

The instructions for this chapter have 5 main parts. Click each Part name to see the steps in that part.

[Part 1-Explore a PBO Station and Download Data](#)

View an installed PBO station and download position data

[Part 2-Explore GPS Data](#)

Learn what the numbers in the spreadsheet mean

[Part 3-Generate Time Series Plots](#)

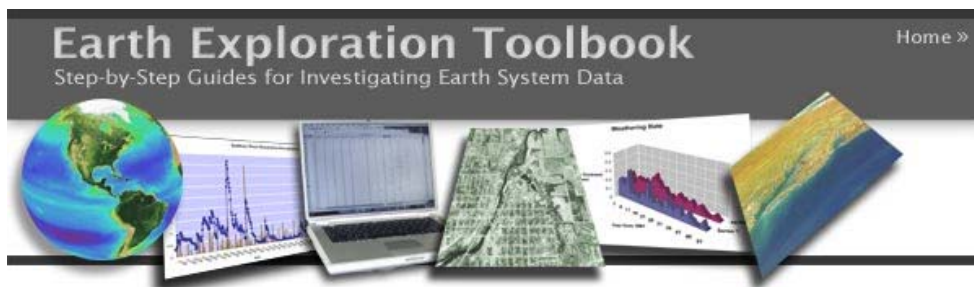
In a spreadsheet program, make graphs of GPS positions over time

[Part 4-Calculating Station Motion](#)

Add a linear trendline to the graph and use its equation to find the average daily motion of a GPS station

[Part 5-Mapping and Interpreting Regional Motion](#)

Plot velocity vectors on a map and use them to interpret the regional geology



Part 1—Explore a PBO Station and Download GPS Data

In any step, click the Show me link to reveal extra information. If you prefer a printout of the full set of instructions for this part, choose Print from the File menu.

Step 1-Explore the SEAT PBO GPS station

NOTE: The instructions in this chapter all refer to the SEAT (Seattle, Washington) GPS station. As the analysis procedures are the same for any GPS station, the instructions can serve as a model for analyzing data from any station. In a class setting, assigning unique stations to individuals or pairs of students will enable the class to compile a single map with many velocity vectors.

This list shows the four-character code and nearest city for stations in three geographic areas of the Pacific Northwest. If you are producing velocity vectors for multiple stations, choose roughly equal numbers from each of the three regions to facilitate comparisons among them.

Coastal stations

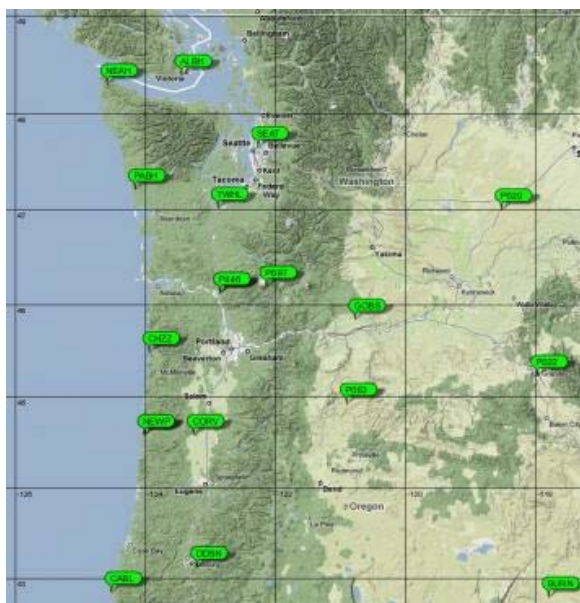
NEAH = Neah Bay, WA
PABH = Pacific Beach, WA
CHZZ = Tillamook, OR
NEWP = Newport, OR
CABL = Port Orford, OR

The Urban Corridor: Willamette Valley / Puget Lowlands

ALBH = Albert Head, CA
SEAT = Seattle, WA
TWHL = Tumwater, WA
CORV = Corvallis, OR
P446 = Kelso, WA
DDSN = Roseburg, OR

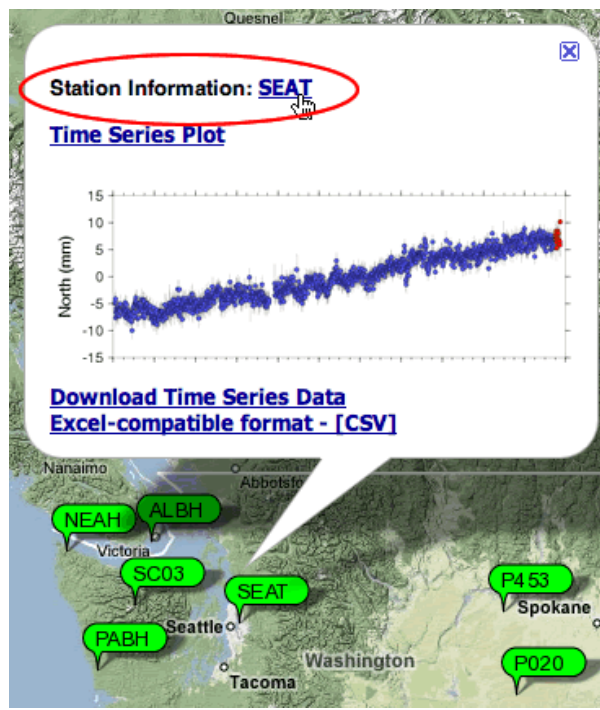
Eastern WA or Eastern OR

P020 = Lind, WA
GOBS = Goldendale Observatory,
WA
P063 = Shaniko, OR
P022 = La Grande, OR
BURN = Burns Junction, OR



Map of GPS stations in the Pacific Northwest. Click the image for a larger view.

1. Go to UNAVCO's [Data for Educators page](#) (will open in a new window)
2. In the Google Map interface, zoom in on the Pacific Northwest. Locate and click the label for the **SEAT** station.
3. In the information bubble that pops up, click the link for Station Information: **SEAT**



- In the new Location Map that comes up, choose the Satellite view and zoom in to take a close look at the PBO station location.
- Under **More links** on the left, click the PBO Station Home Page link.



- On the SEAT home page, click the image for a larger view of the SEAT station. Click the link for the Station Log and scan through the entries that describe the station.

Talk about it...

What factors do you think need to be considered when deciding where to install GPS monuments? Discuss some of the criteria for station placement that you think would ensure the most accurate, continuous data.

Step 2-Download SEAT GPS Dataset and Open it in a Spreadsheet

- Go back to UNAVCO's [Data for Educators page](#) and click the SEAT label in the map again.
- In the information bubble, click the **Download Time Series Data Excel-compatible format - [CSV]** link.
- Depending on your browser program and preferences on your computer, clicking this button may:
 - open the file directly into a spreadsheet program such as Excel
 - prompt you to save the SEAT.pbo.csv file onto your computer
 - show you the data in a browser window

In order to generate the graphs for this activity, you'll need to have the dataset open in your spreadsheet program. If necessary, use the tips below to save the file and open it. Note that the following instructions all refer to Microsoft Excel. If you are using another spreadsheet program, look for similar commands.

• If the file is saved on your computer,

- Try double-clicking its icon to open it.
- If it doesn't open into a spreadsheet by double-clicking it, open your spreadsheet program first, then choose **File > Open...** and browse to where you stored the file.
- If a data-import "Wizard" prompts you when opening the file, go with the default choices.
- If the Wizard gets it wrong, try again, indicating that the data are delimited by commas.

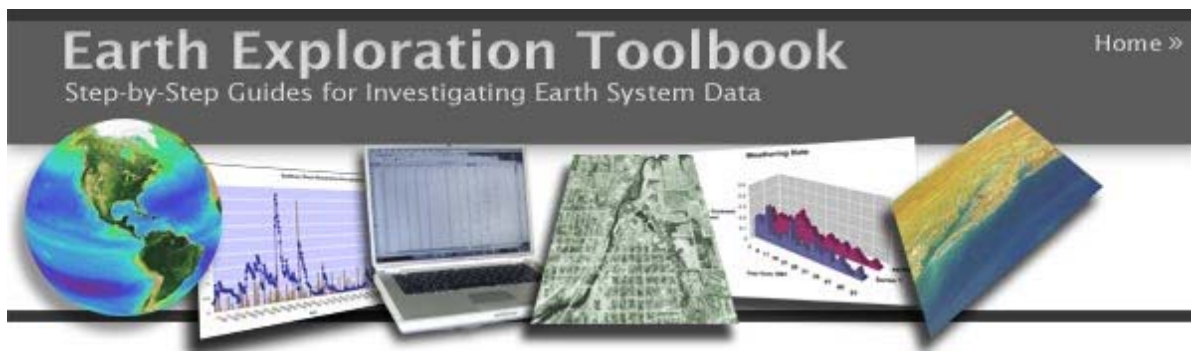
- If your browser displays the data in a browser window

1. Go back to the Data for Educators page and click the SEAT label in the map again.
2. Right-click (control-click with a one-button mouse) the **Download Time Series Data Excel-compatible format - [CSV]** link. Choose your browser's command to **Save Link As...**, then save the file to your computer.
3. Follow the instructions above to open the file.

- If your computer refuses to save the file, but you can see the data in an html page

1. Choose **File > Select All** then **Edit > Copy**.
2. Start Excel and open a new document. Select (highlight) Column A then choose **Edit > Paste**.
3. Choose **Data > Text to Columns...** When prompted, indicate that the data are **delimited by commas**. Apply Date, Number (with 2 decimal places), and Text formatting to the columns as appropriate.
4. Click Finish, then save the file as a Excel Worksheet (.xls).

	A	B	C	D	E	F	G	H
1	PBO Station Position Time Series							
2	Format Version	1.0.1						
3	4-character ID	P020						
4	Station name	DRYLND RSH WA2004						
5	Begin Date	6/17/04						
6	End Date	5/8/08						
7	Release Date	5/10/08						
8	Reference point	47.00220873 -118.565769 480.12308 meters elevation						
9	Date	North (mm)	East (mm)	Vertical (mm)	North Std. Dev	East Std. Dev	Vertical Std. Dev	Quality
10	6/17/04	0.81	-1.14	0.94	1.46	1.42	4.91	final
11	6/18/04	-1.15	0.81	-0.67	1.51	1.33	4.99	final
12	6/19/04	-1.03	-0.27	-2.61	1.57	1.35	5.17	final
13	6/20/04	-0.95	0.63	4.87	2.2	2.03	7.5	final
14	6/21/04	-1.74	-1.49	0.35	1.38	1.19	4.61	final
15	6/22/04	-1.1	0.54	6.33	1.48	1.29	4.93	final
16	6/23/04	0.14	2.43	2.95	1.52	1.38	5.01	final
17	6/24/04	-1.46	1.16	7.87	1.54	1.32	5.07	final
18	6/25/04	-1.25	0.42	5.19	1.7	1.44	5.71	final
19	6/26/04	-2.43	-0.21	5.98	1.7	1.64	5.67	final
20	6/27/04	-0.75	0.46	0.68	1.61	1.36	5.31	final
21	6/28/04	0.9	-1.14	2.4	1.64	1.43	5.46	final
22	6/29/04	-1.86	0.44	-0.29	1.67	1.45	5.57	final
23	6/30/04	-0.87	1.81	0.45	1.59	1.34	5.28	final
24	7/1/04	-1.29	-0.26	-1.13	2.31	1.97	8.35	final
25	7/2/04	-2.64	-0.55	4.43	1.57	1.36	5.22	final



Part 2—Explore GPS Data

In any step, click the Show me link to reveal extra information. If you prefer a printout of the full set of instructions for this part, choose Print from the File menu.

Step 1-Learn what the values mean

1. Take a look at the data at the top of your spreadsheet. The first eight rows of the file contain information about the SEAT GPS station.
2. Row 8 shows the **Reference Position** of the station: this is the zero point from which initial GPS positions were measured. The latitude, longitude, and elevation reported for the Reference Position describe the location of the single point where the unit was first installed.
3. Line 9 shows the column headings for the GPS position data.
4. Below row 9, the first column of data contains the dates for which GPS positions were collected.

The SEAT station was installed in 1995. Processed data from the station is available from 2004, when UNAVCO and its partners began to offer to offer it as part of the EarthScope Plate Boundary Observatory and PBO Nucleus project. Eventually, processed data will be available from PBO and PBO Nucleus GPS stations from their installation dates through the present.

5. Values in the columns labeled North (mm), East (mm), and Vertical (mm) represent the daily location of the station with respect to a reference point. All three measurements are necessary to characterize the position of the GPS unit in three dimensions.
 - The **North** column represents the distance (in mm) between the unit and the zero point in a North-South direction. Positive values indicate distances north of the zero point; negative values indicate distances south of the zero point.
 - The **East** column shows how far East (+) or West (-) of the zero position the unit is, and
 - The **Vertical** column shows how far above (+) or below (-) the zero point the unit is.

Each day, all the GPS position values are normalized to the new average position of the entire dataset...

As the GPS site moves over time, its average location since installation moves with it—if this doesn't make sense, explore the concept with a graphical example. For historical reasons, this continually changing average position is always used as the zero point from which measurements are made. Each day, the past positions of the unit are recalculated to show their distance from the new average location. The result is that position values indicate the distance from the unit's average position on the specific Release Date of the dataset.

Though the physical position of the unit measured on a specific date doesn't change over time, the distance to the point from which it is measured does. The result is that a single date will show different values for the unit's position over time as the zero point moves. Another result is that the initial measurements do not begin at zero.

6. The remaining columns show the standard deviation of the data values in each direction and a qualifier about the data quality. This activity does not address these concepts.

Daily Positions

The values given in the spreadsheet are daily positions for each GPS unit. These positions are 24-hour averages of location data collected every 15 seconds. Averaging removes position errors due to processes such as electronic noise in the receiver, deviations in expected satellite positions, and reflection and atmospheric delay of the GPS signals.

Step 2-Practice Interpreting the Data

1. Consider the meaning of this data record. Describe what it tells about the SEAT GPS unit.

Date	North (mm)	East (mm)	Vertical (mm)
6/30/06	-1.13	3.48	5.56

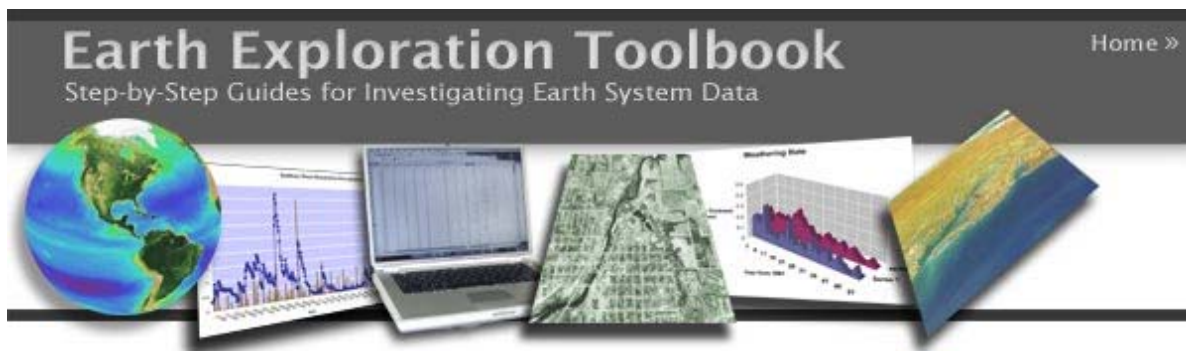
On June 6, 2006, the GPS unit was located 1.13 mm south of the zero point, 3.48 mm east of the zero point, and 5.56 mm above the zero point.

2. Check these data to interpret the location of the SEAT GPS unit one year later.

Date	North (mm)	East (mm)	Vertical (mm)
6/30/07	4.50	3.95	-12.33

On June 6, 2007, the GPS unit was located 4.59 mm north of the zero point, 3.95 mm east of the zero point, and 12.33 mm below the zero point.

3. Scan down the values in the columns of North and East position data. You'll see that the position of the GPS station changes slightly every day. Over longer periods, from the beginning of the records to the end, for instance, a general trend in the position of the GPS unit becomes obvious.



Part 3—Generate Time Series Plots

In any step, click the Show me link to reveal extra information. If you prefer a printout of the full set of instructions for this part, choose Print from the File menu.

Step 1-Consider How to Calculate the Rate of Station Motion

The rate of station motion is a measure of its change in position over time. Given that your spreadsheet describes a series of positions at different times, it seems that it would be simple to calculate the rate of station motion using the standard distance formula, $\text{Distance} = \text{Rate} * \text{Time}$. However, as daily positions of the station show substantial variation, the long term trend of the station's change in position is a much more valid measurement of a station's motion.

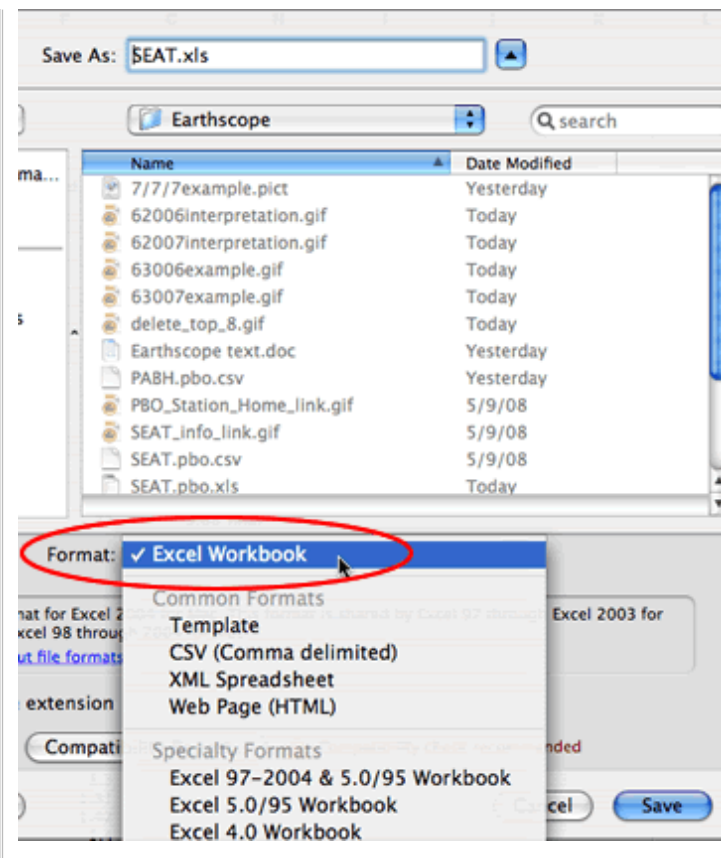
To calculate the velocity of a station, the GPS data are plotted into graphs comparing position to time. This type of graph is called a **Time Series Plot (TSP)**. The slope of the trend line of data in a TSP reveals the velocity of the station in a specific direction.

In this activity, you will construct a North TSP and an East TSP to calculate the station's velocity in each direction. You'll combine these two velocity vectors to calculate the total horizontal motion of the station. The vertical motion of the GPS station will not be explored in this activity, however, it is a useful parameter for analyzing crustal movement near glaciers, volcanoes, calderas, and normal & reverse faults.

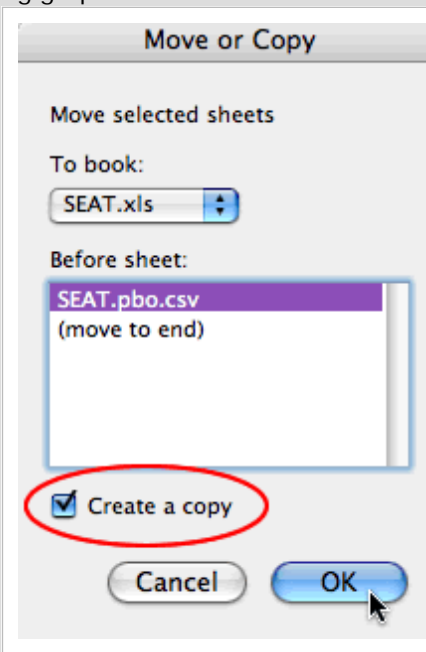
Step 2-Prepare your Spreadsheet for Graphing

1. Save your spreadsheet as an Excel Worksheet (.xls)

Choose **File > Save As...** In the dialog box, choose a location to save the file on your computer and use the pull-down menu to change the format to Excel Workbook.



2. Apply appropriate formats to the first four columns of data.
 - Click in a column header to select the column.
 - Choose **Format > Cells...**
 - Select Date for the first column and Number, with 2 decimal places for the next three columns.
3. Choose **Edit > Move or Copy Sheet...** and copy your current worksheet onto a new worksheet for making graphs.



4. On your second worksheet, delete the top 8 rows of information to make it easier for you to generate graphs.

Click and drag your cursor in the number column at the far left to select rows 1

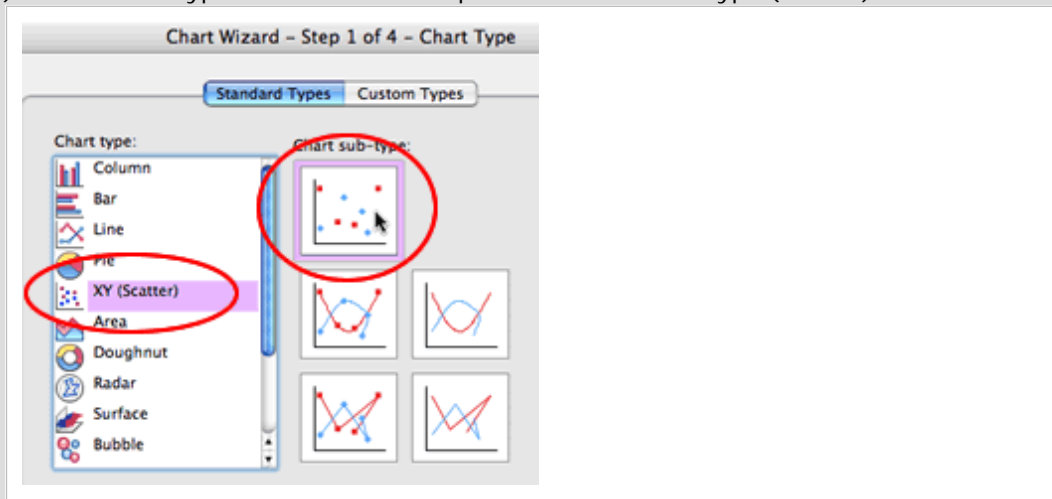
through 8, then select **Edit > Delete**

	A	B	C	D	E	F
1	PBO Station Position Time Series					
2	Format Version 1.0.1					
3	4-character ID SEAT					
4	Station name SEAT_PNGA_WA1995					
5	Begin Date		1/6/04			
6	End Date		5/8/08			
7	Release Date		5/10/08			
8	Reference point 47.65397704 -122.309475 44.22568 meters elevation					
9	Date	North (mm)	East (mm)	Vertical (mm)	North Std. Dev.	East Std. Dev.
10	1/6/04	-5.01	-8.53	-2.77	1.55	
11	1/7/04	-4.72	-8.44	5.14	1.73	
12	1/8/04	-4.18	-8.08	-1.58	1.64	

5. Save your file again.

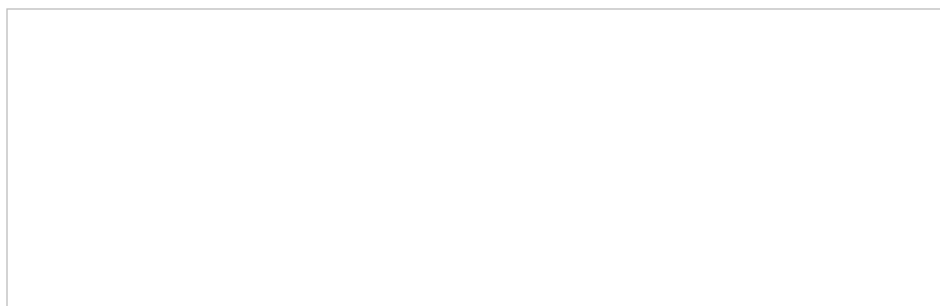
Step 3-Generate a Time Series Plot (TSP) for the North Position Data

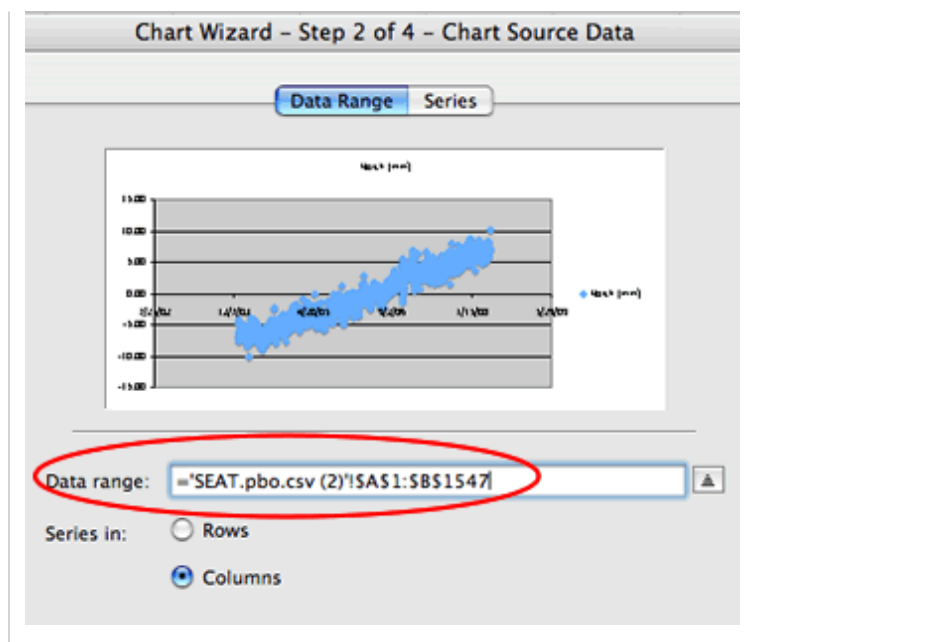
1. Click the column A header to select the Date column.
2. Control-click (Command-click on a Macintosh) the column B header to add the North column to your selection. NOTE: When you come back to these instructions for the East Time Series Plot, use this same method to select two columns of data that are not directly next to one another.
3. Click the Chart Wizard icon or select **Insert > Chart**
4. Make a graph that shows Dates on the X axis and North Positions on the Y axis. Choose the XY (Scatter) under Chart Type and the first example under Chart Sub-type (scatter). Click Next.



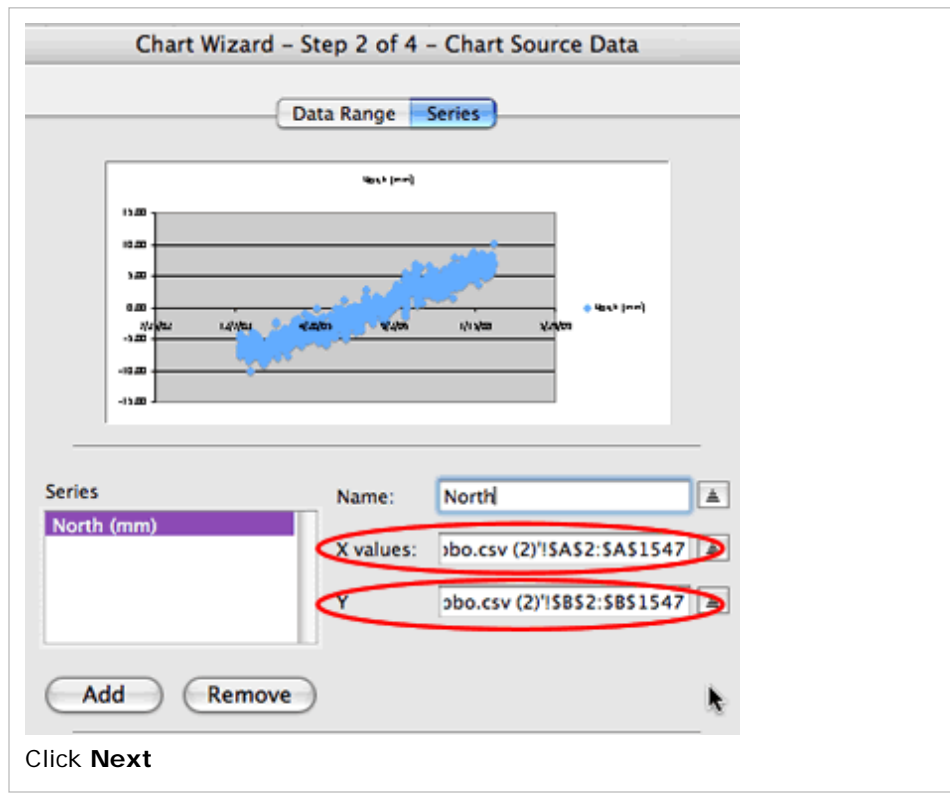
Based on your data selection, Excel's Chart Wizard tries to interpret what kind of graph you'd like to create. Sometimes it is right, but it can also be wrong... If you don't end up with the graph you expect, you'll need to come back up to this point and inspect the cell addresses of the **Series** that will be plotted on the X and Y axes.

In Step 2 of 4 of the Chart Wizard, the Data Range tab will show the cell addresses of all the cells you selected. For the North example, this includes addresses in columns A and B. As your data are in columns, the **Columns** radio button should be selected.



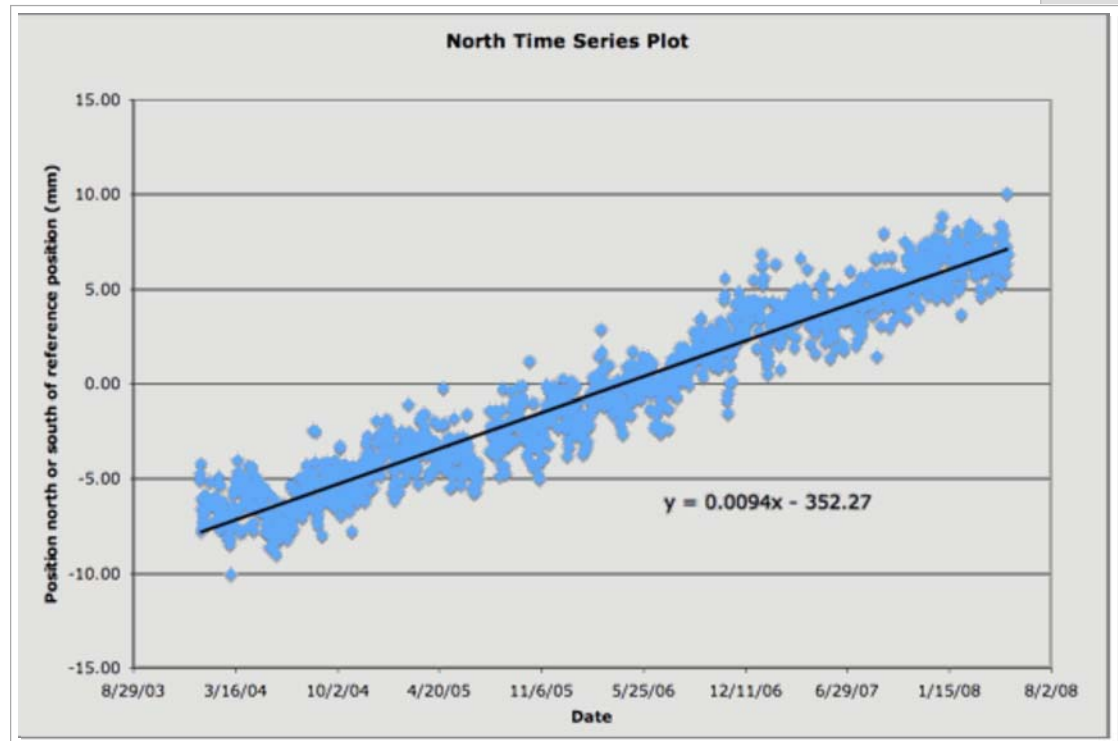


Still in Step 2 of 4, click the **Series** tab to check or modify which data series will be plotted on each axis. You want to plot **Date** values (cell addresses from column A) on the **X** axis, and **North** positions on the **Y** axis.



5. In Step 3 of 4 in the Chart Wizard,
 - click the **Titles** tab and give descriptive names to your graph and both axes.
 - under the **Legend** tab, uncheck the **Show Legend** box as legends have no meaning for scatter plots
 - choose your own preferences for options under the other tabs.
6. In step 4 of 4 in the Chart Wizard, click the radio button to place the chart **in a new sheet** and click **Finish**.
7. Take a look at your graph. The x-axis may appear in the middle of the graph, but if you have Dates along the X axis and North positions on the Y axis, choose **File > Save** to save your work.

If your graph shows something very different from the one below, back up to the troubleshooting tips under the blue box above. Enter the data series manually to generate an appropriate graph.



Step 4-Clean up the graph

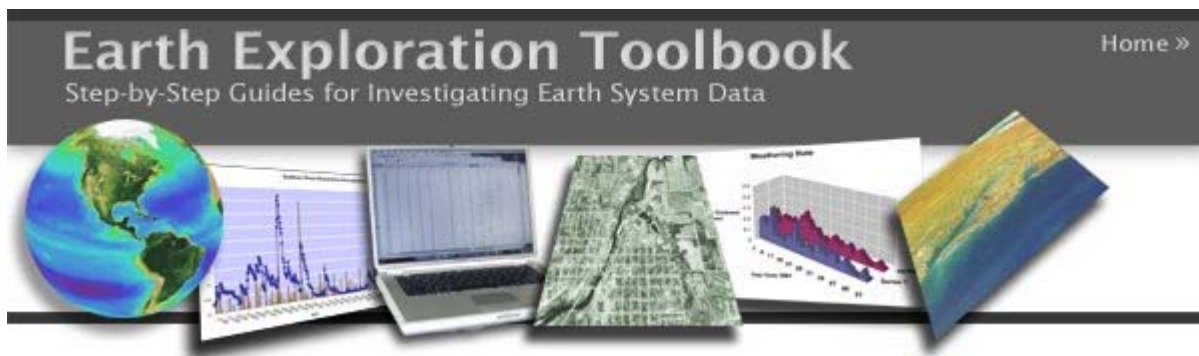
1. Change the placement where the x-axis crosses the y-axis.
 - Double-click any number on the **Y axis**.
 - Click the **Scale** tab.
 - For the **Value (x) axis crosses at**, type in the minimum Y value from your graph, for example **-10**, then click **OK**.
2. If necessary, adjust the number format and grid units of the x-axis.
 - Double-click any date on the x axis of your graph.
 - If your dates appear in an odd format, click the **Number** tab and select **Date**. Under **Type** select the mm/dd/yy option.
 - If your data are 'squished' in the middle of the graph, click the **Scale** tab and change the values in the x axis scale so the data fill the graph.
 - Make any other adjustments as desired to change the appearance of your graph then click **OK**.
3. Save your file.

Talk About It...

What does this graph tell you? Think about and discuss what the graphical representation of the data indicates about the location on Earth where the data were collected.

Step 5-Generate a Time Series Plot (TSP) for the East Position Data

Follow the procedure outlined in Steps 3 and 4 above to create the East positions Time Series Plot for the SEAT GPS data.



Earth Exploration Toolbook

Step-by-Step Guides for Investigating Earth System Data

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Part 4—Calculating Station Motion

In any step, click the Show me link to reveal extra information. If you prefer a printout of the full set of instructions for this part, choose Print from the File menu.

Step 1-Add a Linear Trendline to the Time Series Plots

1. On the sheet that contains each graph, choose **Chart > Add Trendline...**
2. In the **Type** tab, under Trend/Regression type, choose **Linear**.
3. Click the **Options** tab. Check the box next to **Display equation on chart** and click OK.
4. On your graph, click the equation to select it and move it to where it is clearly visible. If desired, increase the font size so the equation is readable.

Step 2-Calculate a Velocity Vector for Each GPS Time Series Plot

1. The equation of the trendline generated from each TSP is in the form $y = mx + b$. In this equation,
 - **y** represents the North (or East) position in millimeters
 - **m** represents the slope of the line
 - **x** represents time in days, and
 - **b** represents the y intercept. This value is not meaningful for these calculations.

For this dataset, **m** is the velocity of the station in mm/day. Positive slope values indicate motion to the north (or east); negative slope values indicate motion to the south (or west). Velocity directions depend upon which data were used to generate the TSP.

To calculate the **average annual velocity** of GPS stations in either direction, multiply the daily velocity by 365.25 days/year.

2. What is the SEAT station's average annual velocity in the north-south direction?
3. What is the SEAT station's average annual velocity in the east-west direction?

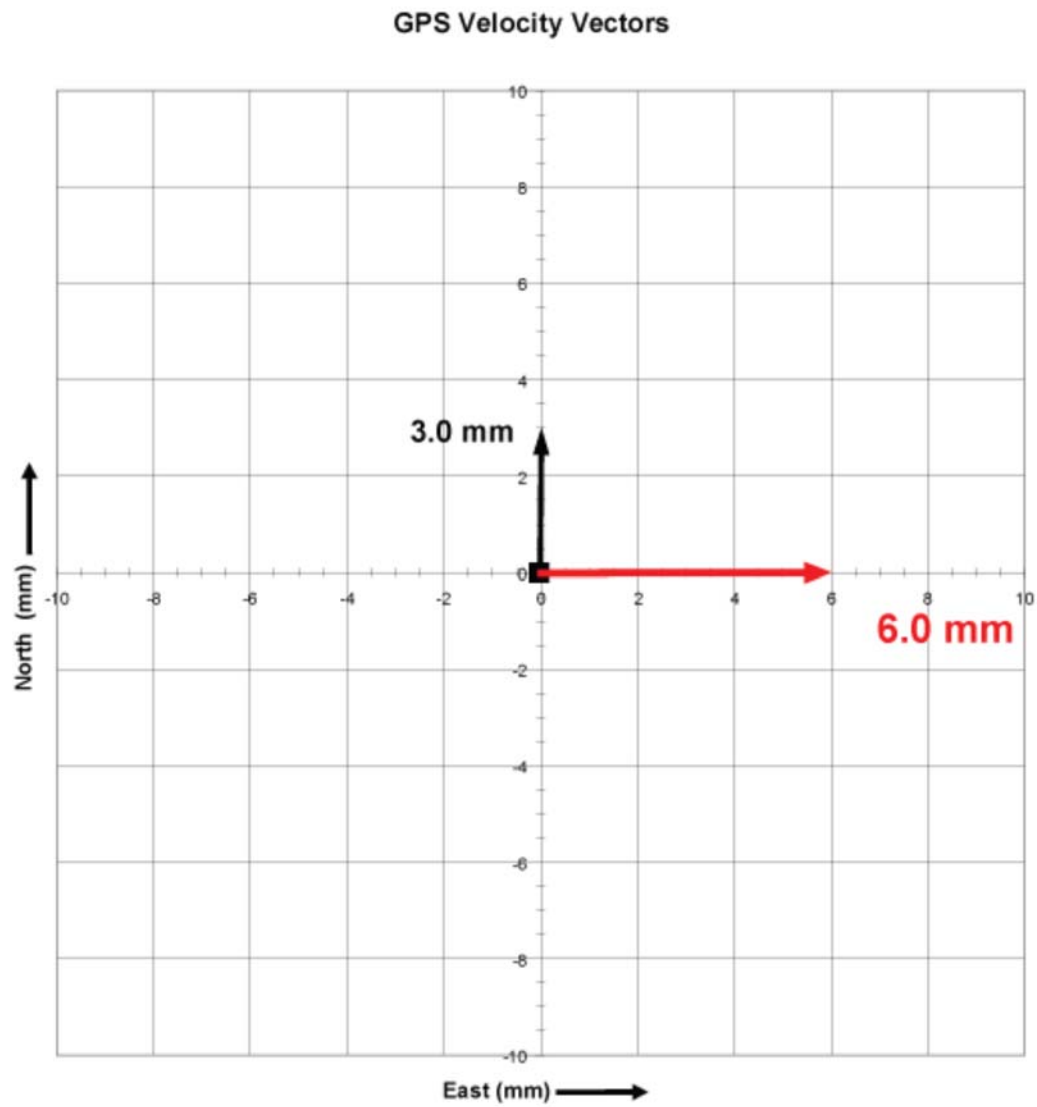
NOTE: You can find an online calculator by typing an equation into an Internet search box.

Step 3-Determine the Yearly Motion of the GPS station.

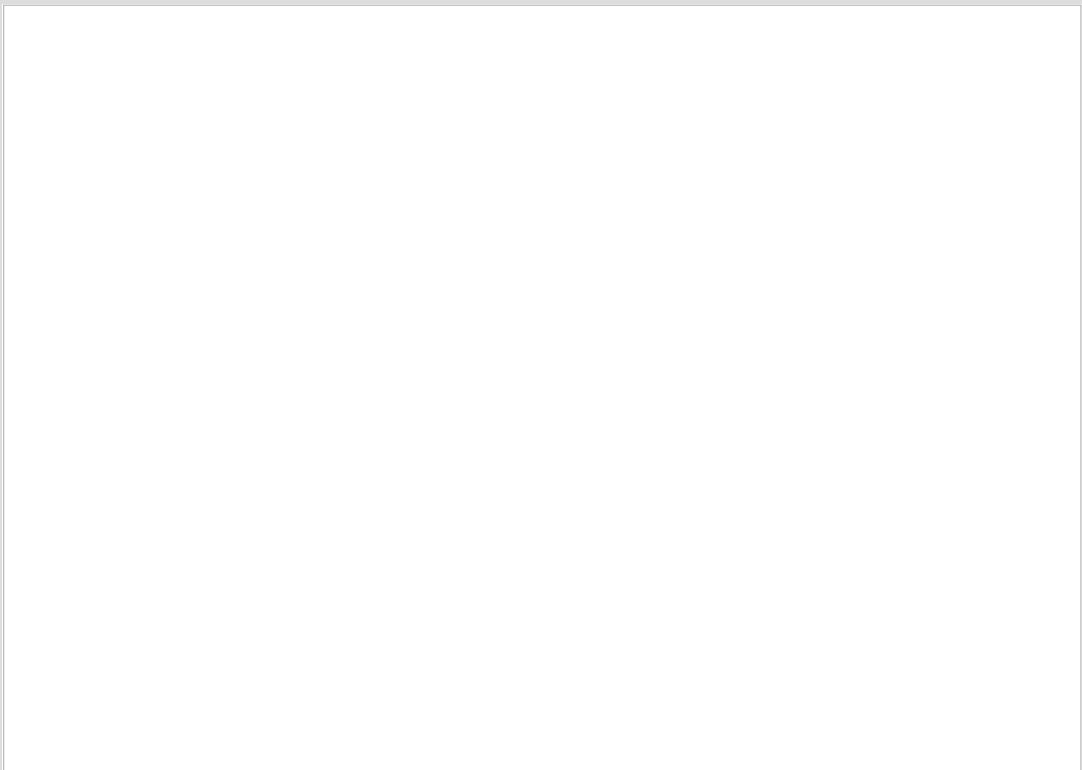
The actual horizontal motion of a GPS station over a year is represented by the vector that results by adding north and east velocity vectors together. Work through examples of both methods used to determine the annual velocity. The examples will use average annual velocities of 3 mm/yr to the north and 6 mm/yr to the east.

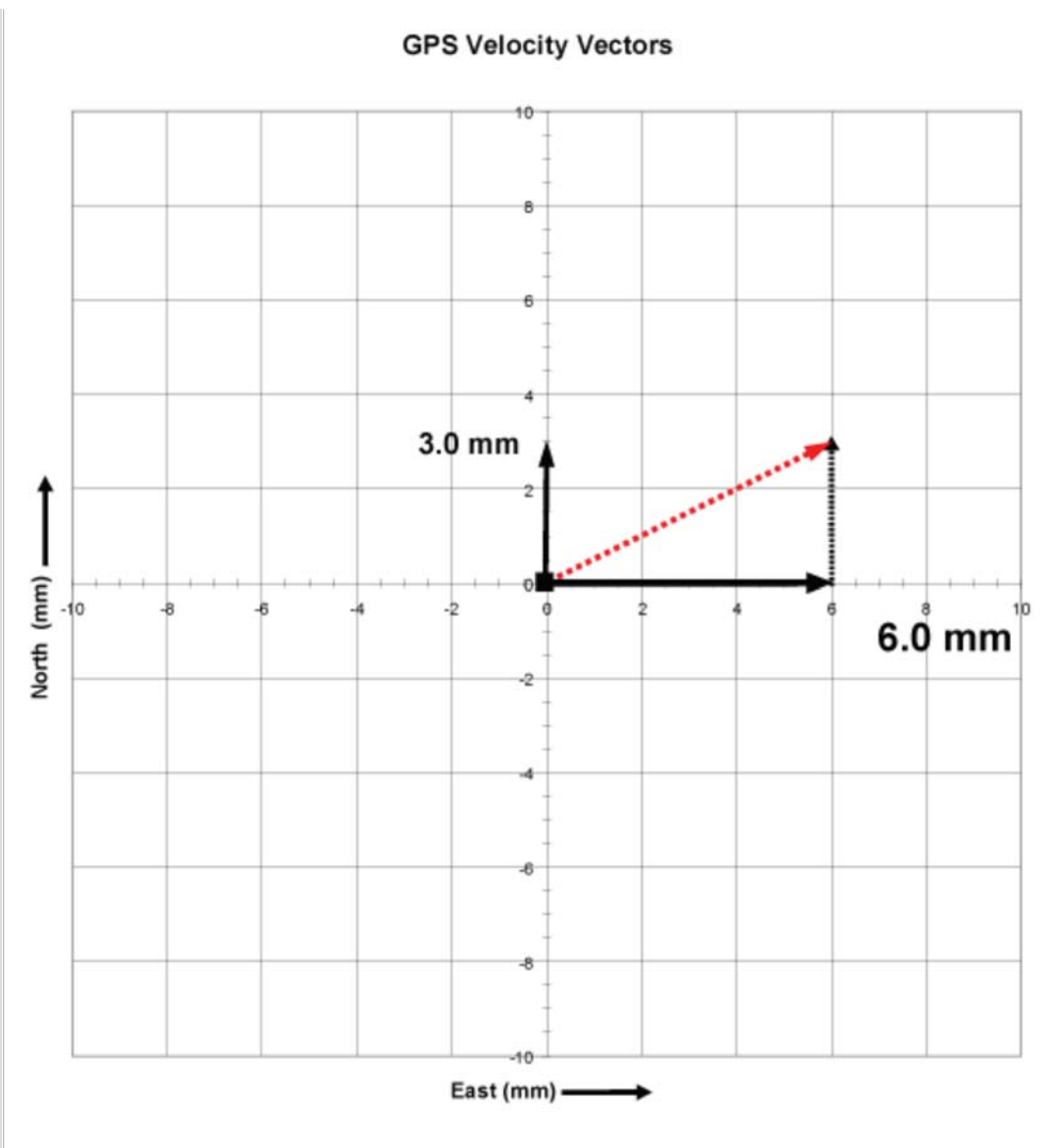
Graphical "Head-to-Tail" Method

1. Draw an orthogonal set of X and Y axes on a piece of graph paper. Scale each axis from -10 to +10. Be sure to use the same distance per unit on both axes.
2. Draw the north-south vector on the Y axis and the east-west vector on the X axis.



3. Add the vectors together to graphically get the resultant vector.





4. To characterize this vector so you could overlay it on a map, measure its length in the same units you used on the graph paper. Use a protractor to measure the angle from North.

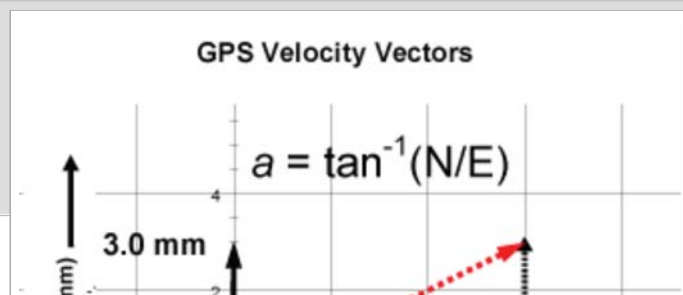
Mathematical Method

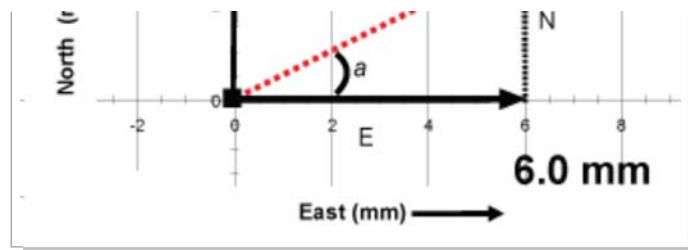
Quantitative values for both the rate of motion and direction (the two components of velocity) of a GPS station can be calculated from the north and east velocities.

1. Calculate the length of the vector (the rate of motion) using the Pythagorean Theorem
 $a^2 + b^2 = c^2$

$$\begin{aligned} a^2 + b^2 &= c^2 \\ 3^2 + 6^2 &= c^2 \\ 45 &= c^2 \\ \text{sq. root } (45) &= c \\ 6.7 \text{ mm/yr} &= c \end{aligned}$$

2. 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.





<http://www.carbidedepot.com/formulas-trigrightright.asp>

<http://www.csgnetwork.com/righttricalc.html>

http://www.calculator.com/calcs/calc_sci.html

$$a = \tan^{-1}(N/E)$$

$$a = \tan^{-1}(3/6)$$

$$a = \tan^{-1}(.5)$$

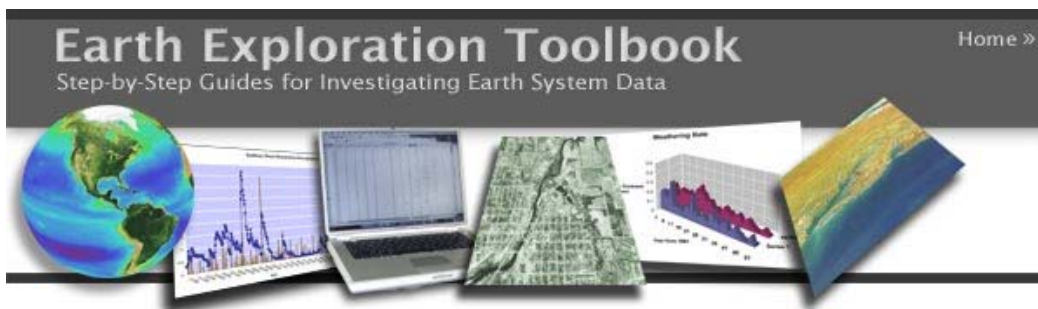
$$a = 26.6 \text{ degrees}$$

The solution indicates the direction of motion in degrees from east. Generally, when mapping vectors, it is easier to use degrees from north. Calculate the angle from north by subtracting angle a from 90 degrees.

$$\text{Direction from North} = 90 - a$$

$$\text{Direction from North} = 90 - 26.6$$

$$\text{Direction from North} = 63.4 \text{ degrees}$$



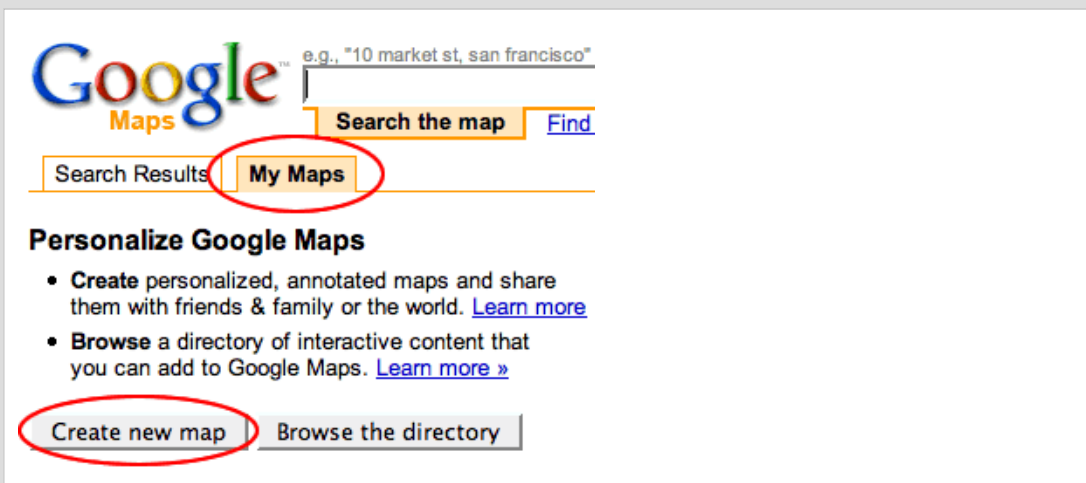
Part 5—Mapping and Interpreting Regional Motion

In any step, click the Show me link to reveal extra information. If you prefer a printout of the full set of instructions for this part, choose Print from the File menu.

Step 1-Plot your velocity vector(s) on a map

The velocity vector you produced is useful as a graphic element to represent plate motion on a map. The scale of motion for your vector must be exaggerated compared to the map scale, but its direction and length will provide a clear visual representation of the motion recorded at that location.

- To plot your vector, you'll access a base map that shows the locations of the GPS stations. **Select** (highlight) and **Copy** the following line of text:
http://www.unavco.org:8080/cws/modules/pnw_eo.kml
- Go to [Google Maps](#) (will open in a new window).
- Paste the text you copied above into the "Search the map" field (choose **Edit > Paste**) then click the "Search Maps" button.
- Click the **My Maps** tab, then click **Create new map**.



- Google Maps requires users to have a Google Account to use their services. If you already have an account, sign in.

If you have appropriate permission to set up online accounts, click the **Create an account now** link and proceed through the instructions. If you can't set up online accounts or you are not comfortable with the Google agreement, complete this portion of the activity on a hard copy map.

- Give your map a name and decide if you want it to be Public or Unlisted. Click the placemarks to find the station for which you produced the annual velocity vector.
- Select the "Draw a line" tool and click once on the location that represents your GPS station. Note that as you move your cursor away from the start point, the length of your line is shown on the screen. To finish a line, double-click where you want it to end. Draw a few practice lines so you are comfortable with the tool, then delete them.
- A convenient scale to use for drawing velocity vectors is 1 mm/year = 10 miles. Thus, a rate of 6.9 mm/year would have a vector with a length of 69 miles. Note the length (in miles) of the vector you are plotting.
- To reproduce your vector at the correct angle from north, hold a protractor up to your screen, or open an online protractor in another window.

- Open an [online protractor](#) in a new window. Move the window to the side of your monitor that you use the least.

2. Find the correct angle from north on the protractor. Align the edge of a piece of paper along that angle and use two very small pieces of tape to tape it onto your monitor.
 3. Go back to your map. When you draw your velocity vector, make certain that it is parallel to the edge of the paper.
10. Select the "Draw a shape" tool and practice drawing a few small triangles. Delete them after you are familiar with how the tool works. Note that you can only move one point at a time after a shape is drawn.
 11. Complete your vector by drawing a triangle whose point is on the extreme end of the line you drew. Make sure that the arrow head does not make your vector longer than the line you drew.

Step 2-Interpret Motion and Deformation from Vectors

Compile several velocity vectors in the region onto a single map. Even if you are working alone, you can download data and produce velocity vectors for a few additional stations fairly quickly—you'll likely be surprised at how much more easily and quickly you can complete the task the second and third times you do it!

Talk about it

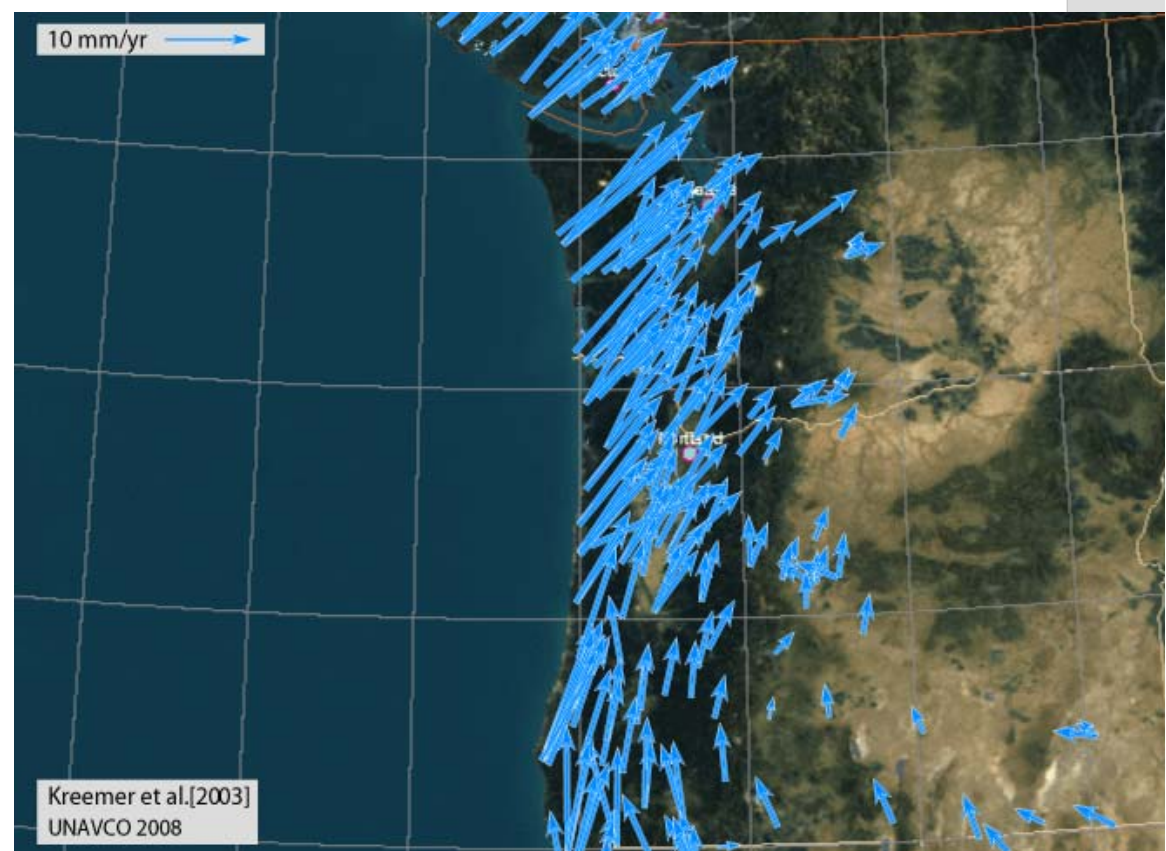
Examine the pattern of velocity vectors on your map. Consider what the differences in the vectors indicate about that portion of the North American plate.

- Should the North American plate be considered "rigid"?
- Which portions of the plate would you expect to be experiencing the most intense deformation and regional metamorphism?
- Is there a relationship between the magnitude of the velocity vectors and their geographic locations (coastal, urban corridor, or Eastern)?
- What possible outcomes can you imagine if different portions of the plate continue moving at different rates over a million years?

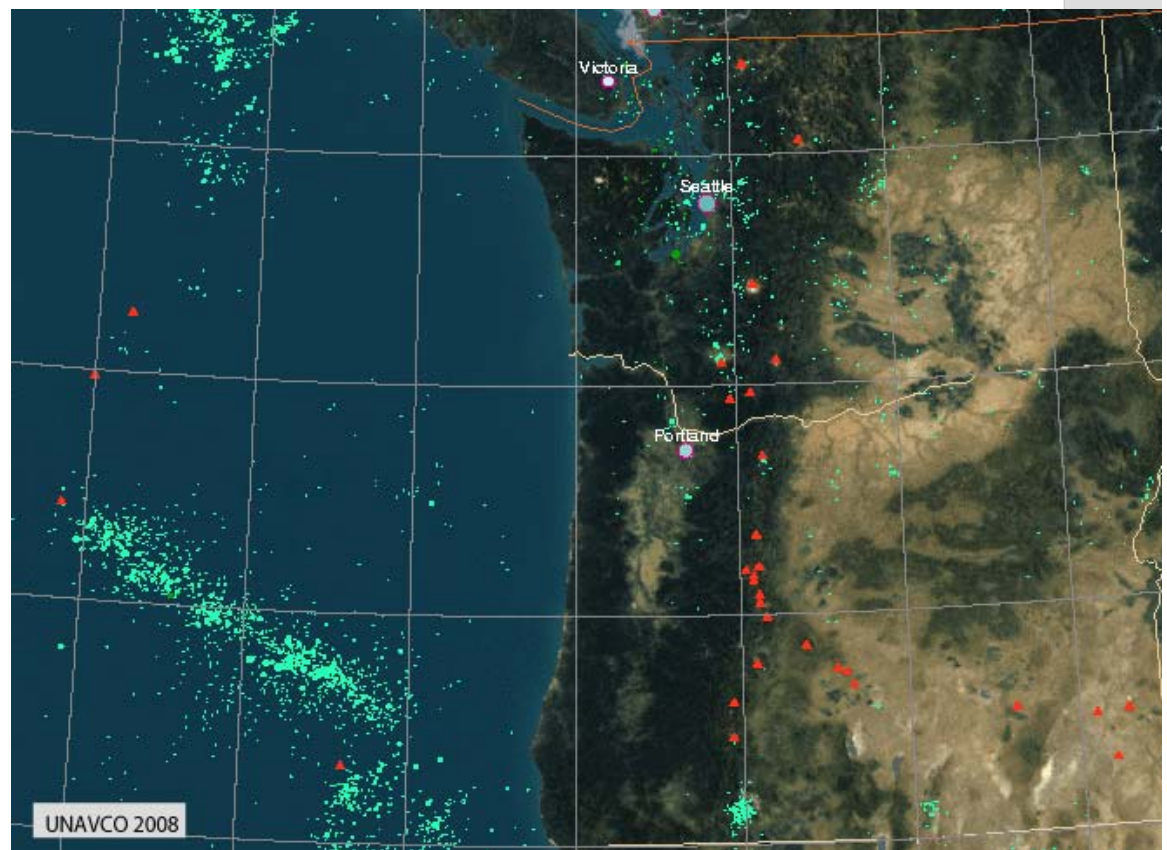
Step 3-Consider Other Geologic Processes and Features in the Region

Plate tectonic researchers make and study maps that are similar to the one you produced. Automated data processing and mapping functions allow them to plot and view velocity vectors for many GPS stations at once.

1. Show and examine the map below. Revisit the **Talk About It...** questions from above in light of additional information on the map.

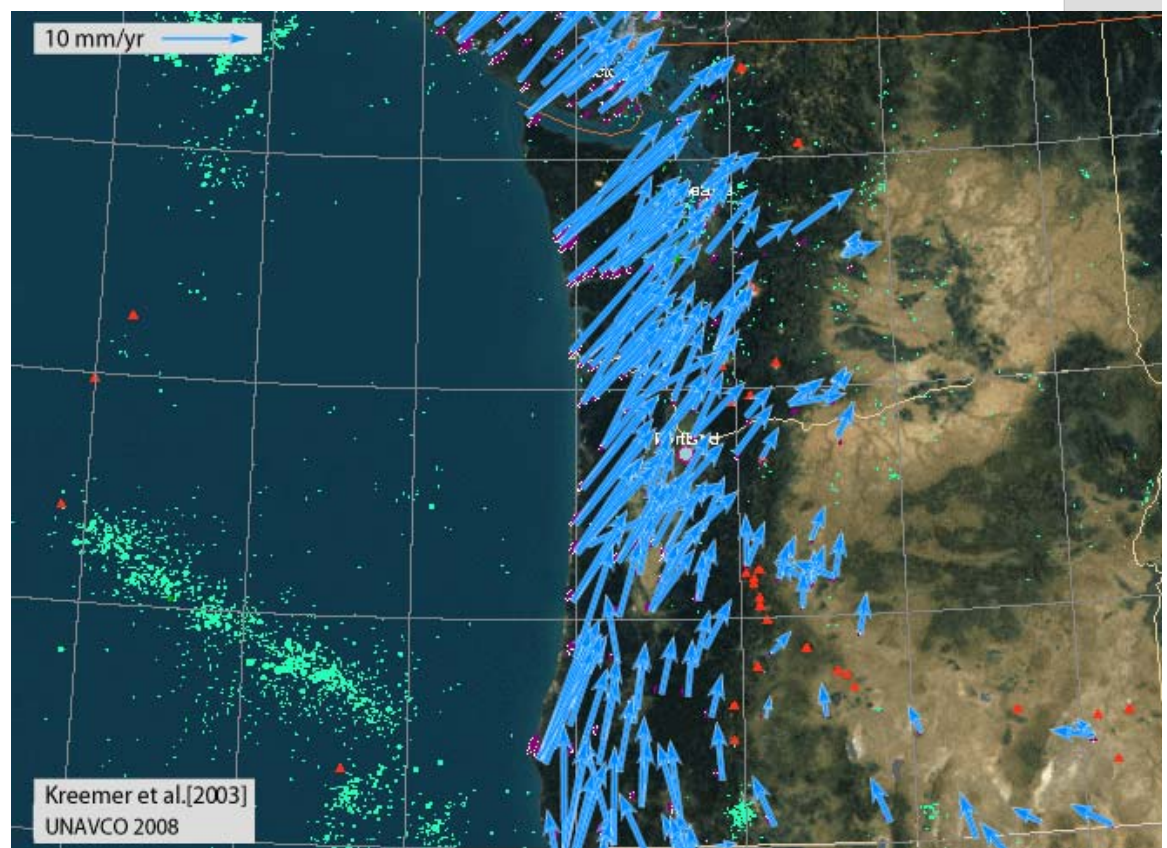


2. What other data would you need to interpret the geologic setting of the region?



Light green dots show the locations of historic earthquakes in the region. Red triangles show locations of volcanoes.

3. How does the location of earthquakes and volcanoes complement the story revealed by the velocity vectors?
4. What relationships do you think might exist among earthquakes, volcanoes, and motion?



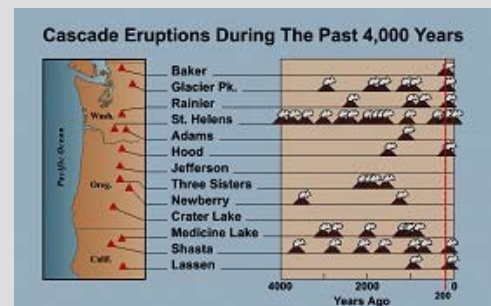
5. Can you detect a relationship between the locations of earthquakes and the velocity of the GPS stations?
6. Describe how the information on the final map refines your mental model of processes near the Cascadia Subduction Zone.

Use the additional information below to help integrate your knowledge of station motion, seismic hazards, and volcanic hazards.

Cascadia Subduction Zone Seismic Hazards Three types of earthquakes are associated with the CSZ: large subduction zone earthquakes, small to moderate deep earthquakes in the Juan de Fuca plate, and small to moderate shallow earthquakes in the North American plate. Subduction zone earthquakes occur on the plate interface between the subducting plate and the overlying plate. The top of the subduction zone can remain locked for years, before slipping in magnitude 9+ megaquakes. The last subduction zone earthquake was in 1700. This earthquake was hypothesized by Brian Atwater of the United States Geological Survey. He studied Japanese paintings, writings, records, and Native American oral histories to piece together the records of a tsunami that struck Japan and the Pacific Northwest in 1700. He traced the evidence back to a large earthquake on the Cascadia Subduction Zone. Because subduction zone earthquakes have the greatest magnitudes and are the most likely to be accompanied by a tsunami, they are the most dangerous hazard for the Pacific Northwest. Significant hazards are also associated with deep and shallow earthquakes, though these are not as catastrophic.

Volcanic Hazards

A line of active volcanoes called the Cascades parallels the coast of the Pacific Northwest. Volcanic chains such as this one commonly form above subduction zones: as a plate plunges into the mantle, higher temperatures and pressures begin to partially melt the plate at about 100 km depth. These conditions cause the plate to "sweat" out volatiles, and these enhance melting of the surrounding materials. The melted material—magma—rises to the surface, resulting in a line of volcanoes parallel to the offshore trench where one plate moves beneath the other. The last major eruption in the Cascades volcanoes was Mount St. Helens in 1980. Mount St. Helens is not the only active Cascade volcano; all of the Cascade volcanoes are capable of having a major eruption. There is significant risk associated with a volcanic eruption, so careful monitoring is necessary, and scientists need continued support in their efforts to predict the next eruption. Both the United States Geological Survey (USGS) and EarthScope have installed instrumentation on the Cascade volcanoes.



Eruption chart for the Cascade Volcanoes. Most of the Cascades have erupted during the past 4,000 years, some have erupted multiple times.

New models for tectonic motions

The concept that Earth's crust consists of rigid plates that move relative to one another is a unifying theory that connects many seemingly unrelated geologic phenomena. These include the location of linear mountain chains, volcanoes, earthquakes, and deep-sea spreading ridges. The new continuous high-precision PBO data are allowing scientists to further refine the plate tectonic model, and test hypotheses concerning the nature of boundary zones and the rigidity of plates. For example, as the Juan de Fuca plate subducts under the North American plate, it does so at an angle to the trench (subduction is to the northeast, while the trench is roughly oriented north-south) and rotates the upper-plate, breaking it up into smaller rotating blocks. In addition, Oregon is squeezing against Washington, which is responsible for upper plate shallow earthquakes and faults, such as the 2004 Nisqually earthquake.