Name ____________________ Class ________________ Data ______________

Reading GPS Time Series Plots Worksheet

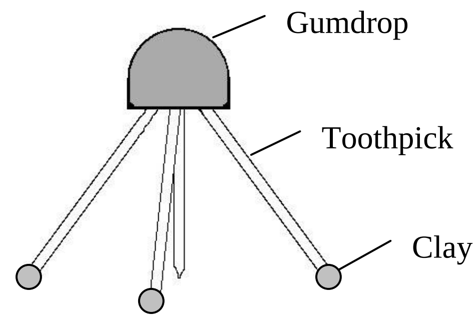
By: Roger Groom and Cate Fox-Lent, UNAVCO Master Teachers in-Residence, Shelley Olds, UNAVCO

The Global Positioning System, GPS, is used to study the Earth, how tectonic plates move, and how Earth's tectonic plates deform. GPS monuments are attached the ground and measure how the plate moves. While the GPS units in a car measure movement in miles per hour, high-precision GPS units used for scientific studies measure how fast or slow the Earth's plates move and can measure **a few millimeters in a year.** Even millimeters can be important because slow moving rock can cause big earthquakes.

Part 1: Build a gum-drop model of a GPS monument and pinpoint location with GPS.

Materials: 1 gum drop = GPS receiver; 4 toothpicks (3 legs, 1 center post) = monument braces; 3 small clay feet = cement; ¼ sheet transparency = 'see-through' crust

Procedure:



1. Insert 3 toothpicks diagonally into the gumdrop (the GPS receiver). The toothpicks will act as the legs (braces to hold the monument steady).
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 acts as cement to hold the GPS station in place. In reality, the legs of a GPS station are cemented deep into the ground. So, if the ground moves, the GPS station also moves.
4. Set aside this model for now.

Pinpointing location with GPS

1. What do the pieces of bubblegum represent?

2. What does the length of string represent?

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

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

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

Name ____________________ Class ________________ Data ______________

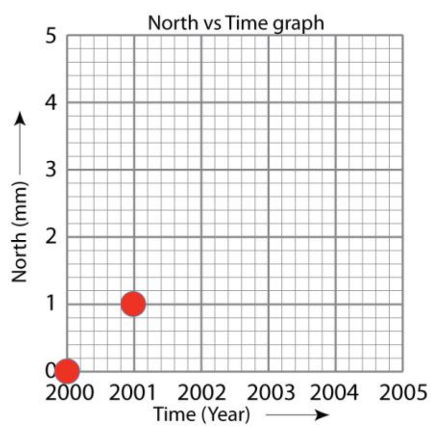
Part 2: Determine the direction of movement of high-precision GPS Monument A
Similar to a car GPS unit, high-precision GPS data is collected as coordinates such as latitude, longitude, and elevation. To make analysis easier, scientists convert the data into four parts: north, east, vertical elevation, and time.

The data in the table show how far GPS Monument A has moved each year. The first column shows the Time in Years. The next three columns show how far the monument moved each year in the North-South, East-West, and the vertical directions. We will make four graphs to study this data.

GPS Monument A

Year	North (mm)	East (mm)	Height (mm)
2000	0	0	0
2001	1	1	0
2002	2	2	0
2003	3	3	0
2004	4	4	0
2005	5	5	0

1. Make a **North vs Time (year)** graph by placing a dot on the graph paper marking each year. On your graph paper, each block represents 1 millimeter (mm).

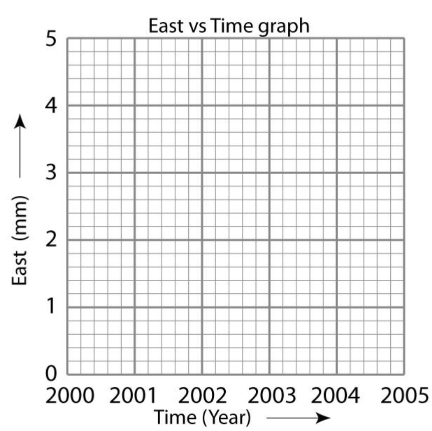


The locations of the monument for the years 2000 and 2001 have been plotted for you.
A. What direction is GPS Monument A moving? North or South?
Your Answer ____________________

B. What direction would the monument move if the North position ***decreased*** from 5 to 0 from year 2000 to 2005?

Your answer (North or South): ______________________

2. Make an **East vs Time (year)** graph showing how GPS Monument A moved every year.



A. What direction is GPS Monument A moving? East or West?
Your answer: _________________________________

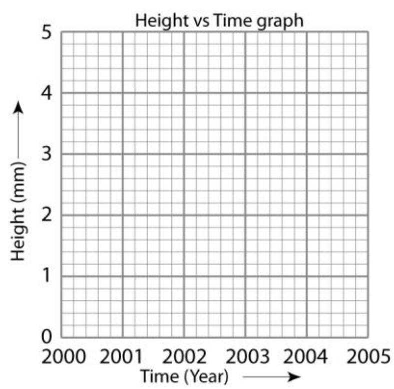
B. What direction would the monument move if the East positions ***decreased*** from 5 mm to 0 mm from years 2000 to 2005?
Your answer (East or West): ________________________

Name ____________________ Class ________________ Data ______________

GPS Monument A

Year	North (mm)	East (mm)	Height (mm)
2000	0	0	0
2001	1	1	0
2002	2	2	0
2003	3	3	0
2004	4	4	0
2005	5	5	0

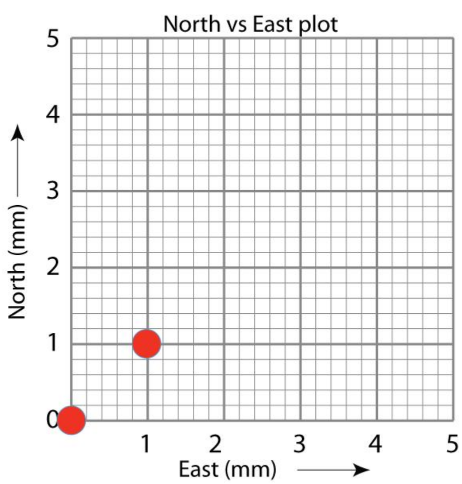
3. Make a **Height vs Time (year)** graph showing how GPS Monument A moved every year.



Describe the motion of the monument in the vertical direction. What direction is GPS Monument A moving vertically?

Your answer: _________________________

4. Finally, plot the North and East positions together on the map grid. North is on the y-axis and East is on the x-axis. The positions for years 2000 and 2001 have been plotted.



- **Plot** the locations of the GPS monument for years 2002 through 2005.
- **Draw** an arrow with the tail at the first point and the arrowhead at the last data point.
- Move your gum-drop GPS monument from its starting position (2000) to the end position (2005).

According to your map grid, what direction is your GPS monument moving?

Your answer: _________________________

Name ____________________ Class ________________ Data ______________

Part 3: Determine the direction of movement of high-precision GPS Monument B

The data in the table show how far Monument B has moved each year. The first column shows the Time in Years.

GPS Monument B		
Year	**North (mm)**	**East (mm)**
2000	0	0
2001	-1	-2
2002	-2	-4
2003	-3	-6
2004	-4	-8
2005	-5	-10

Focus on the **North** data:

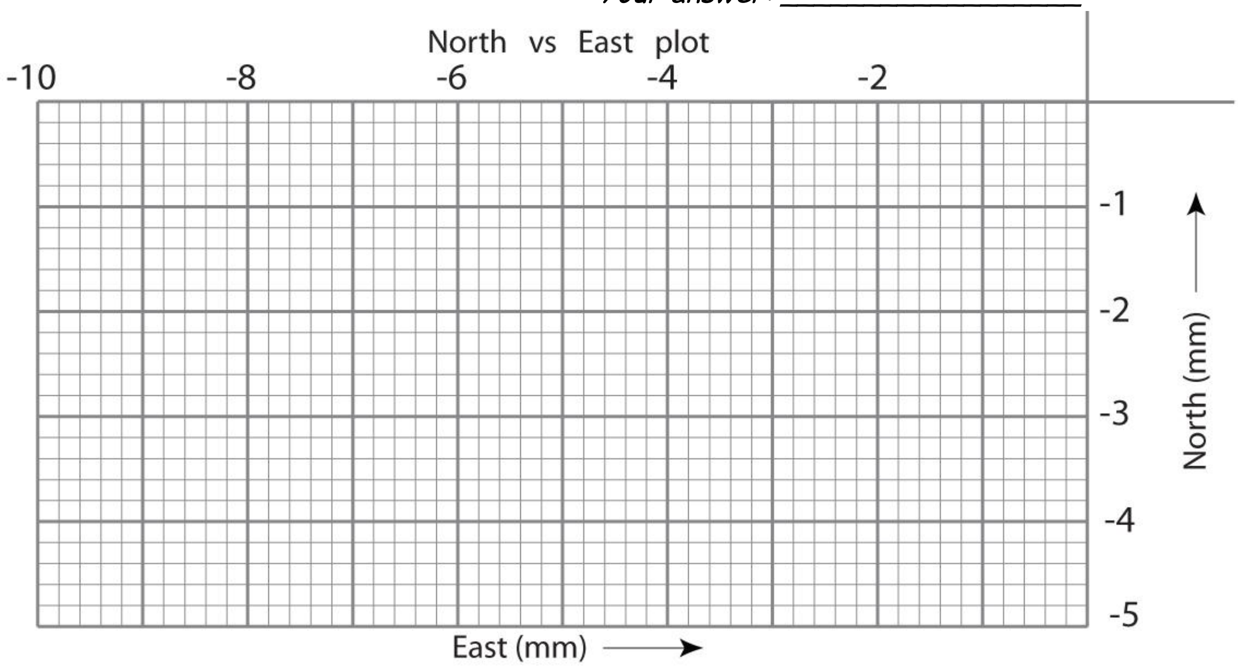
A. Is Monument B moving in a more positive or negative direction?
Your answer: __________________

B. Is GPS Monument B moving North or South?
Your answer: _______________

Now, focus on the **East** data:

C. Is Monument B moving in a more positive or negative direction?
Your answer: __________________

D. Is GPS Monument B moving East or West?
Your answer: _________________



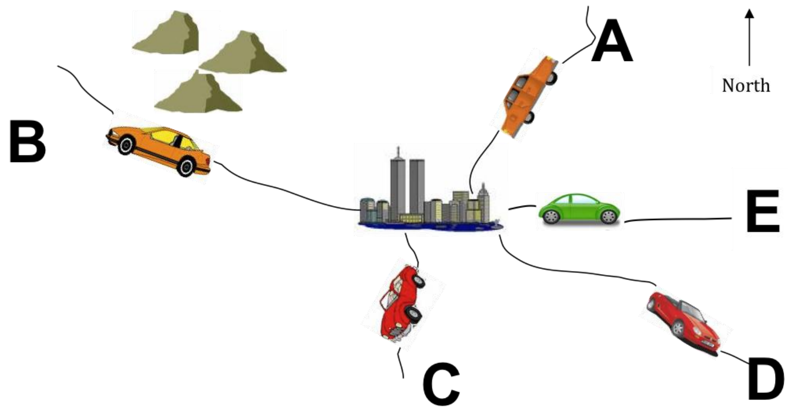
For this part, plot North vs East movement:

1. **Plot** the North and East together on the map grid. The positions from years 1999 and 2000 have been plotted for you. Plot the location for years 2001 through 2005.
2. **Draw** an arrow with the tail at the first point and the arrowhead at the last data point.
3. **Move** your gum-drop GPS monument from its starting position (2000) to the end position (2005).

According to your map, what direction is your GPS monument moving?

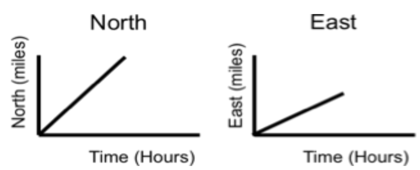
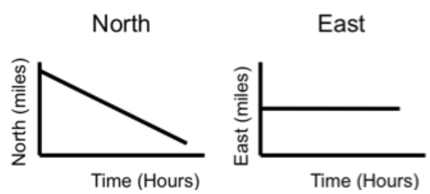
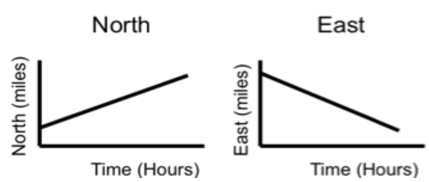
Your answer: ____________________________

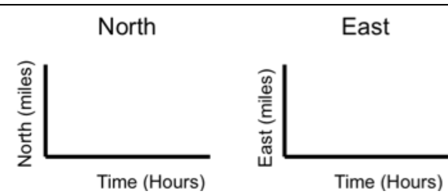
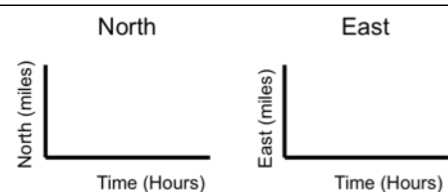
Part 4: Apply your knowledge



Which car matches the graphs?

1. Look at the sets of graphed data below and **describe the direction** each set of graphs indicates.
2. Identify the letter of the car (on the map) that most closely matches the direction of the graphs. The first example has been done for you. Refer to the previous pages for help.

		Direction	Car letter
i.		*north-northeast*	*Car A*
ii.			
iii.			

For the two cars remaining, identify the car letter and direction it is move, and draw the North & East graphs that match each car's direction.	
iv. Car letter _______ is moving _________	
v. Car letter _______ is moving _________	

Good job! Now you can look at scientific GPS time series plots and figure out the direction our Earth's tectonic plates are moving!

Name ____________________ Class ________________ Data ______________

Student Worksheet: Exploring Plate Motion and Deformation in California Using GPS Data

By: Cate Fox-Lent, UNAVCO Master Teacher Andy Newman, Georgia Institute of Technology, Shelley Olds, UNAVCO; June 2011

Overview: What's happening in California? Earthquakes are shifting the landscape, creeping faults are bending the countryside, and the land is moving, but where? In this activity you will work with GPS data downloaded directly from the UNAVCO website to explore plate motion and deformation in California. By analyzing multiple GPS time series plots you can determine the directions and rates of regional deformation. Remember, the GPS stations are permanently cemented to the ground, so if a GPS monument is moving … the Earth's plate is moving or deforming. Let's look at the GPS data from California.

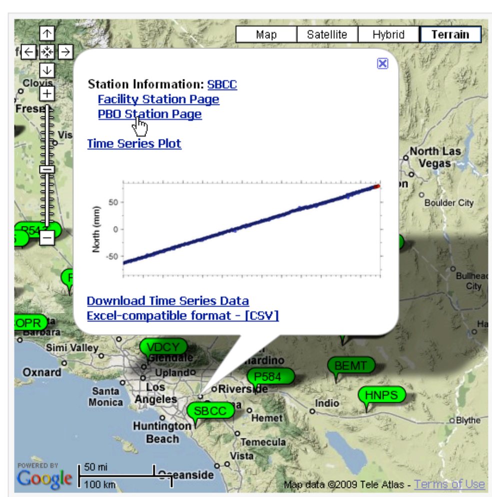
Part 1: Analyze real time-series data of two GPS stations

Work with a partner to study the data for two GPS monuments BEMT and SBCC to determine plate tectonic motion and complete the questions.

If you have access to the Internet, follow the instructions below. Otherwise, fill in the table below using the station information provided on page 5 and the time series plots on page 6.

1. Start at www.unavco.org and click on the link for **Data for Educators** (the direct link is: http://www.unavco.org/edu_outreach/data.html)
2. Move the map (click and drag on the map) until you can see California and zoom to bring **BEMT** and **SBCC** into view. [hint: double click on the ocean near southern California multiple times to zoom in]
3. Click on the green balloon with the station name (BEMT or SBCC) and click on the link for **PBO Station Page** to navigate to the Overview Page about the GPS station.

Selected GPS Stations



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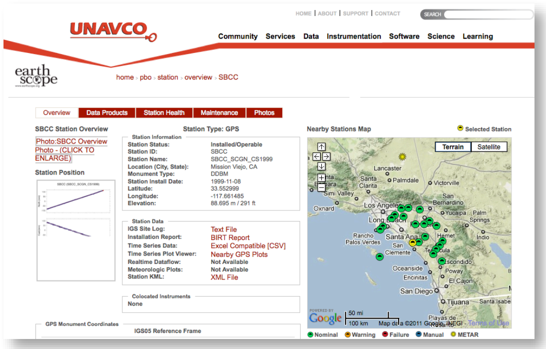
4. Use the information provided on the **Overview page.** Notice that nearby GPS stations are also shown on the station area map.

SBCC

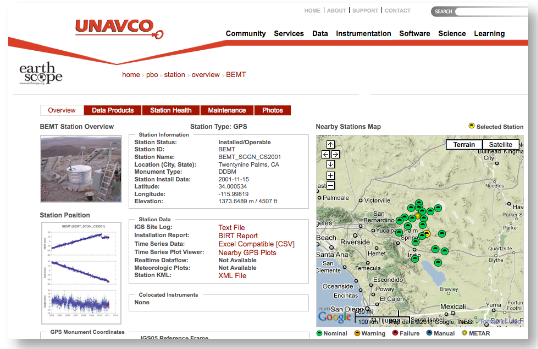


In which city and state is SBCC located?

What is the latitude and longitude listed under SNARF Reference Frame (to 3 decimal places)?

What is the elevation?

BEMT

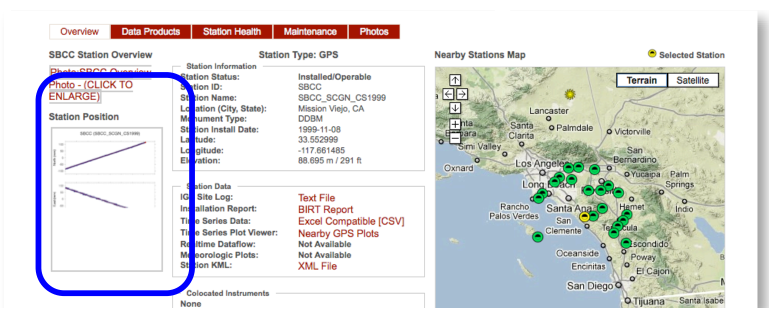


In which city and state is BEMT located?

What is the latitude and longitude listed under SNARF Reference Frame? (to 3 decimal places)?

What is the elevation?

5. Click on the graph below **Station Position**. Study the plot entitled, "Most Recent Raw Data Times Series Plot".



6. Calculate the SPEED of each GPS monument.
(The convention is to **use a negative number for velocities to the south or west**)

a. SBCC: How far (on average) has the station moved per year? (Calculate the speed over 5 years, then divide by 5)

b. SBCC **North** = __________ mm/year

Moving North or South?

a. BEMT: How far (on average) has the station moved? (Calculate the speed over 5 years, then divide by 5)

b. BEMT **North** = __________ mm/year

Moving North or South?

What do you think happened at BEMT?

Name ____________________ Class ________________ Data ______________

c. SBCC **East** = ___________ mm/year

Moving East or West?

d. Study SBCC's **height (vertical)** time-series. Examine the **trend line** (the light red line going through the height data) then describe the motion vertically (up, down, stable):

____

e. When was SBCC at its highest elevation? How much has the station moved vertically since 2004?

c. BEMT **East** = ___________ mm/year

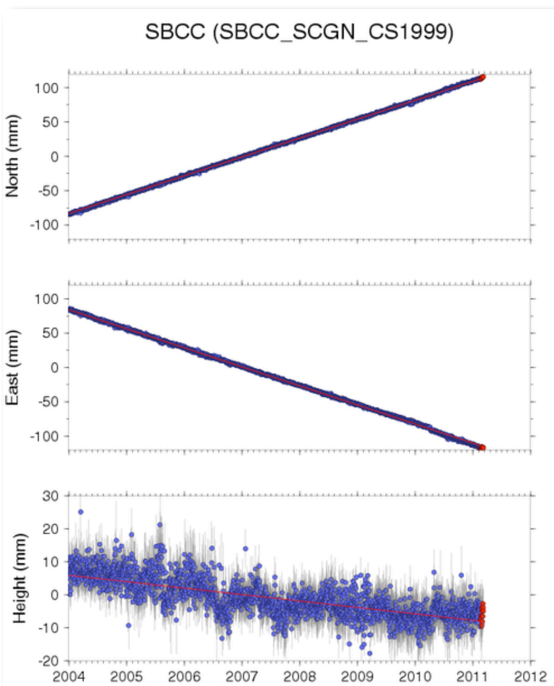
Moving East or West?

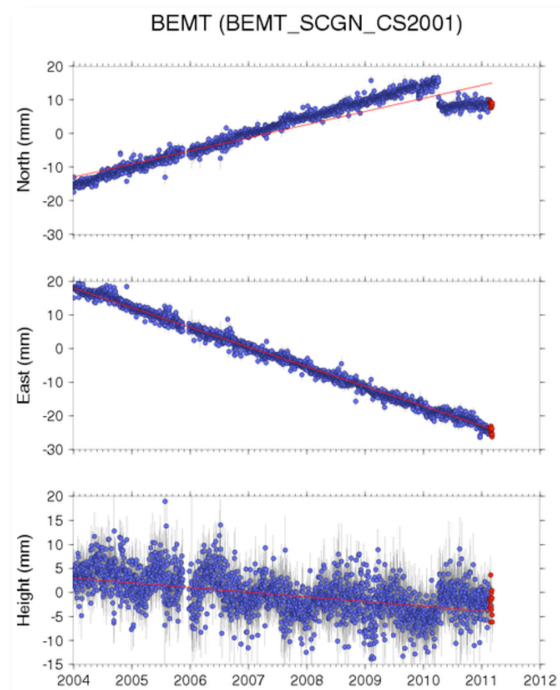
d. Study BEMT's **height (vertical)** time-series. Examine the **trend line** (the light red line going through the height data) then describe the motion vertically (up, down, stable):

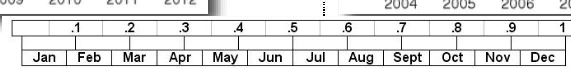
____

e. When was BEMT at its highest elevation? How much has the station moved vertically since 2004?

If you do not have Internet access, use the time-series plots below. The dates on these plots will not match the newest plots.

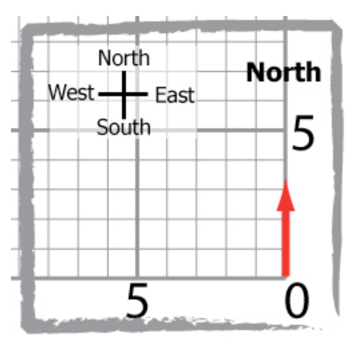






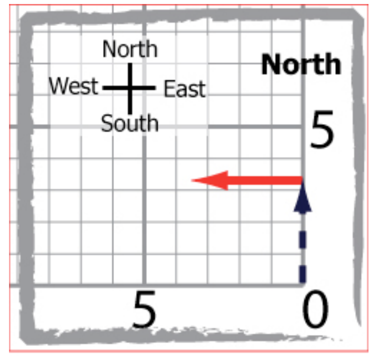
7. Plotting GPS motion on a map grid. On the map grids below:

a. Draw a faint arrow to show the **annual** North movement

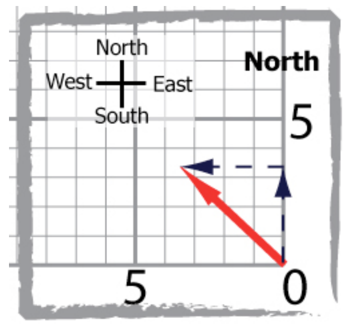


UNAVCO

b. From the end point of the North arrow, draw an arrow to show the **annual** East motion

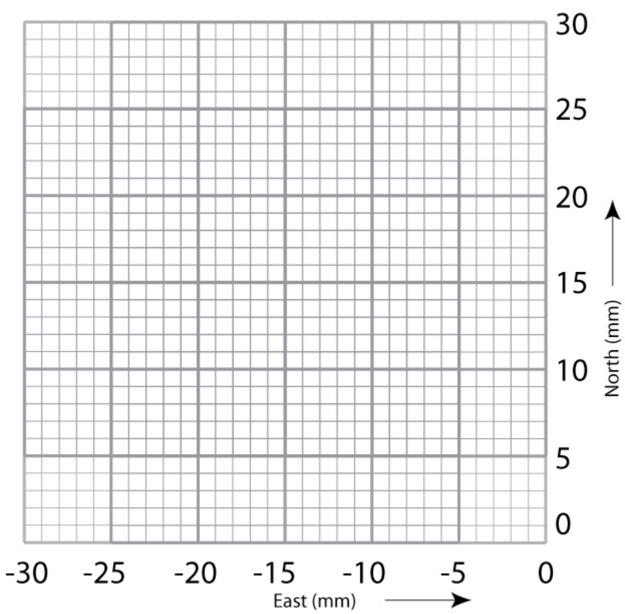


c. Draw a diagonal arrow from (0,0) to the end point of the East arrow. This final arrow (vector) shows the overall annual direction and distance of motion of the GPS station and the land beneath it.

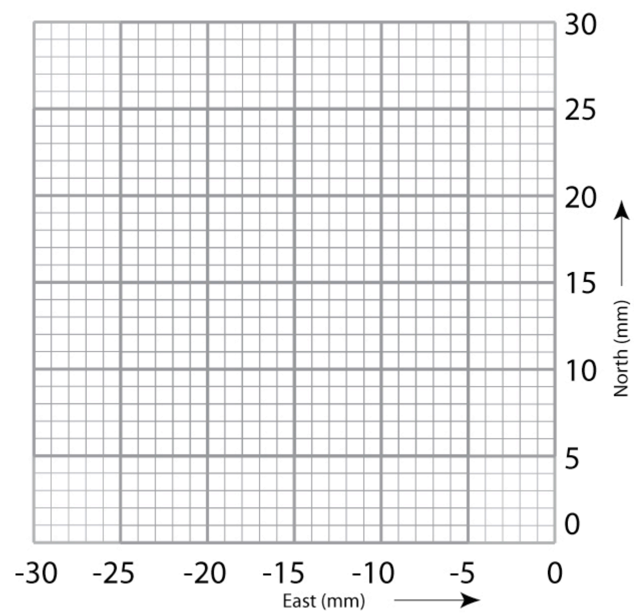


Using a millimeters-scale ruler, measure the length of the final vector and label the vector with the speed in mm/year. (each edge of the smallest squares should be a millimeter)

SBCC map grid



BEMT map grid



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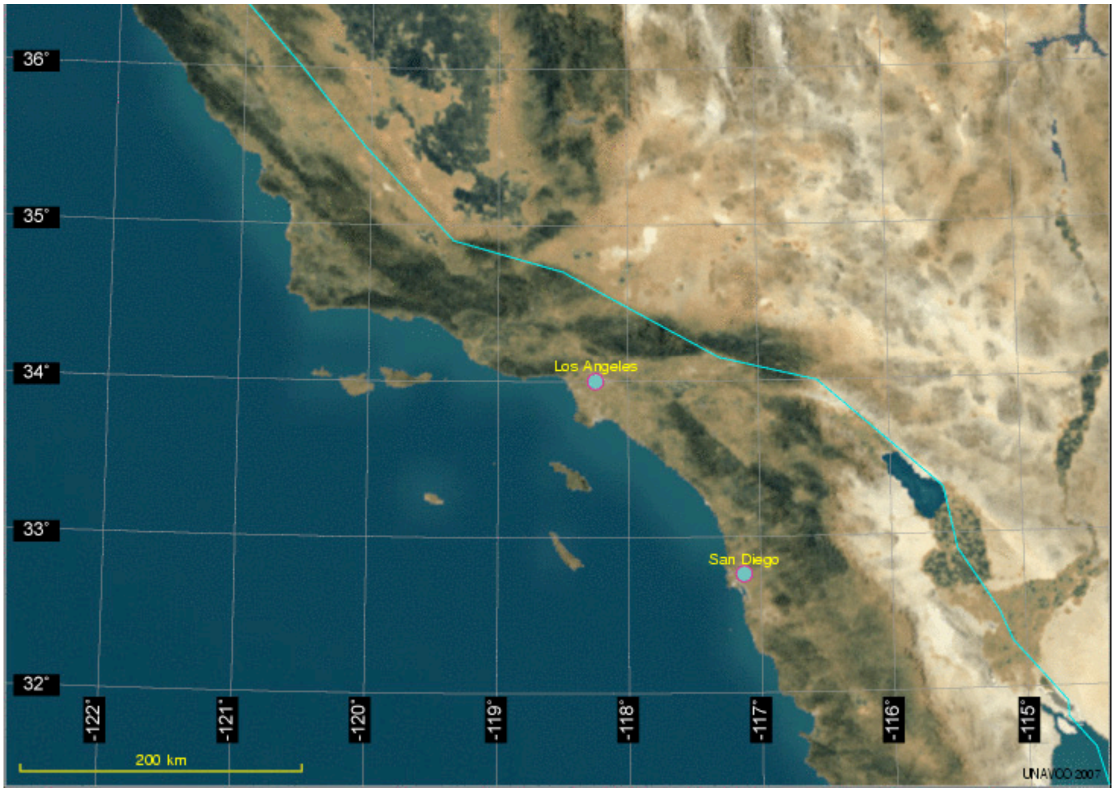


8. Plotting the GPS vectors on a map and analysis Work with your partner:

i. Plot the locations of the GPS stations on the map.

ii. Draw the vectors for BEMT and SBCC vectors

iii. Answer the following questions:

a. Describe how the SBCC and BEMT are different and how they are the same. Which station is moving faster?

b. What would be some reasons for the differences in their rates?

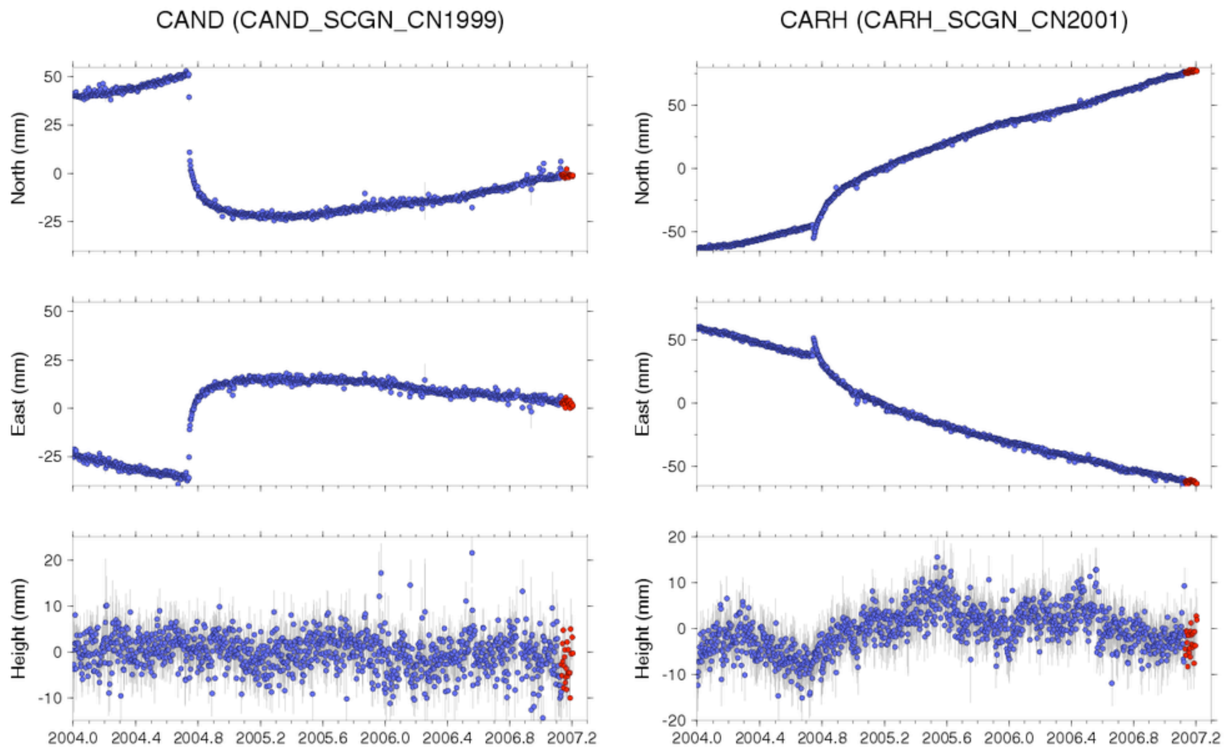
c. Remember that the GPS monuments are cemented into the ground, if they are moving, then the ground must be moving.

d. In 1000 years, how far has SBCC moved; how far has BEMT moved?

e. If the two GPS stations started off directly across from each other (perpendicular to their movement) and are moving in the same direction, how much further will SBCC have moved in 1000 years compared to BEMT? Based on what you know about the San Andreas Fault, how will this movement occur? All at once?

Name ____________________ Class ________________ Data ______________

Before turning to Part 2, study the time series plots for GPS monuments CAND and CARH. What could cause these two GPS stations to move like this?



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Name ____________________ Class ________________ Data ______________

Part 2: Investigate deformation at two GPS stations in California

1. According to the position time series plots, when did the earthquake occur? Use the conversion chart to provide the month and year.

2. How much slip on the fault occurred during the event using the CAND time series plot?

3. Describe how the CAND GPS station's position changed during the earthquake.

4. Describe how the CAND GPS station's position changed after the earthquake.

5. *Optional:* Using the equation provided, which is a simplified estimate for the moment magnitude? What was the magnitude of the Parkfield earthquake based on the slip that you calculated?

$M = \frac{\log_{10}(D) + 6.32}{0.9}$ where M = magnitude D = average slip in meters [1000 mm = 1 meter]	

How well does moment magnitude match the measured magnitude of the earthquake?

More questions to consider

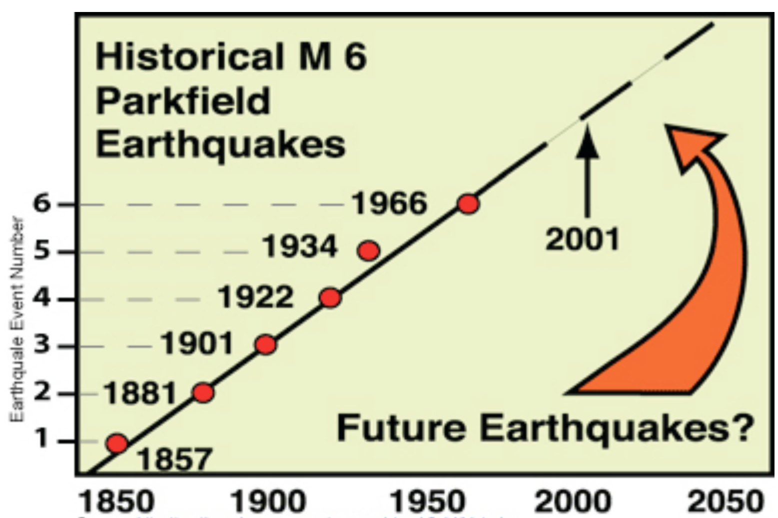
The Parkfield section of the San Andreas fault has not experienced a magnitude 6.0 (or greater) earthquake since the 2004 event, but the North American and Pacific plates continue to grind past one another.

1. Based on the data about the total slip due to the Parkfield earthquake at CAND and CAHR, and the fact that the plate is moving ~22mm/yr at Parkfield, how long should it take to build enough strain energy to generate an earthquake with a similar magnitude?

2. Look at the diagram from the USGS illustrating when earthquakes with magnitudes similar to the 2004 events have occurred along the Parkfield section of the San Andreas fault. How often did these earthquakes occur?

3. Does your calculation from #1 agree with the observed value from #2?

4. If you answered "no" to #3, can you think of a reason why?



Source: http://earthquake.usgs.gov/research/parkfield/hist.php
Modified by UNAVCO / Andy Newman

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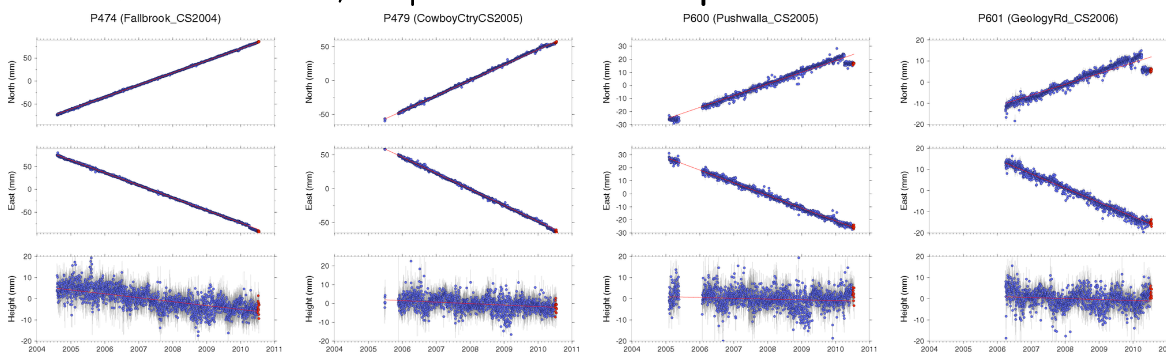
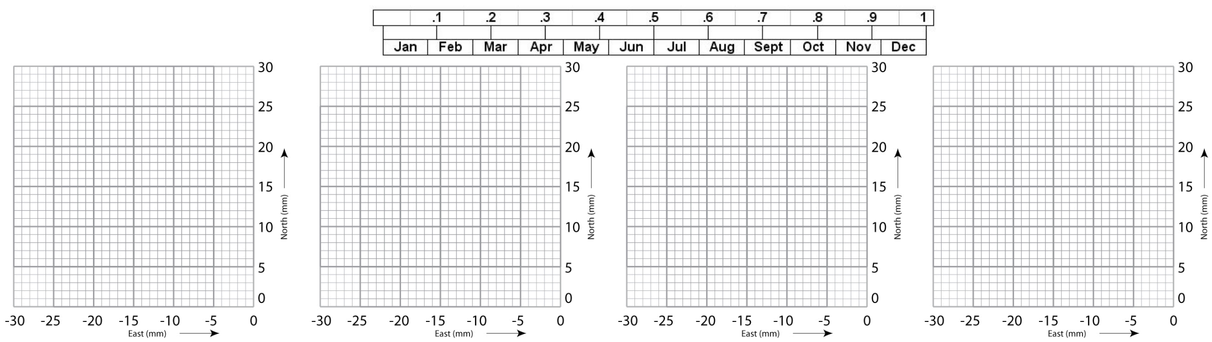
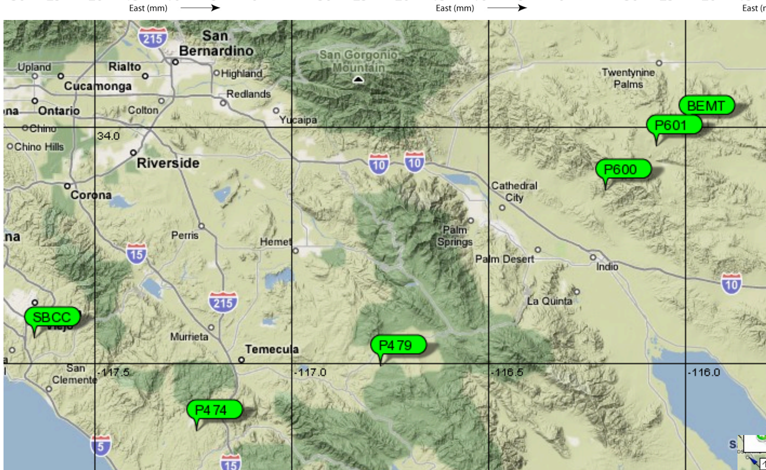
Extension: Explore More GPS locations near BEMT and SBCC

If time permits, take a look at additional GPS stations near BEMT and SBCC, create velocity vectors for each station, and **plot them on the map.**







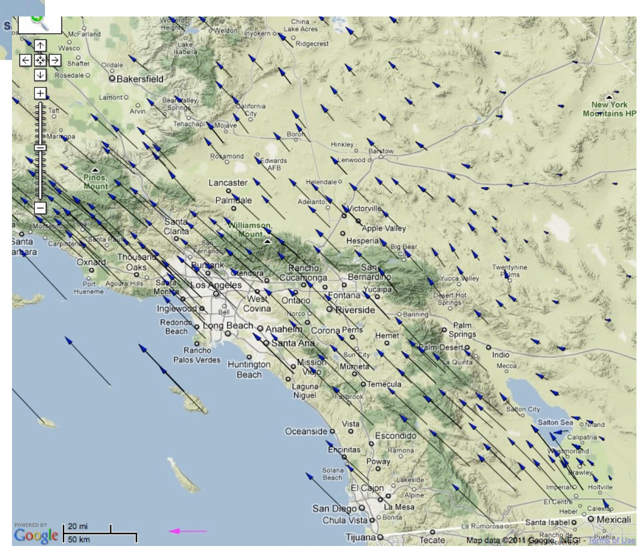
What do you notice about the resulting vectors of these GPS stations?

How do the velocities at each station change from west to east?

Using these extra stations, where would you place the location of the plate boundary/the San Andreas fault?

What other types of data might you explore to support your decision for this location?

How do your vectors compare to the vectors in the map to the right?



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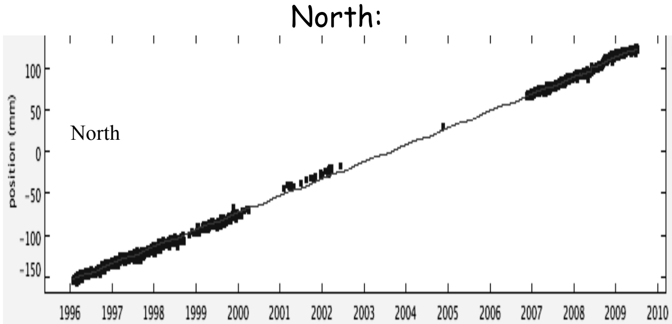
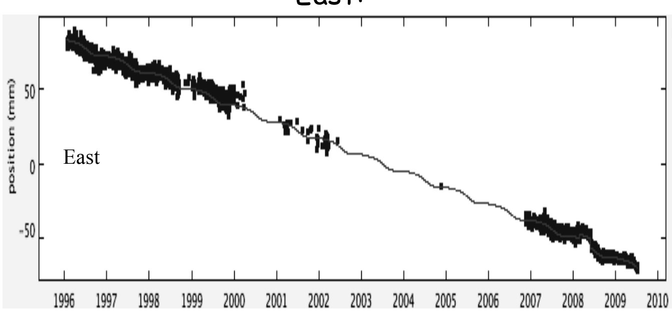
Surprising Discoveries About Iceland: Determine the direction of movement of high-precision GPS Monuments

GPS Monument REYK

North:

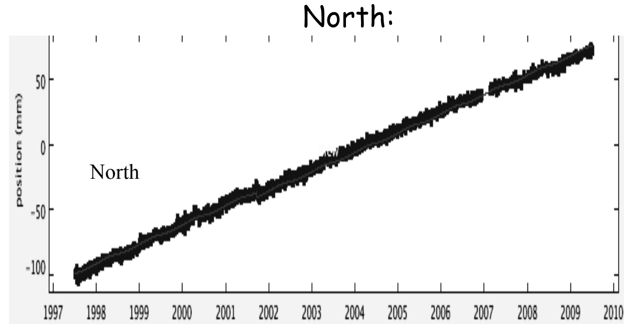


East:

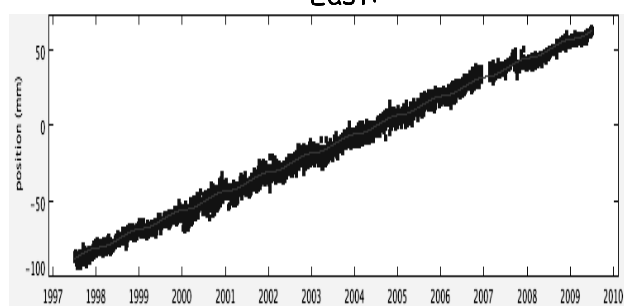


GPS Monument HOFN

North:



East:



1. What general direction are Monument REYK and HOFN moving? How you determine this?

   REYK is moving ______ *HOFN is moving* _____

2. Are the two monuments moving towards each other, away from each other, or in the same direction?

Name ____________________ Class ________________ Data ______________

3. Calculate annual motions in N/S and E/W directions for REYK and HOFN. (Directions to the south and east are written as negative numbers).

REYK is moving: ________ millimeters/year to the (North or South) ________

REYK is moving: ________ millimeters/year to the (East or West) ___________

HOFN is moving: ________ millimeters/year to the (North or South) ________

HOFN is moving: ________ millimeters/year to the (East or West) ___________

4. On the map, write the speed of each station for the north and east (in mm/yr) near the GPS stations. Use your GPS model to simulate the motion. **Do you still agree with your answer in question 2?**

5. Now draw your vectors on the graph paper (each block = 1mm) and add them together. Draw a scale bar on the bottom of the map using the length of the vector as 10 mm/yr.

6. Describe how the vectors are different and how they are the same.

7. Remember that the monuments are cemented into the ground. If they are moving then the ground must be moving. If you flew in a plane over Iceland then flew over Iceland 500 years later, what would you see? How much further apart will the stations moved in the east – west direction?

8. Give one possible explanation for the way the ground is moving in Iceland.

9. Look at the map in the presentation showing the location of lava eruptions in Iceland. Sketch in the mid-Atlantic ridge shown in the slide on your map. In what way does this support or conflict with your explanation?

Bonus:

10. There are gaps in the data for REYK. Given what you know about how GPS data are collected, give two possible causes for the gaps.

11. Calculate the magnitude of the resulting vector.