UNAVCO

Exploring plate motion and deformation in California with GPS

Student worksheet

Since 2000, over 800,000 deaths worldwide and nearly 750 deaths in the United States have been attributed to earthquakes. If it was possible to predict the timing, location and magnitude of an earthquake, many lives could be saved. Interest in the possibility of a dependable method for earthquake prediction increased among the scientific community in the 1970's. In 1977, Congress created the National Earthquake Hazards Reduction Program (NEHRP). Currently, the Program involves four agencies: the US Geological Survey (USGS), National Science Foundation (NSF), Federal Emergency Management Agency (FEMA), and the National Institute for Standards and Technology (NIST).

The Program focuses on both the prediction of shaking and the mitigation of risk, and includes research in earthquake science, earthquake engineering and social science. Currently, the earthquake prediction activities under NEHRP are concentrated in the Parkfield Earthquake Prediction Experiment.

In 1984 the United States Geological Survey predicted that a Magnitude 6 earthquake would occur on the San Andreas fault near Parkfield within five years of 1988. The prediction was based on a sequence of 6 similar earthquakes that occured on a regular basis from 1857 to 1966. In anticipation of this earthquake, geologists placed a large and varied suite of instruments along the Parkfield segment of the San Andreas Fault — which included GPS stations.

But rarely does the Earth cooperate when everyone is watching …

Study area for the Parkfield Earthquake Experiment at Parkfield, California. The San Andreas Fault (red line) last ruptured here in 1966 (yellow zone). Brown squares represent sites of geophysical monitoring instruments, including seismometers, strainmeters, creepmeters, and global positioning system (GPS) receivers.
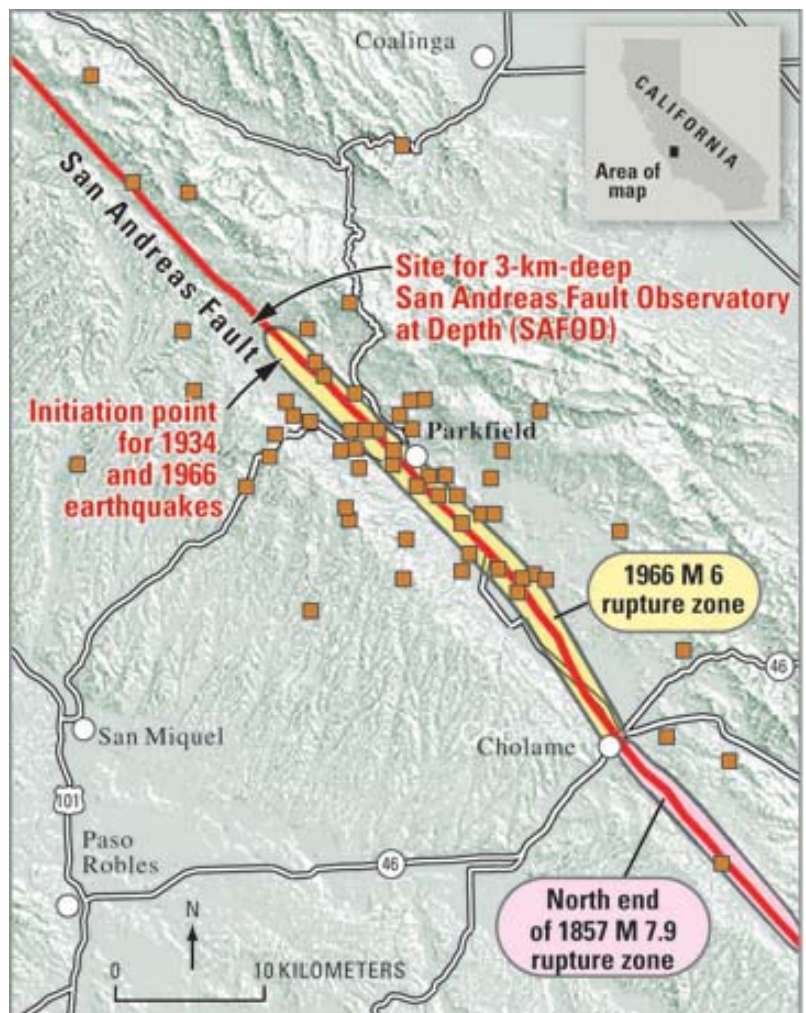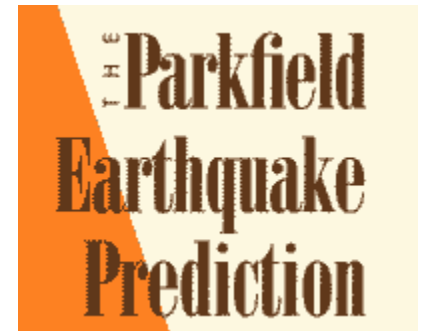
What's happening in California? Earthquakes are shifting the landscape, faults are bending the countryside, and the land is creeping and shaking. But, where? In this activity you will work with GPS data downloaded directly from the UNAVCO website to explore plate motion and deformation in California. By analyzing multiple GPS time series plots you can determine the directions and rates of regional deformation. Remember, the GPS stations are permanently concreted to the ground, so if a GPS monument is moving, the Earth's tectonic plate below it 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 to complete the questions. You will be using the UNAVCO Velocity Viewer to search for and access this data.

If you have access to the Internet, follow the instructions below. Otherwise, fill in the table below using the time series plots on page 3.
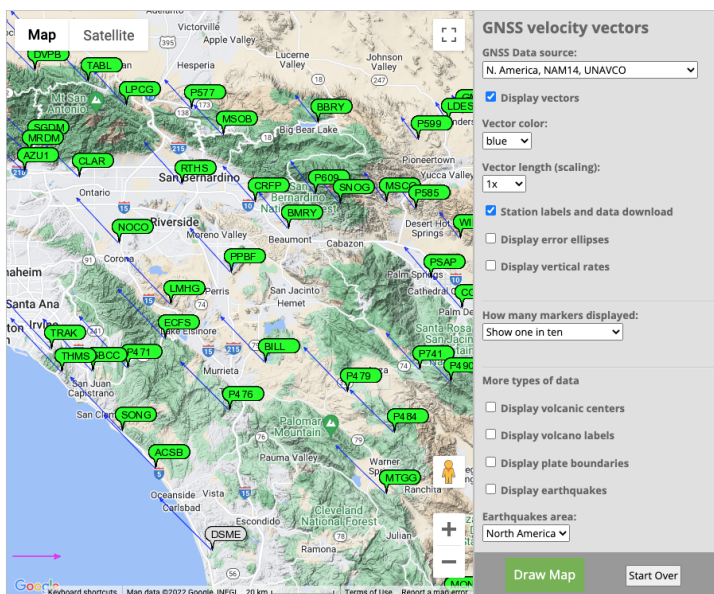

1. Access the UNAVCO Velocity Viewer via a search or this link https://bit.ly/3N6PKSq. Make sure that your settings look like those on the image at left.
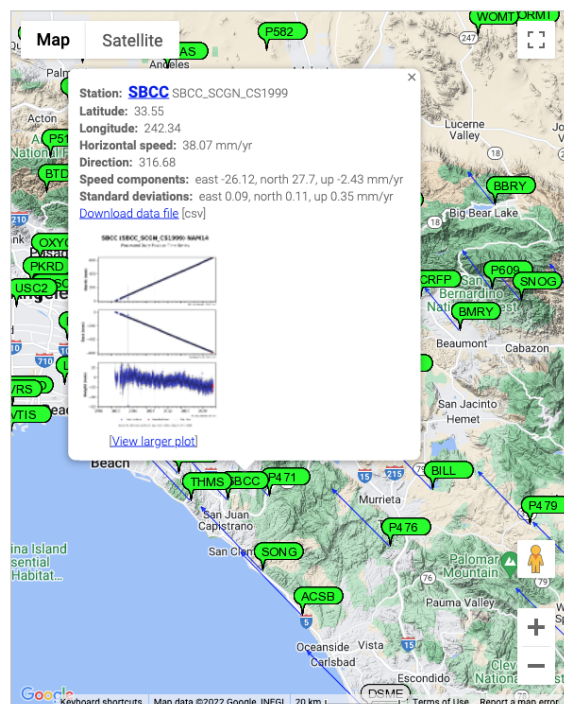
2. Move the map (click and drag on the map or use the +/- in the bottom right corner) until you can see California and then zoom to bring BEMT and SBCC into view (these are located in Southern California).

3. Click on the green balloon with the station name (BEMT or SBCC) and click on the **BOLD** station name to navigate to the Overview Page about the GPS station.

4. Use the information provided on the Overview page to answer the following questions.
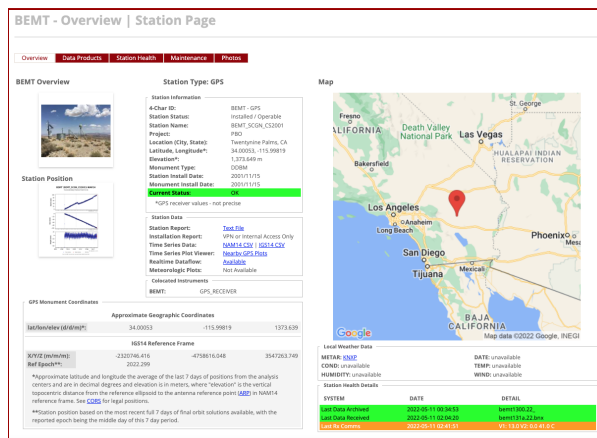
SBCC	BEMT
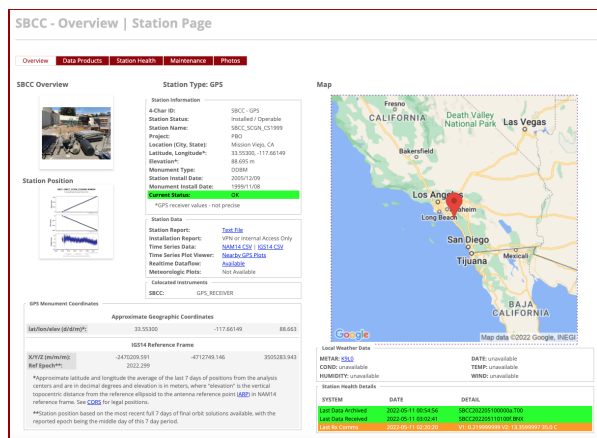
SBCC

In which city and state is SBCC located?

_____

What are the latitude and longitude provided (to 3 decimal places)?
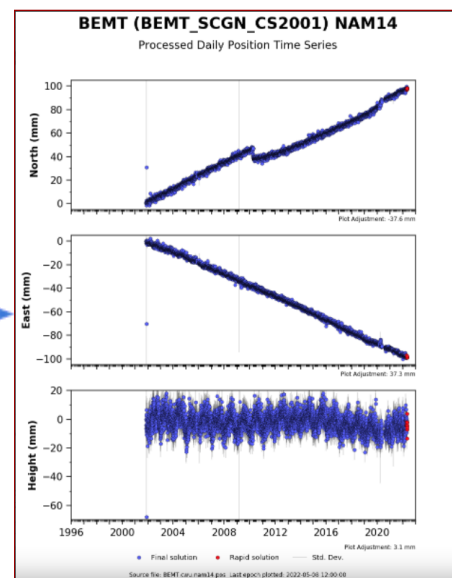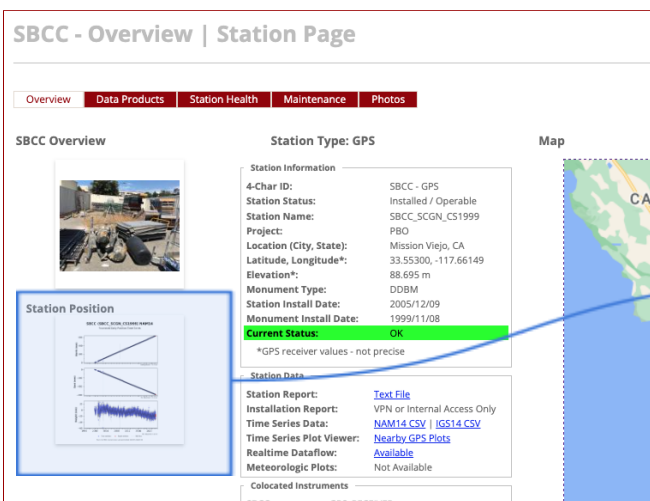
_____

What is the elevation? _____

BEMT

In which city and state is BEMT located?

_____

What are the latitude and longitude provided (to 3 decimal places)?

_____

What is the elevation? _____

5. Click on the graph below Station Overview. 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 five years, and then divide by 5)

_____

b. SBCC North = _____ mm/year
 Moving north or south?

c. SBCC East = _____ mm/year
 Moving east or west?

d. Study SBCC's height (vertical) time series and describe the motion (up, down, stable. etc):

_____

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

_____

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

_____

b. BEMT North = _____ mm/year
 Moving north or south?

What do you think happened at BEMT?

_____

_____

c. BEMT East = _____ mm/year
 Moving east or west?

d. Study BEMT's height (vertical) time series and describe the motion (up, down, stable, etc):

_____

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

_____

7. Plotting GPS motion on a map grid. Copy the information regarding motion from the previous page onto the following map of Southern California. Follow the procedure below to plot the motion on the SBCC and BEMT grids (found on the map on the next page).

## Drawing vectors to show velocity

What is a vector?

A vector is a special type of arrow that shows velocity and direction of motion. We can draw a vector to show the north motion and another vector to show the east (or west) motion. By adding them together we can show the total horizontal motion!

Anatomy of a Vector
A vector indicates the direction and speed of an object.

The *length* of the vector shows the GPS station's *speed** (the longer the arrow, the faster the ground is moving).
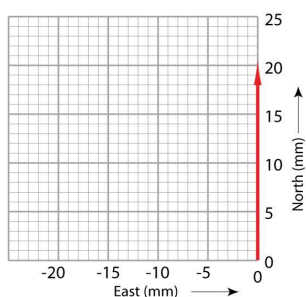
The **vector's tail** is the starting location of the GPS monument.

The **direction the vector points** is the direction the GPS station is moving.

The **length of the vector** represents the velocity the GPS monument and the land beneath it is moving.
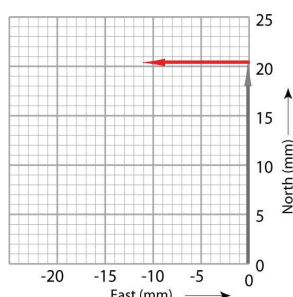
Faster

Slower

The vector points in the *direction* the GPS station is moving.

The GPS station is located at the vector's tail.
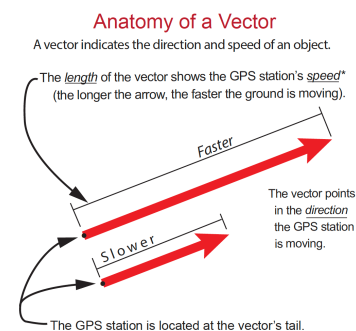
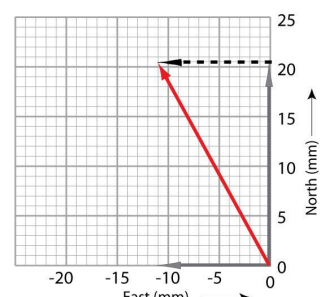| Adding vectors: Step 1.	Step 2.	Step 3.
a. Start at the origin (0,0) draw a light arrow along the north axis the length equal to the north velocity (e.g. one block is 1 mm/yr.)	b. Draw the east vector from the end of the north vector's arrowhead. (A vector moving west is drawn to the west.)	c. Draw a diagonal arrow from (0,0) to the arrowhead of the east vector. This new vector is the sum of the north and east vectors. This final arrow (vector) shows the overall annual direction and distance of motion of the GPS station and the land.

d. Mark the length of the diagonal arrow—the total horizontal velocity vector—on a scrap of paper. Measure its length against an axis, where each square represents one millimeter (1 mm).

Following the steps above, use the graph paper on the map near SBCC to add the North and East velocities together to find the total horizontal velocity for SBCC on the previous page.

Using the same procedure, draw the total horizontal motion vector for BEMT.

Determine the length of the resultant vector - this is the total motion in mm/yr. Record this on the map.
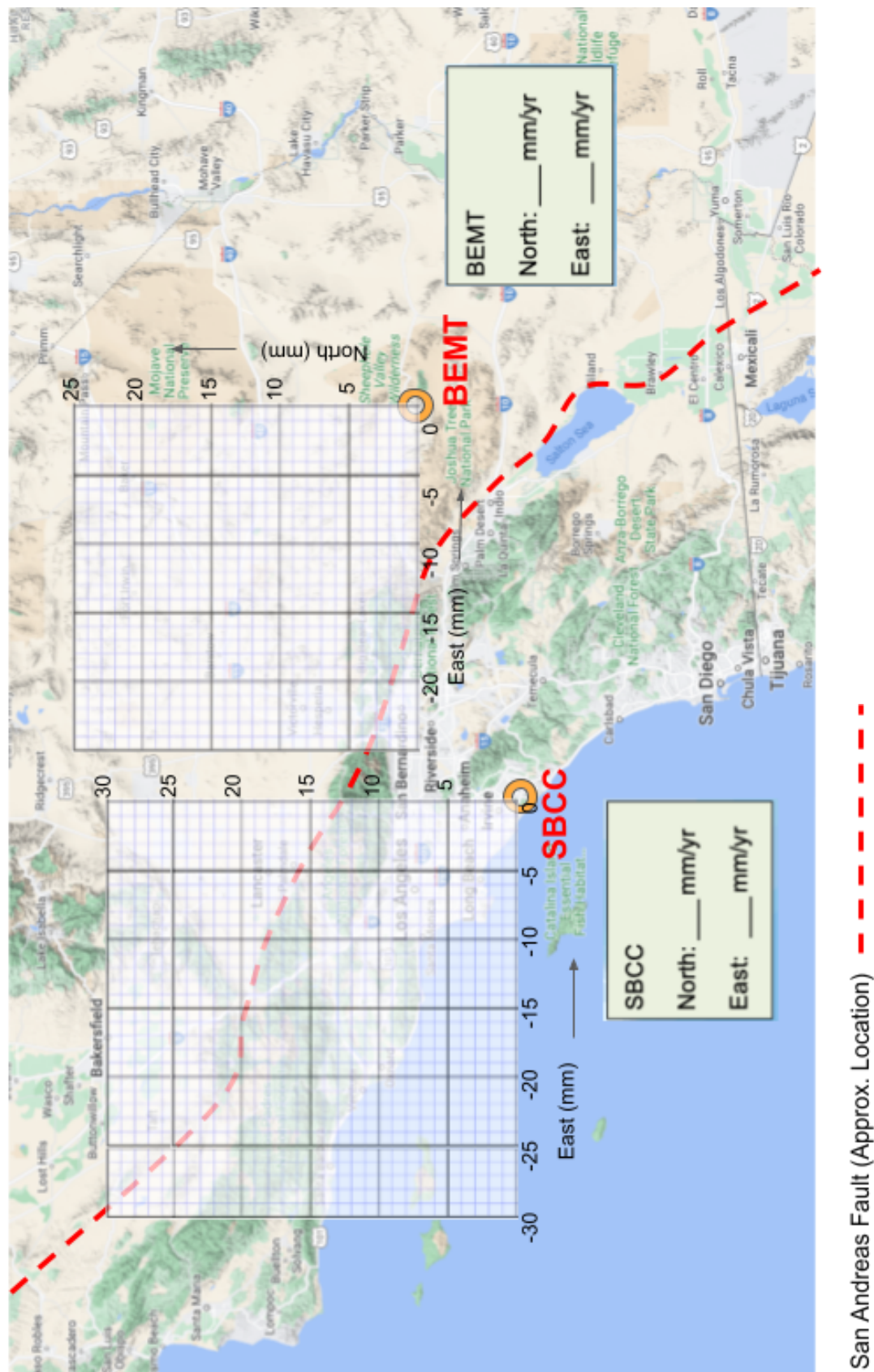
8. Use the vectors for SBCC and BEMT that you just drew to answer the following questions:

    A. Describe how the SBCC and BEMT vectors 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. In 1000 years, how far has SBCC moved; how far has BEMT moved?

    D. If the two GPS stations are moving in the same direction, how much farther 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?

Before beginning Part 2, study the time series plots for GPS monuments CAND and CARH which are, respectively, to the north and south of Parkfield, California

Turn to your partner and discuss what could have caused these two GPS stations to move like this? Construct a explanation that you can share with the class.

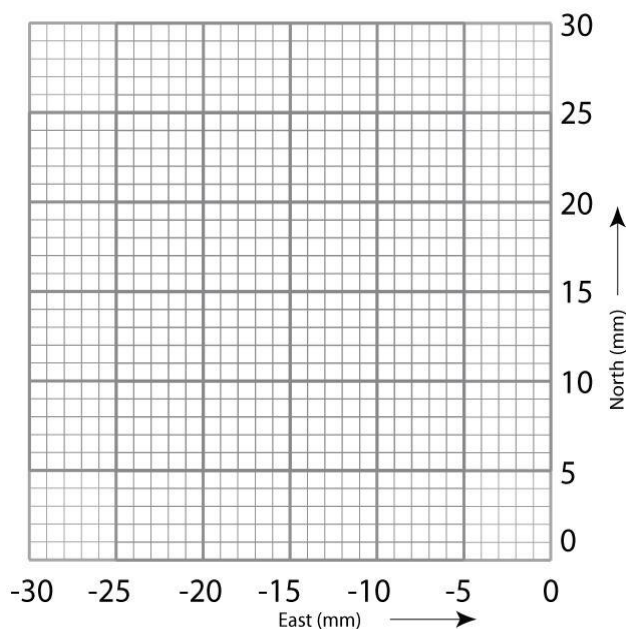CARH (CARH_SCGN_CN2001)

CAND (CAND_SCGN_CN1999)
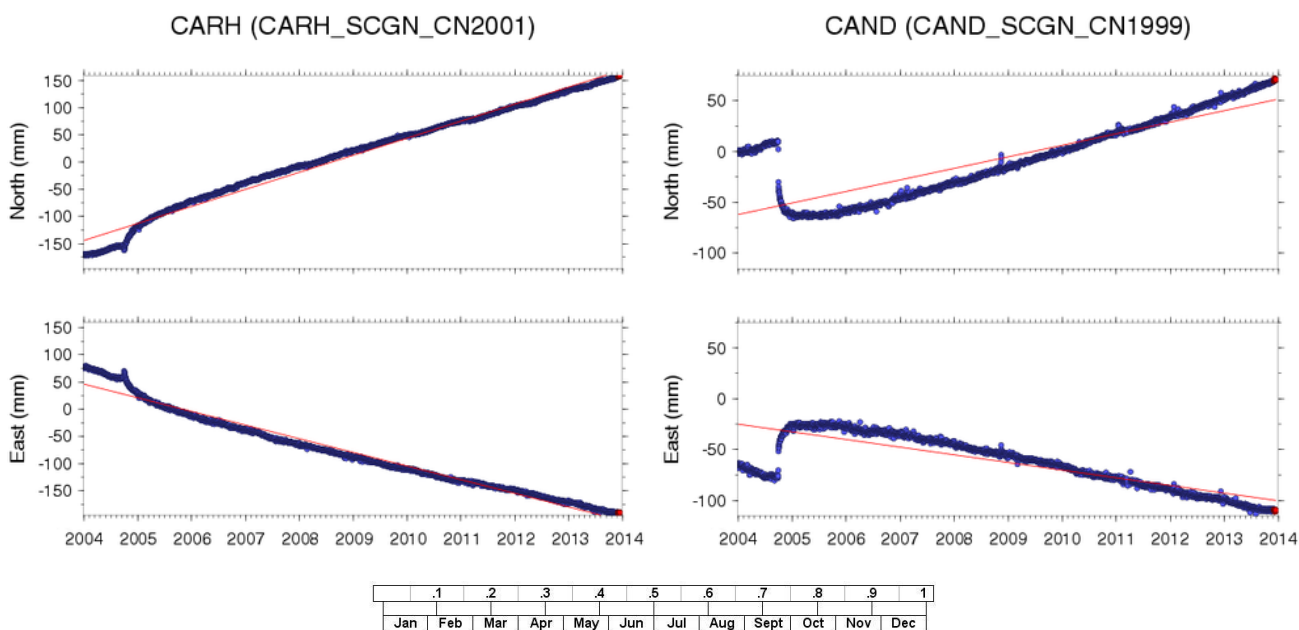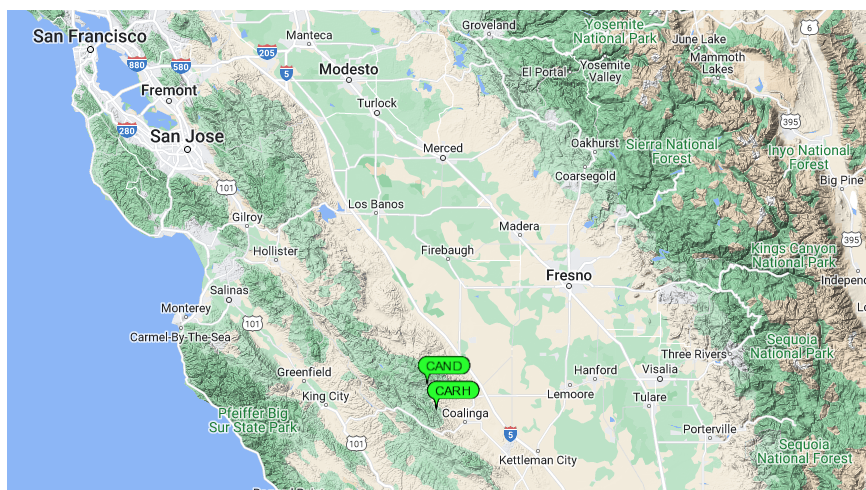
Extension for Part 1: Explore more GPS locations near BEMT and SBCC

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 on page 12.

P474 (Fallbrook_CS2004)
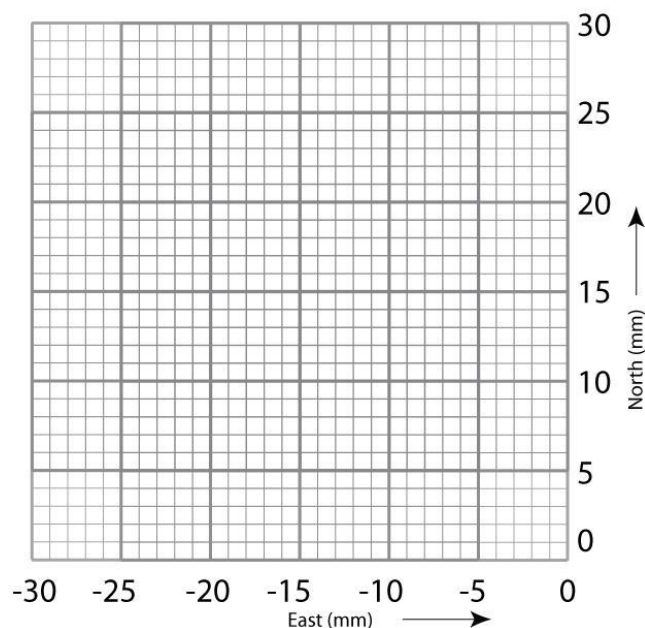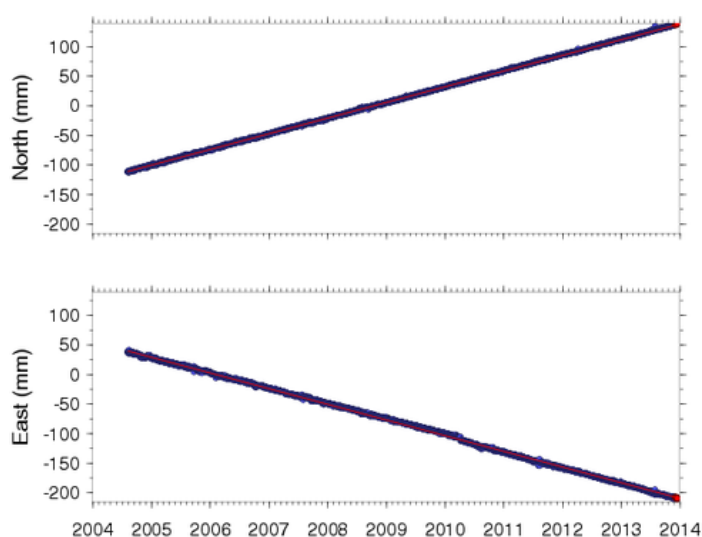
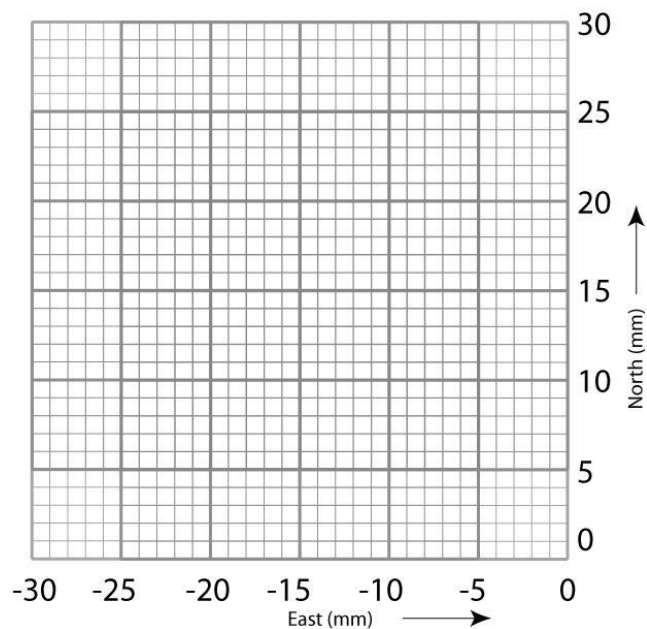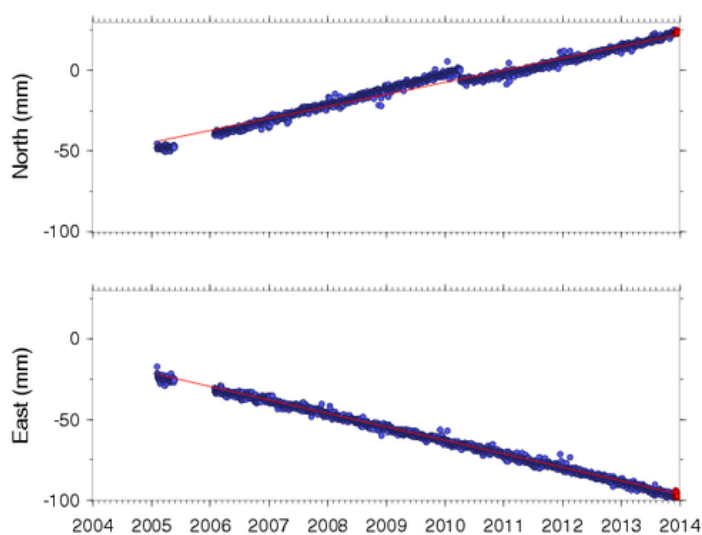|	.1	.2	.3	.4	.5	.6	.7	.8	.9	1
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec

P479 (CowboyCtryCS2005)

P600 (Pushwalla_CS2005)
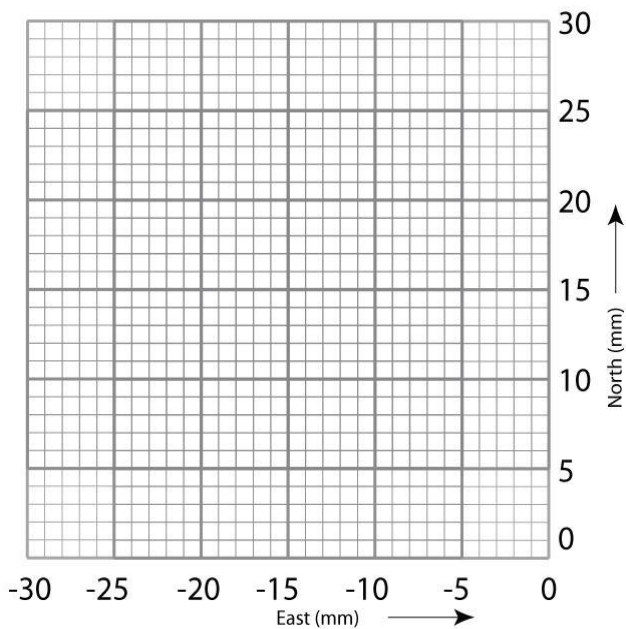
P601 (GeologyRd_CS2006)
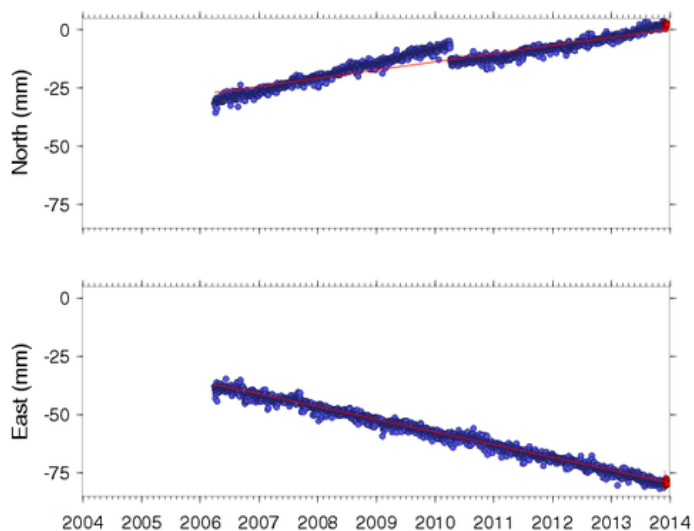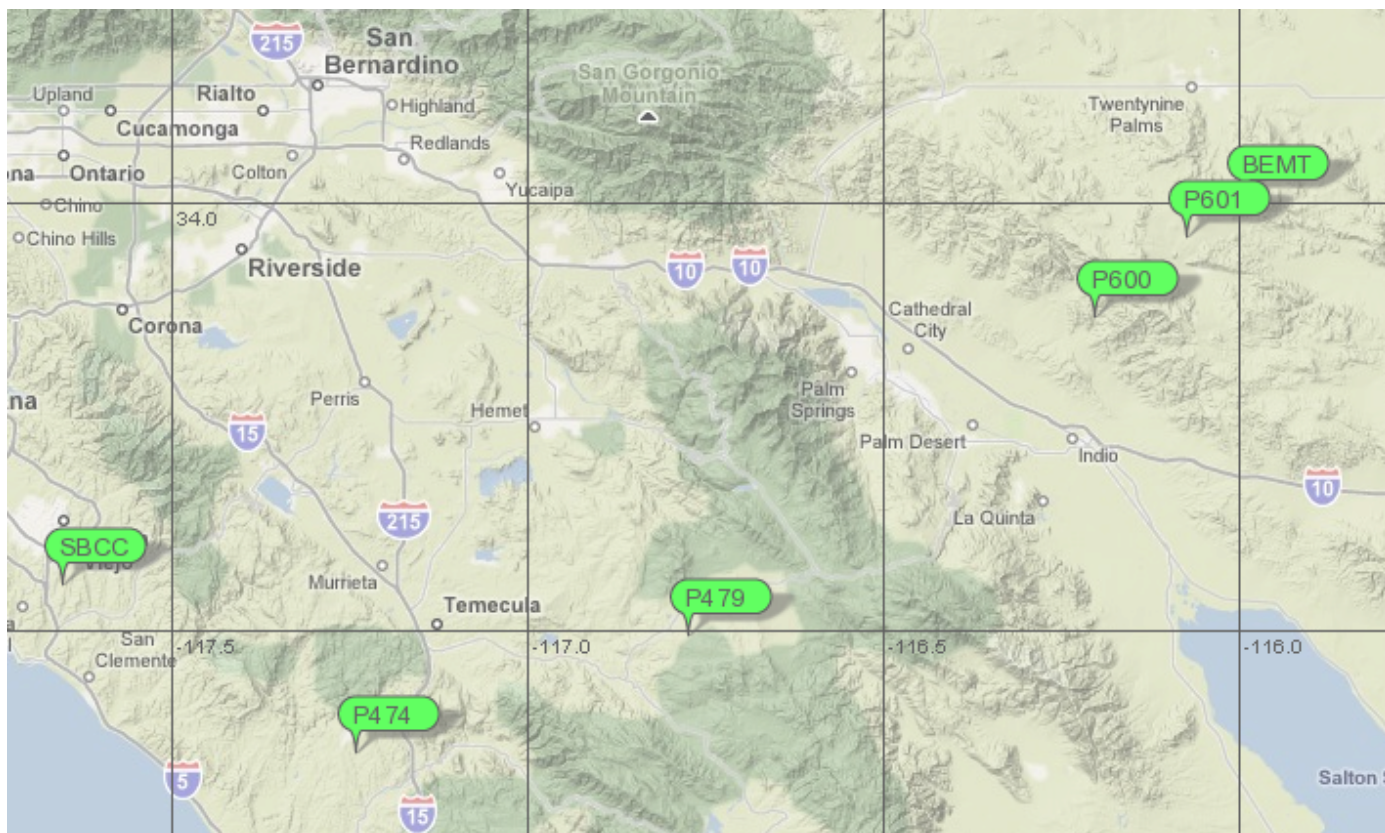
1. What do you notice about the resulting vectors of these GPS stations?

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

3. Using these extra stations, sketch on your map where you would place the plate boundary—the San Andreas fault?

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

5. Using the UNAVCO Velocity Viewer, center the image on Southern California and confirm the setting shown in the image at right. How do your vectors compare to the vectors displayed on the map?

6. Sketch in the San Andreas Fault on your map. Think about the velocity of P474, how far will the ground move in 100 years? Compared to BEMT and P601, what might happen along the San Andreas fault or other faults in between the two stations?

GNSS velocity vectors

GNSS Data source:

N. America, NAM14, UNAVCO

☑ Display vectors

Vector color:

blue

Vector length (scaling):

1x

☐ Station labels and data download

☐ Display error ellipses

☐ Display vertical rates

How many markers displayed:

Show one in five

More types of data

☐ Display volcanic centers

☐ Display volcano labels

☐ Display plate boundaries

☐ Display earthquakes

Earthquakes area:

North America

As discussed at the start of this lesson, the USGS predicted that a Magnitude 6 earthquake would occur on the San Andreas fault near Parkfield within five years of 1988. In anticipation of this earthquake, geologists placed a large and varied suite of instruments along the Parkfield segment of the San Andreas Fault. Those sensors included the CAND and CARH GPS stations - and an earthquake did indeed occur …

Part 2: Investigate deformation at two GPS stations in California

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

2. Using the CAND time series plot, how much did the fault slip during the event?

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, and the slip you calculated, what was the magnitude of the Parkfield earthquake?

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

How well does the magnitude match the measured magnitude (M = 6.0) of the earthquake?
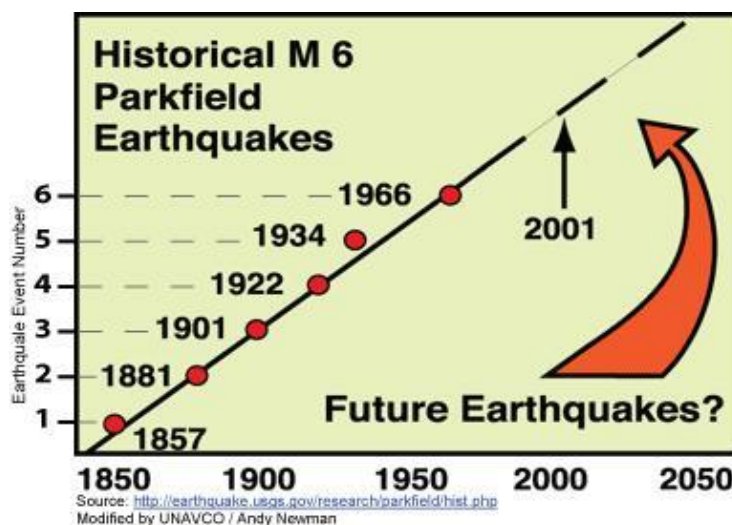
The Parkfield section of the San Andreas fault has not experienced a magnitude 6.0 (or greater) earthquake since the 2004 event, but the North American and Pacific plates continue to grind past each other.

1. Based on the data about the total slip due to the Parkfield earthquake at CAND and CAHR, and the fact that the Pacific plate is moving ~17mm/yr past the North American plate at Parkfield, how long should it take to build enough energy to generate an earthquake with a similar magnitude?

2. Look at the diagram from the USGS at right 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?

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

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

4. If you answered "no" to question 3, how could you explain the difference?

The town of Parkfield, CA lies a few hundred meters east of the main trace of the San Andreas fault. Parkfield bridge (foreground), built in 1932, was damaged in 1934, and 1966 Parkfield earthquakes. Credit: USGS

Extension for Part 2: Explore more GPS locations near CAND and CARH

Explore the extent of movement (post-seismic relaxation) after the Parkfield earthquake by looking at additional GPS stations. Look at a few additional GPS stations near CAND and CARH, such as MNMC (located due north of CAND), MASW (located south of CARH), etc.

GNSS velocity vectors

GNSS Data source:
N. America, NAM14, UNAVCO

☑ Display vectors

Vector color:
blue

Vector length (scaling):
1x

☑ Station labels and data download

☐ Display error ellipses

☐ Display vertical rates

How many markers displayed:
Show all

More types of data

☐ Display volcanic centers

☐ Display volcano labels

☐ Display plate boundaries

☐ Display earthquakes

Earthquakes area:
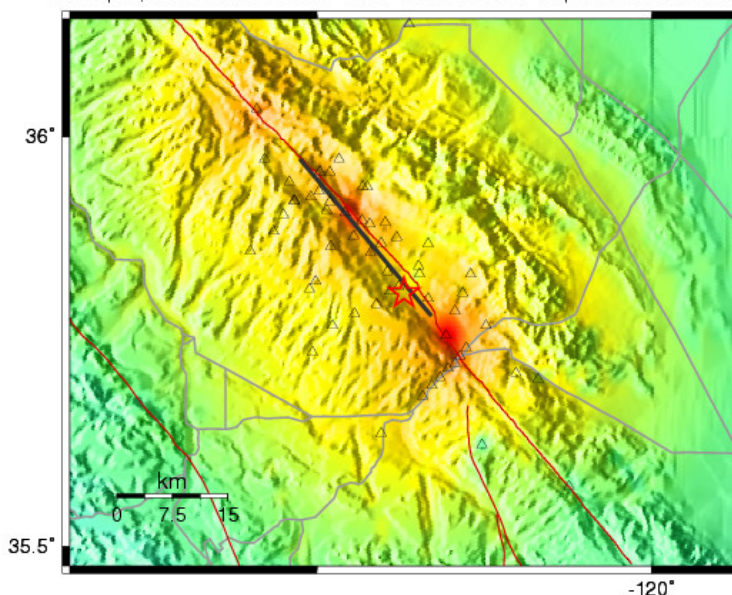North America

Using the UNAVCO Velocity Viewer, move the map to center on Parkfield. Once there, change the settings to match those in the image at left.

What is the total slip for movement at these stations? Do they all show the Parkfield earthquake? Why not?

Locate these stations on your map and label them with the 4-character ID (such as MNMC) and the maximum slip that occurred during and after the Parkfield event.

CISN Rapid Instrumental Intensity Map Epicenter: 11 km SSE of Parkfield, CA
Tue Sep 28, 2004 10:15:24 AM PDT M 6.0 N35.81 W120.37 Depth: 7.9km ID:51147892

Processed: Mon Nov 15, 2004 11:42:21 AM PST,

Now look at the intensity shake map from the Parkfield earthquake. You can access this map at https://bit.ly/3sxgbJ5

You can also study a map made from more than 14,000 reports by citizens who felt the shaking in a program by the USGS called "Did You Feel It?" (https://on.doi.gov/39obg6z)

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

What are the similarities and differences between the intensity of the shaking and the map you created?