Measuring Earth with GPS, Unit 2: Earthquakes
Activity 3 Student Exercise: Analyze, Interpret, and Apply

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In this activity, you will learn how to analyze and interpret scientific data after describing it. You will conclude by using that data to support a recommendation you make about an issue relevant to society. The questions guide you through the process that scientists use when they work to solve scientific questions. 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: 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 Part 1, you will use your understanding of the relationships between the tectonic plate motion and earthquakes to write a hypothesis. You will use that hypothesis to make predictions, and you will test those predictions in Part 2.

If you have not already done so, watch the animation titled "GPS and Relative Plate Motion."

1. The animation explained Earth processes that can cause horizontal position of the bedrock to change. Circle 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 figured out in Activity 2.1, 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). In this activity 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.

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.

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

3. Earthquakes happen where stress builds up along a fault because the two sides of the fault are moving at _____ (the same / different) rates.

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

A   B ↑ C ↑
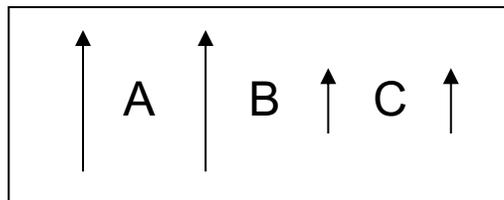
4. Write a hypothesis explaining which location is most likely to experience earthquakes by filling in the blanks:

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

5. Circle how confident you are in your hypothesis.

       Not confident   Somewhat confident   Confident

Part 2: Observing and describing long-term rates from GPS data

Below are data from three GPS stations in Central California. In this part of the activity, 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. Larger versions of these figures are included separately.
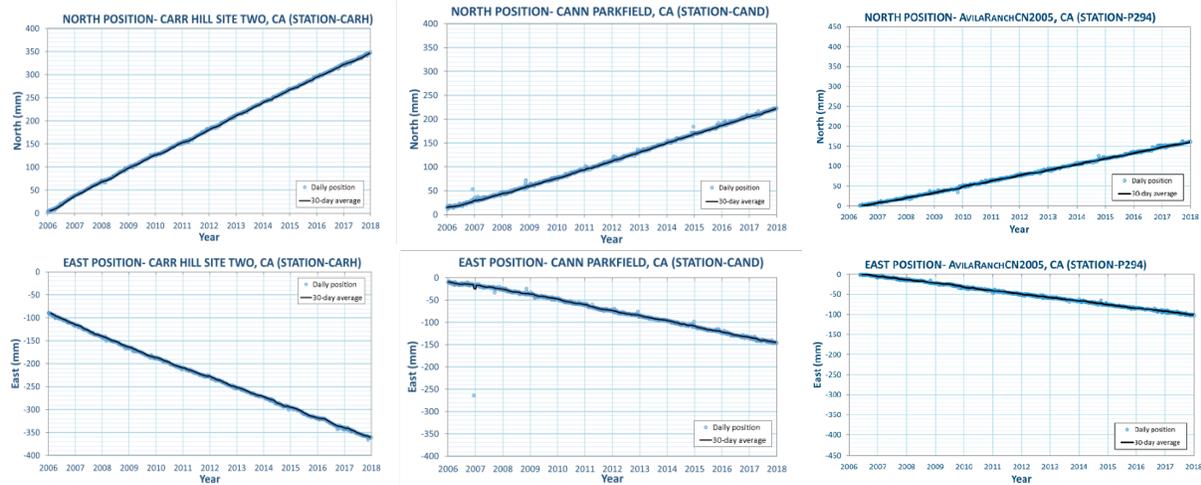

Figure 1. North and East GPS data from station CARH, CAND, and P294 near Parkfield in California from the beginning of January 2006 to 2018.

When scientists look at data in graphs, they look for overall trends and describe the data using words and numbers. Answer the following questions to describe your observations of the data as a scientist.

6. Pick a five-year interval and fill in the tables below to calculate the overall long-term rate in each direction (north–south and east–west) that the GPS station is moving. Remember to include units.

North–South	CARH	CAND	P294
Is the station traveling north or south?	north south	north south	north south
Distance (difference in position from the beginning to the end)			
Time (years from the beginning to the end)	5 years	5 years	5 years
Long-term rate (distance divided by time)			

East–West	CARH		CAND		P294	
Is the station traveling east or west?	east	west	east	west	east	west
Distance (difference in position from the beginning to the end)						
Time (years from the beginning to the end)	5 years		5 years		5 years	
Long-term rate (distance divided by time)						

To calculate the total rate of movement, use the math trick: square the north–south rate, square the east–west rate, and add them together; then take the square root of that sum. Here is the equation:

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

7. Fill in the table below by calculating the total rate and using the directions above.

	CARH		CAND		P294	
Total rate of movement with units						
Direction of movement	northeast	northwest	northeast	northwest	northeast	northwest
	southeast	southwest	southeast	southwest	southeast	southwest

8. Use the data from the table to create vectors showing the long-term rate of movement of the GPS stations on the grids.

9. Transfer the vector arrows onto the map starting from the correct GPS station. Pay particular attention that the arrow length is correct relative to the other stations.
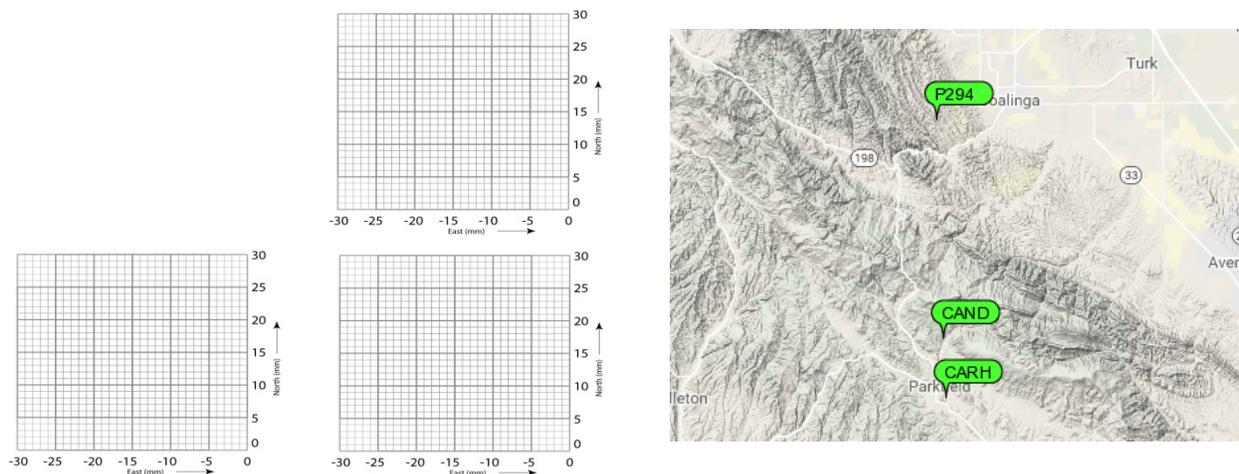
10. Do your calculated rates and directions (Question 7) match the rates and directions in the vectors (Question 7—use the scale next to the grid to measure the length of the vector)?

        Yes   No   (if not, you will need to make changes so they do match)

11. 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

Circle the phrase below that explains your prediction:

    It/they are moving faster.   It/they are moving at different rates.

    It/they are farthest apart.   It/they are moving together.

The two stations you chose are moving in the same direction, but they're getting farther apart each year because they're moving at different rates. Use the stations you chose in your answer above to answer the next questions.

12. To calculate how much further apart the two stations are getting, you need to _____ (add / subtract) their rates because the stations are moving in _____ (the same / different) direction.

13. Using the rates you calculated for each of the stations, calculate how much farther apart the stations will be each year.

14. How much farther apart will the stations be after… (remember units)

    10 years _____   50 years _____

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.

15. 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 3: Observing and describing GPS data during an earthquake

GPS can not only measure long-term movement over many years, but can also measure quick motions, like the ground jumping during an earthquake.

In Part 2, you predicted that the most likely location for an earthquake would be between GPS stations CARH and CAND. As it turns out, there was an earthquake there, recorded by the GPS stations in 2004. Before we look at the GPS data from the earthquake, let's take a step back to think about how ground motion during an earthquake where tectonic plates slip past each other would appear in GPS graphs, so we can feel confident that we can interpret the GPS data correctly.

The four graphs below show the north–south position of GPS stations over time.
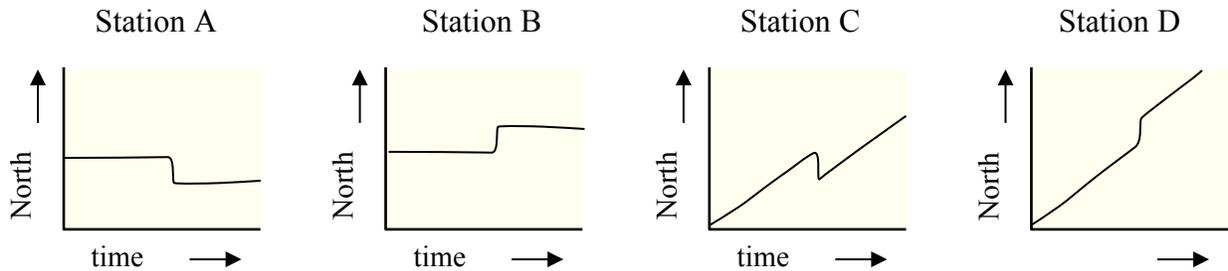
16. Which two of the above graphs show a GPS station that is stationary, except when it quickly moves during an earthquake?

       Station A   Station B   Station C   Station D

Explain why you chose this answer.

17. Which one of the above graphs shows a GPS station that is slowly moving north, except when it quickly moves north during an earthquake?

       Station A   Station B   Station C   Station D

Explain why you chose this answer.

18. For the station you chose for the previous question, draw how the graph would look if the earthquake moved the station twice as far.
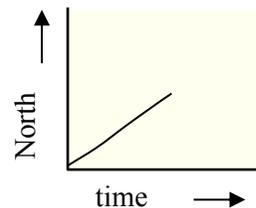
Consider a fault oriented northwest–southeast along the transform plate boundary in California. The entire area is moving toward the northwest. Imagine there is a GPS station on either side of the fault.

GPS station E   GPS station F   GPS station G   GPS station H
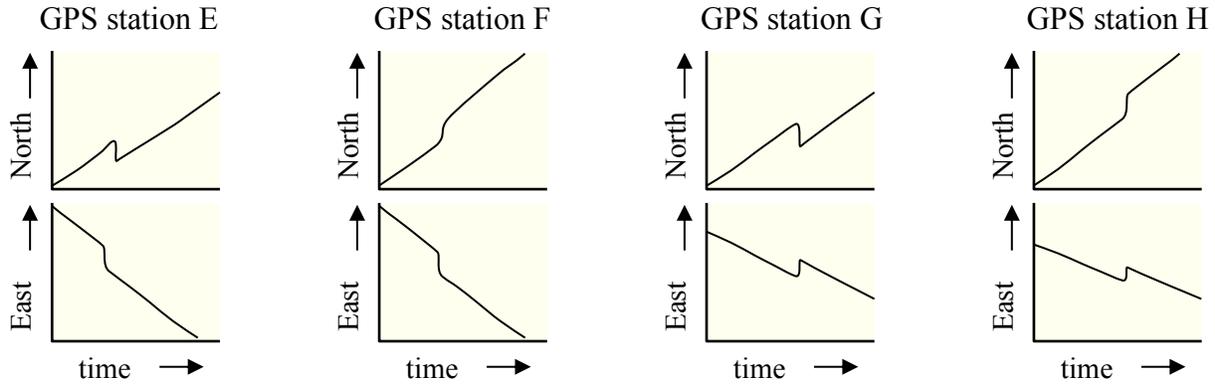
19. During the earthquake, which station shows a GPS station that moved to the northwest?

E   F   G   H

20. During the earthquake, which station shows a GPS station that moved to the southeast?

E   F   G   H

Station CARH is on the western side of the San Andreas Fault (the transform plate boundary in California) and Station CAND on the eastern side. In this part of the activity, you will make observations to describe the data showing movement during an earthquake that moved the stations on both sides of the fault. Larger versions of these figures are included separately.
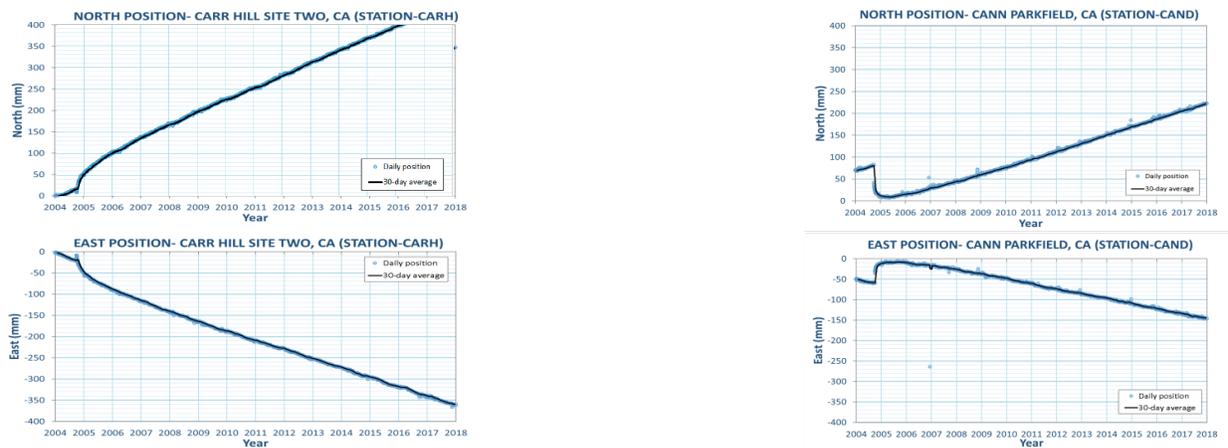

Figure 1. North and East GPS data from station CARH and CAND near Parkfield in California from the beginning of January 2004 to 2018.

21. How do you know there was an earthquake?

Here we will calculate the total amount of displacement along the fault during the earthquake. To do so, you will first need to figure out amount of slip from an earthquake a single GPS station recorded: (1) Draw a straight line indicating the long-term trend along the dots showing the GPS position before and after the earthquake. (2) Draw a vertical line at the time of the earthquake (since it took no time). (3) The difference in the before and after position (from lines showing the long-term rate) along the vertical line is the amount the ground moved as measured by the GPS station during the earthquake.

22. Once you have the slip recorded by the GPS station in the north–south and east–west directions, you need to apply the equation you learned to combine the north–south and east–west directions of movement (in Question 7). Don't forget to include units.

      Total slip of Station CARH during the earthquake: _____

          In what direction?   northeast   northwest   southeast   southwest

      Total slip of Station CAND during the earthquake: _____

          In what direction?   northeast   northwest   southeast   southwest

The ground on both sides of the fault moves, so to calculate the total displacement along the fault, the movement of GPS stations on either side of the fault must both be measured.

23. To calculate the total displacement, you need to _____ (add / subtract) their rates because the stations are moving in _____ (the same / different) directions.

      Total overall displacement during the earthquake: _____

24. How many years of building up stress through long-term movement (Question 13) were needed to equal the distance of total displacement during the earthquake (Question 22)?

Part 4: Interpreting earthquake size from GPS data

The total amount of displacement on a fault is related to the size of earthquake, as measured by the moment magnitude. The moment magnitude does not measure the damage done, but it is related. For example, magnitudes between 5 and 6 can cause minor damage, between 6 and 7 often cause a lot of damage, and greater than 7 generally cause severe damage.

25. Use the displacement you calculated in Question 23 to estimate the moment magnitude of the earthquake using the graph to the right.
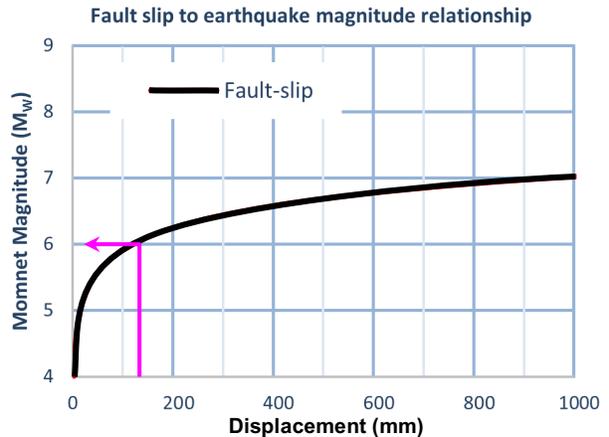
Moment magnitude = _____

Figure 3: Graph showing the relationship between fault displacement and earthquake size for a strike-slip fault.

26. In the time since the earthquake in 2004, how much new potential displacement has built up? Use the long-term rates to calculate this.

27. If there were an earthquake today that has the displacement you just calculated, what would the earthquake's moment magnitude be?

28. What sort of damage could it cause?

     minor damage   a lot of damage   severe damage

Part 5: 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 below. Each arrow is a velocity vector, calculated in the same way that you calculated vectors earlier in this activity. 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.
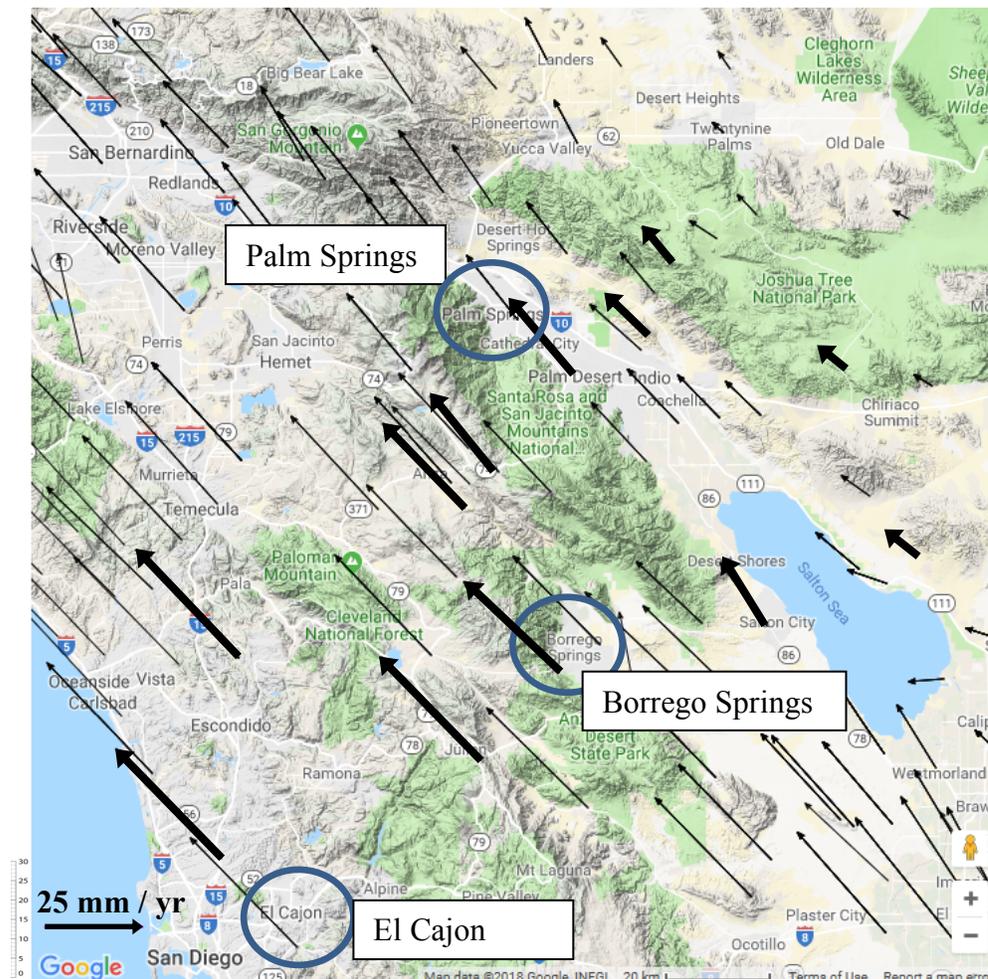

Figure 4. Screenshot of GPS Velocity Viewer (NAM08; https://www.unavco.org/software/visualization/GPS-Velocity-Viewer/GPS-Velocity-Viewer.html) with three locations and several vectors highlighted.

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?"

29. 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. You will need to explain to your friend how GPS station motion can play a role in learning about earthquakes.

Be sure to include the following points in your letter to receive full credit:

• You include a clear statement about what advice you would give your friend.

• You use words to describe the data supporting your argument.

• You use numerical rates (numbers plus units based on the size of the vectors) to support your argument. Correctly include what the rate measures.

• You refer back to your hypothesis.

• You explain the link between GPS motion, plate motion, and earthquakes.

• You compare this location to the plate movement and earthquake in Parkfield (measured by stations CARH and CAND).

Part 6: Reflecting on your results

Scientists reflect on the decisions they make while solving a problem. They also think about how they may change their approach the next time, perhaps because they learned by doing something the hard way or perhaps because they came up with ways to simplify their approach.

30. Assumptions in science are things that you assume to be true but you cannot confirm that it is true. Scientists have to make assumptions because the world is very complicated and we do not have a limitless amount of time, data, or instruments to confirm every assumption.

Listed below are some of the assumptions we made when we used data from bedrock GPS stations in California to make an argument of worldwide consequences. Circle which one is NOT an assumption.

It is safer where GPS stations move at the same rate.   The GPS motion is the plate motion.

Other faults act similar to these in California.   The stations were moving to the northwest.

Active faults are in areas where the rates on the two sides are different.

31. If you could have one more piece of information to support your argument, what data would you collect? Explain how you would use this information to support your argument.

Think about how you approached answering the questions in this entire activity.

32. What aspect of working with the GPS data was easiest for you?

33. What aspect of working with the GPS data was hardest for you?

34. You may be asked to describe, analyze, interpret, and apply GPS data again in this class. Make three notes to your future self of skills you developed that you can use or how you would change your approach when presented with GPS data again.