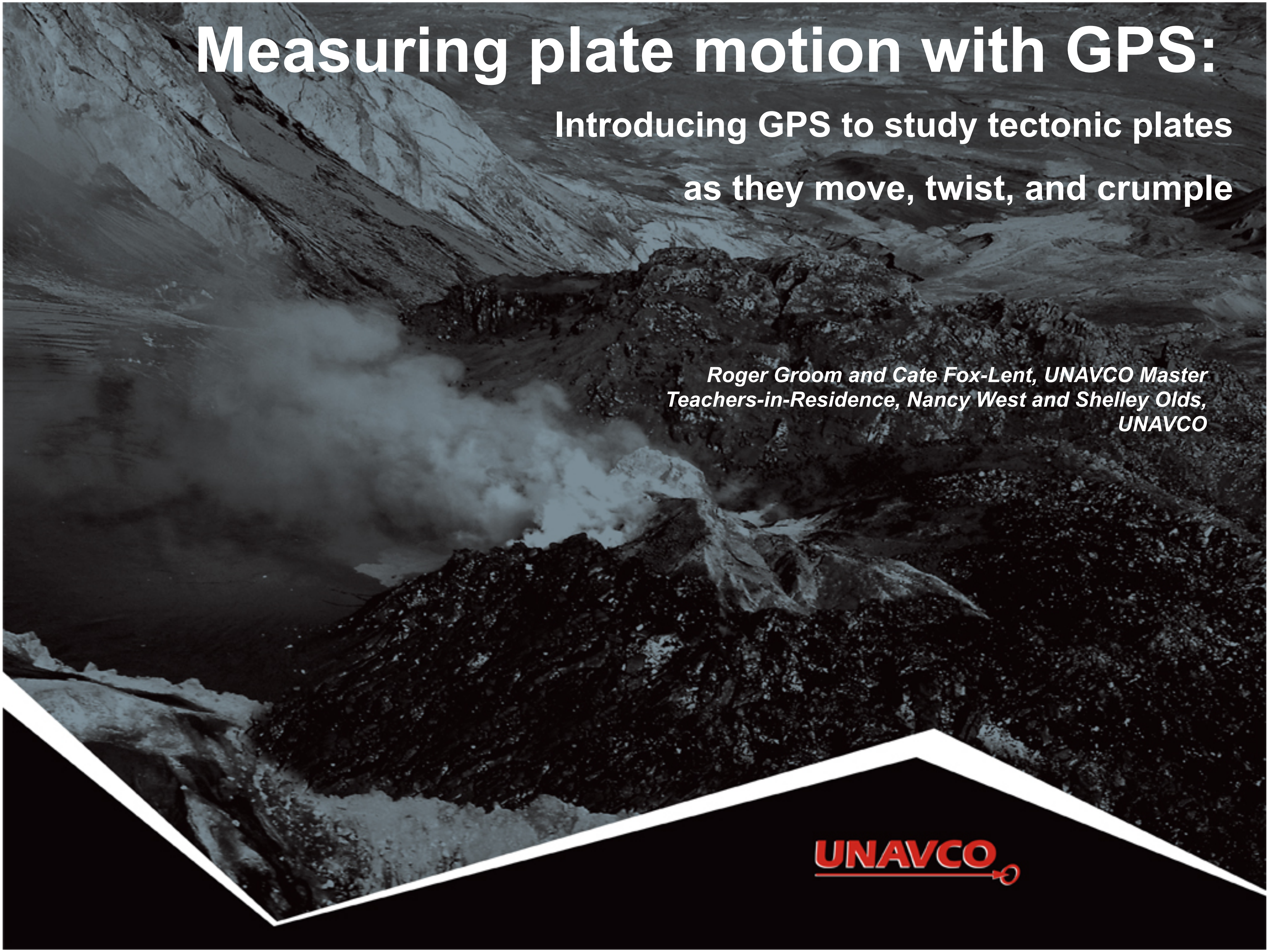


Measuring plate motion with GPS:

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.

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).

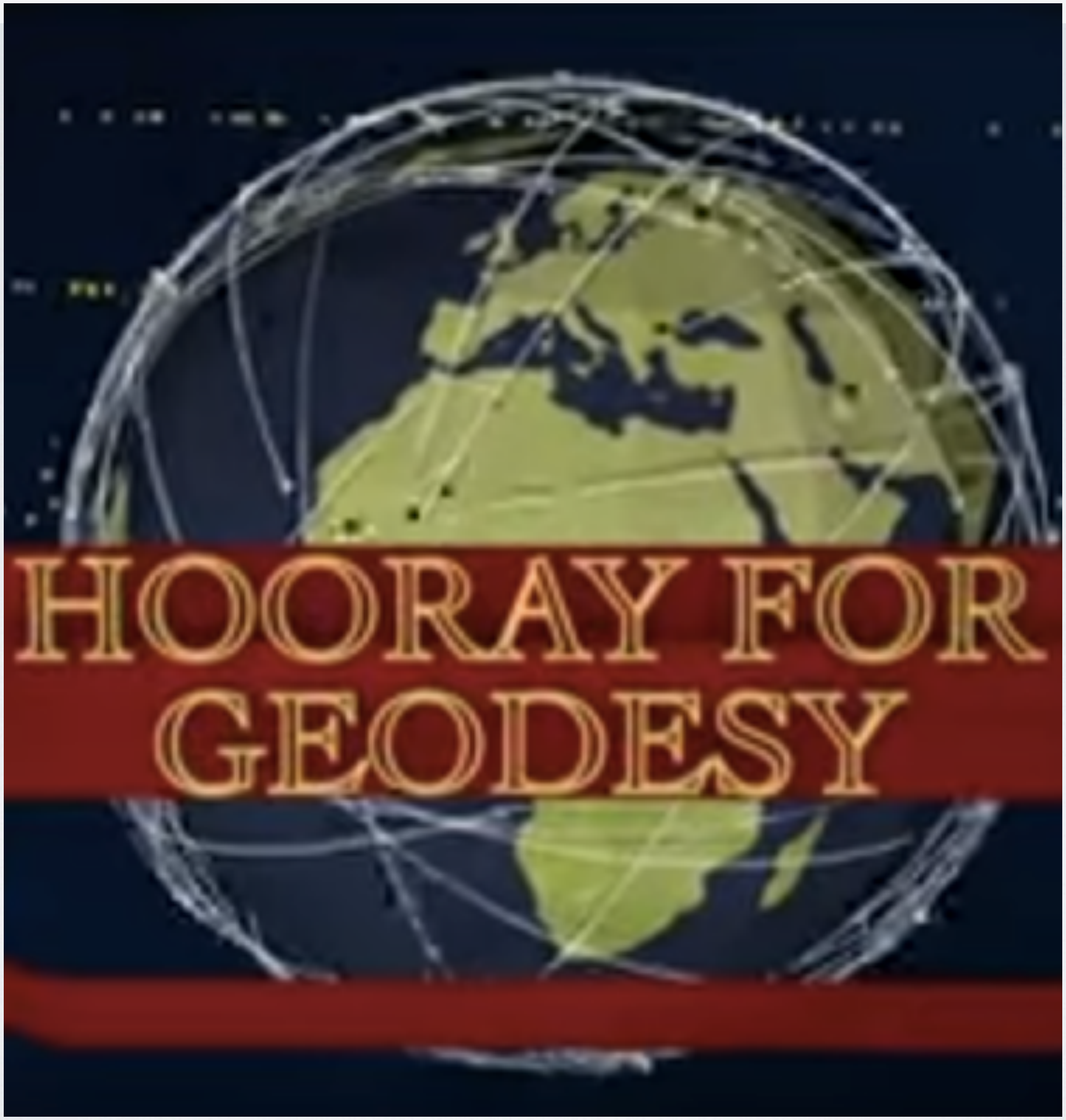
4. Place on a small piece of transparent paper ("see-through" crust).

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).

NASA's Brief History of Geodesy



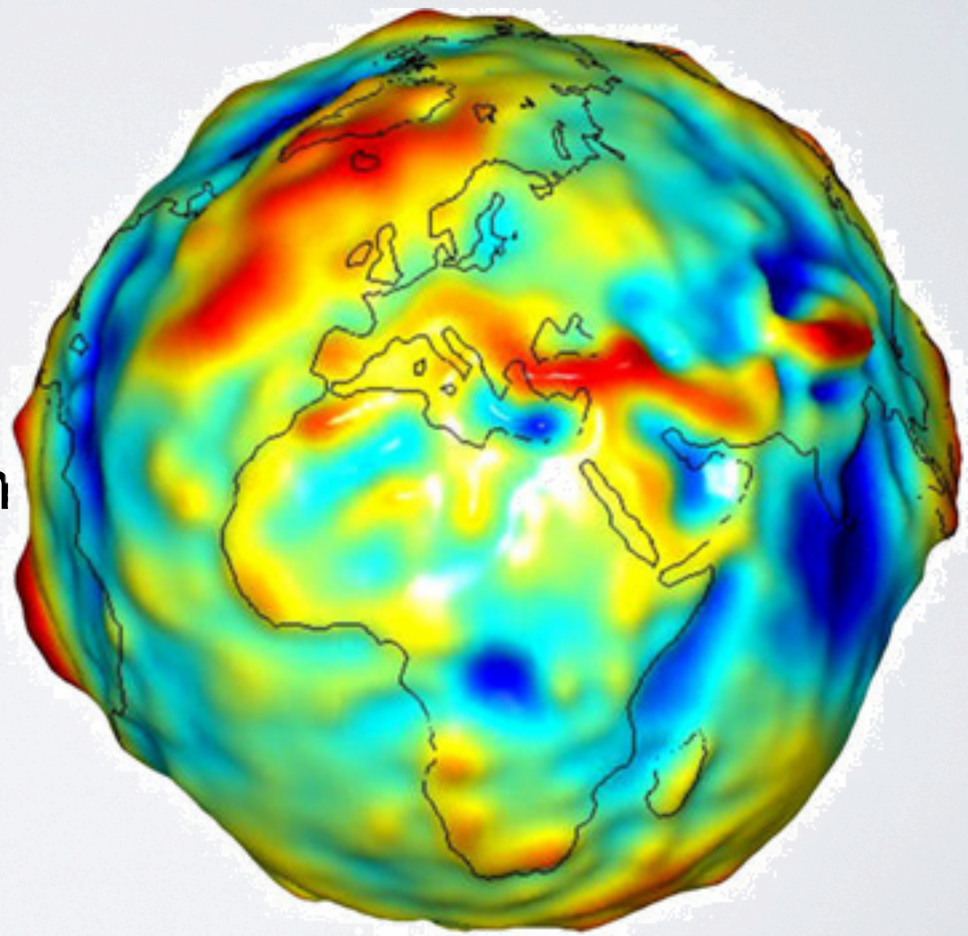
http://bit.ly/nasawhatisgeodesy

About geodesy

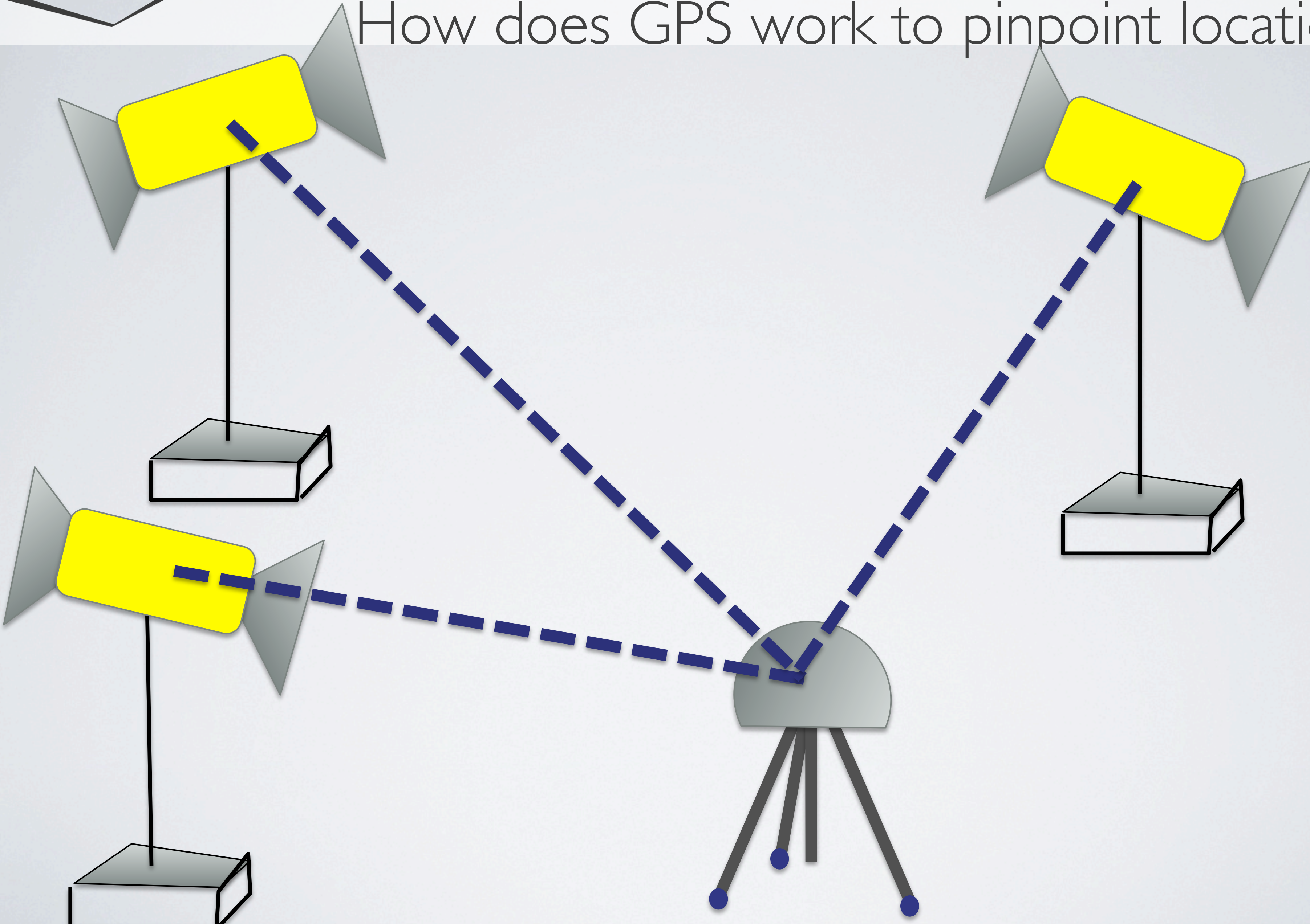
Geodesy is the science of …

measuring Earth's

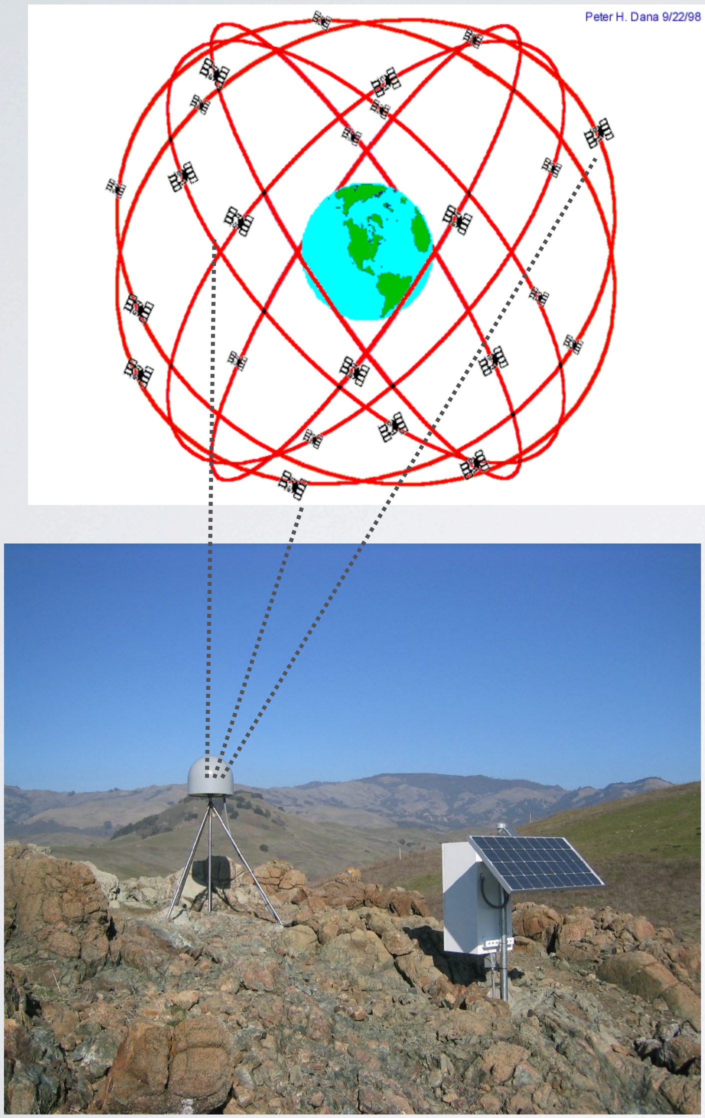
- size,
- shape,
- orientation,
- gravitational field, and
- variations of these with time.



Demonstration
How does GPS work to pinpoint location?

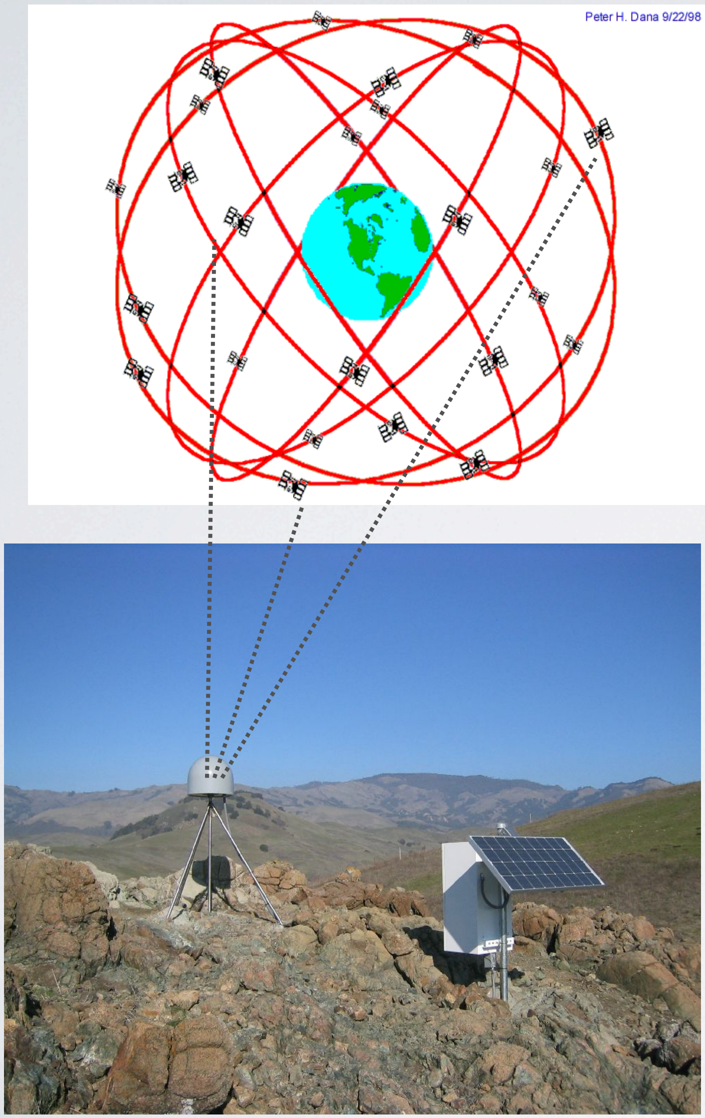


How GPS Works - Basics



- 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.

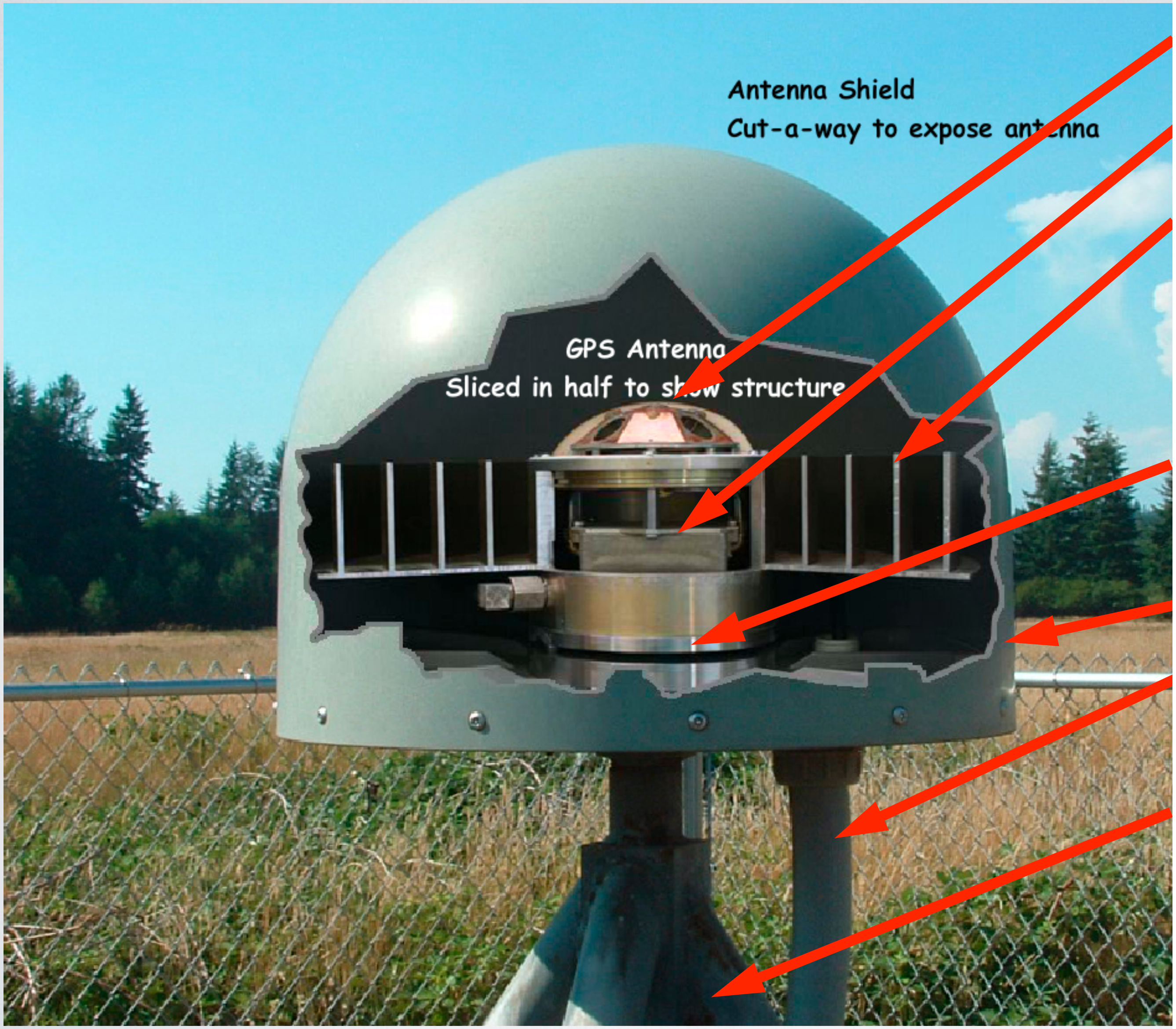
Equipment enclosure:

- GPS receiver
- Power storage: Batteries
- Communications: radio modem
- Data storage: memory cards

UNAVCO

A high precision GPS antenna is much bigger than a cell phone

Anatomy of a GPS Antenna



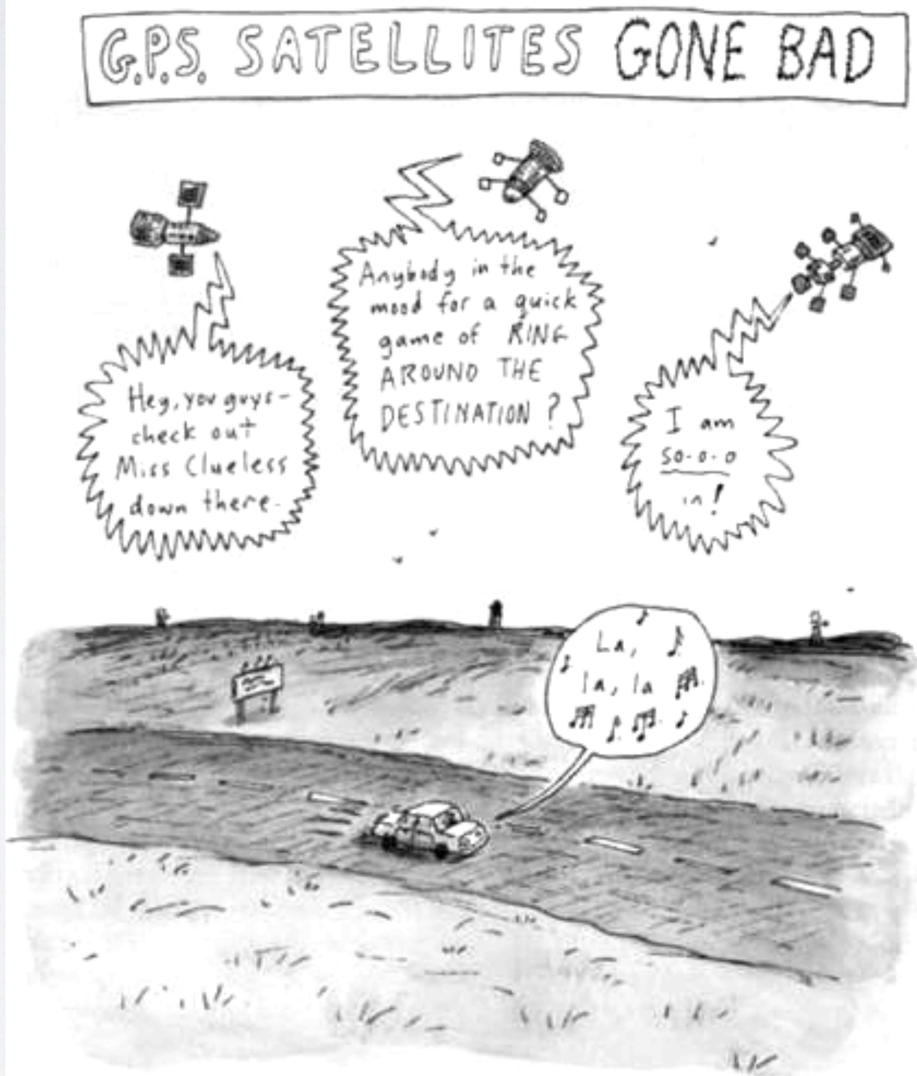
- Antenna
- Signal Amplifier
- Choke ring (to dampen unwanted signals)
- Antenna mount
- Dome
- Power & signal cable
- Tripod supports

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)

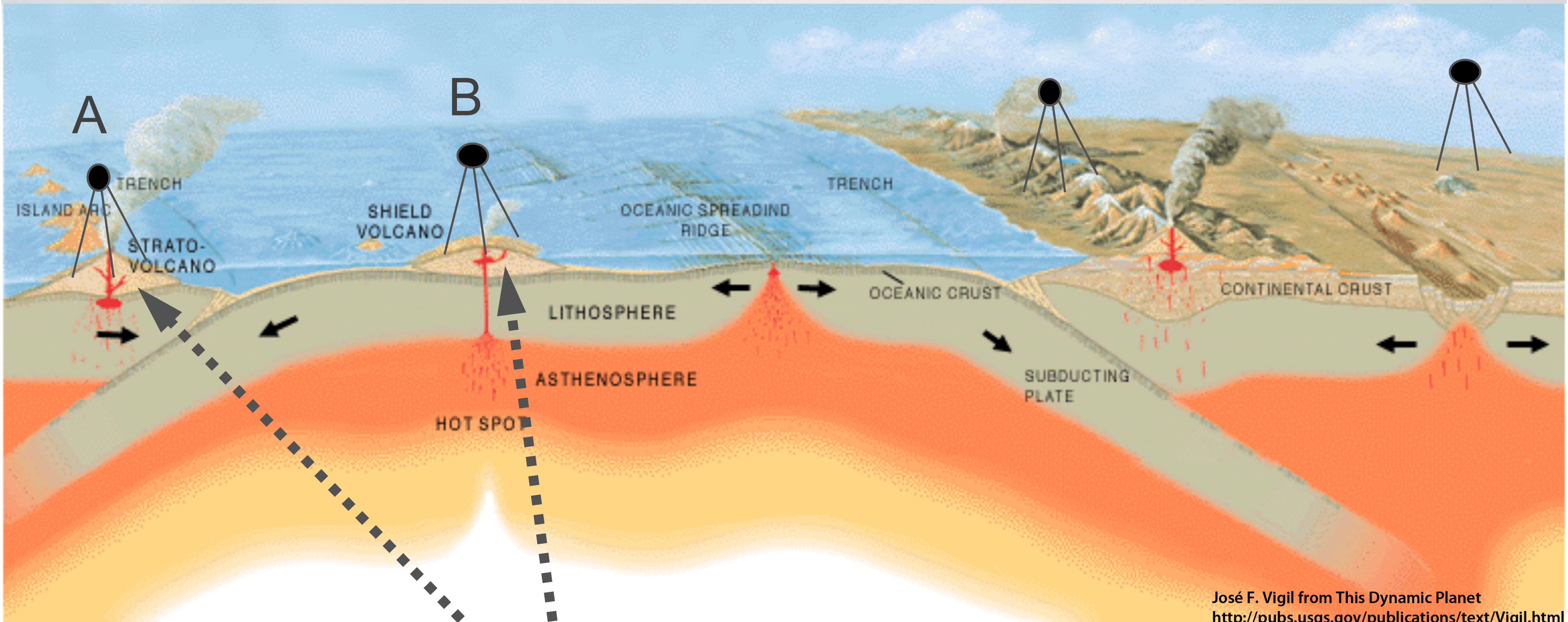
* historical



The New Yorker, Roz Chast

Movement of GPS stations

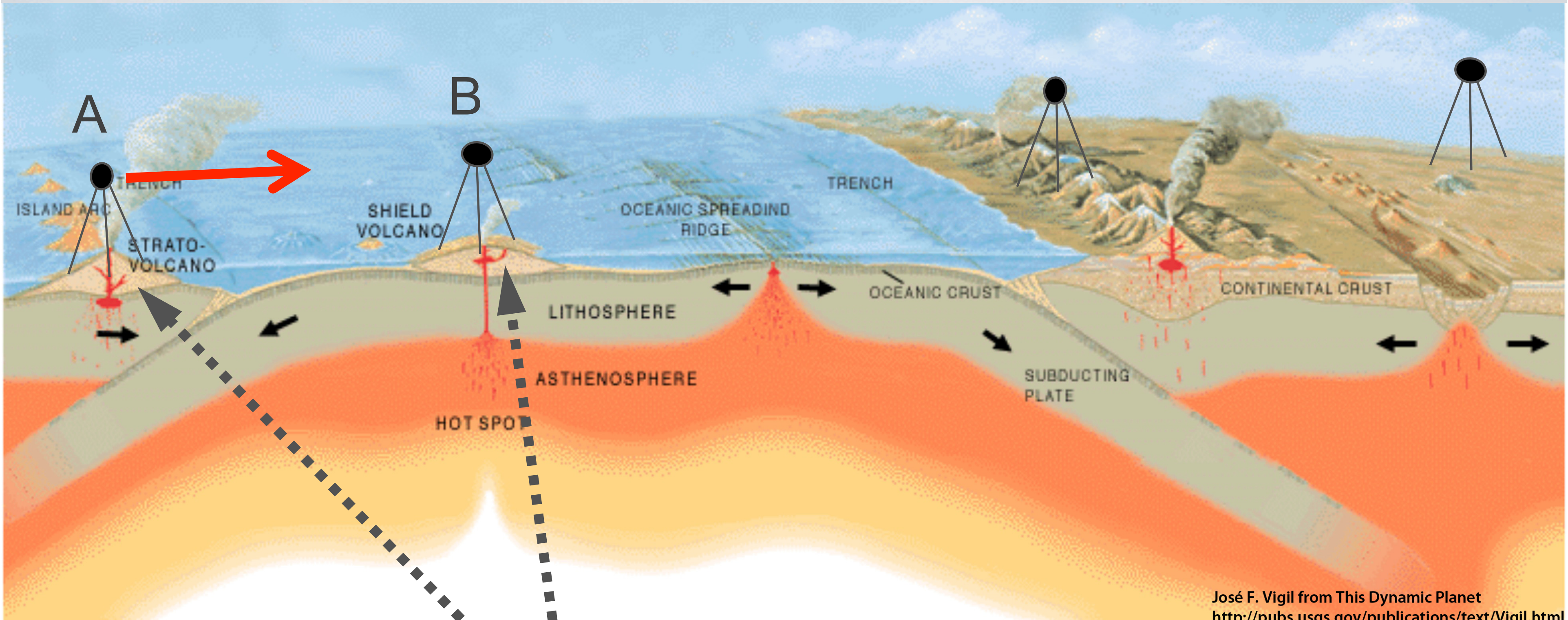
GPS station positions change as plates move.



How will Station A move relative to Station B?

Movement of GPS stations

GPS station positions change as plates move.



José F. Vigil from This Dynamic Planet
http://pubs.usgs.gov/publications/text/Vigil.html

GPS Station A is moving toward B.

Part 2: What can GPS tell us about Iceland?

Introduction: Measuring GPS Movement with Time Series Plots:

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

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

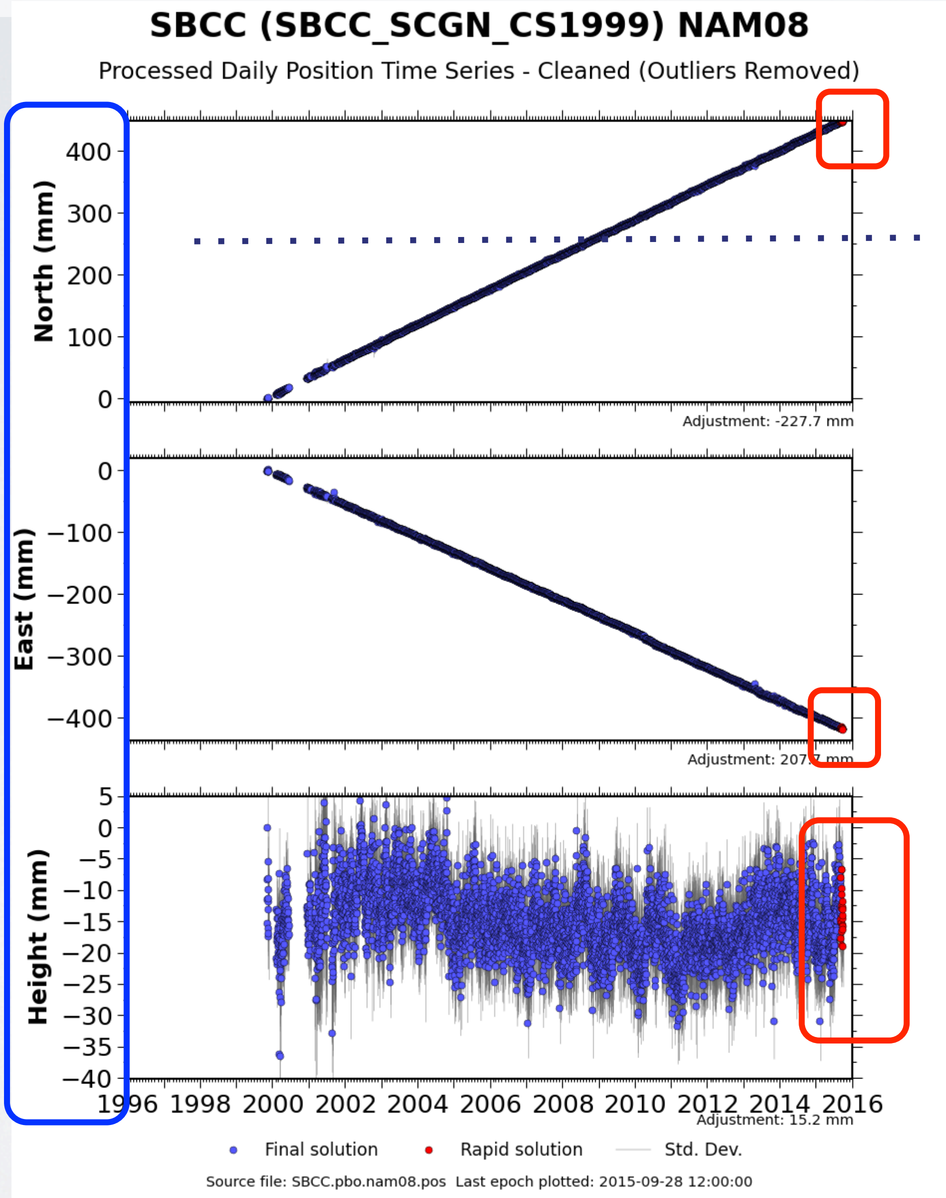
3 separate plots :

- North
- East
- Height (Vertical)

X-axis: Time

Y-axis: Distance GPS has moved

*Vertical scales vary per plot.



Red points:

Rapid position estimates

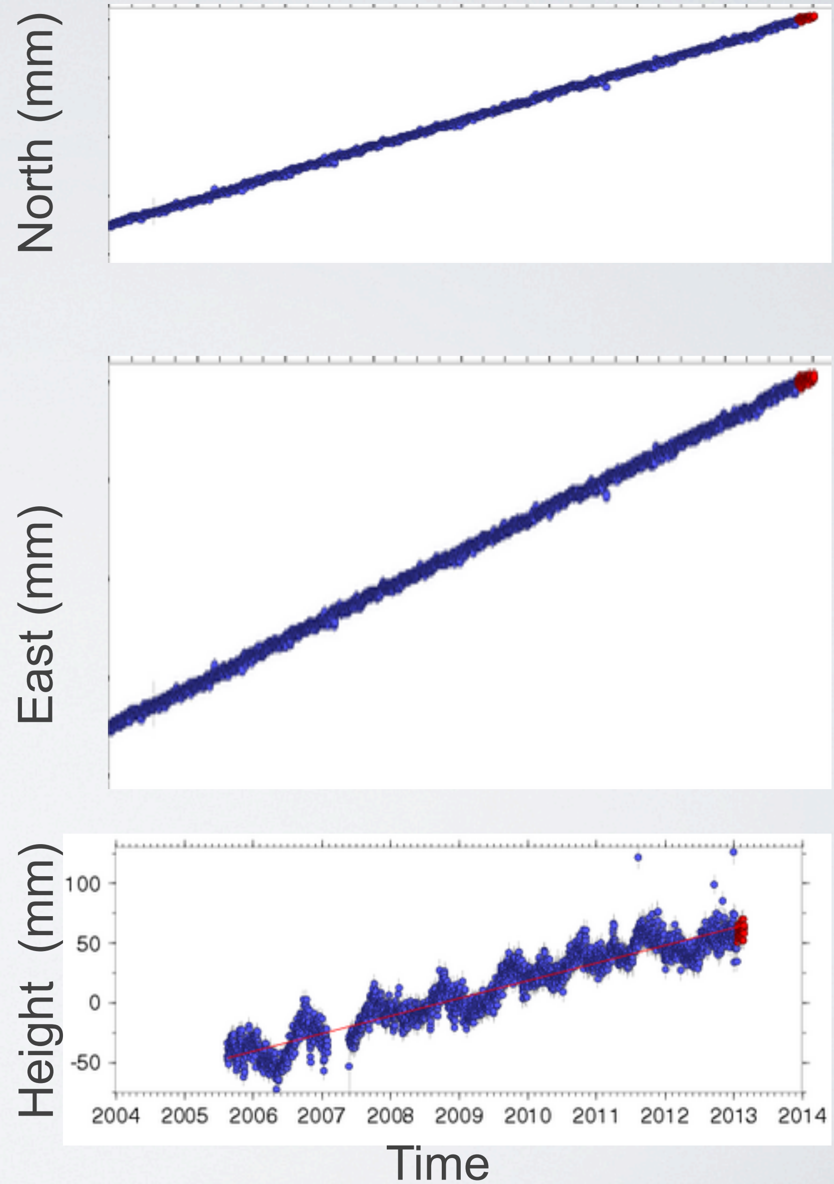
Which way are we going?

Is the GPS station moving

north or south?

east or west?

up or down?



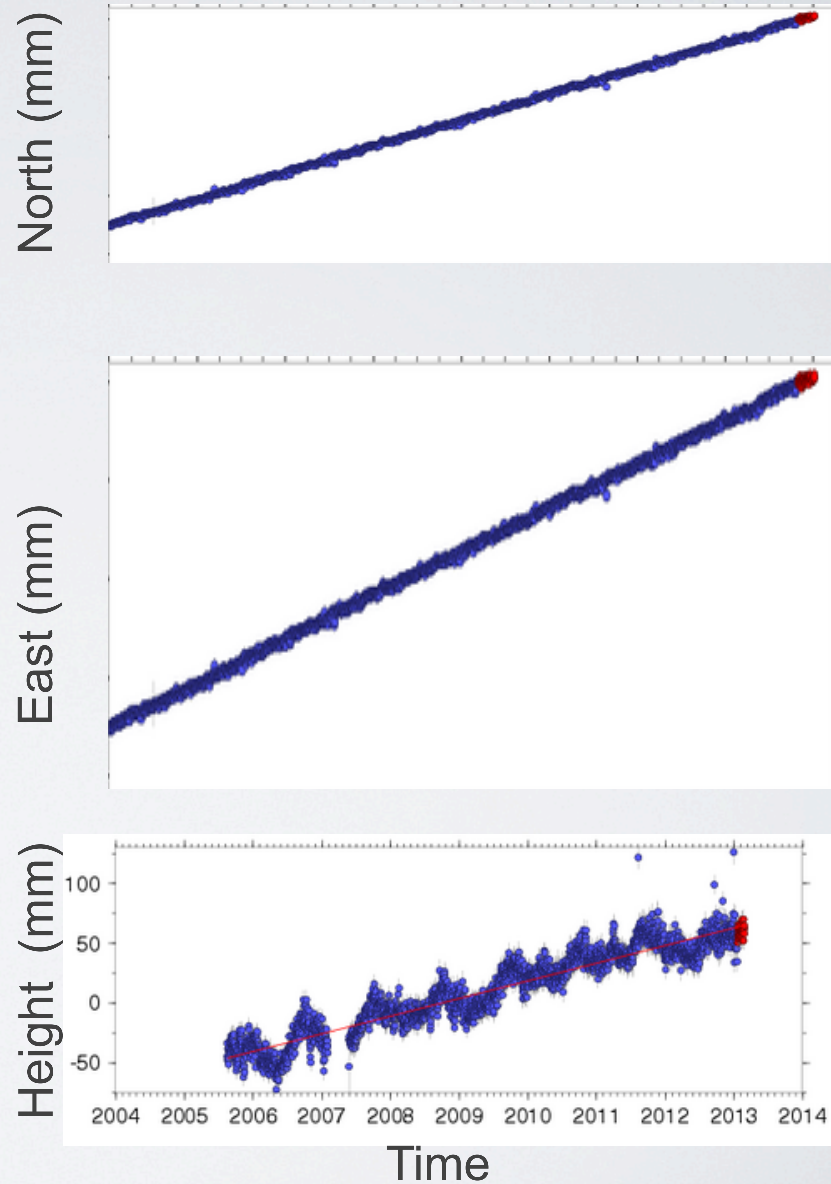
Which way are we going?

Positive slope:

The station is moving **north**.

The station is moving **east**.

The station is moving **up**.



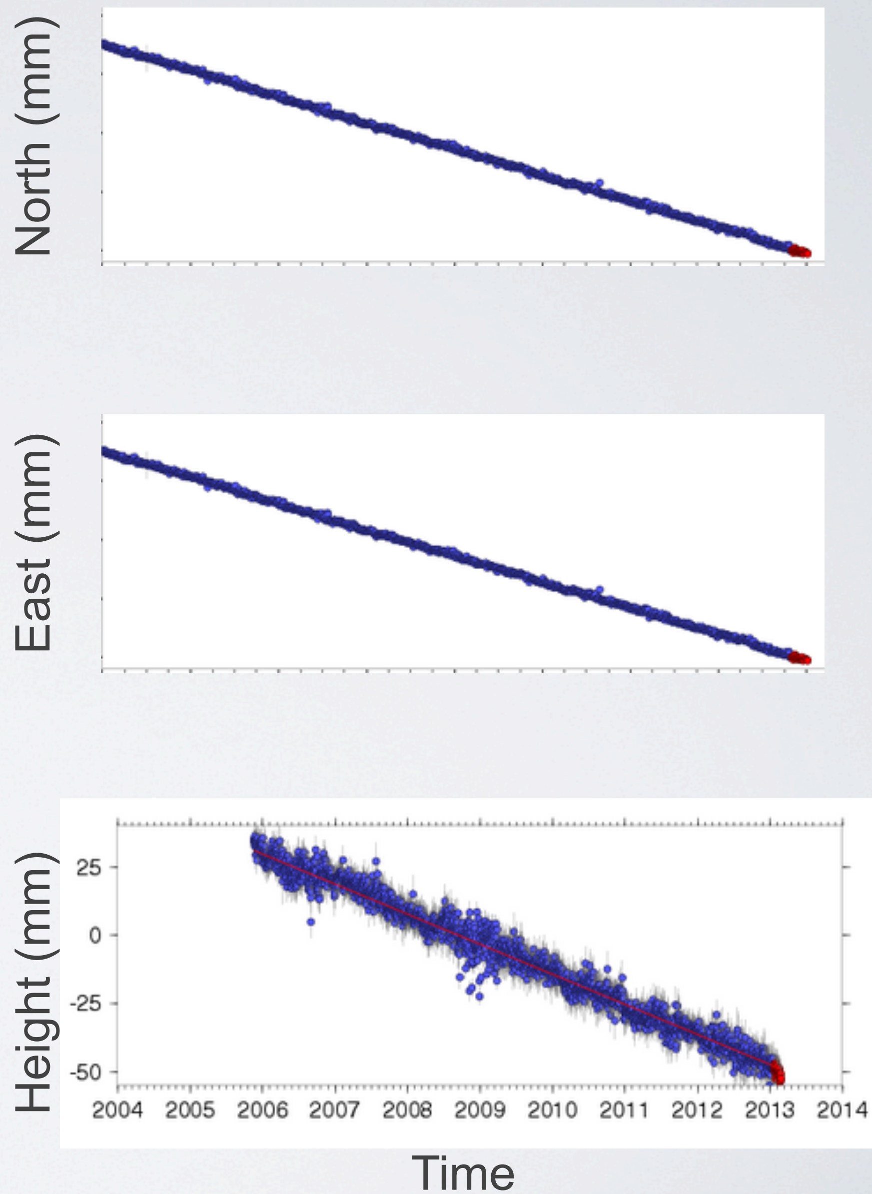
Which way are we going?

Is the GPS station moving

north or south?

east or west?

up or down?



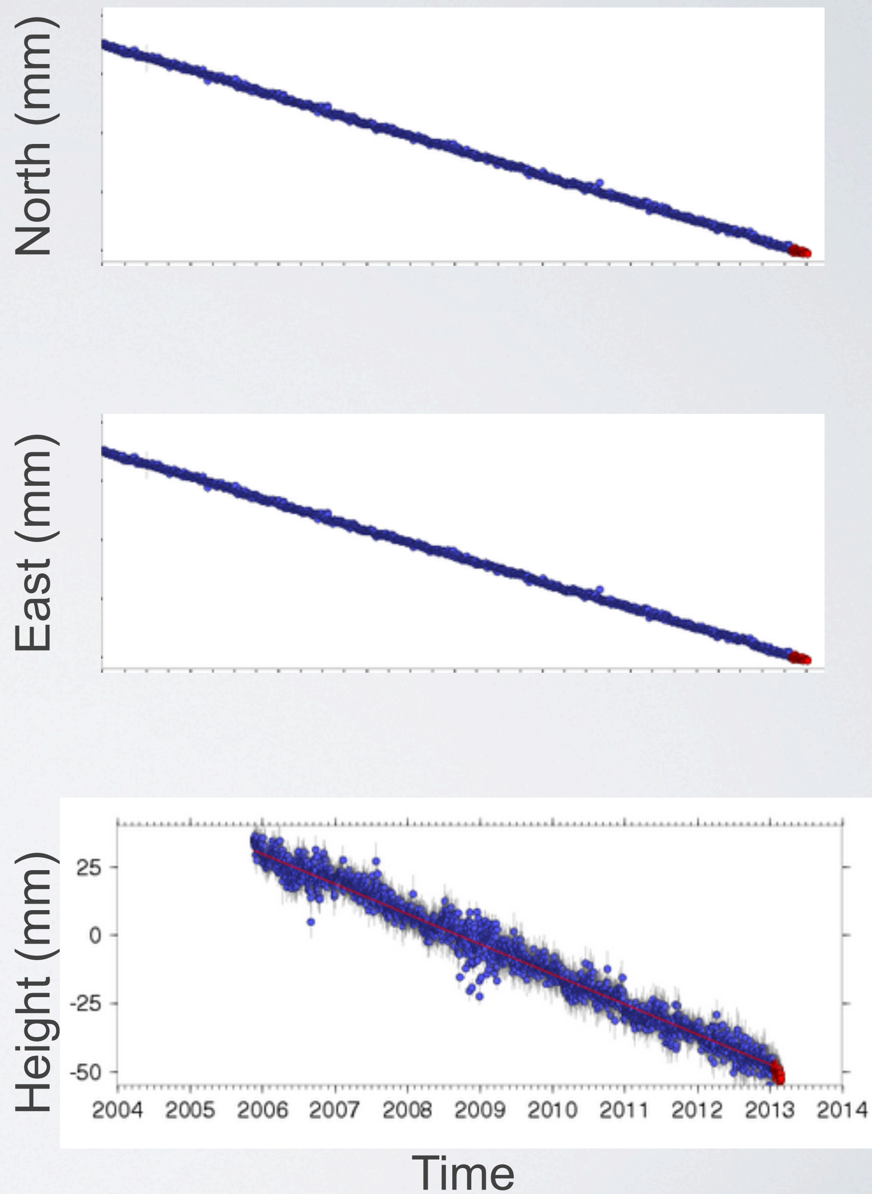
Which way are we going?

Negative slope:

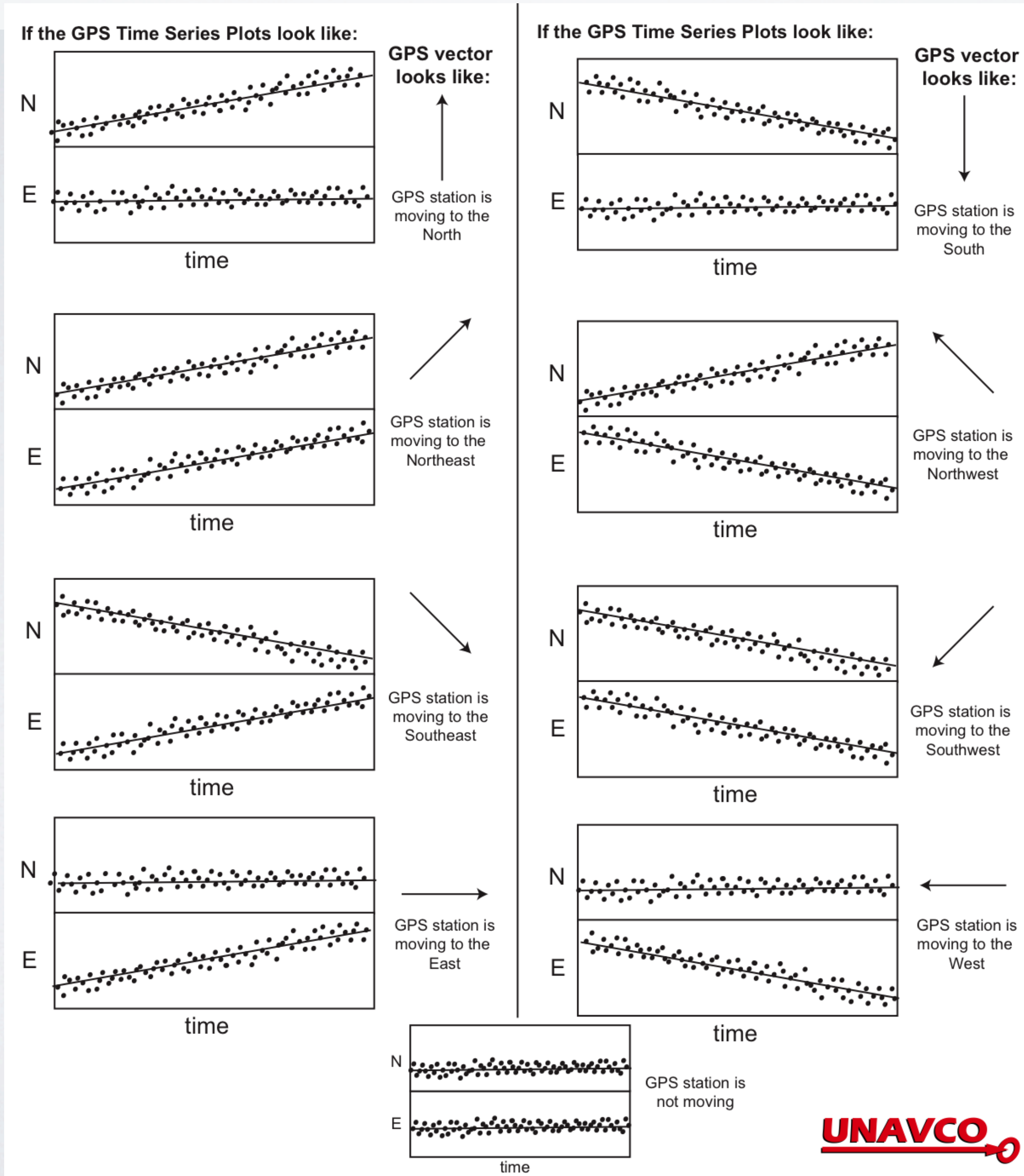
The station is moving **south**.

The station is moving **west**.

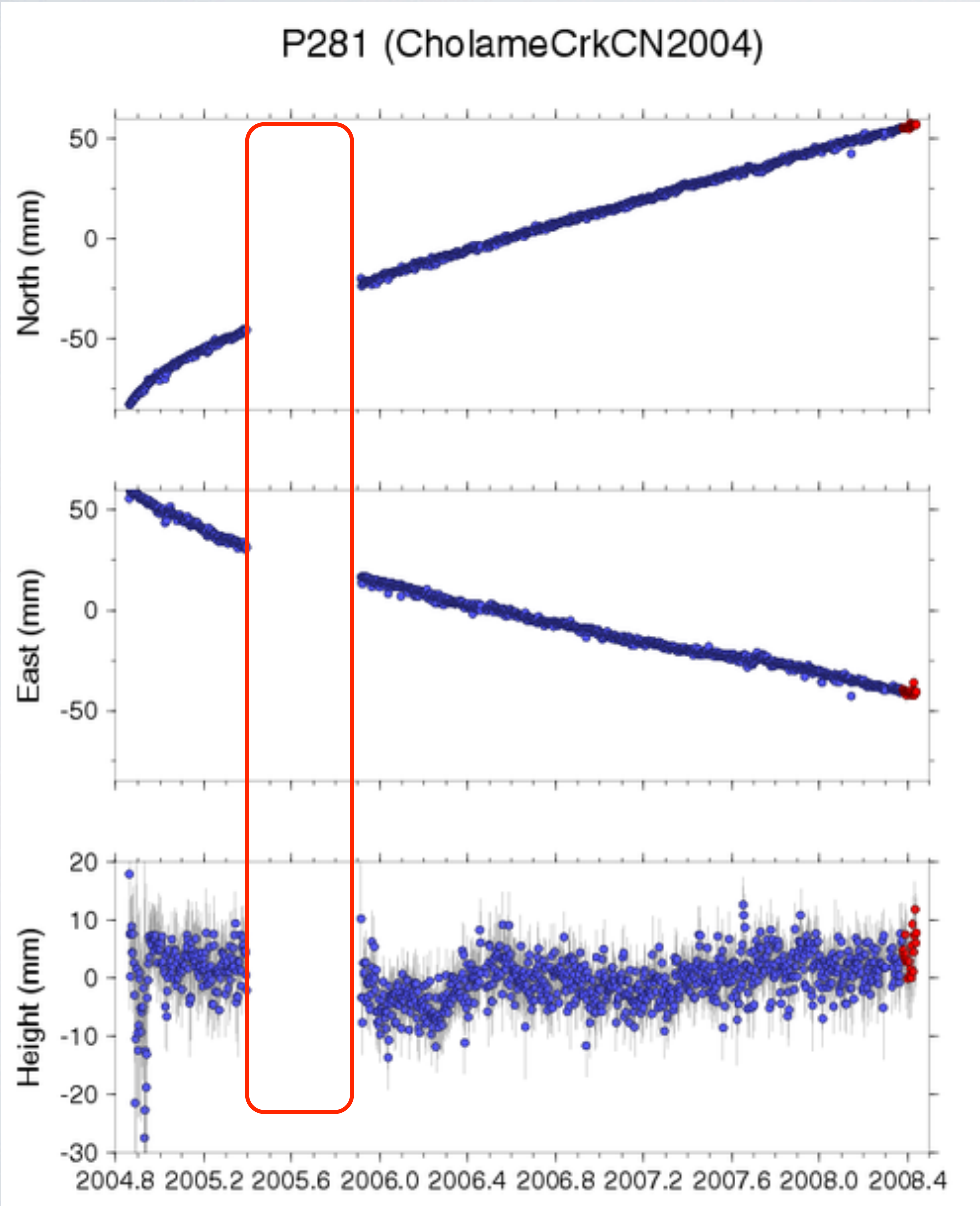
The station is moving **down**.



Time series plots



Gaps in data

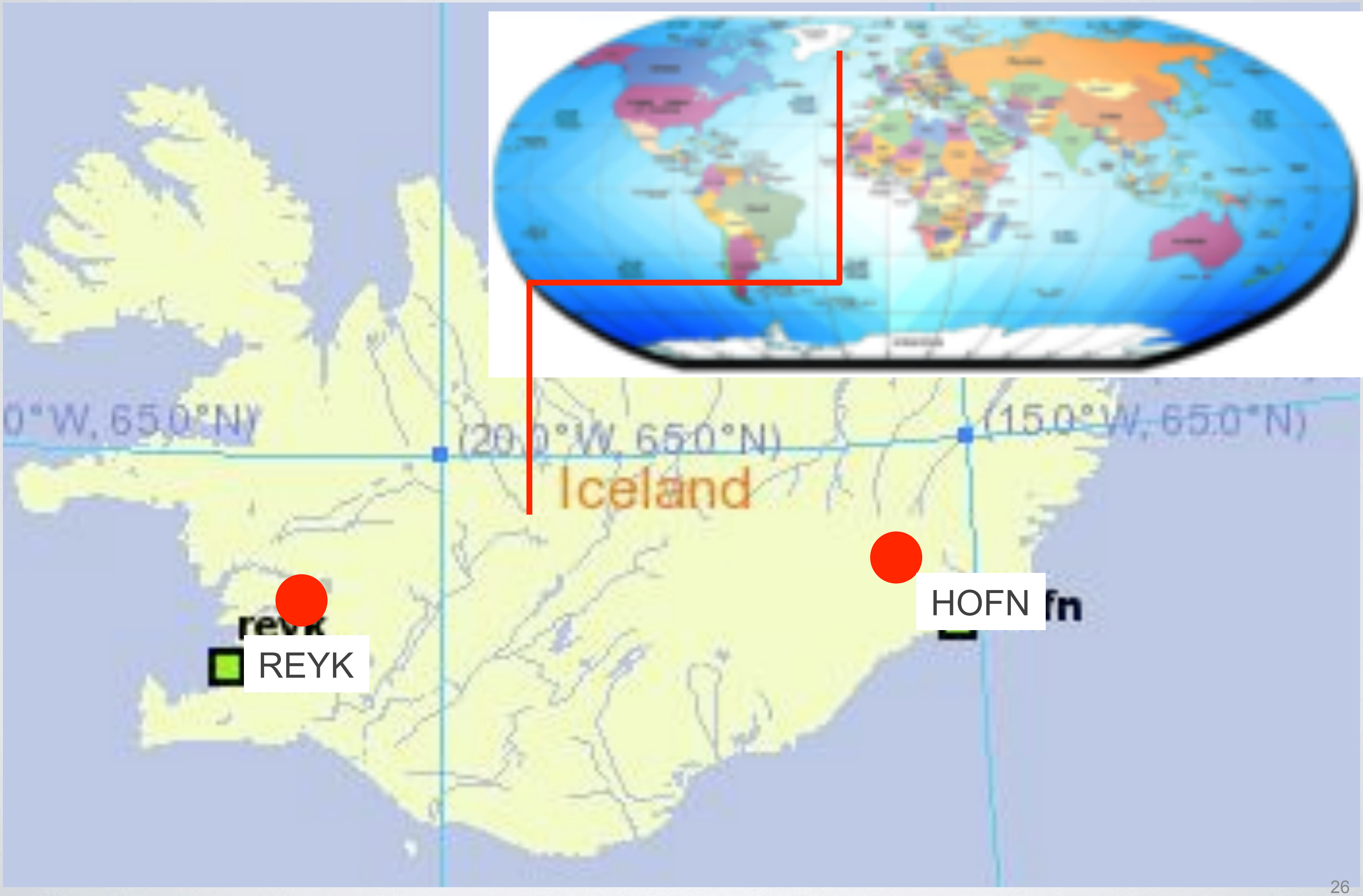


Causes:

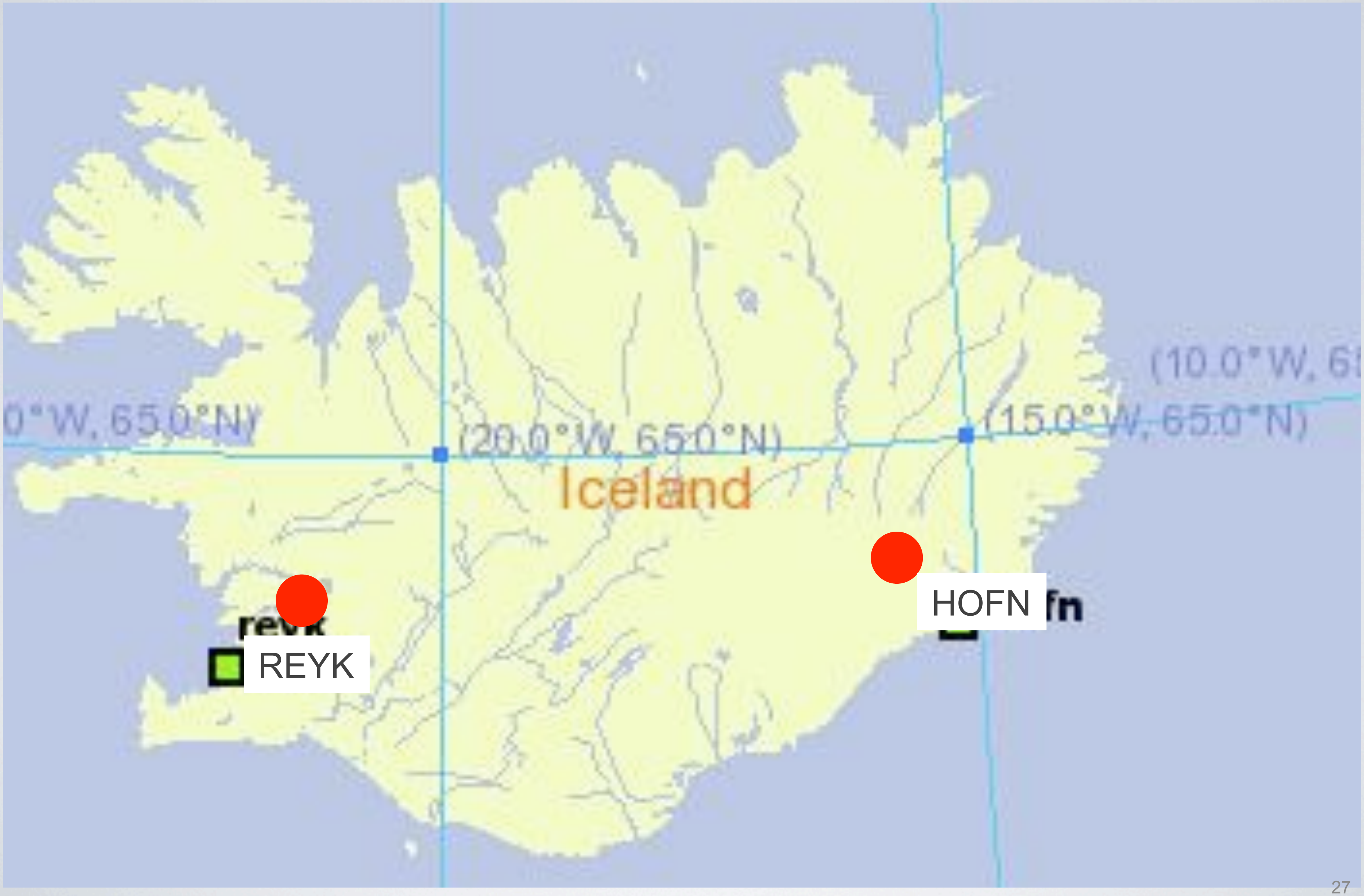
- Power outages
- Snow coverage
- Equipment failure
- Vandalism
- Wildlife
- Etc.

Exploring Iceland's GPS data and maps

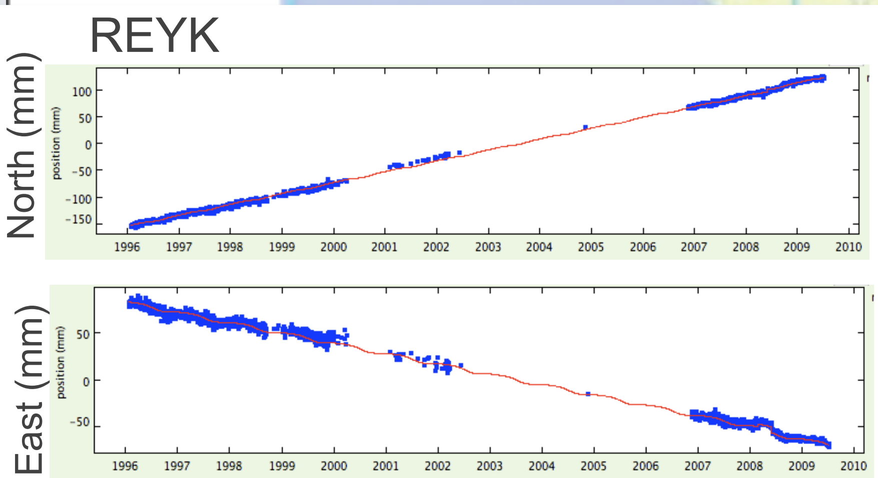
Where is Iceland?

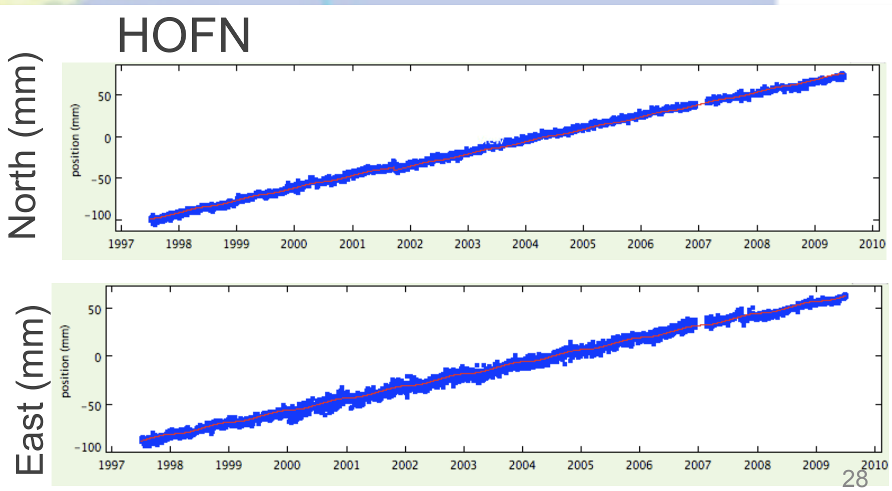


Iceland's GPS Data: REYK & HOFN



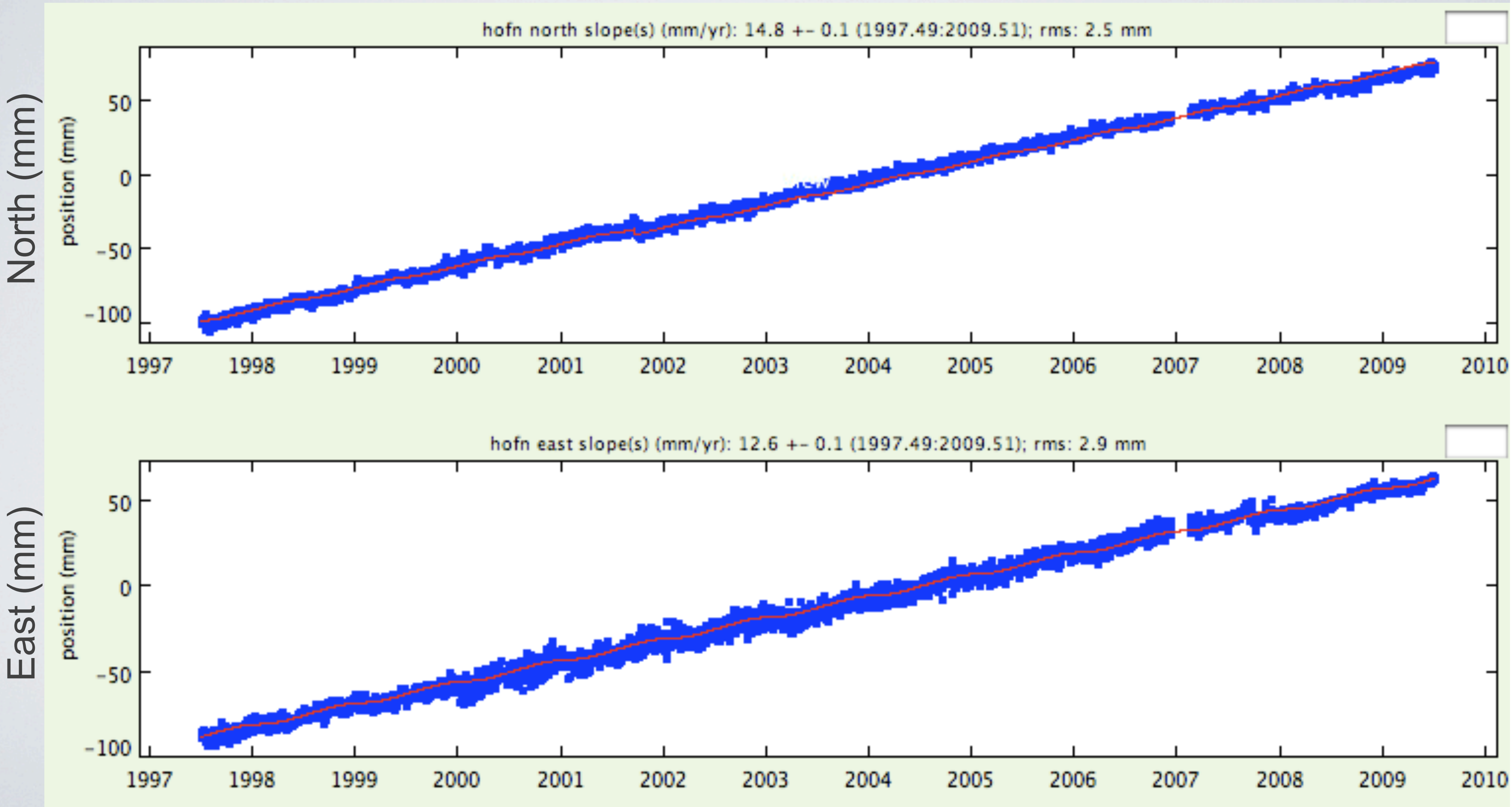
Iceland's GPS data





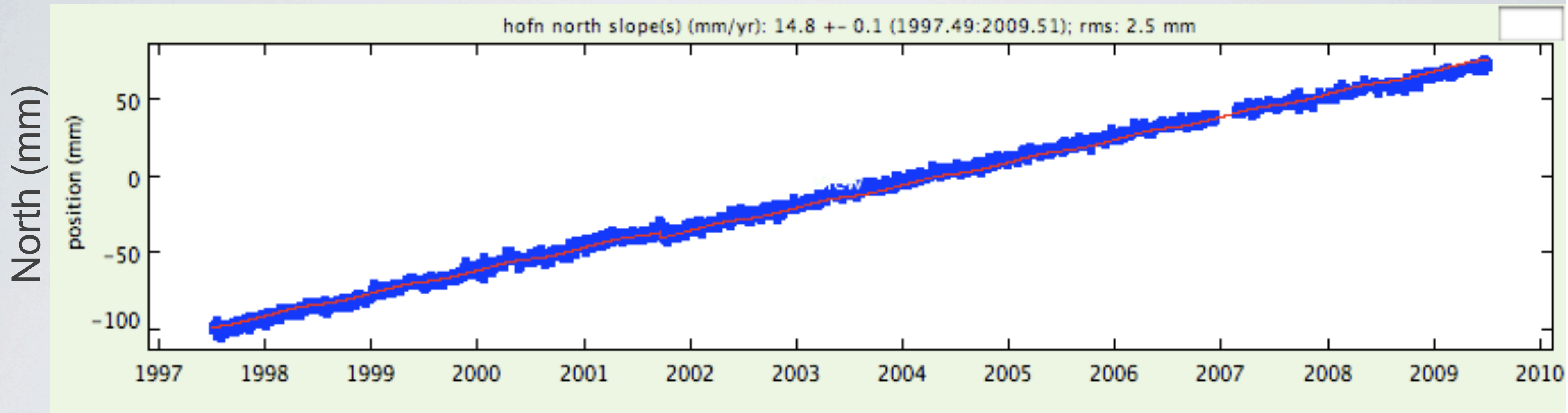
Calculating velocities of the GPS stations

What are the units of measurement for this data?



GPS monument HOFN: north

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

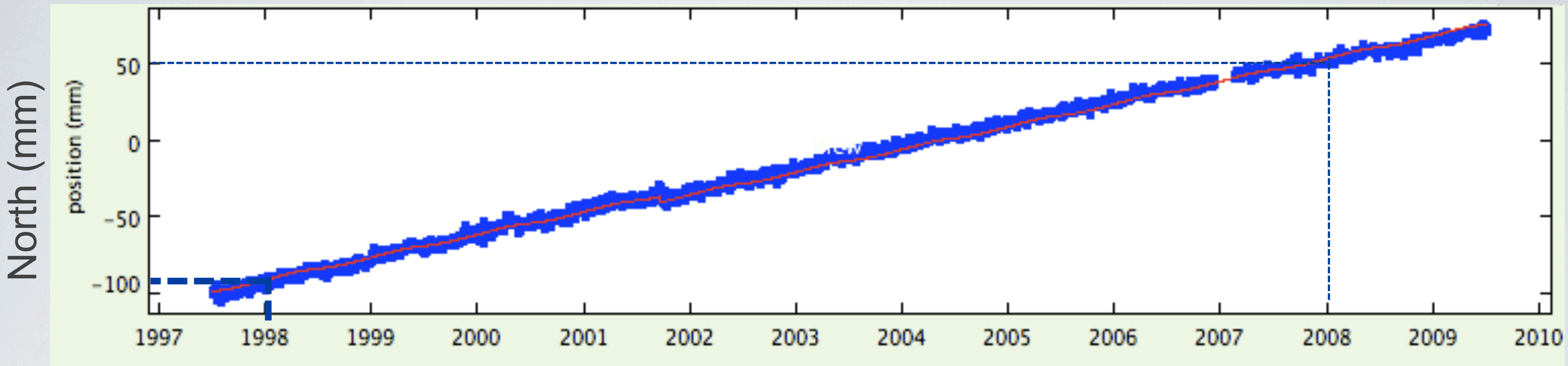


Let's look at 1998 and 2008.

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

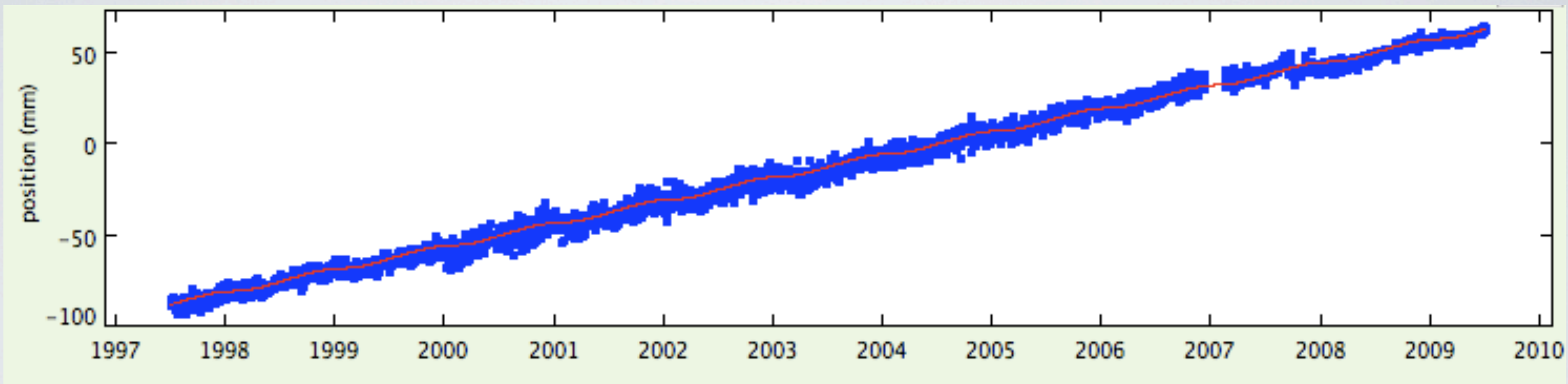
Change in position = 50 – (-98) = 148 mm

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?

East (mm)



Average position on 1/1/2008 = ______ mm

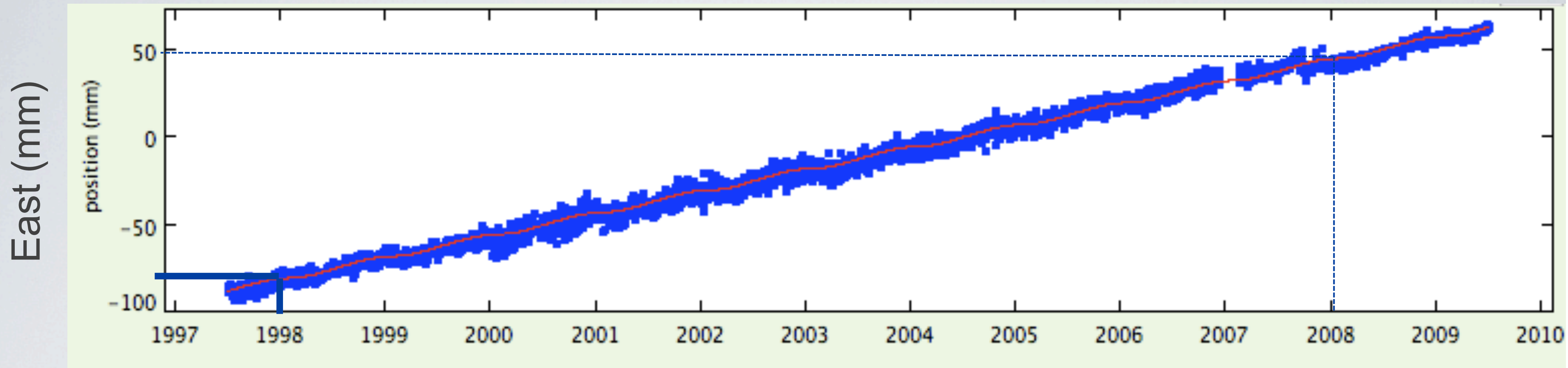
Average position on 1/1/1998 = ______ mm

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?



Average position on 1/1/2008 = 50 mm

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

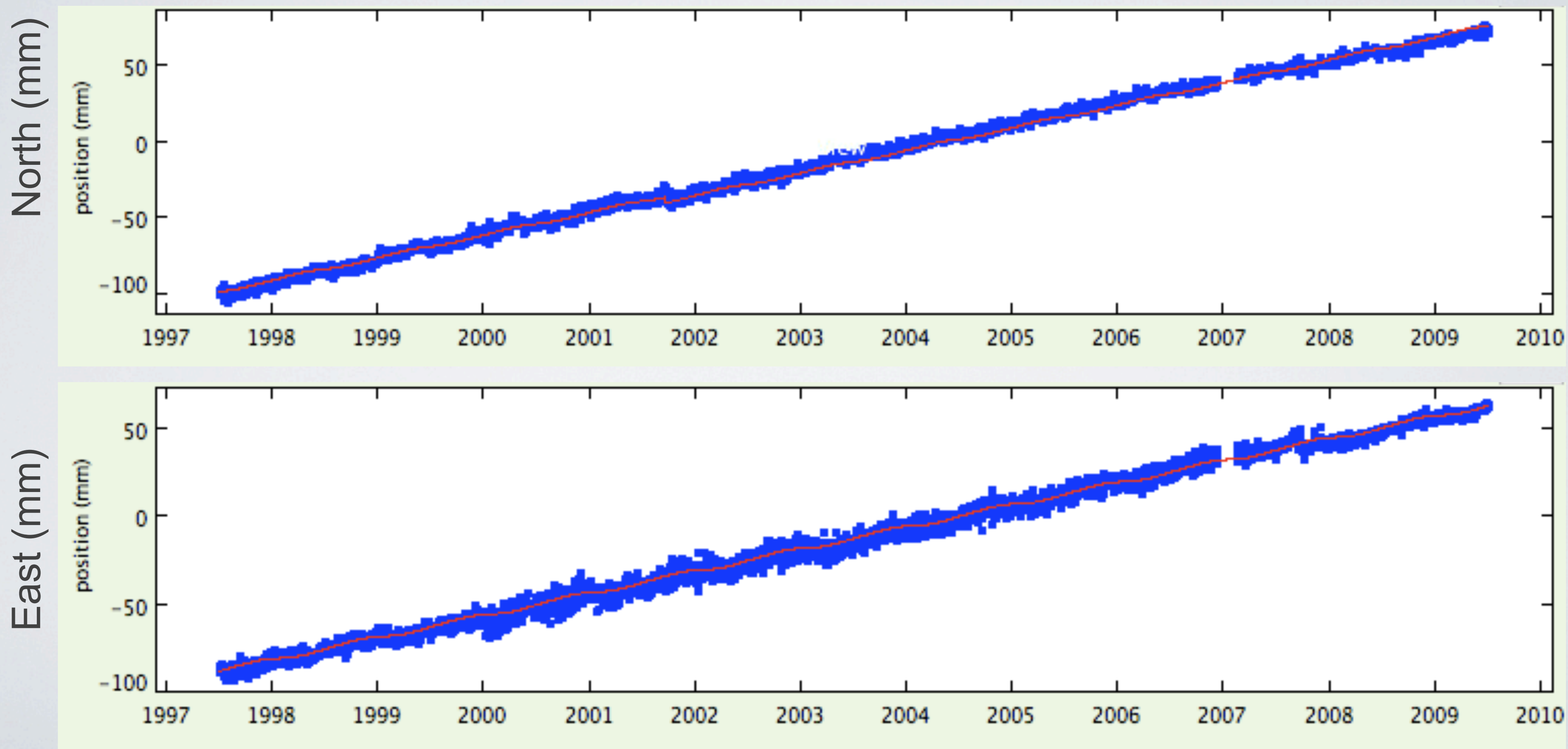
Speed of HOFN east = 130 mm/10 years

= 13 mm/yr to the east for HOFN

GPS monument HOFN

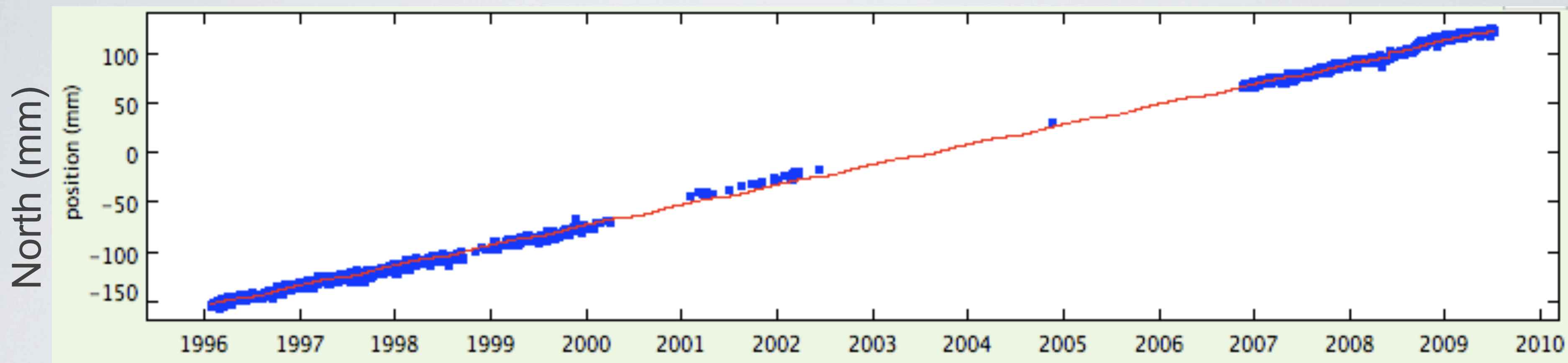
What direction is Monument HOFN moving?

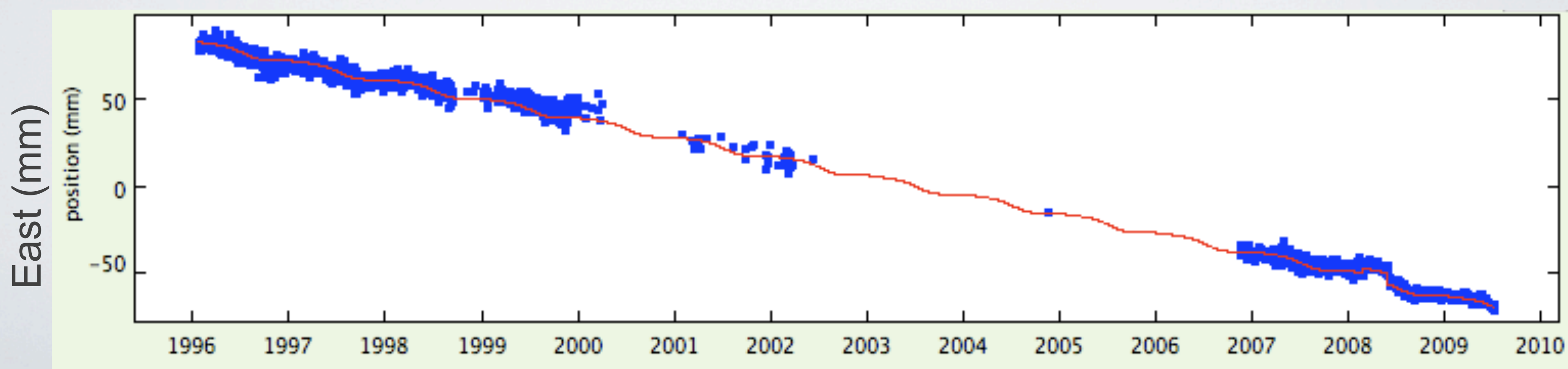
a) north only
b) northwest
c) northeast
d) southwest



GPS monument REYK

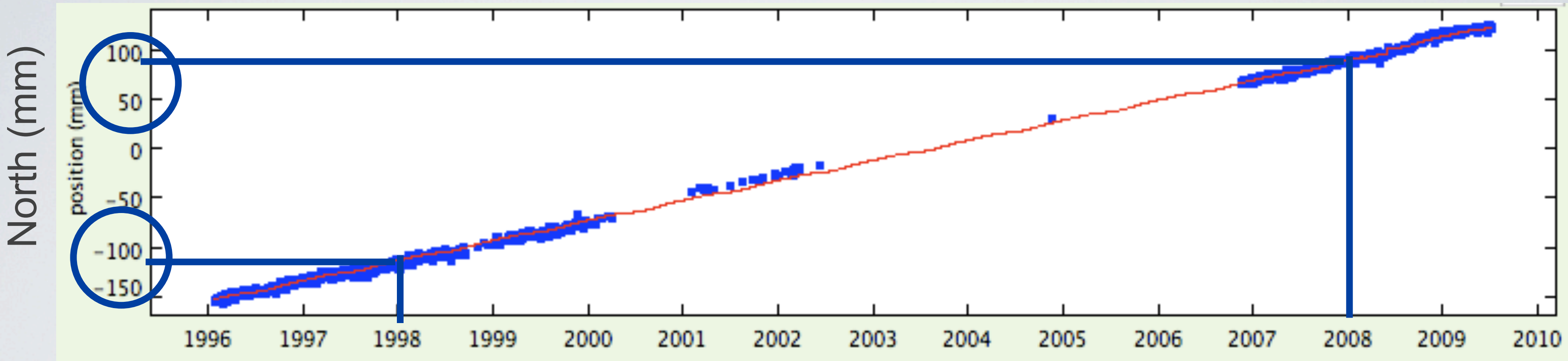
Think, then discuss with your neighbor: What direction is monument REYK moving? About how fast?





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

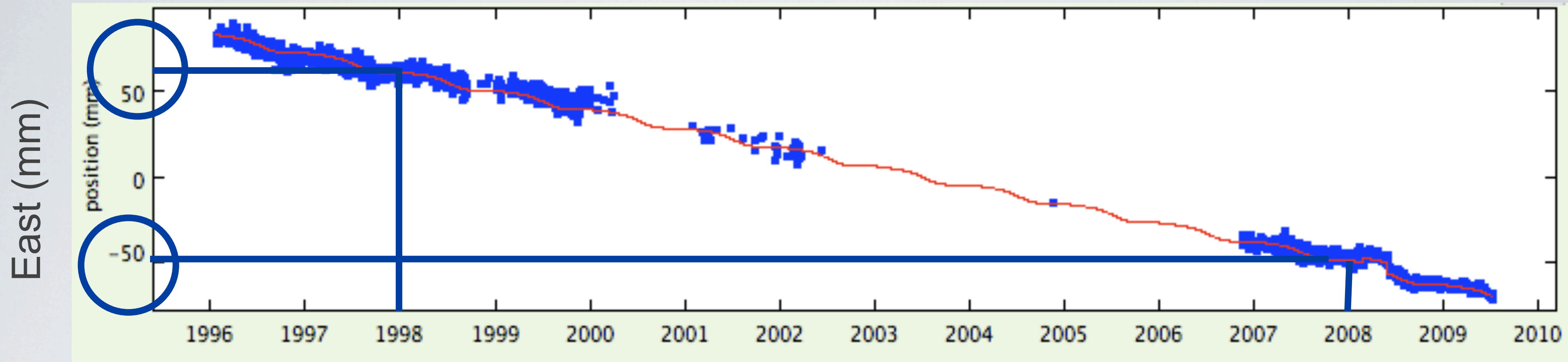
Speed of REYK north = (90 – -115) mm/10 years

= 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

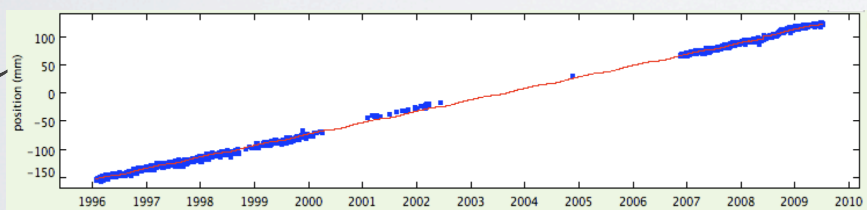
There must be an easier way to show this!

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

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

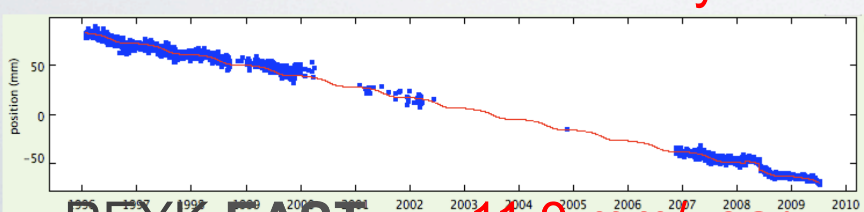
REYK

North (mm)



REYK **North** = 20.5 mm/year

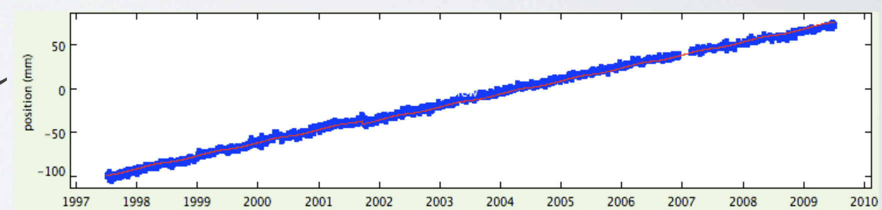
East (mm)



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

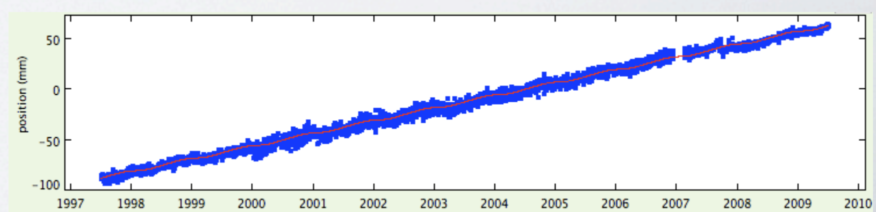
HOFN

North (mm)



HOFN **North** = 15.0 mm/year

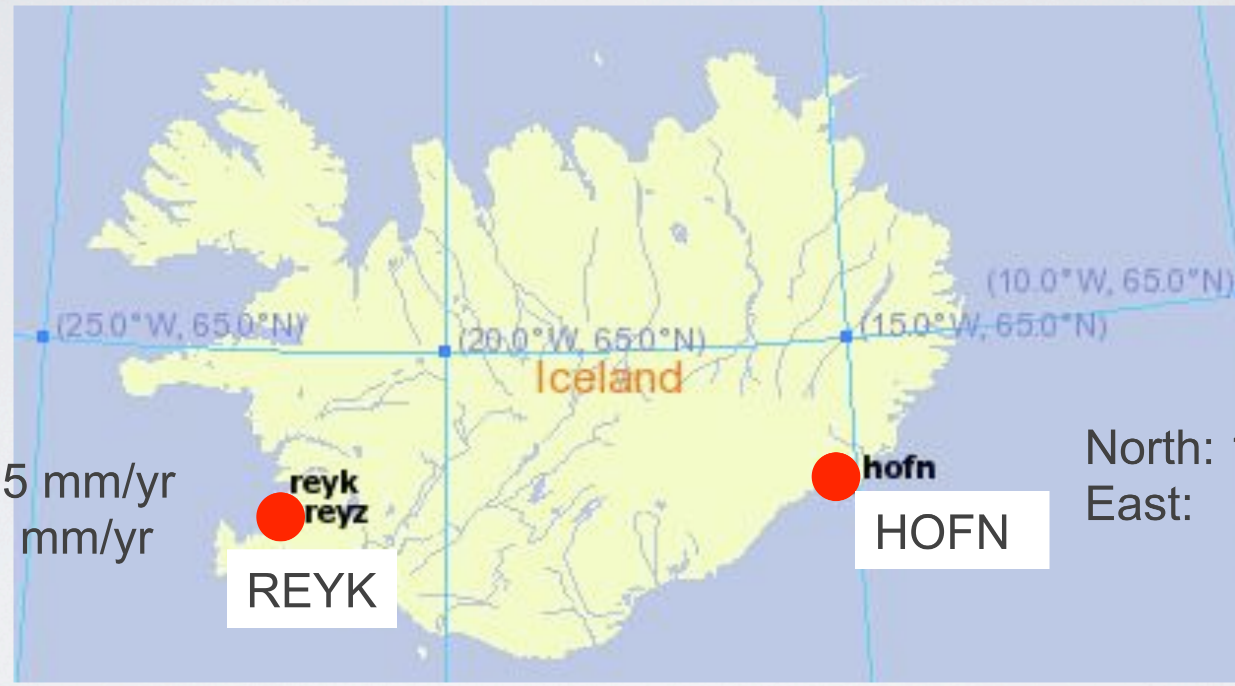
East (mm)



HOFN **EAST** = 13.0 mm/year

Are REYK and HOFN moving…

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

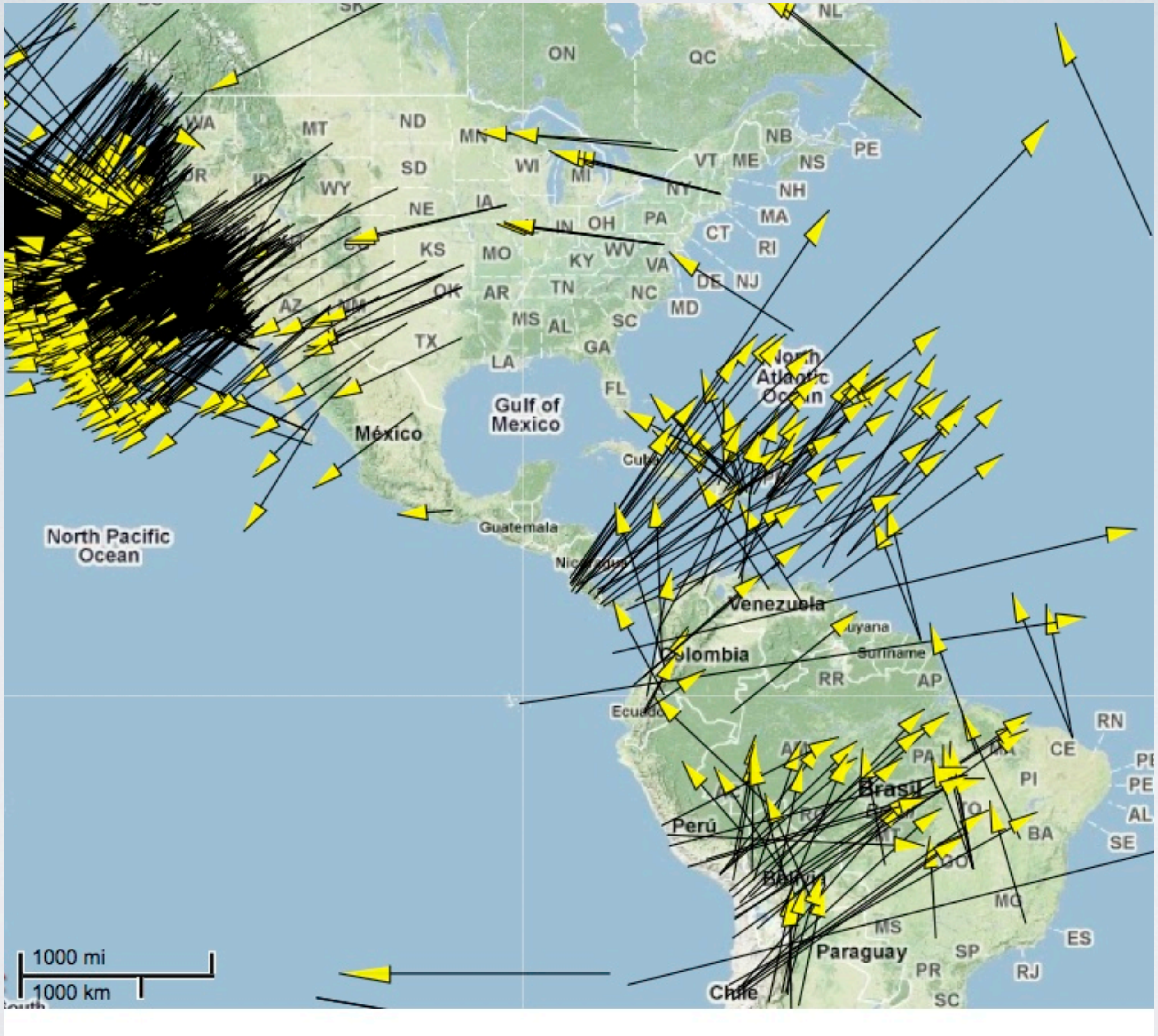


North: 20.5 mm/yr
East: -11 mm/yr

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

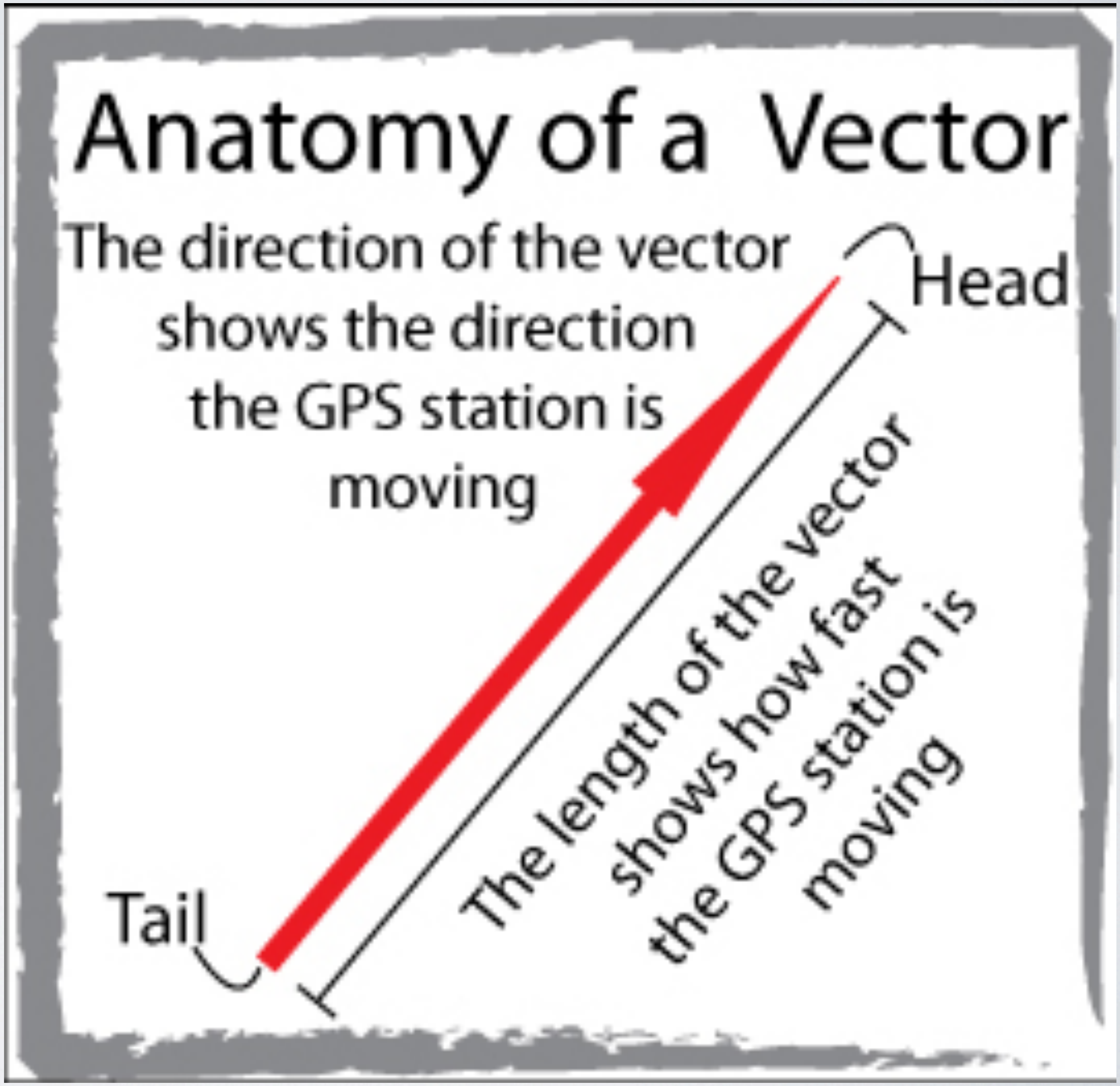
Mimic these motions with your GPS models.

Mapping plate movement



What is a vector?

A vector shows Velocity and direction of motion.



Graph paper as a map

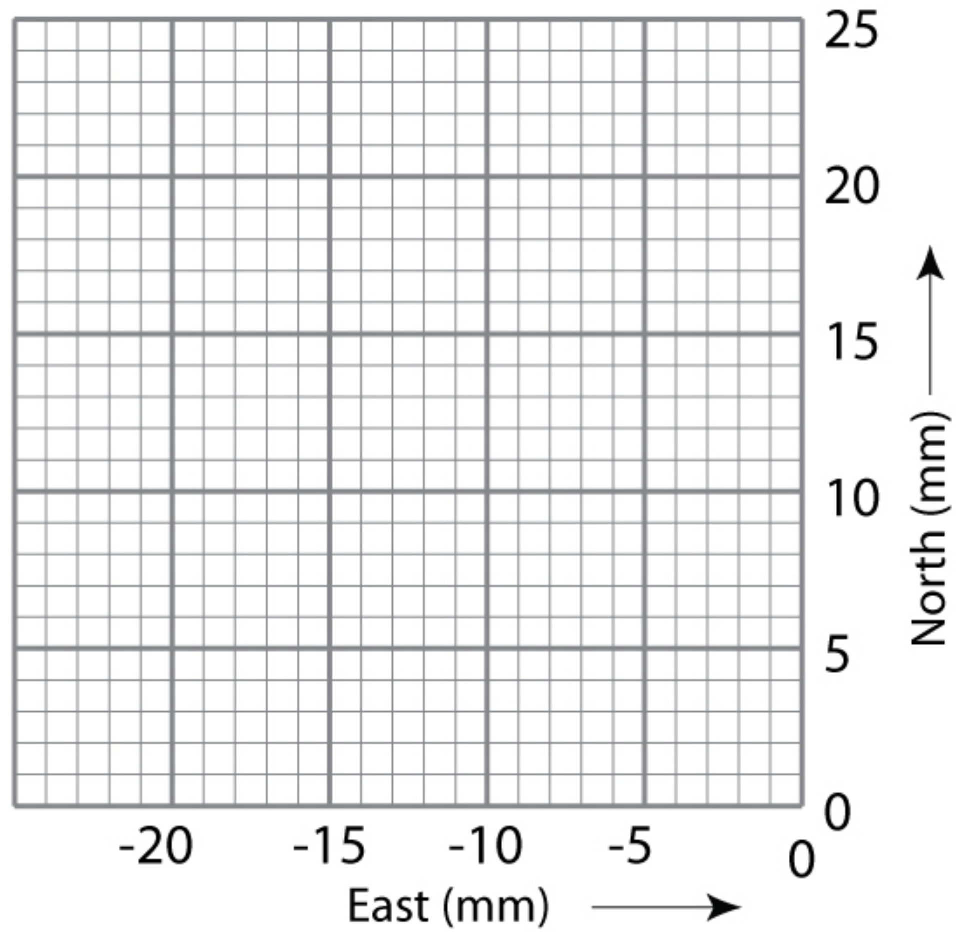
Each axis uses the same scale.

X-axis: east in millimeters (per year)

Y-axis: north in millimeters (per year)

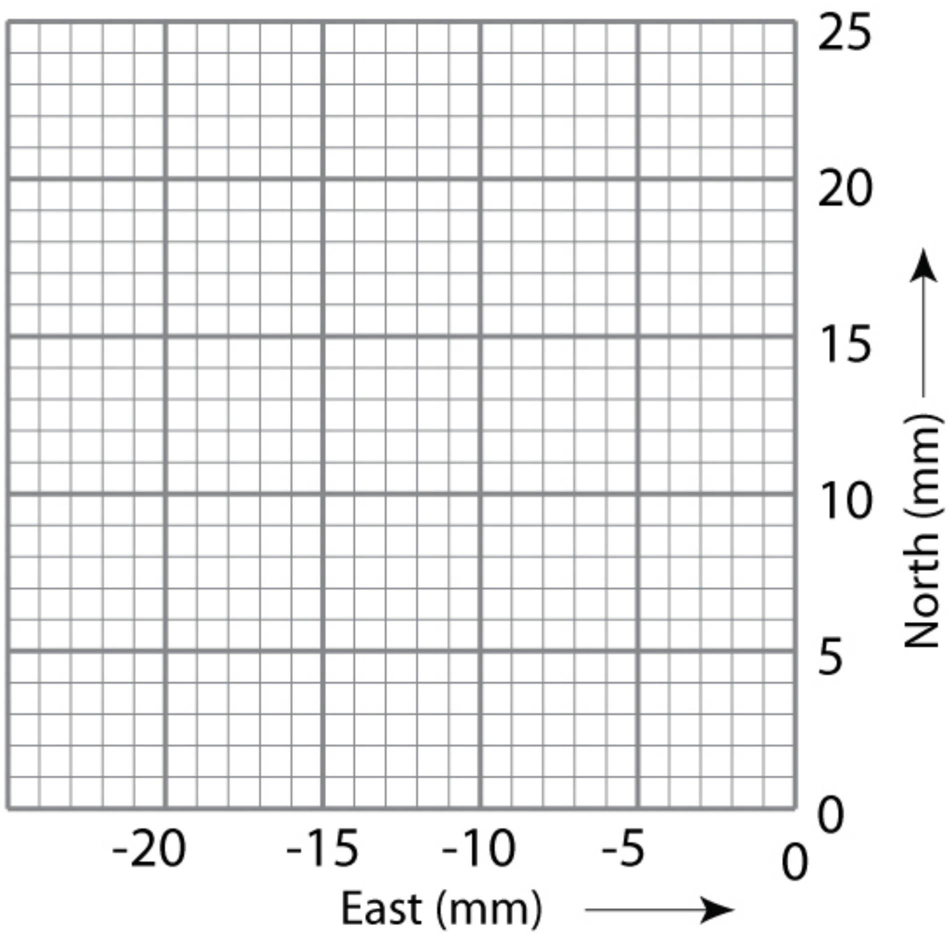
On your graph paper, each block represents 1 mm.

Where is the origin on this graph paper?

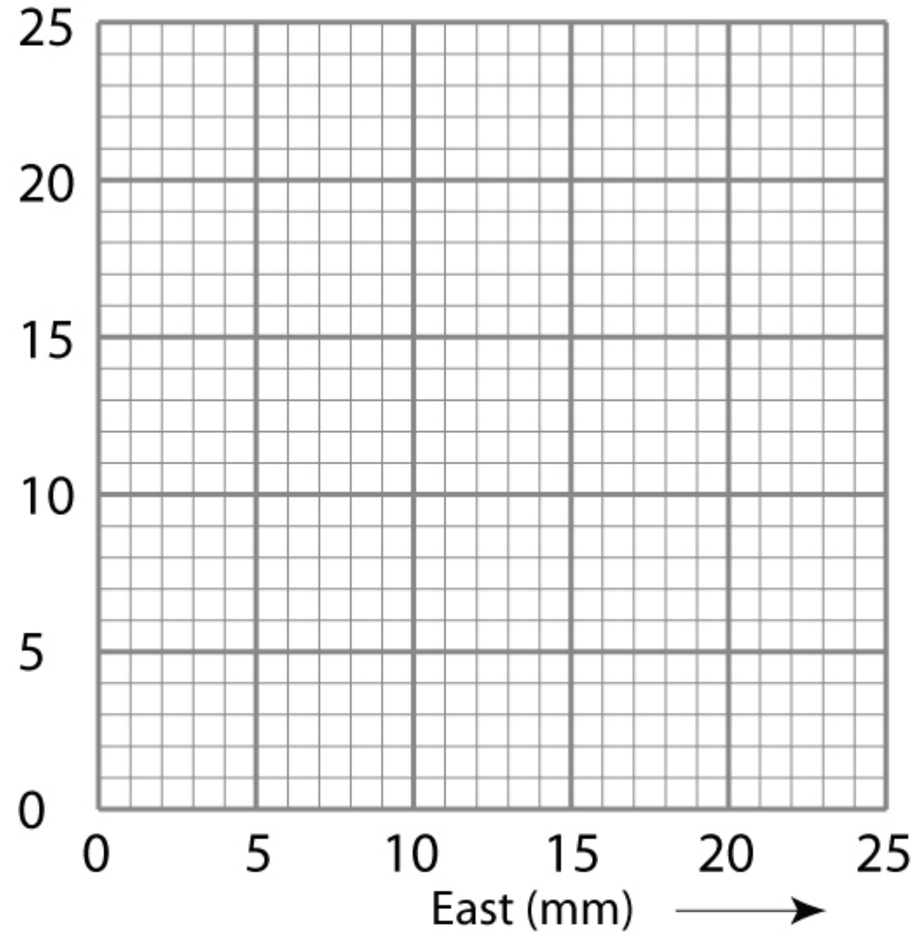


Graph paper as a map

REYK

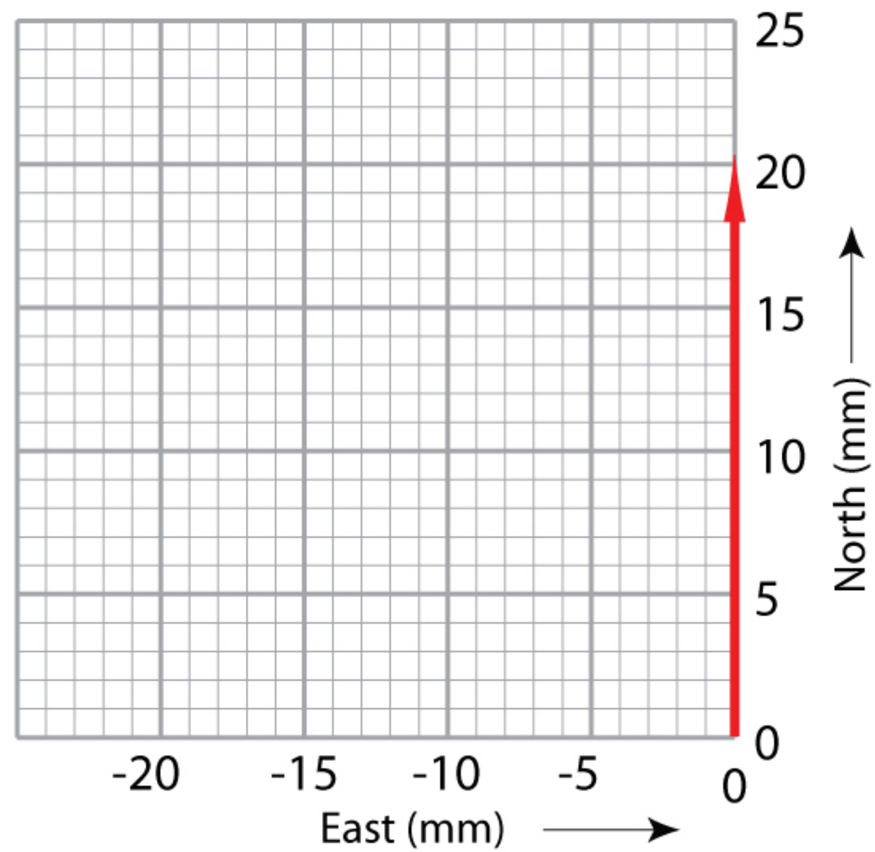


HOFN



Plotting REYK vectors

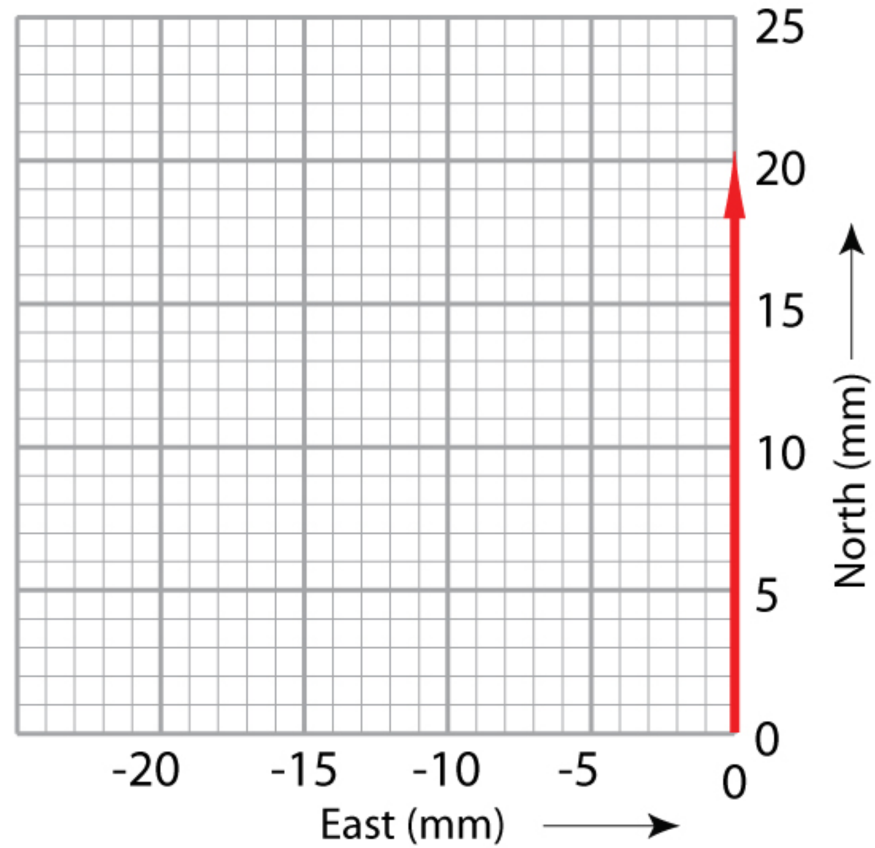
- Vector: magnitude and direction
  - Tail is the GPS monument location.
  - Length of arrow is the magnitude.
  - Shows direction on a map.



Plotting REYK vectors

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

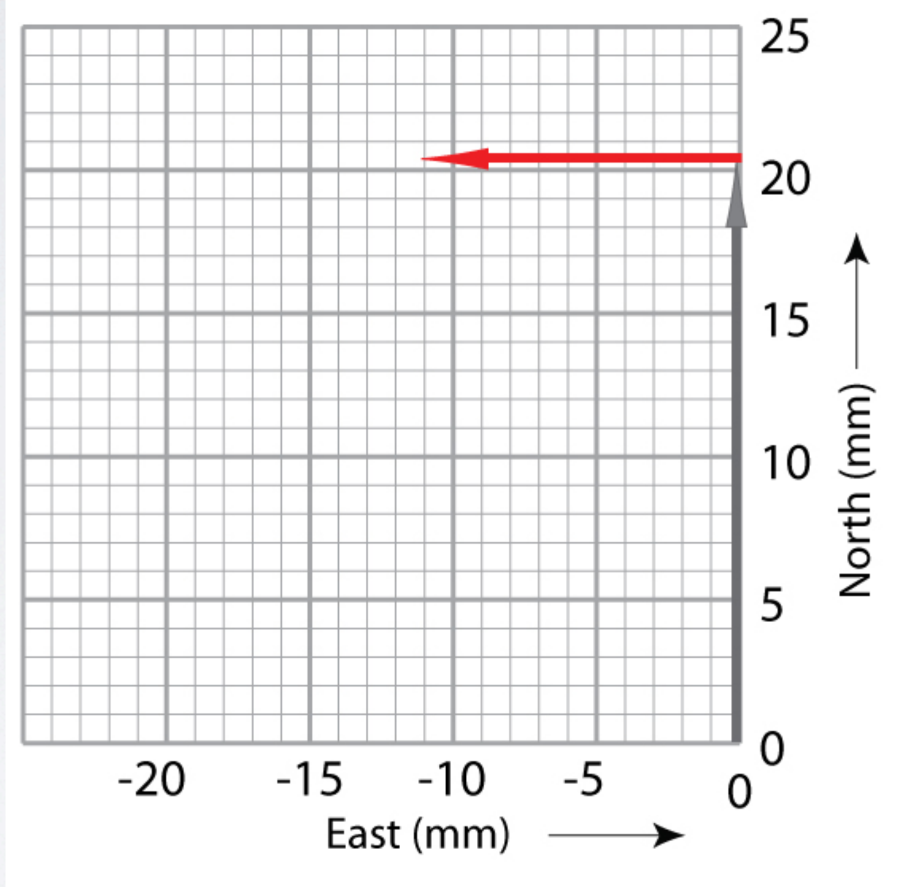
- GPS monument REYK moves 20.5 mm to the north per year
- Draw a vector arrow 20.5 blocks along the north axis.



Plotting REYK vectors

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

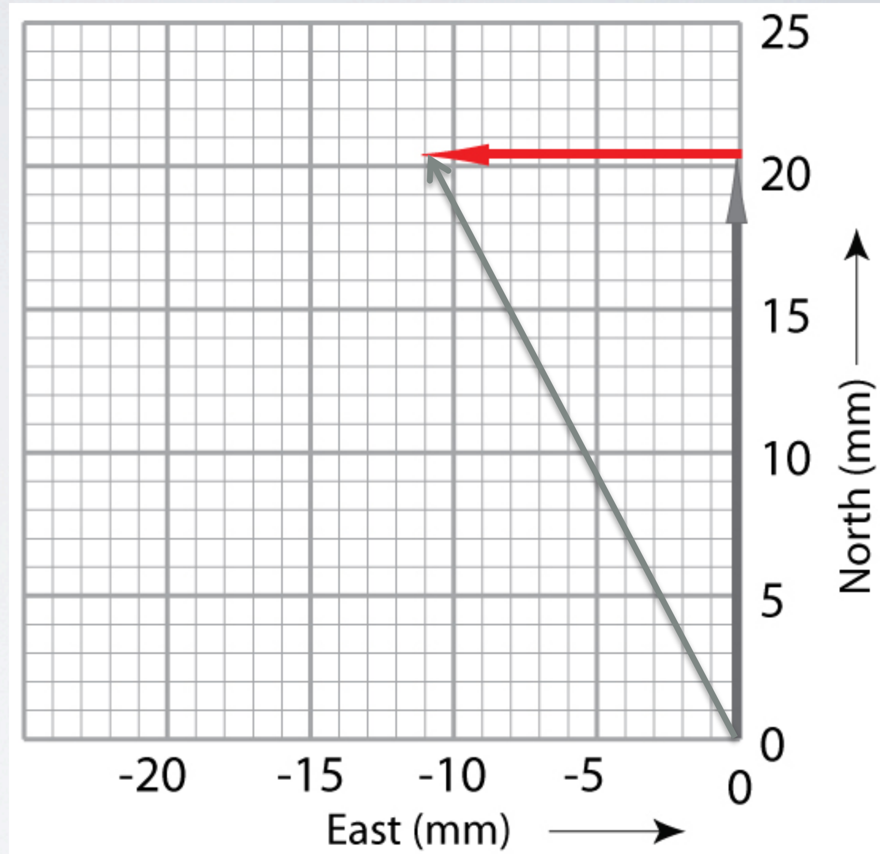
Draw the vector -11.0 blocks (mm) beginning at the head of the north arrow



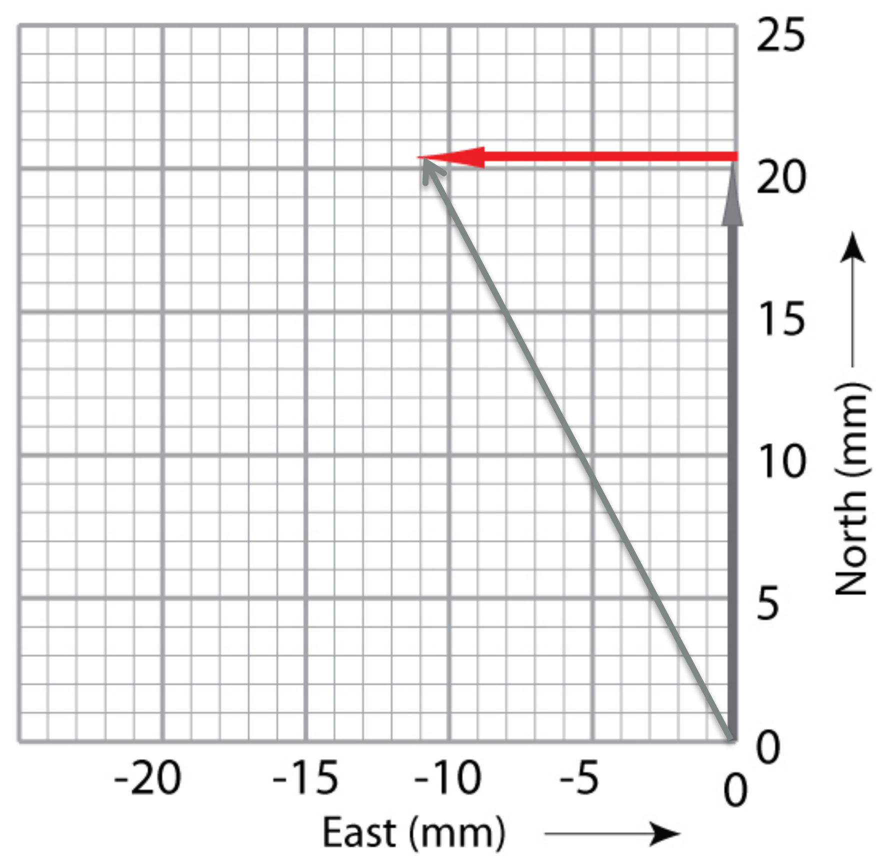
Adding REYK vectors

Step 3. Draw 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



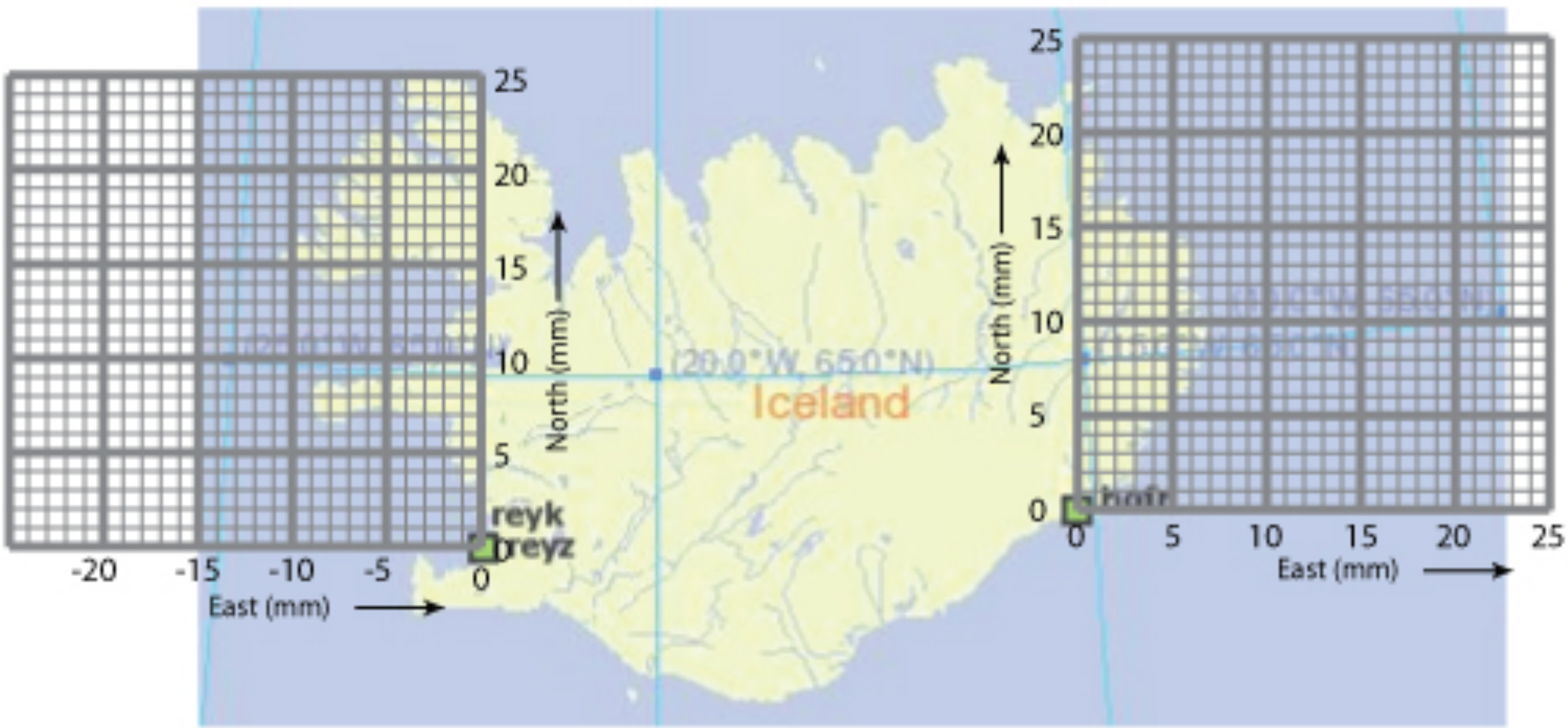
Or, use the Pythagorean theorem to add the vectors to find the sum.

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

_____ mm/yr to the

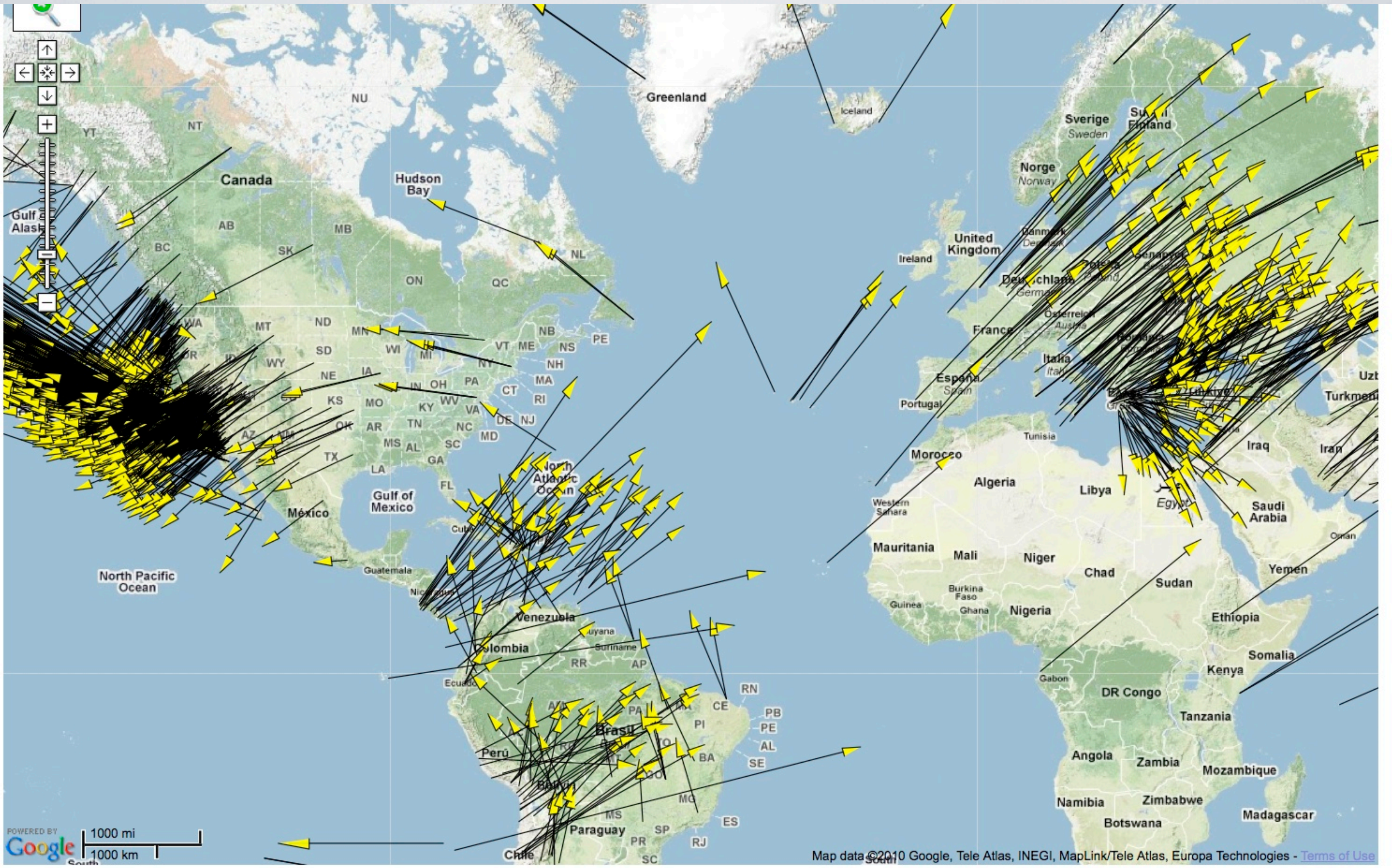
_____

Mapping vectors



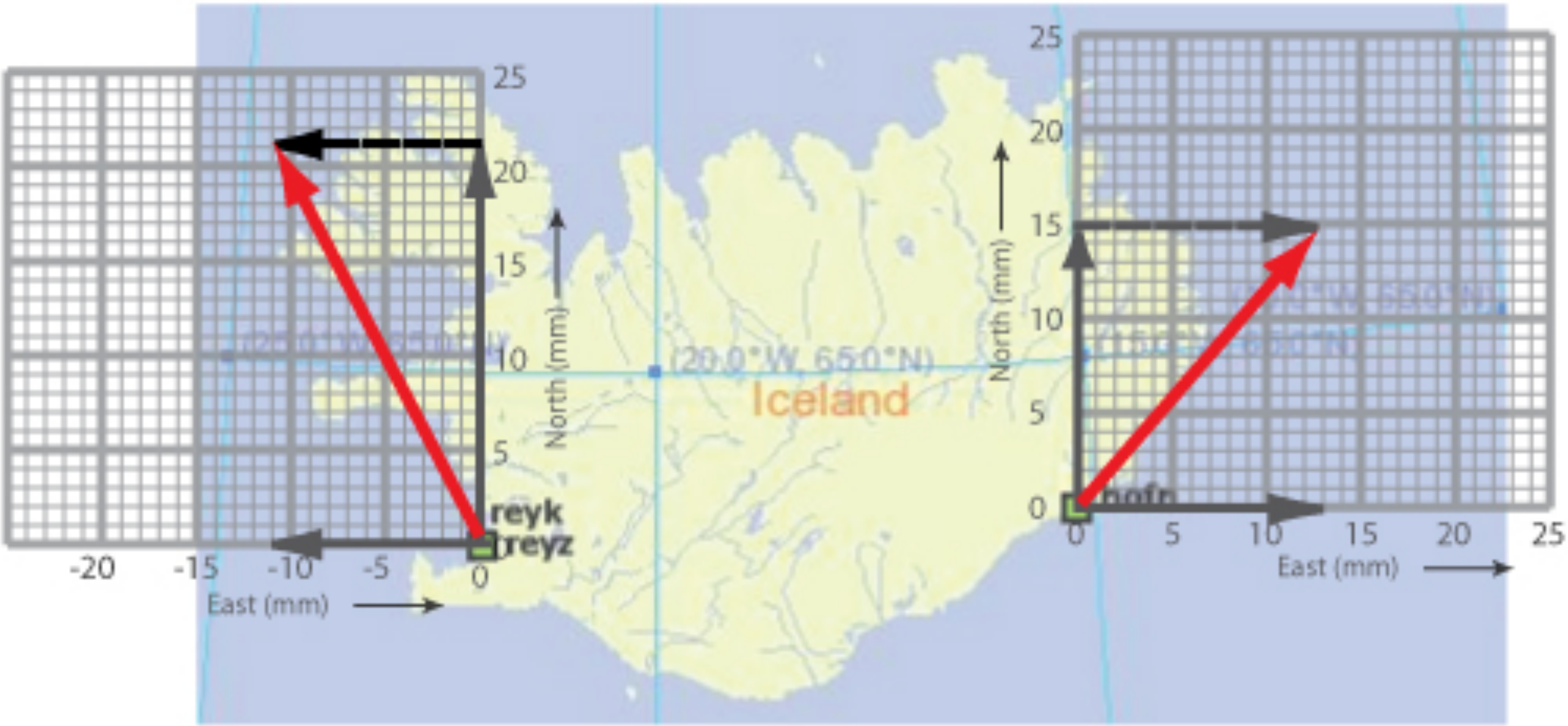
Now do HOFN on your own – compare with a neighbor

Looking at the world view of motion



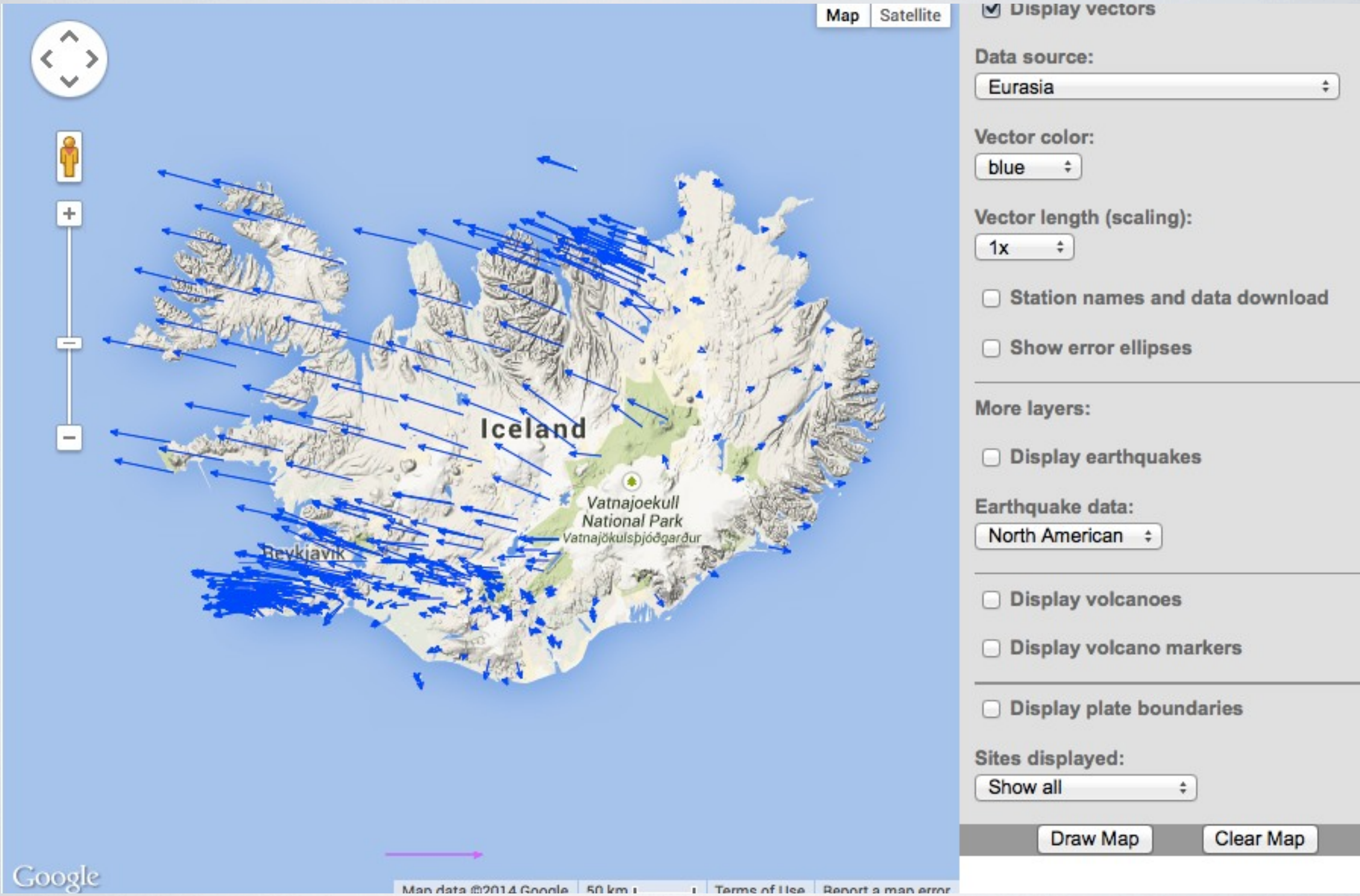
Perspective of looking from space

What is happening to Iceland?

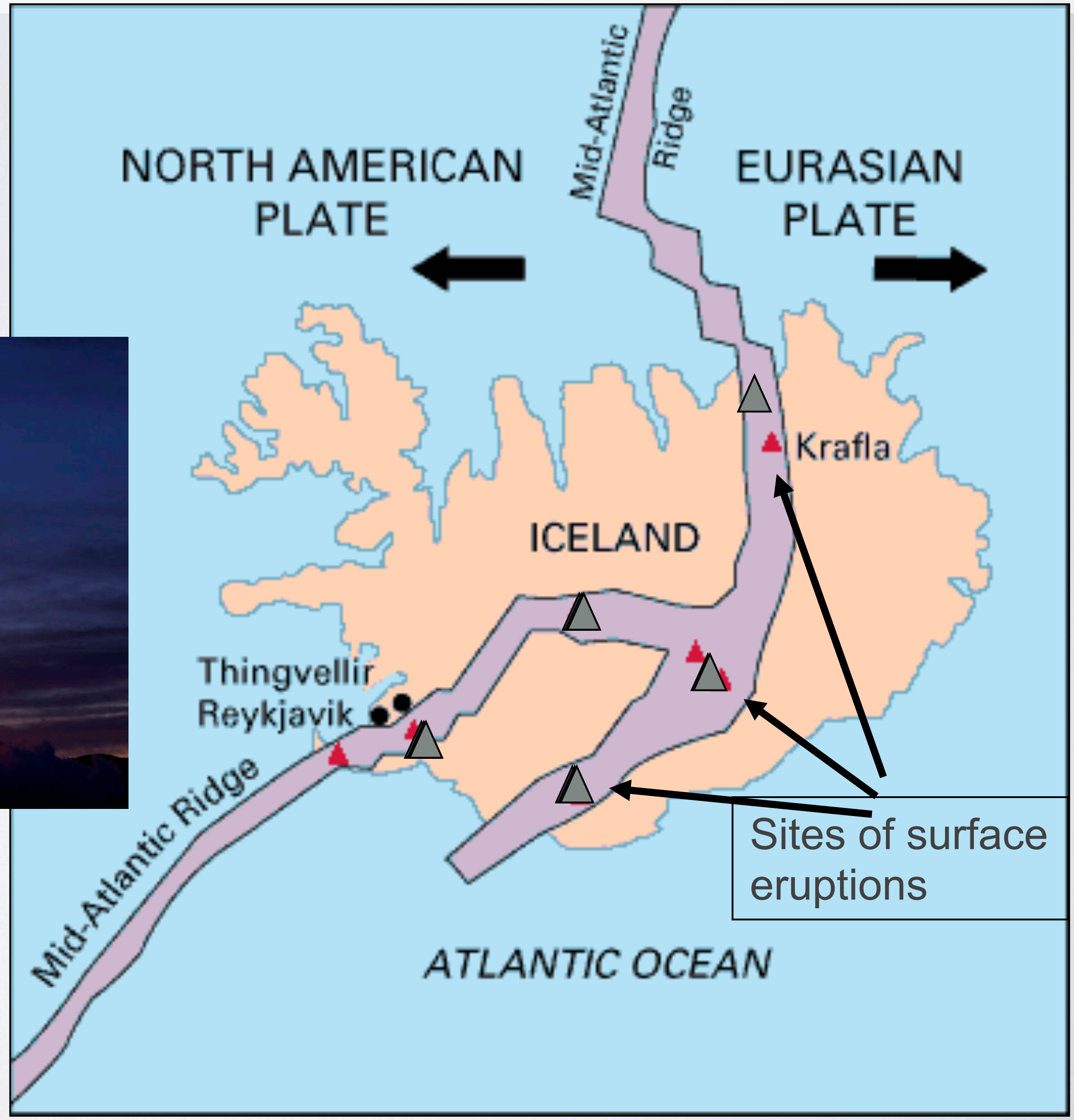


Extra credit – – if you were sitting at HOFN for a very long time, how would REYK be moving?

Motion of western Iceland when eastern Iceland is not moving



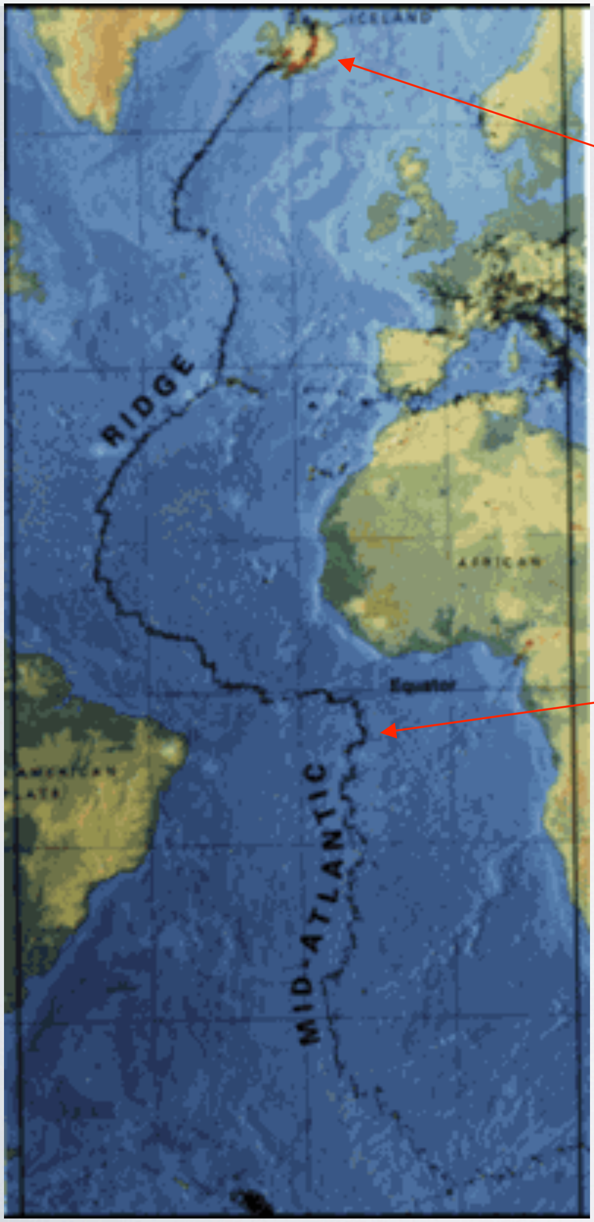
Rifting



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

Fissures opening

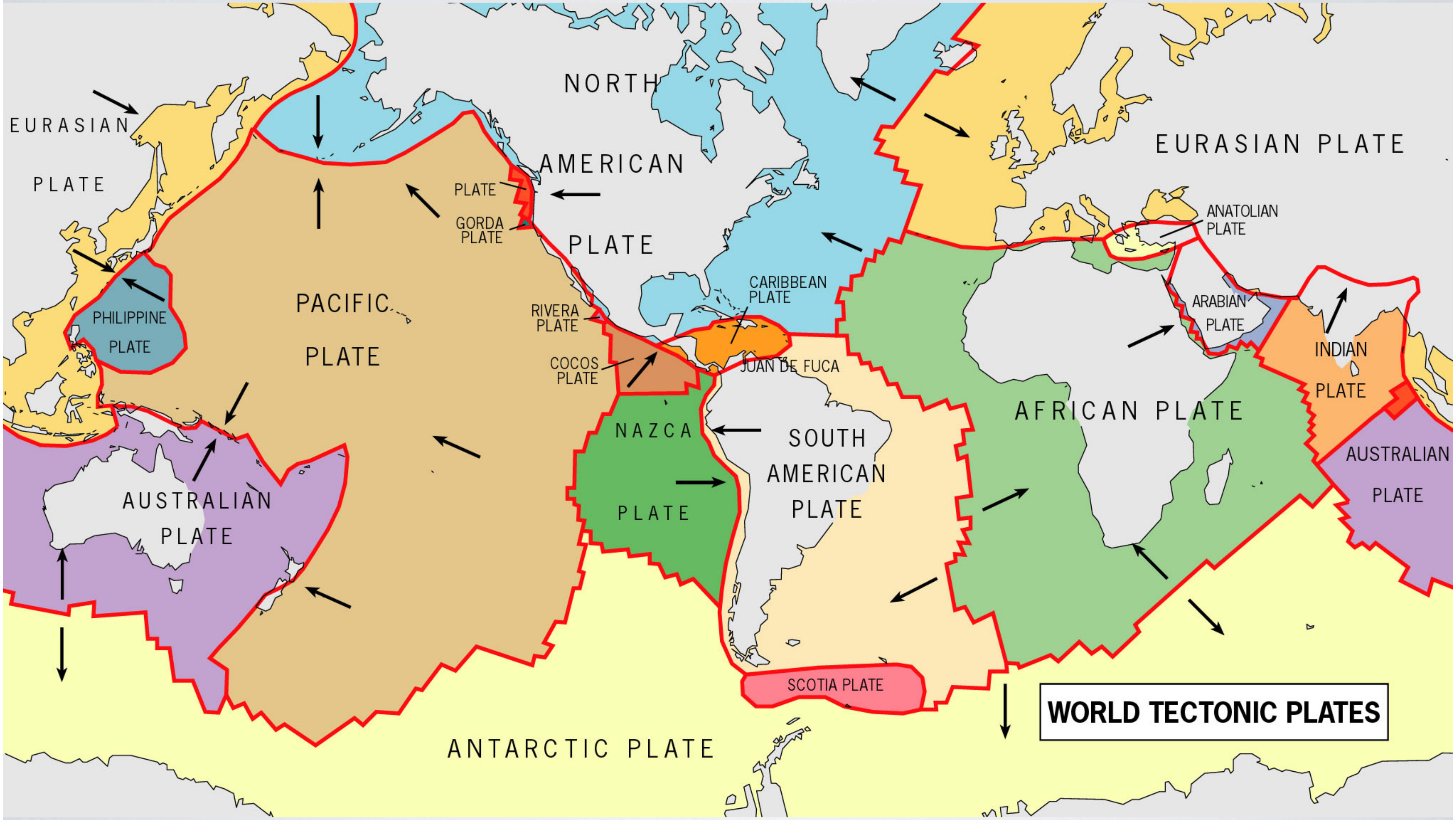
Mid-Atlantic Ridge



Iceland

Mid-Atlantic Ridge

Viewing another region: Africa

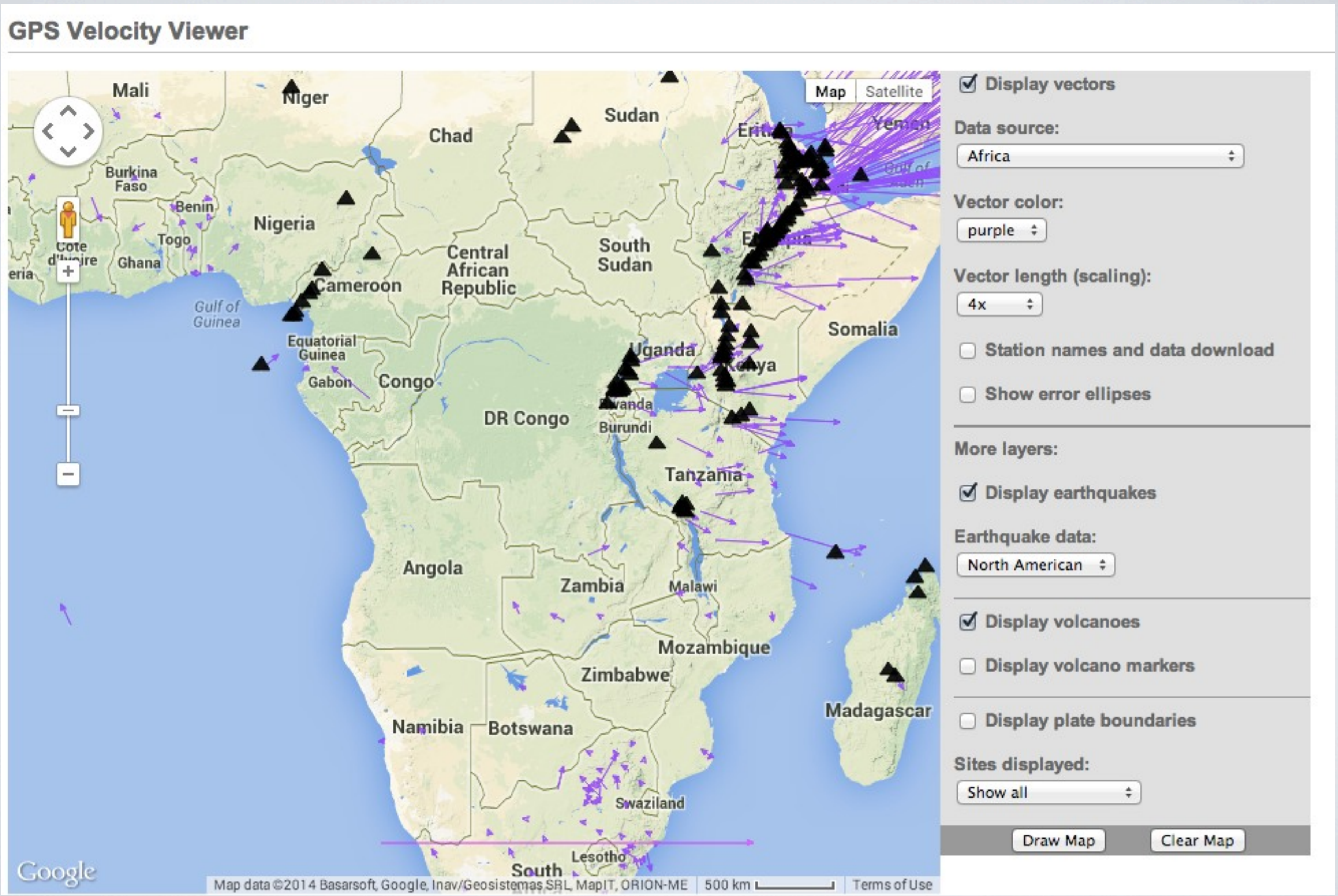


What's happening here?

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?

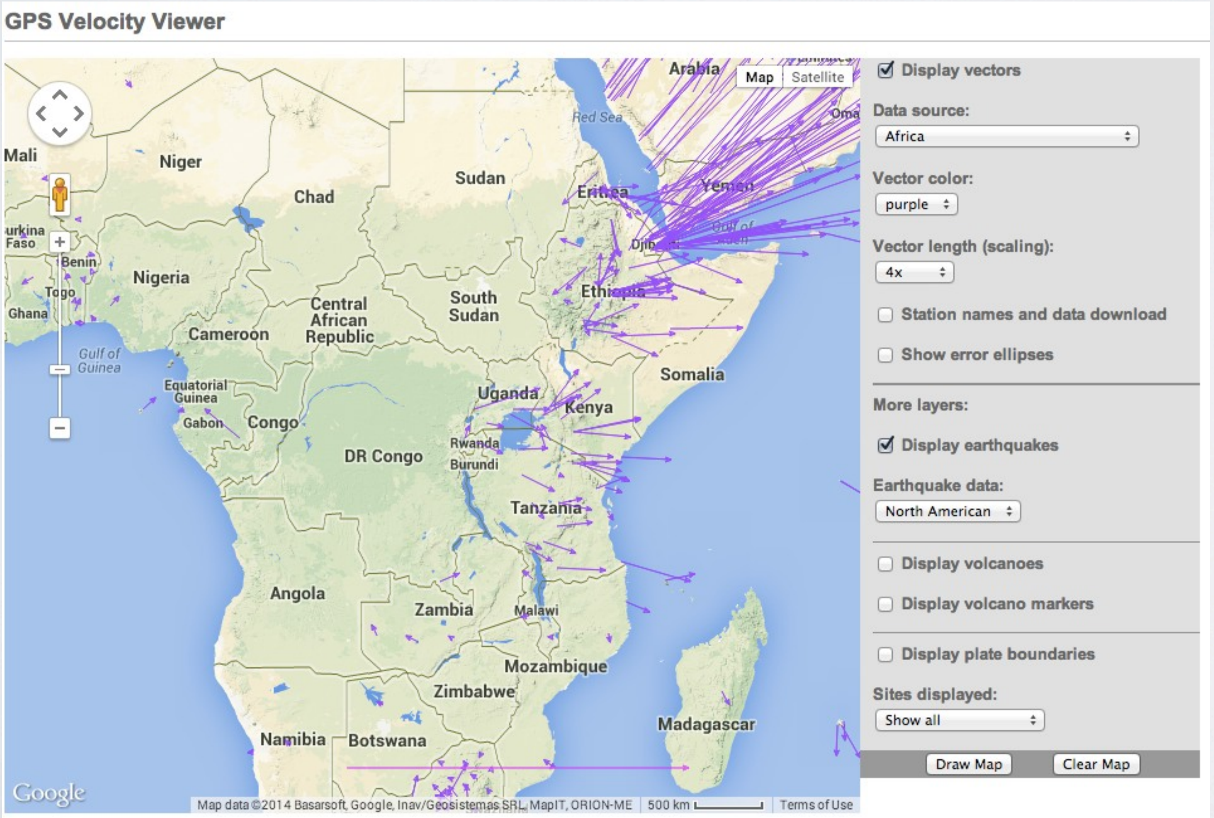
Volcanoes of Africa



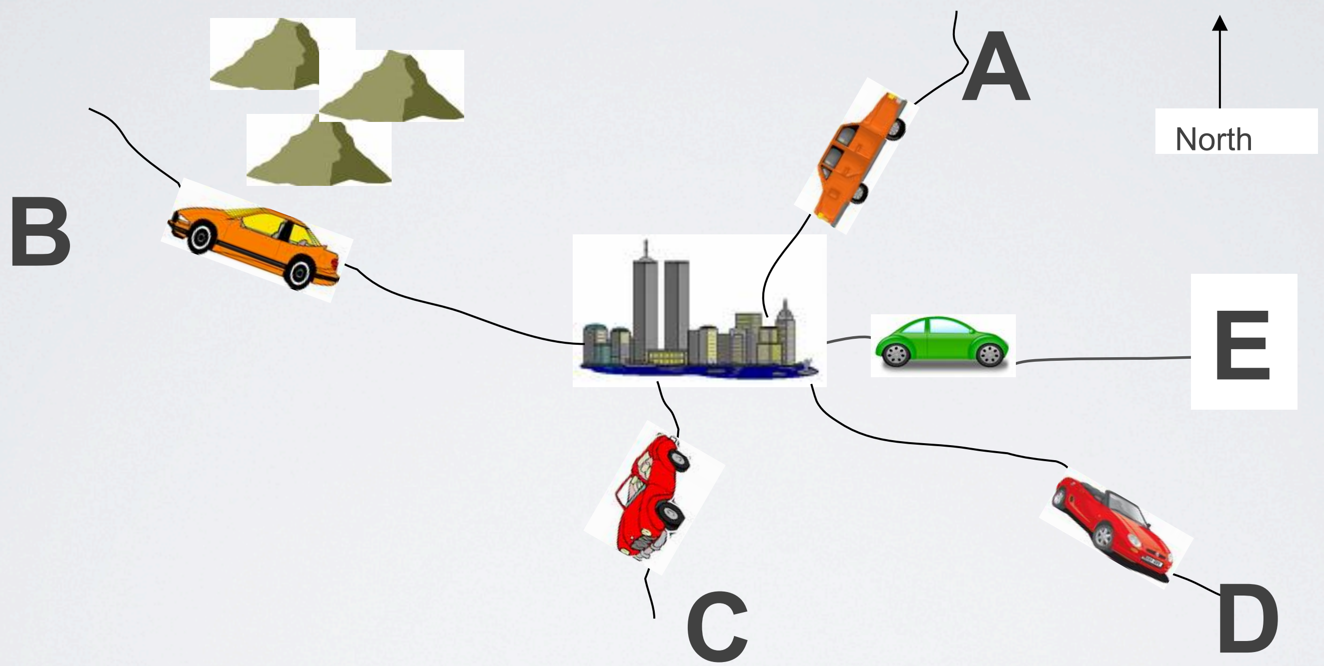
Explore more:

UNAVCO Velocity Viewer:

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

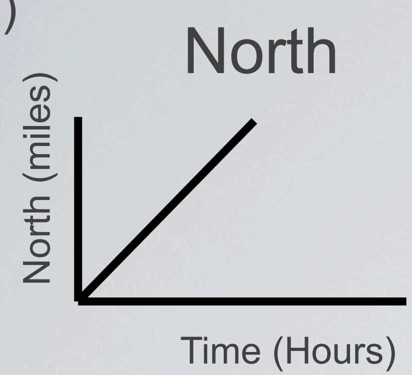


Part 3: Apply your knowledge



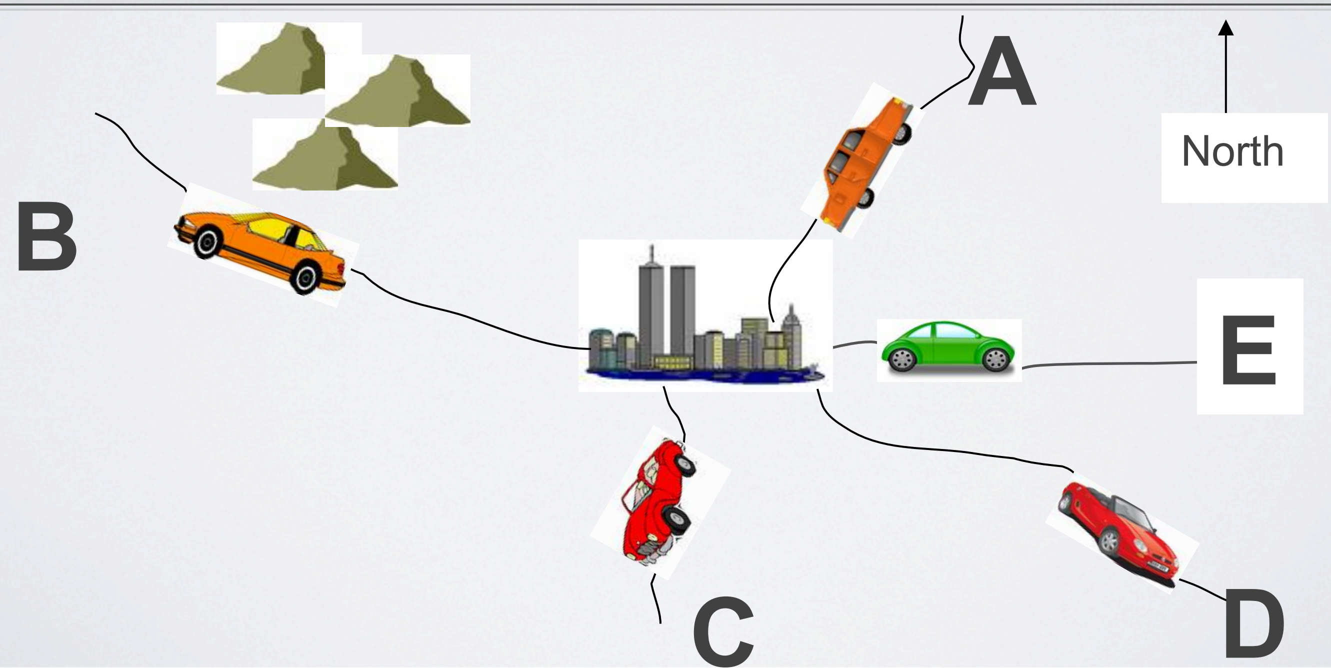
Match cars and graphs

i)



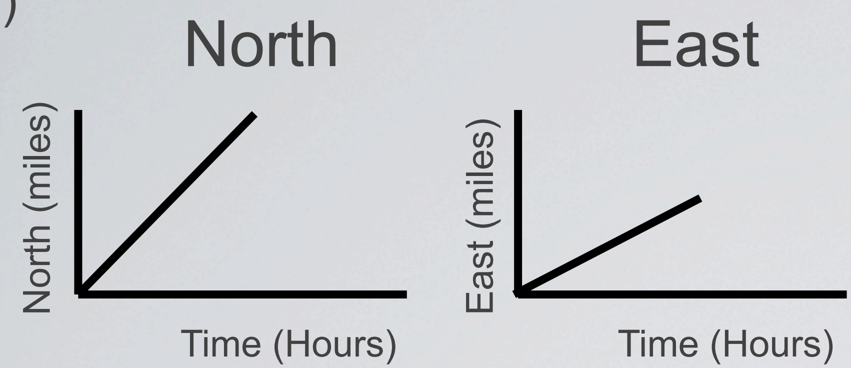
What direction? ______________

Which car? ______________



Match cars and graphs

i)

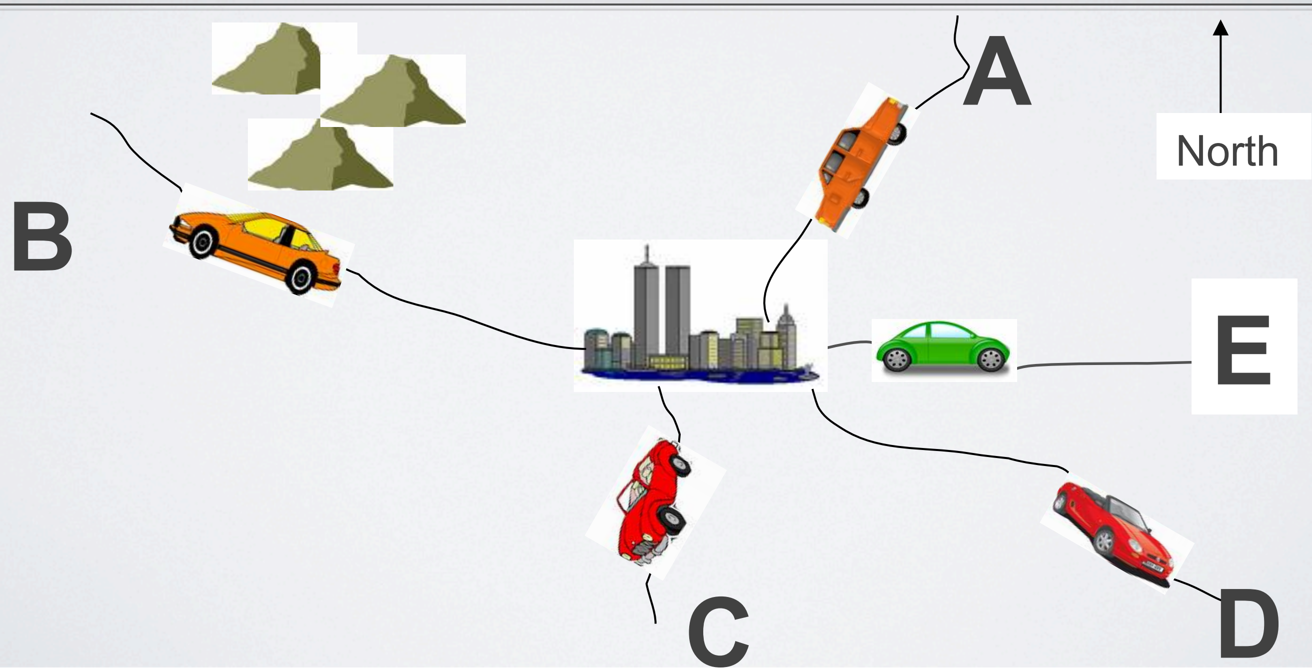


What direction?

North-Northeast

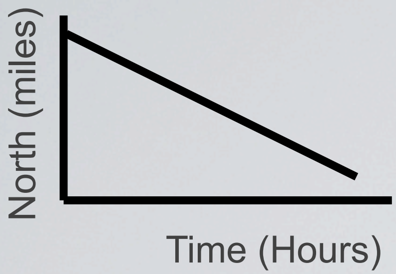
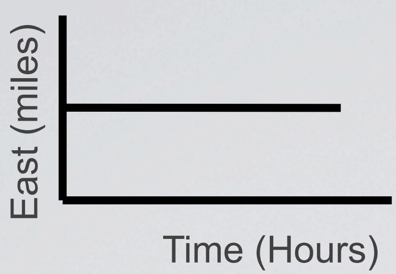
Which car?

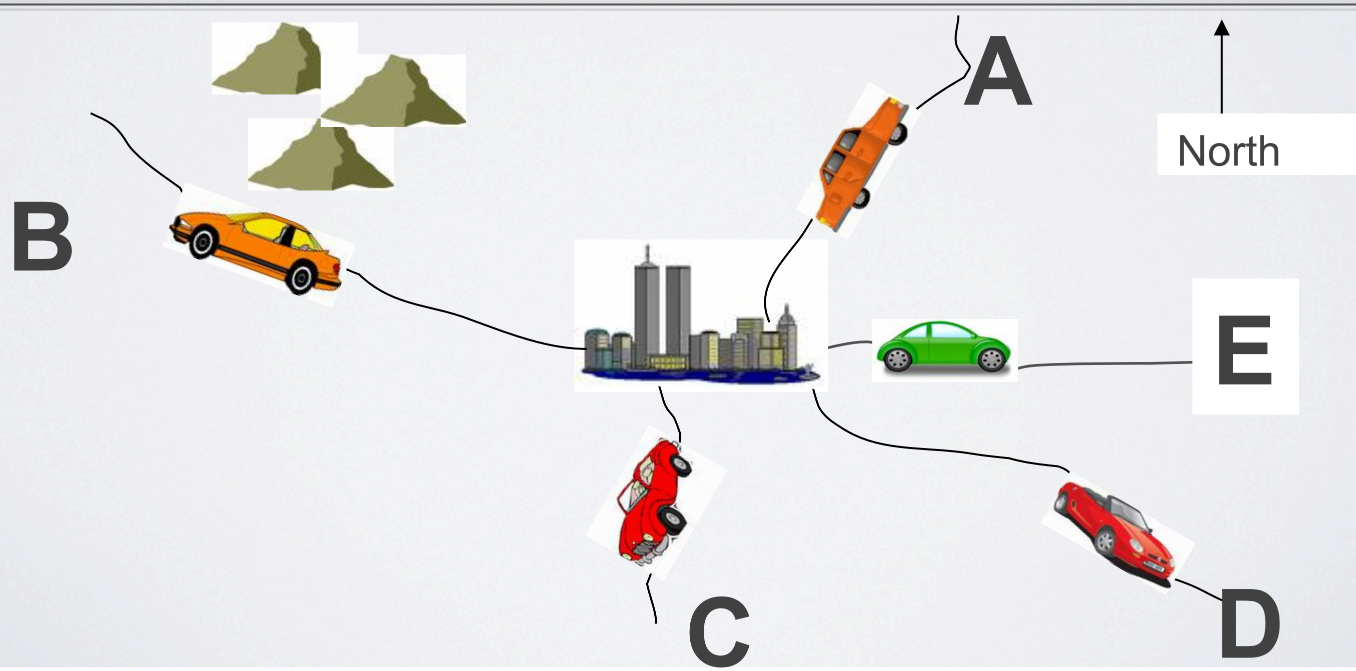
Car A



Match cars and graphs

ii)

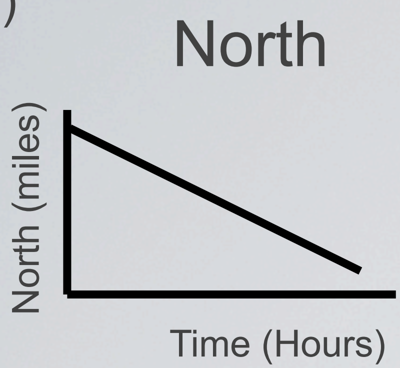
North	East	What direction?	Which car?
		______	______

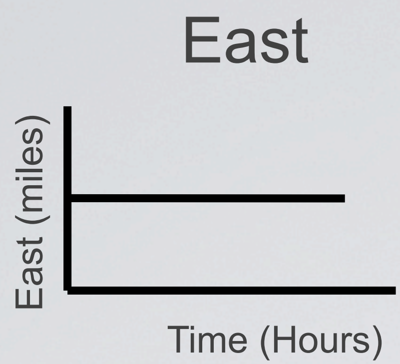


UNAVCO

Match cars and graphs

ii)



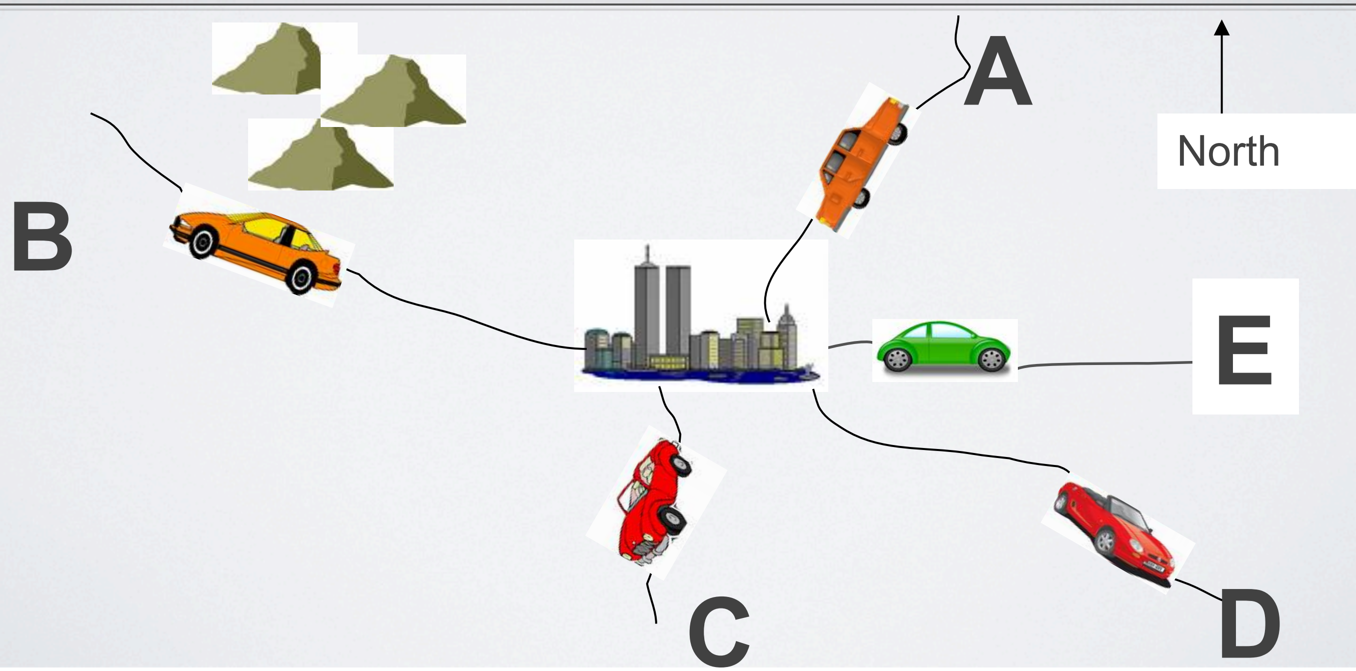


What direction?

South

Which car?

Car C



What direction is car D moving?

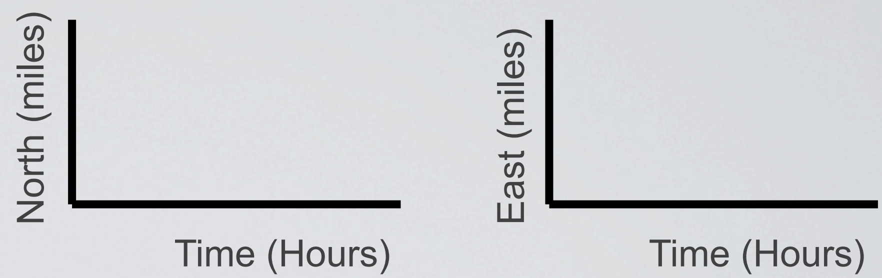
v) What direction is Car D moving?

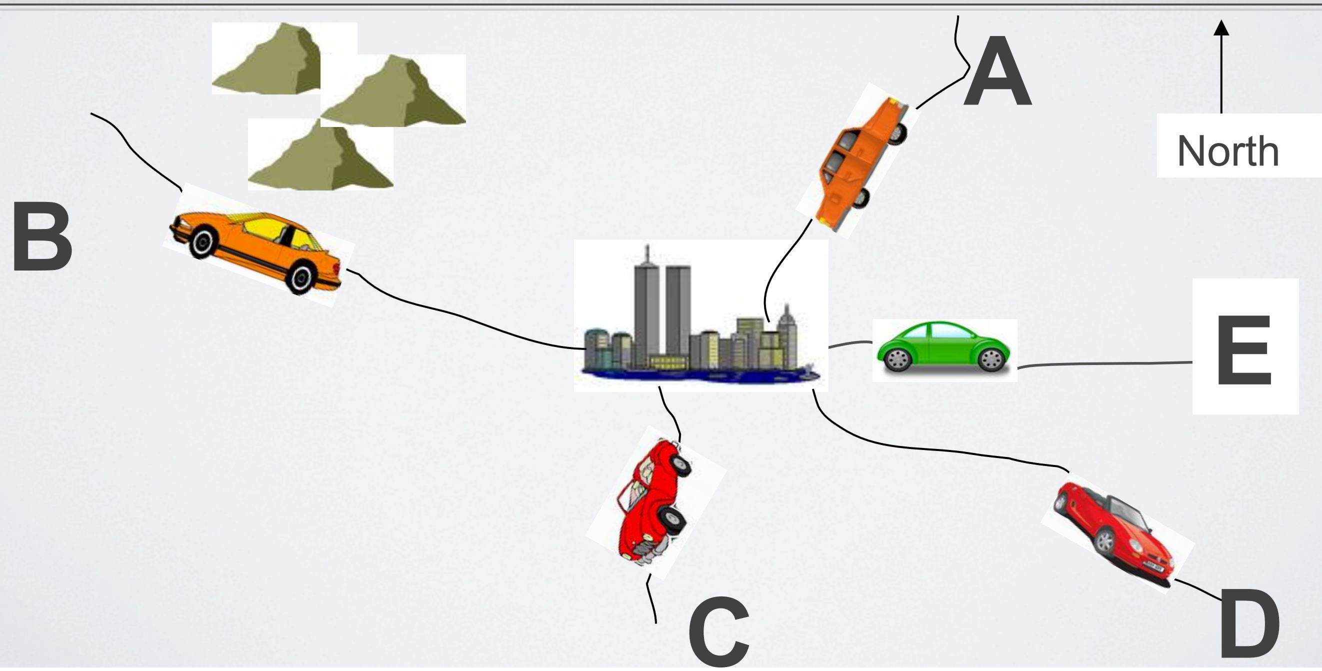
____

Draw the north and east graphs

North

East



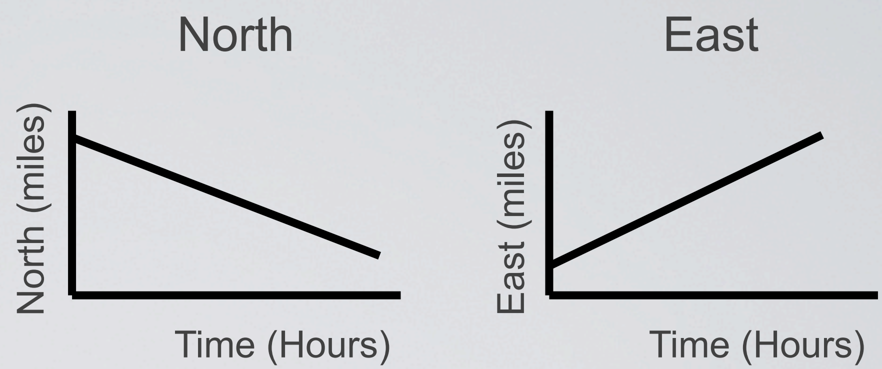


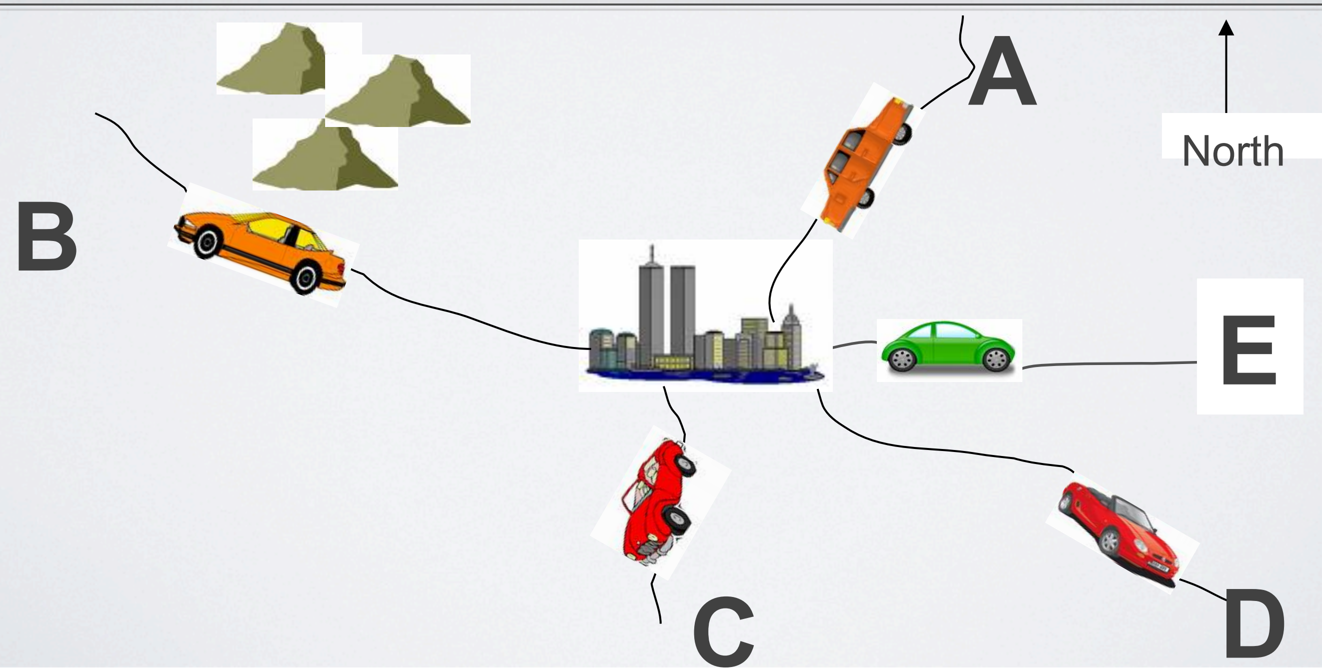
What direction is car D moving?

v) What direction is Car D moving?

Southeast

Draw the north and east graphs





UNAVCO

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