Measuring plate motion with GPS:
Introducing GPS to study tectonic plates as they move, twist, and crumple

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By the end of this activity…

You should be able to:

• Describe generally how GPS works;

• Interpret graphs in a GPS time series plot;

• Determine velocity vectors from GPS time series plots;

• Explain relative motions of tectonic plates in Iceland;

and

• Explore global GPS data.
Part 1: Modeling GPS

To build a gumdrop model of a GPS monument:

1. Use one gumdrop as the receiver (GPS monument).
2. Use toothpicks as three legs and one center post (monument braces).
3. Form feet from three small lumps of clay (concrete).
4. Place on a small piece of transparent paper (“see-through” crust).
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About geodesy

Geodesy is the science of ...
measuring Earth’s

• size,
• shape,
• orientation,
• gravitational field, and
• variations of these with time.
Demonstration

How does GPS work to pinpoint location?
How GPS Works - Basics

- Satellites broadcast their name and position in space.
- The GPS ‘listens’ only.
- GPS antenna collects the satellite signals and sends the signals to the GPS receiver.
- GPS receiver calculates the GPS antenna to satellite distance.
How GPS Works - Basics

- To locate the GPS receiver:
  - Three satellites for rough location
  - Fourth satellite corrects time errors, improving location accuracy.
  - Ground stations, (called the Control Segment), monitor satellite location & health, correct orbits & time synchronization.
- Position can be calculated within to a millimeter.
Anatomy of a High-precision Permanent GPS Station

GPS antenna inside of dome

Tripod legs are cemented 10 – 30 feet into the ground

Solar panel(s) for power.

Equipment enclosure:
- GPS receiver
- Power storage: Batteries
- Communications: radio modem
- Data storage: memory cards
A high precision GPS antenna is much bigger than a cell phone.

- 32 cm (~12.6 in)
- 42 cm (~16.5 in)
Anatomy of a GPS Antenna

- Antenna
- Signal Amplifier
- Choke ring (to dampen unwanted signals)
- Antenna mount
- Dome
- Power & signal cable
- Tripod supports
High precision GPS Corrects Some of these Sources of Error –

Some GPS Error Sources

• Selective Availability*
• Satellite orbits
• Satellite and receiver clock errors
• Atmospheric delays
  • Ionosphere
  • Troposphere
• Multi-path (reflections of signals)
• Human errors (trained staff)

* historical

The New Yorker, Roz Chast
GPS station positions change as plates move.

How will Station A move relative to Station B?
GPS station positions change as plates move.

GPS Station A is moving toward B.
Part 2: What can GPS tell us about Iceland?
Introduction: Measuring GPS Movement with Time Series Plots:

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**Data for SBCC GPS STATION**

- Located near Mission Viejo, CA
- Position data collected every 30 seconds
- One position for each day:
  - North
  - East
  - Vertical
GPS time series plots

3 separate plots:
- North
- East
- Height (Vertical)

X-axis: Time
Y-axis: Distance

GPS has moved

*Vertical scales vary per plot.

Red points:
Rapid position estimates
Which way are we going?

Is the GPS station moving

north or south?

east or west?

up or down?
Positive slope:

The station is moving north.

The station is moving east.

The station is moving up.
Which way are we going?

Is the GPS station moving north or south?

East or west?

Up or down?
Negative slope:

The station is moving south.

The station is moving west.

The station is moving down.
Time series plots

If the GPS Time Series Plots look like:

- **GPS vector looks like:**
  - N
  - E

- **GPS station is moving to:**
  - North
  - Northeast
  - Southeast
  - East

- **time**

- **GPS vector looks like:**
  - N
  - E

- **GPS station is moving to:**
  - South
  - Northwest
  - Southwest
  - West

- **GPS station is not moving**

- **time**
Gaps in data

Causes:

- Power outages
- Snow coverage
- Equipment failure
- Vandalism
- Wildlife
- Etc.
Exploring Iceland’s GPS data and maps
Where is Iceland?
Iceland’s GPS Data: REYK & HOFN
Iceland’s GPS data

REYK

HOFN
Calculating velocities of the GPS stations

What are the units of measurement for this data?

North (mm)

East (mm)
GPS monument HOFN: north

How quickly is HOFN moving in the north-south direction?


Average position on 1/1/2008 = ______ mm
Average position on 1/1/1998 = ______ mm
Average position on 1/1/2008 = 50 mm
Average position on 1/1/1998 = -98 mm

Change in position = 50 – (-98) = 148 mm
Annual speed of HOFN north = 148 mm/10 years
= 14.8 mm/yr to the north for HOFN
How quickly is HOFN moving in the east - west direction?

Average position on 1/1/2008 = ______ mm
Average position on 1/1/1998 = ______ mm

Speed of HOFN east = ___ mm/10 years
= _____ /yr to the (east or west)
How quickly is HOFN moving in the east - west direction?

Average position on 1/1/2008 = 50 mm
Average position on 1/1/1998 = -80 mm

Speed of HOFN east = 130 mm/10 years
= 13 mm/yr to the east for HOFN
What direction is Monument HOFN moving?

a) north only  
b) northwest  
c) northeast  
d) southwest
Think, then discuss with your neighbor: What direction is monument REYK moving? About how fast?
How quickly is REYK moving in the north - south direction?

Average position on 1/1/2008 = 90 mm
Average position on 1/1/1998 = -115 mm
Speed of REYK north = (90 – -115) mm/10 years
= 205 mm/10 yr
= 20.5 mm/yr to the north for REYK
GPS monument REYK

How quickly are they moving in the east - west direction?

Average position on 1/1/2008 = -50 mm
Average position on 1/1/1998 = 60 mm
Speed of REYK (east) = (-50 - 60) mm/10 years
= -110 mm/10 yrs
= 110 mm/10yr to the west
= -11 mm/yr to the west for REYK
Displaying velocities on a map

There must be an easier way to show this!

North: REYK = 20.5 mm/year
East: REYK = -11.0 mm/year

North: HOFN = 15.0 mm/year
East: HOFN = 13.0 mm/year
Are REYK and HOFN moving…

towards each other, away from each other, or in the same direction?

Mimic these motions with your GPS models.
Mapping plate movement
A vector shows velocity and direction of motion.
Graph paper as a map

Each axis uses the same scale.

**X-axis**: east in millimeters (per year)

**Y-axis**: north in millimeters (per year)

On your graph paper, each block represents 1 mm.

Where is the origin on this graph paper?
Graph paper as a map

REYK

HOFN

East (mm)

North (mm)

-20 -15 -10 -5 0

0 5 10 15 20 25

0 5 10 15 20 25

25
Plotting REYK vectors

- Vector: magnitude and direction
  - Tail is the GPS monument location.
  - Length of arrow is the magnitude.
  - Shows direction on a map.
Plotting REYK vectors

Step 1. Draw the first vector along the north axis with the tail at 0.

- GPS monument REYK moves 20.5 mm to the north per year
- Draw a vector arrow 20.5 blocks along the north axis.
Step 2. Place the tail of the east vector at the head of the north vector.

Draw the vector -11.0 blocks (mm) beginning at the head of the north arrow.
Step 3. 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.
Another approach to adding vectors

Or, use the Pythagorean theorem to add the vectors to find the sum.

GPS monument moves at: \( \sqrt{x^2 + y^2} = \) _____ mm/yr to the _____
Now do HOFN on your own – compare with a neighbor.
Looking at the world view of motion

Perspective of looking from space
What is happening to Iceland?

Extra credit – if you were sitting at HOFN for a very long time, how would REYK be moving?
Motion of western Iceland when eastern Iceland is not moving
Rifting Sites of surface eruptions

NORTH AMERICAN PLATE

EURASIAN PLATE

ICELAND

ATLANTIC OCEAN

Sites of surface eruptions

Mid-Atlantic Ridge

Krafla

Thingvellir

Reykjavik
Fissures opening
Viewing another region: Africa
What’s happening here?

Study the vectors. Reference frame is keeping the mainland Africa fixed. What do you notice about East Africa?

How are the motions similar and different from Iceland?
Volcanoes of Africa

GPS Velocity Viewer

Data source: Africa
Vector color: purple
Vector length (scaling): 4x
Station names and data download
Show error ellipses
More layers:
- Display earthquakes
- Display volcanoes
- Display volcano markers
- Display plate boundaries
Sites displayed: Show all

Draw Map  Clear Map
UNAVCO Velocity Viewer:

Part 3: Apply your knowledge
Match cars and graphs

North

East

What direction?

Which car?

North (miles) vs. Time (Hours)

East (miles) vs. Time (Hours)

Car A

Car B

Car C

Car D

Car E
Match cars and graphs

What direction?
North-Northeast

Which car?
Car A

<table>
<thead>
<tr>
<th>North (miles)</th>
<th>East (miles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time (Hours)</td>
<td>Time (Hours)</td>
</tr>
</tbody>
</table>
Match cars and graphs

ii) North

East

What direction?

Which car?

North

East

Time (Hours)

Time (Hours)

North

East

B

C

D

E

A

North
Match cars and graphs

ii) North

East

What direction?

South

Which car?

Car C

Time (Hours)

North (miles)

East (miles)

Time (Hours)
What direction is car D moving?

Draw the north and east graphs

North

East

North (miles)

East (miles)

Time (Hours)

Time (Hours)
v) What direction is Car D moving?

Southeast

Draw the north and east graphs

North

North (miles)

East

East (miles)

Time (Hours)

Time (Hours)
You should now be able to:

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Contact: education @ unavco.org

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