Measuring Earth with GPS, Unit 2: Earthquakes
Activity 1 Student Exercise: Observe and Describe

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

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

Hi, I'm Jordan, a geoscientist who uses GPS data to better understand how tectonic plates move. In this activity, I will guide you to describe scientific data from GPS stations on the bedrock in California by making careful observations, and you will use those observations to make a scientific interpretation. I hope to model for you the process that scientists like me use when we work to solve scientific questions. ***Be sure to read what I say, because I will give you clues to help make sure you understand****.*

Part 1: The ground is moving?

When I, as a scientist, look at data, I begin by determining what the graph is showing and then make observations by describing the trends. We will focus on motion over individual years.

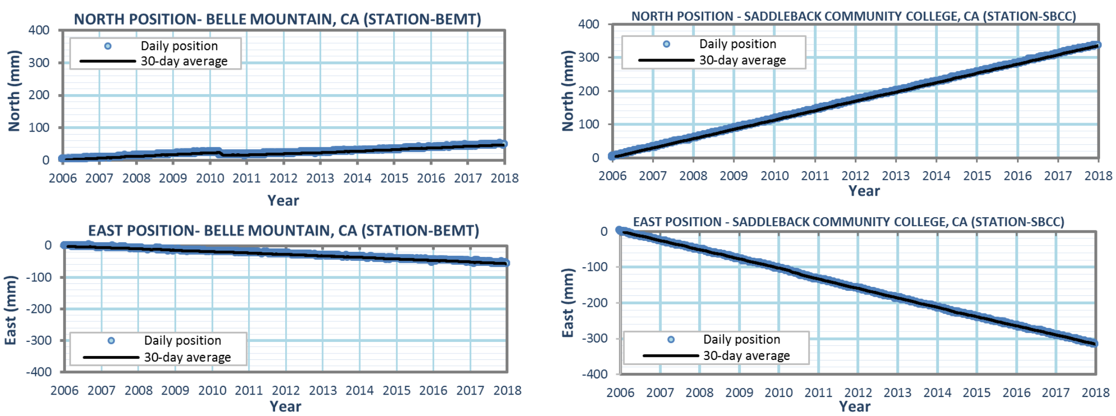


Figure 1. GPS data from station SBCC near Mission Viejo in California and station BEMT near Twentynine Palms in California from the beginning of January 2006 to the end of December 2017.

Let's first examine Figure 1 that shows the GPS data. A larger version is included separately to make reading the numbers easier and more accurate. The first thing I do when looking at a graph is to read the title, look at the axes, and make some general observations.

1. What does the horizontal (x-) axis show? What are the units?

   time position motion station — years millimeters

   What does the vertical (y-) axis show? What are the units?

   time position motion station — years millimeters

2. How do you know the ground is moving?

Part 2: What hypotheses might explain the ground motion at different stations?

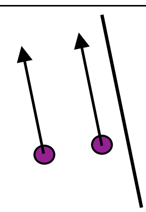
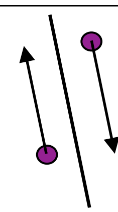
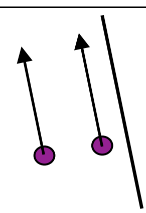
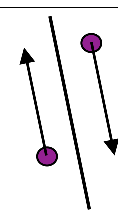
After scientists realized there was a transform plate boundary running from the northwest to southeast in California, they installed GPS stations to see how the tectonic plates were moving and to help confirm the location of the plate boundary. Here are two possible hypotheses that relate the direction the two GPS stations were moving to their location relative to the transform plate boundary:

Hypothesis A: The stations will move in opposite directions parallel to the plate boundary because they are on opposite sides of a transform plate boundary.

Hypothesis B: The stations will move in the same direction parallel to the plate boundary because they are on the same side of a transform plate boundary.

Geoscientists often work with more than one hypothesis (we call them "multiple working hypotheses"), and that is what we'll do here. We will keep these two hypotheses in mind as we better describe the data to try to determine which one explains the data better.

3. Let's make some predictions based on these hypotheses, and then we will later compare the GPS data to them. Fill in the table below by circling which prediction matches each hypothesis for each row.

Hypothesis	**The rate and direction the hypothesis predicts the GPS stations move**	
Hypothesis A	same rate; moving same direction (northwest) 	same rate; moving opposite directions 
Hypothesis B	same rate; moving same direction (northwest) 	same rate; moving opposite directions 

Part 3: How fast is the ground moving and in what direction?

After making overall observations as we did in Part 1, I describe the data using numbers. Using numbers allows us be more precise in our observations and description of horizontal movement.

When describing how something changes position over time, scientists calculate the rate (speed) of change. I'm guessing you have done this if you describe a car's speed. If a car is traveling at a rate of 60 miles per hour, it is traveling a distance of 60 miles over the time of 1 hour (60 miles divided by 1 hour equals 60 miles/hour).

4. Pick a five-year interval and fill in the tables below to calculate the rate in each direction (north–south and east–west) that the GPS stations are moving. Remember to include units, and the units for rates will be a unit of distance over a unit of time.

North–South	**SBCC**	**BEMT**
Is the station traveling north or south?	north south	north south
Distance (difference in position from the beginning to the end of the time interval you chose)		
Time (years from the beginning to the end)	5 years	5 years
Rate (distance divided by time)		

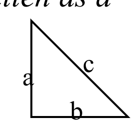
East–West	**SBCC**	**BEMT**
Is the station traveling east or west?	east west	east west
Distance (difference in position from the beginning to the end of the time interval you chose)		
Time (years from the beginning to the end)	5 years	5 years
Rate (distance divided by time)		

I like to make multiple measurements to make sure that I'm not making a calculation error and that the data are consistent. For SBCC, I'm getting rates that range from 25 to 30 mm/year as the north movement and -25 to -30 mm/year as it moves west. Make sure your numbers are in the same range.

You've calculated how far the GPS stations move to the north and to the west each year. But, we'd like to know exactly how far they move horizontally in total each year and in what specific direction. First, to figure out the total rate of movement, I like to use a neat little math trick: 1) square the north–south rate, 2) square the east–west rate, 3) add them together; 4) then take the square root of that sum. Here is the equation:

$$\text{total rate} = \sqrt{(\text{north–south rate})^2 + (\text{east–west rate})^2}$$

The Pythagorean Theorem is often written as $a^2 + b^2 = c^2$

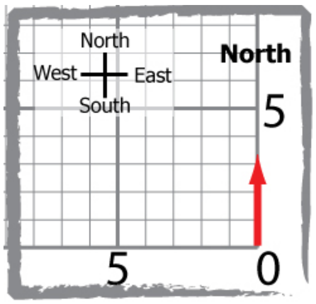


5. Fill in the table below by calculating the total rate and using the directions from Question 4.

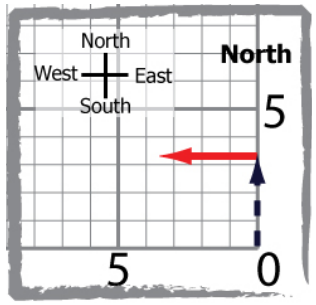
	SBCC	**BEMT**
Total rate of movement (remember units!)		
Direction of movement	northeast northwest southeast southwest	northeast northwest southeast southwest

I like to double-check my calculations of total rate to make sure they make sense. We can do this by creating vectors. Vectors are arrows that show the exact direction of movement, and their length shows the rate of movement. Here are directions to create a vector:

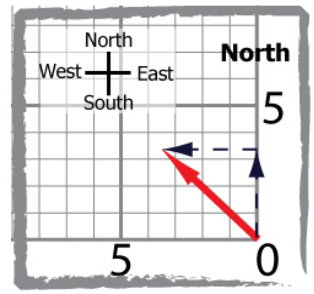
a. Draw a guide arrow to show the annual north–south movement.



b. From the end point of the north arrow, draw a guide arrow to show the annual east–west movement.

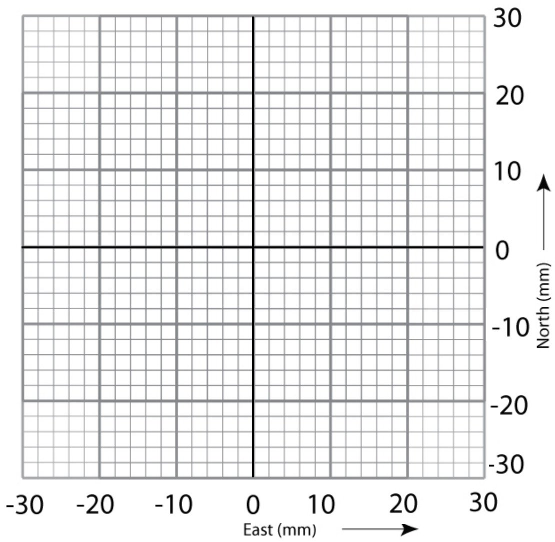


c. Draw the vector from (0,0) to the end point of the east arrow.

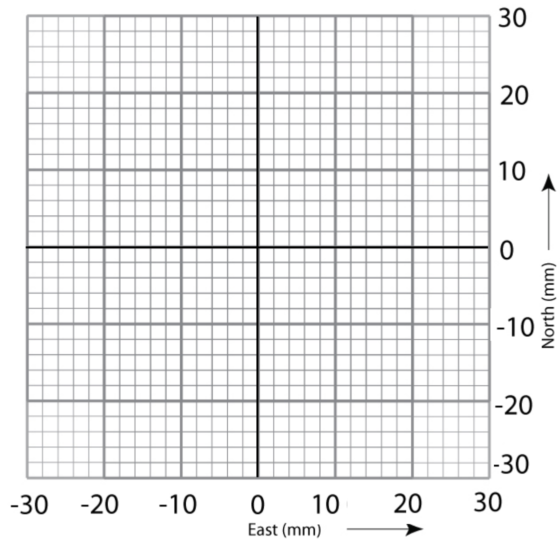


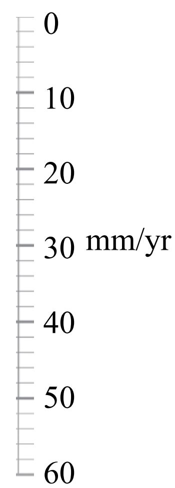
6. Draw the vector following the directions to determine the direction of motion for the two GPS stations, using the north–south and east–west rates you calculated in Question 4.

SBCC



BEMT





7. Fill in the table below using the vectors you drew. They show the exact direction of motion. Measure the diagonal length of the vector arrows with the scale to the right to determine the total rate. Don't just fill in the rate that you previously calculated.

	SBCC	**BEMT**
Total rate of movement (remember units!)		
Direction of movement	northeast northwest southeast southwest	northeast northwest southeast southwest

8. Compare your rates calculated with the equation to the rates measured from the vectors on the graphs. Are they similar? If not, rework both strategies to determine which one is correct.

Yes No

9. Look back at the 2 graphs of GPS data. How do you know from looking at the graphs that Station SBCC is moving faster than Station BEMT? Circle two of the choices.

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.

10. Look back at the graphs. How do you know from looking at the graph that both stations are moving in the same direction to the northwest? Circle two of the choices.

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.

11. Write a summary statement describing the rate of motion (speed, including units) and direction of motion for the SBCC and BEMT GPS stations.

Part 4: Which hypothesis best explains why the ground is moving?

Let's look back at our multiple working hypotheses and see which ones our observations and data support, so we can make sense of the ground movement recorded in the GPS data.

12. Review your predictions made in Question 3 and your observations of the data (Part 3). Circle the hypothesis that is best supported by the data and explain your choice using the data from Part 3.

Hypothesis A Hypothesis B Neither hypothesis

Sometimes when I collect data, I am surprised when it doesn't fit well with my predictions from my hypotheses, as is happening here. When this happens, I try to make sense of the data and figure out why something is happening. Sometimes it's helpful to collect more data. Other times, it's helpful to re-examine the predictions or the hypotheses. Let's first collect more data by looking at a map.

13. This map of California shows the locations of the two GPS stations with the transform plate boundary drawn in black. Are the GPS stations on the same plate or different plates?

Same plate, same side of plate boundary   Different plates, opposite sides of plate boundary

14. Draw the two vectors from Question 6 on this map. Start the vectors at each GPS station and keep the length and direction to the northwest approximately the same as what you drew in Question 6.

Figure 2. 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.

Next, let's re-examine our predictions from our hypotheses. 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.

15. 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?

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

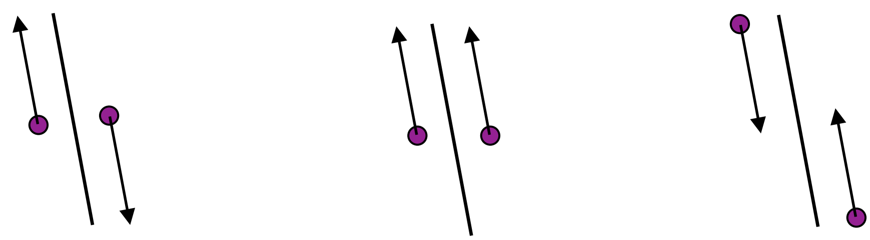
It moves to my left and gets closer over time.   It moves to my left and gets farther over time

16. 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

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



I want to make sure that we're on the same page about which arrows show the best representation of the relative motion of the stations. I want to bring to your attention that the center diagram above shows the two stations moving together at the same rate, which isn't what they're doing.

18. Review your hypotheses, your predictions, your observations of the data, and your responses to the questions above. Rewrite Hypothesis A so it is supported by the data. Be sure to include the stations' relative motion and their position relative to the plate boundary.

The stations will move in…

19. Circle how confident you are in your explanation as to why the GPS stations are moving the way they are.

Not confident Somewhat confident Confident

20. Name one piece of additional data that you would like in order to test your explanation.