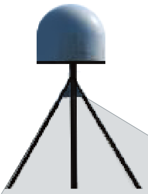
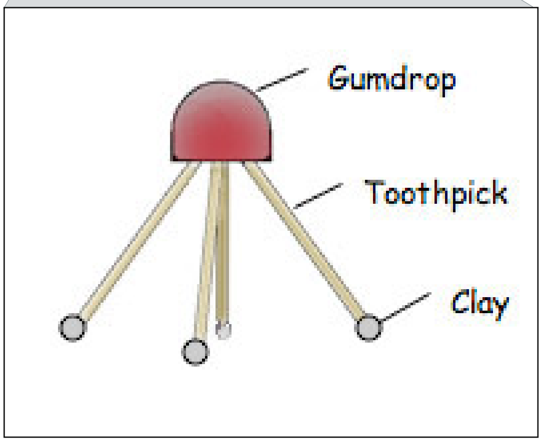


Activity—Cascadia GPS (gumdrop GPS)

Students build gumdrop global positioning system (GPS) stations while learning how GPS satellites can determine locations of points on Earth's surface.



Science Standards (NGSS; pg. 287)

- From Molecules to Organisms—Structures and Processes: MS-LS1-8
- 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: 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

Students then analyze data from **EarthScope's Plate Boundary Observatory** (PBO) to discover:

1) Precise measurements of Earth processes are often "noisy" but, over several years, trends in scientific data can still be deciphered to provide critical insight into how our planet works.
2) GPS stations on the Pacific Coast are moving toward the northeast at about 15 mm/year while stations in the Puget Lowlands and Willamette Valley are moving northeast at about 7 mm/year and stations east of the Cascades are not moving.
3) These velocities result from compression (squeezing) of the Pacific Northwest active continental margin near the boundary between the North American and Juan de Fuca plates. This boundary is currently "Locked and Loading" as both plates deform near the plate boundary.
4) Elastic energy stored as the Pacific Northwest continental margin is compressed will be released in the next Cascadia megathrust earthquake.

Additional Resources on this DVD relevant to Cascadia GPS

VIDEO—demonstrations of this activity are in the in the **RESOURCES** folder for this activity

GPS_INTRO Activity_VideoDemo_Part1&2.mov &

GPS_INTRO Activity_VideoDemo_Part3-5.mov

(or online:**http://www.iris.edu/hq/programs/education_and_outreach/animations#GPS** & scroll down)

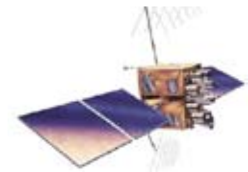
ANIMATIONS—about using GPS to monitor tectonics are in the folder:

2. ANIMATIONS Cascadia Earthquakes & Tsunamis

Cascadia GPS & ETS > Subduction_GPSevidence_LandJumps.mov (and others)

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 the Earth within a few meters, and people are most familiar with GPS units in cars to help with directions, or for recreation, like hiking. A specific type of GPS called **differential GPS**, or dGPS, is extremely precise and can be used to show tectonic plate movement of millimeters!

Basically, there are 24 GPS **satellites** cruising 12,000 miles above the Earth moving at about 7500 kilometers an hour. That's almost 2 kilometers a second – yes, a second. The satellites send out radio wave signals in all directions.



Receivers 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. Computers can then translate small changes to large changes by looking at larger intervals of time.

dGPS is so much more accurate because it uses some very fancy computing to take out errors due to the atmosphere and inaccurate clocks, for example, The picture on the student handout shows a **GPS Monument.** 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 modem to UNAVCO for further processing. Scientists can then use long-term positional data to interpret plate motions and boundary interactions.

LESSON PLAN

This is a multi-day lesson, and could take 2 – 3 lessons (hour long) to complete.

Introduction:

Have students stand up and try to only move a millimeter. With every movement, say it's too much. This will impress upon them the accuracy of the dGPS system. The satellite system can detect movements of *parts of continents* moving millimeters.

PART I: Building a GPS 'Monument'

Materials:

- Sharp toothpicks work best.
- Gumdrops can be found at larger stores with bulk candy.
- Only small amounts of modeling clay are necessary.
- Transparencies can be cut into quarter sheets.

Procedure:

1. Building the monument 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 station movement in Part III.
2. Have students place gumdrop monument in middle of transparency sheet. Clay represents the concrete that 'glues' the monument to Earth's surface.
3. If doing the activity over two days, have students write their name on a piece of scrap paper and place gumdrop monument on top.

PART II: Pinpointing Location

Supplies:

- 3 ring stands (without rings)
- 3 'satellites' to place at 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 stands
- gumdrop monument from Part I

Demonstration Procedure: (use video clip to get full setup)

1. Premark locations of ring stands such that all 3 strings meet in one location on table surface.
2. Explain that satellites are flying above Earth's surface at same altitude and ring stands represent that height.
3. Explain relationship between gumdrop monument (built in Part I) and satellite – they 'talk' to each other and establish the *distance* between them.
4. The string represents the distance between the satellite and monument.
5. Have a student come and move one string (held tautly) in all directions to indicate that the *distance* is known, but the *direction* isn't.
6. Have another student move a 2nd string around and note where strings intersect – there should be 4 possible places this happens. Emphasize again that the only known entity is the *distance* between the monument and satellite.
7. Have a third student move the 3rd string to show where all 3 intersect. There should be two places – one on the Earth surface, and one far up. 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.

Note: activity can be done in groups following same directions.

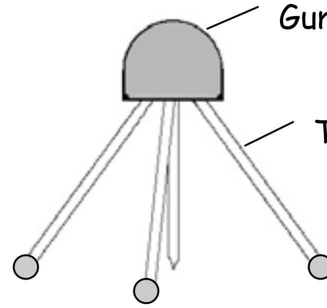
CASCADIA GPS ANALYSIS Name: ____________________________ Class: ___

Today's Date: _________

PART I: Building a GPS 'Monument'

Materials: 4 toothpicks, 1 gumdrop, modeling clay, ruler, 1/4 sheet transparency

Procedure:



1. Insert 3 toothpicks diagonally into the gumdrop. These will act as the legs.
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). The clay will act as a cement to hold the GPS station in place. In reality the legs of a GPS station are cemented deep into the ground so that if the ground moves, so does the GPS station.

PART II: Pinpointing Location

1. What do the tops of the stands (not the stand itself) represent?

2. What does the length of string represent?

3. How many satellites are needed to pinpoint the location of a spot on the Earth?

4. Why wouldn't one or two satellites work? Can you draw a diagram to show this?

5. Draw the setup of the demonstration in the space to the right.

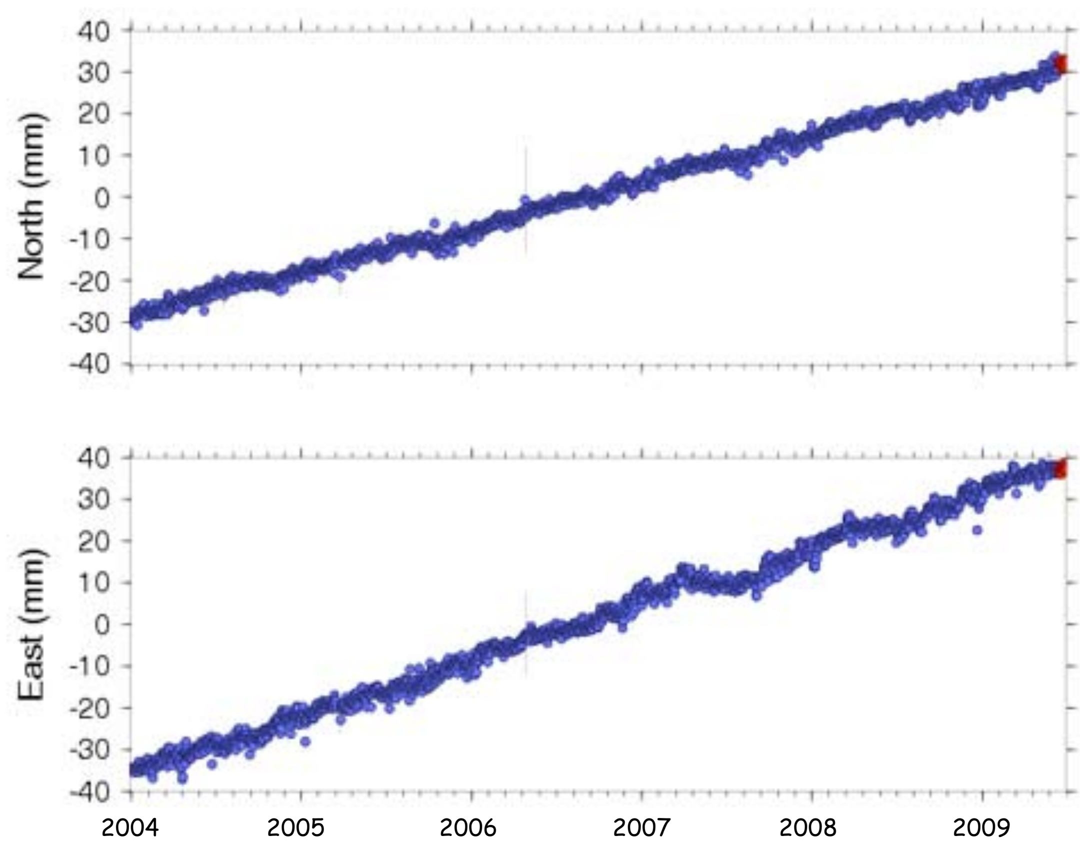
PART III: Measuring Cascadia GPS/Tectonic Movement

Materials: Colored pencil (for drawing trend lines), ruler

dGPS stations collect data in 3 parts which are shown in **Time Series Plots** (**Time Series or TSP)**, where time is always on X-axis:

- North/South movement over time (abbreviated N/S)
- East/West movement over time (abbreviated E/W)
- Height (up/down) movement over time (not shown in this activity)

Pacific Beach, Washington GPS Data



6. What are the units of measurement for these time series? Circle the best choice.

a) centimeters and months b) meters and years
c) millimeters and years d) centimeters and years

7. How long of a time period is shown in the time series plots?

a) 3 years b) 4 years c) 5 years d) 5 1/2 years

8. How far North did the Pacific Beach station move on the time series? Hint: calculate the *change* in position over time.

    a) 30 millimeters b) 40 milllimeters
    c) 60 millimeters d) 90 millimeters

9. Did the station move South in the same time period?

    a) No, because trend line only moves up.
    b) Yes, because trend line moves down.
    c) Can't tell from time plots given.

10. How far East did the station (and therefore the Earth below it) move on the TSP? Remember to use a straightedge to help.

    a) -35 millimeters b) 40 milllimeters
    c) 60 millimeters d) 73 millimeters

11. What overall direction was this station moving?

    a) North only b) Northwest
    c) Northeast d) Southwest

12. What was the annual movement in the North direction?

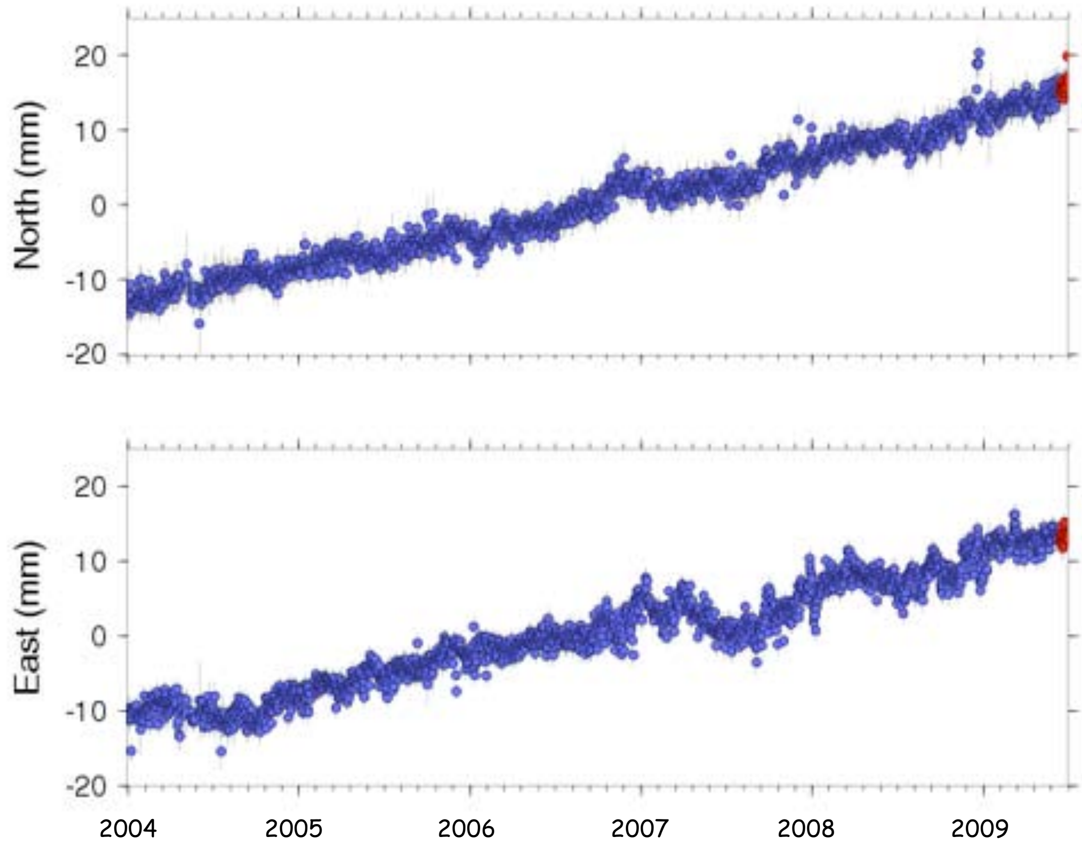
    a) 60 mm/yr b) 3 years c) 10.9 mm/yr d) 16 mm/yr

13. Calculate the annual Eastward movement:

    a) 73 mm/yr b) 13.3 mm/yr c) 401.5 mm/year d) 0 mm/yr

Using the TSPs for Tumwater, WA and Othello, WA below, calculate N/S and E/W motion and answer questions for each TSP.

Tumwater, Washington GPS Data



14. How long of a time period is indicated on these time series?

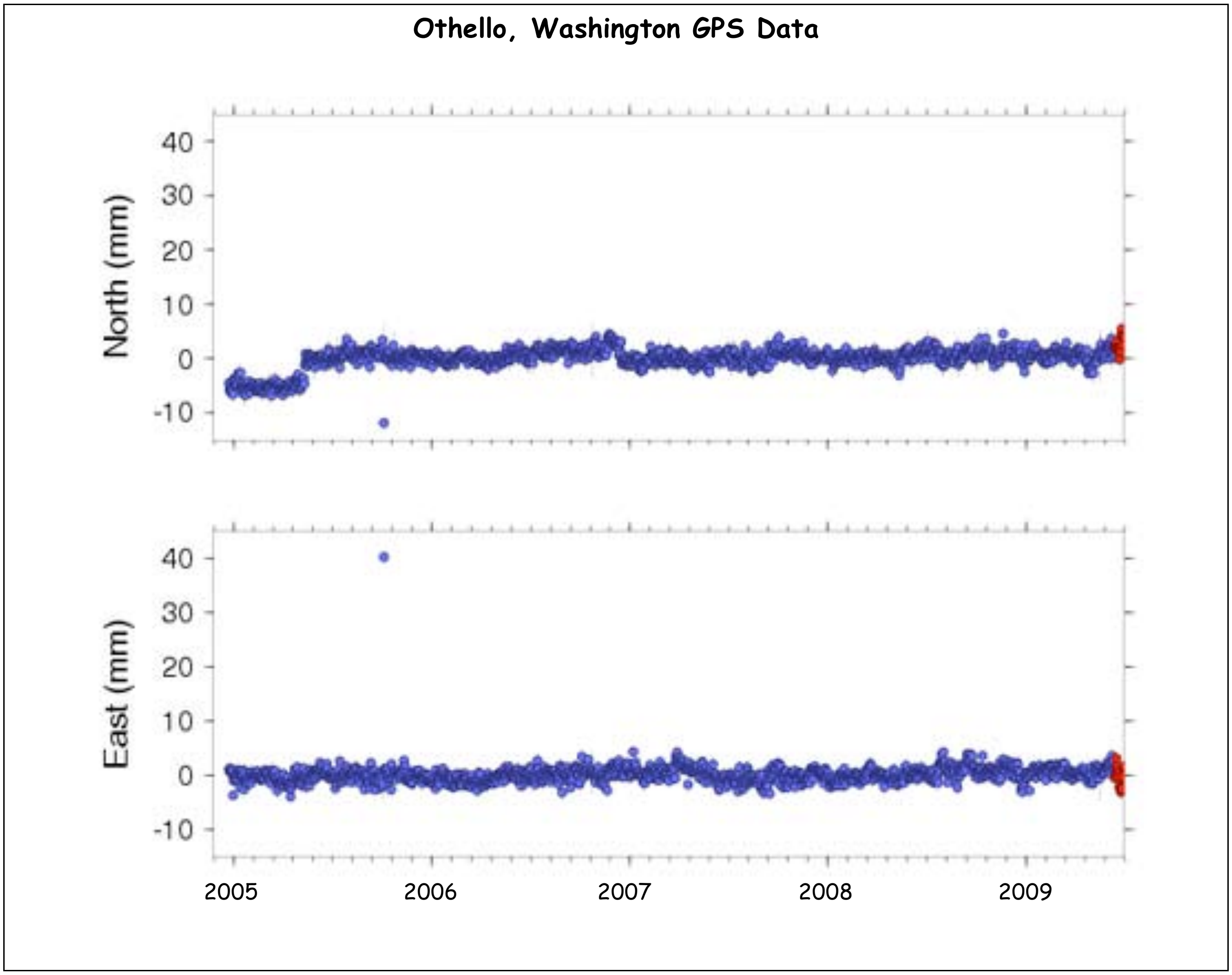
15. Was Tumwater moving North or South? How do you know?

16. How far North or South did Tumwater station move between over the time period?

17. Was Tumwater station moving East or West? How do you know?

18. How far East or West did it move over the whole time period of data collection?

19. What are annual motions in N/S and E/W directions?



20. How long of a time period is indicated on these time series? Be careful here!

21. Was Othello moving North or South? If so, how far?

22. Was Othello station moving East or West?

23. What are the annual motions in the N/S direction?

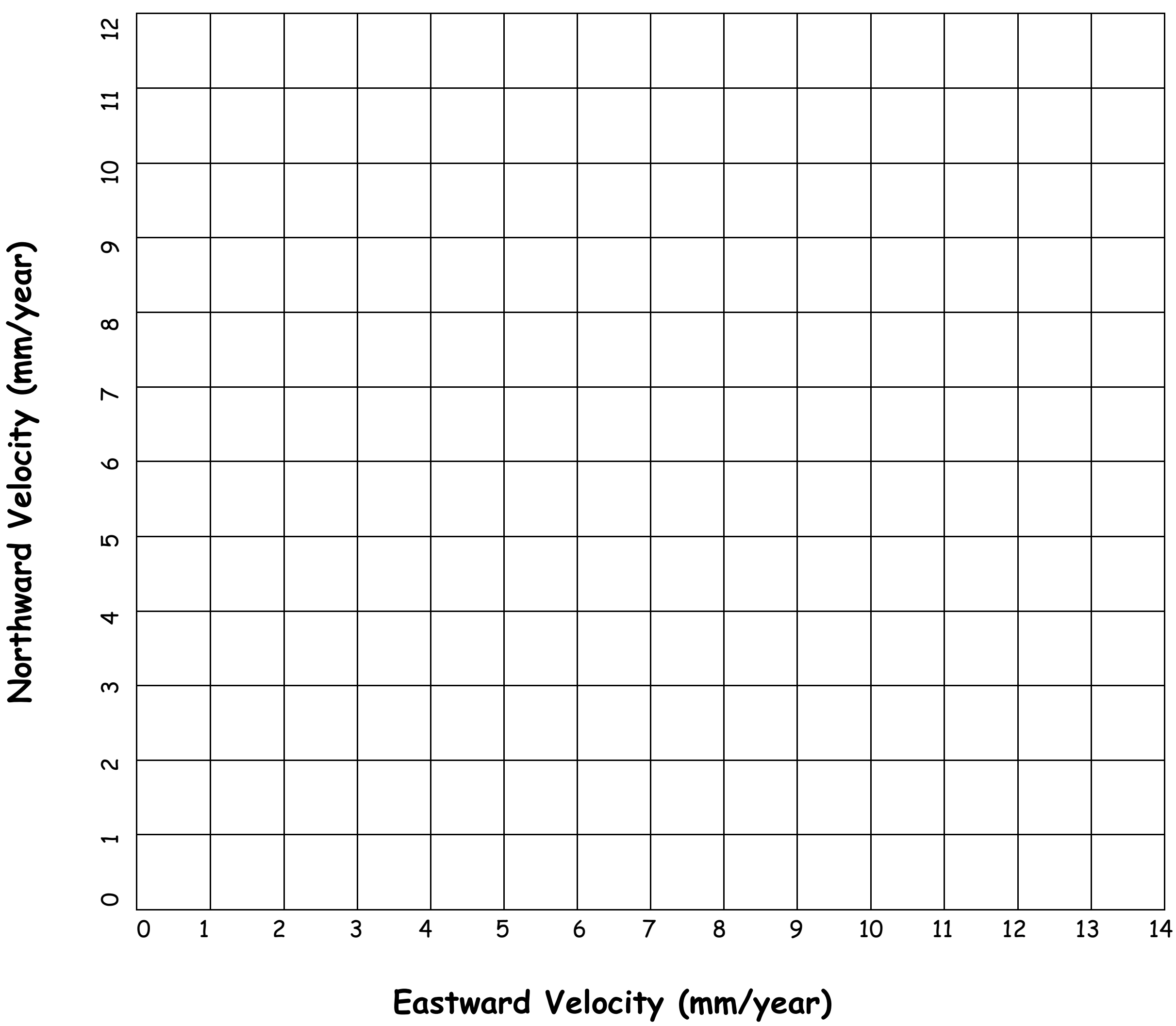
PART IV: Plotting GPS Station Motion

Materials: Cascadia GPS Analysis Grid (last page of packet), 3 different colored pencils, ruler

Procedure:

1. Using one colored pencil, start at (0,0) and draw a faint arrow to show the **annual** North movement of the Pacific Beach station.
2. From end point of the North arrow, draw an arrow to show the **annual** East motion.
3. Draw a diagonal arrow from (0,0) to the end point of the East arrow. This final arrow (vector) shows the overall annual direction and distance of motion of the Pacific Beach GPS station.
4. Using a centimeter ruler, measure the length of the final vector and label the vector with distance in mm/year. **Note**: Scale on grid is centimeters, but actual movement is millimeters – that's why you label 'mm/year'.
5. Using different colors, draw vectors for Tumwater and Othello stations.
6. Complete key indicating colors of your 3 GPS station vectors.

KEY:	Color	Station Location	Station Group (Coastal, Urban Corridor, or Eastern)
	☐		
	☐		
	☐		



Procedure (continued):

7. Place gumdrop station (on top of transparency) at 0,0 and move the transparency sheet along one of the Northeast vectors to simulate the direction of the land at that point.

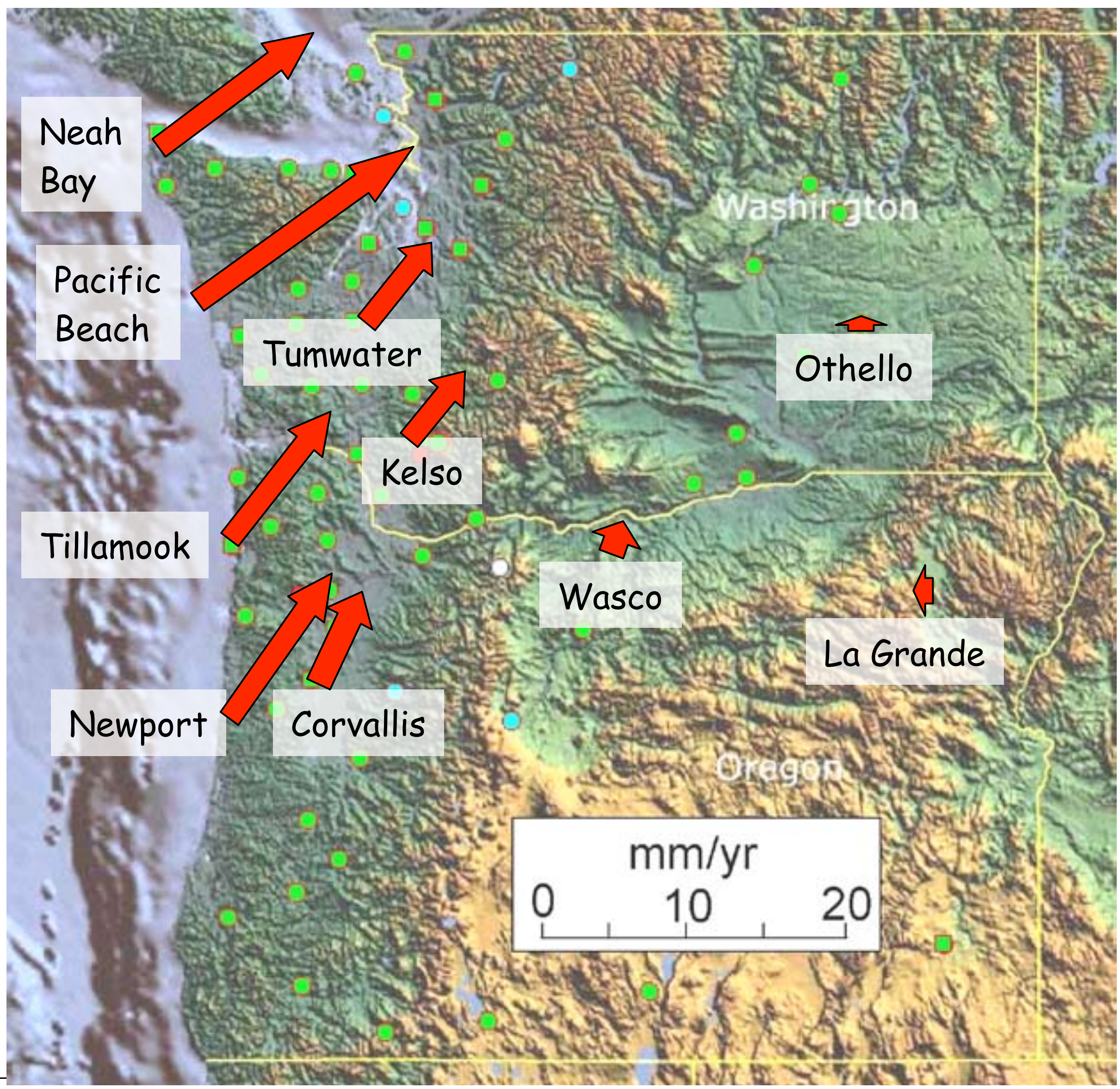
PART V: Analysis of GPS Station Motion

24. The map below shows the direction and speed of several GPS stations in the Pacific Northwest. What do you observe about:

a) the stations along the coast?

b) the stations slightly inland (Tumwater, Kelso, Corvallis)?

c) stations east of the Cascades (Wasco, Othello, La Grande?



25. Over time, what will happen to the distance between stations on the coast and stations east of the Cascades?

    a) Distance gets shorter
    b) Distance gets longer
    c) Distance stays the same

26. What does this indicate about the forces acting on the Pacific Northwest? What's happening to the edge of the continent?

Answers to PART II:

1. The tops of the stands represent where the satellites are – all are at the same height above the Earth.
2. The length of string represents the distance between monuments and satellites.
3. At least 3 satellites are needed to pinpoint the location of the monument on the surface. In reality more than 3 are used.
4. One or two satellites wouldn't work between the distances intersect at an infinity of points (one satellite), or at least 4 points (with two satellites).
5. Students will draw setup with 3 stands, strings, and gumdrop monument.

PART III: Measuring Cascadia GPS/Tectonic Movement

Procedure:

1. Review metric system (millimeter, centimeter, meter, kilometer)
2. Review cardinal directions
3. There are hundreds of dGPS stations in operation.
4. Instruct students how to 'read' a TSP. Use example from Pacific Beach as example to do as whole class.
5. Vertical is not used because it is more difficult to determine a change in altitude. Imagine a satellite overhead looking for side-to-side motion, and then trying to determine vertical motion.
6. With a ruler, draw a line to best show trend of TSP.
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 (TSP)

a) All plots have a Y-axis with 'zero' with positive numbers above the line and negative numbers below the line.
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' or opposite direction is moving South.
c) The same is true for East/West – movement in a positive direction is movement to the East, and anything moving in the negative direction is moving West.
d) Height is vertical movement either up or down following the same rules as the North and East plots.
e) 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.
f) The scale on the axes will vary and the units may vary as well.
g) Height plots vary a lot – it's tougher to accurately pinpoint the vertical position.

h) Usually N/S and E/W movement is easier to see a pattern with compared to height. But remember that there are a lot of errors that must be corrected, so the data won't always be perfect, or in a clear pattern.
i) The data in the examples are very linear – usually they're a lot messier.
j) The time scale is shown by years and tenths (1/10) of years, not by months.
k) Receivers collect a positional measurement every 15 seconds. That's 5,760 measurements a day. These are averaged to get one point for each day that shows up on a time series.
l) Most plots do not start right at '0' on the y-axis; what is important is the *change* in position.
m) The movements that dGPS receivers show are very small – millimeters or centimeters at most. But just think how much movement that would mean over thousands of years!

Answers to PART III:

Pacific Beach, WA
6. C – millimeters and years
7. D – 5 1/2 years (from 2004 to 2009.5)
8. C – 60 millimeters (started at –30 and moved to 30 = total of 60 mm)
9. A – No, station didn't move South because trend line only moves in positive direction
10. D – 73 millimeters (started at –35 and moved to 38 = total of 73 mm)
11. C – Northeast
12. C – 10.9 mm/year (60 mm north divided by 5.5 years = 10.9 mm/year)
13. B – 13.3 mm/year (73 mm east divided by 5.5 years = 13.3 mm/year)

Tumwater, WA
14. The time period shown is 5 1/2 years (2004 – 2009.5)
15. Tumwater was moving North due to the upward direction on the N/S plot.
16. Tumwater moved approximately 28 mm North (started at –12 and moved to 16 = total of 28 mm)
17. Tumwater was moving mostly eastward (other than a couple times of westward motion)
18. Tumwater moved approximately 26 mm East (started at –12 and moved to 14 = total of 26 mm). Depending on where trend line is drawn the numbers for this may be slightly different.
19. Annual motions are North 5.1 mm/year (28 mm / 5.5 yr) and East 4.7 mm/yr (26 mm / 5/5 yr)

Othello, WA
20. The time period is 4 1/2 years (from 2005 – 2009.5)
21. Othello has moved North ever so slightly – approximately 6 mm over time period shown depending on how trend line is drawn.
22. Othello was not moving East or West.
23. Othello is moving (depending on how you draw trend line) approximately North 1.3 mm/year (6 mm / 4.5 years)

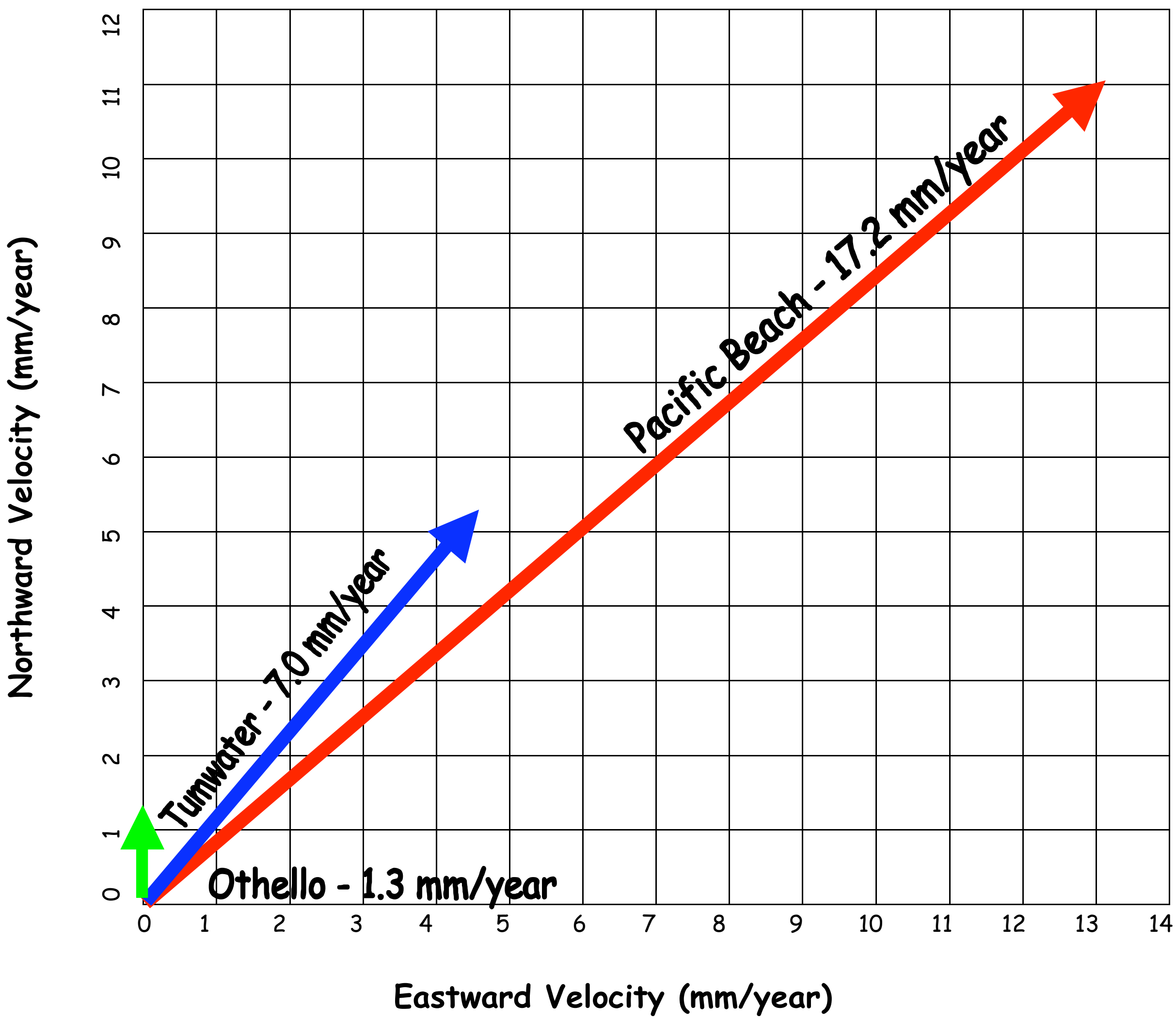
Answer Key to Student Worksheets

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 centimeters to make graphing easier. Actual movement is in millimeters but this is far too hard to see at 1:1 scale.

Student vector graph should look like this (colors may vary):



3. The GPS gumdrop stations will move along path of vectors, mimicking the movement of the tectonic plate with GPS station attached.

Answer Key to Student Worksheets

PART V: Analysis of GPS Station Motion

The big picture result of the activity is that coastal stations of Oregon and Washington are being pushed toward the northeast at about 1/2 of the velocity of Juan de Fuca Plate motion with respect to interior North America. Urban corridor stations are being pushed toward the northeast at about 1/4 of the velocity of Juan de Fuca Plate motion with respect to interior North America. Stations east of the Cascades are not moving at all or are barely moving. The clear implication is that coastal areas are moving towards eastern areas as the active continental margin is being compressed in SW – NE direction. Strain is building within the Pacific Northwest margin of the North American Plate as the Juan de Fuca Plate pushes the North American Plate margin toward the northeast. This accumulating strain will eventually be released in the next great earthquake on the Cascadia Subduction Zone. The plate boundary regions of the Juan de Fuca and North American plates are "locked and loading".

Further implications of the "locked and loading" nature of the Pacific Northwest continental margin are elastic energy will be stored up over long intervals of time and then suddenly released in the next great Cascadia earthquake. For example, over the average 500 years recurrence time between great earthquakes, the coastal stations will move northeast about 7.5 meters (25 feet). During the next great earthquake, the stored energy due to the slow NE movement will suddenly be released as the coastal areas rapidly rebound the same distance towards the southwest.

Procedure:

1. Lead students to answers from observations of the Pacific Northwest vector map.
2. Discuss big picture after students realize that the region is being squeezed.

Answers to PART V:

24a. Stations along the coast are moving towards the northeast much faster compared to other stations.
24b. Stations along urban corridor are moving northeast about half as fast as the coast.
24c. Stations east of the Cascades are essentially stationary.
25. A – distance gets shorter
26. The forces on the Pacific Northwest are pushing the edge of the continent northeast towards the inland areas.

Possible Extensions:

1. Cascadia PBO Observations (MS Word document **CascadiaPBObservations.doc**)
This will enable teacher to find PBO data on UNAVCO website, plot time series (using Excel), and find latest velocity vectors from UNAVCO. The directions on the Cascadia PBO Observations document explain how to use the PBO Data PowerPoint, named **PBOData09.ppt**. Our experience is that careful trend line fitting will yield velocities that are within 0.1 mm/year of the actual velocities determined by UNAVCO. Files that accompany the activity are: **PBOMap.pdf**, Grid Plot (in **PBOData09.ppt**).

   You can also use the Cascadia GPC Analysis Grid sheet (MS Word, **Cascadia GPS Analysis Grid.doc**) as a handout for students to complete. The back of the sheet has a map where students can draw the actual vectors themselves in millimeter scale using a ruler.

   Doing the slide show of the **PBOData09.ppt** will show how the vectors are calculated for each of the stations used, and ends with the regional map showing compression of the continental margin.

2. **Episodic Tremor and Slip**
Recent discovery shows that periodically there are low level tremors of the continental margin as the Juan de Fuca plate at depth slips beneath North America. These tremors are much longer duration than a typical earthquake and are sometimes called "slow earthquakes". During these slow earthquakes, the GPS stations above the slipping zone move backwards compared to their normal northeastward motion.

   A comprehensive PowerPoint explains the development of the theory of Episodic Tremor and Slip. There is a student worksheet (**ETS StudentWorksheet.doc**) that accompanies the PowerPoint. It is a multi-day 'lesson' and incorporates a series of activities and animations. These are in the folder **EpisodicTremorSlip PowerPoint.** One of the activities, the two-block Earthquake Machine (block and sandpaper model demonstrated in the workshop), is included in this TOTLE pdf file.

http://cws.unavco.org:8080/cws/modules/cws/modules/ETS_pacificnorthwest/