Measuring Fault Parameters and Slip from Geodetic Imaging Data using GeoGateway Online Tools

Seismological Society of America 2019 Workshop, Seattle

Instructors:

Andrea Donnellan, Jet Propulsion Laboratory, California Institute of Technology

Lisa Grant Ludwig, University of California, Irvine

Jay Parker, Jet Propulsion Laboratory , California Institute of Technology

John Rundle, University of California, Davis

Agenda

• 1:00 pm	Welcome and Introductions	Andrea Donnellan
• 1:15 pm	GeoGateway Overview	Andrea Donnellan
• 1:30 pm	GeoGateway User Guide	Lisa Grant Ludwig
• 1:45 pm	UAVSAR	Andrea Donnellan
• 2:15 pm	GPS Tools	Jay Parker
• *2:45 pm*	*Break*	
• 3:00 pm	Seismicity and Forecast tools	John Rundle
• 3:30 pm	User exploration	Andrea Donnellan
• 4:15 pm	Wrap-up and questions	Andrea Donnellan
• *4:30 pm*	*Adjourn*	

Workshop Overview

- Overview of geodetic imaging
- Hands-on experience working with GeoGateway tools
- Learning objectives:
  - Gain an understanding of GPS time series
  - Produce GPS station velocities, displacements, coseismic offsets and postseismic motions
  - Analyze UAVSAR data to measure fault slip and crustal deformation
  - Learn to identify signals reflecting solid Earth processes versus signal from error sources
- Target users for workshop
  - Geologists and students who want to apply geodetic imaging data to their research

GeoGateway Overview

- Online tools for analysis, modeling, and response using geodetic imaging data
- Main application of GeoGateway is to analyze and model crustal deformation related to earthquakes, and measure fault slip
- Focus of tools
  - Airborne InSAR data from NASA's airborne UAVSAR platform
  - Global Positioning System (GPS) position time series, displacements, and velocities
- Other tools
  - Data layering
  - Faults
  - Seismicity
  - Forecasting
  - Modeling

http://geo-gateway.org

Data types and products

UAVSAR: NASA's L-band InSAR platform

- Sub-cm detection of surface deformation
- Has measured
  - Landslides
  - Levees
  - Subsidence
  - Earthquakes
  - Volcanoes
  - Wildfire scars
  - Glaciers

GNSS: Global Navigation Satellite System

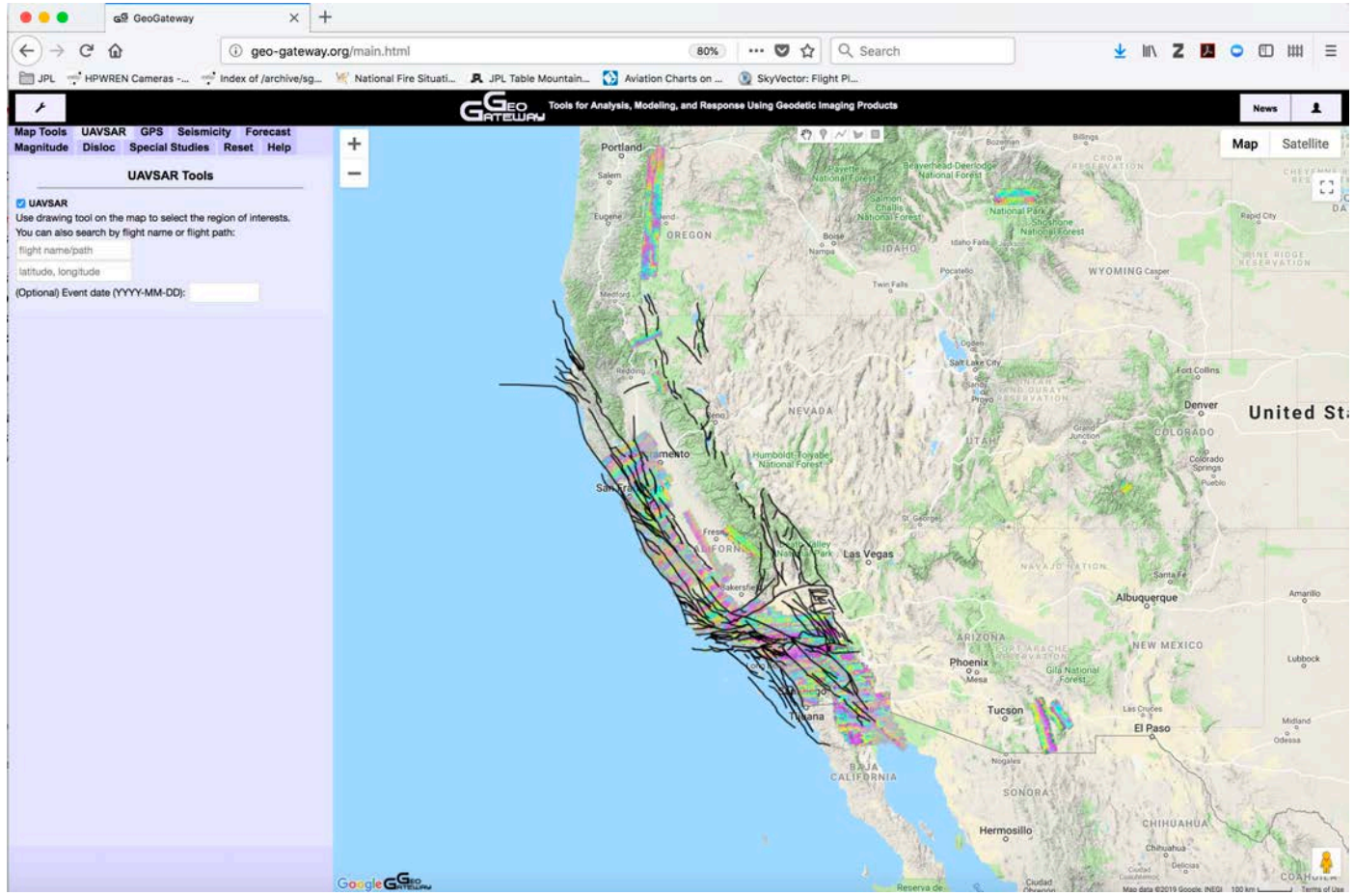
- Precise position time series
- Daily to sub-daily solutions
- Accuracies are sub-mm globally
- Provide rates to better than 1 mm/yr
- Limitations
  - Stations widely separated by 10 km or more
  - Difficult to infer smaller scale processes

Other Data Products

- UCERF-3 faults
- Seismicity
- User generated KML overlays

Geographic Coverage

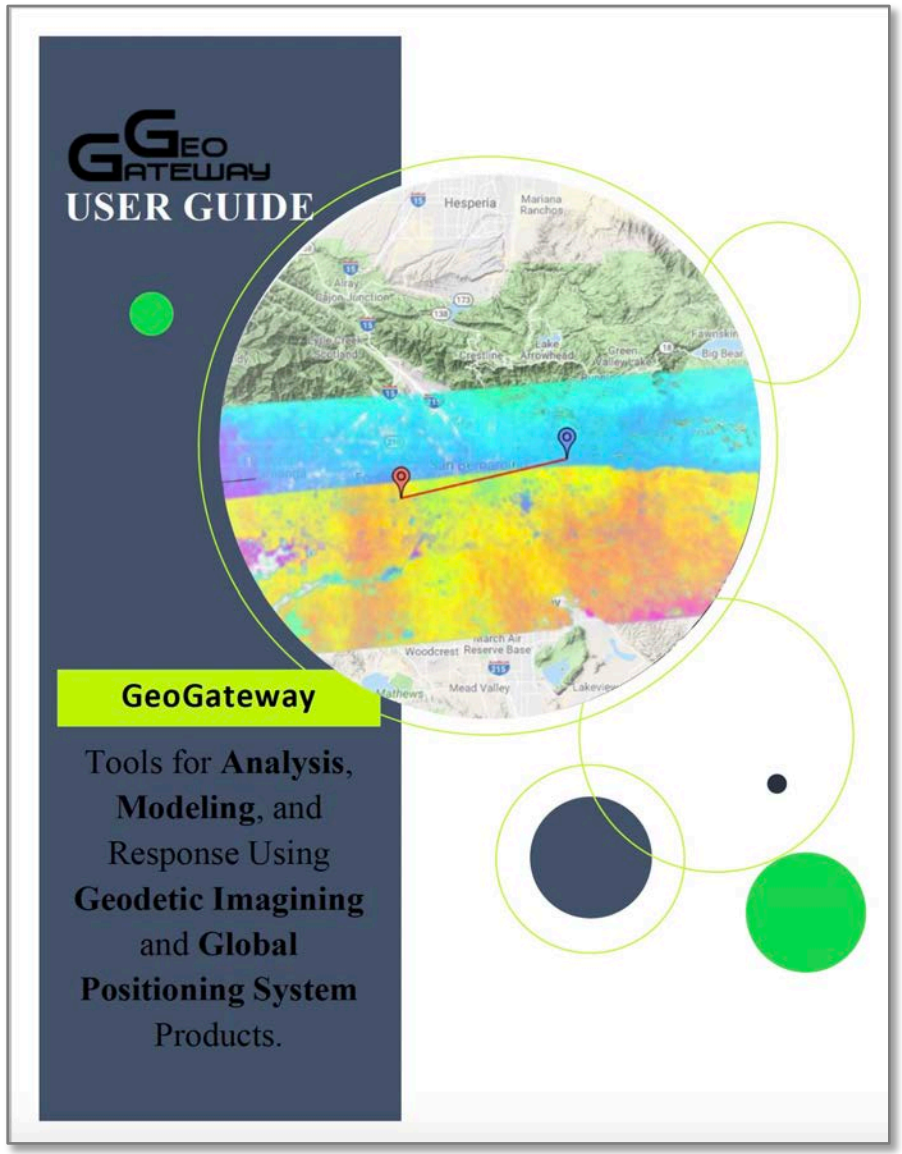
- Global
- Focus on California
  - Majority of UAVSAR flights
  - UCERF-3 digitized faults
  - Abundance of GNSS stations
  - Dense Seismic Network



Limitations

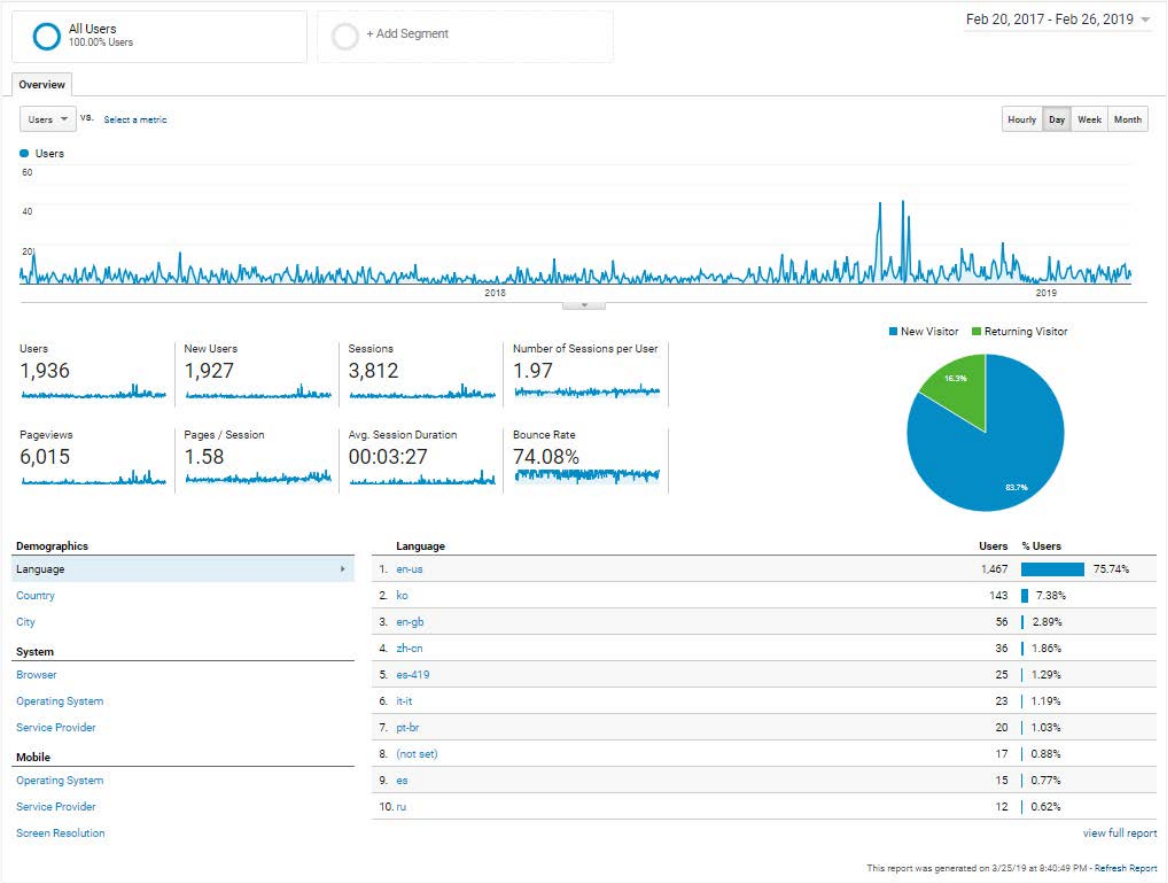
- Advantages:
  - Designed for rapid analysis of geodetic imaging data
  - Allows for context from other data types
- Not suitable for full analysis
  - Can download products for further analysis
- Uncertainty quantification is limited
- No stacking of InSAR products (yet?)
- User workspace is limited (so far)
- Possible bugs – please file feedback reports!

GeoGateway User Guide



If you build it, users will use it….?

If not, create a User guide!



Make it useful

- New users
  - Upper division undergraduate through senior scientists
- Experienced users - reference
- Approach
  - Recruit senior undergraduate to learn GeoGateway by trying to use it, and then design a User Guide based on that experience

Megan Mirkhanian

A valuable member of the GeoGateway Team

April 5, 2019
3rd consecutive All Academic Award
Mountain Pacific Sports Federation

GeoGateway User Guide

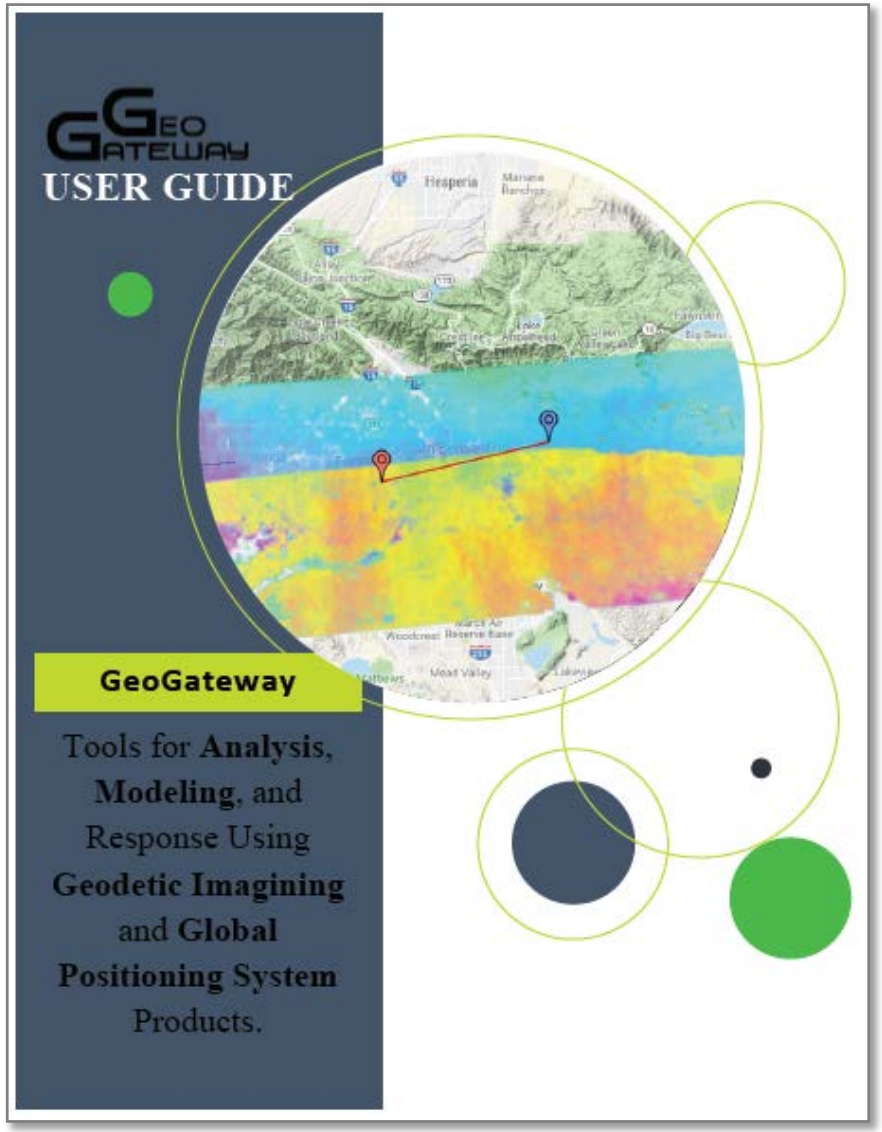


Table of Contents

Acknowledgments

GeoGateway Overview

GeoGateway Homepage

Map Tools

- *KML*
- *UCERF3 Faults*
- *Show State Boundaries*
- *Show Coastlines*

UAVSAR

- Exercise (Model and Analyze Interferograms)

Global Positioning System (GPS)

- Exercise (Produce GPS Velocities, Offsets, and Displacements)

Seismicity

Forecast

Moment Magnitude Calculator

- Exercise (Calculating Moment Magnitude)

Dislocation (Disloc)

Special Studies

Reset Tab

Help Tab

Citations

GeoGateway User Guide

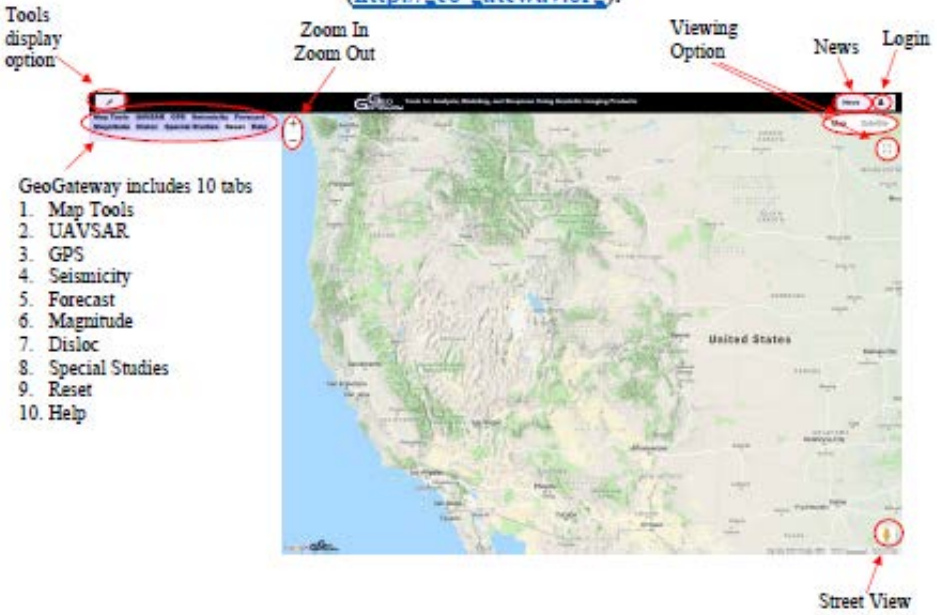
geo-gateway.org

Tools for Analysis, Modeling, and Response Using Geodetic Imaging Products

Welcome to GEO GATEWAY

GeoGateway is a web map-based science gateway supported by NASA's ACCESS program.

The gateway can only be accessed via internet at (http://geo-gateway.org).



GeoGateway includes 10 tabs

1. Map Tools
2. UAVSAR
3. GPS
4. Seismicity
5. Forecast
6. Magnitude
7. Disloc
8. Special Studies
9. Reset
10. Help

Map Tools

KML Mapper

KML (Keyhole Markup Language) Mapper is a file format used for viewing geographic modeling information.

For *example*, siting the USGS website below,

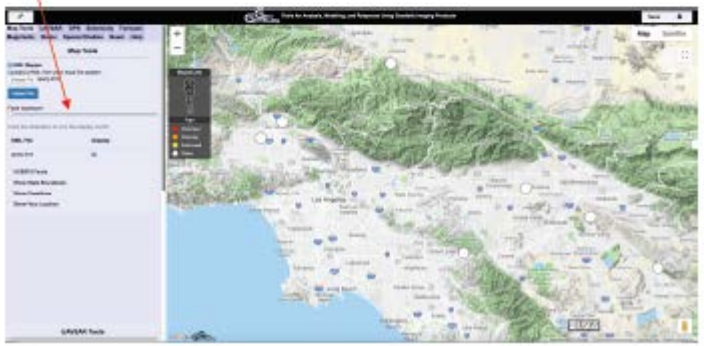
https://earthquake.usgs.gov/earthquakes/search/

allows for a user to search through an earthquake catalog in which the selected earthquake data can be downloaded into a KML file and uploaded into GeoGateway as shown in the image below.
Once uploaded into GeoGateway, the KML files are displayed.

By clicking the box in the "Display" section, next to the chosen KML File, the file will be displayed on the map.

In this case, the KML file named "query" is displayed on the map.

The "Fade baselayer" option fades the background map, while the KML file does not fade.



GeoGateway User Guide

Exercise : Model and Analyze Interferograms

Go to http://geo-gateway.org

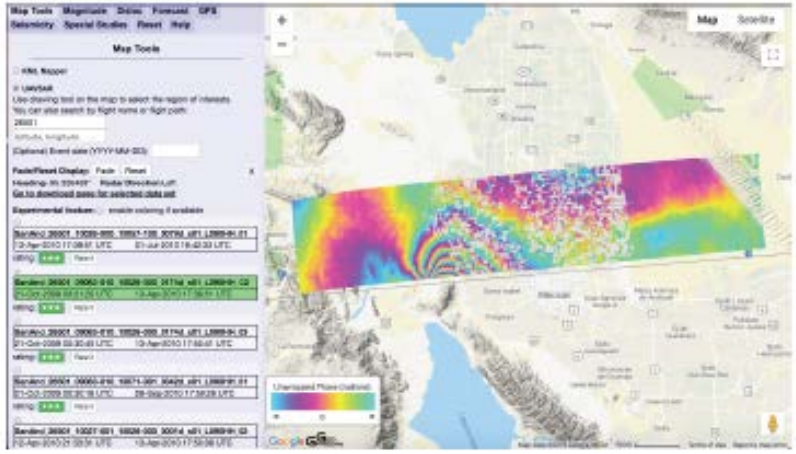
Click the "**Map Tools**" tab on the top left.

Check UAVSAR box

There are two methods a user may use to search for a UAVSAR Interferogram.

1. The "flight name/path" directly finds the flight name and path wanted
2. The "latitude, longitude" option returns all flight paths crossing paths with those coordinates.
   In the case of this exercise, enter 26501 (flight name/path) in the search window and hit return.

Select second line in list
(Name is SanAnd_26501_09083-010_10028-000_0174d_s01_L090HH_C2, should end in C2)

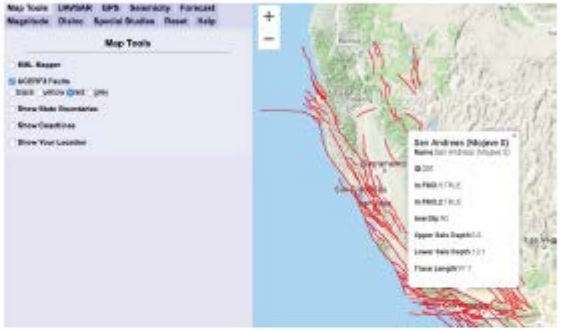


Click on "**Experimental feature: enable coloring if available**" just above the list of repeat pass interferometry (RPI) products

Re-select second line in list
(Name is SanAnd_26501_09083-010_10028-000_0174d_s01_L090HH_C2, should end in C2)

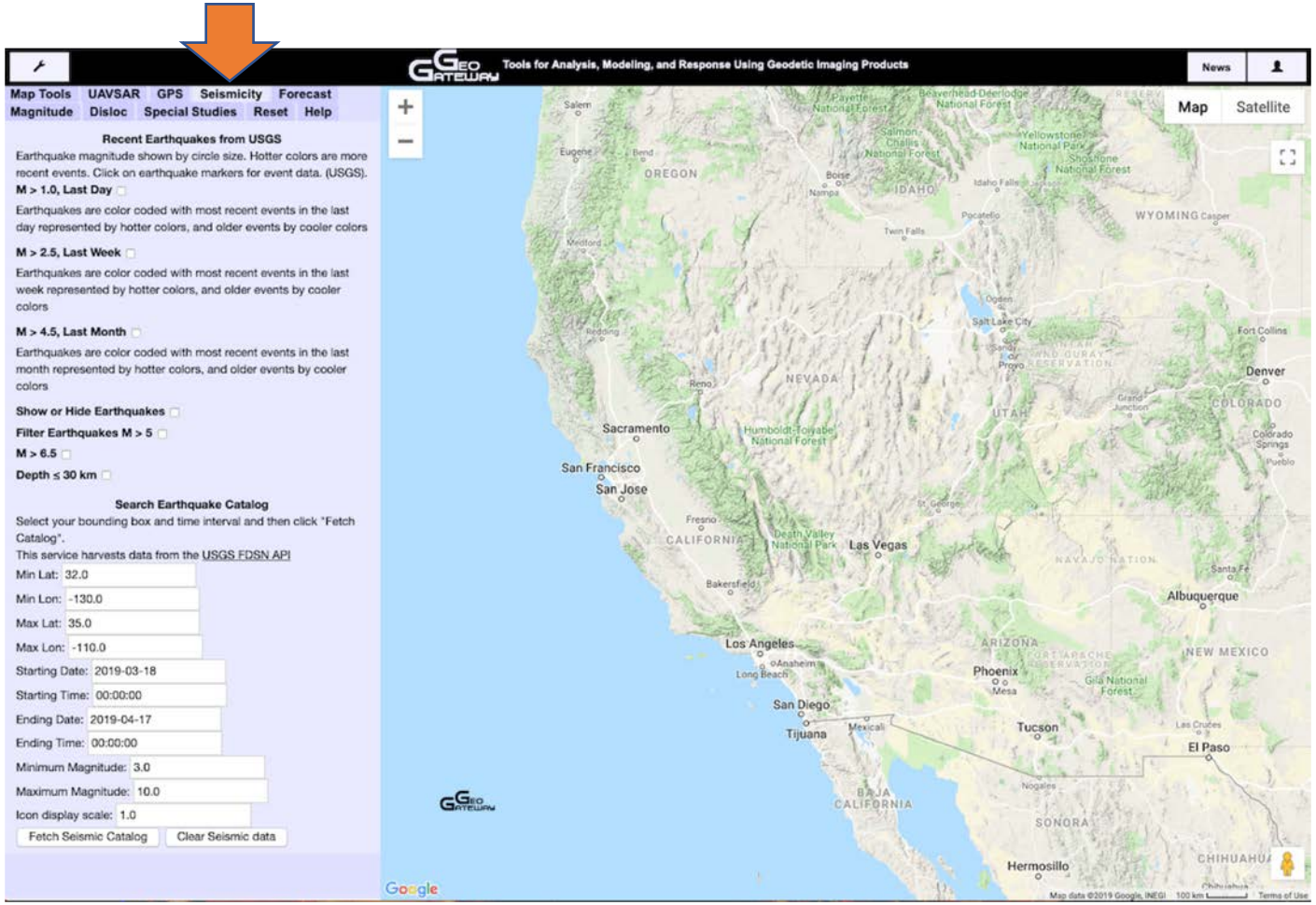
UCERF3 Faults
(Uniform California Earthquake Rupture Forecast, version 3)

The United States Geological Survey (USGS) UCERF3 faults allows users to insert California's fault lines. To input these fault lines, check the box next to "UCERF3 Faults". To choose the color of the fault lines click on the circle referring to either black, yellow, red, or grey. To understand more about a fault line, click on the fault.

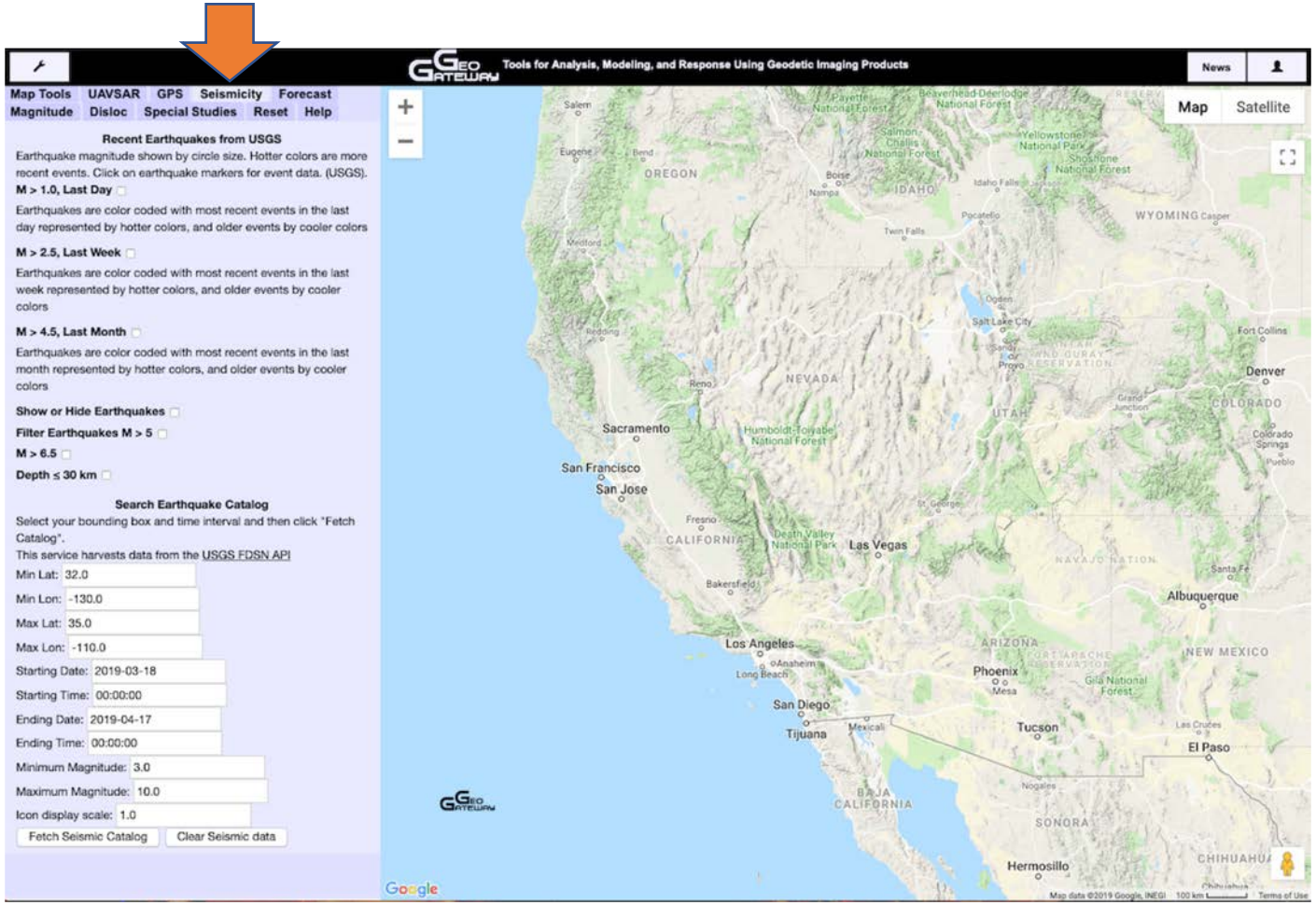


Show State Boundaries
To show state boundaries within the United States check the box next to "Show State Boundaries".

Seismicity Tab



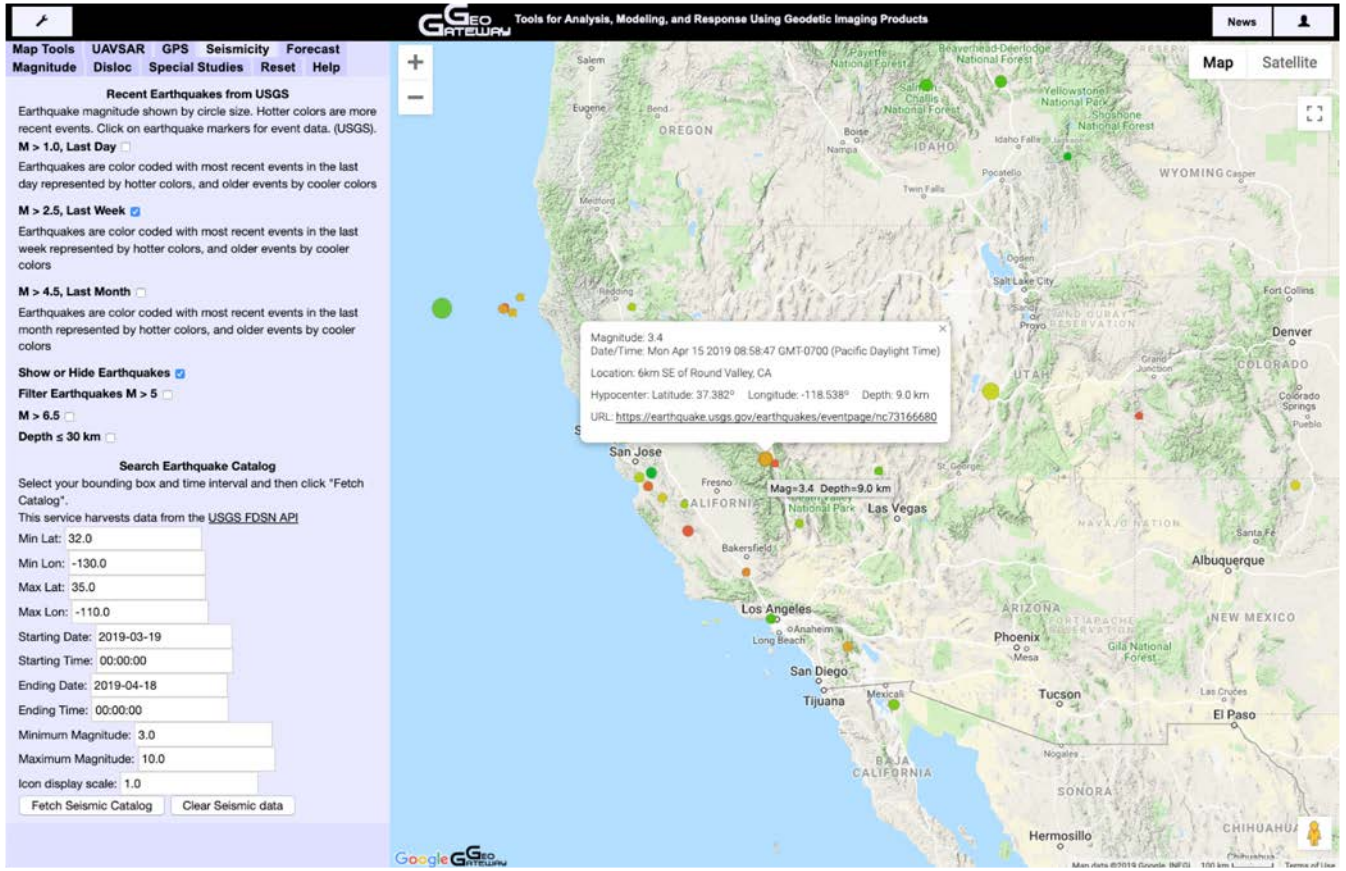
Seismicity Tab



Seismicity Tab – Display Earthquake Feeds

First Feature:

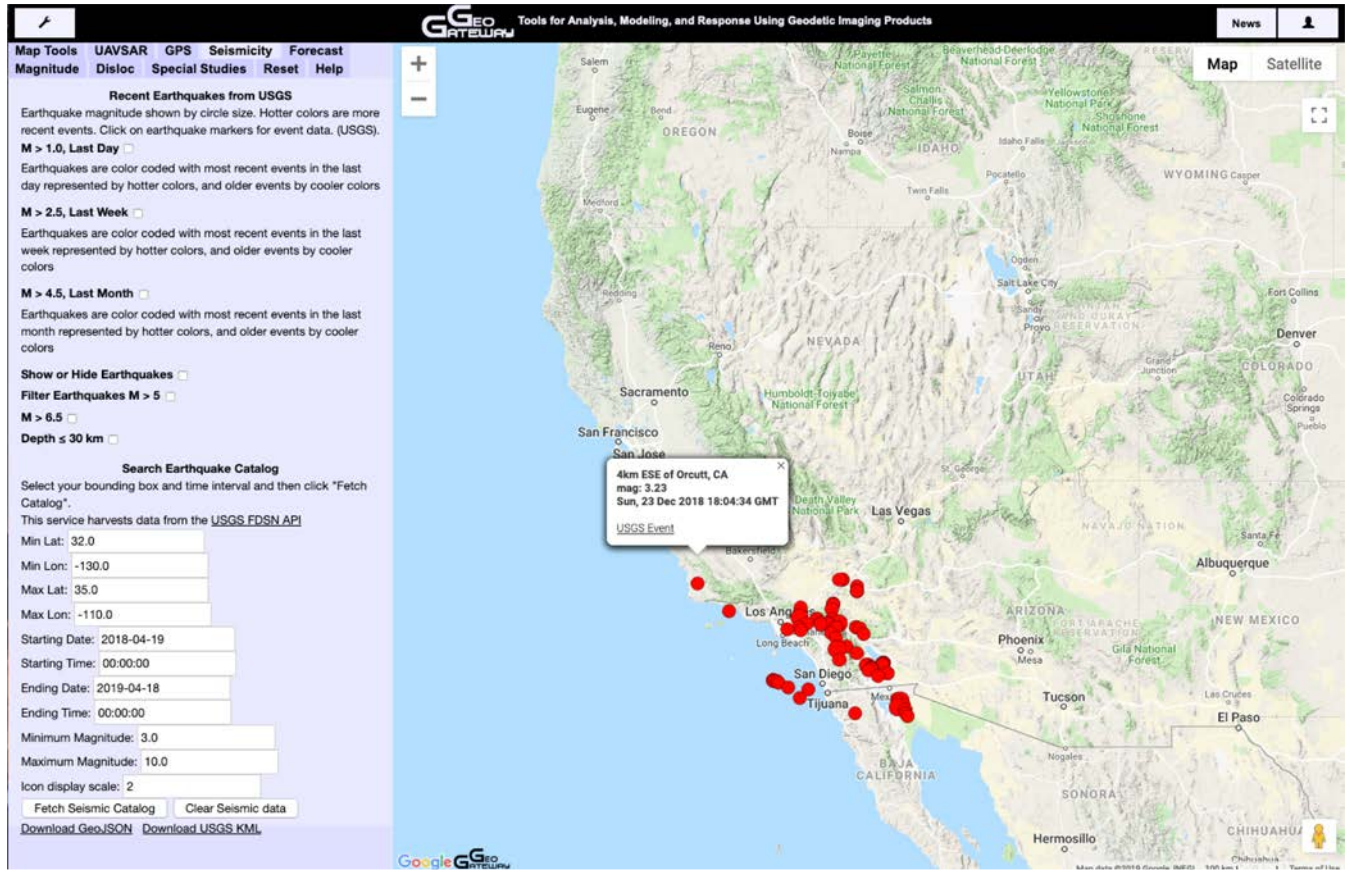
- Display seismic data from USGS feeds.
- Color coded for age of event, cooler colors for earlier events, hotter colors for later events.
- Event size corresponds to magnitude.
- Click on event for tooltips.



Seismicity Tab – Display Catalog Events

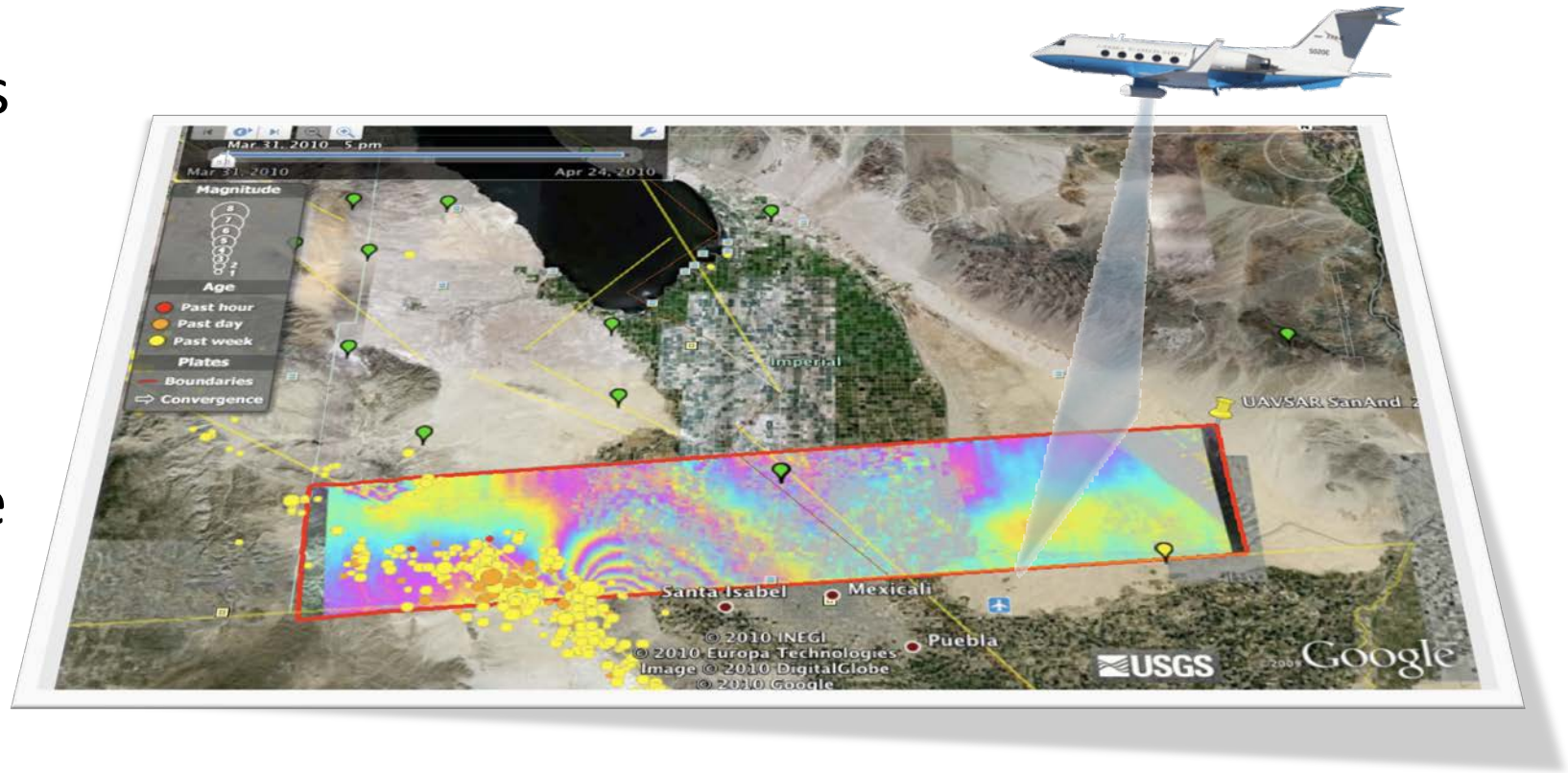
Second Feature:

- Display seismic data from USGS catalog.
- Event size corresponds to magnitude.
- Set display scale for icons.
- Click on event for tooltips.



UAVSAR

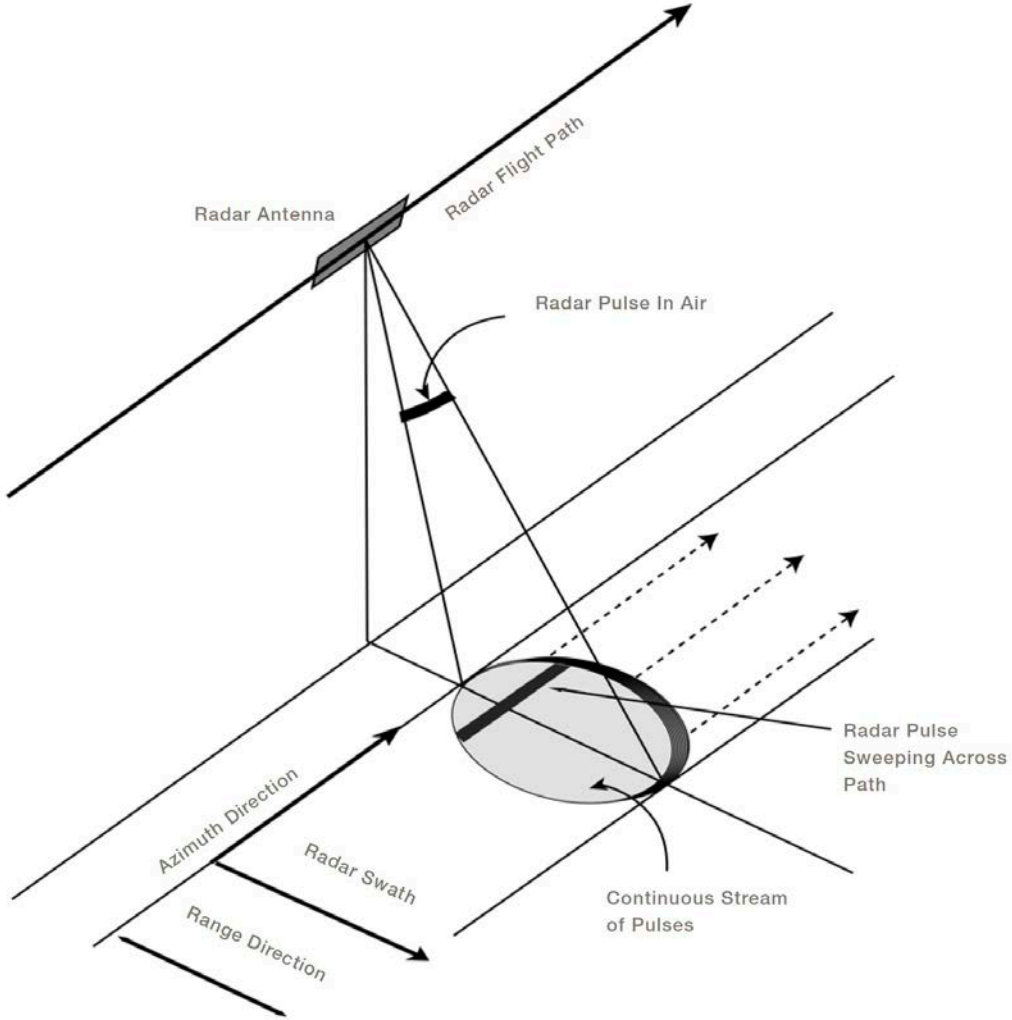
- Basic InSAR concepts
- Selecting data products
- Displaying individual lines
- Color mapping
- Line of sight tool
- Downloading products
- Example from User Guide



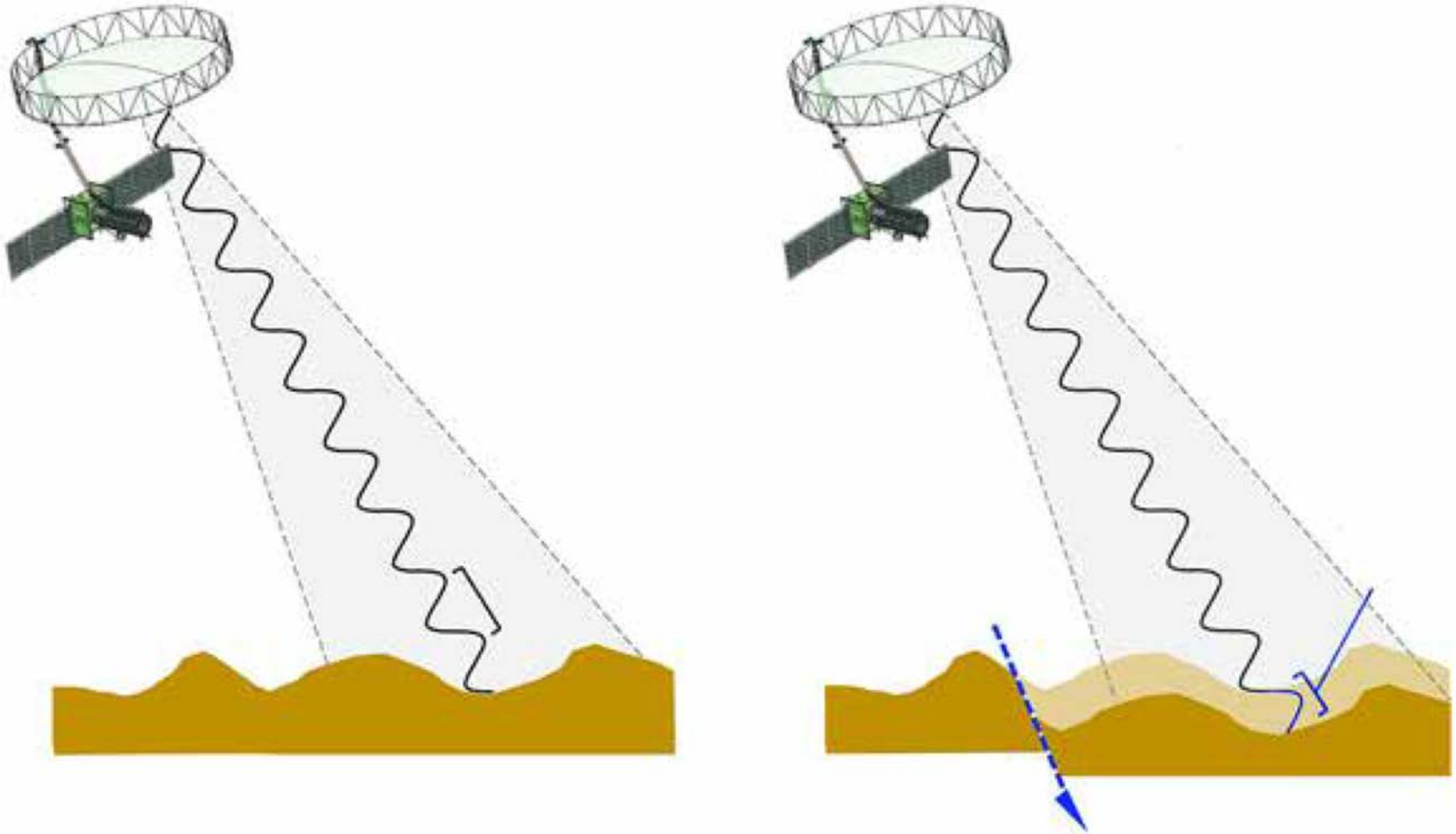
Basic InSAR Concepts

- Basic InSAR concepts
- Selecting data products
- Displaying individual lines
- Color mapping
- Line of sight tool
- Downloading products
- User Guide Example

Synthetic Aperture Radar

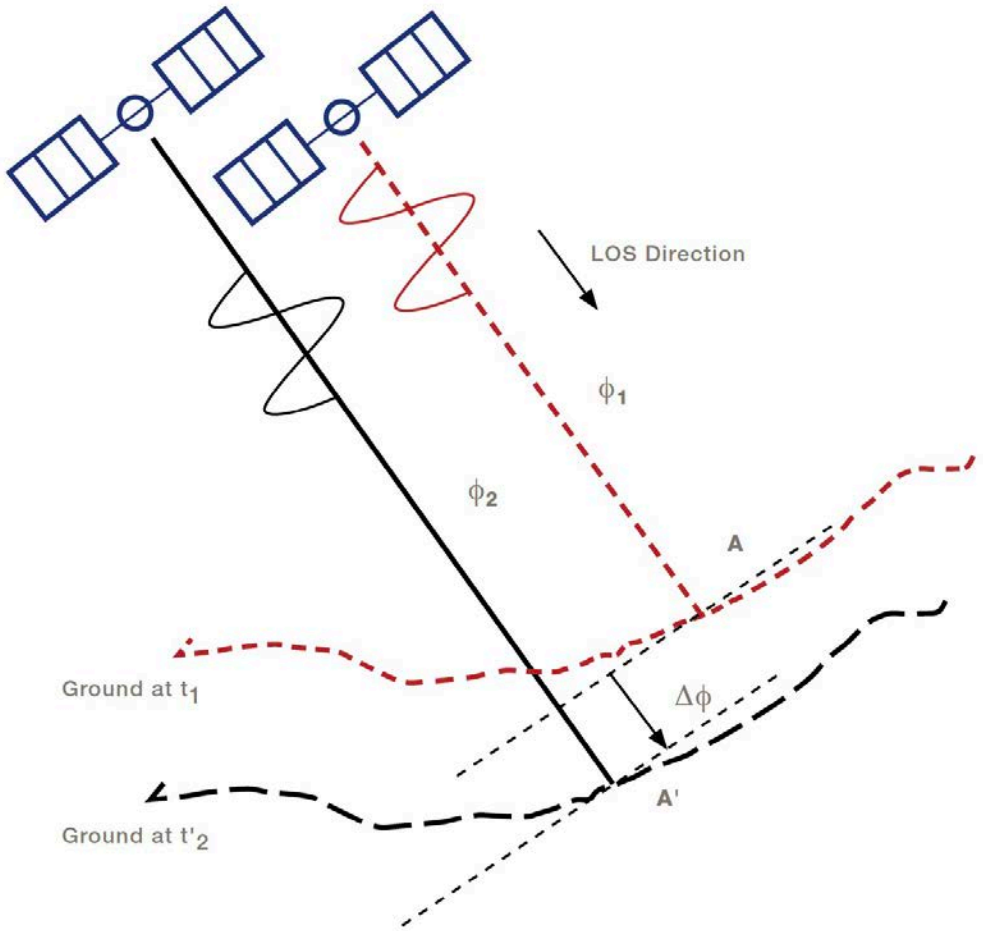


InSAR Phase Difference



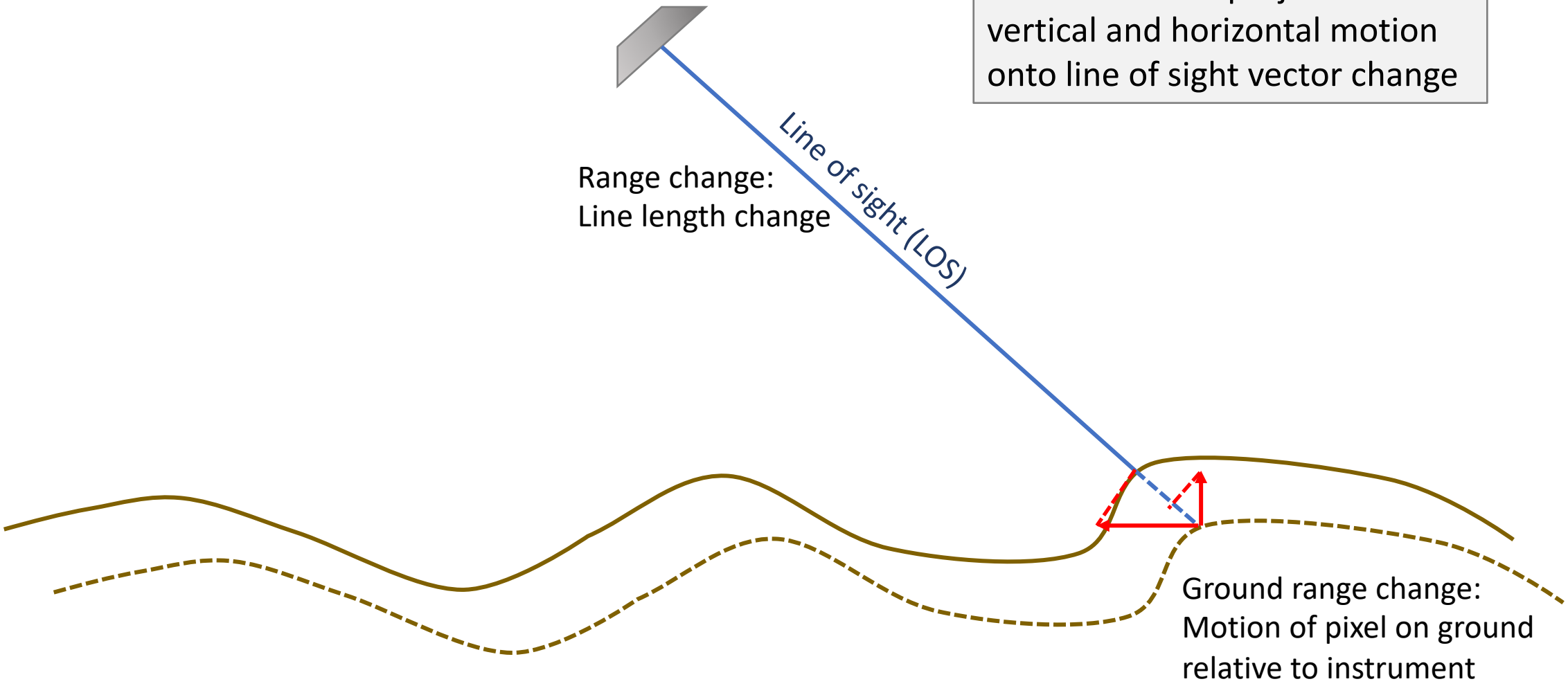
Phase Difference

- UAVSAR raw image pairs 1 m resolution
- UAVSAR unwrapped products 7 m



Line of Sight

Combination of projection of vertical and horizontal motion onto line of sight vector change



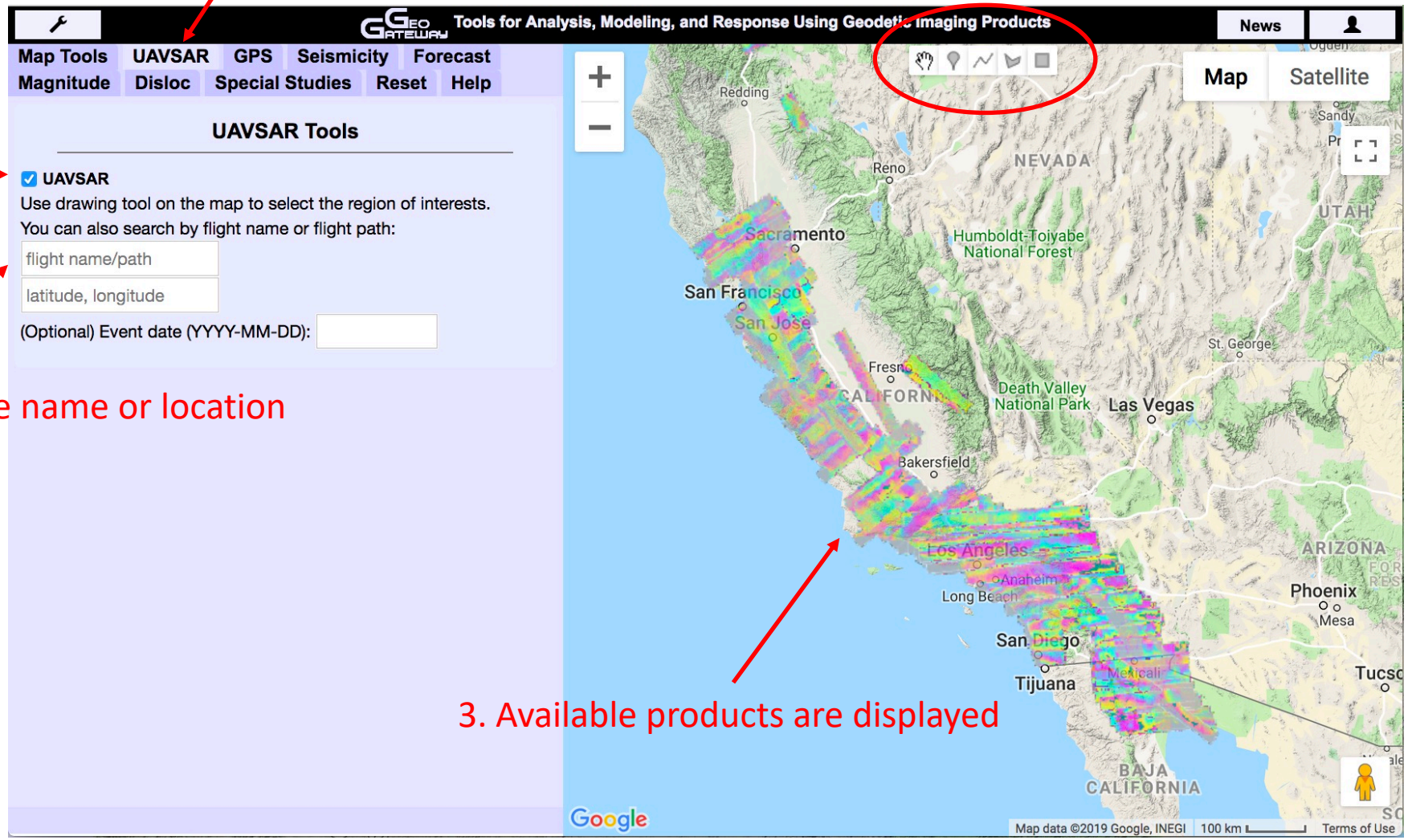
Selecting Data Products

4a. Select by point, line, region

1. Click on UAVSAR tab

2. Check UAVSAR box

4b. Select by line name or location

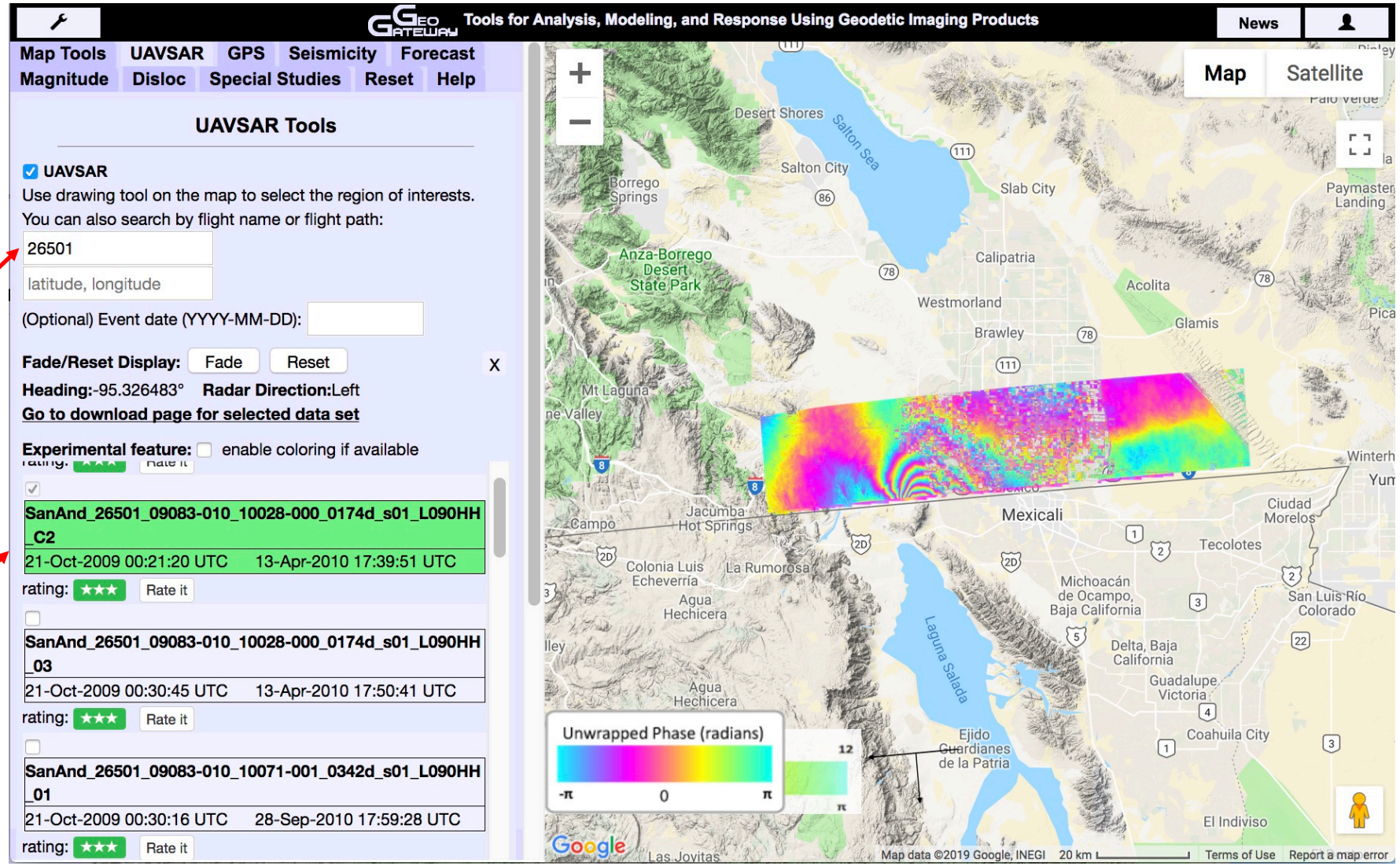


3. Available products are displayed

Displaying Individual Lines

Selected by line name

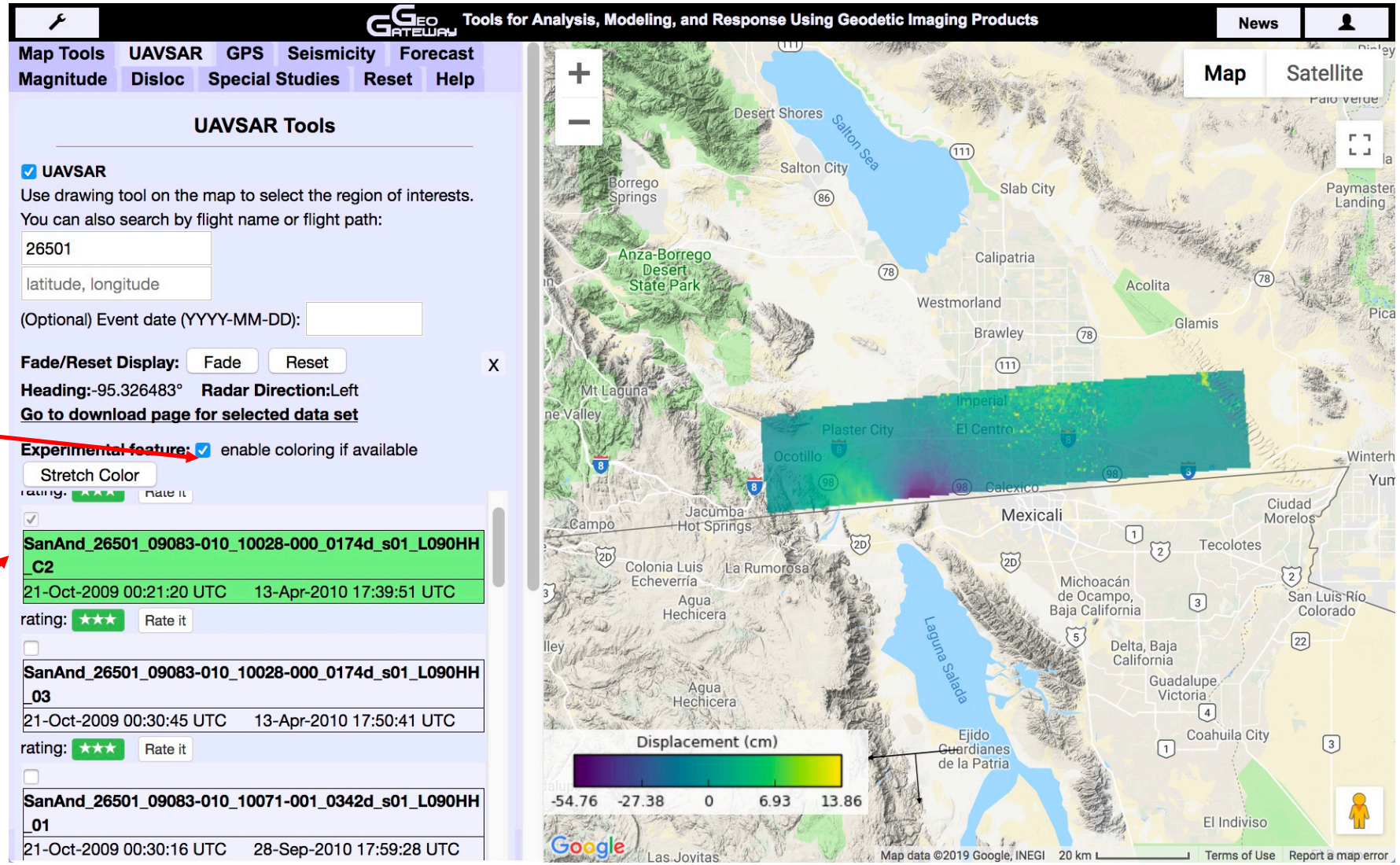
Click on line of interest



Color Mapping

Click on enable color mapping

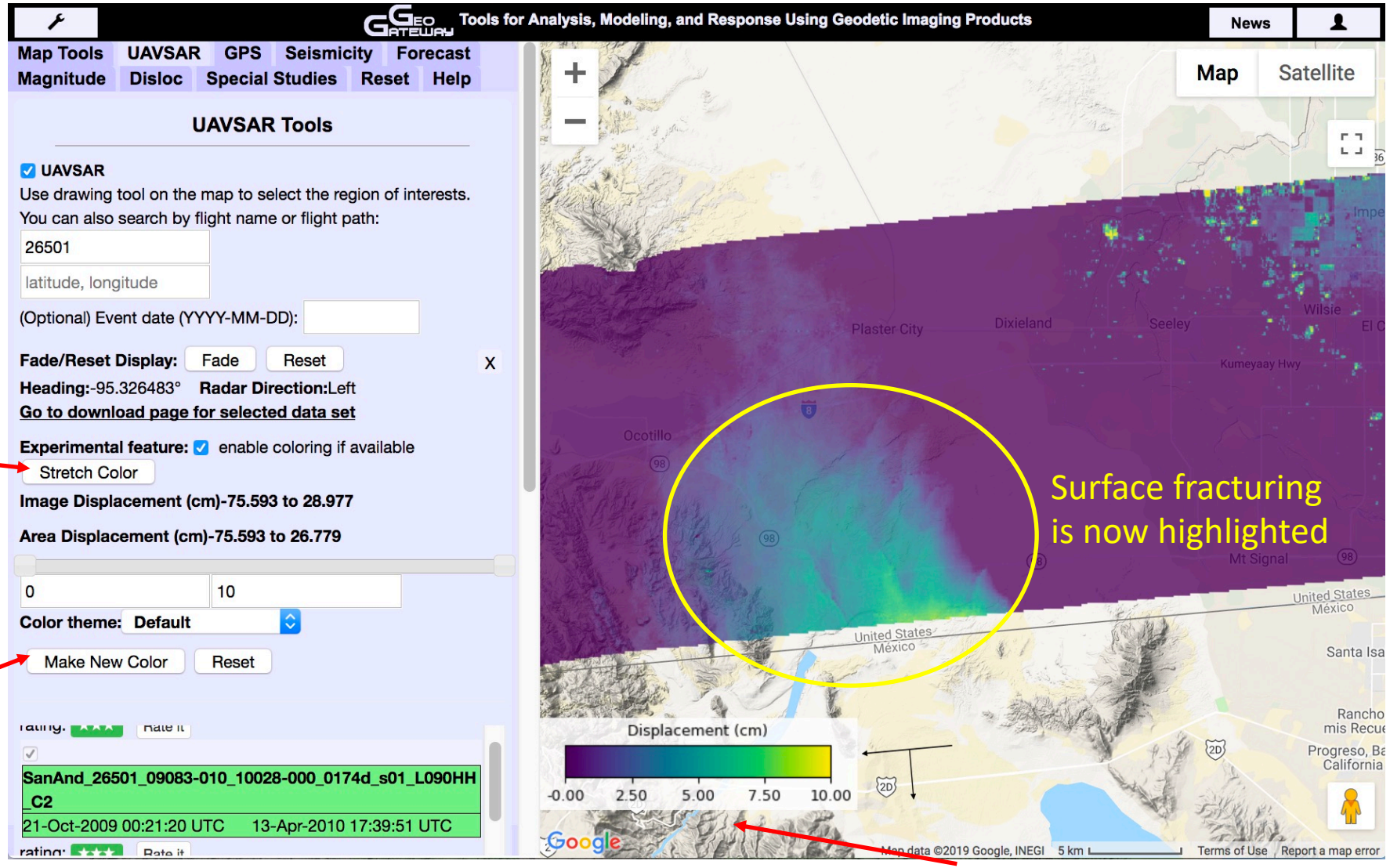
Click on line of interest **again**



Color Mapping – stretch color

Zoom into area of interest
Click on stretch color

Make new color



Surface fracturing is now highlighted

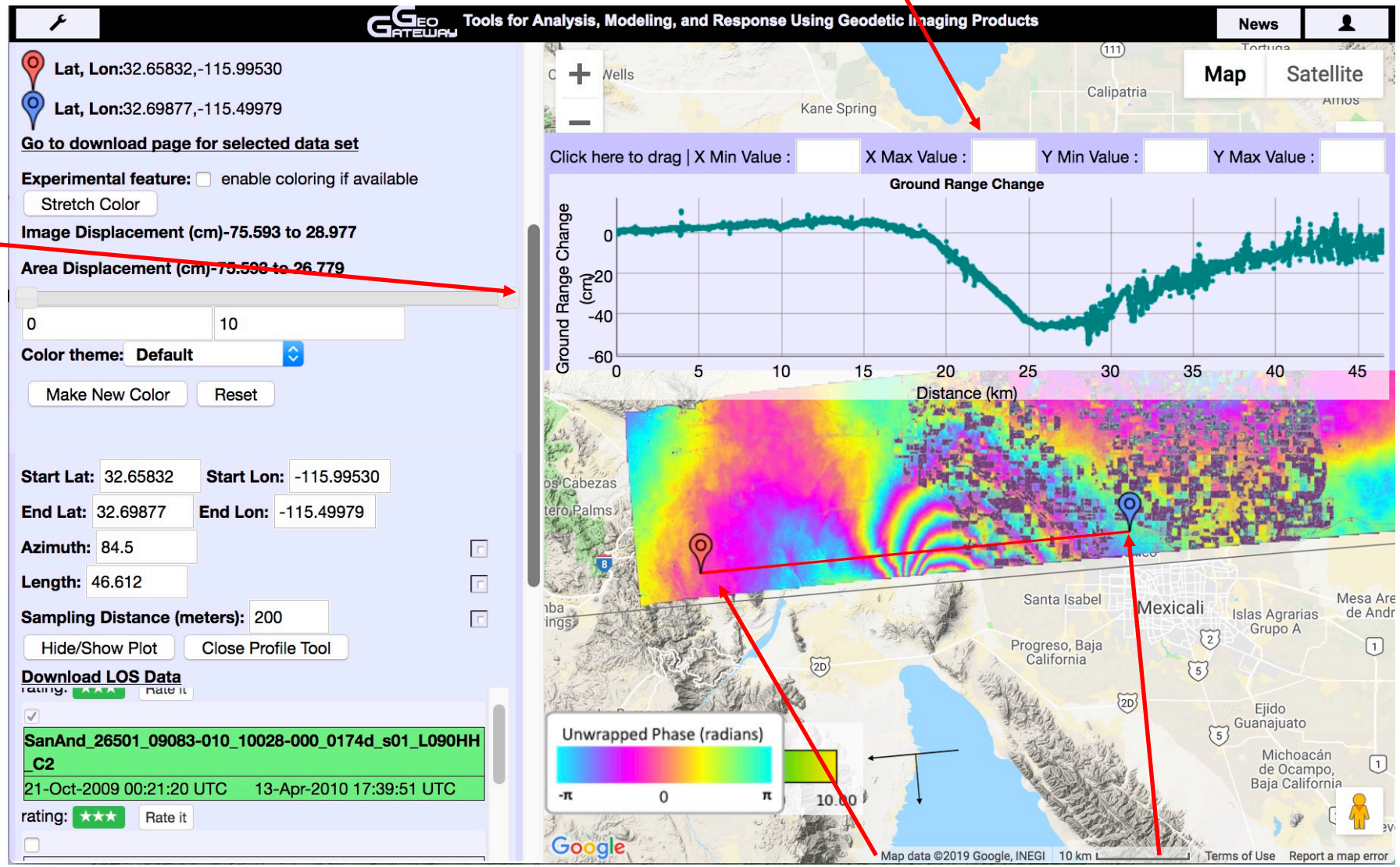
Use color scale as guide

Line of Sight Tool

Change zoom in by editing max/min values of plot

Scroll to line of sight parameters if necessary

Change parameters for line endpoints



Click on map

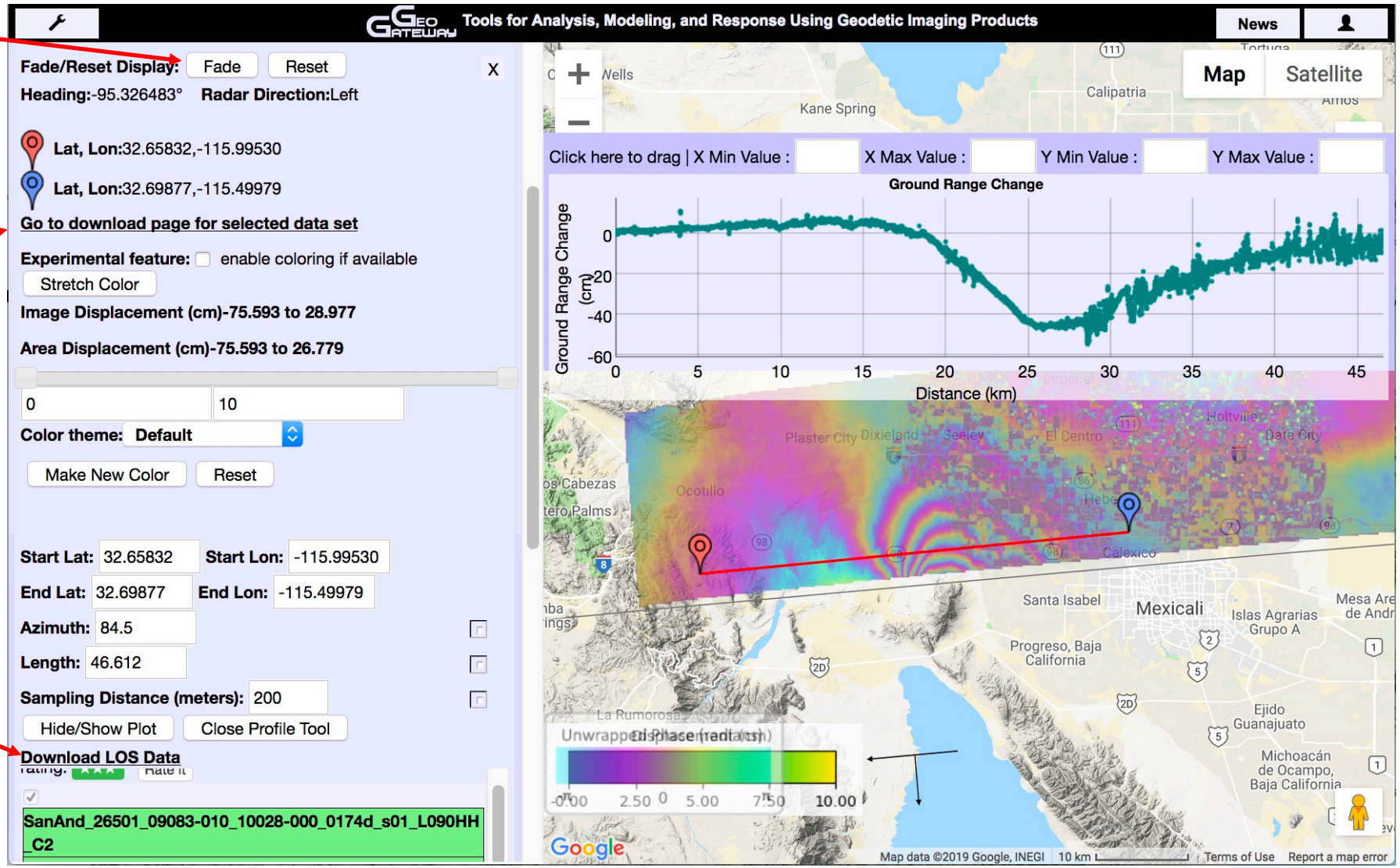
Adjust endpoints

Downloading Products

Fade product helps to highlight fault overlays or underlying terrain

Download UAVSAR products

Download displayed line of sight profile



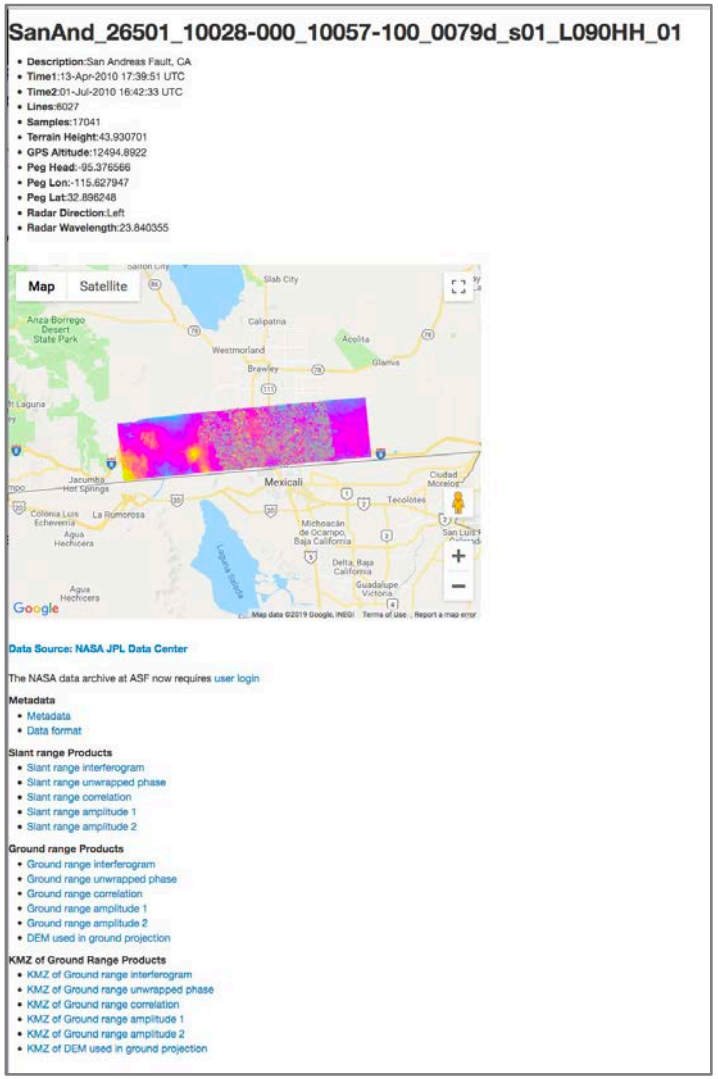
Downloading Products – Line of Sight

csv or comma separated values file for reading into plotting or other program

SanAnd_26501_09083-010_10028-000_0174d_s01_L090HH_C2.csv

```
SanAnd_26501_09083-010_10028-000_0174d_s01_L090HH_C2
start, 32.65831504965435, -115.99529842854872
end, 32.6987721413161, -115.4997906160487
azimuth, 84.5
length, 46.612
Lon, Lat, Distance (km), Displacement, Elevation Angle
-115.995298,32.658315,0.000000,0.638524,28.195952
-115.995243,32.658320,0.005227,-0.129439,28.195974
-115.995187,32.658324,0.010454,-0.129439,28.195996
-115.995132,32.658329,0.015681,-0.119658,28.196018
-115.995076,32.658333,0.020908,0.951220,28.196039
-115.995021,32.658338,0.026135,0.951220,28.196061
-115.994965,32.658342,0.031362,0.629896,28.196083
-115.994910,32.658347,0.036589,-0.448417,28.196105
-115.994854,32.658351,0.041816,-0.292972,28.196127
-115.994798,32.658356,0.047043,-0.292972,28.196149
-115.994743,32.658360,0.052270,-0.180903,28.196170
-115.994687,32.658365,0.057497,-0.093986,28.196192
-115.994632,32.658369,0.062724,-0.093986,28.196214
-115.994576,32.658374,0.067951,-0.154526,28.196236
-115.994521,32.658379,0.073178,-0.391667,28.196258
-115.994465,32.658383,0.078405,0.854002,28.196280
-115.994410,32.658388,0.083632,0.854002,28.196301
-115.994354,32.658392,0.088859,0.076780,28.196323
-115.994298,32.658397,0.094086,0.368074,28.196345
-115.994243,32.658401,0.099313,0.111894,28.196367
-115.994187,32.658406,0.104540,0.111894,28.196389
-115.994132,32.658410,0.109766,0.468984,28.196411
-115.994076,32.658415,0.114994,0.611336,28.196432
-115.994021,32.658419,0.120220,0.611336,28.196454
-115.993965,32.658424,0.125447,0.347635,28.196476
```

Downloading Products – UAVSAR



SanAnd_26501_10028-000_10057-100_0079d_s01_L090HH_01

- **Description:**San Andreas Fault, CA
- **Time1:**13-Apr-2010 17:39:51 UTC
- **Time2:**01-Jul-2010 16:42:33 UTC
- **Lines:**6027
- **Samples:**17041
- **Terrain Height:**43.930701
- **GPS Altitude:**12494.8922
- **Peg Head:**-95.376566
- **Peg Lon:**-115.627947
- **Peg Lat:**32.896248
- **Radar Direction:**Left
- **Radar Wavelength:**23.840355

Data Source: NASA JPL Data Center

The NASA data archive at ASF now requires user login

Metadata

- Metadata
- Data format

Slant range Products

- Slant range interferogram
- Slant range unwrapped phase
- Slant range correlation
- Slant range amplitude 1
- Slant range amplitude 2

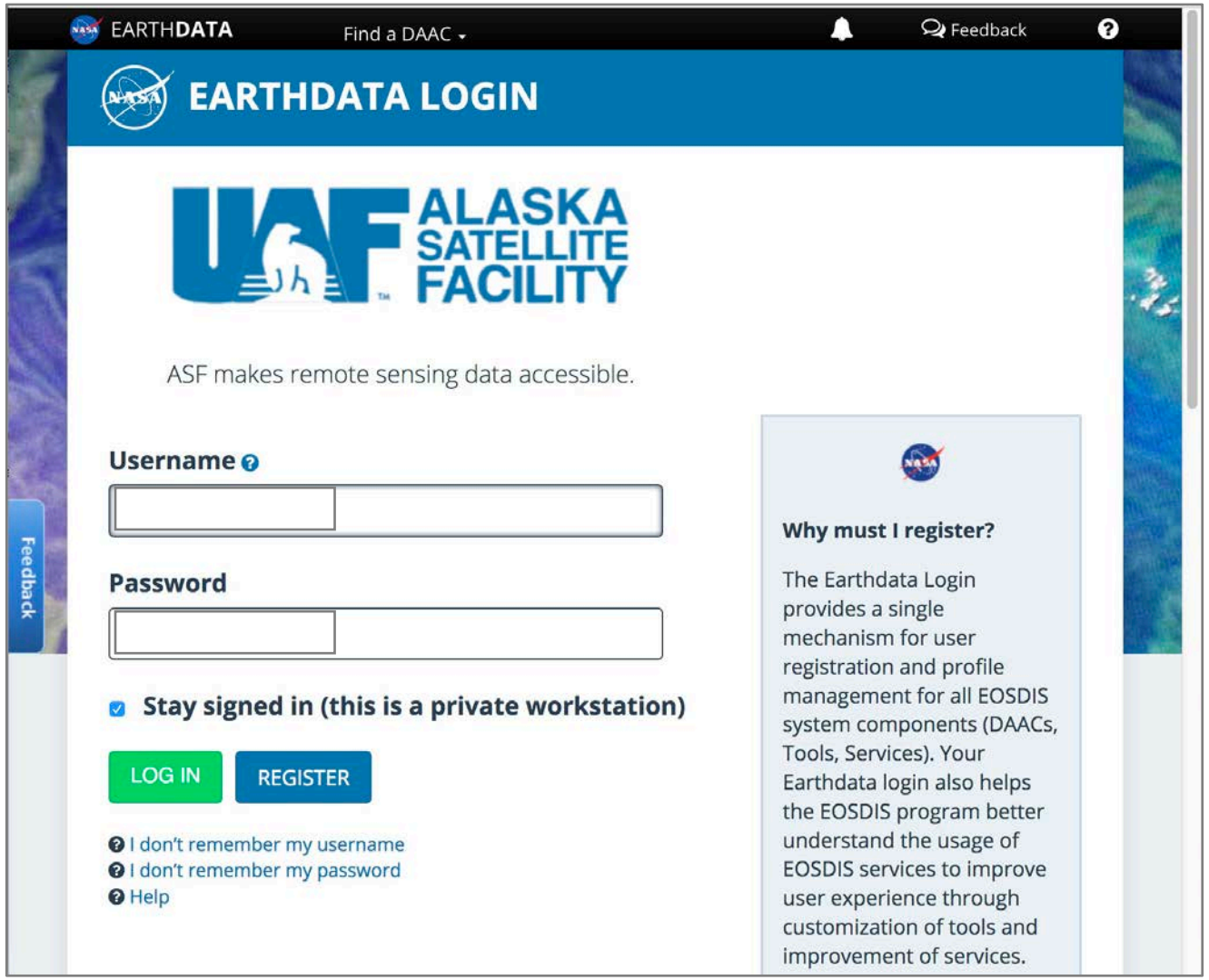
Ground range Products

- Ground range interferogram
- Ground range unwrapped phase
- Ground range correlation
- Ground range amplitude 1
- Ground range amplitude 2
- DEM used in ground projection

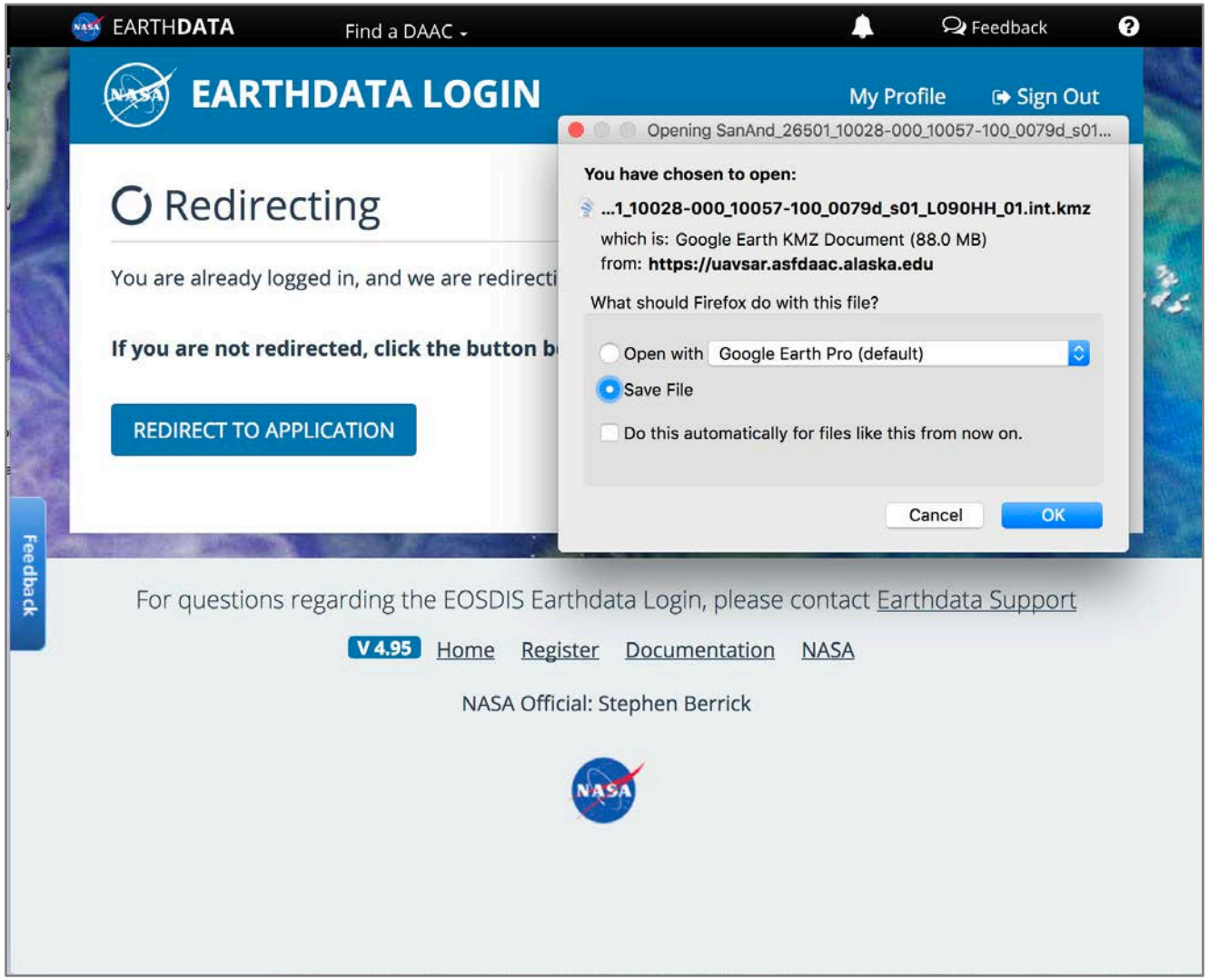
KMZ of Ground Range Products

- KMZ of Ground range interferogram
- KMZ of Ground range unwrapped phase
- KMZ of Ground range correlation
- KMZ of Ground range amplitude 1
- KMZ of Ground range amplitude 2
- KMZ of DEM used in ground projection

Downloading Products – UAVSAR



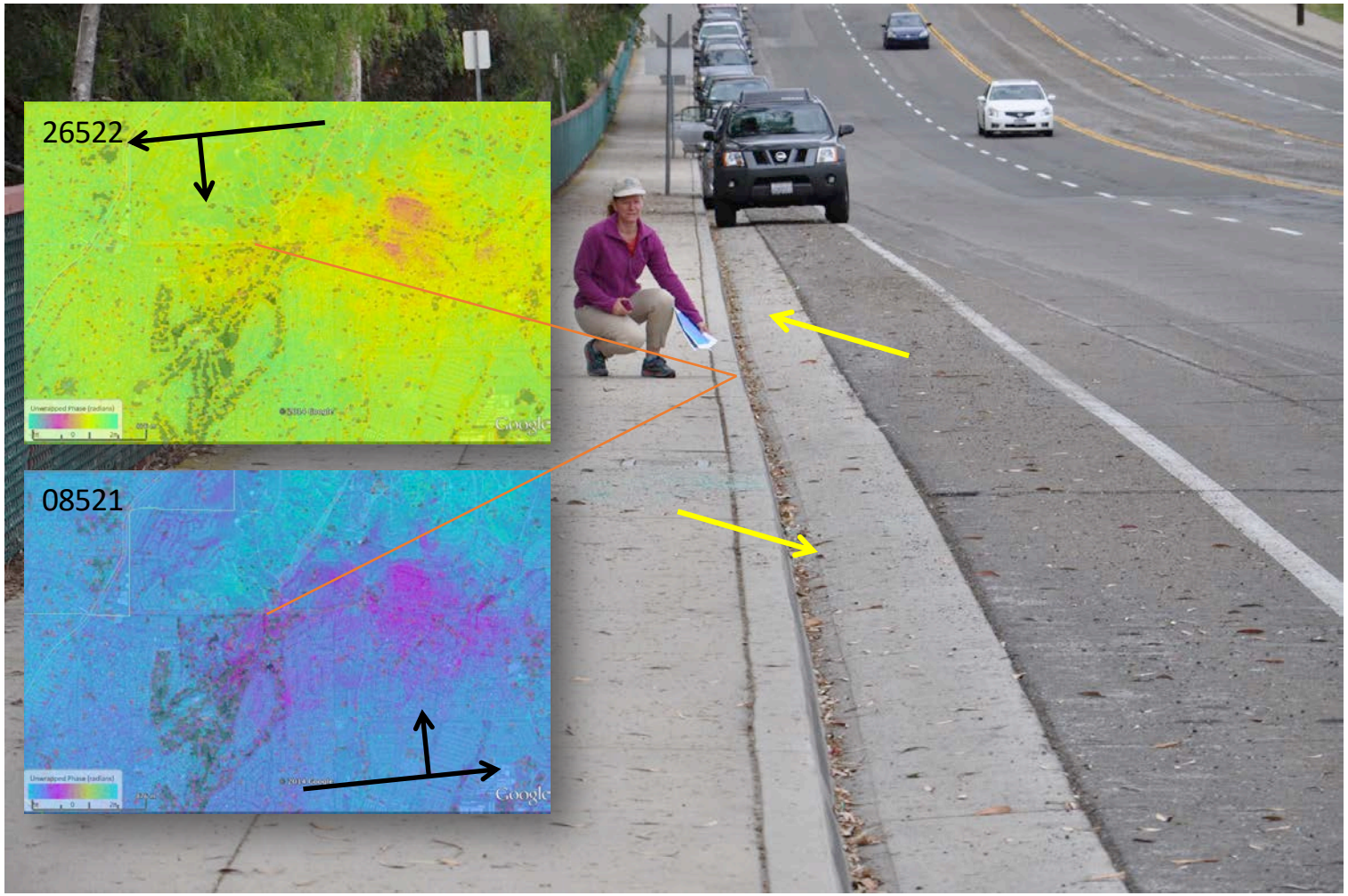
Downloading Products – UAVSAR



Location Awareness – Useful in the field

Show location option under map tools is being updated due to new security policies

La Habra earthquake



User Guide Example

Exercise : Model and Analyze Interferograms

Go to http://geo-gateway.org

Click the "**Map Tools**" tab on the top left.

Check UAVSAR box

There are two methods a user may use to search for a UAVSAR Interferogram.

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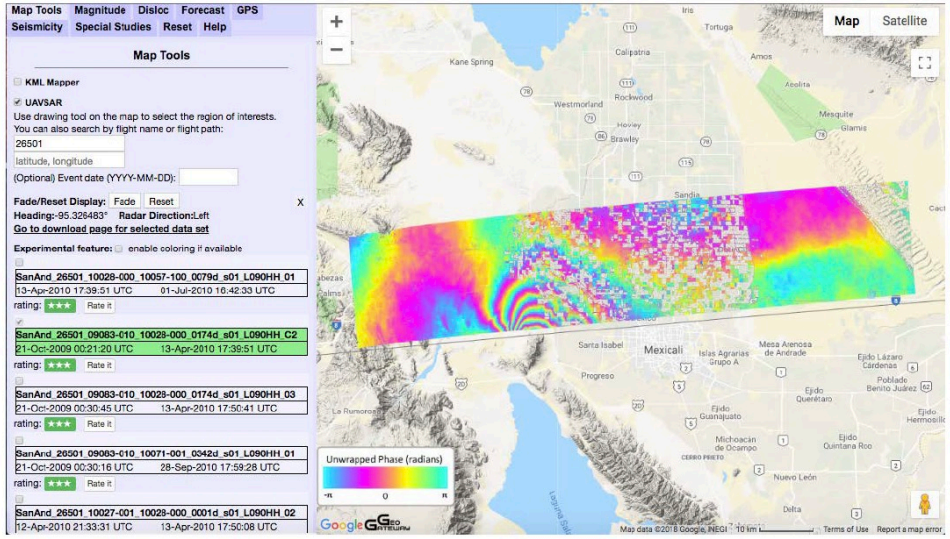


Click on "**Experimental feature: enable coloring if available**" just above the list of repeat pass interferometry (RPI) products

Re-select second line in list
(Name is SanAnd_26501_09083-010_10028-000_0174d_s01_L090HH_C2, should end in C2)

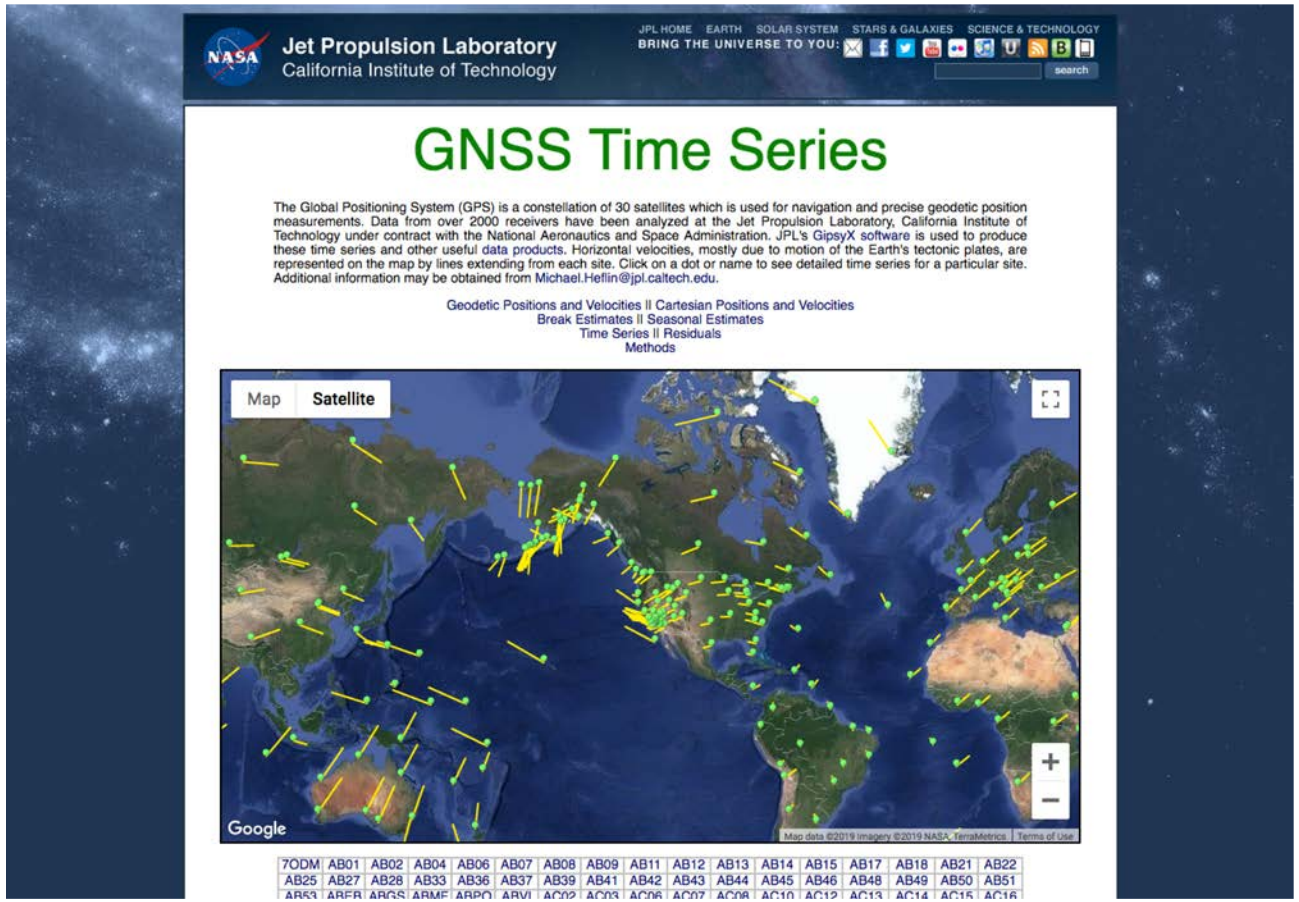
GPS Tools

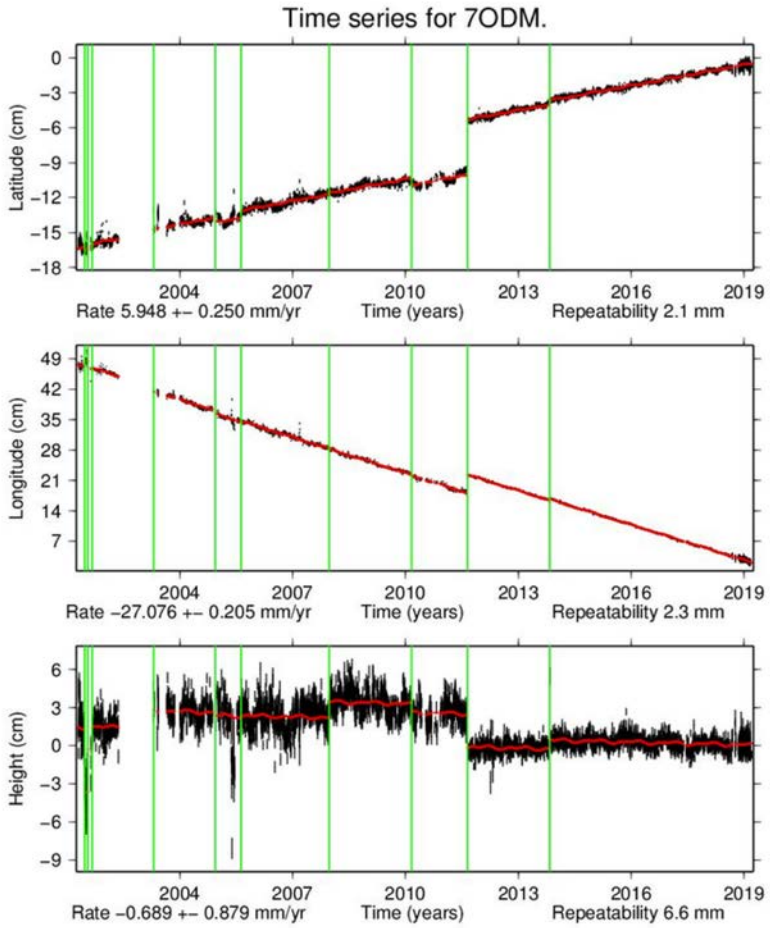
- EMC: Velocity
- Coseismic
- Postseismic
- Displacement
- Model
- Reference station
- Product download

GPS = Global Positioning System

GNSS = Global Navigation Satellite System

GNSS (GPS) Time Series





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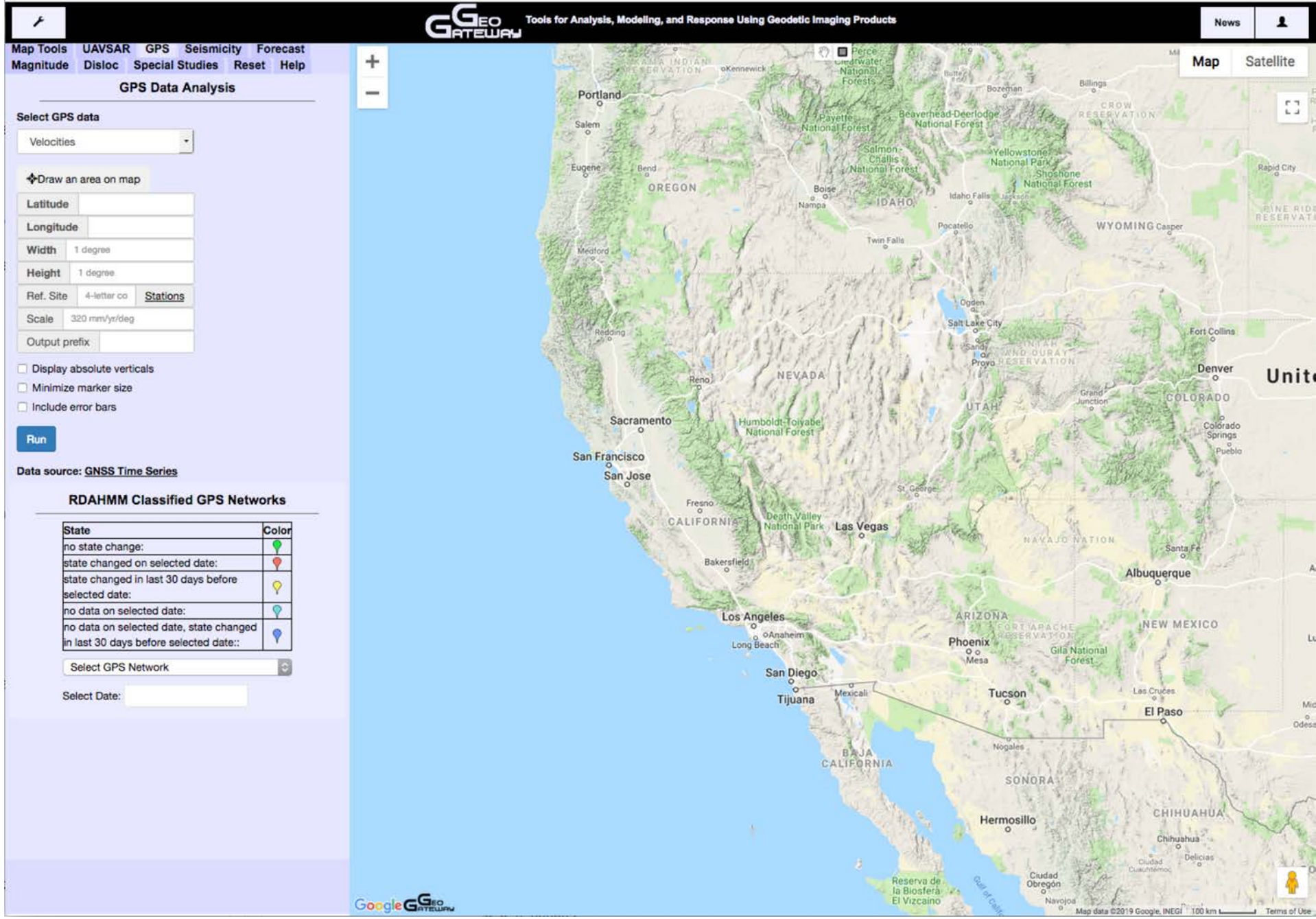
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Special Studies
Reset
Help
GPS Data Analysis
Select GPS data
Velocities
Draw an area on map
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Display absolute verticals
Minimize marker size
Include error bars
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Data source: GNSS Time Series
RDAHMM Classified GPS Networks
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state changed on selected date:
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Salem
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OREGON
Boise
IDAHO
WYOMING
Salt Lake City
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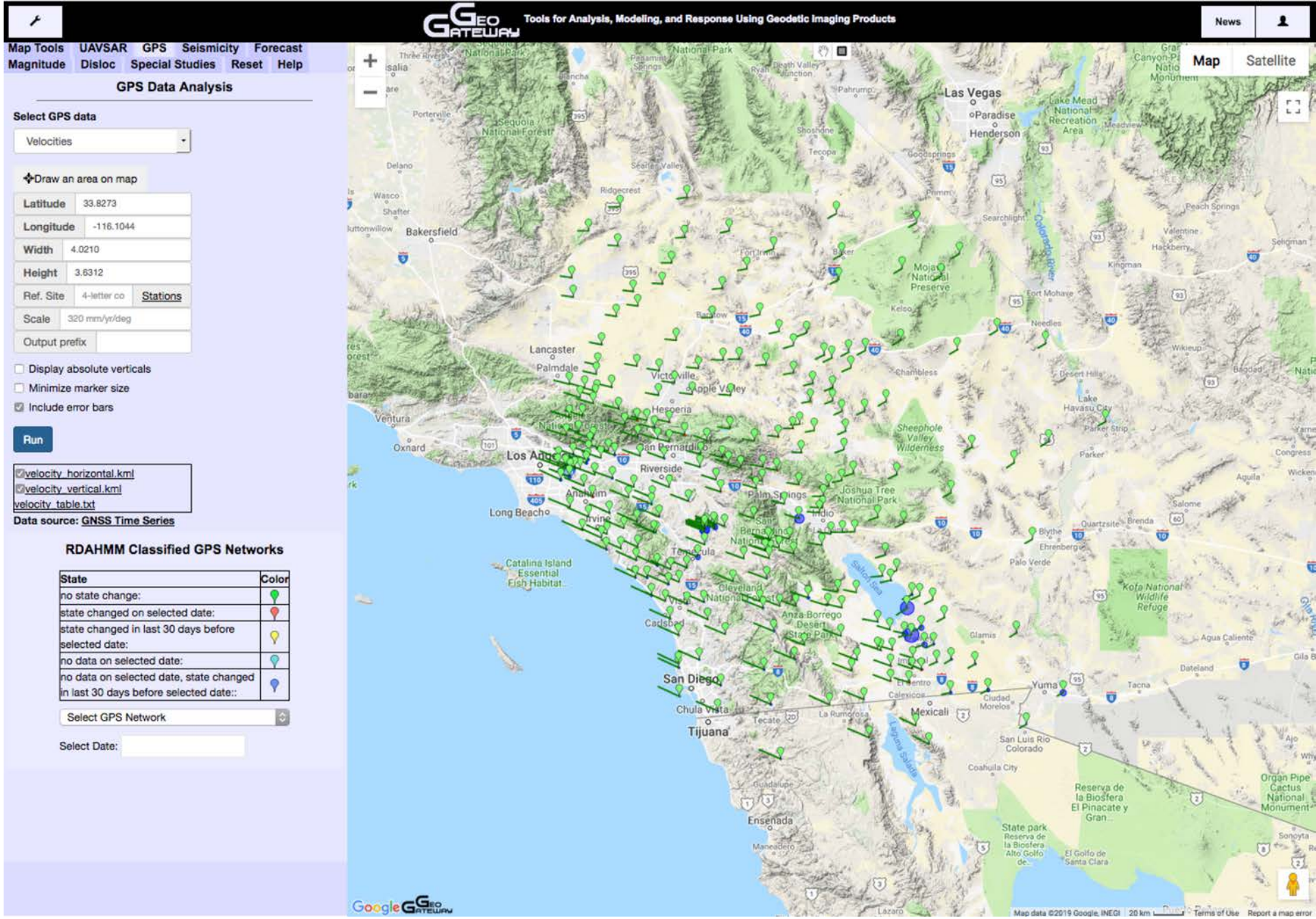
Velocity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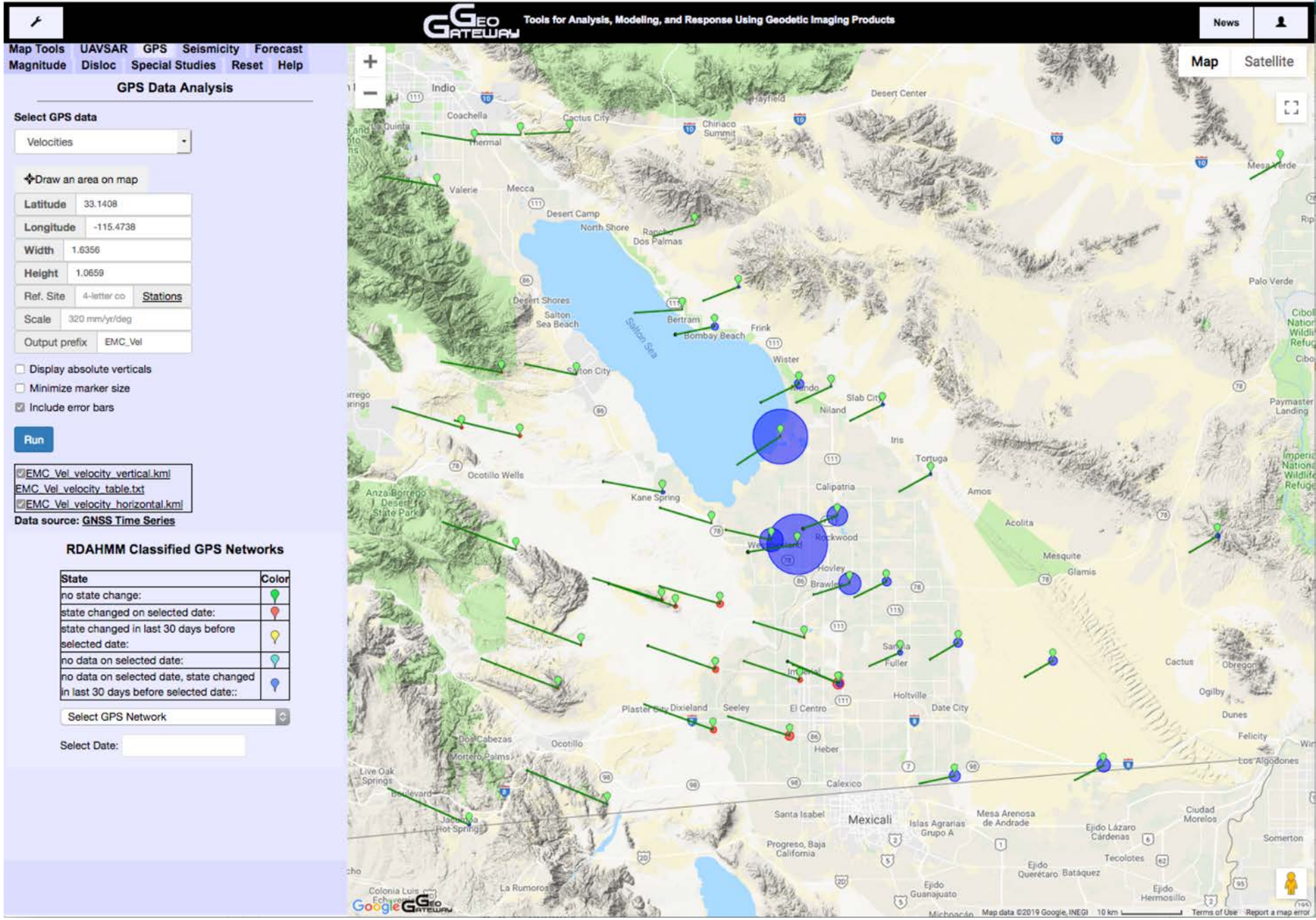
Tijuana
Mexicali
Yuma
Riverside
Palm Springs
Joshua Tree National Park
Mojave National Preserve
Sheephole Valley Wilderness
Kofa National Wildlife Refuge
Anza-Borrego Desert State Park
Catalina Island Essential Fish Habitat
Reserva de la Biosfera El Pinacate y Gran...
Organ Pipe Cactus National Monument
Google

Velocity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Map
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Coachella
Thermal
Desert Center
Mecca
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North Shore
Salton Sea
Bombay Beach
Frink
Wister
Niland
Slab City
Iris
Tortuga
Calipatria
Amos
Ocotillo Wells
Kane Spring
Rockwood
Acolita
Mesquite
Glamis
Hovley
Brawley
Imperial
Fuller
Holtville
Date City
El Centro
Seeley
Dixieland
Heber
Calexico
Ocotillo
Mexicali
Santa Isabel
Progreso, Baja California
Cactus
Obregon
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Dunes
Felicity
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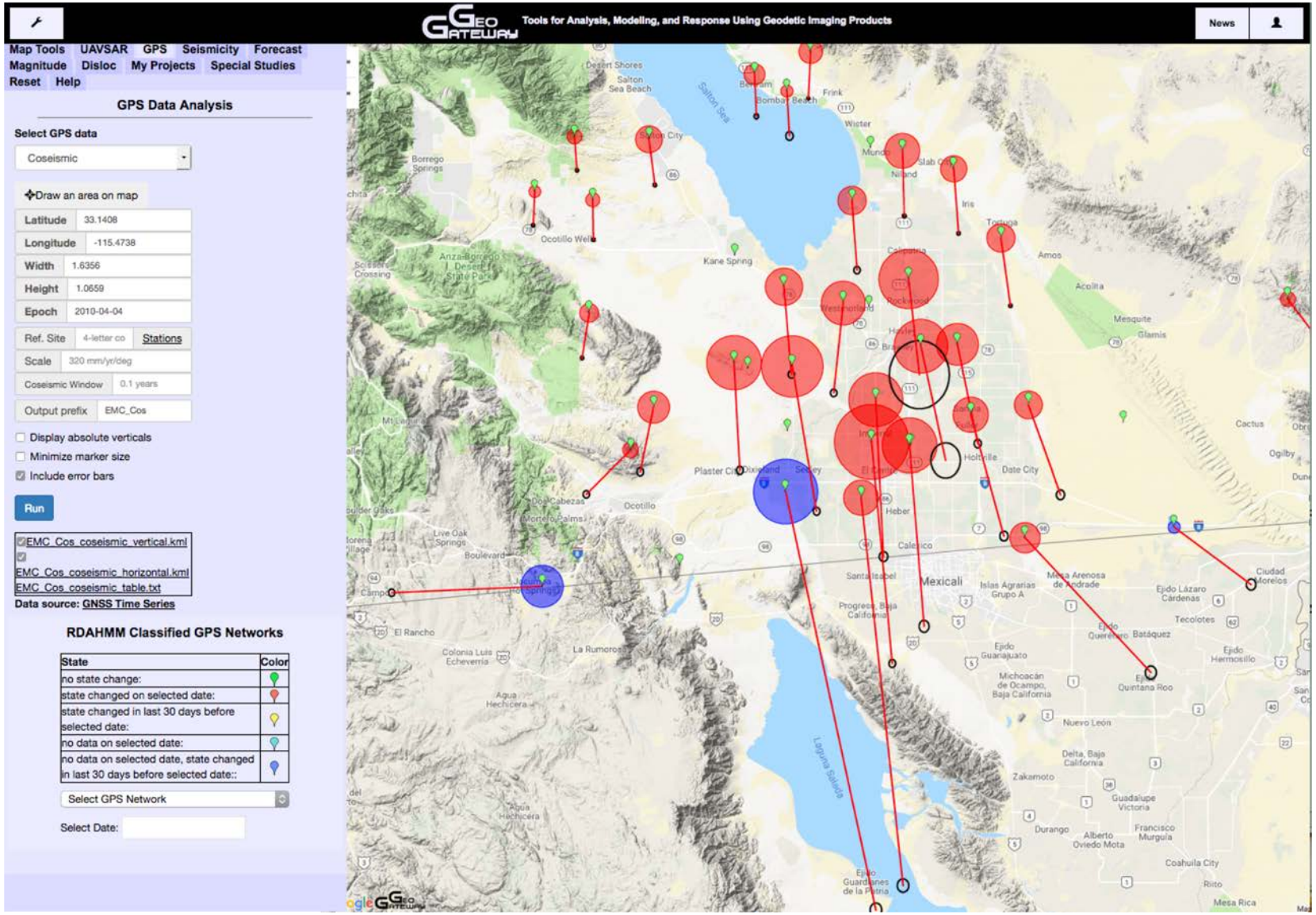
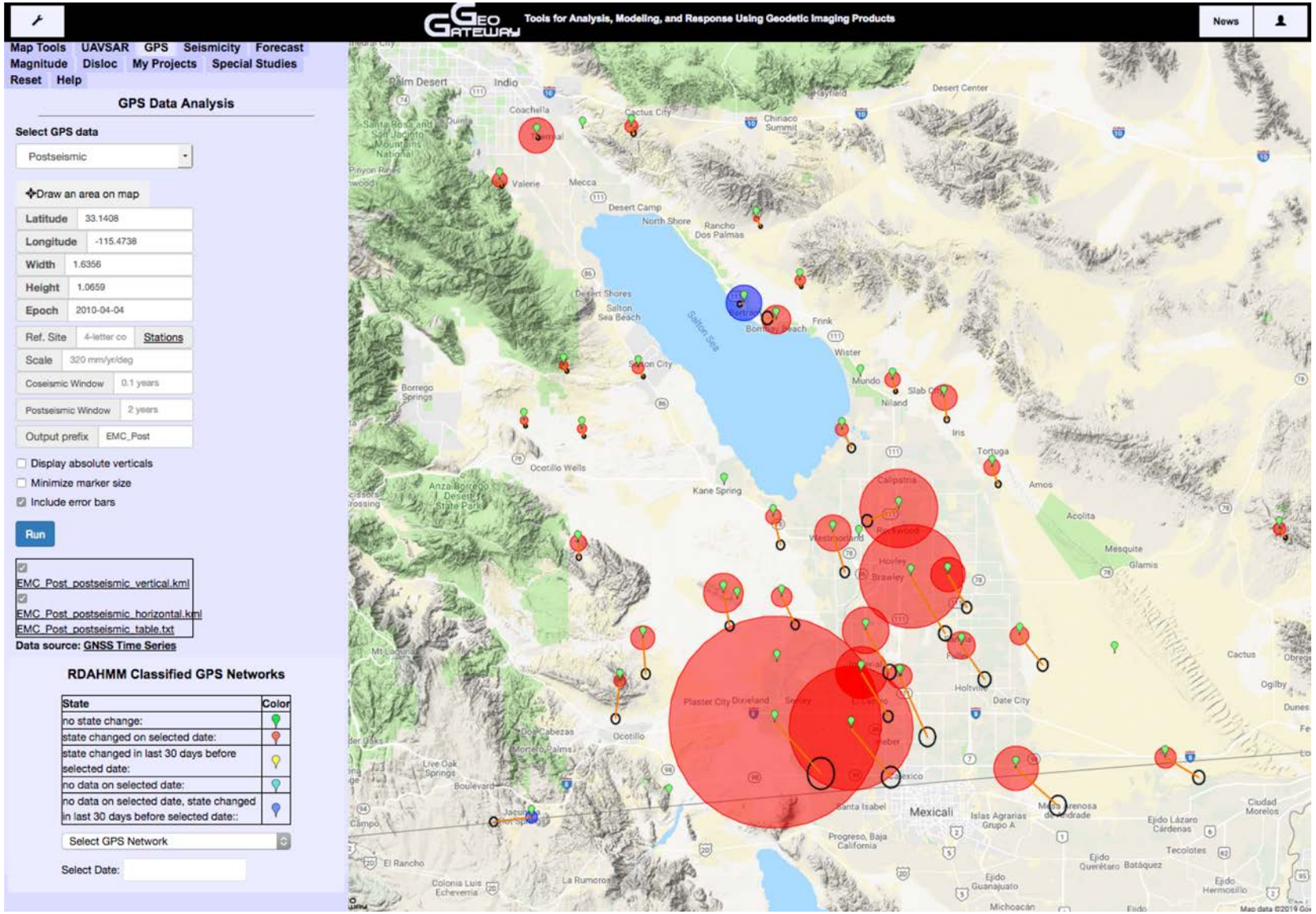
EMC Coseismic (1)

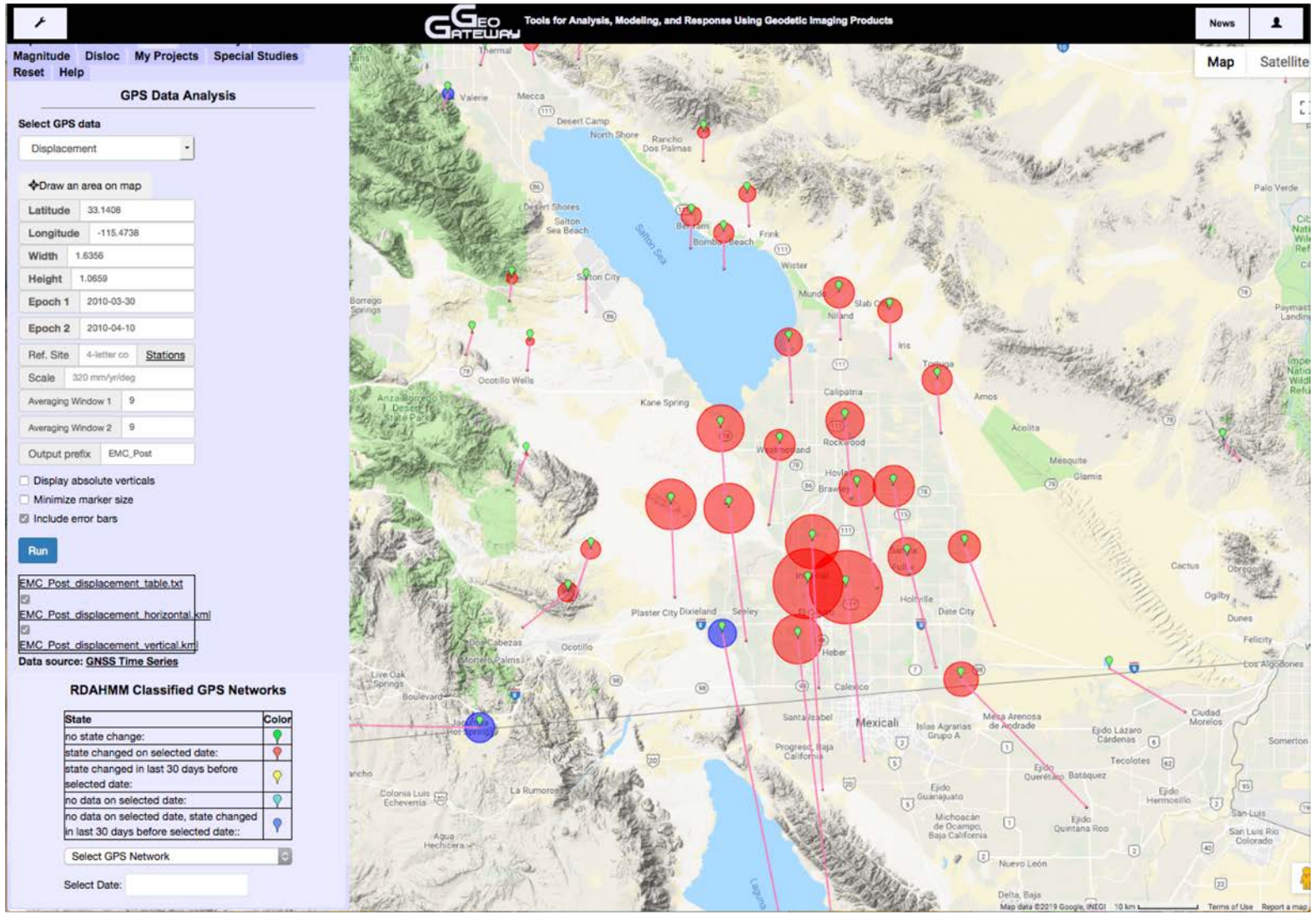


EMC Postseismic



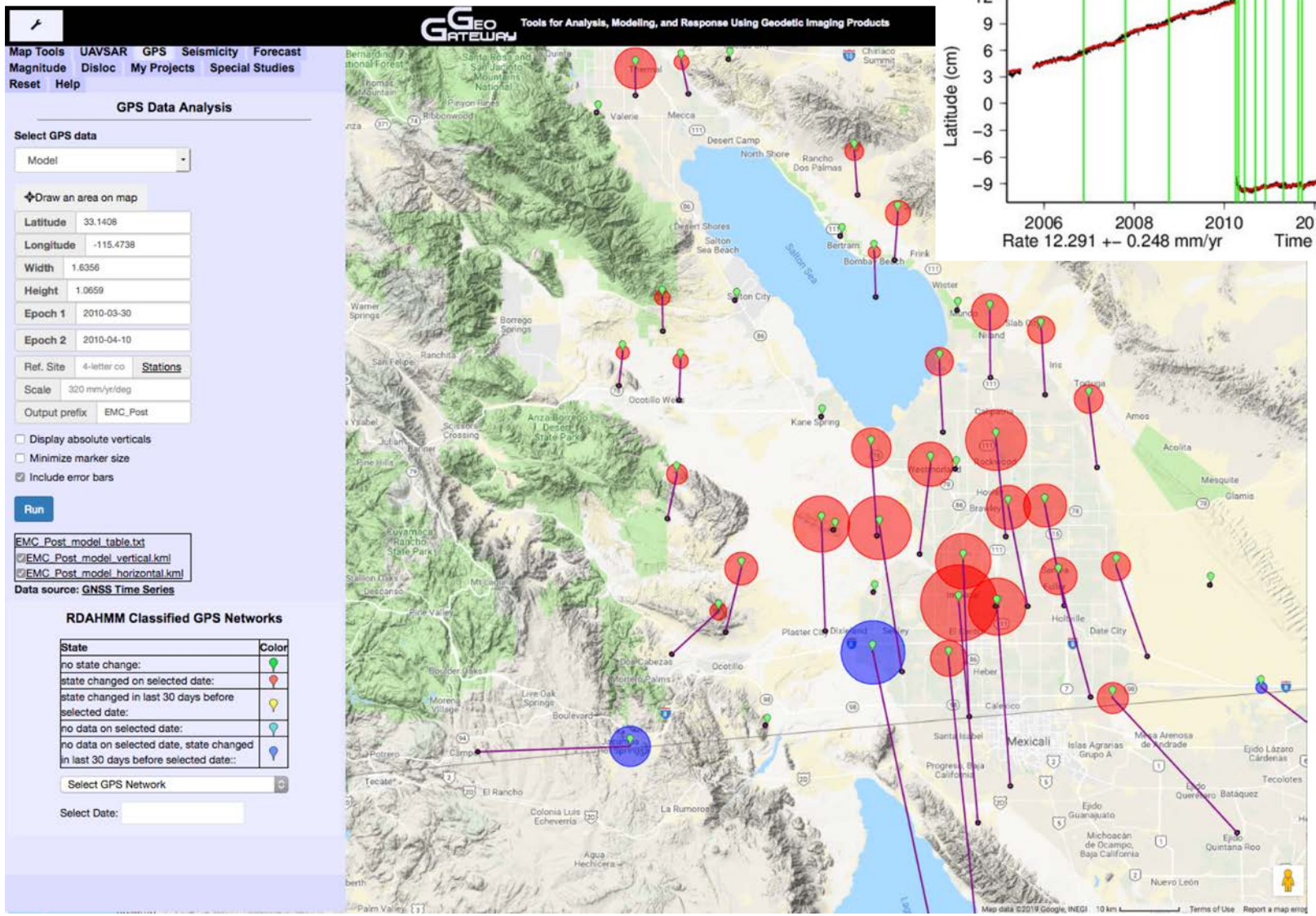
EMC Displacement (Coseismic 2)

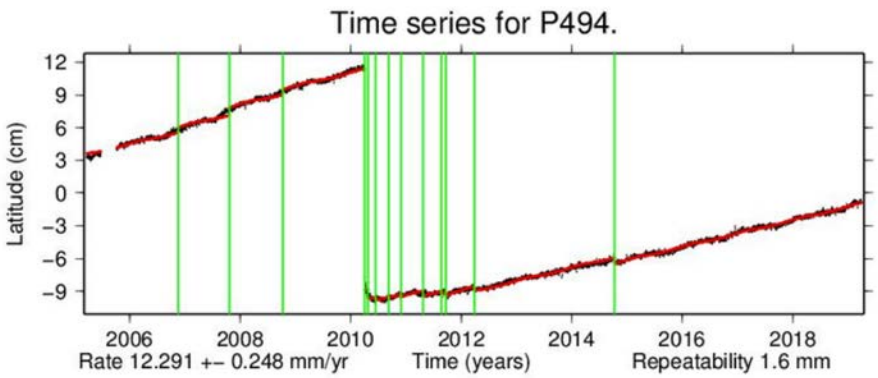
Alternative
to Coseismic



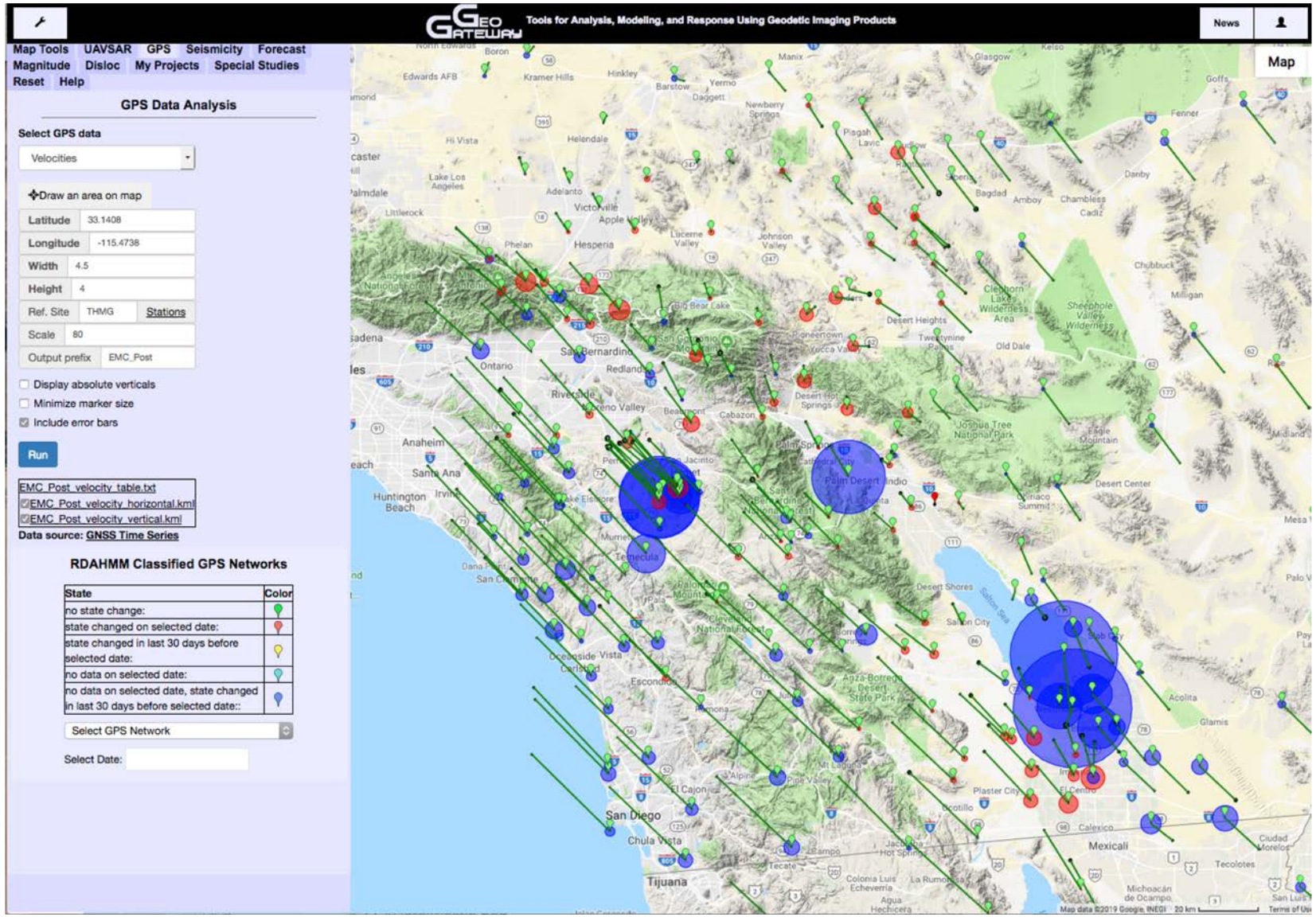
EMC Model (Coseismic 3)

Alternative to Coseismic





Reference Station



Product Download

156.56.177.220:8000/static/kml7092201958181658 23/EMC_Post_velocity_table.txt

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Site	Lon	Lat	Delta E	Delta N	Delta V	Sigma E	Sigma N	Sigma V
7ODM	-117.093197	34.116408	-4.925000	5.516000	-0.515000	0.205000	0.250000	0.879000
ACSB	-117.444894	33.274266	-16.620000	17.253000	-2.149000	0.178000	0.209000	0.714000
AGMT	-116.429381	34.594281	3.589000	-3.692000	0.044000	0.106000	0.128000	0.420000
AR27	-117.324933	33.341849	-16.076000	16.591000	-2.027000	0.176000	0.209000	0.699000
AR53	-117.476508	33.381136	-16.037000	16.888000	-1.998000	0.178000	0.208000	0.706000
AVRY	-117.153975	34.468302	-1.593000	2.423000	0.763000	0.072000	0.085000	0.291000
AZRY	-116.629701	33.540074	-9.443000	10.998000	0.405000	0.115000	0.136000	0.477000
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BEMT	-115.998193	34.000533	4.816000	-5.552000	-0.224000	0.108000	0.128000	0.429000
BILL	-117.064605	33.578245	-13.401000	13.907000	-0.613000	0.104000	0.121000	0.425000
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COKG	-115.728503	32.850513	-10.393000	10.932000	1.633000	0.267000	0.303000	1.037000
COTD	-116.386893	33.732487	-4.360000	7.368000	-8.806000	0.179000	0.196000	0.743000

156.56.177.220:8000/static/kml7092201958181658 23/EMC_Post_velocity_table.txt

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HMTG	-117.001505	33.708097	-11.630000	12.259000	-2.197000	0.373000	0.436000	1.448000
HNPS	-115.635338	33.705005	5.315000	-8.063000	-0.498000	0.120000	0.146000	0.559000
HW62	-114.844705	34.064957	7.632000	-10.032000	0.515000	0.208000	0.249000	0.837000
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IDQG	-116.238987	33.767973	-1.917000	1.267000	0.659000	0.329000	0.389000	1.344000
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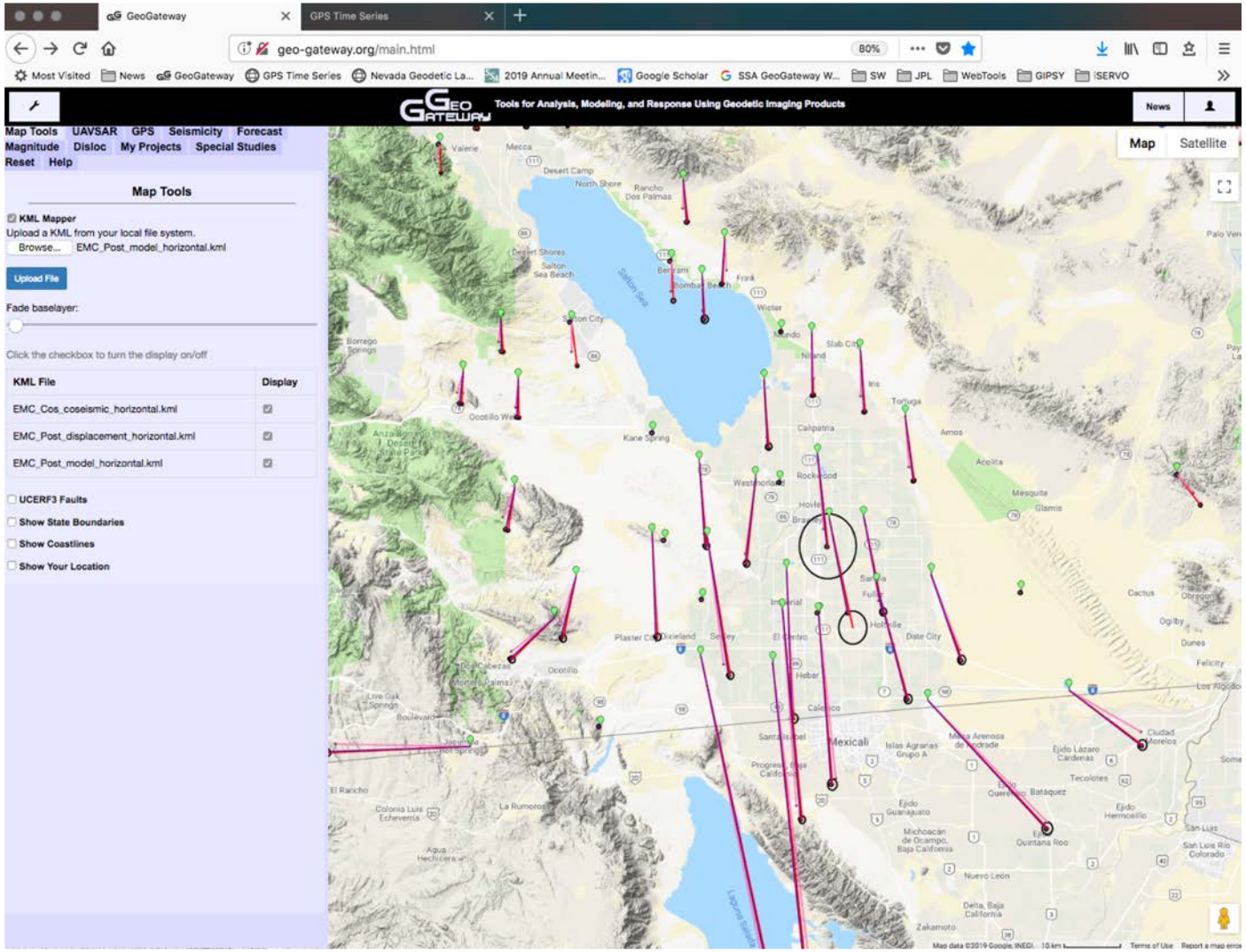
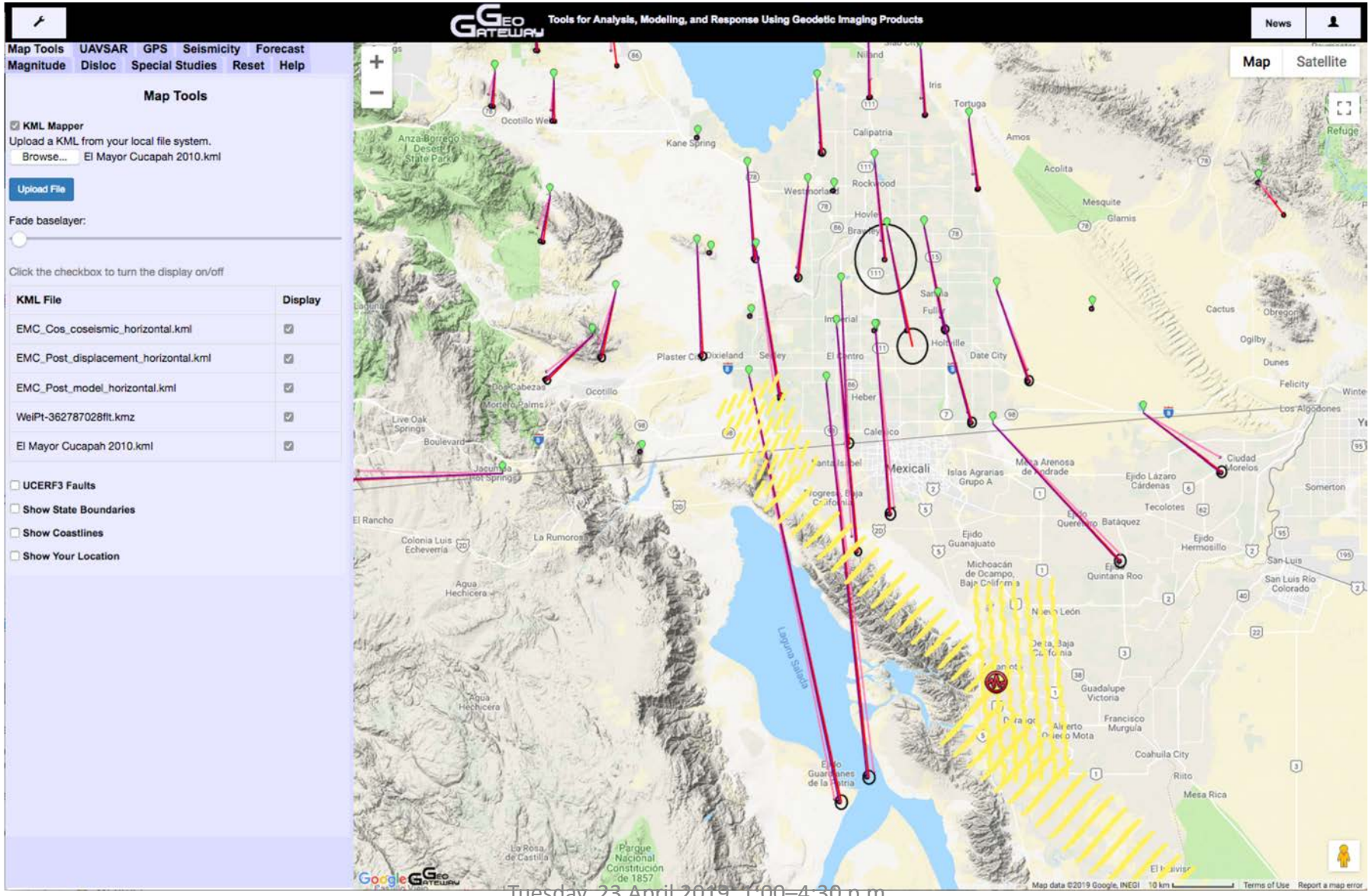


Overlaying kmz: Import Fault



Break

15 min

Seismicity and Forecast Tools

- Seismicity preset options and window
- Forecast
- Seismicity plots and nowcast

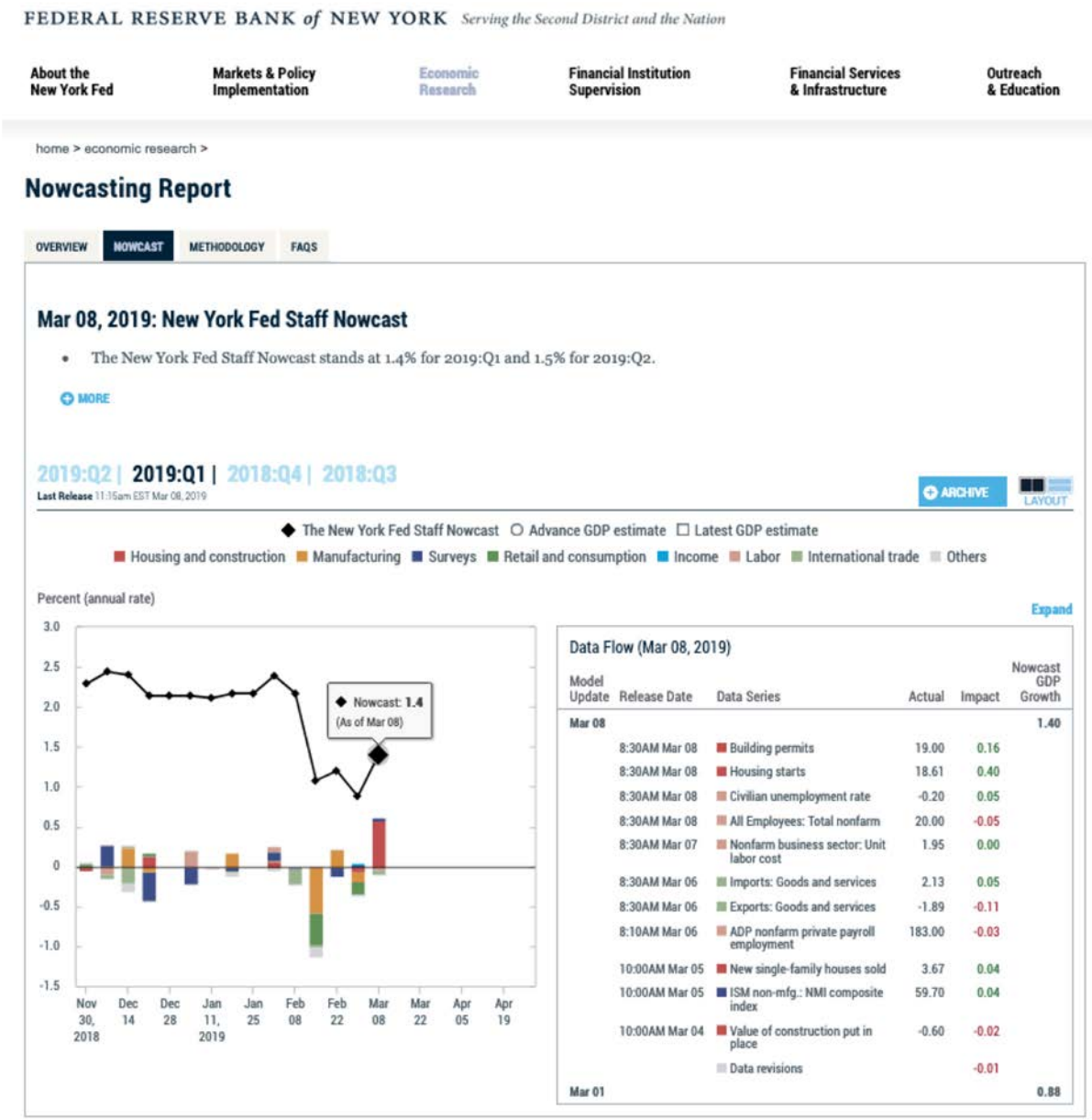
Nowcasting

The term "Nowcasting" was first used to describe the current state of the economic/business cycle

Forecasting is a probability of future activity in the hazard (earthquake) cycle

Nowcasting describes the current state of the hazard cycle

GDP Nowcast from the Federal Reserve Bank of New York as of March 8, 2019



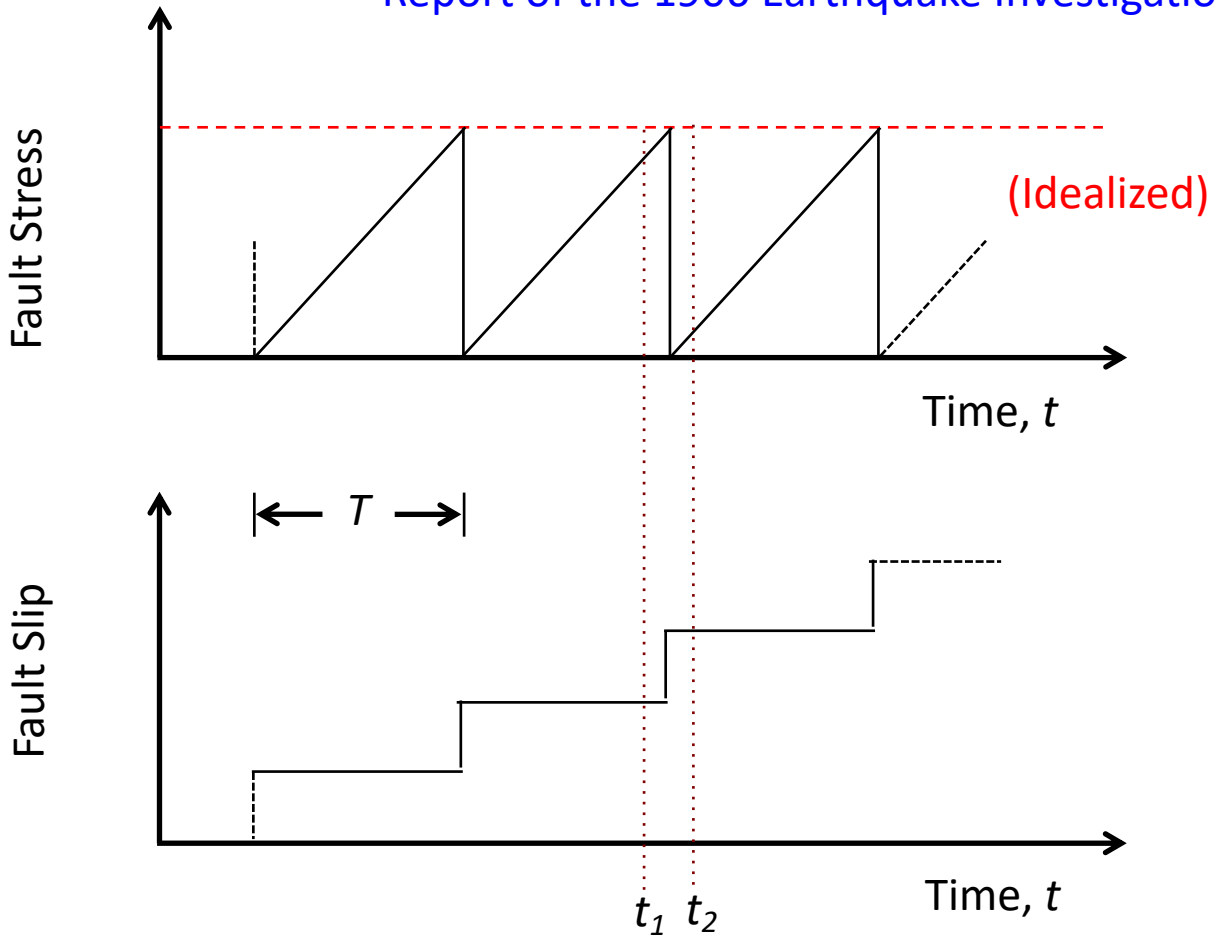
Earthquake Nowcasting

- Forecasting computes a probability of future earthquakes from past earthquakes
- Nowcasting estimates the current dynamical state of the system using proxy data (small earthquakes)
- Our implementation of nowcasting focuses on seismically active regions rather than on faults
- For a given seismically active region, we seek to determine the current progress of the region through its recurring earthquake cycle
- Primary data source is online earthquake catalogs from the USGS
- These methods are now being used routinely in Japan and Greece

Nowcasting can provide the initial conditions for forecasting

The Earthquake Cycle Arises from Elastic Rebound

Report of the 1906 Earthquake Investigation (1910)



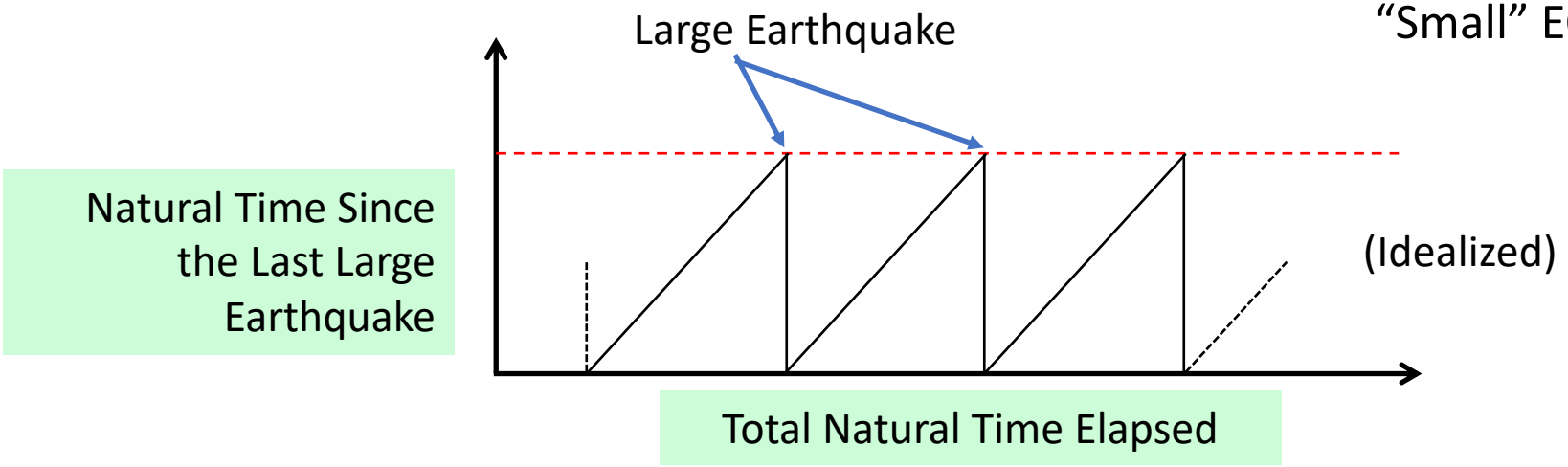
Harry Fielding Reid (1859-1944)

But: How do we measure the time-dependent state of stress on every fault?

Nowcasting: Use Small Earthquake Counts as Proxy Data for Stress

Natural Time = Count of Small Earthquakes

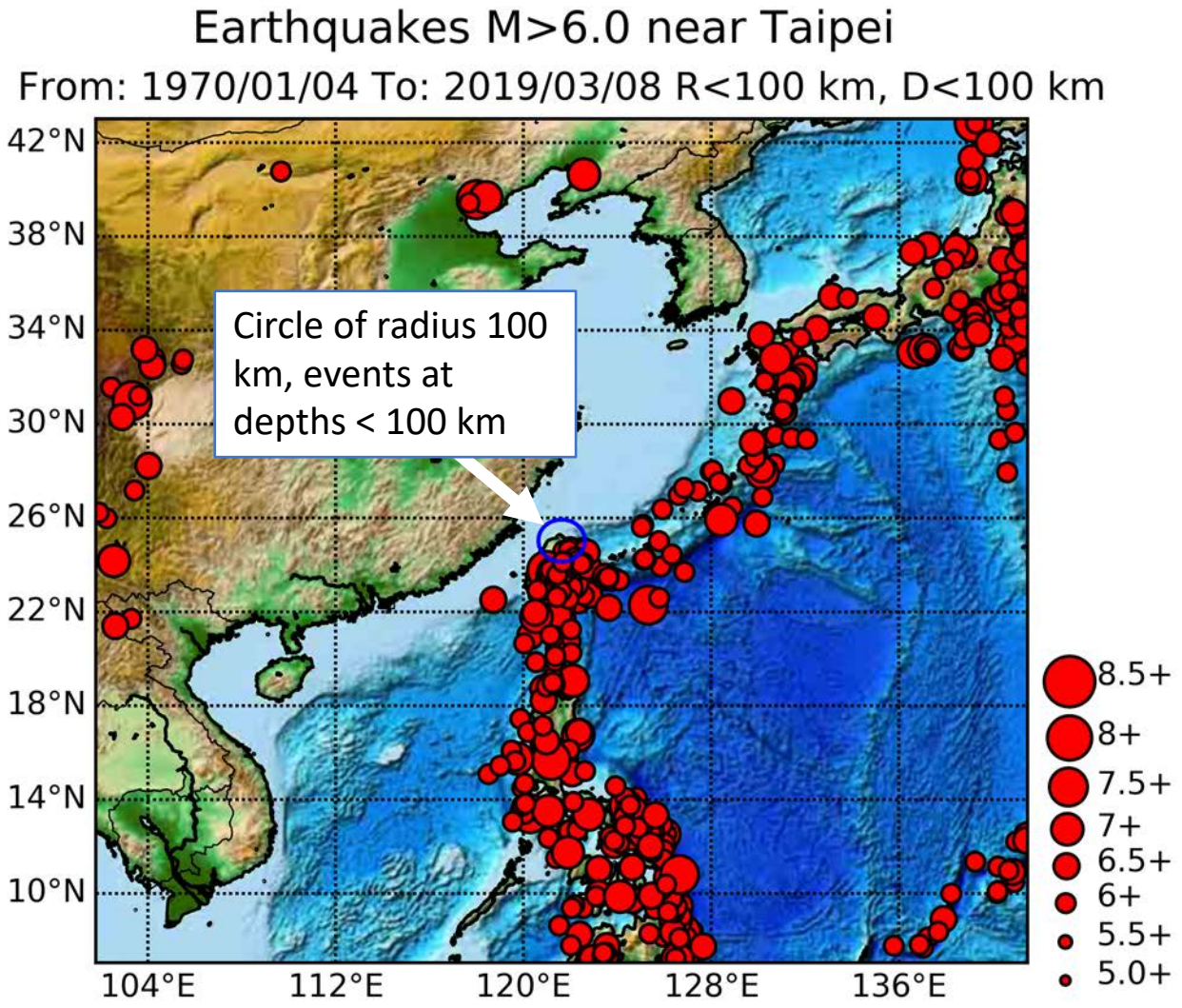
Example:
"Large" EQ: M > 6
"Small" EQ: 6 > M > 4



Accumulating small earthquakes are readily observable proxy data, unlike stress

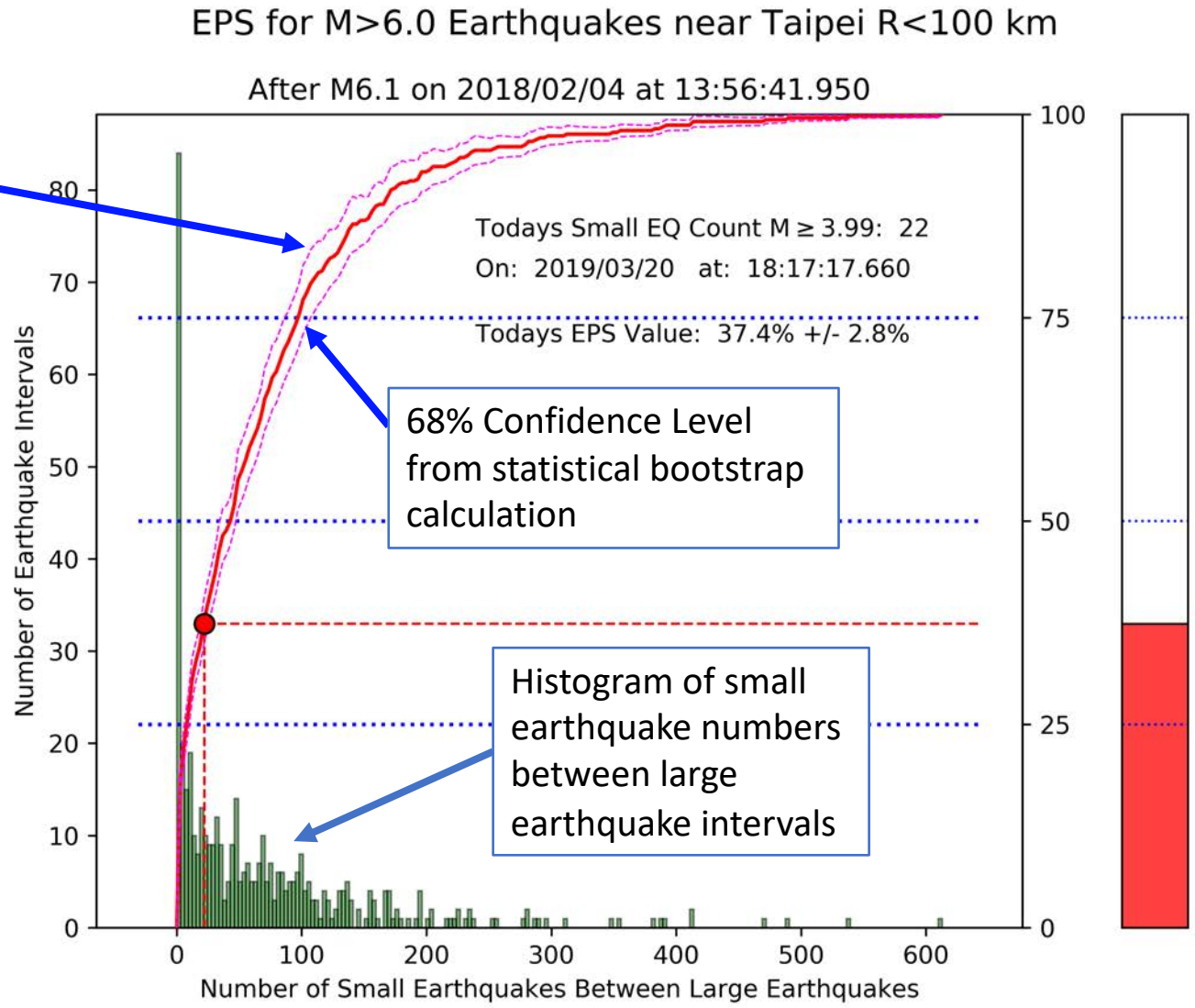
The average number of small earthquakes for every large earthquake is known to be constant

Seismicity around Taipei



Taipei

Earthquake Potential Score



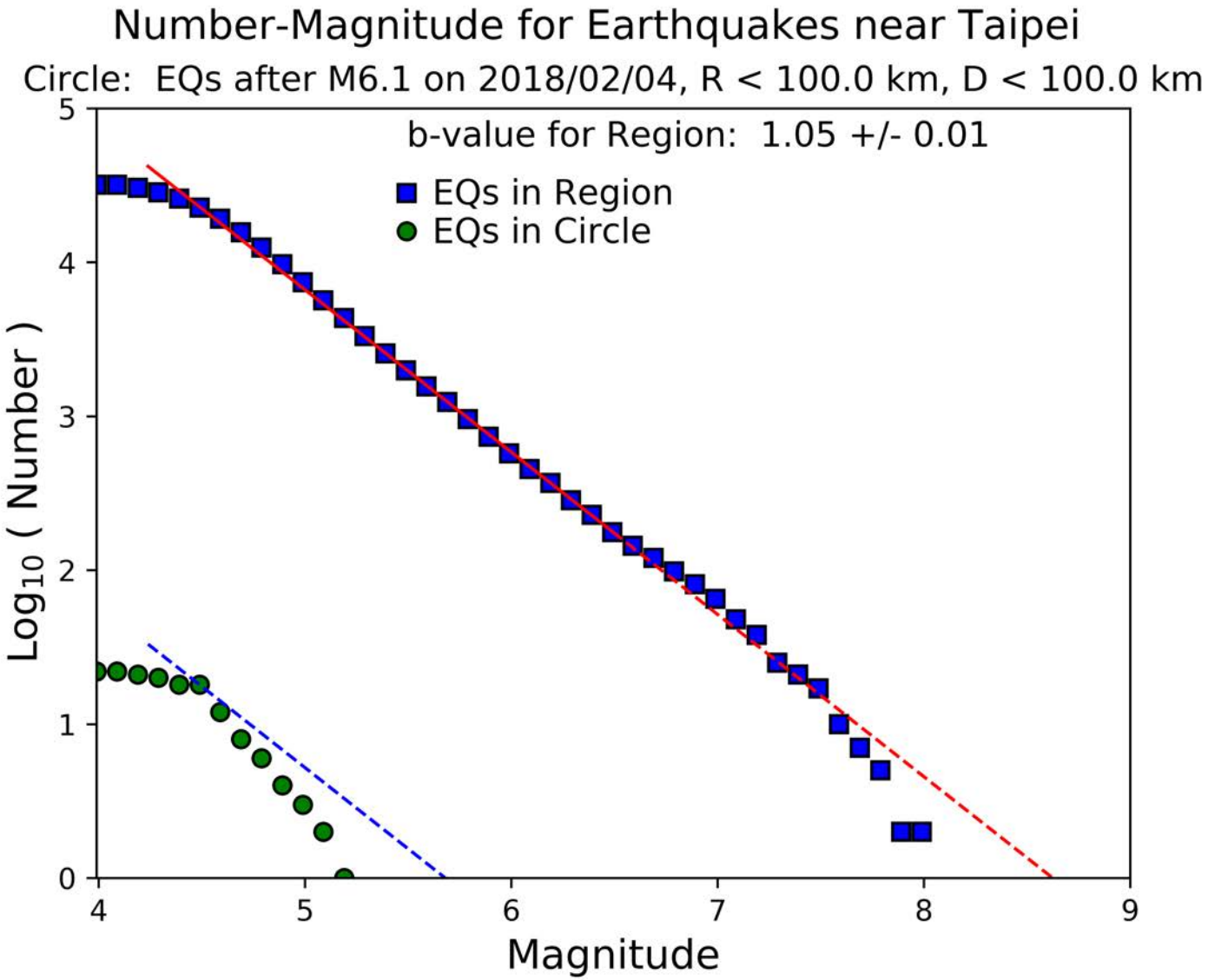
Cumulative Distribution Function of small earthquake intervals

68% Confidence Level from statistical bootstrap calculation

Histogram of small earthquake numbers between large earthquake intervals

Taipei

Number-Magnitude Diagram



Taipei

Earthquake Forecasting

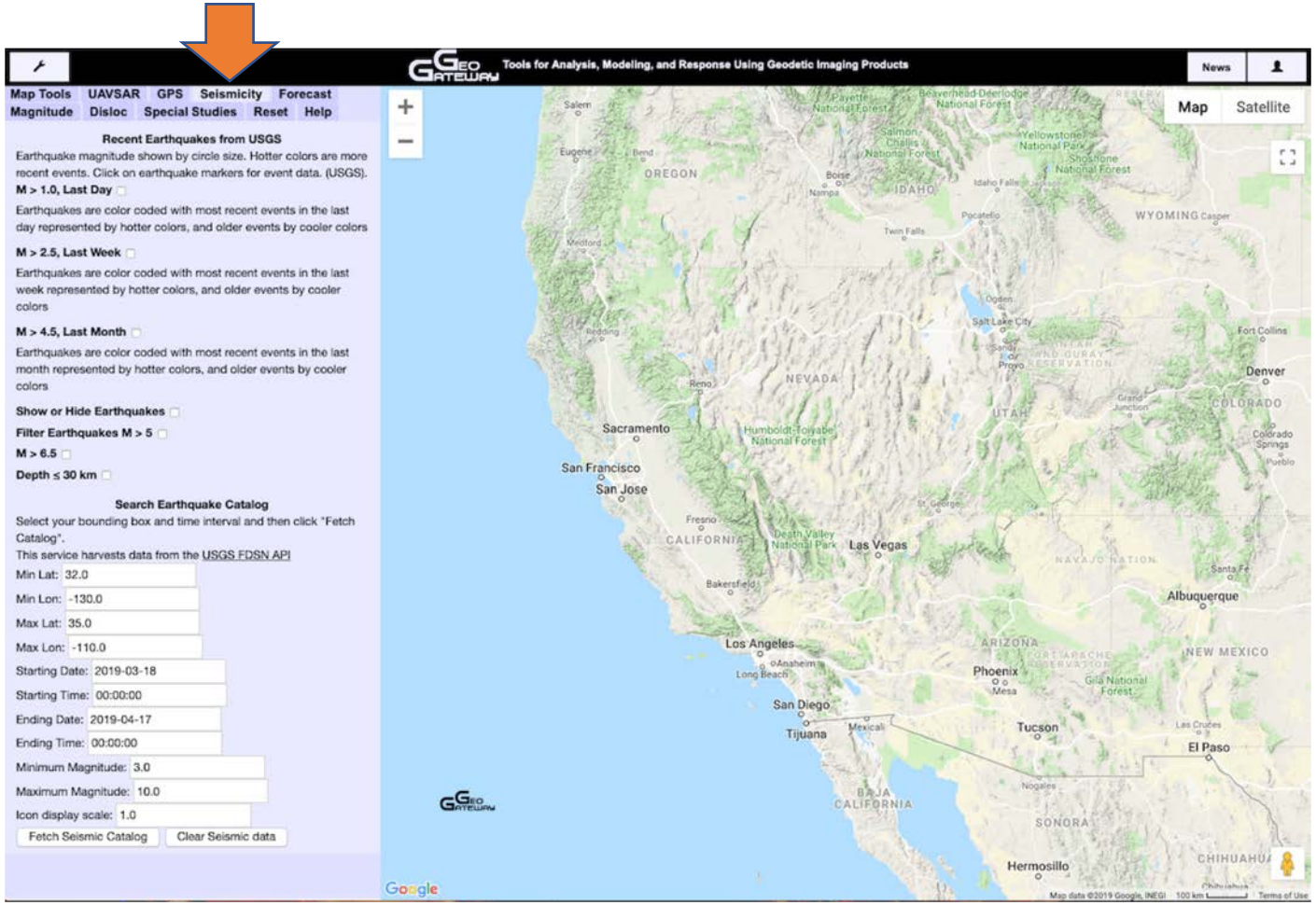
- Most forecasting approaches are fault-based
- Fault-based models require highly detailed knowledge on all the faults in the model, their histories of slip, and need initial conditions:
  - Fault locations, geometries, mode of rupture
  - Friction parameters
  - Interaction strength with other faults
  - Current dynamical state of the fault system is unknown ("initial conditions")
- Data on previous and historical fault ruptures is sparse or non-existent:
  - Earthquake catalogs are unreliable before about 1950
  - Field data from trench excavations are incomplete and reveal nothing about slip at depth
  - Earthquakes on submarine faults are particularly problematic

From Nowcasts to Forecasts

Forecasting with the Natural Time Weibull Method: JR Holliday et al. (2014)

- As in Nowcasting, we use seismically active areas rather than faults
- Nowcasting provides the initial conditions for forecasting
- The forecast model begins by counting small earthquakes since the last large earthquake (Nowcasting)
- The model builds on the Nowcast by projecting the count forward in time using the current rate of small earthquake activity and Weibull (1952) probabilities, which are frequently used for engineering failure analysis
- The influence of earthquakes outside the selected region is included using a simple correlation function
- The result is a fully automated computation of probability for future large earthquake occurrence
- Automation allows backtesting and optimization

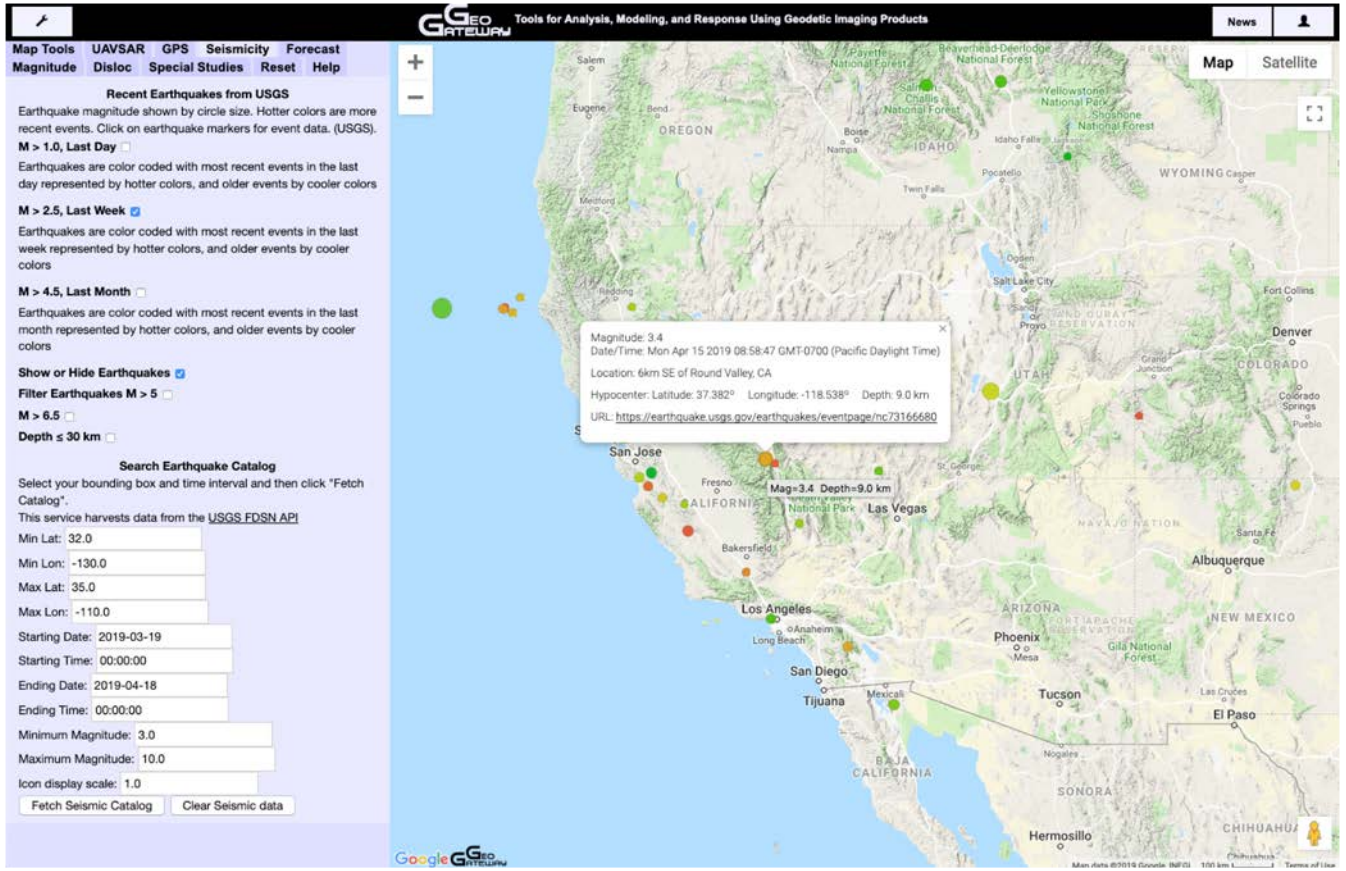
Seismicity Tab



Seismicity Tab – Display Earthquake Feeds

First Feature:

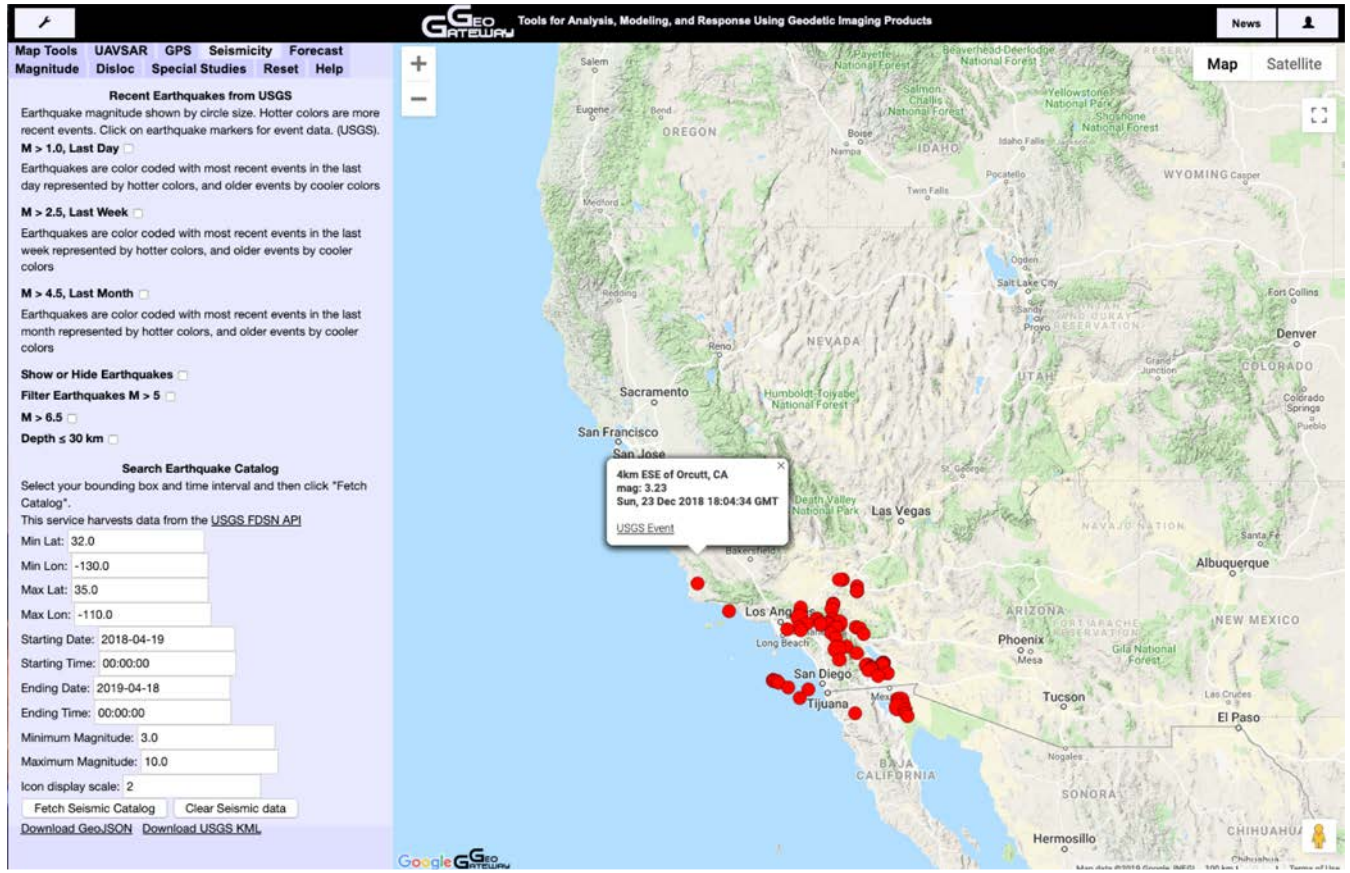
- Display seismic data from USGS feeds.
- Color coded for age of event, cooler colors for earlier events, hotter colors for later events.
- Event size corresponds to magnitude.
- Click on event for tooltips.



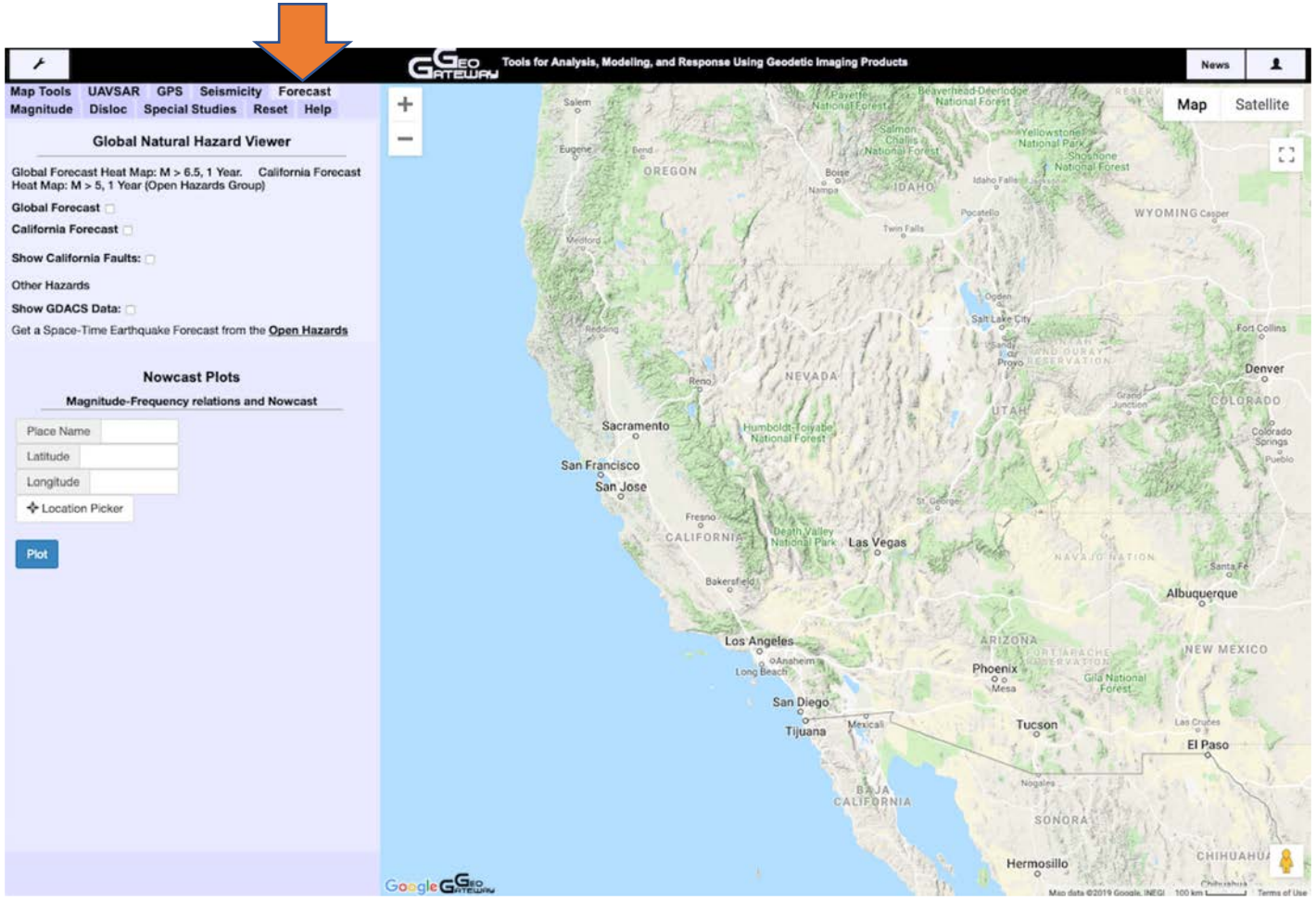
Seismicity Tab – Display Catalog Events

Second Feature:

- Display seismic data from USGS catalog.
- Event size corresponds to magnitude.
- Set display scale for icons.
- Click on event for tooltips.



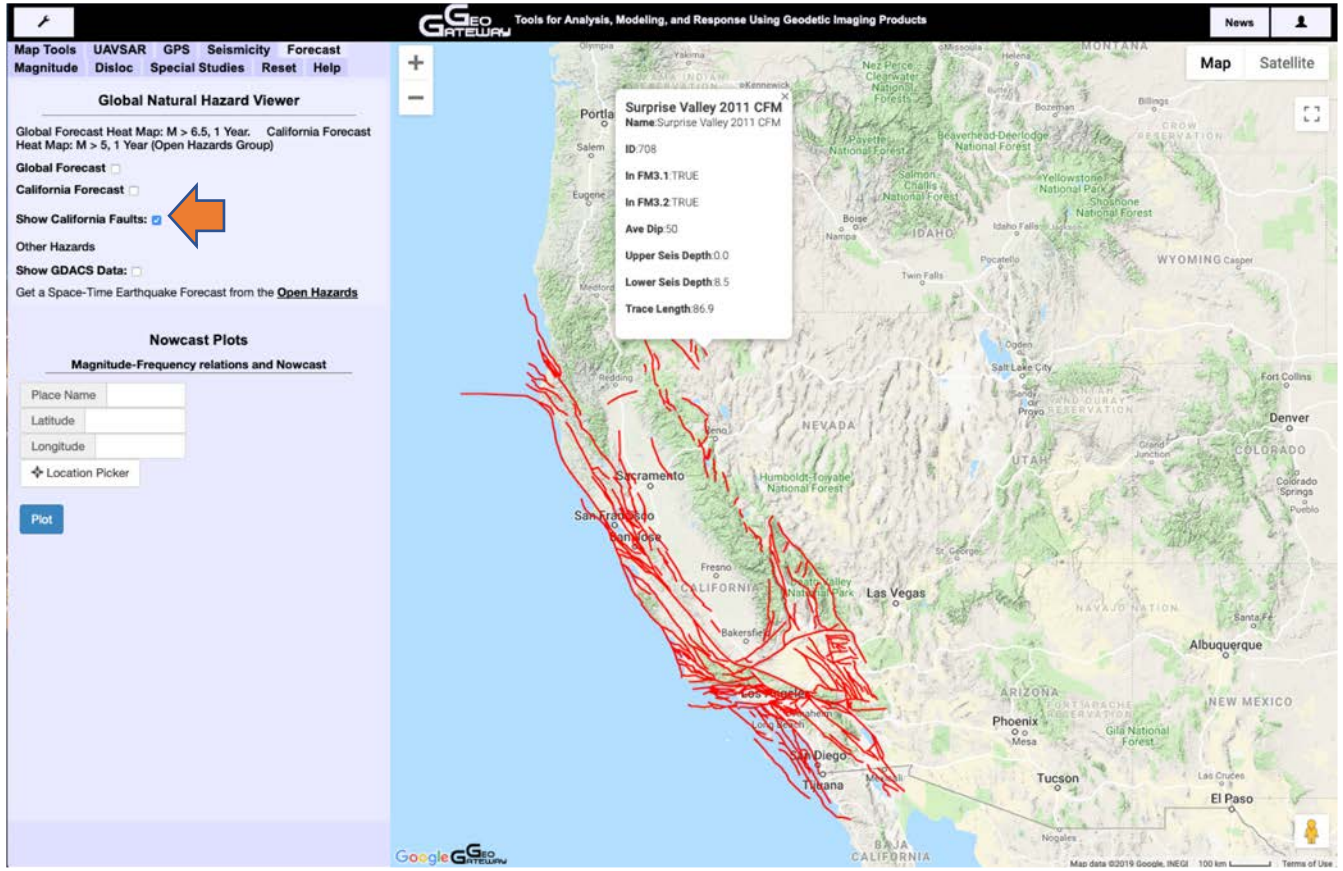
Forecast Tab



Forecast Tab – Display Faults

First Feature:

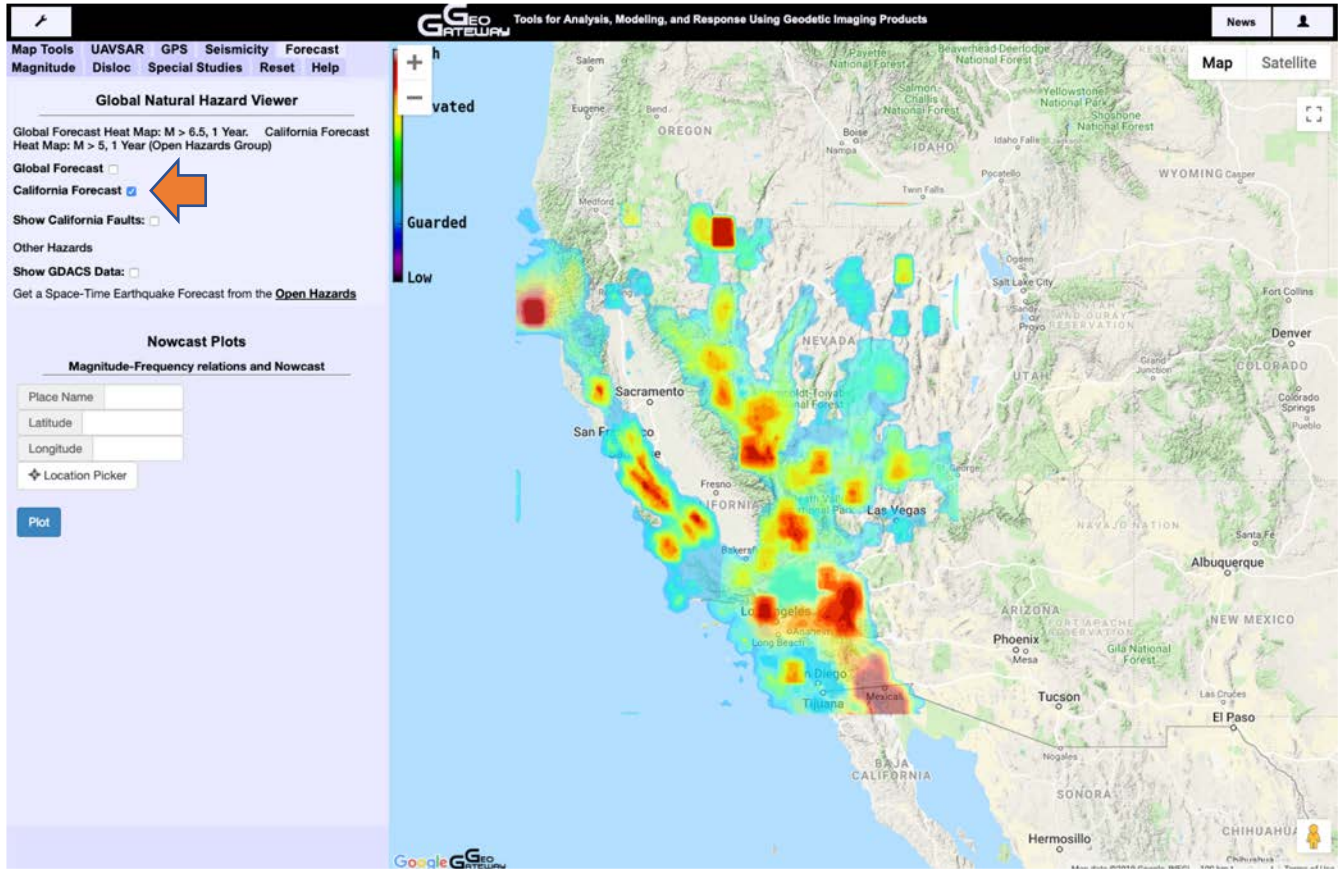
- Display California faults from USGS UCERF3 database.
- Click on the fault trace for tooltips.



Forecast Tab – Display California Forecast

Second Feature:

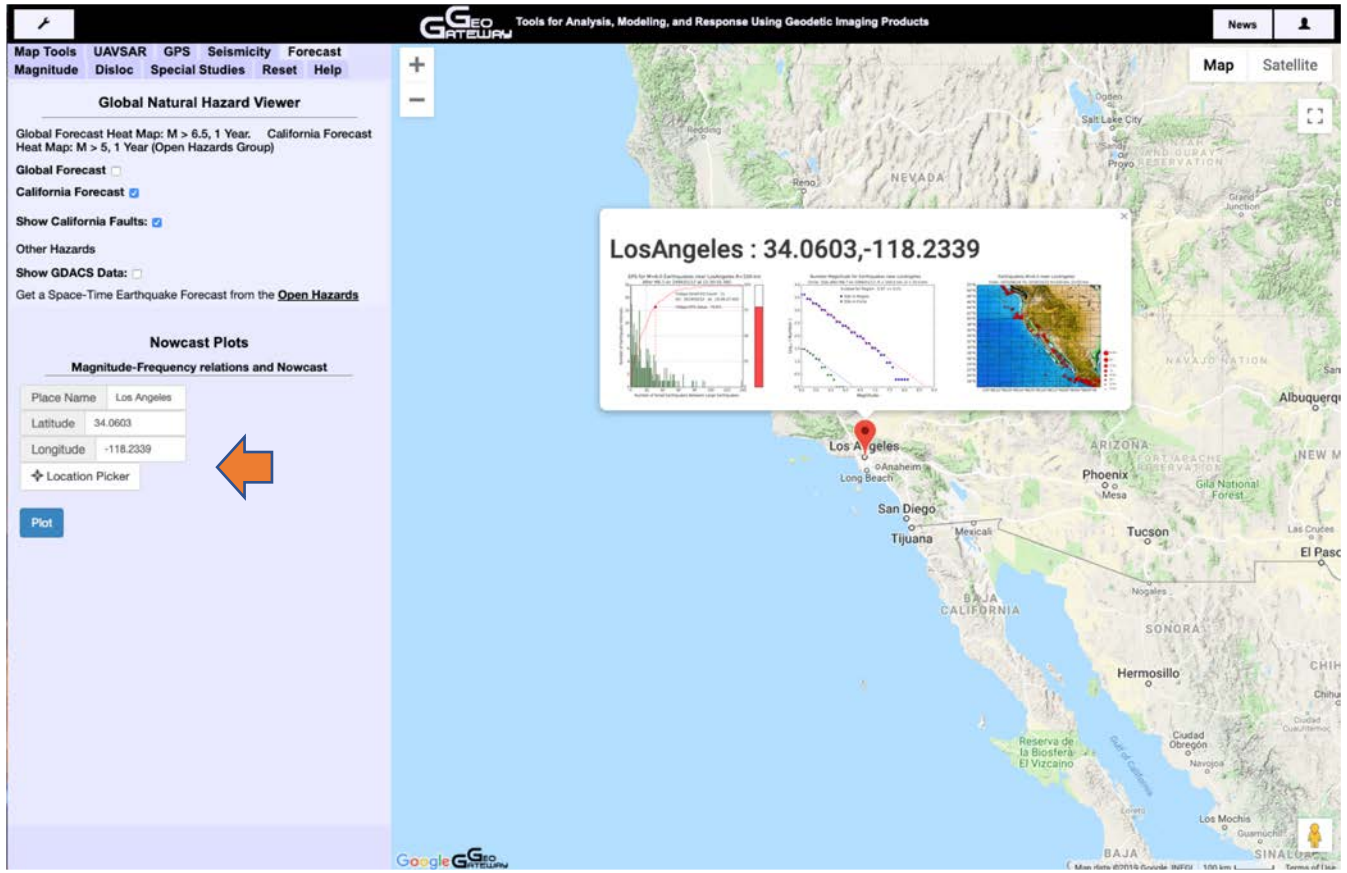
- Display a California earthquake forecast for M>6.5 earthquakes within 1 year.
- Updated daily.
- Uses Natural Time Weibull forecast from www.openhazards.com
- Click on the radio boxes for California forecast or Global forecast.
- Data from United Nations Global Disaster Alert Coordination System can also be displayed



Forecast Tab – Display Nowcast

Third Feature:

- Display Nowcast for earthquakes within 100 km and M>6
- Click on Location Picker, then on map to set marker.
- Enter name of location.
- Click on Plot button.
- Pop-up tab will appear with nowcast, magnitude-frequency, and regional plot of large earthquakes



User Exploration

- Analyze UAVSAR and layer faults
- Produce GPS velocities, offsets, and displacements
- Download and upload KML file
- Plot seismicity
- Compute forecasts and nowcasts

Questions?

15 min