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Measuring Plate Motion with GPS: Iceland

Teacher Guide

Topics Earth processes, Earth structure, Mathematics, Engineering and technology, Plate tectonics, deformation, earthquakes, interpreting data, identifying patterns, graphing skills, constructing explanations

Grade Levels 6 – 12

Time 1hr 20min (1 or 2 class periods)

Summary

In this activity, students analyze scientific data to study the motion of tectonic plates and conclude that the Mid-Atlantic Ridge is rifting Iceland, pushing/pulling Iceland apart. Through physical modeling and discussion, students develop an understanding of the architecture of the Global Positioning System (GPS) —from satellites to research quality stations on the ground. Students learn to interpret time series data collected by the stations, cast it as horizontal north-south and east-west vectors, and add those vectors graphically. Students then interpret their total horizontal vectors from Iceland in the context of a divergent plate boundary. Finally, students extend their understanding of GPS data with an abstraction using cars and maps and explore GPS vectors in the context of global plate tectonics.

Lesson Objectives *Students will be able to:*

- Describe how a Global Positioning System (GPS) works in general terms and why a GPS monument needs at least three satellites to determine its position.
- Illustrate GPS data as velocity vectors on a map.
- Add vectors graphically to produce total horizontal velocity vectors.
- Analyze the graphical representation of vectors and infer that Iceland and the Mid-Atlantic Ridge are moving away from each other (rifting).
- Explore and describe tectonic plate motions via velocity vectors using UNAVCO's Velocity Viewer (extension)

Next Generation Science Standards (NGSS)

Performance Expectations	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.
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.
HS-ESS2-1	Develop a model to illustrate how Earth's internal and surface processes operate at different spatial and temporal scales to form continental and ocean-floor features

See Appendix A for alignment to Common Core State Standards for Mathematics (CCSSM) and the Science and Engineering Practices, Crosscutting Concepts, and Disciplinary Core Ideas from *A Framework for K-12 Science Education*.

By: Roger Groom, Cate Fox-Lent, and Shelley Olds, UNAVCO. Revised by Nancy West, Kathleen Alexander and David Thesenga

Universal Design for Instruction (UDI):

Universal Design for Instruction principles have been incorporated in this lesson in order to accommodate for differences in strengths, challenges, and abilities among students. Specifically, multiple, accessible instructional methods (visual, auditory & kinesthetic), group work that values different skills and roles, multiple methods of assessment, and frequent transitions provides rich support for learning and reduces barriers to the curriculum.

Lesson Overview

1. Activation of prior knowledge related to GPS is followed by a **PowerPoint presentation**: Measuring plate motion with GPS: Introducing GPS to study tectonic plates as they move, twist, and crumple.
2. The teacher and students cooperatively **create and work with model GPS monuments** and the satellite network that feeds time signals to the monuments.
3. Students **analyze and interpret GPS data**, using **time series plots** in order to develop total horizontal **velocity vectors** of plate motion in Iceland.
4. Extension: using the Velocity Viewer, students **explore a map interface and interpret GPS velocity vector data** around the world to identify other divergent zones and other plate motions.
5. As a summative activity, students **apply knowledge** of plate movements

Materials

- Student lab worksheets—one copy per student, pair, or group
- Computer and a projector (instructor), computers (students for extension)
- Gumdrops
- Toothpicks
- Modeling clay
- Transparencies (cut into 4 squares each)
- 4 ring stands (or student volunteers)
- 4 satellite representations (e.g., Double Bubble gum)
- String
- 1 gumdrop monument (created from toothpicks, gumdrop, and modeling clay)

Students need a general understanding of plate tectonics for this lesson. Many excellent learning resources are available online covering evidence that support the theory of plate tectonics. Many of these resources take a global view of plate tectonics; this lesson explores how high-precision GPS can be used to measure regional plate movement and deformation.

Teaching Tips and General Background

A variety of geologic phenomena including earthquakes, volcanic eruptions, and mountain building occur at plate boundaries, all of which cause the Earth's surface, the crust, to deform. When deformation occurs, points on Earth's surface change location (north-south, east-west, up-down). Precise GPS instruments can measure the change in position. Earth scientists use this data to record how much and how quickly Earth's crust is moving due to plate tectonics and to better understand the underlying processes of the deformation.

Before starting the lesson, review these videos on how to demonstrate how GPS works (*NOTE: these videos are meant to inform the instruction of teachers, not to be shown to students).*

- In addition to following the steps below, watch this video https://youtu.be/hqxwYWr879s on finding pinpointing location with GPS and this video (http://bit.ly/HowGPSworks-demo) that t demonstrates how to build a monument (the second half also suggests ways to demonstrate how a GPS monument gathers location information). Note: it is more accurate to use 4 satellites to find the precise position.
- A second video (http://bit.ly/GPSdemo-part3) on YouTube provides background for teachers about time series plots. (On YouTube search for "GPS gumdrop activity 3-5.").

Key points for the demonstration

- GPS satellites are in orbit above Earth's surface at an altitude of 20,200 km (12,600 mi)
- Each satellite sends a signal many times a second and 'talks' to the GPS antenna (note, the GPS station does not send any signals back to the satellite); the GPS receiver calculates the *how long it takes for the signal to reach the antenna* and then calculates the *distance* between the satellite and antenna.
    - The string represents the distance between the satellite and a monument after this distance is calculated.
- The GPS needs 4 satellites to find its position on Earth.
    - With one satellite, the GPS could be anywhere on the surface of a sphere with a radius equal to the distance between the GPS and the satellite.
    - With two satellites, the monument could be anywhere on the circle of the two intersecting spheres.
    - With three satellites, the GPS could be at one of the two points where three spheres intersect. The Earth is the fourth sphere (the satellites know where the Earth is).
    - Since time is part of the calculation to find a position, a 4th satellite provides precise location to correct position errors caused by in clocks on the satellite and GPS.
- These measurements are being made while satellites are moving at 2 km/sec!
- Review this video for teaching: NASA's Brief History of Geodesy (http://bit.ly/nasawhatisgeodesy).
- Note: GPS is owned and operated by the United States. There are satellite constellation systems providing positioning, navigation, and timing, and are generally called Global Navigation Satellite Systems (GNSS).

Part 1: How does GPS work to pinpoint a location on Earth?

Activation of Prior Knowledge

- Assess students' level of prior knowledge by facilitating a preliminary discussion of GPS technology. Some questions to launch a discussion may include:
  - What is GPS technology?
  - What does GPS stand for?
  - How does GPS technology work?
  - What is GPS technology used for?
  - Who uses GPS technology?

Procedure (Pinpoint location with GPS)

- In advance, mark locations of ring stands such that all three strings meet in one location
- Launch the accompanying PowerPoint presentation, ***Measuring Plate Motion with GPS: Introducing GPS*** *to study tectonic plates as they move, twist, and crumple*.
- Show the video, NASA's Brief History of Geodesy (http://bit.ly/nasawhatisgeodesy),
  - Engage the class in a brief discussion about geodesy and uses of GPS.
  - Ask a volunteer to provide an explanation of Geodesy and remind your students that Geodesy is the study of the Earth's size, shape, orientation, gravitational field, and variations of these with time.
  - Pose the question, "How can GPS data be used in the field of Geodesy and geology?" before advancing to the next slide.
- At the "GPS Basics" slide, stop and model how satellites pinpoint the location of a GPS station. For the demonstration you will need 4 ring stands (or 4 volunteers), 4 'satellites' (e.g. Double Bubble gum) to place at the top of the stand to represent satellites, 4 lengths of string of different lengths (all longer than the height of the stand), and 1 gumdrop monument.
  - I. Ask volunteers to distribute the student worksheet.
    - *Differentiation: Arrange students in either pairs or groups of three for this activity, pairing students with different strengths and challenges together. Consider assigning group roles to facilitate active participation in all students. Group roles may include: Scribe, Group Leader, Artist, Discussion Director, etc.*
  - II. Explain
    - Satellites are flying above Earth's surface at an altitude of 20,200 km (12,600 mi); the ring stands represent that altitude. The bubble gum represents the satellites.
    - The pieces of the GPS "gumdrop" monument:
      - The gumdrop is the GPS antenna;
      - Each toothpick is a leg of the monument – the legs are cemented up to 30 feet into the ground.
      - The putty is the cement holding the GPS monument in place.
      - The *"place marker" of the* monument is the slightly shorter toothpick sticking straight down from the middle of the gumdrop so that the tip of this toothpick is barely above the surface.
    - Gumdrop 'GPS' monument and the satellites relationship

- The satellite 'talks' (broadcasts) to the GPS its satellite name and current position in space; the GPS receiver calculates *how long it takes for the signal to reach the GPS* and then calculates the *distance* between them. Measuring the distance is called ***trilateration***.
- The string represents the distance between the satellite and a monument after this distance is calculated. This calculation is happening every second, sometimes 10 times a second!

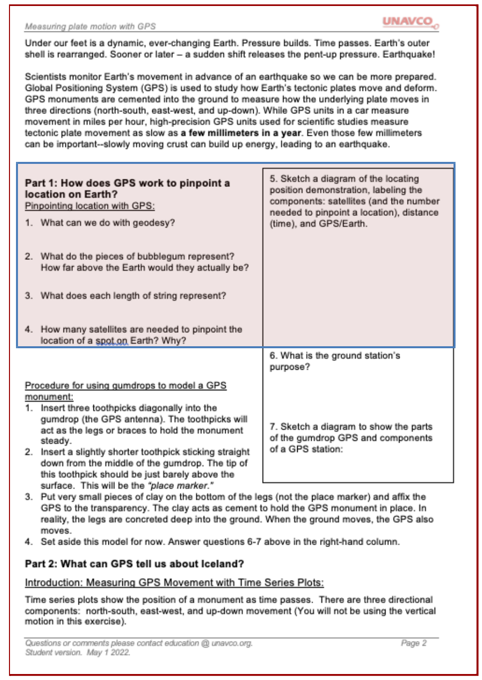
III. Demonstrate how the location of the GPS becomes more pinpointed with one, two, three, then four satellites.

- o One satellite (GPS could be anywhere on the surface of the sphere with the satellite in the center).
  - Ask a student to move one string (held tautly) in all directions to indicate that the *distance* (approximately 20,000 km) is known, but the *direction* isn't. The GPS could be anywhere on the surface of the sphere with the satellite (at least where the satellite had been at that moment since it is moving) at its center.
- o Two satellites (GPS could be anywhere on the circle of the two intersecting spheres):
  - Ask another student to hold the string taut and move the 2nd string in the shape of the sphere. Then move the 1st and 2nd strings together, so that the strings stay taut and ask what shape is made by this movement (a circle). Emphasize again that the only known entity is the *distance* between the monument and satellite.
- o Three satellites (The GPS could be at one of the two points where three spheres intersect.)
  - Ask a third student to move the 3rd string along with 1st and 2nd strings to show where all three strings intersect.
  - The Earth is the fourth sphere (the satellites know where the Earth is).
- o Since time is part of the calculation to find a position, a 4th satellite provides even more precision in location to correct position errors caused by clocks on the satellite and GPS. Modern GPS antennas will connect to many more satellites for even more precision

IV. Place the gumdrop GPS monument where the three strings intersect.

V. Remind students that the GPS measures the time it takes for the signal to go from the Satellite to the GPS monument then calculates the distance - this happens while satellites are moving at 2 kilometers/second!

VI. Ask your students to complete the questions 1 - 5 in Part 1 of the worksheet.


Measuring plate motion with GPS

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Under our feet is a dynamic, ever-changing Earth. Pressure builds. Time passes. Earth's outer shell is rearranged. Sooner or later – a sudden shift releases the pent-up pressure. Earthquake!

Scientists monitor Earth's movement in advance of an earthquake so we can be more prepared. Global Positioning System (GPS) is used to study how Earth's tectonic plates move and deform. GPS monuments are cemented into the ground to measure how the underlying plate moves in three directions (north-south, east-west, and up-down). While GPS units in a car measure movement in miles per hour, high-precision GPS units used for scientific studies measure tectonic plate movement as slow as **a few millimeters in a year**. Even those few millimeters can be important--slowly moving crust can build up energy, leading to an earthquake.

Part 1: How does GPS work to pinpoint a location on Earth?
Pinpointing location with GPS:

1. What can we do with geodesy?
2. What do the pieces of bubblegum represent? How far above the Earth would they actually be?
3. What does each length of string represent?
4. How many satellites are needed to pinpoint the location of a spot on Earth? Why?

5. Sketch a diagram of the locating position demonstration, labeling the components: satellites (and the number needed to pinpoint a location), distance (time), and GPS/Earth.

6. What is the ground station's purpose?

7. Sketch a diagram to show the parts of the gumdrop GPS and components of a GPS station:

Procedure for using gumdrops to model a GPS monument:

1. Insert three toothpicks diagonally into the gumdrop (the GPS antenna). The toothpicks will act as the legs or braces to hold the monument steady.
2. Insert a slightly shorter toothpick sticking straight down from the middle of the gumdrop. The tip of this toothpick should be just barely above the surface. This will be the *"place marker."*
3. Put very small pieces of clay on the bottom of the legs (not the place marker) and affix the GPS to the transparency. The clay acts as cement to hold the GPS monument in place. In reality, the legs are concreted deep into the ground. When the ground moves, the GPS also moves.
4. Set aside this model for now. Answer questions 6-7 above in the right-hand column.

Part 2: What can GPS tell us about Iceland?

Introduction: Measuring GPS Movement with Time Series Plots:

Time series plots show the position of a monument as time passes. There are three directional components: north-south, east-west, and up-down movement (You will not be using the vertical motion in this exercise).

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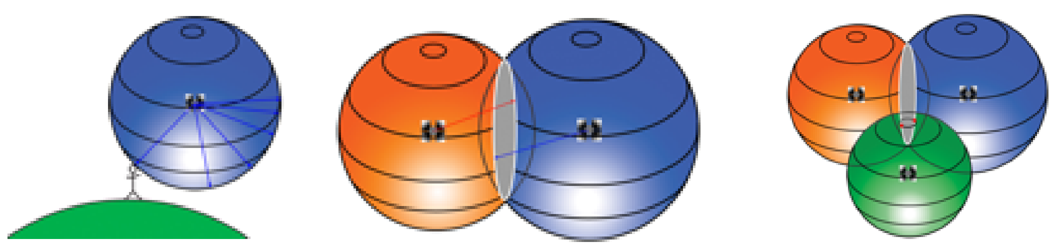
Student version. May 1 2022.

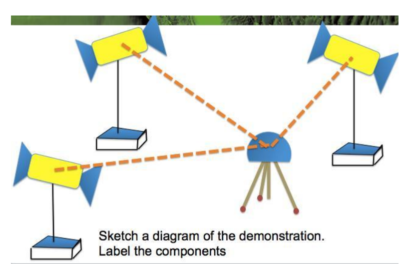
Worksheet Questions 1 – 5

When all students have completed all 5 questions, summarize core concepts and assess levels of comprehension by posing the following questions to the class:

1. What can we do with geodesy?
   Various answers here. The video, A Brief history of Geodesy, provides many good examples. Finding locations, navigation, laying out railroads and streets, etc.
2. What do the pieces of bubblegum represent? How far above the Earth would they actually be?
   The tops of the stands represent where the satellites are. They all are at the same height above the Earth. The bubble gum represents the satellites. The satellites are approximately 20,000 km above the surface of the Earth.
3. What does each length of string represent?
   The string represents the distance between monuments and satellites.
4. How many satellites are needed to pinpoint the location of a spot on the Earth? Why?
   At least four satellites are needed to pinpoint the location of the monument on the surface of the earth (the intersection of 3 spheres is 2 points; A 4th satellite is used to fixed position errors caused by differences in clocks on the satellite and GPS.



5. Sketch a diagram of the locating position demonstration, labeling the components: satellites (and the number needed to pinpoint a location), distance (time), and GPS/Earth.
   Students should draw the setup with three stands, strings, and the gumdrop monument. They may also wish to draw the intersecting spheres



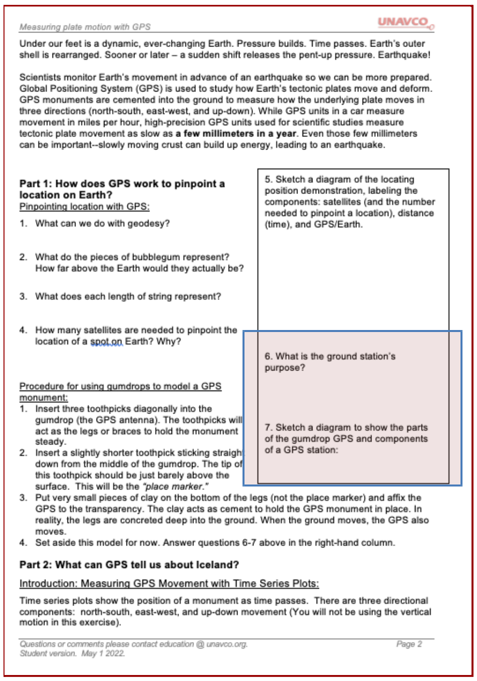
Build a model of a GPS monument

I. If you would like your students to work in pairs or small groups, arrange students into teams at this time.

II. Ask volunteers to distribute materials. Each team will need 2 gumdrops, 8 toothpicks, modeling clay, and two ¼ squares of a transparency in order to make 2 stations. Allow students time to construct 2 GPS stations.

Differentiation: This would be a great opportunity to allow more energetic students to get out of their seats and walk around!

III. With the "Modeling GPS" slide displayed, allow students to sketch a diagram of a GPS station. Walk among students and assess levels of understanding, asking questions and providing clarification where necessary.



Measuring plate motion with GPS

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Part 1: How does GPS work to pinpoint a location on Earth?

Pinpointing location with GPS:

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2. What do the pieces of bubblegum represent? How far above the Earth would they actually be?
3. What does each length of string represent?
4. How many satellites are needed to pinpoint the location of a spot on Earth? Why?

5. Sketch a diagram of the locating position demonstration, labeling the components: satellites (and the number needed to pinpoint a location), distance (time), and GPS/Earth.

6. What is the ground station's purpose?

7. Sketch a diagram to show the parts of the gumdrop GPS and components of a GPS station:

Procedure for using gumdrops to model a GPS monument:

1. Insert three toothpicks diagonally into the gumdrop (the GPS antenna). The toothpicks will act as the legs or braces to hold the monument steady.
2. Insert a slightly shorter toothpick sticking straight down from the middle of the gumdrop. The tip of this toothpick should be just barely above the surface. This will be the *"place marker."*
3. Put very small pieces of clay on the bottom of the legs (not the place marker) and affix the GPS to the transparency. The clay acts as cement to hold the GPS monument in place. In reality, the legs are concreted deep into the ground. When the ground moves, the GPS also moves.
4. Set aside this model for now. Answer questions 6-7 above in the right-hand column.

Part 2: What can GPS tell us about Iceland?

Introduction: Measuring GPS Movement with Time Series Plots:

Time series plots show the position of a monument as time passes. There are three directional components: north-south, east-west, and up-down movement (You will not be using the vertical motion in this exercise).

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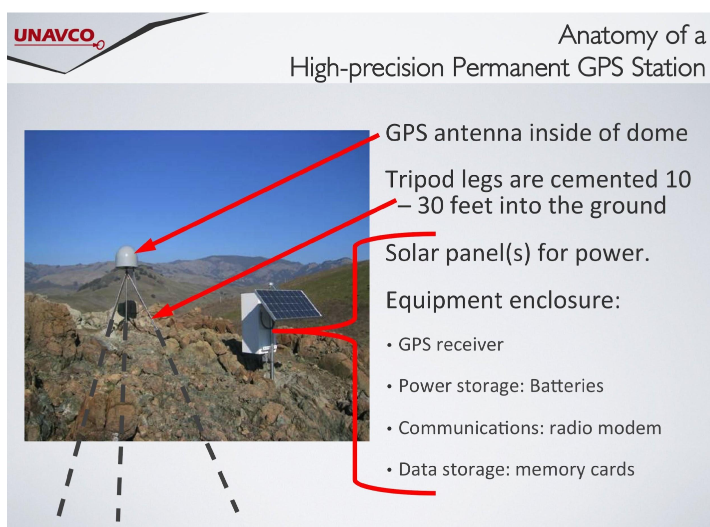
Worksheet question 6 – 7

5. What is the ground station's purpose?

   Ground stations (called the Control Segment) monitor satellite location & health, correct orbits & time synchronization

6. Sketch a diagram to show the parts of the gumdrop GPS and components of a GPS station:

- The gumdrop is the GPS antenna;
- Each toothpick is a tripod leg of the monument – the legs are cemented up to 10 feet into the ground.
- The putty is the cement holding the GPS monument in place.



- GPS antenna inside the dome
- GPS antenna inside of dome
- Tripod legs are cemented 10 – 30 feet into the ground
- Solar panel(s) for power.
- Equipment enclosure:
  - GPS receiver
  - Power storage: Batteries
  - Communications: radio modem
  - Data storage: memory cards

Ask several students to share their answer to Questions 5 - 7 with the class.

Closure/Assessment of Part I

- When all students have completed their diagrams summarize core concepts and assess levels of comprehension by posing the questions on the worksheet to the class.
- Ask several students to share their diagrams of the GPS locating position demonstration (question 5) and components of a GPS station with the class.

Part 2: What can GPS tell us about Iceland?

Introduction: Measuring GPS Movement with Time Series Plots

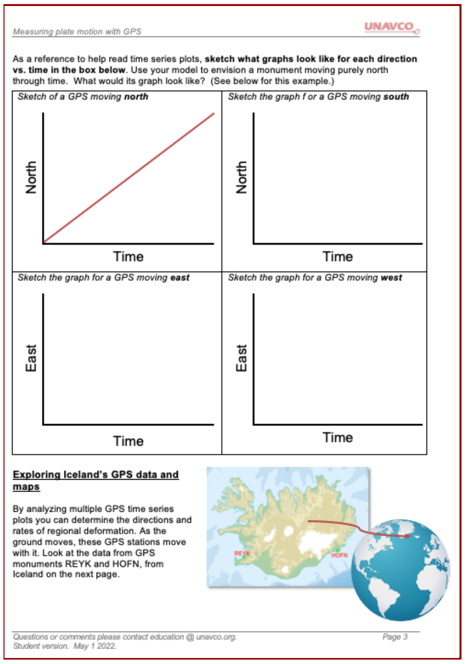
I. Display the “Measuring GPS Movement with Time Series Plots” slide. Inform students that they are viewing data collected from a single GPS station. Explain that the data from the GPS stations in the Network of the Americas (NOTA) operated by UNAVCO (which is one of the EarthScope projects) is freely available to the public. Each GPS station has a data file which contains the daily change in position.

II. Ask students to flip to page 3 of their student worksheets.

III. Display the “GPS Time Series Plots” slide. Explain to your students that time series plots show the position of a monument as time passes. There are three components: north-south, east-west, and up-down movement. We are not using the vertical motion in this exercise.
   - *A second video (http://bit.ly/GPSdemo-part3) on YouTube provides background for teachers about time series plots. (On YouTube search for “GPS gumdrop activity 3-5.”)*

IV. [Optional - Currently the next 4 slides are hidden in the PowerPoint] Walk through the slides to help students learn how to read the time series plots. Discuss the slides as your students fill in the box on their worksheets as a reference.
   - On the “Time Series Plots” slide, discuss the relationship between time series plots and direction with your students, asking questions to assess for comprehension.
   - On the “Gaps in Data” slide, discuss the gaps that may occur in data with your students.

Worksheet



Measuring plate motion with GPS

As a reference to help read time series plots, **sketch what graphs look like for each direction vs. time in the box below**. Use your model to envision a monument moving purely north through time. What would its graph look like? (See below for this example.)

Exploring Iceland's GPS data and maps

By analyzing multiple GPS time series plots you can determine the directions and rates of regional deformation. As the ground moves, these GPS stations move with it. Look at the data from GPS monuments REYK and HOFN, from Iceland on the next page.

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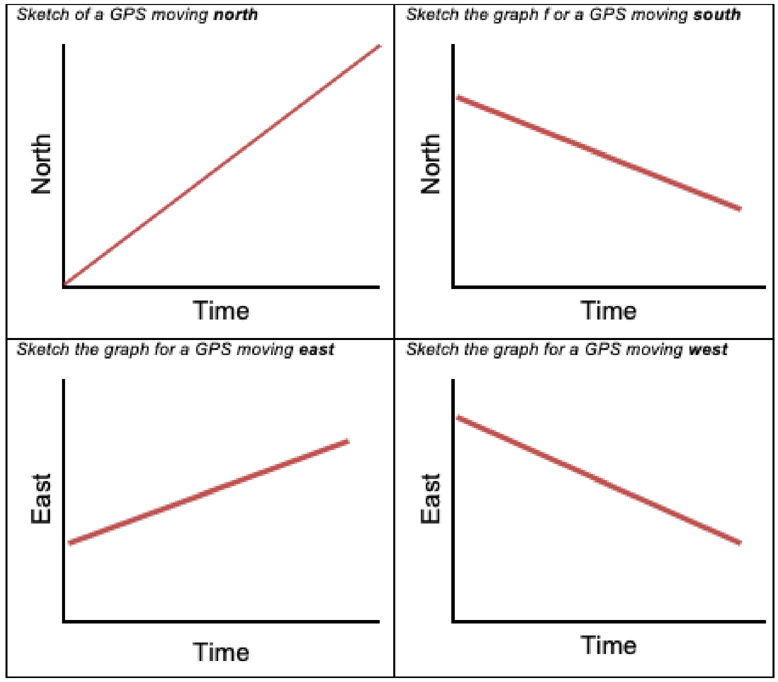


Bonus – what does the graph for a GPS monument not moving east or west look like?

Closure (Measuring GPS Movement with Time Series Plots)

- Use a think-pair-share model to revisit core concepts covered in the lesson before proceeding. Some questions to consider posing may be:
  - How are satellites used to locate the position of a GPS station? (see the answer sheet, questions 3 and 4)
  - Why is it necessary to have at least 3 satellites to pinpoint the exact location of a GPS station? The intersection of three spheres are 2 points; the Earth acts as the 4th sphere. A 4th satellite is used to fix position errors caused by differences in clocks on the satellite and GPS.
  - What is the GPS station measuring? The GPS is measuring the movement of the land beneath the GPS
  - What is a time series plot? What does it show? How can a time series plot be used to show the direction of movement? The plot shows motion in three directions: North-South, East-West, and Up-Down of the GPS and the ground beneath it
  - Optional: Show the last two slides (hidden) in Part 1 about the movement of GPS stations to reinforce that the GPS stations are measuring the movement of tectonic plates.

If you are splitting this lesson across two periods, this may be an appropriate point to conclude Day One.

PART 3: Exploring Iceland's GPS Data and Maps

Activation of Prior Knowledge

- If you are splitting this lesson across two class periods, consider beginning Day 2 by revisiting the questions posed at the conclusion of Day 1.
- As a quick pre-assessment, you may also wish to ask your students, "How can GPS data be used to study the Earth?"

Procedure

I. Orient the students by showing the slide with the world map and perhaps having students use a large wall map or globe to find Iceland.

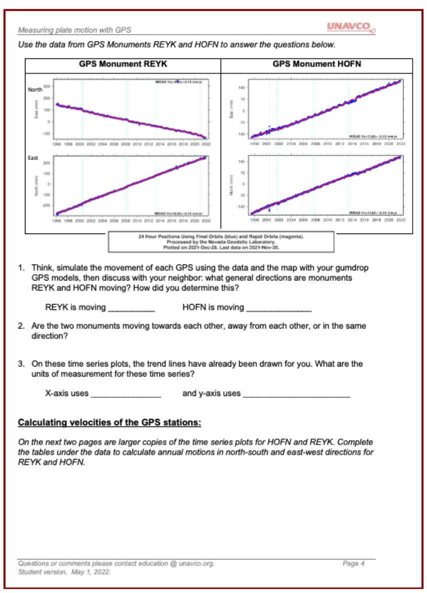
II. Display the "Iceland's GPS data: REYK and HOFN" slide. Explain to students that they will be analyzing data collected from two GPS stations on Iceland, REYK (in the town of Reykjavik) and HOFN (in the town of Hofn) to see how the tectonic plates underlying the monuments are moving.

III. Show students the next slide that shows both the plots for both GPS stations. Allow students to complete questions 1-3 on their worksheets either independently or in pairs.

IV. Display the "Units on time series plots" slide and discuss the answers for 1 – 3.

Worksheet:

By analyzing multiple GPS time series plots you can determine the directions and rates of regional deformation. As the ground moves, these GPS stations move with it. Look at the data from GPS monuments REYK and HOFN, from Iceland.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Use the data from GPS Monuments REYK and HOFN to answer the questions below.

1. Think, simulate the movement of each GPS using the data and the map with your gumdrop GPS models, then discuss with your neighbor: what general directions are monuments REYK and HOFN moving? How did you determine this?

   REYK is moving __________ HOFN is moving ______________

2. Are the two monuments moving towards each other, away from each other, or in the same direction?

3. On these time series plots, the trend lines have already been drawn for you. What are the units of measurement for these time series?

   X-axis uses ______________ and y-axis uses ______________________

Calculating velocities of the GPS stations:

On the next two pages are larger copies of the time series plots for HOFN and REYK. Complete the tables under the data to calculate annual motions in north-south and east-west directions for REYK and HOFN.

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1. Think, simulate the movement of each GPS using the data and the map, then discuss with your neighbor: what general directions are monuments REYK and HOFN moving? How did you determine this?

REYK is moving ___northwest___ HOFN is moving ___northeast___

2. Are the two monuments moving towards each other, away from each other, or in the same direction? away from each other

3. On these time series plots, the trend lines have already been drawn for you. What are the units of measurement for these time series?

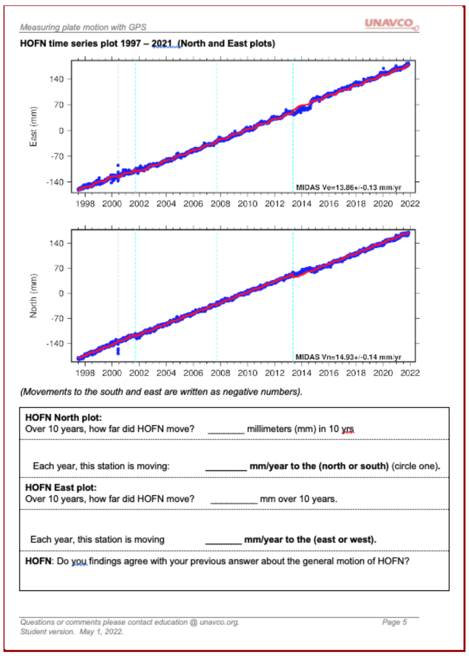
X-axis uses ___time in years___ and y-axis uses ___millimeters___

Calculating velocities of the GPS stations:

Procedure

I. (Optional) Work through the North component of HOFN together.

II. Have students complete the remaining questions for the East component of the **HOFN time series plot** on their worksheets and "GPS Monument REYK" questions. Students may work independently, in pairs, or with the think-pair-share model. Check for understanding by going through their answers for the velocities for HOFN and REYK. (Optional: walk through the slides that are hidden)



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HOFN time series plot 1997 – 2021 (North and East plots)

(Movements to the south and east are written as negative numbers).

HOFN North plot: Over 10 years, how far did HOFN move? ______ millimeters (mm) in 10 yrs
Each year, this station is moving: ______ **mm/year to the (north or south)** (circle one).
HOFN East plot: Over 10 years, how far did HOFN move? ______ mm over 10 years.
Each year, this station is moving ______ **mm/year to the (east or west).**
HOFN: Do you findings agree with your previous answer about the general motion of HOFN?

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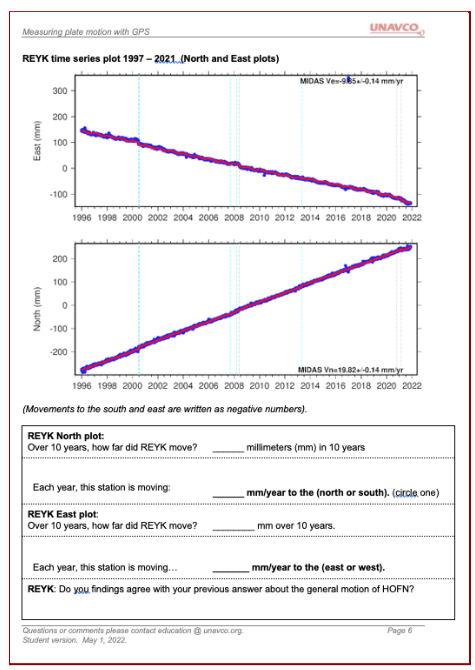
Worksheet:

HOFN North Plot	
Over 10 years, how far did HOFN move?	148 millimeters (mm) in 10 yrs
Each year, this station is moving:	14.8 mm/year to the **(north** or south)

HOFN East Plot	
Over 10 years, how far did HOFN move?	131 mm over 10 years
Each year, this station is moving	13.1 mm/year to the **(east** or west)

HOFN: Do your findings agree with your previous answer about the general motion of HOFN?

Students should answer yes, to the **Northeast**



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REYK time series plot 1997 – 2021 (North and East plots)

(Movements to the south and east are written as negative numbers).

REYK North plot: Over 10 years, how far did REYK move? ______ millimeters (mm) in 10 years
Each year, this station is moving: ______ **mm/year to the (north or south).** (circle one)
REYK East plot: Over 10 years, how far did REYK move? ______ mm over 10 years.
Each year, this station is moving… ______ **mm/year to the (east or west).**
REYK: Do you findings agree with your previous answer about the general motion of HOFN?

Questions or comments please contact education @ unavco.org. Page 6
Student version. May 1, 2022.

REYK North Plot	
Over 10 years, how far did REYK move?	204 millimeters (mm) in 10 yrs
Each year, this station is moving:	20.4 mm/year to the **(north** or south)

REYK East Plot	
Over 10 years, how far did REYK move?	-108 mm over 10 years
Each year, this station is moving	-10.8 mm/year to the (east or **west**)

REYK: Do your findings agree with your previous answer about the general motion of REYK?

Students should answer yes, to the **Northwest**

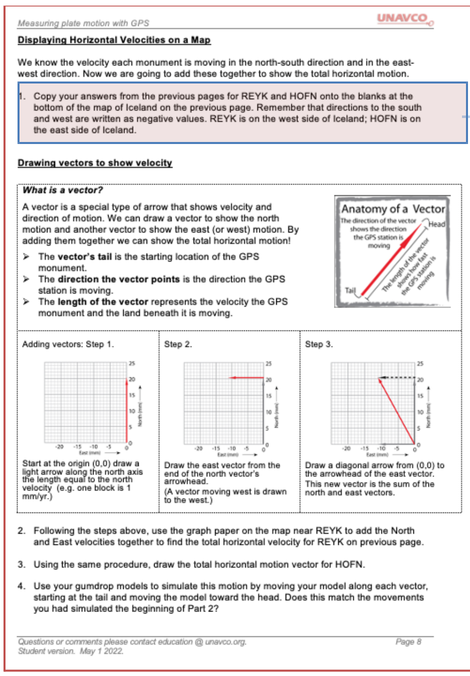
Displaying Velocities on a Map:

Procedure

I. Display the slide, "Displaying velocities on a map: There must be an easier way to show this! Prompt students to copy their answers for REYK and HOFN onto the map – making sure they have copied correctly.

II. Display the slide, "Are REYK and HOFN moving…" and have students simulate the movement of REYK and HOFN with their models. Monitor understanding either by walking around the classroom, asking students to show you the motion of the GPS stations with their models, or allow students to share their responses with the class.

Worksheet



Measuring plate motion with GPS

Displaying Horizontal Velocities on a Map

We know the velocity each monument is moving in the north-south direction and in the east-west direction. Now we are going to add these together to show the total horizontal motion.

1. Copy your answers from the previous pages for REYK and HOFN onto the blanks at the bottom of the map of Iceland on the previous page. Remember that directions to the south and west are written as negative values. REYK is on the west side of Iceland; HOFN is on the east side of Iceland.

Drawing vectors to show velocity

What is a vector?

A vector is a special type of arrow that shows velocity and direction of motion. We can draw a vector to show the north motion and another vector to show the east (or west) motion. By adding them together we can show the total horizontal motion!

- The **vector's tail** is the starting location of the GPS monument.
- The **direction the vector points** is the direction the GPS station is moving.
- The **length of the vector** represents the velocity the GPS monument and the land beneath it is moving.

Adding vectors: Step 1. Start at the origin (0,0) draw a light arrow along the north axis the length equal to the north velocity (e.g. one block is 1 mm/yr.)

Step 2. Draw the east vector from the end of the north vector's arrowhead. (A vector moving west is drawn to the west.)

Step 3. Draw a diagonal arrow from (0,0) to the arrowhead of the east vector. This new vector is the sum of the north and east vectors.

2. Following the steps above, use the graph paper on the map near REYK to add the North and East velocities together to find the total horizontal velocity for REYK on previous page.
3. Using the same procedure, draw the total horizontal motion vector for HOFN.
4. Use your gumdrop models to simulate this motion by moving your model along each vector, starting at the tail and moving the model toward the head. Does this match the movements you had simulated the beginning of Part 2?

Questions or comments please contact education @ unavco.org. *Page 8*
Student version. May 1 2022.

REYK
North: 20.4 mm/yr
East: -10.8 mm/yr

HOFN
North: 14.8 mm/yr
East: 13.1 mm/yr

Drawing vectors to show velocity

Procedure

I. Ask your students, "If you were geologists, how would you represent this information so that it could be easily interpreted by others?"

II. Display the "**Mapping plate movement**" slide and explain how vectors can be used to show the velocity of motion.

III. Explain that they will be making a map like this one, zoomed into Iceland.

IV. Ask students to look at the steps for creating a vector in their packets and display the "What is a vector?" slide. (The map of Iceland and graphs included in the lab worksheets may be used for graphing. However, you may also wish to distribute extra graph paper at this time for students to create a "rough copy" as they practice drawing vectors.)

Differentiation: If you do choose to provide students with extra graph paper, this would be a great opportunity to allow more energetic students to get out of their seats and walk around!

V. Explain that all vectors have magnitude and direction. With GPS monuments, the magnitude is the speed at which it moves. The direction is the direction the GPS moves, or its azimuth.

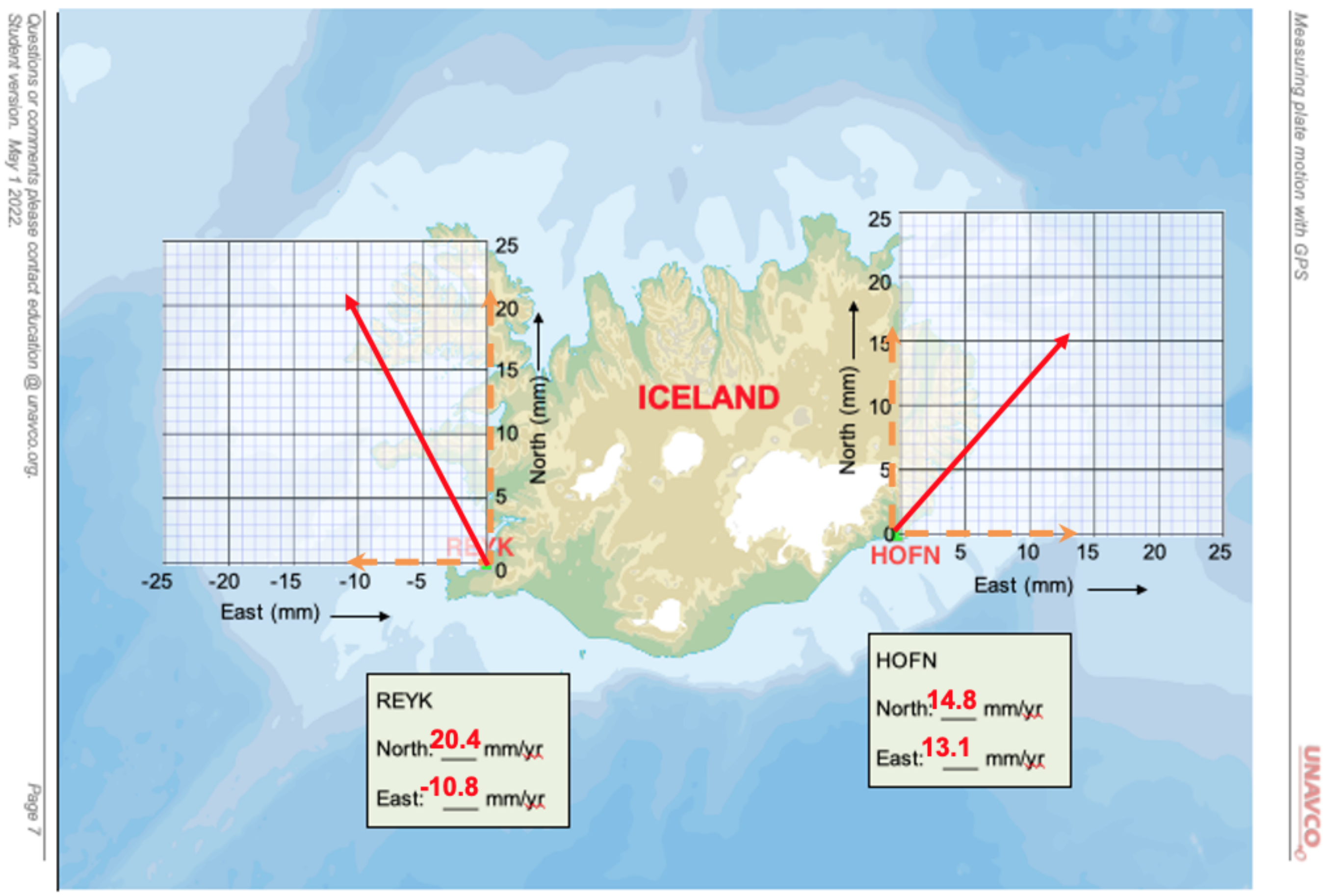
- Vector's tail = starting location of the GPS monument.
- Direction the vector points = direction the GPS station is moving.
- Length of the vector = how fast the GPS station is moving.
- See the What is a vector in the Student Worksheet

VI. Continue through the PowerPoint as students draw the vectors on the map on their worksheets and illustrate vectors on their graph paper. Monitor students as they simulate the motion of both GPS stations with their models.

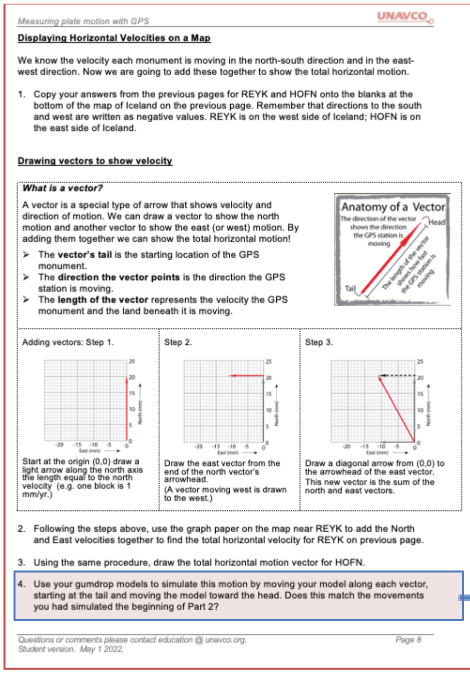
VII. With the “Mapping Vectors” slide displayed, tell students that after collecting and displaying data, it is now time to analyze and synthesize data in order to draw scientific conclusions. Allow students time to work through the “Interpreting the data and maps” section of their worksheets with a partner. Walk among students as they work, providing clarification and support where necessary.

- *Differentiation: Display an online timer on the board for 10-15 minutes to keep students on task.*
- *Differentiation: Students who finish early may continue on to the bonus questions.*

Worksheet:



Worksheet:


Measuring plate motion with GPS UNAVCO

Displaying Horizontal Velocities on a Map

We know the velocity each monument is moving in the north-south direction and in the east-west direction. Now we are going to add these together to show the total horizontal motion.

1. Copy your answers from the previous pages for REYK and HOFN onto the blanks at the bottom of the map of Iceland on the previous page. Remember that directions to the south and west are written as negative values. REYK is on the west side of Iceland; HOFN is on the east side of Iceland.

Drawing vectors to show velocity

What is a vector?

A vector is a special type of arrow that shows velocity and direction of motion. We can draw a vector to show the north motion and another vector to show the east (or west) motion. By adding them together we can show the total horizontal motion!

- The **vector's tail** is the starting location of the GPS monument.
- The **direction the vector points** is the direction the GPS station is moving.
- The **length of the vector** represents the velocity the GPS monument and the land beneath it is moving.

Start at the origin (0,0) draw a light arrow along the north axis the length equal to the north velocity (e.g. one block is 1 mm/yr.)

Draw the east vector from the end of the north vector's arrowhead. (A vector moving west is drawn to the west.)

Draw a diagonal arrow from (0,0) to the arrowhead of the east vector. This new vector is the sum of the north and east vectors.

2. Following the steps above, use the graph paper on the map near REYK to add the North and East velocities together to find the total horizontal velocity for REYK on previous page.
3. Using the same procedure, draw the total horizontal motion vector for HOFN.
4. Use your gumdrop models to simulate this motion by moving your model along each vector, starting at the tail and moving the model toward the head. Does this match the movements you had simulated the beginning of Part 2?

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4. Use your gumdrop models to simulate this motion by moving your model along each vector, starting at the tail and moving the model toward the head. Does this match the movements you had simulated at the beginning of Part 2?

Students use their gumdrop GPS models to illustrate the stations moving away from each other (to the northwest and northeast).

Closure: Interpreting the data and maps

1. When all students have completed questions, review all answers as a class by calling on volunteers to share what they have concluded.

2. At the slide, "***Looking at the World View of Motion"***, explain that these vectors show the movements of the different tectonic plates from the perspective of someone not sitting on Earth, but looking down from space.

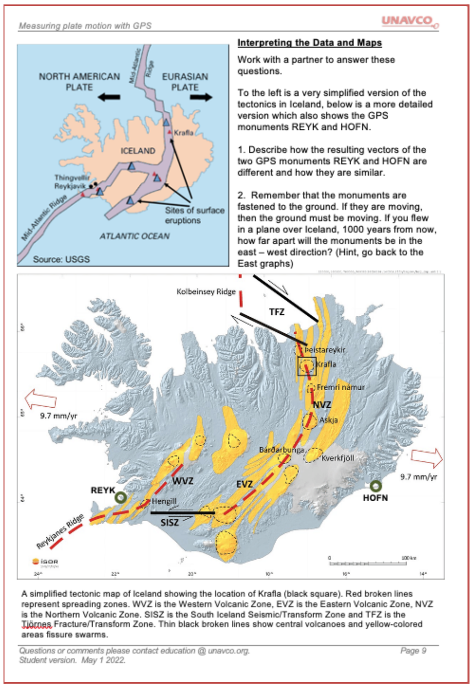
   Extending the Understanding: If you were sitting at HOFN for a very long time, how would REYK be moving? (You would subtract the movement of HOFN from REYK – the easier way is to go back to the North and East vectors,

   Subtract REYK north (20.4 mm/yr) - HOFN north (14.8 mm/yr) = 5.2 mm/yr North

   REYK east (-10.8 mm/yr) - HOFN East (13.1) = - 23.9 mm/yr East

   Then add the two vectors together.

3. Display the next slide and ask, "What is happening to Iceland?" Show slides and explain rifting, fissure openings, and the Mid-Atlantic ridge as you display the next 3 slides.


Measuring plate motion with GPS

Interpreting the Data and Maps

Work with a partner to answer these questions.

To the left is a very simplified version of the tectonics in Iceland, below is a more detailed version which also shows the GPS monuments REYK and HOFN.

1. Describe how the resulting vectors of the two GPS monuments REYK and HOFN are different and how they are similar.

2. Remember that the monuments are fastened to the ground. If they are moving, then the ground must be moving. If you flew in a plane over Iceland, 1000 years from now, how far apart will the monuments be in the east – west direction? (Hint, go back to the East graphs)

A simplified tectonic map of Iceland showing the location of Krafla (black square). Red broken lines represent spreading zones. WVZ is the Western Volcanic Zone, EVZ is the Eastern Volcanic Zone, NVZ is the Northern Volcanic Zone. SISZ is the South Iceland Seismic/Transform Zone and TFZ is the Tjörnes Fracture/Transform Zone. Thin black broken lines show central volcanoes and yellow-colored areas fissure swarms.

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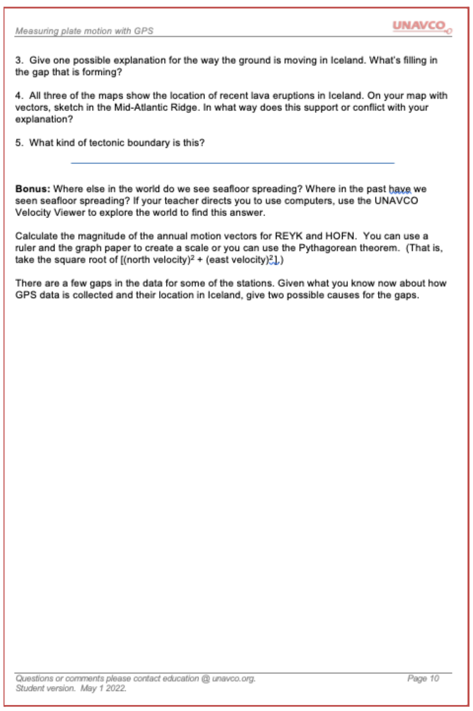

Measuring plate motion with GPS

3. Give one possible explanation for the way the ground is moving in Iceland. What's filling in the gap that is forming?

4. All three of the maps show the location of recent lava eruptions in Iceland. On your map with vectors, sketch in the Mid-Atlantic Ridge. In what way does this support or conflict with your explanation?

5. What kind of tectonic boundary is this?

Bonus: Where else in the world do we see seafloor spreading? Where in the past have we seen seafloor spreading? If your teacher directs you to use computers, use the UNAVCO Velocity Viewer to explore the world to find this answer.

Calculate the magnitude of the annual motion vectors for REYK and HOFN. You can use a ruler and the graph paper to create a scale or you can use the Pythagorean theorem. (That is, take the square root of [(north velocity)^2 + (east velocity)^2].)

There are a few gaps in the data for some of the stations. Given what you know now about how GPS data is collected and their location in Iceland, give two possible causes for the gaps.

Questions or comments please contact education @ unavco.org. Page 10
Student version. May 1 2022.

Worksheet

1. Describe how the resulting vectors of the two GPS monuments are different and how they are the same.

   The vector for REYK is longer (thus moving faster). The two vectors are moving away from each other in the E-W direction, but both are moving north.

2. Remember that the monuments are fastened to the ground. If they are moving, then the ground must be moving. If you flew in a plane over Iceland, 1000 years from now, how far apart will the monuments be in the east – west direction? (Hint, go back to the East graphs)

   You wouldn't even see the tectonic motion.

   REYK is moving west @ 10.8 mm/yr
   HOFN is moving east @ 13. 1 mm/yr

   Add these together to get total separation per year = 10.8 + 13.1 = 23.9 (round up to 24 mm/ yr). Over 1000 years = 24 mm * 1000 = 24,000 mm.

   Ask the students to convert to meters, reminding them that 1000 mm = 1 meter. 24 meters!

3. Give one possible explanation for the way the ground is moving in Iceland. What's filling in the gap that is forming?

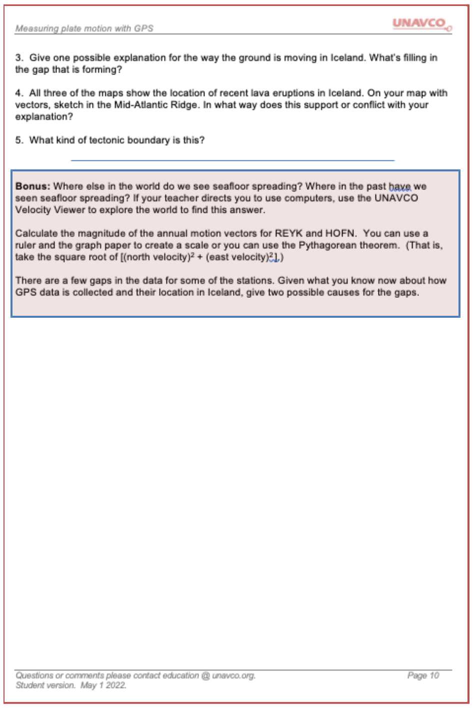
   Some students might say that a valley or hole is opening up in the ground. Others might say that the earth is breaking apart, etc. The North American tectonic plate and the European plate are moving apart in this location, and in fact, all along the Mid-Atlantic Ridge. Magma fills in the gap turning into lava.

4. The map shows the location of recent lava eruptions in Iceland. On your map with vectors, sketch in the Mid-Atlantic Ridge. In what way does this support or conflict with your explanation?

When tectonic plates move apart, they stretch the crust of the earth, making it thinner. This allows magma from the mantle to break through the crust in an eruption.

5. What kind of tectonic boundary is this?

Divergent boundary – in this case the plates are the Eurasian Plate and the North American Plate



Measuring plate motion with GPS

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4. All three of the maps show the location of recent lava eruptions in Iceland. On your map with vectors, sketch in the Mid-Atlantic Ridge. In what way does this support or conflict with your explanation?

5. What kind of tectonic boundary is this?

Bonus: Where else in the world do we see seafloor spreading? Where in the past have we seen seafloor spreading? If your teacher directs you to use computers, use the UNAVCO Velocity Viewer to explore the world to find this answer.

Calculate the magnitude of the annual motion vectors for REYK and HOFN. You can use a ruler and the graph paper to create a scale or you can use the Pythagorean theorem. (That is, take the square root of [(north velocity)^2 + (east velocity)^2].)

There are a few gaps in the data for some of the stations. Given what you know now about how GPS data is collected and their location in Iceland, give two possible causes for the gaps.

Questions or comments please contact education @ unavco.org. Page 10
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Bonus:

Where else in the world do we see seafloor spreading? Where in the past have we seen it? (Have students use the UNAVCO Velocity Viewer to explore the world to find this answer.)

Answers will vary. Some other examples are East Africa, the middle of the Atlantic Ocean, off the coast of the Pacific Northwest (between Juan de Fuca and the Pacific Plate), the Rio Grande Rift, and around Antarctica are possible answers. In the past, we have seen evidence of rifting along the Eastern seaboard, the Midcontinent Rift System in the upper-midwest and the Rhine River valley in Germany.

Calculate the magnitude of the annual motion vectors for REYK and HOFN. You can use a ruler and the graph paper to create a scale or you can use the Pythagorean theorem. (That is, take the square root of [(north velocity)^2 + (east velocity)^2].)

REYK: 23.1 mm/yr to the northwest. HOFN: 19.8 mm/yr to the northeast.

There are a few gaps in the data for some of the stations. Given what you know now about how GPS data is collected and their location in Iceland, give two possible causes for the gaps.

REYK is in Iceland. Possible causes for missing data are that the equipment iced up, batteries died, or the station was destroyed by wildlife, weather, or a volcanic eruption. In this case, when the station stopped working, about five years passed before an engineer could get to the site to fix it.

Show the slides on East Africa and discuss the vectors showing the motions of Africa and East Africa. Have the students study the vectors. The reference frame is Africa fixed. What do you notice about East Africa? How are the motions similar and different from Iceland?

The vectors in East Africa point mostly to the east or northeast, while the vectors on mainland Africa either are very short or pointing west. East Africa, from this perspective, is moving away from Africa creating a rift. This is similar to the motions seen in Iceland. Students could explore more.

Extension – Exploring Plate Motions Using GPS Data on the UNAVCO Velocity Map Tool

Introduction

- Tell students that they will now have the opportunity to look at scientific GPS vectors plots and figure out the direction our Earth's tectonic plates are moving!
- Ask students, "What do you predict you will observe on a global vector map?

Procedure

I. Transition students onto computers, ask that they bring their lab sheets, and direct them to the UNAVCO Velocity Viewer (The link is under the map. Or, search for "UNAVCO velocity.").

II. Go over the key features of the Velocity Viewer:
   a. High precision GPS with an observatory of multiple GPS stations;
   b. Web-based free platform;
   c. Data-sets: near-real time (NOTA) and recent (GSRM);
   d. Plate motion is relative to a reference frame; (read about reference frames (https://www.unavco.org/software/visualization/GPS-Velocity-Viewer/GPS-Velocity-Viewer-frames.html) and
   e. Changing the reference frame changes the perspective of plate motion.

III. The concept of a reference frame is important to this activity. A 'reference frame' is a point of view. If your reference frame is North America, you are standing on North America, seeing how other places move, from your point of view. Motion is relative to where you are – for example a car is moving towards you only if you are in front of the car's position. Therefore, if students need to consider their reference frame when viewing the vectors and making conclusions.
   a. If students are challenged by this (and this would be understandable), project the Velocity Viewer and select different reference frames to see how the vectors change for a given area.
   b. Iceland does not have a reference frame as yet. Proposals have been made and an example of the movement of Icelandic GPS stations using this proposed reference frame is shown on the student worksheet and in the slide deck.

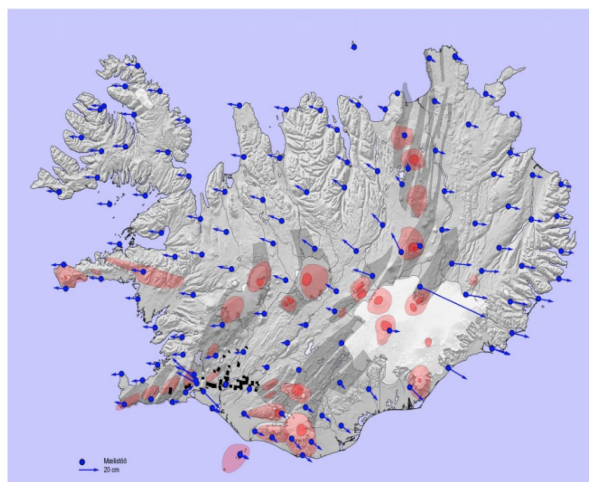
IV. Students should have the freedom to explore during this activity! Tell students to experiment with the tool using the questions on their lab sheets to guide their

Acronyms and Additional Info

NOTA (Network of the Americas: https://www.unavco.org/projects/major-projects/nota/nota.html

GSRM (Global Strain Rate Map): http://geodesy.unr.edu/gsrm.php

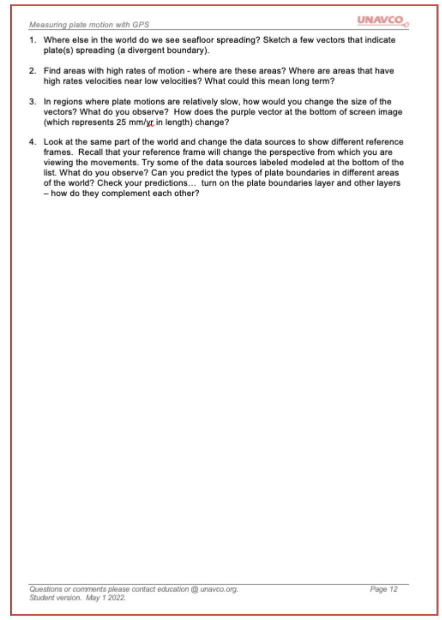
GNSS (Global Navigational Satellite System): https://www.gps.gov/systems/gnss/



Source: Dynamic Reference Frames of Iceland, Halfdan Pascal Kierulf et al.

exploration. As the students work through the extension activity, walk among students in order to ask questions, clarify misunderstandings, and assess for understanding.

Worksheet



Measuring plate motion with GPS UNAVCO

1. Where else in the world do we see seafloor spreading? Sketch a few vectors that indicate plate(s) spreading (a divergent boundary).

2. Find areas with high rates of motion - where are these areas? Where are areas that have high rates velocities near low velocities? What could this mean long term?

3. In regions where plate motions are relatively slow, how would you change the size of the vectors? What do you observe? How does the purple vector at the bottom of screen image (which represents 25 mm/yr in length) change?

4. Look at the same part of the world and change the data sources to show different reference frames. Recall that your reference frame will change the perspective from which you are viewing the movements. Try some of the data sources labeled modeled at the bottom of the list. What do you observe? Can you predict the types of plate boundaries in different areas of the world? Check your predictions… turn on the plate boundaries layer and other layers – how do they complement each other?

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Student version. May 1 2022.

1. Where else in the world do we see seafloor spreading? Sketch a few vectors that indicate plate(s) spreading (a divergent boundary)
   Answers will vary. Some other examples are East Africa, the middle of the Atlantic Ocean, off the coast of the Pacific Northwest (between Juan de Fuca and the Pacific Plate), the Rio Grande Rift, and around Antarctica are possible answers. In the past, we have seen rifting along the Eastern seaboard and the Rhine River valley.

2. Find areas with high rates of motion - where are these areas? Where are areas that have high rates of velocities near low velocities? What could this mean long term?

   Answers will vary depending on the reference frame (data source). Guide students to look at the North America region using the North American reference from (NAM08) and a world reference frame (IGS08). Areas with the highest rates of motion will have the longest vectors! See if your students are able to make this connection independently. If not, pose questions to help students arrive at this conclusion (e.g., If a plate is moving quickly, will its motion be represented by a relatively long or short vector?

   In NAM08, some places with high rates of motion are California, the coast of the Pacific Northwest, and Alaska.

   In IGS08 – lots of places, the Himalayas, near Japan, near Turkey, near Sumatra, etc.]

3. In regions where plate motions are relatively slow, how would you change the size of the vectors?? What do you observe? How does the purple vector (which represents 25 mm/yr in length) change?
   To the right of the map, the "Velocity vector size scaling" option controls the size of the vectors. Change the Vector Length (scaling) then remember to click on Draw Map. The length of the vector 'grows' – and the purple vector also grows proportionally.
4. Look at the same part of the world and change the data sources to show different reference frames. Try some of the data sources labeled modeled at the bottom of the list. What do you observe? Can you predict the types of plate boundaries in different areas of the world? Check your predictions… turn on the plate boundaries layer and other layers – how do they complement each other?
   Answers will vary. Through careful observation of the vectors, plate boundaries are most likely found where the vectors either change speed quickly or are in different directions from each other.

Conclusion (Extension)

Hold a final, open-ended discussion where students share what they discovered using the UNAVCO Velocity Viewer. Use the questions that they have answered as a guide for the discussion.

Lesson Conclusion: Inflation on Geldingadalir Volcano

The 2021 eruption of Geldingadalir on the Reykjanes Peninsula was Iceland's longest lasting eruption of the 21st Century (overtaking the 2014 Holuhraun eruption in Northeastern Iceland). The lesson concludes with a closer look at this major eruption, the future of the area, and the potential role that GPS stations have in predicting the future.

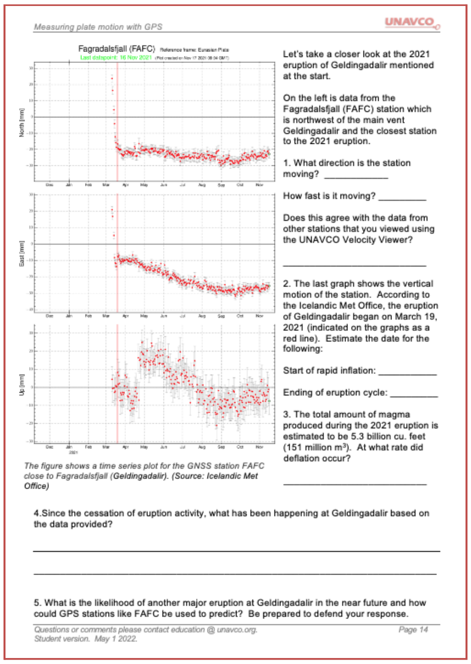
Introduction

- Have students read the March 3, 2021 article from *The Guardian* almost 2 weeks before the eruption (https://www.theguardian.com/world/2021/mar/03/scientists-in-iceland-say-strong-signs-volcanic-eruption-is-imminent) and on the beginning of the eruption on March 19, 2021 (https://www.theguardian.com/world/2021/mar/19/iceland-volcano-eruption-under-way-in-fagradalsfjall-near-reykjavik). The second article contains two videos of the eruption in progress.
- After reading, ask students if the eruption was expected and what role measured earthquakes had in expecting an eruption in the area?
- Review with students that multiple sources of information are used to recognize the onset of volcanic activity and that earthquakes and plate motions in Iceland are tightly related.

Procedure

1. Students may be unfamiliar with the concept of inflation, review this with your students. More information on this can be found from the Cascades Volcanic Observatory (USGS) https://www.usgs.gov/observatories/cascades-volcano-observatory/deformation-monitoring-measures-inflation-and-deflation
2. Review the use of GPS station data in determining direction of plate motion; identify the vertical movement portion of the complete triptych of graphs and recognize that this is new information but that it still shows the motion of the GPS station.
3. Allow students time to work through the last section of their worksheets with a partner. Walk among students as they work, providing clarification and support where necessary. Let students know that Question 5 will be used in class discussion and to encourage well supported and thought-out defenses of their conclusions.
    a. For younger students this may be easier to do as a class and identify the dates and amounts on a projected image. You can combine this exercise with the discussion conclusion.
    b. Students may be challenged in determining the rate of movement. They can arrive at this in two different ways depending on the dates they choose: 1) if they consider just the portion of the map with a slope, the station will be moving twice as fast as the other stations; 2) if they consider the entirety of the graph Mar. 18 to Nov. 16, the rate is essentially in line with the other stations at ~0.06 mm/day.
    c. Use Question 5 as an opportunity for discussion as students offer up ideas with support; challenge them to think beyond the obvious. This question and discussion are meant to flow into the Wrap-Up for the entire lesson.

Worksheet


Measuring plate motion with GPS

Fagradalsfjall (FAFC)

Last datapoint: 16 Nov 2021

Let's take a closer look at the 2021 eruption of Geldingadalir mentioned at the start.

On the left is data from the Fagradalsfjall (FAFC) station which is northwest of the main vent Geldingadalir and the closest station to the 2021 eruption.

1. What direction is the station moving? ___________

How fast is it moving? ________

Does this agree with the data from other stations that you viewed using the UNAVCO Velocity Viewer?

____

2. The last graph shows the vertical motion of the station. According to the Icelandic Met Office, the eruption of Geldingadalir began on March 19, 2021 (indicated on the graphs as a red line). Estimate the date for the following:

Start of rapid inflation: __________

Ending of eruption cycle: ________

3. The total amount of magma produced during the 2021 eruption is estimated to be 5.3 billion cu. feet (151 million m^3). At what rate did deflation occur?

____

The figure shows a time series plot for the GNSS station FAFC close to Fagradalsfjall (Geldingadalir). (Source: Icelandic Met Office)

4.Since the cessation of eruption activity, what has been happening at Geldingadalir based on the data provided?

____

____

5. What is the likelihood of another major eruption at Geldingadalir in the near future and how could GPS stations like FAFC be used to predict? Be prepared to defend your response.

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Student version. May 1 2022.

1. What direction is the station moving? At the end of the data, the station is generally staying in position; however during the eruptive phase the station was moving westward

How fast is it moving?
~0.13 mm/day (Apr. 15, -10mm; Sept. 15, -30mm = 20mm over 153 days)

~0.06 mm/day (Mar. 18, -10mm; Nov. 16, -25mm = 15mm over 243 days)

Does this agree with the data from other stations that you viewed using the UNAVCO Velocity Viewer? Depending on their work either about twice as fast or essentially the same. Stations in the vicinity of FAFC such as KLOF, GRIN, and LAMB are moving at ~0.05 mm/day.

2. The last graph shows the vertical motion of the station. According to the Icelandic Met Office, the eruption of Geldingadalir began on March 19, 2021 (indicated on the graphs as a red line). Estimate the dates for the following:

Start of rapid inflation: April 20, 2021

Ending of eruption cycle: September 1, 2021

3. The total amount of magma produced during the 2021 eruption is estimated to be 5.3 billion cu. feet (151 million m^3). At what rate did deflation occur? 0.28 mm/day (May 1, 20mm and September 1, -15mm = 35mm over 123 days)

4.Since the cessation of eruption activity, what has been happening at Geldingadalir based on the data provided? Since roughly September 1, 2021, the magma chamber beneath Geldingadalir has been inflating. Using the data provided it has been inflating at a rate of 0.14 mm/day (September 1, -15mm and November 16, -4mm = 11mm over 76 days)

5. What is the likelihood of another major eruption at Geldingadalir in the near future and how could GPS stations like FAFC be used to predict? Be prepared to defend your response. There are many factors involved here, not only inflation. The Icelandic Met Office is evaluating the likelihood of an eruption using inflation as well as emitted gases and earthquakes. A variety of student responses are possible. Some students may extrapolate assuming a constant re-inflation rate of 0.14mm/day; others may notice that Geldeingadalir was nearly at the same vertical height (~4mm shy) of the height when the 2021 eruption first began.

Wrap Up

- Hold a final classroom discussion in order to summarize acquired knowledge. Some questions to ask may include:
  - o How does a GPS system work?
  - o How many satellites are needed to pinpoint a GPS location? Why?
  - o What is a time-series plot? How are they used?
  - o What are velocity vectors? How are they used?

  - o As geologists, what have we been able to conclude by analyzing GPS data?
- What are additional applications of time-series plots and velocity vectors?

Appendix A: Relevant excerpts from *A Framework for K-12 Science Education* as cited in the *Next Generation Science Standards*

Common Core State Standards for Mathematics (CCSSM):

Performance Expectation	Students who demonstrate understanding can:
Ratios and Proportional Relationships 6.RP.3	Use ratio and rate reasoning to solve real-world and mathematical problems, e.g., by reasoning about tables of equivalent ratios, tape diagrams, double number line diagrams, or equations.
Statistics and Probability 6.SP.4	Display numerical data in plots on a number line, including dot plots, histograms, and box plots.
Statistics and Probability 8.SP.1	Construct and interpret scatter plots for bivariate measurement data to investigate patterns of association between two quantities. Describe patterns such as clustering, outliers, positive or negative association, linear association, and nonlinear association.
Statistics and Probability 8.SP.2	Know that straight lines are widely used to model relationships between two quantitative variables. For scatter plots that suggest a linear association, informally fit a straight line, and informally assess the model fit by judging the closeness of the data points to the line.
Interpreting Categorical and Quantitative Data. S-ID	Represent data with plots on the real number line (dot plots, histograms, and box plots).
Understand and apply the Pythagorean Theorem. 8.G.7	Understand and apply the Pythagorean theorem to determine unknown side lengths in right triangles in real-world and mathematical problems in two and three dimensions.

3D Alignment:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Analyzing and Interpreting Data: *Analyze and interpret data to provide evidence for phenomena.* Developing and using models; Using mathematics and computational thinking	ESS2.A: Earth's Materials and Systems: *The planet's systems interact over scales that range from microscopic to global in size, and they operate over fractions of a second to billions of years. These interactions have shaped Earth's history and will determine its future. [grade 8]*	Scale Proportion and Quantity: *Time, space, and energy phenomena can be observed at various scaled using models to study systems that are too large or too small.* Patterns:

Constructing explanations (for science) and designing solutions (for engineering)	ESS3.B: Natural Hazards *Mapping the history of natural hazards in a region, combined with an understanding of related geologic forces, can help forecast the locations and likelihoods of future events. [grade 8]* PS2.A: *Forces and Motions: All positions of objects and the directions of forces and motions must be described in an arbitrarily chosen reference frame and arbitrarily chosen units of size. In order to share information with other people, these choices must also be shared. [grade 8]* ESS3.B: *Natural Hazards: Natural hazards and other geologic events have shaped the course of human history; [they] have significantly altered the sizes of human populations and have driven human migrations. [grade 12]*	*Graphs, charts, and images can be used to identify patterns in data.* Stability and Change: *Stability might be disturbed either by sudden events or gradual changes that accumulate over time*