

G141 Lab 2: Exploring Plate Motion and Deformation in California Using GPS Data

Based on an exercise developed by Cate Fox-Lent, Andrew Newman, and Shelley Olds, UNAVCO Consortium

Overview: Through the miracle of modern GPS technology, we can actually observe the process of plate tectonics as the plates are moving in real time. Because plates move slowly (only a few centimeters per year), we need to follow the positions of points on Earth’s surface over a period of several years, as they gradually track the motions of the plates. In this activity we will work with actual GPS data from California to explore plate motion and Earth deformation in the Pacific – North America plate boundary zone. By analyzing multiple GPS time series plots we can determine the directions and rates of regional deformation. Because the GPS stations are permanently cemented to the ground, the motion of a GPS monument is considered to be representative of that segment of the Earth’s tectonic plate. We will be using data recorded by UNAVCO consortium (www.unavco.org), a group of academic and government scientists studying Earth motions using GPS and related technologies. Specifically, we will use data from two stations that are part of the National Science Foundation’s “Plate Boundary Observatory” experiment (<http://www.earthscope.org/observatories/pbo>), which has installed some 800 GPS sites across the western United States to study in detail the processes associated with earthquakes, volcanoes, and plate tectonics in the region.

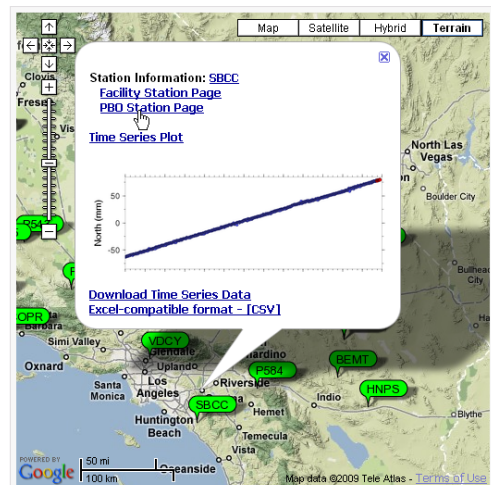
Part 1: Analyze real time-series data of two GPS stations

We’re going to be using data from two GPS stations in California to observe how they’re moving with respect to the North American continent. Work with a partner to study the data for two GPS monuments BEMT and SBCC to determine plate tectonic motion and complete the questions below.

If you have access to the Internet, follow the instructions below. Otherwise, fill in the table below using the station information provided on page 2 and the time series plots on page 4.

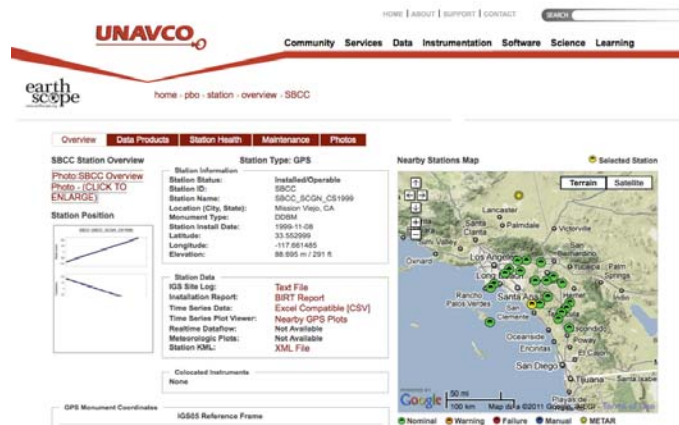
1. Start at www.unavco.org and click on the link for **Data for Educators** (the direct link is: http://www.unavco.org/edu_outreach/data.html)
2. Move the map (click and drag on the map) until you can see California and zoom to bring **BEMT** and **SBCC** into view. [Hint: double click on the ocean near 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



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

SBCC

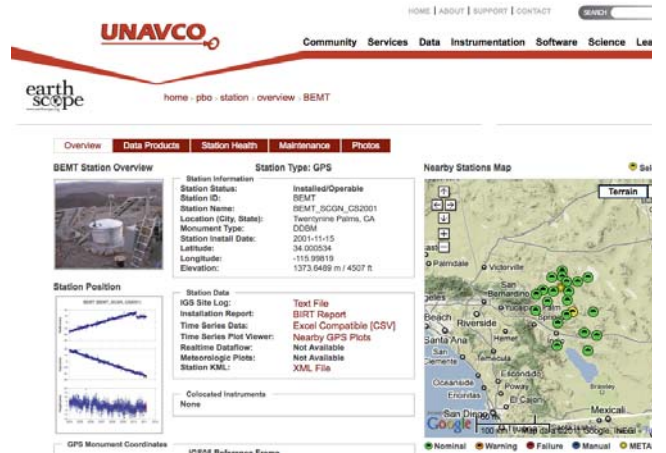


In which city and state is SBCC located?

What is the latitude and longitude?

What is the elevation?

BEMT



In which city and state is BEMT located?

What is the latitude and longitude?

What is the elevation?

Using the latitude and longitude, plot the location of the two stations on the map of Southern California.



5. Study the time-series plots for SBCC and BEMT by clicking on the Station Position Time Series Plot. These plots show the position of the GPS monument as a function of time—over a period of 6-7 years. Each point on the plot represents a daily estimate of position of that point, with respect to North America. The **reference guide** shows how these plots are used to indicate horizontal motion of the Earth’s surface. [Hint: you can study these plots on screen by double-clicking, then ctrl + to zoom in.]



6. What direction is GPS monument SBCC moving?

What direction is GPS monument BEMT moving?

7. Explain how you used the GPS time series to determine the directions of the two GPS monuments.

8. Work through the next steps to find out what direction and how fast each GPS station is moving
SBCC: What is the first month and year of data shown on the time-series?

[Hint: Each major tick mark is a tenth of a year. Use the conversion chart on p. 4 to convert to date.]

What is the most recent date on the time series plot?

BEMT: What is the first month and year of data shown on the time-series?

[Hint: Each major tick mark is a tenth of a year. Use the conversion chart on p. 4 to convert to date.]

What is the most recent date on the time series plot?

9. Now calculate the SPEED (in the horizontal direction) of each GPS monument in each direction. (The convention is to **use a negative number for velocities to the south or west**).

[If you don’t have internet access, recent time series plots are on the next page.]

In the six years from 2004-2010, how far has the station moved? [Hint: your answer should be in **mm**; then circle the direction of movement. Is it to the north or south, or east or west?]

Based on this motion, how fast has it moved? [Now your answer should be in **mm/yr**.]

a. SBCC **North** = _____ mm (North or South)

Velocity = _____ mm/yr

b. SBCC **East** = _____ mm (East or West)

Velocity = _____ mm/yr

c. Study the **vertical** time-series and describe the motion vertically (up, down, stable):

d. When was the station at its highest elevation?

e. How much has the station’s **vertical** position changed since 2004?

In the six years from 2004-2010, how far has the station moved? Based on this motion, how fast has it moved? [Hint: You’ll note that there’s a strange ‘jump’ in the position of BEMT in early 2010. We’ll come back to that jump later. For now, use the period from 2004 to the beginning of 2010 to calculate its velocity.]

a. BEMT **North** = _____ mm (North or South)

Velocity = _____ mm/yr

b. BEMT **East** = _____ mm (East or West)

Velocity = _____ mm/yr

c. Study the **vertical** time-series and describe the motion vertically (up, down, stable):

d. When was the station at its highest elevation?

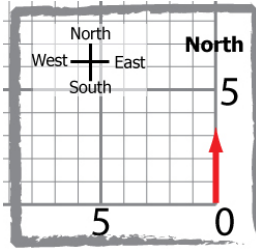
e. How much has the station’s **vertical** position changed since 2004?

10. Now that you have calculated the speed with which each GPS station is moving in the North and East directions, we can turn these speeds into “vectors” by adding the North and East vectors together.

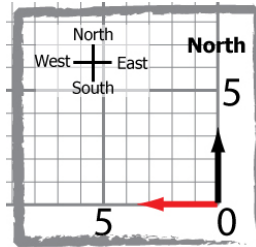
a. **Plot** the north-south and east-west vectors on the graph paper.

b. **Add** the two vectors together to determine the resulting magnitude + direction of the resulting velocity vector, take a look at the example:

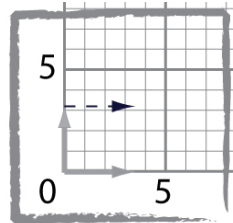
1) Plot the North vector



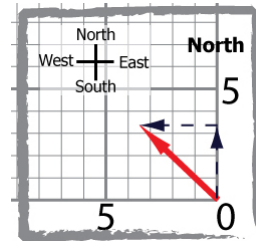
2) Plot the East vector



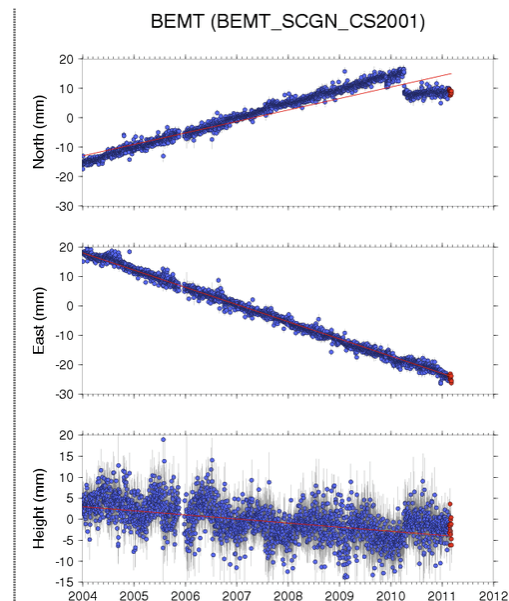
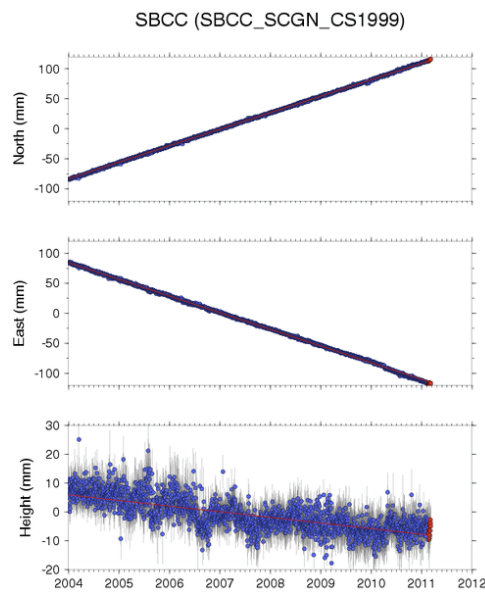
3) Re-draw the East arrow at the head of the North arrow



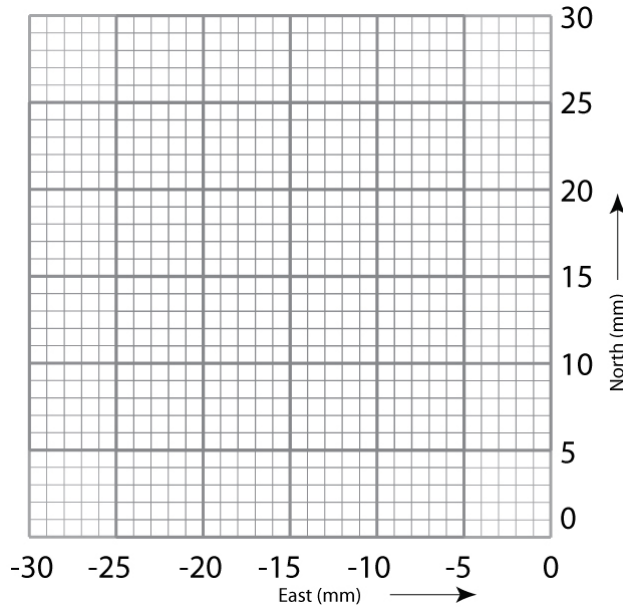
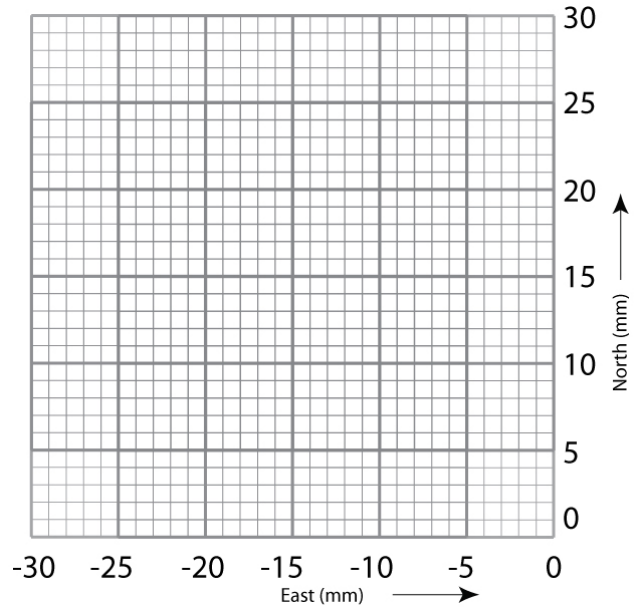
4) Add vectors together using the tail to head method



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



	.1	.2	.3	.4	.5	.6	.7	.8	.9	1	
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec

SBCC**BEMT**

11. Now return to the map of southern California, draw both vectors (at the same scale as this graph) and **answer the following questions.**

- Describe similarities and differences in the orientation and scale of the two vectors. Which station is moving faster?
- Explain what plate tectonic process might explain this pattern of GPS motions.
- Remember that the monuments are cemented into the ground. If they are moving, then the ground must be moving. In 100 years, how far will each of the stations have moved?
- These same motions can extend to geological time scales. How far will they move in 1 million years?

12. The ‘Velocity Field’. Now that you have computed vectors for two GPS stations in southern California, let’s see how this fits in with the ‘big picture’ of plate boundary movements in California. Set your browser to the “UNAVCO Velocity Map Viewer” (<http://geon.unavco.org/unavco/GPSVelocityViewer.php>), which presents all of the GPS velocity vectors available in a given map region, using a Google Map interface. Make sure that the map parameters are set as follows:

- data source = “PBO GPS Velocities, snf01”
- velocity vectors = on
- velocity vector error ellipses = off
- vertical motion symbols = off
- tectonic plate boundaries = on
- earthquakes, volcanoes = off
- how many symbols to show = show half

Click “Draw Map” to refresh the map display. You should see several hundred GPS velocity vectors in the area, shown with respect to the North American plate (i.e., how these points would move from the point of view of an observer in Indiana!).

- Is there a systematic pattern to the velocity vectors? If so, describe the pattern you observe.
- How rapidly are points on the Pacific Plate moving with respect to North America? In what direction?
- Where is the strongest gradient in the velocity field (in other words, in what area do the lengths of the GPS vectors change most rapidly)?
- What is the relation of these GPS velocities with the tectonic features that mark the North America – Pacific plate boundary?
- How do points situated within the North American plate (i.e., east of the San Andreas Fault) appear to move relative to North America? Why do you think they move this way?

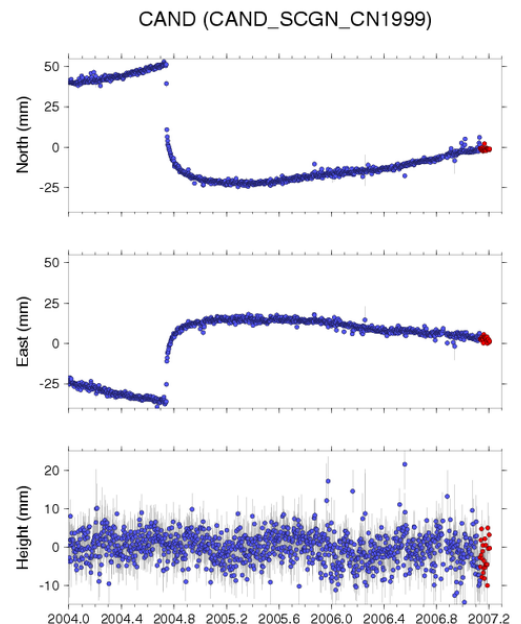
13. Changing Reference Frames. We’ve been looking at the way points on the Earth’s surface in California appear to move with respect to an observer in North America. How would this ‘velocity field’ look to an observer standing on the Pacific Plate? In order to answer that question, we’ll change the “reference velocity” to that of the Pacific Plate. From the “Data Source” menu, select “GSRM Pacific”, and then “Draw Map” to refresh the map image.

- Describe the pattern of GPS velocities in this view. How has the velocity field changed?

Part 2: Using GPS to track Earth motions during earthquakes [Extra Credit!]

Finally, let’s return to the strange ‘jump’ we observed in the BEMT time series in 2010. What might cause this sort of sudden change in Earth position? The figure at right shows an even better example of the same phenomenon. This is a similar time series plots for GPS monument CAND, which is located adjacent to the San Andreas fault, during the period surrounding the magnitude 6.0 Parkfield earthquake that occurred along the San Andreas fault in 2004.

- Using the position time series plots, can you tell when the earthquake occurred? Use the conversion chart (p. 4) to provide the month and approximate day of the earthquake.



- b. Describe how the CAND GPS station's position changed on the day of the earthquake.
- c. We now recognize that earthquakes can trigger Earth movements that last for weeks or months following an earthquake. Describe how the CAND GPS station's position changed in the aftermath of the Parkfield earthquake.
- d. What do you think might cause this pattern of motion?
- e. The CAND time series plot can be used to estimate how much slip (in mm) on the fault occurred during the event. What's your best estimate of fault movement?
- f. Using the equation provided, which is a simplified estimate for the earthquake's "moment magnitude", what was the magnitude of the Parkfield earthquake based on the slip that you calculated?

$M = \frac{\log_{10}(D) + 6.32}{0.9}$ <p>where M = magnitude D = average slip in meters</p> <p>[1000 mm = 1 meter]</p>	
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How well does moment magnitude match the measured magnitude of the earthquake?

- g. Finally, with this knowledge, let's return to the original time series, for station BEMT. What do you think happened in 2010? On what date?
- h. Using the U.S. Geological Survey's list of significant earthquakes in 2010 (<http://earthquake.usgs.gov/earthquakes/eqinthenews/2010/>), find your best candidate for the event that might have triggered this sudden offset of the Earth in southern California.