Measuring Earth with GPS, Unit 3: Glaciers
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This is the full lab handout. It includes the information you need to complete the lab. However, you will submit your lab answers on Blackboard.

Learning Outcomes:
- Students will observe, describe, analyze, interpret, and apply time-series GPS data related to bedrock motion near glaciers
- Students will explain how changing ice mass causes annual and decadal bedrock motion near glaciers as measured by GPS
- Students will draw on GPS data to make a societal recommendation relative to glacial change

GPS stations precisely record the position of the solid ground they are on, and they were first installed to measure plate motion. However, geoscientists analyzing GPS data realized that earthquakes and plate motion are not the only geological processes that cause the ground to move.

In this first part of the lab, you will look at scientific data from a GPS station on the bedrock near Skagway Glacier in Alaska by making careful observations, and you will use those observations to make a scientific interpretation.

Part 1: Why is the ground moving up and down?

Figure 1. Vertical GPS data from station AB44 on the ground near Skagway Glacier in Alaska from the beginning of January 2006 to the end of December 2017.

Examine Figure 1 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.
1. What does the vertical (y-) axis show and what are the units?
   - time in years
   - vertical position in millimeters
   - motion in millimeters per year

2. Look at the time scale. The points on the graph rise and fall in a cycle that lasts how long?
   - day
   - month
   - year
   - decade

When scientists first noticed that the ground was moving up and down each year, they wanted to know why. Two of the hypotheses are:

**Hypothesis A**: The ground elevation rises because the ground expands when it freezes, and it lowers when the ground contracts as it thaws.

**Hypothesis B**: The ground elevation lowers because the weight of the snow presses it down, and the ground elevation rises when the snow melts.

Geoscientists often work with more than one hypothesis (called “multiple working hypotheses”). You will try to determine which one explains the data better. First, let’s make some predictions based on these hypotheses, and then we will later compare the GPS data to them.

3. If Hypothesis A is correct, then the highest point each year would be during the months of ____________. If Hypothesis B is correct, then the highest point each year would be during the months of ____________.

4. Look at several different years on the graph. During what months is the ground the highest?

5. Approximately how far is the ground moving up and down each year? This distance is called the annual range.
   - About 2 millimeters, which is about the thickness of a penny
   - About 40 millimeters, which is about the length of a paper clip
   - About 700 millimeters, which is about the height of a table

6. Which parenthesis shows the annual range?

   ![Diagram of annual range]

7. What number is the best to use when describing the movement of the ground over a single year to help compare it to other years?
The range of vertical movement, because it is consistent from year to year, even though the highs and lows aren’t the same from year to year.

The height of the high point, because it shows how high the ground rises each year, even though it is changing from year to year.

The GPS data show when and how much the ground is moving, but they don’t show why. We need to look at other data to help us learn why, and below are photos of the GPS station to help do that. The GPS stations are drilled deep into the bedrock, so the only thing that causes the station to move is the movement of the bedrock.

8. Find the months that the Figure 2 and 3 photos were taken. Which choice correctly labels the arrows?

   Figure 2: A snow; Figure 3: B snow
   Figure 2: A no snow; Figure 3: B snow
   Figure 2: B snow; Figure 3: A no snow
   Figure 2: B no snow; Figure 3: A snow

9. (2 points) Look at your predictions based on the hypotheses, and look at your observations of the data. Which hypothesis is best supported by the data and what causes the height of the ground to change over the course of a year?

Hypothesis A, the weight of the snow
Hypothesis A, the freezing of the ground
Hypothesis B, the weight of the snow
Hypothesis B, the freezing of the ground

**Part 2: Animation**

Watch the animation titled, *Glaciers are Retreating: How can we measure the full ice loss?* (https://www.youtube.com/watch?v=qmSrAQpolj4). Keep in mind that the GPS stations are installed on the bedrock next to the glacier, not the glacier itself. Pay particular attention to what is causing the yearly change in GPS height compared to the long-term trend in change.

10. What explains the direction and reason that ice sheets flow in Greenland?

They flow uphill towards the mountains because of fjords.
They flow uphill towards the mountains because of the grounding line.
They flow downhill towards the ocean because of crevasses.
They flow downhill towards the ocean because of gravity.

11. What happens to the bedrock’s vertical surface when glacial mass is added to the ground and when it is removed?

When glacial mass is added, it goes up. When glacial mass is removed, it goes up.
When glacial mass is added, it goes up. When glacial mass is removed, it goes down.
When glacial mass is added, it goes down. When glacial mass is removed, it goes up.
When glacial mass is added, it goes down. When glacial mass is removed, it goes down.

12. What causes the yearly up and down motion of the bedrock near glaciers?

Seasonal changes with the ground freezing in the winter (causing the ground to rise) and the ground thawing in the summer (causing the ground to lower)
Seasonal changes with snow melting in the summer (causing the ground to rise) and snow accumulating in the winter (causing the ground to lower).
The glacier is melting and getting smaller, so it weighs down less on the ground, causing the ground to rise.
The climate is getting warming, so the ground is expanding due to the extra heat, causing the ground to rise.
13. What causes the long-term trend of rising bedrock near glaciers?
Seasonal changes with the ground freezing in the winter (causing the ground to rise) and the ground thawing in the summer (causing the ground to lower).
Seasonal changes with snow melting in the summer (causing the ground to rise) and snow accumulating in the winter (causing the ground to lower).
The climate is getting warming, so the ground is expanding due to the extra heat, causing the ground to rise.
The glacier is melting and getting smaller, so it weighs down less on the ground, causing the ground to rise.

Part 3: What does the long term trend tell us about glaciers and problems facing society?
In this part, you will learn how to analyze and interpret scientific data. 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 a GPS station near Helheim Glacier in Greenland to better understand long-term trends that can be interpreted by analyzing GPS position of bedrock near the glacier.
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.

14. The animation explained Earth processes that cause the bedrock vertical position to change. Which two processes cause the position of the GPS station attached to the bedrock to rise?
snowfall and thinning of glacier
snowfall and thickening of glacier
snowmelt and thinning of glacier
snowmelt and thickening of glacier

15. (2 points) A hypothesis includes both how you predict one variable to affect another and why you think that relationship exists. Write a hypothesis about the effect of a glacier’s size on the surrounding vertical elevation of bedrock by finishing the sentence:

The bedrock elevation would rise if a glacier becomes __________ (smaller/larger) because there is __________ (more/less) weight pushing down the bedrock. The opposite will cause the bedrock elevation to lower.
16. Imagine there is a glacier that is shrinking over many years. Use your hypotheses to make a prediction: When the vertical position of the bedrock GPS unit is plotted against time in a time-series diagram, what would the trend look like? Which graph above best fits your prediction?

Below in Figure 4 are data from Station KULU near Helheim Glacier in Greenland.

When you previously looked at GPS data from near a glacier in Alaska, you looked at the annual range of motion – how much the ground near the glacier moved up and down in a single year and why. For this glacier, you’re going to look at the long term rate of change – how is the position of the ground is changing over many years.

When describing how something changes position over time, scientists calculate the rate (speed) of change. Notice that the rate is different than the annual range. For example, you use the range if you describe how far a car drove each day, but you use the rate 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).
Pick a five-year interval. Calculate the rate of change for the KULU GPS station near Helheim Glacier during that interval. Use the 30-day average line, and be sure to start and end at the same time of year.

Distance (difference in height from the beginning to the end): __________ mm
Time (number of years from the beginning to the end): _____5_____ years
Rate (distance divided by time): __________ mm/year

17. (2 points) Which number best matches the rate you calculated for the vertical motion of the GPS station over 5 years?

   8 mm/year          20 mm/year          60 mm/year          110 mm/year

18. Which of the following does the rate you calculated measure?

   Total amount glacier melts   Total amount sea level rises   Total amount bedrock moves
   Amount glacier melts per year Amount sea level rises per year Amount bedrock moves per year

19. Which statement summarizes what you can interpret about the size of Helheim Glacier?

   It is growing over many years.
   It is shrinking over many years.
   It is staying the same size over many years.

   The size of Helheim Glacier is being measured in multiple ways, in addition to GPS. For example, the thickness of the ice has been measured by satellites, and those data show the ice is thinning. The total amount of ice has also been measured by its gravitational pull on satellites, and those data show the amount of ice has been shrinking.

20. Based on this additional evidence, do your hypothesis (Question 15), prediction (Question 16), and interpretation of GPS data (Question 19) make sense together? If they do not, you will need to fix something!

   Yes          No

   Scientists use their interpretations of what is happening in the world around us to learn how society may be affected and help people make informed decisions. In this part, you will apply your interpretations of your observations of the elevation of the GPS station near Helheim Glacier to help a person make an informed decision.
21. Apply your interpretation of the changing size of Helheim Glacier to determine how it affects the level of water in the ocean:

The changing size of the glacier __________ (adds water to/takes water from) the ocean, which will cause the sea level to __________ (rise/fall) __________ (worldwide/only in Greenland).

22. Which causation relationship is correct?
Melting glaciers cause bedrock to rise.
Rising sea level causes rising bedrock.
Rising bedrock causes glaciers to melt.

23. Which other causation relationship is correct?
Rising sea level causes melting glaciers.
Melting glaciers cause sea level to rise.
Rising bedrock causes sea level to rise.

Imagine you have a cousin Maria who says, “Who cares if the sizes of glaciers are changing? It won’t affect me on the East Coast of the United States. I just won’t invest in glacier tourism. Instead, I am going to invest in beachfront property for when I retire.”

Do you agree or disagree? Formulate an argument to support or refute the statement. Write a letter to your relative with the purpose of encouraging or discouraging her to invest in beachfront property, using GPS data from Alaska and Greenland 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.

24. Which answer best matches your response for Section 1 of the letter?
Dear Maria, I agree that the size of glaciers won’t impact you on the East Coast, and I agree you should invest in beachfront property when you retire.
Dear Maria, I agree that the size of glaciers won’t impact you on the East Coast, but I do not agree you should invest in beachfront property when you retire.
Dear Maria, I think the size of glaciers will impact you on the East Coast, but I agree you should invest in beachfront property when you retire.
Dear Maria, I think the size of glaciers will impact you on the East Coast, and I do not agree you should invest in beachfront property when you retire.
25. (2 points) Which answer best matches your response for Section 2 of the letter?

I give you this recommendation because GPS stations in Alaska and Greenland show that the sea level is rising.

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

We can interpret this GPS data to mean that the glaciers are rising because the sea level is rising.

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

As the glaciers shrink, they cause sea level to rise near them, so you do not need to worry about beachfront property on the East Coast.

25. Assumptions in science are things that you assume to be true but may not be. Scientists have to make assumptions because the world is very complicated and we do not have a limitless amount of instruments, data, or time. All but one of the following are assumptions that you made when you used data from a bedrock station near glaciers in Greenland and Alaska to make an argument of world-wide consequences. Which of these is NOT an assumption you made?

- Decreased glacial size is because of melting
- The analyzed glaciers are behaving the same as most other glaciers around the world
- The GPS station near Helheim glacier is rising over time
- Water from the melting glacier is being added to the oceans and causes sea level to rise
- The ground motion measured by the GPS is caused by changing glacial size
Part 4: Looking at Sea Level Rise

Visit the [NOAA Sea Level Rise Viewer website](https://coast.noaa.gov/slr/). Move the sea level up and down with the toggle on the left. Zoom into Rhode Island and other areas of the coastal United States. You can also see scenarios by clicking on the blue water icons. For reference, Rhode Island is predicted to have about 3 feet of sea level rise by 2060.

26. Which state is most impacted by 1 foot of sea level rise?

California  
Florida  
Louisiana  
Rhode Island

27. (3 points) Describe 3 things you learned about sea level rise and the coast from the NOAA Sea Level Rise Viewer that you found interesting. At least one thing you describe should be specific enough to demonstrate you spent some time playing around with the webpage.

Part 5: Reflection

28. (4 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?