

INSTRUCTOR INFORMATION

Alaska GPS Analysis of Plate Tectonics and Earthquakes

Background

Technology is amazing. The Global Positioning System, known as GPS, has been around for many years, and its applications are many. In a nutshell, GPS can be used to locate where you are on Earth's surface within a few meters or millimeters, depending on the device. People are most familiar with GPS units in phones or cars to help with directions or handheld devices for hiking. Fewer people realize that high precision research-grade GPS can be used to show tectonic plate movement of just a few millimeters!

There are 24-32 GPS satellites cruising 20,000 kilometers above the Earth moving at about 7500 kilometers per hour. That's almost 2 kilometers per second – yes, 2 kilometers every second! The satellites send out radio wave signals in all directions. GPS receivers on the ground (figure lower right) can tell how long it takes for the radio waves to reach them, and using some math, computers can calculate the distance between the receiver and the satellite. By using the distance between a GPS receiver and multiple satellites, researchers can calculate where the receiver is and how it changes over time.

High precision GPS stations are so much more accurate because they use some very sophisticated computing to take out errors due to the atmosphere and clock inaccuracies, for example. The picture here and the one on the student handout show a GPS Station, a GPS antenna on a stand that is securely rooted in rock layers below soil. Inside the dome is the GPS antenna that receives the radio waves and sends the signal to an attached receiver. The resulting positional data are then sent via Internet to a data center for further processing. Scientists can then use long-term positional data to interpret plate motions and plate boundary interactions.

Audience & Time

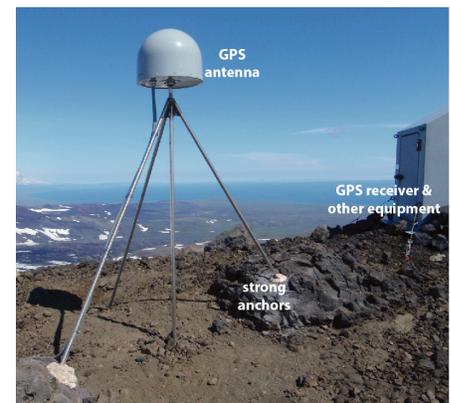
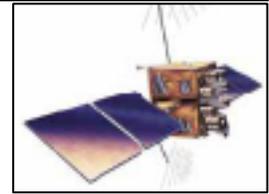
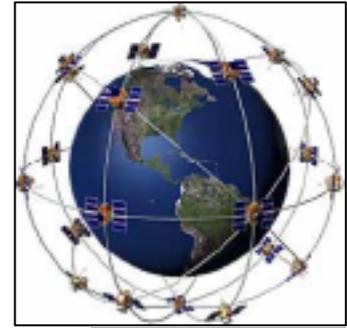
This activity can be done with introductory geoscience learners in secondary school or early college. Total time is 2-3 hours. With secondary students it would probably be best split over 2-3 days. Early college level could probably complete at home after starting in class.

Skills and concepts that student need

Learners should be familiar with plate tectonics and earthquakes. The instructor should definitely give a brief introduction to GPS systems at the start of the activity if the students are not already familiar.

Content/concepts goals for this activity

Students will be able to:



- Diagram and describe the basic components of the GPS system and a GPS station
- Construct a small model GPS station
- Interpret high precision GPS data

Higher order thinking skills goals

- Calculate tectonic velocities from GPS time series data and graph resulting vectors
- Synthesize results from three GPS stations to determine the implications for future earthquakes in south central Alaska.

Engagement

Have students stand up and try to move just one millimeter. With every movement, say it's too much. This will impress upon them the accuracy of the GPS system. This system can detect plate tectonic movements of continents and even millimeter-scale deformation of parts of continents near plate boundaries.

PART I: Building a GPS 'Station'

Procedure

1. Building the station should take a few minutes, and it's the hook. Students will use the gumdrop model for Part II (if doing Pinpointing Location portion in groups), and also to model movement of the station in Part IV.
2. Have students place gumdrop station in middle of transparency sheet. Clay represents the concrete that 'glues' the station to the Earth.
3. Students can also draw and color on the transparency sheet to represent rock layers. The key is that students understand that it's crustal rock, not just the station or soil, that moves.
4. If doing the activity over two days, have students write their name on a piece of scrap paper and place gumdrop station on top to save for next day.

Materials

- Sharp wooden toothpicks work best. Gumdrops can be found at larger stores in the bulk candy section. Can also use the smaller 'spice drops' available at most stores, but it's tougher to get toothpicks in smaller gumdrops.
- Only small amounts of modeling clay are necessary.
- Transparencies can be cut into quarter sheets. You can even use smaller pieces if necessary. Cutting one sheet into six pieces works well.



PART II: Pinpointing Location with GPS

There are 3 methods to do the demonstration, which vary in scale. Some videos on them are:

https://www.iris.edu/hq/inclass/video/gps_monitors_deformation_in_subduction_zone_part_1_intro - Option 1

<https://www.youtube.com/watch?v=hqxwYWr879s&list=PLzmugeDoplFOWUv5oeaqi3vqXoZOGmTiD&index=3&t=1s> – Option 2/3

Option 1 – Smaller Scale

Procedure

1. Premark locations of ring stands so that all 3 strings meet in one location on table surface. You will have to set this up and cut the strings beforehand.
2. Explain that satellites are flying above Earth's surface at same altitude and ring stands represent that height.
3. Explain relationship between gumdrop station (built in Part I) and satellite – the station “listens” to the signals from satellites and uses the time offset to establish the distance between the station and the satellites.
4. The string represents the distance from the satellite to the station.
5. Have a student move one string (held taut) in all directions to indicate that the distance is known, but the direction is not. A sphere around the top of the ring stand is established with radius equaling the distance from that satellite to the station.
6. Have another student move a 2nd string around and note where strings intersect – there is a circle of possible places this happens. Emphasize again that the only known entity is the distance from the satellite to the station.
7. Have a third student move the 3rd string to show where all 3 strings intersect. There should be two places – one on Earth's surface and one in space –where all 3 strings intersect. Note that computers can automatically detect that the one in space is non-sensical.
8. Place the gumdrop at the point where 3 strings intersect.
9. Remind students that these measurements are taking place while satellites are moving at 2 kilometers/second!
10. Have students complete Part II questions on worksheet.

Materials

- 3 ring stands (without rings).
- 3 ‘satellites’ to place at top of ring stands. BubbleYum gum has a shape similar to GPS satellites and is an attention grabber. You could also print small pictures of satellites to tape to top of ring stands.
- Strings of 3 different lengths taped to tops of ring stands – all must be at least as long as height of ring stand.
- Gumdrop station from Part I.

Option 2 – Larger Scale

Procedure

1. Tape one end of each length of twine to the wall next to each ‘satellite’. Find a location somewhere on the floor of the room where you want the GPS station to be located. Cut the twine so that all 3 strings meet at the GPS station. You will have to set this up and cut the strings beforehand.
2. Coil up the long strings and tape them up on the wall so you can easily pull them down and hand to a student.
3. Follow the demonstration procedure Option 1 to have one, then two, then three students locate the point of intersection of the three lengths of twine = location of the GPS station.

Option 3 – Largest Scale

Present demonstration just as with Option 2 above, only use much longer string and use the gym or outdoor basketball hoops.

PART III: Measuring Alaska GPS/Tectonic Movement

Procedure

1. Review metric system (millimeter, centimeter, meter, kilometer).
2. Review compass directions.
3. There are thousands of GPS stations in operation, more than 1100 stations in the National Science Foundation's Network of the Americas (NOTA)
<https://www.unavco.org/instrumentation/networks/status/nota>
4. Instruct students how to 'read' a time series plot. Use the data from Montague Island as example to do with whole class. The optional presentation associated with this activity overviews this if you need a refresher or see this video
https://www.iris.edu/hq/inclass/video/gps_monitors_deformation_in_subduction_zone_part_2_using_real_data
5. Vertical position is not used because it is more complex to interpret. Winter snow loads and deglaciation can complicate vertical motions of GPS stations in Alaska.
6. With a ruler, draw a line of best fit to show trend of time series plot. Try to draw the line so that there are as many data points above that line as below the line. Using a clear ruler works particularly well.
7. Using y-axis mm scale, determine overall change in position in given time period.
8. Calculate annual movement by dividing overall change in position by total time period.

Detail on Interpreting Time Series Plots

- a) All plots have a Y-axis with 'zero' and positive numbers above the line and negative numbers below the line. Numberless tick marks on the right mirror the measurements.
- b) The 'North' plot shows North and South movement
–anything moving in the 'positive' (up) direction is moving North, and anything moving in the 'negative' (down) is moving South.
- c) The same is true for East/West – movement in a positive direction (up) is movement to the East, and anything moving in the negative (down) direction is moving West.
- d) Most time series do not include gridlines, so it's helpful to use a ruler or straightedge (a clear one is best) to calculate how much movement there is.
- e) The scale on the axes will vary and the units may vary as well so examine the labels carefully.
- f) Remember that the underlying technology is complex and there are occasional problems like instrument failures. The time series plots can have gaps and glitches and nonlinearities. The example time series plots in this activity are relatively clean and clear and the instructor answer key offers a few explanations of minor observable complications.
- g) The time scale is shown by years and twelfths-of-years (months).
- h) Receivers collect a positional measurement every second. That's 86,400 measurements a day. These are averaged to get the one data point for each day that is shown on a time series.
- i) The velocities of GPS stations are small – millimeters or centimeters per year. But just think how much movement that would mean over thousands of years! An easy equivalent to remember is 1 mm/yr is the same velocity as 1 kilometer/1 million years.

PART IV: Plotting GPS Station Motion

Procedure

1. Follow procedures on student handout. Confusion may arise about scale translation of centimeters to millimeters. Scale used on the grid is designed to make graphing easy. Actual movement is in millimeters but this is too hard to see if the grid were drawn at 1:1 scale.
2. Vector graph should look like the example provided on Answer Key. Colors used may vary.
3. The GPS gumdrop stations will move along path of vectors, mimicking the movement of the tectonic plate with GPS station attached.

PART V: Analysis of GPS Station Motion

The big-picture result of the activity is that GPS stations in the Prince William Sound area and southeast coast of the Kenai Peninsula are being pushed toward the northwest with respect to interior Alaska.

These GPS stations are moving northwest because the shallow portion of the North American continental margin is locked by friction to the Pacific Plate that is northwest toward North America in the Gulf of Alaska. The rate of northwest motion is highest for locations farthest to the southeast, like Montague Island, that are closest to the Aleutian Trench where the Pacific and North American plates meet on the seafloor. Along a transect from Montague Island to Anchorage, the rate of northwest motion gets progressively slower until the GPS stations near Anchorage are moving very slowly compared to the rapid northwest motion of Montague Island.

The clear implication is that the continental margin between the Aleutian Trench and Anchorage is being compressed in SE – NW direction. Strain is building within the continental margin of the North American Plate as the Pacific Plate pushes the North American Plate margin toward the northwest. This accumulating strain will eventually be released in the next major or great earthquake on the Alaska - Aleutian Subduction Zone or thrust fault(s) within the continental margin.

The plate boundary regions of the Pacific and North American plates are essentially “locked and loading” as they store elastic energy that will be released in future earthquakes. When the stored energy due to the slow northwest motion is suddenly released in the next major earthquake, the Prince William Sound area and southeast coast of the Kenai Peninsula will move towards the southeast. For example, during the 1964 Great Alaska Earthquake, Latouche Island in Prince William Sound was displaced nearly 20 meters toward the southeast and uplifted by 3 meters.

Procedure

1. Help the students to answers from observations of the GPS vector map.
2. Discuss big picture and earthquake implications after students realize that the region is being squeezed.
3. A further demonstration is taking a piece of paper or cloth and holding the right side of it stationary, and then pushing the left side towards the right. The paper/cloth will buckle.

NGSS Alignment

Disciplinary Core Ideas

- Motion and Stability—Forces and Interactions: HS-PS2-1, MS-PS2-2
- Energy: MS-PS3-1, MS-PS3-2, HS-PS3-2, MS-PS3-5
- Waves and Their Applications in Technologies for Information Transfer: HS-PS4-2, MS-PS4-3, HS-PS4-5
- Earth’s Systems: 5-ESS2-1, HS-ESS2-1, MS-ESS2-2, HS-ESS2-2, MS-ESS2-3, HS-ESS2-3
- Earth and Human Activity: HS-ESS3-1, MS-ESS3-2

Science and Engineering Practices

4. Analyzing and Interpreting Data
5. Using Mathematics and Computational Thinking
6. Constructing Explanations and Designing Solutions

Crosscutting Concepts

2. Cause and Effect
4. Systems and System Models
7. Stability and Change