Exploring Plate Motion and Deformation in California with GPS

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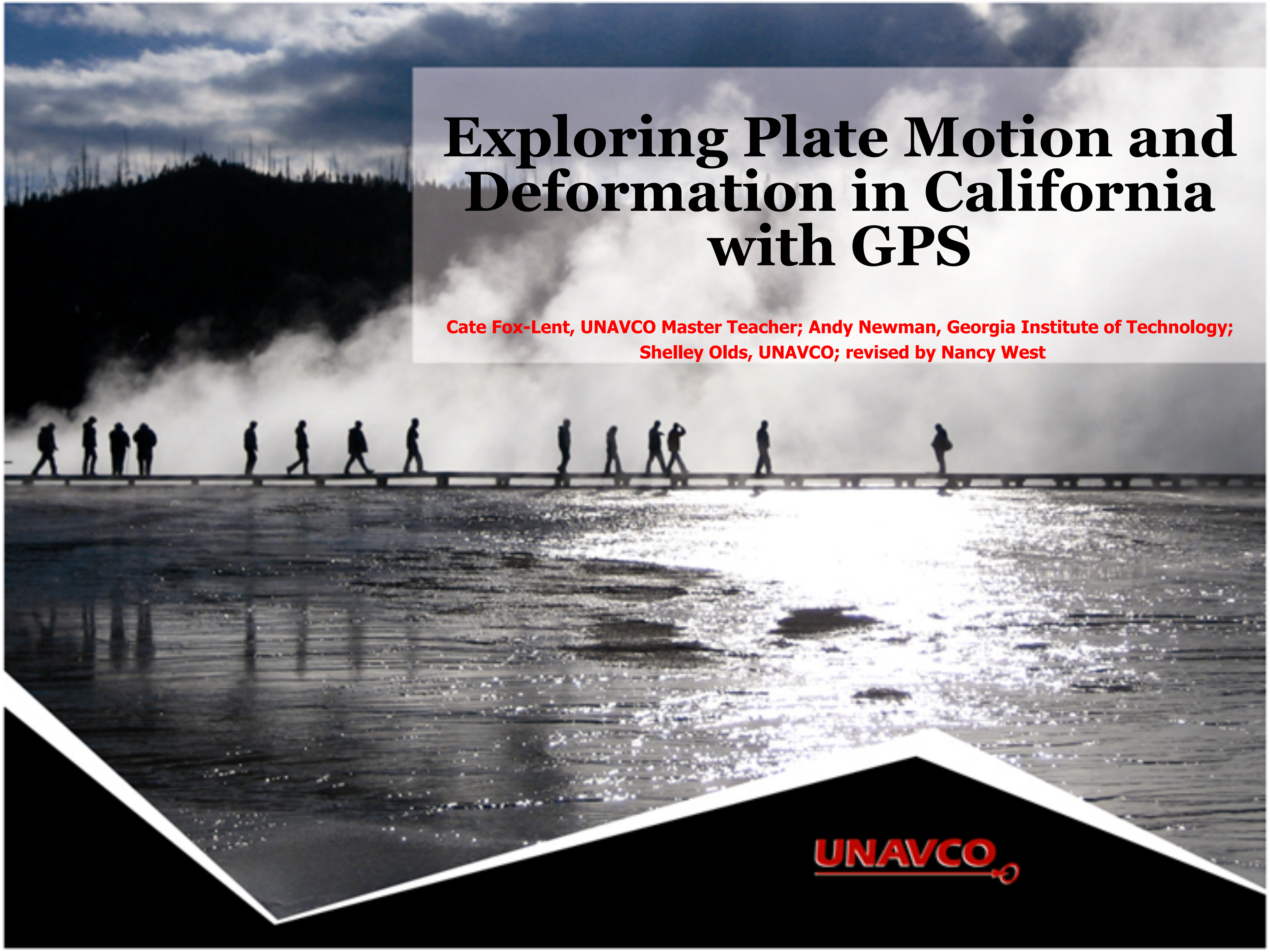
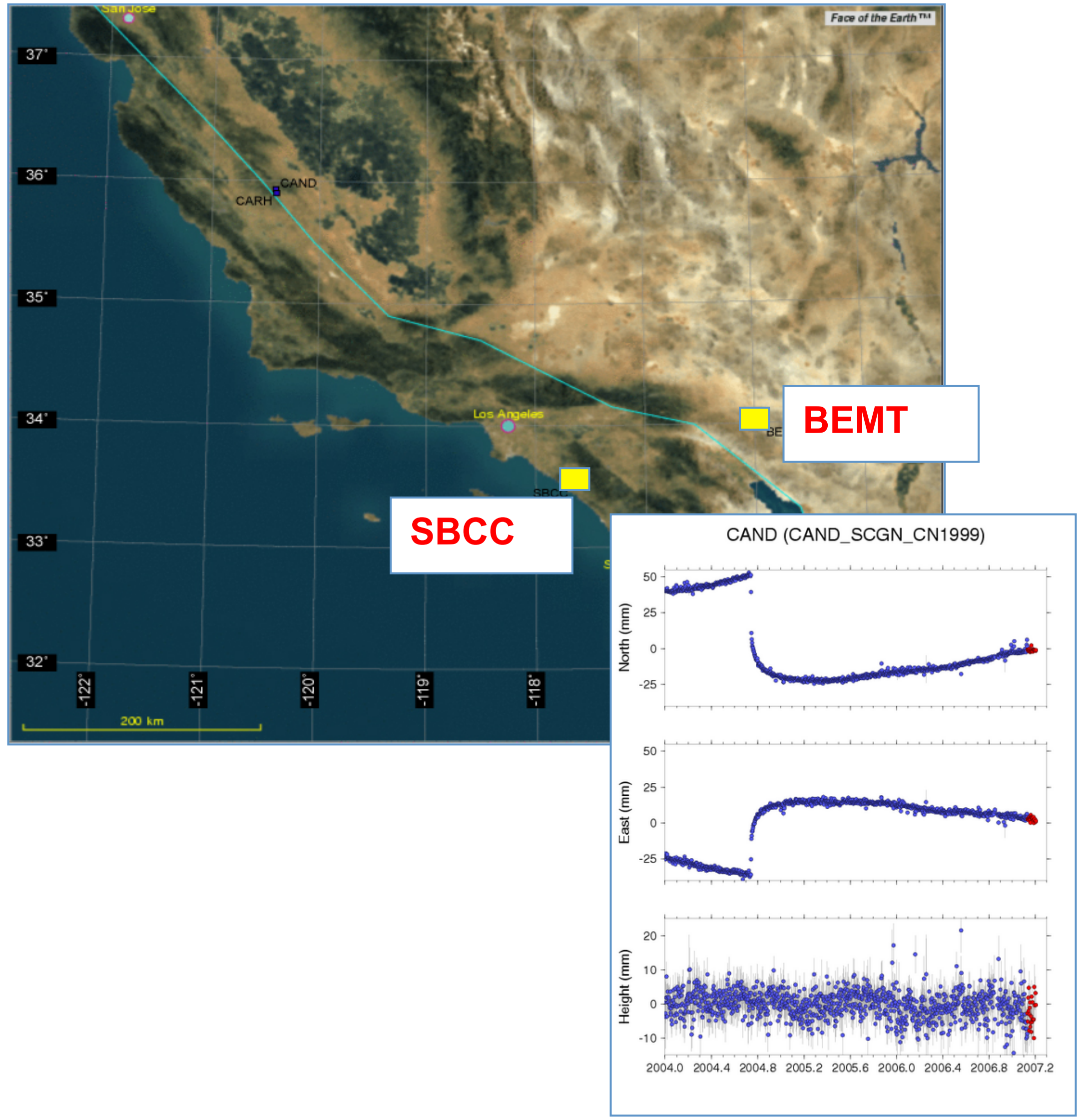


Organization

Part 1: Analyze GPS data from two stations to determine tectonic plate motion

Part 2: Investigate deformation of the crust at two stations in California

Extension: explore more GPS data



Activity outcomes

You should be able to:

- Describe high-precision GPS and its application to plate tectonics;
- Interpret GPS graphs to determine how the GPS station is moving; and
- Describe tectonic plate motions along the San Andreas fault.

Processed data

SBCC GPS STATION

- Near Mission Viejo, CA.
- Position data is collected every 30 seconds.
- One position reading is developed for each day:
  - North
  - East
  - Vertical

Date	North (mm)	East (mm)	Vertical (mm)
1/1/2004	-37.67	36.57	2.33
1/2/2004	-38.04	35.73	5.63
1/3/2004	-37.16	35.83	4.69
1/4/2004	-37.34	36.34	5.36
1/5/2004	-37.59	36.44	9.11
…	…	…	…
1/1/2005	-9.43	9.63	2.36
1/1/2006	16.48	-18.09	7.35
1/1/2007	45.98	-43.42	-6.43

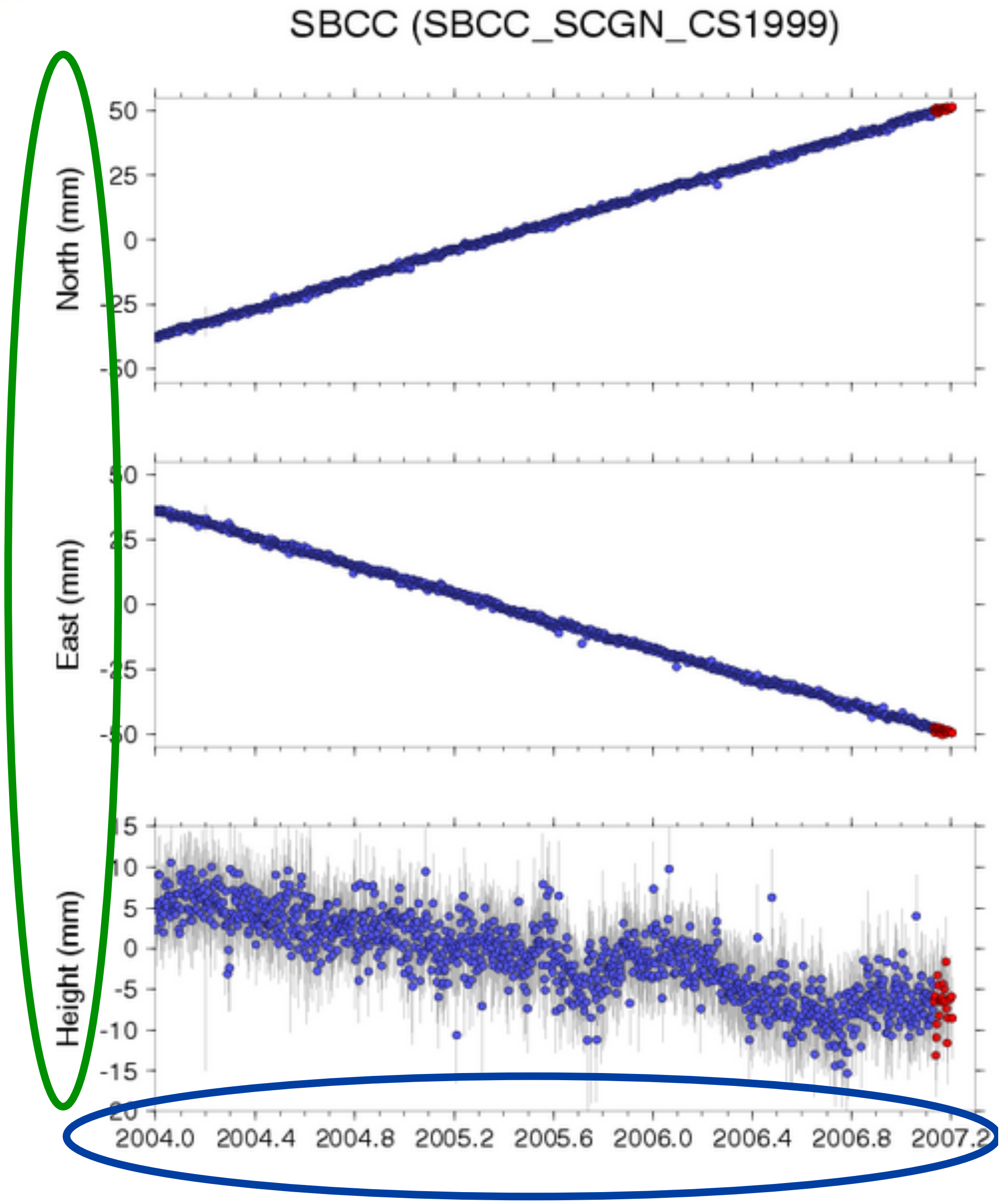
Position time series plot

X-axis:

- Date in 10ths of year or months

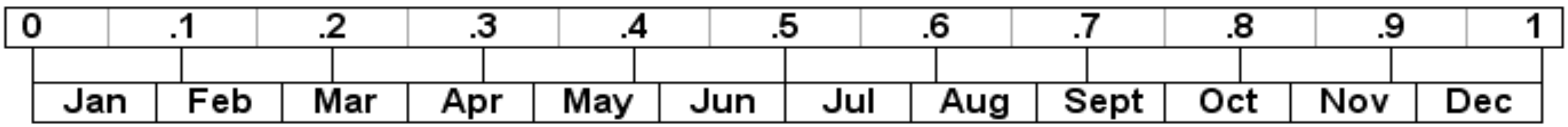
Y-axis:

- North
- East
- Height (or Vertical) in millimeters

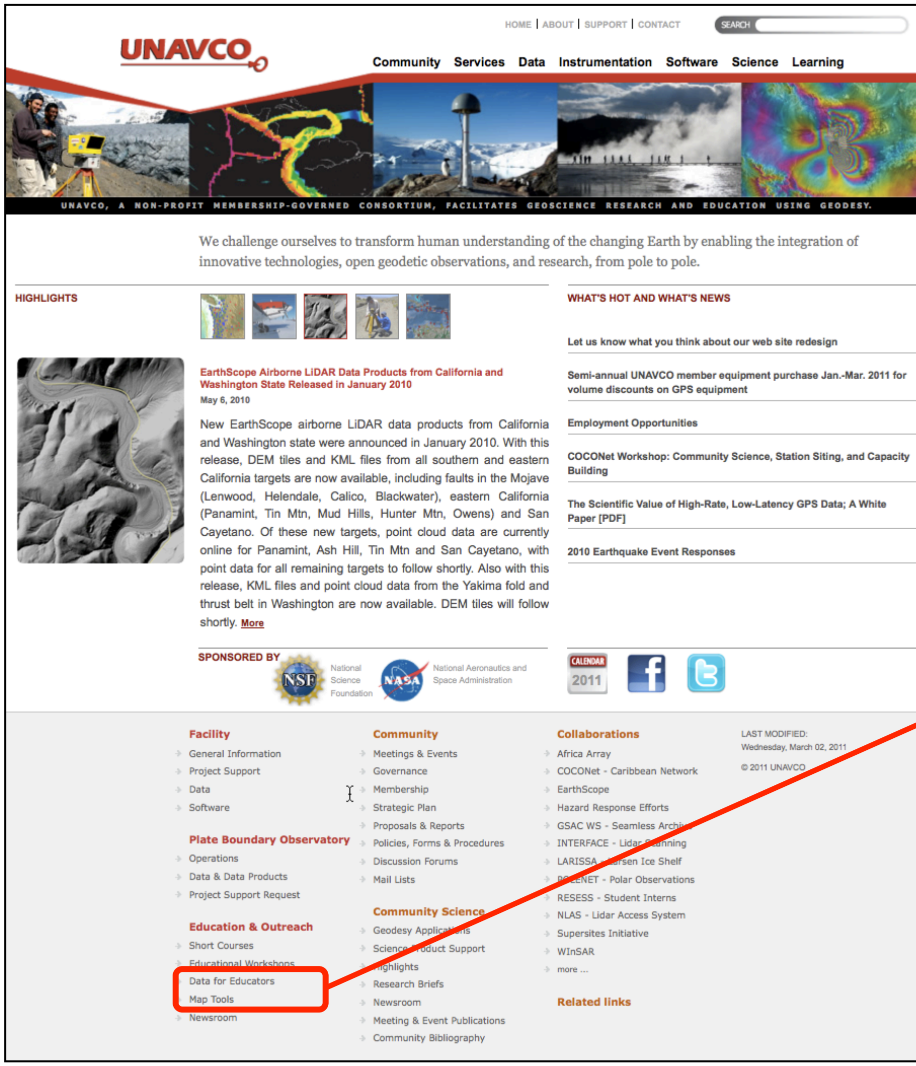


Units of measurement

X-axis is typically shown as 10ths of a year.



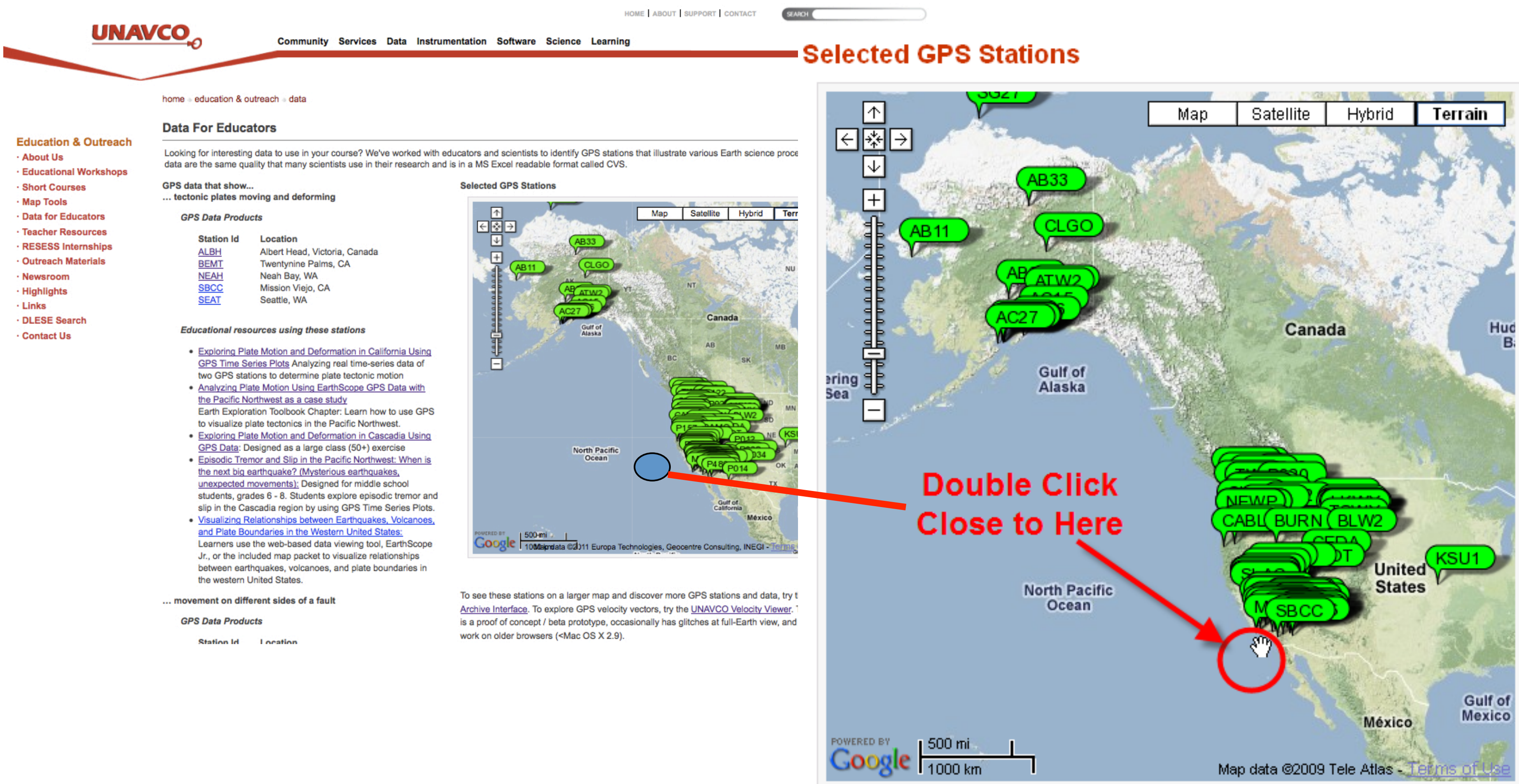
Part 1: Time series data



1. Go to http://www.unavco.org/

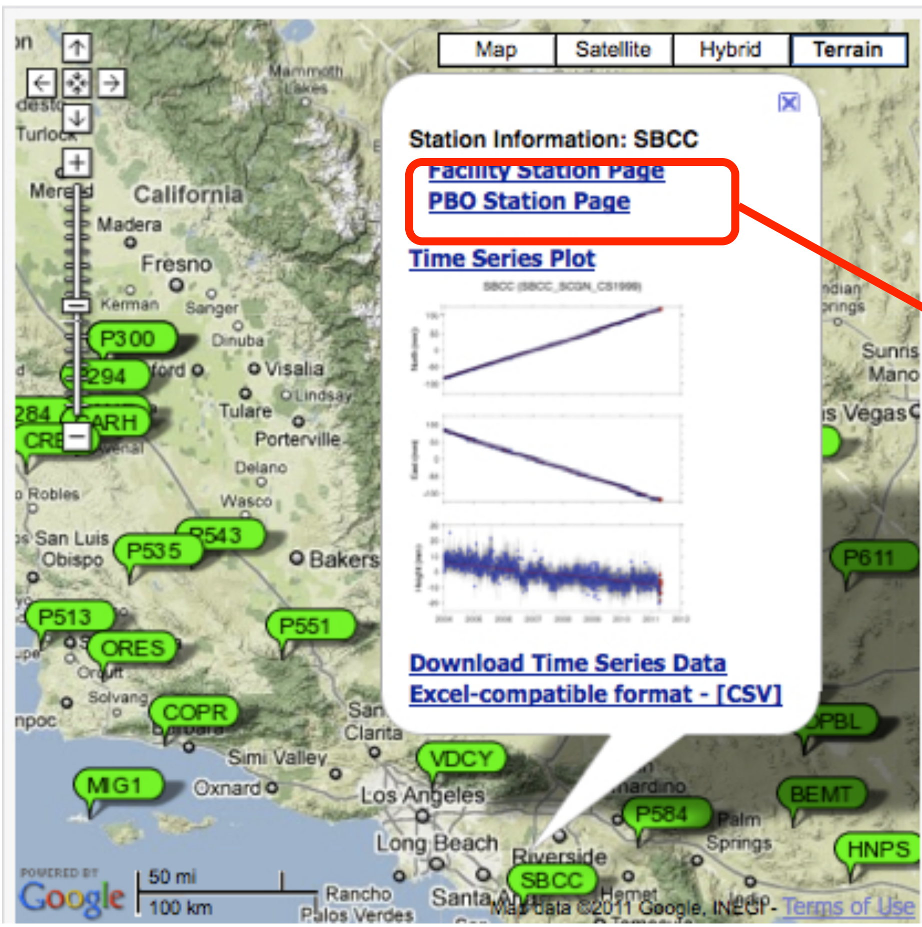
Click on "Data for Educators"

Data for Educators website



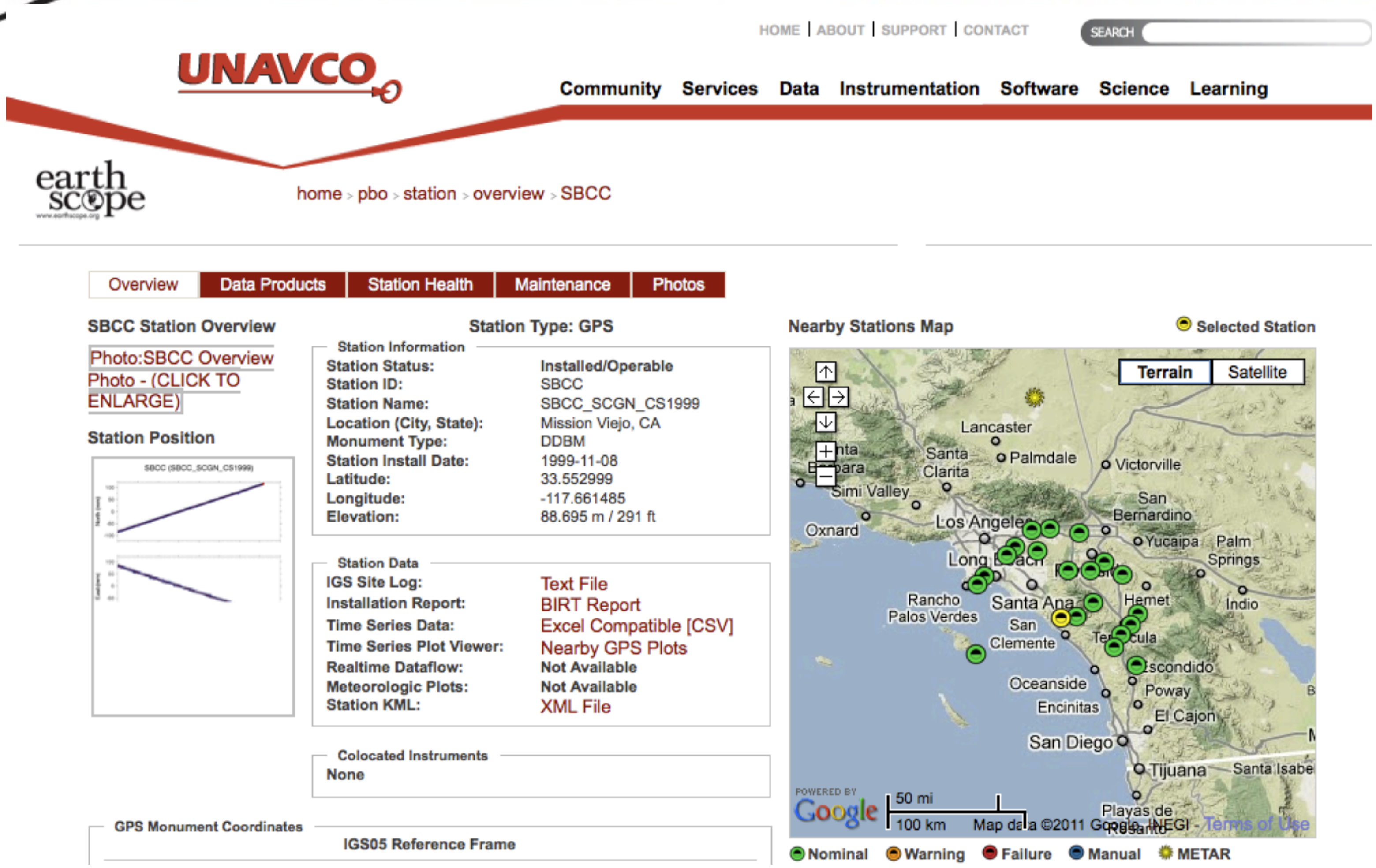
2. Zoom in near Southern California.

3. Click on the balloon labeled “SBCC” or “BEMT” near Los Angeles.



Click on the link for “PBO Station Page.”

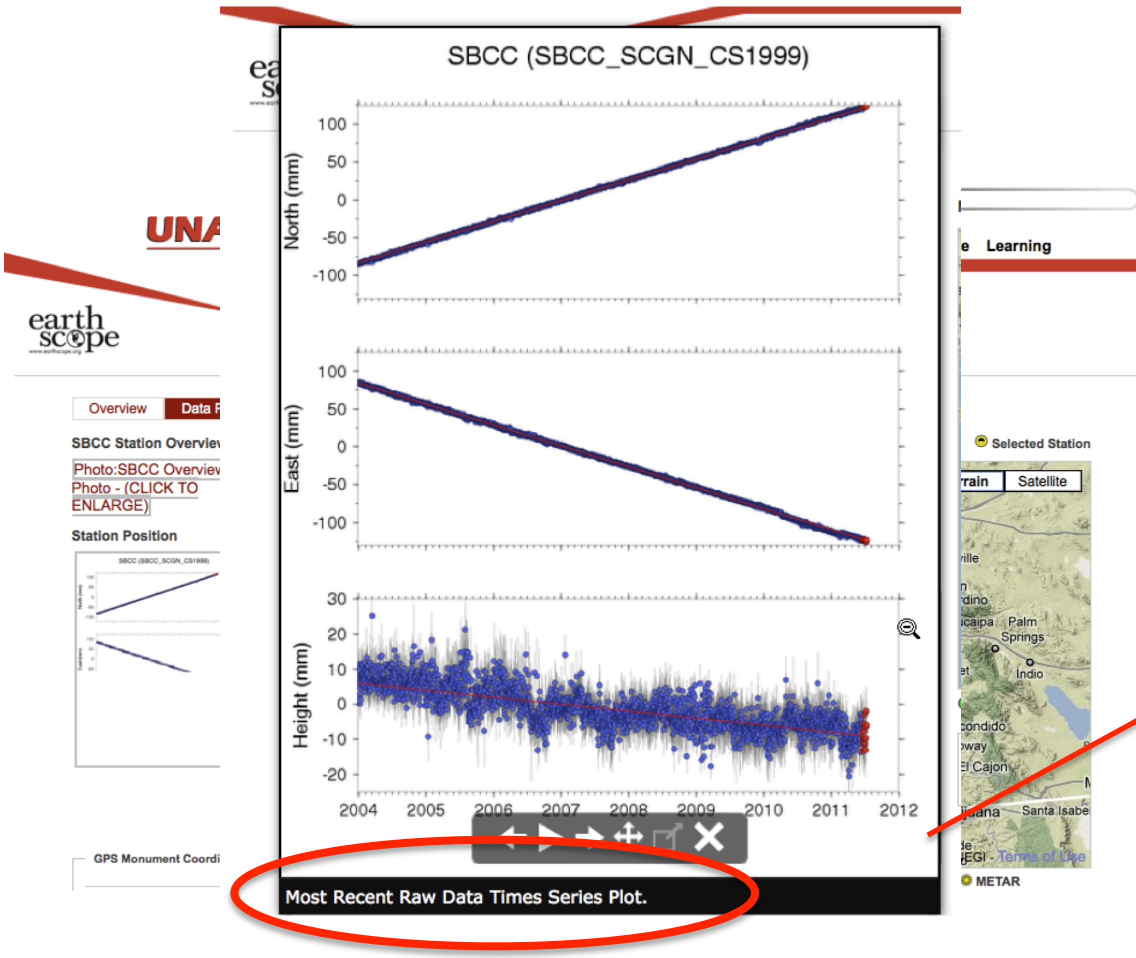
Overview page



4. Retrieve the station’s information and time series plot.

Overview page

5. Work with a partner to answer questions 4 and 6 about BEMT and SBCC.

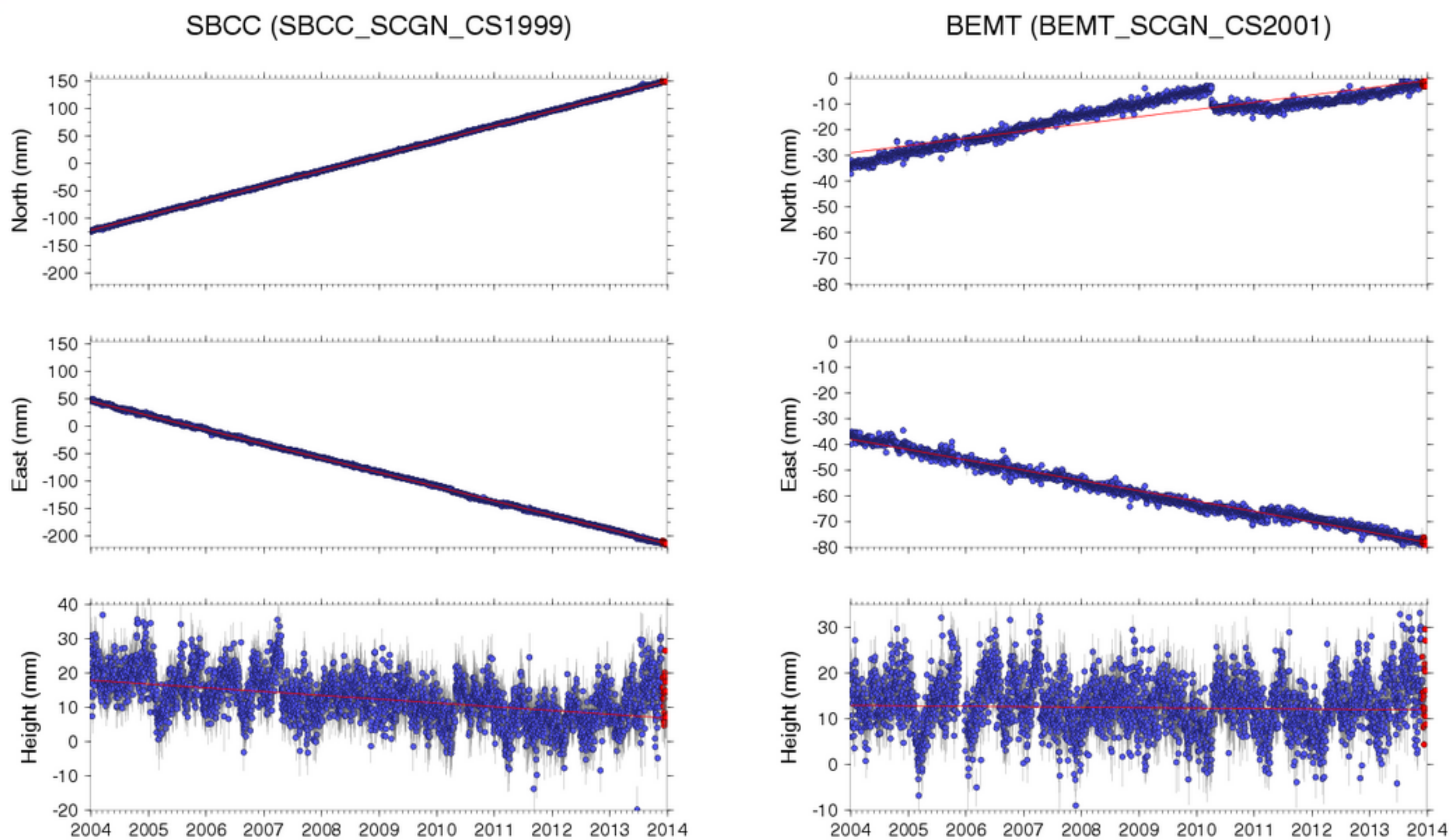


✓Use the elevation listed under SNARF.

✓Click on the Station Position graph.

✓Use the Station Position plot "Most Recent Raw Data Times Series Plot."

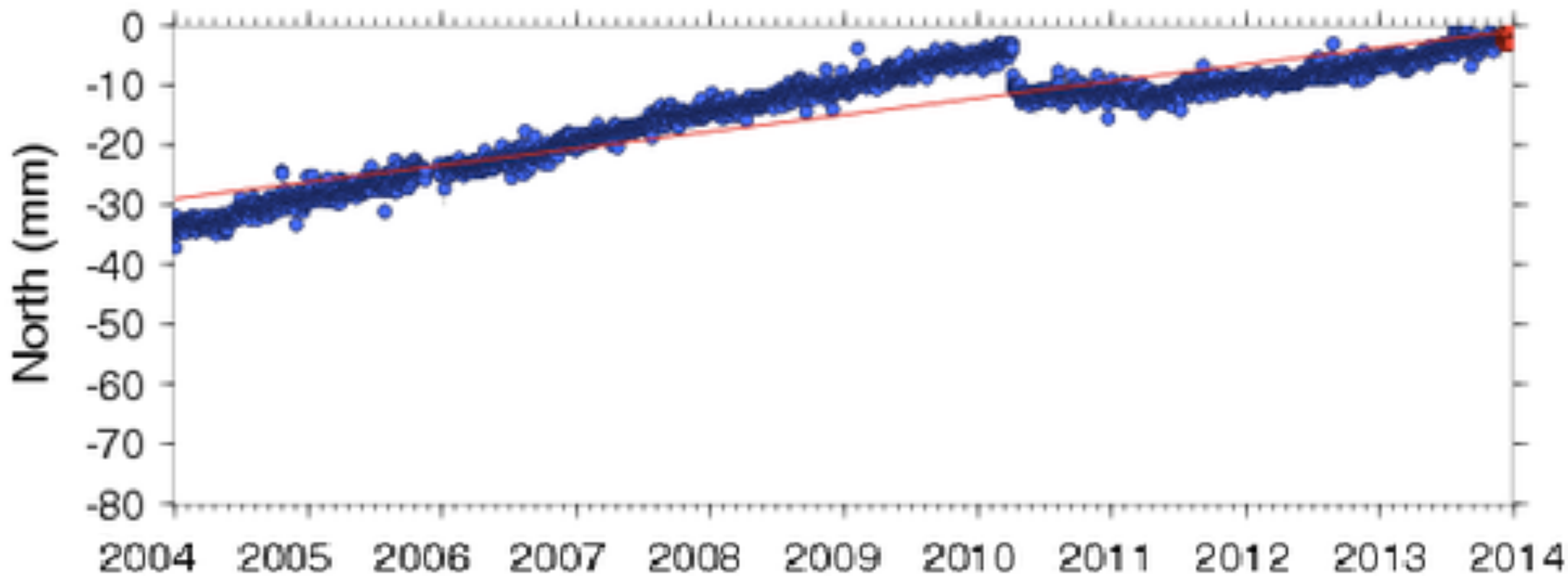
BEMT and SBCC



What are the units of measurement for these time series?

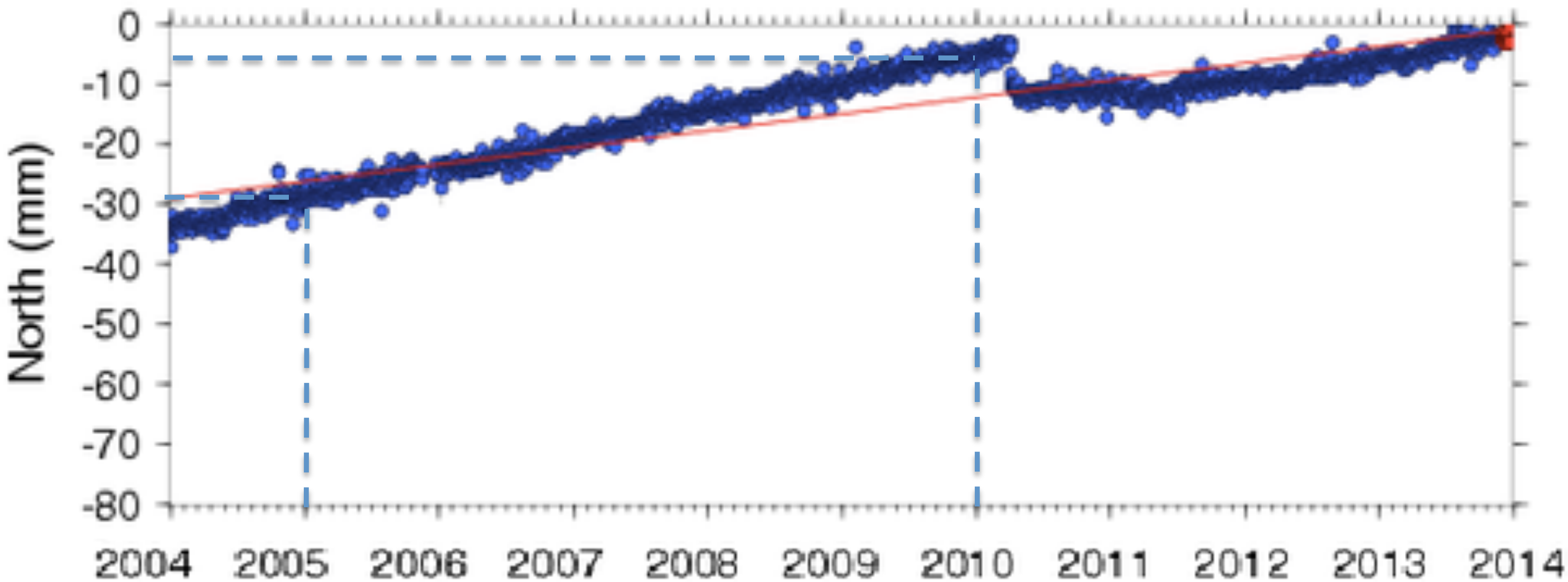
BEMT

How quickly is BEMT moving north or south?



Average position on 1/1/2010 = ______ mm
Average position on 1/1/2005 = ______ mm

How quickly is BEMT moving north or south?



Average position on 1/1/2010 = __- 6 __ mm
Average position on 1/1/2005 = __-29 _ mm

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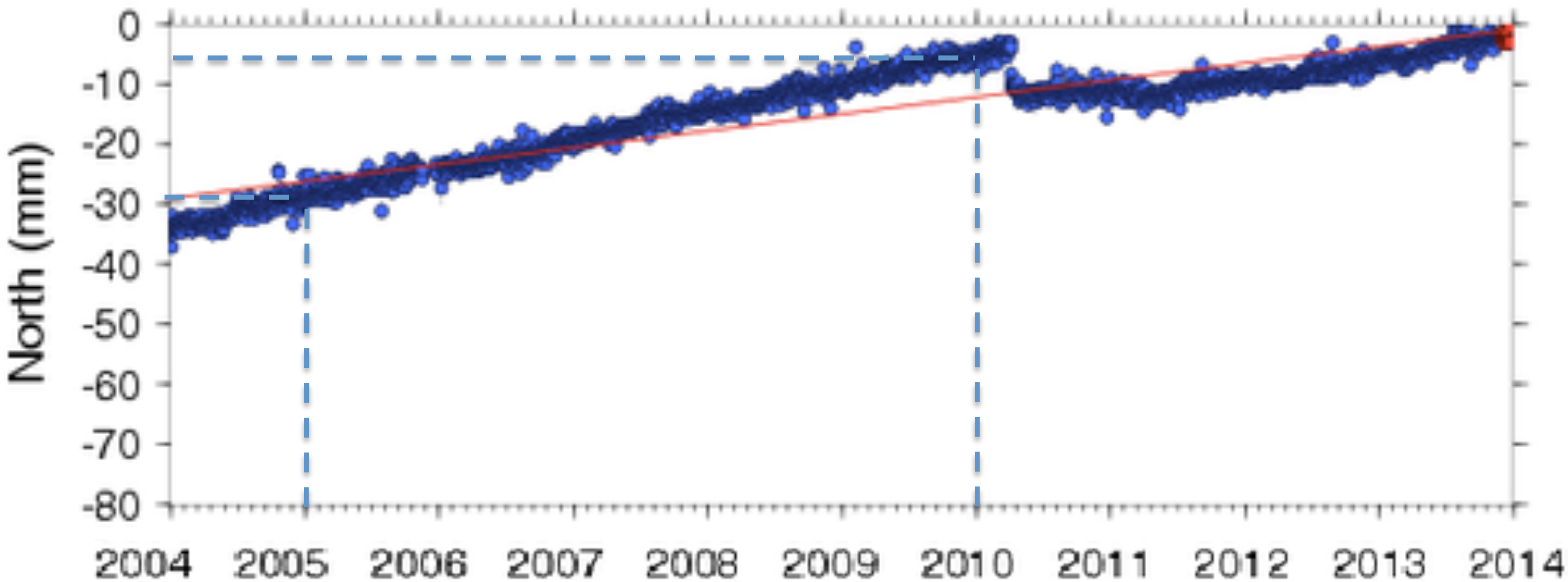
BEMT

How quickly is BEMT moving north or south?

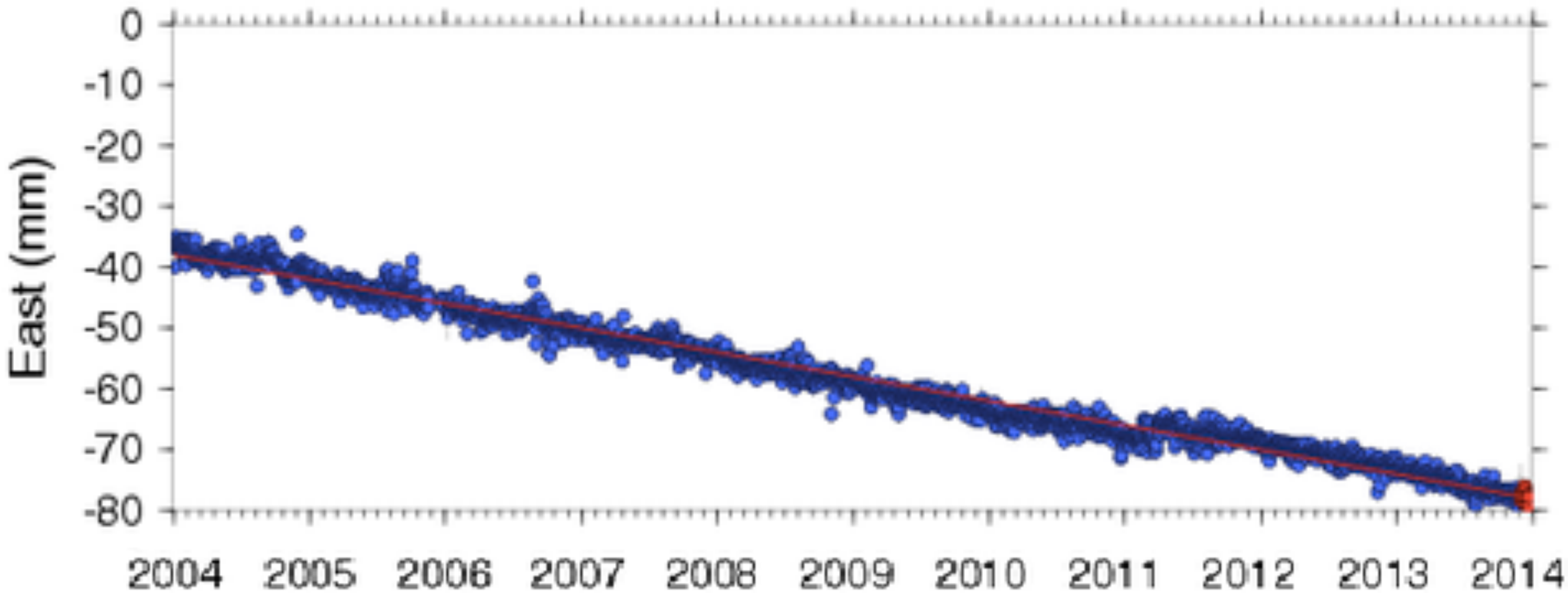


Annual northward speed of BEMT = ($^{-}6$ - $^{-}29$ mm)/5 years

= 23 mm/5yrs

= 4.6 mm/yr to the north for BEMT (+/- 0.2?)

How quickly is BEMT moving east or west?



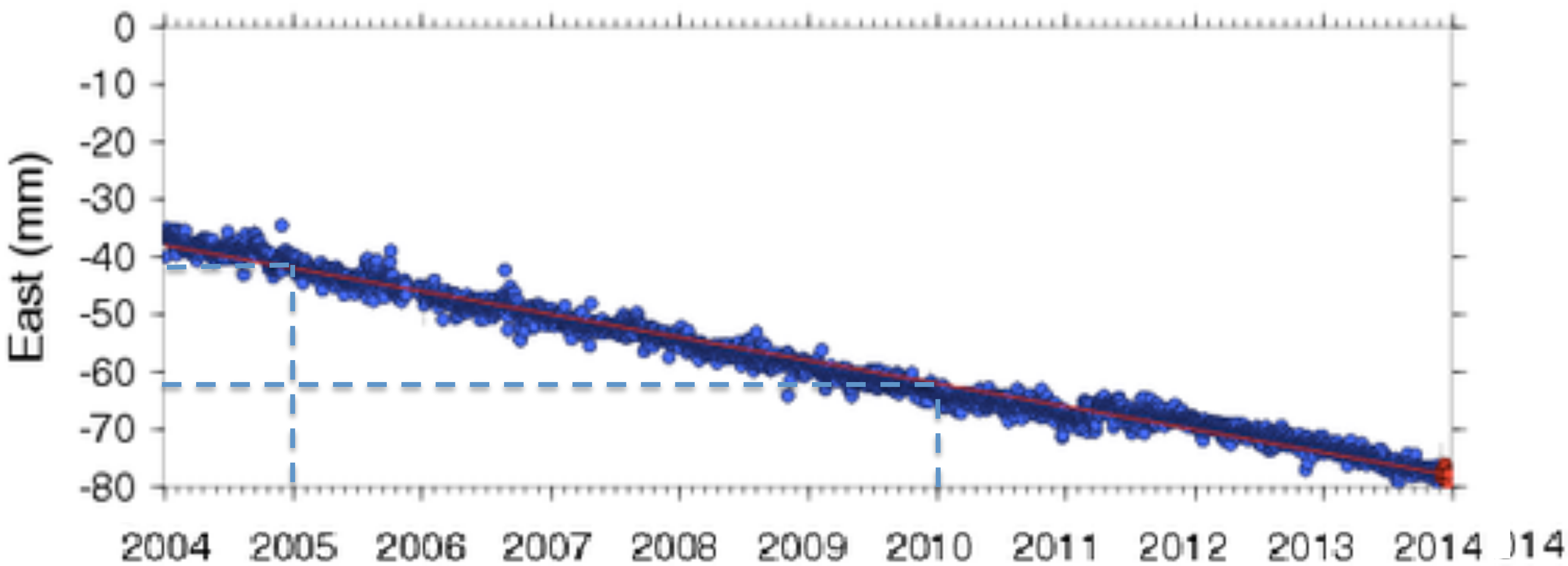
What general direction is BEMT moving?

Average position on 1/1/2010 = _______ mm

Average position on 1/1/2005 = _______ mm

BEMT

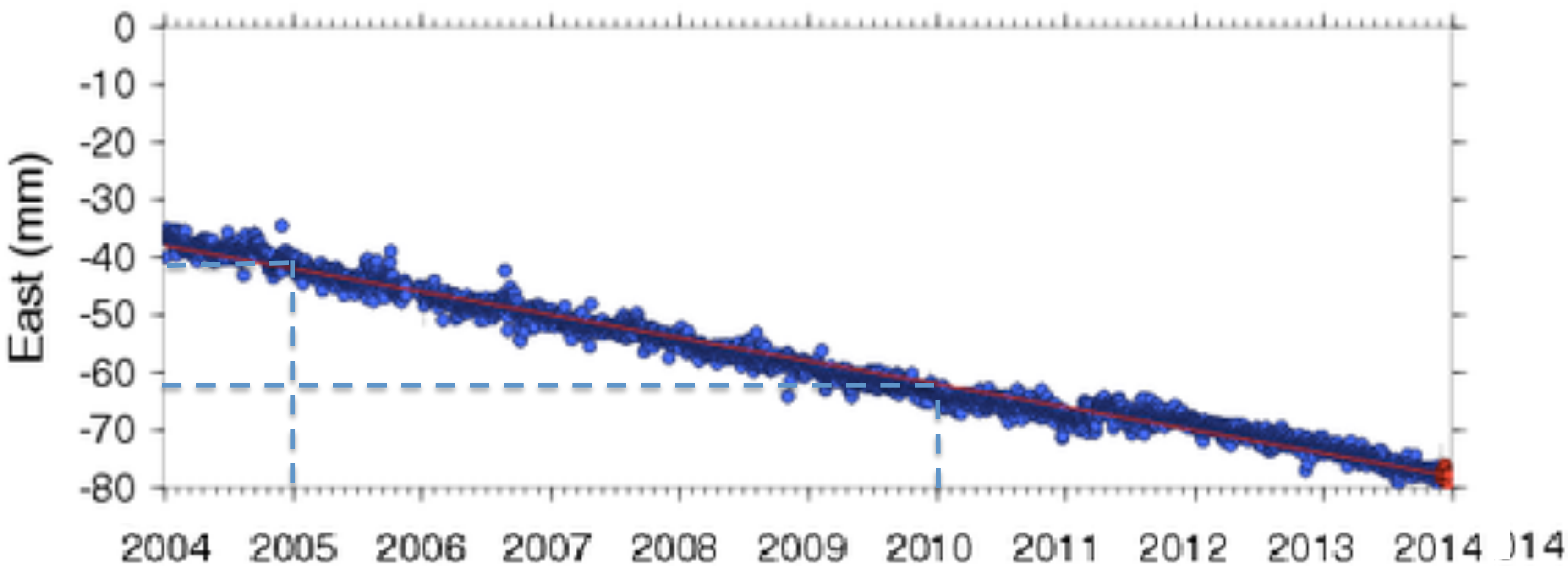
How quickly is BEMT moving east or west?



Average position on 1/1/2010 = __-62 __ mm

Average position on 1/1/2005 = __-42 __ mm

How quickly is BEMT moving east or west?

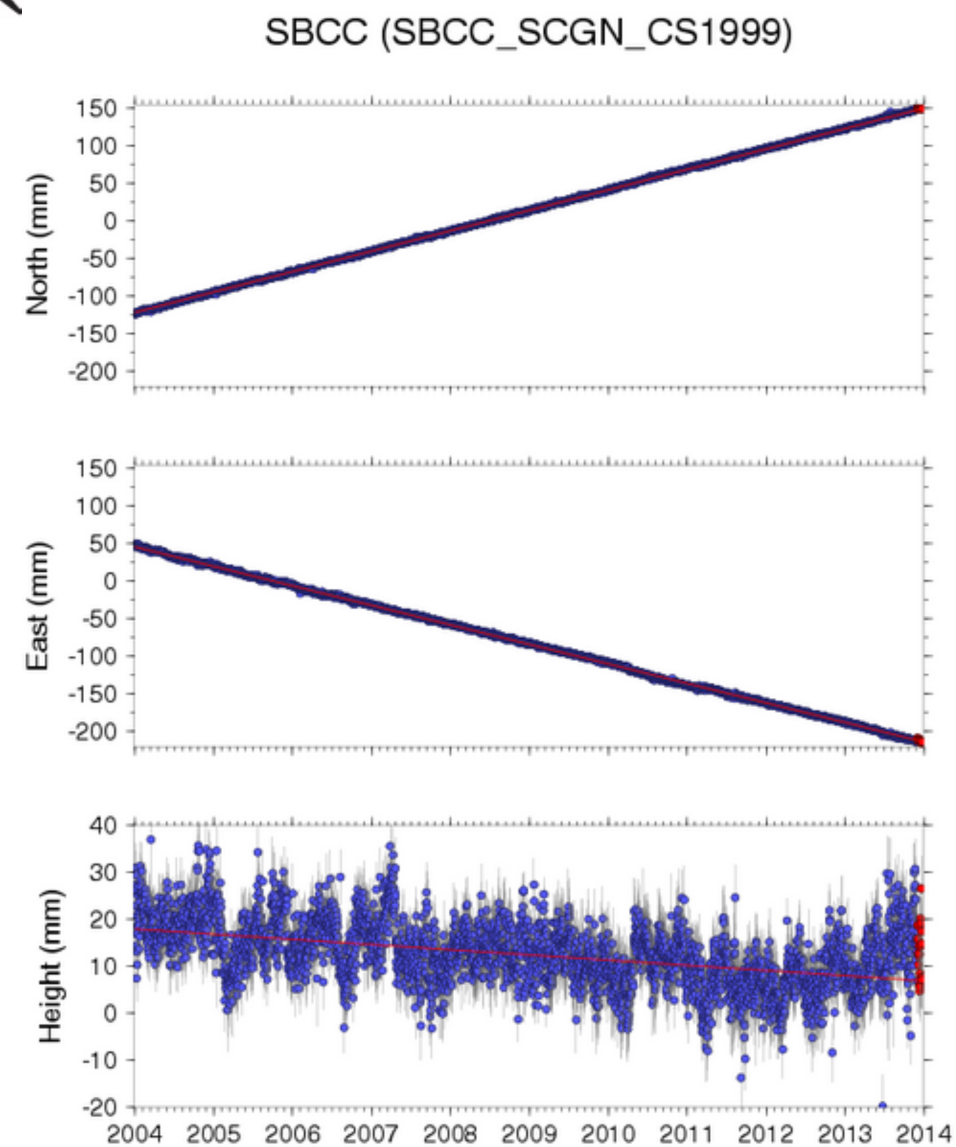


Annual speed of BEMT north = $({}^{-}62 - {}^{-}42$ mm)/5 years

= $^{-}20$ mm/5yrs

= $^{-}4.0$ mm/yr. BEMT is moving westward.

How quickly is SBCC moving?



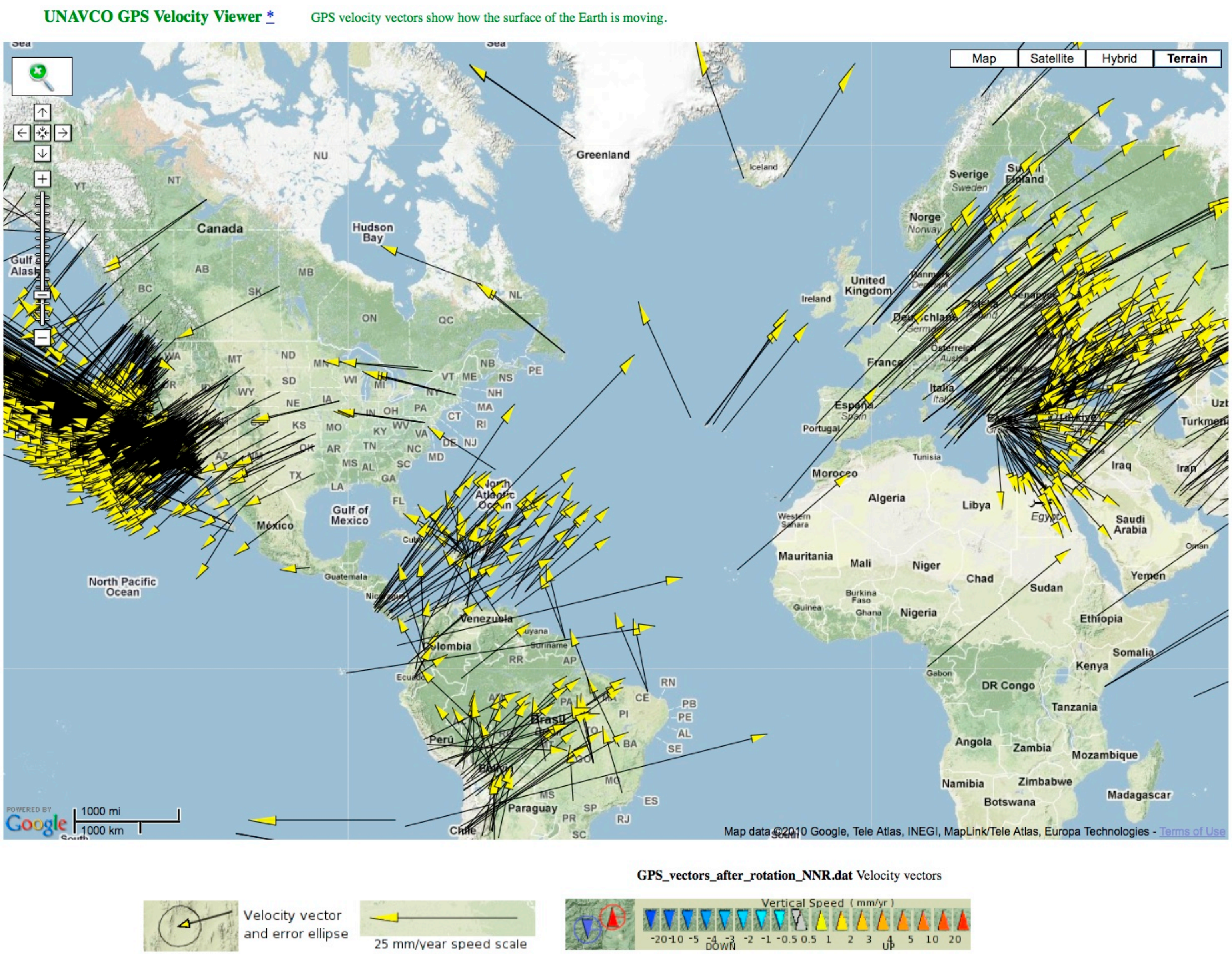
Now do SBCC.

Speed of SBCC:

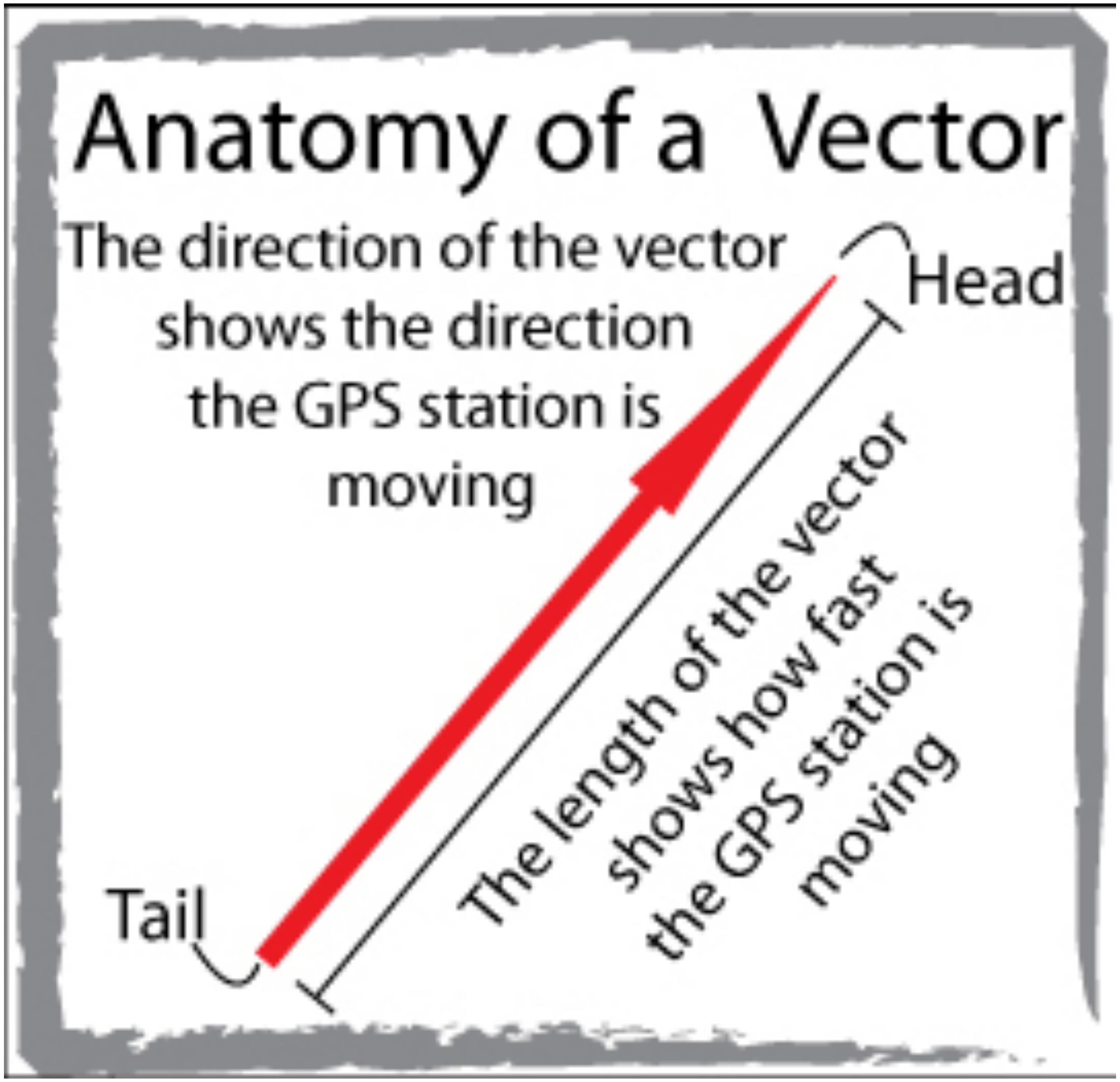
= 27.3 mm/yr to the north

= 26.1 mm/yr to the west

Plate movement via vectors



What's a vector?



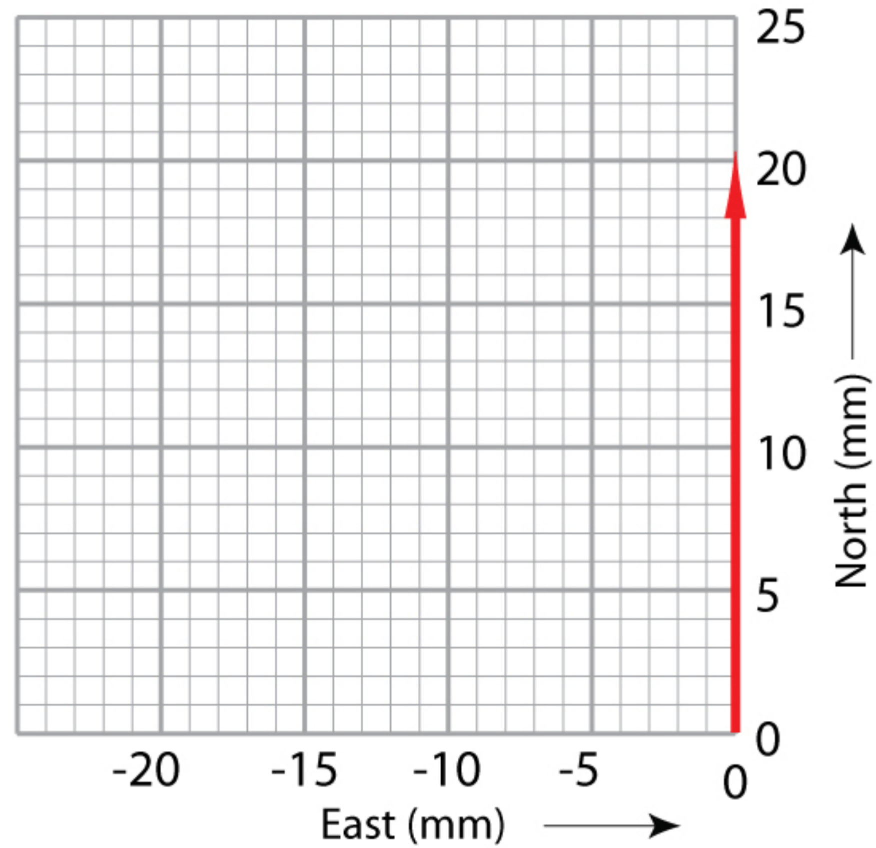
A vector shows speed and direction of motion.

Graph paper as a map

Each axis uses the same scale--millimeters.

On your graph paper, each block represents 1 mm.

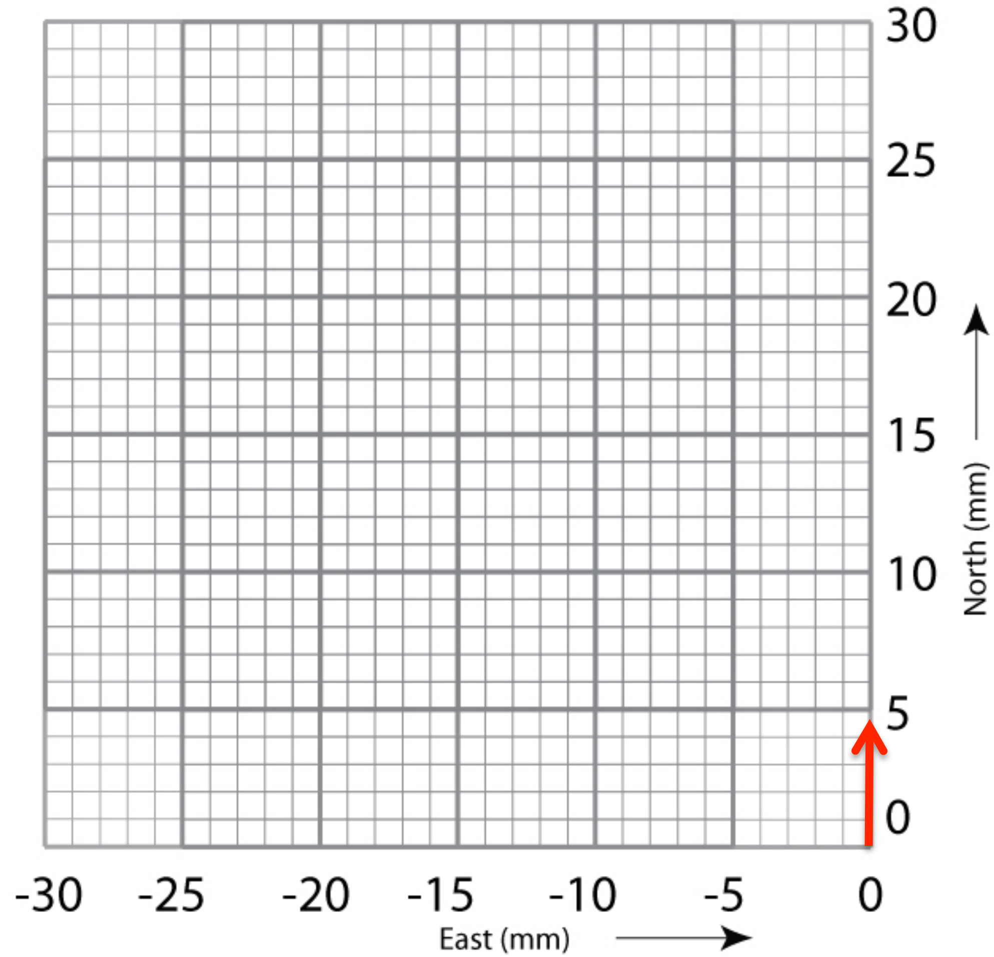
Where is the origin on this graph?



Plotting vectors: North

Step 1. Draw the first vector along the North axis with the tail at (0, 0).

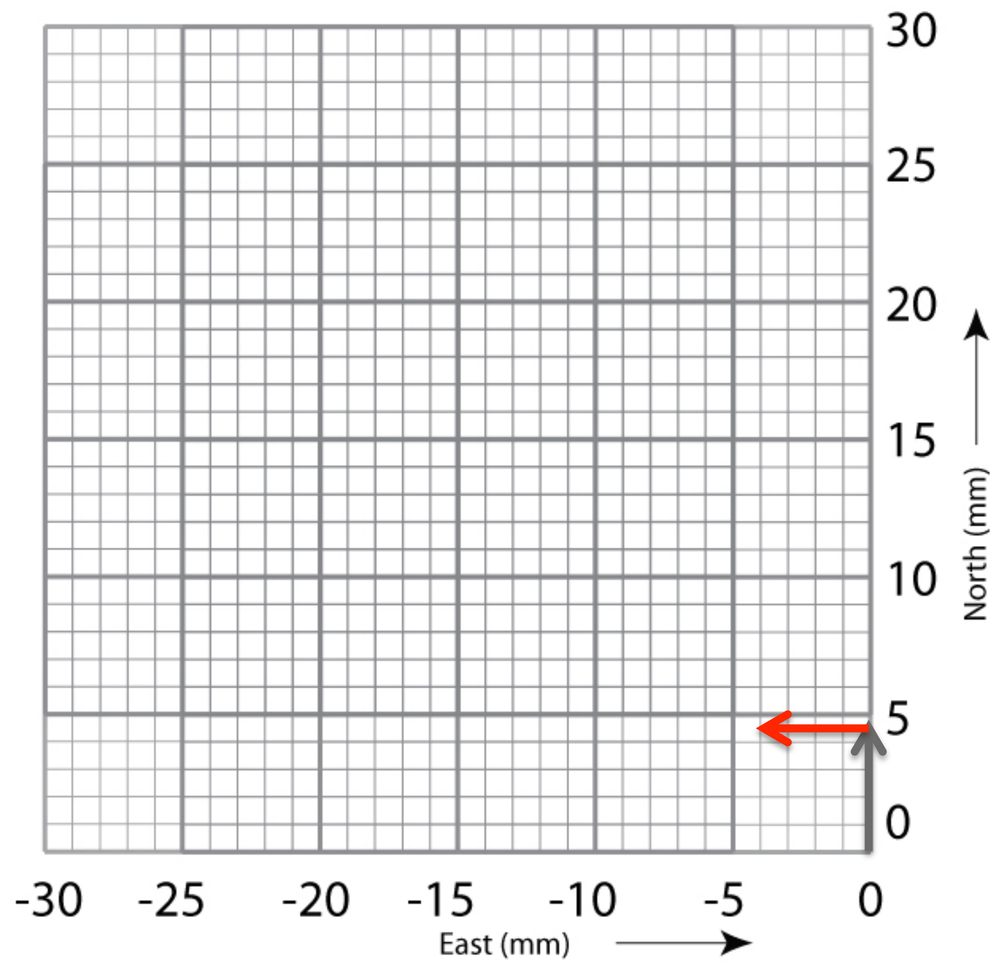
To show BEMT moving 4.6 mm to the north every year, draw a vector 4.6 blocks along the north axis.



Plotting vectors: East

Step 2. Draw the east vector from the end point of the north vector.

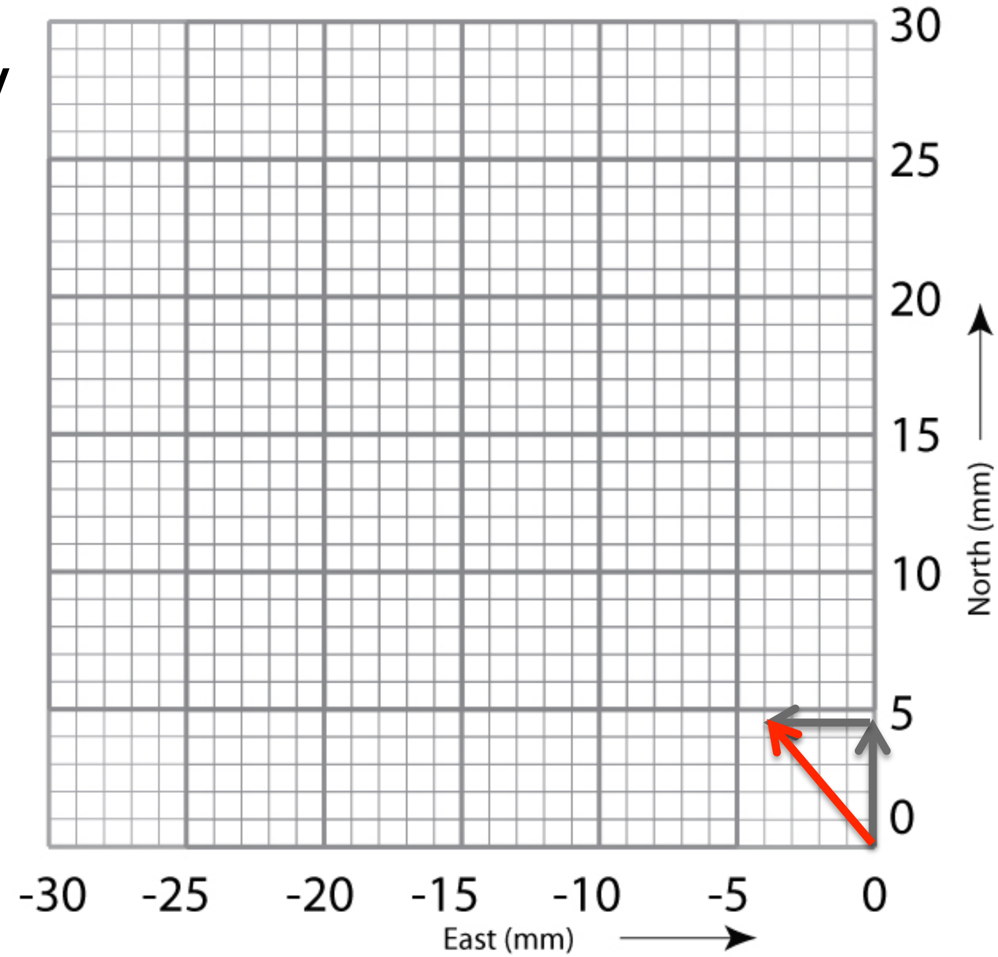
Draw the vector $^{-}4.0$ blocks (mm).



Adding vectors graphically

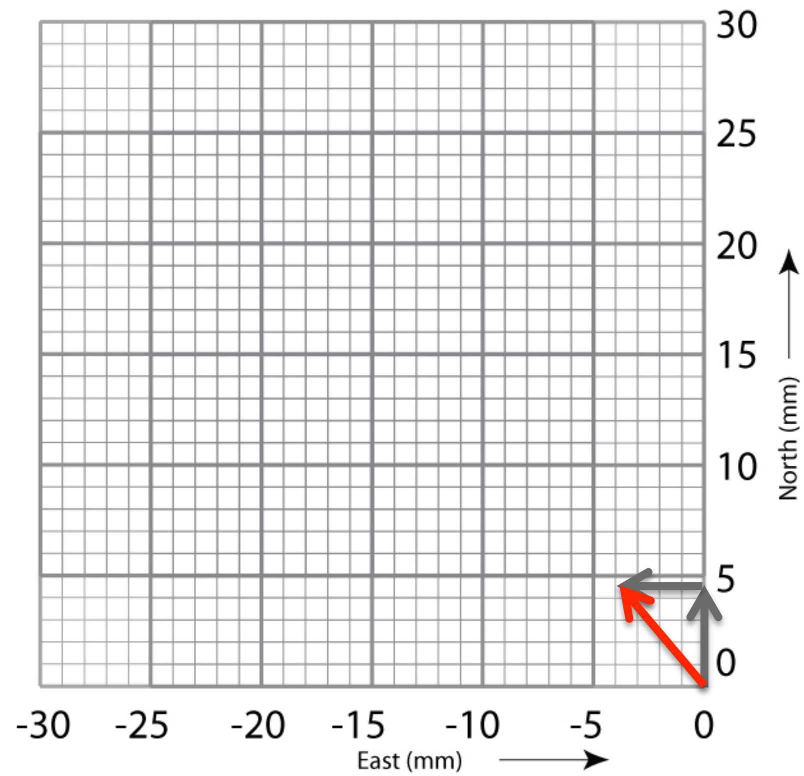
Step 3. Add the vectors by drawing a new vector from the origin (0, 0) to the end of the east arrow.

This final vector shows the direction and distance the GPS station and the land beneath it moves each year.



Adding vectors mathematically

Apply the Pythagorean theorem:



BEMT moves $\sqrt{x^2 + y^2}$

$= \sqrt{4.6^2 + 4.0^2}$

= 6.1 mm/yr to the northwest.

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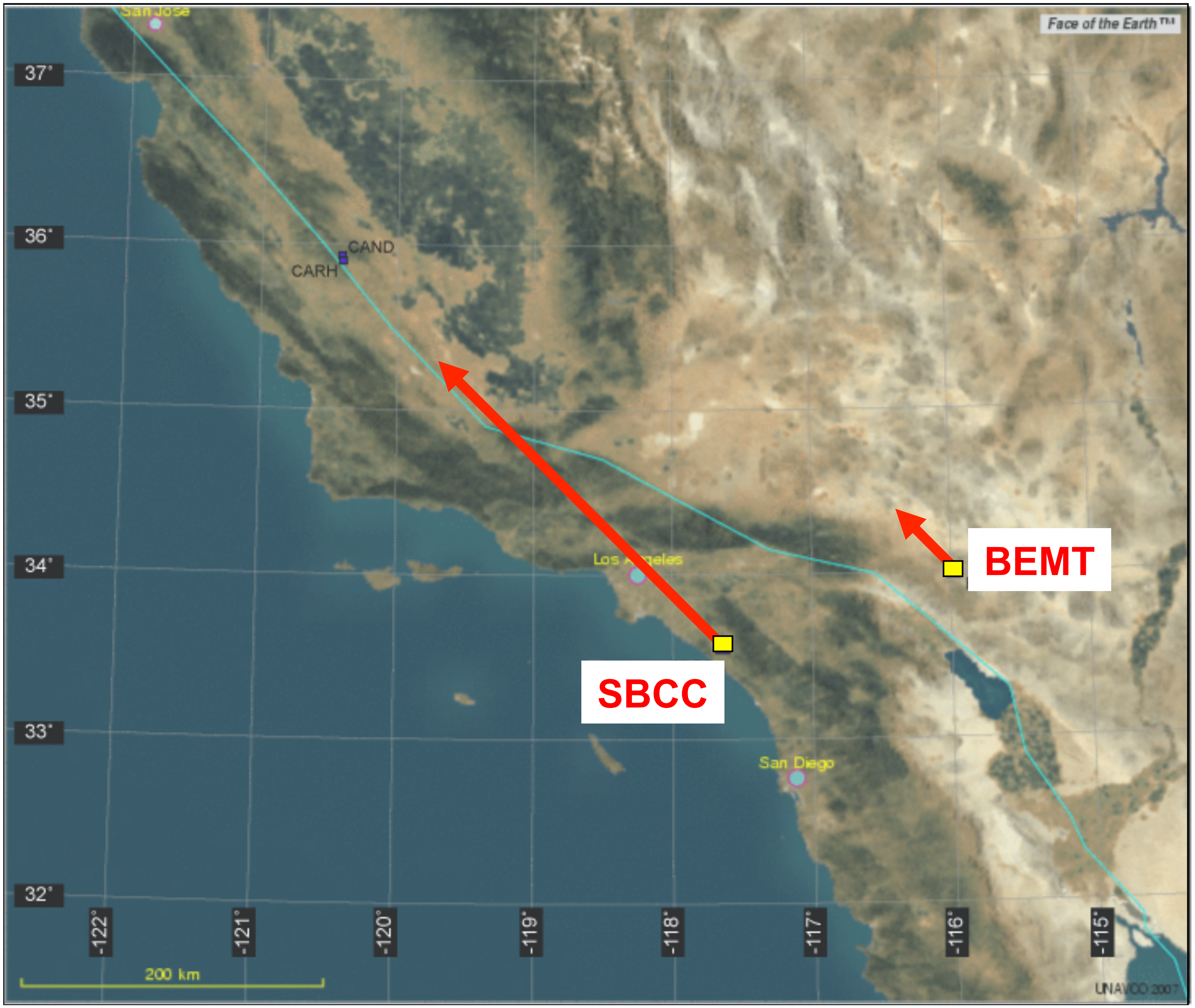
Velocity of tectonic plates



BEMT:

4.6 mm N

-4.0 mm E

= 6.1 mm/yr to the northwest

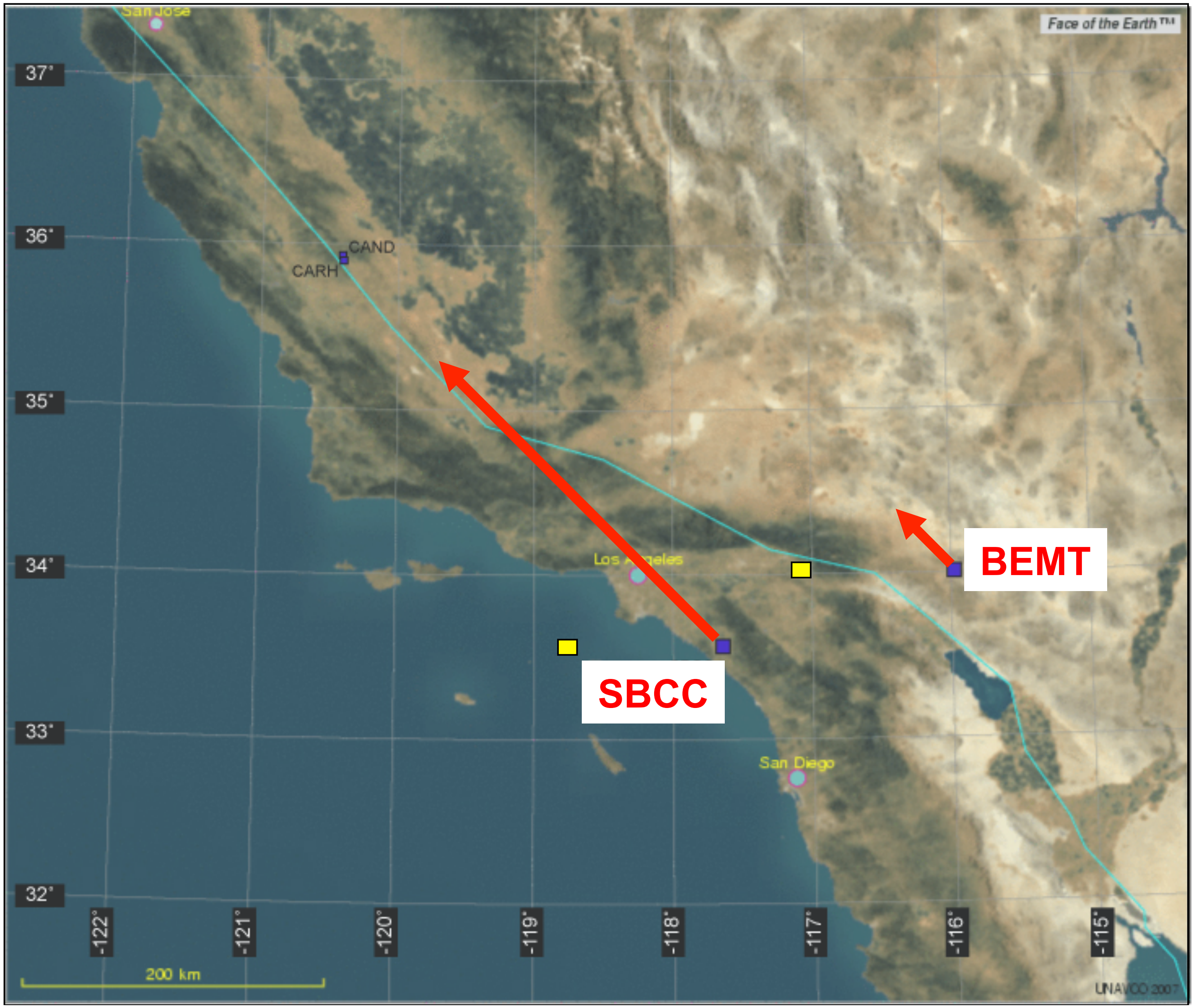
SBCC:

27.3 mm N

-26.1 mm E

= 37.8 mm/yr to the northwest

Wait a minute!



The vectors point the same direction

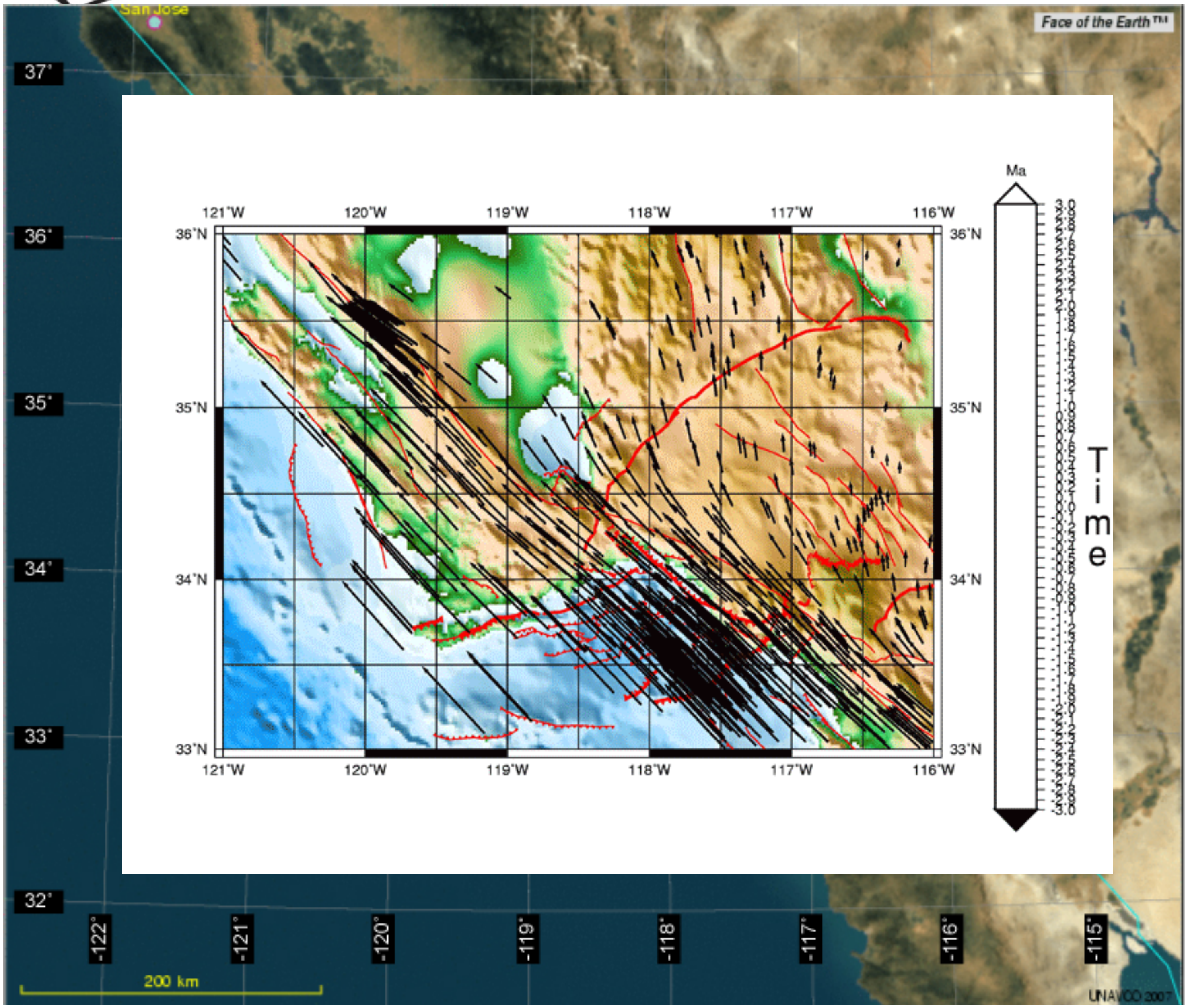
…

But this is a transform fault!

The velocities are relative to the center of North America.

Imagine you are on a three-lane highway, driving in the middle lane…

Modeling the past and future

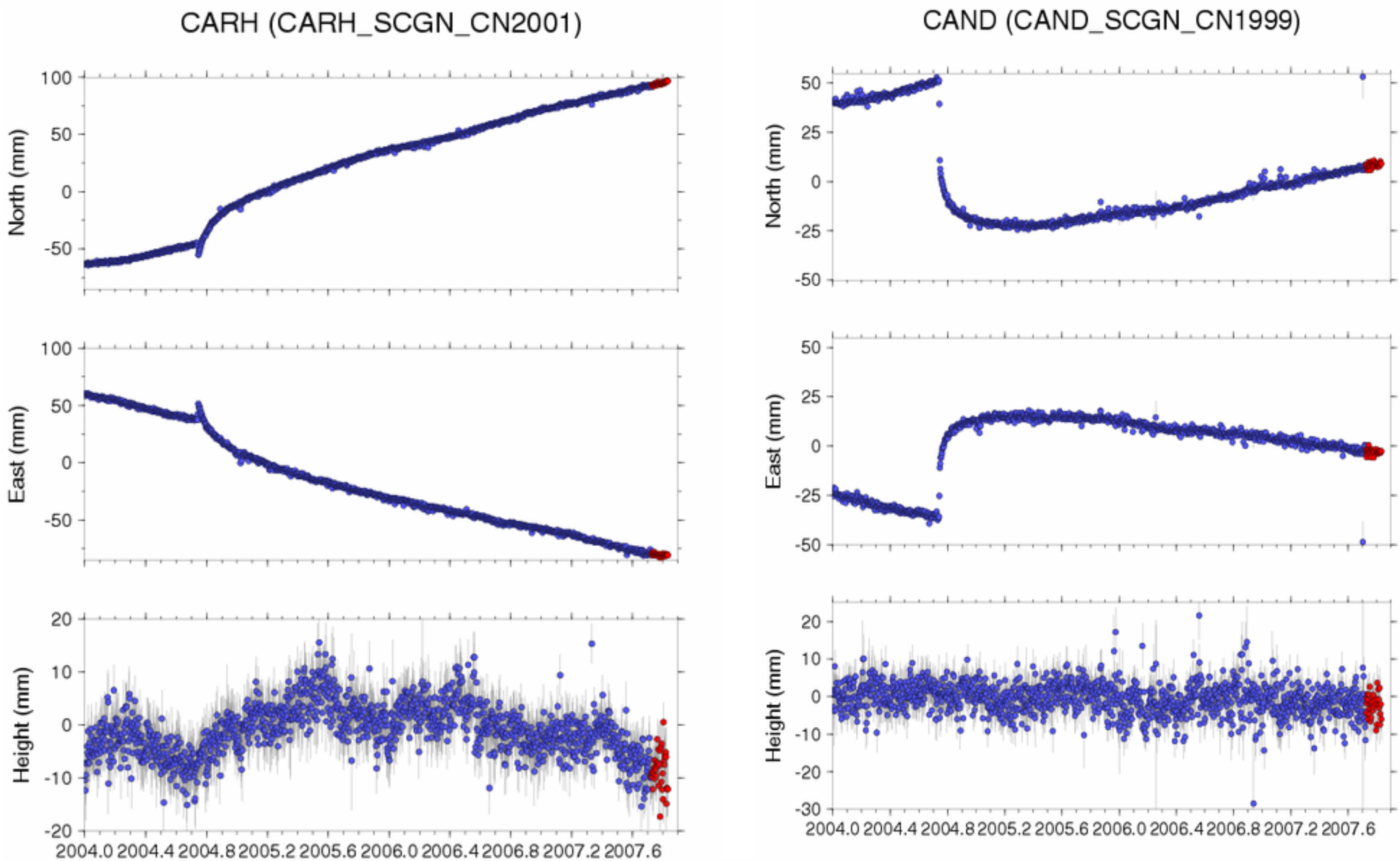


+ 3 million years

Now

- 3 million years

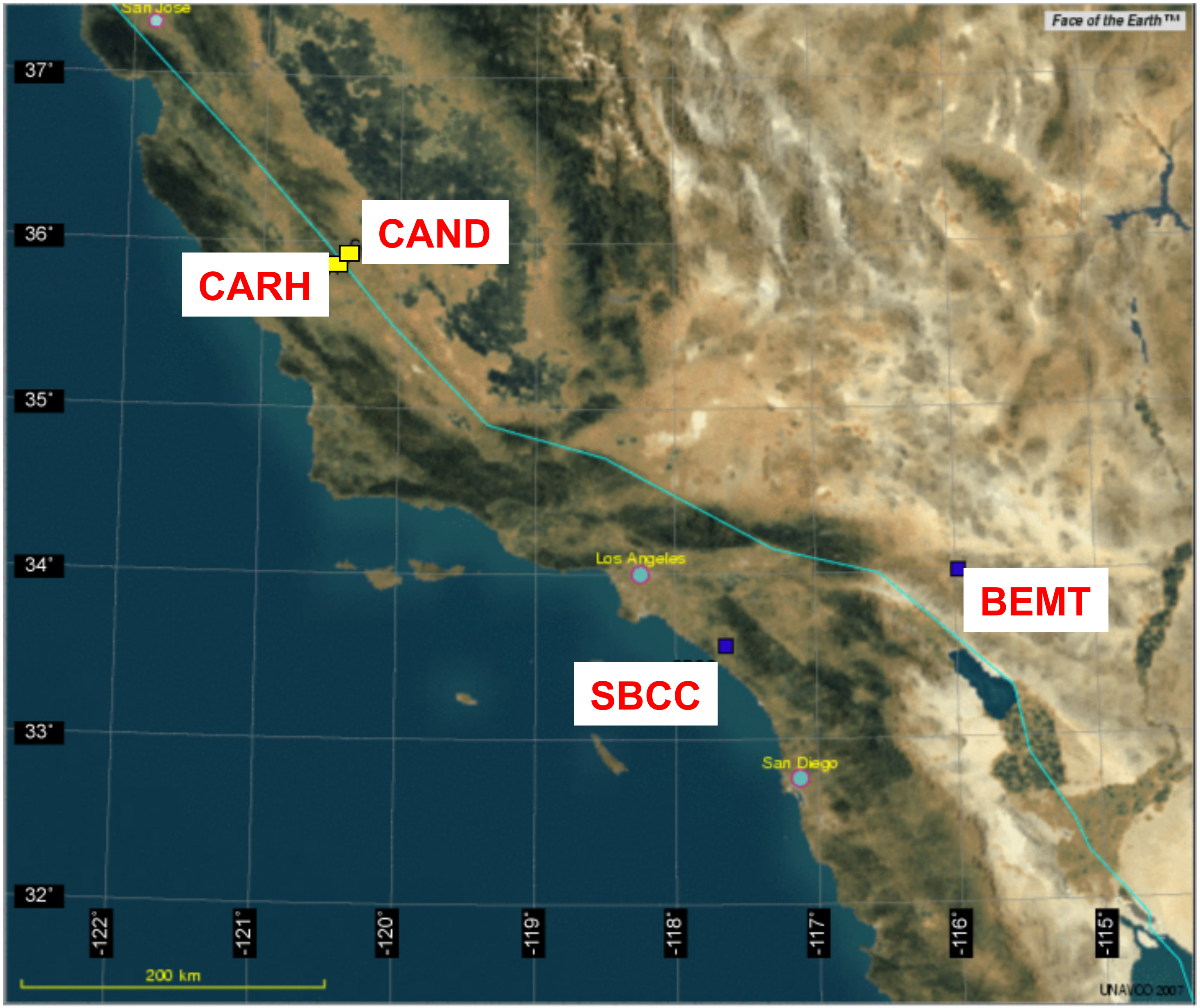
What's happening here?



0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec

Part 2: Deformation



CAND:
Lat: 35.94
Long: -120.43

CARH
Lat: 35.89
Long: -120.43

GPS and earthquakes

How much slip on the fault occurred during the event (using the CAND time series plot)?

~ 75 mm south and ~ 60 mm east, resulting in 96 mm combined slip to the southeast.

How did the CAND station's position change--

during the earthquake? It jumped to the SE.

after the earthquake?

It continued to move SE until ~Jan 2005, then resumed its NW movement.

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]

$$M = \frac{\log_{10}(.096) + 6.32}{0.9}$$

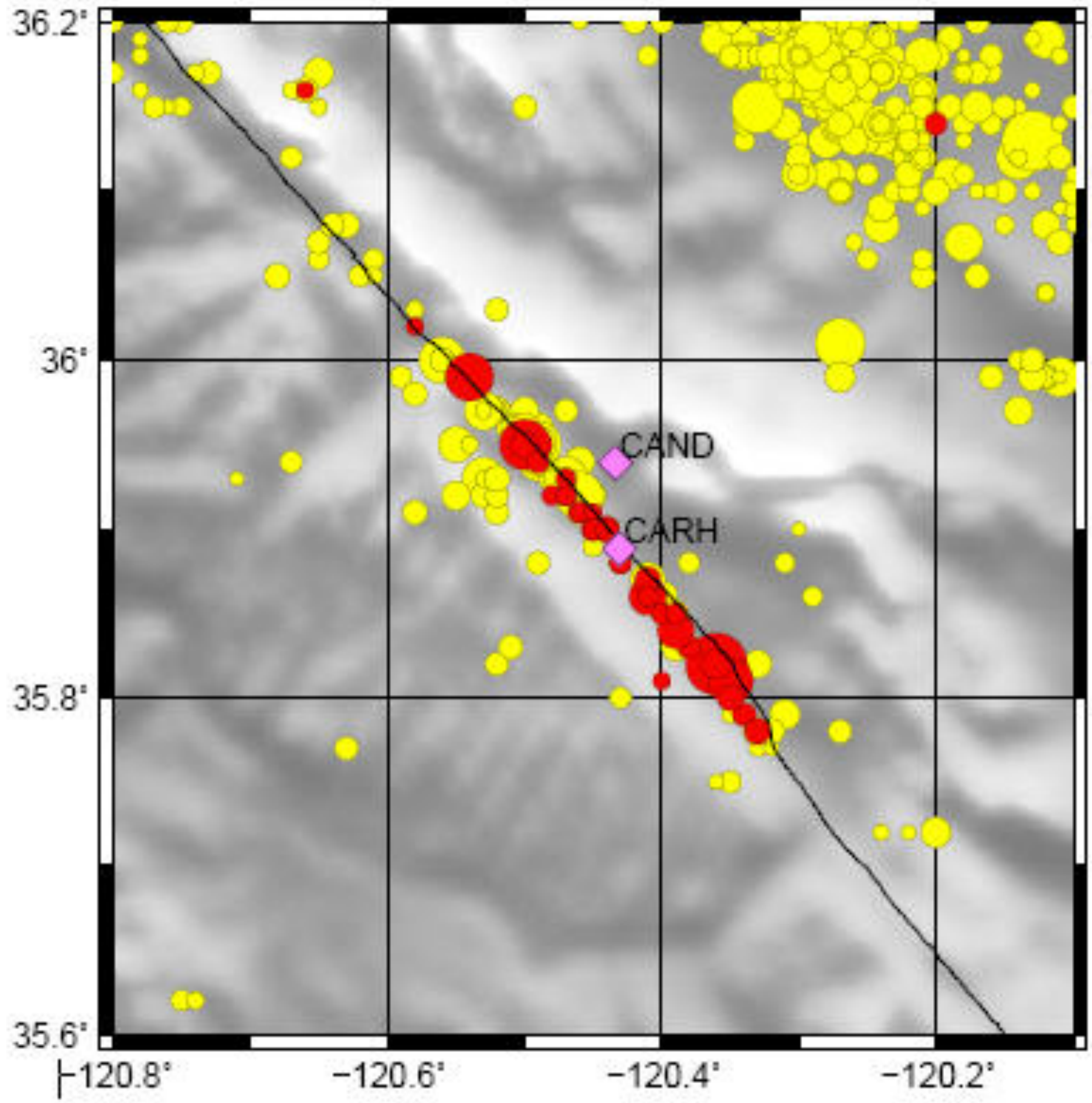
M = 5.9

(According to the USGS, the Parkfield earthquake was a magnitude 6.0 quake.)

Recurring earthquakes

Red = epicenters of the main 2004 shock and aftershocks within one month of event

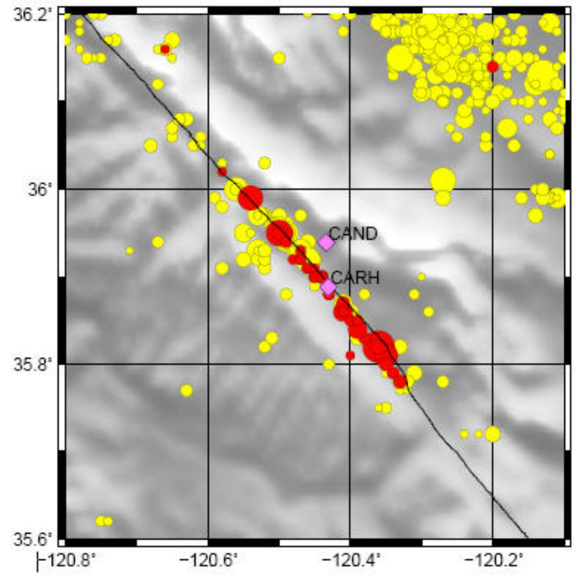
Yellow = earthquakes 1973–2006



Recurring earthquakes

~96 mm total slip in 2004.

There, the Pacific plate moves past the North American plate ~17mm/yr.



How long should it take to build enough strain to cause an earthquake with a similar magnitude?

96mm/17 mm per year = ~5.6 years

Recurring earthquakes

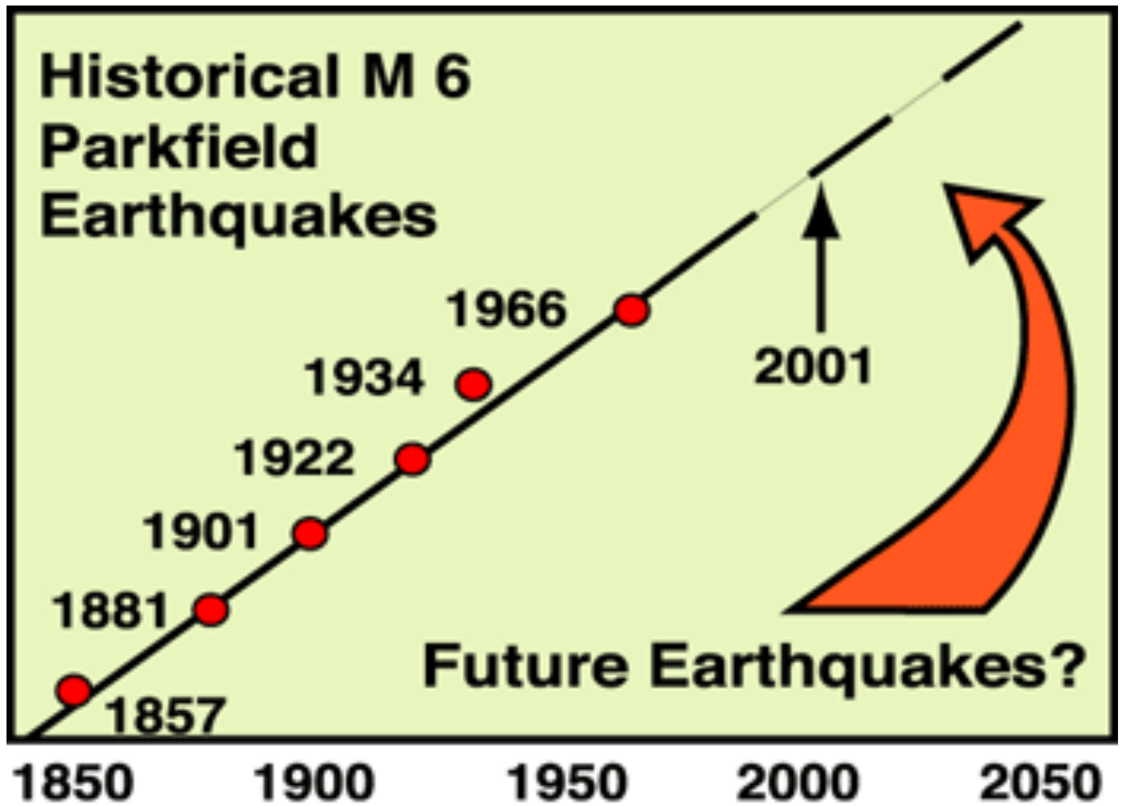
Observed frequency of M6 earthquakes during the 20th century?

~every 20 years

Predicted frequency:

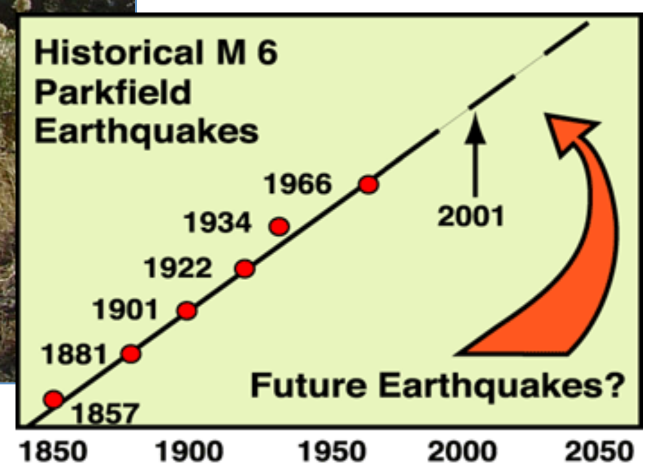
96mm / 17 mm per year = ~5.6 years

Why are these numbers different?

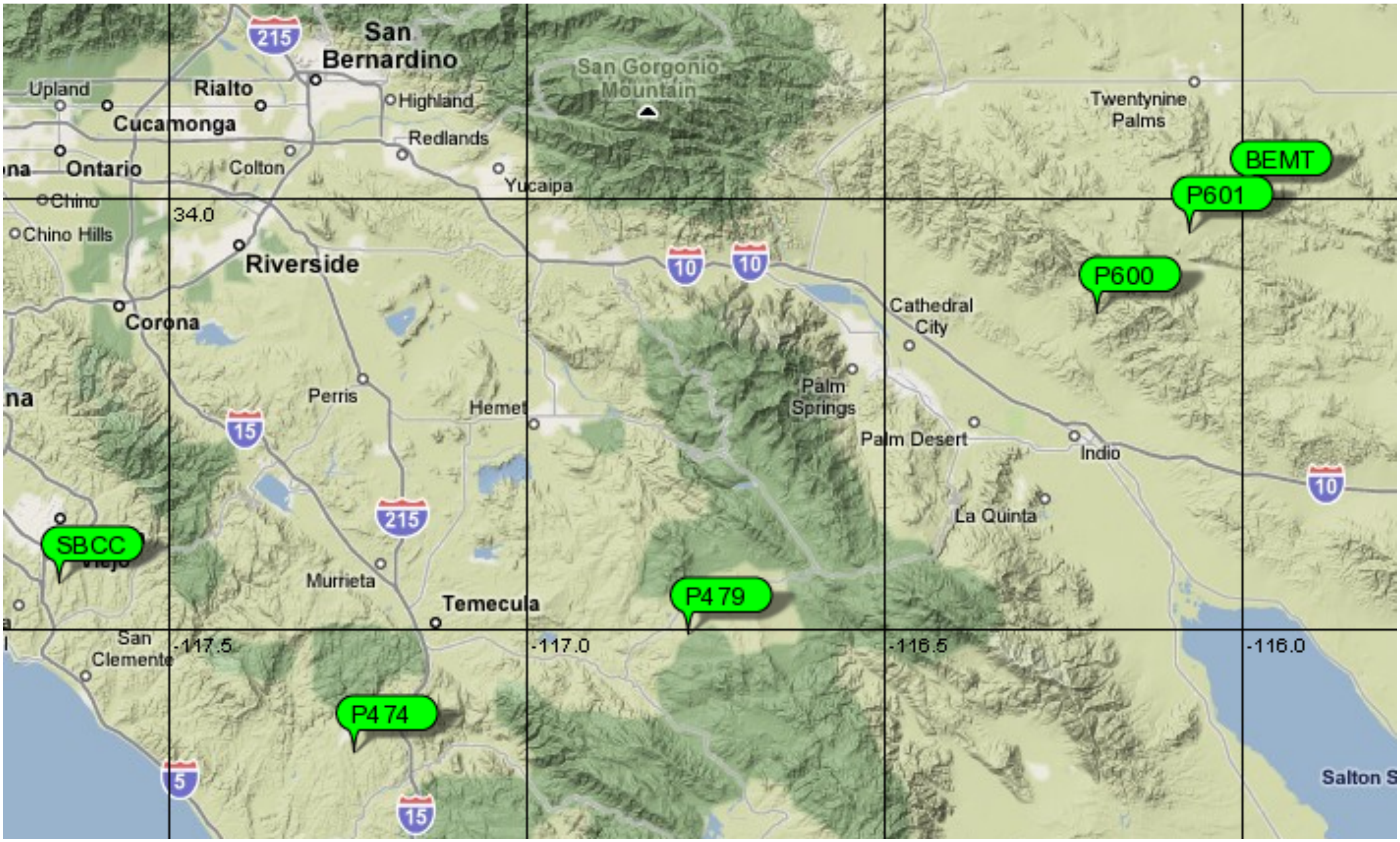


Recurring earthquakes

Why are the numbers different?



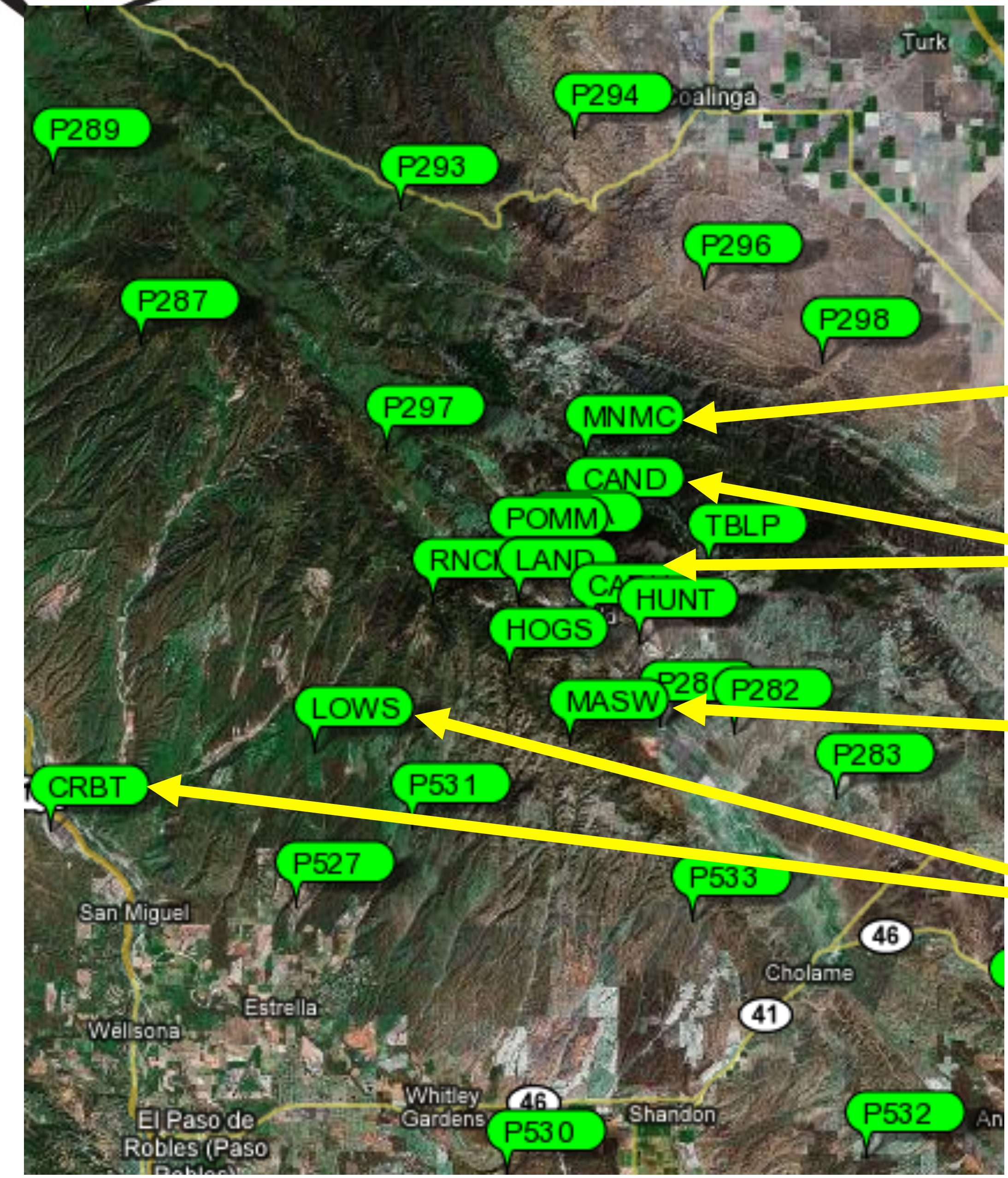
Explore more sites



Explore more sites

Station	North	East
P474	26.63	-26.70
P479	22.38	-23.04
P600	7.53	-8.35
P601	3.62	-5.46

Explore more sites



Choose sites increasingly far from the epicenter, such as:

MNMC

CAND & CARH

MASW

LOWS & CRBT,

and so on…

Explore more sites

Station	North	East
CRBT	32.15	-26.55
LOWS	32.48	-26.05
MASW	33.22	-25.25
MNMC	11.15	-7.63

What you learned today

- How high-precision GPS works and its application to plate tectonics;
- How to find GPS and tectonic plate velocities from GPS time series plots;
- How the Pacific plate moves compared to the North American plate along the San Andreas fault; and
- That motion on faults continues after earthquakes.

Questions

Contact: education @ unavco.org

http://www.unavco.org/

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