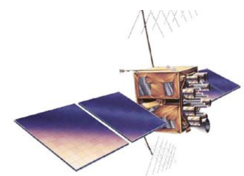
Cascadia GPS Analysis: Teacher Information

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 per hour. That's almost 2 kilometers per second – yes, 2 kilometers every 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 sophisticated 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 Internet to UNAVCO for further processing. Scientists can then use long-term positional data to interpret plate motions and plate boundary interactions.

NGSS STANDARD 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	**Crosscutting Concepts**
4. Analyzing and Interpreting Data 5. Using Mathematics and Computational Thinking 6. Constructing Explanations and Designing Solutions	2. Cause and Effect 4. Systems and System Models 7. Stability and Change

LESSON PLAN

This is a multi-day lesson, and could take 2 – 3 lessons (hour long) to complete. IRIS Education and Outreach has a two-part video to demonstrate all parts of this activity:
http://www.iris.edu/hq/inclass/video/gps_monitors_deformation_in_subduction_zone_part_1_intro
http://www.iris.edu/hq/inclass/video/gps_monitors_deformation_in_subduction_zone_part_2_using_real_data

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. Can also use the smaller 'spice drops' available at most stores, but it's tougher to get toothpicks in.
- 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 6th should be large enough.

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 IV.
2. Have students place gumdrop monument in middle of transparency sheet. Clay represents the concrete that 'glues' the monument to Earth's surface rock layers beneath the soil.
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 monument 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 monument on top to save for next day.

PART II: Pinpointing Location

There are three methods to do the demonstration, which vary in scale.

Option One – Smaller Scale

Supplies:

- 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 stands
- Gumdrop monument from Part I

Demonstration 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 before hand.
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. A sphere around the top of the ring stand is established with radius equaling the distance from the satellite.
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* between the monument and satellite.
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.

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

Option Two – Larger Scale

Supplies:

- 3 long lengths of twine (construction twine works fine) that will reach from high up on the walls to a central point somewhere in the room.
- Tape to hold up twine on wall.
- 3 'satellites' to place at top of ring stands. BubbleYum gum still will work. You could also print larger pictures of satellites to tape on the walls.
- Gumdrop monument from Part I, or a larger version of a GPS monument.

Demonstration Procedure:

11. Tape ends of strings on walls so that all 3 strings meet in one location somewhere on the floor of the room. You will have to set this up and cut the strings before hand.
12. Coil up the long strings and tape them up on the wall so you can easily pull them down and hand to a student.
13. Follow same procedure as above for locating the three places where all 3 strings (distances) meet.

Option Three – Largest Scale

Demonstration Procedure:

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

Here is a video you could also use:

https://www.youtube.com/watch?v=IoRQiNFzT0k

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. It would be much more difficult to see the up/down motion.
6. With a ruler, draw a line of best fit to show trend of TSP. Try to draw the line so that there are an equal number of points above and below the line. Using a clear ruler works best.
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’ and positive numbers above the line and negative numbers below the line. Numberless tickmarks 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’ 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) 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.
f) 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.
g) The data in the examples are very linear – usually they’re a lot messier.
h) The time scale is shown by years and twelfths of years.
i) Receivers collect a positional measurement every second. That’s 86,400 measurements a day. These are averaged to get one point for each day that shows up on a time series.
j) Most plots now start right at ‘0’ on the y-axis; what is important is the *change* in position. However, sometimes you will need to use the trend lines, not the points, to determine change in position.
k) 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! An easy equivalent to remember is 1 mm/yr is the same as 1 kilometer/1 million years.

Answers to Student Worksheet are shown below on Answer Key.

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.
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.

For added effect, have 3 students put their gumdrop models on ONE map (page 7 of the student worksheet) and then simultaneously have them move the gumdrops the appropriate distance along the vector in the same time period. Although cramped, it shows the shortening effect of the western margin quite well.

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 (in Willamette Valley of Oregon or Puget Lowland of Washington) 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 suddenly released as the coastal areas 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.
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.

TEACHER ANSWER KEY

UNAVCO

Name: ______________________________________

Today's Date: ______________________

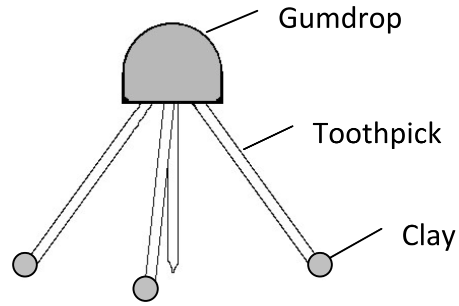
CASCADIA GPS ANALYSIS

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.
4. Position the GPS Monument on top of a piece of clear transparency.



PART II: Pinpointing Location

1. What do the tops of the string holders on the walls represent?

   The tops of the strings represent where satellites are – all are at the same height above the Earth.

2. What does the length of string represent?

   The length of string represents the distance between monuments and satellites.

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

   At least 3 satellites are needed to pinpoint the location of the monument on the surface. In reality more than 3 are used.

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

   One satellite wouldn't work because the station could be an infinity of points around that one satellite. Two wouldn't work because the two spheres around 2 satellites intersect at an infinity of points around the circle where the two spheres intersect.

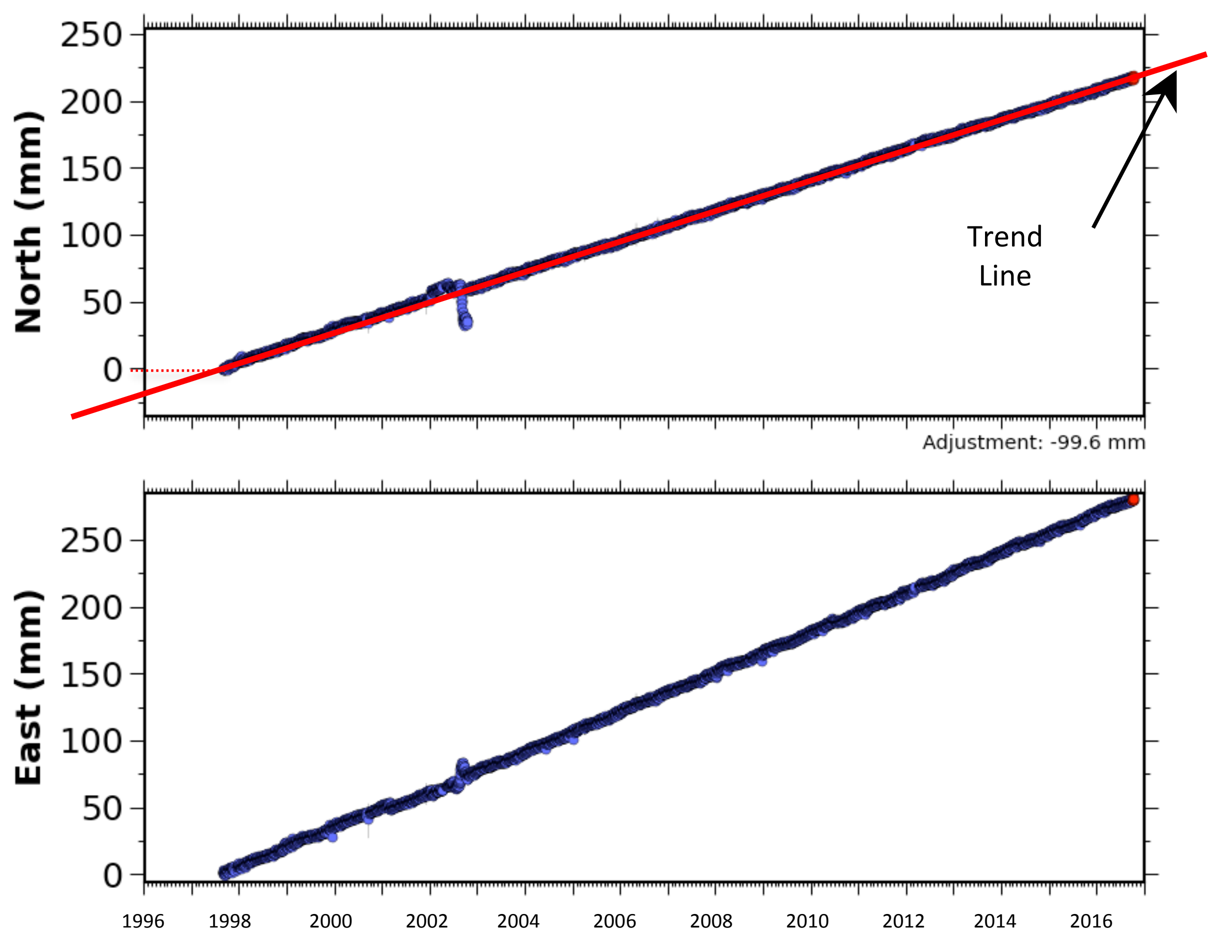
5. Draw the setup of the demonstration in the space to the right.

PART III: Measuring Cascadia GPS/Tectonic Movement

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

- High precision GPS stations collect data in 3 parts shown in **Time Series Plots** (**Time Series or TSP)**:
  - 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)
- X-axis measures time.
- Each dot on the TSPs is the average position of the station for one day.

Pacific Beach, Washington GPS Data – Coastal Station



The first thing to do is draw a "**trend line**." Position a ruler (clear works best) so that the trend line represents the average of the plots above and below the line. Draw the line so that it crosses the axes on both sides. Note the example above. Draw a trend line for the East portion of the Pacific Beach TSP.

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. If each dot is the average position for any given day, how long of a timespan has this station been collecting data?

   a) 10 years   b) 15 years   c) 19 years   d) 20 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) 200 millimeters   b) 215 milllimeters
   c) 230 millimeters   d) 275 millimeters

9. Did the station move South over the period of time relative to its starting position (1st measurement)?

   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) 205 millimeters   b) 215 milllimeters
   c) 280 millimeters   d) 300 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? *(Hint: Divide distance traveled by # of years)*

   a) 10 mm/yr   b) 11.3 mm/yr   c) 16 mm/yr   d) 200 mm/yr

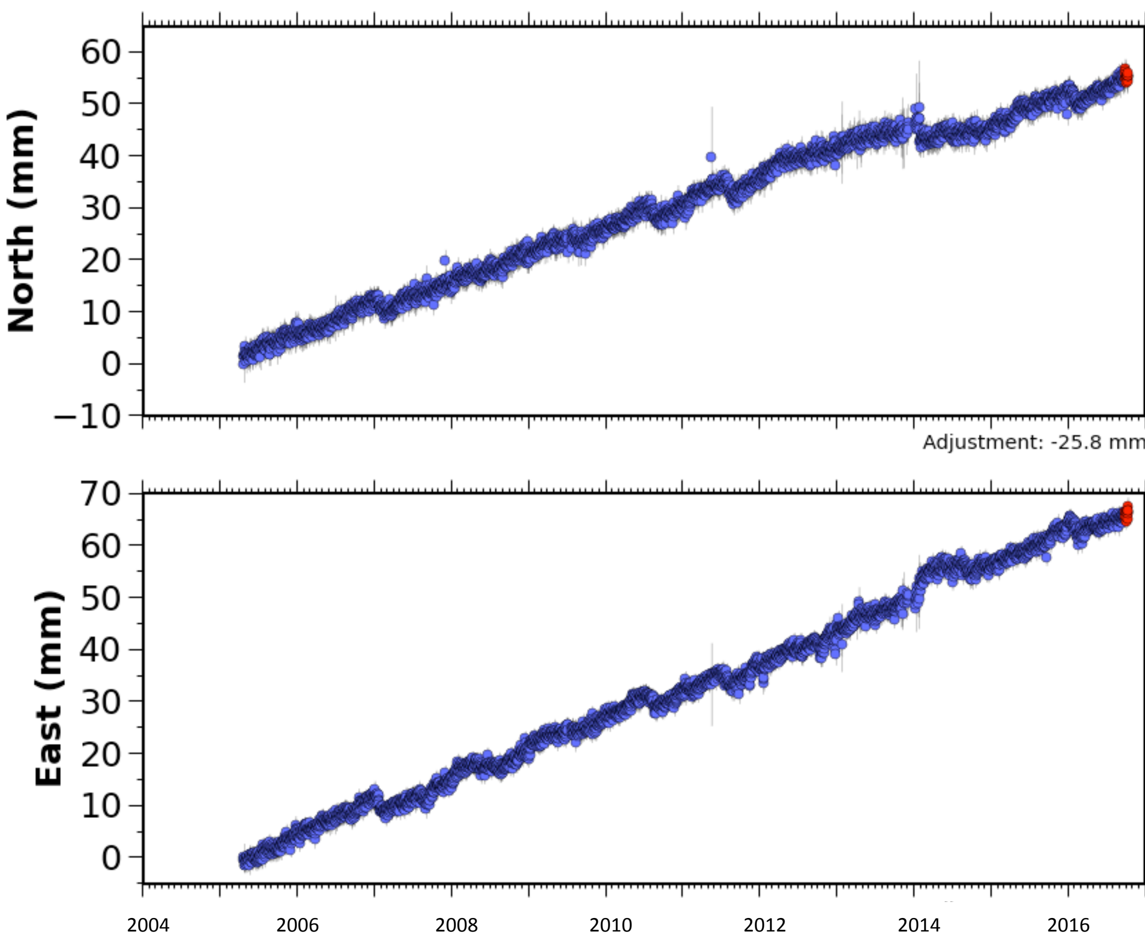
13. Calculate the annual Eastward movement:

   a) 4 mm/yr   b) 13.3 mm/yr   c) 14.7 mm/year   d) 280 mm/yr

Using the TSPs below for Grapeview, WA and Lind, WA, calculate N/S and E/W motion and answer questions for each TSP. Start with drawing trend lines that cross both vertical axes.

Note that some positions (dots) are 'off' the general trend, or there is a gap in the data. Those might be times when maintenance was being done on the station, or there was some error that was being corrected. You can ignore those points when doing your trend lines and calculations.

Grapeview, Washington GPS Data – <u>Urban Corridor Station</u>



14. According to this data, how long of a time period has this station been in operation? *Note that each small line on X-axis is one month, or 1/12th of a year.*

May 2005 – Sept 2016 is about 11.5 years

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

Grapeview was moving North due to the upward direction on the N/S plot. Intermittently is moved S (down).

16. How far North or South did it move since data has been recorded?

It moved approximately 56 mm North.

17. Overall, was Grapeview station moving East or West? How do you know?

Grapeview was moving East due to the upward direction on the E/W plot. Intermittently is moved W (down).

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

It moved approximately 67 mm East.

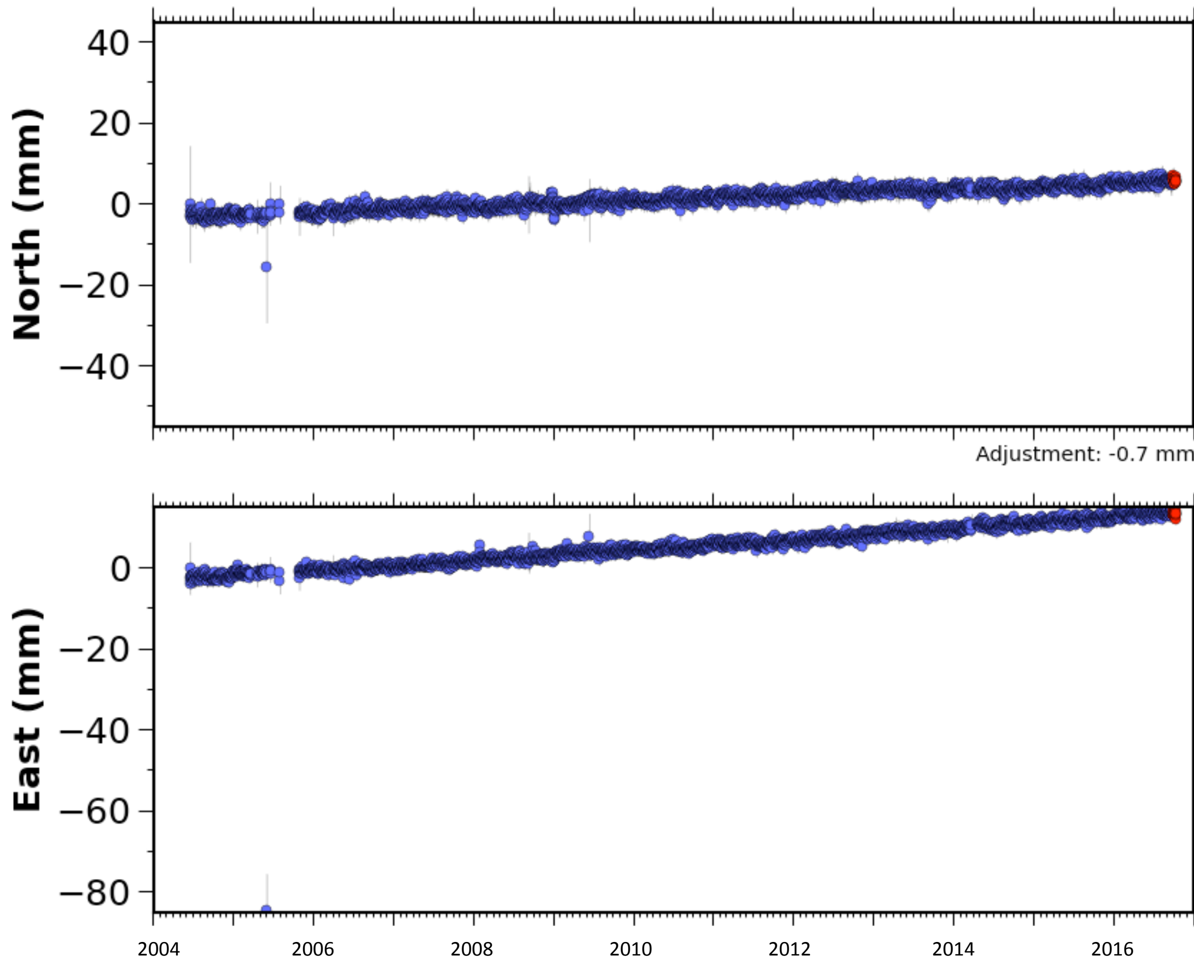
19. Were there any times when the station wasn't moving NW? If so, when, and what direction??

It moved Southwest in early 2007, mid 2010, mid 2011, early 2014, and early 2016.

20. Calculate <u>annual</u> motions in N/S and E/W directions.

Annual motions are North 4.9 mm/year (56 mm / 11.5 yr) and East 5.8 mm/yr (67 mm / 11.5 yr)

Lind, Washington GPS Data – <u>Eastern Station</u>



21. According to this data, how long of a time period has this station been in operation?

May 2004 – Sept 2016 is about 12.5 years

22. Was Lind moving North or South? If so, how far? *Be careful with measurements. Use the trend line to better indicate the starting position. Hint: it's below '0'.*

Lind was moving very slightly North. Trend line shows it's starting at -1 and moving to about 5, for total of 6 mm.

23. Was Othello station moving East or West? If so, how far? *Again, be careful.*

Lind was moving very slightly East. Trend line shows it's starting at -2 and moving to about 12, for total of 14 mm.

24. What are the <u>annual</u> motions in the N/S and E/W directions?

Annual motions are North 0.5 mm/year (6 mm / 12.5 yr) and East 1.1 mm/yr (14 mm / 12.5 yr)

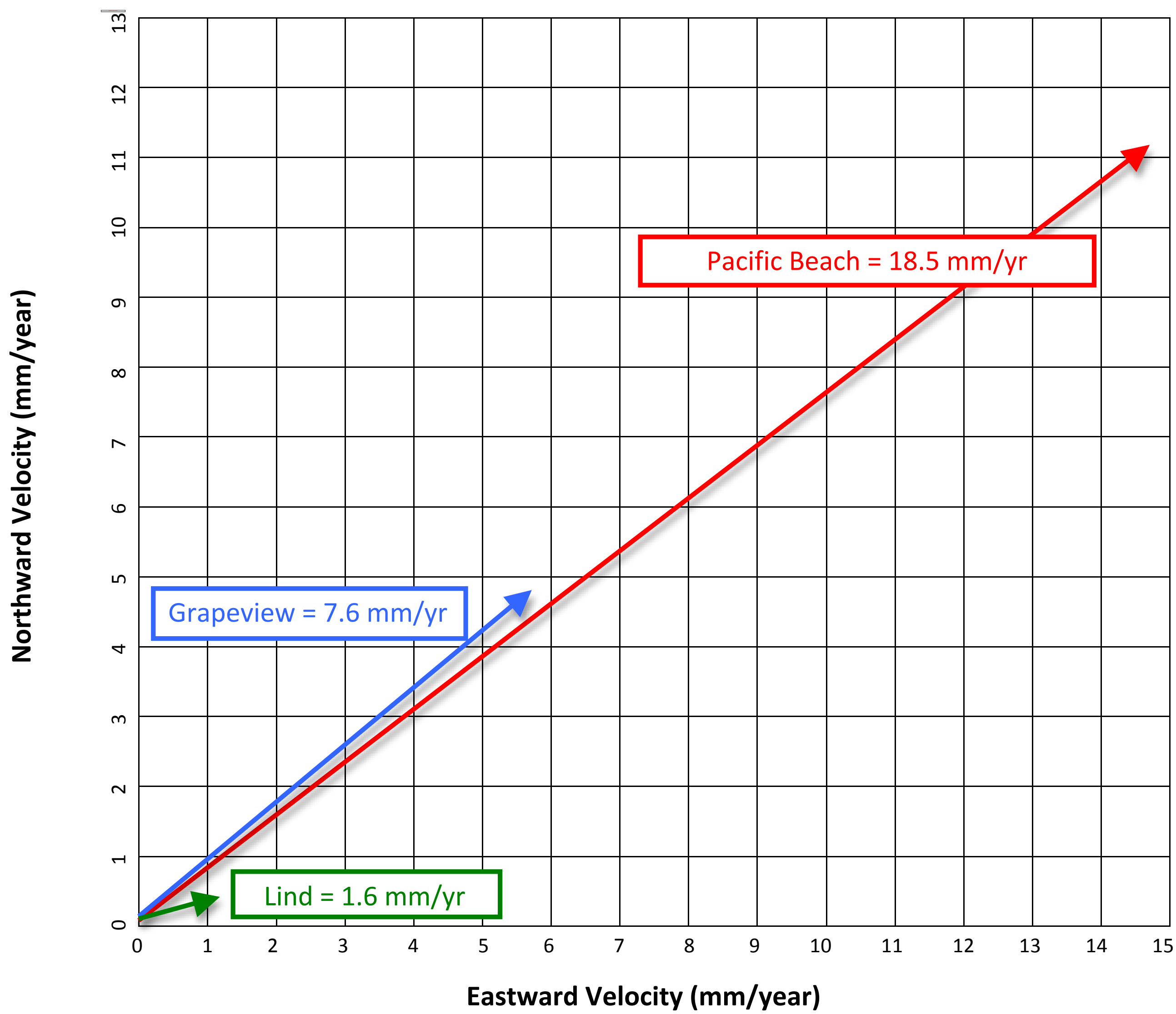
PART IV: Plotting GPS Station Motion

<u>Materials</u>:
Cascadia GPS Analysis Grid (next 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 rate 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 Grapeview and Lind stations.
6. Complete key indicating colors of your 3 GPS station vectors.

KEY: Color	Station Location	Station Group (Coastal, Urban Corridor, or Eastern)
Red	Pacific Beach, WA	Coastal
Blue	Grapeview, WA	Urban Corridor
Green	Lind, WA	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 motion of the land at that point.

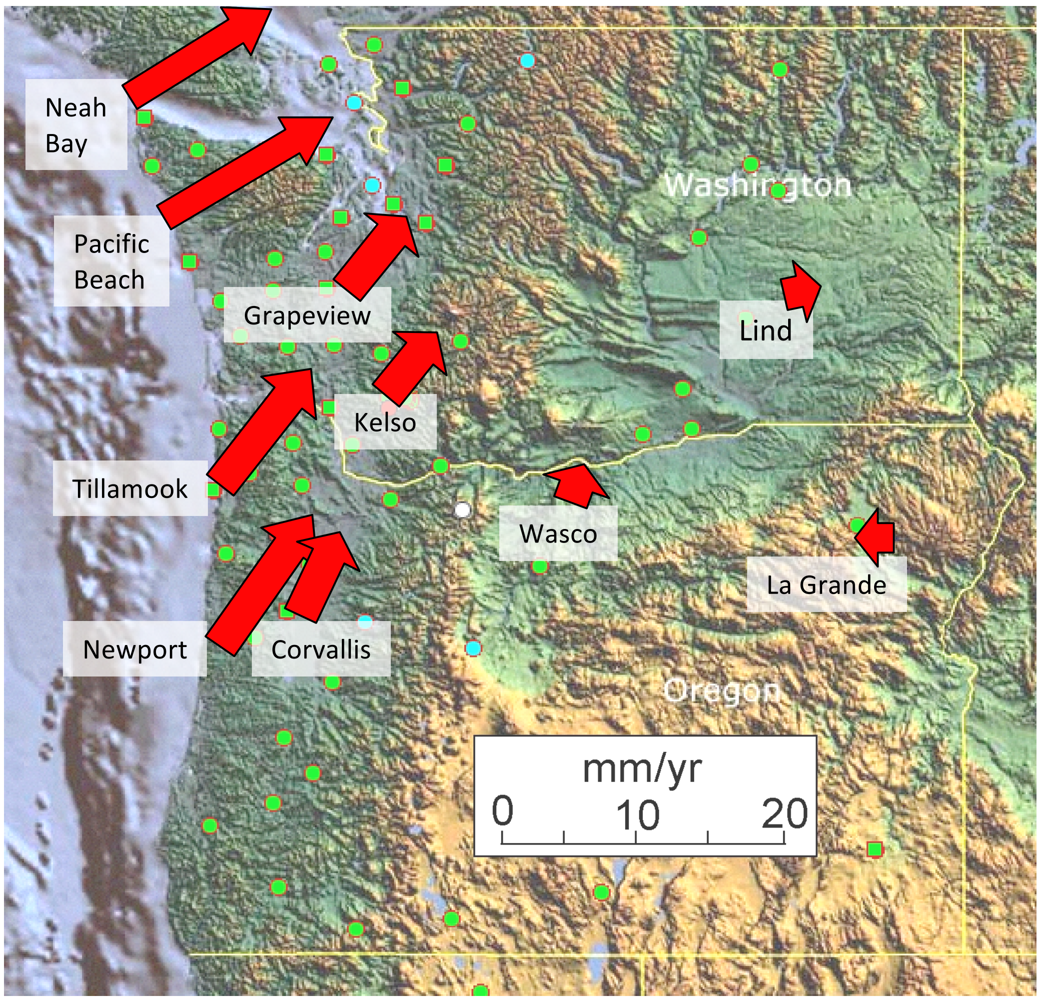
PART V: Analysis of GPS Station Motion

25. 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? They are moving NE must faster than the other stations inland.

b) the stations slightly inland (Grapeview, Kelso, Corvallis)? They are moving NE about half as fast.

c) stations east of the Cascades (Wasco, Lind, La Grande? Moving NE just barely – almost stationary.



26. 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

27. What does this indicate about the forces acting on the Pacific Northwest? What's happening to the edge of the continent? The western edge of the PNW is being pushed NE faster than the inland areas. As it does so, the region is being compressed in a NE – SW direction. The region is being loaded like a spring.