



Measuring Earth with GPS: Earthquakes

Karen M. Kortz (Community College of Rhode Island) and Jessica J. Smay (San Jose City College)

This is the full lab handout. It includes the information you need to complete the lab. However, you will submit your lab answers on your learning management system.

Learning outcomes:

- Students will observe, describe, analyze, interpret, and apply time-series GPS data related to horizontal bedrock motion resulting from plate tectonics
- Students will interpret absolute and relative bedrock motion near plate boundaries and its relationship to earthquakes as measured by GPS
- Students will draw on GPS data to make a societal recommendation relative to earthquakes

GPS stations precisely record the position of the solid ground they are on, and they were first installed to measure plate motion.

In this lab, you will learn how to analyze and interpret scientific data after describing it, an important step for scientists in the process of science. You will conclude by using that data to support a recommendation you make about an issue relevant to society. This particular activity uses data from GPS stations in California to better interpret earthquake hazards by analyzing GPS position of bedrock near a transform plate boundary.

Part 1: The ground is moving?

Visit the [UNAVCO GPS Velocity Viewer website](https://www.unavco.org/software/visualization/GPS-Velocity-Viewer/GPS-Velocity-Viewer.html) (<https://www.unavco.org/software/visualization/GPS-Velocity-Viewer/GPS-Velocity-Viewer.html>). This website shows arrows indicating the motion of GPS stations. Move around the map and zoom in and out. If the area in which you're looking has only short arrows, then you can change the "Vector length (scaling)" to be a larger number and click on "Draw map." If the area you're looking at does not have very many arrows, then you can display data from more stations by changing "How many markers displayed" then click on "Draw map."

1. Using the information displayed on the map, what is a correct observation (not interpretation)?

GPS stations are spaced regularly across the United States.

The plate boundaries along the West Coast are causing the GPS stations there to move faster.

The GPS stations cause some areas to have more earthquakes than other areas.

The arrows in western North America are mostly larger than the arrows in eastern North America.

2. (2 points) What are two or three things that you're wondering after making observations of the arrows showing GPS station motion on the map? Note that the motion is due to slow motion of the ground, not earthquakes.



Figure 1. This is GPS station P056 in California.

GPS stations are attached to the ground, so they move if the ground moves. They record data in three directions: north-south, east-west, and vertical. These three directions need to be combined to determine the overall direction of motion of the GPS station. We will work with the horizontal motion in this lab.

- North-south: The y-axis is labeled north, so the GPS station is moving northward if the numbers over time are increasing, and southward if the numbers over time are decreasing.
- East-west: The y-axis is labeled east, so the GPS station is moving eastward if the numbers over time are increasing, and westward if the numbers over time are decreasing.
- Vertical: The y-axis is labeled height, so the GPS station is rising if the numbers over time are increasing, and lowering if the numbers over time are decreasing.

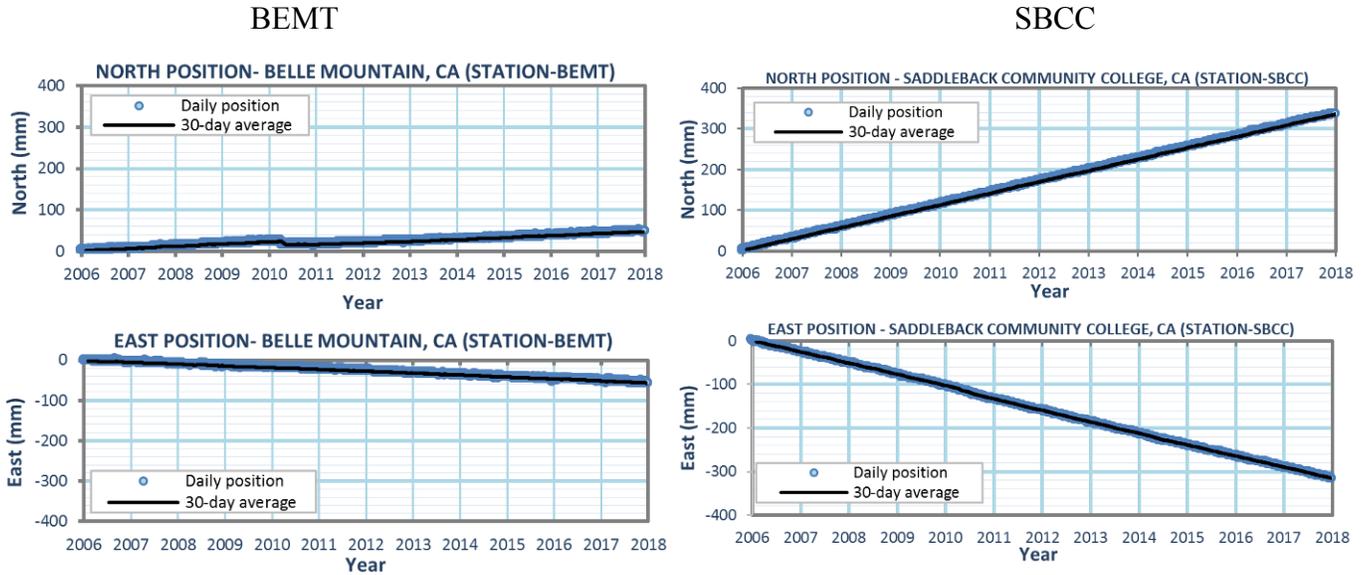


Figure 2. GPS data from station SBCC near Mission Viejo in California and station BEMT near Twentynine Palms in California from the beginning of January 2006 to the end of December 2017. The two left graphs are BEMT and the two right graphs are SBCC. The top graphs are North-South motion and the bottom graphs are East-West motion.

Let's examine Figure 2 that shows the GPS data. The first thing to do when looking at a graph is to read the title, look at the axes, and make some general observations.

3. What does the horizontal (x-) axis show and what are the units?

time in years position in millimeters motion in millimeters per year

4. What does the vertical (y-) axis show and what are the units?

time in years position in millimeters motion in millimeters per year

5. Read the text on the previous page. What would the east position numbers do over time if the station is moving westward?

They would increase. They would decrease. They would remain the same.

6. In what direction is BEMT moving (the two left graphs)?

north and west north and east south and west south and east

7. In what direction is SBCC moving (the two right graphs)?

north and west north and east south and west south and east

8. How do you know that Station SBCC is moving faster than Station BEMT? (Select **two**)

Graph lines trend in the same direction. SBCC moves more millimeters each year.

The slopes for SBCC are steeper. Both show positive north and negative east movement.

Part 2: How are these motions related to the plate boundary?

Scientists installed GPS stations in California to see how the tectonic plates were moving and to help confirm the location of the plate boundary. The map of California in Figure 3 shows the location of the two GPS stations with the transform plate boundary drawn in black. The red arrows show the direction and speed of each GPS station.



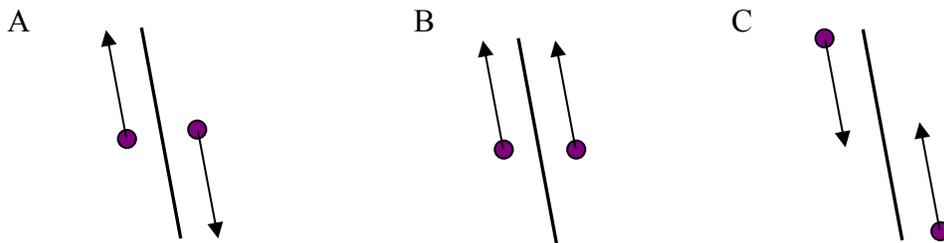
Figure 3. A map of southern California showing the locations of GPS stations SBCC near Mission Viejo in California and station BEMT near Twentynine Palms in California.

Although the stations are on different plates, they're moving in the same direction! Let's look more closely at the data to determine how the plates are moving relative to each other. The word "relative" means "in comparison to." So if we are on one plate, we want to determine how the other plate moves compared to it. We are shifting our reference frame, or point of view.

9. If you were at Station BEMT, moving along with it as it moves and looking toward SBCC, how would Station SBCC move relative to you? Similarly, if you were at Station SBCC, moving along with it as it moves, how would Station BEMT move relative to you?

- | | |
|---|---|
| It moves to my right and gets closer over time. | It moves to my right and gets farther over time |
| It moves to my left and gets closer over time. | It moves to my left and gets farther over time |

10. Therefore, which arrows show the best representation of the relative motion of the stations?



Part 3: Animation

Watch the animation titled, [UNAVCO Measuring Plate Tectonics with GPS](https://www.youtube.com/watch?v=S1m1tAGbFL4) (<https://www.youtube.com/watch?v=S1m1tAGbFL4>). Answer the questions below.

11. How are the motions of high-precision GPS networks shown on maps?
as dots as different colors as arrows
12. What direction are GPS stations on both sides of the San Andreas Fault moving?
Northwest Northeast Southwest Southeast
13. Why are there earthquakes on the San Andreas Fault?
The Pacific Plate is moving faster than the North American Plate
The plates are moving in opposite directions

Part 4: Writing a hypothesis about GPS data and earthquakes

Geologists make hypotheses to explain how one thing affects another and why the relationship exists. They use their hypotheses to make predictions that they can then test by collecting data. In this part of the lab, you will use your understanding of the relationships between the tectonic plate motion and earthquakes to write a hypothesis.

14. The animation explained Earth processes that can cause horizontal position of the bedrock to change. What is the main global process that causes the position of GPS stations attached to the bedrock to move?
precipitation tectonic plate motion glacier size volcanic eruptions landslides

As we previously figured out, in southern California the western side of the transform plate boundary in California (the Pacific Plate) is moving north faster than eastern side of the plate boundary (the North American Plate). Next we will consider the motion of GPS stations on either side of the plate boundary in another part of California to learn more about earthquakes.

The San Andreas Fault is a fault that extends along the transform plate boundary through California. Earthquakes happen when the bedrock on either side of a fault suddenly moves and releases energy, shaking the ground. The two tectonic plates are constantly moving (which can be measured by GPS), but there are not continual earthquakes. Why? Because the two sides are locked together by friction along the fault. As the plates continue to move, the stress builds up along the stuck fault. Once the stress builds up enough, it will overcome the friction, the two sides will suddenly move, and there will be an earthquake. Over time, the stress will build up once again. This explanation of why earthquakes occur is called the elastic rebound theory.

Watch this helpful 11-second [USGS animation showing the elastic rebound theory](https://www.usgs.gov/media/videos/elastic-rebound) (<https://www.usgs.gov/media/videos/elastic-rebound>).

GPS stations can measure the long-term movement of the ground, indicating the tectonic plate motion and resulting build-up of stress along the fault. GPS stations can also measure how far the ground near a fault moves during an earthquake.

15. Read the paragraphs above. How can GPS stations be used to predict where earthquakes happen?

GPS can measure how much the ground moves during an earthquake.

GPS can measure how far the ground moves, which can be used to see what areas are stressed.

GPS can measure how fast areas are moving, which can be used to see what plates are fastest.

16. Based on the 11-second USGS animation of the elastic rebound theory, which of these is first?

When the forces trying to make the edges slip overcome the friction making them stick, there is an earthquake.

The bending and subsequent “catching up” of the crust is called “elastic rebound.”

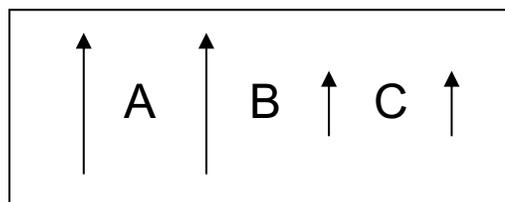
As tectonic plates are slowly moving, their edges are locked in place, causing bending of the crust along plate edges.

17. Earthquakes happen where stress builds up along a fault because the two sides of the fault are moving at _____ speeds.

the same

different

The simple map below shows arrows indicating the motion of four GPS stations, and the letters indicate three locations.



18. (2 points) Write a hypothesis explaining which location is most likely to experience earthquakes by filling in the blanks:

Location _____ (A / B / C) is mostly likely to experience earthquakes because the surrounding ground is moving _____ (faster / slower / at different speeds).

Part 5: Observing and describing long-term rates from GPS data

Below in Figure 4 are data from three GPS stations in Central California. In this part of the lab, you will make observations to describe the data related to the long-term motion of the GPS stations. You will then apply your hypothesis to make predictions about where you expect earthquakes to happen.

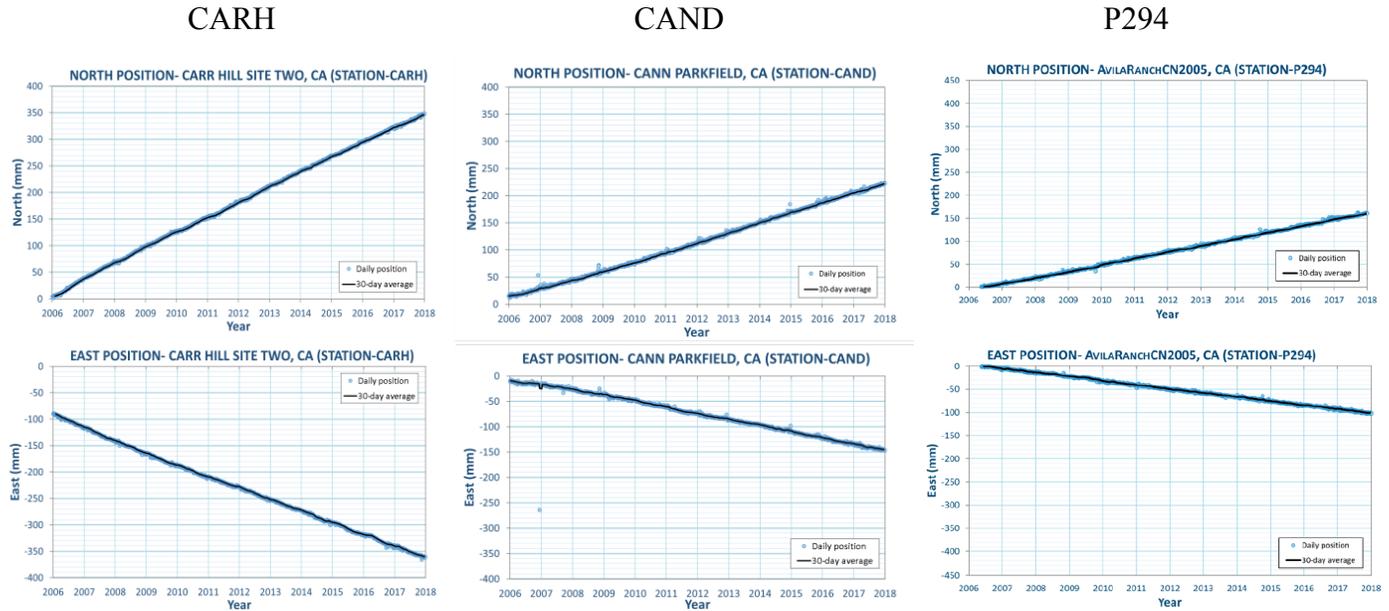


Figure 4. North and East GPS data from station CARH (left), CAND (middle), and P294 (right) in California from the beginning of January 2006 to 2018.

19. In what direction is CARH moving?
 north and west north and east south and west south and east

20. In what direction is CAND moving?
 north and west north and east south and west south and east

21. In what direction is P294 moving?
 north and west north and east south and west south and east

22. Which two stations are moving at the most similar speed?
 CARH and CAND CAND and P294 P294 and CARH

23. Examine your hypothesis and make a prediction of where you would expect earthquakes:
near CARH between CARH & CAND near CAND between CAND & P294 near P294

24. Which sentence best explains your prediction?

It/they are moving faster.

It/they are moving at different speeds.

It/they are farthest apart.

It/they are moving together.

You can use the data to calculate how fast stations CARH and CAND are moving. CARH is moving 38 mm/year and CAND is moving 21 mm/year. This means that they are getting 17 mm further apart each year.

25. How far apart will the two stations be after 10 years? _____ mm

26. How far apart will the two stations be after 100 years? Divide this number by 1000 to convert it to meters. _____ m

The further the stations slowly move apart, the higher the stress on the fault, and the more likely there will be an earthquake. Also, the further the stations slowly move apart, the further they will suddenly move during an earthquake, resulting in a larger earthquake.

27. Fill in the relationship between time, likelihood of an earthquake, and earthquake size:

More stress on a fault results in a _____ (smaller / greater) chance of an earthquake and a _____ (smaller / larger) earthquake.

Part 6: Applying data interpretation to society

Scientists use their interpretations of what is happening in the world around us to learn how society may be affected and to help people make informed decisions. In this part, you will apply your interpretations of your observations of the motion of the GPS station in California to help a person make an informed decision.

Look at the map in Figure 5 below. Each arrow shows the direction and speed of motion at a GPS station. Some of the arrows are bold, but that is to make them easier to see, and they do not have a different meaning. Note the arrow for scale at the bottom left, showing the length of a 25 mm/year vector.

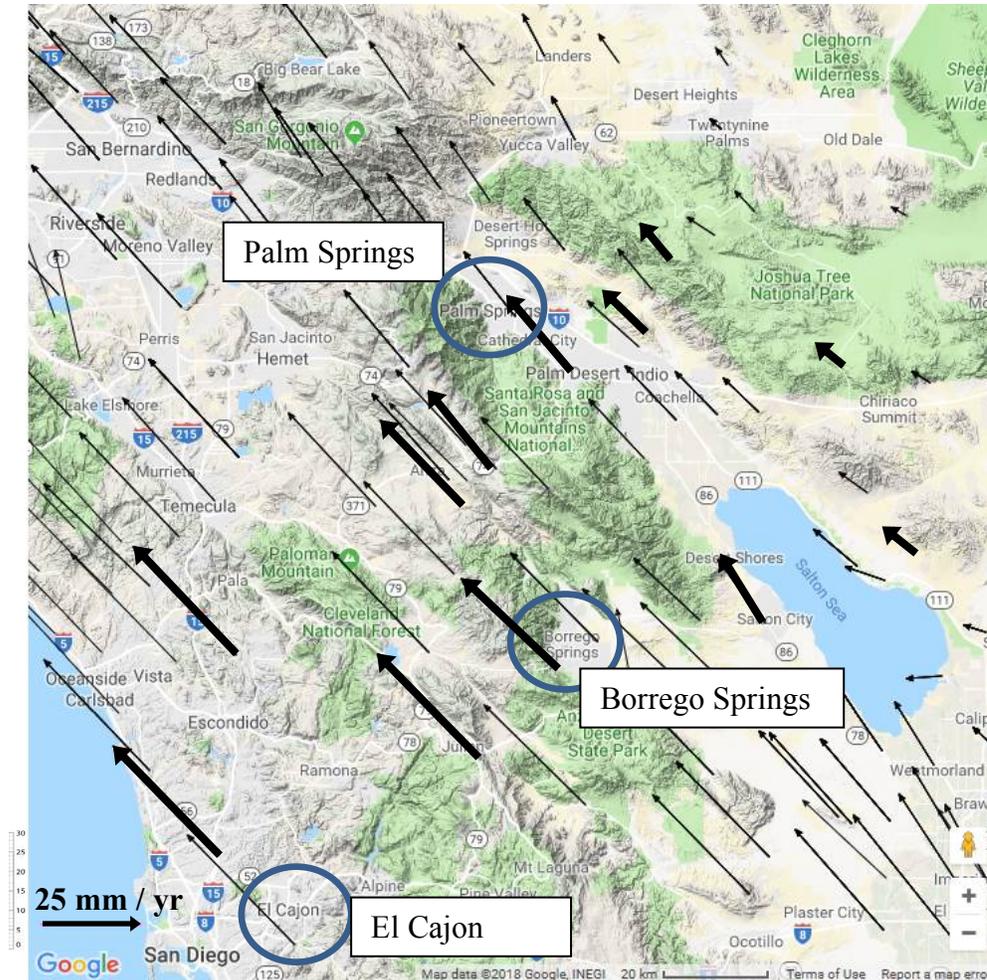


Figure 5. Screenshot of GPS Velocity Viewer (NAM08; <https://www.unavco.org/software/visualization/GPS-Velocity-Viewer/GPS-Velocity-Viewer.html>) with three locations and several vectors highlighted. The bold arrows are just to make them easier to see, and they do not have a special meaning.

Imagine you have a friend Alix who says, “I would like to live near one of the jobs I’ve been offered in Southern California. I narrowed it down to the three locations circled on the map. However, I can’t afford earthquake insurance. Where do you think I should live?”

Where do you think your friend should move? Formulate an argument to support your recommendation, keeping your hypothesis in mind. Write a letter to your friend with the purpose of encouraging or discouraging them to move to each of the locations to avoid earthquake hazards, using GPS data from California to support your argument.

There are four sections to the letter written below. Select which answers best match your response for each of the four sections.

28. (2 points) Which answer best matches your response for Section 1 of the letter?

Dear Alix, I think you should move to El Cajon.

Dear Alix, I think you should move to Palm Springs.

Dear Alix, I think you should move to Borrego Springs.

29. Which answer best matches your response for Section 2 of the letter?

I give you this recommendation because the GPS stations near there are moving at about the same speed, as shown by the arrows being about the same size.

I give you this recommendation because the GPS stations near there are moving the slowest, as shown by the arrows being the shortest.

I give you this recommendation because it has some of the flattest ground near it.

30. Which answer best matches your response for Section 3 of the letter?

In comparison, the arrows near Palm Springs and Berrego Springs have different rates of ground motion near them. Therefore, they are more likely to experience earthquakes because the surrounding ground is moving at different speeds.

In comparison, the arrows near El Cajon and Berrego Springs have faster rates of ground motion near them. Therefore, they are more likely to experience earthquakes because the surrounding ground is moving faster.

In comparison, the arrows near El Cajon and Palm Springs show that the mountains are growing. Therefore, they are more likely to experience earthquakes because the mountains are getting higher.

31. Which answer best matches your response for Section 4 of the letter?

Earthquakes happen when the stress in the bending ground overcomes the friction, so the ground moves, releasing energy. This is less likely to happen at El Cajon.

Earthquakes happen when the stress builds up in the fastest moving ground, so the ground moves, releasing energy. This is less likely to happen at Palm Springs.

Earthquakes happen when the weight of mountains cause stress in the ground, so the ground moves, releasing energy. This is less likely to happen at Borrego Springs.

Part 7: Find Your Own GPS Station

Visit the [NOTA GNSS/GPS Stations Network Monitoring website](https://www.unavco.org/instrumentation/networks/status/nota/gps) (<https://www.unavco.org/instrumentation/networks/status/nota/gps>). The website shares GPS data from the United States and Central America. Move the map around and zoom in and out to see the locations of GPS stations.

32. Where are more GPS stations located?

Western United States

Central United States

Eastern United States

Zoom in to find an individual GPS station. Click on the green station icon, then when the information about the station status pops up, click on the blue station name (it's generally 4 letters/numbers long). On the overview page it brings you to, there is information about the station, a photo of the station, graphs of the GPS data, and a map. You can click on the red buttons to download the GPS data, see more photos, see the maintenance log, etc.

33. (2 points) In the space below, tell me the station name, the state/country it is in, and 2 things you learned about the station that you found interesting.

Part 8: Reflection

34. (3 points) Answer one of these questions using 3-5 sentences: What surprised you most when you were completing this lab? OR What did you find most interesting when completing this lab? OR How did information in this lab relate to something you knew previously?