving faster and squeezing the inland areas, that indicates a convergent boundary, with the Juan de Fuca pushing against and under the North American plate.*
b. What could that mean is happening to the ground along the boundary? Explain what forces are acting on the land. Model your thinking with your hands. *As the coastal area on the Pacific Plate moves northwest, it is causing stress to build up along the boundary. This build-up of stress will eventually release in an earthquake.* *Modeling with hands should show that where the left and right hands rub against each other in a transform motion, there is deformation of the skin, followed by a sudden movement.* 	b. What does that mean is happening to the ground along the boundary? Explain what forces are acting on the land. Model your thinking with your hands. *As the coastal area on the Juan de Fuca moves northeast, it causes stress to build up along the boundary.* *Modeling with hands should show that as the "subducting" hand dives under the overriding "plate", the fingertips of the upper hand are forced backward.* 

Directions for Section C:

11. Section C asks learners to shade in areas that have the greatest differences in vector length to indicate higher hazard potential.

12. If printed copies of the full GPS vector maps are available in color, present those. When having learners make observations, challenge them to look for overall visual patterns, as well as any anomalies. For example, on the OR/WA map, there is a cluster of GPS vectors indicating a higher density of GPS stations on Mount St. Helens. In CA, there appear to be vectors in the "ocean" and are data from GPS stations on offshore islands.

13. Discuss and point out observations from learners by using the maps provided in Appendix J – Full GPS Vector Maps of the Western United States.

14. When coloring the areas that show different rates of ground motion or different directions (#18 on the 45-min Learner Outline), challenge learners to be precise.

15. After learners have finished shading their maps, show the Earthquake Shaking Potential Maps for CA, OR, and WA (Appendix K). Their shading should mirror the shake-potential maps reasonably closely. Note: the CA map has a finer color distinction on the San Andreas fault that will be discussed later.

Questions for Discussion:

a. Does having a higher number of GPS stations mean the risk in those areas is higher?

- *Misconceptions are addressed in # 20-21 on the 45-min Learner Outline about higher density equaling more danger of earthquakes. At this point, instructors explain that it is the deformation of the land, shown by distinct differences in GPS vector velocity, that indicates areas of greater concern.*

b. Circle the statement, or statements, to the right that you believe to be true.

- *True statements are 1) the density of GPS stations is just that—there are more GPS stations in a given area, and 2) Areas with a big difference between the lengths of GPS vectors are the areas of higher risk of earthquakes*.

Further Questions for Discussion:

Ask learners to share their thoughts on the last four questions of the outline.

a. What was modeled in the activity with the elastic material model, and why is that important (#22)?

- *Expected Response: The elastic modeling reinforces that unequal vector lengths determined by GPS sensors are more important for recognizing hazard areas. Referring to Figure 7, the bands within each region (west, central, eastern—in purple) would stay stretched about the same length because that group of learners moved at the same pace and direction. The bands denoted in blue between the different regions would, however, be stretched the most because of the unequal ground motion on either side of the San Andreas fault. The elastic between the easternmost learners and the central learners will become stretched, but not nearly the same as between the west and east sides of the San Andreas.*

b. What object or material might be used to model the tectonic motions of the Pacific Northwest (#23)?

- *To simulate the convergent boundary in the Pacific Northwest, something that would build up potential energy as it was compressed would be needed. A spring would work well because a spring pushes back as it is compressed. A strip of wood or even a long piece of pasta would work as well as it would bend upward and want to spring back. A large thin piece of plastic would also work and would model not only the bending upward, but also the larger flat plane of a tectonic plate*.

c. Whether you have a transform boundary or a convergent one, why might it be beneficial to know what type of boundary it is, and how does GPS data play a role (#24)?

- *Knowing what type of boundary exists would allow scientists and emergency management personnel to predict what type of motion to expect, and direction of movement. Knowing GPS further allows scientists to have an idea of rate of movement, therefore how much potential energy is building up.*

d. What are the impacts on life and society (#25)?

- *With a higher density of GPS stations geologists can fine-tune their understanding of ground deformation over time and further develop potential shaking maps. Responses here will vary and will incorporate multiple perspectives on earthquake safety. The key is awareness and preparation. Using the scientific information learned from GPS data, we can improve situational awareness, save many lives, and protect infrastructure thereby creating a more resilient society. In fact, GPS data, combined with seismic data, are a significant component of the ShakeAlert Early Earthquake Warning System. The detection of motion from a sudden release of energy in an earthquake allows the ShakeAlert system to broadcast areas of imminent shaking hazards.*

Compression—When stress forces are applied to an area and the area lessens in volume and increases in potential energy.

Convergent Boundary—When two or more tectonic plates are moving towards each other and either being shortened or heightened due to compression, or causing subduction. Differences in density will determine plate behavior. Two continental plates colliding will force the plates together and upward creating non-volcanic mountains. When involving oceanic lithosphere, the more-dense oceanic plate will "subduct" and move below the less-dense lithosphere.

Crustal Deformation—When Earth's surface changes shape due to tectonic forces.

Divergent Boundary—Where two tectonic plates are separating from each other.

Geodetic instrument—An instrument, such as permanently installed GPS instruments, which precisely measures the movement of the surface of the Earth.

Global Positioning System (GPS)—Provides positioning, navigation, and timing services and is an United States-owned constellation of satellites and ground tracking stations along with receiver equipment.

Global Navigation Satellite Systems (GNSS)— Any of, or some combination of, the operational satellite constellation systems providing positioning, navigation, and timing, at this time including GPS, Galileo (EU), BeiDou (China), GLONASS (Russia), QZSS (Japan), IRNSS —NAVIC (India).

Reference Frames—An area set as a stationary point so that all other plate motions can be measured with respect to it.

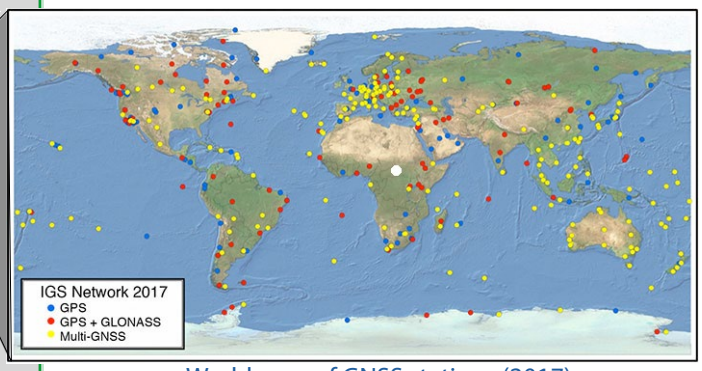
Speed—The distance of movement in a specified amount of time.

Transform Boundary—When two tectonic plates are moving horizontally with respect to each other with little vertical movement. Also referred to as a "strike-slip" motion.

Vector—A visual representation of the velocity of movement with speed indicated by the length of the vector and the direction indicating the direction of movement from North.

Velocity—The speed and direction of movement.

Velocity Vector—An arrow that represents velocity, both speed (as the length of the vector) and direction.



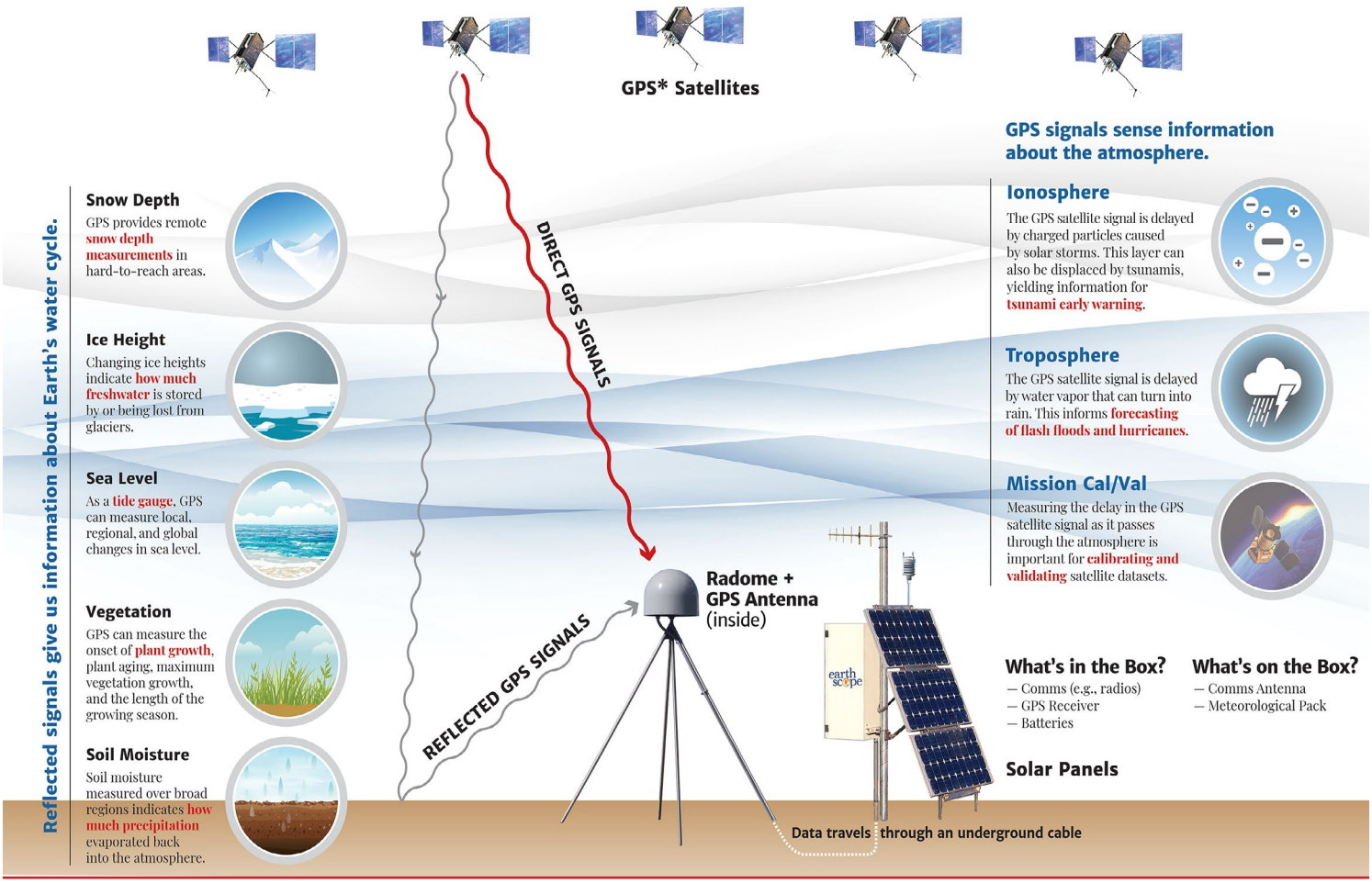
World map of GNSS stations (2017)

APPENDIX B: BACKGROUND ON GPS AND REFERENCE FRAMES

Page 2

GPS data collection and processing is much more complicated than what is explained in these activities. Background noise, tidal forces moving the ground up and down, seasonal water and snow loading, post-glacial isostatic rebound, and other non-tectonic motions are removed as part of the data processing so that the dominant motion in the data are from tectonic motions. The data from GPS are often represented as velocities in three directions, up-down, north-south, and east-west, allowing calculation of an average annual velocity. When the data are displayed on maps, the horizontal velocities are added together to create a single vector. This movement is displayed as vectors on maps showing displacement over time, typically in mm/year [infograp vailable from UNAVCO].

What GPS Can Tell Us About Earth—High-precision GPS stations measure natural phenomena and hazards)



Note about reference frames: Every tectonic plate on Earth is in motion. Since every location on the Earth is moving, how do we know how fast a single place is moving? For plate motions, we think of one plate or region as fixed and not moving. We then compare the motions of other places to this fixed place. For example, in this activity, we use a reference frame which removes the average background motion of the mid-continent of North America, such as Nebraska and Kansas.

This reference frame, called the North American Reference Frame, shows the motion of the regions of the western United States compared to this fixed region. By subtracting out the background motion, it is easier to observe the interactions between the North American plate and adjoining Pacific and Juan de Fuca tectonic plates.

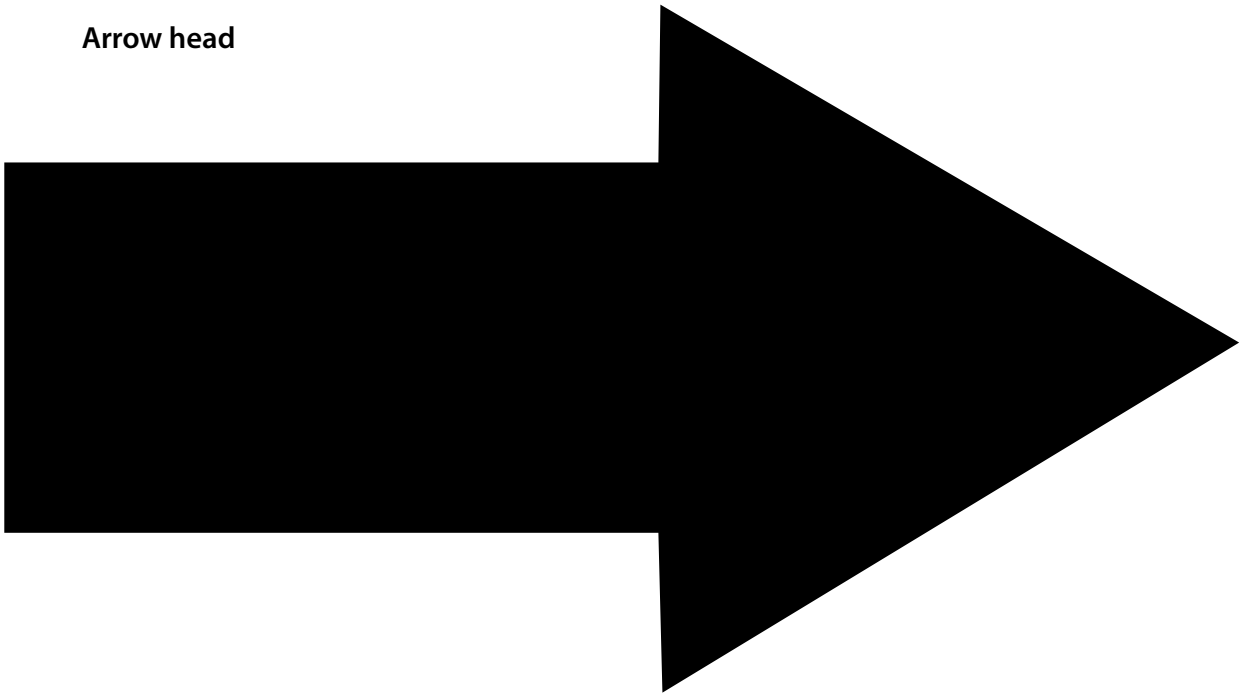
APPENDIX C: Printable Vector Components for Kinesthetic Activity

Example of the scale of a vector. The number of tail sections printed will vary depending on the length of the vectors. These can also be enlarged on a printer to make larger vectors.

Tail section

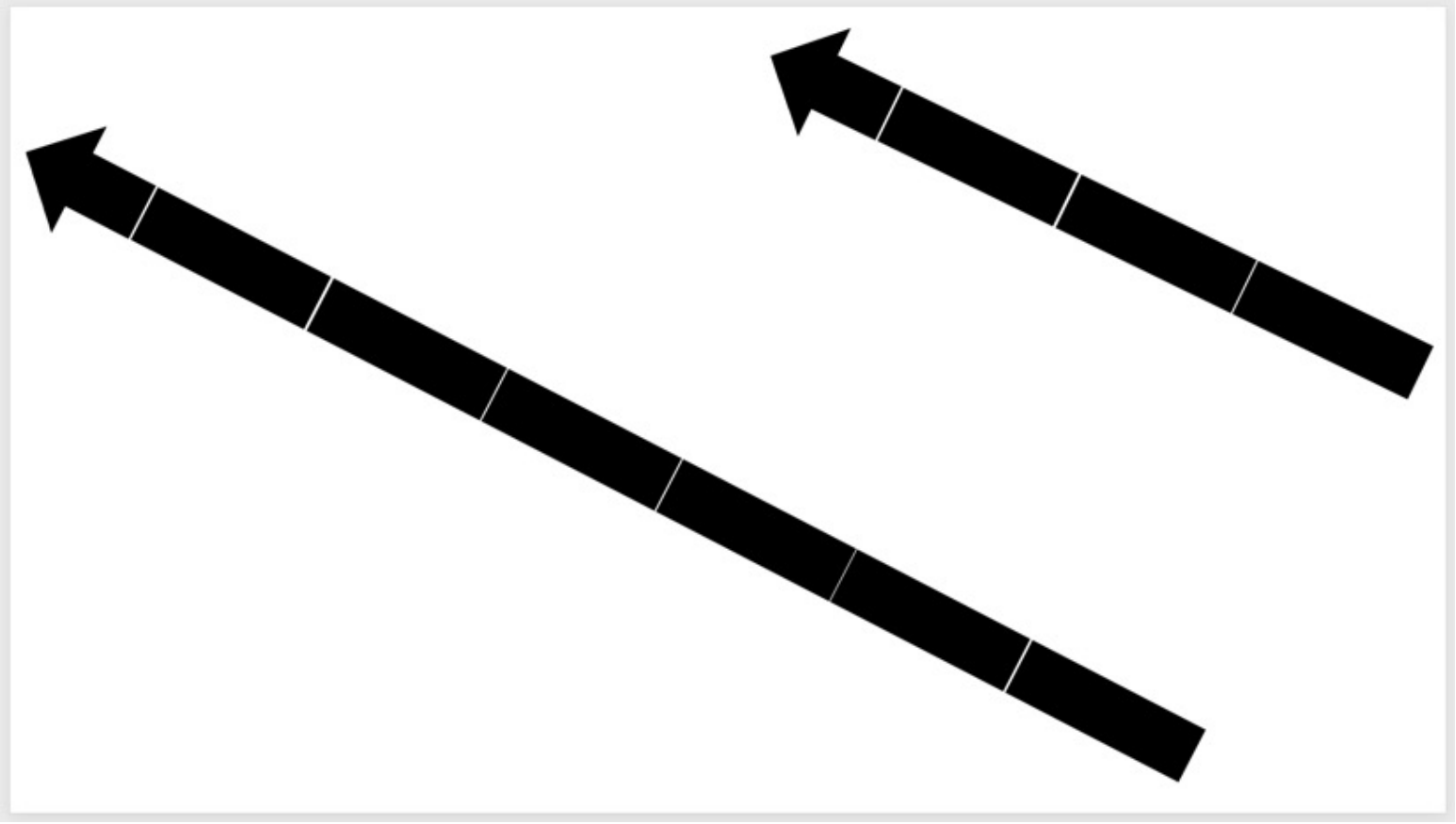


Arrow head



Example of what two vectors taped on the floor should look like.

- Short vector should be approximately 3 feet (90 cm) long
- Long vector should be approximately 6 feet (180 cm) long
- Arrows need to be large enough to see from a distance and survive being walked on. Alternatively, arrows could be drawn on butcher paper, or made with tape.



Page 2

Southern California GPS Vector Map

Note: Vector scale is 1:1
Measured vector length equals actual annual movement



Shading indicates area shown on map

Source of CA inset map:
https://pubs.usgs.gov/of/2005/1305/

Oregon/Washington GPS Vector Map

Note: Vector scale is 1:1
Measured vector length equals actual annual movement



Source of west coast inset map:
https://pubs.usgs.gov/of/2005/1305/

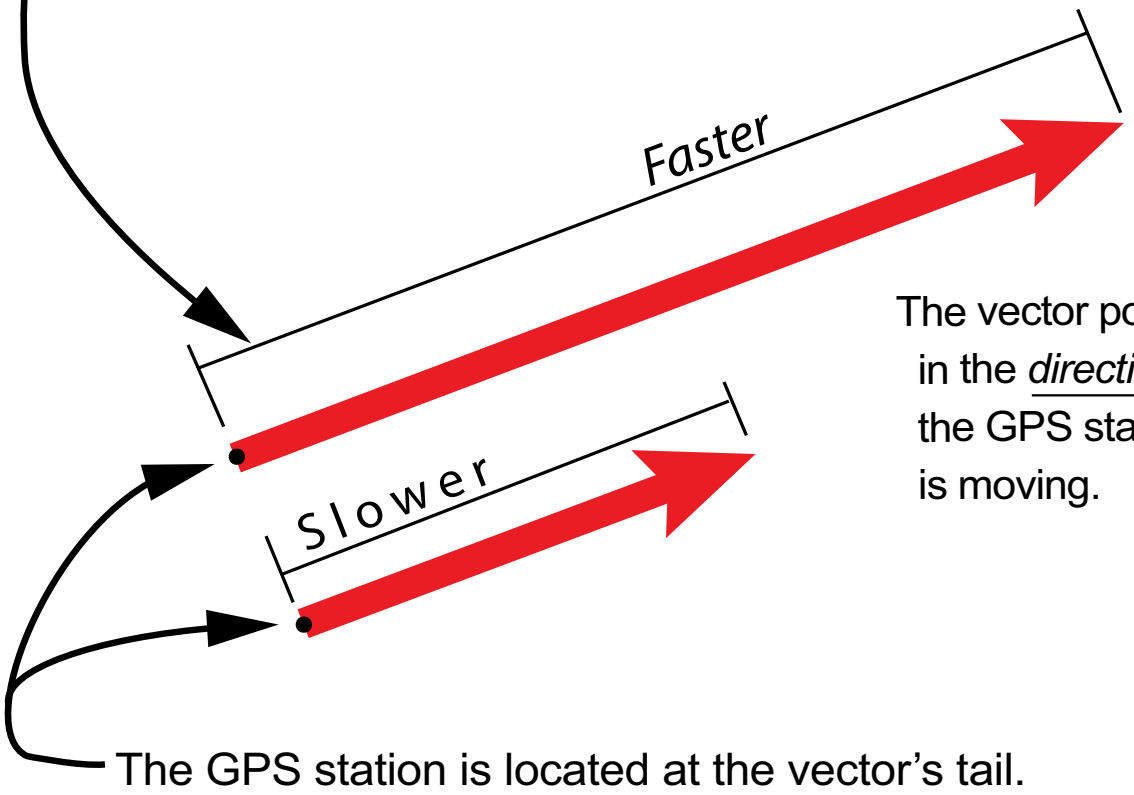
Anatomy of a Vector

High-precision GPS stations attached to the ground collect data about the ground's motion at a location. A vector represents the speed (length of the vector) and the direction that a specific piece of ground is moving.

Anatomy of a Vector

A vector indicates the direction and speed of an object.

The *length* of the vector shows the GPS station's *speed** (the longer the arrow, the faster the ground is moving).



The vector points in the *direction* the GPS station is moving.

The GPS station is located at the vector's tail.

***Speed** = **D**istance the GPS station moved over **T**ime (**S** = **D**/**T**)

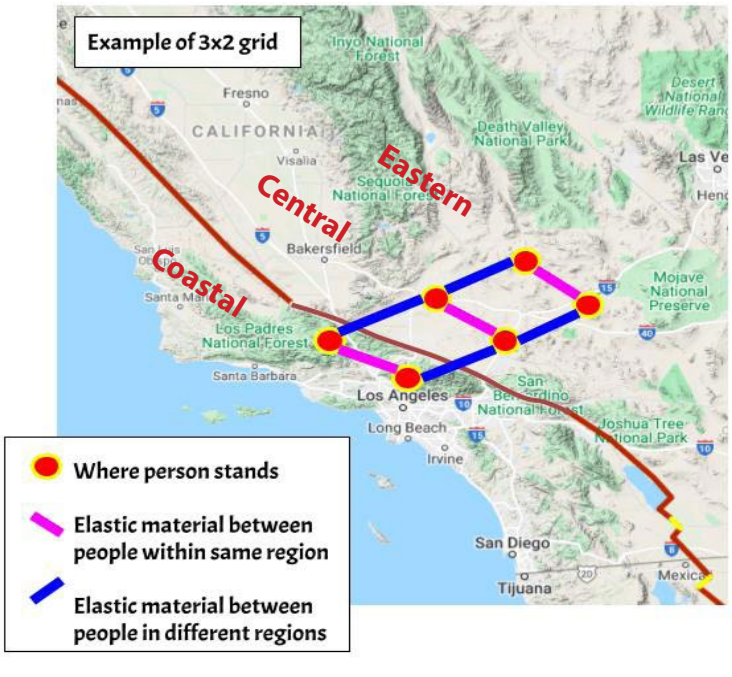
Speed is measured in **mm/year**. For example, if the short arrow above is 2 mm/year, the long arrow is 4 mm/year, twice as fast.

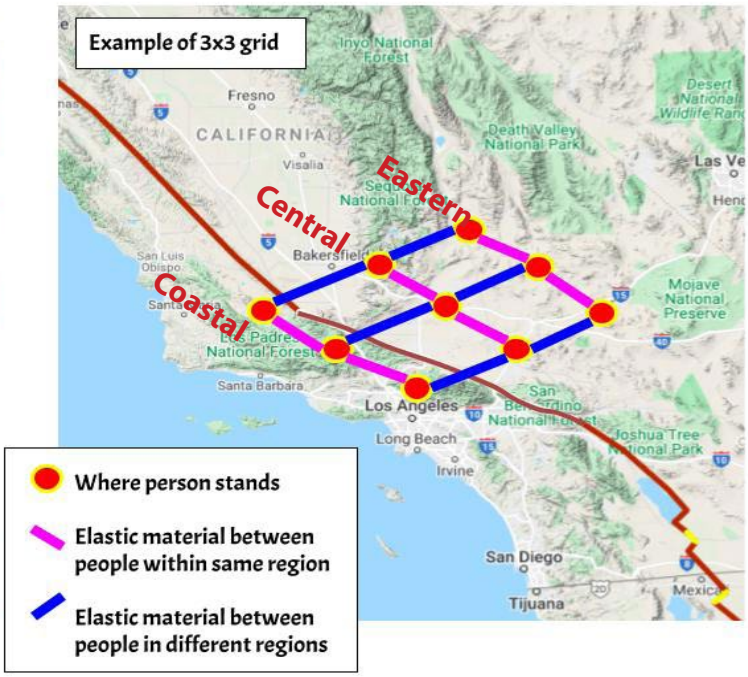
APPENDIX E: Human-scale modeling of ground deformation with Generic GPS Station Signs

Page 2

In this model, learners will act out the vector motion of typical ground motions for different regions of California: Coastal, Central, and Eastern. Learners will be connected to each other with stretchy/elastic bands.

See 20-minute activity preparation and directions sections for instructions to set-up and run the human-scale model.





The image on the left shows a 6-station grid. On the right is a 9-station grid.

A

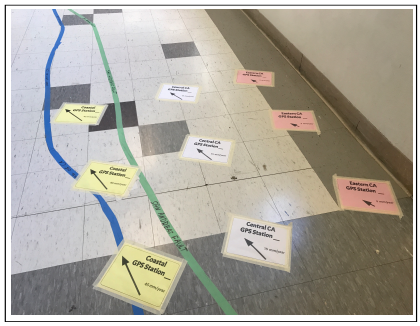


B



Eastern Central Coastal

C



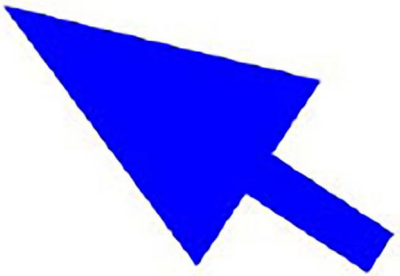
Students represent GPS stations. The blue line on the floor is the CA coastline. The green line represents the San Andreas Fault. **A** shows location of GPS stations (learners) before movement. **B** shows where the GPS stations have moved over a period of time. **C** shows the initial setup of the coastline, San Andreas Fault, and the location of the GPS Station signs.

Coastal CA
GPS Station
45 mm/year

Central CA
GPS Station
15 mm/year

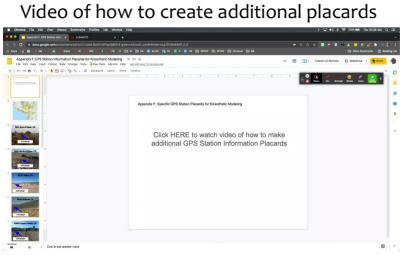
Eastern CA GPS Station __

3 mm/year



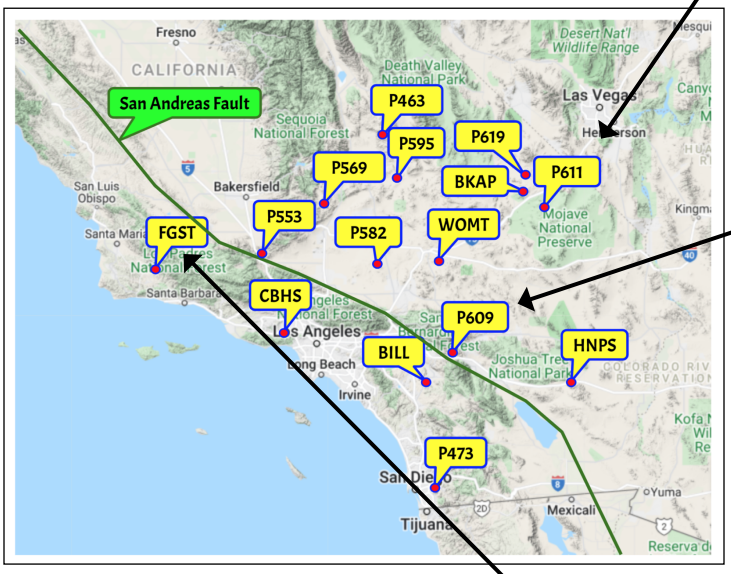
APPENDIX F: GPS Station Information Placards

Video of how to create additional placards

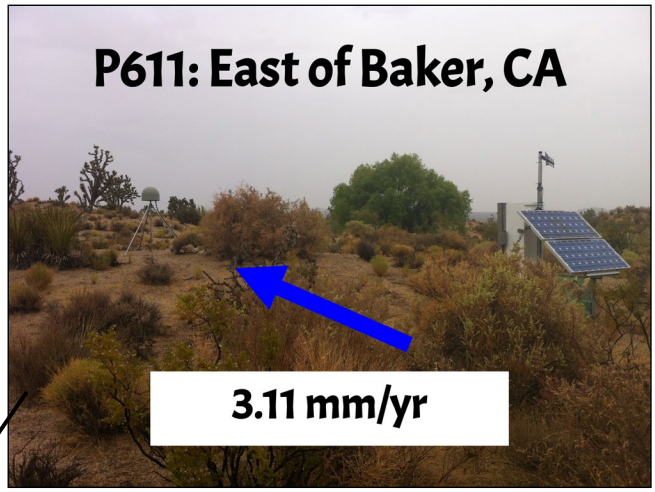


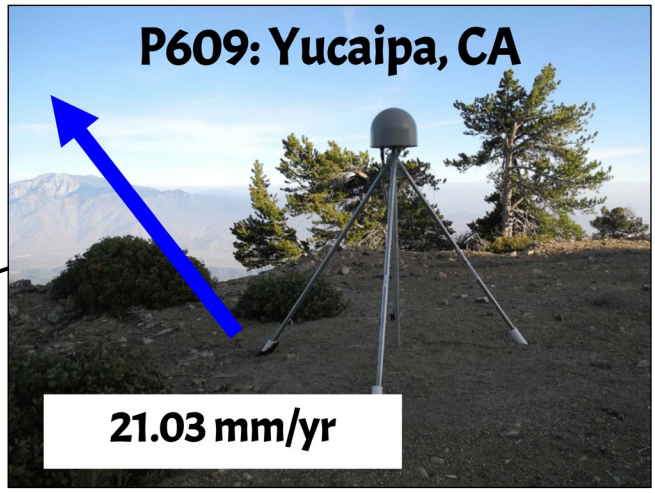
Instructions:

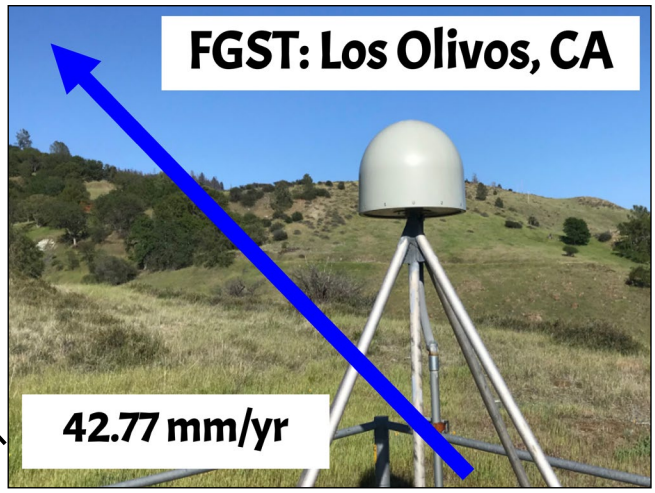
1. The images below illustrate a suite of GPS Station Placards that can be used in lieu of the generic station signs in Appendix E.There are multiple stations in each region (coastal, central, and eastern).The PPT can be accessed here. The PDF of the files can be accessed here.
2. One can add placards based on the number of learners or to include a particular GPS station. Watch the **video** to learn how to make additional placards using data from UNAVCO's Velocity Viewer.
3. Tape placards in their appropriate locations based on the map of CA.
4. Have learners stand on placards to orient their direction and annual movement. Elastic material between learners should be slightly longer than the distance between GPS Station placards.
5. Continue with directions from the 20-minute activity.



The map above indicates which GPS stations were used for the placards shown to the right.







APPENDIX G: 20-Min Activity Summary Handout

GPS Station Movement and Land Deformation

Name		Period/Class		Date	

Use this handout to summarize the kinesthetic activity using current GPS data to show how the land beneath our feet is moving, crumpling, sliding, and stretching.

Procedure and Questions

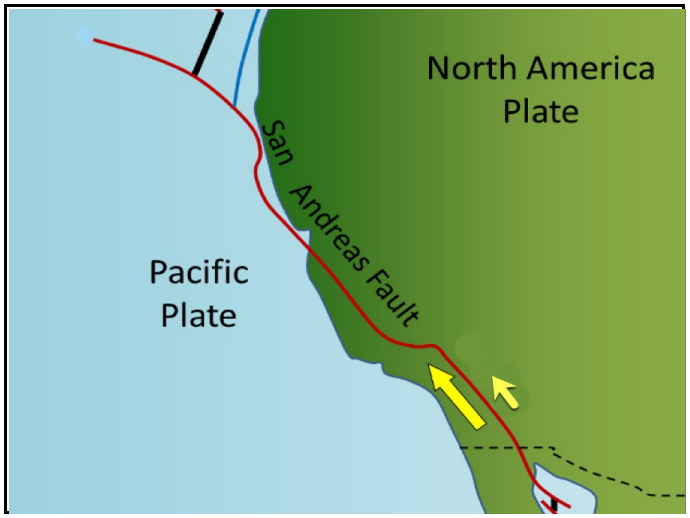
1. In the space to the right, sketch a **vector**. Label the head, tail, and where a GPS station would be located.

Complete the following sentence about vector length:
The longer the vector, the _____ the GPS station is moving.

2. The map to the right shows the motions of the major tectonic plates on the west coast.

   a. Locate the vectors on either side of the San Andreas Fault.

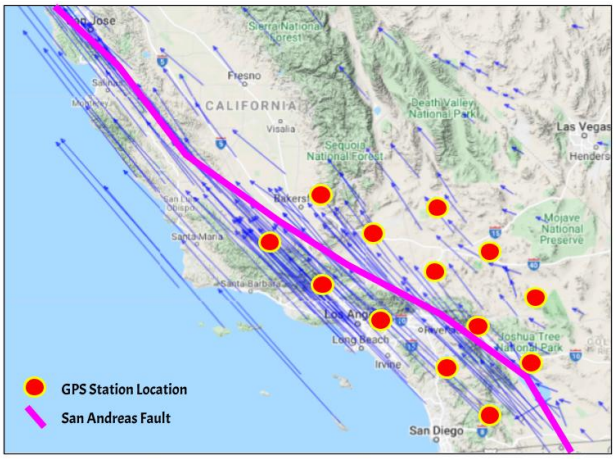
   b. In your own words, explain what the vectors indicate.

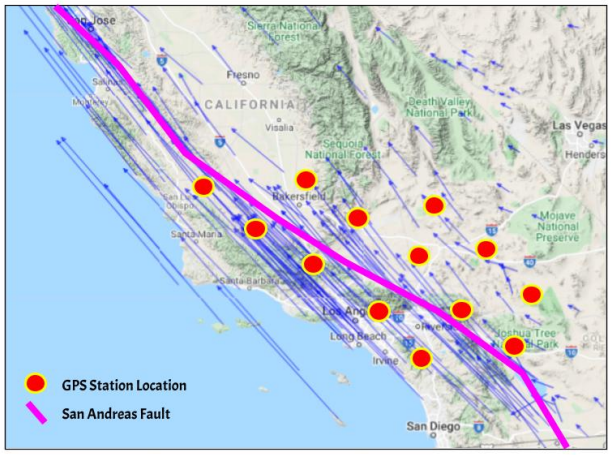


Where two tectonic plates slide past one another is known as a **transform boundary**. The San Andreas Fault is the best-known transform boundary in the United States.

3. In the activity, elastic bands were used to connect different people standing on different GPS station locations. What does the elastic material represent?

4. On the diagrams below, each dot represents one of the GPS stations that you just modeled. The image on the left is 'before' the movement, and the image on the right is where the GPS stations have moved over a period of time.





5. In your own words, explain what is happening to the land along the San Andreas Fault. Feel free to draw on the image to help explain your thinking.

APPENDIX H: 45-minute Activity Learner Outline

Exploring GPS Vectors and Crustal Motion

Name		Period/Class		Date	

Are tectonic plates still moving? How do we know? Let's explore evidence of tectonic plate motion using current GPS data to see how the land beneath our feet is moving, crumpling, sliding, and stretching.

In this activity, you will either study posters or use vector map handouts (either the Tectonics Motions of Southern California or Tectonics Motions of Oregon and Washington) to do the following things:

1. Measure the amount of ground motion in multiple areas indicated by GPS data.
2. Analyze evidence of different types of crustal motion based on GPS data, and act out motions.
3. Consider the hazards and societal impact that might result due to these motions.

SECTION A: Measuring Ground Motion with GPS Vectors

Procedure and Questions

1. In the space to the right, sketch a vector. Label the head, tail, and where a GPS station would be located.		Complete the following sentence about vector length: *The longer the vector, the _____ the GPS station is moving.*
2. On your map, circle the vector scale bar. The scale bar on this map is a 1:1 scale. This means that the length of the vectors on the map show the actual average distance the GPS station moves in a year.		
a. What is the length of the scale bar arrow? b. Therefore, how many millimeters of GPS station movement does the arrow represent?	A. _____ millimeters B. _____ millimeters	
3. Indicate which map you are working with by circling the name.	**Southern California** or **Oregon/Washington**	
4. Using the North arrow, what direction do most of the vectors point?		
5. Measure the longest vector. How long, in millimeters, is the vector?	_____ millimeters	
6. While the amount the ground moved in one year may not seem like much, multiply it by 100 to show how far it would move in 100 years.	_____ mm/year x 100 years = _____ mm in 100 years	
7. Divide the total number of millimeters moved by 1000. This will convert millimeters to meters moved in 100 years. Think of how far it will move in 1 million years!	_____ mm/100 years ÷ 1000 = _____ meters in 100 years	

SECTION B: Understanding Crustal Motion using GPS Data

8. Pick a vector in the coastal area. Using one of the colored pencils, circle it and measure it. This is the annual movement of that coastal GPS station.
9. Pick a vector in an inland area that is clearly a different size than the coastal one. In a different color, circle it and measure it to find the annual distance moved.

10. In the space to the right, complete the statement using the data you measured.

The coastal GPS station moved _____ mm in one year compared to the inland GPS station that moved _____ mm in one year.

11. Draw a circle around the entire area along the coast that shows a higher amount of movement. Use the same color as you did when circling the vector from the coastal area. Be careful to circle just the map area, not the vectors.

12. Do the same for the area east of the coastal areas that shows motion in the same direction, but in general has less motion. Use the same color as you did when circling the vector from the inland area.

13. Use the image to the right to circle the name of the tectonic plate that appears to be moving the quickest.

14. Which of the following choices best describes the motion that the tectonic plates are showing? Circle the choice.

    A. *Tectonic plates are moving in opposite directions and are getting farther away from each other.*

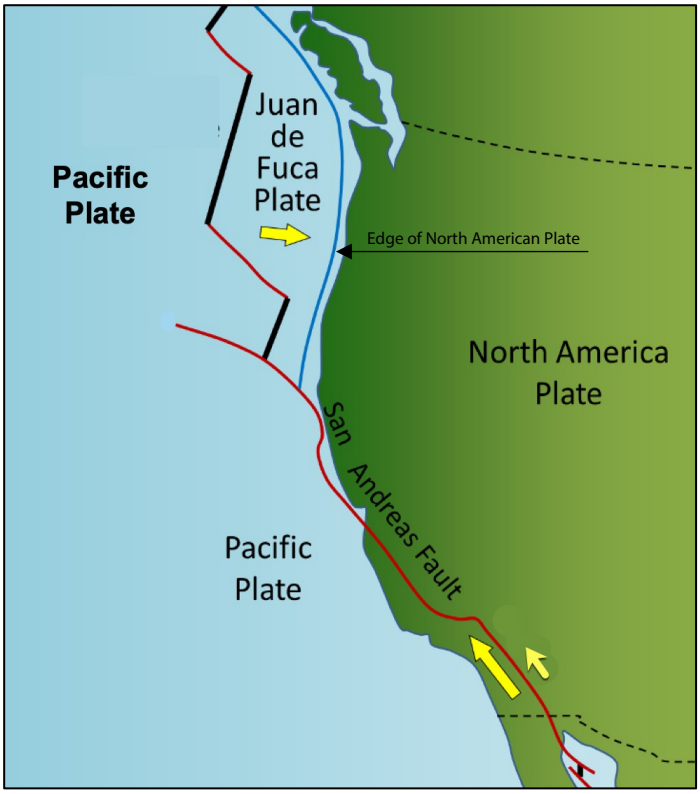
    B. *One tectonic plate is moving towards another one and running into it.*

    C. *One tectonic plate is sliding past another one that's moving in the same direction, but slower.*

15. Where two or more tectonic plates interact, it is called a **plate boundary**. Based on the information provided by your instructor, what is the type of plate boundary that exists on your map . . .

    a. Between the Pacific Plate and North American Plate: _____

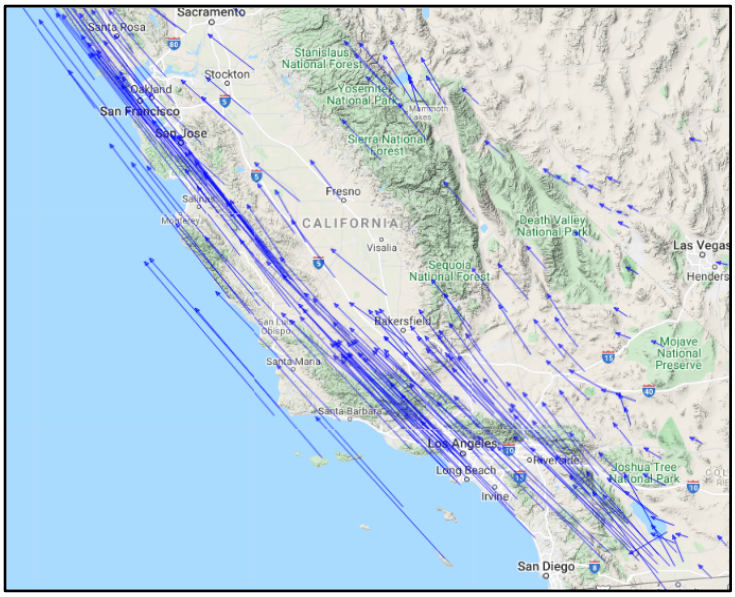
    b. Between the Juan de Fuca Plate and the North American Plate: _____

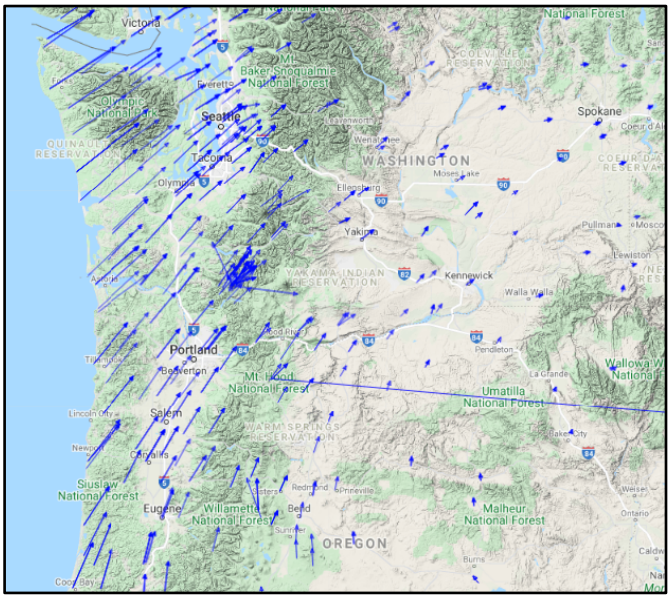


SECTION C: USING GPS DATA TO DETERMINE POTENTIAL HAZARDS

GPS data show that some regions of the Earth's surface are moving faster than others. This causes deformation of the ground surface in those areas, and it leads to earthquakes when the ground finally breaks. Knowing where the ground motions are unequal can indicate areas of greater danger.

Below are GPS vector maps for the same areas you have been studying in Section A. The difference is simply in the number of GPS data vectors that are shown. The maps used in Section A limited the number of vectors shown to make it easier to find and measure individual vectors. Here are nearly all (CA) and all (OR/WA) the GPS data. It paints a slightly different picture.





16. Make observations on the two maps. Besides having more vectors, what else do you notice? What stands out?

17. Using the same colored pencils as you used before when circling areas of different vector length in questions 11 and 12 above, lightly shade the maps for the areas you circled. Try to accurately pinpoint the transition from faster moving areas to slower moving areas.

18. Using a third color, shade in the areas much further inland that have very little motion as indicated by GPS data.

Now, compare your circled areas above on your maps to the Earthquake Shaking Potential Maps of California, Oregon, and Washington that your instructor will show you.

19. What is the correlation between your colored areas on the GPS Vector maps and the Earthquake Shaking Potential maps? What did you observe when you compared your colored maps to the official shaking potential maps?

A common misconception about GPS data is that the density of GPS stations indicates the areas that have the highest risk. While they may be related, this isn't necessarily true in every case.

20. Circle the statement, or statements, to the right that you believe to be true. 21. After discussion, cross out the statements that are false.	*A. The number of GPS stations in an area automatically means there is more danger there.* *B. The density of GPS stations is just that - there are more GPS stations in a given area.* *C. A GPS station with the longest vector will be the place with the largest earthquake potential.* *D. Areas with a big difference between the lengths of GPS vectors are the areas of higher risk of earthquake shaking.*

Connect back to the scenario of the GPS data in California using the elastic material.

22. What did the elastic material represent? What was modeled in the activity with the elastic material, and why is that important?	
23. Brainstorm: What object(s) or material(s) might be used to model the converging tectonic motions of the Pacific Northwest?	
24. Whether you have a transform boundary or a convergent one, why might it be beneficial to know what type of boundary it is. How do GPS data play a role?	
25. What might be the impact on your life? School? Society?	

The ShakeAlert ® Early Earthquake Warning System incorporates high-precision GPS data. Being aware of higher risk areas allows scientists and public health officials to mitigate the risk and produce far more favorable outcomes in the case of a major earthquake. For more information refer to the USGS ShakeAlert website.

APPENDIX I: Instructor Answer Keys for 20-Min Activity Summary Handout and 45-min Learner Outline

20-Minute Summary Handout: GPS Station Movement and Land Deformation – ANSWER KEY

Name		Period/Class		Date	

Use this handout to summarize the kinesthetic activity using current GPS data to show how the land beneath our feet is moving, crumpling, sliding, and stretching.

Procedure and Questions

1. In the space to the right, sketch a vector. Label the head, tail, and where a GPS station would be located.



Complete the following sentence about vector length:
The longer the vector, the ***faster*** *the GPS station is moving.*

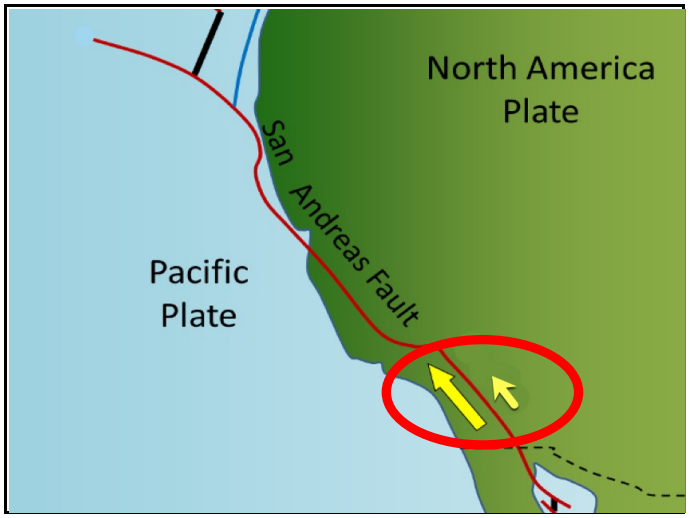
2. The map to the right shows the motions of the major tectonic plates on the west coast.

   a. Locate the vectors on either side of the San Andreas Fault.

   b. In your own words, explain what the vectors indicate.

   The vectors indicate that the Pacific Plate is moving faster than the North American plate because the vector on the Pacific Plate is longer.

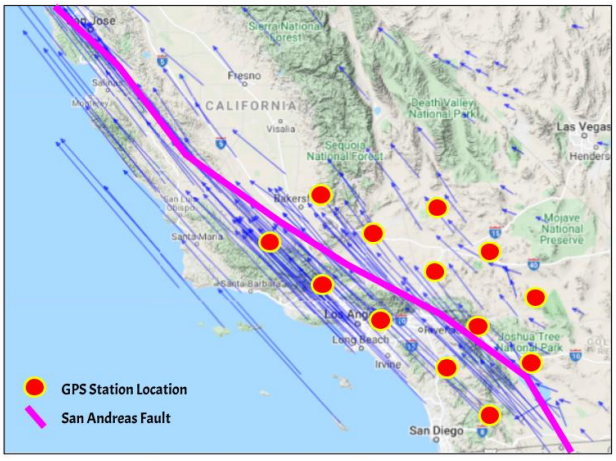
Where two tectonic plates slide past one another is known as a **transform boundary**. The San Andreas Fault is the best-known transform boundary in the United States.

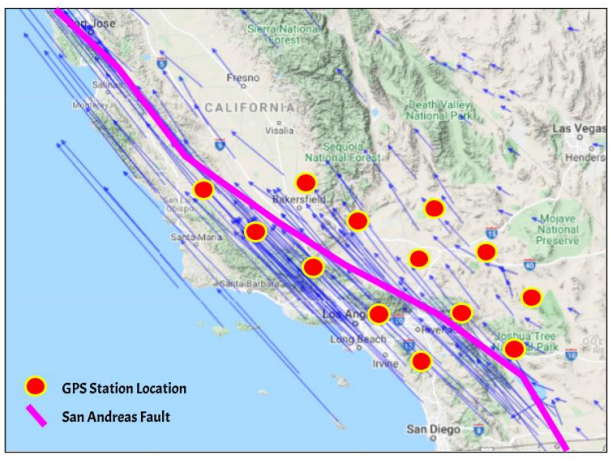


3. In the activity, elastic bands were used to connect different people standing on different GPS station locations. What does the elastic material represent?

The elastic material represents the land connecting all the GPS stations. As the material stretches, it simulates the land being deformed.

4. On the diagrams below, each dot represents one of the GPS stations that you just modeled. The image on the left is 'before' the movement, and the image on the right is where the GPS stations have moved over a period of time.





5. In your own words, explain what is happening to the land along the San Andreas Fault. Feel free to draw on the image to help explain your thinking.

Doing the activity shows the land along the San Andreas Fault is getting deformed, buckled, and stretched as the west side of the fault is moving faster than the east side of the fault. The farther the Pacific Plate moves, the more the deformation. Eventually, this could lead to the land breaking in an earthquake.

APPENDIX I: Answer Key

45-Minute Learner Outline: Exploring GPS Vectors and Crustal Motion – ANSWER KEY

Name		Period/Class		Date	

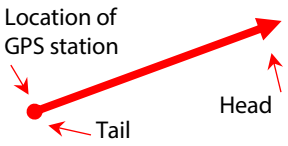
Are tectonic plates still moving? How do we know? Let's explore evidence of tectonic plate motion using current GPS data to see how the land beneath our feet is moving, crumpling, sliding, and stretching.

In this activity, you will either study posters or use vector map handouts (either the Tectonics Motions of Southern California or Tectonics Motions of Oregon and Washington) to do the following things:

1. Measure the amount of ground motion in multiple areas indicated by GPS data.
2. Analyze evidence of different types of crustal motion based on GPS data, and act out motions.
3. Consider the hazards and societal impact that might result due to these motions.

SECTION A: Measuring Ground Motion with GPS Vectors

Procedure and Questions

1. In the space to the right, sketch a vector. Label the head, tail, and where a GPS station would be located.		Complete the following sentence about vector length: *The longer the vector, the* ***faster*** *the GPS station is moving.*
2. On your map, circle the vector scale bar. The scale bar on this map is a 1:1 scale. This means that the length of the vectors on the map show the actual average distance the GPS station moves in a year.		
a. What is the length of the scale bar arrow? b. Therefore, how many millimeters of GPS station movement does the arrow represent?	A. ***10*** millimeters B. ***10*** millimeters	
3. Indicate which map you are working with by circling the name.	**Southern Calif. (in blue)** or **Ore/Wash (in green)**	
4. Using the North arrow, what direction do most of the vectors point?	**SoCal = northwest** **OR/WA = east, northeast**	
5. Measure the longest vector. How long, in millimeters, is the vector?	**About 45 mm** or **about 18 mm**	
6. While the amount the ground moved in one year may not seem like much, multiply it by 100 to show how far it would move in 100 years.	**45 mm/year x 100 years = 4500 mm** **18 mm/year x 100 years = 1800 mm**	
7. Divide the total number of millimeters moved by 1000. This will convert millimeters to meters moved in 100 years. Think of how far it will move in 1 million years!	**4500 mm/100 years ÷ 1000 = 4.5 meters** **1800 mm/100 years ÷ 1000 = 1.8 meters** **(450, 000 meters** **180,000 meters)**	

8. Pick a vector in the coastal area. Using one of the colored pencils, circle it and measure it. This is the annual movement of that coastal GPS station.
9. Pick a vector in an inland area that is clearly a different size than the coastal one. In a different color, circle it and measure it to find the annual distance moved.

10. In the space to the right, complete the statement using the data you measured.

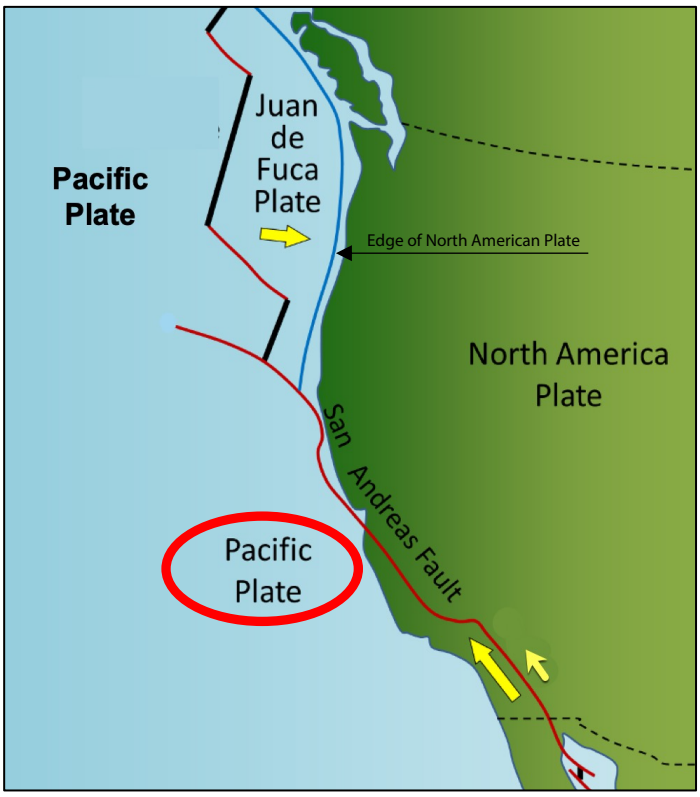
The coastal GPS station moved _____ mm in one year compared to the inland GPS station that moved _____ mm in one year.

(Answers here will vary anywhere between 1 mm/yr to 45 mm/year depending on the vectors chosen)

11. Draw a circle around the entire area along the coast that shows a higher amount of movement. Use the same color as you did when circling the vector from the coastal area.

12. Do the same for the area east of the coastal areas that shows motion in the same direction, but in general has less motion. Use the same color as you did when circling the vector from the inland area.

13. Use the image to the right to circle the name of the tectonic plate that appears to be moving the quickest.



14. Which of the following choices best describes the motion that the tectonic plates are showing? Circle the choice.

   A. Tectonic plates are moving in opposite directions and are getting farther away from each other.

   B. One tectonic plate is moving towards another one and running into it.

   C. One tectonic plate is sliding past another one that's moving in the same direction, but slower.

15. Where two or more tectonic plates interact, it is called a **plate boundary**. Based on the information provided by your instructor, what is the type of plate boundary that exists on your map . . .

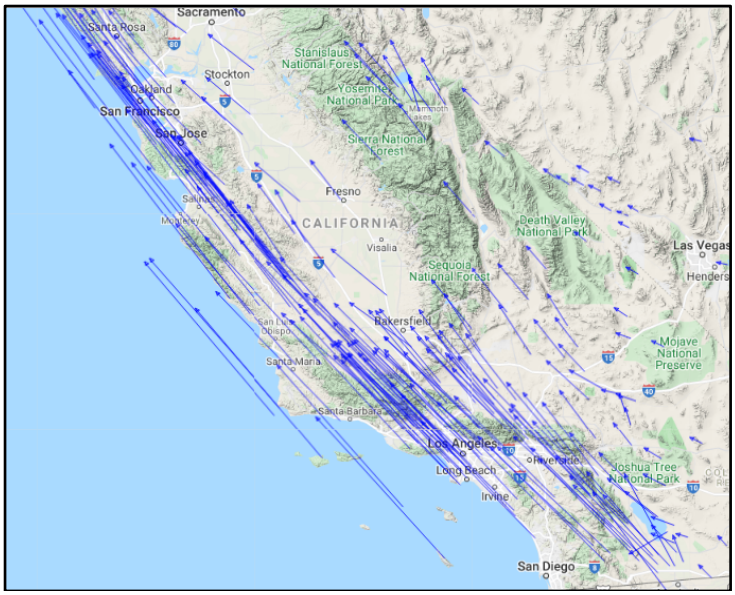
   a. Between the Pacific Plate and North American Plate:
   ___ ***Transform Boundary*** _____

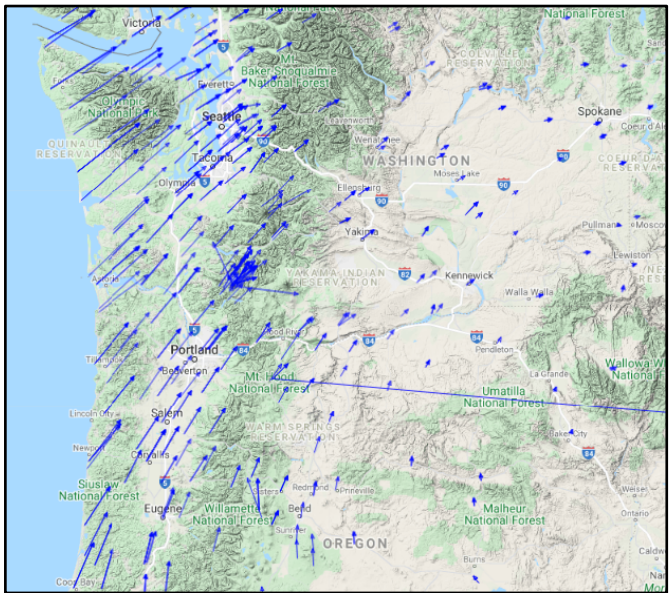
   b. Between the Juan de Fuca Plate and the North American Plate:
   ___ ***Convergent Boundary*** _____

SECTION C: USING GPS DATA TO DETERMINE POTENTIAL HAZARDS

GPS data show that some regions of the Earth's surface are moving faster than others. This causes deformation of the ground surface in those areas, and it leads to earthquakes when the ground finally breaks. Knowing where the ground motions are unequal can indicate areas of greater danger.

Below are GPS vector maps for the same areas you have been studying in Section A. The difference is simply in the number of GPS data vectors that are shown. The maps used in Section A limited the number of vectors shown to make it easier to find and measure individual vectors. Here are nearly all (CA) and all (OR/WA) the GPS data. It paints a slightly different picture.





16. Make observations on the two maps. Besides having more vectors, what else do you notice? What stands out?

Observations will vary and should include: - ***Lots of vectors clumped together (extra monitoring around Mt. St. Helens)*** - ***Super long vectors mostly along the coast.*** - ***Shorter vectors further inland.*** - ***Tiny vectors far inland.*** - ***A couple of vectors seem to not be pointing the same direction as most of the others.***	***Observations will vary and should include:*** - **Shorter vectors overall compared to CA.** - **Longer vectors along the coast the farther north you go.** - **Large clump of vectors in west central WA** - **Twisted appearance of overall vectors**

17. Using the same colored pencils as you used before when circling areas of different vector length in questions 11 and 12 above, lightly shade the maps for the areas you circled. Try to accurately pinpoint the transition from faster moving areas to slower moving areas.

18. Using a third color, shade in the areas much further inland that have very little motion as indicated by GPS data.

Now, compare your circled areas above on your maps to the Earthquake Shaking Potential Maps of California, Oregon, and Washington that your instructor will show you.

19. What is the correlation between your colored areas on the GPS Vector maps and the Earthquake Shaking Potential maps? What did you observe when you compared your colored maps to the official shaking potential maps?	***Learners should see a direct correlation between their coloring and the EQ Shaking Potential maps. They will see the areas of largest vectors will be the most hazardous and the smaller the vectors, the smaller the shaking potential.*** ***An exception is the very obvious high-hazard region right along the San Andreas fault. Learners should recognize that is the area of highest difference between vector lengths in a smaller area.***

A common misconception about GPS data is that the density of GPS stations indicates the areas that have the highest risk. While they may be related, this isn't necessarily true in every case.

20. Circle the statement, or statements, to the right that you believe to be true. 21. After discussion, cross out the statements that are false.	~~*A. The number of GPS stations in an area automatically means there is more danger there.*~~ ***B. The density of GPS stations is just that - there are more GPS stations in a given area.*** ~~*C. A GPS station with the longest vector will be the place with the largest earthquake potential.*~~ ***D. Areas with a big difference between the lengths of GPS vectors are the areas of higher risk of earthquake shaking.***

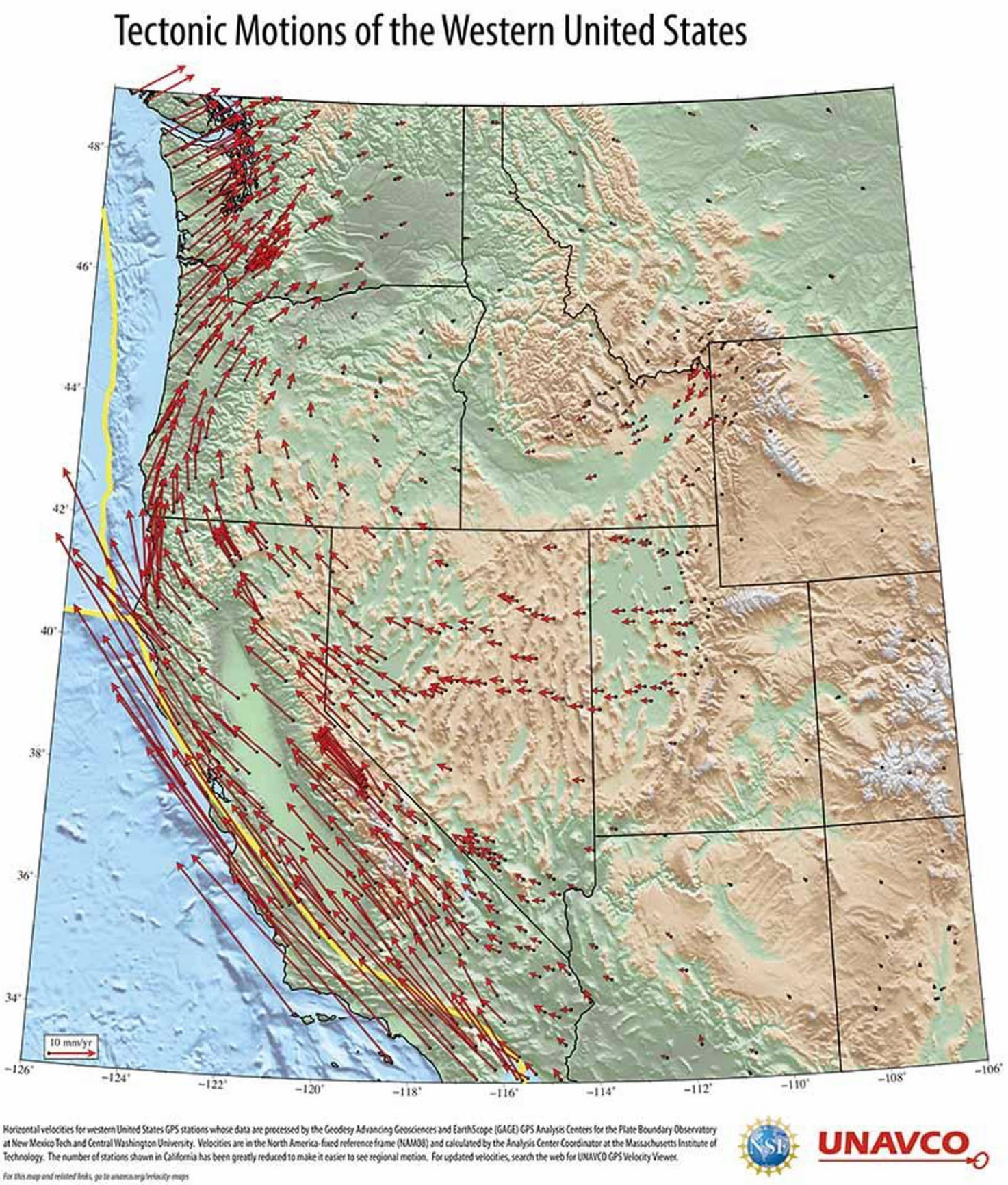
Connect back to the scenario of the GPS data in California using the elastic material.

22. What did the elastic material represent? What was modeled in the activity with the elastic material, and why is that important?	*The elastic material represents the land connecting all the GPS stations. As the material stretches, it models the land being stretched and deformed and increases the risk of it breaking. This is important because it simulates the potential breaking of the land, which is an earthquake.*
23. Brainstorm: What object(s) or material(s) might be used to model the converging tectonic motions of the Pacific Northwest?	*Answers will vary but might include springs, wood, plastic, spongy material - anything that deforms when stretched but wants to spring back to its original shape.*
24. Whether you have a transform boundary or a convergent one, why might it be beneficial to know what type of boundary it is. How do GPS data play a role?	*Knowing what type of boundary exists would allow scientists to predict what type of motion to expect, and direction of movement. Knowing GPS also allows scientists to have an idea of rate of movement, therefore how much potential energy is building up.*
25. What might be the impact on your life? School? Society?	*Responses here will vary and will incorporate multiple perspectives on how far reaching earthquake safety needs to be. The key is awareness and preparation. If we use the scientific information we learn from GPS, we can turn it into situational awareness and save myriad lives and infrastructure, and can build a more resilient society.*

The ShakeAlert ® Early Earthquake Warning System incorporates high-precision GPS data. Being aware of higher risk areas allows scientists and public health officials to mitigate the risk and produce far more favorable outcomes in the case of a major earthquake. For more information refer to the USGS ShakeAlert website.

APPENDIX J: Full GPS Vector Maps of the Western United States: California, Oregon, and Washington

Page 2



Earthquake Shaking Potential for California

2016

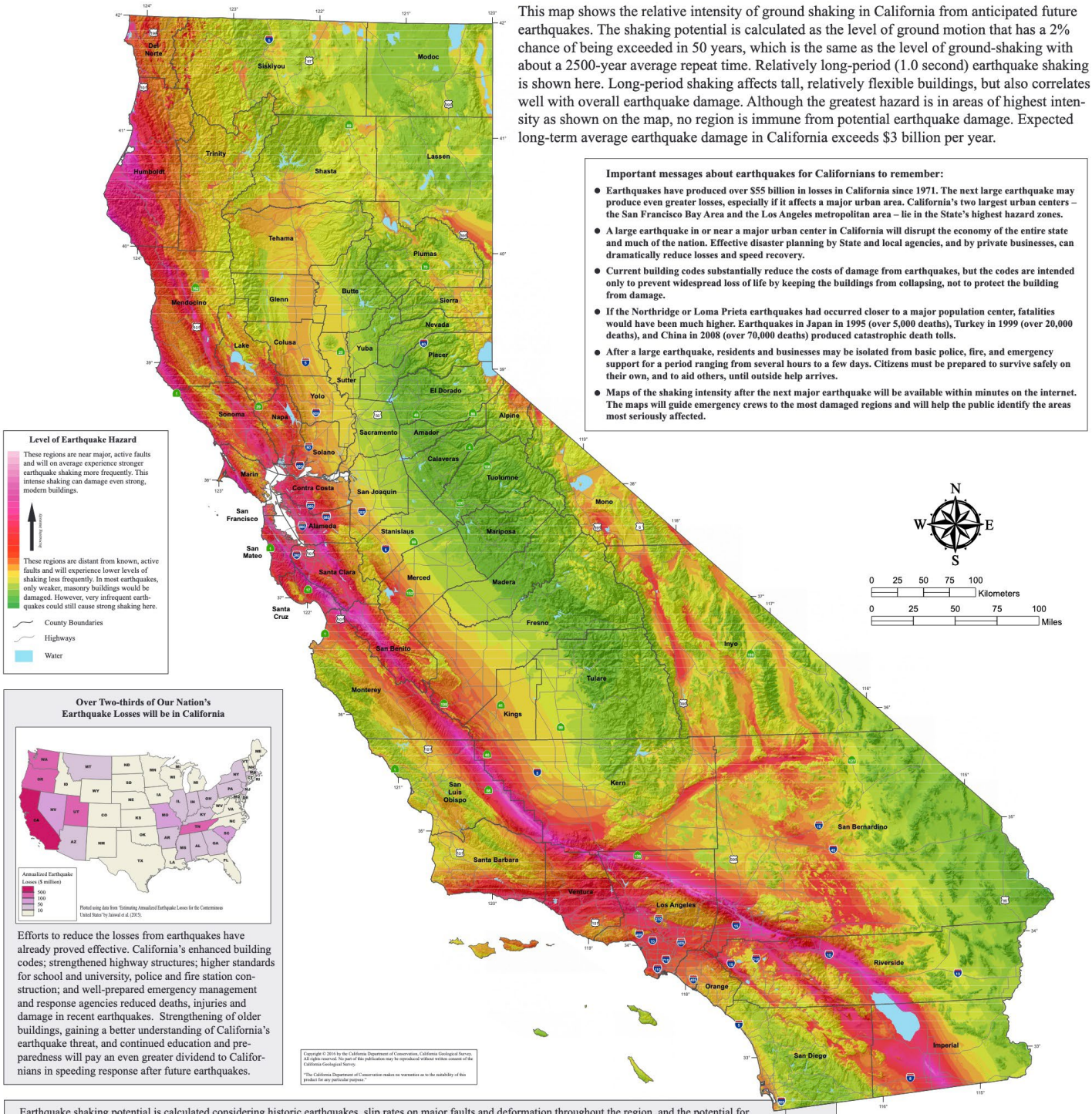
D. Branum[1], R. Chen[1], M. Petersen[2] and C. Wills[1]

[1]California Geological Survey, [2]United States Geological Survey

This map shows the relative intensity of ground shaking in California from anticipated future earthquakes. The shaking potential is calculated as the level of ground motion that has a 2% chance of being exceeded in 50 years, which is the same as the level of ground-shaking with about a 2500-year average repeat time. Relatively long-period (1.0 second) earthquake shaking is shown here. Long-period shaking affects tall, relatively flexible buildings, but also correlates well with overall earthquake damage. Although the greatest hazard is in areas of highest intensity as shown on the map, no region is immune from potential earthquake damage. Expected long-term average earthquake damage in California exceeds $3 billion per year.

Important messages about earthquakes for Californians to remember:

- **Earthquakes have produced over $55 billion in losses in California since 1971. The next large earthquake may produce even greater losses, especially if it affects a major urban area. California's two largest urban centers – the San Francisco Bay Area and the Los Angeles metropolitan area – lie in the State's highest hazard zones.**
- **A large earthquake in or near a major urban center in California will disrupt the economy of the entire state and much of the nation. Effective disaster planning by State and local agencies, and by private businesses, can dramatically reduce losses and speed recovery.**
- **Current building codes substantially reduce the costs of damage from earthquakes, but the codes are intended only to prevent widespread loss of life by keeping the buildings from collapsing, not to protect the building from damage.**
- **If the Northridge or Loma Prieta earthquakes had occurred closer to a major population center, fatalities would have been much higher. Earthquakes in Japan in 1995 (over 5,000 deaths), Turkey in 1999 (over 20,000 deaths), and China in 2008 (over 70,000 deaths) produced catastrophic death tolls.**
- **After a large earthquake, residents and businesses may be isolated from basic police, fire, and emergency support for a period ranging from several hours to a few days. Citizens must be prepared to survive safely on their own, and to aid others, until outside help arrives.**
- **Maps of the shaking intensity after the next major earthquake will be available within minutes on the internet. The maps will guide emergency crews to the most damaged regions and will help the public identify the areas most seriously affected.**



Level of Earthquake Hazard

These regions are near major, active faults and will on average experience stronger earthquake shaking more frequently. This intense shaking can damage even strong, modern buildings.

Increasing Intensity

These regions are distant from known, active faults and will experience lower levels of shaking less frequently. In most earthquakes, only weaker, masonry buildings would be damaged. However, very infrequent earthquakes could still cause strong shaking here.

County Boundaries

Highways

Water

Over Two-thirds of Our Nation's Earthquake Losses will be in California

Efforts to reduce the losses from earthquakes have already proved effective. California's enhanced building codes; strengthened highway structures; higher standards for school and university, police and fire station construction; and well-prepared emergency management and response agencies reduced deaths, injuries and damage in recent earthquakes. Strengthening of older buildings, gaining a better understanding of California's earthquake threat, and continued education and preparedness will pay an even greater dividend to Californians in speeding response after future earthquakes.

Copyright © 2016 by the California Department of Conservation, California Geological Survey. All rights reserved. No part of this publication may be reproduced without written consent of the California Geological Survey.

"The California Department of Conservation makes no warranties as to the suitability of this product for any particular purpose."

Earthquake shaking potential is calculated considering historic earthquakes, slip rates on major faults and deformation throughout the region, and the potential for amplification of seismic waves by near-surface geologic materials. The complete analysis is called a Probabilistic Seismic Hazard Analysis. The resulting earthquake shaking potential is used in developing building code design values, estimating future earthquake losses and prioritizing earthquake retrofit.

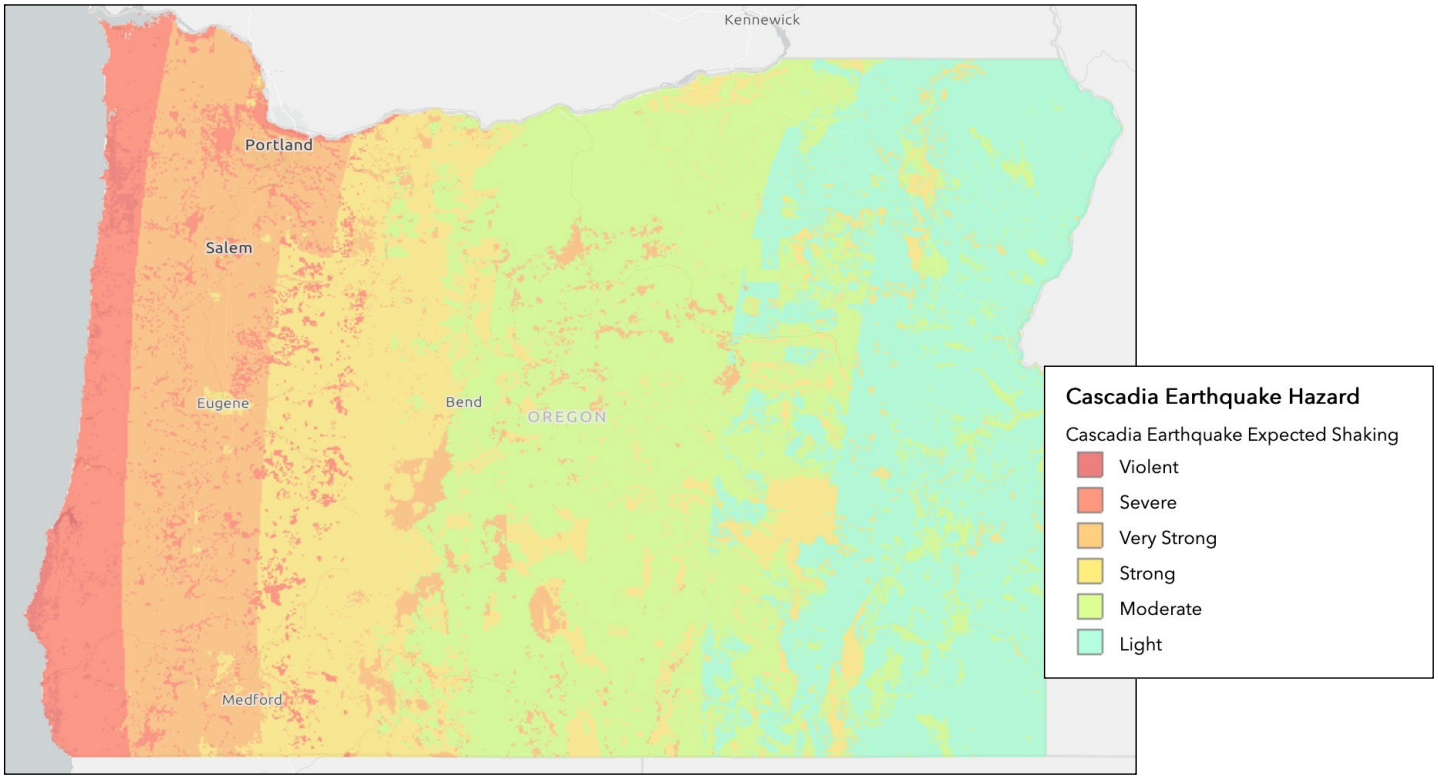
References

Field, E.H., Biasi, G.P., Bird, P., Dawson, T.E., Felzer, K.R., Jackson, D.D., Johnson, K.M., Jordan, T.H., Madden, C., Michael, A.J., Milner, K.R., Page, M.T., Parsons, T., Powers, P.M., Shaw, B.E., Thatcher, W.R., Weldon, R.J., II, and Zeng, Y., 2013, *Uniform California Earthquake Rupture Forecast, Version 3 (UCERF3)—The Time-*

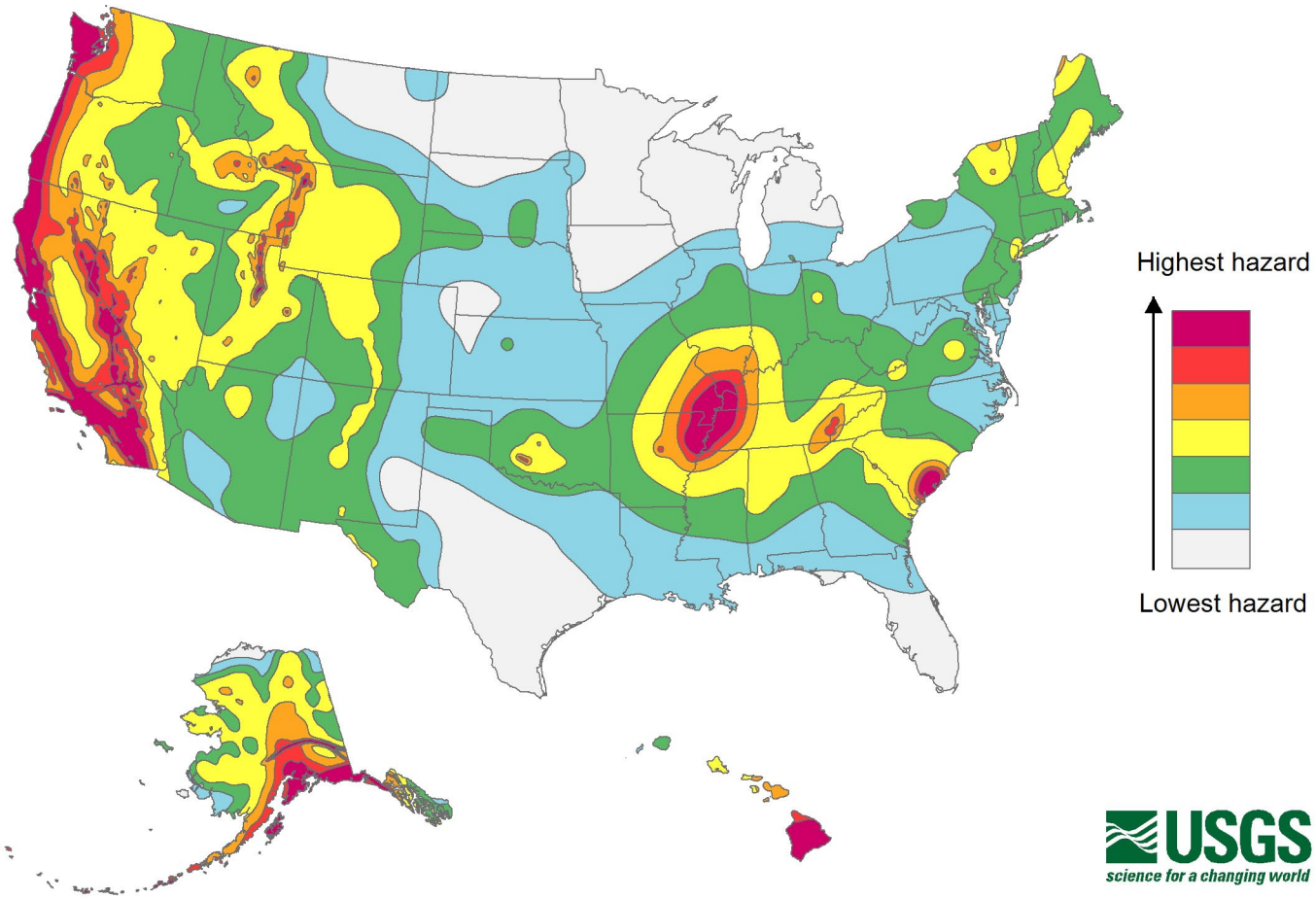
Washington shaking hazard map can be downloaded from the Washington State Department of Natural Resources. Warmer colors indicate greater shaking hazard potential from a Cascadia subduction zone earthquake



Oregon shaking hazard map can be downloaded from the Oregon Department of Geology and Mineral Resources. Warmer colors indicate greater shaking hazard potential from a Cascadia subduction zone earthquake



This seismic hazard map of the United States can be downloaded from the U.S. Geological Survey

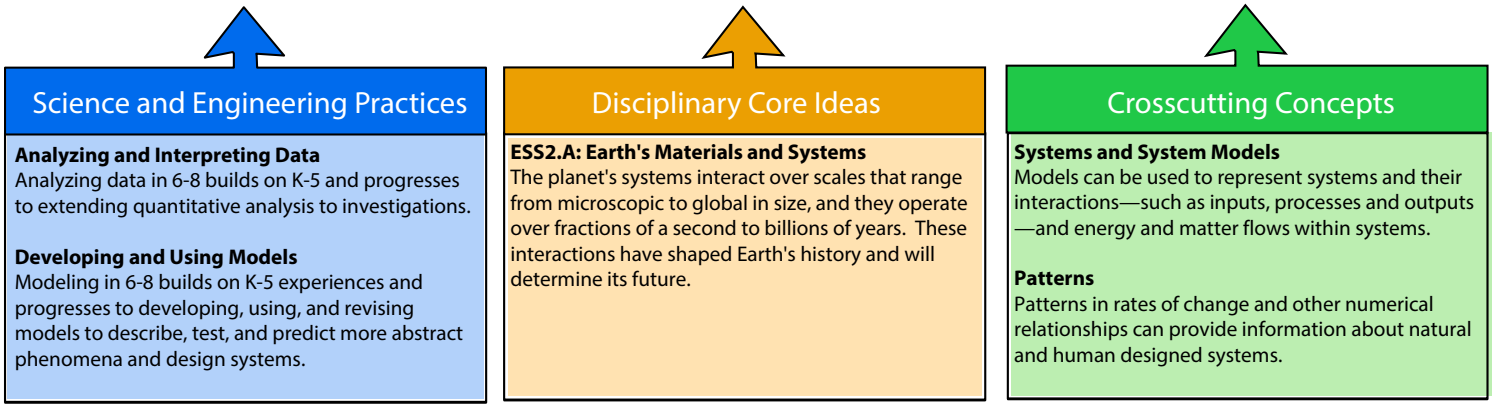


Earthquake hazard map showing peak ground accelerations having a 2 percent probability of being exceeded in 50 years, for a firm rock site. The map is based on the most recent USGS models for the conterminous U.S. (2018), Hawaii (1998), and Alaska (2007). The models are based on seismicity and fault-slip rates, and take into account the frequency of earthquakes of various magnitudes. Locally, the hazard may be greater than shown, because site geology may amplify ground motions.

History of Earth

Students who demonstrate understanding can:

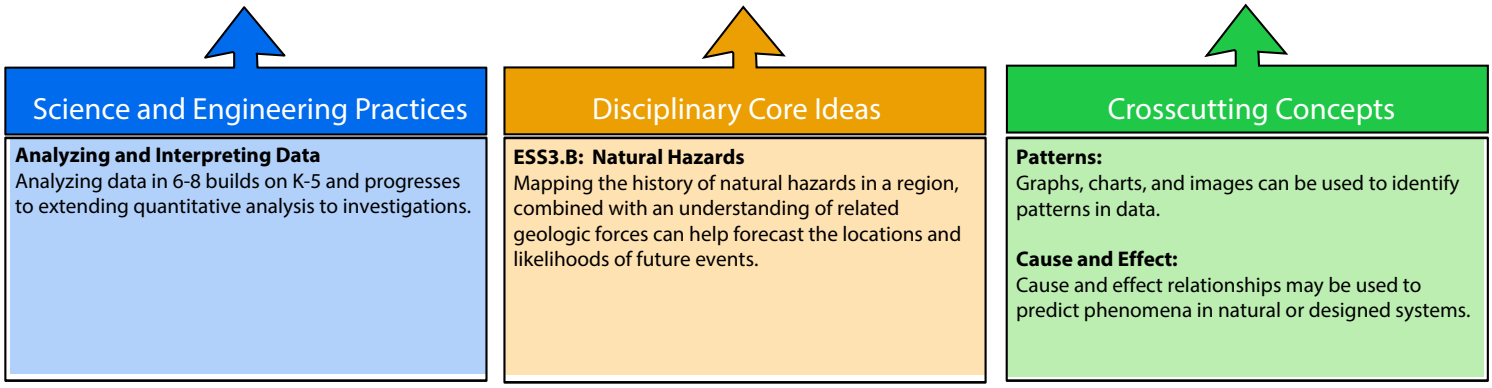
MS-ESS2-2. Construct an explanation based on evidence for how geoscience processes have changed Earth's surface at varying time and spatial scales. [Clarification Statement: Emphasis is on how processes change Earth's surface at time and spatial scales that can be large (such as slow plate motions or the uplift of large mountain ranges) or small (such as rapid landslides or microscopic geochemical reactions), and how many geoscience processes (such as earthquakes, volcanoes, and meteor impacts) usually behave gradually but are punctuated by catastrophic events. Examples of geoscience processes include surface weathering and deposition by the movements of water, ice, and wind. Emphasis is on geoscience processes that shape local geographic features, where appropriate.]



Human Impacts

Students who demonstrate understanding can:

MS-ESS3-2. Analyze and interpret data on natural hazards to forecast future catastrophic events and inform the development of technologies to mitigate their effects. [Clarification Statement: Emphasis is on how some natural hazards, such as volcanic eruptions and severe weather, are preceded by phenomena that allow for reliable predictions, but others, such as earthquakes, occur suddenly and with no notice, and thus are not yet predictable. Examples of natural hazards can be taken from interior processes (such as earthquakes and volcanic eruptions), surface processes (such as mass wasting and tsunamis), or severe weather events (such as hurricanes, tornadoes, and floods). Examples of data can include the locations, magnitudes, and frequencies of the natural hazards. Examples of technologies can be global (such as satellite systems to monitor hurricanes or forest fires) or local (such as building basements in tornado-prone regions or reservoirs to mitigate droughts).]



Creative Commons Attribution 4.0 International License

All educational, outreach, and community engagement materials developed through UNAVCO are made freely available under a Creative Commons Attribution 4.0 International (CC BY 4.0) (link: https://creativecommons.org/licenses/by/4.0/) license.









GAGE National Science Foundation's Geodetic Facility for the Advancement of Geoscience

SAGE National Science Foundation's Seismological Facility for the Advancement of Geoscience

UNAVCO

IRIS