California Spatial Reference Network (CSRN)
Continuous GPS Stations (CGPS):
Usage, Advantages and Limitations

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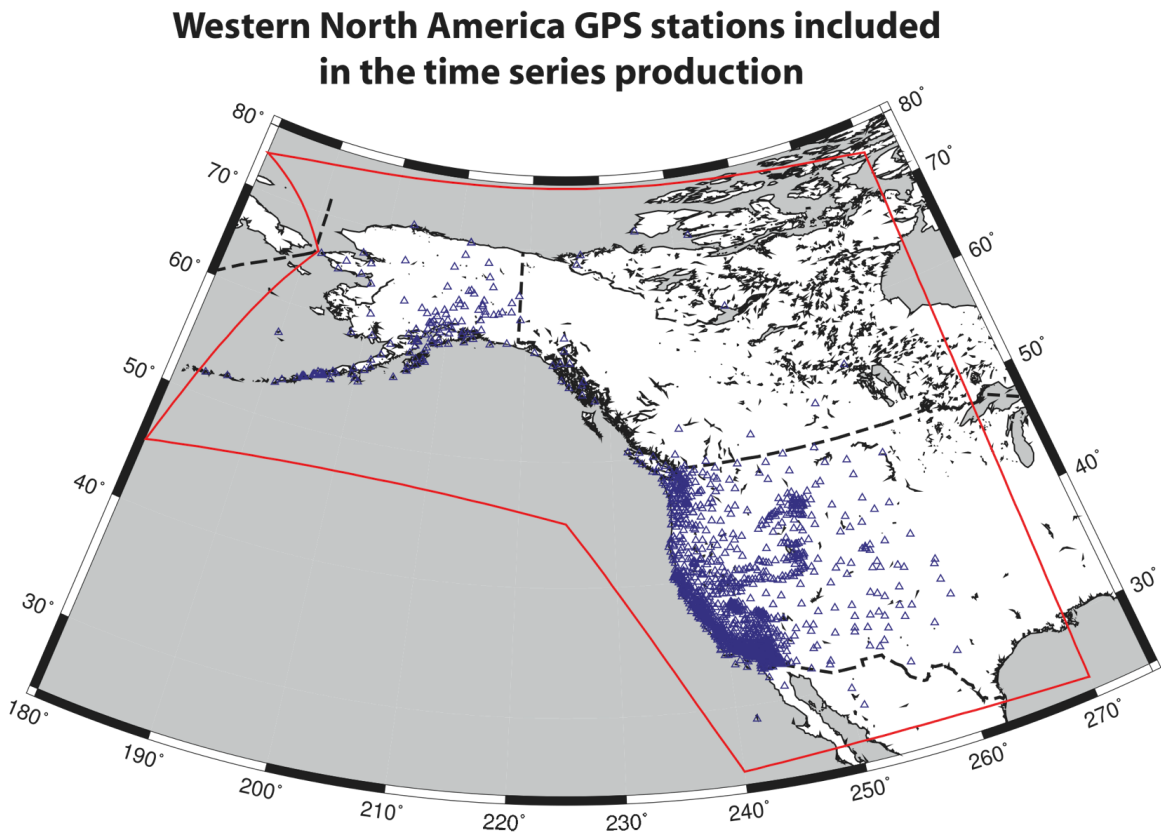
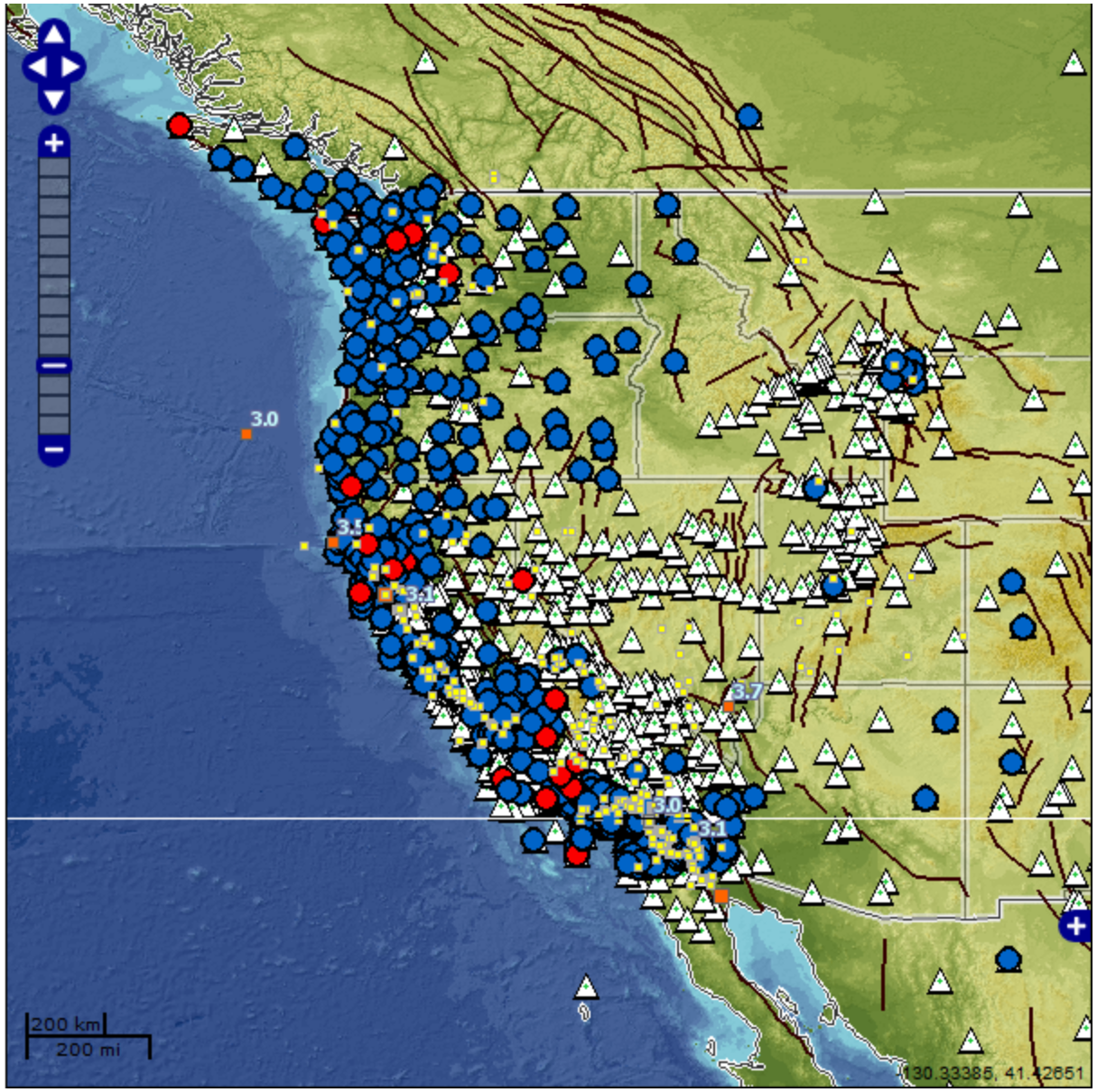
California Real Time Network
CLSA/CSRC Seminar
Ontario, CA
September 28, 2012
Sacramento, CA
October 5, 2012

CGPS Data & Metadata

- **RINEX files archived at SOPAC from over 2000 stations in Western NA including PBO, SCIGN, BARD, WCDA and PANGA stations & global stations**
- **Earliest CGPS data are from 1991 – two decades worth**
- **Use a common source of metadata to reduce systematic errors**
- **RINEX data processed independently at JPL (GIPSY software) and SOPAC (GAMIT software)**
- **Combination daily position time series is produced & updated weekly**



Real-Time CGPS Stations



- **Many of the CGPS stations have been upgraded to real time operations**
- **The NASA-supported Real-time Earthquake Analysis for Disaster Mitigation Network (READI) leverages the 500+ station real-time GPS network in Western North America to prototype an earthquake and tsunami early warning system.**
- **Data are collected from a variety of sources (PBO, SCIGN, CRTN, BARD, PANGA, WCDA)**

http://sopac.ucsd.edu/projects/realtime/READI/

Relevant CGPS Metadata

Essential:

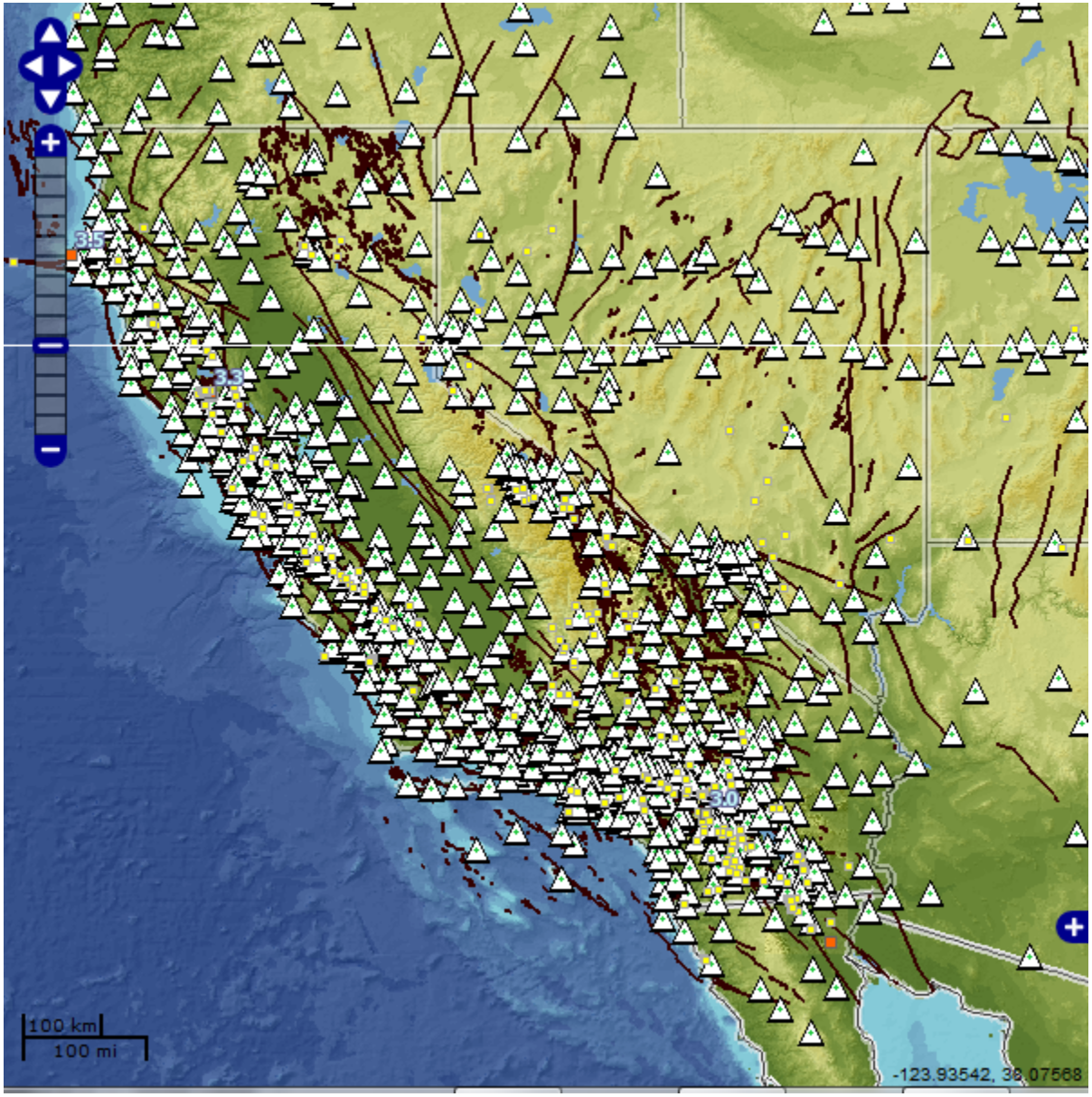
- Coordinates of CGPS stations
- Type/manufacturer of antenna
- Type/manufacturer of receiver
- Antenna reference point (ARP)
- Antenna offsets from reference point (height, mainly)

Less Important:

- Receiver serial number
- Antenna serial number

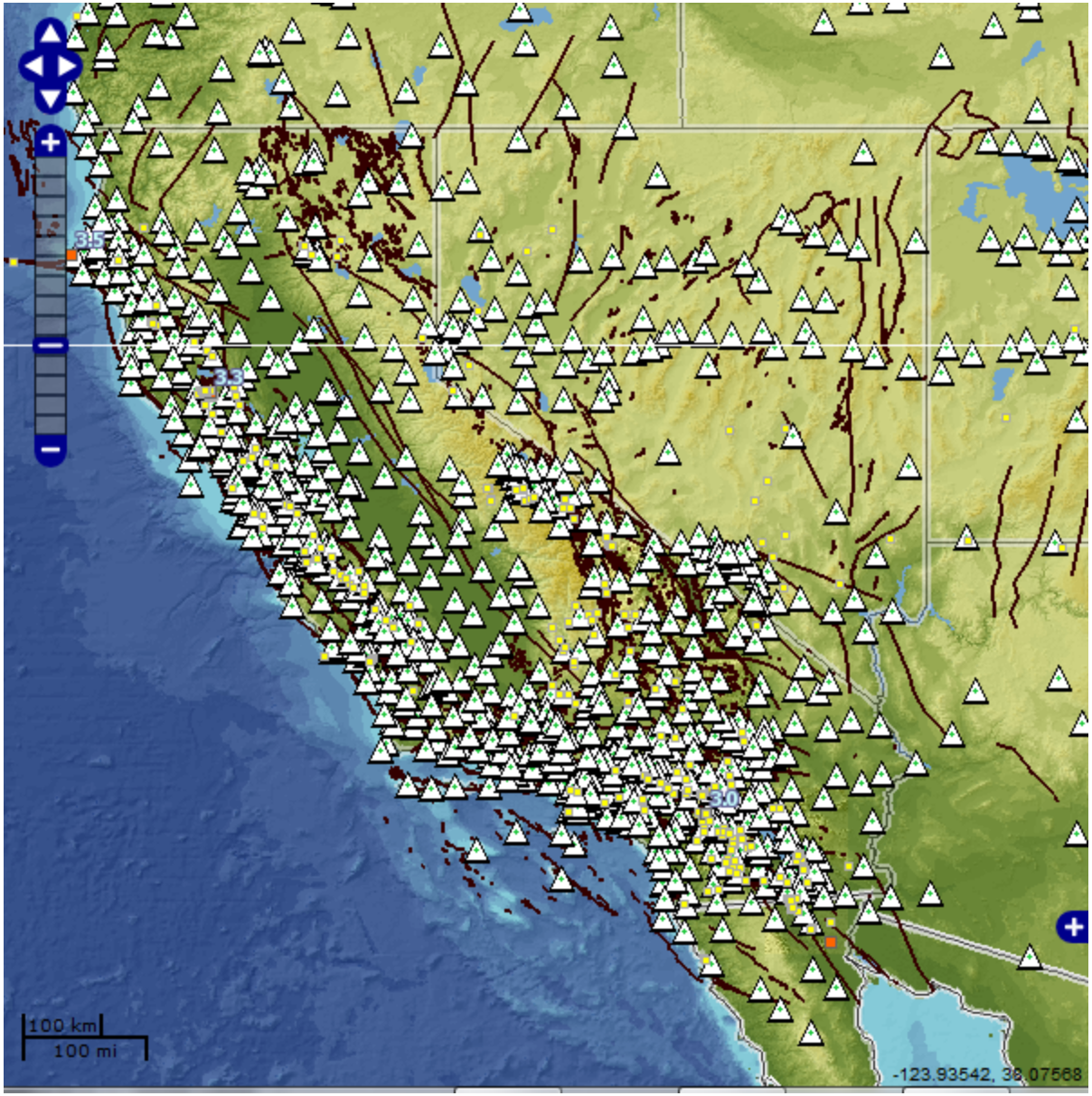
Transmitted in RTCM 3 message for real-time stations

California Spatial Reference Network (CSRN), based on Continuous GPS Stations (CGPS)

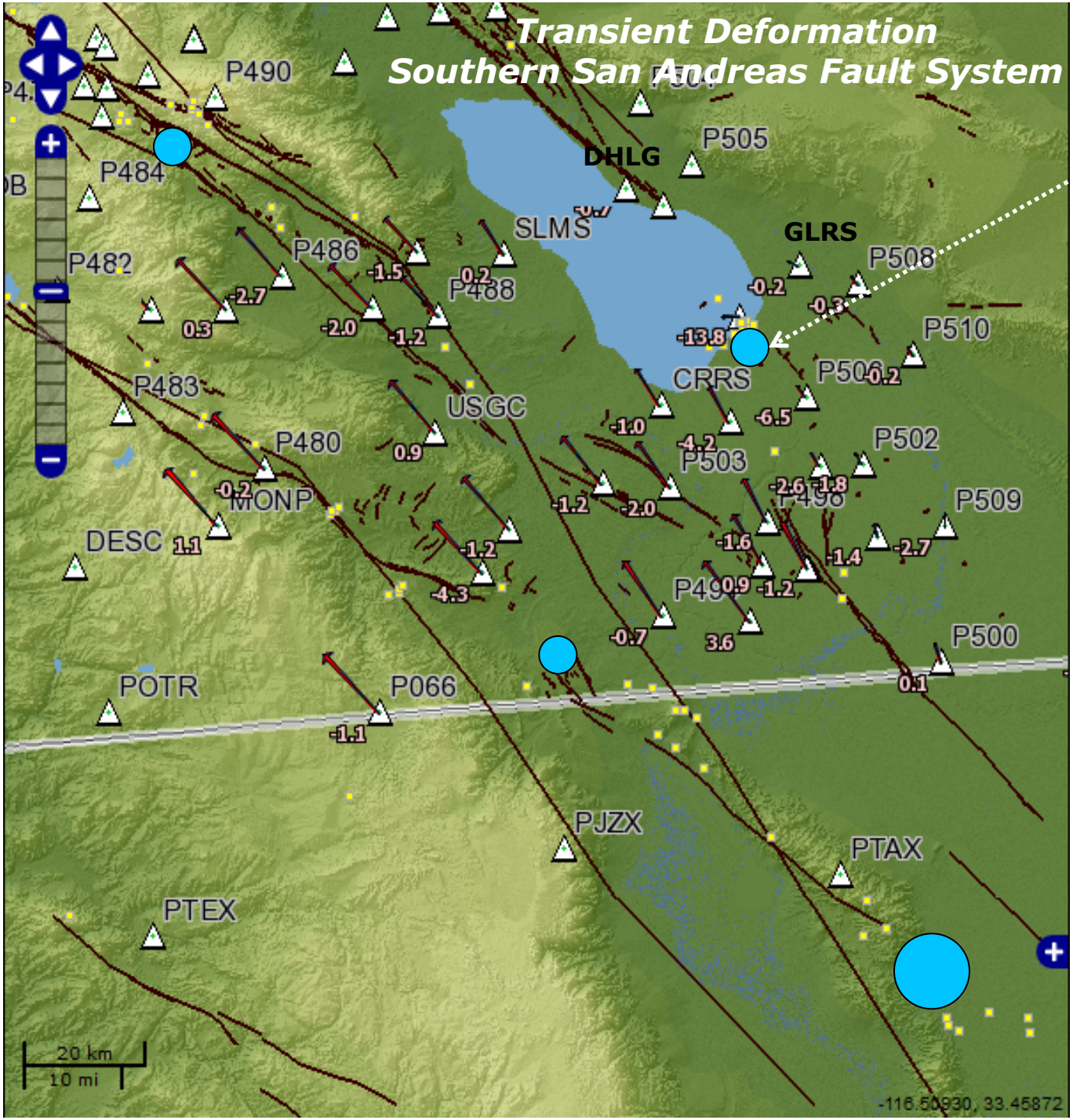


- **Stations built to strict standards for mm-level crustal deformation research (SCIGN, BARD, PBO)**
- **With a few exceptions, monumentation consists of braced, deeply-anchored stainless steel rods or braced, shallow-anchored rods in bedrock – a few rooftops at legacy stations**
- **Mix of receivers (Trimble, Topcon, Ashtech, Leica) but choke rings antennas used almost exclusively**
- **Limited number of Topcon G-3A receivers provide GNSS capability**

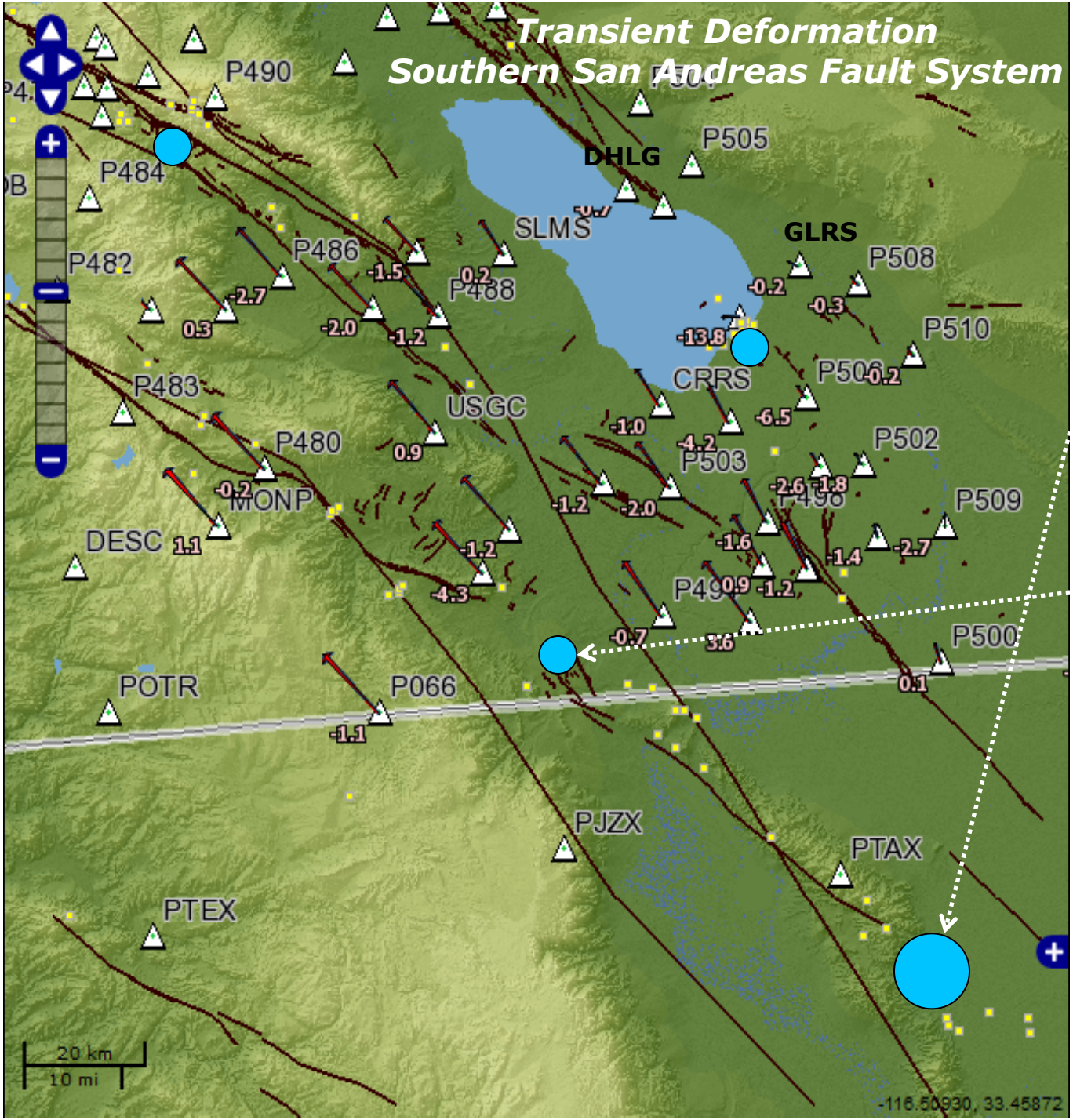
California Spatial Reference Network (CSRN), based on Continuous GPS Stations (CGPS)



- **Data sampled at 15 s rate and downloaded once per day by several groups (archived at SOPAC)**
- **Daily 3-D position time series basis for California Spatial Reference System (CSRS) maintained by CSRC**
- **CGPS daily position time series modeled for tectonic motion (station velocities), coseismic deformation (offsets), postseismic deformation, subsidence, and seasonal effects**

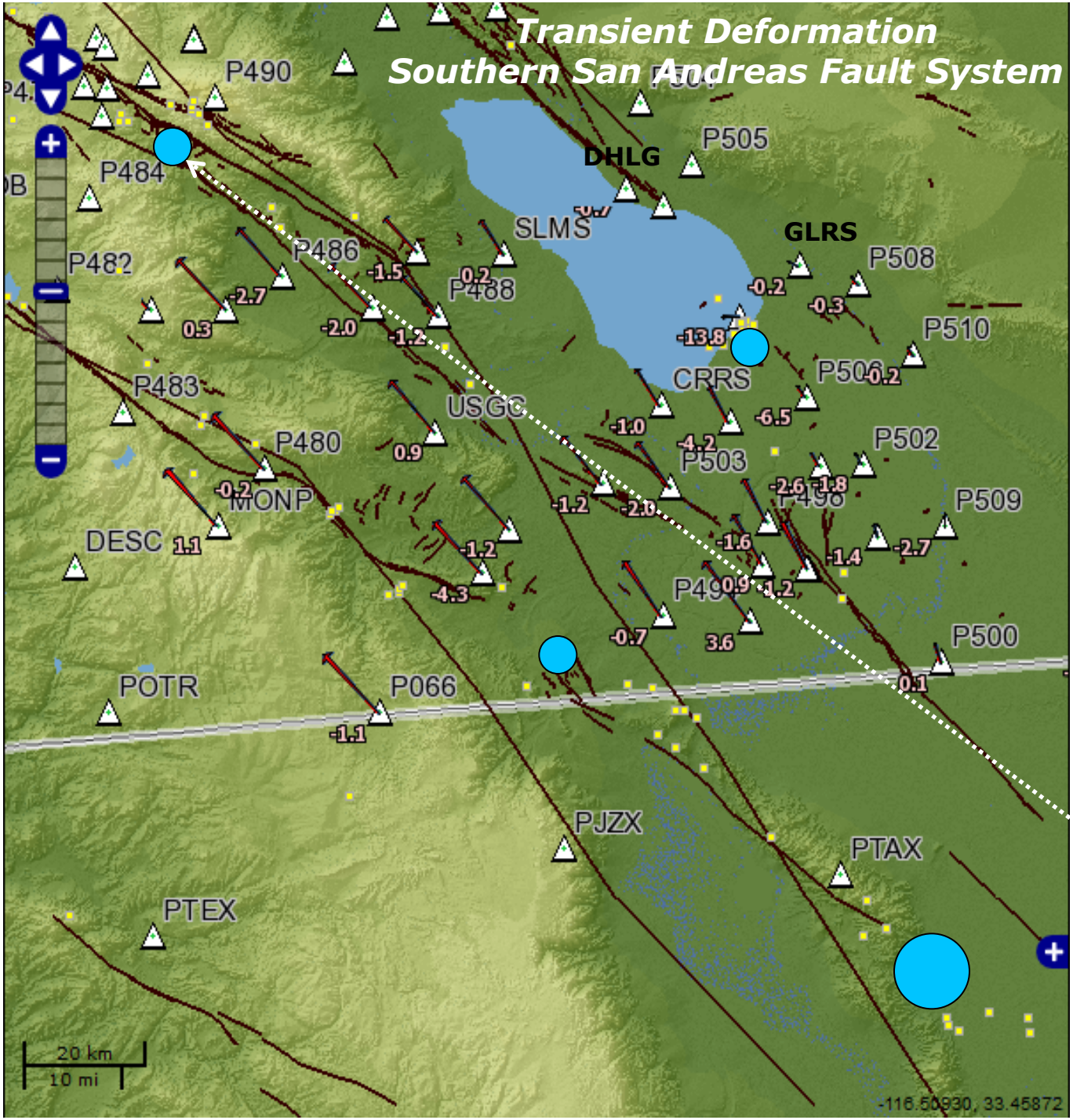


Sep 2, 2005 Mw 5.1
Obsidian Buttes
Seismic Swarm
(CRRS,DHLG,GLRS)



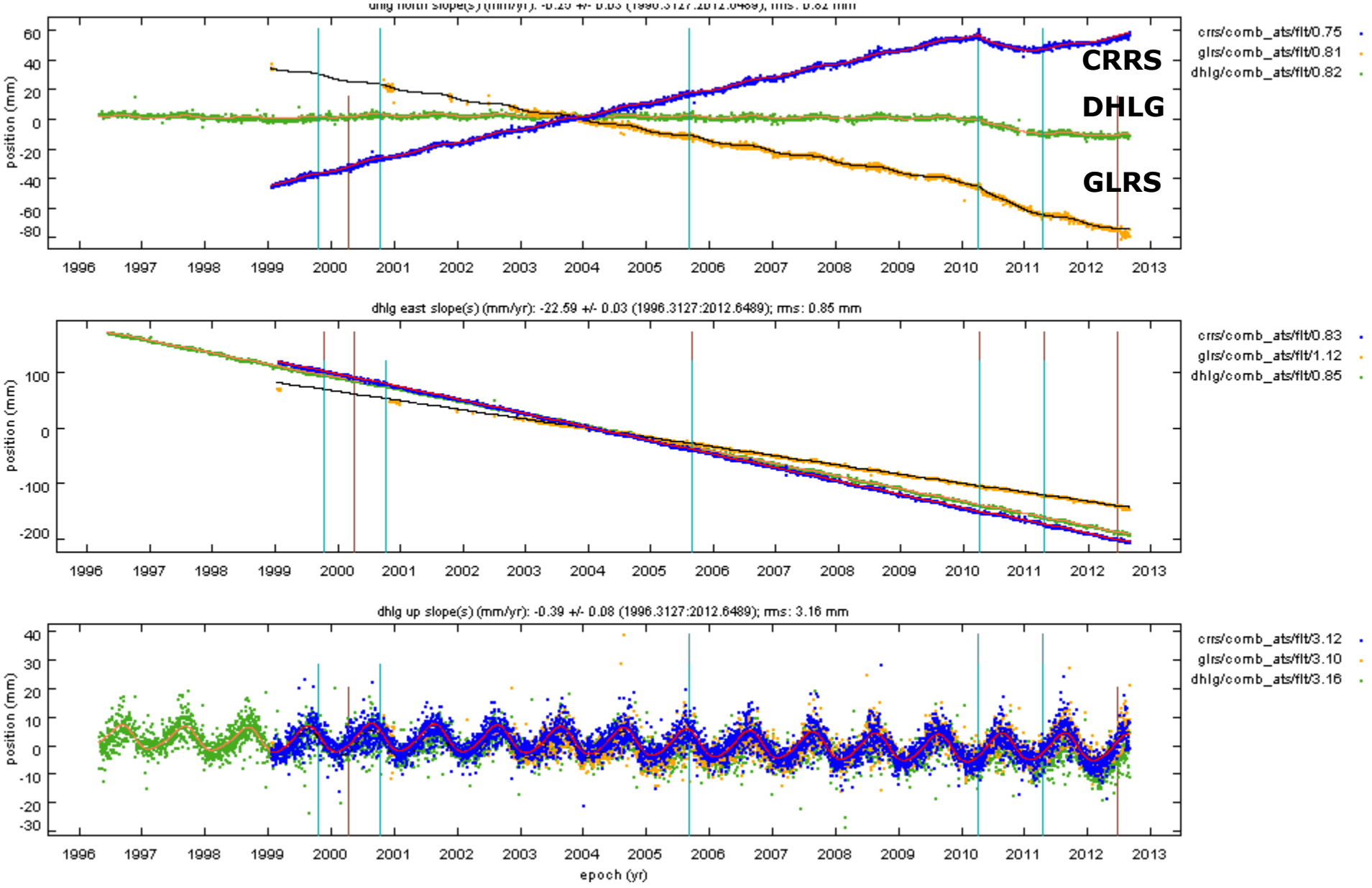
Apr 4, 2010 Mw 7.2 El Mayor-Cucapah Earthquake (209 stations)

Jun 15, 2010 Mw 5.7 Ocotillo El Mayor-Cucapah Aftershock (7 stations)

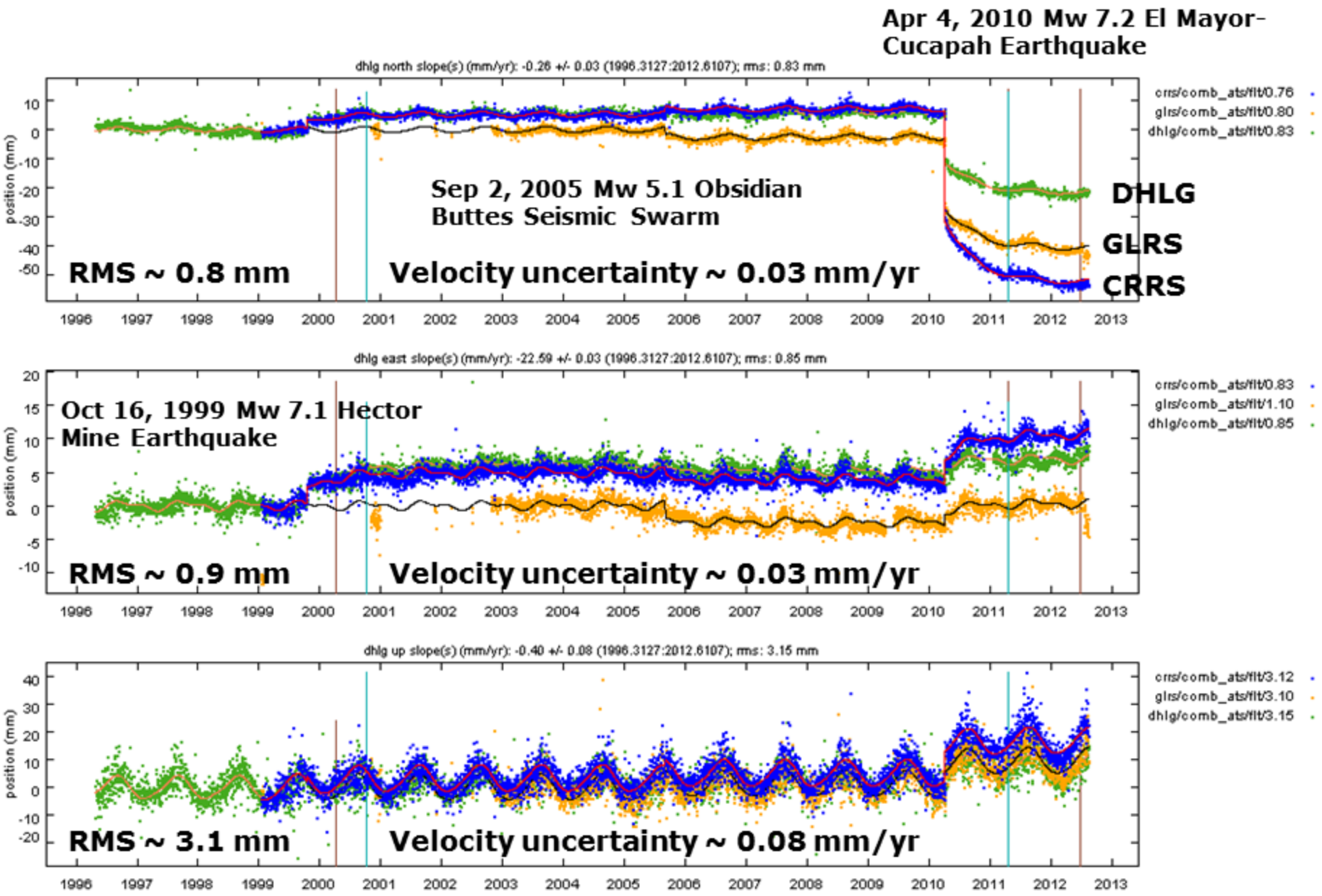


Jul 7, 2010 Mw 5.4
Borrego Springs
(P484&P490)

Trended Coordinate Time Series (offsets removed)

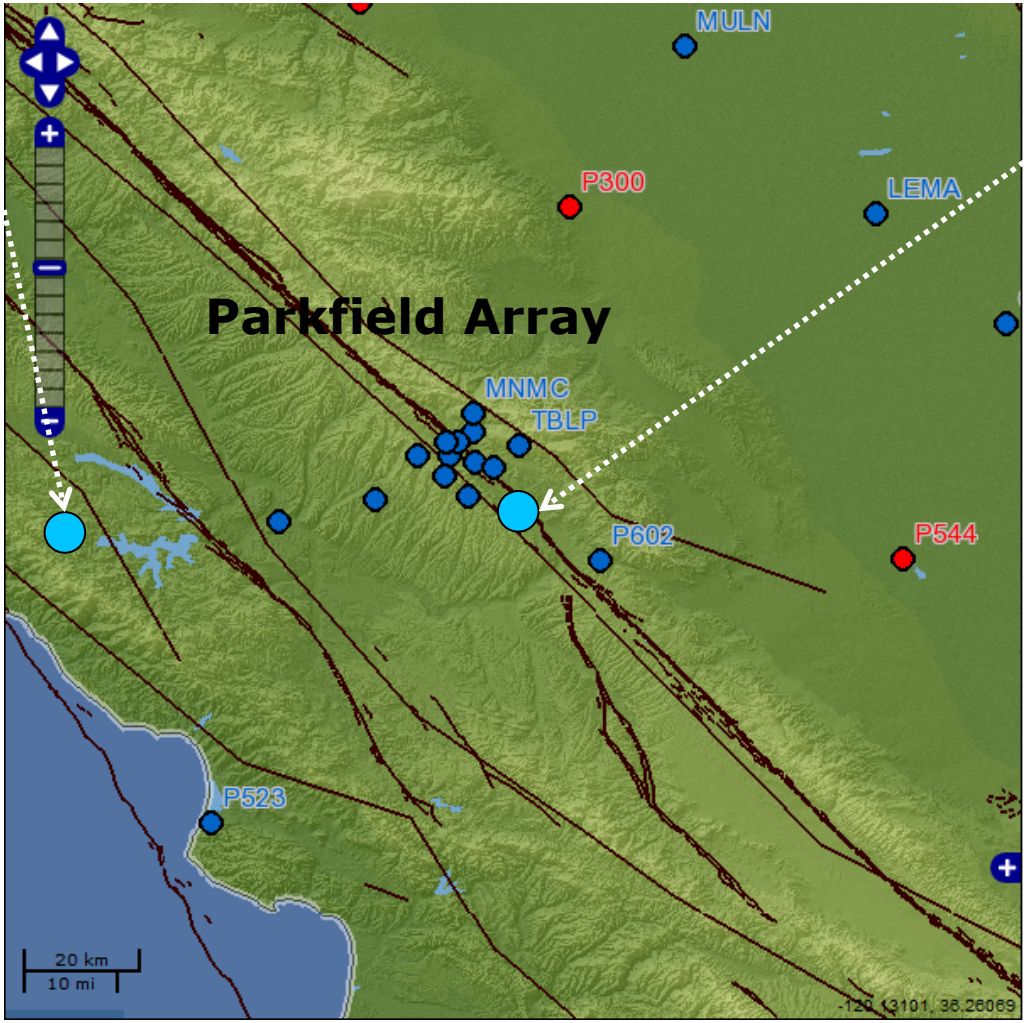


Modeled Coordinate Time Series



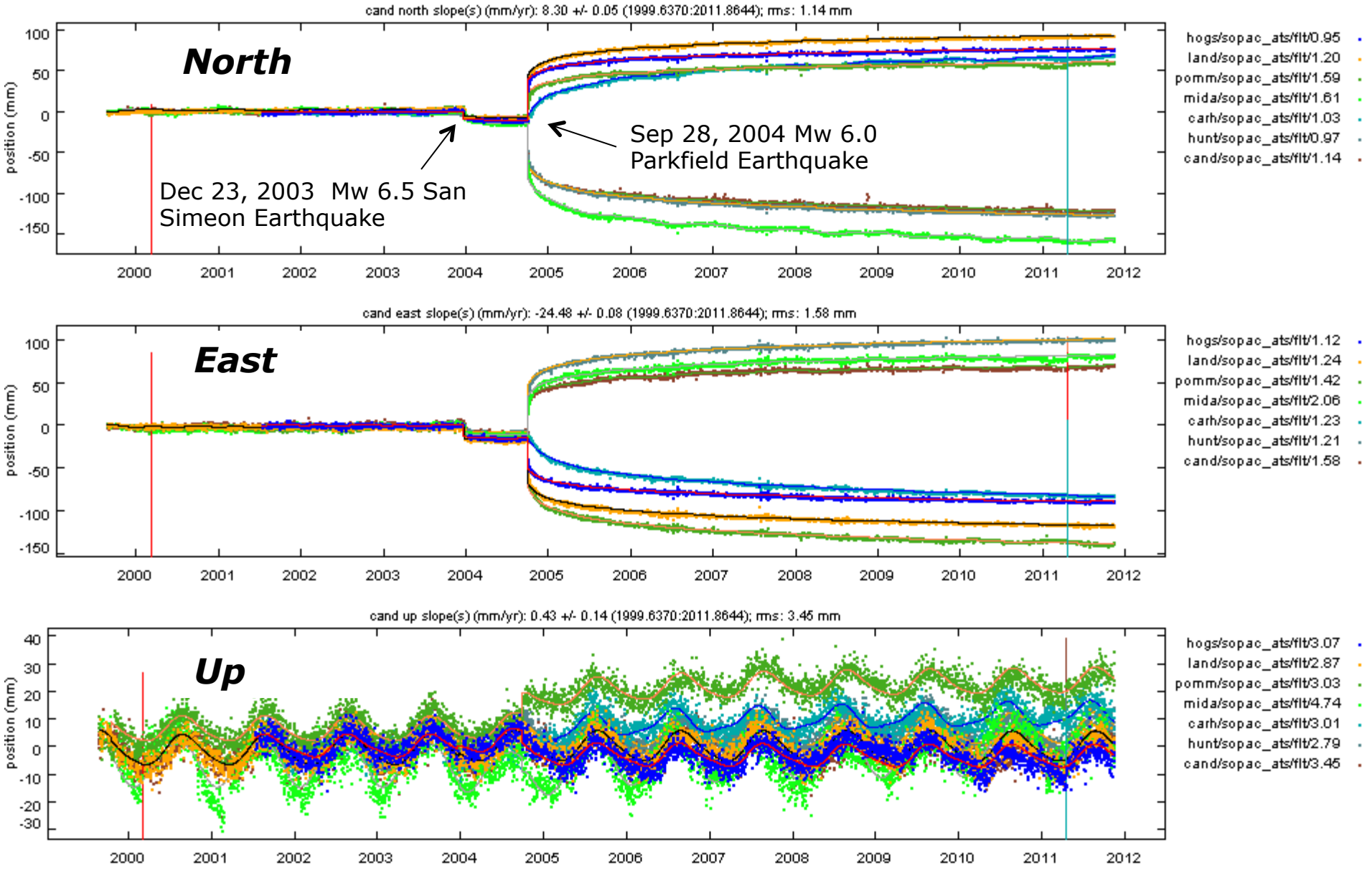
Transient Deformation: Central California

Dec 23, 2003 Mw 6.5 San Simeon Earthquake (23 stations)



Sep 28, 2004 Mw 6.0 Parkfield Earthquake (28 stations)

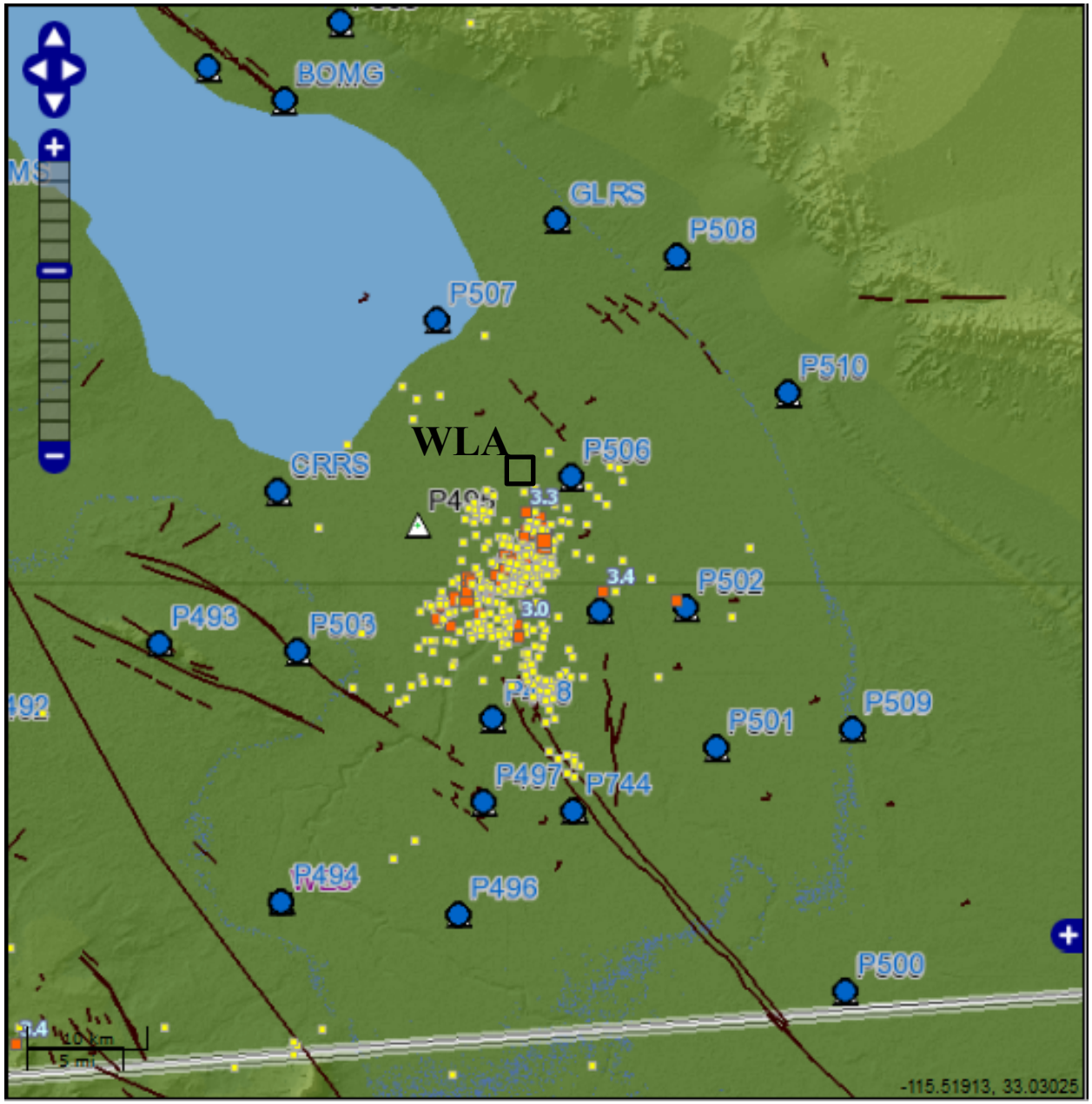
Transient Deformation: Central California



Significant Earthquakes in Western North America (1996-2012)

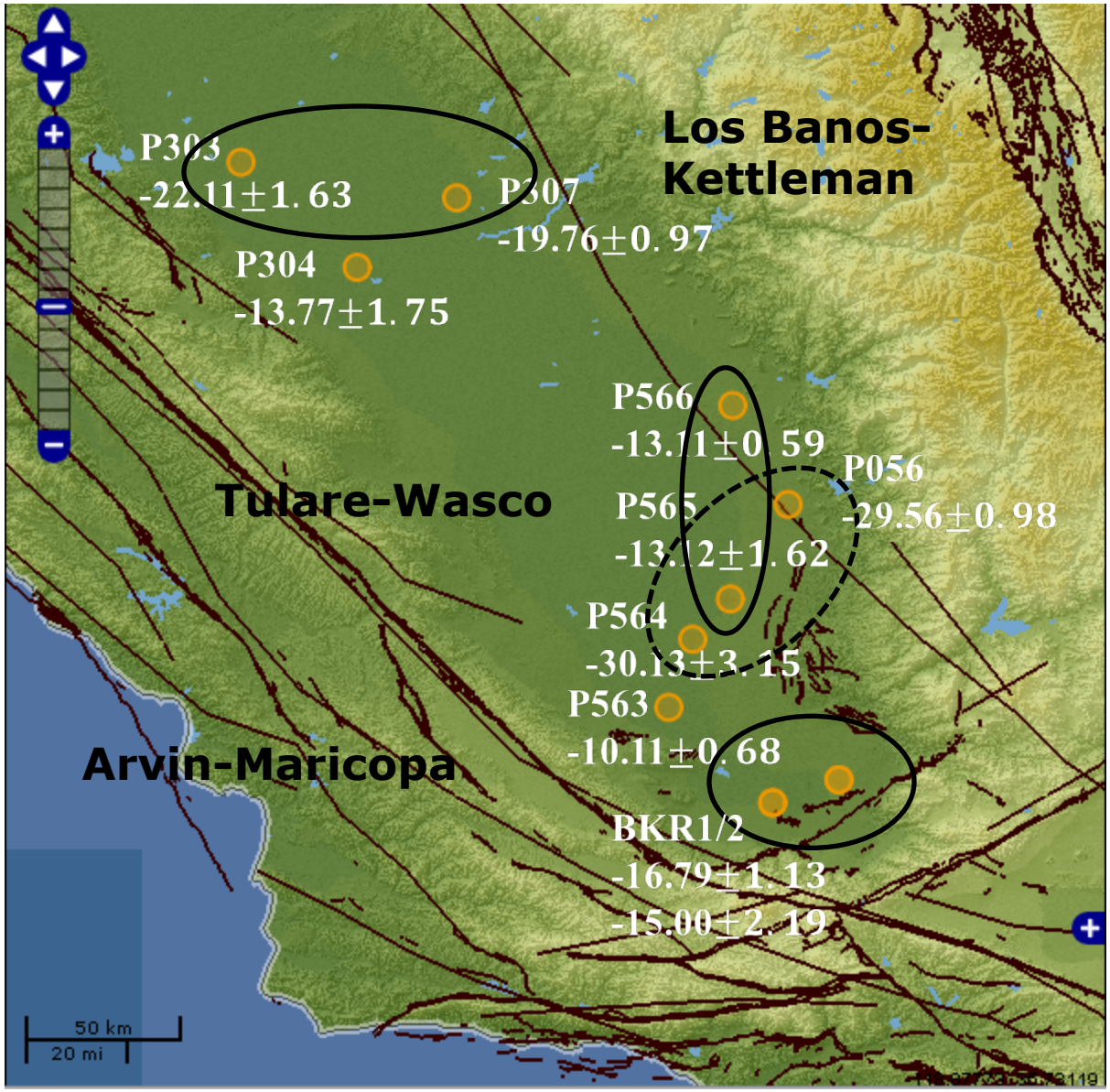
10/16/1999	**Hector Mine, Southern California**	**7.1**	**142**	**exp**	**OPRD: 6 km**	**LAND: 408 km**
2/29/2001	Nisqually Fault, Seattle	6.8	4	exp	RPT1: 30 km	HUSB: 340 km
11/3/2002	Denali, Alaska	7.9	12	exp	GNAA: 136 km	KEN1: 441 km
12/22/2003	**Cambria, San Simeon, Central California**	**6.5**	**23**	**log**	**P278: 4 km**	**ORES: 131 km**
6/28/2004	Queen Charlotte Fault	6.8	4	exp	AC64: 1023 km	AC63: 1139 km
9/28/2004	**Parkfield, Central California**	**6.0**	**28**	**log**	**P281: 4 km**	**CUHS: 115 km**
6/12/2005	Anza, Southern California	5.2	0		AZRY: 8 km	
6/15/2005	**Gorda Plate, CA**	**7.2**	**5**	**exp**	**CME1: 188 km**	**P170: 216 km**
6/16/2005	Yucaipa, Southern California	4.9	0		CRFP: 15 km	
9/2/2005	**Obsidian Buttes Swarm, Salton Trough**	**5.1**	**3**	**exp**	**GLRS: 5 km**	**DHLG: 31 km**
10/3/2006	Superstition Hill Seismic Swarm - silent slip	4.7	0		CRRS: 16 km	
10/31/2007	Alum Rock, San Jose, California	5.6	1	none	MHCB: 7 km	
7/29/2008	Chino Hills, California	5.5	1	none	TWMS: 4 km	
1/10/2010	Eureka Earthquake, Offshore Northern Califor	6.5	11	exp	P159: 45 km	P156: 95 km
2/4/2010	Offshore Northern California, Humboldt Coun	5.9	0		P159: 60 km	
4/4/2010	**El Mayor-Cucapah, Northern Baja California**	**7.2**	**208**	**exp**	**P500: 62 km**	**P567: 485 km**
6/15/2010	**Aftershock, El Mayor-Cucapah**	**5.7**	**7**	**exp**	**P481: 16 km**	**P496: 31 km**
7/7/2010	**Borrego Springs, Southern California**	**5.4**	**3**	**exp**	**P490: 13 km**	**P742, P484: 14 k**
8/26/2012	**Brawley Swarm, Imperial Valley**	**5.3, 5.4**	**2**	**none**	**P506: 8 km**	**P498, P499**

Brawley Earthquake Swarm (August 26, 2012)



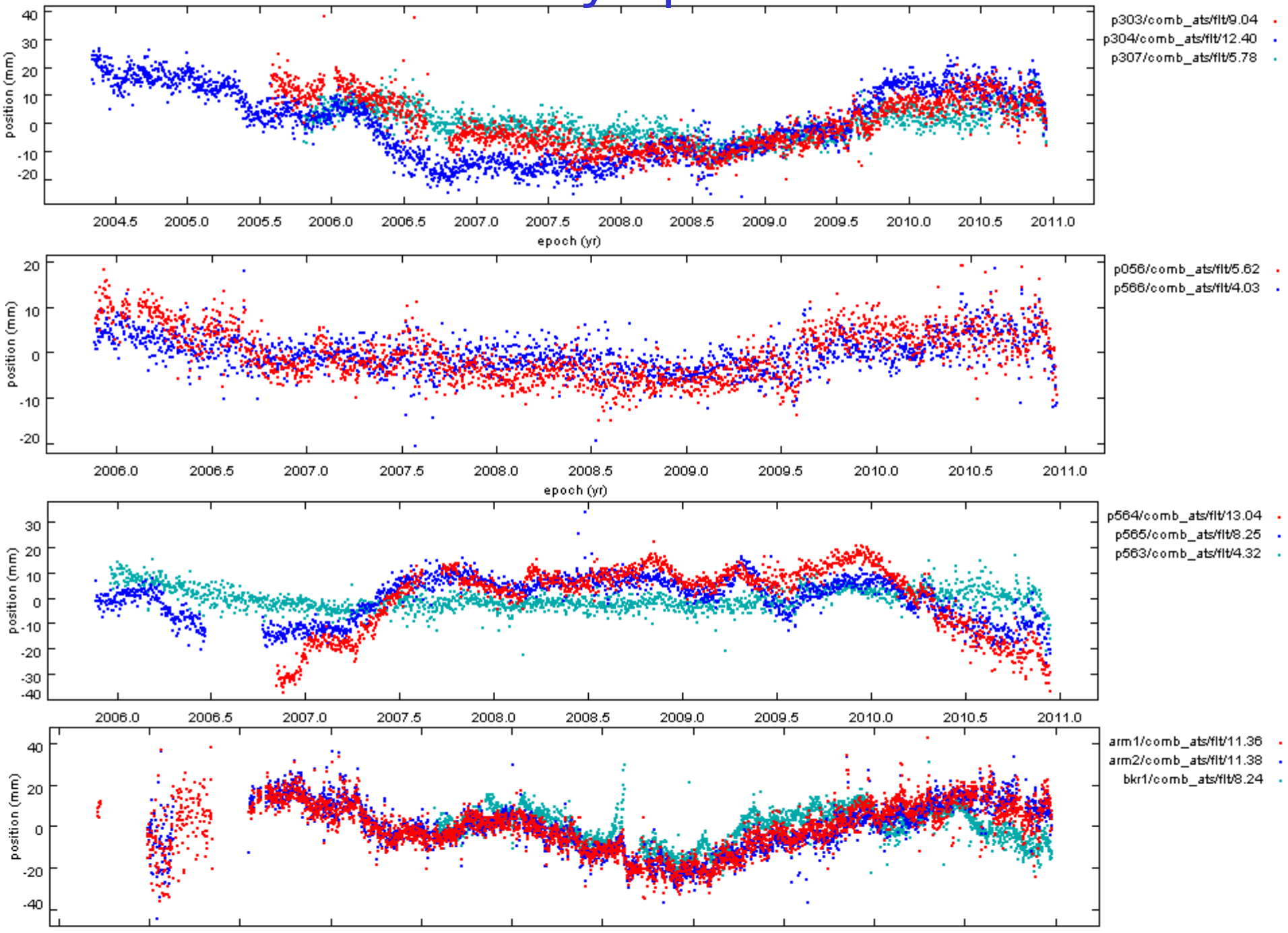
- **Hundreds of earthquakes over a 24-hour period, largest Mw 5.3 and 5.4**
- **PBO and SCIGN real-time GPS stations in the vicinity operated during event**

Non-Tectonic Effects
Subsidence in the Central Valley

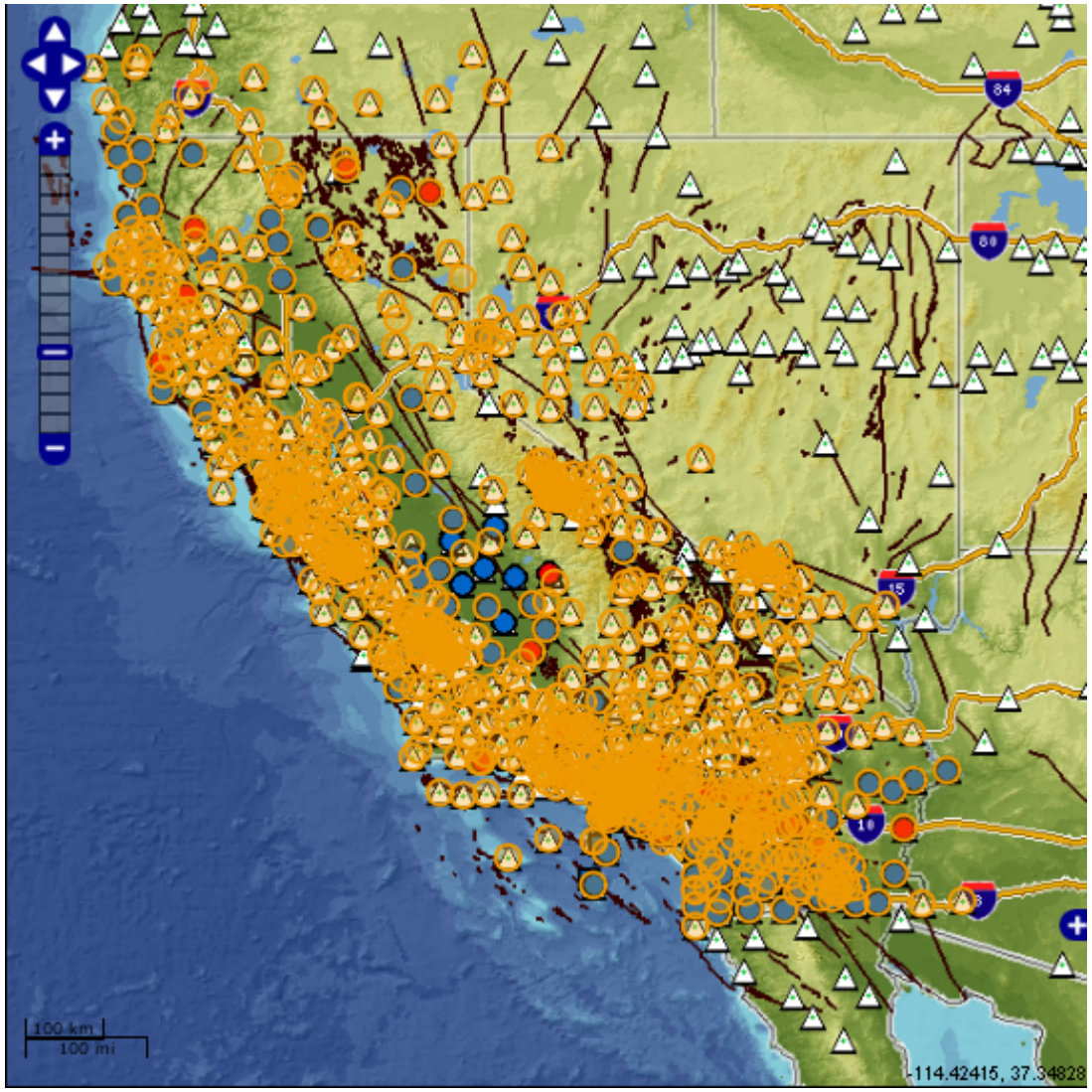


Significant subsidence, but also transient changes in horizontal coordinates complicate the datum problem

Central Valley: Up Residuals



CSRS Coordinate Epoch (2011.00)



- **830 CGPS stations (766@epoch 2009.00; 551@epoch 2007.00) – includes observations until 2011.2918**
- **ITRF2005 coordinates & velocities**
- **NAD83(NSRS2007) coordinates & velocities**
- **Includes uncertainties to comply with California Public Resources Codes**
- **Coseismic and postseismic deformation model from Mw 7.2 El Mayor Cucapah earthquake in northern Baja California**

http://csrc.ucsd.edu/input/csrc/csrsEpoch2011.00.xls

SECTOR Epoch-Date Coordinates (Rollout of New Version in October)

SECTOR: Scripps Epoch Coordinate Tool and Online Resource

Results: Coordinates for reference epoch 2012.6571

Use the links for site information, maps, time series plots and model terms.

(*): Plots and terms are shown in WGS84 geodetic datum, converted from ITRF2005.

Time series problems? Try: Non-applet plots , or download the Sun Java plug-in (and restart your browser)

Site	X (m)	Y (m)	Z (m)	Latitude (deg.)	Longitude (deg.)	Height (m)	Time Series (*)	Model Terms (*)
	ITRF2005			WGS84 / NAD83				
p472 (map)	-2442691.6274 +/- 0.0013	-4772473.2977 +/- 0.0018	3443722.2301 +/- 0.0013	32.88920937 +/- 0.0007 NAD83: 32.88920617	-117.10469648 +/- 0.0011 NAD83: -117.10468243	137.8465 +/- 0.0022 NAD83: 138.5943	view	terms
sio5 (map)	-2456115.2737 +/- 0.0014	-4768905.6658 +/- 0.0021	3439232.5057 +/- 0.0016	32.84073518 +/- 0.0008 NAD83: 32.84073200	-117.24969102 +/- 0.0011 NAD83: -117.24967695	185.5309 +/- 0.0027 NAD83: 186.2759	view	terms
ucsb (map)	-2621293.4604 +/- 0.0022	-4568930.8557 +/- 0.0033	3584356.8382 +/- 0.0029	34.41330690 +/- 0.0019 NAD83: 34.41330382	-119.84381630 +/- 0.0015 NAD83: -119.84380162	-9.6027 +/- 0.0043 NAD83: -8.9559	view	terms

Get Epoch-Specific Coordinates:

[option: reload site code list on next line using only sites in array:] ALL | Reload Site List | array maps

Select site code: NONE | Enter space-separated sites: sio5 p472 uc: [choose *one* site option]

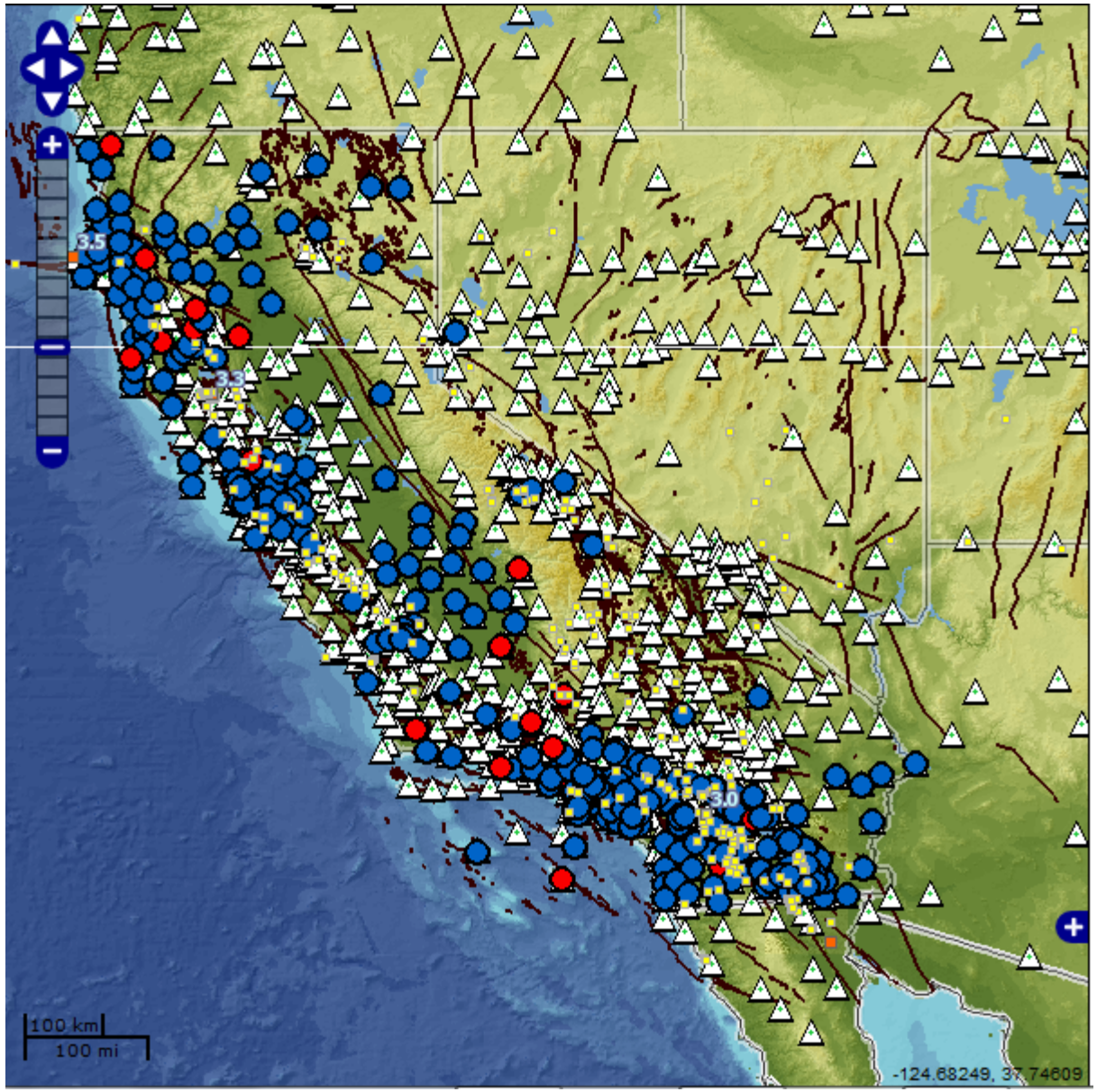
Select year: 2012 | Enter day-of-year: 241 | Select decimal year: NONE (e.g,. 2008.0000) [choose *one* date option]

Select additional datums: NAD83 | Reference frame : ITRF2005

Degrees type : Decimal / Deg/Min/Sec | Output format type : HTML / CSV | Get Coordinates

http://sopac.ucsd.edu/processing/coordinates/

California Real Time GPS Network (CRTN)

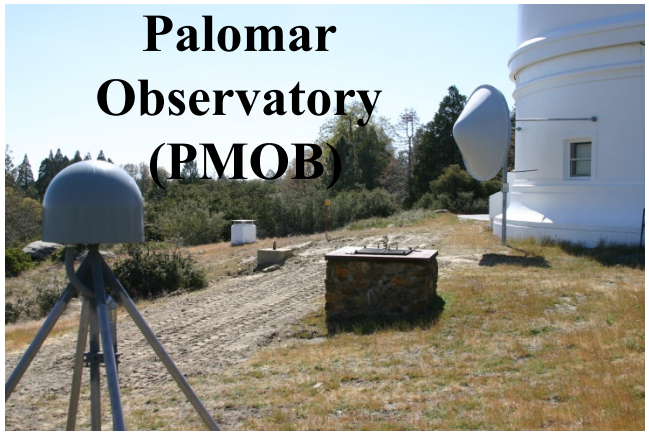


CRTN is a multipurpose statewide real-time network that utilizes the existing geophysical CGPS infrastructure in California. Started in 2003, 1 Hz RTCM 3.0 data are available from ~300 stations from 2 CRTN servers (SC & NC) at SIO with a latency of ~0.4 s. Data are directly collected from SCIGN/ PBO stations via UCSD's HPWREN, and from servers at UNAVCO/PBO, USGS Pasadena, UC Berkeley, Caltrans, Orange County, and Metropolitan Water District.

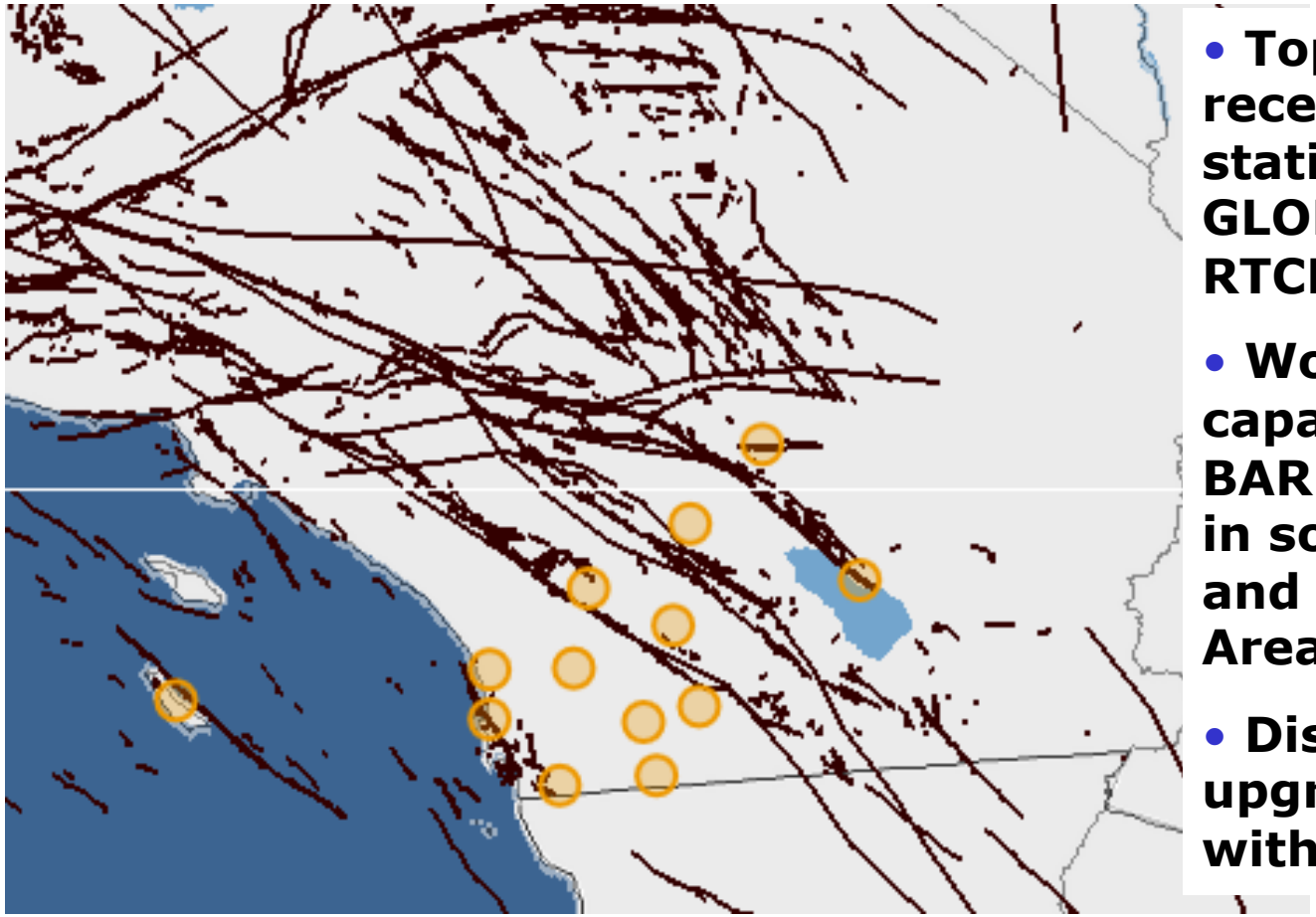
Typical CRTN Site Infrastructure

banner

Banner Communications Hub



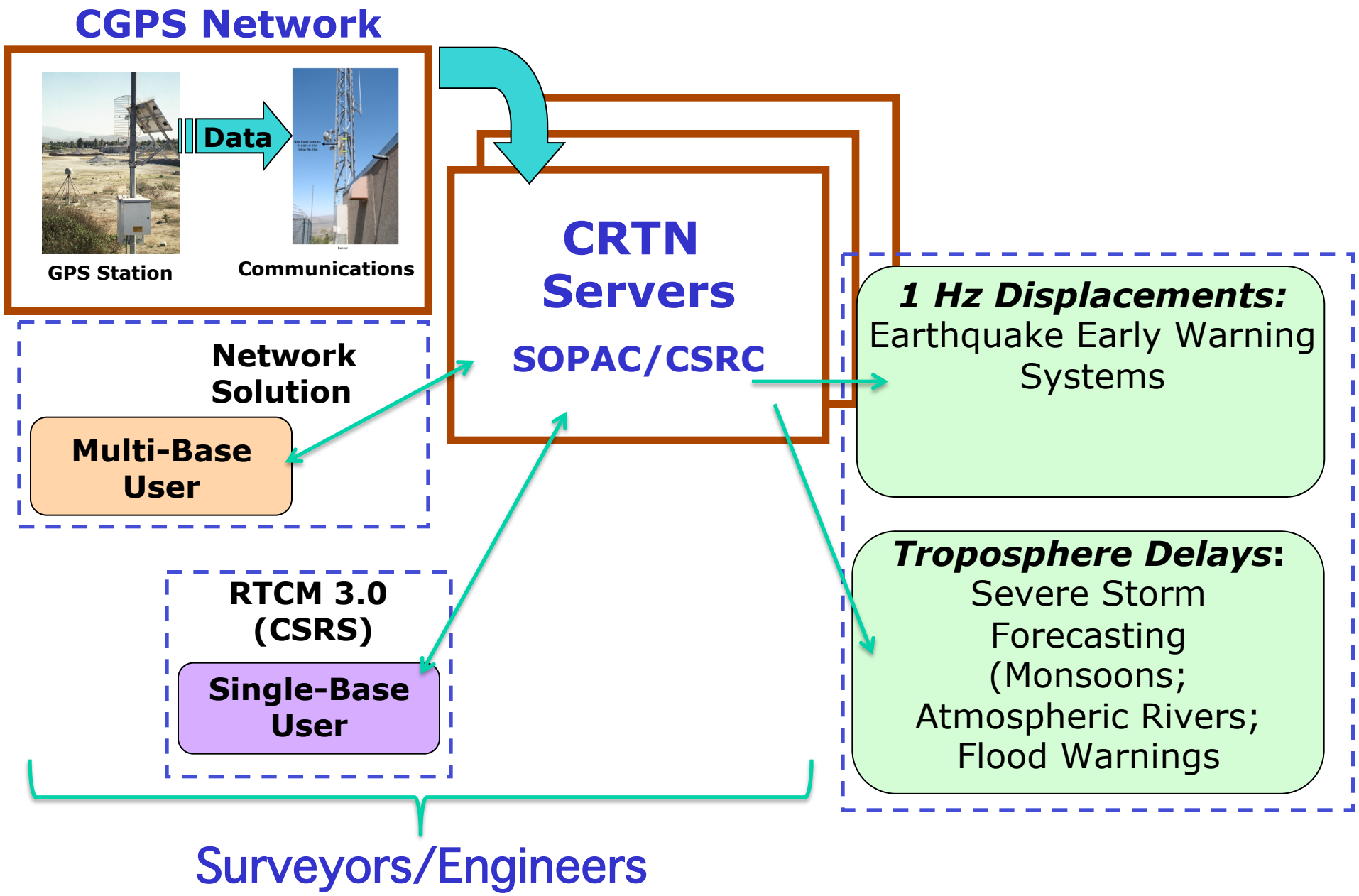
Current GNSS Capability



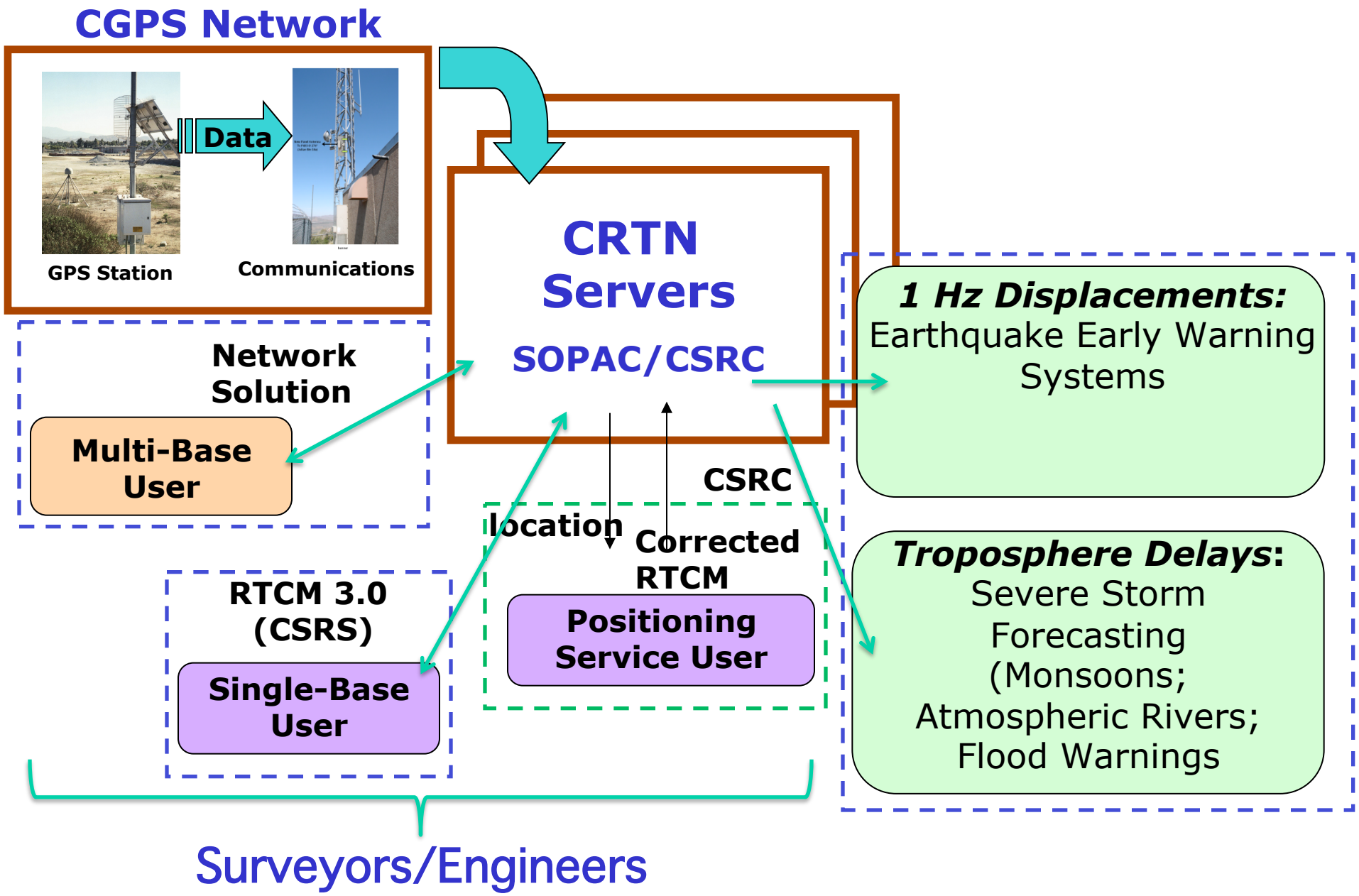
- **Topcon NET-G3A receivers at 15 CRTN stations now stream GLONASS data in their RTCM messages**
- **Working on extending capability to USGS and BARD Topcon receivers, in southern California and the greater SF Bay Area**
- **Discussions on upgrading PBO stations with GNSS receivers**

Stations upgraded: DESC, DHLG,KYVW,MONP, MVFD, NSSS, PIN1, PIN2, PMOB, POTR, RAAP, SCIP, SIO5

Applications & Features of CRTN



Applications & Features of CRTN



CRTN – Single Base User

- March 1, 2012 – real-time data availability transitioned to NTRIP protocol
- An NTRIP account (username & password) is required, and requested by emailing the CSRC director (ybock@ucsd.edu)
- As of today, 104 companies/agencies registered – 8 multi-account (CRTN Consortium) users
- CRTN Web Page: http://sopac.ucsd.edu/projects/realtime/CRTN/
- CRTN Access File:

http://sopac.ucsd.edu/input/realtime/CRTN_Access.xls

CRTN – NTRIP

Northern California
IP: 132.239.154.101
Port: 2103

Southern California
IP: 132.239.152.72
Port: 2103

RTCM 3.0

Mountpoints: "SITE_ RTCM3"
SITE=4-character code

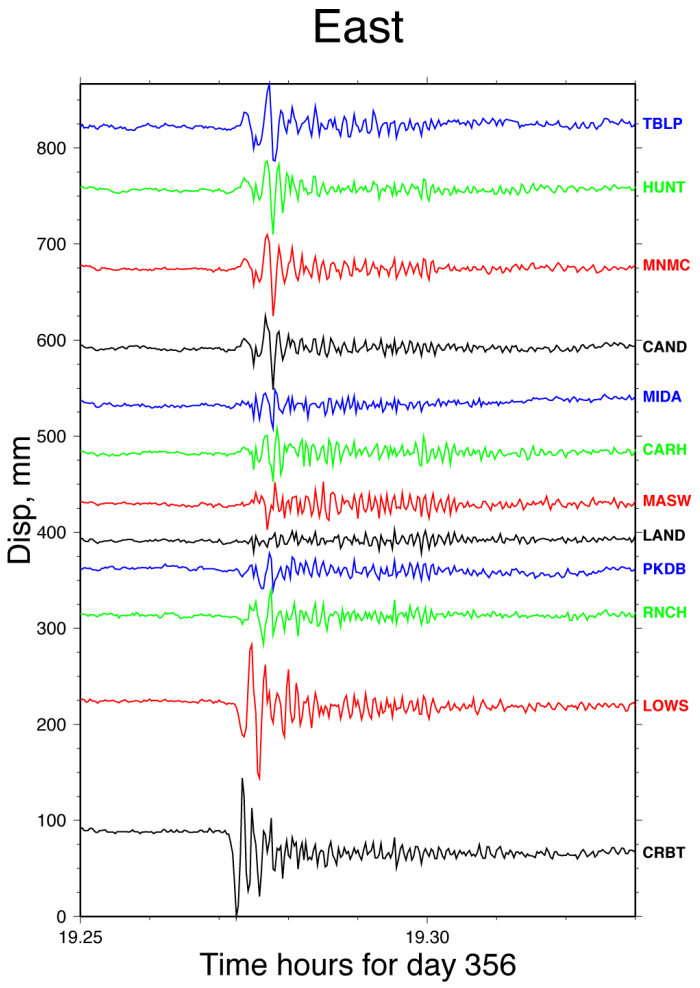
CSRC 2011.00 Epoch NAD83 (NSRS2007) Coordinates

Orange Circles:
16km (10 mile) Radius

CRTN as a Test Bed for Early Warning Systems for Natural Hazards

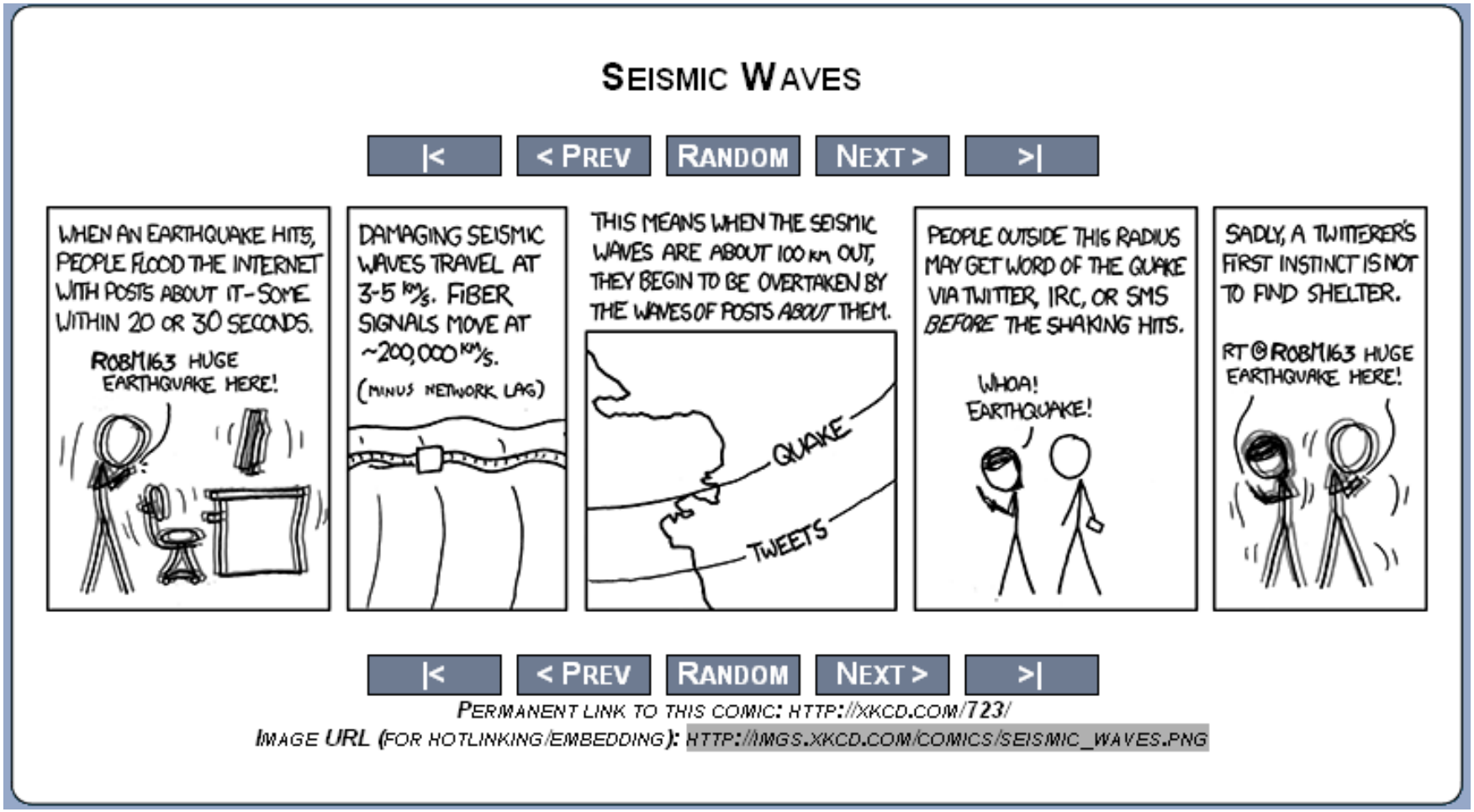
- **GPS seismology**
- **Tsunami warning**
- **Severe storm and flooding forecasts**
- **Structural monitoring**
- **Volcano monitoring**

LA freeway after 1994 Northridge earthquake



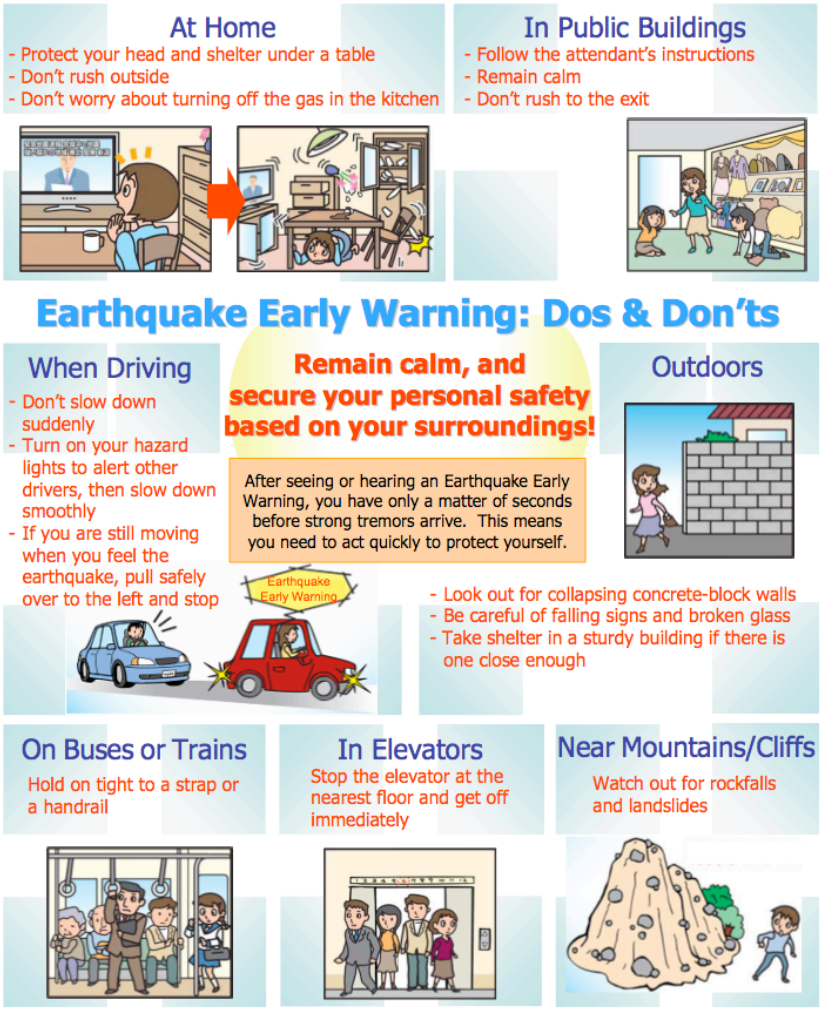
Displacement waveforms, 2004 Parkfield event

Popular Description of Earthquake Early Warning



Radio waves are faster than seismic waves
P (primary) wave carries information - compressional
S (secondary) wave carries energy – shearing, shaking
(Hiroo Kanamori)

Uses of Earthquake Early Warning



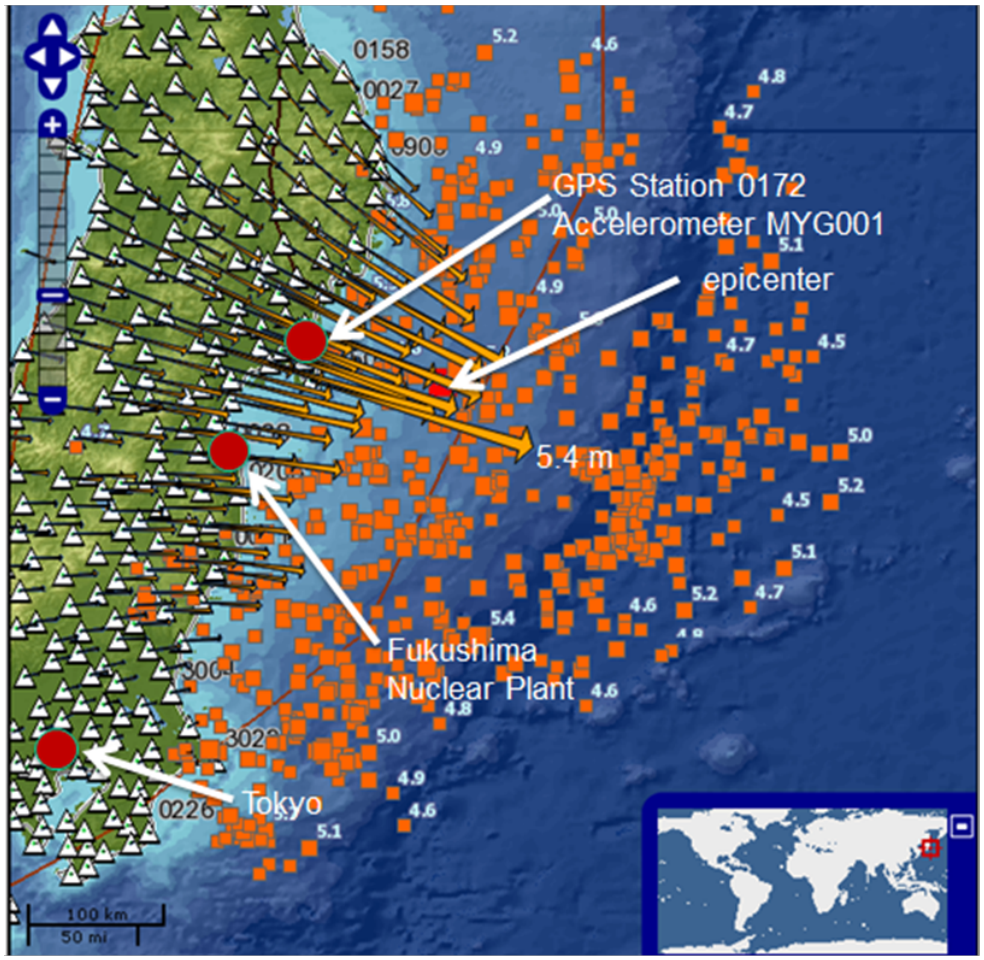
Public service guidelines for earthquake early warning in Japan

Some targets of early warning:

- emergency service providers
- transportation (public & private)
- power plants – **nuclear**
- gas supplies
- factories
- schools
- hospitals
- shopping malls
- police
- structures (dams, bridges)
- public (see graphic to the left)

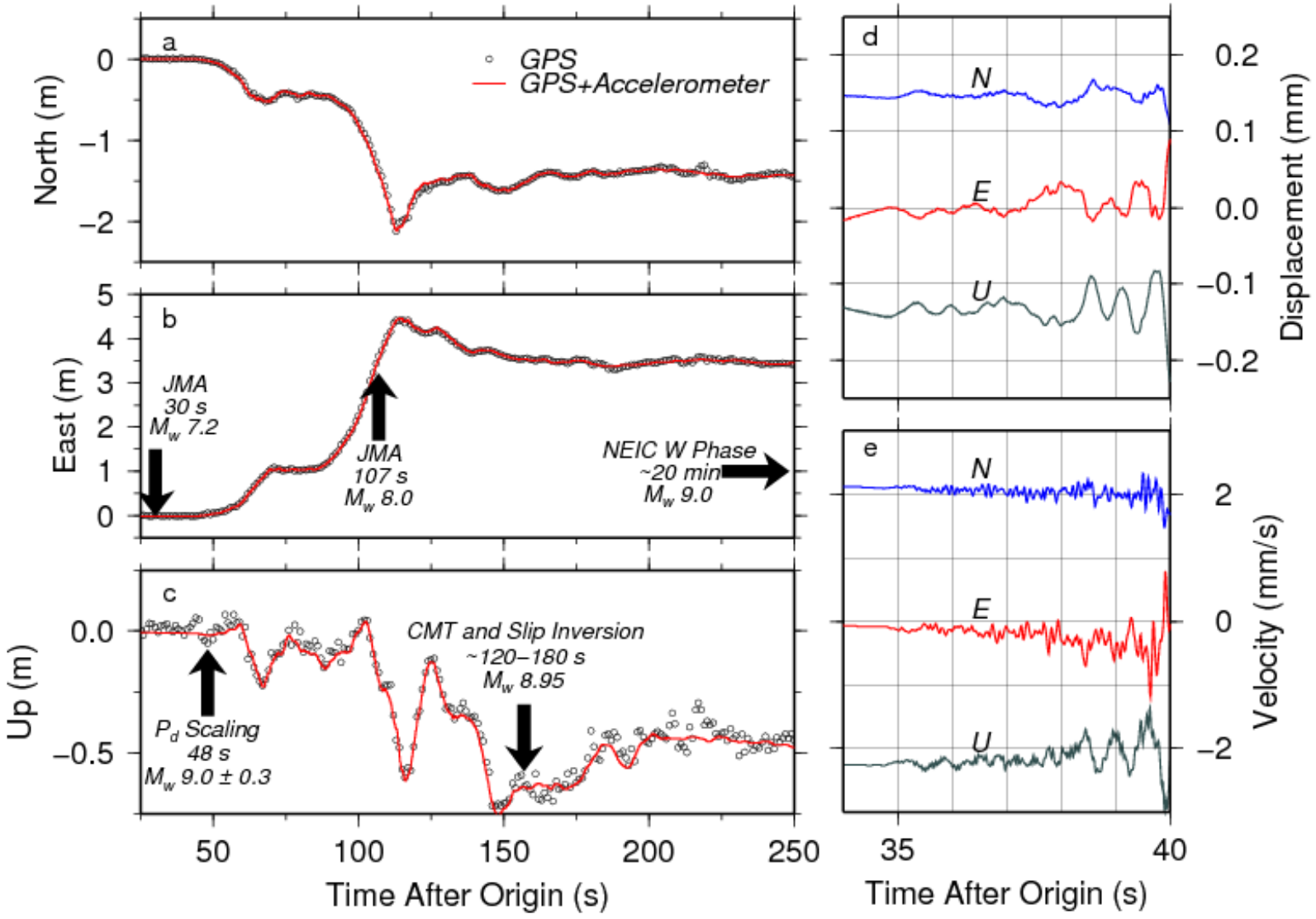
Of course, this requires interfacing properly with first responders and development of automatic procedures and rapid response guidelines.

March 11, 2011 Mw 9.0 Tohoku-oki Earthquake



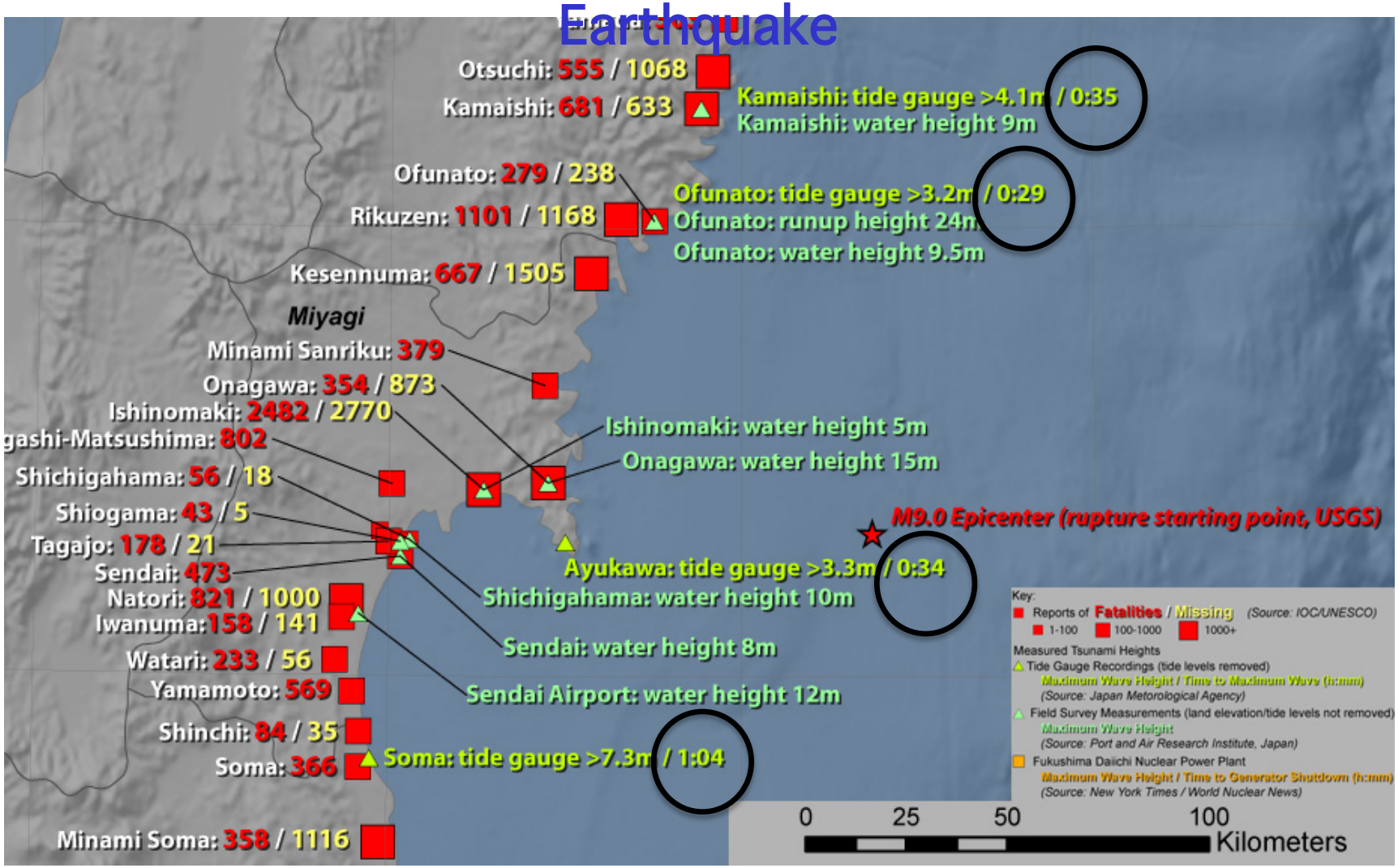
- **Coseismic displacements in the epicentral region computed from Japan's 1200+ station CGPS Network (GEONET) by ARIA group at Caltech/JPL (Susan Owen, PI).**
- **Processed ~ 870 1 Hz GEONET stations in simulated real-time mode using instantaneous positioning, 1538 triangles.**
- **We identified 142 "collocated" NIED stations with triggered 100 Hz KiK-net and K-Net accelerometer data (e.g., 0172/MYG001) & estimated displacements using Kalman filter**

Displacements at a Nearby Coastal Station: Tohoku-oki & Rapid Modeling of the Earthquake



Movie here

Tsunami Travel Times for 2011 Tohoku-oki Earthquake



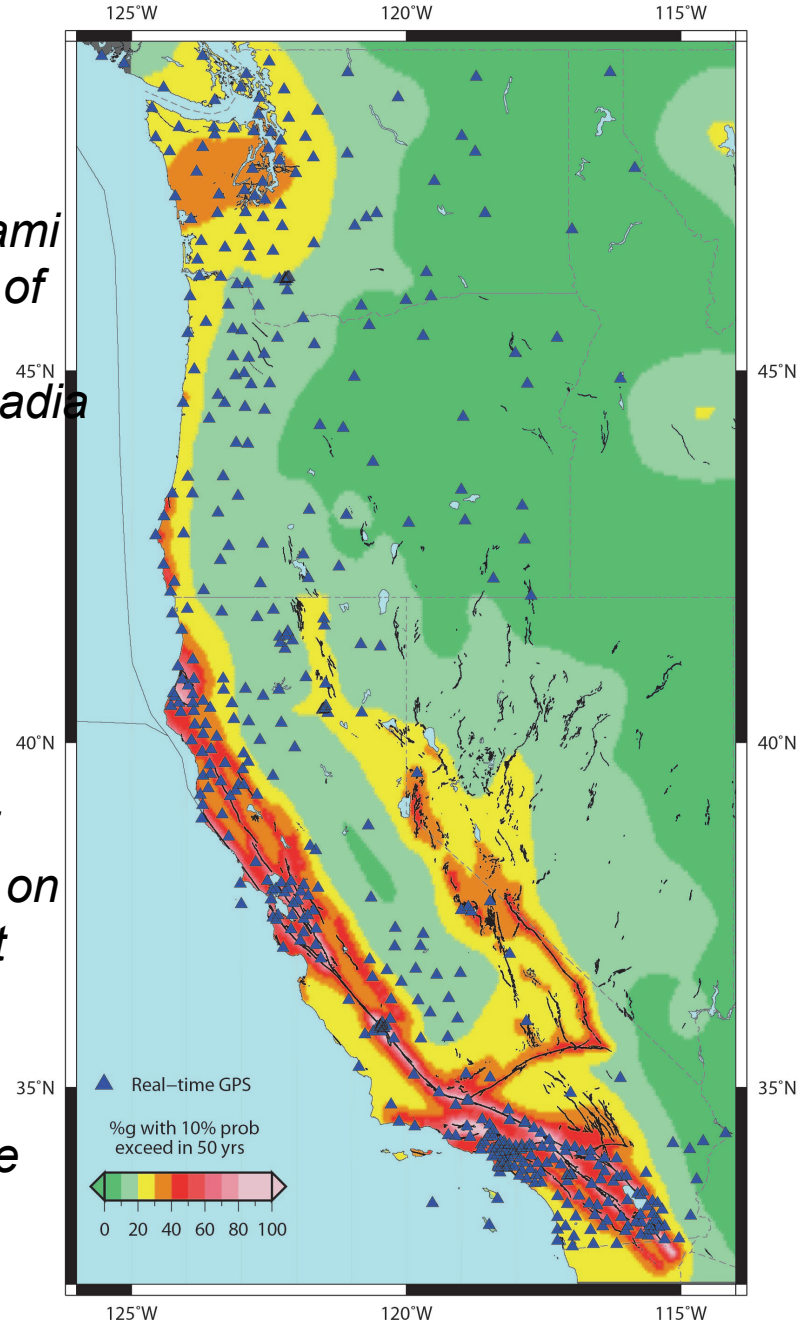
Rapid modeling of large subduction zone earthquakes is critical for accurate tsunami warnings

Earthquake Hazards for the West Coast

Earthquake/tsunami of the magnitude of Tohoku-oki is possible on Cascadia Subduction Zone

Increasing risk of large earthquake on the Hayward fault

Overdue large earthquake on the southern San Andreas fault

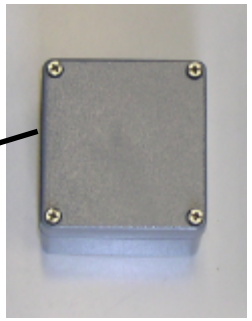


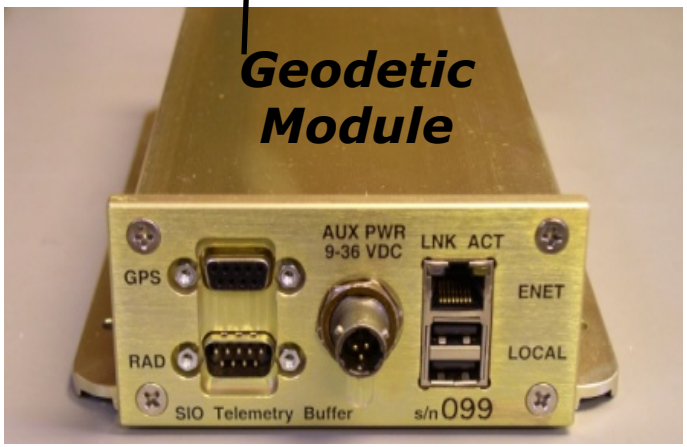
500+ stations of the real-time continuous GPS stations comprising the READI network. The network stations are overlain on a USGS seismic hazard map showing areas forecast to have a 10-percent probability of exceeding a certain level of ground shaking within the next 50 years. Areas in shades of red have the strongest shaking, while areas in green shades have the weakest shaking.

CRTN Station Upgrades

Met Module

MEMS Accelerometer Module



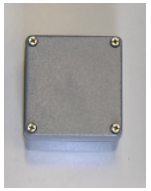


Geodetic Module

New Observations

GPS/GNSS

+



MEMS Accelerometer Module

=

Very-high-rate (1-100 Hz) broadband <u>displacements</u> with 1-2 s latency and mm accuracy in three dimensions

+

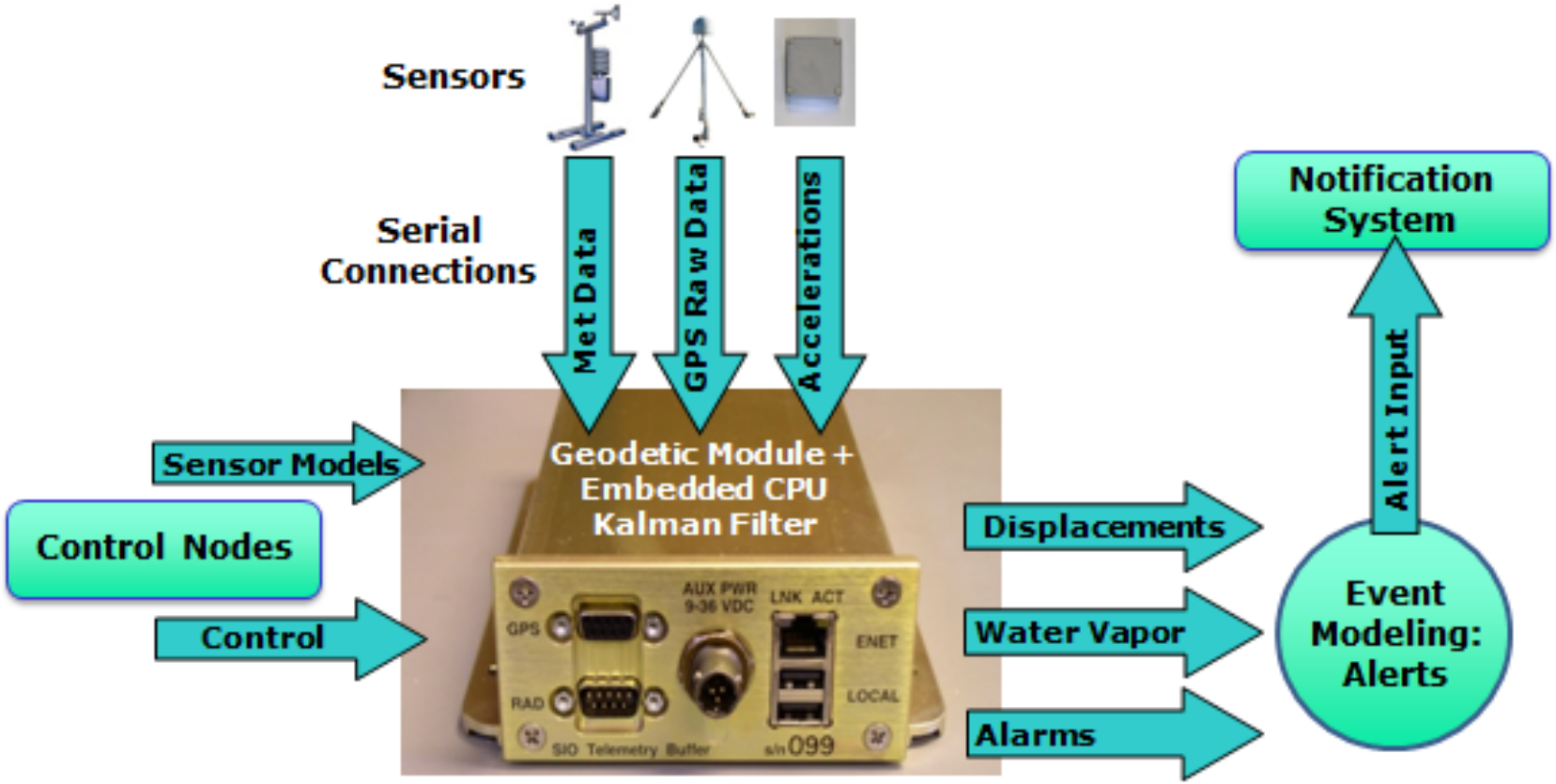
MEMS Met Sensors (pressure, temperature)

=

Continuous mm-level <u>precipitable water</u>

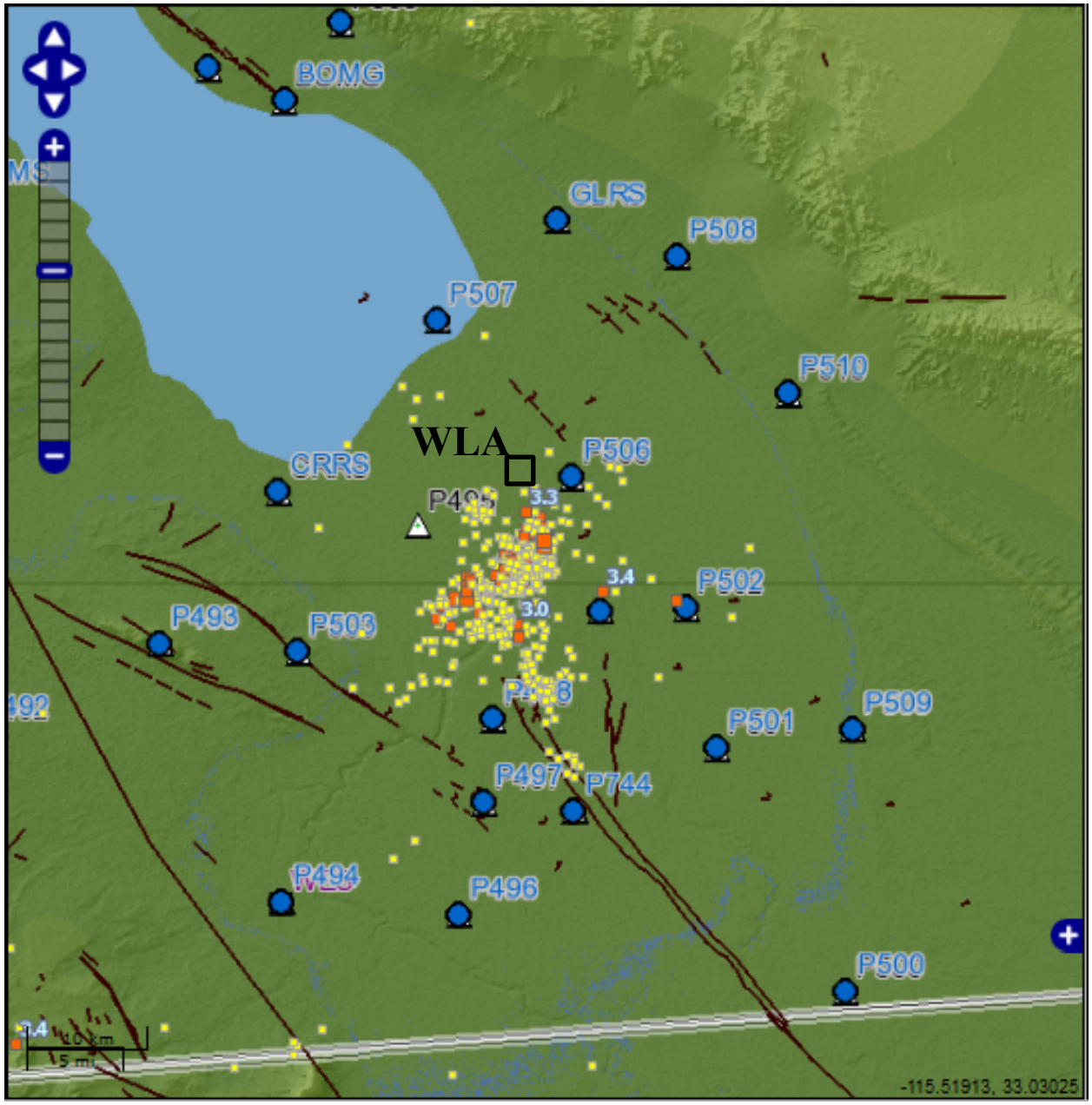
(integrated water vapor in troposphere)

Elements of Early Warning System Being Developed under NASA Funding



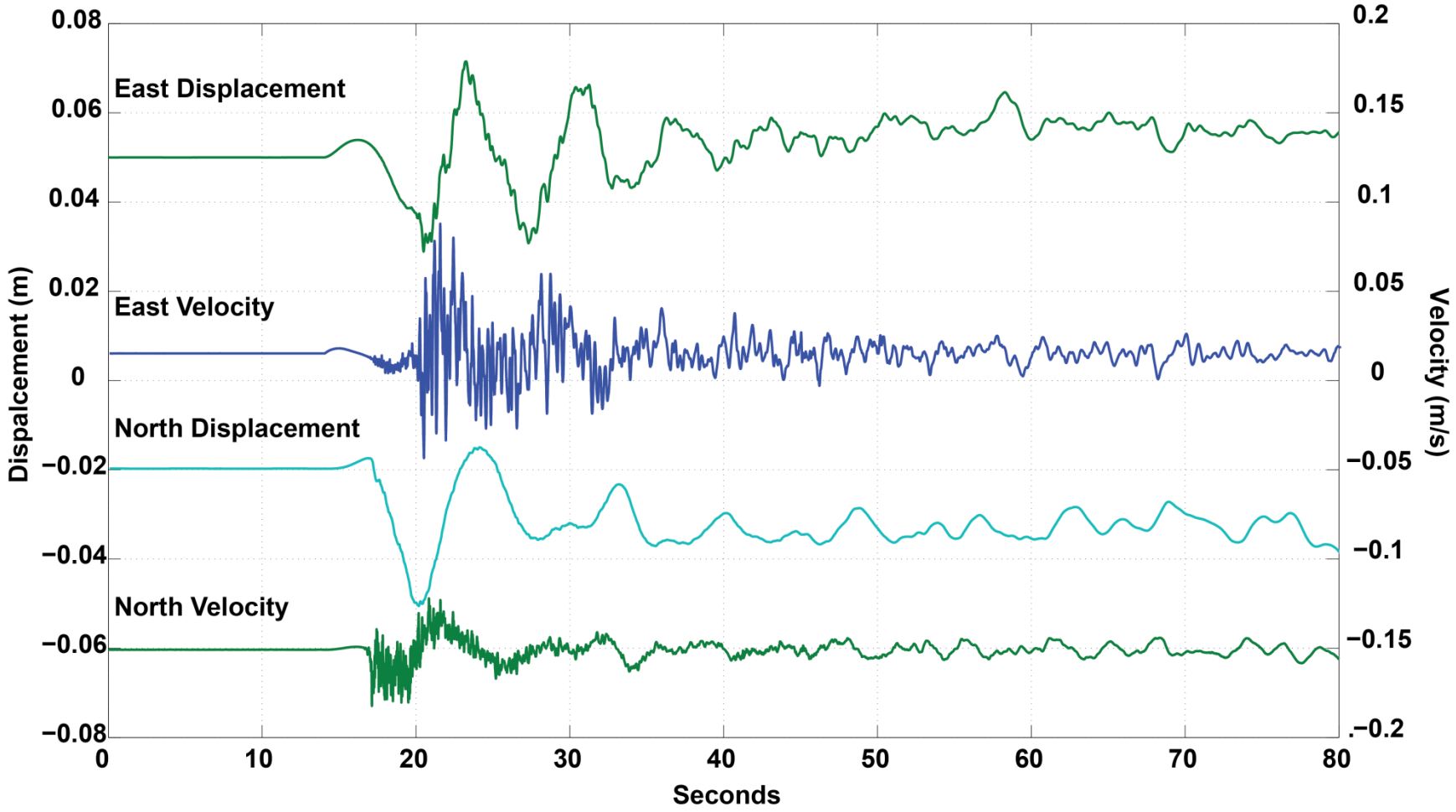
Precise Point Positioning Client

2012 Brawley Seismic Swarm



- **PBO and SCIGN real-time GPS stations in the vicinity of Brawley Swarm of August 26, 2012, operated at 1 Hz during event**
- **WLA (Wildlife Liquefaction Array) is accelerometer run by Jamie Steidl (UCSB), continuously at 200 Hz, ~ 5 km from P506**

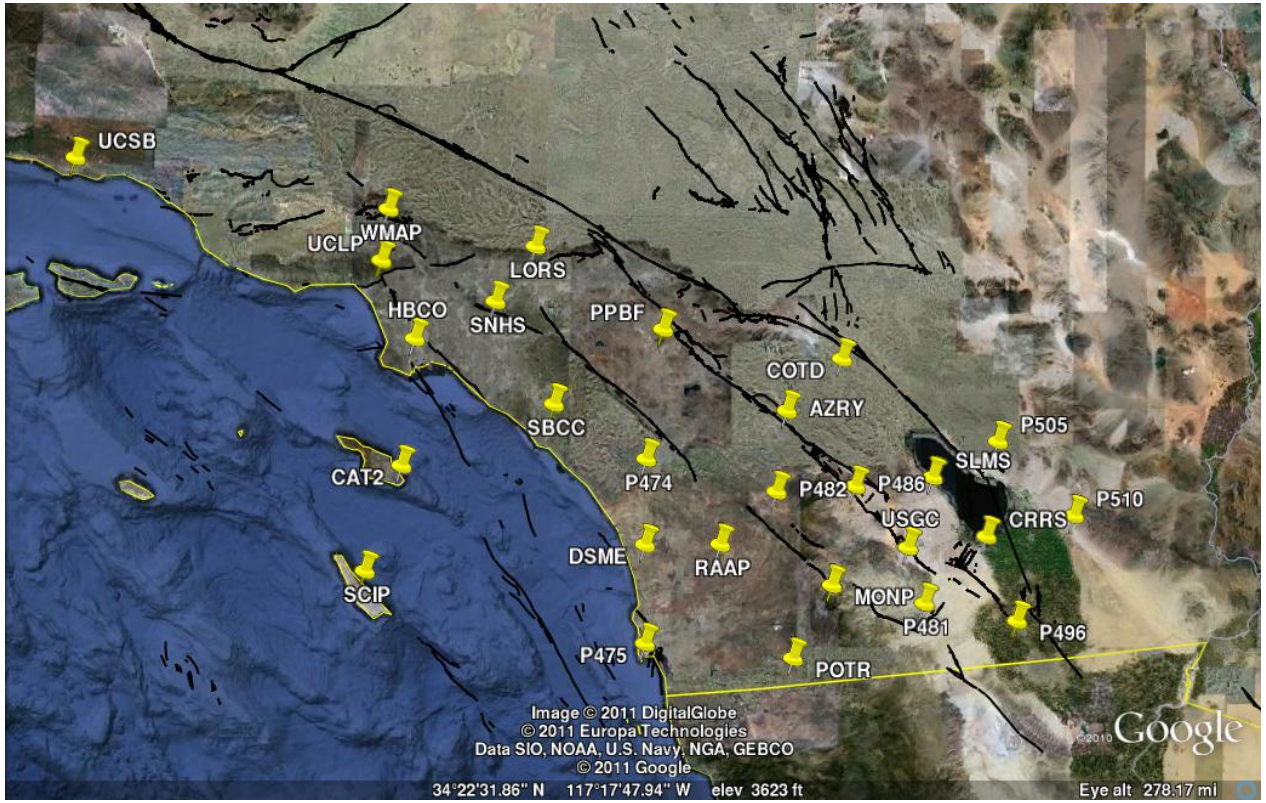
Horizontal Displacement & Velocity Waveforms (200 Hz) from Kalman Filtered GPS P506 (1Hz) & Accelerometer WLA (200Hz) Brawley Swarm (M=5.4, 20:57 UTC, 8/26/2012) Showing Dynamic Motion and Coseismic Offsets



Uses methodology of Bock et al., 2011, BSSA

Waveforms from D. Melgar, B., J. Geng, J. Steidl, B. Crowell, Y. Bock

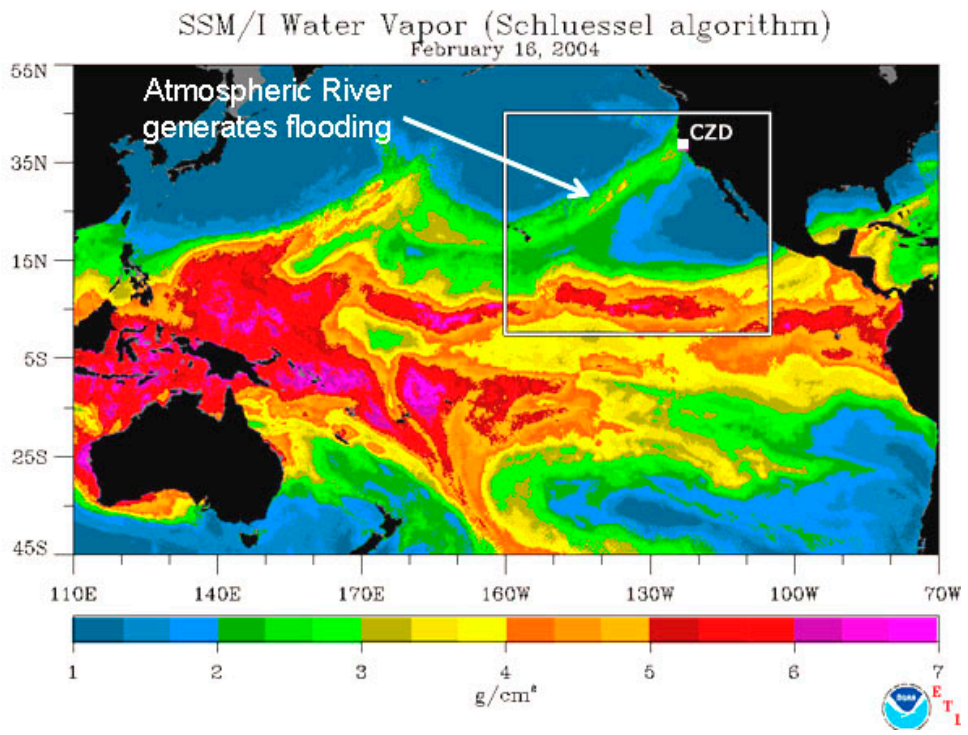
GPS Meteorology Network

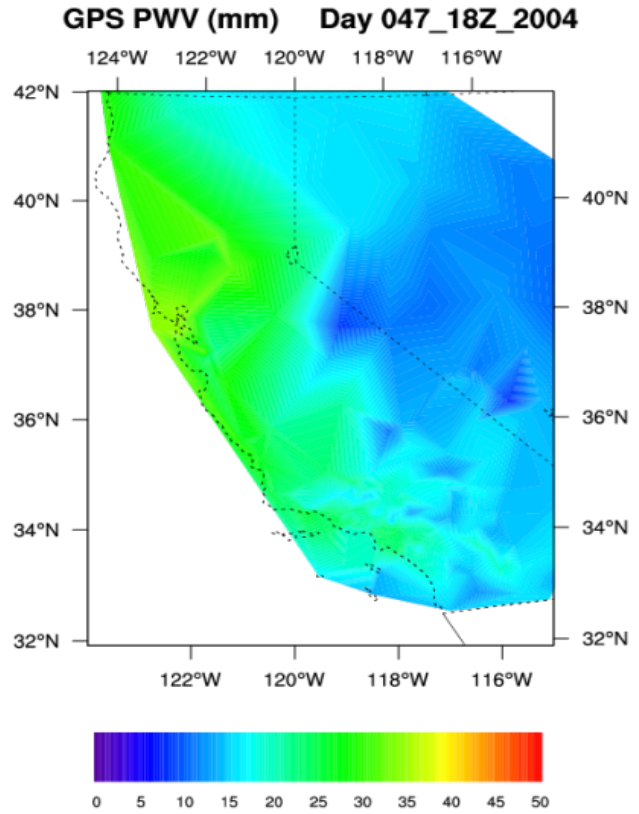


Adding Geodetic modules and meteorological sensor module to existing GPS stations

Monitoring network in collaboration with NOAA and U.S. Weather Service Offices in San Diego and Los Angeles (Oxnard), funded by NASA (4-year project)

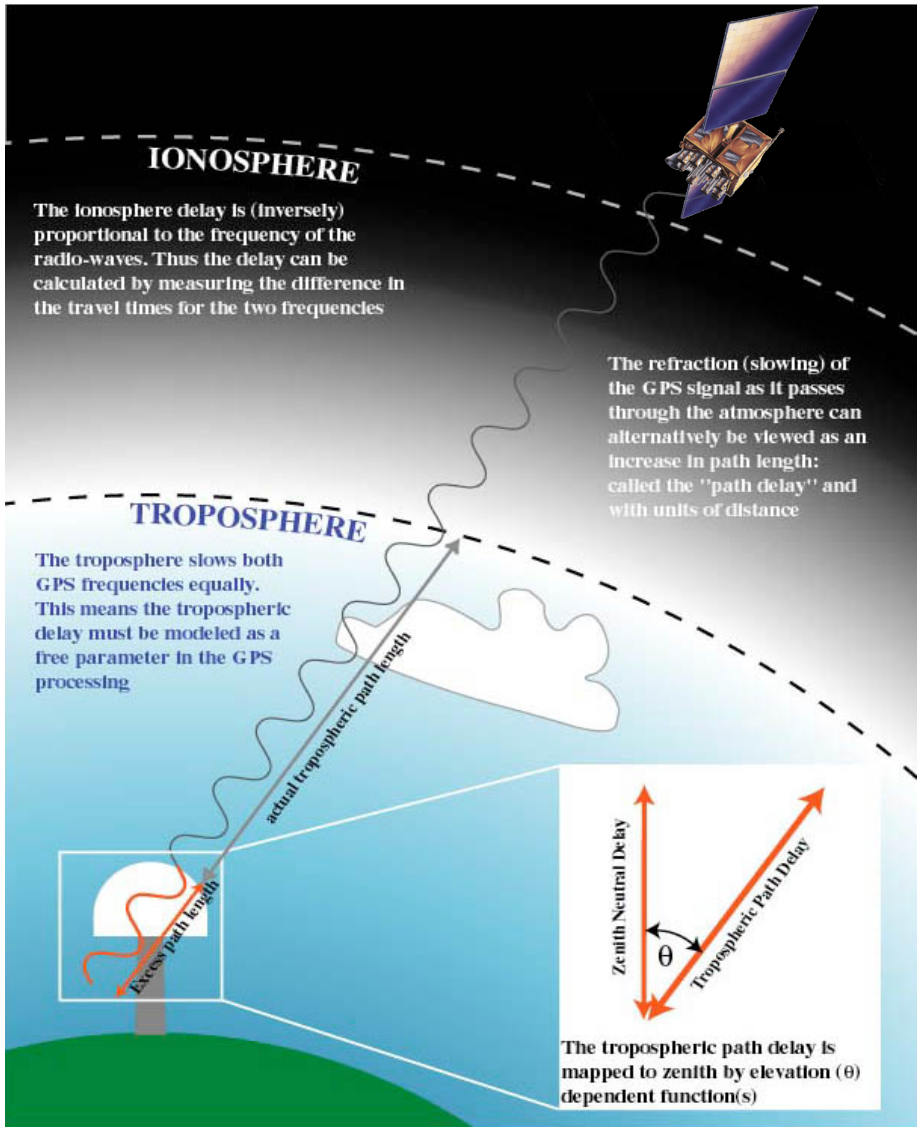
Monitoring Extreme Weather: Atmospheric Rivers





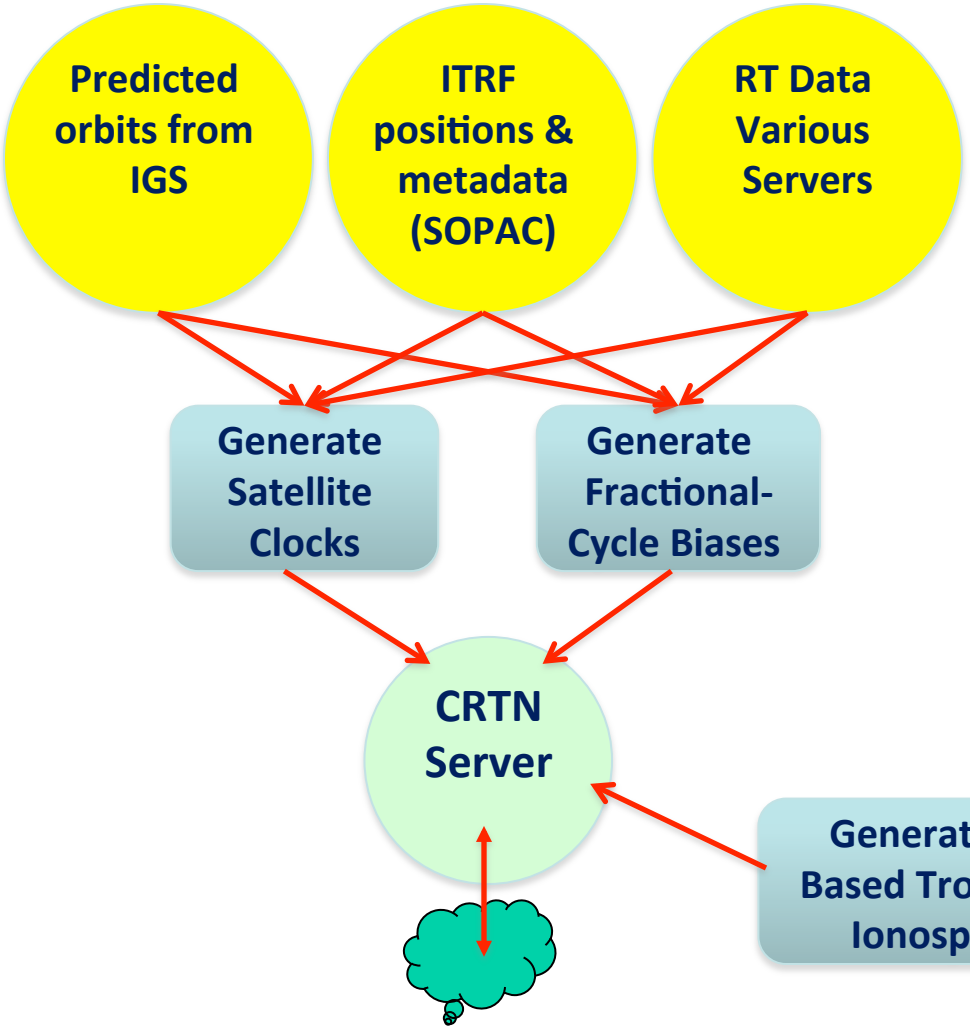
Real-time GPS-derived precipitable water fills a critical gap in forecasting the development of extreme weather events. The plot on left is an SSM/I precipitable water image that shows an atmospheric river connecting the tropics to the California coastline. The plot on the right shows an enhanced area of PW on the GPS image for approximately the same time.

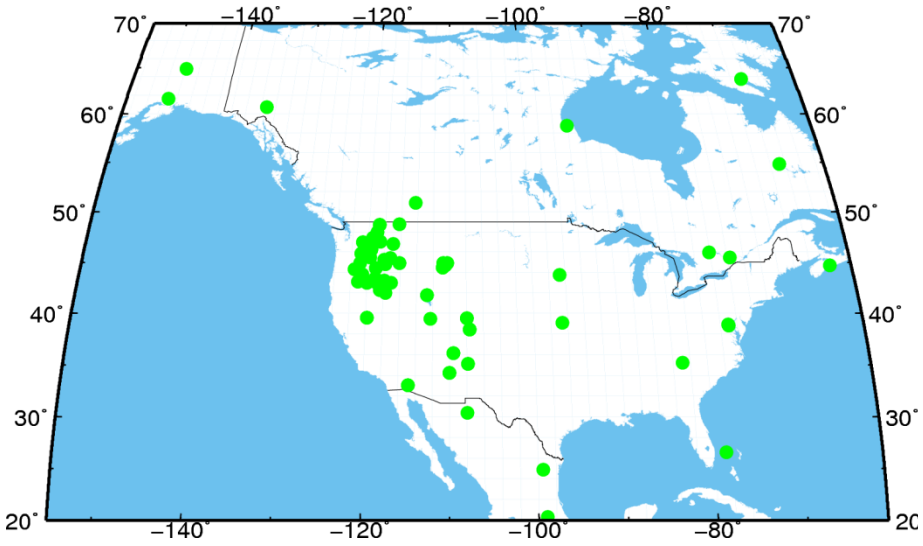
Major Sources of GPS Positioning Error



- **Troposphere: Height**
- **Ionosphere: Rapid ambiguity resolution, horizontal (particularly in east direction)**
- **Orbital Error : 3-D**
- **Antenna multipath**
- **Metadata errors**

Prototype Real-Time Precise Point Positioning System at SOPAC





75 stations used as reference stations which are located 500 km away from western US coast

GPS/GNSS Positioning, Real-time Surveying, Reference Frames

- The natural reference frame of GPS/GNSS is an Earth-Centered Earth-Fixed Reference Frame (ITRF)
- ITRF is defined by the positions and velocities of a global network of space geodetic tracking stations, to account for plate tectonic motions
- Precise GPS orbits (IGS) and broadcast ephemeris are with respect to ITRF (currently ITRF2008)

In California:

- We experience tectonic motion, earthquakes, subsidence, and volcanic activity so the reference network is deforming, while surveyors would like a static datum
- Multiple reference frames in use are tied to North America and the National Spatial Reference System (e.g., NAD83)
- Multiple epoch dates are in use
- Multiple positioning sources are available

CSRC/CRTN Can Help!

New Projects at SOPAC/CSRC

- Re-analysis of all CGPS data since 1992 in ITRF2008
- Publish new CSRS epoch-date coordinates tied to NGS National Adjustment of 2011 (NA2011), NAD 83(2011) epoch 2010.00 – can be provided for multiple reference epochs
- Implement statewide "network solution" for CRTN users, based on precise point positioning (PPP) architecture developed at SOPAC, accessible through NTRIP servers and existing field equipment
- Extension of prototype early warning system along the West coast
- Refresh relevant websites (CSRC, SOPAC, CRTN)

Relevant Websites

Scripps Orbit and Permanent Array Center (SOPAC):
http://sopac.ucsd.edu

GPS Explorer (create free user account):
http://geoapp.ucsd.edu

California Spatial Reference Center (CSRC):
http://csrc.ucsd.edu

California Real Time Network (CRTN):
http://sopac.ucsd.edu/projects/realtime/CRTN

THE END

Sorry I couldn't be there with you

Copy of presentation is available

Contact me with any questions
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