### Background Information

Before starting this EET chapter, students have been introduced to key concepts of Plate Tectonics. The activity deepens student understanding of plate tectonics by focusing on the details of plate movement in a particular region.

**The Global Positioning System (GPS)**

The global positioning system (GPS) is a fleet of about 30 satellites orbiting Earth approximately 20,000 kilometers above the planet's surface. A GPS receiver on the ground picks up signals from these satellites, and processes them to determine its position via a sophisticated form of triangulation. A position can be calculated using signals from three satellites, but at least four satellites are always used to minimize errors due to signal timing and less-than-optimal satellite spacing in the sky. You may already be familiar with handheld GPS units which people use for navigation in cars, recreation (hiking and geo-caching), mapmaking, and land planning. There are several important differences between handheld GPS units and the high-precision ("differential") GPS units that Earth scientists use in their research.

Handheld GPS receivers calculate positions that are known as autonomous solutions. In other words, each handheld GPS receiver is independent from all other receivers and uses only satellites to calculate positions. As a result, handheld GPS receivers are unable to correct for many error sources and their accuracy is on the order of meters.

Differential GPS uses two GPS receivers to calculate a position: a stationary receiver ("base station") whose location is accurately known from surveying, plus a roving ("moving") receiver. Both receivers continuously calculate their positions from the satellites. The base station compares the calculated position with its known location and "differences" between the two measurements to determine the error in the GPS signal. Then, the base station sends the error corrections to the roving receiver. Using differential GPS for navigation allows scientists to minimize the errors associated with measuring positions. To obtain positions such as those described in this chapter, scientists use a more advanced type of differential processing to generate a *network solution*. In this network processing, a large number of fixed GPS receivers are processed together to achieve very precise relative positions. These relative positions are related to an "absolute" reference frame to give coordinates with respect to Earth's surface itself.

**Using GPS to Study Plate Motion and Crustal Deformation**

GPS stations used for geodesy are cemented into the ground so that the instrument is tightly coupled with the bedrock. Changes in the location of a GPS station are therefore caused by movement of the Earth's surface. By comparing the motion of several GPS stations in a region over time, scientists can detect motion of tectonic plates and infer deformation of the Earth's crust.

Although slight motion occurs continuously, when an earthquake event happens, the ground on either side of the fault moves instantaneously, sometimes resulting in strong shaking. GPS measurements enable scientists to map the location and distance of these displacements. Although we cannot feel it, the crust on either side of the fault continues to slip even when earthquakes are not occuring. Scientists can record this motion with GPS. By comparing the locations of GPS monuments on different plates, scientists can detect the rate at which the plates are moving.

**Analyzing GPS Station Data**

UNAVCO's Data for Educators site provides prepared time-series plots and downloadable GPS data, primarily for stations located within the United States. The data show daily positions of the station compared to its reference location. The set of data includes positions measured in the North, East, and vertical directions from the reference location.

Plotting a station's position in North and East directions over time reveals the overall direction and average rate that a station is moving. Trendlines from the North and East plots are used to generate a composite vector that shows the horizontal motion of the station over time.

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**GPS Data Exploration**

In this activity, you will access Global Positioning System (GPS) data from the Plate Boundary Observatory (PBO) and analyze the data in a spreadsheet to measure the motion of GPS stations in the Pacific Northwest. From your analysis, you will generate and map annual velocity vectors of GPS stations. Finally, you will explore patterns in the direction and length of velocity vectors on the map to understand tectonic motion and surface deformation associated with the subduction of the Juan de Fuca plate under the North American plate.

From an easy-to-use map interface, you can access information about GPS stations and the data you collect. You will learn about the network of GPS monuments and how position data collected at these sites are analyzed to reveal plate motion. The activity provides complete instructions for calculating north-south and east-west velocity vectors for a GPS station and combining them to produce a vector that represents the annual horizontal motion of the station. After plotting velocity vectors on a map, you will be asked to examine the pattern of direction and lengths. With first-hand experience in producing and mapping station velocity vectors, you will be better prepared to use the patterns to interpret regional geology.

*This chapter is part of and adapted from the* [*Earth Exploration Toolbook*](http://serc.carleton.edu/eet/index.html) *at http://serc.carleton.edu/eet/platemotion/index.html. Each chapter provides teachers and/or students with direct practice for using scientific tools to analyze Earth science data. Students should begin with the Case Study section.*

Materials Needed:

- Computers and Internet

- Microsoft Excel or similar spreadsheet software

- Rulers

- Protractor

- Graph Paper

Case Study:

## Global Positioning System (GPS) Technologies Document Plate MotionCSZ.gif

When Albert Wegener first proposed the idea of continental drift, many scientists viewed him as the laughingstock of his day. Except for the "coincidental" fit of a few coastlines and some interesting fossil distributions, most members of the scientific community could not accept that continents moved, because they saw no evidence of motion. Today, Global Positioning System (GPS) technologies are providing direct evidence of plate motion. High-precision GPS data document tectonic motion, and these data are being used to refine models and create visualizations that convey our current understanding of plate tectonics.

Most plates move less than a millimeter per day; this movement is imperceptible to human senses. However, this daily motion translates to 1-10 centimeters of movement over a year, and that yearly motion translates to 10-50 kilometers of movement over a million years. This slow but relentless motion eventually results in soaring mountains, rumbling earthquakes, and exploding volcanoes.

One place where plates have been moving for millions of years is the Pacific Northwest, where the Juan de Fuca plate dives under the North American plate in a process known as subduction. The region is called the Cascadia Subduction Zone (CSZ). Processes associated with the CSZ have generated the scenic landscape for which the Pacific Northwest is known, including the rugged Cascades and Coast Range Mountains. The subduction zone is also responsible for large earthquakes, volcanic eruptions, and occasional tsunamis.

## The Plate Boundary Observatory Collects and Analyzes GPS DataPBO_Stations

The Plate Boundary Observatory (PBO) collects location data from a network of continuous high-precision GPS units that are coupled to bedrock across the CSZ. GPS technology has matured to the point that it can be used to detect the very small daily motion of tectonic plates. When they were initially used for geodesy, GPS location data were collected only once per year. With motion averaged over an entire year, the details of events that happened on shorter time scales simply didn't show up. With the increased temporal resolution of the PBO network, we can examine fine details of short- and long-term geologic processes.

PBO data enable users to uncover the detailed movement and deformation of the "rigid" tectonic plates near the CSZ. Small differences in the motions of GPS stations can reveal locked portions of the subduction zone where stress is building and the earthquake danger rising. GPS stations can also detect surface bulging due to upwelling magma, perhaps giving early warning of important changes taking place under restless volcanos.

The precision of these data has also facilitated discovery of a newly recognized phenomenon called Episodic Tremor and Slip (ETS). Until recently, motion on a subduction zone fault was assumed to be constant in direction and speed between the time of major earthquakes. Scientists believed that accumulating tectonic pressure along a fault would continue to steadily deform the crustal rocks around the fault until an earthquake occurred, rupturing the fault and releasing the pressure. Now, GPS data have revealed a more interesting and complicated story. At regular intervals, GPS stations on the northern Cascadia margin have exhibited transient motions of 5 or 6 millimeters within a couple of weeks, implying deep fault slip of several centimeters. These transient motions are directed seaward, opposite to the direction of long-term squeezing of the coastal margin. Over the same time period, sensitive seismometers have recorded tremor-like signals that accompany these episodes of deep slip. While earthquakes usually last just seconds or minutes, this slow release of pulsing seismic energy occurs over the entire one or two weeks of slip. The total amount of seismic energy released in these events is large, on average equalling that of a magnitude 6.6 earthquake.

The significance of ETS events is currently being debated, but consensus is arising that they represent a fairly rapid release of some of the subduction zone's stored stress. This release can cause a transfer of stress to shallower faults. Some researchers are exploring how these events might aid them in the prediction of the next large earthquake in the region. As a result, ETS represents an important new observation of unexpected behavior on a subduction zone—one that wouldn't have been made without high-resolution GPS data.

In this investigation, you examine GPS data to explore plate motion and its relation to regional geology. Specifically, find the annual velocity vector of one or more PBO stations in the Pacific Northwest and plot them on a map. By compiling a map showing velocity vectors for several GPS stations, you can determine the general motion of the North American plate and explore the smaller-scale differences of motion in the region.

**Instructions**:

|  |  |
| --- | --- |
| Part 1 - Getting the Data   * Open up your internet browser and head to UNAVCO’s data for educators page:   + <http://www.unavco.org/education/resources/data-for-educators/data-for-educators.html> * On the right of the page, you should see a map of the world that you can interact with. On this map, zoom in on the state of Washington. * Once zoomed in enough, right next to Seattle, you should plainly see a green marker denoting the SEAT station. Click on the SEAT station. | GPS1.png |
| * In the tab that opens on the map, click the link that says “Download Time Series Data [CSV]” * Choose the option to open the file with Microsoft Excel, or similar spreadsheet software of your choosing   + **Note**: you can click the Find GPS Data option for a little bit more information about the station itself. * If you cannot download or open the file from the web, use this address to download a data set directly:   + <http://d32ogoqmya1dw8.cloudfront.net/files/eet/platemotion/seattle_csv_file.csv> | GPS2.png |
| Part 2 - Exploring the GPS Data   * The first eight rows of the spreadsheet gives you basic information about the GPS station you are investigating * In your student answer sheet you will notice a section asking for station names and reference positions. Fill them in now. | GPS3.png |
| Part 3 - Making Time-Series Plots   * Save your spreadsheet by clicking   “File → Save As”   * + Be sure to name your file so that you can recognize which station it belongs to   + Choose the option to save as type: “Excel Workbook” * In your spreadsheet, click the “Move or Copy” option at the bottom. * Check the box to “Create a Copy” and click “ok”. * In the second sheet, delete the top eight rows of information | GPS4.png |
| * Format the first four columns of the data set   + Right-Click column header (A - D)   + Choose Format Cells   + For column A, choose the category Date and select the “mm/dd/yy” format   + For columns B - D, choose category Number and specify it to two decimal places. * Save! | GPS5.png |
| * Select the column A header by clicking on it, then Control + click the column B header * When both columns are selected, click to insert a scatter plot of Time vs. North with just markers   + Be sure your graph shows the dates on the X axis and the north positions on the Y. | GPS6.png |
| * Format your plot:   + If X-axis intercepts the Y in the wrong spot, right click the Y-axis and fill in where you would like it to intercept.   + If values on the X-axis are not showing properly, right click the X-axis and choose the Date - mm/dd/yy option   + Be sure to label and title your plot appropriately. * Save your file again. |  |
| * Select column A again and control + click column C. * Make a second scatter plot of Time vs. East following the same format as the first plot.   + Again, be sure to fix the X and Y axis as needed and to label them appropriately. * Save. | GPS7.png |
| Part 4 - Calculating Station Motion   * In each plot that you created, right click the data inside and click the option to add a trendline. * In the box that opens up to format the trendline, choose linear and click the box to “Display the Equation on Chart.” * Click close and move the equation somewhere on the chart you can clearly see it   + Feel free to adjust the font size and color if you desire. | GPS8.png |
| * The trendlines are in the y = mx + b format   + y represents the North or East position   + m is the slope of the line   + x represents time in days   + b is the y intercept (can be ignored) * The slope of your trendlines is equivalent to the average daily velocity of your station in the North and East directions.   + Positive slope equals movement North or East, negative slope equals movement South or West. * Using your trendlines, calculate your average annual velocities.   + Fill in section of your Student Answer Sheet | **TIP: To calculate the average annual velocity of GPS stations in either direction, multiply the daily velocity by 365.25 days/year.** |
| Part 5 - Combining Velocities and Making a Vector   * **Graph Method**:   + Draw a set of X / Y axis, both with a range of -10 to 10, each unit representing a mm.   + Draw your North-South vector on the Y-axis and your East-East vector on the X-axis.   + Add the vecotrs together graphically to get overall vector.   + Overlay your vector on map included and measure angle from North using a protractor. Use same units as on graph, mm preferably. | example_resultant_vector.png |
| * **Mathematical Method**:   + Calculate length of resultant vecotr using the pythagorean theorum:     - a2 + b2 = c2   + Calculate the direction of motion using the relationship that the angle, a, is equal to the inverse tangent of the length of the north vector divided by the length of the east vector. | **a = tan-1(N/E)**  **a = tan-1(3/6)**  **a = tan-1(.5)**  **a = 26.6 degrees**  \* Indicates the direction of motion in degrees from east. |
| * **Links to calculators**:   + <http://www.calculator.com/calcs/calc_sci.html>   + <http://www.csgnetwork.com/righttricalc.html>   + <http://www.carbidedepot.com/formulas-trigright.asp> | angle_formula_350.gif |
| Part 6 - Other Stations   * Using the same methods you just used, produce velocity vecotrs for additional stations in the continental Unites States   + It should be much easier and faster now that you have done it once. |  |

Credit:

**Analyzing Plate Motion Using EarthScope GPS Data**

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This work has been modified and adapted from:

<http://serc.carleton.edu/eet/platemotion/index.html>

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**Analyzing Plate Motion Using EarthScope GPS Data: Answer Sheet**

Stations Used:

|  |  |
| --- | --- |
| Station name: \_SEAT\_PNGA\_WA1995\_\_\_\_\_  Latitude : \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  Longitude: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  Annual Velocity N: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  Annual Velocity E: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  Overall Vector Velocity: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  Degrees from (N / E): \_\_\_\_\_\_\_\_\_ | Station name: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  Latitude : \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  Longitude: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  Annual Velocity N: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  Annual Velocity E: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  Overall Vector Velocity: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  Degrees from (N / E): \_\_\_\_\_\_\_\_\_ |
| Station name: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  Latitude : \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  Longitude: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  Annual Velocity N: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  Annual Velocity E: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  Overall Vector Velocity: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  Degrees from (N / E): \_\_\_\_\_\_\_\_\_ | Station name: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  Latitude : \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  Longitude: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  Annual Velocity N: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  Annual Velocity E: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  Overall Vector Velocity: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  Degrees from (N / E): \_\_\_\_\_\_\_\_\_ |
| Station name: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  Latitude : \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  Longitude: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  Annual Velocity N: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  Annual Velocity E: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  Overall Vector Velocity: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  Degrees from (N / E): \_\_\_\_\_\_\_\_\_ | Station name: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  Latitude : \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  Longitude: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  Annual Velocity N: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  Annual Velocity E: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  Overall Vector Velocity: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  Degrees from (N / E): \_\_\_\_\_\_\_\_\_ |

Part 1:

1.) What types of data are readily available to you when you select the SEAT station in the website? (<http://pbo.unavco.org/station/overview/SEAT>)

2.) How is this data gathered? Explain the GPS process and how information is extrapolated from the signals passing from satellites to receiver.

3.)What factors do you think need to be considered when deciding where to install GPS monuments?

Part 2:

4.) Briefly describe the information given to you in the top 8 lines of the initial spreadsheet.

5.) What is the reference position? Why is this an important piece of data to have?

6.) Choose 2 random dates in the spreadsheet. On those dates, describe the position of the GPS unit in terms of North/South, East/West, and Up/Down (in terms of the reference position).

Part 3:

7.) Briefly describe what each graph tells you?

Part 4:

8.) What does each part of the trendline represent in your graphs? ( y = mx + b )

9.) What is the SEAT station's average annual velocity in the north-south direction?

10.) What is the SEAT station's average annual velocity in the east-west direction?

Part 5:

11.) Using either the graphical or mathematical method, what is the length and angle of the resulting vector?

**Discussion Questions**:

Be sure to discuss each of these questions with your group before you answer them on this sheet.

1.) What tectonic plates are located around the stations you and your group chose? Should the North American Plate be considered “rigid”? Why or why not?

2.) Which sections of the North American Plate would you expect to undergo the most regional deformation and metamorphism?

3.) Is there a relationship between the magnitude of the velocity vectors and their geographic location?

4.) What do you predict the future outcome of this movement pattern will be over time? Think in terms of millions of years.

5.) What relationship exists between these plate motions and earthquake and volcano activity in the area?

