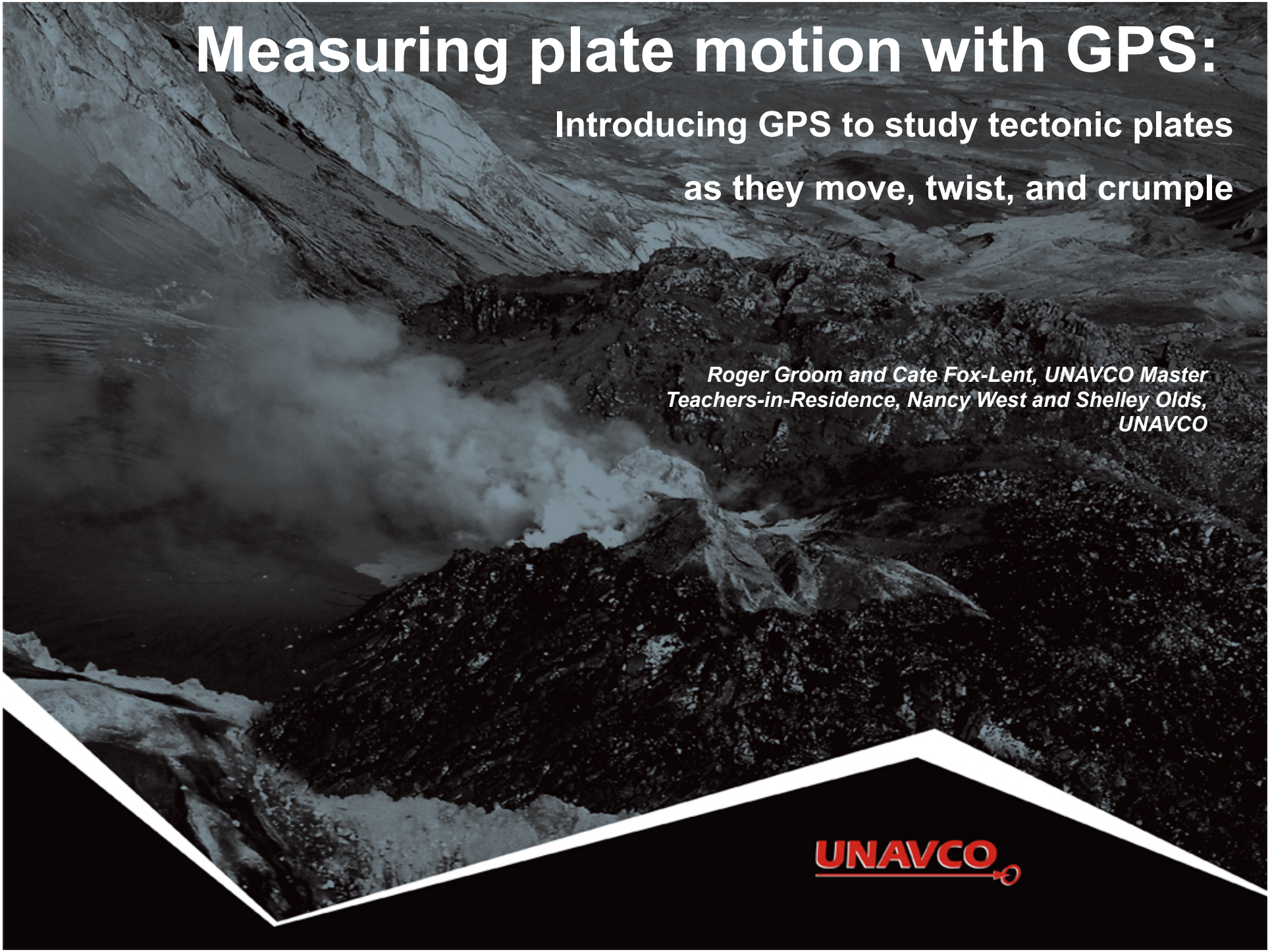


Measuring plate motion with GPS:

Introducing GPS to study tectonic plates as they move, twist, and crumple

Roger Groom and Cate Fox-Lent, UNAVCO Master Teachers-in-Residence, Nancy West and Shelley Olds, UNAVCO

UNAVCO

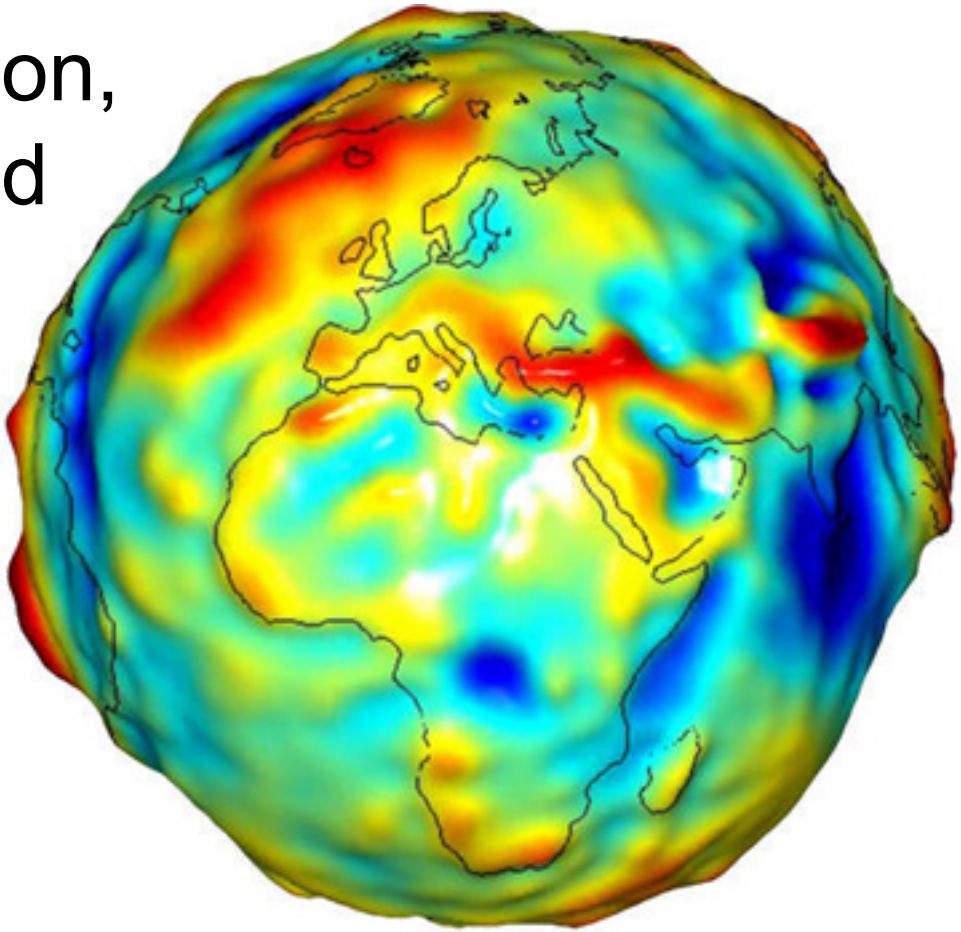
By the end of this activity…

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.

About geodesy

Geodesy is the science of …
measuring Earth's
size, shape, orientation,
gravitational field, and
variations of these
with time.



Anatomy of a GPS station

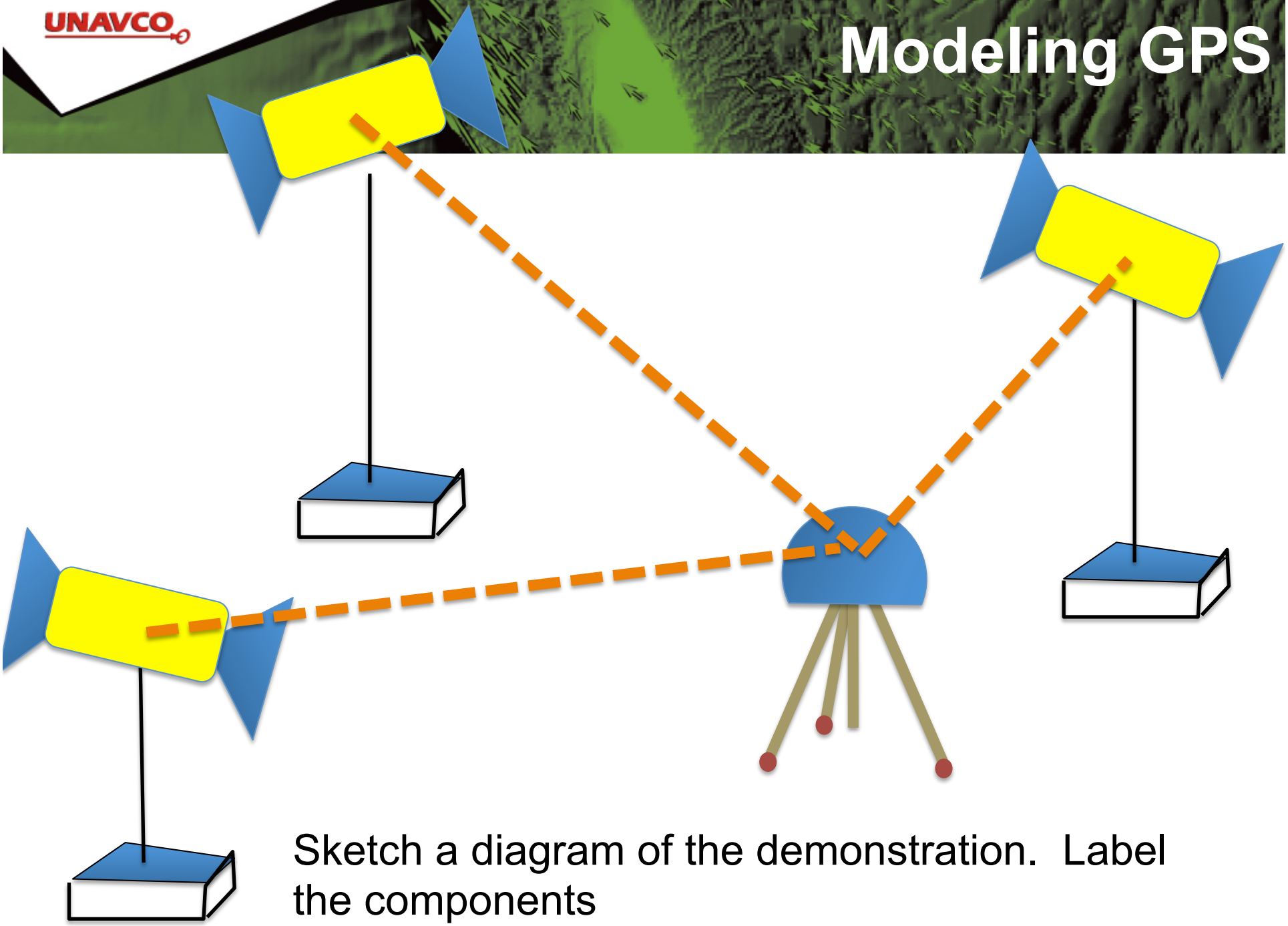
GPS antenna inside the dome is anchored to the ground with braces.

Solar panel for power.

Equipment enclosure includes:

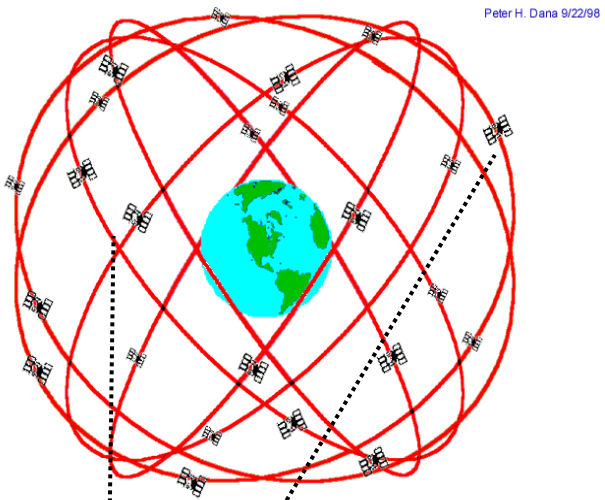
- GPS receiver
- Power/batteries
- Communications
- Data storage

Modeling GPS



Sketch a diagram of the demonstration. Label the components

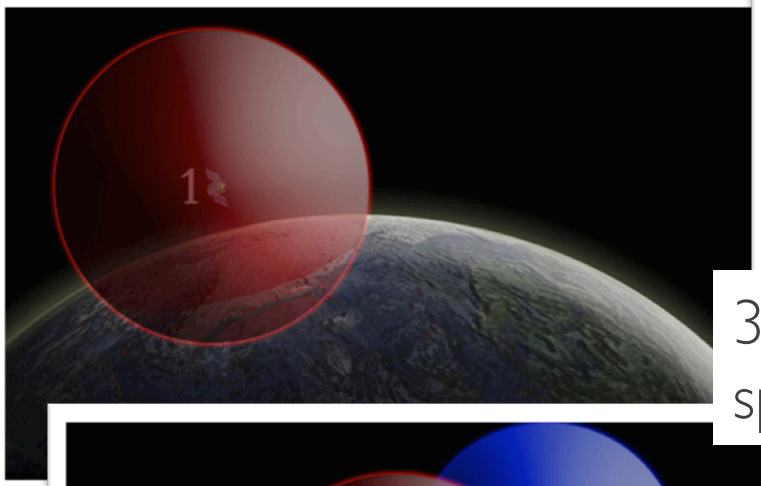
GPS basics

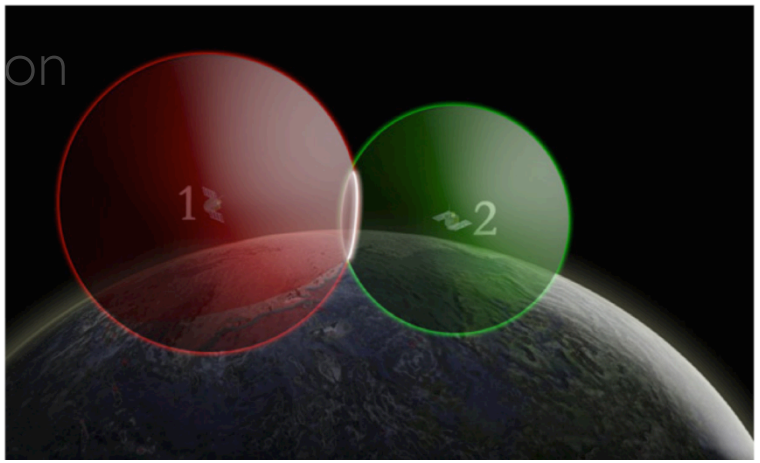


- Three satellite signals locate the receiver in 3D space.
- The fourth satellite is used for time accuracy.
- Position can be located to within less than a centimeter.

One way to find your location – 4 intersecting spheres

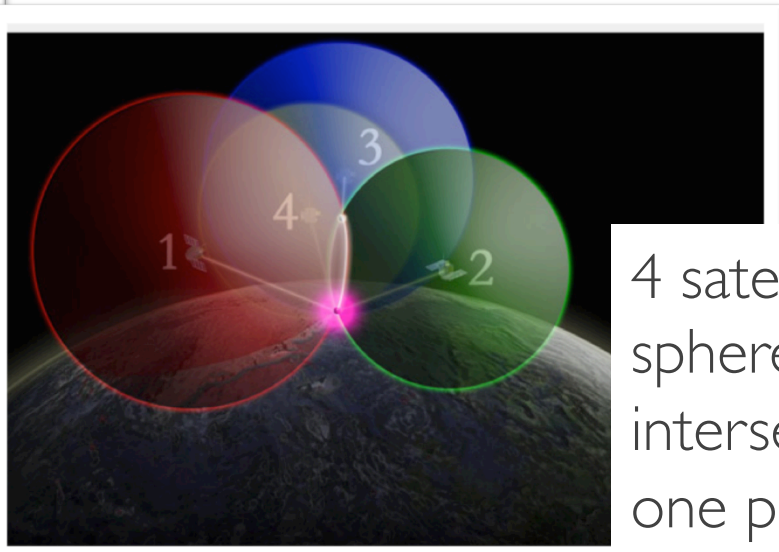
One satellite,
the GPS could be anywhere on the edge of the sphere.





Two satellites,
GPS could be on the circle where spheres intersect.

3 satellites:
spheres intersect in 2 places.

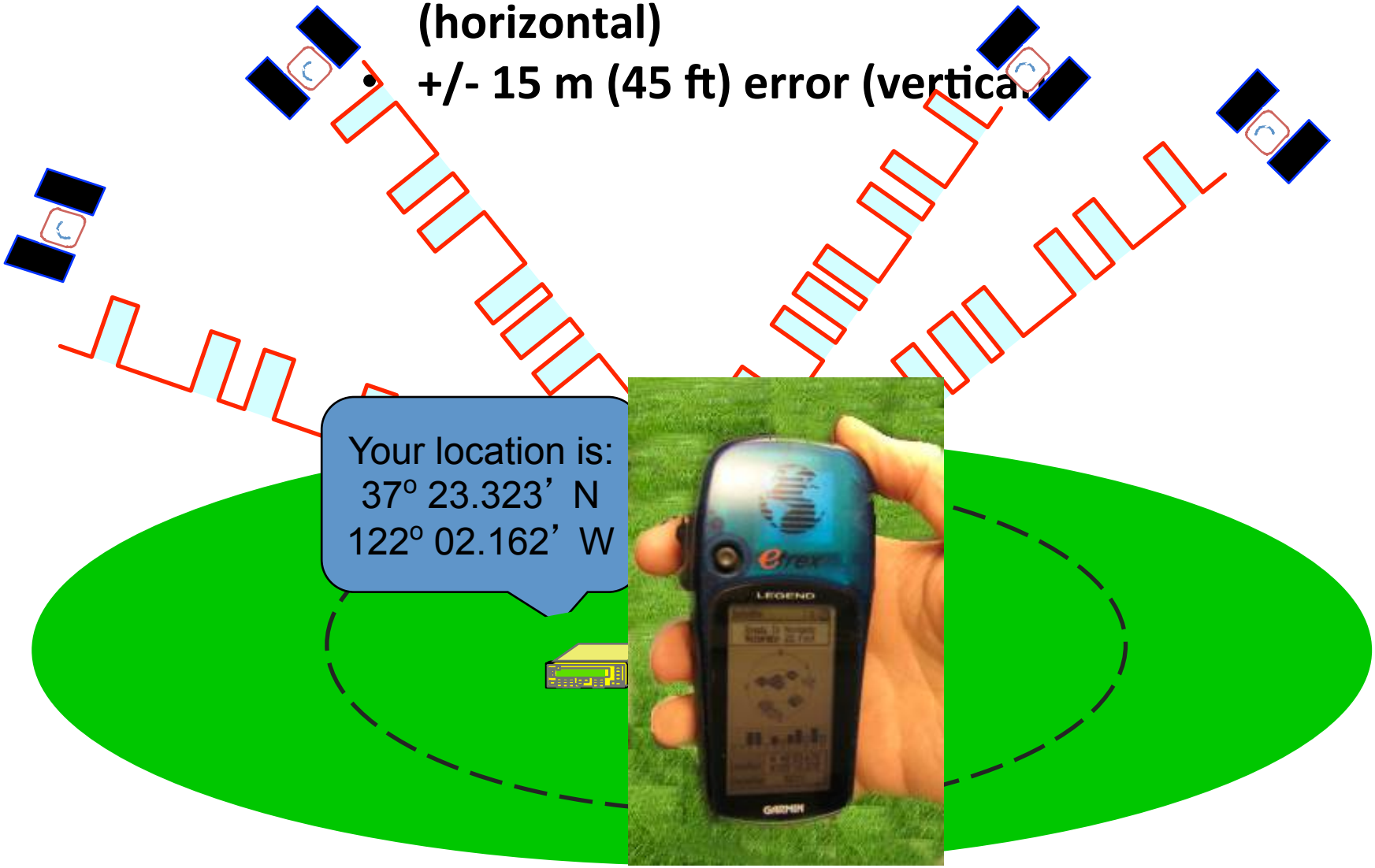


4 satellites,
spheres intersect in one place.

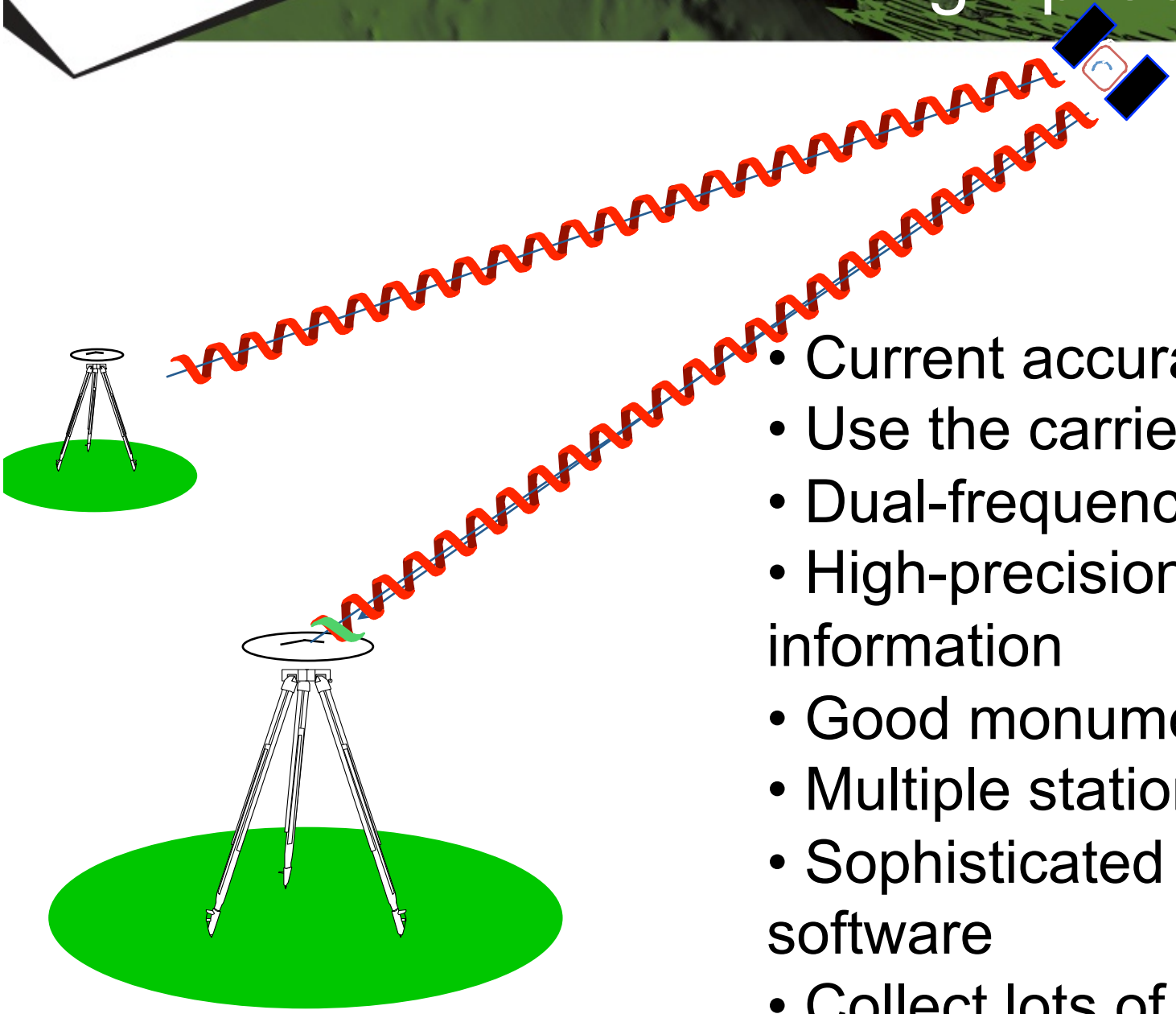
Instantaneous positioning with GPS

Consumer grade accuracy of

- **+/- 10 m (30 ft) error (horizontal)**
- **+/- 15 m (45 ft) error (vertical)**



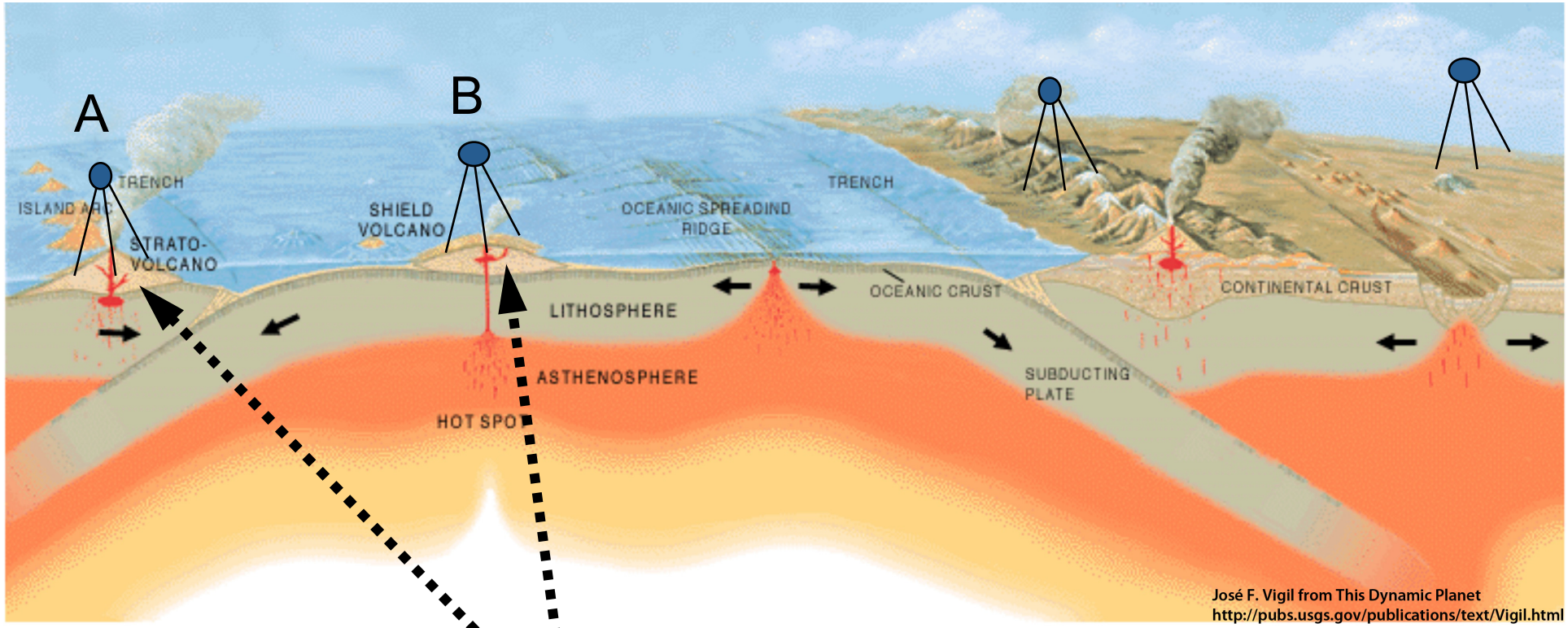
High-precision GPS



- Current accuracies sub-cm.
- Use the carrier phase
- Dual-frequency receivers
- High-precision orbital information
- Good monuments
- Multiple stations
- Sophisticated processing software
- Collect lots of data

Movement of GPS stations

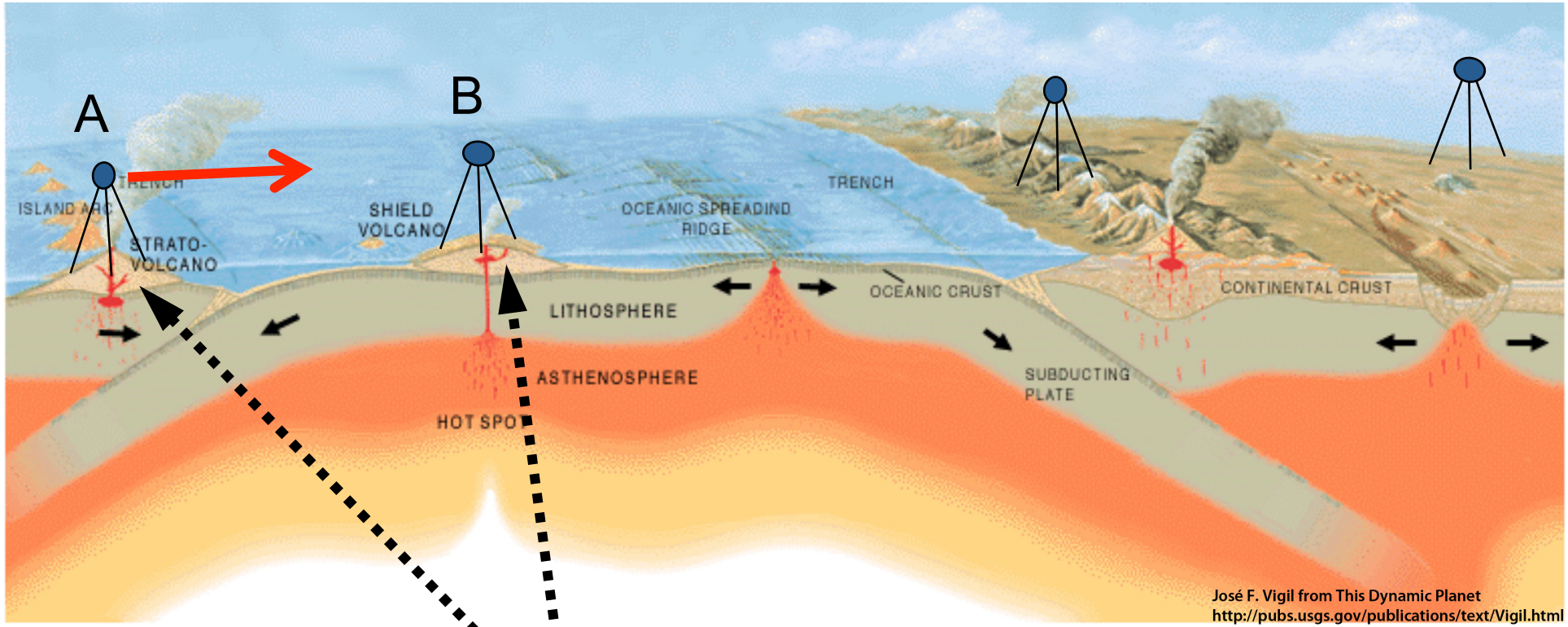
GPS station positions change as plates move.



How will Station A move relative to Station B?

Movement of GPS stations

GPS station positions change as plates move.



GPS Station A is moving toward B.

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).

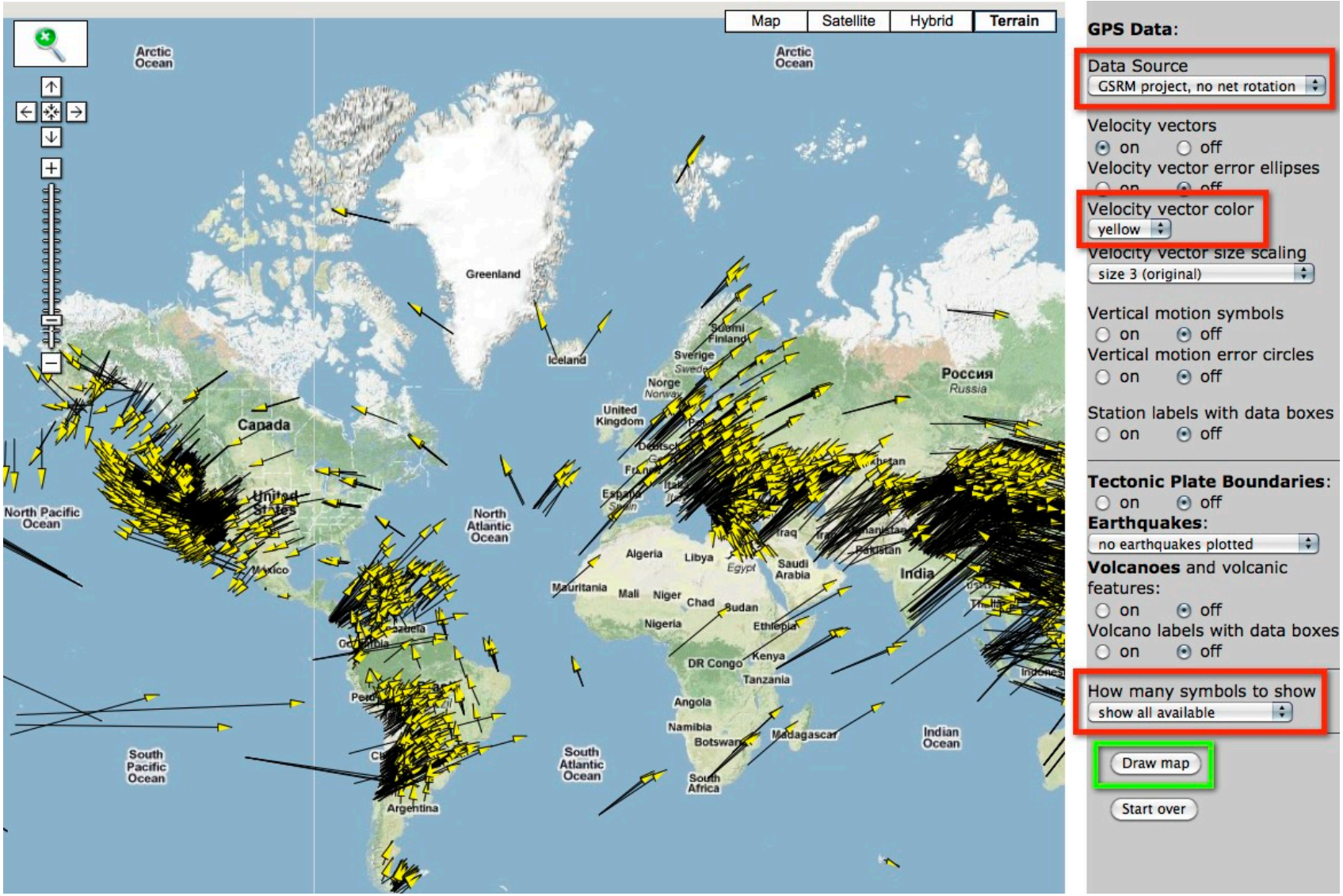
Questions

Contact:
education @ unavco.org
http://www.unavco.org/

Follow UNAVCO on  

Facebook Twitter

GPS Velocity Viewer



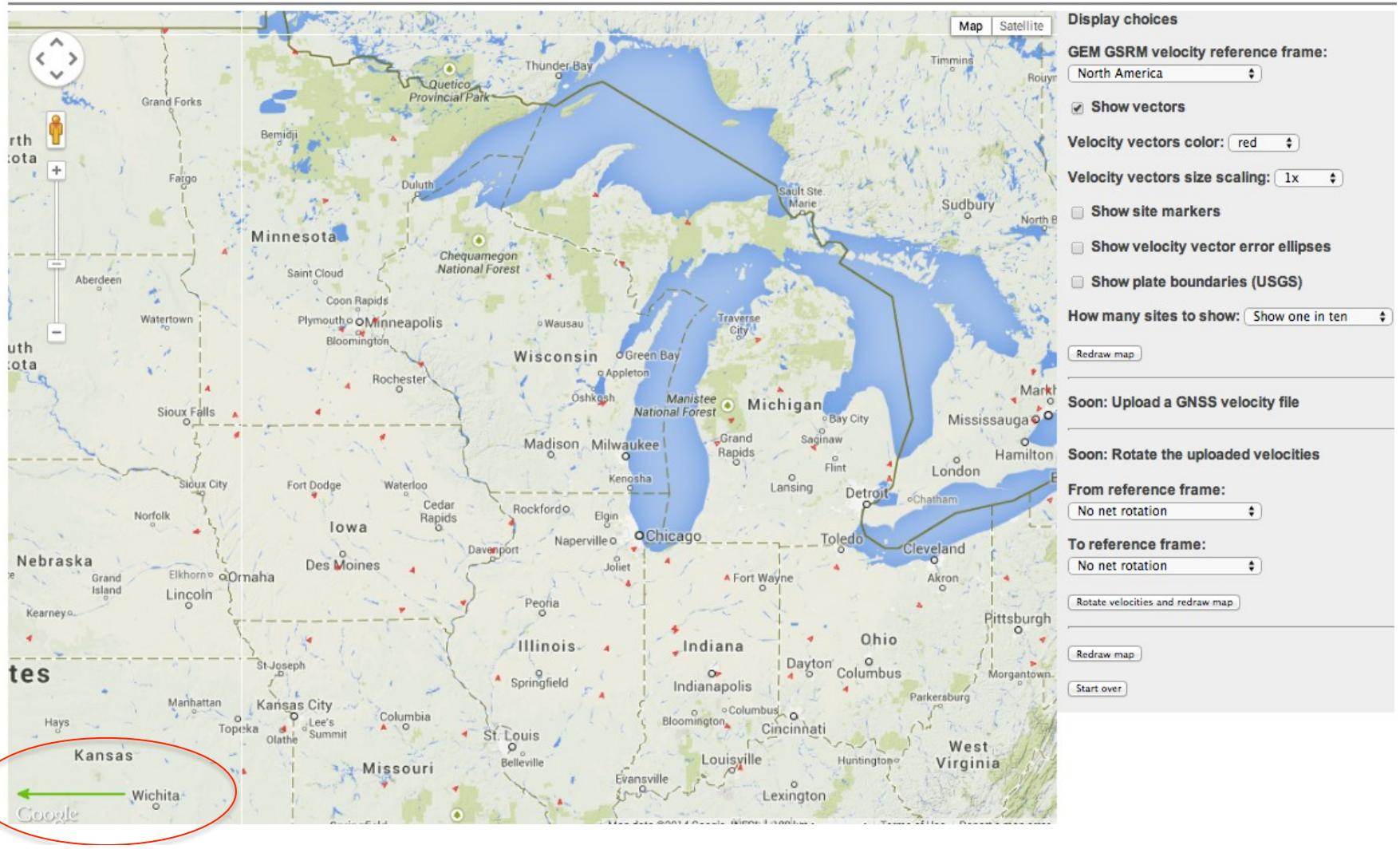
Data source: Global Strain Rate Map Project ; Reference Frame: **No Net Rotation**
UNAVCO GPS Velocity Viewer:
http://facility.unavco.org/data/maps/GPSVelocityViewer/GPSVelocityViewer.html

Nearby PBO GPS Stations

http://www.unavco.org/instrumentation/networks/status/pbo

Velocities – North America reference frame

http://www.unavco.org/software/visualization/GPS-Velocity-Viewer/GPS-Velocity-Viewer.html



Velocities compared to Eurasia

http://www.unavco.org/software/visualization/GPS-Velocity-Viewer/GPS-Velocity-Viewer.html

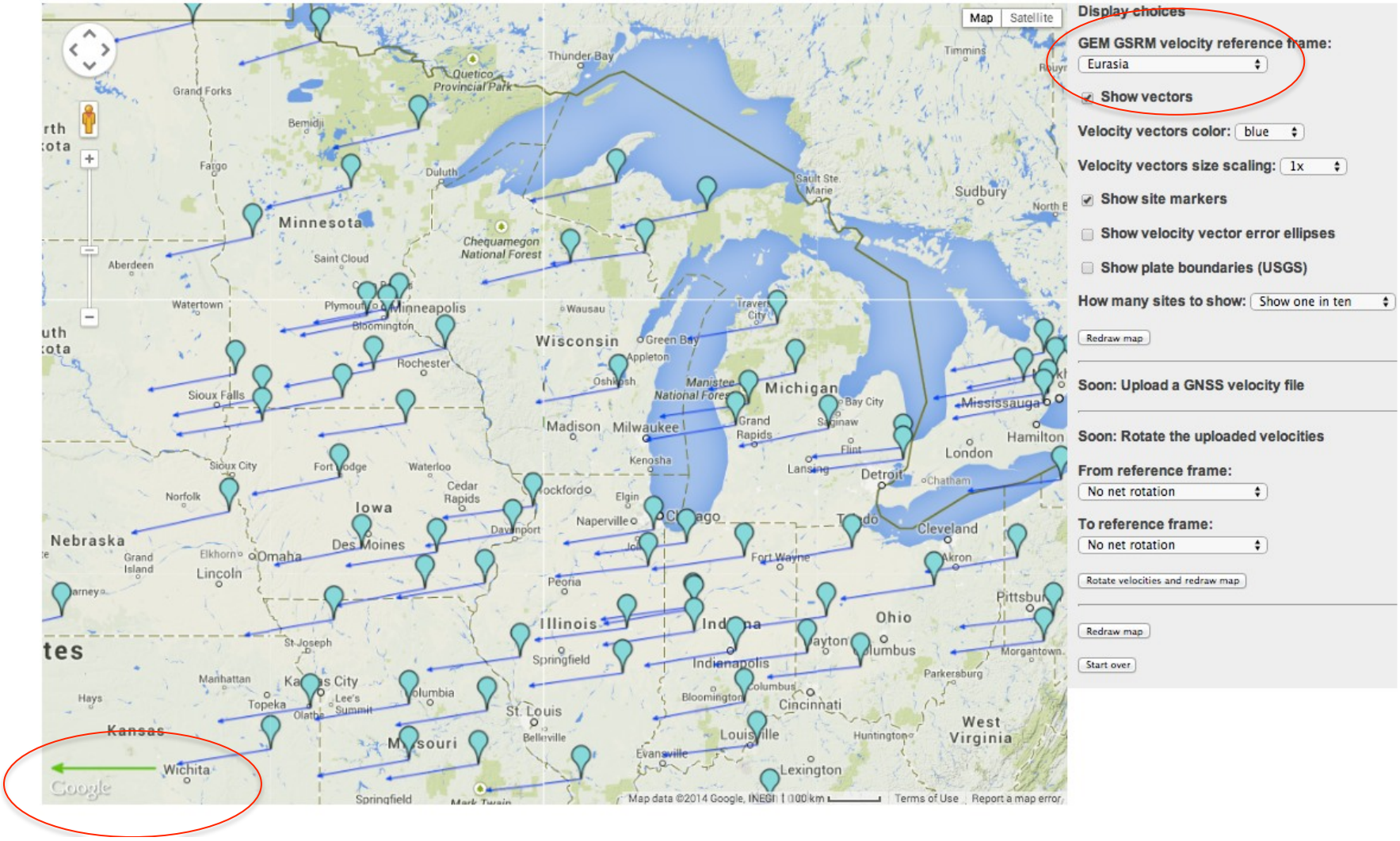
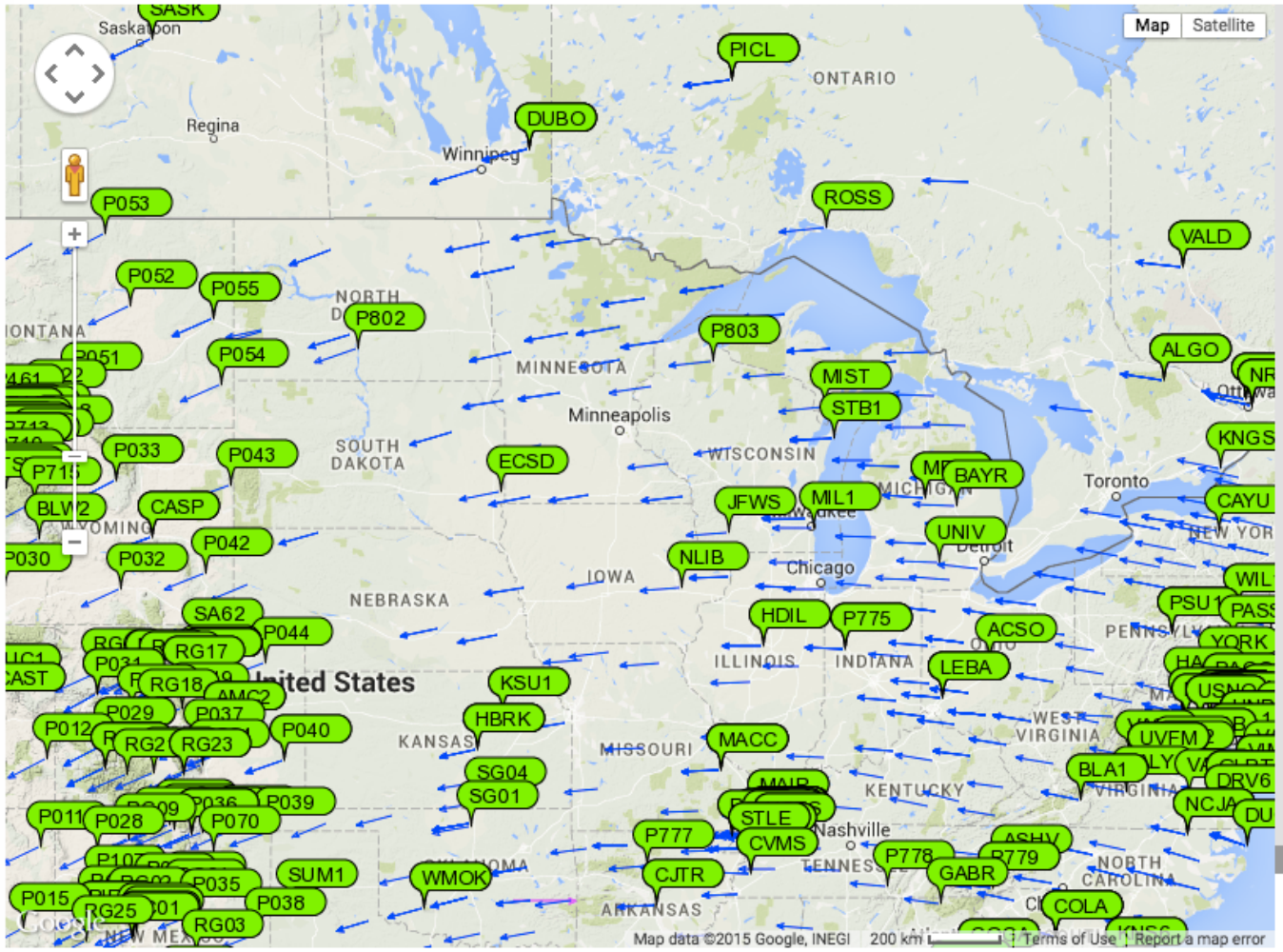


Plate motions from another perspective: world reference frame

UNAVCO

GPS Velocity Viewer



Key

GPS Symbols:

Velocity vector and error ellipse

25 mm/year speed scale

Part 2: Measuring movement

SBCC GPS STATION

- Located near Mission Viejo, CA
- Position data collected every 30 seconds
- One position estimate developed for each day:
  - North
  - East
  - Vertical

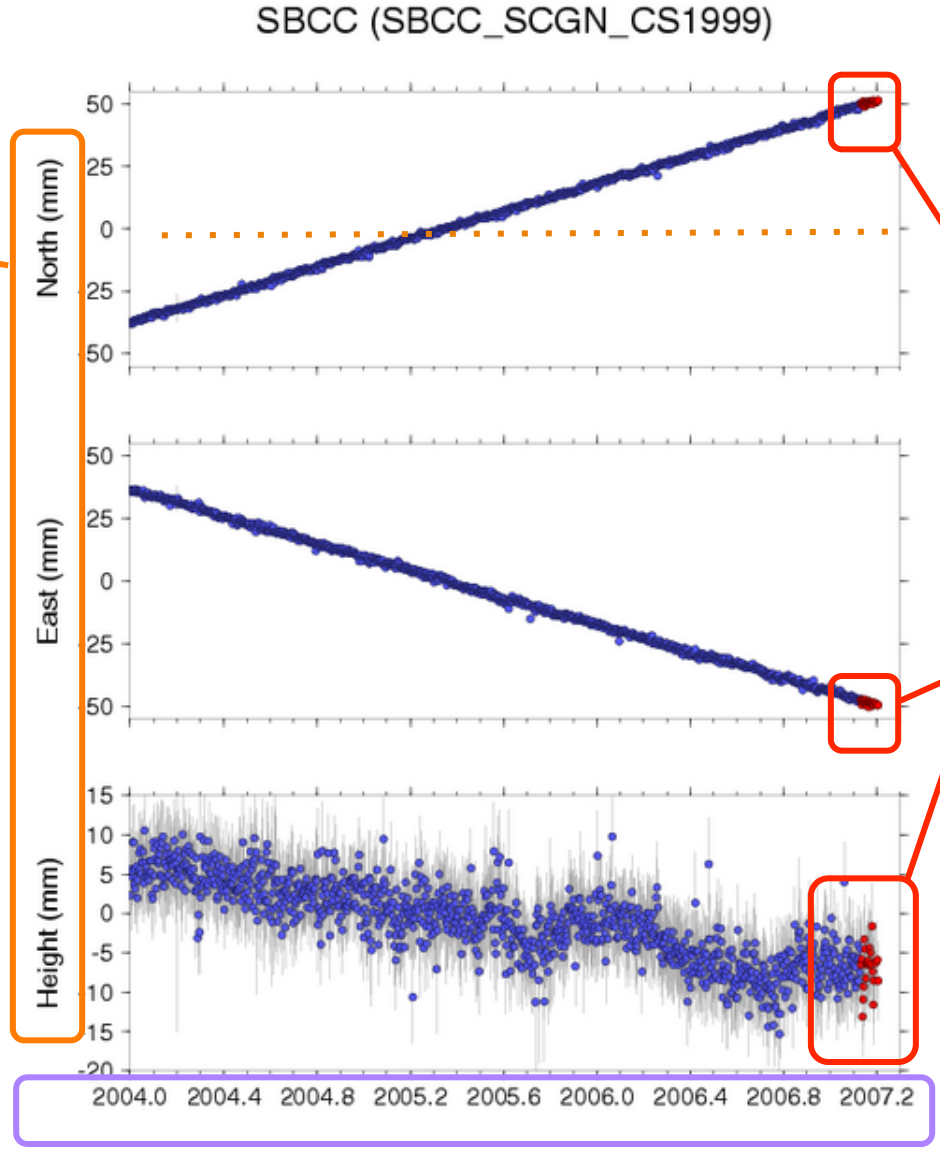
Date	North (mm)	East (mm)	Vertical (mm)
1/1/2004	-37.67	36.57	2.33
1/2/2004	-38.04	35.73	5.63
1/3/2004	-37.16	35.83	4.69
1/4/2004	-37.34	36.34	5.36
1/5/2004	-37.59	36.44	9.11
…	…	…	…
1/1/2005	-9.43	9.63	2.36
1/1/2006	16.48	-18.09	7.35
1/1/2007	45.98	-43.42	-6.43

GPS time series plots

3 separate plots on y-axis:

- North
- East
- Height (Vertical)

Notice that scales vary.



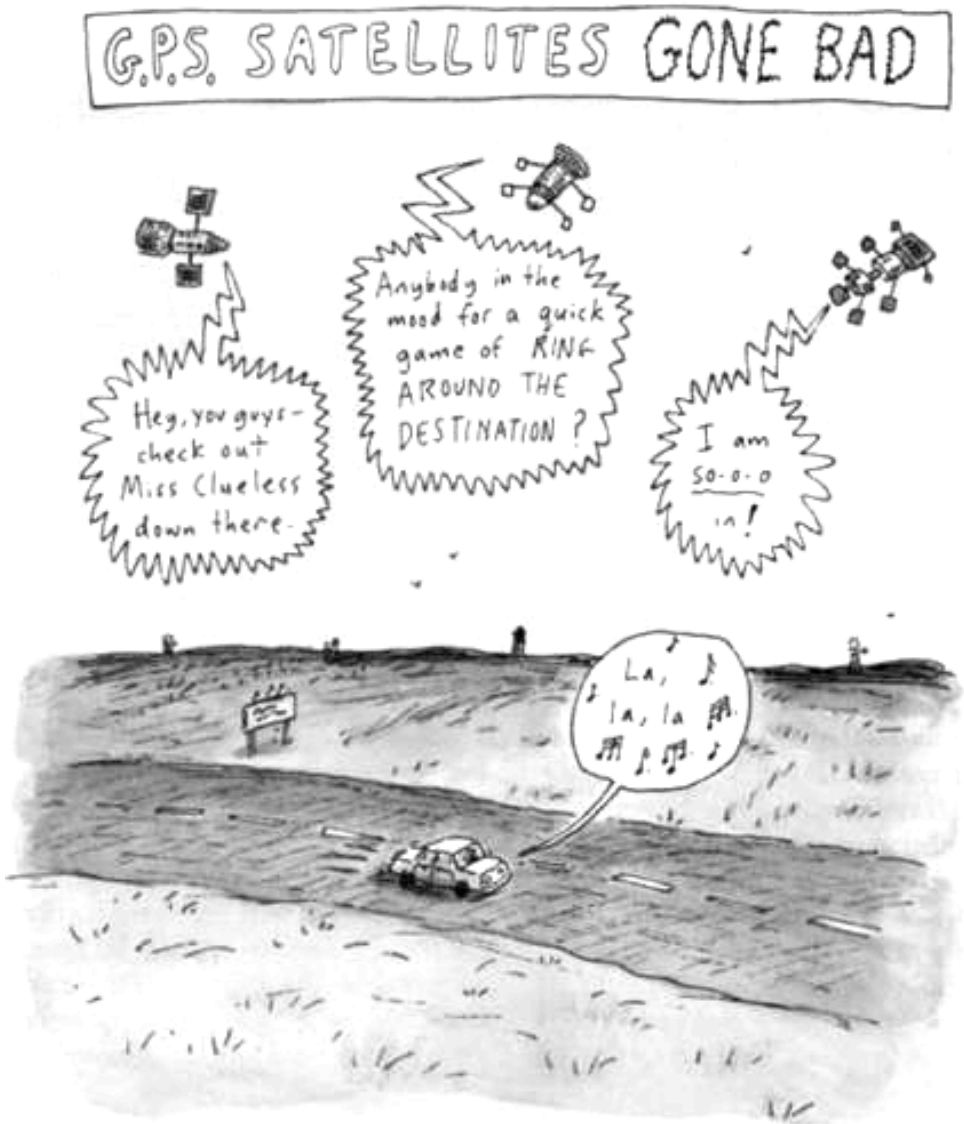
Red points: rapid estimates

X-axis: date of the measurement

Sources of Error

Some GPS Error Sources

- Selective Availability
- Satellite orbits
- Satellite and receiver clock errors
- **Atmospheric delays**
  - Ionosphere
  - Troposphere
- **Multi-path**
- **Human errors**



The New Yorker, Roz Chast

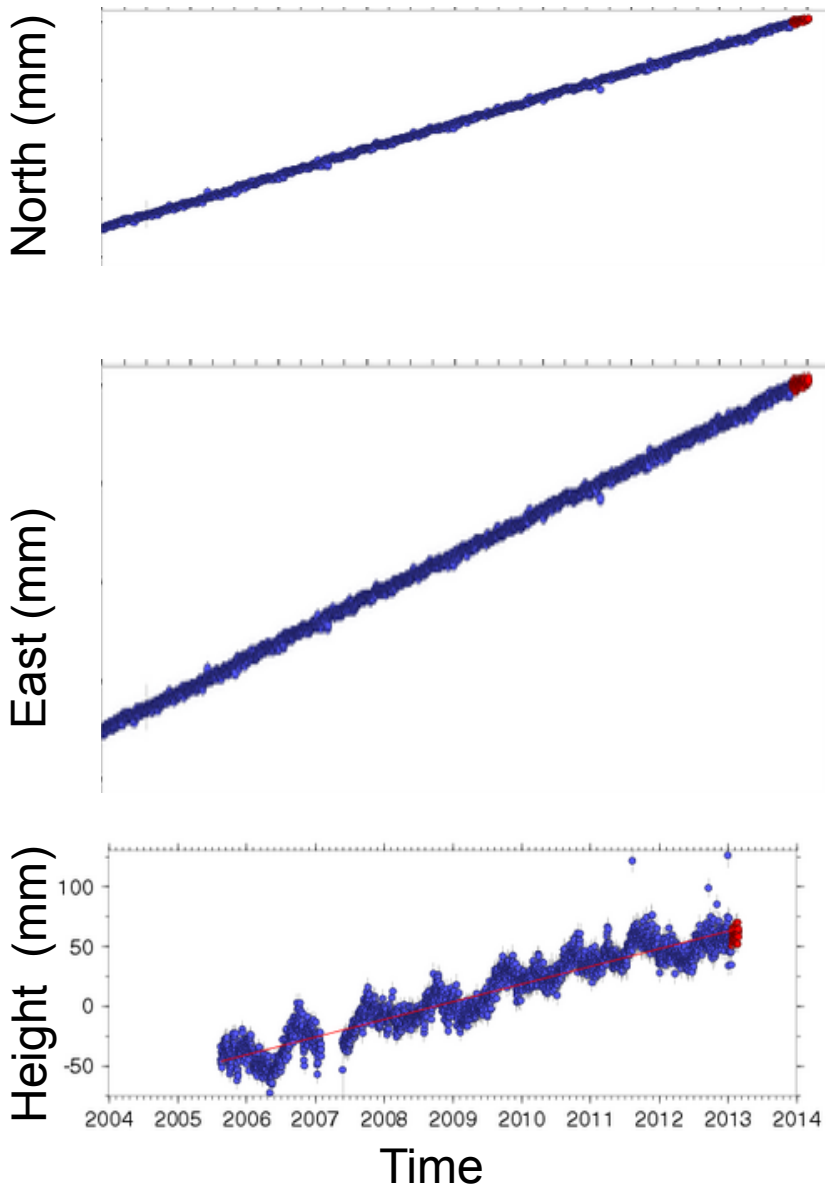
Which way are we going?

Is the GPS station moving

north or south?

east or west?

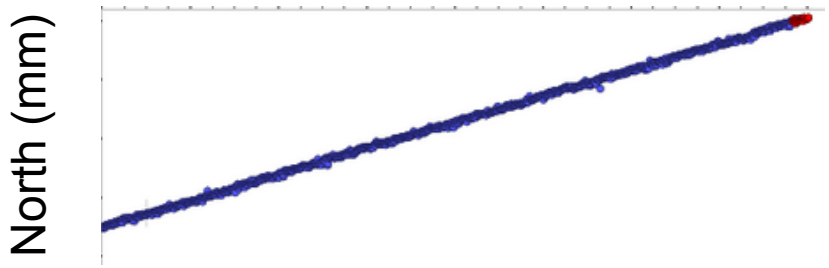
up or down?



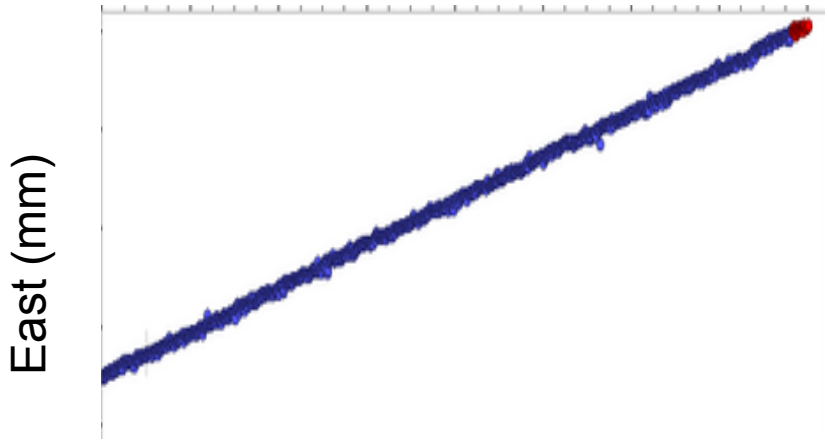
Which way are we going?

Positive slope:

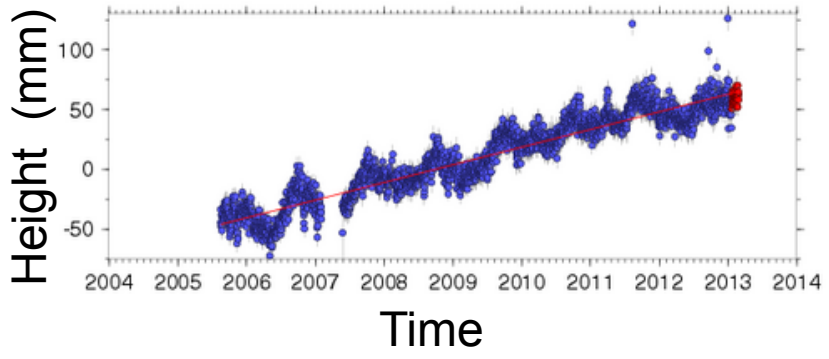
The station is moving **north**.



The station is moving **east**.



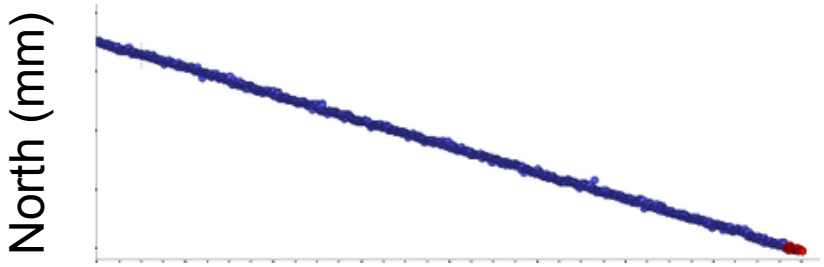
The station is moving **up**.



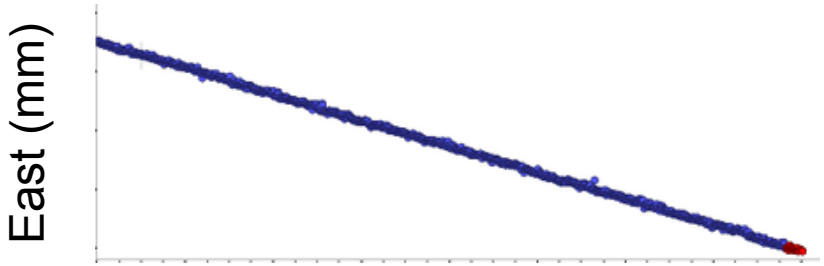
Which way are we going?

Is the GPS station moving

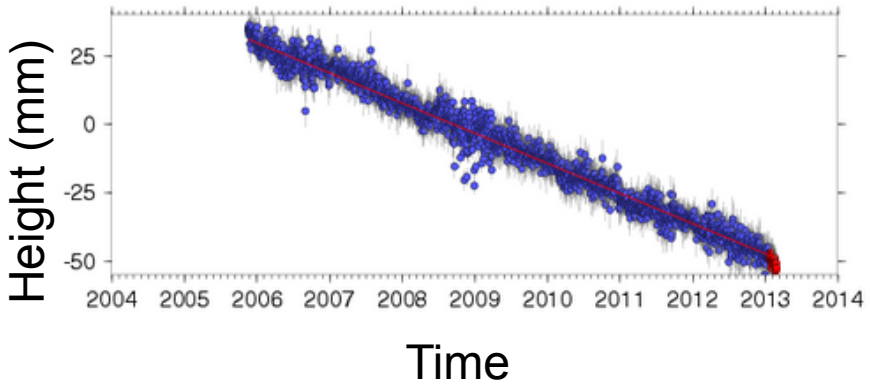
north or south?



east or west?



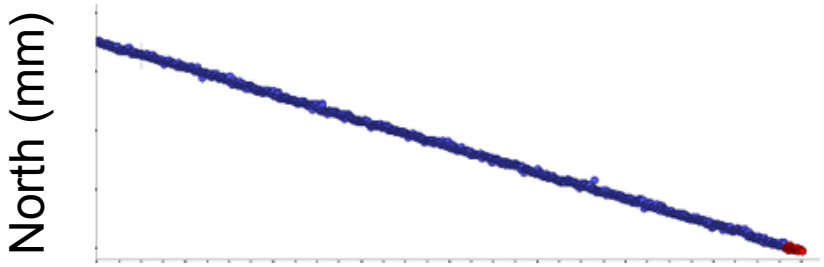
up or down?



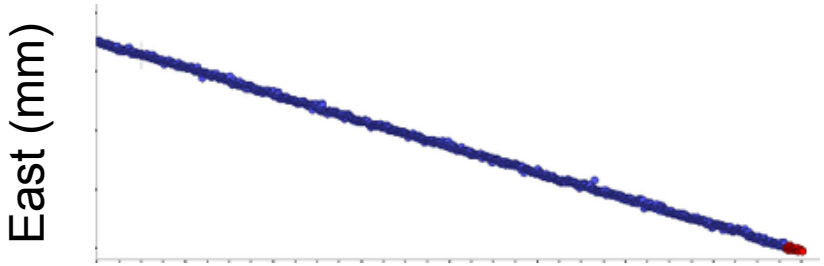
Which way are we going?

Negative slope:

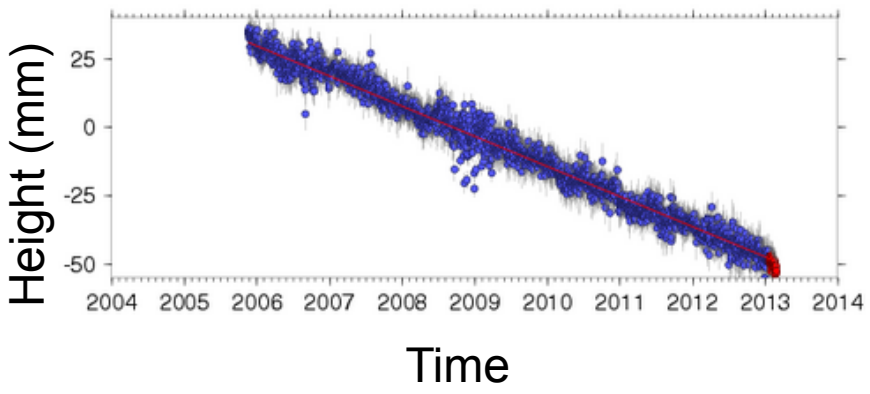
The station is moving **south**.



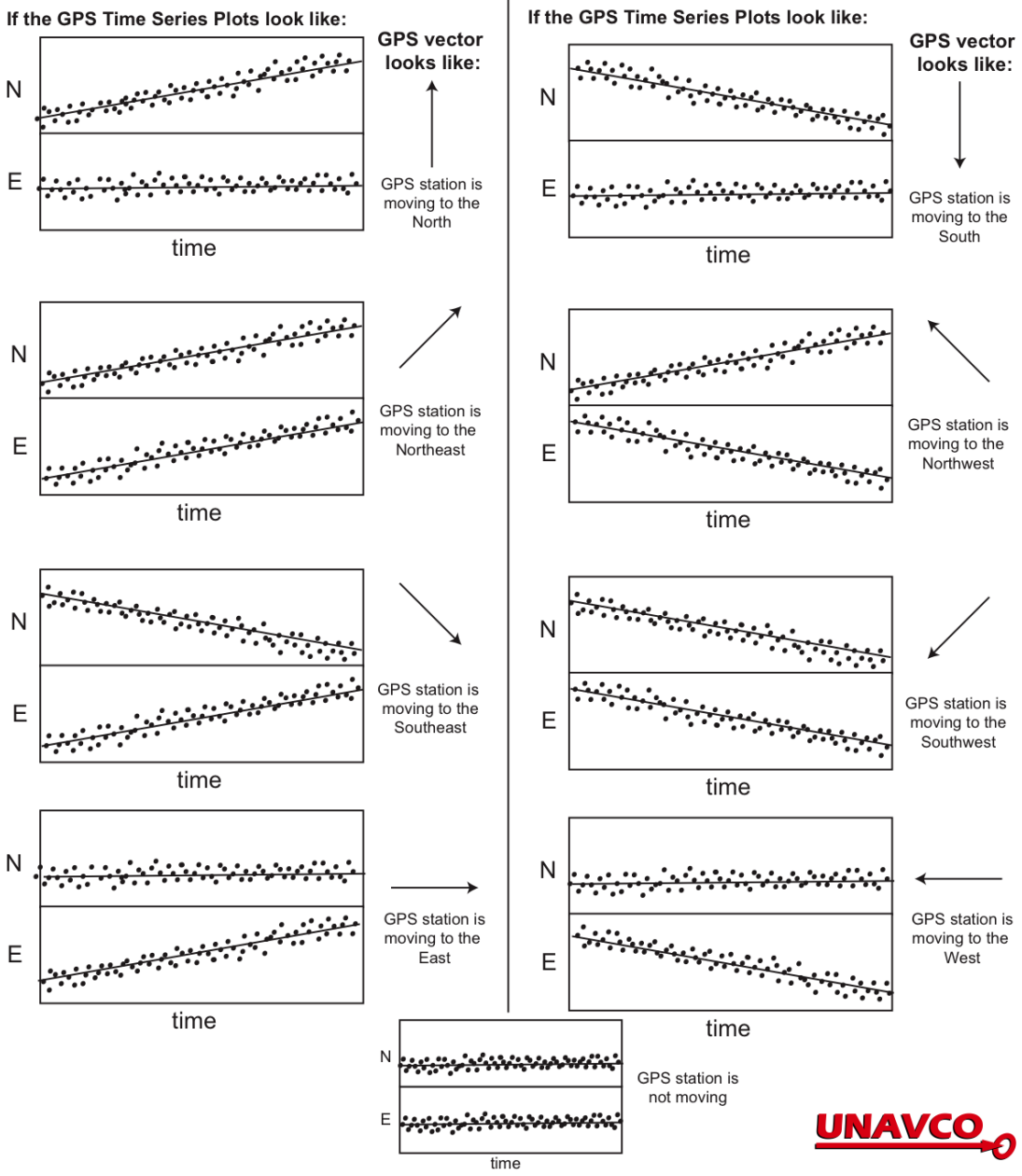
The station is moving **west**.



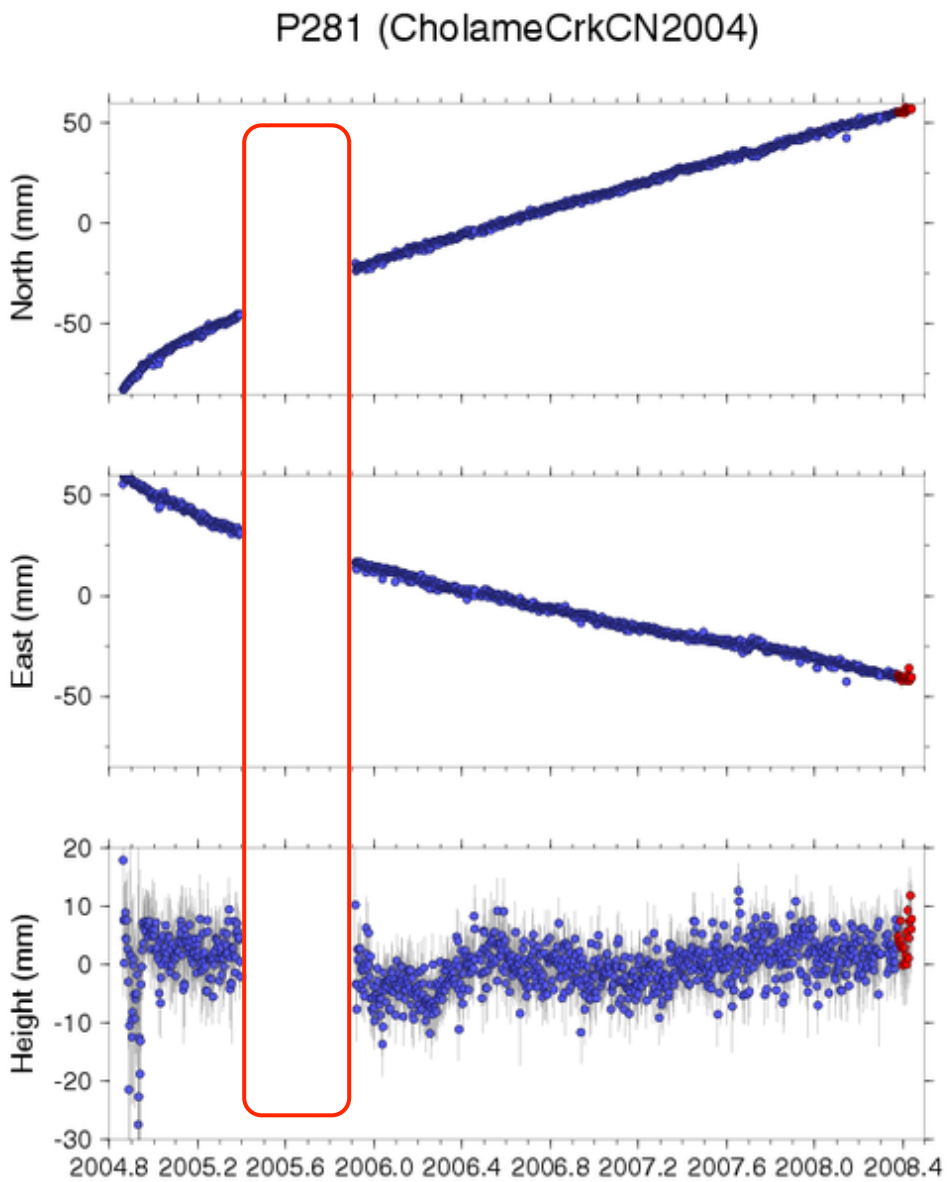
The station is moving **down**.



Time series plots



Gaps in data

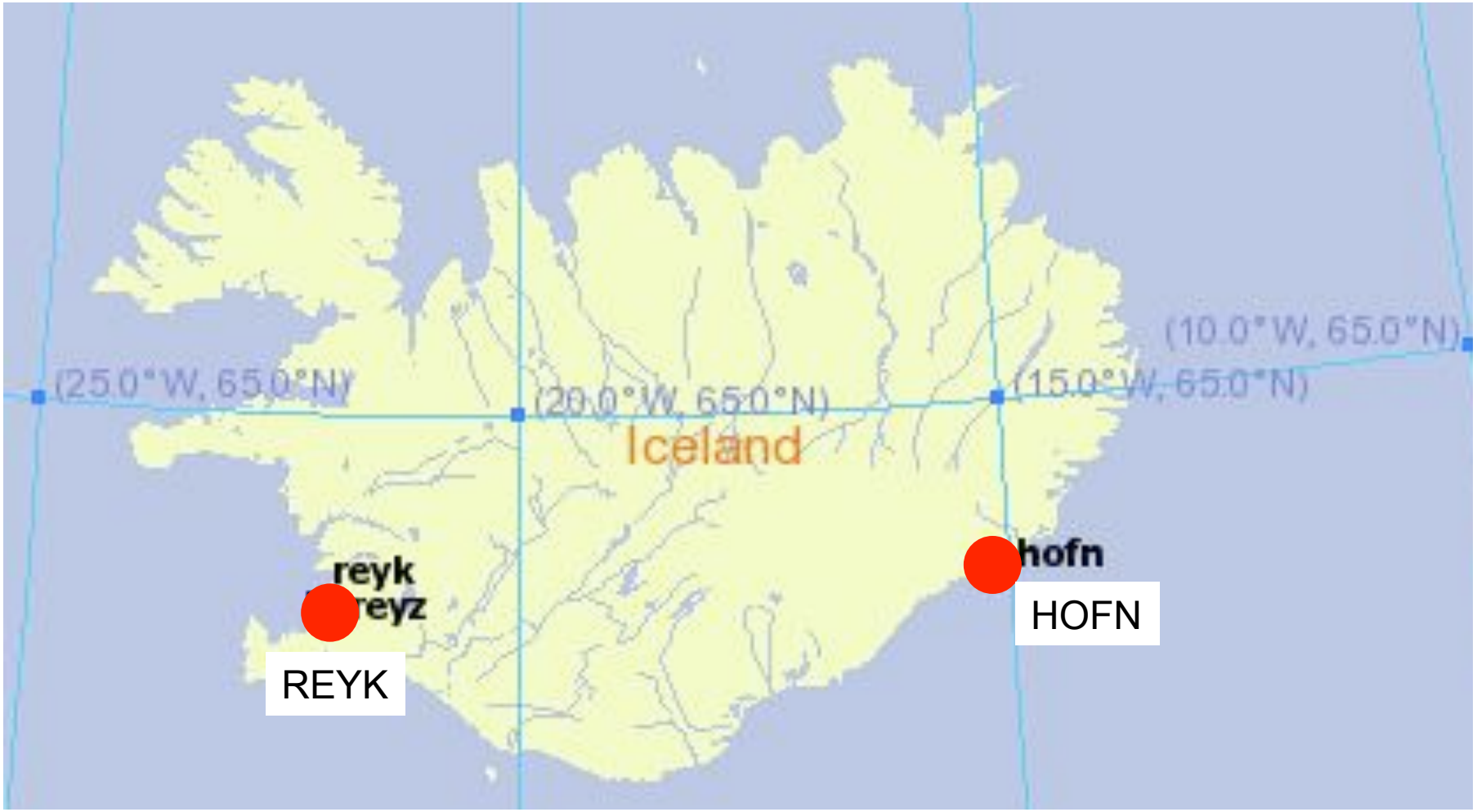


Causes:

- Power outages
- Snow coverage
- Equipment failure
- Vandalism
- Wildlife
- Etc.

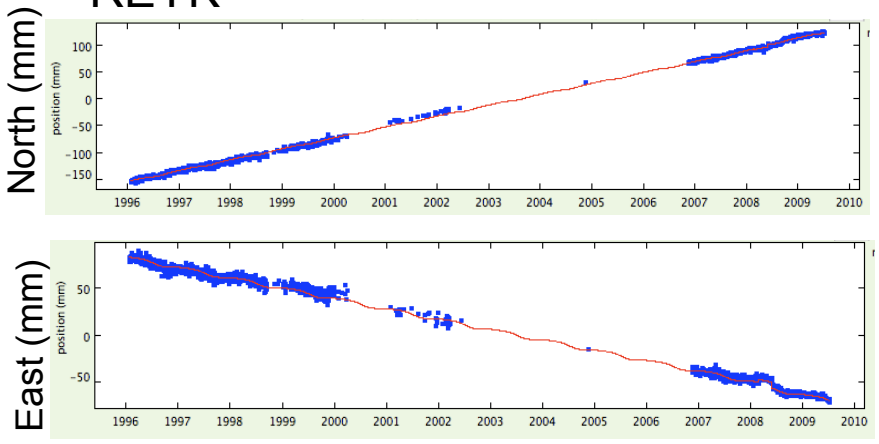
Iceland's GPS data

Iceland's GPS data

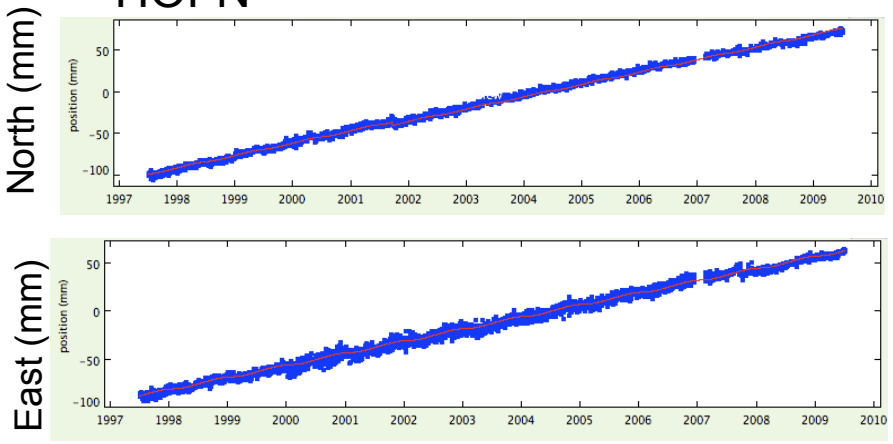


Iceland's GPS data

REYK

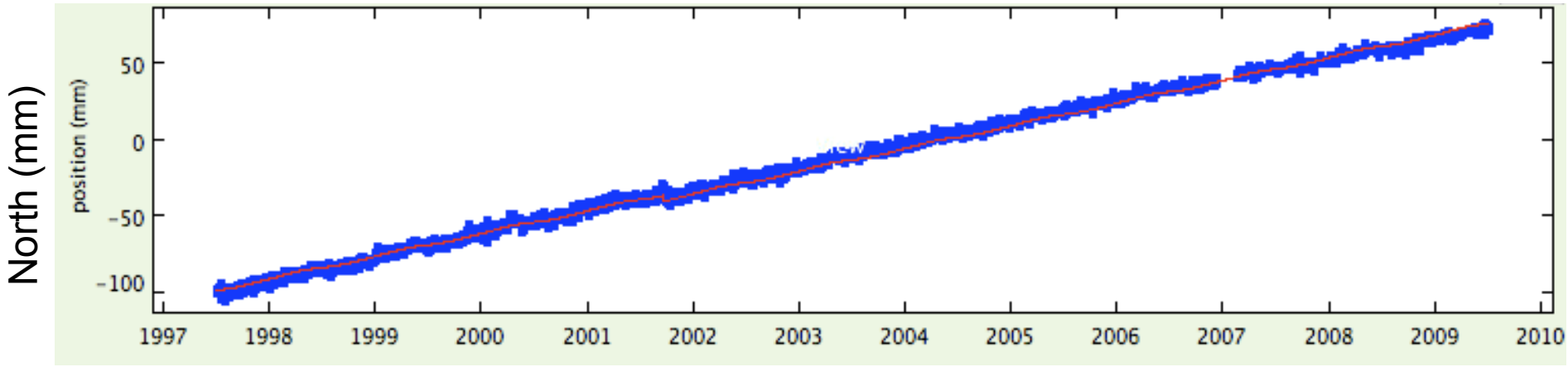


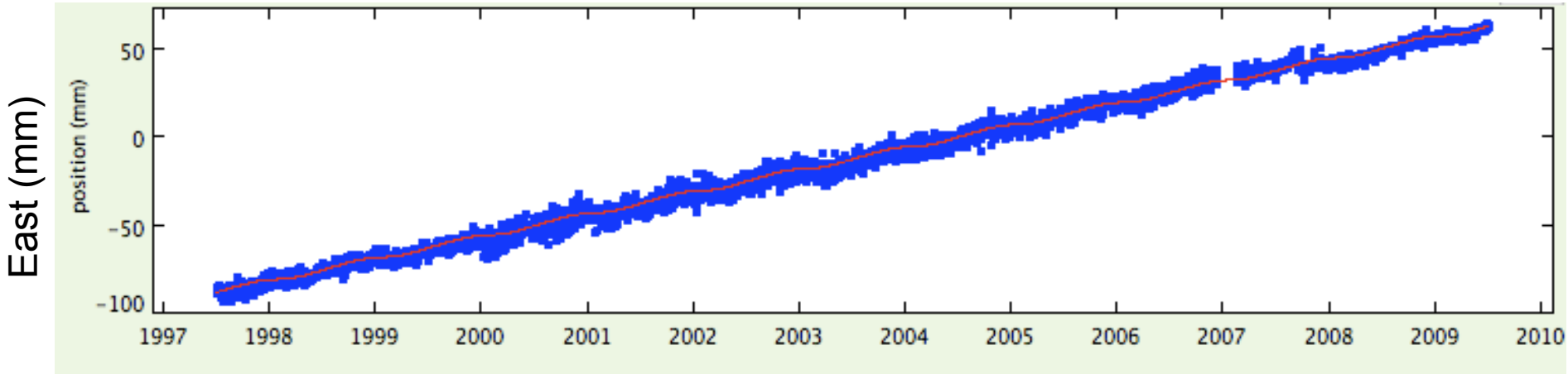
HOFN



Units on time series plots

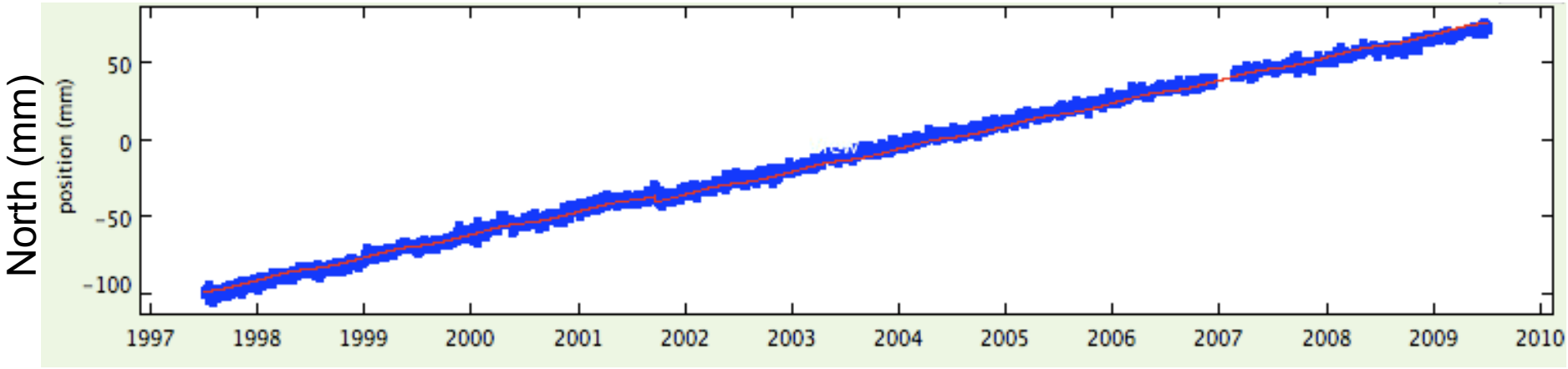
What are the units of measurement for this data?





GPS monument HOFN: north

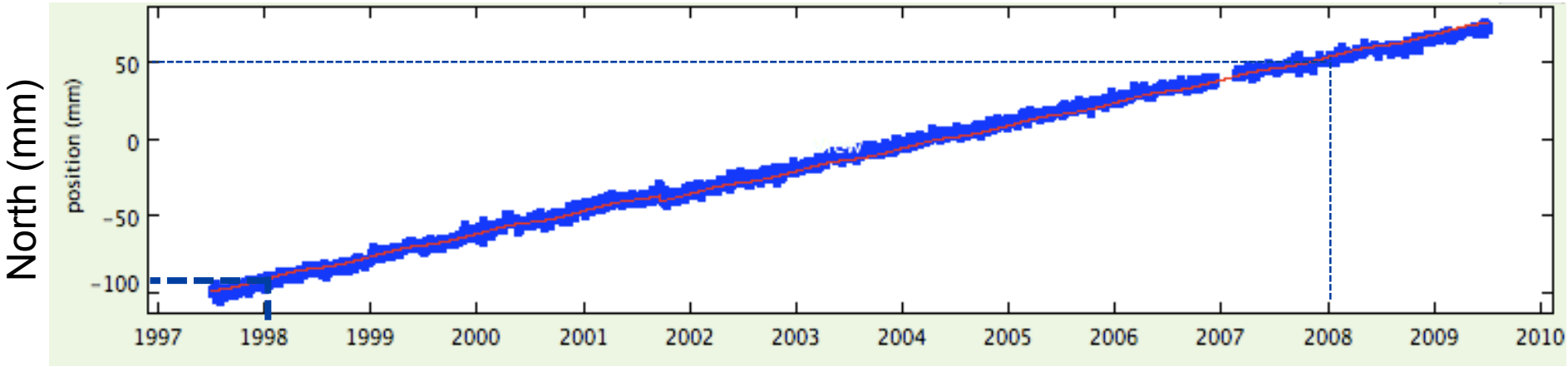
How quickly is HOFN moving in the north - south direction?



Let's look at 1998 and 2008.

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

GPS monument HOFN: north



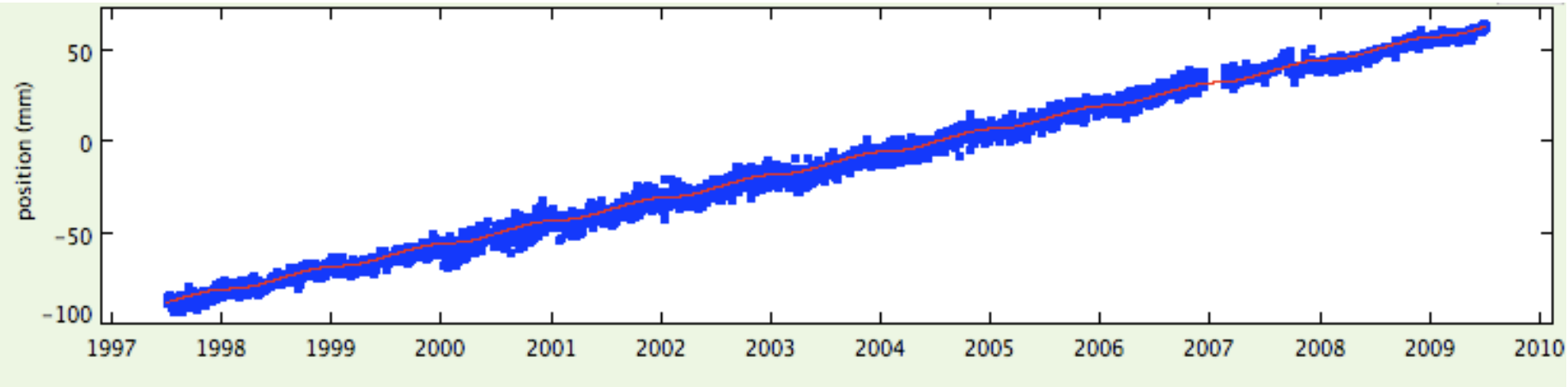
Average position on 1/1/2008 = 50 mm
Average position on 1/1/1998 = -98 mm

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

GPS monument HOFN: east

How quickly is HOFN moving in the east - west direction?



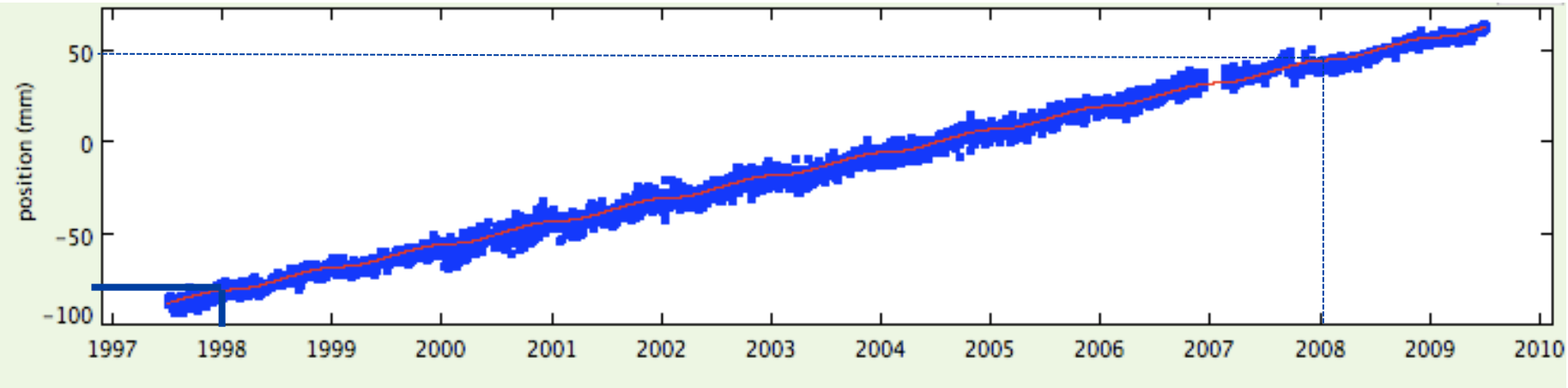
Average position on 1/1/2008 = _____ mm
Average position on 1/1/1998 = _____ mm

Speed of HOFN east = ___ mm/10 years
= ____ /yr to the (east or west)

GPS monument HOFN: east

How quickly is HOFN moving in the east - west direction?

East (mm)



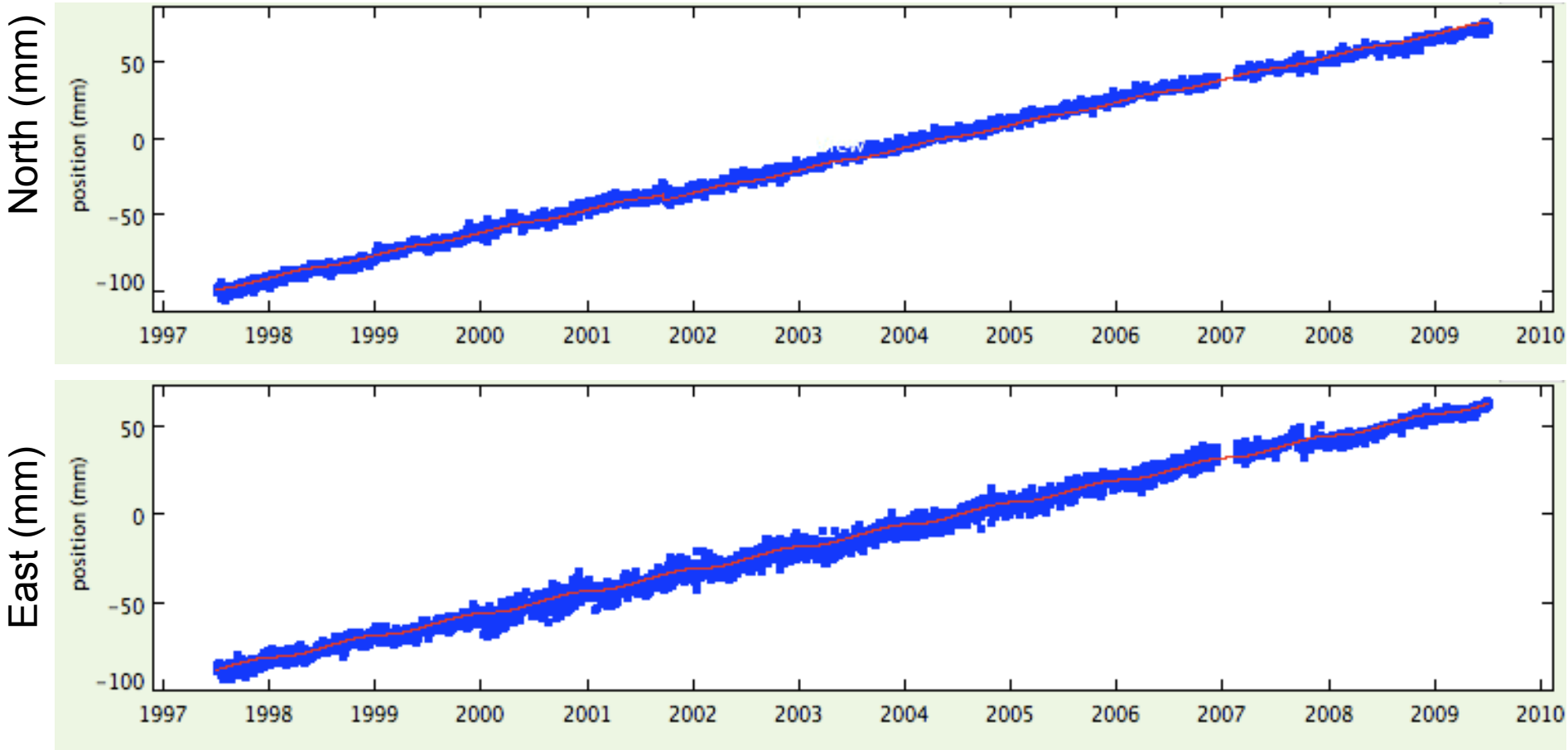
Average position on 1/1/2008 = 50 mm
Average position on 1/1/1998 = -80 mm

Speed of HOFN east = 130 mm/10 years
= 13 mm/yr to the east for HOFN

GPS monument HOFN

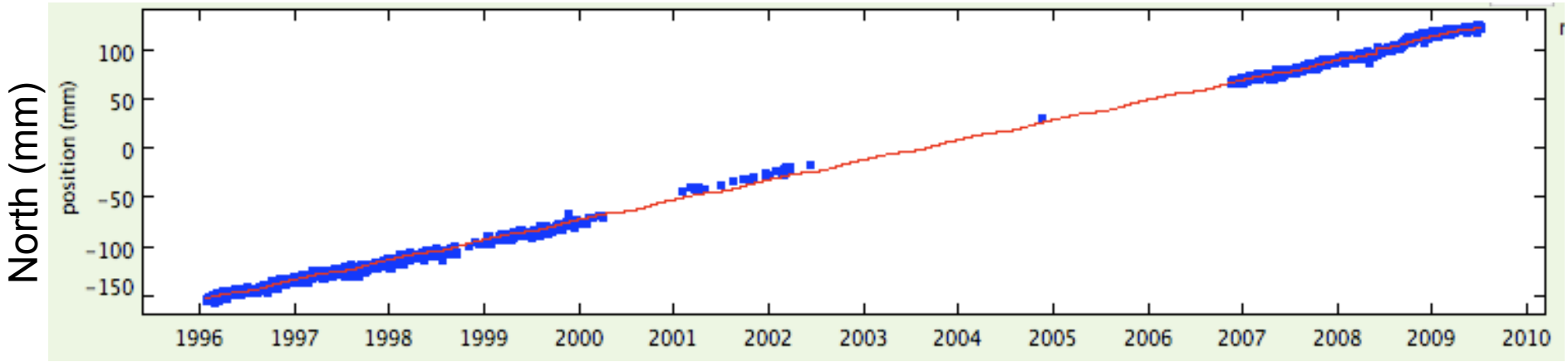
What direction is Monument HOFN moving?

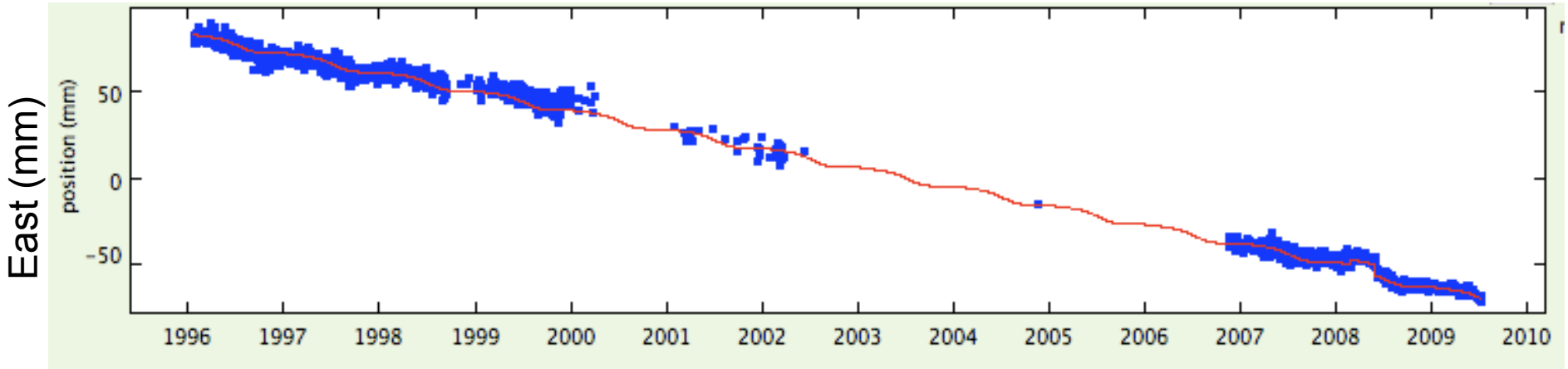
a) north only
b) northwest
c) northeast
d) southwest



GPS monument REYK

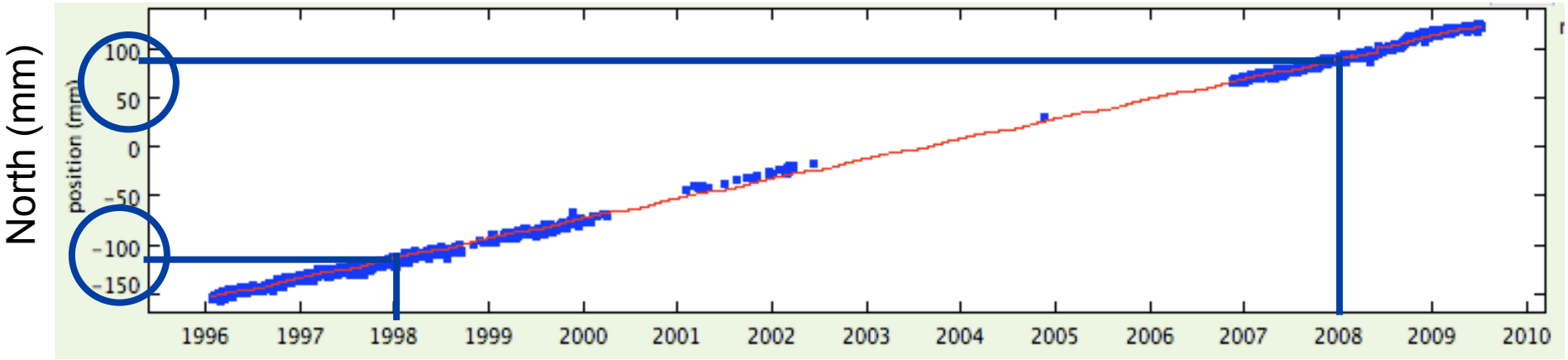
Think, then discuss with your neighbor: What direction is monument REYK moving? About how fast?





GPS monument REYK

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

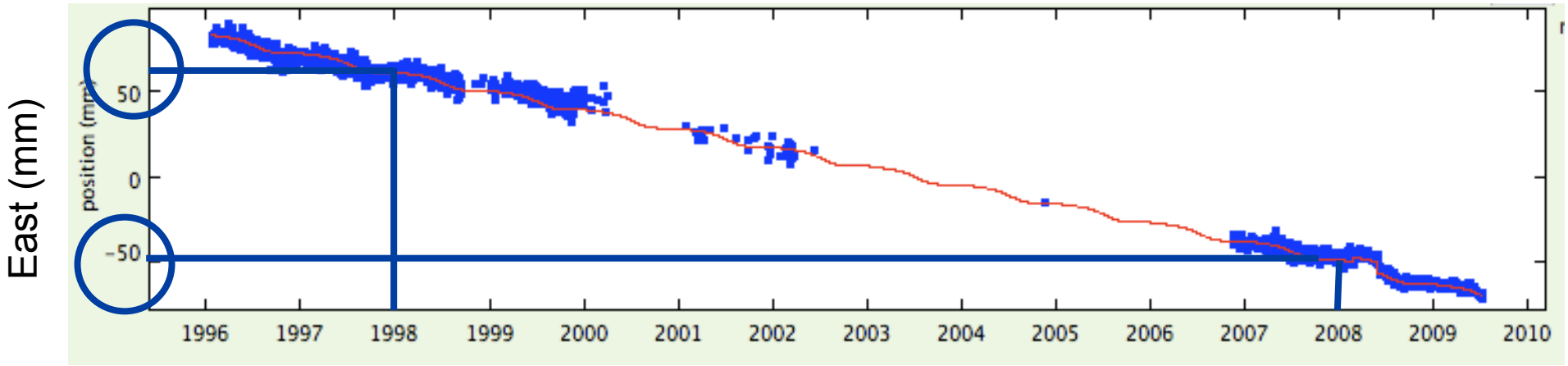


Average position on 1/1/2008 = 90 mm
Average position on 1/1/1998 = -115 mm

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

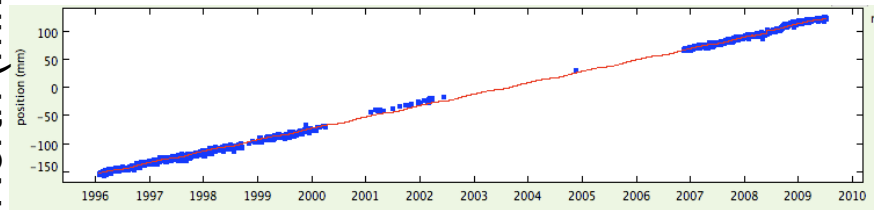
Displaying velocities on a map

There must be an easier way to show this!

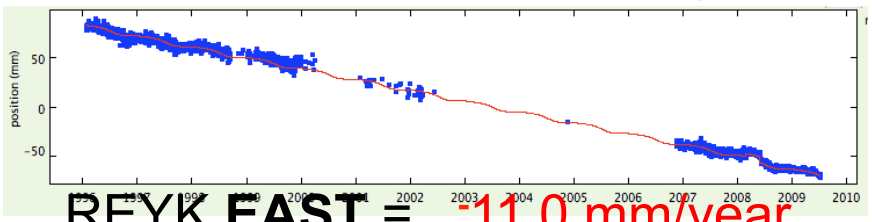
North: 20.5 mm/yr
East: -11 mm/yr

North: 15 mm/yr
East: 13 mm/yr

REYK

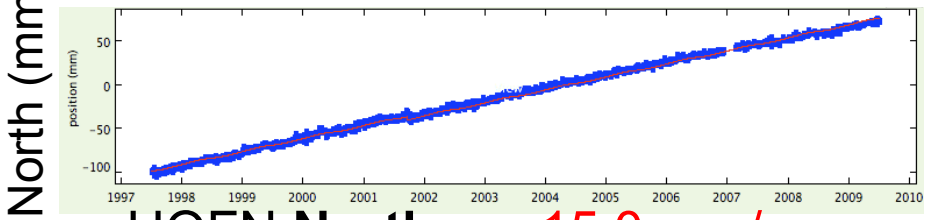


REYK **North** = 20.5 mm/year

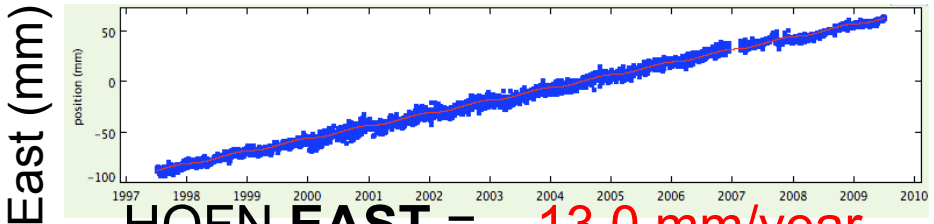


REYK **EAST** = -11.0 mm/year

HOFN



HOFN **North** = 15.0 mm/year



HOFN **EAST** = 13.0 mm/year

Are REYK and HOFN moving…

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

North: 20.5 mm/yr
East: -11 mm/yr

REYK

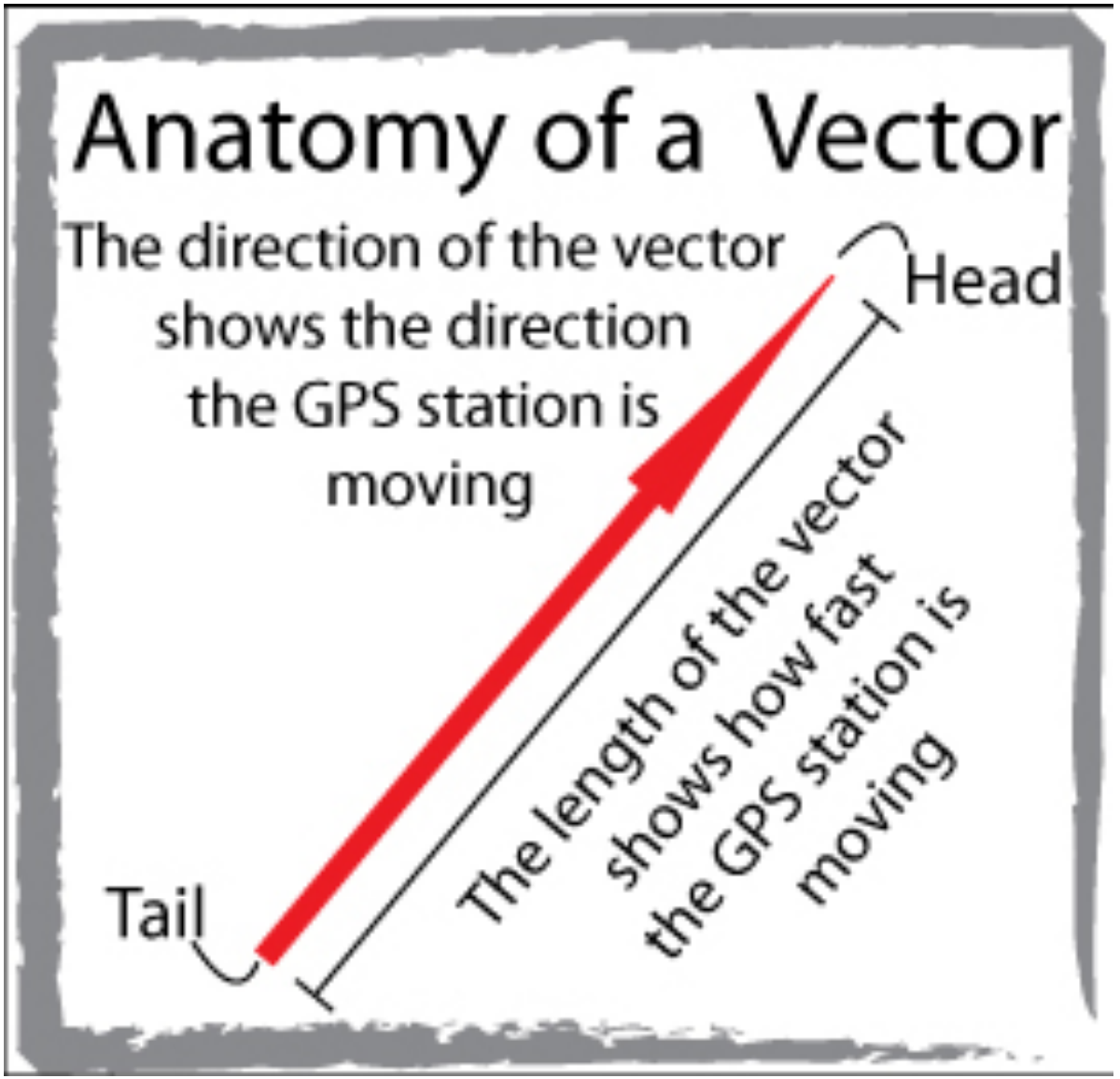
HOFN

North: 15 mm/yr
East: 13 mm/yr

Mimic these motions with your GPS models.

What is a vector?

A vector shows speed and direction.



Graph paper as a map

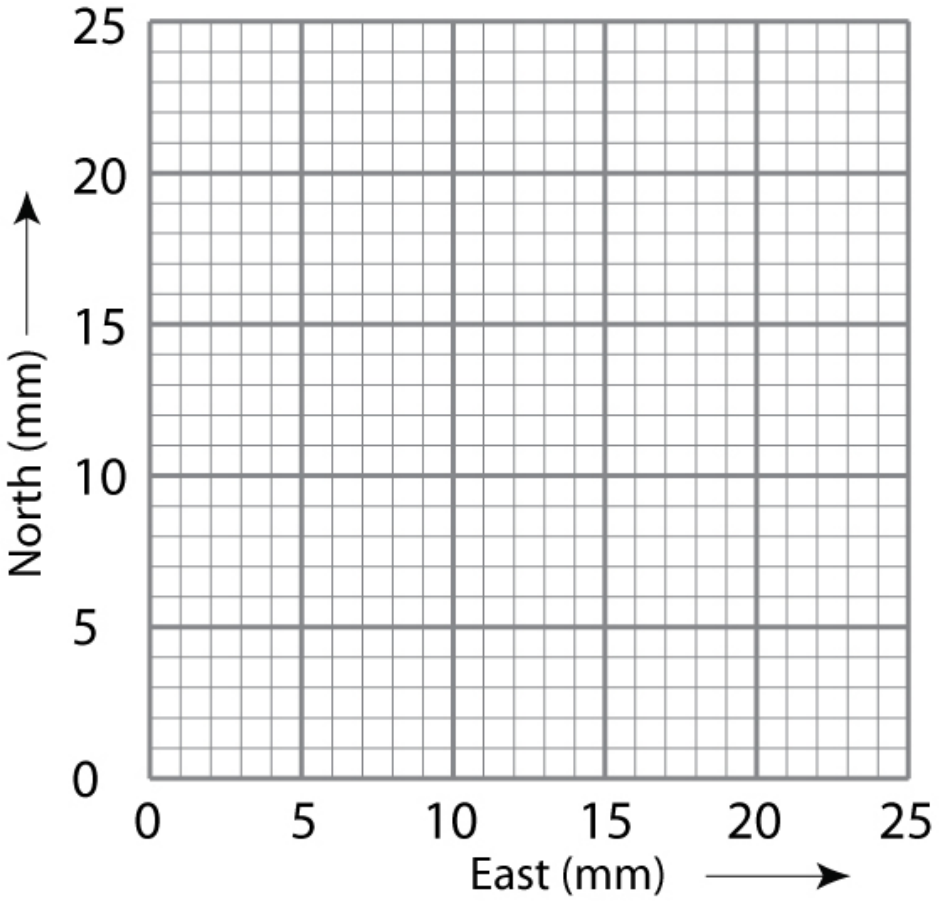
Each axis uses the same scale.

X-axis: east in millimeters

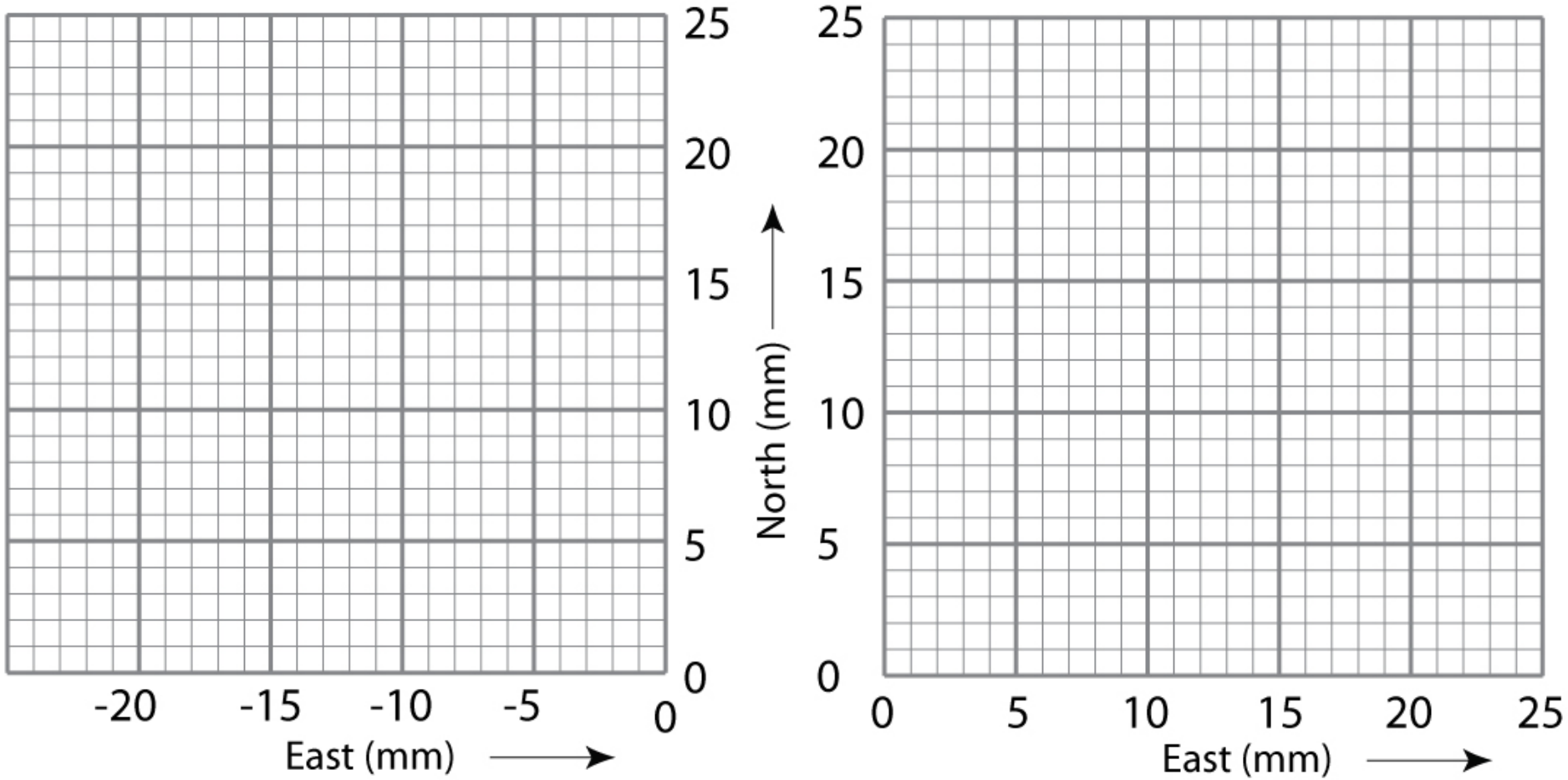
Y-axis: north in millimeters

On your graph paper, each block represents 1 mm.

Where is the origin on this graph paper?

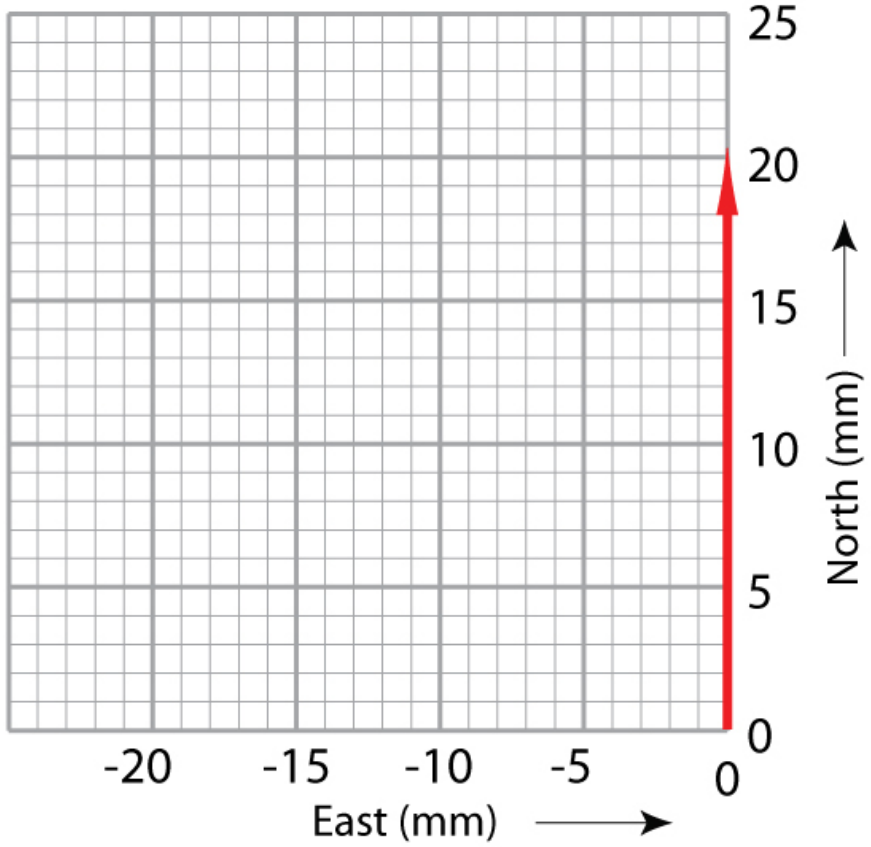


Graph paper as a map



Plotting REYK vectors

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

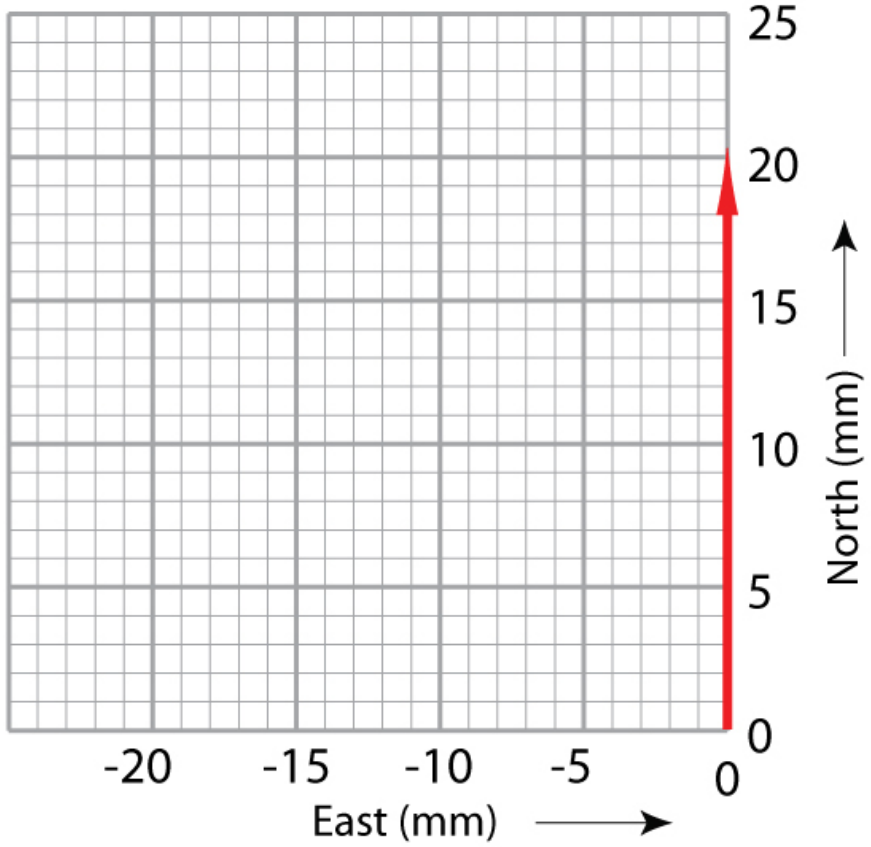


Plotting REYK vectors

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

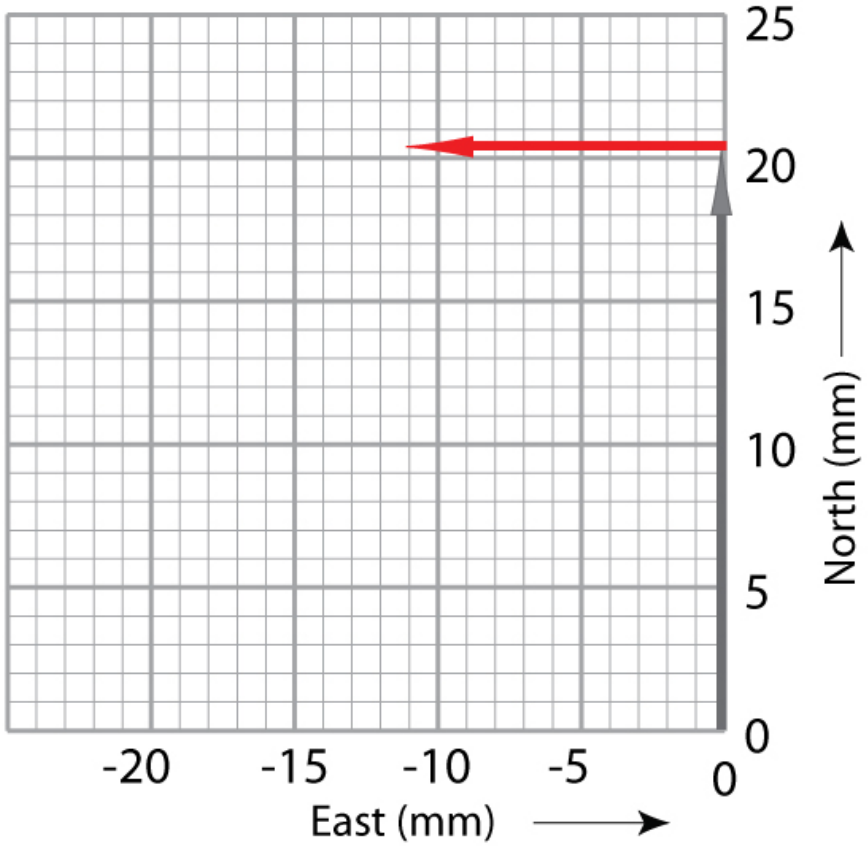
- Draw a vector arrow 20.5 blocks along the north axis.



Plotting REYK vectors

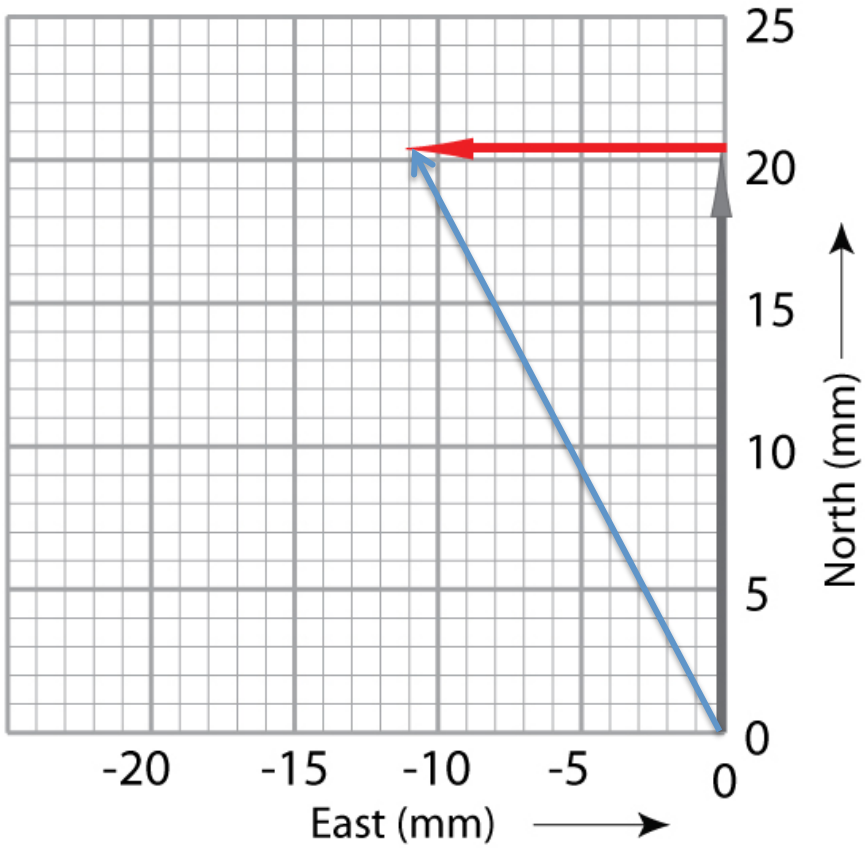
Step 2. Place the tail of the east vector at the head of the north vector.

Draw the vector -11.0 blocks (mm) beginning at the head of the north arrow

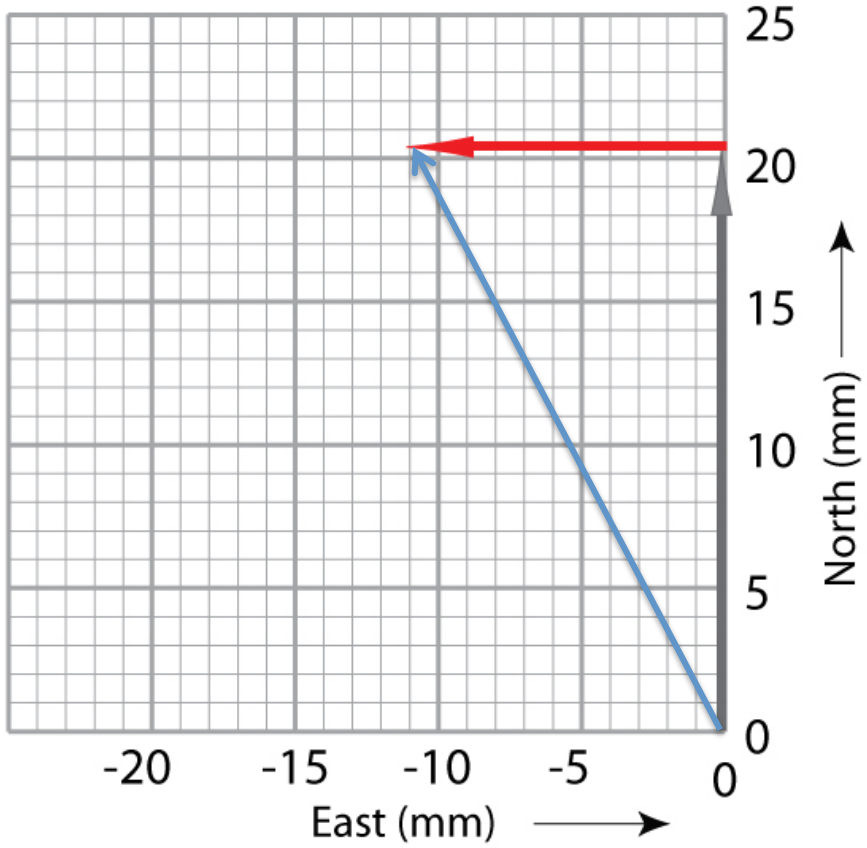


Adding REYK vectors

Step 3. Draw the total vector from the tail of the north vector to the arrowhead of the east vector. This new vector is the sum of the north and east vectors.



Adding vectors

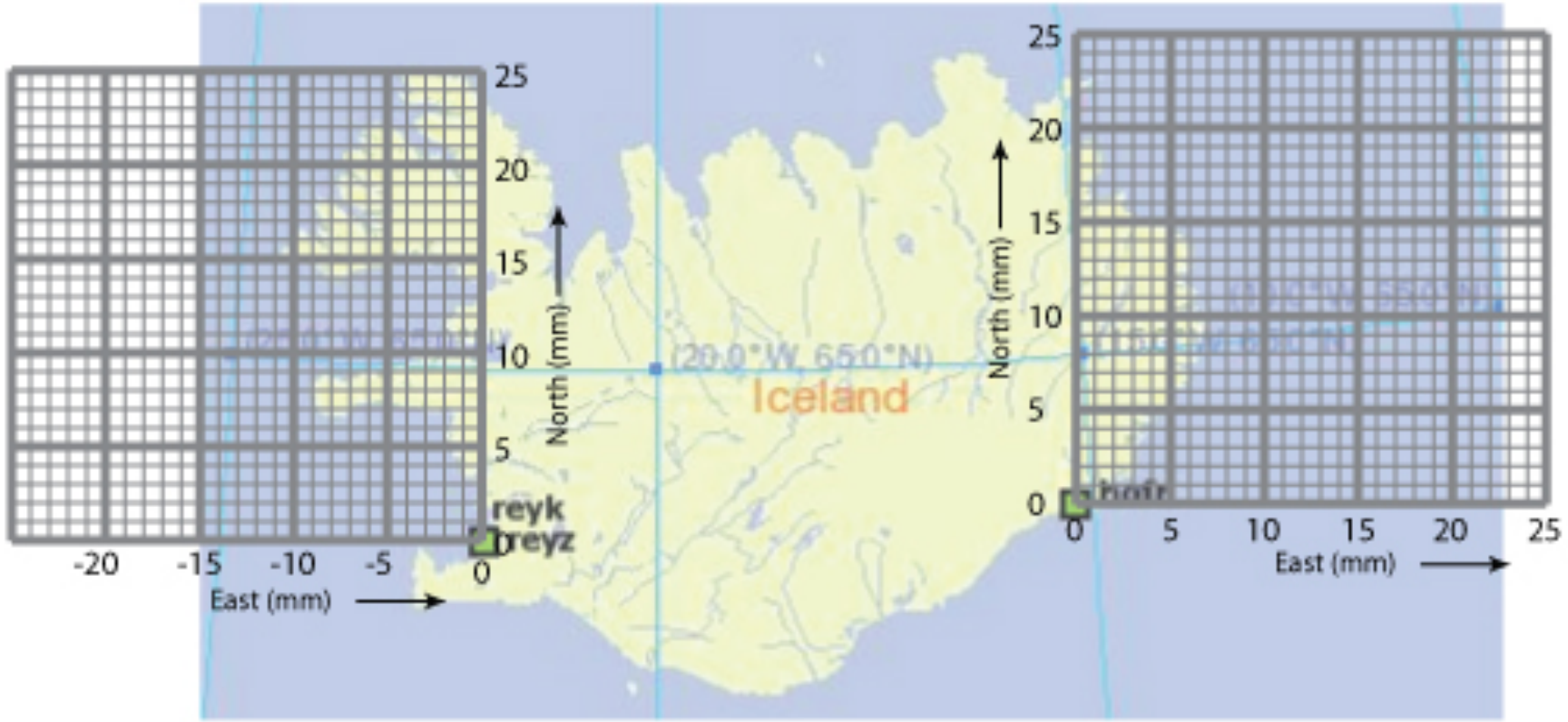


Or, use the Pythagorean theorem to add vectors.

GPS monument moves at: $\sqrt{(x^2 + y^2)}$ =

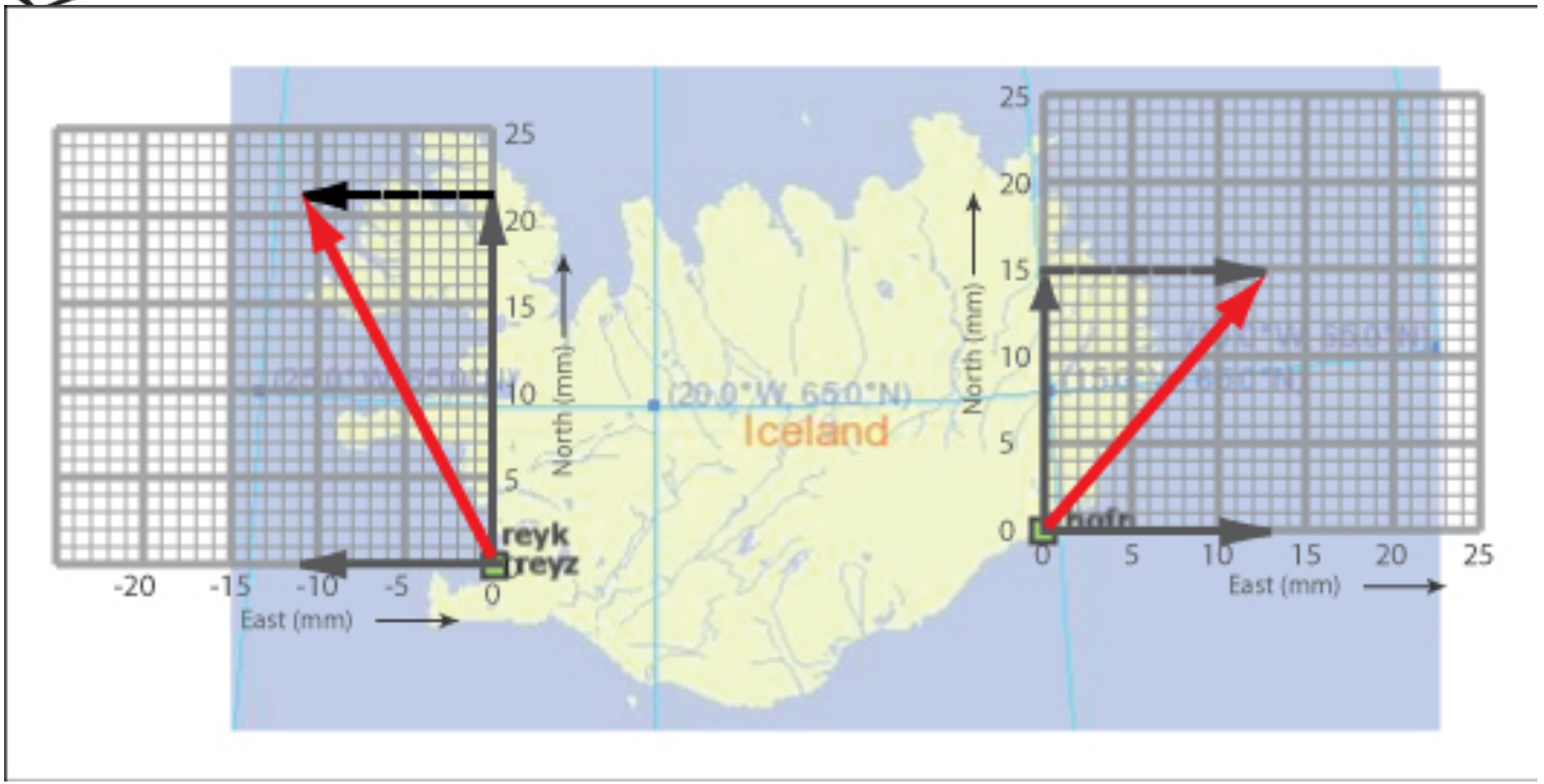
____ mm/yr to the ____

Mapping vectors



1. Graph the vectors for HOFN and REYK.
2. Answer questions in “Thinking through the data and maps.”

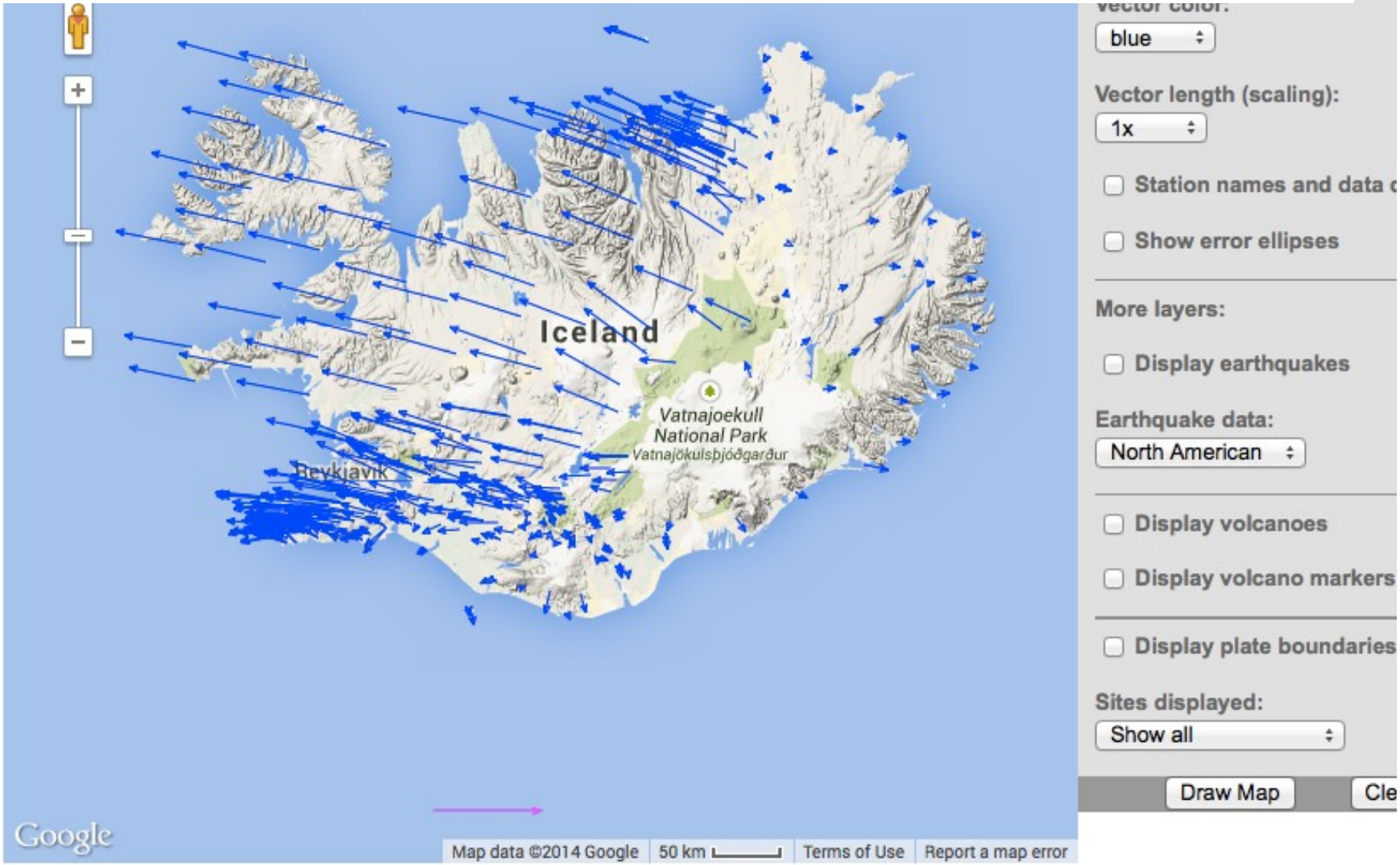
What is happening to Iceland?



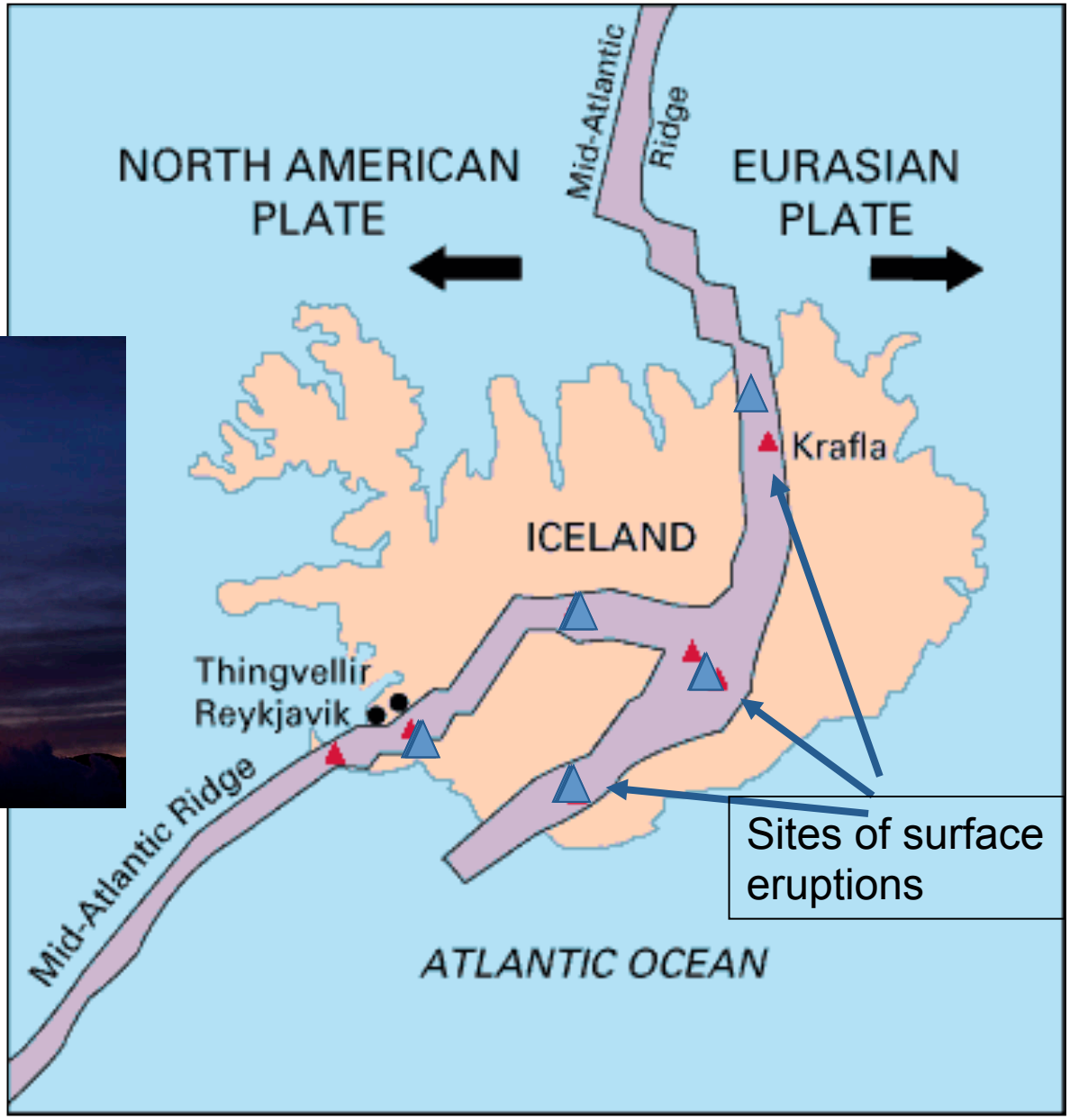
Extra credit – How is REYK moving compared to HOFN ? (pretend HOFN is not moving)

What is happening to Iceland?

Extra credit – How is REYK moving compared to HOFN ? (pretend HOFN is not moving)

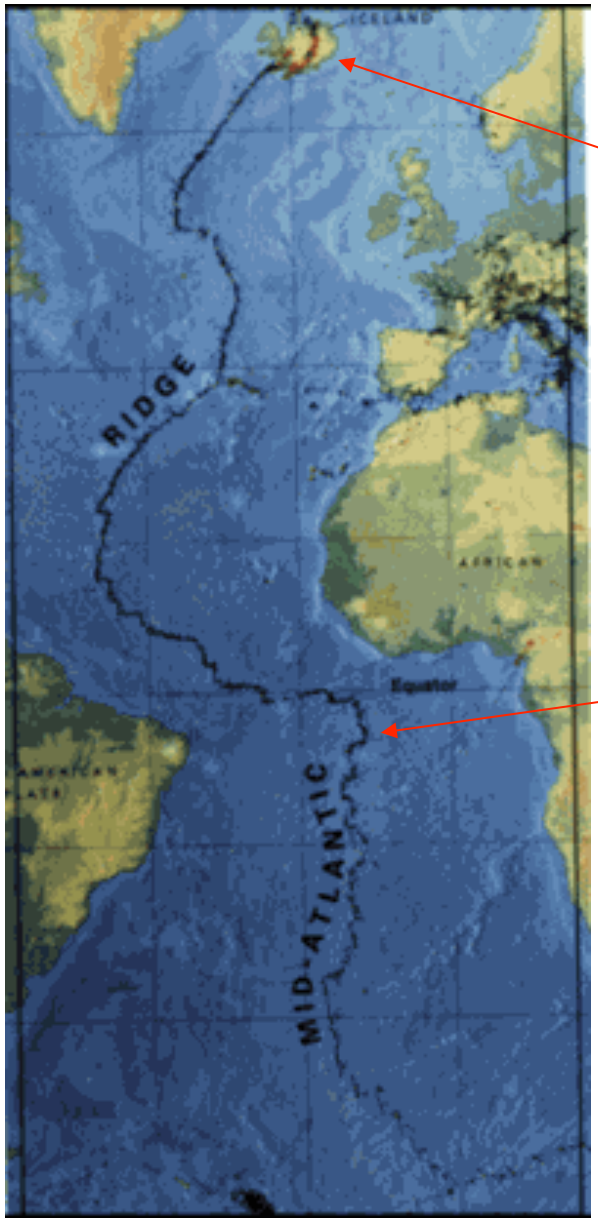


Rifting


NORTH AMERICAN PLATE
Mid-Atlantic Ridge
EURASIAN PLATE
Krafla
ICELAND
Thingvellir
Reykjavik
Mid-Atlantic Ridge
Sites of surface eruptions
ATLANTIC OCEAN

Fissures opening

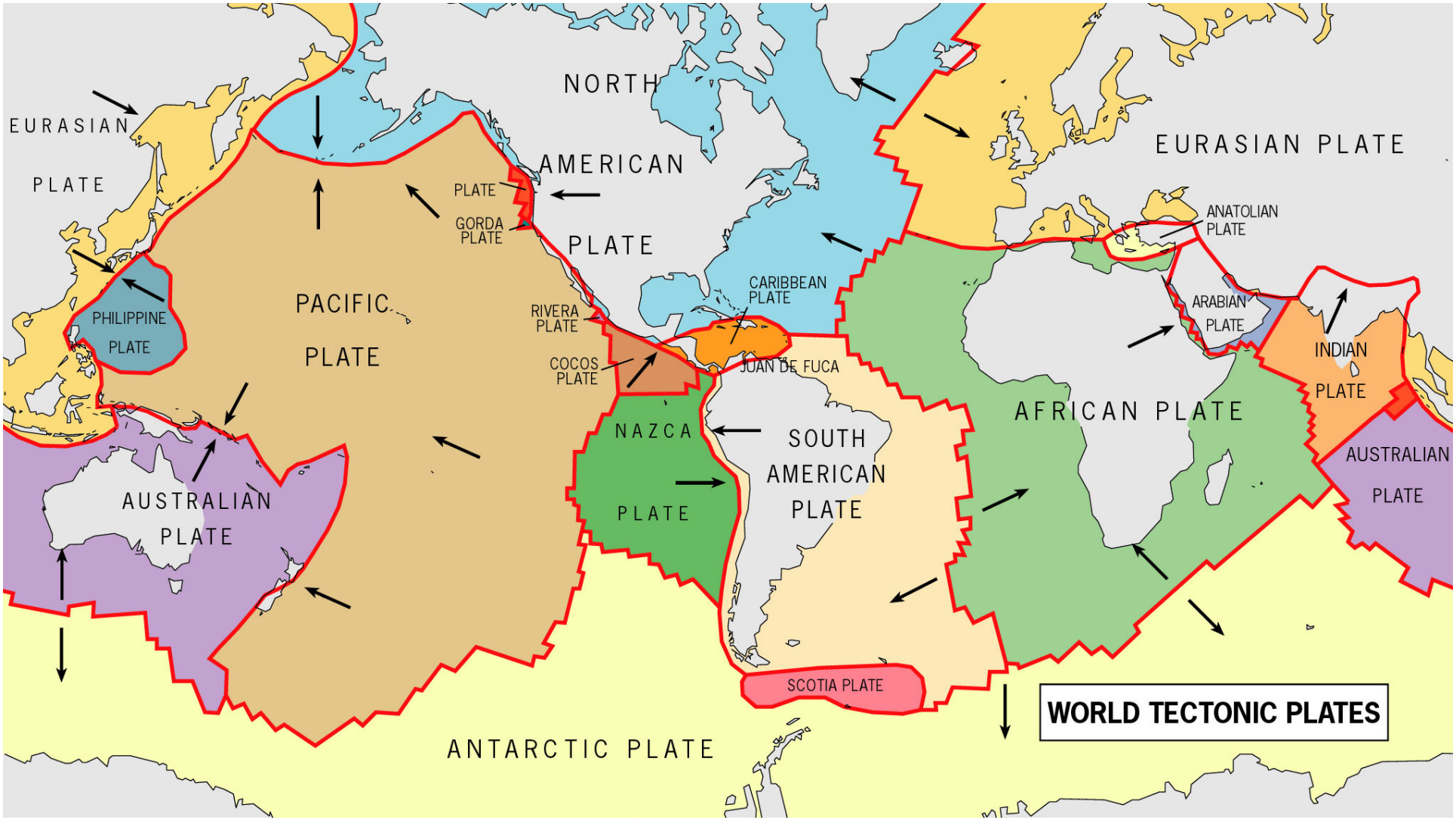
Mid-Atlantic Ridge



Iceland

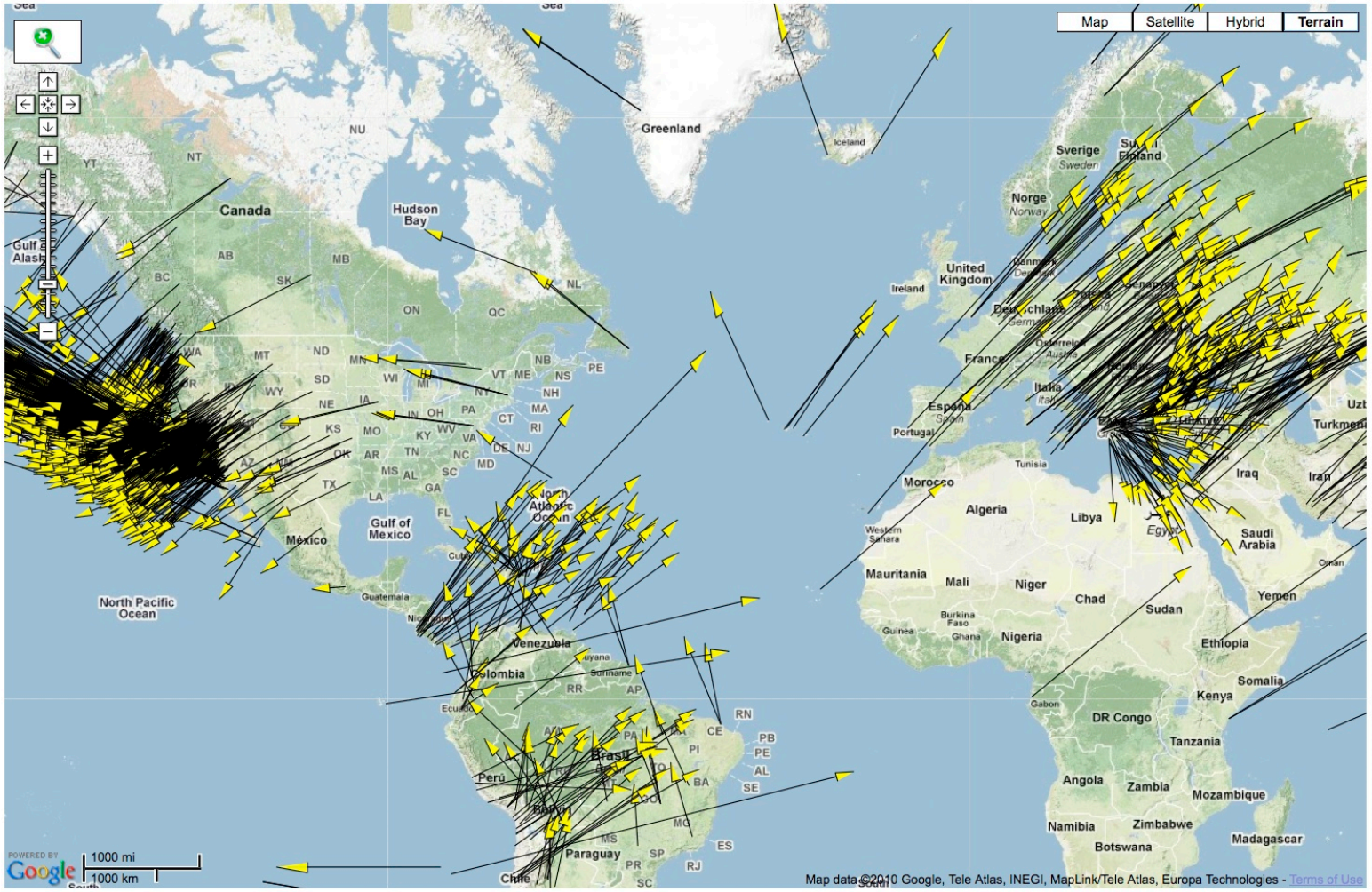
Mid-Atlantic Ridge

East Africa Mystery - worldview



Mapping plate movement

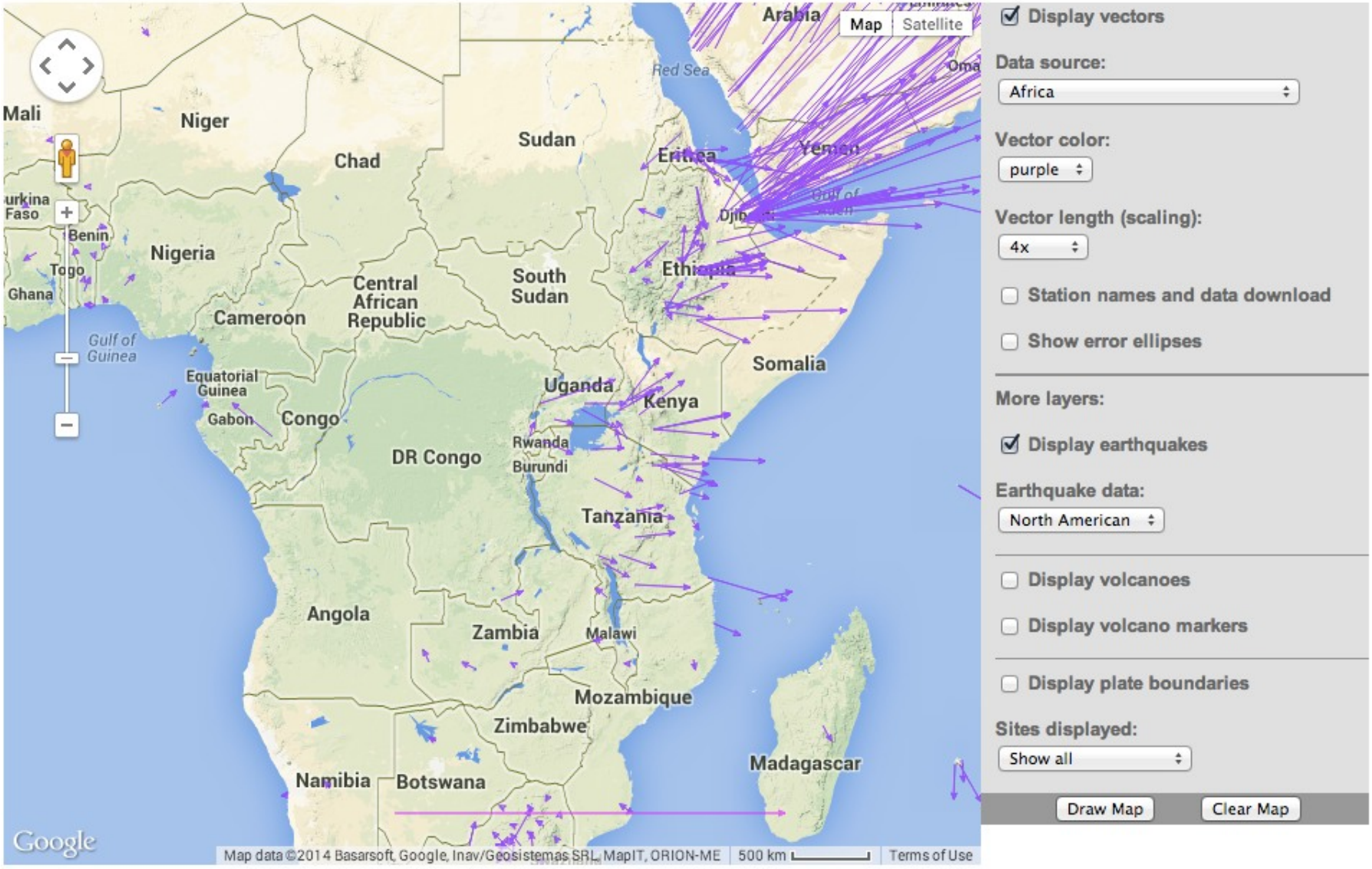
UNAVCO GPS Velocity Viewer * GPS velocity vectors show how the surface of the Earth is moving.



GPS_vectors_after_rotation_NNR.dat Velocity vectors

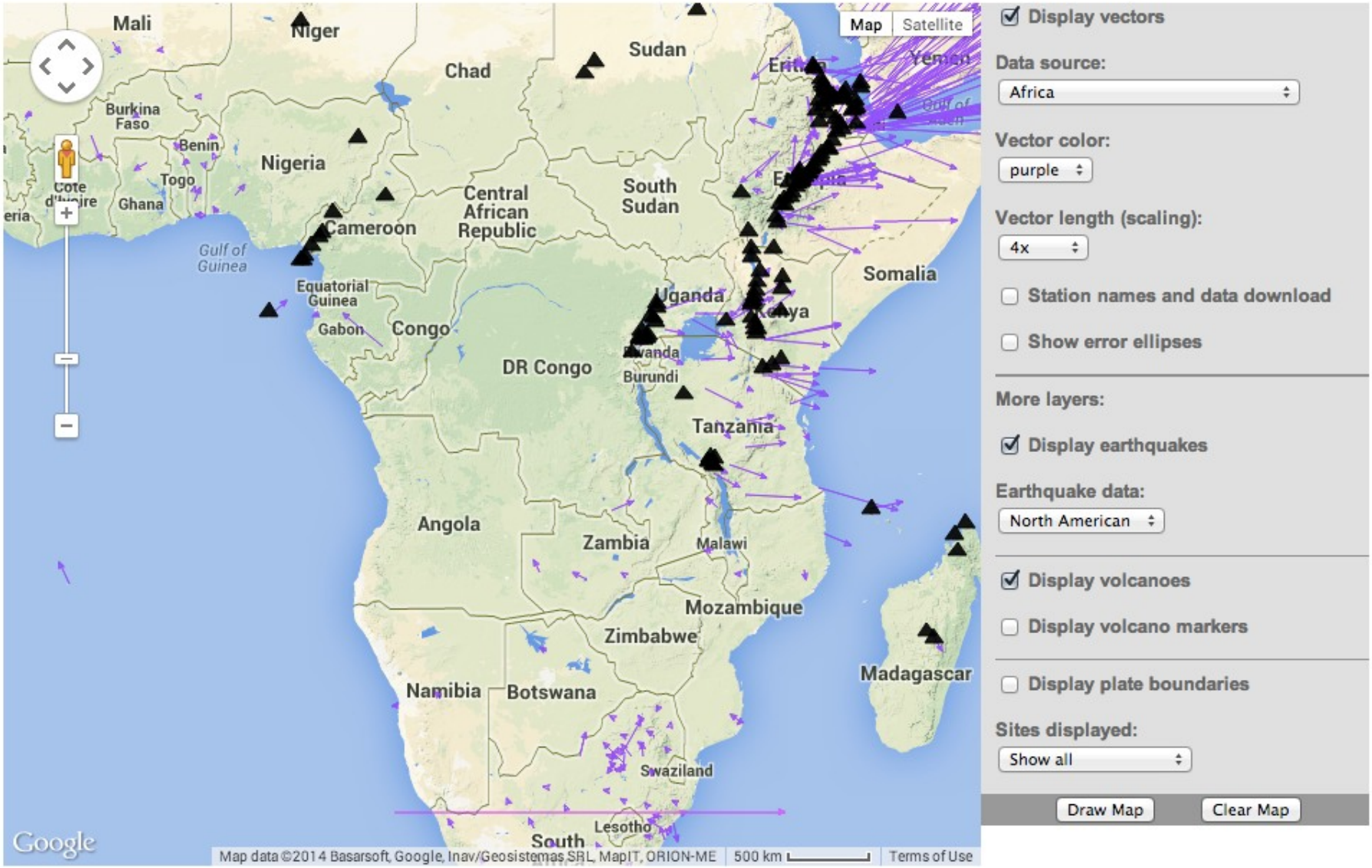
East Africa Mystery - revisited

GPS Velocity Viewer

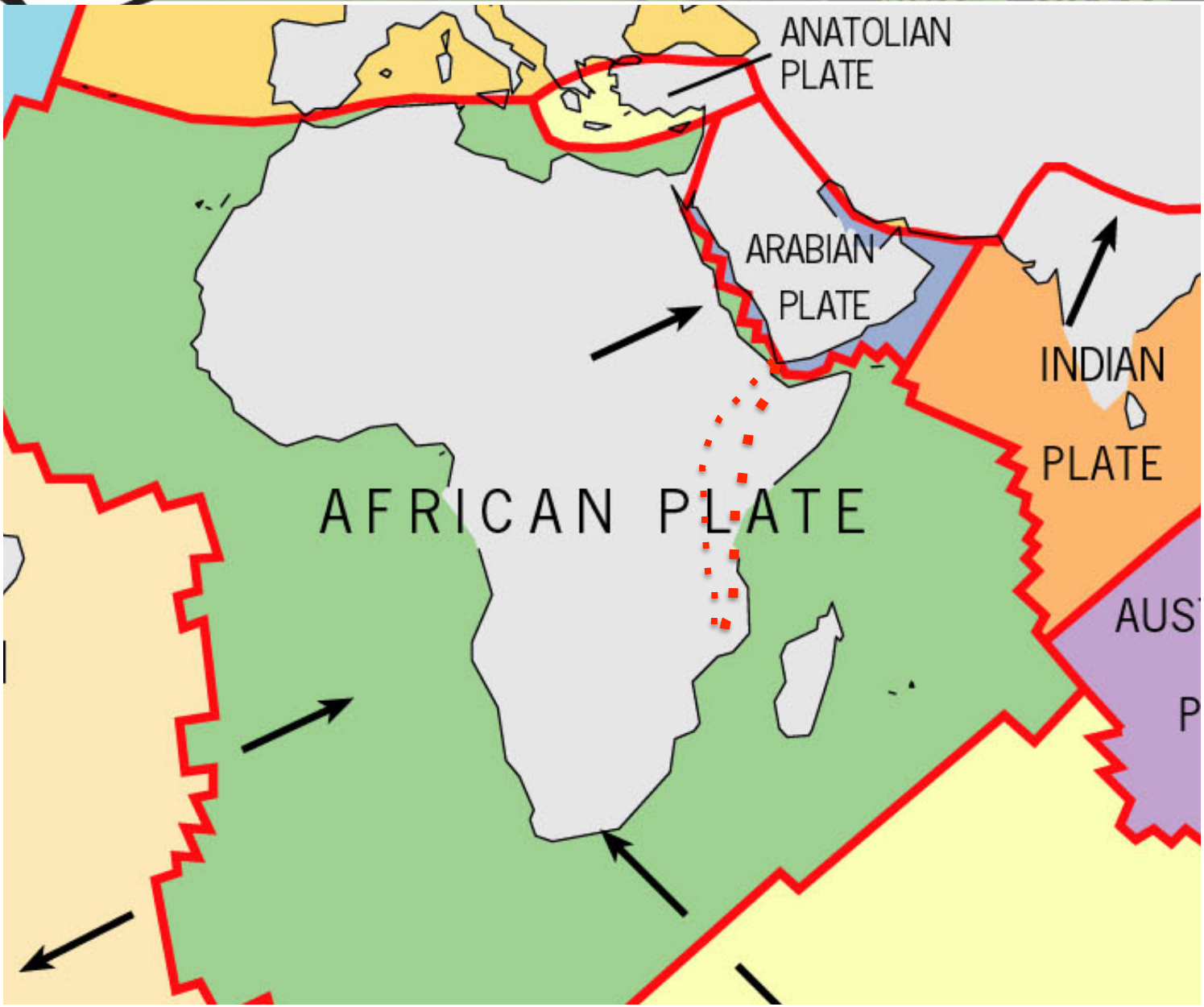


East Africa Mystery - revisited

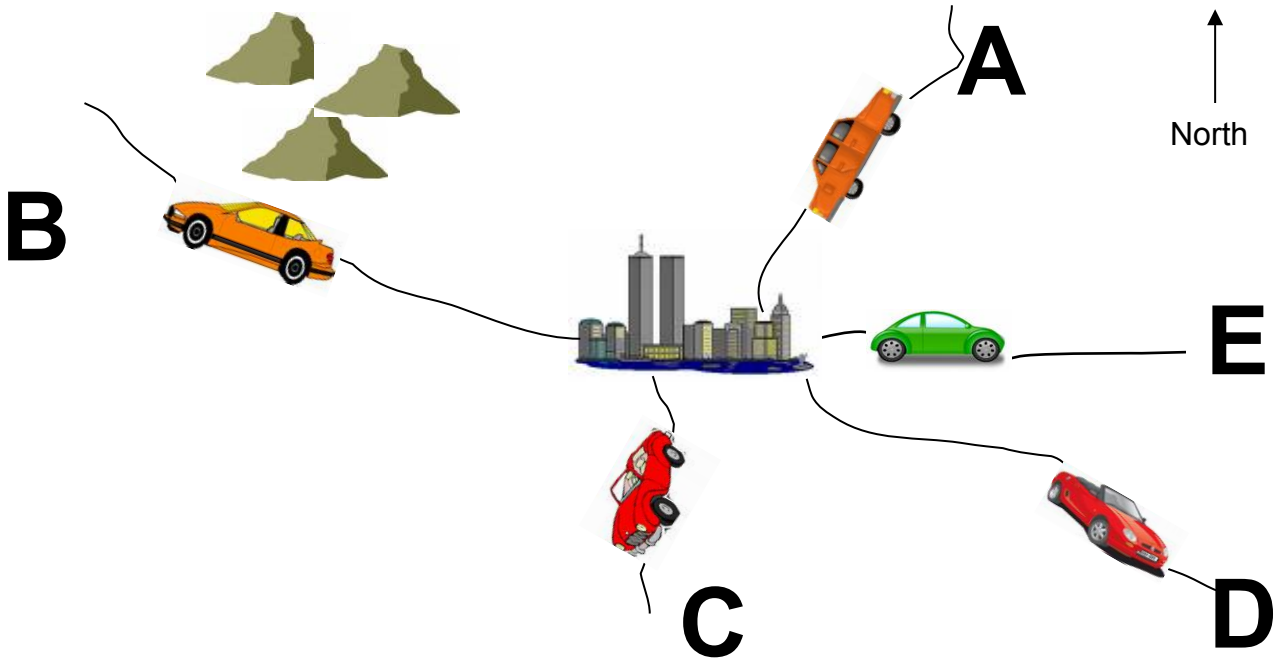
GPS Velocity Viewer



East Africa Mystery - revisited



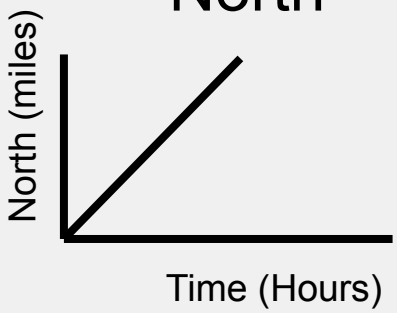
Part 3: Applying knowledge



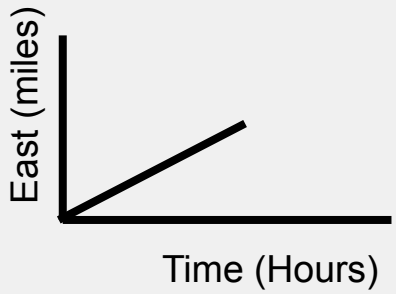
Match cars and graphs

i)

North



East

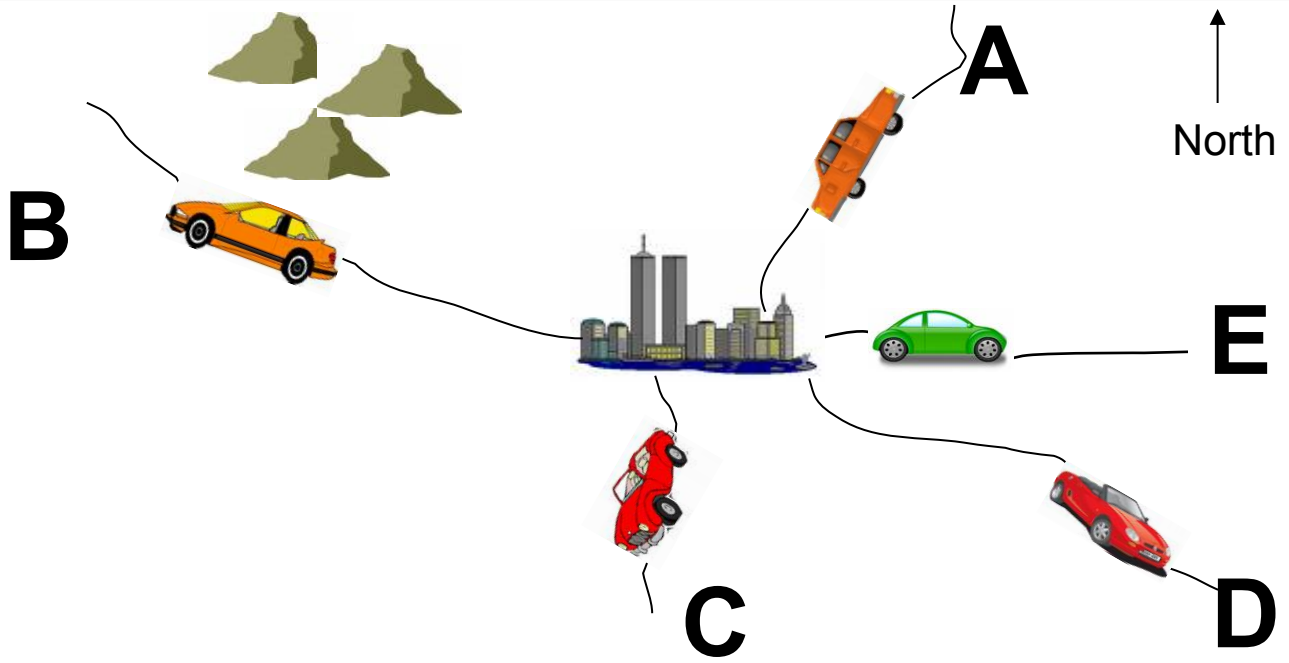


What direction?

_____

Which car?

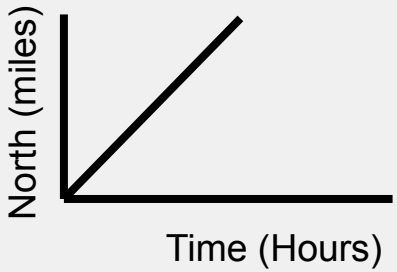
_____



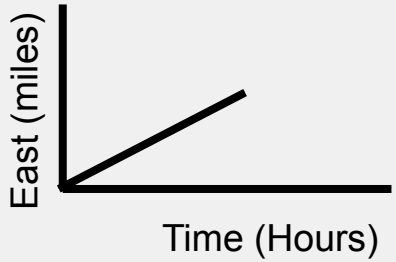
Match cars and graphs

i)

North



East

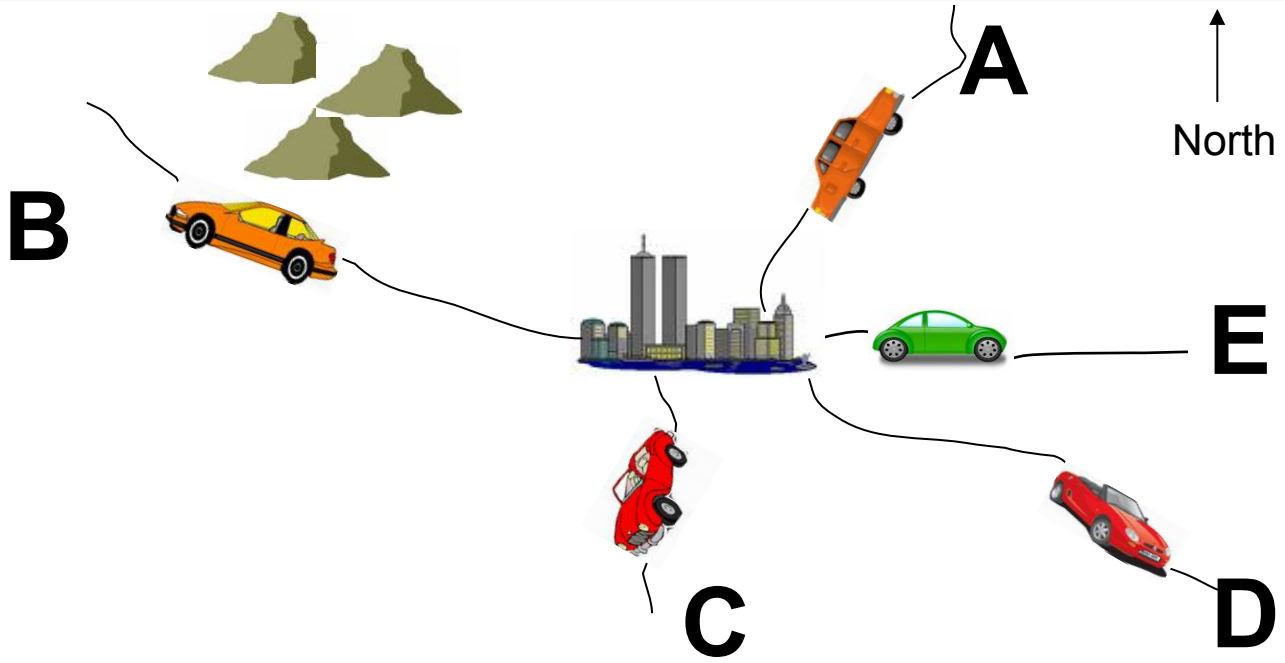


What direction?

North-Northeast

Which car?

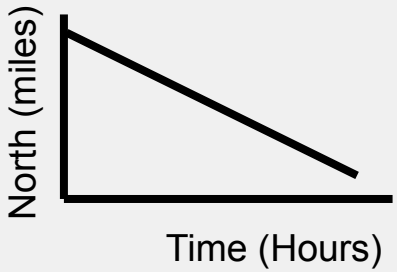
Car A



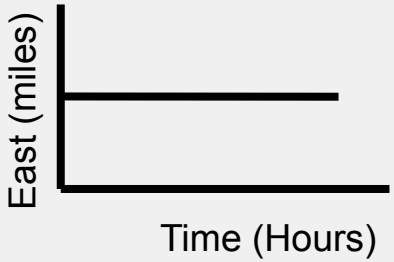
Match cars and graphs

ii)

North

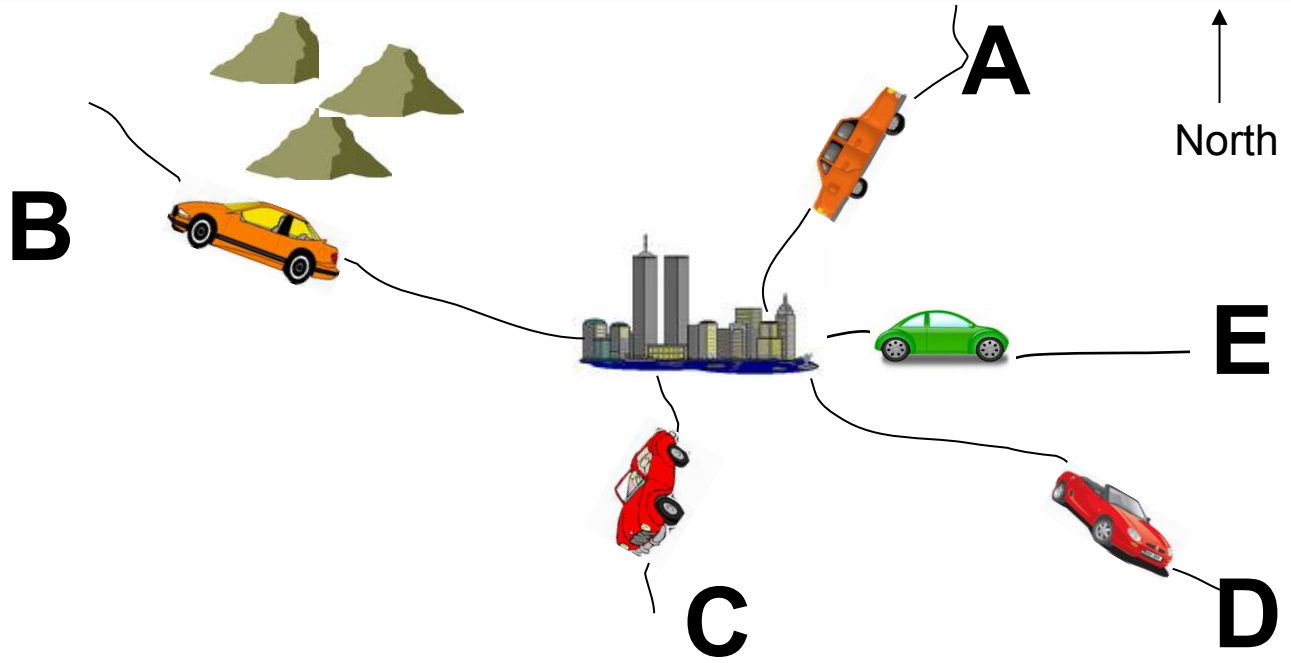


East



What direction?

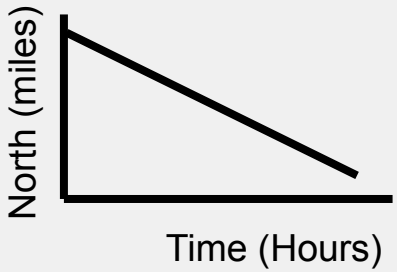
Which car?



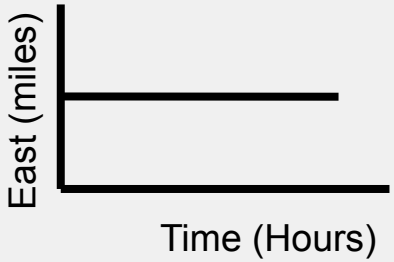
Match cars and graphs

ii)

North



East

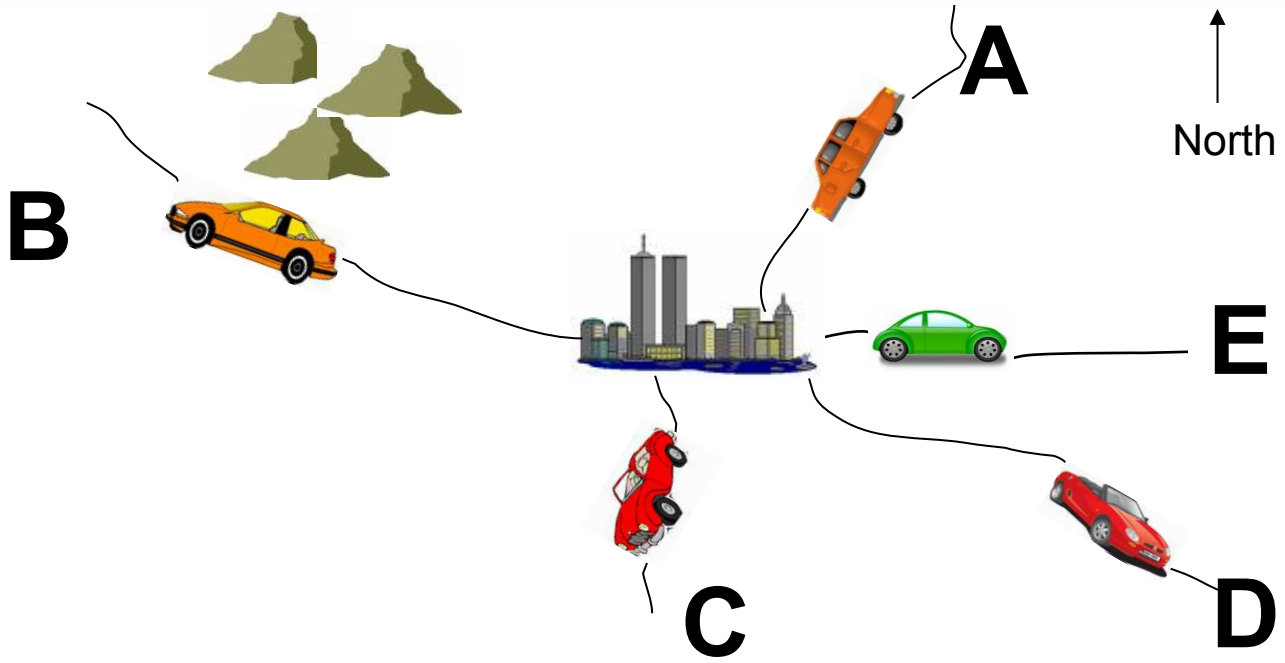


What direction?

South

Which car?

Car C

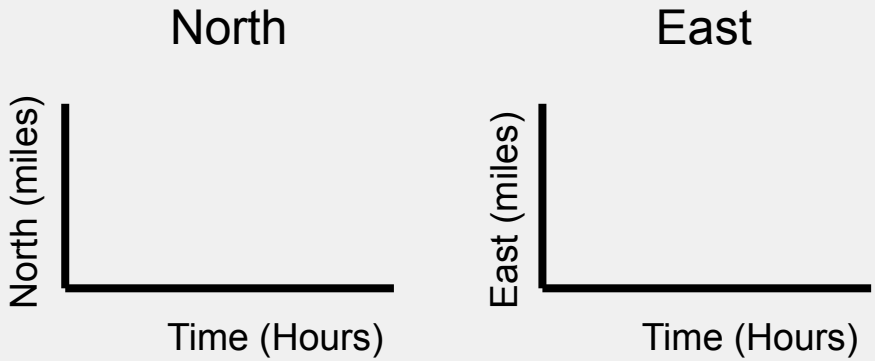


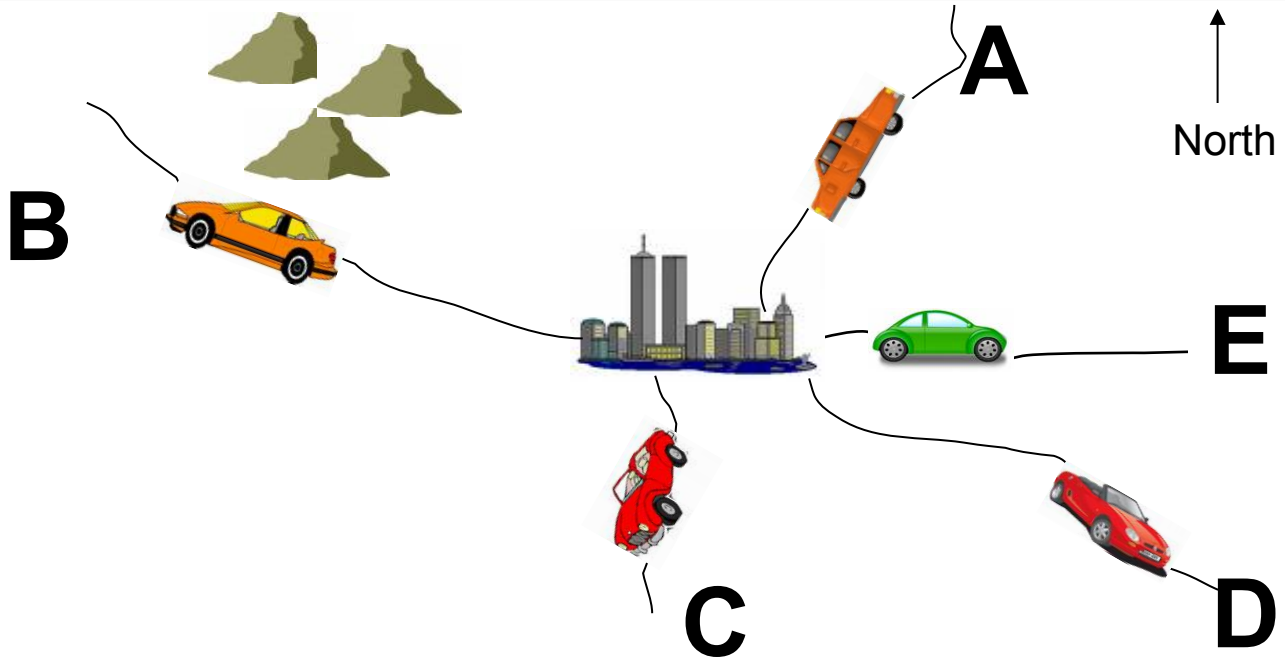
What direction is car D moving?

v) What direction is Car D moving?

_____

Draw the north and east graphs

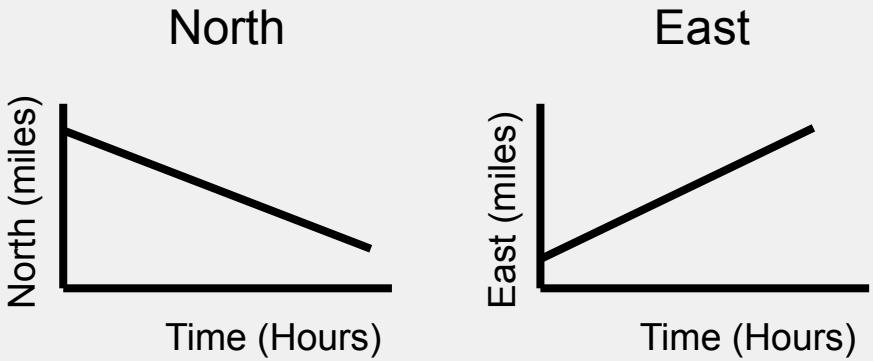




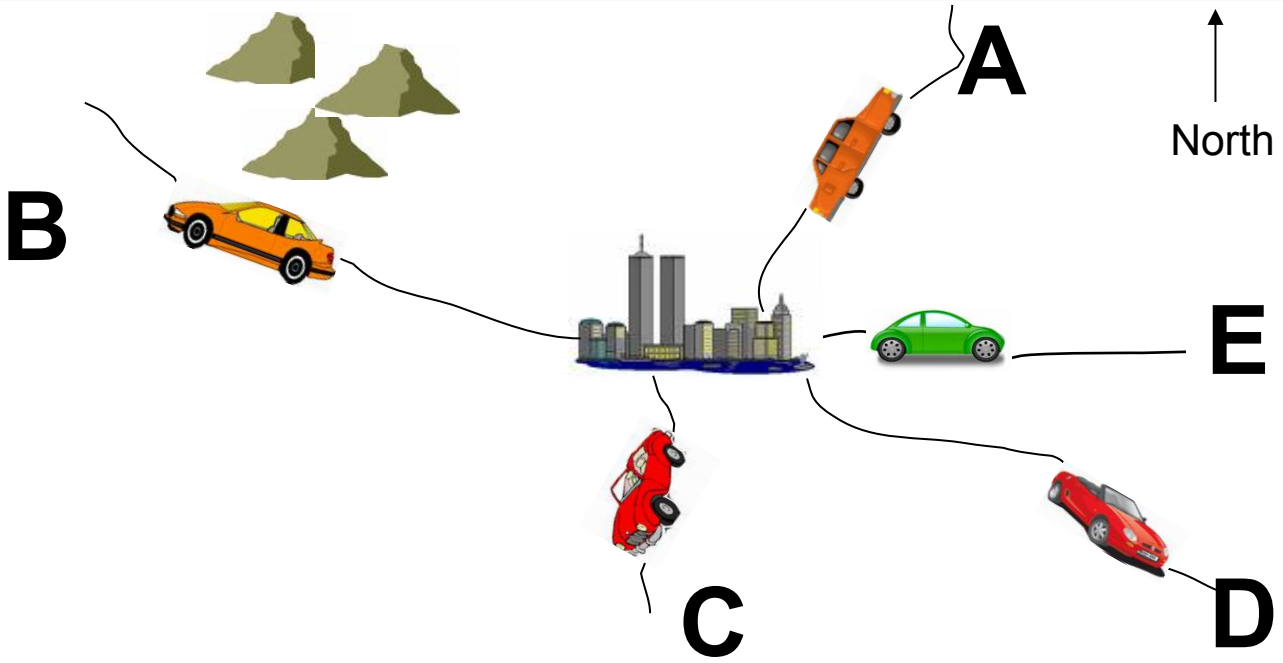
What direction is car D moving?

v) What direction is Car D moving?

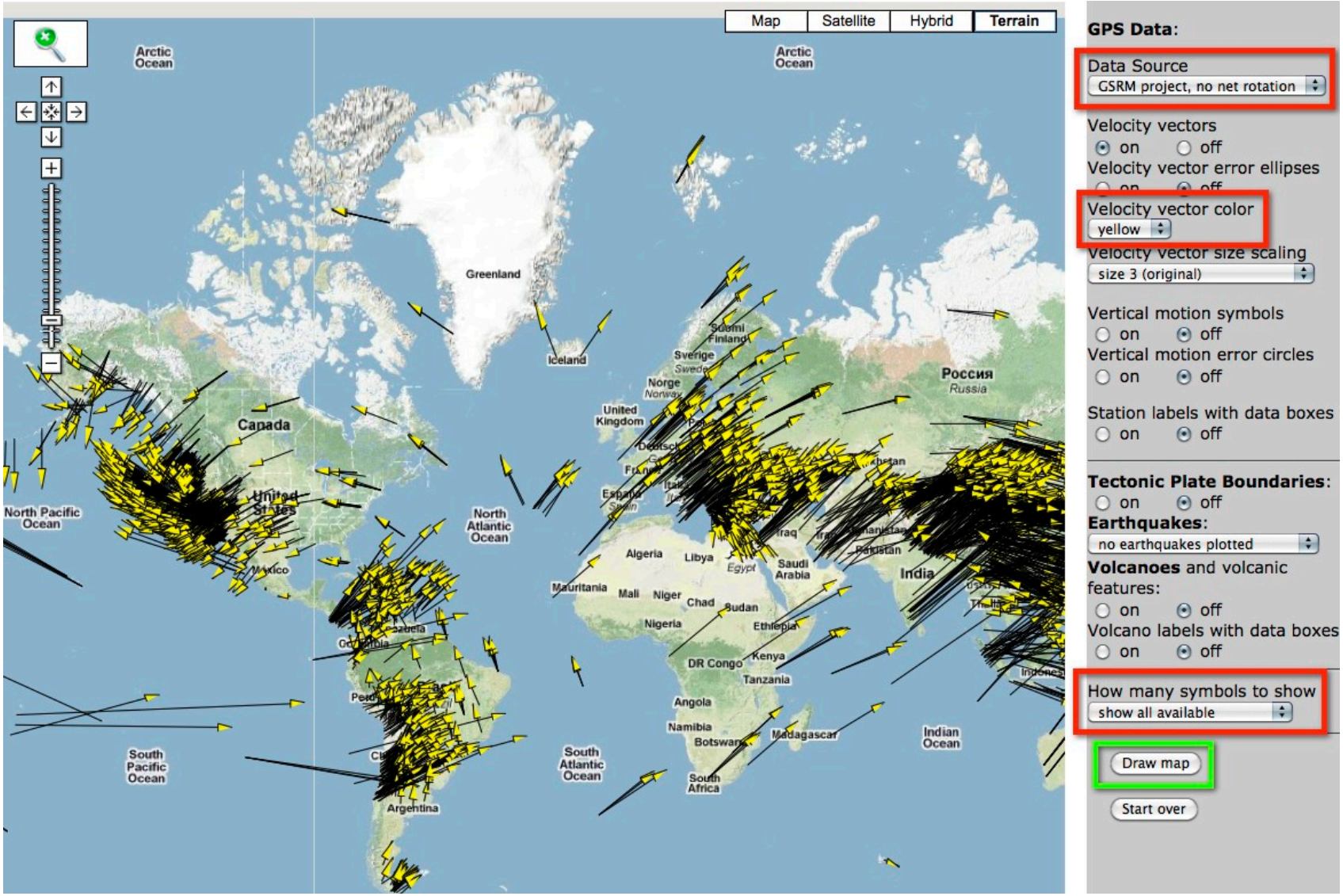
Draw the north and east graphs



Southeast



GPS Velocity Viewer



Data source: Global Strain Rate Map Project ; Reference Frame: **No Net Rotation**
UNAVCO GPS Velocity Viewer:
http://facility.unavco.org/data/maps/GPSVelocityViewer/GPSVelocityViewer.html

Let's explore

- Data for Educators
  - http://www.unavco.org/edu_outreach/data/data.html
- UNAVCO Velocity Viewer
  - http://facility.unavco.org/data/maps/GPSVelocityViewer/GPSVelocityViewer.html

Summary

You should now be able to:

- Describe how GPS works;
- Interpret graphs in a GPS time series plot;
- Determine velocity vectors from GPS time series plots;
- Explain relative plate motions in Iceland; and
- Explore global GPS data.

Questions

Contact:
education @ unavco.org
http://www.unavco.org/

Follow UNAVCO on  

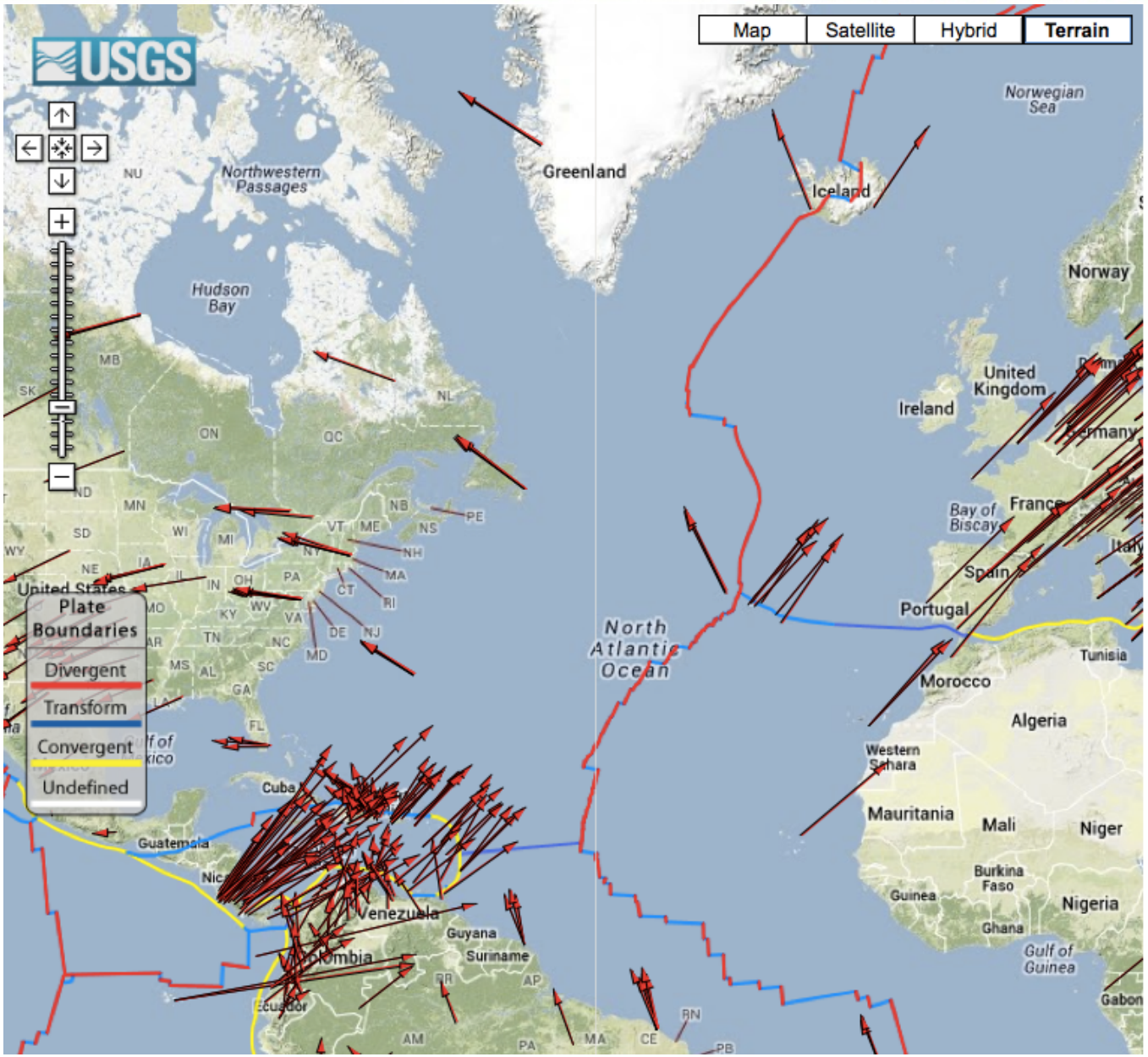
Facebook Twitter

Other tools to explore

- UNAVCO GPS, Earthquake, Volcano Viewer
  - http://geon.unavco.org/unavco/GEV.php

- IRIS Earthquake Browser
  - http://www.iris.washington.edu/servlet/eventserver/map.do

Comparing Plate Movement



GSRM Project GPS Data

Measuring the Crust and Mantle Move

Sources

Ice

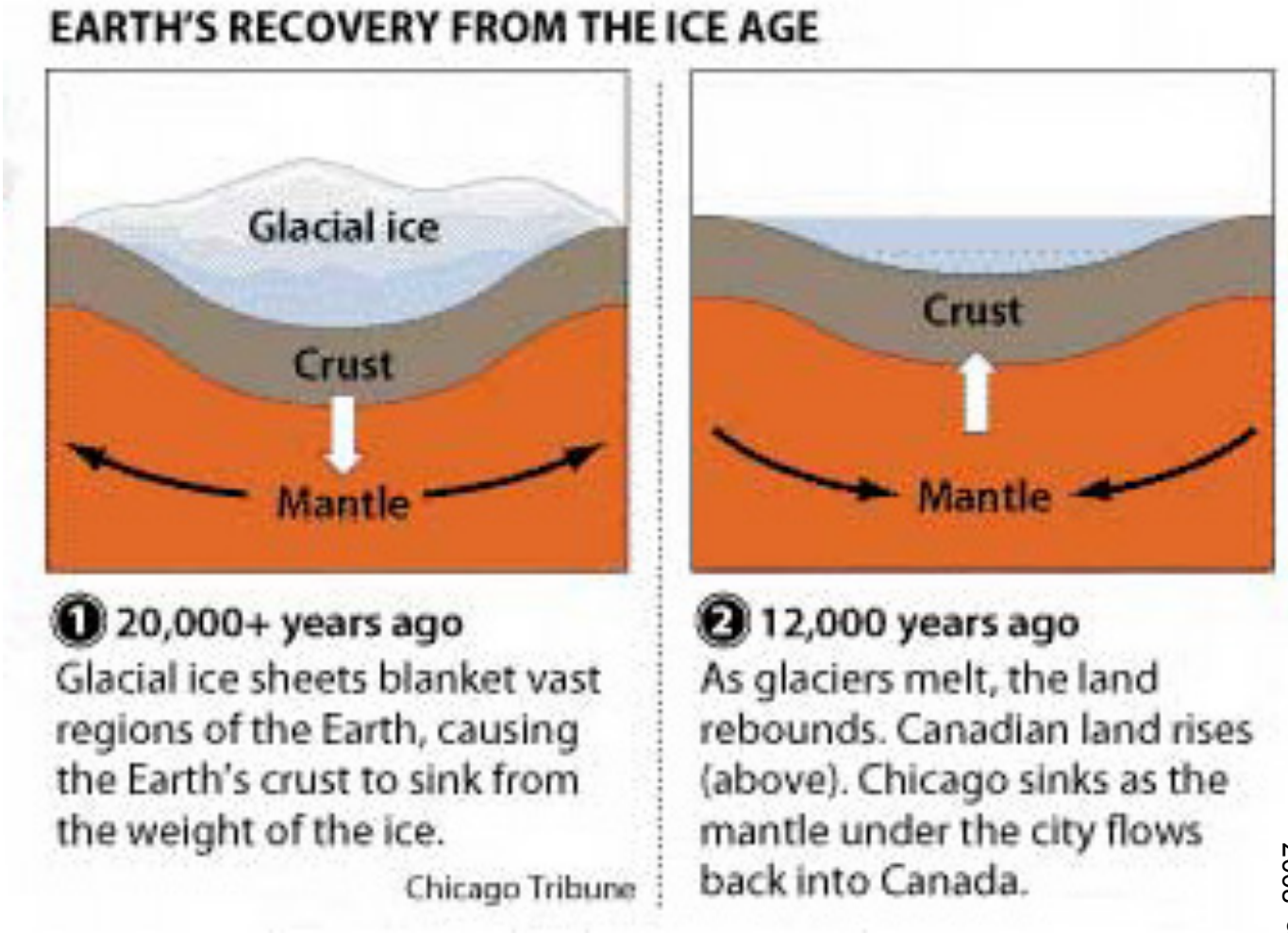
- Ice-age melting
- Present-day melting

Water

- Ocean tides
- Wind-driven surges
- Reservoir depletion

Air

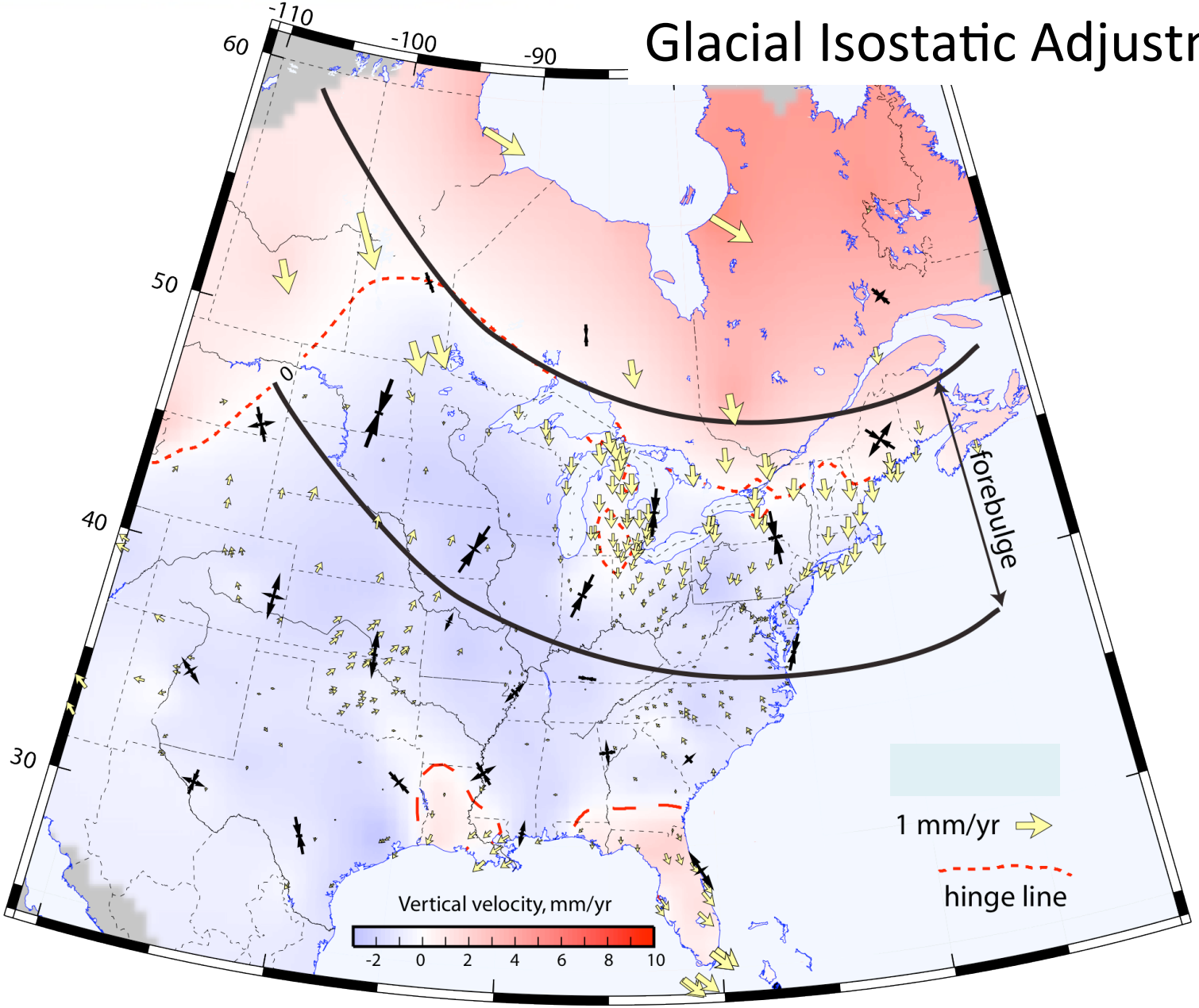
- Water Vapor
- Weather systems as noise and signal (information)



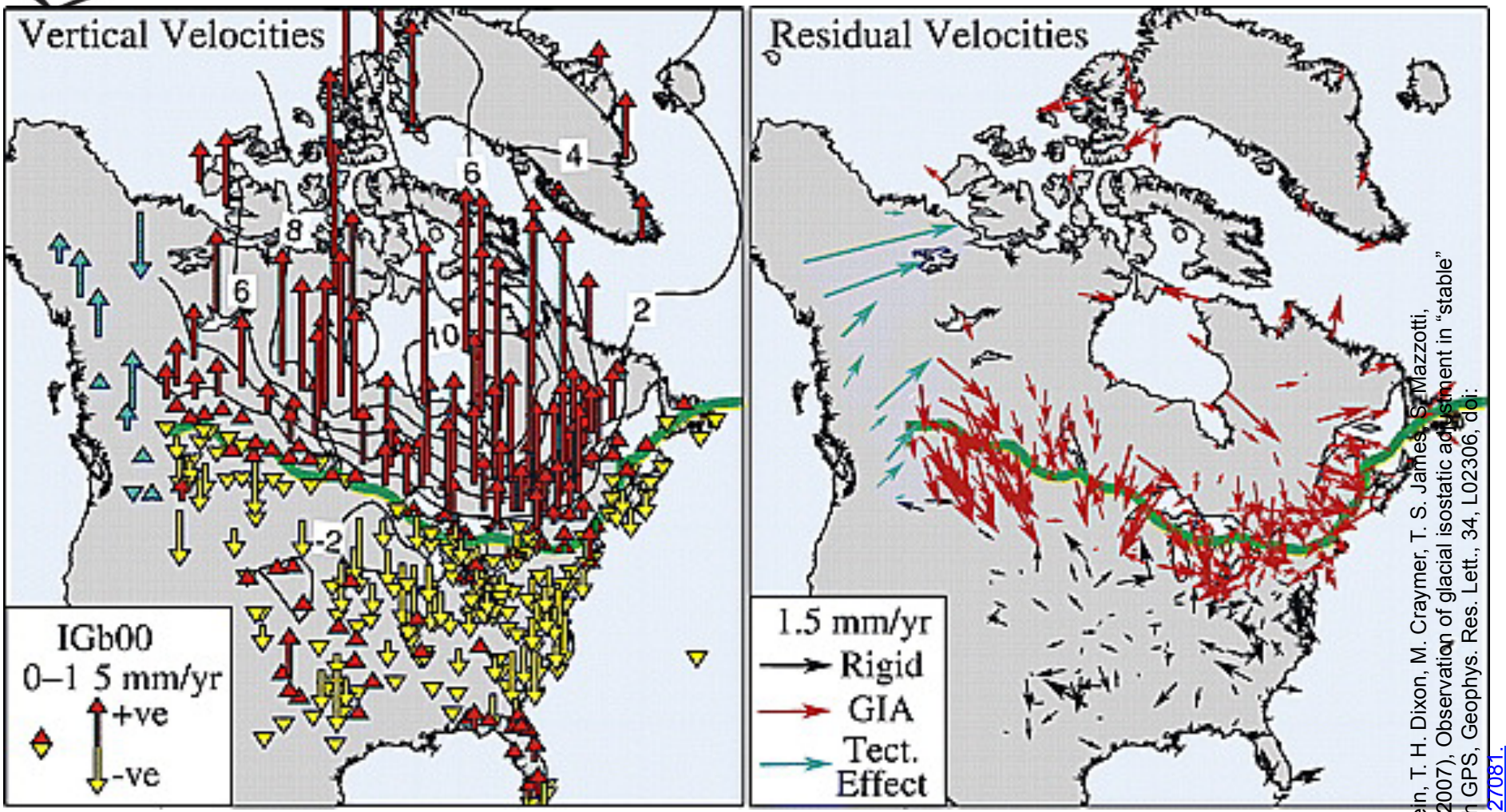
Sella and others, 2007

Measuring the Land Rebound (or Sink)

Glacial Isostatic Adjustment

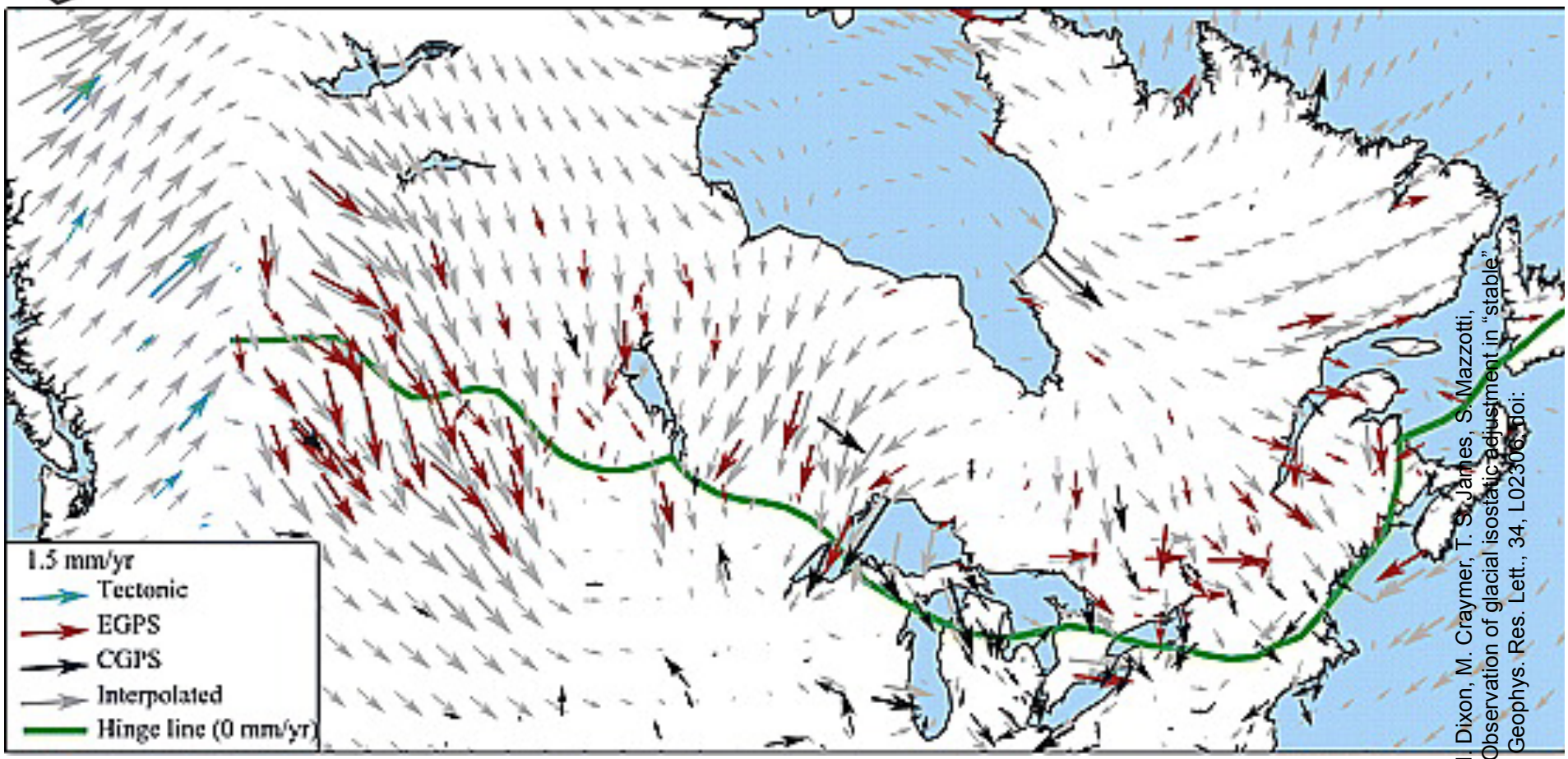


Calais et al., GU 2009



Green line shows 0 mmyr vertical "hinge line" separating uplift from subsidence.
(left) Vertical GPS site motions
(right) Horizontal motion Red vectors represent sites primarily affected by GIA.
Purple vectors represent sites that include effects of tectonics.

Sella, G. F., S. Stein, T. H. Dixon, M. Craymer, T. S. James, S. Mazzotti, and R. K. Dokka (2007), Observation of glacial isostatic adjustment in "stable" North America with GPS, Geophys. Res. Lett., 34, L02306, doi: 10.1029/2006GL027081.



GPS horizontal velocities with motion of rigid North America removed. Interpolated velocity field based on these data derived using GMT

Sella, G. F., S. Stein, T. H. Dixon, M. Craymer, T. S. James, S. Mazzotti, and R. K. Dokka (2007), Observation of glacial isostatic adjustment in "stable" North America with GPS, Geophys. Res. Lett., 34, L02306, doi: 10.1029/2006GL027081.

Horizontal GPS Motions

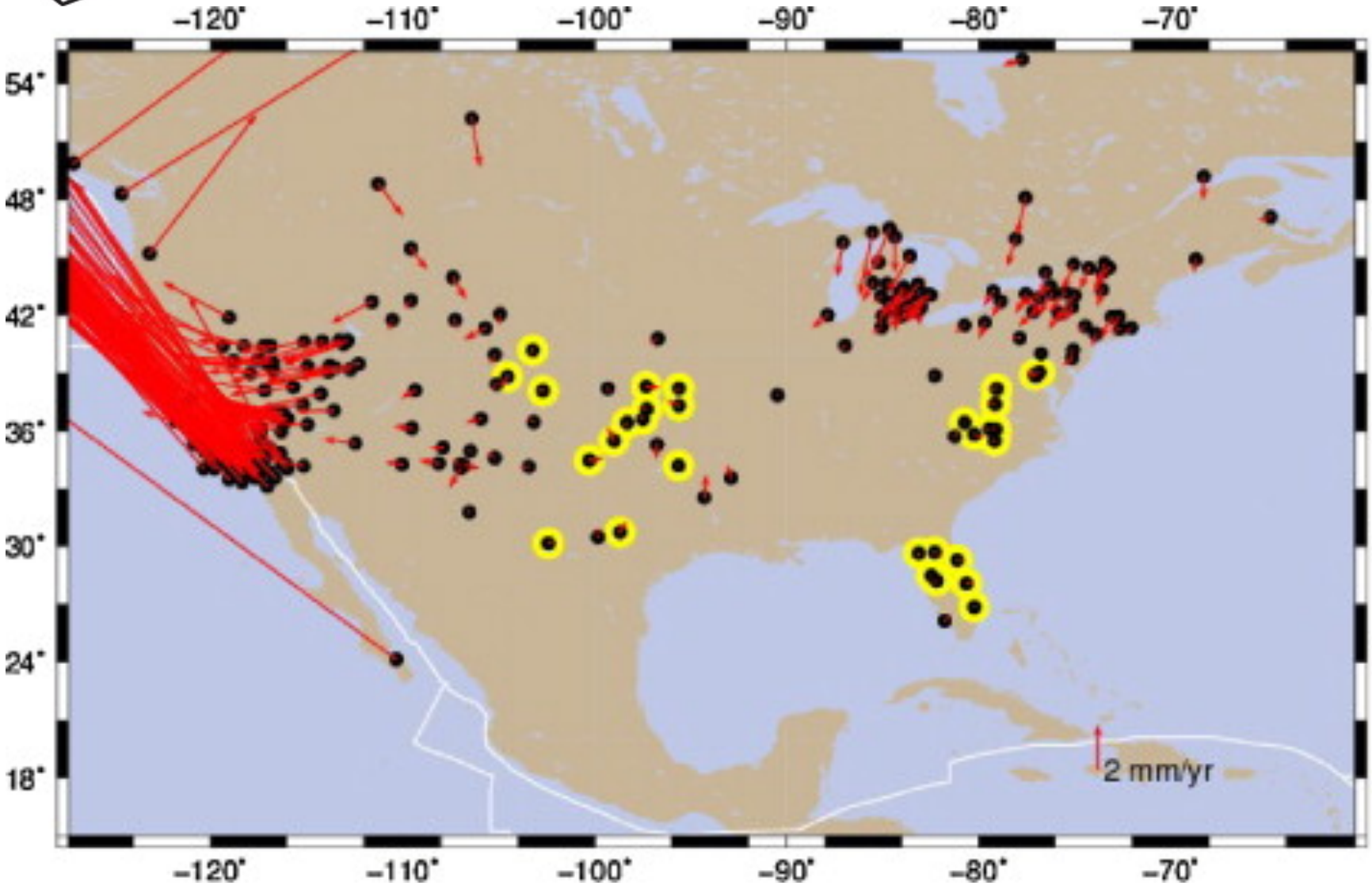
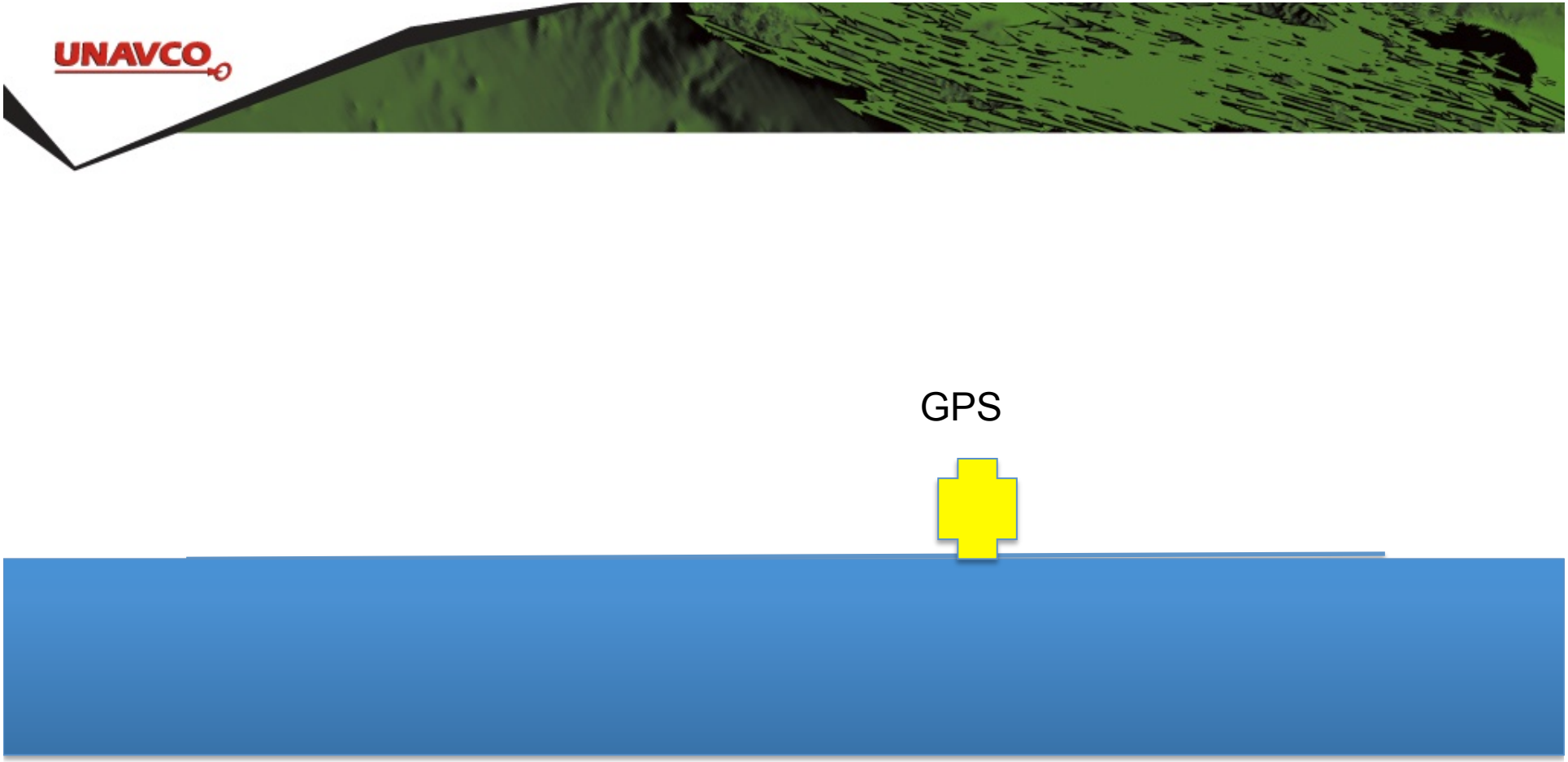
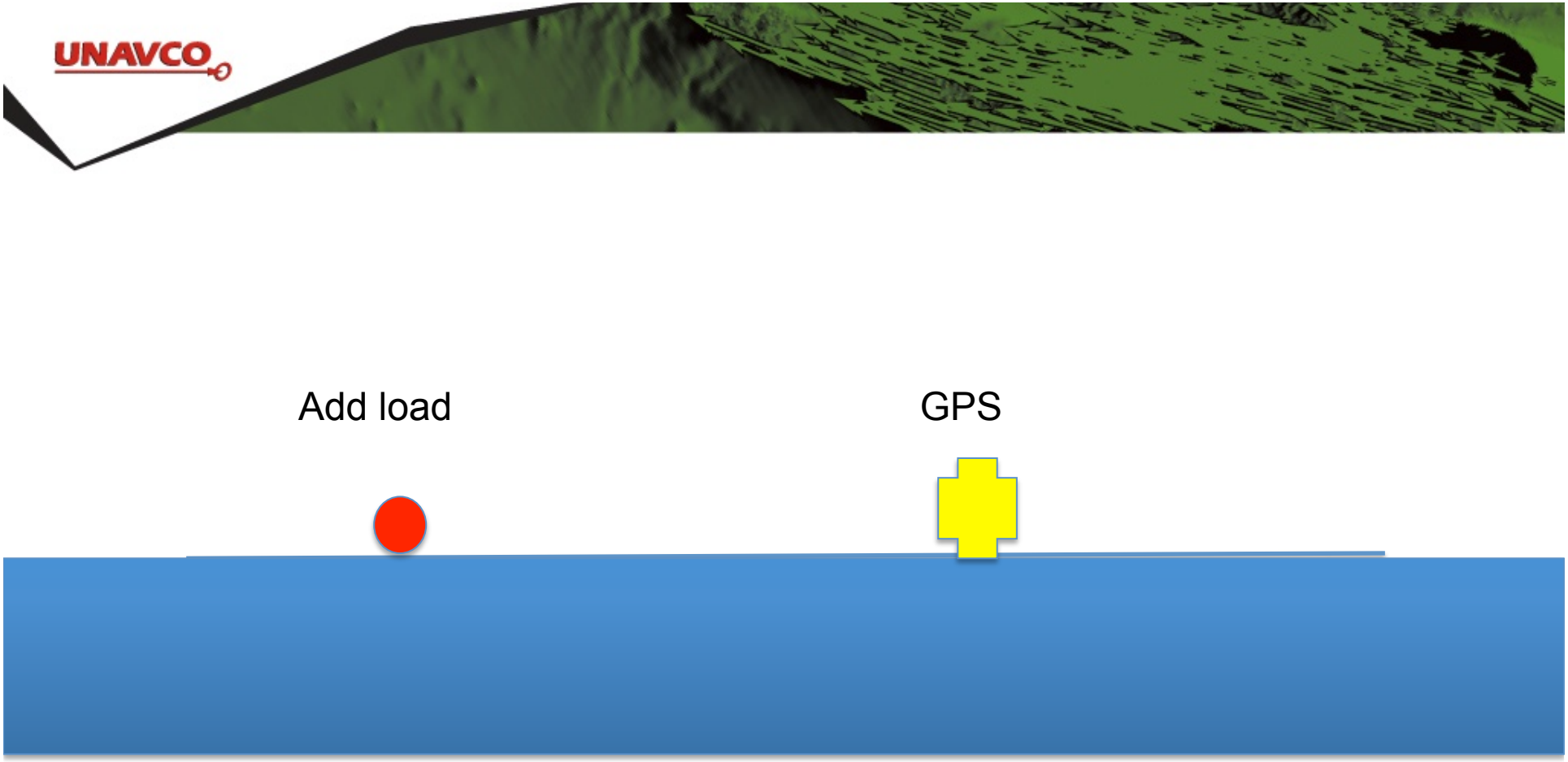


Fig. 5. Assessment of core station selection. Velocities of core stations (with yellow circles) are shown together with other frame stations, indicating the effects of plate boundary deformation in the west, and post-glacial rebound in the northeast. To compar...

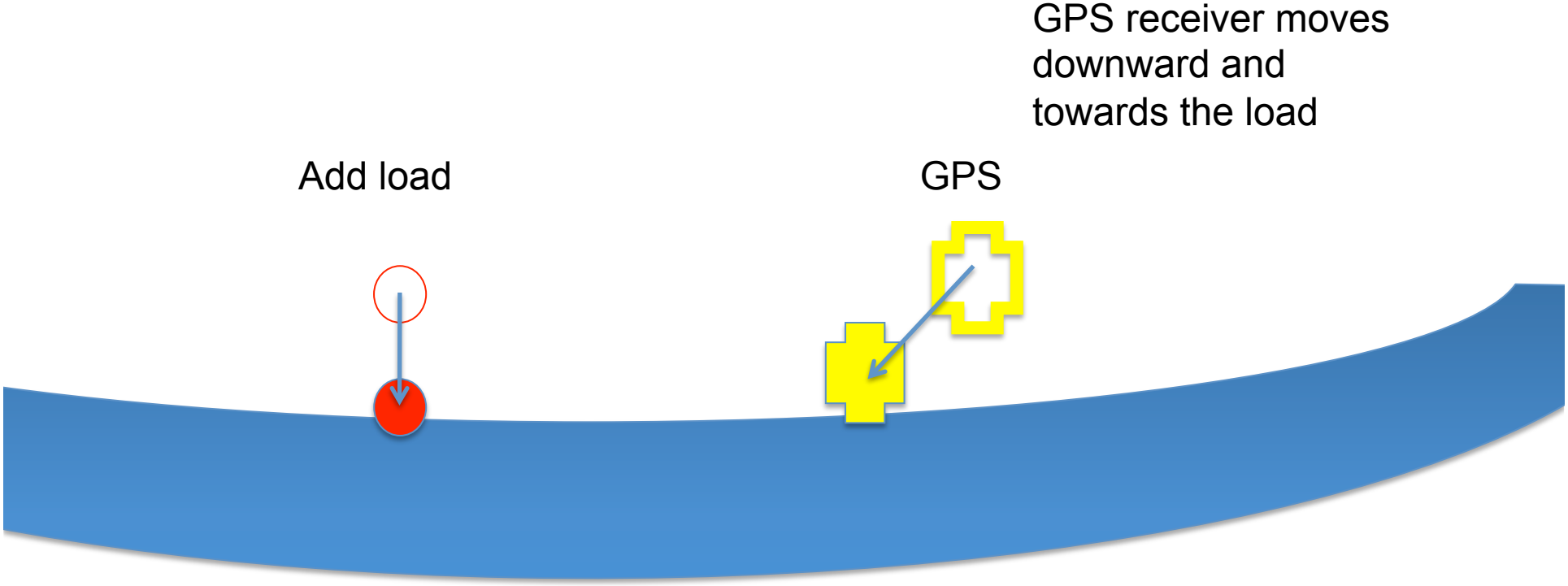
Geoffrey Blewitt, Corné Kreemer, William C. Hammond, Jay M. Goldfarb, **Terrestrial reference frame NA12 for crustal deformation studies in North America**, Journal of Geodynamics, Volume 72, 2013, 11–24. http://dx.doi.org/10.1016/j.jog.2013.08.004


GPS


Add load
GPS

Displacements caused by adding a load

GPS receiver moves downward and towards the load

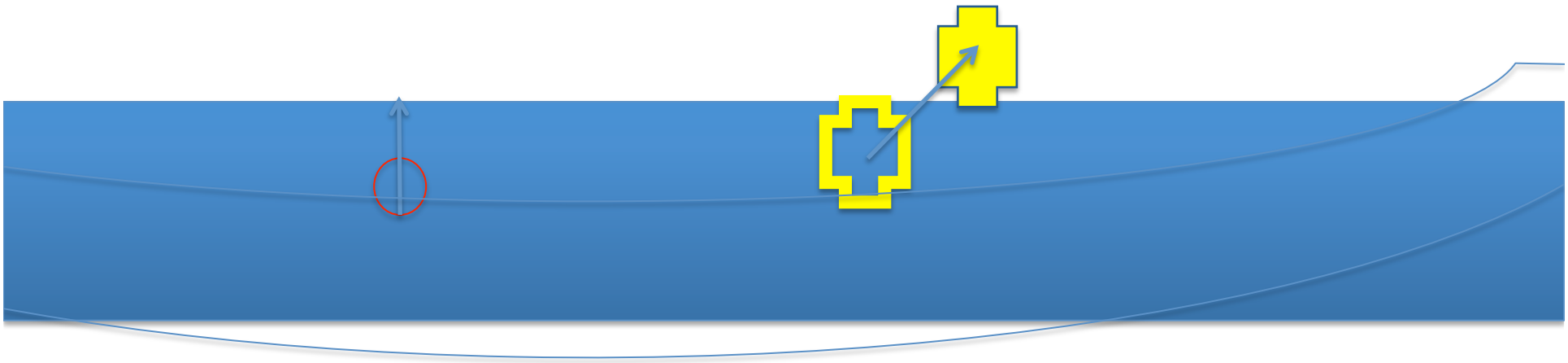


Displacements caused by removing a load

GPS receiver moves upward and away from the load

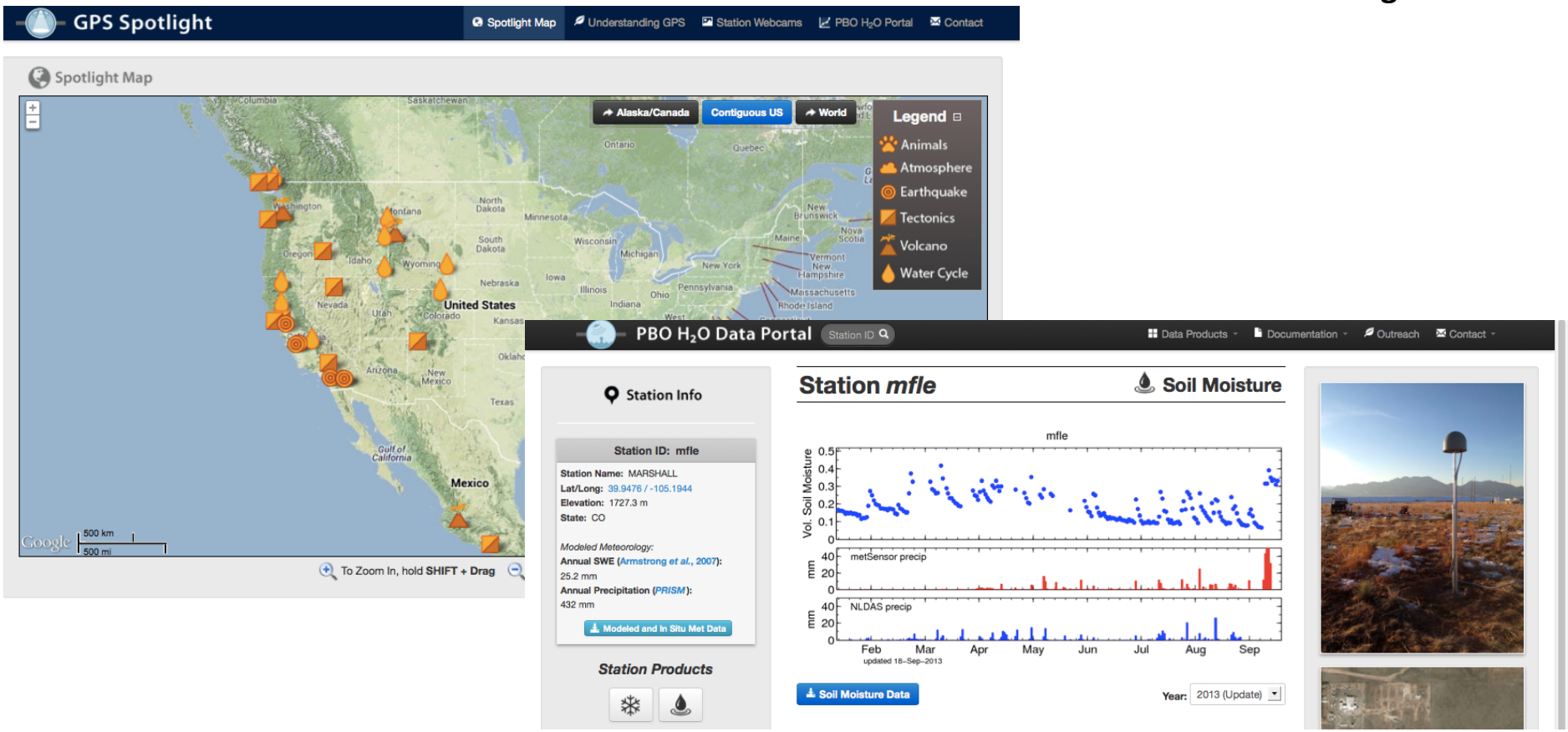
remove load

GPS



Websites shown during demonstration

Learn more about how GPS works and the science learned through research

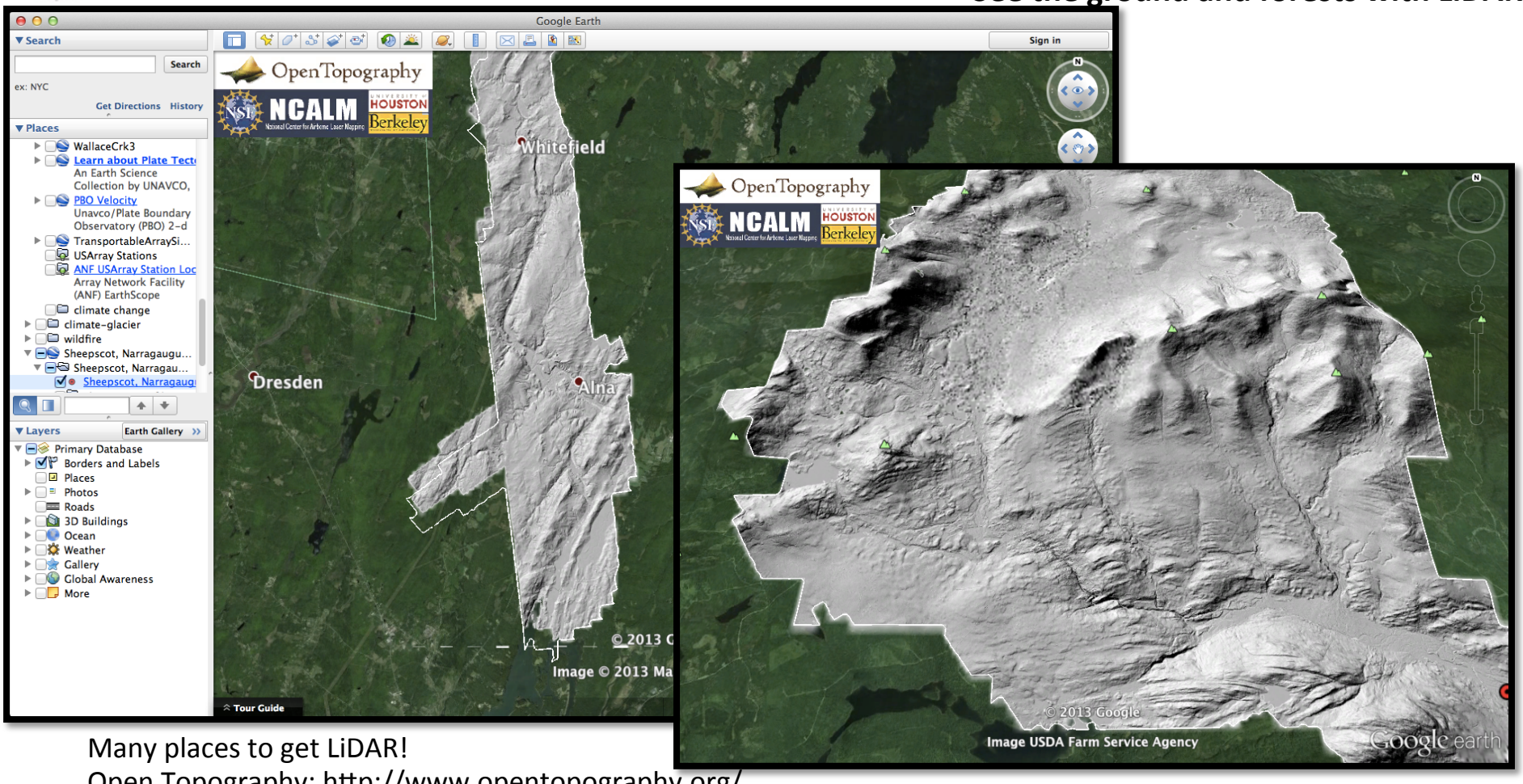


GPS Spotlight: http://xenon.colorado.edu/spotlight/index.php

PBO H2O: http://xenon.colorado.edu/portal/index.php

Websites shown during demonstration

See the ground and forests with LiDAR



Many places to get LiDAR!

Open Topography: http://www.opentopography.org/

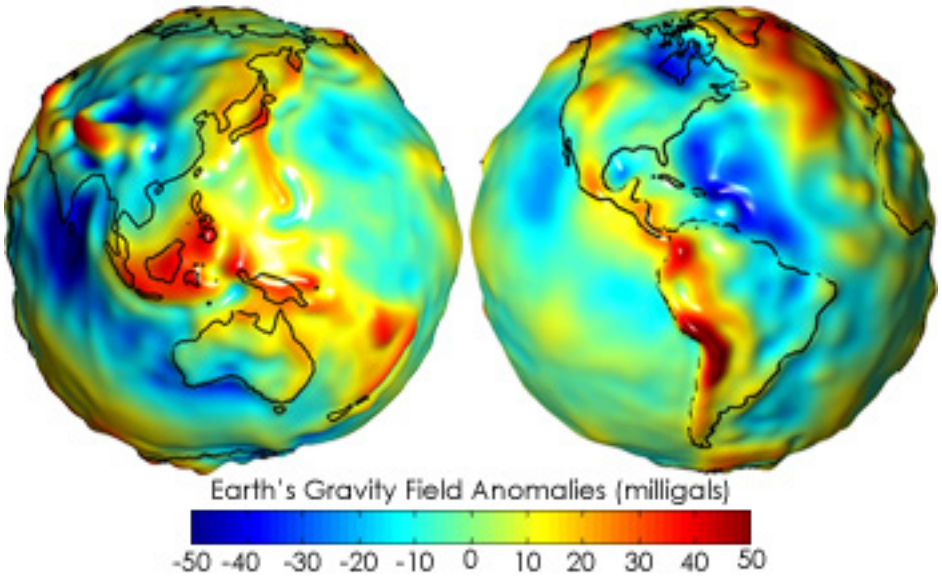
New York: http://gis.ny.gov/elevation/lidar-coverage.htm

Maine: http://www.maine.gov/megis/projects/lidar.shtml

Vermont: http://vcgi.vermont.gov/warehouse/products/ALL-LDR_MIX_LIDAR_STATE_ALL

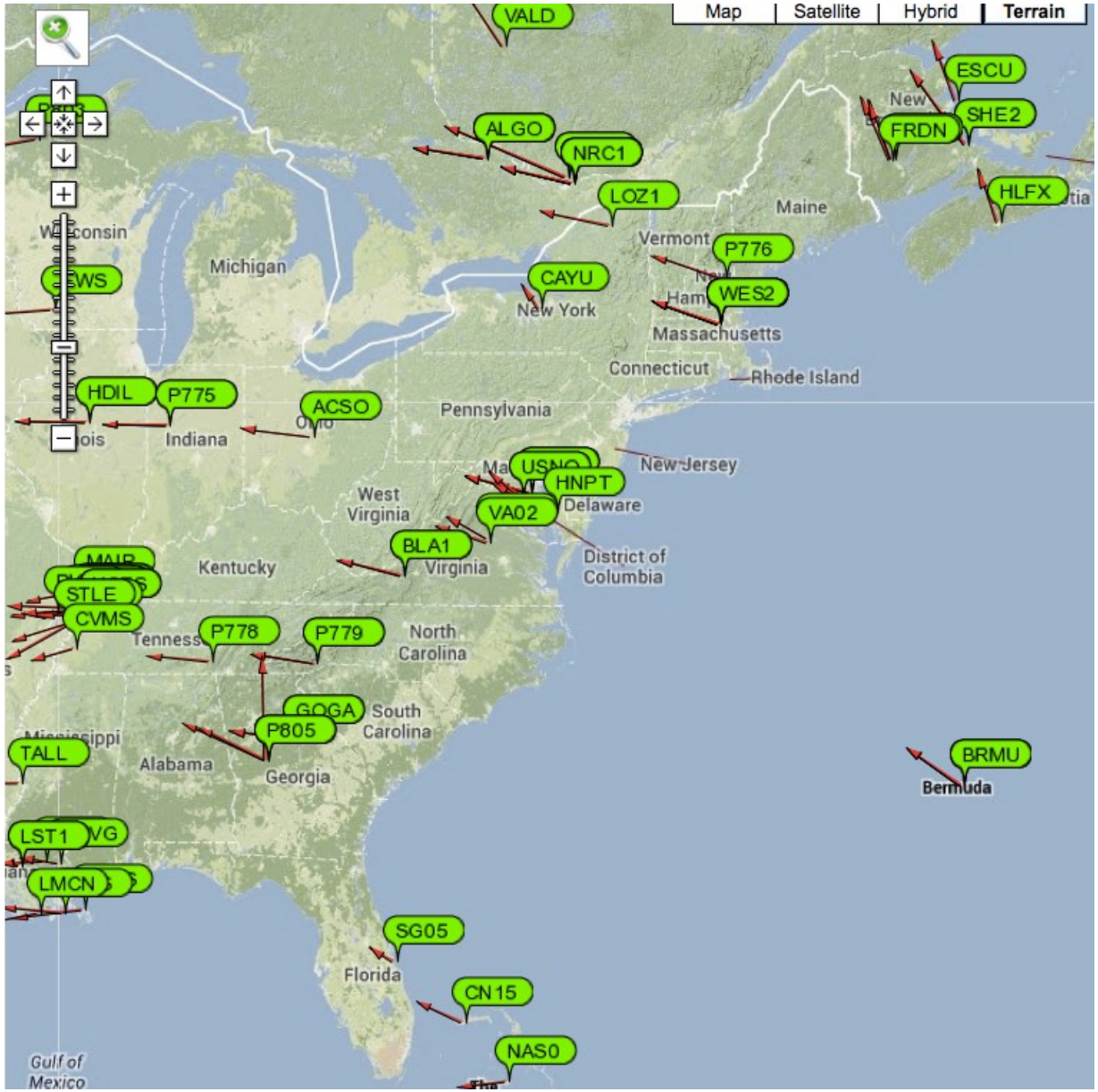
New Hampshire: http://www.granit.unh.edu/resourcelibrary/specialtopics/lidar/

About GRACE



http://earthobservatory.nasa.gov/Features/GRACE/page3.php

Measuring the Plates Move



UNAVCO Plate Boundary Observatory Data