Overview: Seismogenic Zone Experiment Mini-Lessons

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The Margins Seize initiative focused on physical subduction zone processes that generate earthquakes as well as those processes that lead to other less well-known plate boundary interactions such as slow slip and tremor.

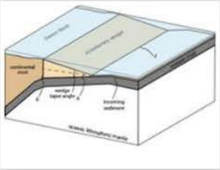
Most of the world's great earthquakes occur in subduction zones; therefore studying the seismic processes that occur in different subduction zones has important implications for hazard assessment and mitigation as well as our understanding of the fundamental physics underlying the theory of plate tectonics.

The Seismogenic Zone Initiative (SEIZE) seeks to address the following questions at the Central American and Nankai Trough focus sites:

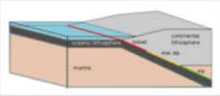
- What is the nature of strong, locked parts of seismogenic zones?
- What are the temporal relationships among stress, strain, and fluid composition throughout the earthquake cycle?
- What controls the up- and down-dip limits of the seismogenic zone?
- What is the nature of the tsunamigenic earthquake zone?
- What is the role of large thrust earthquakes in mass flux of material in the subduction system?

To help integrate important results from SEIZE into geoscience curricula, we have developed mini-lessons intended to introduce students to authentic data and guide student exploration of the different physical processes that occur at different subduction zones.

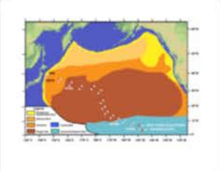
- **Accretionary vs. Erosive Subduction Margins** - This module challenges students to critique the validity of the standard "accretionary prism" cartoon at subduction zones. Using a mass balance approach, students will evaluate the fate of sediment at subduction margins and be able to distinguish erosive from accretionary forearcs.



- **The Spectrum of Fault Slip** - This mini-lesson involves student analysis of data from the Central American focus site and guides students to discover and characterize a range of slip behaviors at subduction zones including slow slip events and ordinary fast-rupturing earthquakes.



- **The Plate Boundary Fault of the 2011 Tohoku Earthquake: Oceanic Provenance and Earthquake Production** - This mini lesson provides an example of how stratigraphy influences tectonics, and vice versa. Students will be able to examine a series of stratigraphic columns and predict the likehood of a tsunamigenic earthquake at the Kurile-Japan-Izu Bonin subduction zone.



Slow Slip Events v. Earthquakes

Using geodetic data to estimate source parameters

Slow slip has been observed in a handful of subduction zone settings . . . So far!

What is a Slow Slip Event?

- Faster than the plate speed but slower than an earthquake
  - Plates go at centimeters per year
  - SSEs go at millimeters per week
  - Earthquakes go at meters per second
- Not detectable by seismometers due to long rise time and slow rupture velocity
- So far most commonly found in subduction zones between the locked zone and the freely slipping zone

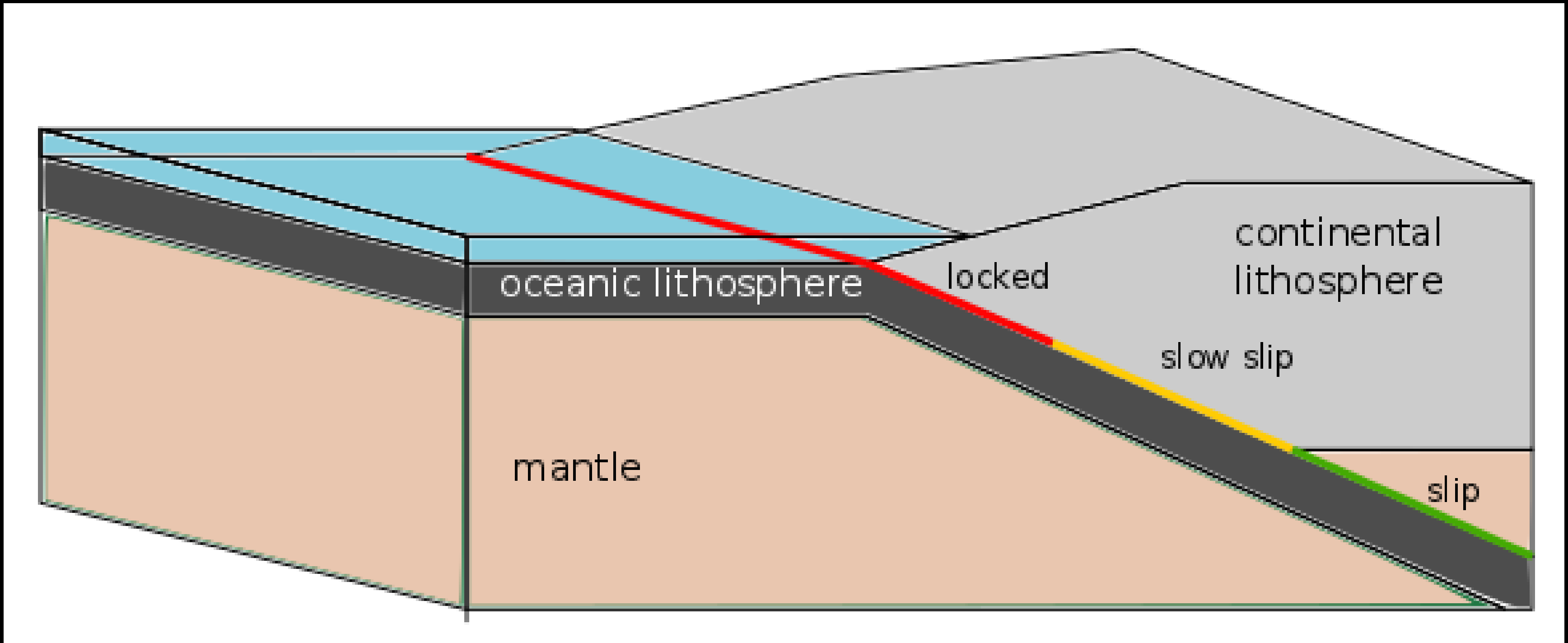
For example, the rise time (how long it takes the rupture to accelerate) for an earthquake is often negligible compared to the rupture duration, but for an SSE, the rise time can be a significant fraction of the overall time of rupture

SSEs and Earthquakes: what's the difference?

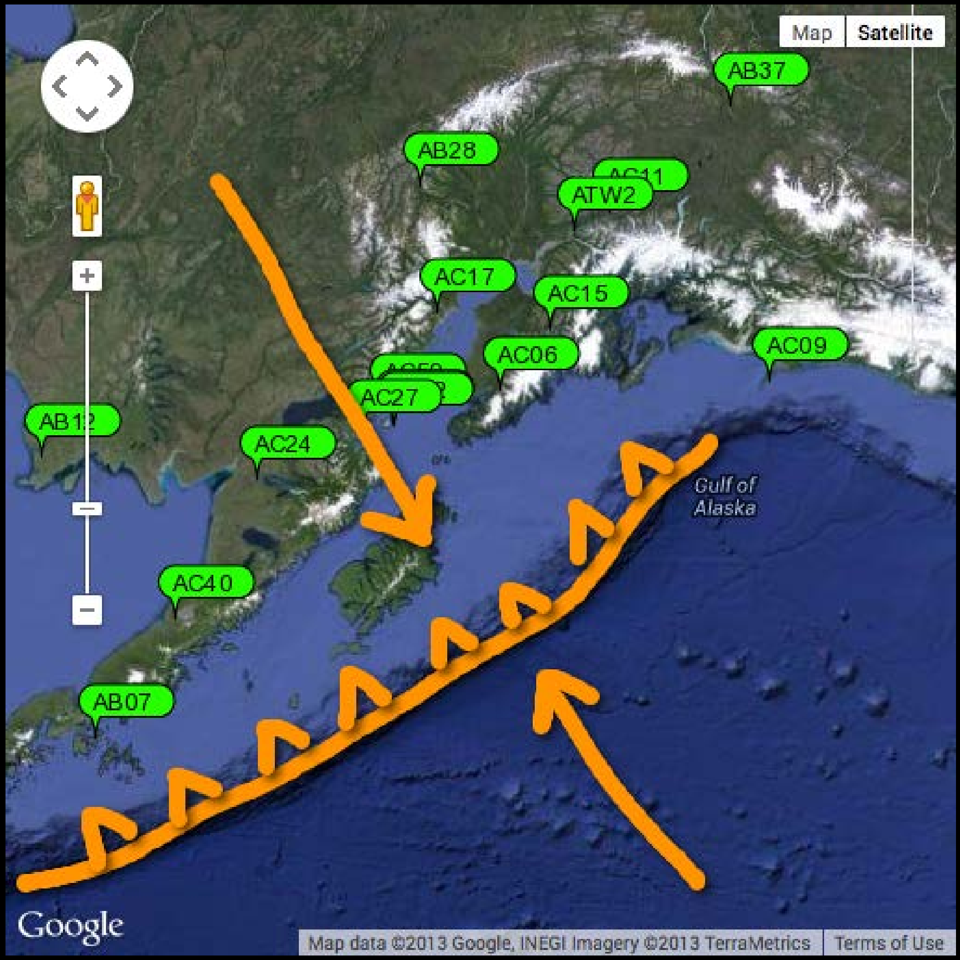
Characteristic	Same or different?	how
duration	different	Earthquakes last seconds to minutes. SSEs last weeks to months
slip	same	Earthquakes and SSEs can slip the same amount but SSEs take a lot longer to do it
magnitude	same	Magnitude depends on the rupture area and amount of slip, not on slip speed, so SSEs and Earthquakes can have the same magnitudes.
how they are detected	different	SSEs cannot be detected with seismometers because they aren't sudden enough to produce seismic waves. GPS or INSAR is necessary.
location	different	In a subduction zone, most earthquakes happen in the locked zone, but SSEs tend to happen downdip of the locked zone

SSEs and earthquakes are both part of the cycle of stress accumulation and release on faults. How are they related to each other and to the general subduction engine is a topic of current research.

SSEs occur between the locked section and the freely slipping section

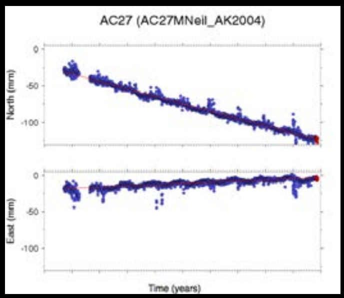


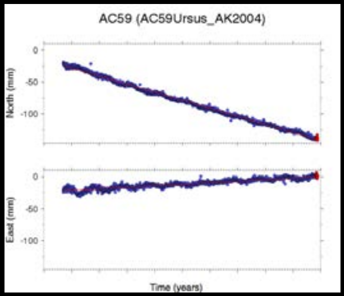
“Textbook” depiction of a subduction zone and associated plate movement

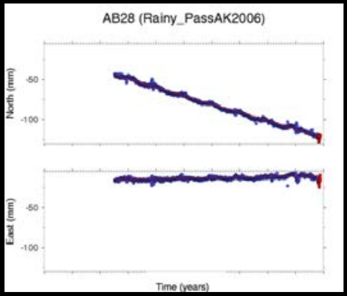


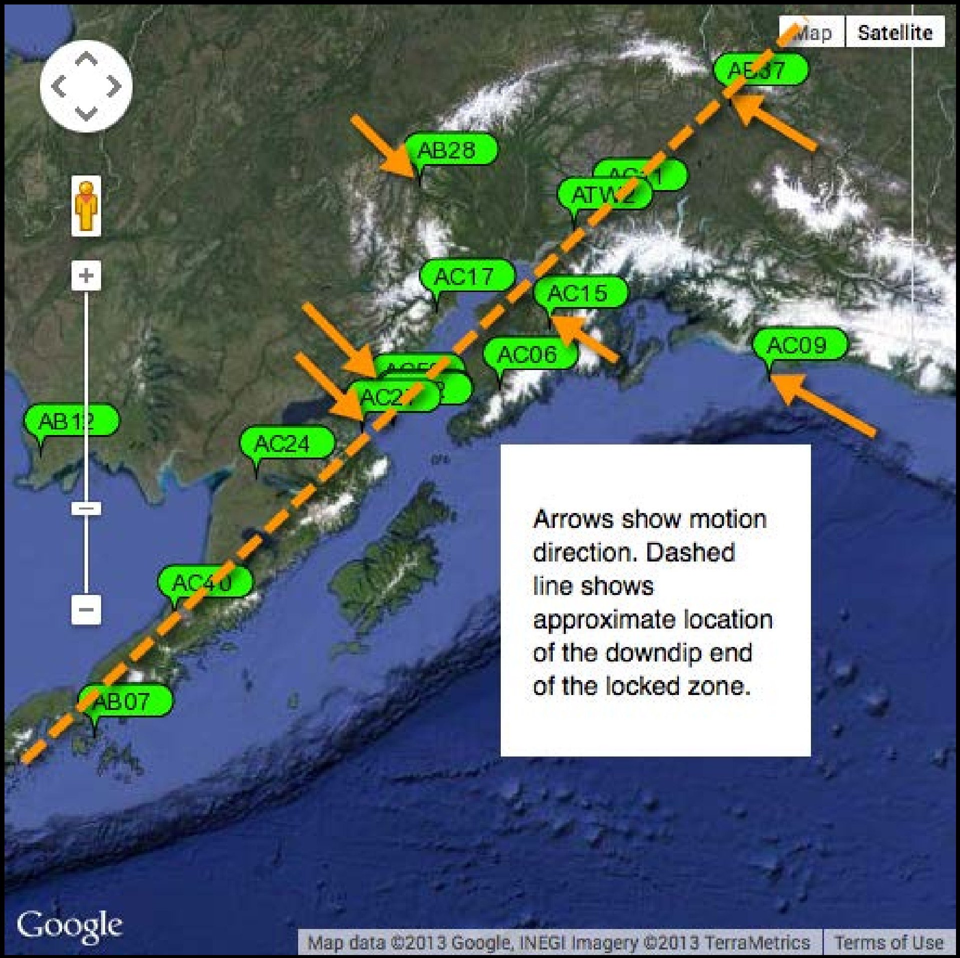
Geodetic data can be used to infer the location of the locked section

These three stations are moving south and east

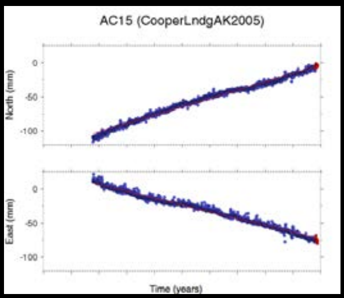


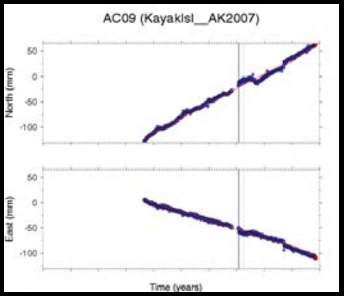


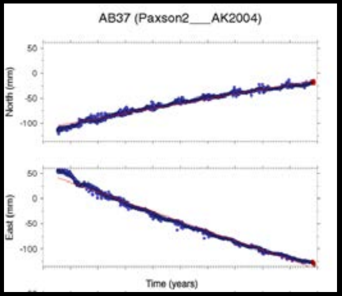




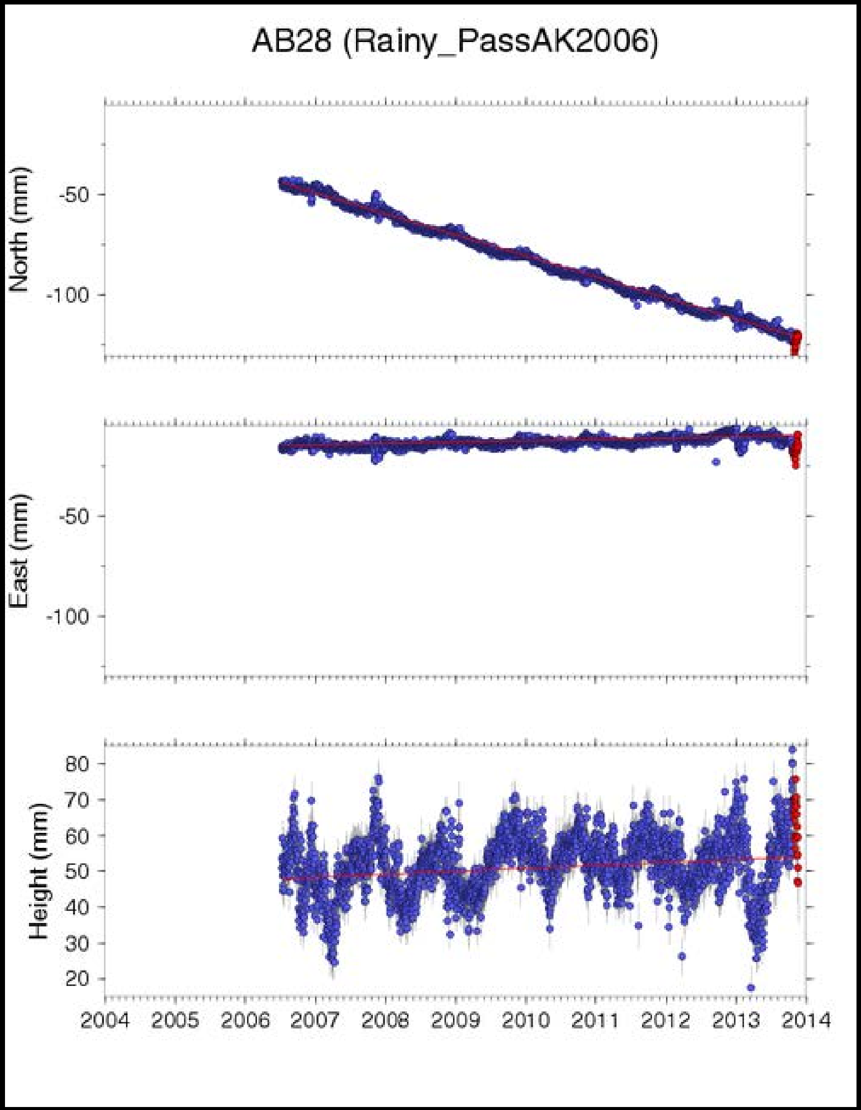
These three stations are moving north and west







How to read GPS time series plots



data from Unavco.org

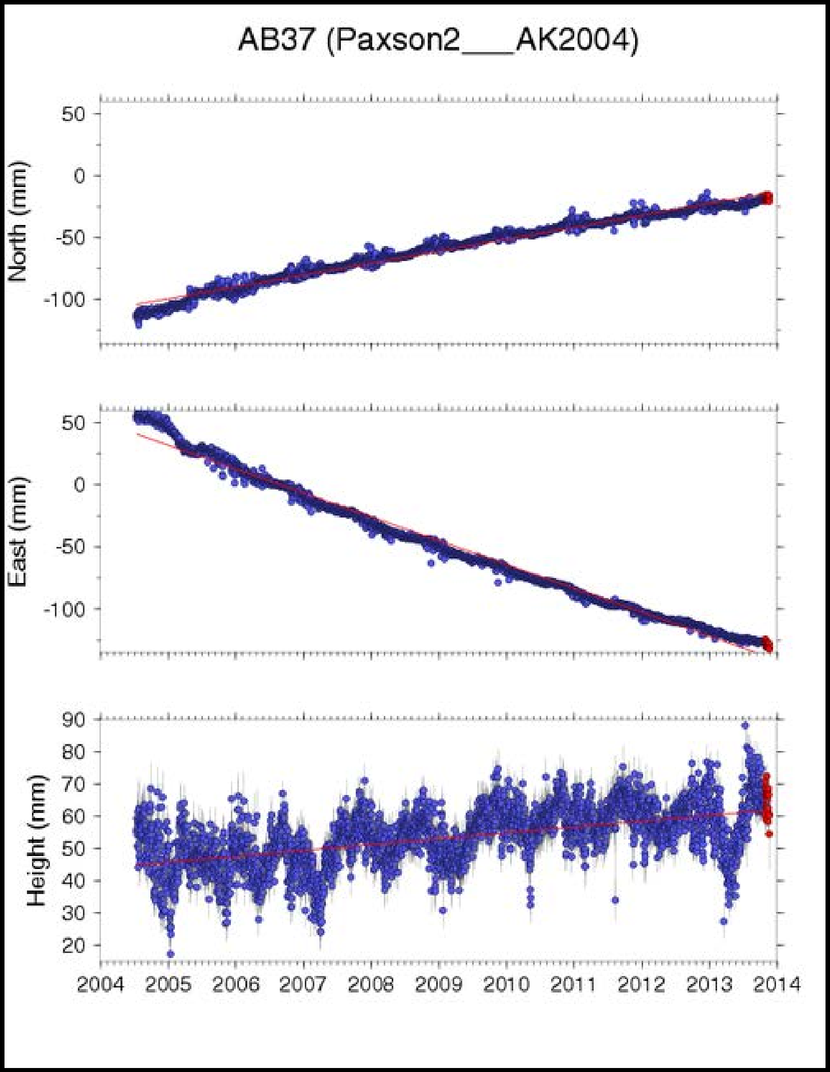
GPS stations have 3 components: North/South, East/West, and up/down.

Time is along the x axis, usually in years and tenths of years.

Each blue dot is a measurement of position, usually taken daily. The red line is an average. The direction of successive positions tells us the direction of motion. The amount of motion per time gives us speed.

Look at the top box first. This station has been moving in the negative north direction, so that is south. The middle box shows a nearly flat line, so that is neither east nor west. The bottom is noisy but averages out to a flat line.
So, overall, this station is moving SOUTH.

Calculate a station's velocity



This station is moving positive north, negative east, and positive vertically. Overall, that is NORTHWEST and UP.

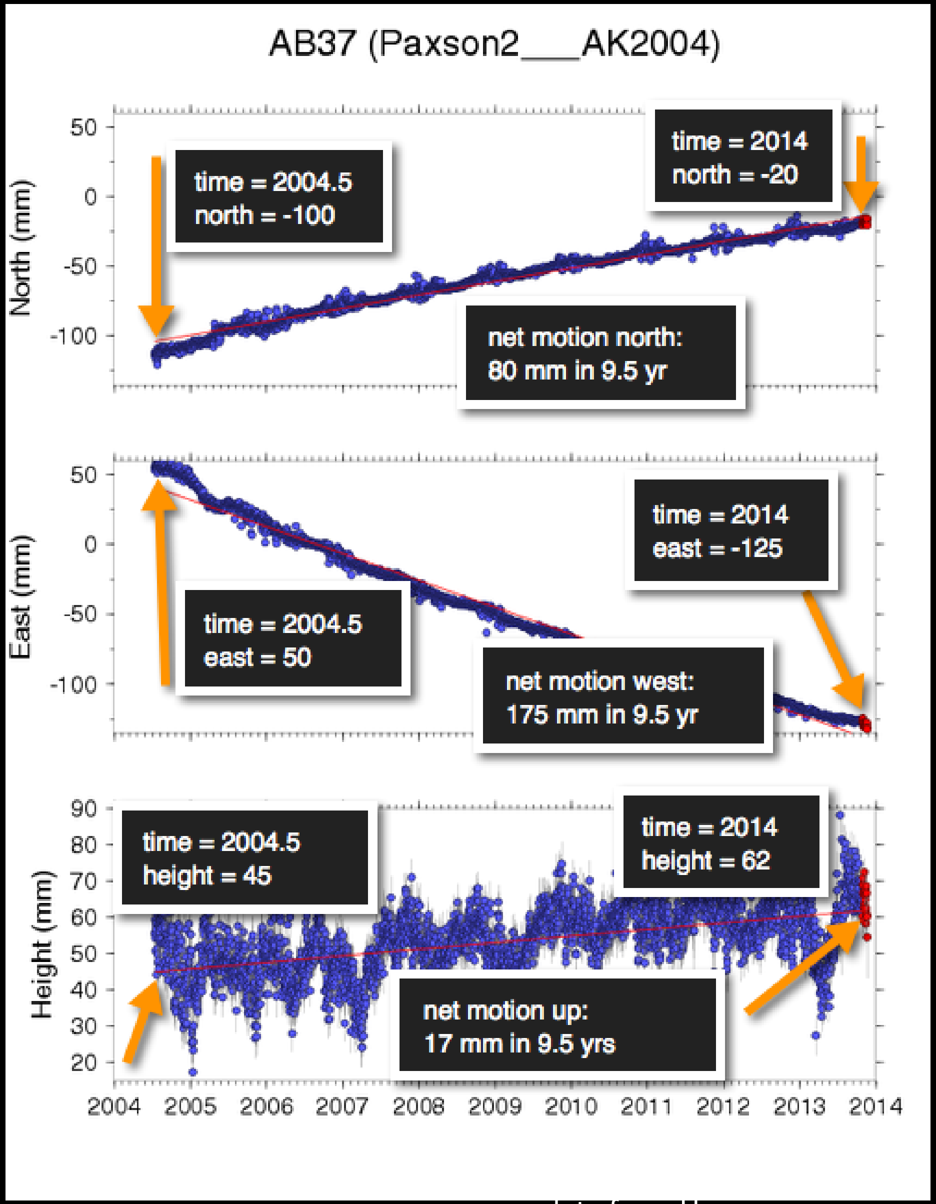
Let's calculate the average velocity of this station.

The way to do it is to observe distance over a period of time for each component, then use vector addition to get an overall velocity.

The next slide walks you through it.

data from Unavco.org

Calculate a station's velocity



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This station is moving positive north, negative east, and positive vertically. Overall, that is NORTHWEST and UP.

Let's calculate the average velocity of this station.

The way to do it is to observe distance over a period of time for each component, then use vector addition to get an overall velocity.

Top≈ 80 mm north in 9.5 years
Middle ≈ 175 mm west in 9.5 years
Bottom ≈ 17 mm up in 9.5 years

Top → 8.4 mm/yr
Middle → 18.4 mm/yr
Bottom → 1.8 mm/yr

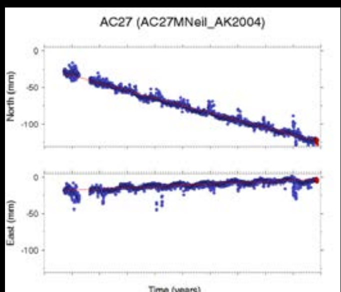
Use vector addition:

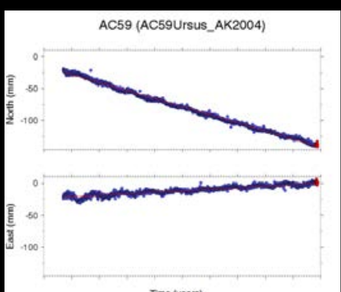
Overall: sqrt(top^2 + $middle^2$ + $bottom^2$)

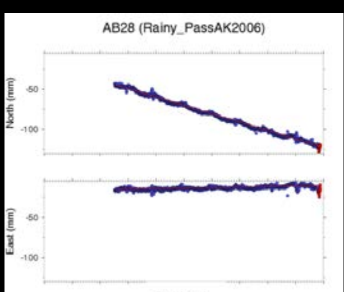
sqrt(70.6 + 338.6 + 3.2) = **20.3 mm/yr N,W,up**

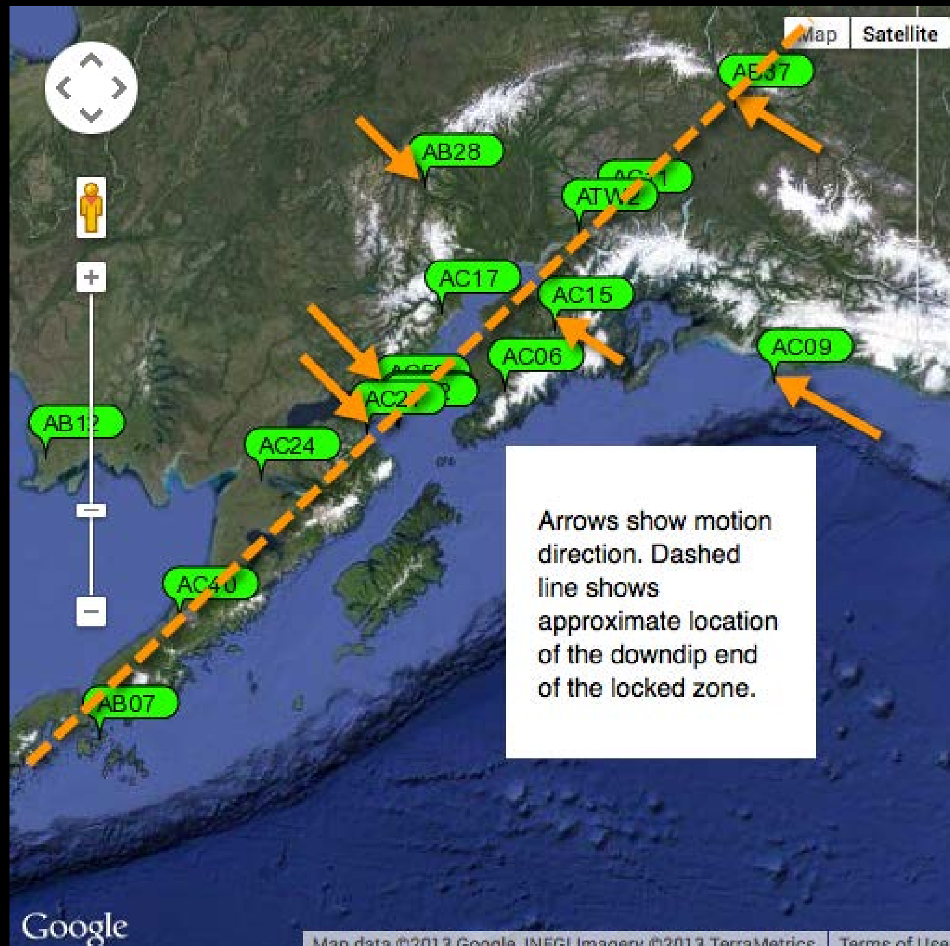
Geodetic data can be used to infer the location of the locked section

These three stations are moving south and east









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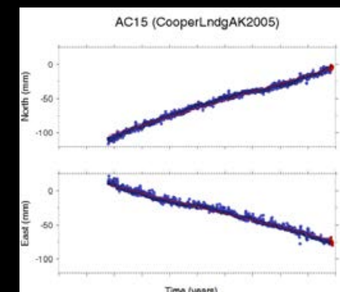
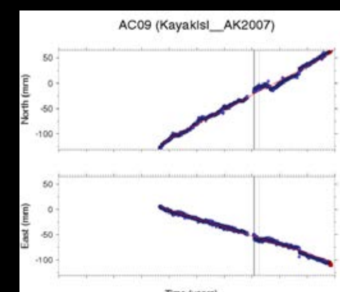
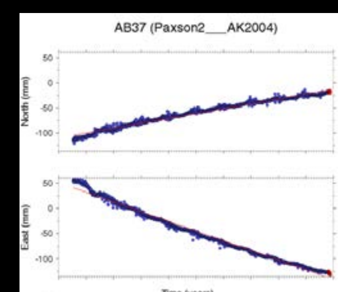
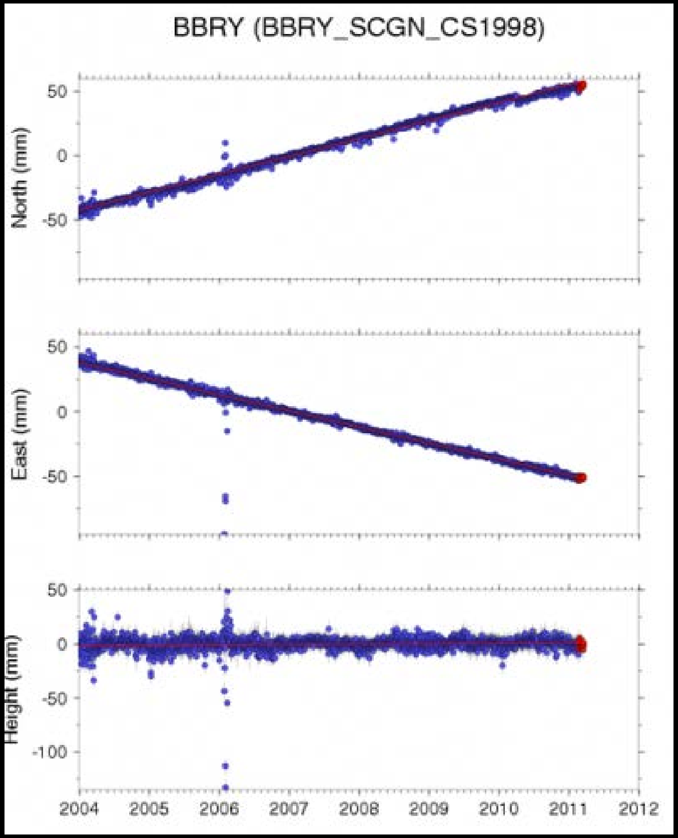


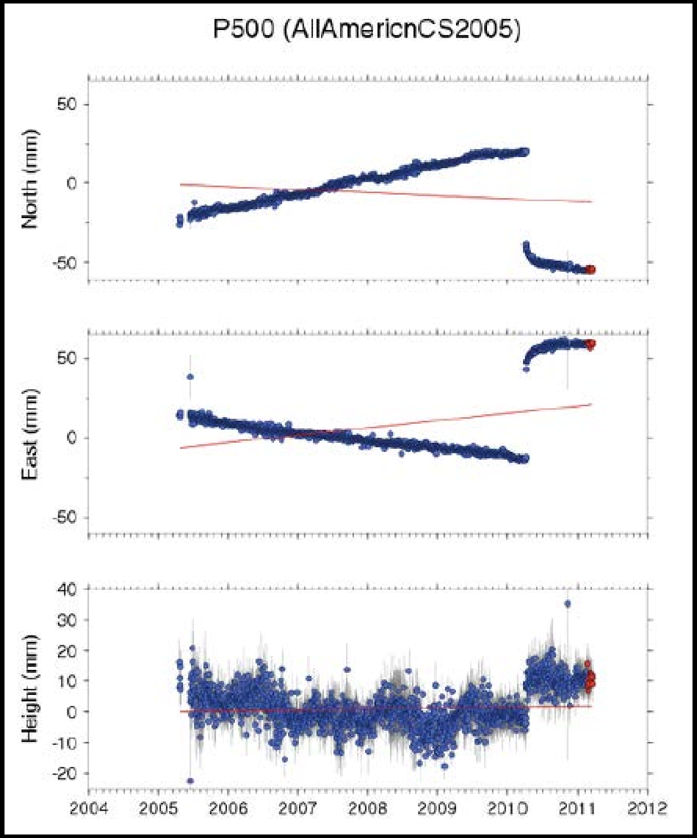




Geodetic time series data



Business as usual

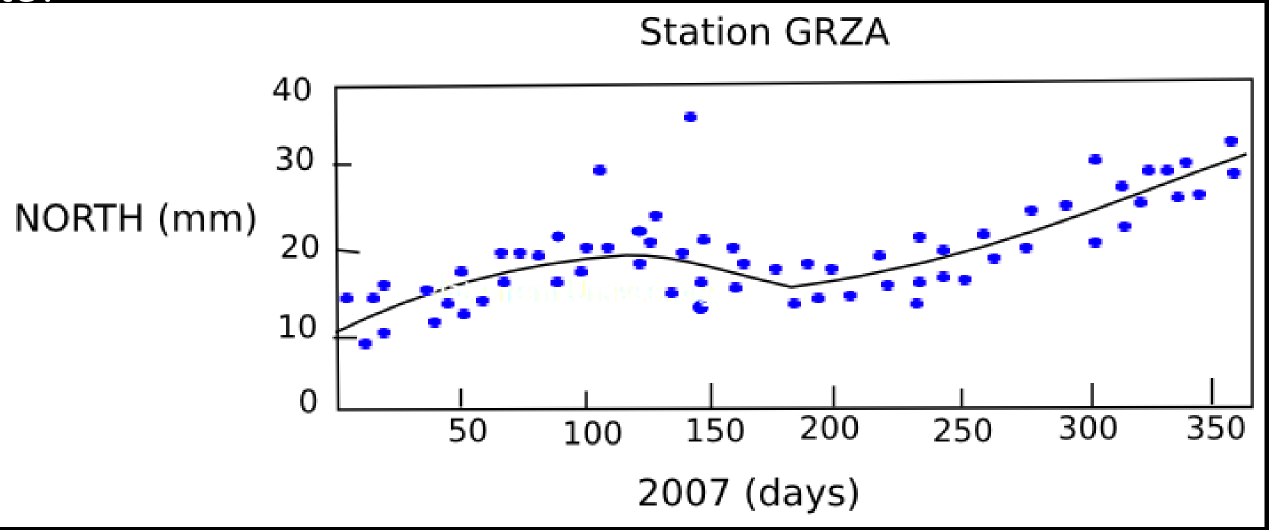


Spot the earthquake!

data from Unavco.org

2007 SSE in Nicoya, Costa Rica

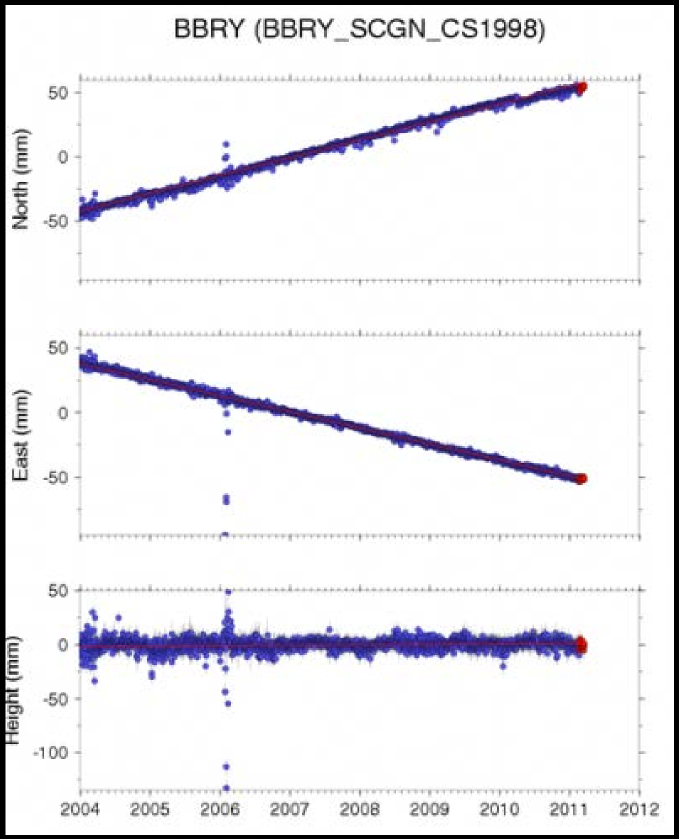
Too fast for the plate rate, too slow for an earthquake.
Quick quiz to check yourself: An SSE involves slip in the same direction an earthquake would move, or in the same direction as background plate rate?



Data recorded during SSE in Nicoya. What is the background plate direction and rate?
What is the duration, direction and rate of the SSE?

Figure modified from Outerbridge, K. C., T. H. Dixon, S. Y. Schwartz, J. I. Walter, M. Protti, V. Gonzalez, J. Biggs, M. Thorwart, and W. Rabbel (2010), A tremor and slip event on the Cocos-Caribbean subduction zone as measured by a global positioning system (GPS) and seismic network on the Nicoya Peninsula, Costa Rica, J. Geophys. Res., 115, B10408, doi:10.1029/2009JB006845

Review of calculations



data from Unavco.org

What's the plate rate at BBRY?

North looks like about 110 mm/7.2 years → 15.28 mm/yr
East looks like about -90 mm/7.2 years → -12.5 mm/yr
Height looks like no appreciable change

Use vector addition:
$N^2 + E^2 = total^2$

So, total = sqrt(233.48 + 156.25)=19.74mm/yr northwest.

Time to work through the problem set.

- The problem set is in two parts.
- 1: make sketches of hypothetical geodetic data given various station locations and plate motions
- 2: Use real data to calculate slip in an earthquake, slip in an SSE, and calculate recurrence interval

For further reading

- Schwartz, S. Y., and J. M. Rokosky (2007), Slow slip events and seismic tremor at circum-pacific subduction zones, Rev. Geophys. 45, RG3004, doi:10.1029/2006RG000208
- Radiguet, M., F. Cotton, M. Vergnolle, M. Campillo, B. Valette, V. Kostoglodov and N. Cotte (2011), Spatial and temporal evolution of a long term slow slip event: the 2006 Guerrero Slow Slip Event, GJI, **184,** 816–828, doi: 10.1111/j.1365-246X.2010.04866.x
- Outerbridge, K. C., T. H. Dixon, S. Y. Schwartz, J. I. Walter, M. Protti, V. Gonzalez, J. Biggs, M. Thorwart, and W. Rabbel (2010), A tremor and slip event on the Cocos-Caribbean subduction zone as measured by a global positioning system (GPS) and seismic network on the Nicoya Peninsula, Costa Rica, J. Geophys. Res., 115, B10408, doi:10.1029/2009JB006845
- Wei, M., J. J. McGuire, and E. Richardson (2012), A slow slip event in the south central Alaska Subduction Zone and related seismicity anomaly, Geophys.Res. Lett., 39, L15309, doi:10.1029/2012GL052351
- McCaffrey, R., L. M. Wallace AND J. Beavan (2008) Slow slip and frictional transition at low temperature at the Hikurangi subduction zone, Nature geoscience, 1,316-320, doi:10.1038/ngeo178
- Vidale, J.E. and Heidi Houston (2012), Slow slip: A new kind of earthquake, Phys. Today 65, 38, doi: 10.1063/PT.3.1399