

A red-toned topographic map of a mountainous region, likely the Sierra Nevada, showing detailed terrain features and elevation changes. The map is the background of the slide.

An Overview of the Plate Boundary Observatory Geodetic Data Products

Christine Puskas and Shelley Olds

UNAVCO
consortium to promote geoscience
research and education



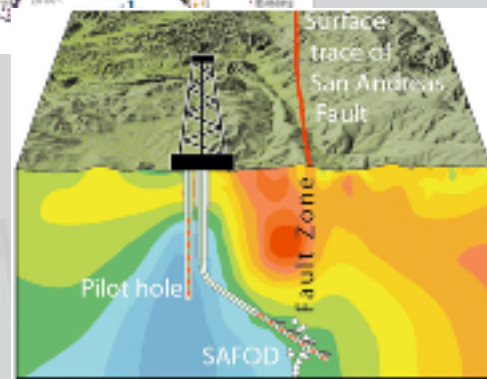
GAGE Facility
support and data services
funded by NSF and NASA



Plate Boundary Observatory
geodetic networks of EarthScope



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- UNAVCO web site tour
- Tectonic plate motion examples and tools
- GPS velocities and time series
- Examples of geophysical events: earthquakes, volcanoes, slow slip
- LiDAR maps
- Community products: Atmospheric applications and local environment

UNAVCO web site - <http://www.unavco.org>

The screenshot shows the UNAVCO website in a web browser. The browser's address bar displays "http://www.unavco.org". The website features a prominent banner celebrating 30 years of innovation in science, with the text "celebrating 30 YEARS of INNOVATION in SCIENCE". Below the banner, there is a navigation menu with links: HOME, ABOUT, CONTACT, and HELP. The main content area is divided into three columns. The left column, titled "WHAT'S HOT", features a photo of a group of people and a headline about the "Workshop: Future of PBO in the GAGE Facility, September 30-21". The middle column, titled "HIGHLIGHTS", features a photo of a group of people and a headline about the "PBO Feature of EarthScope Symposium and Workshop June 12-14". The right column, titled "SCIENCE & SOCIETY", features a graph showing "Earthquake activity (M2.0+) 1990-2010" and a headline about "UNAVCO's Innovative Record the Arrival of Tornadoes at the West Coast of North America". The footer of the website includes logos for sponsors like NSF and NASA, and a list of links for "Community", "Projects", "Instrumentation", "Data", "Software", "Science", and "Education".

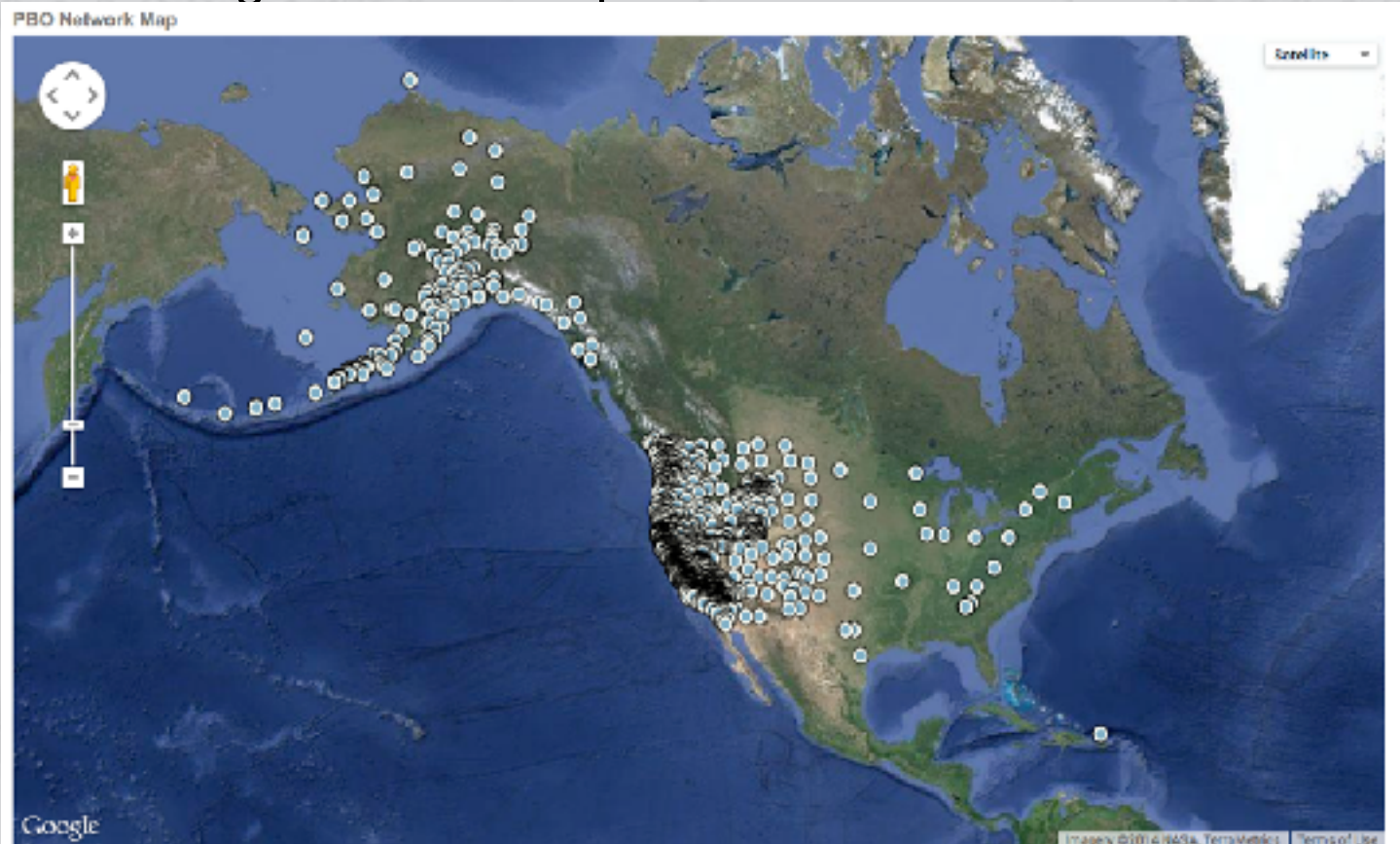
Published
papers from
community

Recent events

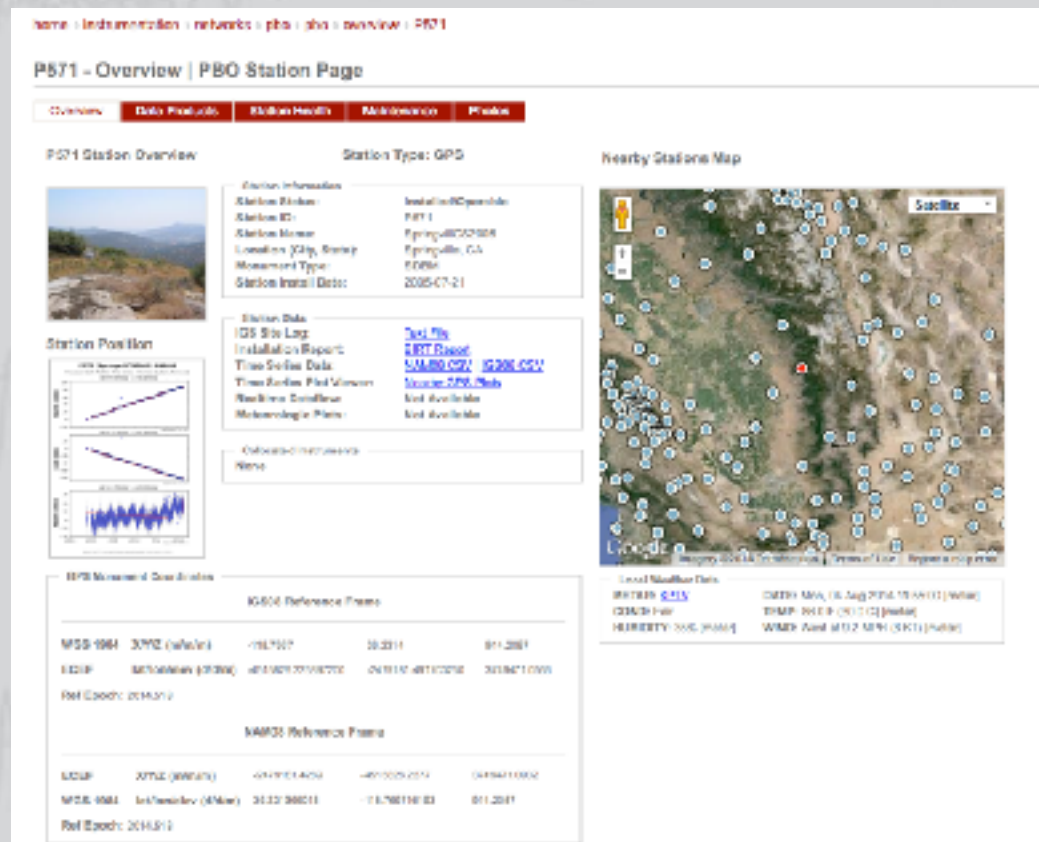
Data Visualization tools and files



Instrumentation - <http://www.unavco.org/instrumentation/instrumentation.html>
Network monitoring - network maps














Instrumentation - <http://www.unavco.org/instrumentation/instrumentation.html>
 Network monitoring - station home pages



Data - <http://www.unavco.org/data/data.html>
Links to ftp sites, web services, documentation

Index of <ftp://data-out.unavco.org/pub/>

 [Up to higher level directory](#)

Name	Size	Last Modified
 LEO		1/17/14 12:00:00 AM
 Readme	1 KB	12/17/07 12:00:00 AM
 cli		12/20/13 12:00:00 AM
 highrate		7/25/14 9:49:00 PM
 hourly		7/25/14 10:02:00 PM
 logs		8/1/14 2:03:00 AM
 nrt		7/25/14 10:02:00 PM
 pickup		5/6/14 4:07:00 PM
 products		7/27/14 4:42:00 AM
 raw		7/25/14 11:20:00 PM
 rinex		7/25/14 10:51:00 PM

Data - <http://www.unavco.org/data/data.html>

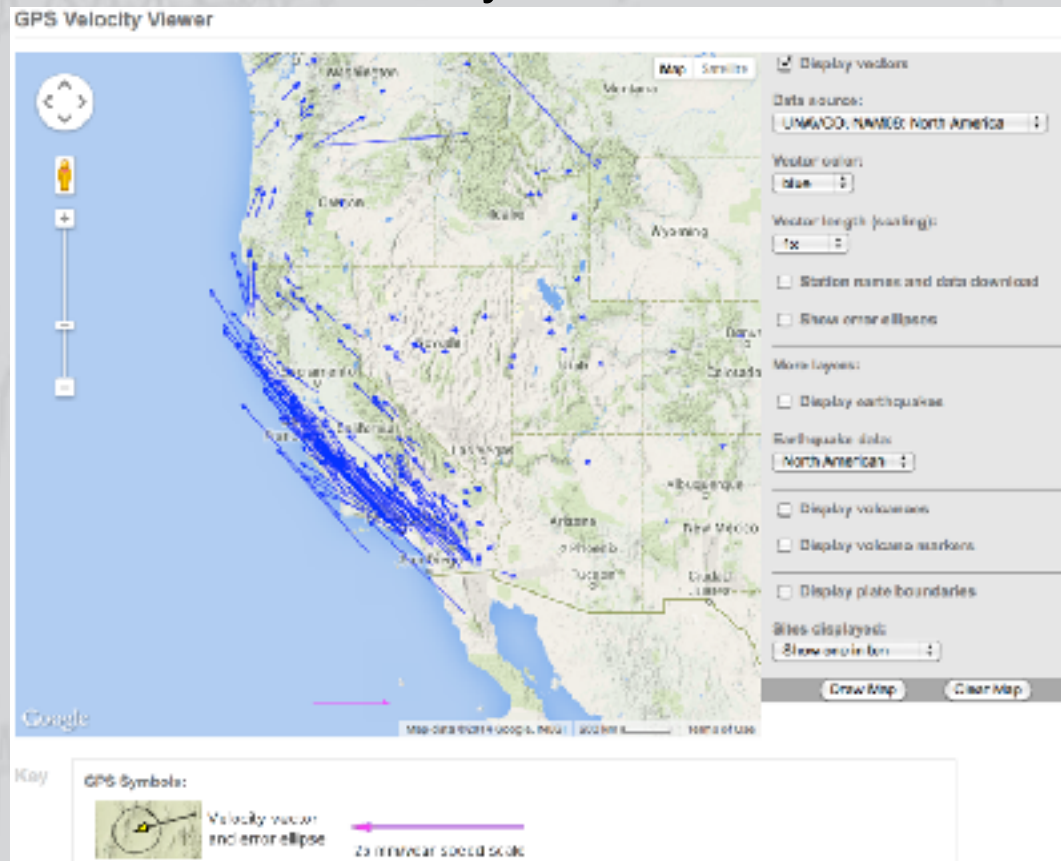
Links to ftp sites, web services, documentation - Data Archive Interface

The screenshot displays the UNAVCO Data Archive Interface, which is used for finding and viewing data. The interface is divided into several sections:

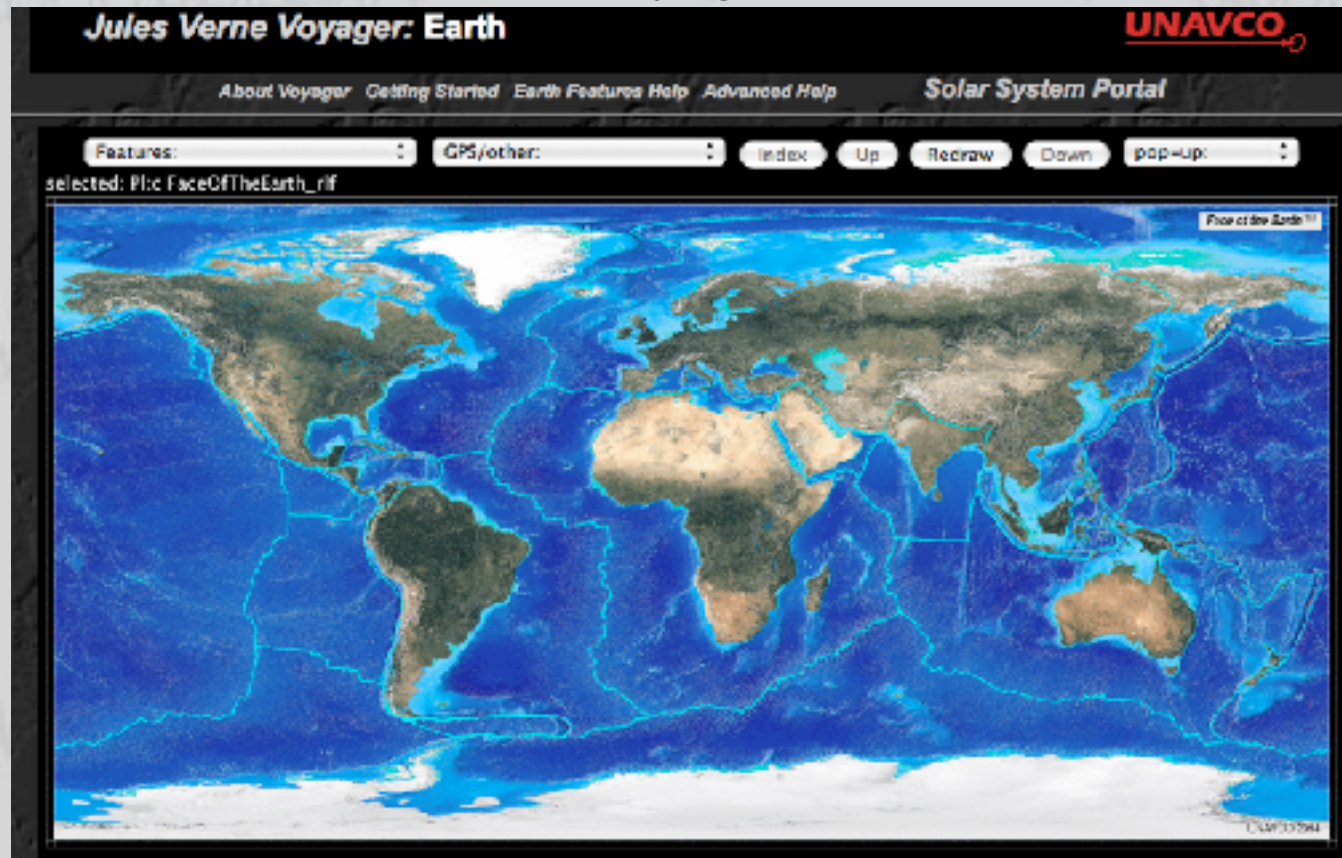
- Metadata:** This section shows a table of data items. The table has columns for 'id', 'name', 'lat', 'lon', 'start date', 'end date', and 'status'. The 'name' column contains various station names, such as 'WIDEWIDE_00000', 'WIDEWIDE_00001', 'WIDEWIDE_00002', etc. The 'lat' and 'lon' columns show coordinates. The 'start date' and 'end date' columns show the time range for each station. The 'status' column shows the current status of the station.
- Spatial:** This section shows a map of the world with green dots indicating the locations of the stations. The map is centered on the Pacific Ocean, showing the Americas and the Pacific Islands.
- Temporal:** This section shows a timeline of the data. The timeline is a horizontal bar chart with a vertical axis representing time (from 1994 to 2011) and a horizontal axis representing the station ID. The bars are colored and labeled with the station ID, showing the duration of the data collection for each station.

On the right side of the interface, there is a sidebar with a 'SUMMARY' section and a 'SEARCH' section. The 'SUMMARY' section shows the total number of items (1,000) and a 'SEARCH' button. The 'SEARCH' section shows a search bar and a 'SEARCH' button.

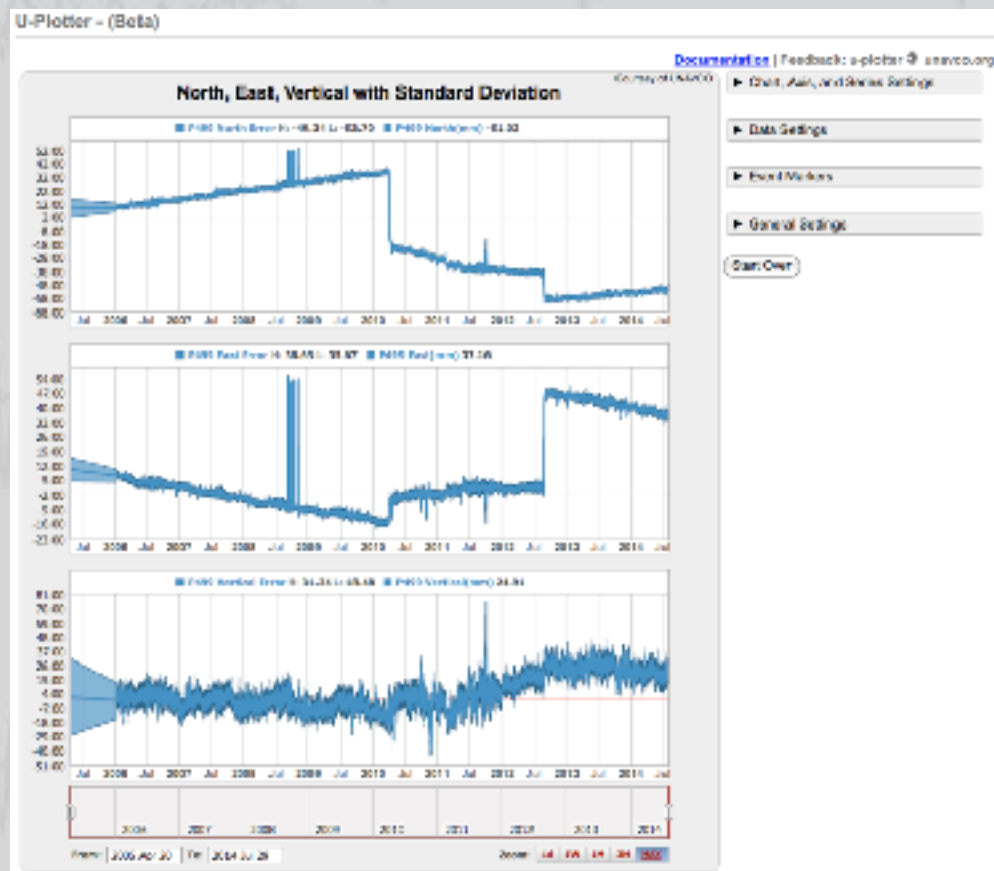
Software - <http://www.unavco.org/software/software.html>
Visualization tools - GPS velocity viewer



Software - <http://www.unavco.org/software/software.html>
Visualization tools - Jules Verne Voyager






Software - <http://www.unavco.org/software/software.html>
Visualization tools - U Plotter



Software - <http://www.unavco.org/software/software.html>
Visualization tools - DAI Plotter

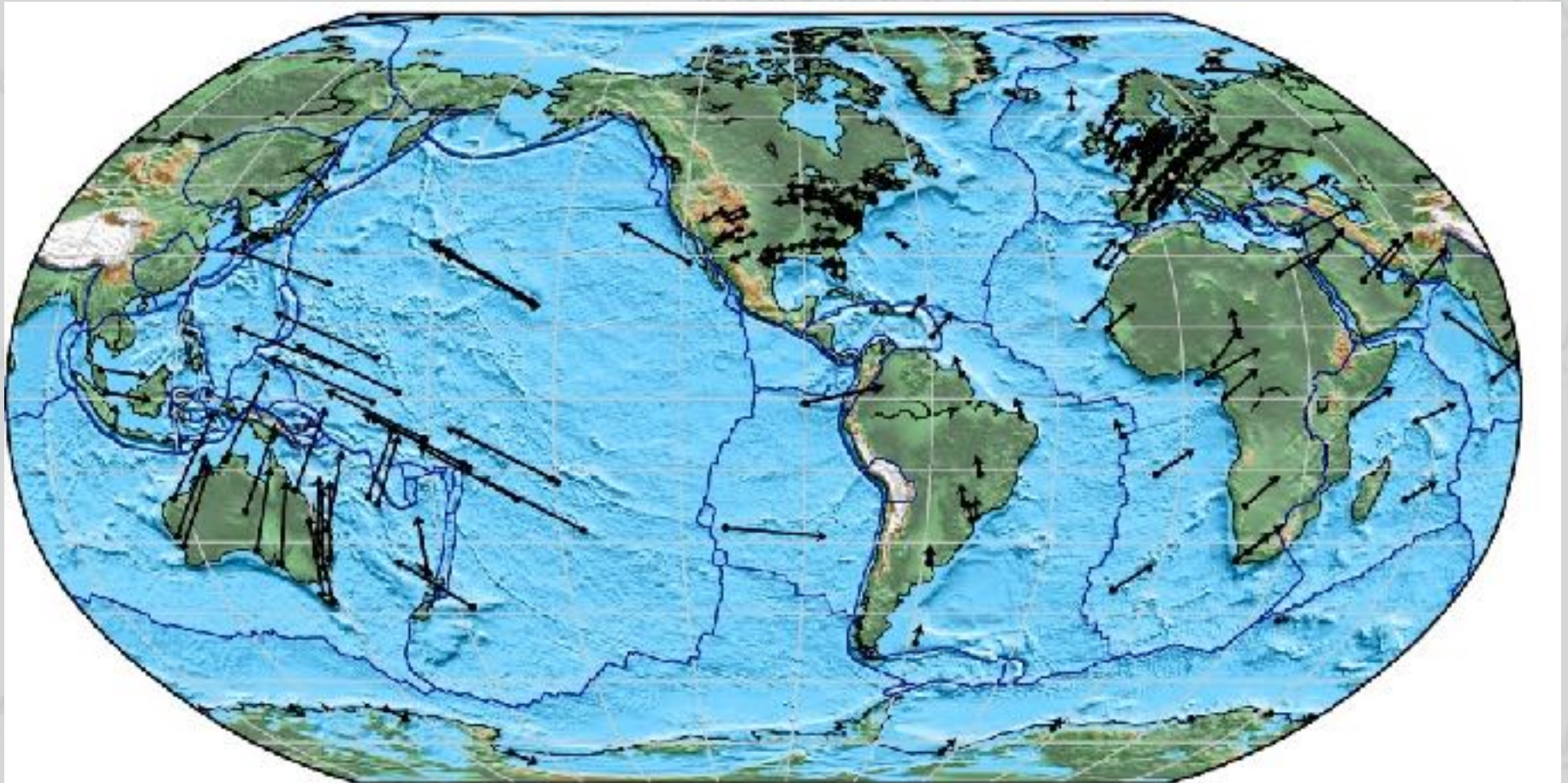


Education - <http://www.unavco.org/education/education.html>
Tools for teachers and students

	<h3>Student Opportunities</h3>	<p>There are many opportunities for students.</p> <p>RESESS is a paid undergraduate research internship, learning community, and mentoring program. Students can participate for up to three summers. Application in the RESESS program is the first step to the student internship. Please check the RESESS website for the application deadline.</p>	<p>UNAVCO Internships offer graduate and upper-level undergraduate students the opportunity to learn various aspects of geodesy research and education.</p> <p>Other REU and Internship opportunities (PDF) Are you looking for geoscience research internship opportunities? Take a look at this (non-inclusive) list of opportunities to see what else is out there!</p> <p>See more Student Opportunities »</p>
	<h3>Advancing Geodetic Skills</h3>	<p>Improve your geodetic skills to learn more about geodesy, the applications of geodesy, and Earth Balance.</p> <p>Early Career Professionals: UNAVCO is helping early career professionals successfully navigate the transition from student to professional.</p>	<p>Short Courses are geared for novices, early-career scientists, graduate students, and upper-level undergraduates, covering many applications of geodetic technologies.</p> <p>Educational Workshops are for college and secondary education faculty to integrate new content into their teaching.</p> <p>Science Seminars are one-hour talks hosted by UNAVCO to provide the community on science topics of interest.</p> <p>See more Advancing Geodetic Skills »</p>
	<h3>Geodesy Teaching & Learning Resources</h3>	<p>Looking for resources that use data and modern teaching techniques to use in your teaching or after-school program? Do you want to explore your world?</p> <p>Data for Educators provides a map with links to interesting high-resolution GPS data, visualization tools, educational materials which incorporate this data.</p> <p>Educational Resources include activities and lab exercises for secondary education (grades 8-12) and undergraduate courses.</p>	<p>Geodesy Tools for Societal Issues (GETSI) Education Resources show the leading resources being developed for engaging undergraduate students in addressing societally important Earth science questions through the use of geodetic data.</p> <p>Map Tools allow you to visually explore datasets for Earth and other worlds.</p> <p>See more Geodesy Teaching & Learning Resources »</p>

Example: Tectonic Plate Motion

IGS08 Plate Velocities and Reference Stations



Example: Tectonic Plate Motion

1. Open a browser and go to UNAVCO -> Education -> Map Tools
2. Select EarthScope Voyager, Jr.
3. Under “Add feature(s)”
 - choose “Tectonic Plates”
4. Under “Add Velocities”
 - choose “No Net Rotation”
5. Click “Make Changes”
6. Try different velocity options
 - N. America
 - Pacific
 - Caribbean



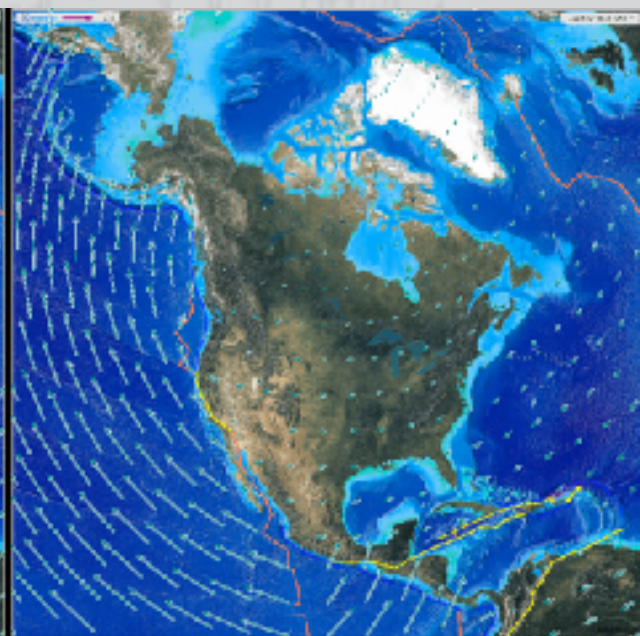
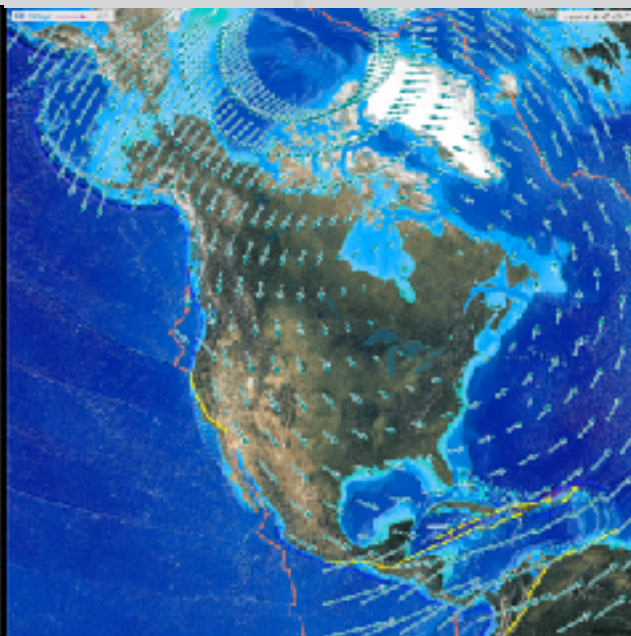
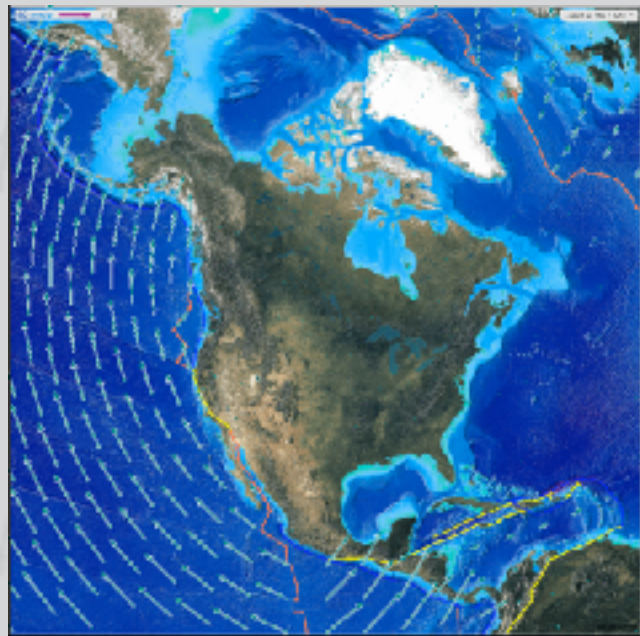
Example: Tectonic Plate Motion

What is the difference between options?

N. America

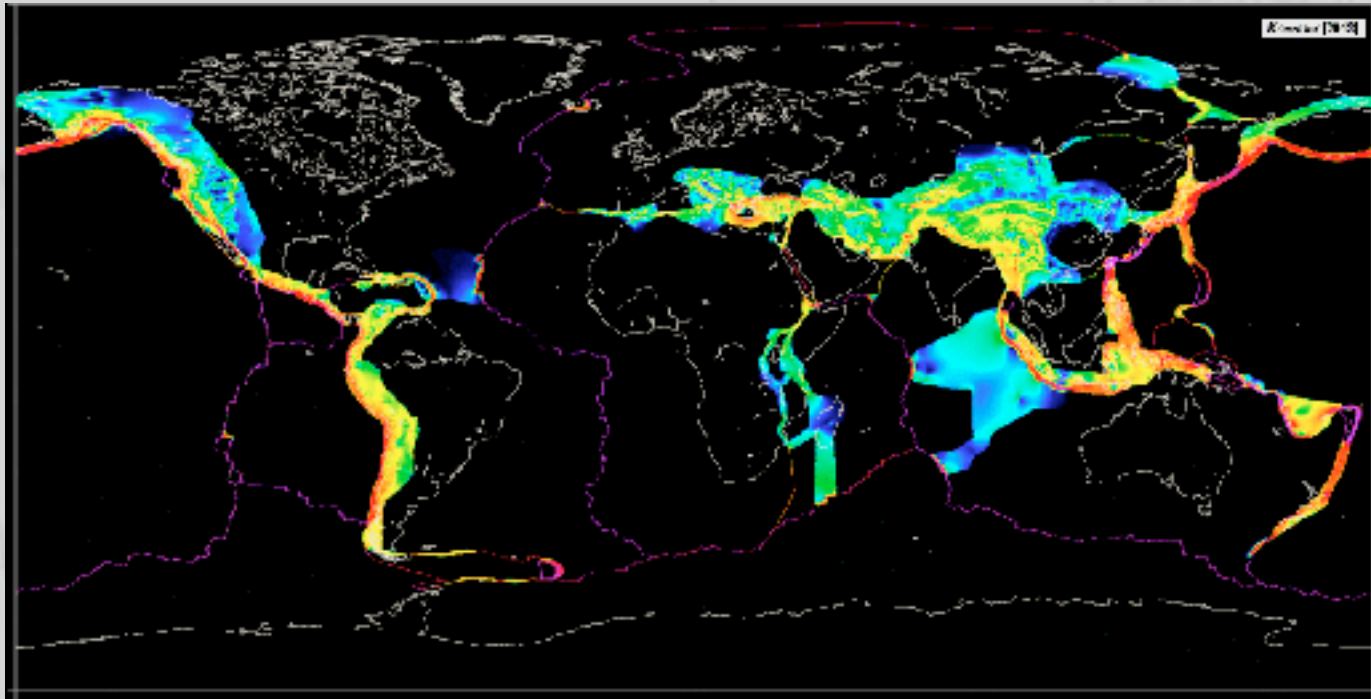
Pacific

Caribbean



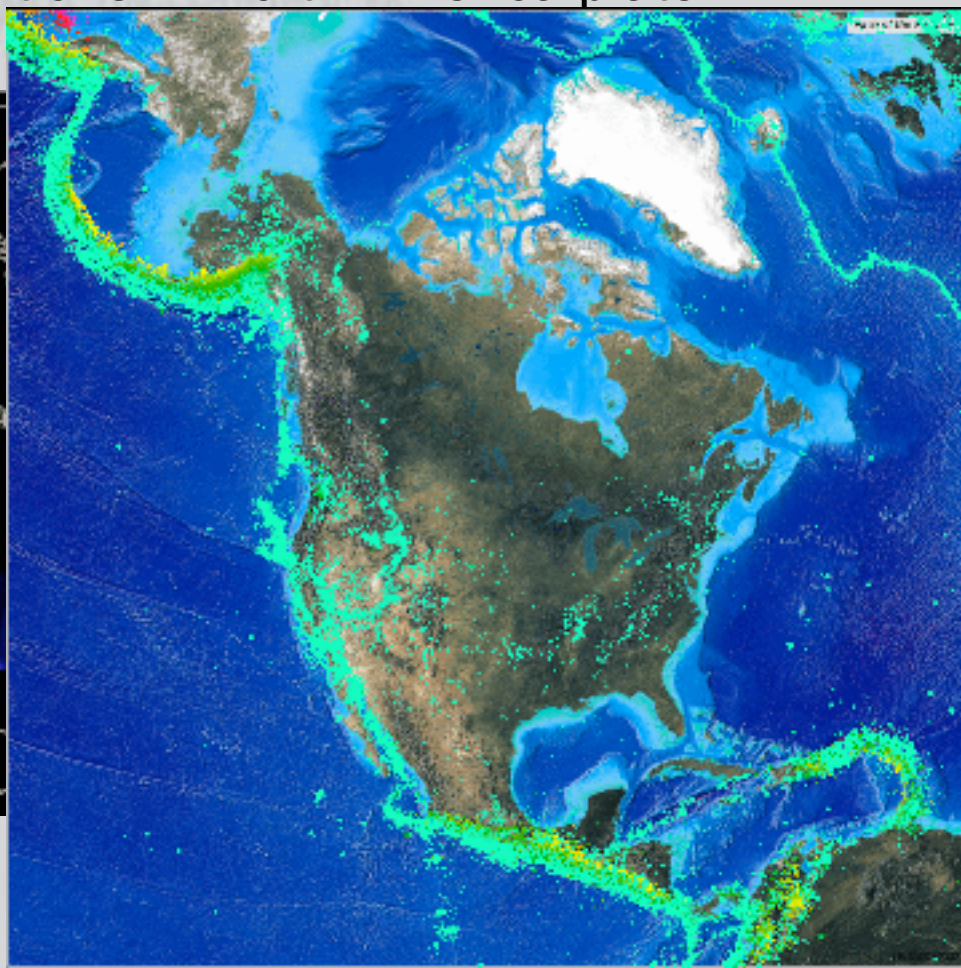
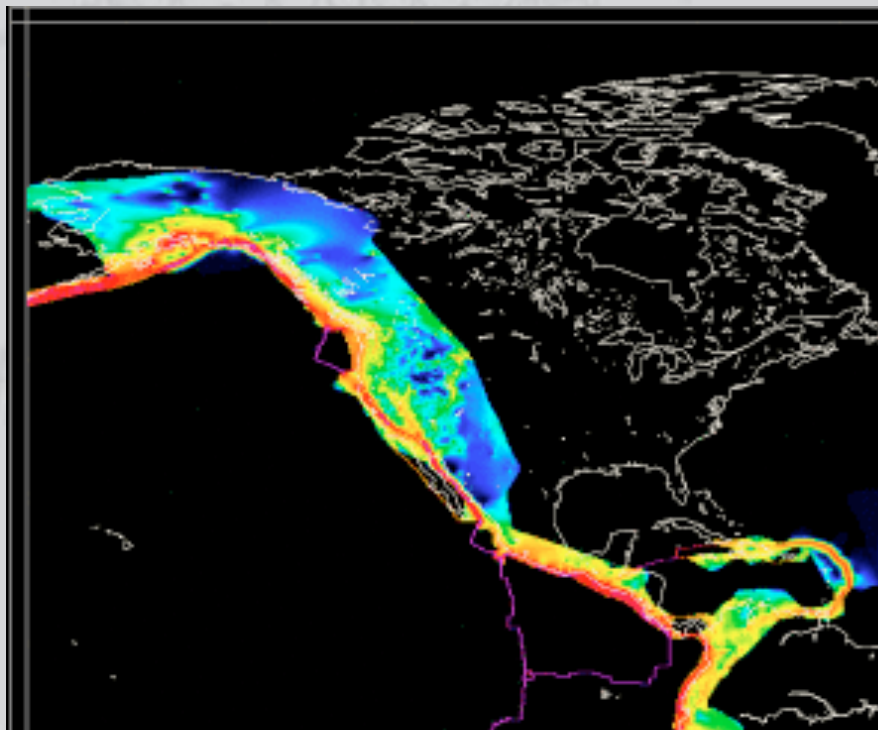
Example: Tectonic Plate Motion

1. Open a browser and go to UNAVCO -> Education -> Map Tools
2. Select Jules Verne Voyager: GEM GSRM
 - Strain measures change in deformation over distance
 - Where is strain located?



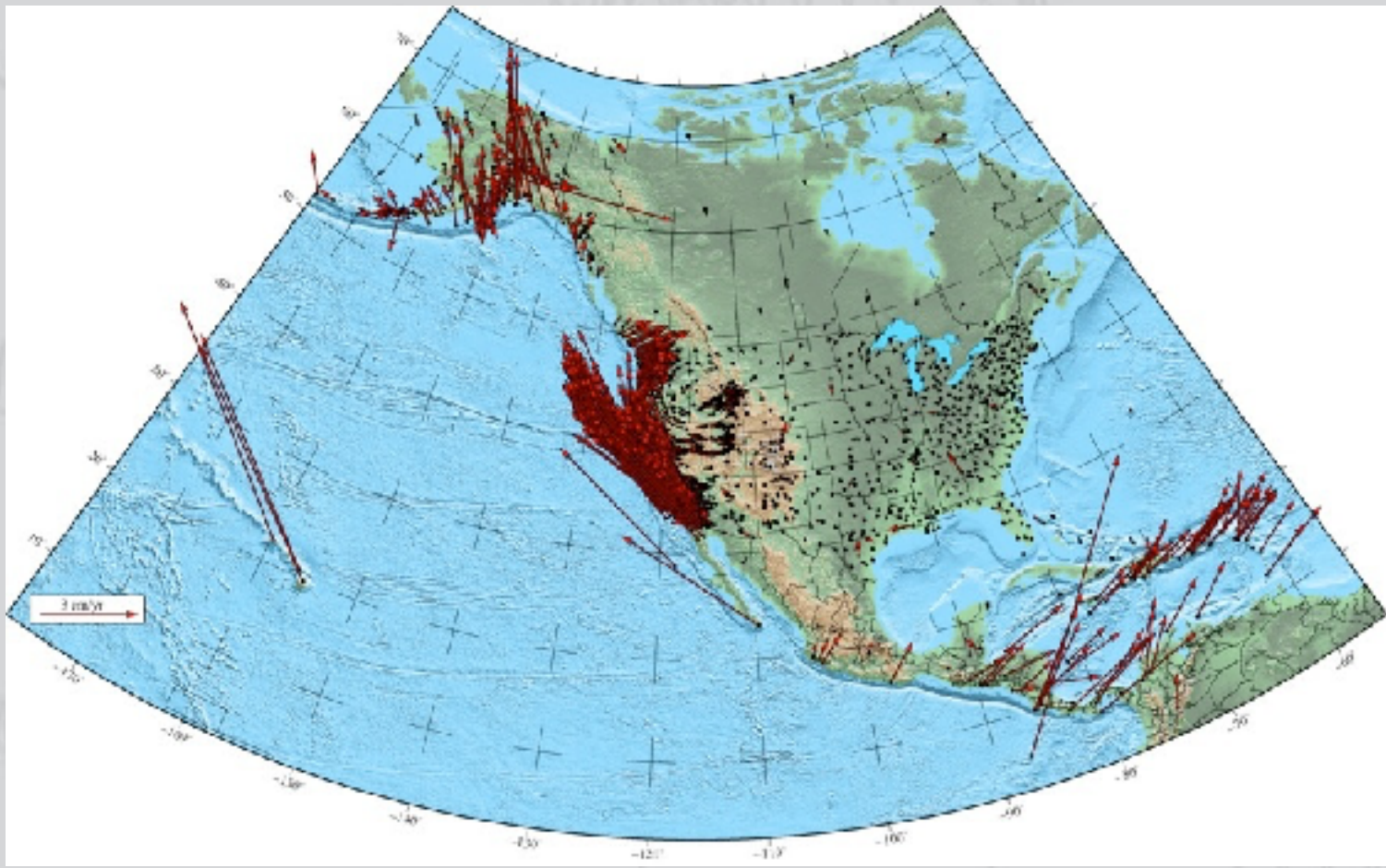
Example: Tectonic Plate Motion

Compare strain with earthquake locations in North America plate



Example: GPS Velocities

GPS velocities, NAM08 reference frame

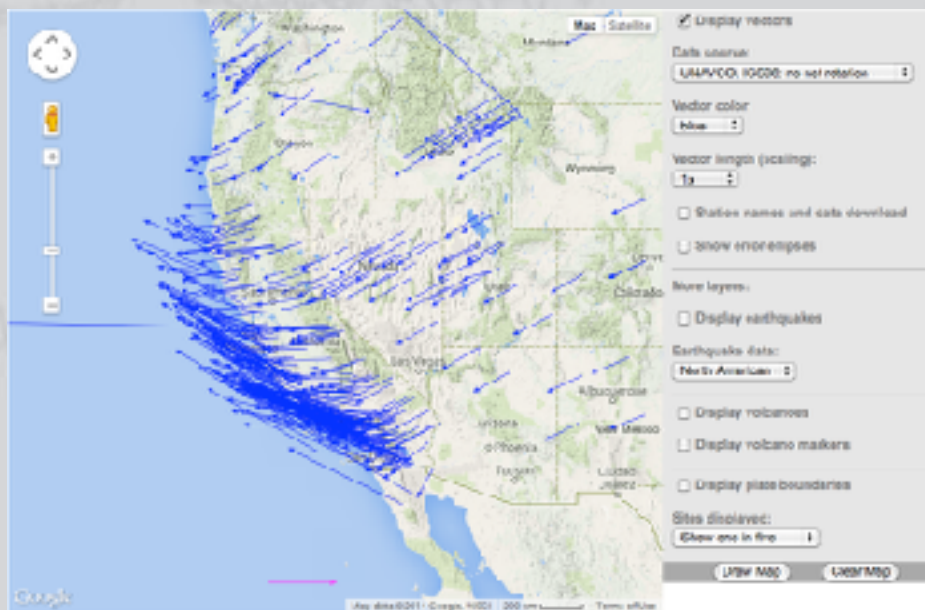


Example: GPS Velocities

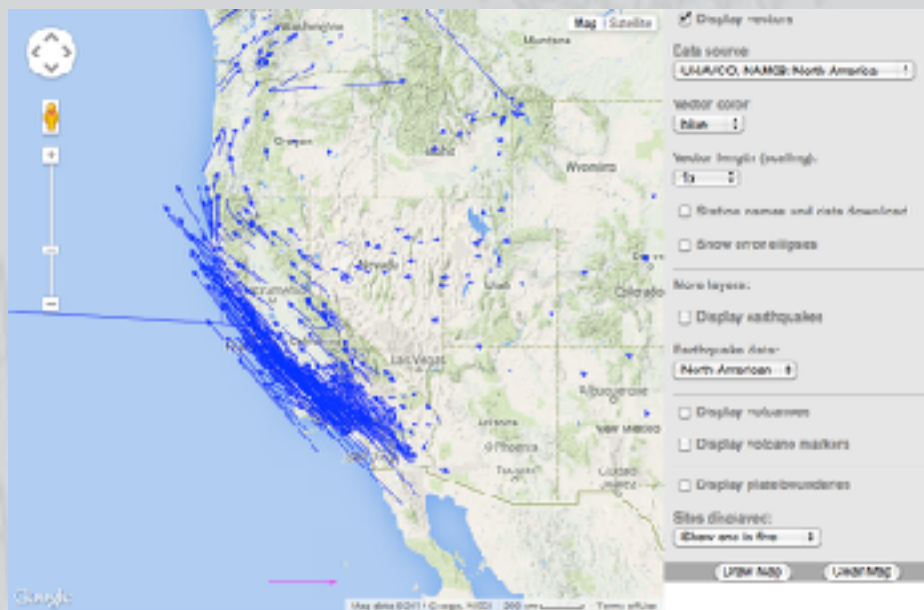
1. Open a browser and go to UNAVCO -> Software -> GPS Velocity Viewer
2. Select options
 - Data source: UNAVCO, IGS08: no net rotation
 - Sites displayed: Show one in five
 - Click “Draw Map” to update
3. Change options
 - Data source: UNAVCO, NAM08: North America
 - Leave other options
 - Draw Map

Example: GPS Velocities

IGS08 Velocities



NAM08 Velocities



- Multiple versions available
- NMT, CWU are Analysis Centers processing data
- PBO = NMT+CWU combined solutions
- IGS05, IGS08, SNF01, NAM08 are reference frames

[illegible]

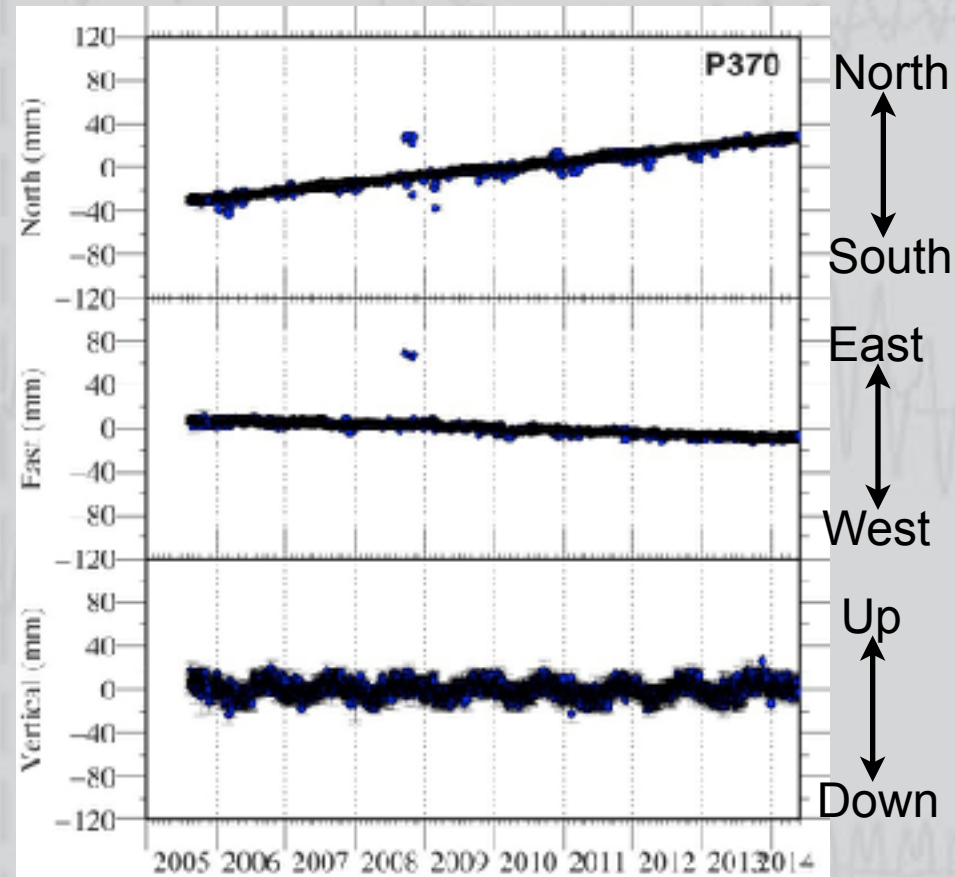
Example: GPS Time Series

- Time series are records of daily position over time

- Divided into north/east/vertical components

- Slope=velocity (barring events)

- Station velocities based on daily position solutions, accounting for events



Example: GPS Time Series

1. Open a browser and go to UNAVCO -> Software -> Data Archive Plotter
2. Enter station name(s) in field and hit Return
 - P100, HWUT
3. Change options
 - Turn off “Maintain Vertical Symmetry”
 - Drag sliders to adjust Y-axis
4. Mouseover plots
 - Get position info at points
 - Vertical bars represent maintenance
 - Drag horizontally to zoom in time
5. Click CSV tab for text data

Example: GPS Time Series

Download station time series from

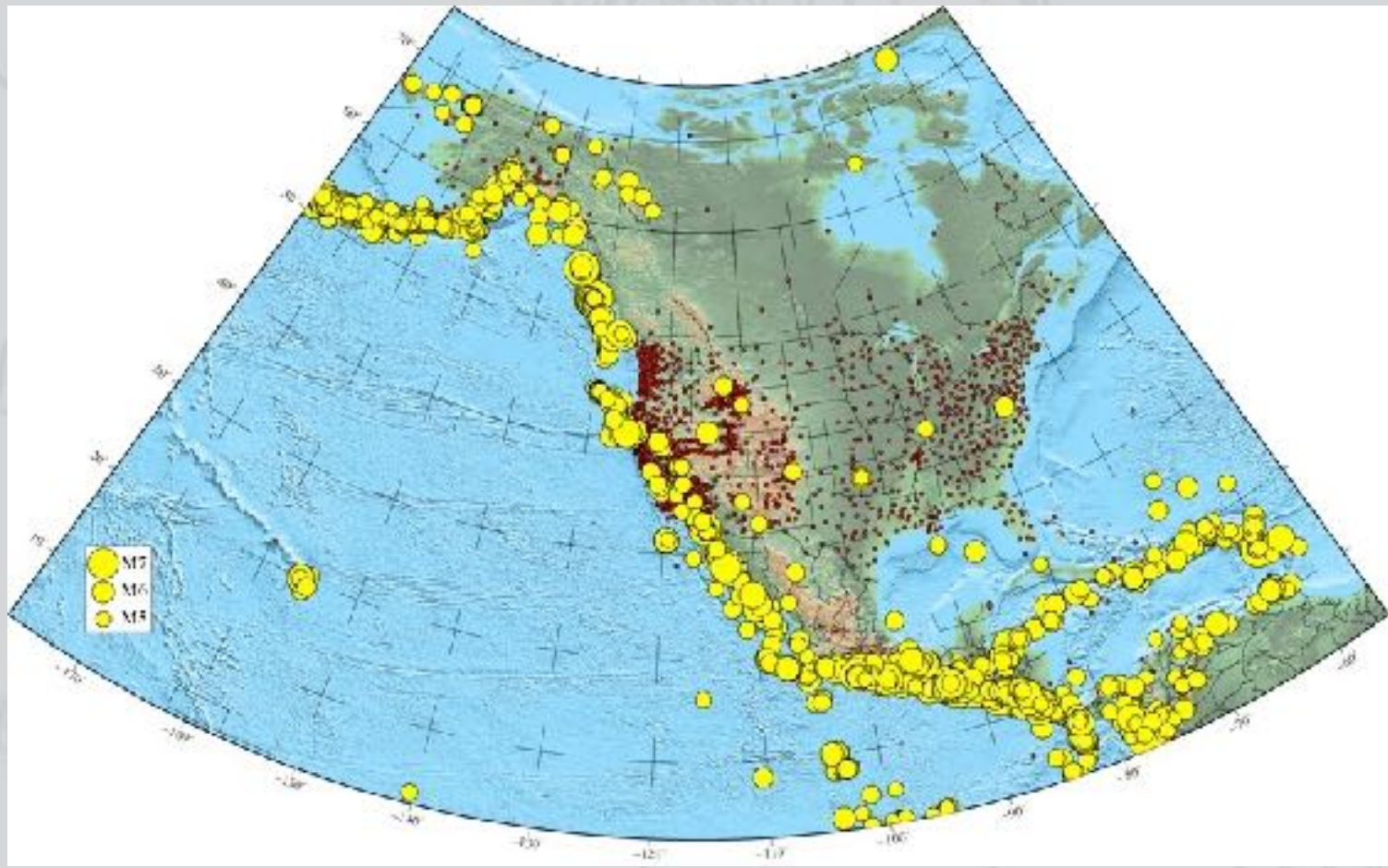
[ftp://data-out.unavco.org/pub/products/position/\\$STA/](ftp://data-out.unavco.org/pub/products/position/$STA/)

- Multiple versions available
- pos files include position, errors, correlations, time series (in meters)
- csv files contain date, time series (in mm)
- rapid files have solutions using rapid orbits (last 2-3 weeks)
- final files use final orbits

	A	B	C	D	E	F	G	H
1	PBO Station Position Time Series, Reference Frame : NAD83							
2	Format Vers	1.1.0						
3	4-character	P370						
4	Station name	AshlandAirDR2005						
5	Begin Date	2005-08-14						
6	End Date	2014-08-09						
7	Release Date	2014-08-05						
8	Reference po	12.1909858	-122.656371	555.01733 meters elevation				
9	Date	North (mm)	East (mm)	Vertical (mm)	North Std. Dev	East Std. Dev	Vertical Std. Dev	Quality
10	8/14/05	-23.87	4.51	9.14	4.53	3.17	14.51	repro
11	8/15/05	-25.56	5.25	7.31	1.6	1.42	5.59	repro
12	8/16/05	-25.52	4.58	2.91	2.04	1.8	7.11	repro
13	8/17/05	-24.96	4.66	7.1	2.12	1.86	7.27	repro
14	8/18/05	-24.02	5.42	17.92	2.14	1.93	6.49	repro
15	8/19/05	-24.46	6.92	8.91	2.09	1.82	6.77	repro
16	8/20/05	-23.75	4.55	3.27	1.74	1.5	6.18	repro
17	8/21/05	-23.45	6.05	0.57	2.52	2.16	7.21	repro

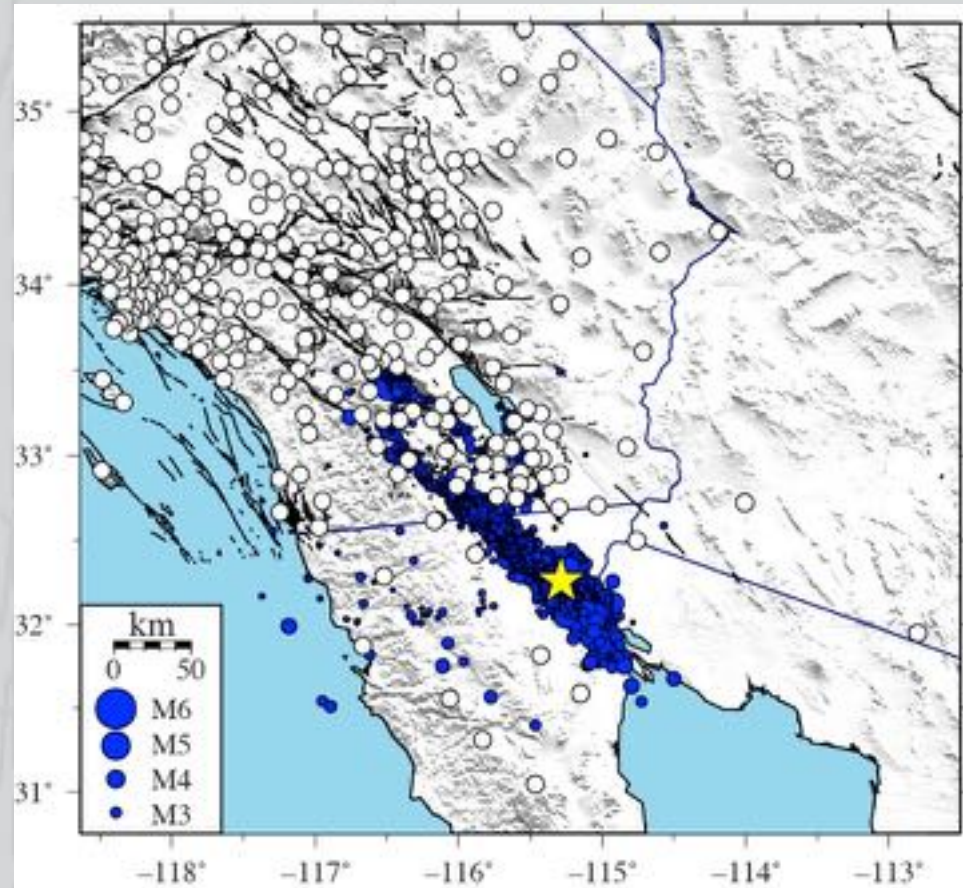
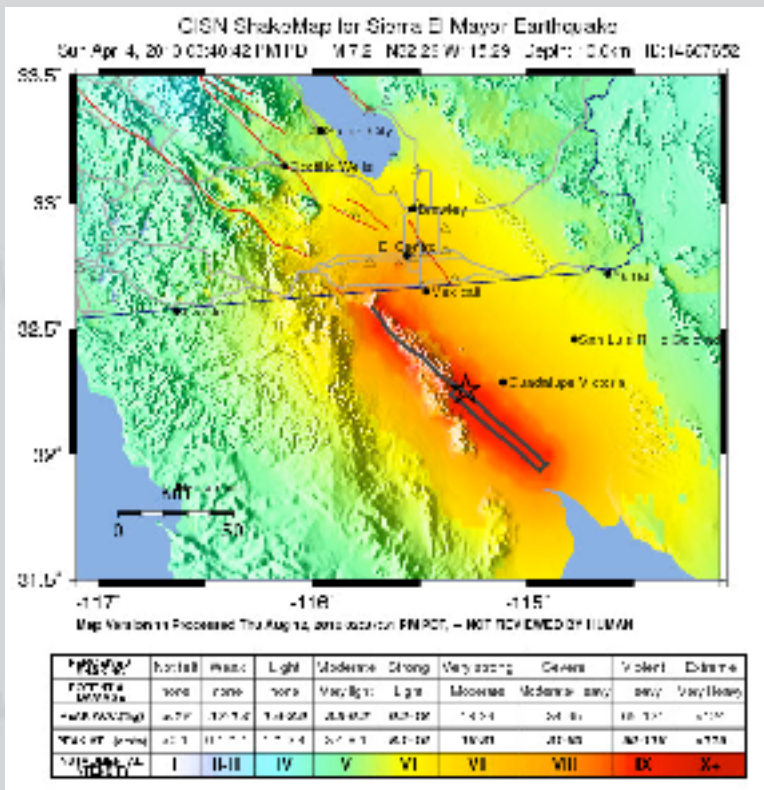
Example: Earthquakes

Earthquakes $M \geq 5$, 2004-2014



Example: Earthquakes

El Mayor-Cucapah earthquake M7.2 April 4, 2010



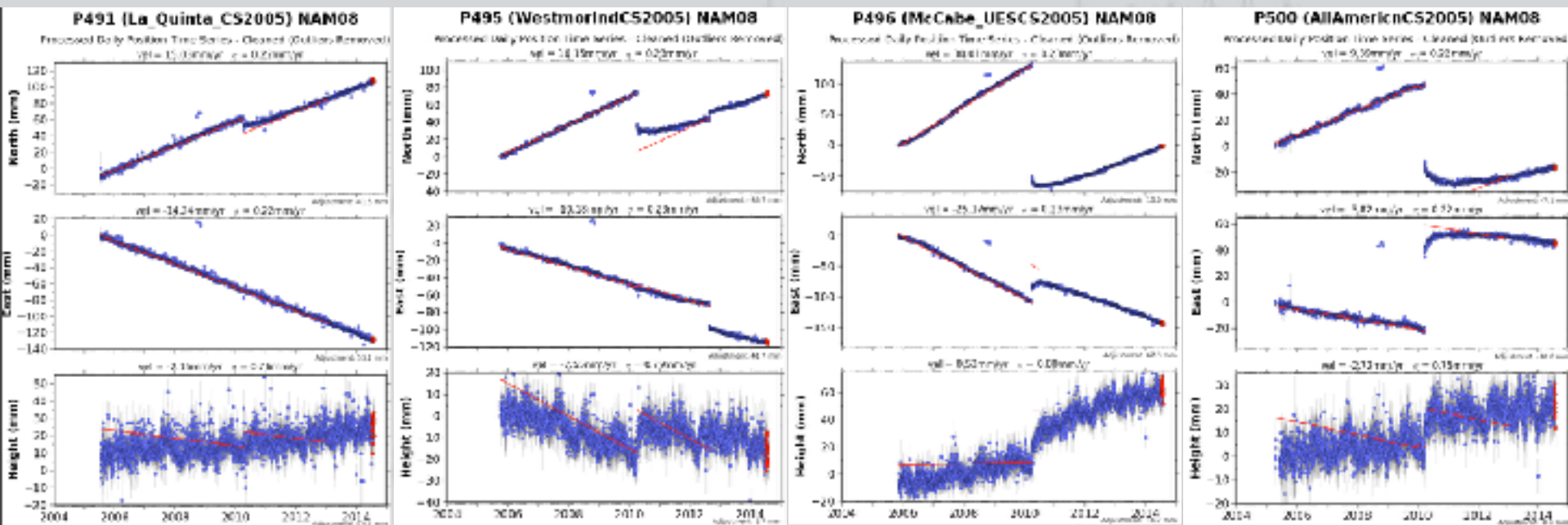
1 Year of Earthquakes after 4/4/2010

Example: Earthquakes

1. Open a browser and go to UNAVCO -> Instrumentation -> core GPS
2. Pick a station between the Salton Sea and California-Mexico border
 - Click on circle to get popup with summary
 - Click on station name to go to station home page
3. What does the earthquake look like?
 - Which direction had the greatest motion?
 - Is the velocity (slope) the same before and after the earthquake?

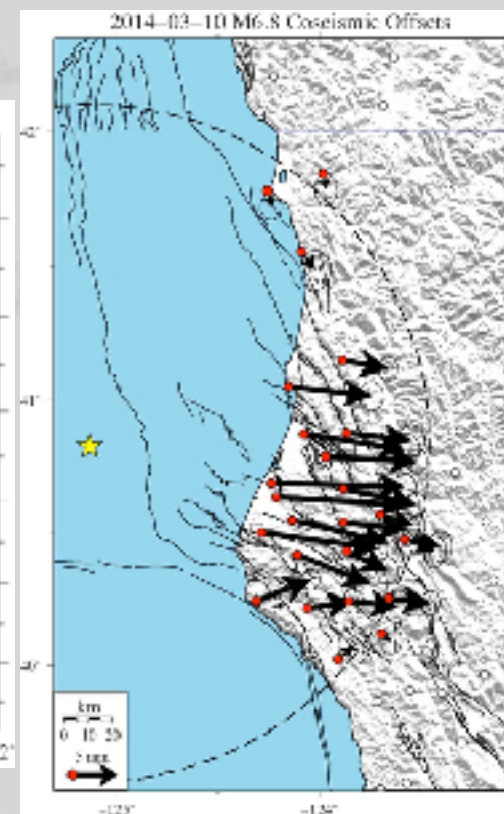
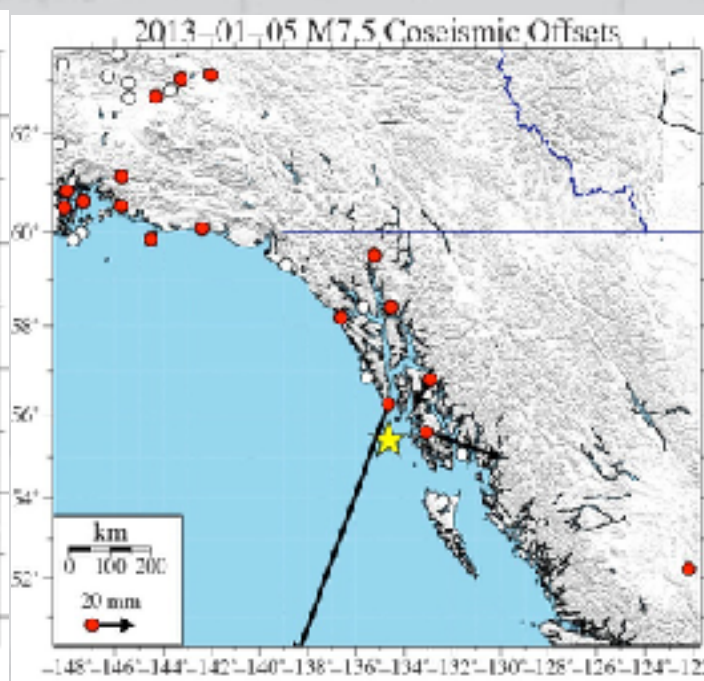
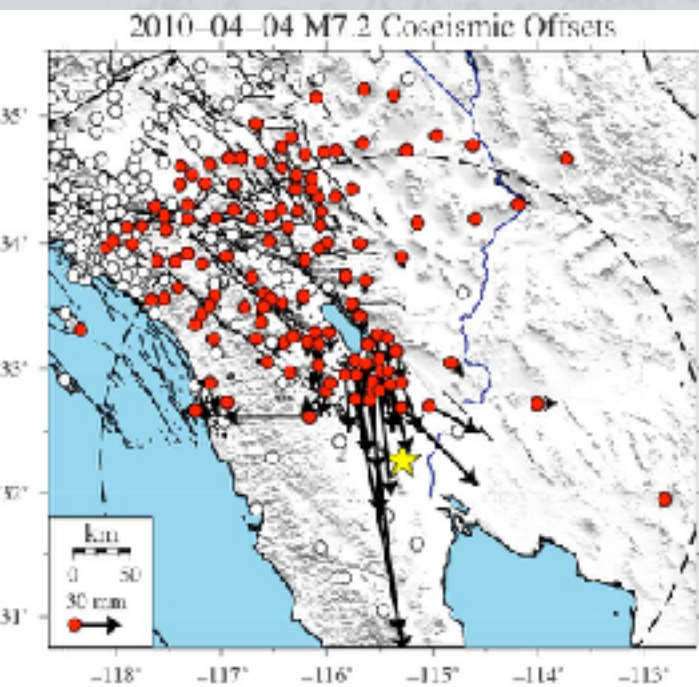
Example: Earthquakes

Static time series from southern California



Example: Earthquakes

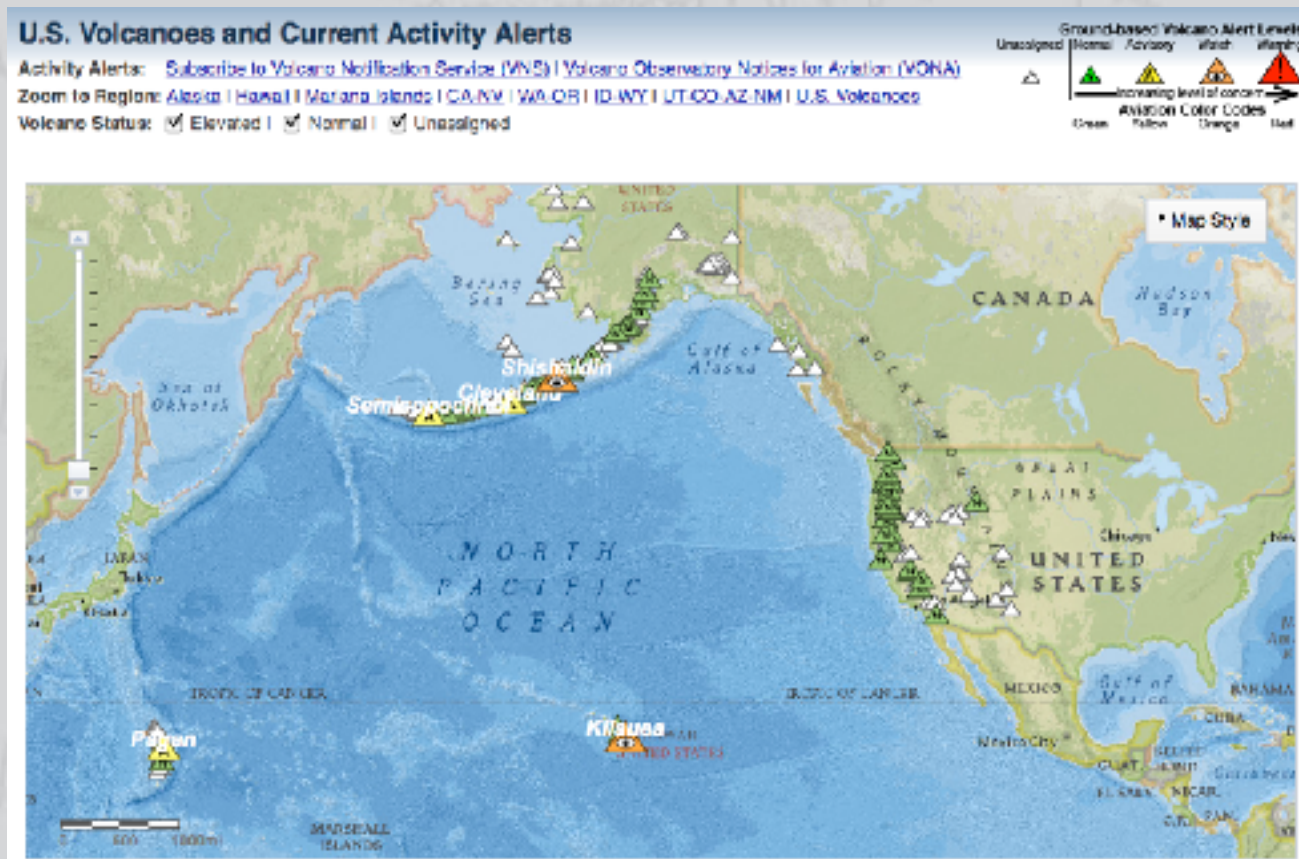
Map view of coseismic offsets from recent earthquakes



Offset text files and ps files can be obtained from
<ftp://data-out.unavco.org/pub/products/event/>

Example: Volcanoes

North America has numerous active and potentially active volcanoes



USGS Volcano Hazards Program

Example: Volcanoes

Subduction zone volcanoes

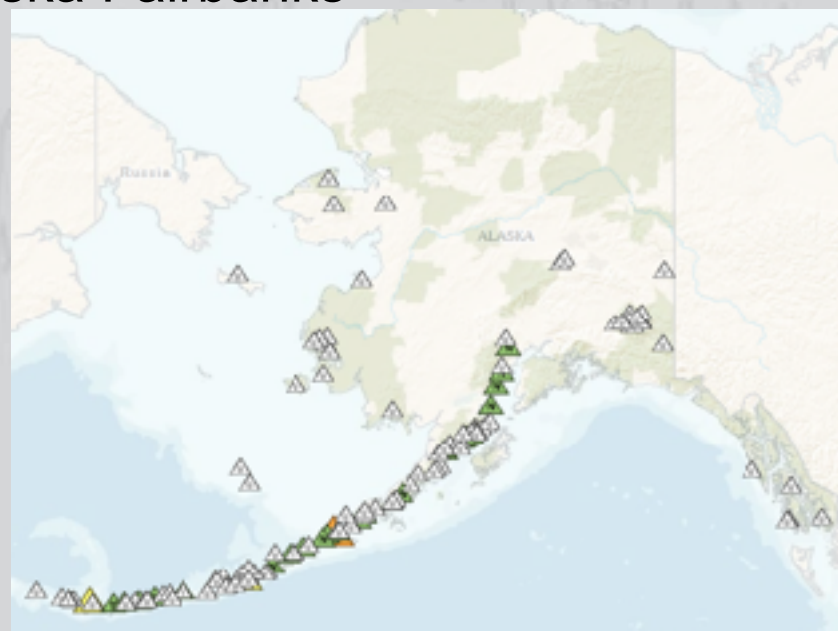
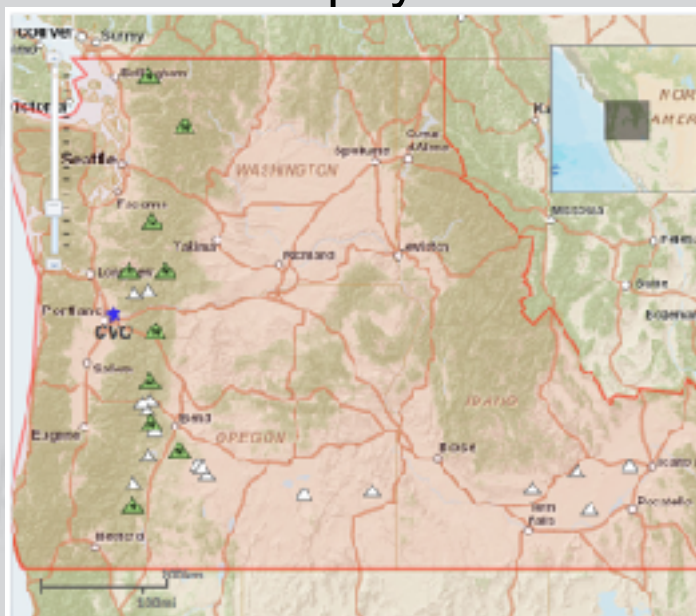
- Cascades arc

Cascades Volcano Observatory

- Aleutian arc

Alaska Volcano Observatory

USGS+Geophysical Inst. Univ. Alaska Fairbanks

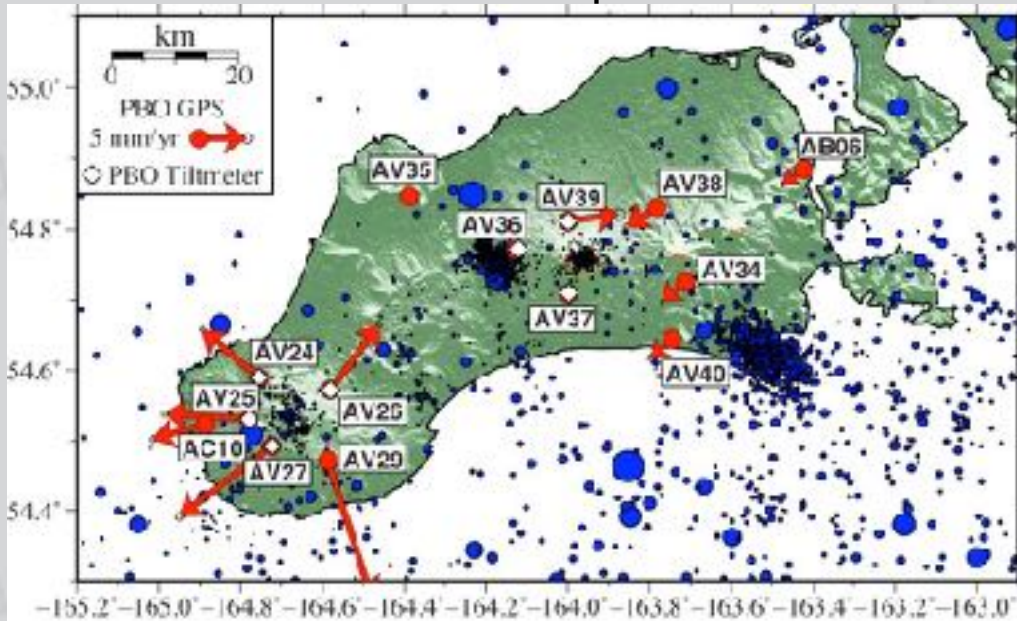


Example: Volcanoes

Westdahl Volcano on Unimak Island, Aleutians

- Last eruption in 1991
- Radial displacement

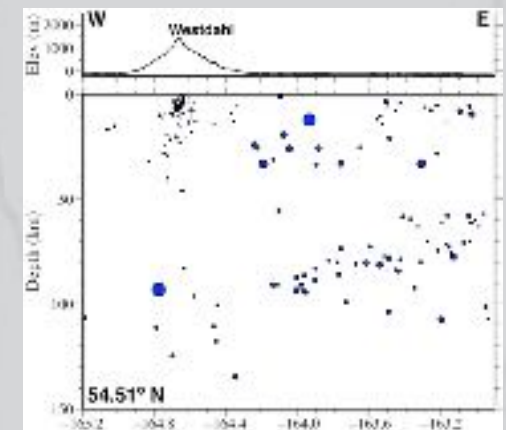
Unimak Island Earthquakes & GPS



Westdahl Fisher Shishaldin
Caldera



Westdahl Cross-Section



Example: Volcanoes

1. Open a browser and go to UNAVCO -> Software -> U-Plotter
2. Choose “GPS Position Time Series” (no Std Dev)
 - Select available stations: AV24, AV25, AV26, AV27, AC10
 - Click “>” to move stations to “Selected Items” window
 - Create plot

GPS Position Time Series

Select Stations:

Available Items:		Selected Items:
AV29	> < <<	AC10
AV14		AV24
AV35		AV25
AV18		AV26
AV37		AV27
AV18		
AV39		
AV40		
AV19		
AV11		

Select date range:

Begin: '889-05-07 00:00:00

End: 2014-05-01 00:00:00

Reference Frame:

☒ nam08

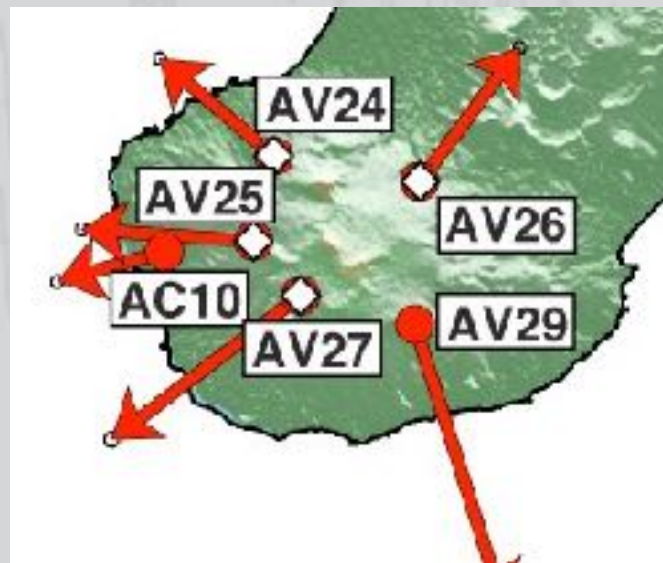
☐ ant01

☐ lga05

☐ lga08

Create Plot Cancel

Stations to plot

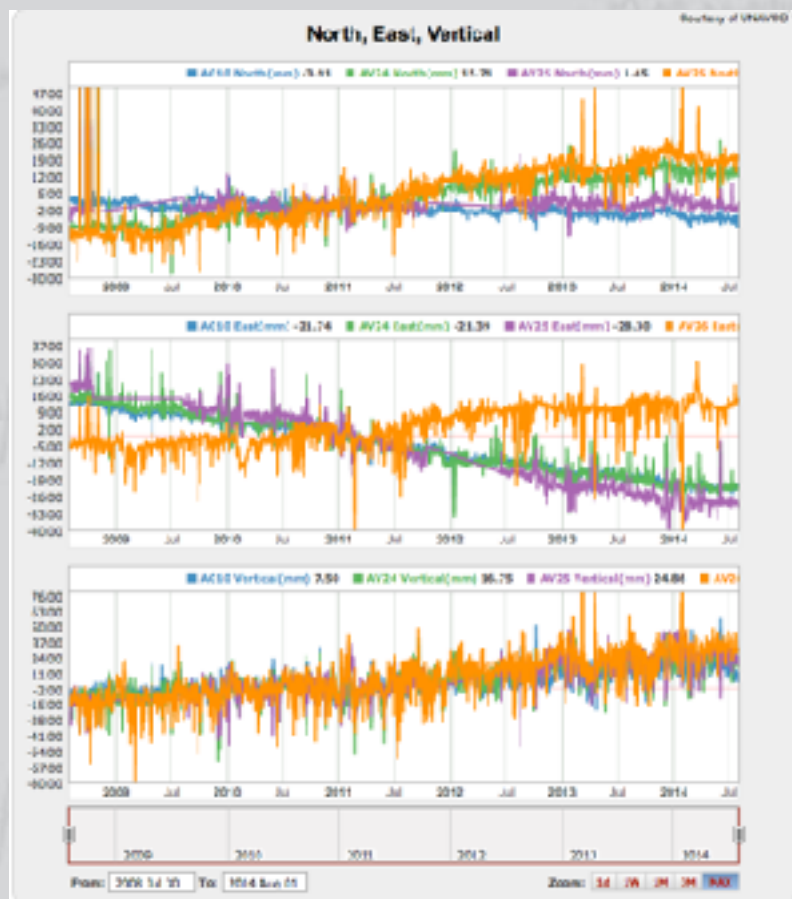


All processed stations

Leave at defaults

Example: Volcanoes

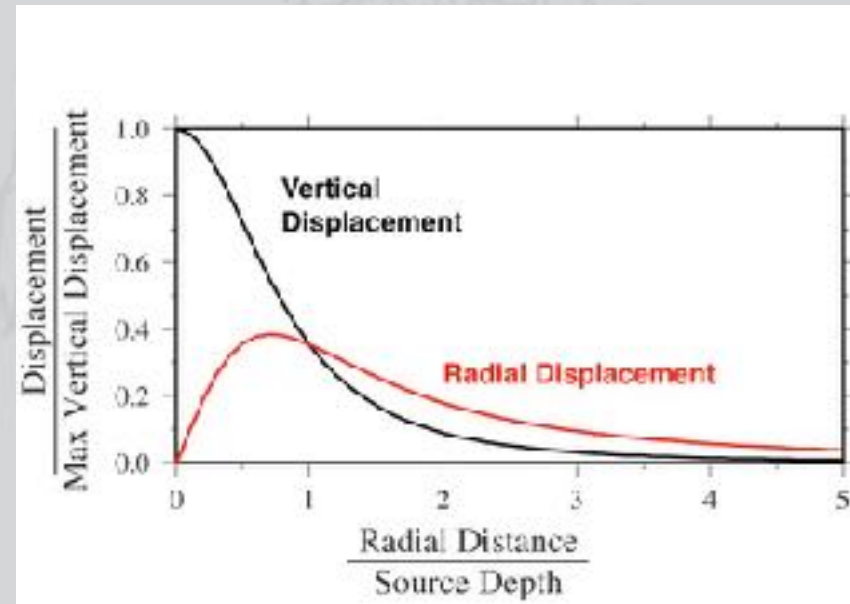
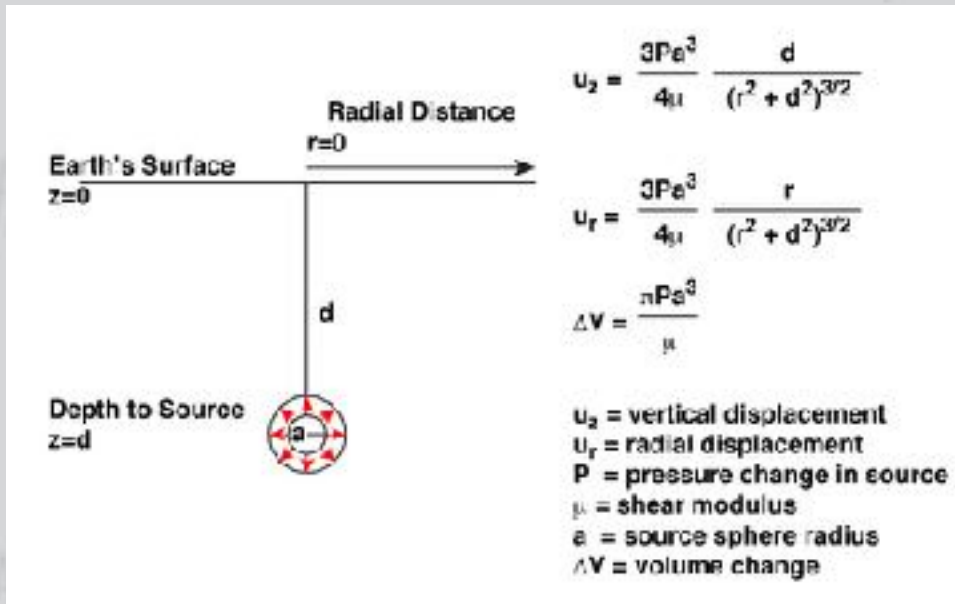
What do the horizontal components look like? The vertical components?



Example: Volcanoes

Radial displacement can be modeled by Mogi source

- Spherical source at depth
- Source radius \ll source depth
- Analytical solutions for surface displacements

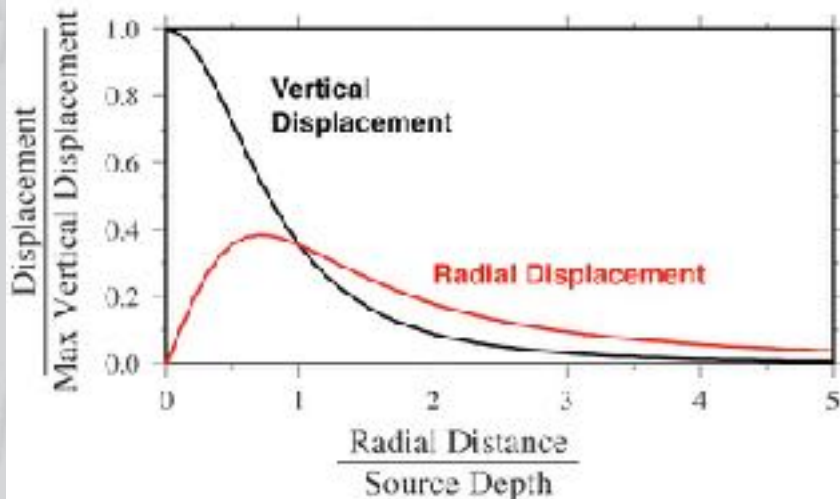


Example: Volcanoes

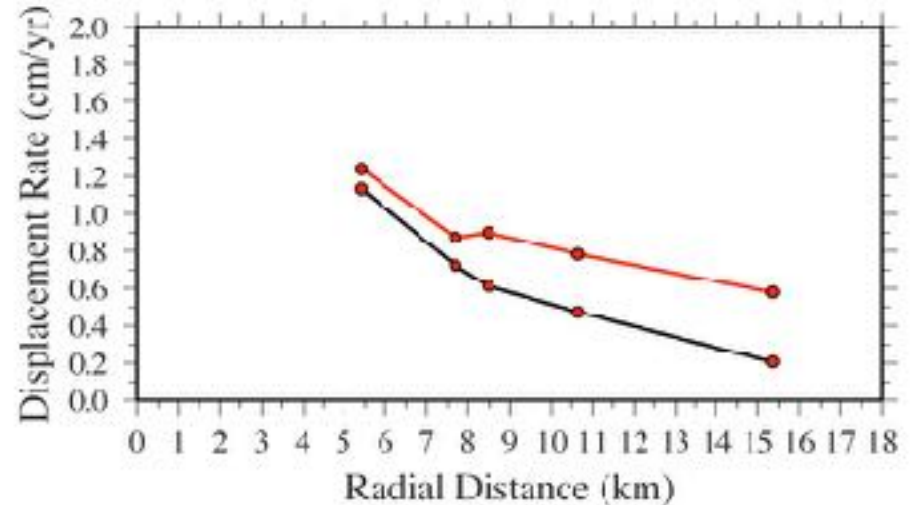
Radial displacement can be modeled by Mogi source

- Vary source depth, location, pressurization to best fit GPS
- Or rearrange terms:

Normalized Model



GPS Velocities vs. Distance from Summit



Example: Volcanoes

Radial displacement can be modeled by Mogi source

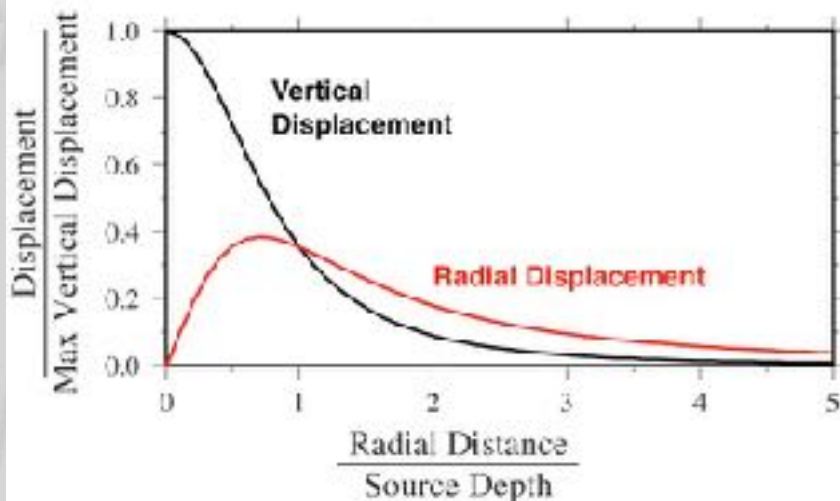
- Vary source depth, location, pressurization to best fit GPS
- Or rearrange terms:

$$d = \frac{r \cdot u_z}{u_r}$$

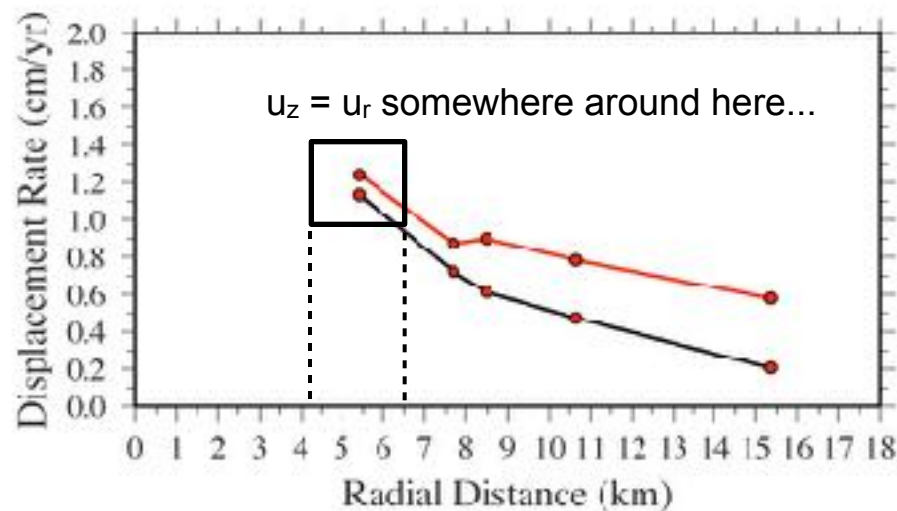


5.0	AV27
6.4	AV26
5.8	AV25
6.4	AV24
5.5	AC10

Normalized Model



GPS Velocities vs. Distance from Summit



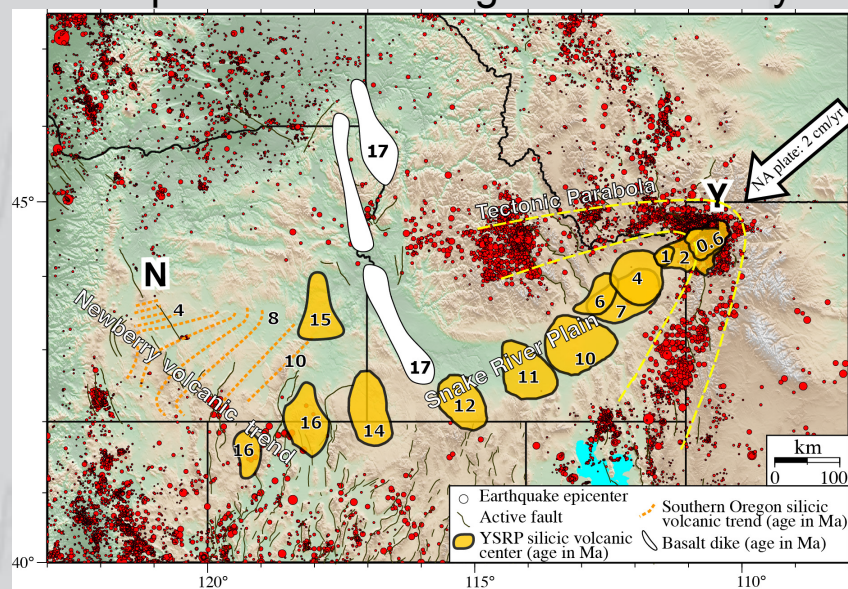
Example: Volcanoes

Hotspot Volcano - Yellowstone Volcanic Field

- Driven by mantle heat source/upper mantle plume
- Yellowstone Volcano Observatory

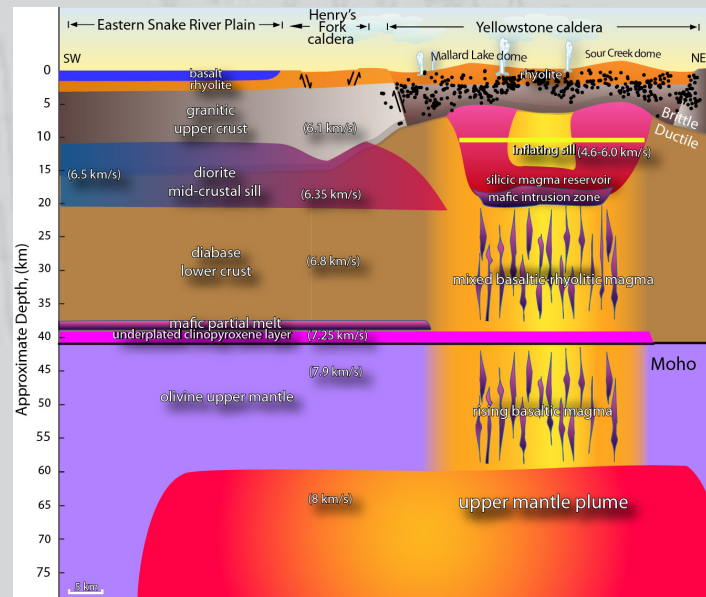
USGS+University of Utah+Yellowstone National Park

Hotspot Track and Regional Seismicity



Smith and Siegel, 2000

Model of Volcano-Tectonic Processes



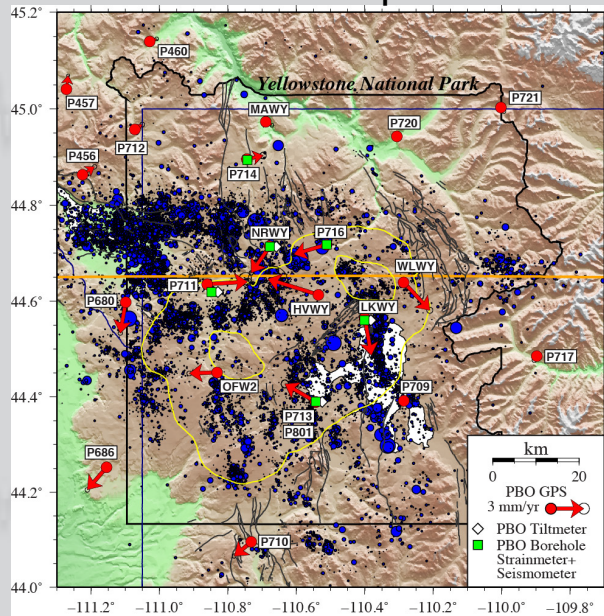
DeNosaquo et al., 2009

Example: Volcanoes

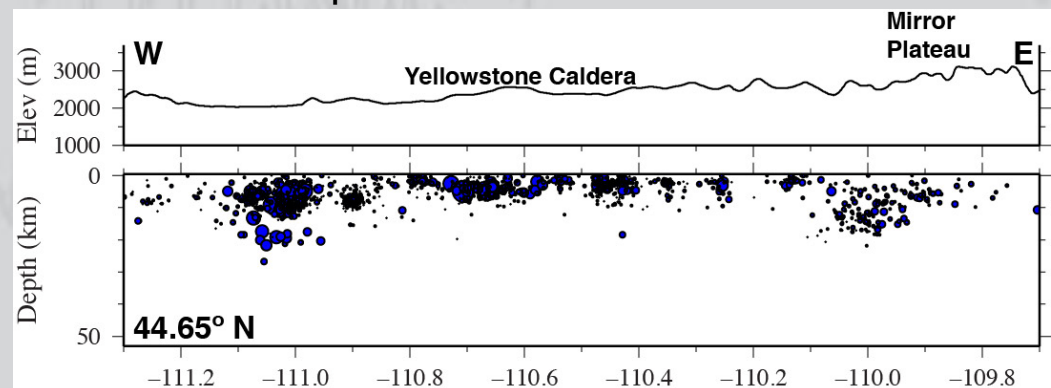
Yellowstone is a restless caldera

- Lots of earthquakes and earthquake swarms
- Large-scale, non-linear deformation
- Active hydrothermal field
- Historic activity not leading to large eruption

1973-2013 M>1 Earthquakes + PBO GPS



Shallow Earthquakes within Yellowstone Caldera

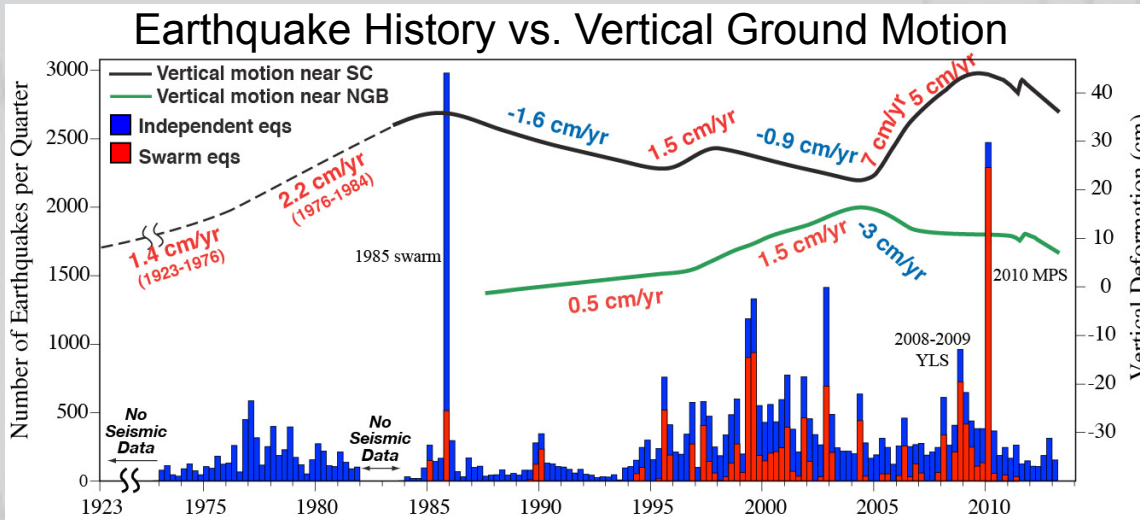


Example: Volcanoes

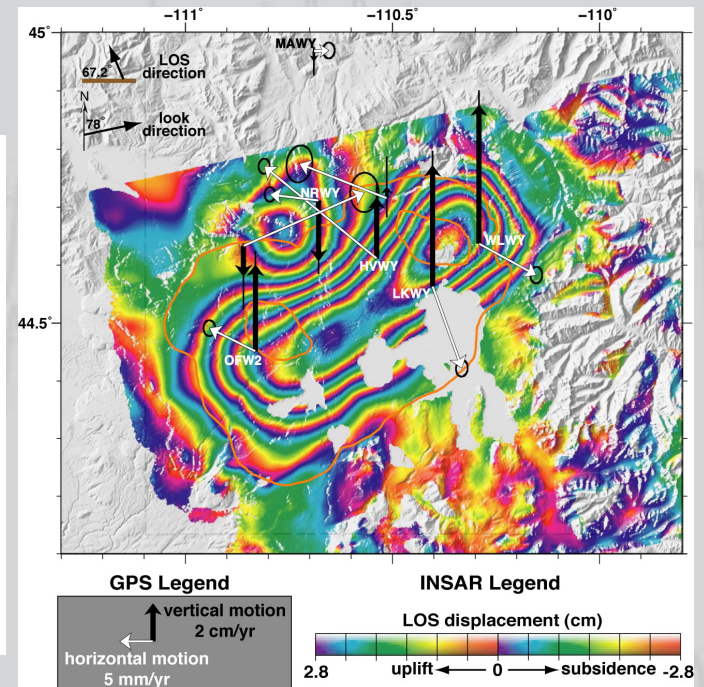
Yellowstone earthquake activity associated with changes in deformation

- Caldera uplift episode followed by large swarms
- Change to subsidence

2004-2006 Rapid Uplift Yellowstone Caldera



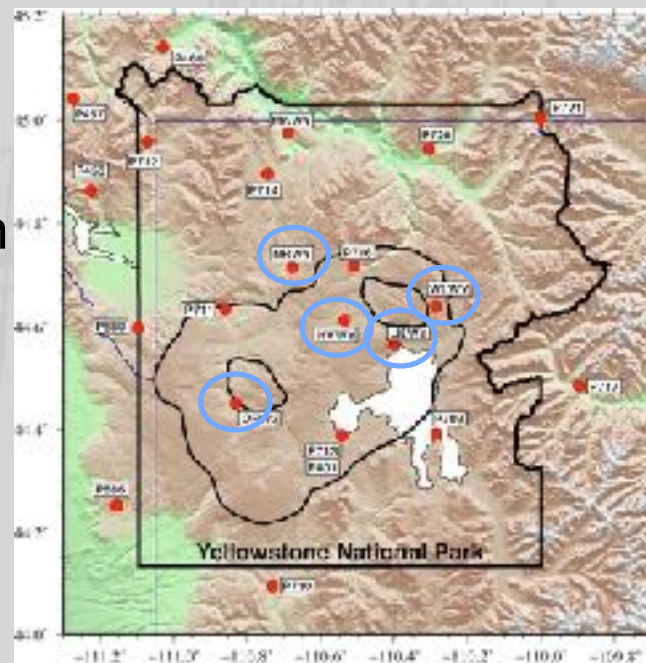
Farrell and Smith, 2013



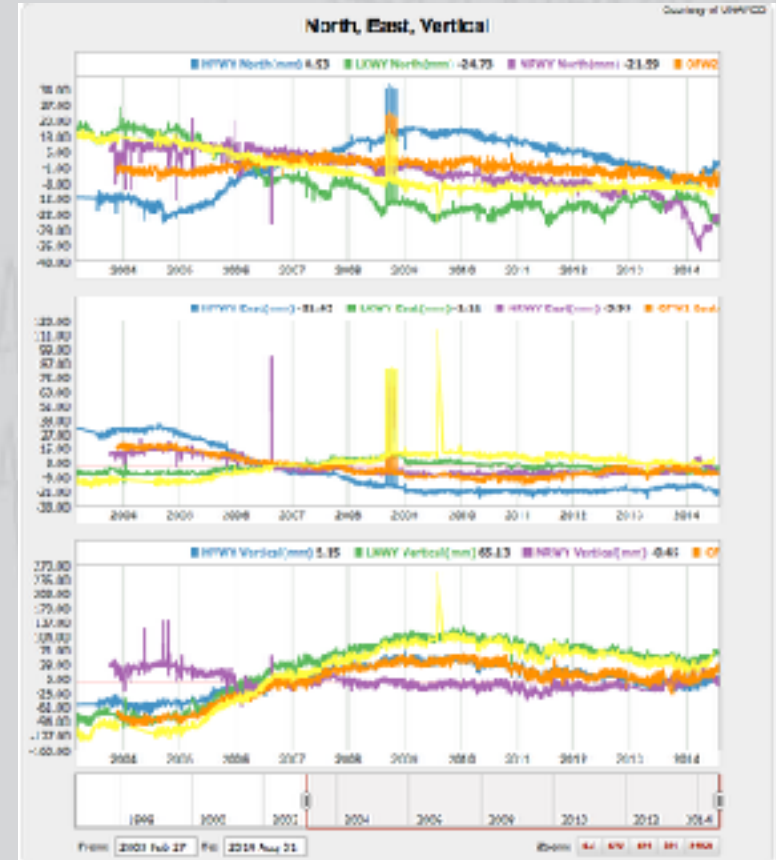
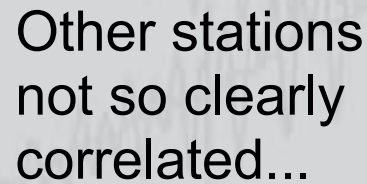
Chang et al., 2007

Example: Volcanoes

1. Open a browser and go to UNAVCO -> Software -> U-Plotter
2. Choose “GPS Position Time Series” (no Std Dev)
 - Select, plot available stations: HVWY, LKWY, NRWY, OFW2, WLWY
 - Slide time window to start ~2003-2004
3. Mouseover time series for dates
 - NRWY = purple time series
 - Note date of sudden change in direction in 2014



South to North
East to West
Up to Down

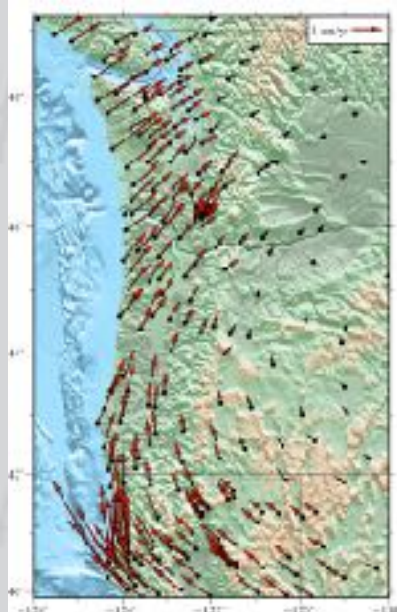


Example: Slow Slip and Tremor

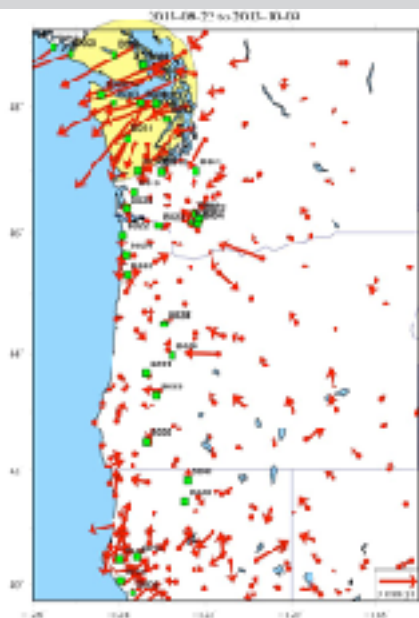
Subduction zone phenomenon

- Transient deformation episodes (2-5 mm) - slow slip
- Seismic tremor at 30-40 km depth

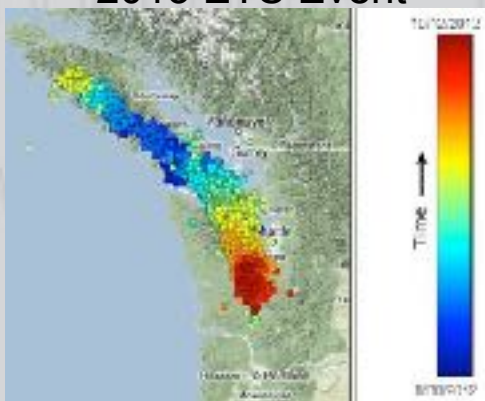
PBO GPS Velocities



Displacements from
2013 ETS Event

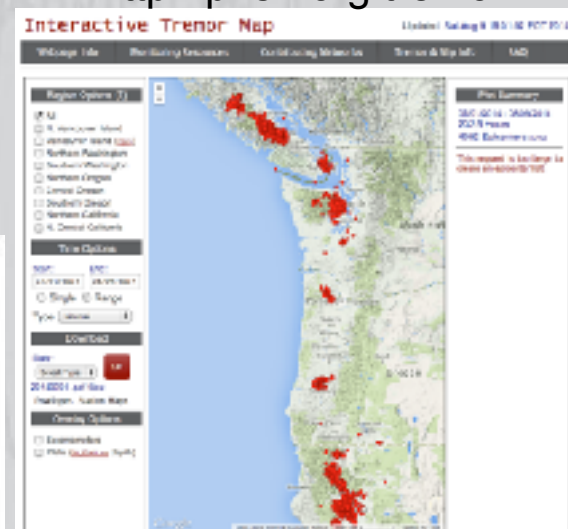


Tremor Locations
2013 ETS Event



PNSN

Last Month's Tremor
<http://pnsn.org/tremor>



Example: Slow Slip and Tremor

1. Open a browser and go to UNAVCO -> Instrumentation -> core GPS
2. Search for P439
 - Click on static plots to get popup
 - Click arrows until detrended plot appears
3. Sawtooth pattern in East component typical of ETS cycle

Notes:

Static time series may contain outliers that affect scaling

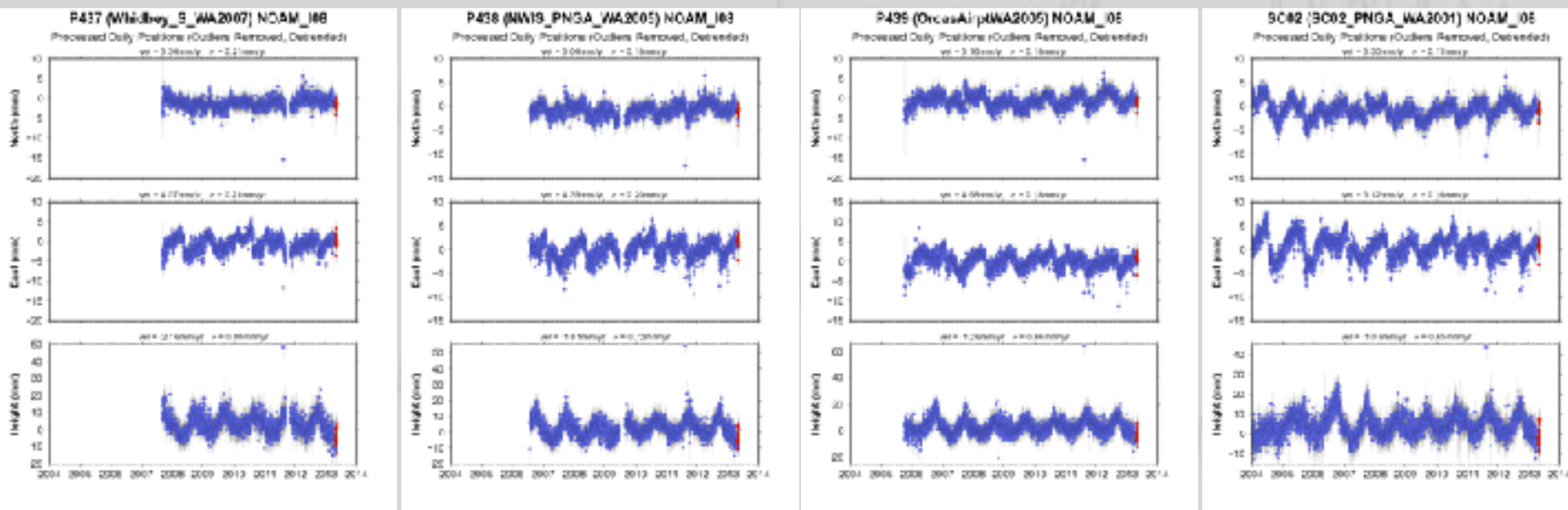
Not all processed stations have home pages



Example: Slow Slip and Tremor

Sample detrended time series showing slip events

- These time series from Vancouver Island, NW Washington
- ETS occurs along entire Cascadia subduction zone

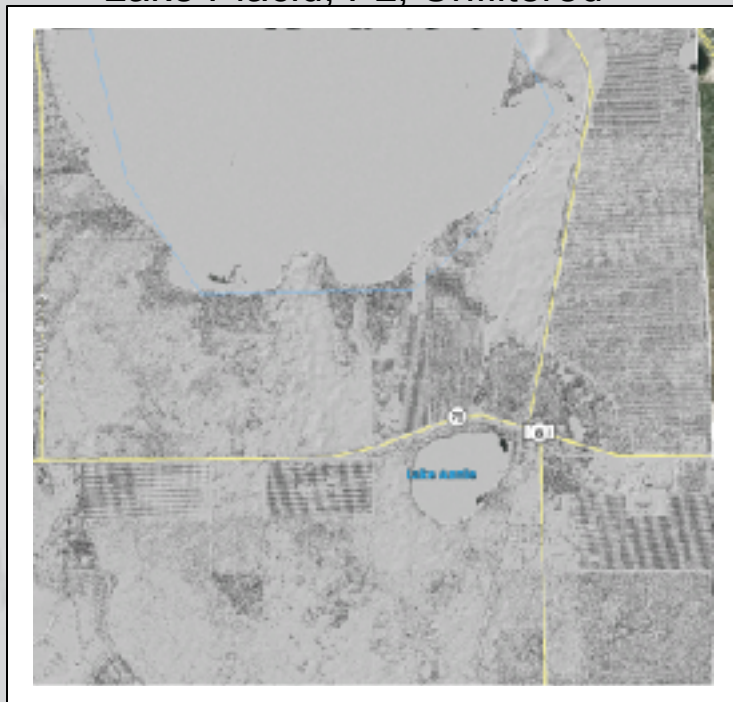


Example: Mapping Landforms

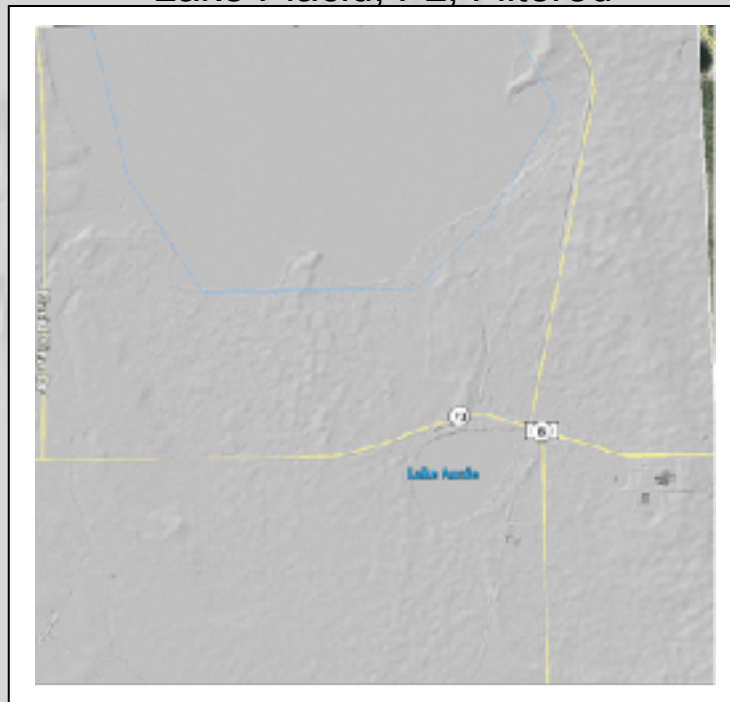
LiDAR data sets

- Detailed shaded topography
- Available in selected parts of the US

Lake Placid, FL, Unfiltered

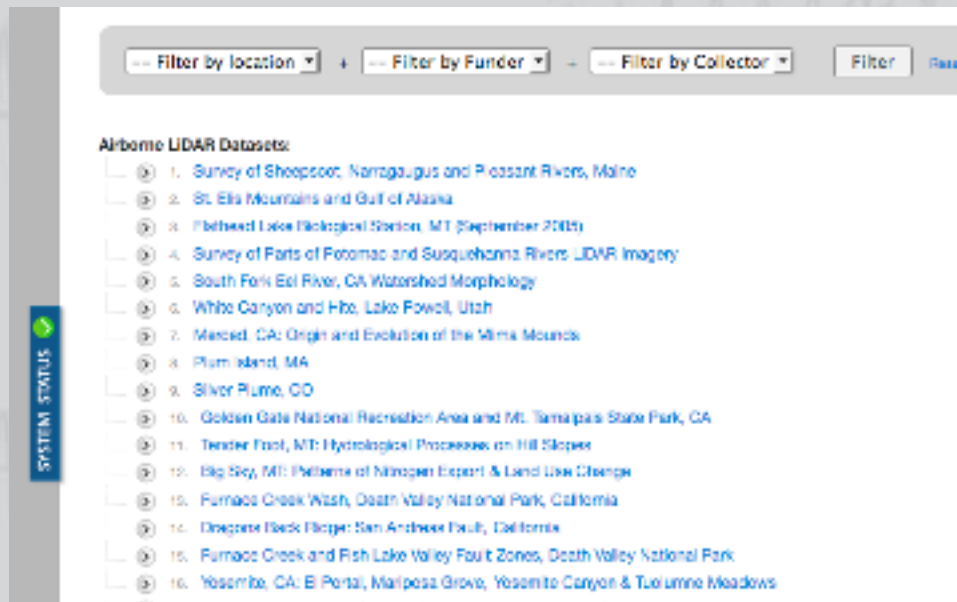


Lake Placid, FL, Filtered



Example: Mapping Landforms

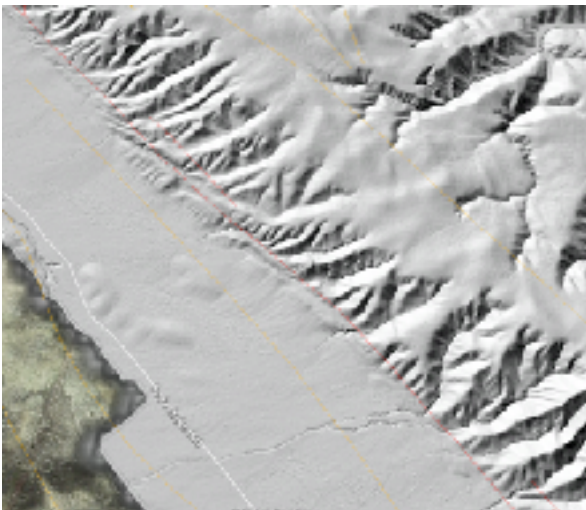
1. Open a browser and go to <http://www.opentopography.org>
2. Select “Find Data” or “Data” tabs
3. Select “Google Earth Files”
 - Download kml/kmz files from list



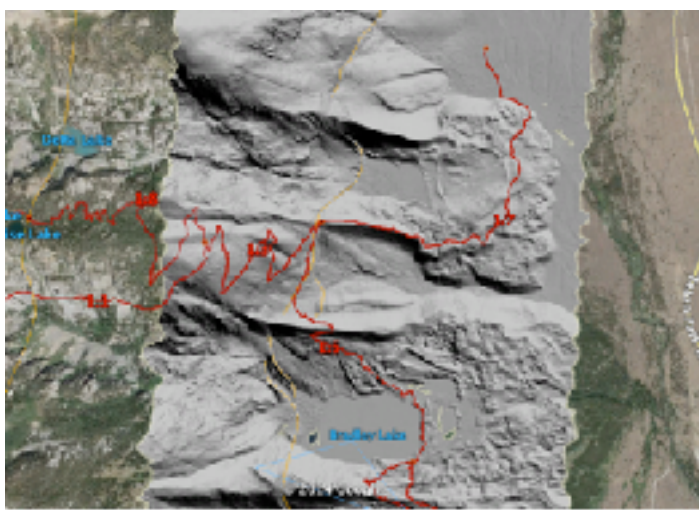
Example: Mapping Landforms

Use LiDAR Google Earth files to study landforms of interest

Fault Scarp & Offset Drainage,
Dragon's Back Ridge, San
Andreas Fault



Fault Scarp & Moraines,
Glacier Gulch
Grand Teton National Park

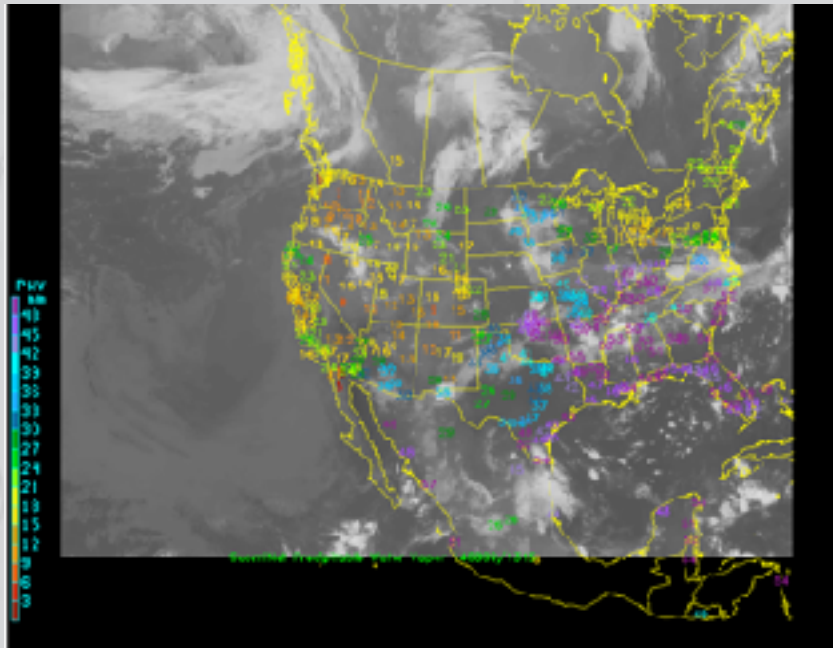


Fault Scarps,
Mirror Plateau
Yellowstone National Park



Example: Precipitable Water Vapor

- GPS data processed to derive precipitable water vapor in troposphere
 - GPS signals refracted by troposphere
- Processed by UCAR (University Corporation for Atmospheric Research)
 - PWV used for weather forecasting and atmospheric research



Example: Precipitable Water Vapor

1. Open a browser and go to UNAVCO -> Data -> Integrated Precipitable Water Vapor (PWV) -> Integrated Precipitable Water Vapor (PWV)
 - Last link will go to UCAR Suominet page
2. Select “Conus Map” from tab bar

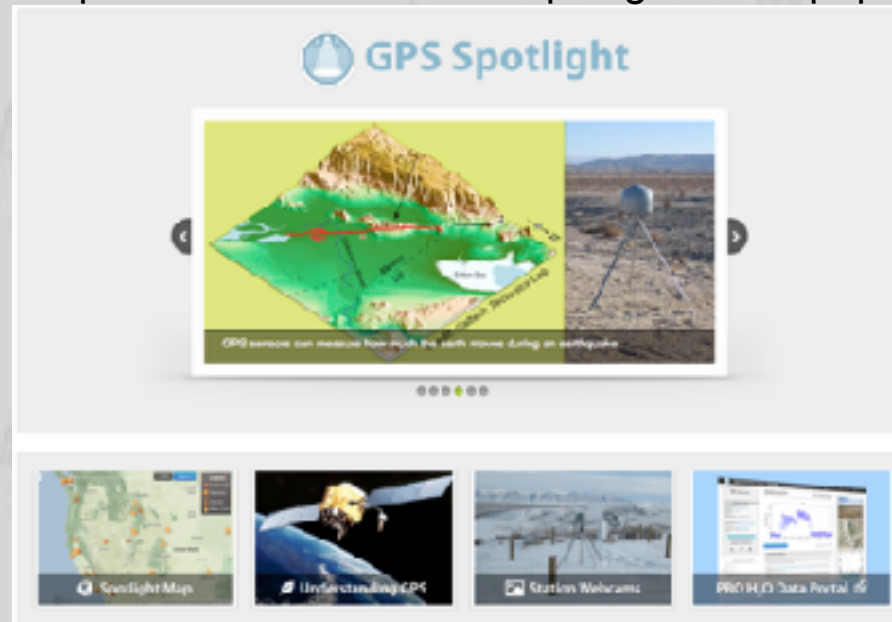
PWV from 1-Hr Solution



Example: GPS Spotlight

- Examples of GPS applications
 - Tectonics, atmosphere, water cycle, animal tracking
- Contributed by GPS Reflections Research Group
University of Colorado - Boulder

<http://xenon.colorado.edu/spotlight/index.php>



Example: PBO H₂O

- Study reflected GPS signals (multipath)
 - Vegetation height, snow depth, soil moisture
- Contributed by GPS Reflections Research Group
University of Colorado - Boulder

<http://xenon.colorado.edu/portal>

The screenshot displays the PBO H₂O website. At the top, the logo "PBO H₂O" is shown with the tagline "Using GPS reflection analysis for a more boundary-free study of the water cycle". Below this is a large image of a landscape with a person and a structure. The main navigation area features four categories: Snow, Vegetation, Soil Moisture, and Water Loading, each with a brief description and a "View data" button.

PBO H₂O
Using GPS reflection analysis for a more boundary-free study of the water cycle

Snow
Snow influences the atmosphere, water budget. Snow measurements are needed both to study climate and to predict snowmelt, flooding, and water availability.
[View data](#)

Vegetation
Measuring changes in vegetation is important for climate and hydrologic modeling applications, validation of satellite estimates of land surface conditions, and testing of ecohydrological hypotheses.
[View data](#)

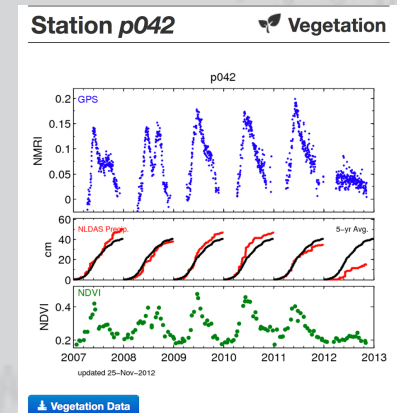
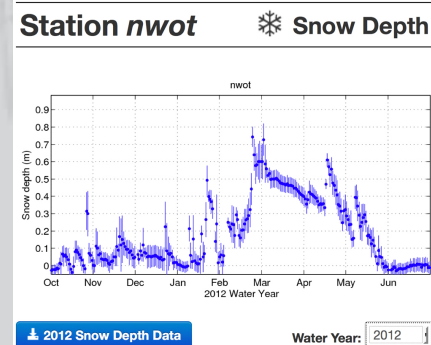
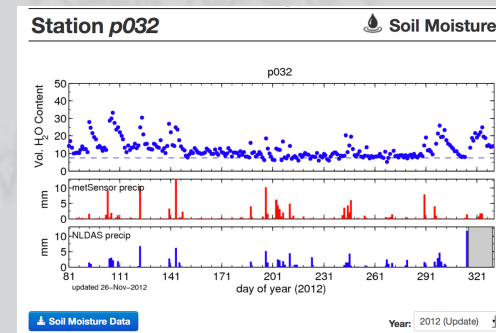
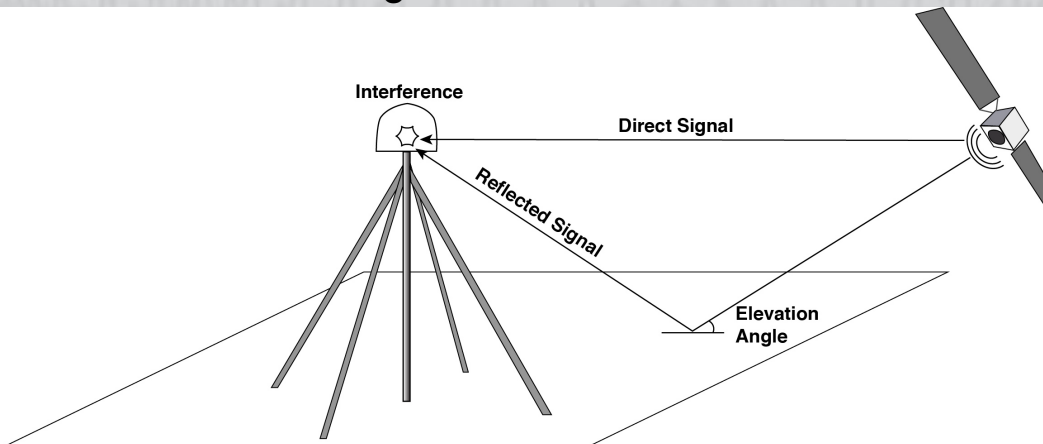
Soil Moisture
Soil moisture affects the partitioning of precipitation into runoff, evapotranspiration, and deep recharge and the fluxes of energy and carbon between the land surface and atmosphere.
[View data](#)

Water Loading
Regional water storage, such as the surface of the Earth, changes in response to changes in the atmosphere. Changes in storage are related through vertical displacement time series.
[View data](#)

Example: PBO H₂O

- Reflected GPS signal interferes with direct signal when satellite is low on the horizon
- Interference pattern depends on reflector properties
 - Cause variations in signal-to-noise ratio, multipath parameter

Satellite Signals and GPS Antenna



Where to get data

Website:

<http://www.unavco.org>

FTP:

<ftp://data-out.unavco.org/pub/products>

subdir event - earthquake offsets

position - station time series

velocity - velocity files

Contact UNAVCO for questions regarding data

puskas@unavco.org

olds@unavco.org

Questions?

