Exploring Plate Motion and Deformation in California with GPS

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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
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.
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

<table>
<thead>
<tr>
<th>Date</th>
<th>North (mm)</th>
<th>East (mm)</th>
<th>Vertical (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/1/2004</td>
<td>-37.67</td>
<td>36.57</td>
<td>2.33</td>
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<tr>
<td>1/2/2004</td>
<td>-38.04</td>
<td>35.73</td>
<td>5.63</td>
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<tr>
<td>1/3/2004</td>
<td>-37.16</td>
<td>35.83</td>
<td>4.69</td>
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<tr>
<td>1/4/2004</td>
<td>-37.34</td>
<td>36.34</td>
<td>5.36</td>
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<tr>
<td>1/5/2004</td>
<td>-37.59</td>
<td>36.44</td>
<td>9.11</td>
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<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>1/1/2005</td>
<td>-9.43</td>
<td>9.63</td>
<td>2.36</td>
</tr>
<tr>
<td>1/1/2006</td>
<td>16.48</td>
<td>-18.09</td>
<td>7.35</td>
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<tr>
<td>1/1/2007</td>
<td>45.98</td>
<td>-43.42</td>
<td>-6.43</td>
</tr>
</tbody>
</table>
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”
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.”
4. Retrieve the station’s information and time series plot.
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.”
What are the units of measurement for these time series?
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
How quickly is BEMT moving north or south?

Annual northward speed of BEMT = \((-6 - -29 \text{ mm})/5\) 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
How quickly is BEMT moving east or west?

Average position on 1/1/2010 = \(-62\) mm
Average position on 1/1/2005 = \(-42\) mm
Annual speed of BEMT north = \((-62 - -42 \text{ mm})/5\) years
= -20 mm/5yrs
= -4.0 mm/yr. BEMT is moving westward.
How quickly is SBCC moving?

Speed of SBCC:

= 27.3 mm/yr to the north

= 26.1 mm/yr to the west

Now do SBCC.
Plate movement via vectors
What’s a vector?

A vector shows speed and direction of motion.

**Anatomy of a Vector**

- The direction of the vector shows the direction the GPS station is moving.
- The length of the vector shows how fast the GPS station is moving.

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What’s a vector?
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?
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.
Step 2. Draw the east vector from the end point of the north vector.

Draw the vector -4.0 blocks (mm).
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 \( \sqrt{x^2 + y^2} \)

\[
= \sqrt{4.6^2 + 4.0^2}
= 6.1 \text{ mm/yr to the northwest.}
\]
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...

SBCC is moving ~5 times more quickly than BEMT.
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

Now

+ 3 million years

- 3 million years
What’s happening here?
Part 2: Deformation

CAND:
Lat: 35.94
Long: -120.43

CARH
Lat: 35.89
Long: -120.43

SBCC

BEMT

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?

\[ M = \log_{10}(D) + 6.32 \]

\[ \frac{0.9}{0.9} \]

where \( M \) = magnitude
\( D \) = average slip in meters

\([1000 \text{ mm } = 1 \text{ meter}]\)

\[ M = \log_{10}(0.096) + 6.32 \]

\[ \frac{0.9}{0.9} \]

\( M = 5.9 \)

(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 ~17 mm/yr.

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

96 mm/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
<table>
<thead>
<tr>
<th>Station</th>
<th>North</th>
<th>East</th>
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</thead>
<tbody>
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<td>P474</td>
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<tr>
<td>P479</td>
<td>22.38</td>
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<tr>
<td>P600</td>
<td>7.53</td>
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<td>P601</td>
<td>3.62</td>
<td>-5.46</td>
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</table>
Choose sites increasingly far from the epicenter, such as:

- MNMC
- CAND & CARH
- MASW
- LOWS & CRBT, and so on…
<table>
<thead>
<tr>
<th>Station</th>
<th>North</th>
<th>East</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRBT</td>
<td>32.15</td>
<td>-26.55</td>
</tr>
<tr>
<td>LOWS</td>
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</tr>
<tr>
<td>MASW</td>
<td>33.22</td>
<td>-25.25</td>
</tr>
<tr>
<td>MNMC</td>
<td>11.15</td>
<td>-7.63</td>
</tr>
</tbody>
</table>
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.
Contact: education @ unavco.org
http://www.unavco.org/

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