Short Course

Plug and Play GPS for Earth Scientists:
Providing Immediate Access to Low-Latency Geodetic Products for Rapid Modeling and Analysis of Natural Hazards

Wednesday morning, January 20, 2016
AfricaArray workshop
University of the Witwatersrand
Johannesburg, South Africa

Instructor: Bill Hammond
whammond@unr.edu
for the Plug and Play team of
UNAVCO, Inc. and the University of Nevada, Reno

UNAVCO, Inc.
6350 Nautilus Drive
Boulder, CO 80301

Nevada Geodetic Laboratory
Nevada Bureau of Mines and Geology
University of Nevada, Reno
Reno NV, 89557

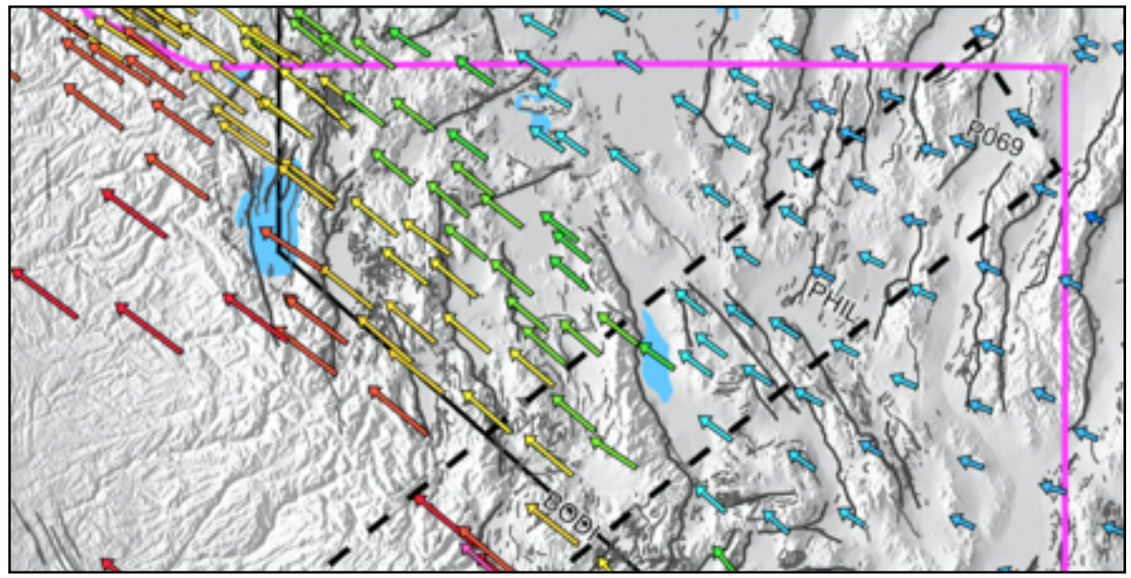
Instructor Introduction: About Bill

Works at the
Nevada Geodetic Laboratory
at the University of Nevada, Reno

Operates a Geodetic Network: MAGNET

Studies active crustal deformation in the Basin and Range, western United States

A long way from Johannesburg, SA



Lives in the Sierra Nevada Mountains near Lake Tahoe

Where it is deep winter!

The Plug and Play Collaborative Team:

University of Nevada, Reno

Geoffrey Blewitt,
UNR Institutional PI

Bill Hammond,
Co-PI

Corné Kreemer,
Co-PI

UNAVCO, Boulder

Chuck Meertens, PI

Fran Boler,
Co-PI

Major funding for project comes from NASA

Agenda For Today

- Introduction of the Plug n Play team and the Instructor (2 minutes)
- Introduction of Plug and Play: Philosophy and Scope (5-10 minutes).
- Plug and Play Data Products (30 minutes)
- Plug and Play - How to Participate (10 minutes)
- Case Study and Exercise (15 minutes)
- Time for Informal Interactions: Instructor and Operators (15 minutes)
- Done in time for the Field Trip!

Plug and Play Course Materials

ftp://gneiss.nbmg.unr.edu/PlugNPlay/ShortCourseAfricaArrayJan2016

Includes:
Agenda
1 Page Handout with description and link to signup form
Short Course slides (.pdf of this presentation)

Plug and Play: Introduction of Scope and Philosophy

- Why are we doing this?
    - Provide FREE GPS data processing service that minimizes effort on part of network operators who contribute data
    - Reduces barriers to maximize scientific impact of GPS networks
    - Promotes of data sharing for science and society
    - Maximize discovery of data for scientific applications
    - Consistent with goals of *AfricaArray* " .. an innovative programme to promote, strengthen and maintain a workforce of highly trained African geoscientists and researchers for Africa."
- Who is involved? The PnP Team players:
    - UNAVCO, UNR
    - plus *beta testers* and *unfunded collaborators*, e.g. USGS, JPL, … and you!
- Who is funding the project?
    - Collaborative NASA ACCESS program project UNAVCO and UNR
    - History of scientific, processing, and data products development at these institutions.

Plug and Play: Introduction of Scope and Philosophy

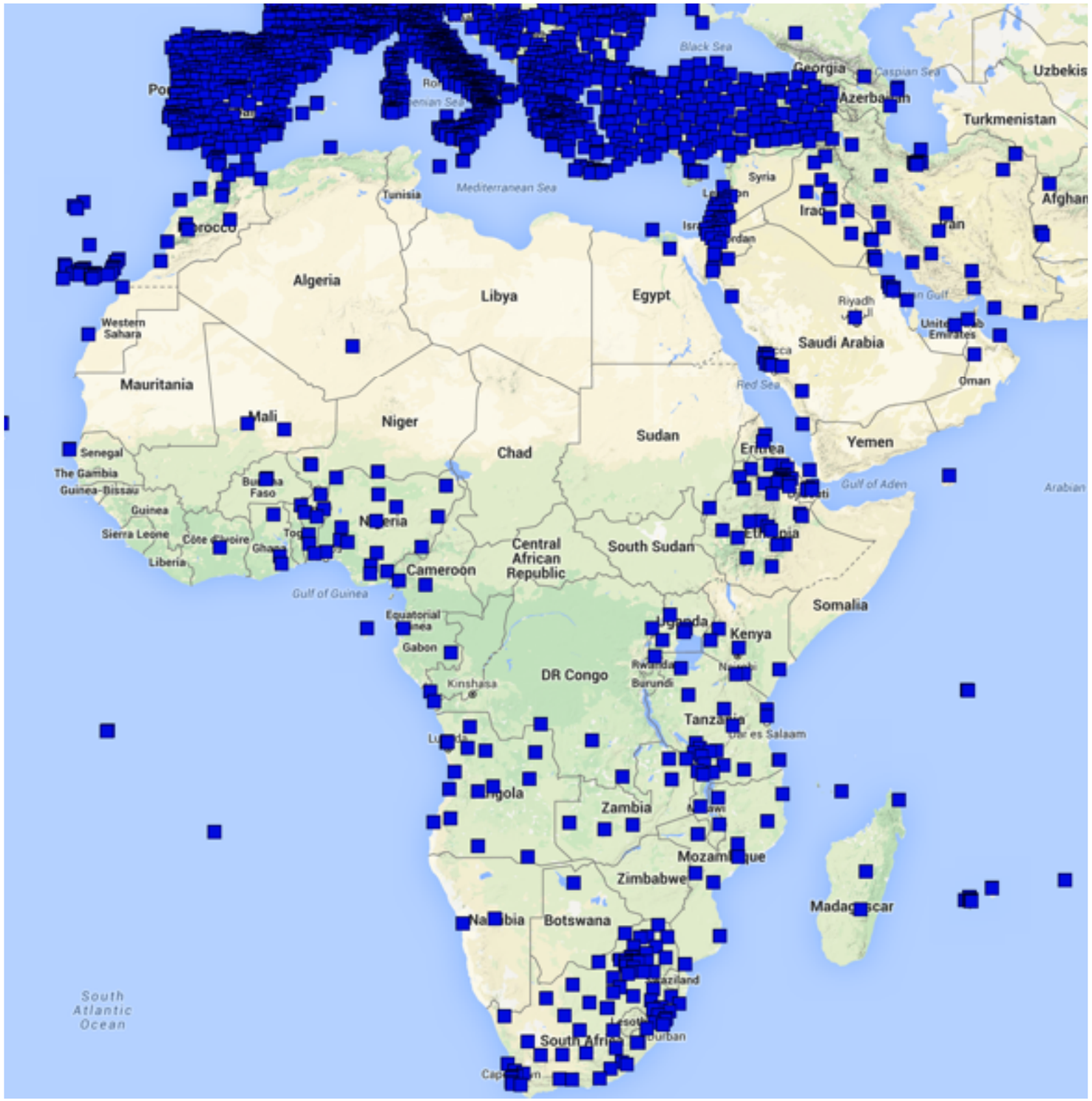
- What is the arrangement?
    - Network operators contribute data to UNAVCO or UNR directly
    - UNR picks up data, processes with GIPSY and generates data products (e.g. time series results files, plots, maps, velocity fields, quality control products, etc.)
    - Data products are placed on open access data products services, e.g. web pages, GSAC services. Open access.
        - **Reduces barriers to setting up or expanding networks.**
- This is a rollout of the service
    - Many of the individual ‘services’ have been available for some time in the form of research projects.
    - Much of this is in beta mode… feedback is welcome.
    - New products available (more later.)
- Plug and Play for AfricaArray
    - If your network’s data is already going to UNAVCO, you may already be getting benefits of the service. See map …

Map of Stations in Africa Processed by NGL

see http://geodesy.unr.edu/NGLStationPages/GPSNetMap.html
to check for individual stations

- Global zoomable Google map (Africa shown here)
- Shows all stations processed by NGL (presently >14000)
- Clickable icons provide detail about station data products and resources
- Updated every day

- Is your network here?
- It could be.
- You would have access to all data products (discussed in next section)
- Incentive to help increase number of stations in Africa



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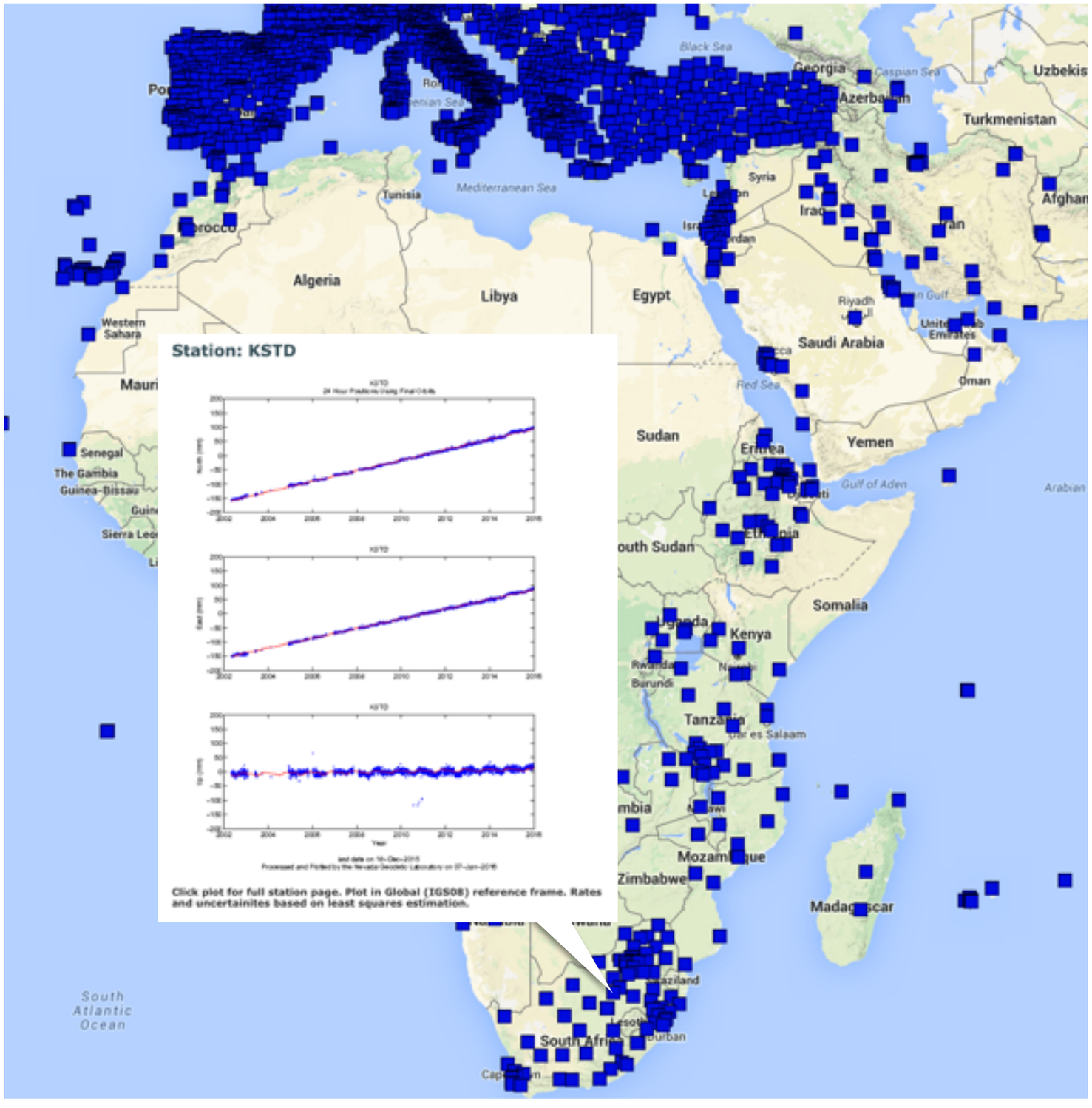


UNAVCO

$$N = 2^{(t-1968)/3.2}$$

Exponential explosion

in stations processed by NGL

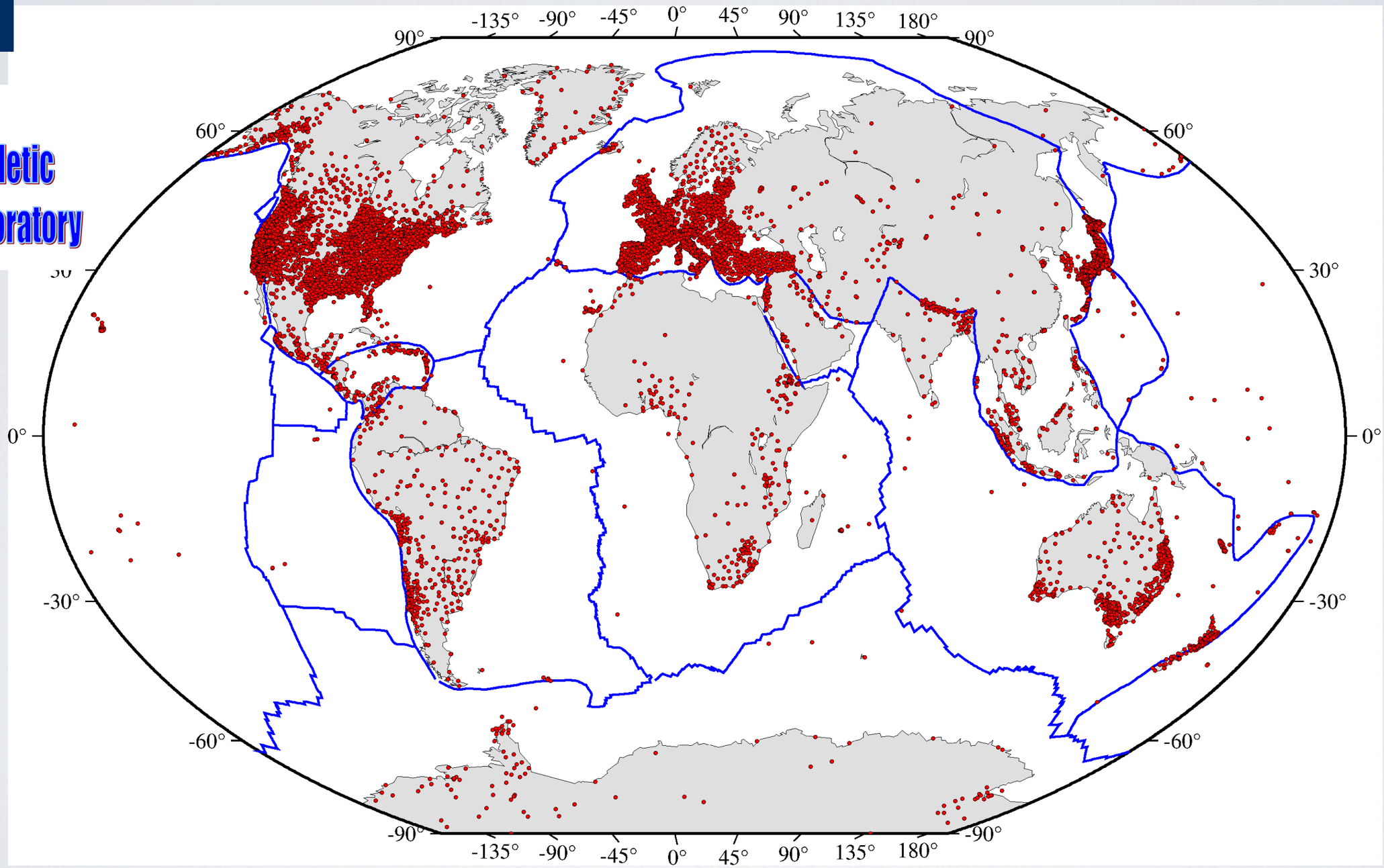
AGU 2013, G33C02, Blewitt et al.

UNAVCO

2015: Exponential explosion

>13,700 stations processed by NGL http://geodesy.unr.edu

Nevada Geodetic Laboratory



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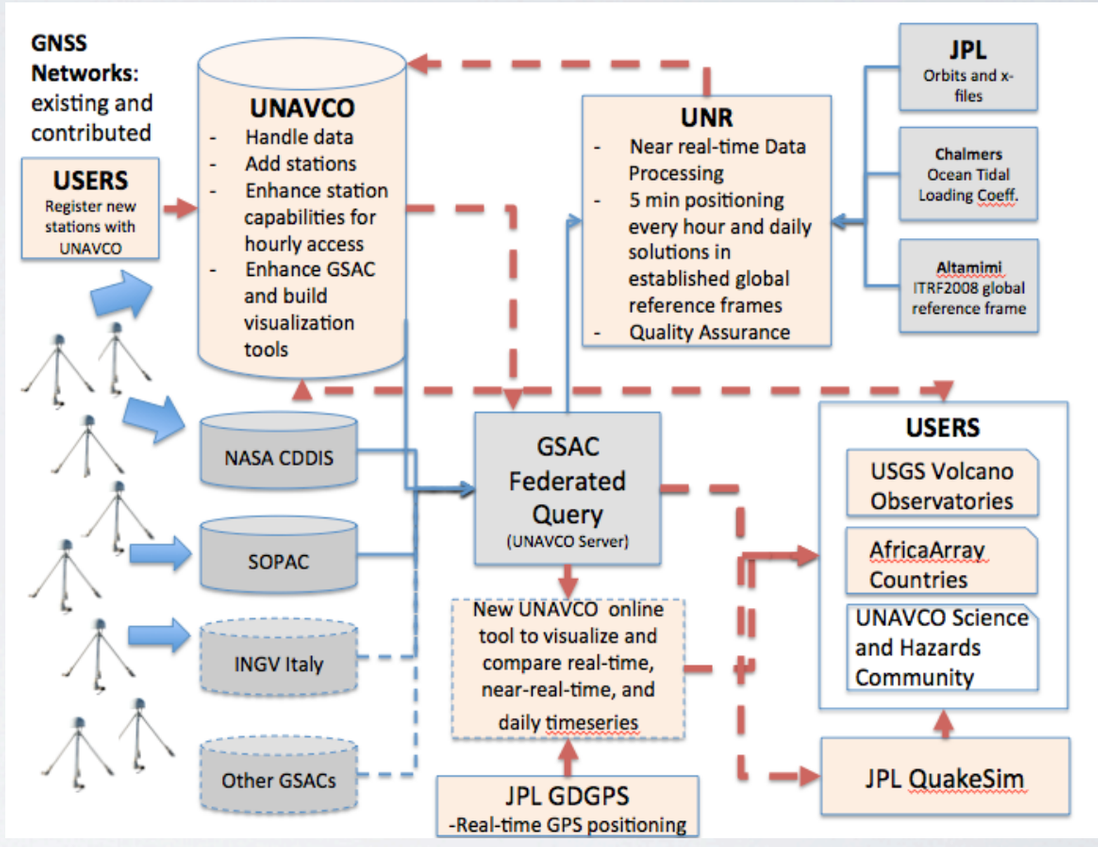
Plug and Play GPS for Earth Scientists: Providing Immediate Access to Low-Latency Geodetic Products for Rapid Modeling and Analysis of Natural Hazards

Plug and Play GPS project Goal: The plug and play concept promotes open accessibility to the scientific potential of GPS by working on the beginning and end of the GPS data processing line.

Objective 1. The system will remove barriers and extend our GPS processing system to facilitate connections to new or undiscovered GPS observations around the globe.

Objective 2. Processing outputs will include openly available daily and sub-daily position time series, time-dependent site velocities and derived strain. Data providers and other end users will have low-latency access to essential data products following the establishment of data streams.

Objective 3. Educate partners and new users in the scientific community on the goals and objectives of this project and how to participate. We will solicit their feedback on how to improve the utility of the system.



Plug and Play GPS project Workflow

Plug and Play: Future Plug n Play Events

- May 2014, NASA Awards Project
- 2015 presentation of service and available data products at workshops, conferences e.g. EarthScope, Fall AGU in San Francisco.
- AfricaArray, January 18-20, 2016
    - Rollout
    - New data products
    - First short course
- UNAVCO Science workshop, Boulder, CO March 28-31
    - Plug and Play highlighted in science sessions
- Less-Short course in Boulder, May 27, 2016
    - **Full day** workshop at UNAVCO facility
    - More extensive explanation of available tools, data resources
    - More information available soon at http://unavco.org

Questions?

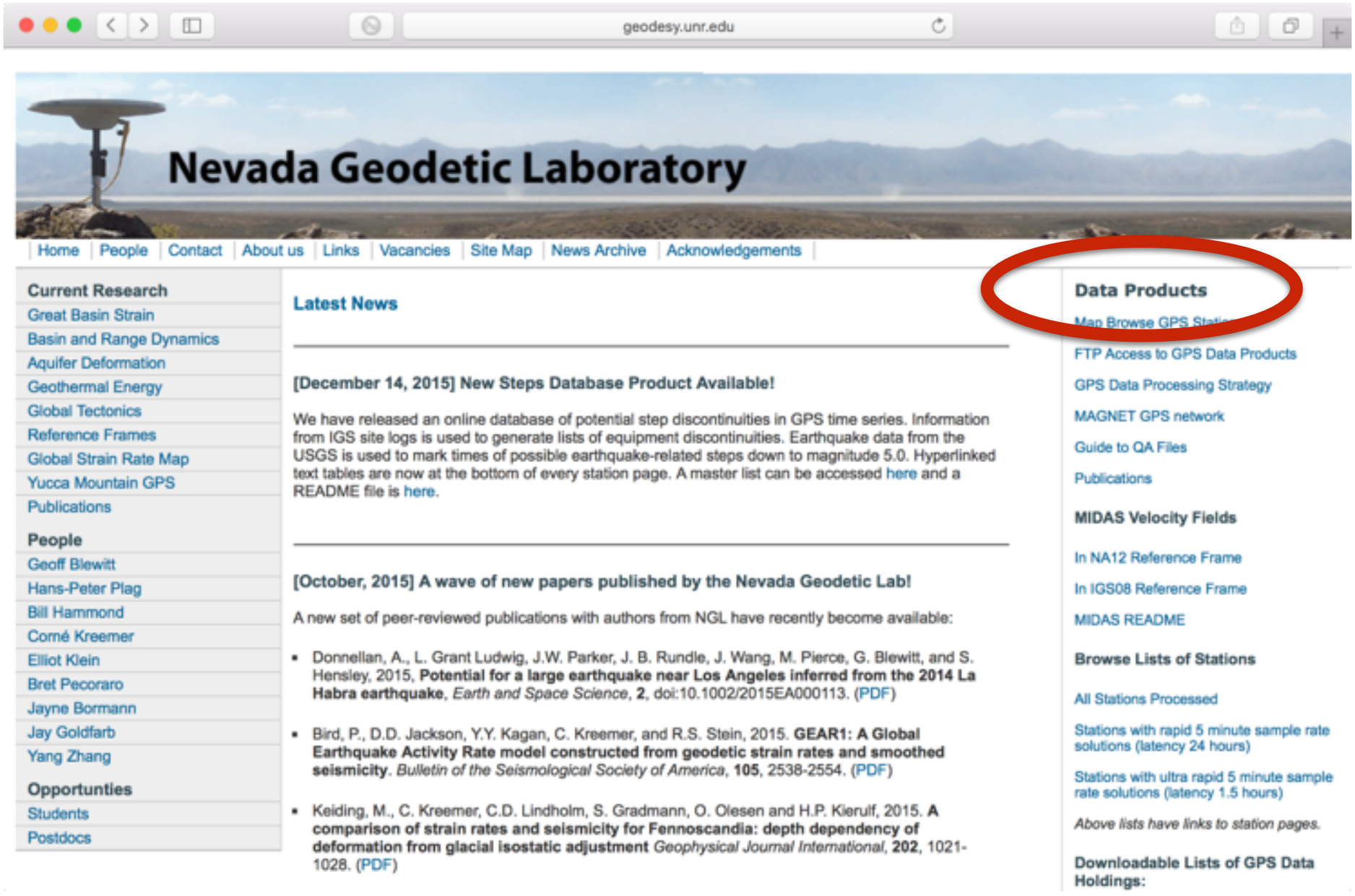
Plug and Play Data Products: An Introduction

Processed GPS Time Series

- A few processing details
- Scope of processing
- Number of stations
- Available formats of processed time series
- Available figures
- Available reference frames
- Available sample rates and latencies
- How to access and search the products

Plug and Play Data Products: An Introduction

Where to Find Things: http://geodesy.unr.edu

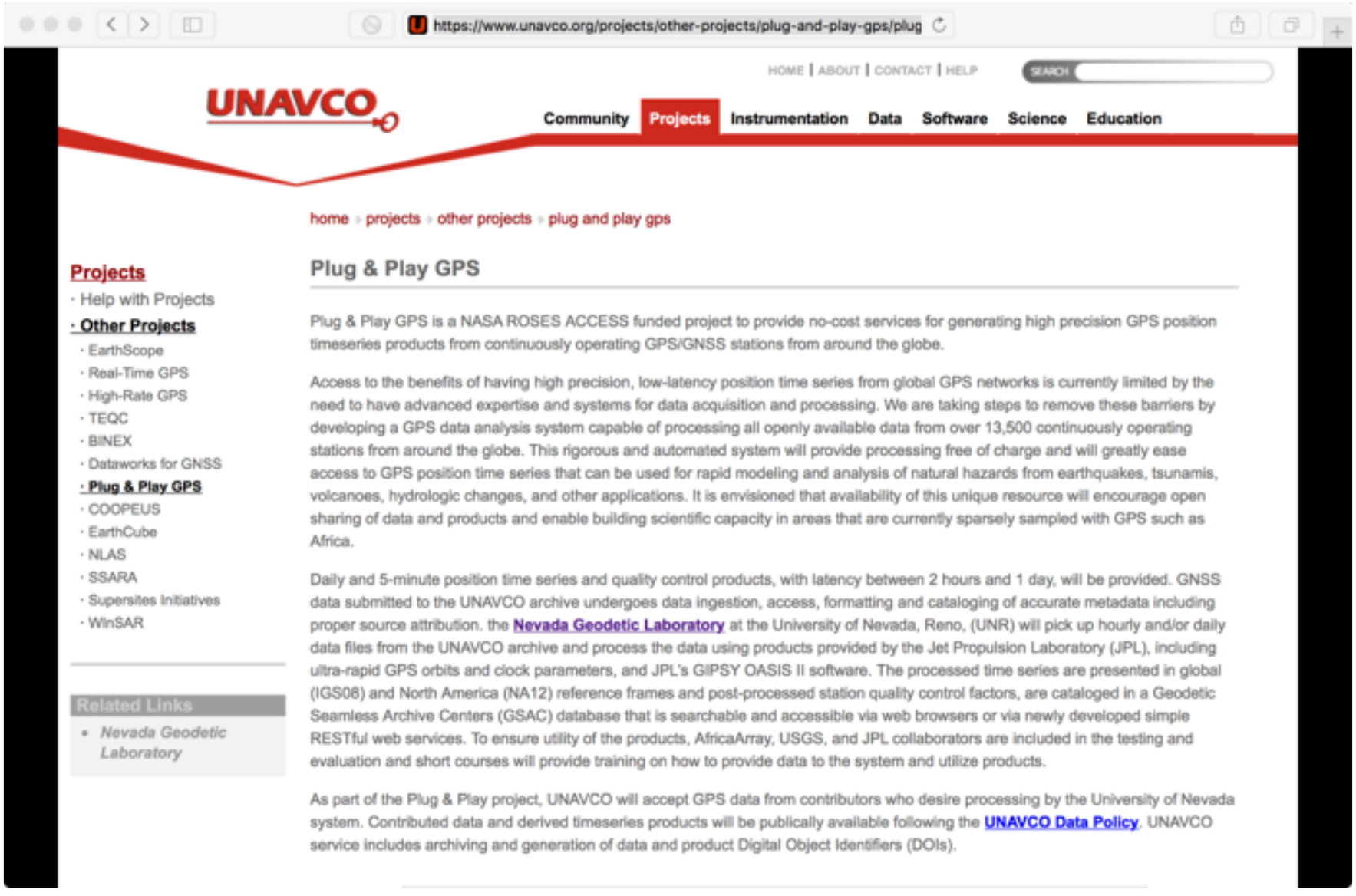


Plug and Play Data Products: An Introduction

Where to Find Things: https://www.unavco.org

https://www.unavco.org/projects/other-projects/plug-and-play-gps/plug-and-play-gps.html

- These are the main portals
- Several search options for products are available
- More later

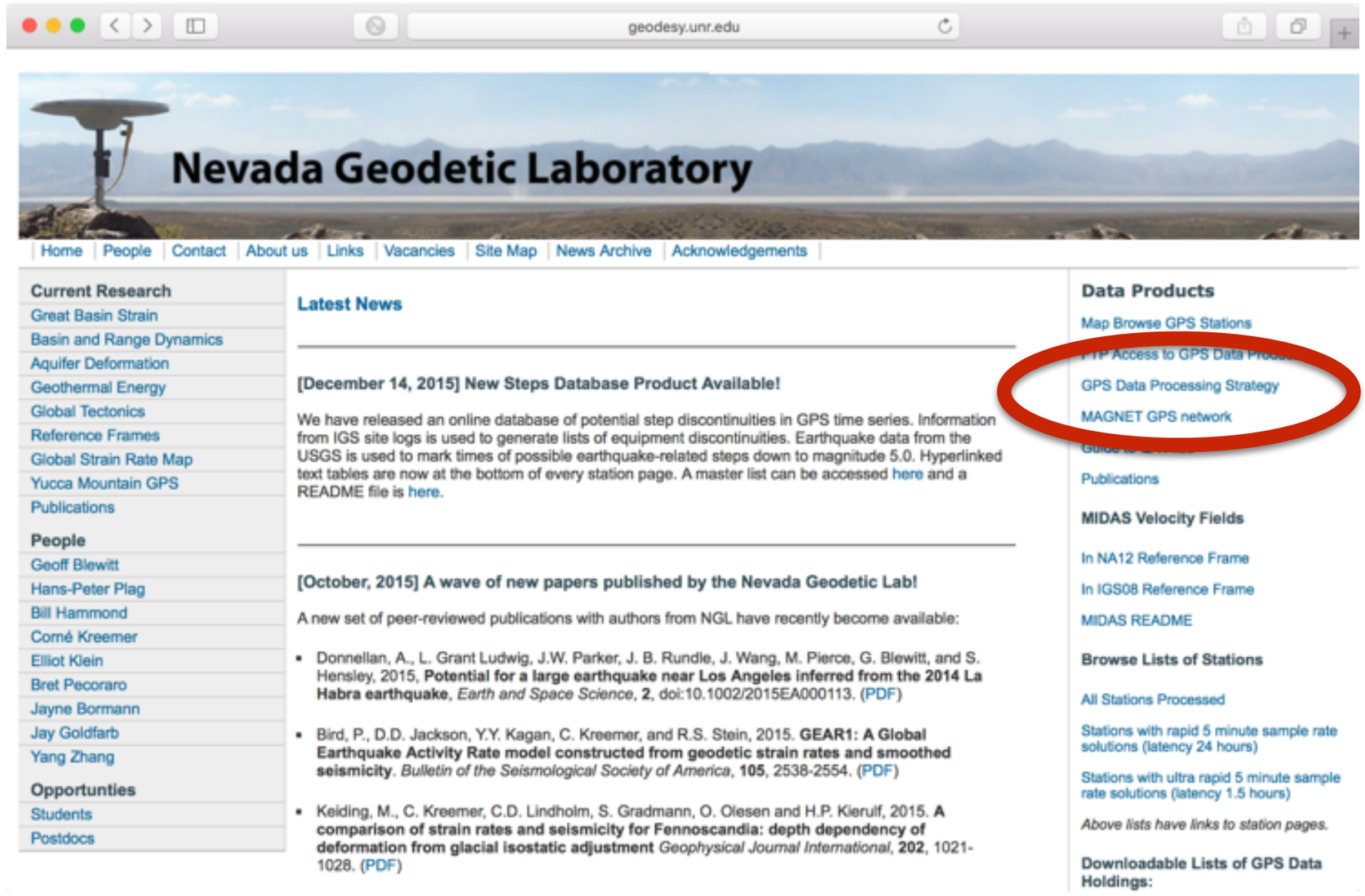


Plug and Play Data Products: An Introduction

Processing

- GIPSY/OASIS software
- Precise Point Positioning
- Use JPL products (e.g. orbits, clock corrections)

- Description of all models documented under “GPS Data Processing Strategy” e.g.:
  - estimated parameters
  - Earth orientation
  - troposphere model
  - ionosphere model
  - Earth tide
  - Ocean tidal loading
  - antenna corrections
  - solar radiation
  - ambiguities, etc.



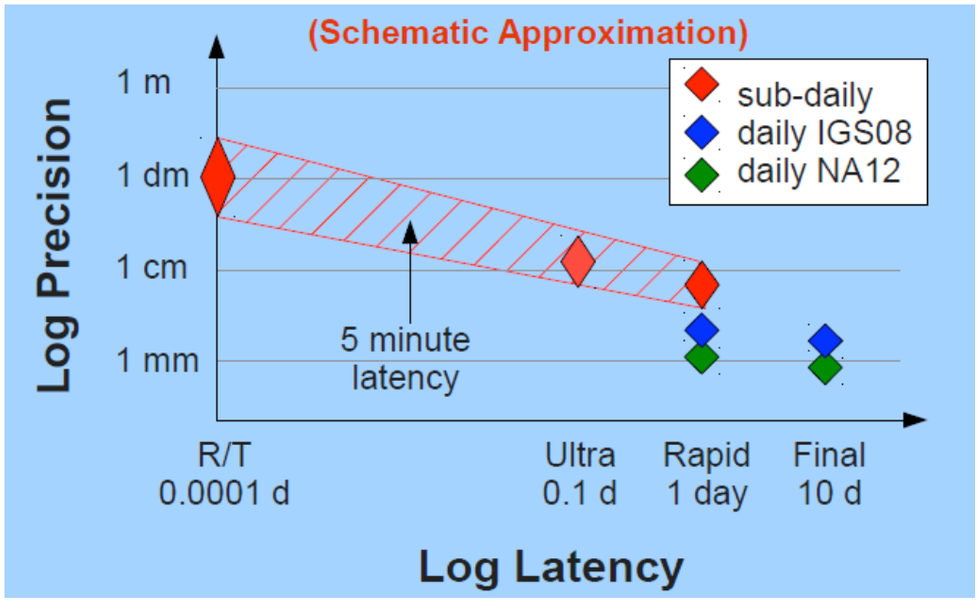
http://geodesy.unr.edu

Plug and Play Data Products: An Introduction

Latencies

- Processing performed using JPL orbits:
  - Final (1-2 weeks)
  - Rapid (24 hours)
  - Ultrarapid (1-2 hours)

- More rapid are least accurate
- We need access to hourly RINEX to get Ultrarapid latency



Data Flow	% of GSAC Stations available	Data Sample Rate	Position Solution Sample Rate	Position Solution Latency	Position Solution Precision	Position Solution Providers
Daily File Down-load	95%	15 second	Once/day	Rapid 1-2 Days	H: 1.5 mm V: 5 mm	UNR (**All** stations proposed) PBO Analysis Centers (only ~1,100 PBO stations); Individual investigators or agencies;
				Final 1-2 weeks	H: 1.5 mm V: 5 mm	
Hourly File Down-load	20%	15 second	Once/5 minutes	Ultrarapid 1-2 hours; Rapid 1 day	PPP:10 mm (global)	UNR (Proposed)
Streams	15%	1 second	Once/second	1 second	RTK Short Baseline (<10km) <1cm RTK Long Baseline (10km-300km) 1-50cm PPP Kinematic (global) 5-10 cm	PBO, NGS (both in development); JPL GDGPS (~100 stations); limited number of other groups

Plug and Play Data Products: An Introduction

Number of Stations

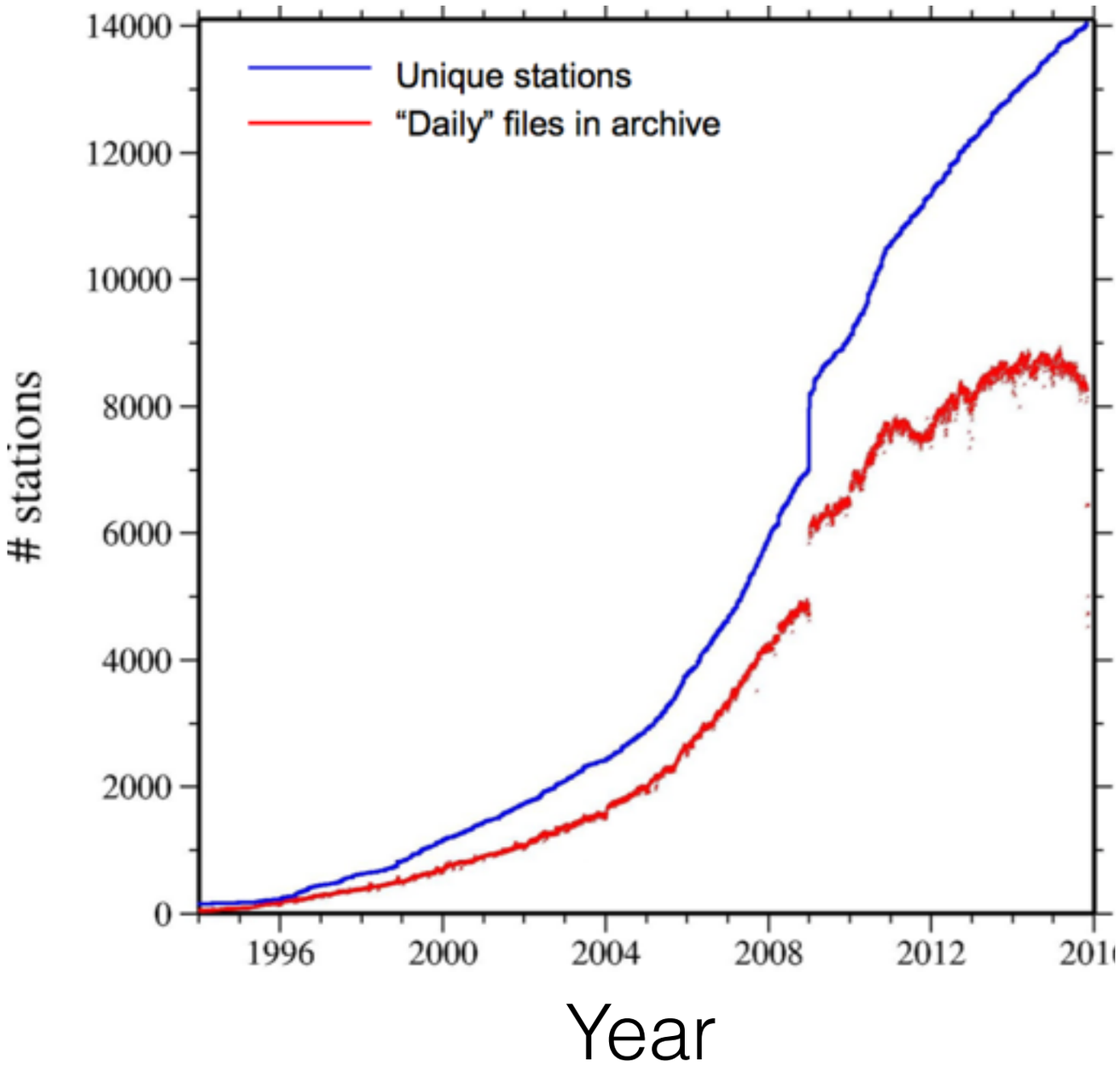
as of 1/10/2015

24 Hour Finals
14112 stations in IGS08
6569 stations in NA12

24 Hour Rapids
10253 stations in FID
5193 stations in NA12

5 Minute Rapids
5,050,019 kenv station-day files

5 Minute UltraRapids
1,799,694 kenv station-day files



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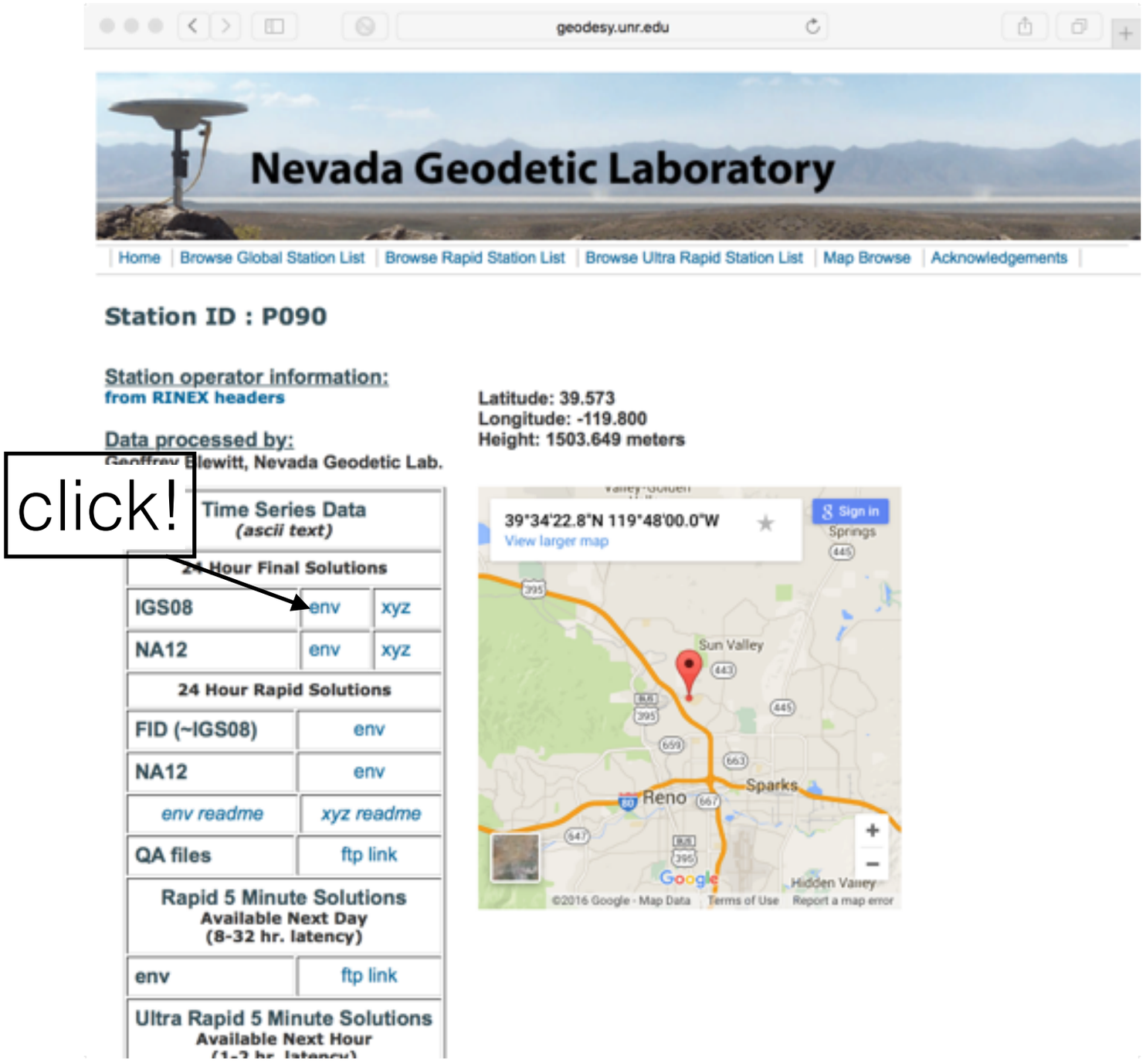

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geodesy.unr.edu

```
site YYMMMDD yyyy.yyyy __MJD week d reflon _e0(m) __east(m) ____n0(m) _north(m) u0(m) ____up(m) _ant(m)
sig_e(m) sig_n(m) sig_u(m) __corr_en __corr_eu __corr_nu
P090 07NOV10 2007.8576 54414 1452 7 -119.8      12  0.884938   4382097  0.181664  1503  0.658770  0.0083
0.000480 0.000602 0.001807  0.013978 -0.052295 -0.165112
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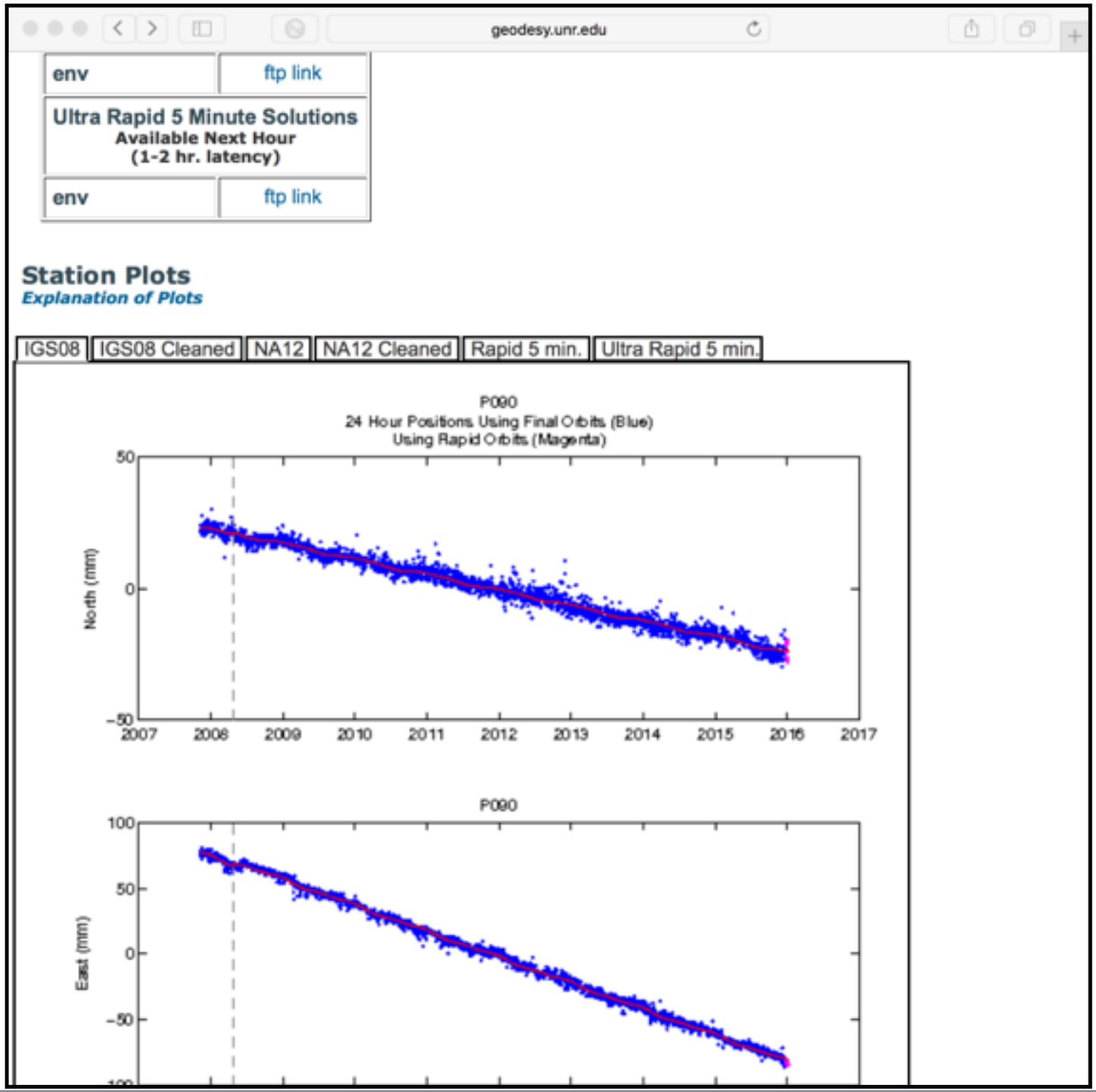

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NEVADA

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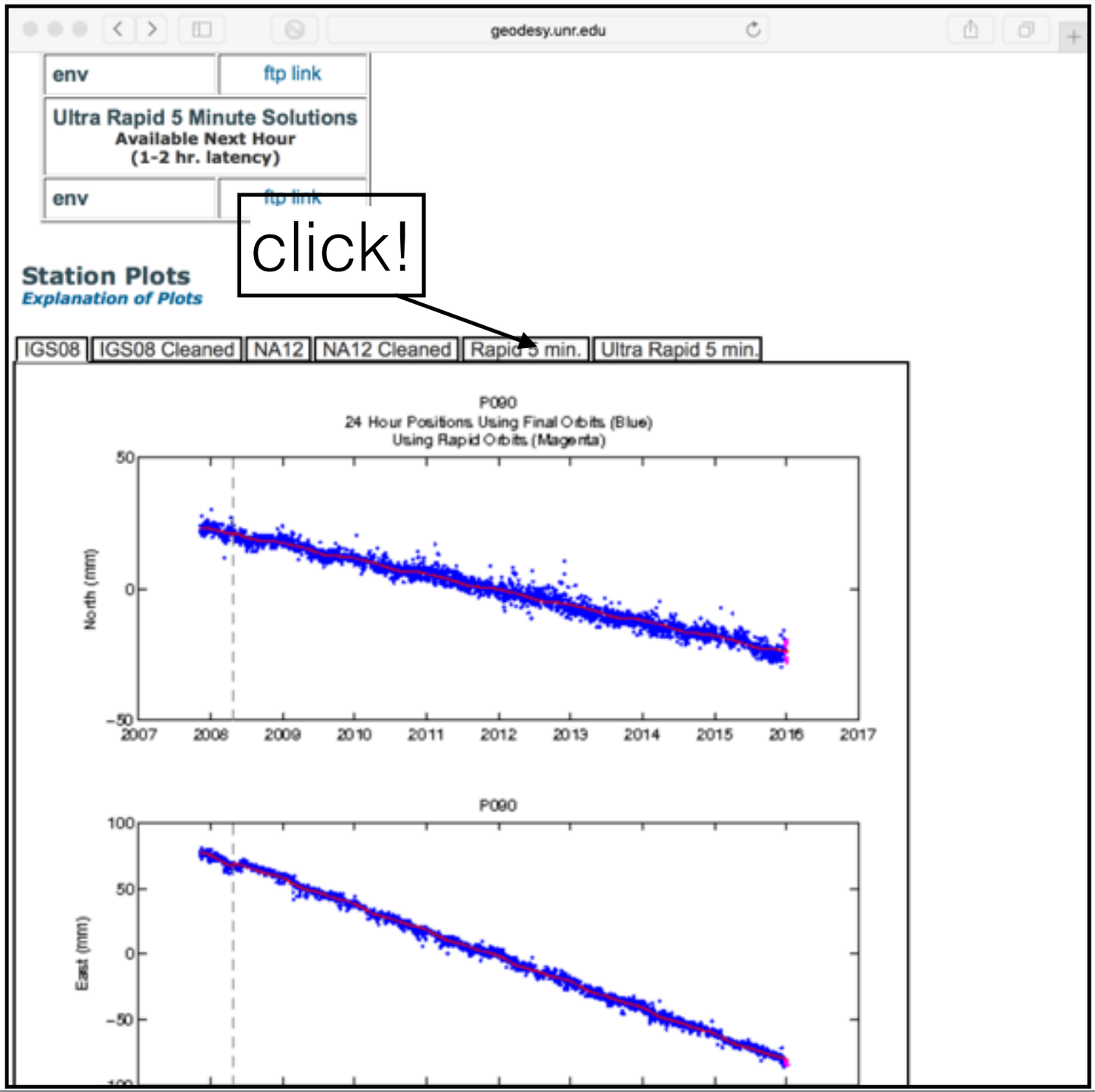

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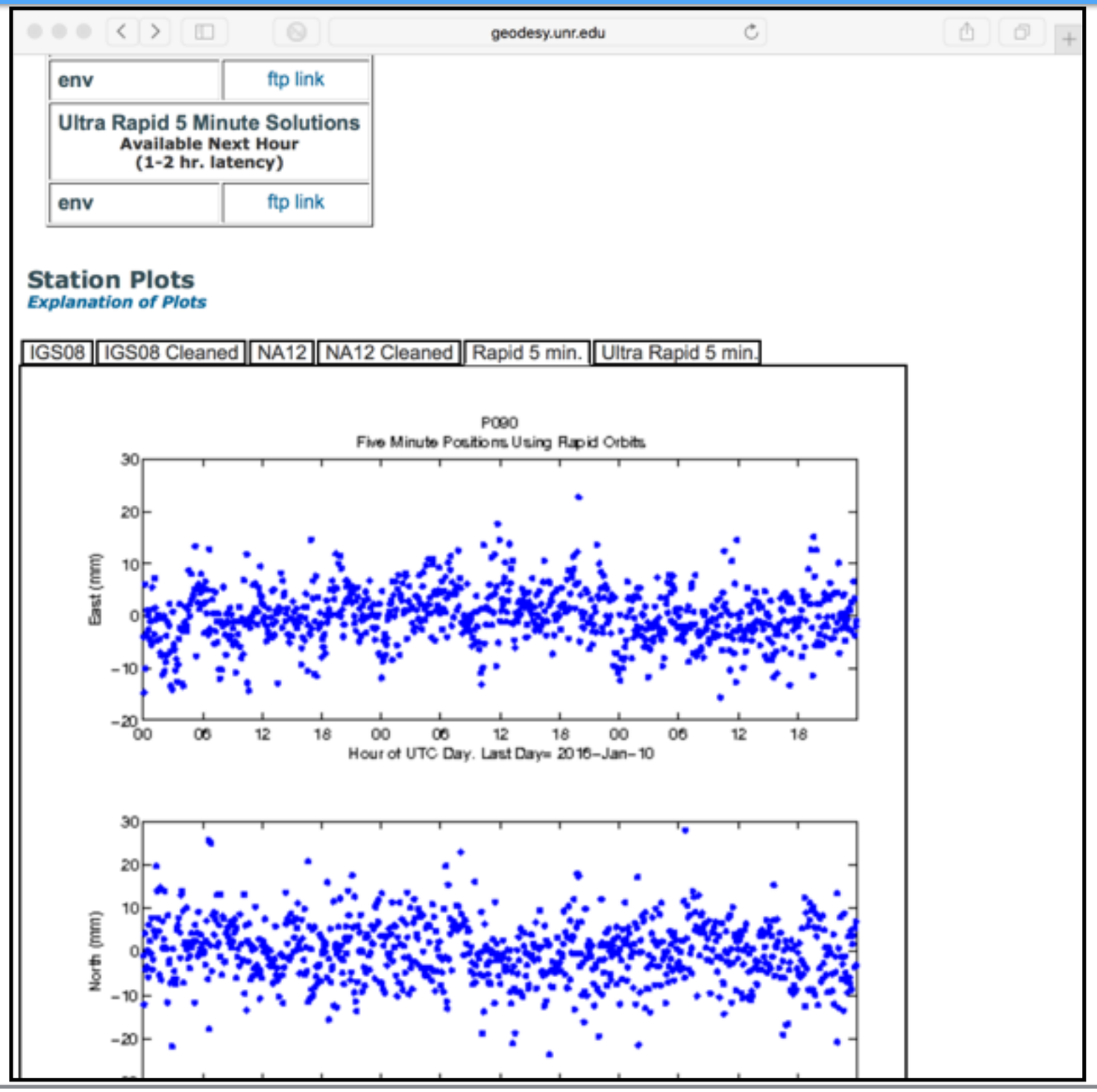

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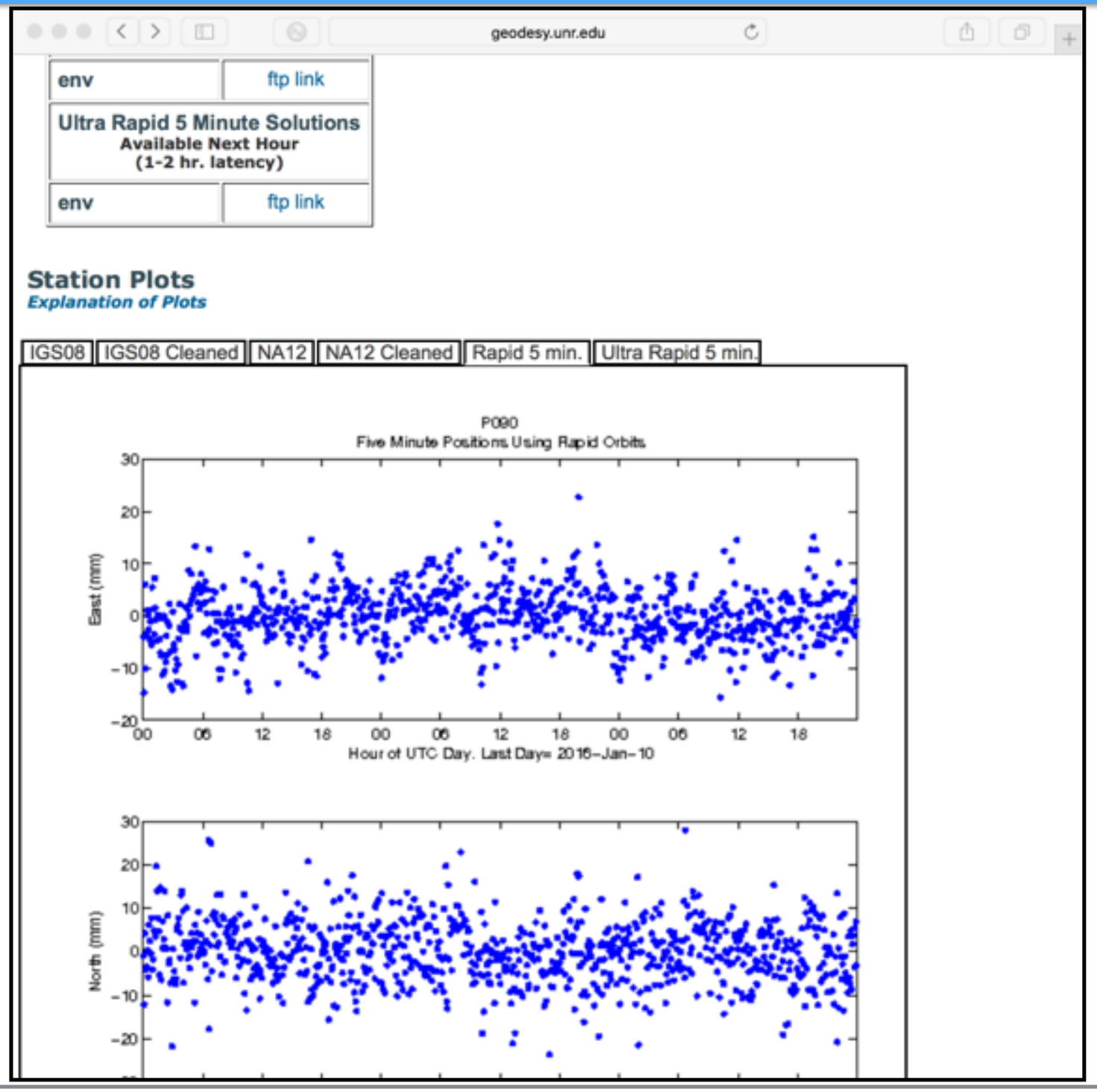
- Useful when earthquakes occur



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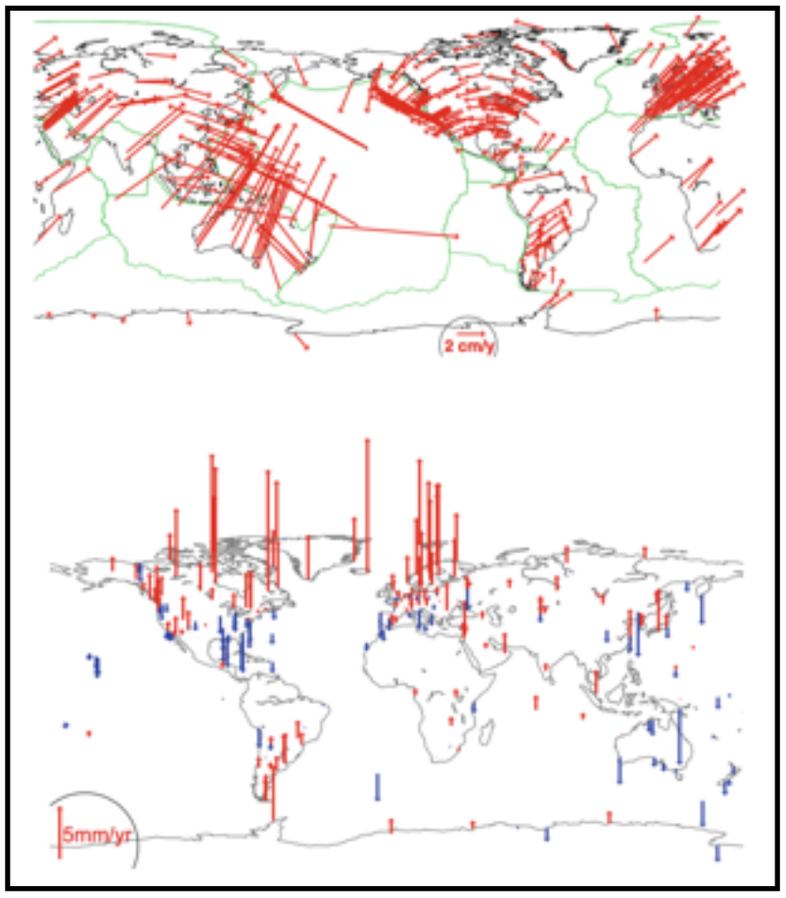
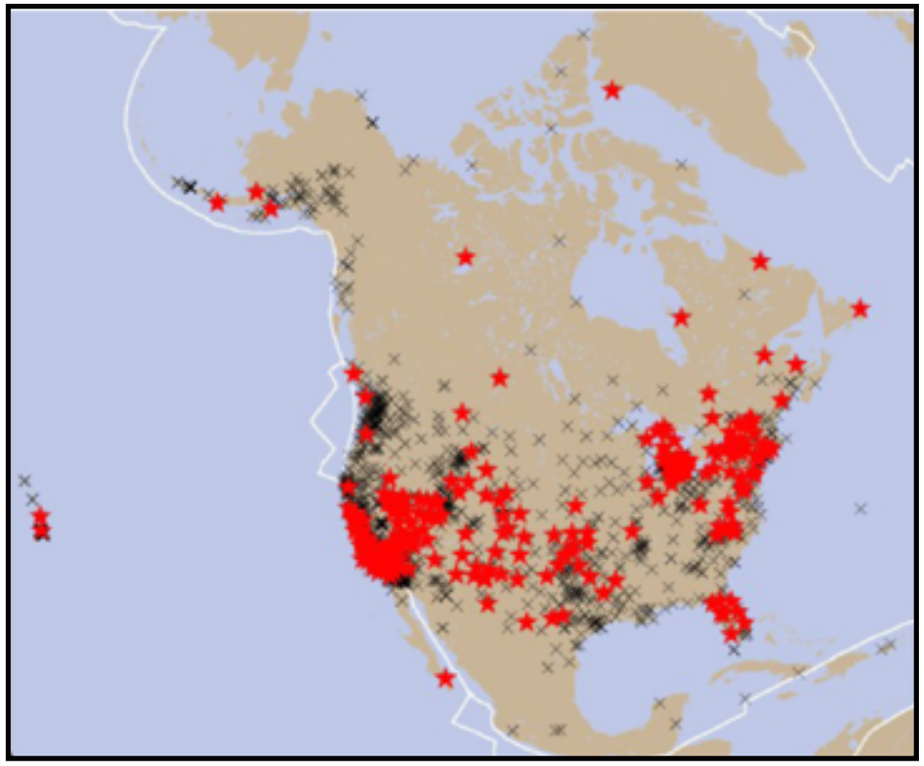


Altamimi, Z., X. Collilieux, L. Métivier, 2011, ITRF2008: an improved solution of the international terrestrial reference frame, J. Geodesy, DOI 10.1007/ s00190-011-0444-4.

Reference Frames

- Currently two frames offered:
  - **IGS08**, GPS version of ITRF08
  - **NA12** a North America Fixed
- Plate-specific frames have plate rotation and common mode signal (on plate scale) removed
- Less scatter in time series compared to IGS08.
- Plans in works for custom frames for
  - Africa
  - South America
  - Eurasia
  - Pacific
  - etc.



Blewitt, G., C. Kreemer, W.C. Hammond and J. Goldfarb (2013). Terrestrial reference frame NA12 for crustal deformation studies in North America, *Journal of Geodynamics*, 72, pp. 11-24, ISSN 0264-3707

UNAVCO · Nevada Geodetic Laboratory · Nevada · NASA

Plug and Play Data Products: An Introduction

Searching for What You Want

Options:

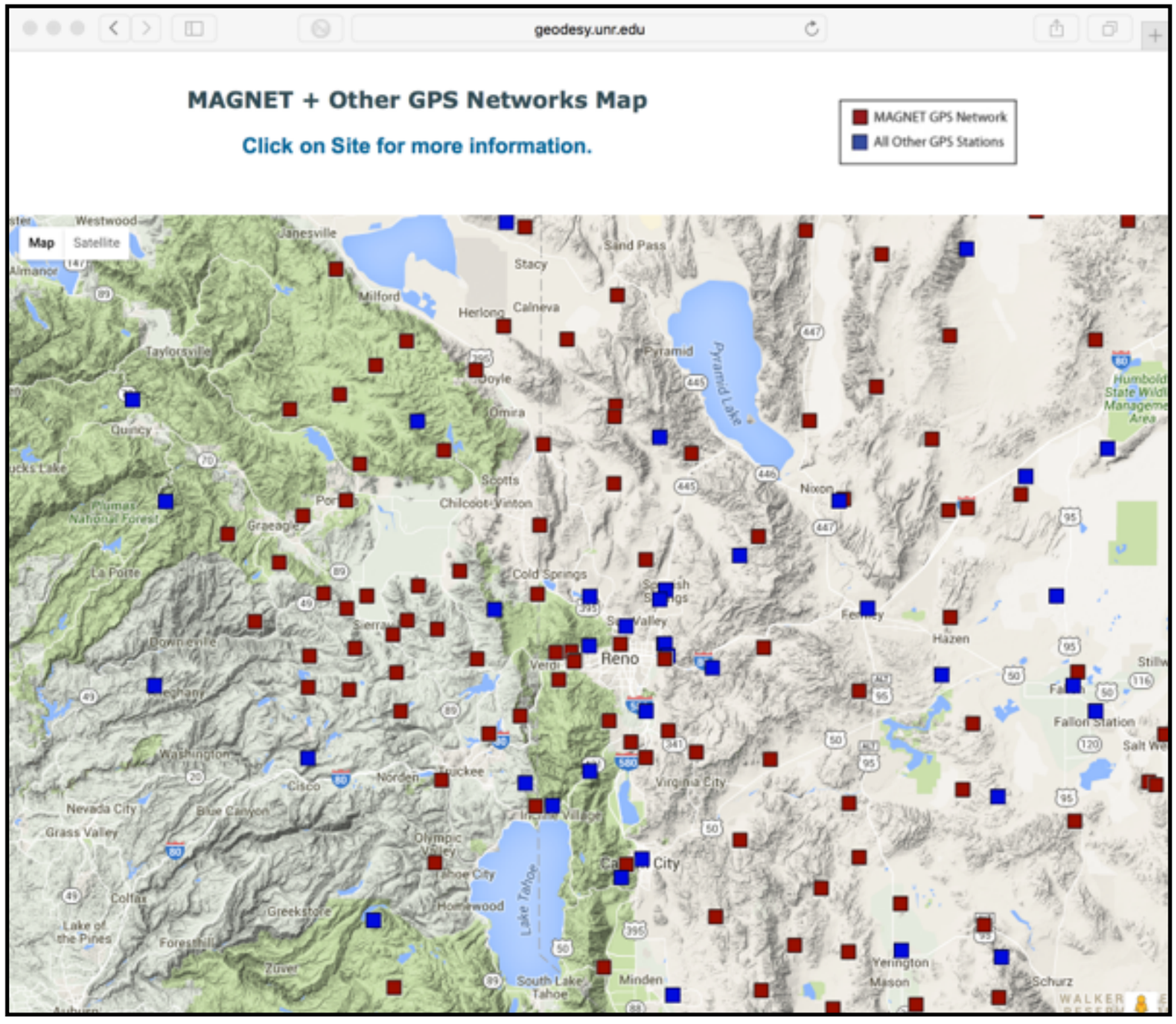
Map Search - using the Google map
Station Lists - text search
Online Data Holdings - machine readable files
GSAC online query tools

Plug and Play Data Products: An Introduction

Map Search

(good if you know geographic location but not station names)

- Hover cursor to see name of station before clicking
- zoom, pan, the usual way
- click to get station page



Plug and Play Data Products: An Introduction

Text Search by Station Name

(good if you know what station you are looking for)

- Step 1, choose what latency you want (final, rapid, ultra rapid)
- Step 2, click on link
- Step 3, get list .
- Step 4, use find function in browser to go right to station

Plug and Play Data Products: An Introduction

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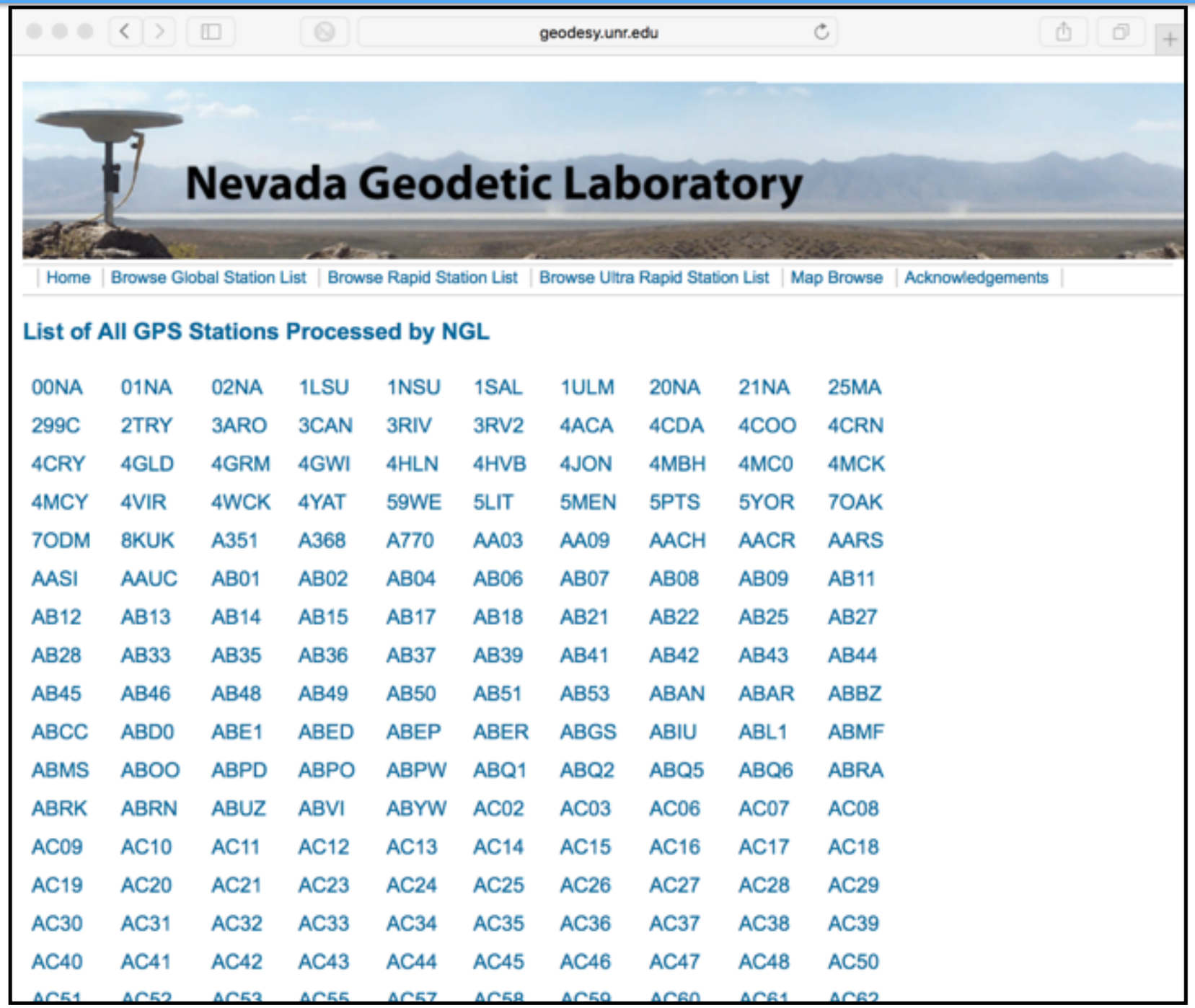
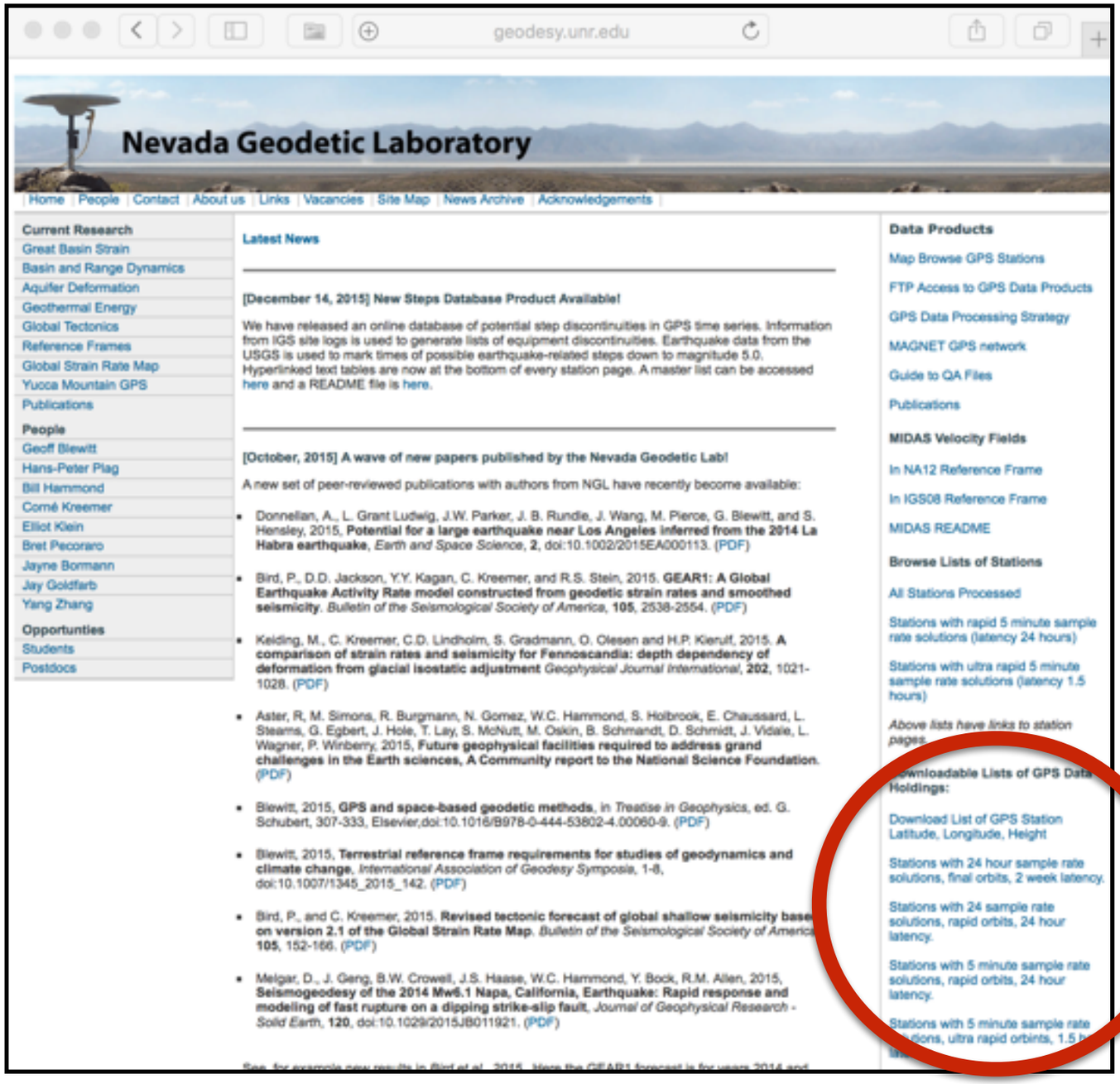


Plug and Play Data Products: An Introduction

Online Data Holdings Files

- Follow the links from our **Data Products Area**
- Text files, updated daily
- Provide:
  - lists of stations we have
  - time span of data available
  - number of solutions
  - name translations if needed
- Separate files for
  - final 24 hour solutions
  - rapid 24 hour solutions
  - rapid 5 minute solutions
  - ultrarapid 5 minute solutions
- Why use these?
- Good for users with intermediate programming skills (e.g. good with greps and awks)



Plug and Play Data Products: An Introduction

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geodesy.unr.edu

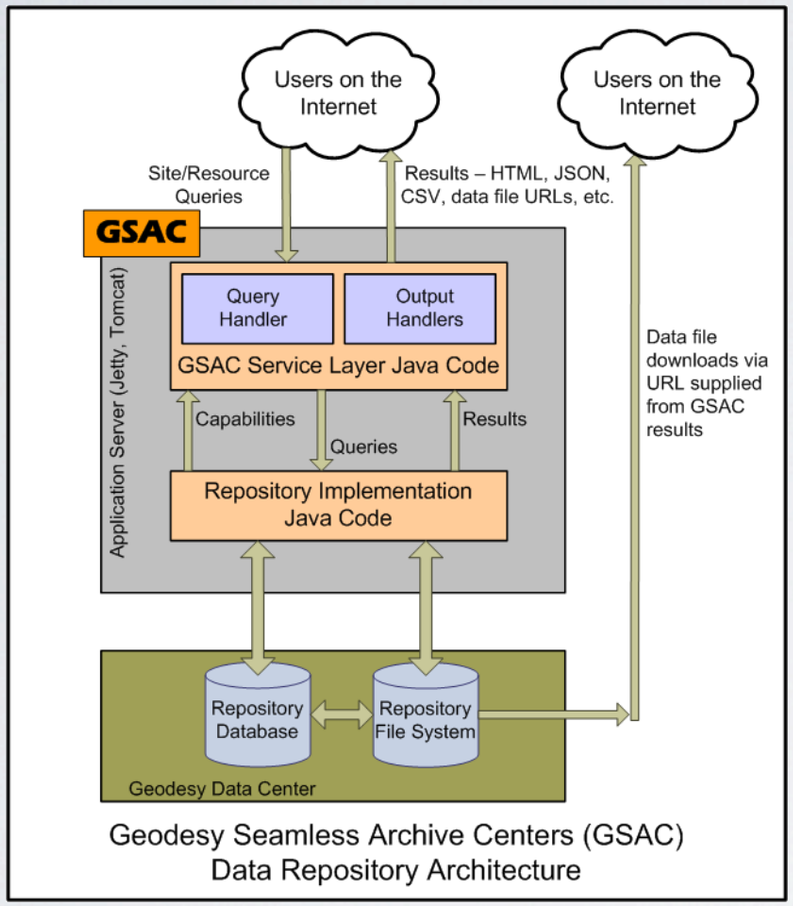
Sta StaOrigName	Lat(deg)	Long(deg)	Hgt(m)	X(m)	Y(m)	Z(m)	Dtbeg	Dtend	Dtmod	NumSol	
00NA	-12.4666	130.8440	104.851	-4073662.2759	4712064.7454	-1367874.5096	2008-03-27	2015-12-26	2016-01-02	2353	
01NA	-12.4782	130.9820	105.409	-4084823.4607	4702026.6696	-1369125.8893	2008-04-08	2013-08-12	2016-01-02	1490	
02NA	-12.3559	130.8817	117.652	-4078496.4388	4711380.1446	-1355915.1775	2008-09-22	2015-10-27	2016-01-02	1832	
1LSU	30.4074	268.8197	-6.487	-113402.8795	-5504361.3939	3209404.2335	2003-04-23	2015-12-26	2016-01-02	4133	
1NSU	31.7508	266.9024	28.071	-293349.5323	-5420742.3561	3336980.8353	2004-01-16	2015-12-26	2016-01-02	3923	
1SAL	45.4307	12.3365	55.417	4380125.6096	957947.7600	4521107.9743	2014-05-07	2015-02-28	2016-01-02	286	
1ULM	32.5290	267.9241	16.000	-194982.0141	-5379221.9515	3410046.8330	2003-06-14	2015-12-26	2016-01-02	4401	
20NA	-23.6982	133.8828	607.104	-4050985.3235	4212133.8047	-2547954.8558	2008-03-27	2015-12-26	2016-01-02	2323	
21NA	-23.7670	133.8792	574.465	-4048578.9259	4210151.5116	-2554917.6312	2008-03-27	2015-12-26	2016-01-02	2784	
25MA	-37.7719	292.2844	373.960	1914328.6149	-4671229.9504	-3885692.6988	2013-05-16	2015-12-26	2016-01-02	879	
299C	64.0289	217.9242	748.177	-2209505.8339	-1721554.0061	5711800.4157	2003-01-12	2007-02-01	2016-01-02	1407	
2TRY	-33.7688	151.1163	80.592	-4647366.8544	2563755.9267	-3525201.4906	2012-01-18	2013-08-28	2016-01-02	564	
3ARO	-38.3821	299.7258	137.523	2482376.5130	-4347528.1128	-3938861.9538	2013-06-12	2015-12-26	2016-01-02	901	
3CAN	40.6136	356.2984	765.697	4839099.9866	-313069.2588	4130439.8138	2009-01-01	2015-11-30	2016-01-02	2266	
3RIV	46.3148	287.4239	-21.729	1321445.8498	-4210578.8551	4589466.7540	2000-06-17	2010-07-30	2016-01-02	18	
3RV2	46.3159	287.4266	-21.491	1321618.2733	-4210427.8787	4589555.3483	2010-07-14	2010-07-29	2016-01-02	3	
4ACA	-27.5985	153.0388	115.195	-5041777.8474	2564619.8794	-2937202.8217	2012-10-26	2015-12-26	2016-01-02	1070	
4CDA	-28.2446	153.5561	52.251	-5034662.0008	2504036.9010	-3000433.8586	2012-02-28	2015-12-14	2016-01-02	1290	
4COO	-27.4915	153.0501	54.718	-5047126.9955	2566080.1198	-2926661.2162	2012-10-26	2015-12-14	2016-01-02	961	
4CRN	-16.9524	145.7425	90.120	-5044072.3773	3435355.2652	-1847819.7903	2012-01-18	2015-12-14	2016-01-02	1340	
4CRY	-26.4161	152.9110	164.360	-5089053.9146	2602967.0896	-2820497.8496	2012-01-17	2015-12-26	2016-01-02	1307	
4GLD	-23.8392	151.2446	60.365	-5117383.7865	2808126.1209	-2562025.5712	2012-02-09	2015-12-14	2016-01-02	1306	
4GRM	-23.8392	151.2446	60.366	-5117383.7599	2808126.1397	-2562025.6070	2012-01-18	2012-01-30	2016-01-02	12	
4GWI	-28.5465	150.3031	258.291	-4870791.3308	2777897.9296	-3029972.0152	2013-12-19	2015-12-22	2016-01-02	670	
4HLN	-27.9219	153.3363	55.571	-5040064.2273	2530892.5250	-2968884.1075	2012-02-28	2015-12-14	2016-01-02	1216	
4HVB	-25.2997	152.8098	73.953	-5132360.3952	2636563.4269	-2709155.0206	2012-01-18	2014-02-03	2016-01-02	661	
4JON	-27.4256	151.4951	422.634	-4978876.8373	2703864.9121	-2920350.8968	2012-10-26	2015-12-26	2016-01-02	919	
4MBH	-25.5344	152.7064	82.959	-5117682.1249	2640709.0562	-2732645.1780	2012-10-26	2015-12-26	2016-01-02	1044	
4MCO	-26.6628	153.0334	66.302	-5083639.6601	2586514.4370	-2844904.7087	2012-02-28	2015-12-14	2016-01-02	1296	
4MCK	-21.1172	149.1589	76.485	-5110746.9724	3051591.5856	-2283532.0532	2012-10-26	2013-12-18	2016-01-02	316	
4MCY	-21.1172	149.1589	76.501	-5110746.9619	3051591.6087	-2283532.0881	2012-01-18	2012-10-14	2016-01-02	264	
4VIR	-27.3759	153.0578	57.986	-5052736.6906	2568078.6012	-2915290.3121	2012-02-28	2012-06-24	2016-01-02	118	
4WCK	-27.0471	150.9571	387.534	-4970022.8571	2759798.4273	-2883044.5298	2012-02-28	2012-03-26	2016-01-02	28	
4YAT	-27.7340	153.2219	63.578	-5043687.6180	2545326.0726	-2950475.2540	2012-02-28	2012-09-03	2016-01-02	174	
59WE	33.4311	247.8169	289.115	-2011877.6148	-4934117.2794	3494120.3332	2010-07-15	2014-07-30	2016-01-02	490	
5LIT	-35.0507	138.8675	393.428	-3937318.5119	3438675.9905	-3642699.3035	2012-02-28	2012-03-24	2016-01-02	26	
5MEN	-35.6892	139.3379	11.717	-3934072.8421	3379317.2845	-3700242.0209	2012-10-31	2014-03-18	2016-01-02	256	
5PTS	36.4292	239.7350	56.523	-2589504.4956	-4437630.7531	3766647.8083	2010-05-01	2011-05-10	2016-01-02	335	
5YOR	-35.0170	137.6063	24.629	-3862036.5903	3525749.6266	-3639428.7261	2014-04-28	2015-12-26	2016-01-02	521	
7OAK	37.5950	245.2409	1713.278	-2119707.4227	-4596082.9515	3870967.7786	2010-10-18	2014-06-13	2016-01-02	50	
7ODM	34.1164	242.9068	762.072	-2407750.8780	-4706536.7233	3557571.3926	2001-04-20	2015-12-26	2016-01-02	4094	
8KUK	-33.1904	118.0840	298.306	-2515389.5459	4714082.1879	-3471808.0506	2012-10-30	2015-12-22	2016-01-02	1022	
A351	-72.9081	74.9101	1907.477	489658.7125	1816031.2158	-6076059.1824	2001-01-11	2009-06-26	2016-01-02	337	
AJ68	-74.2906	66.7922	1235.829	682780.4728	1592449.8432	-6118988.5415	2002-12-19	2010-04-03	2016-01-02	455	
A770	-24.1590	151.8870	126.353	-5135893.5743	2743809.2641	-2594414.9132	2013-12-24	2015-12-26	2016-01-02	669	1770
AA03	8.3290	80.4100	-8.500	1051446.3862	6223098.7057	917795.8094	2014-09-09	2014-09-12	2016-01-02	4	
AA09	5.9567	80.5446	-89.364	1042162.3213	6257649.8339	657490.9938	2014-09-08	2014-09-13	2016-01-02	6	
AACH	50.7679	6.0884	263.286	4019427.7061	428731.1738	4917460.4109	2011-10-20	2011-12-23	2016-01-02	65	
AACR	9.9388	275.8821	1123.929	644009.0052	-6251064.2621	1093780.8637	2013-06-02	2015-11-07	2016-01-02	635	
AARS	50.9633	4.8361	104.668	4010937.4678	339354.2331	4931056.2586	2009-08-07	2015-12-17	2016-01-02	1647	
AASI	68.7193	307.2067	56.282	1403876.4604	-1849092.6568	5920733.5044	2007-06-01	2008-06-14	2016-01-02	376	

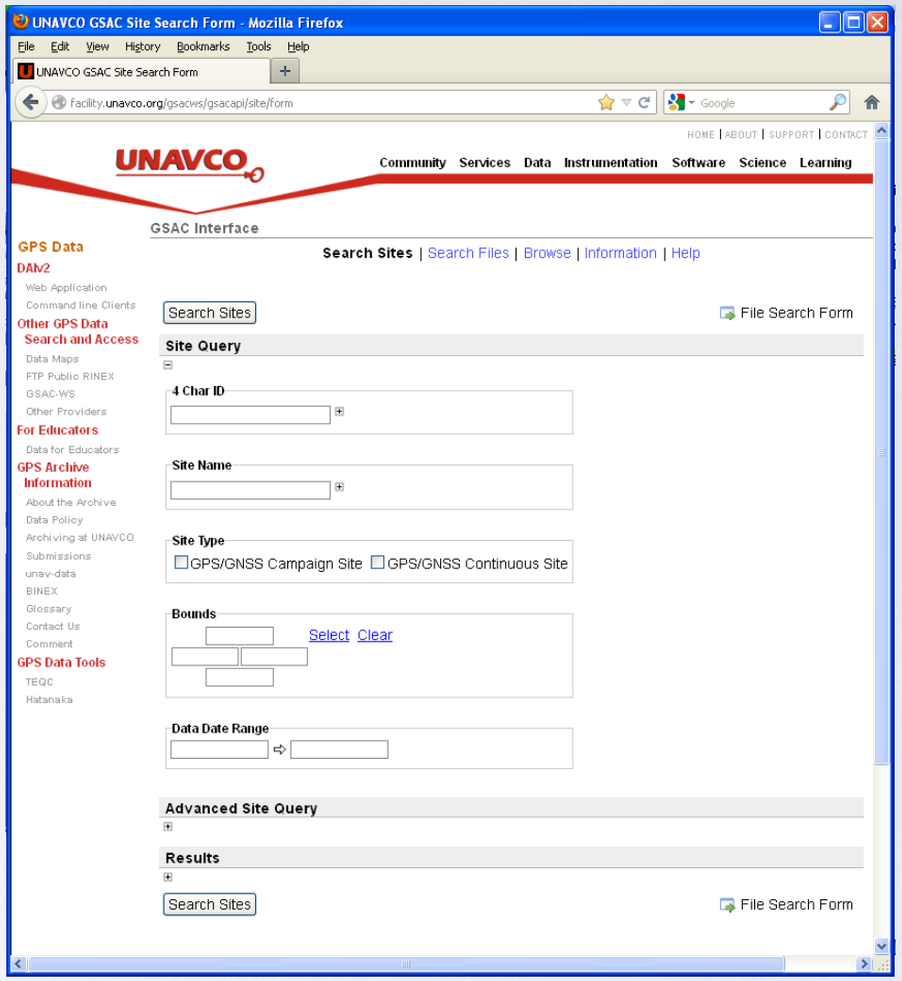
- Melgar, D., J. Geng, B.W. Crowell, J.S. Haase, W.C. Hammond, Y. Bock, R.M. Allen, 2015, **Seismogeodesy of the 2014 Mw6.1 Napa, California, Earthquake: Rapid response and modeling of fast rupture on a dipping strike-slip fault**, *Journal of Geophysical Research - Solid Earth*, **120**, doi:10.1029/2015JB011921. (PDF)

Stations with 5 minute sample rate solutions, rapid orbits, 24 hour latency.

Stations with 5 minute sample rate solutions, ultra rapid orbits, 1.5 h

Geodesy Seamless Archive Centers (GSAC) Web Services – A Software Package for Geoscience Data Centers





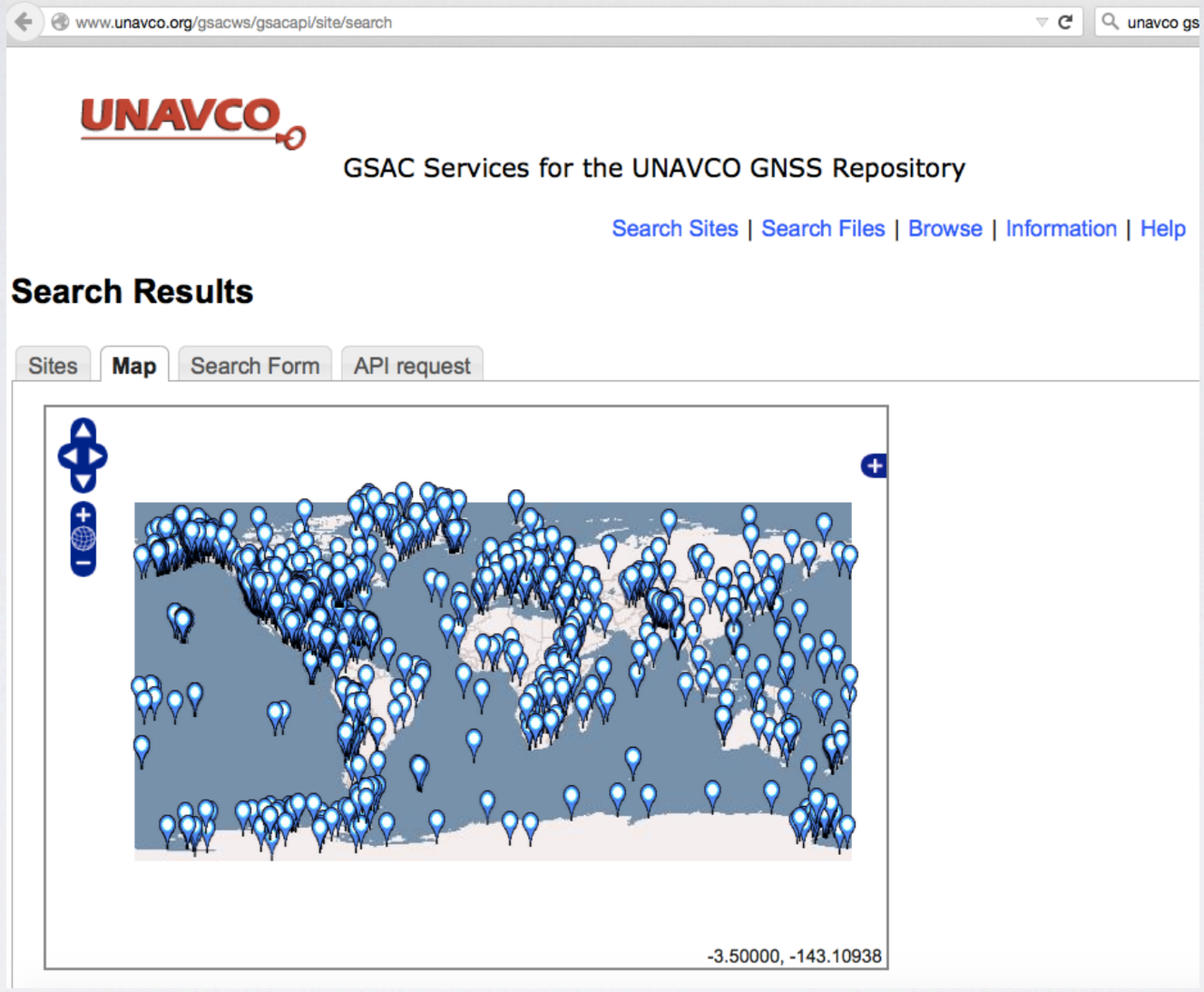
- Start with existing repository and metadata
- Small set of required metadata; any optional metadata
- Download Java code from Sourceforge project
- Simple installation and configuration

Upon installation and configuration GSAC provides:

- Web user interface
- Operating web services
- Documentation for users of web services API
- Ability to federate with other GSAC centers

Documentation http://www.unavco.org/software/data-management/gsac/gsac.html

Geodesy Seamless Archive Centers (GSAC) Web Services – UNAVCO Managed Repository



- The UNAVCO GSAC searches the UNAVCO archives only. UNAVCO hosts data from ~3,500 stations from many countries providing continuous data

Documentation http://www.unavco.org/software/data-management/gsac/gsac.html

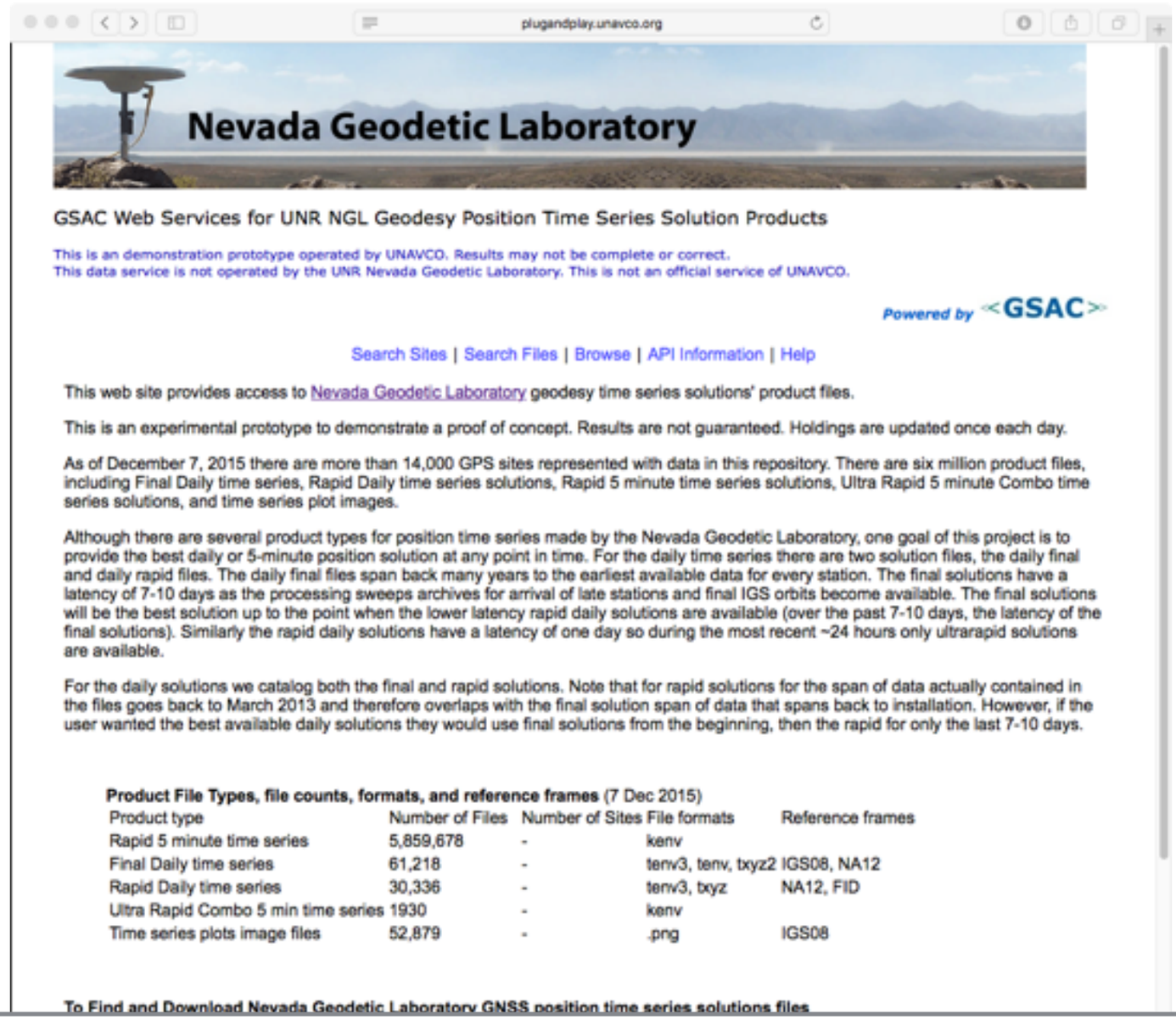
Plug and Play Data Products: An Introduction

Special GSAC Query for UNR files

http://plugandplay.unavco.org:8080/unrgsac/gsacapi/

Search for files including:

- Time series
- Plots (.png)
- Quality Control files
- In any latency
- In any frame
- specify sites
- specify data date ranges
- Many output options
- e.g. wget scripts for direct downloads
- Still under development



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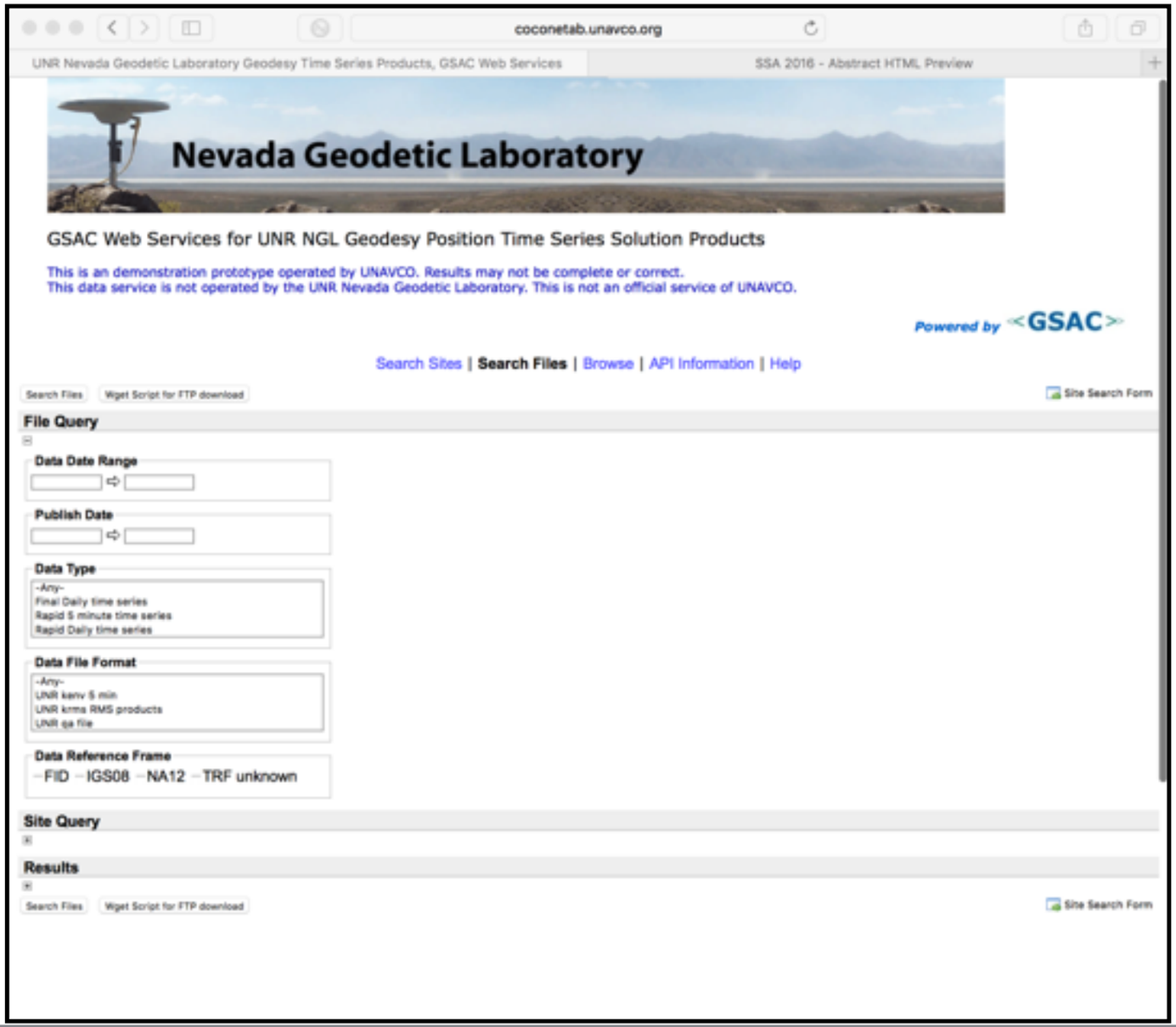

Simple Restful Web Service for Timeseries

UNR data using combined final and rapid files:
http://unagi.int.unavco.org:5000/gps/data/position/P378/v2?referenceFrame=igs08&analysisCenter=unr&starttime=2015-11-30T00:00:00&endtime=2015-12-02T00:00:00&tsFormat=iso8601&report=long

```
# fields: DateTime, X, Y, Z, X Std. Dev, Y Std. Dev, Z Std. Dev, XY Correlation, XZ Correlation, YZ Correlation, North
Latitude, East Longitude, Height,  North, East, Vertical, North Std. Dev.(m), East Std. Dev.(m), Vertical Std. Dev.(m),
NorthEast Correlation, NorthVertical Correlation, EastVertical Correlation, Solution
# field_unit: ISO 8601 datetime UTC, meters, meters, meters, millimeters, millimeters, millimeters, number, number, number,
degrees, degrees, meters, meters, meters, meters, meters, meters, meters, number, number, number, UTF-8
# field_type: string, float, float, float, float, float, float, float, float, float, float, float, float, float, float, float, float, float,
float, float, float, float, float, float, string
# attribution: http: www.unavco.org/community/policies_forms/attribution/attribution.html
# myURI: http://unagi.int.unavco.org:5000/gps/data/position/P378/v2?
referenceFrame=igs08&analysisCenter=unr&starttime=2015-11-30T00:00:00&endtime=2015-12-02T00:00:00&tsFormat=iso8601&report=long
# XYZ Reference Coordinate: x: -2475699.7712 y: -3822330.29648 z: 4450718.27949
# Applied Offset: x: 0 y: 0 z: 0
2015-11-30T00:00:00,-2475699.869468970224261,-3822330.289946420118213,4450718.256974049843848,0.000860970301321,0.0011497148740
99,0.001277278291350,0.773765182532420,-0.769955989181483,-0.701141881563536,44.534981963033061,-122.930882522434459,83.1209957
33886957,-49.6688164866,-86.0351683839,18.3794425503,0.4624840289,0.6436160957,1.7511198786,-247.6263002044,-173.2377149944,-77
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2015-12-01T00:00:00,-2475699.868869829922915,-3822330.288743469864130,4450718.255798240192235,0.000875976771472,0.0011700849172
12,0.001274559446847,0.779128063274658,-0.771200678588542,-0.707302465449681,44.534981963918717,-122.930882524335260,83.1192191
97891653,-49.5704001640,-86.1862498952,16.6029079022,0.4652102570,0.6454525118,1.7685887801,-232.8672141550,-172.2778330665,-11
0.1741539511,rapid
```

Plug and Play Data Products: An Introduction

Velocity Fields

- MIDAS… what is it?
- How to get it.
- Caveats

MIDAS: Robust Trend Estimator for Accurate GPS Station Velocities Without Step Detection

Geoff Blewitt
Nevada Geodetic Laboratory
University of Nevada, Reno, USA

co-authors:
Corné Kreemer, Bill Hammond, and Julien Gazeaux

AfricaArray workshop - January 20, 2016 - University of the Witwatersrand - Johannesburg, South Africa

Robust Velocity Estimator (MIDAS): Median temporal filtering

- **MIDAS is based on Theil-Sen (1950), with the following innovations:**

1) Median difference of solutions 365 days apart

$$\hat{v} = \text{median}_i \left(x_{i+365} - x_i \right)$$

- insensitive to seasonality AND steps

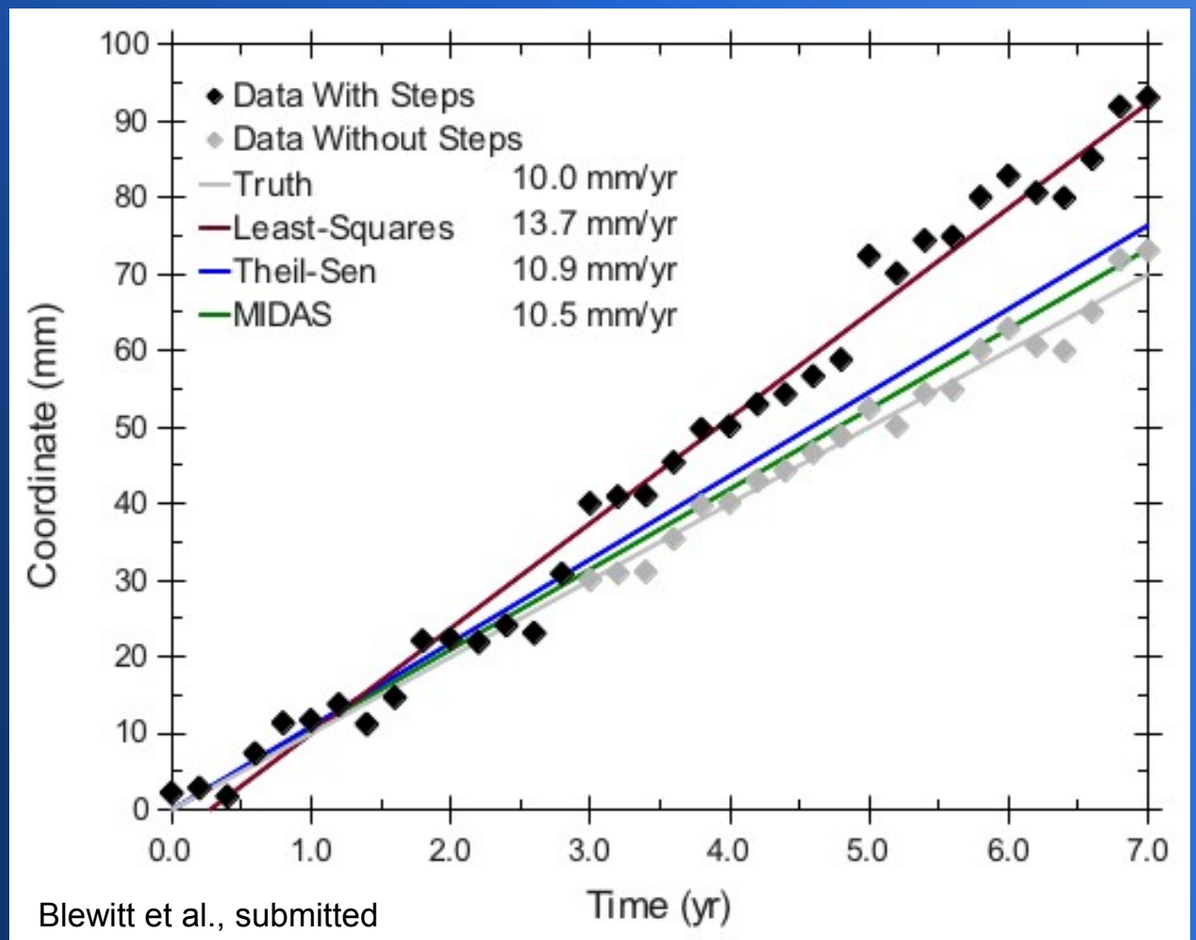
2) Robust estimate of standard deviation

$$\sigma = 1.4826 \, \text{median}_i \left| x_{i+365} - x_i - \hat{v} \right|$$

3) Remove 2-sigma tails and recompute median

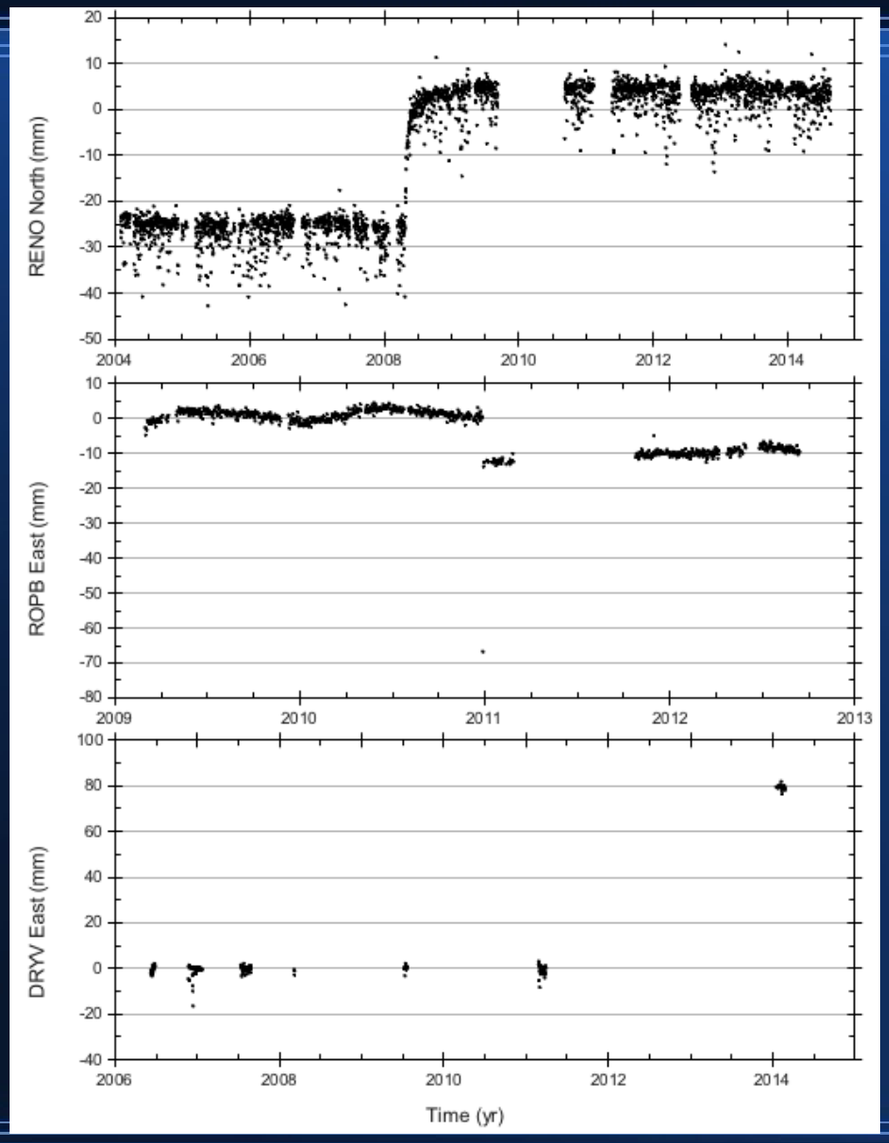
4) Compute MIDAS velocity uncertainty

$$\sigma_v = 1.2533 \frac{\sigma}{\sqrt{N/4}}$$



Blewitt et al., submitted

MIDAS (median temporal filter) velocity is insensitive to steps



- **Detrended time series**
  - Station affected by M_w5.0 earthquake 2008/04/26
  - Station with undocumented equipment change
  - Campaign station monument vandalized and replaced

UNAVCO

MIDAS SUMMARY

Key Points on MIDAS

- Automatic, non-parametric estimator of time-series trend
- GPS velocities are robust to outliers, steps, and seasonality
- Velocities are the most accurate of all automatic methods tested

Operations

- MIDAS velocities now updated weekly > 13,700 stations

Open Access

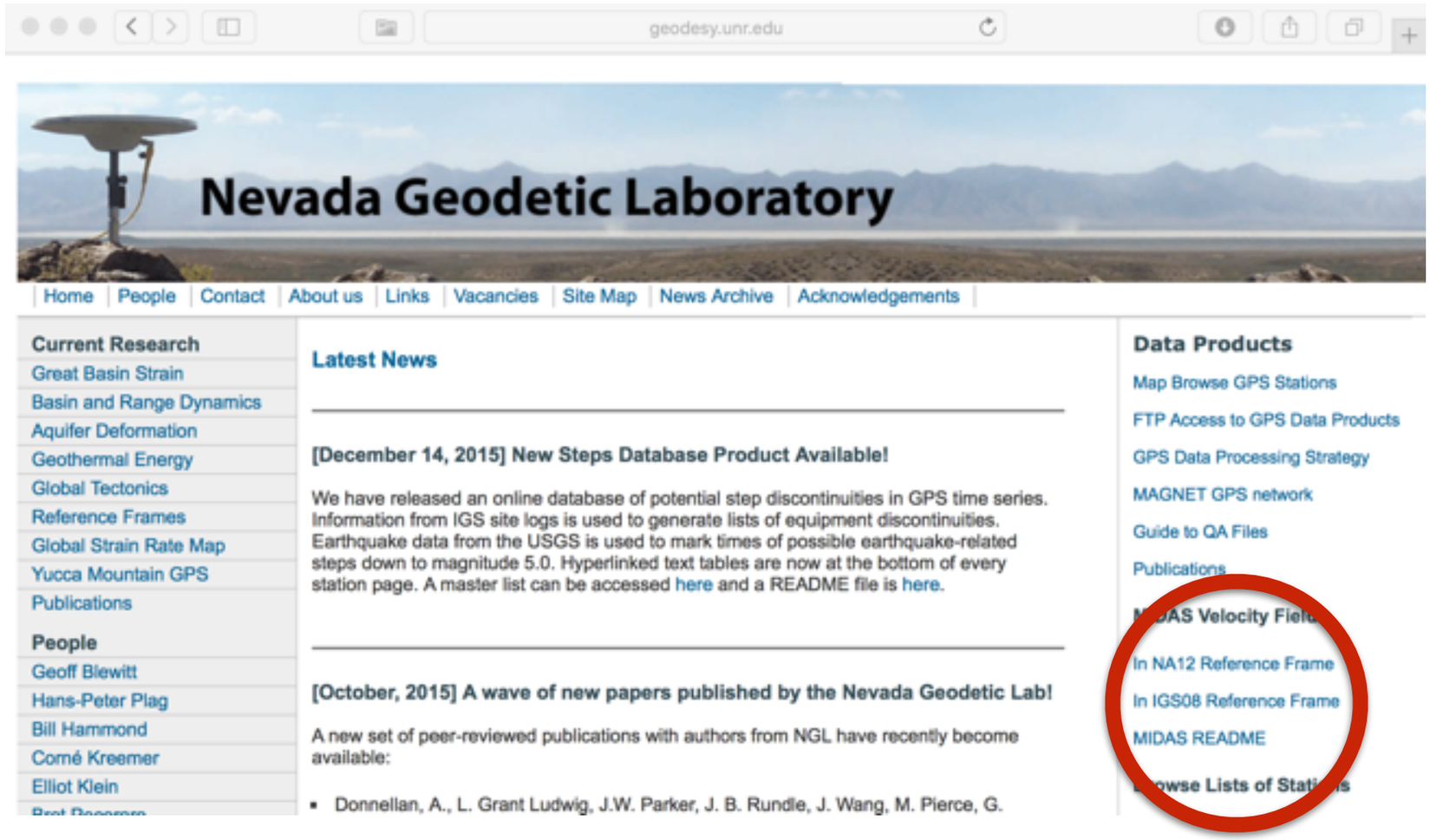
- Make MIDAS JGR paper freely available
- Make MIDAS velocities public
- Make MIDAS software public

Plug and Play Data Products: An Introduction

MIDAS velocity field

How to get it

- Go to NGL Data products
- Hit the link…
- Consult the README for column definitions



Also soon to appear as an option on the UNAVCO velocity field plotter:
https://www.unavco.org/software/visualization/GPS-Velocity-Viewer/GPS-Velocity-Viewer.html

Plug and Play Data Products: An Introduction

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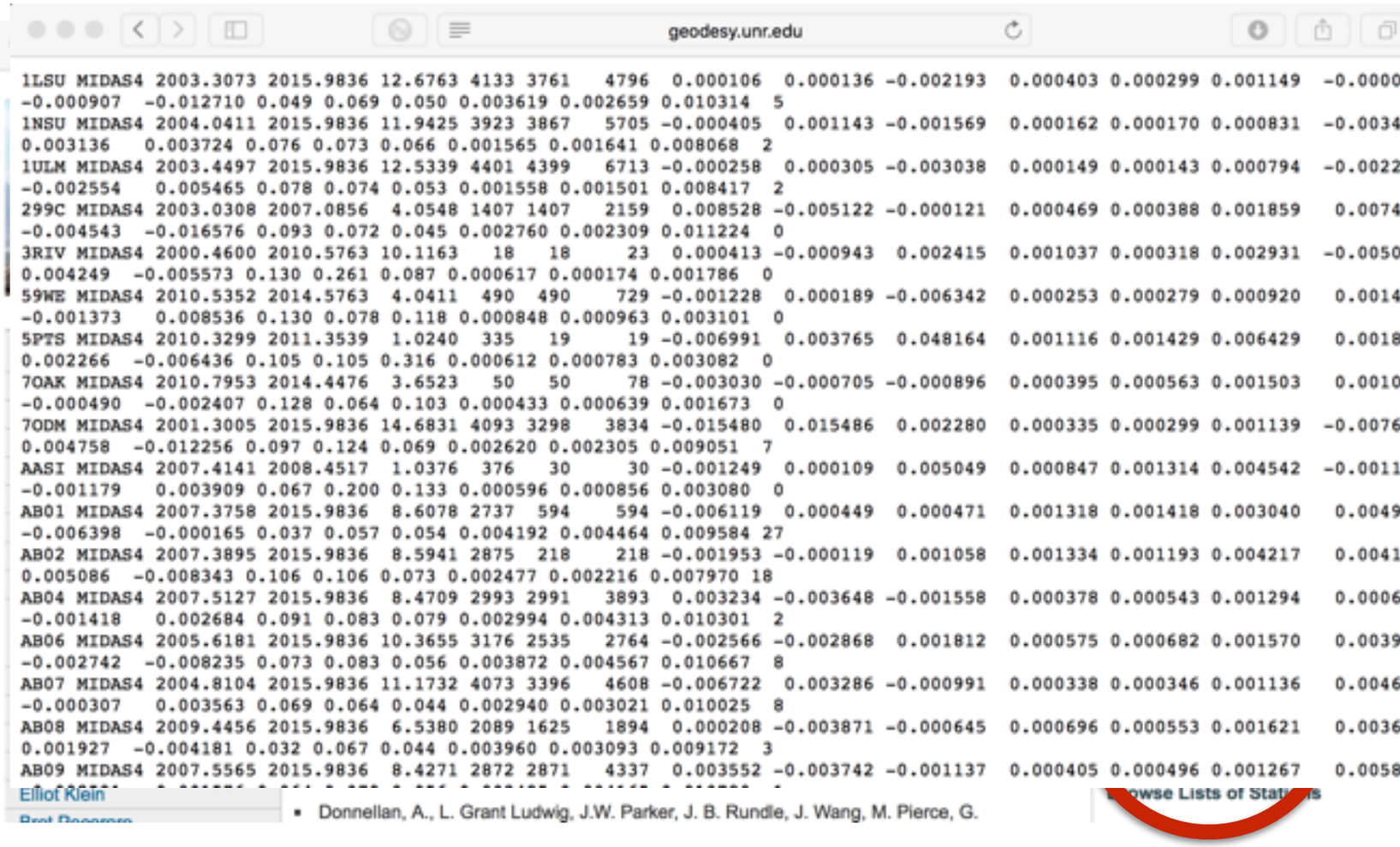


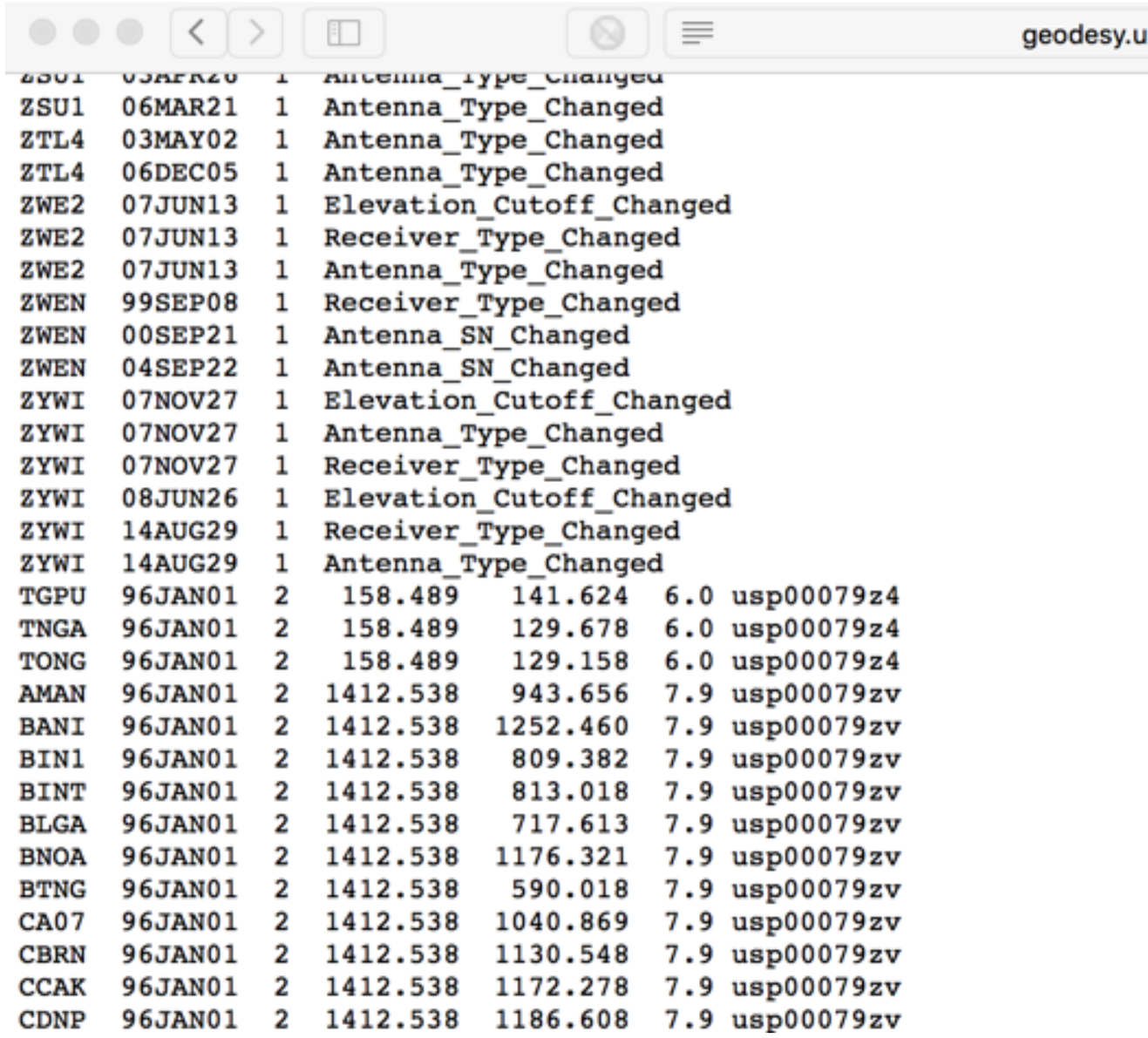
Also soon to appear as an option on the UNAVCO velocity field plotter:
https://www.unavco.org/software/visualization/GPS-Velocity-Viewer/GPS-Velocity-Viewer.html

MIDAS Properties and Caveats

- Available in IGS08 and NA12 frames only right now
- Applied to all time series over 1 year in duration
- Automatically generated. No hands on review.
- Steps and outliers ignored.
- If time series is non-linear, median-based algorithm picks one velocity (the mode)
- Does not necessarily represent strain accumulation part of seismic cycle only.

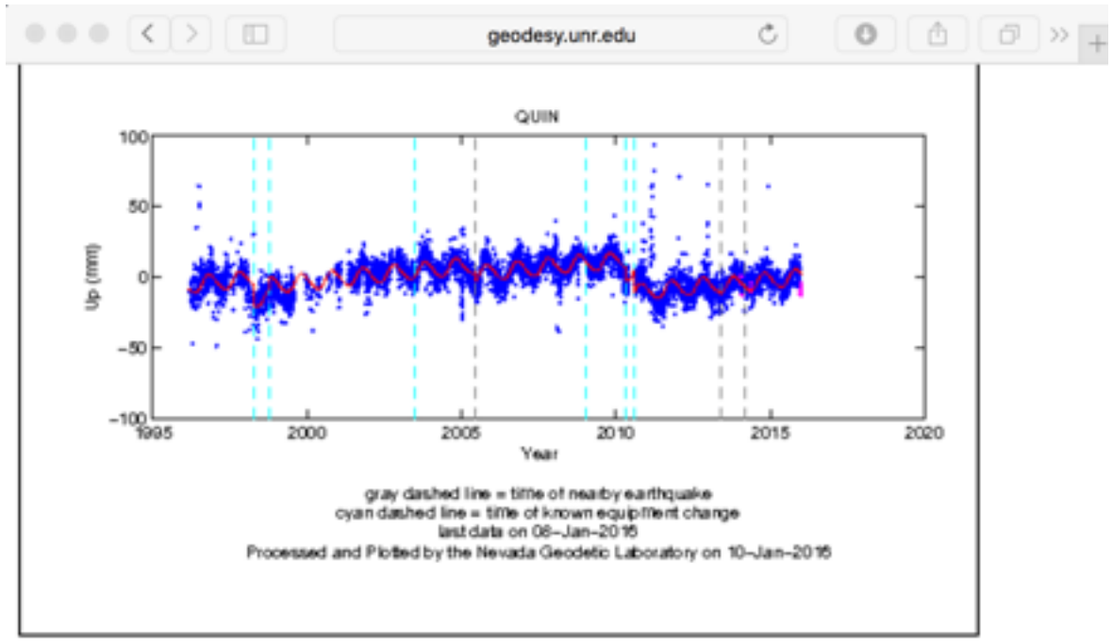
Steps and Discontinuities Database

- Earthquakes and equipment change events often cause discontinuities in time series.
- Important to know when these occur
- Get our list of known events from our Data Products section of http://geodesy.unr.edu
- Marked for equipment if change of antenna, receiver, radome in log file.
- Earthquake marked if epicenter is with distance function of magnitude from station
- Links to USGS event page provided
- Also see tables specific for each station at the bottom of each Station Page



Steps and Discontinuities Database

- Earthquakes and equipment change events often cause discontinuities in time series.
- Important to know when these occur
- Get our list of known events from our Data Products section of http://geodesy.unr.edu
- Marked for equipment if change of antenna, receiver, radome in log file.
- Earthquake marked if epicenter is with distance function of magnitude from station
- Links to USGS event page provided
- Also see tables specific for each station at the bottom of each Station Page



Steps Information for this station

Station ID	Date (YYMMMDD)	Code	Type/EventID
QUIN	98APR01	1	Antenna_SN_Changed
QUIN	98OCT13	1	Antenna_SN_Changed
QUIN	03JUL09	1	Receiver_Type_Changed
QUIN	09JAN15	1	Antenna_Type_Changed
QUIN	10MAY07	1	Radome_Changed
QUIN	10AUG12	1	Radome_Changed
QUIN	05JUN15	2	iscgem7143782
QUIN	13MAY24	2	nc71996906
QUIN	14MAR10	2	nc72182046

Code=1 is time of an equipment change from IGS log file (antenna, receiver or firmware change)

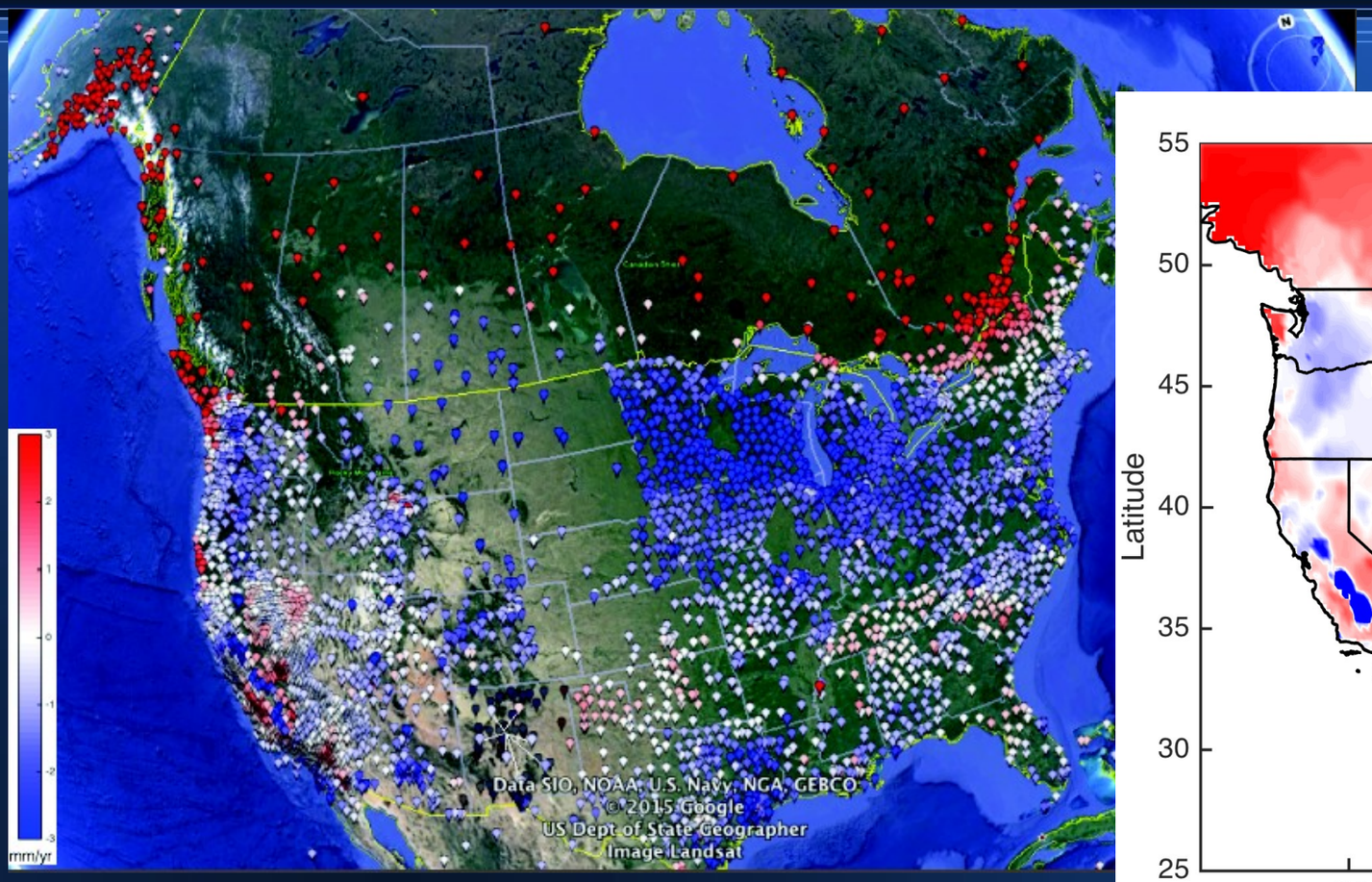
Code=2 is possible earthquake step where epicenter is within 10^(0.5*mag - 0.8) degrees of station

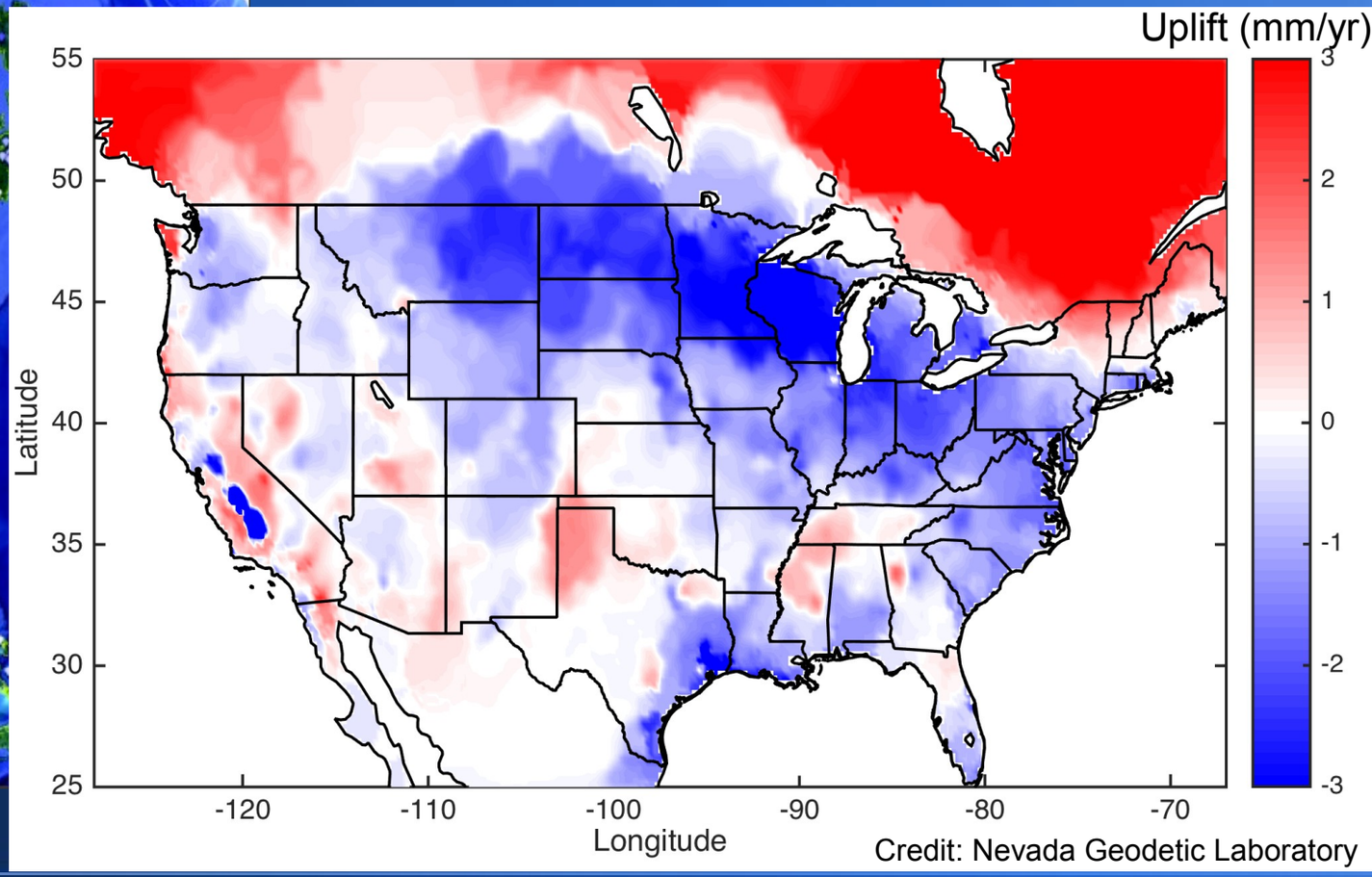
Link to full steps file for all stations.

Products Coming Soon
(some Imminent, some Aspirational)

- More reference frames for existing products: e.g. tectonic plate based frames for Africa, South America, Eurasia, Pacific
- Median spatial filtered velocities
- Uplift Maps based on GPS imaging (flat maps and .kml)
- Better time series plotting tools
- Strain rate maps
- Earthquake offset pages, put out with lowest possible latencies

GPS data can now be used to image uplift.

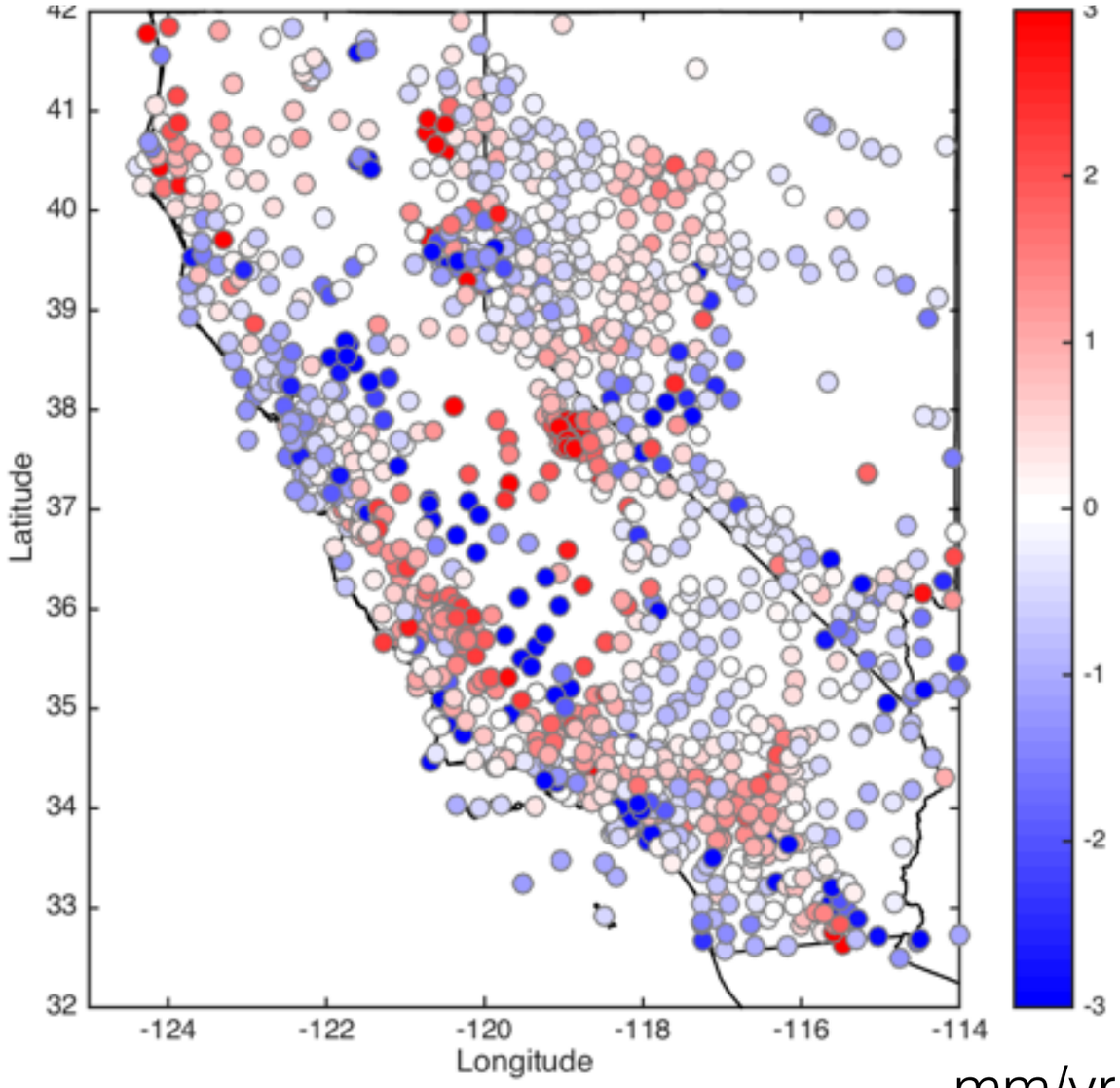




Credit: Nevada Geodetic Laboratory

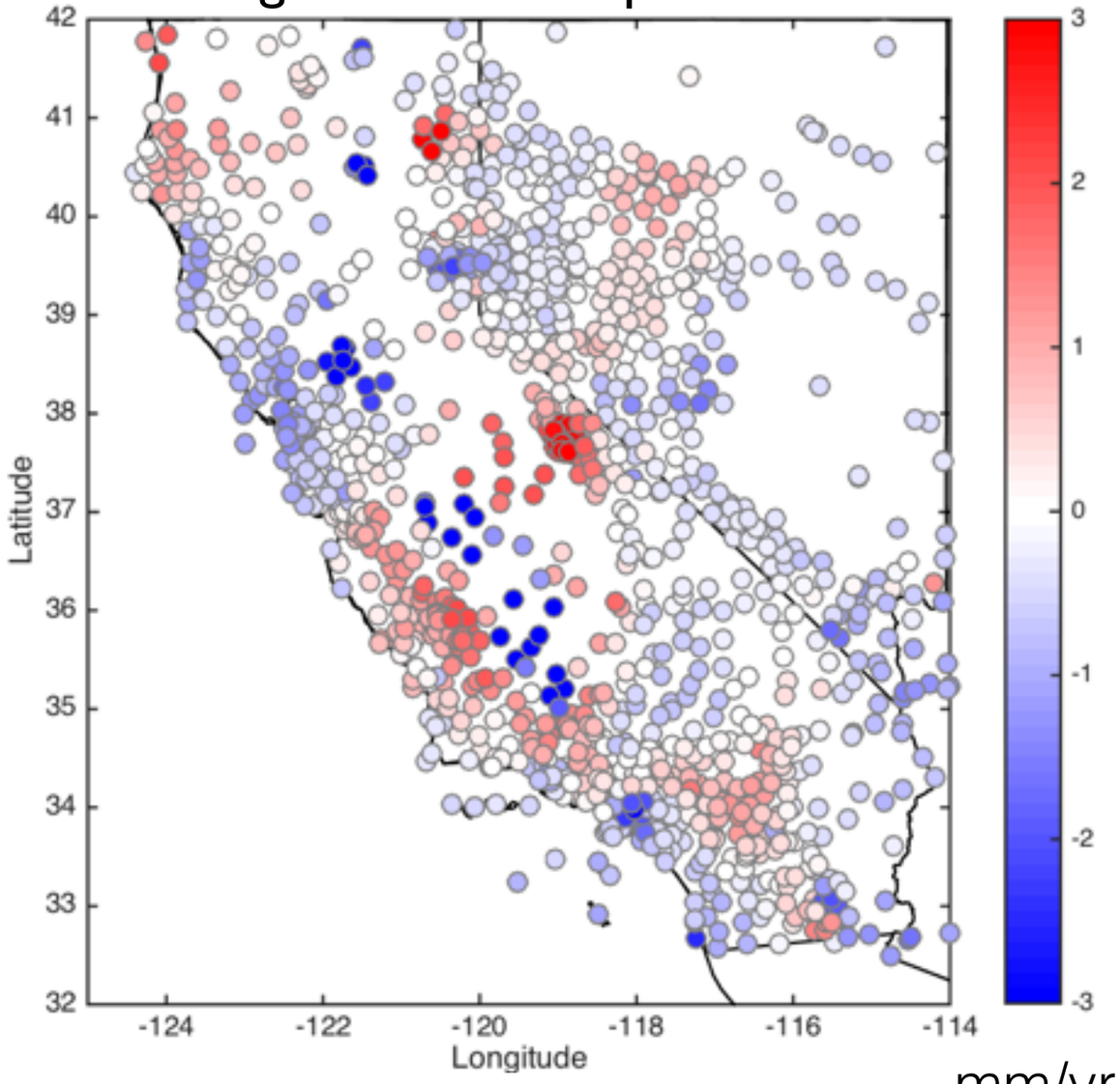
Median Spatial Filtering of GPS Velocities

MIDAS Vertical Rates



mm/yr

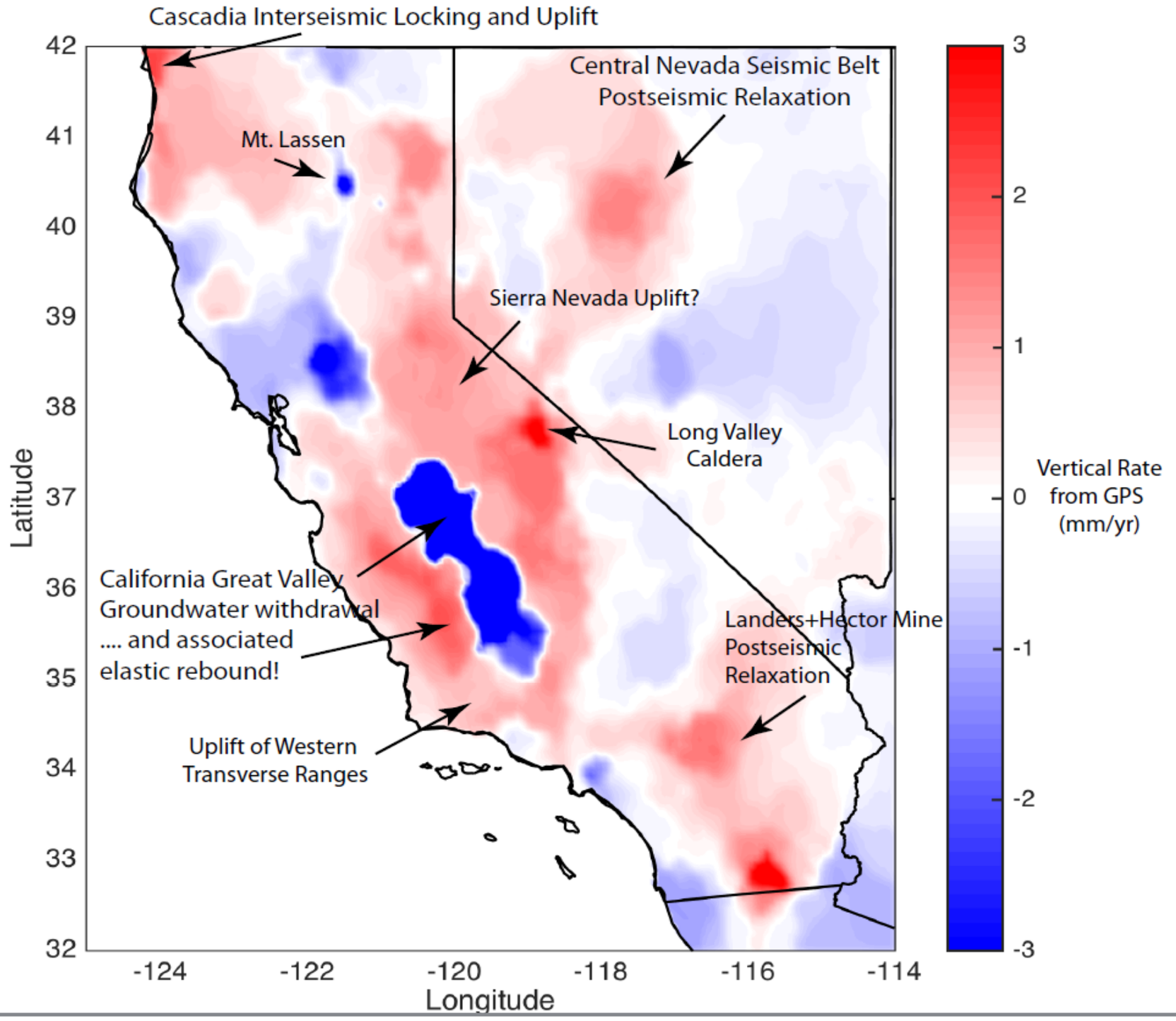
MIDAS Rates Despeckled
Weighted-Median Spatial Filtered



mm/yr

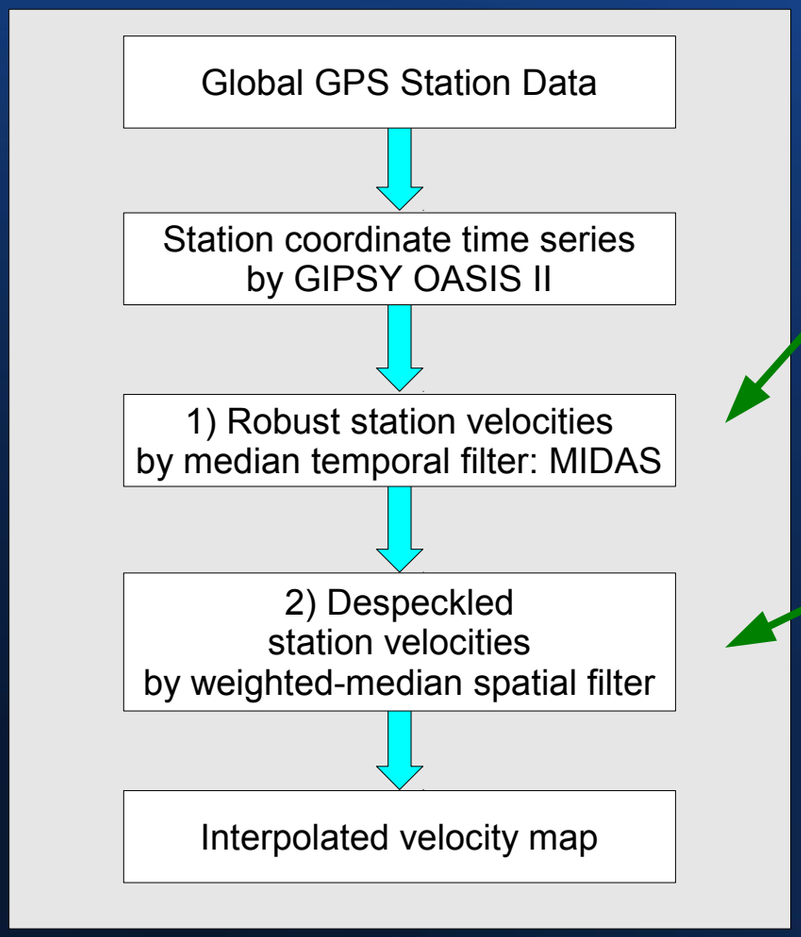
Plug and Play Data Products: An Introduction

"GPS imaging"



“GPS Imaging”

How does GPS Imaging work?



1) Median filtering in the temporal domain

- MIDAS robust trend estimator
  - Based on Theil-Sen (1950, 1968)
- Find the median trend between pairs of points separated by 365 days
- Robust to outliers, seasonality, step functions

2) Median filtering in the spatial domain

- Voting scheme on the Delauney triangulation
- Despeckles images; robust to spatial outliers
- Preserves linear boundaries between domains
- Honors the inherent resolution of the network

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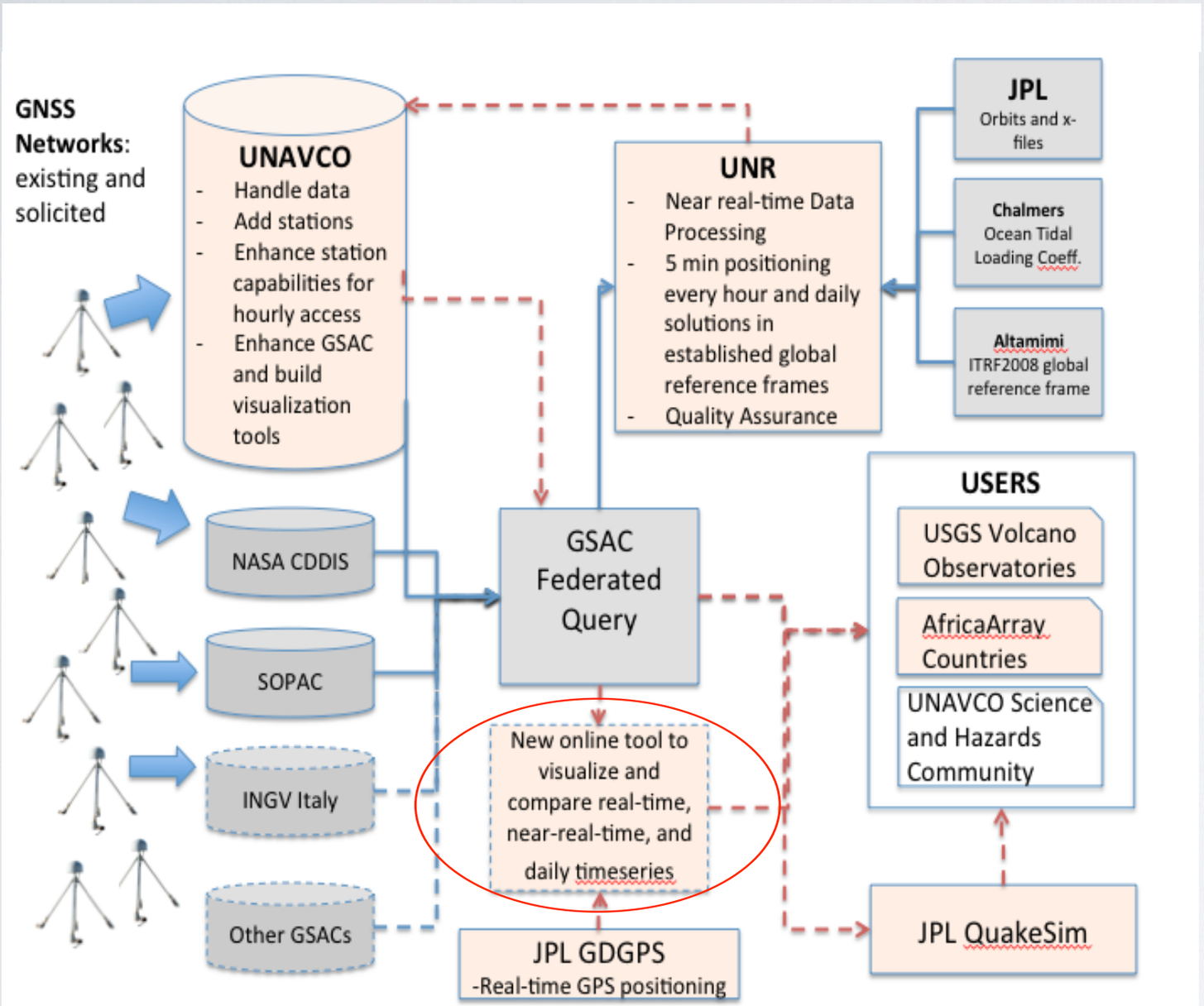
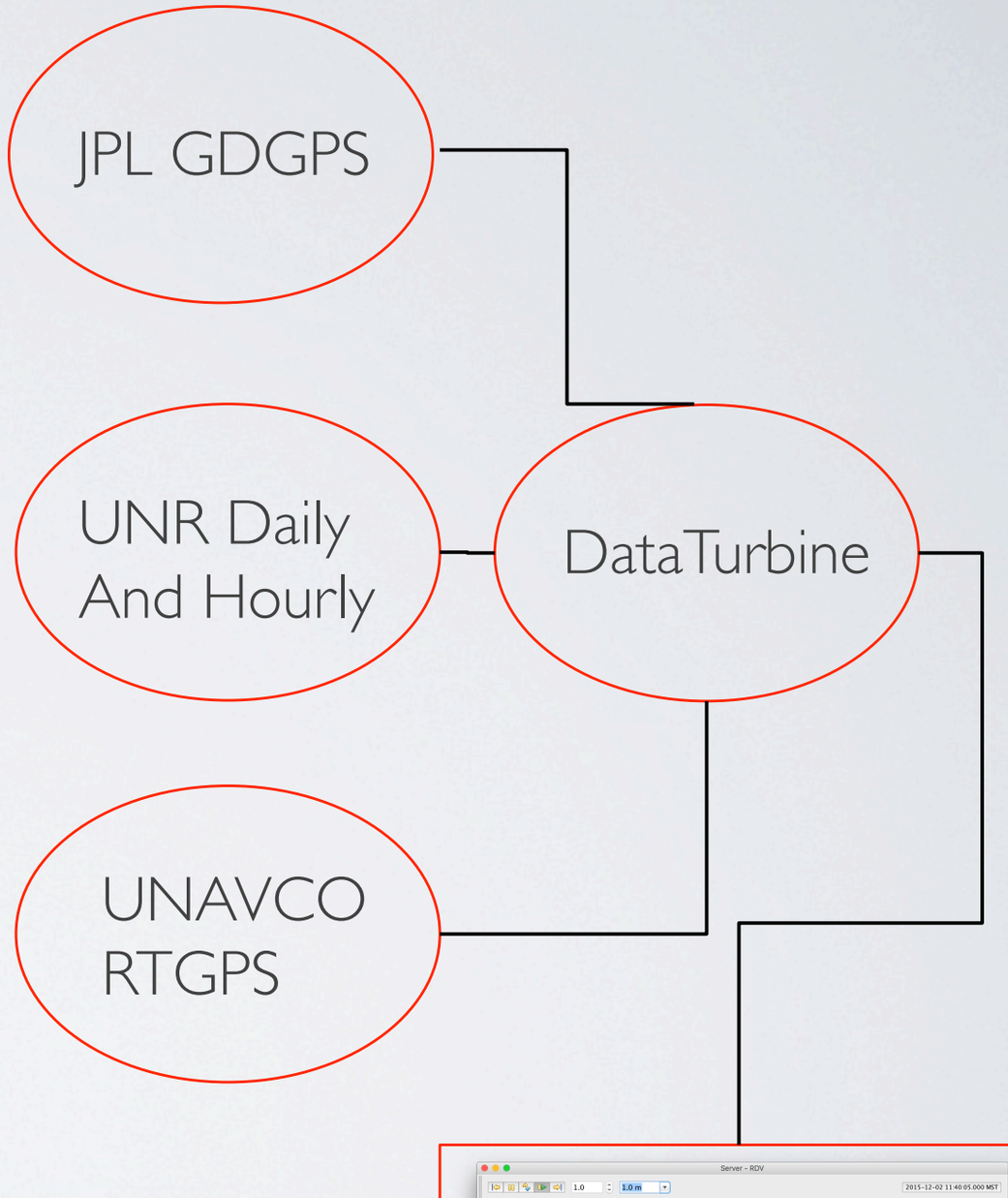
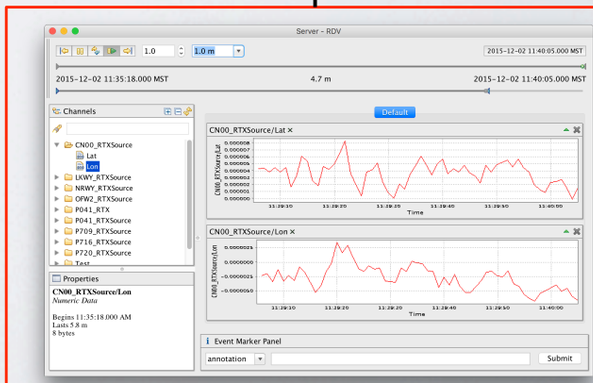
Plug and Play Conceptual Workflow
Multi-sample, latency Buffer and Display







UNAVCO

DataTurbine

www.dataturbine.org

dataturbine

OPEN SOURCE DATA TURBINE INITIATIVE

Empowering the Scientific Community with Streaming Data Middleware

Home | News | Publications | Documentation | Sensor Pod | Download | Contact Us

User login

Username *

Password *

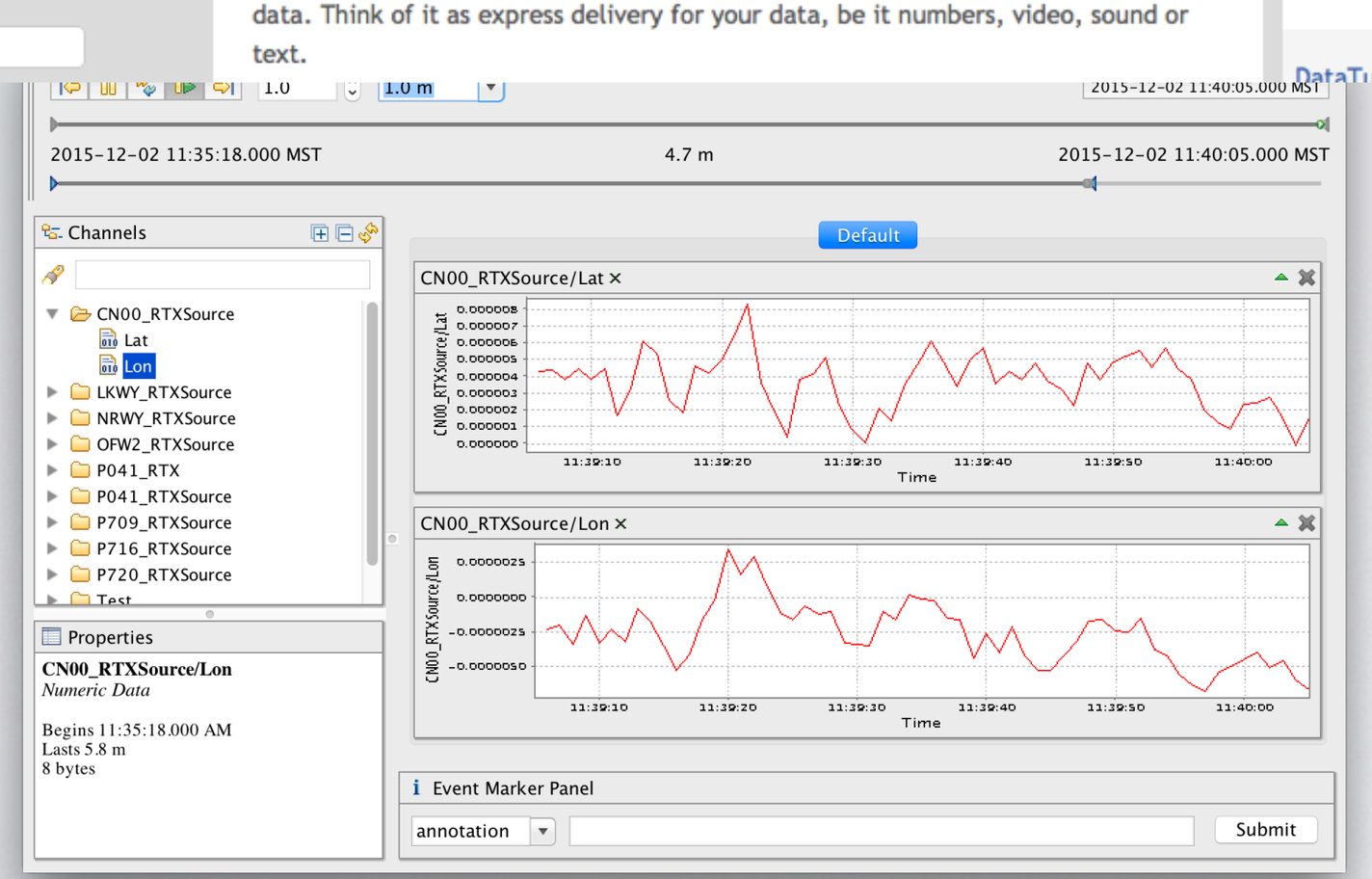
DataTurbine

In a Nutshell

DataTurbine is a *robust real-time streaming data engine* that lets you quickly stream live data from experiments, labs, web cams and even Java enabled cell phones. It acts as a "*black box*" to which applications and devices send and receive data. Think of it as express delivery for your data, be it numbers, video, sound or text.

Latest News

OSDT Usability Survey	Sep 29 2015
New OSDT Flyer Available	Sep 15 2015
DataTurbine V3.4R3 Now Available	Jun 11

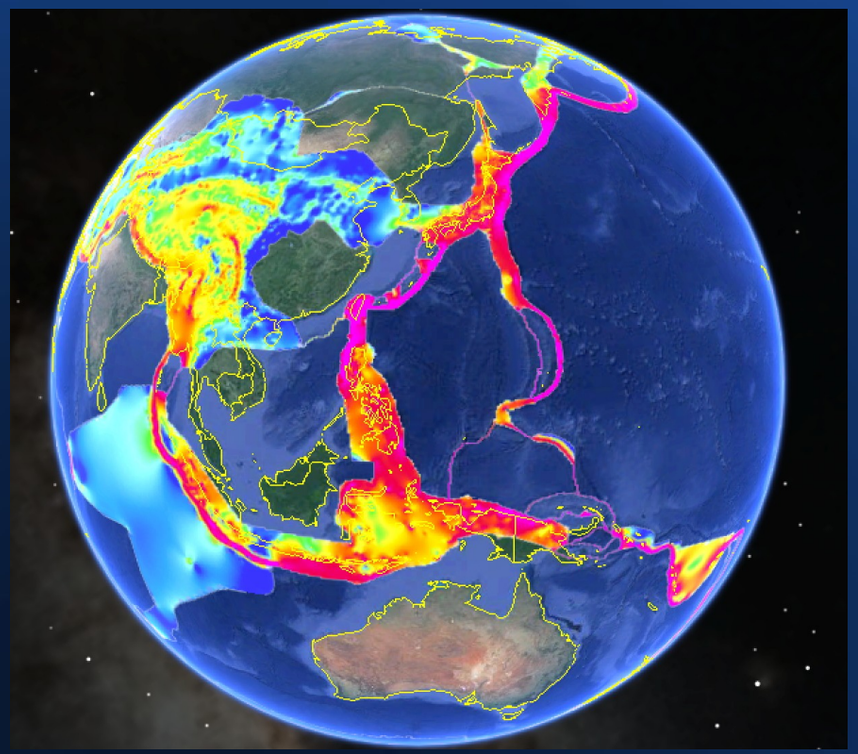


Daily, hourly and streaming 1 sec GPS data and strainmeter data will be ingested into a DataTurbine providing a time-buffered storage and common access for plotting and viewing.

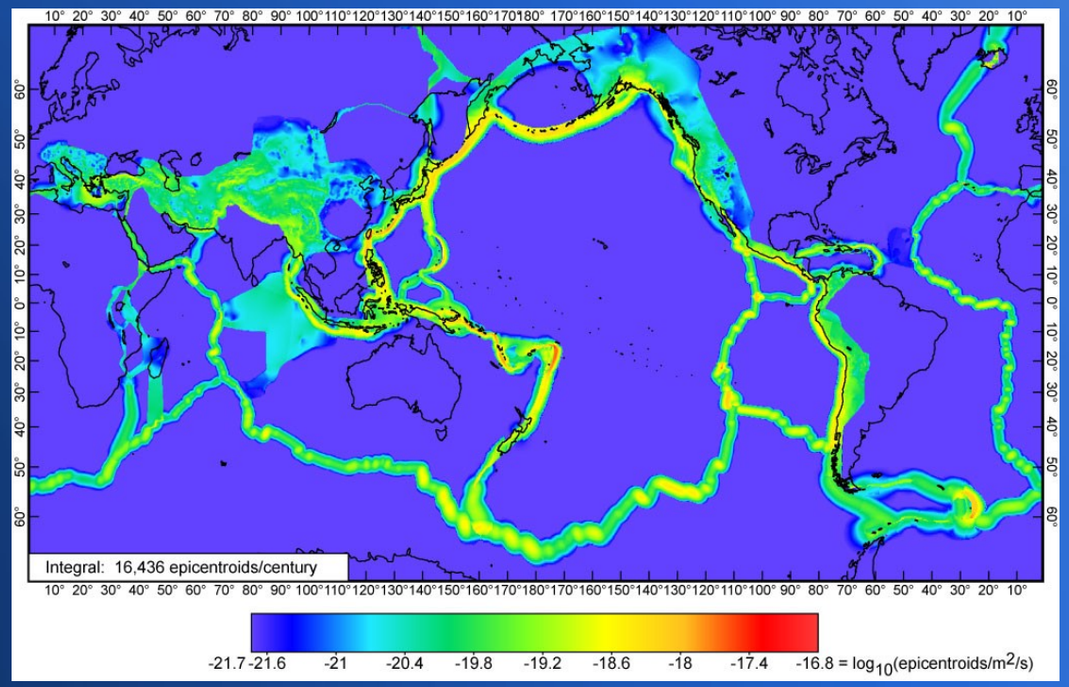
Strain Rate Maps

GPS data are used to image crustal deformation.

- **Global Strain Rate Map** [Kreemer et al., 2014]



- **Earthquake Forecast** [Bird & Kreemer, 2015]



Products Coming Soon
(some Imminent, some Aspirational)

Suggestions Welcome!

End of Section on Description of Data Products

Questions?

How To Participate and Sign Up (The *Plug*)

The Basic Arrangement

1) **You** put your data online so UNAVCO can access it

2) **We** provide data products, free of charge

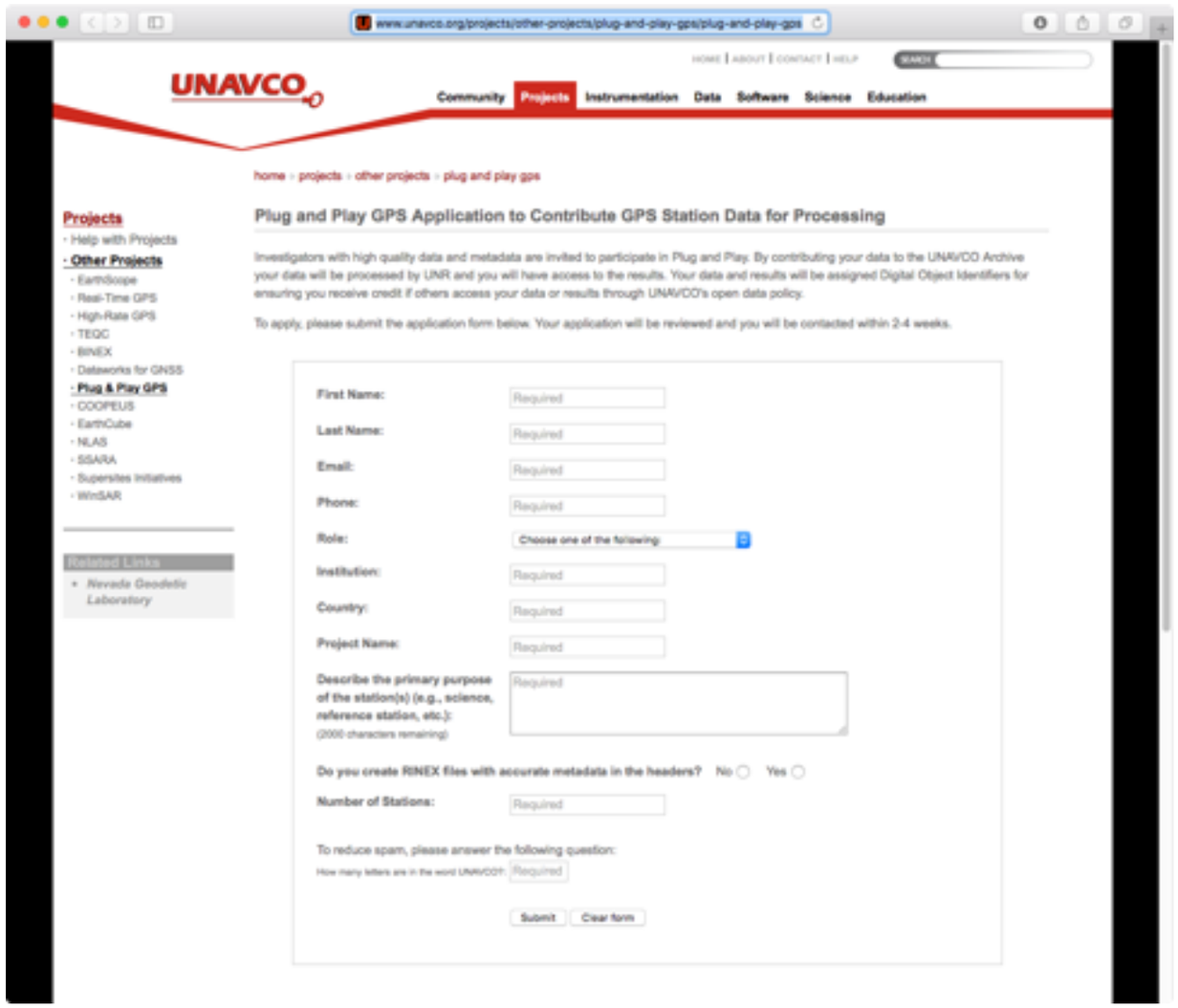
3) **Access** to data products remain open and unrestricted to all

How To Participate and Sign Up (The *Plug*)

Easy! Go To:

http://www.unavco.org/projects/other-projects/plug-and-play-gps/plug-and-play-gps-application.html

- Takes you to UNAVCO's registration form
- Very Simple:
  - Name
  - Email
  - Phone number
  - Role
  - Country
  - Project Name
  - Describe primary purpose of station (e.g. Science, reference station)
  - Do you create RINEX with accurate metadata in the headers? (Y/N)
  - Number of stations

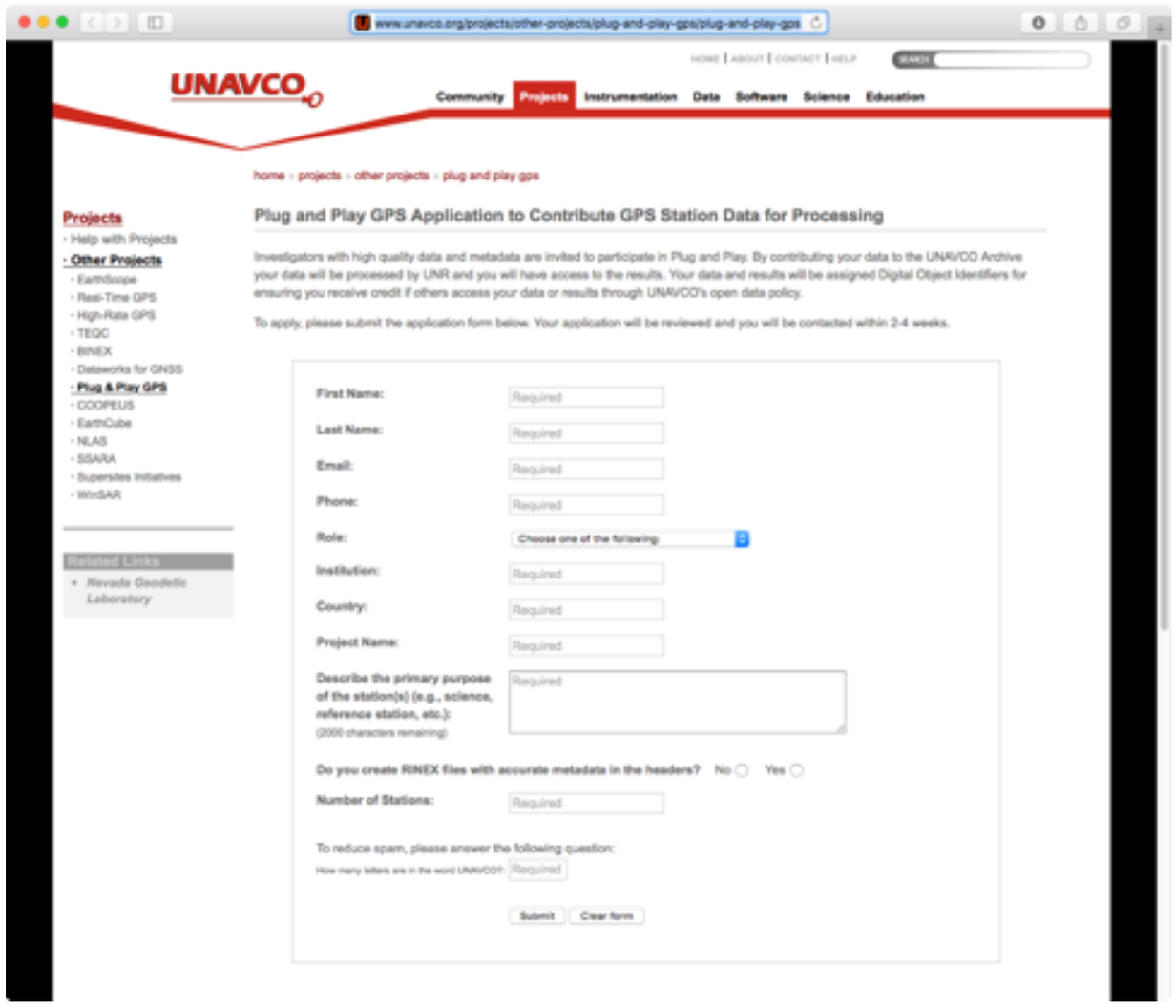


- Sends and email to the PnP Team Members

How To Participate and Sign Up (The *Plug*)

Then What?

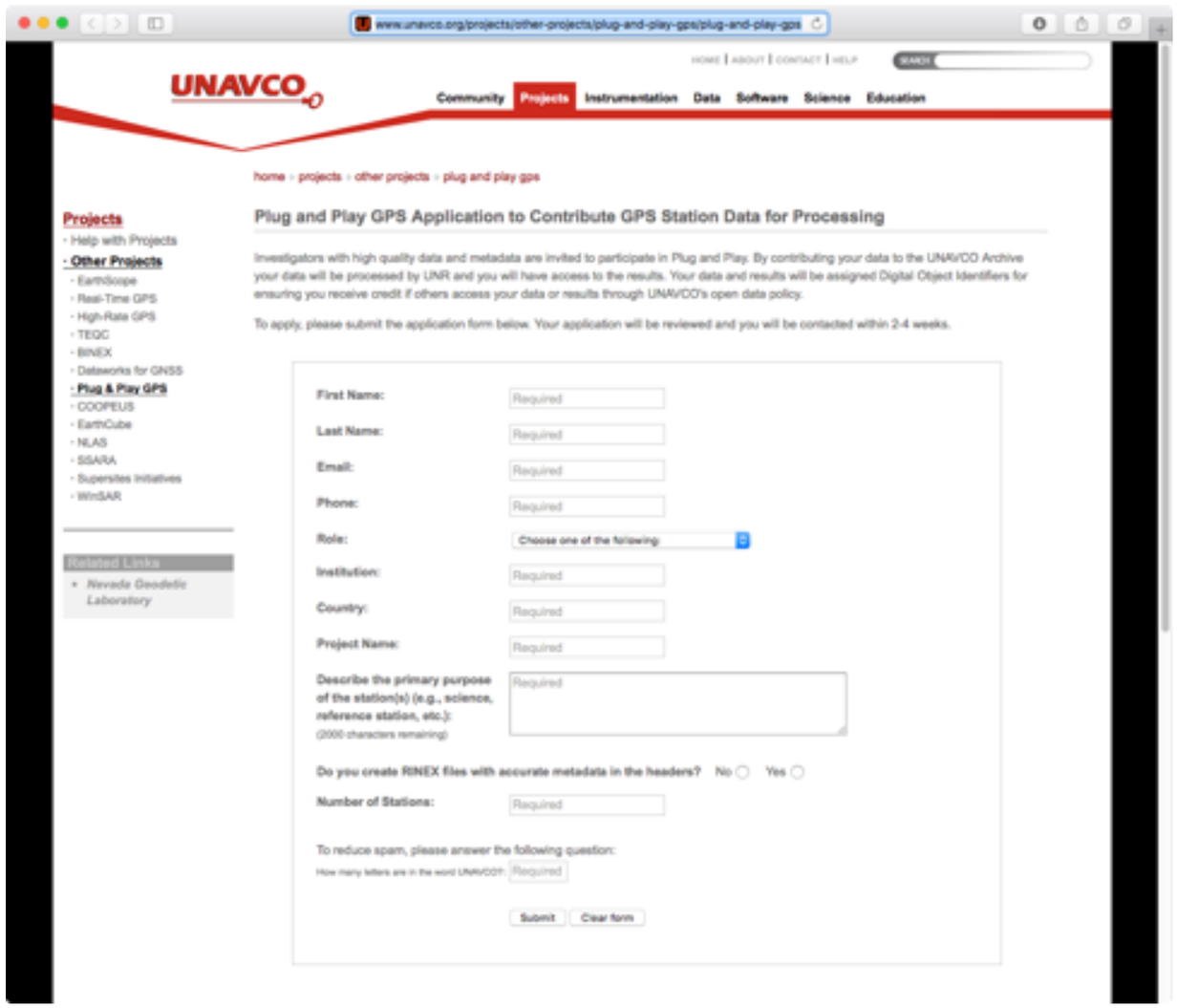
- Someone will contact you, email probably.
- This is new, rollout this week.
- Beta Mode
- Who will be first?
- You will get instructions on how to get RINEX to UNAVCO
  - directory structures, etc.
- Review of data, possibly you will get some feedback on suitability/completeness of data
- Metadata are crucial. Compete headers needed!
- Once UNAVCO approves UNR will be made aware of it and pick it up for processing + products.



How To Participate and Sign Up (The *Plug*)

Then What?

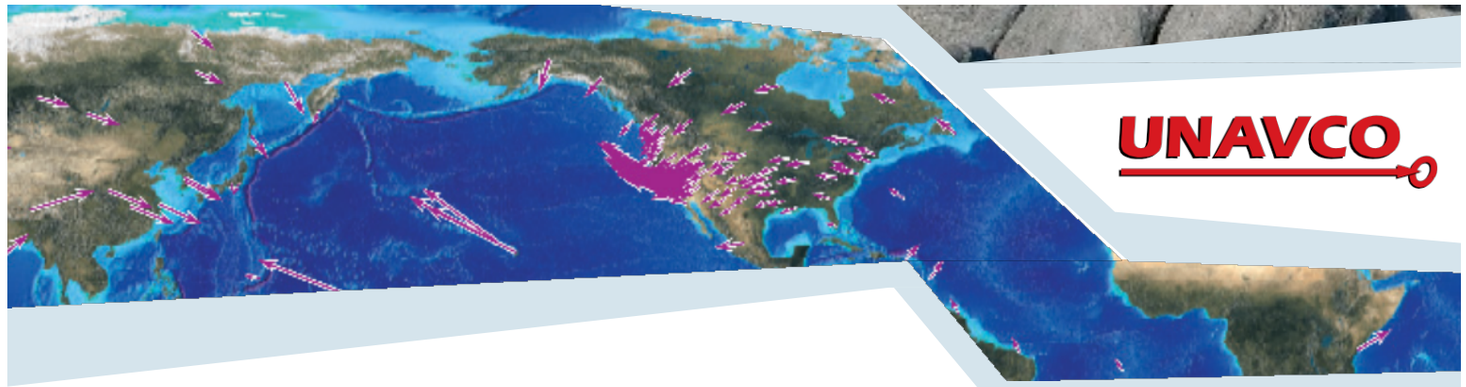
- We know this works because we already are doing it
- How is this different than what we do now?
- Check and see if your data are already in our system.



How To Participate and Sign Up (The *Plug*)

See One Page Handout on Plug and Play:

Has clickable link so you don't have to remember it all.

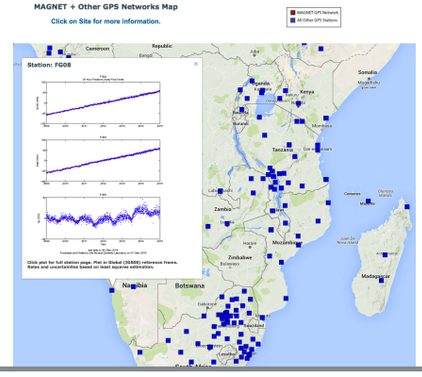


UNAVCO

Plug and Play GPS for You!

Access to the benefits of high precision, low-latency position time series from global GPS networks is currently limited by the need to have advanced expertise and systems for data acquisition and processing. We are taking steps to remove these barriers by developing a system capable of processing all GPS data available in open archives. Currently we process data from over 14,000 continuously operating stations from around the globe. For openly contributed data, this rigorous and automated system provides processed data products (e.g. position time series, plots, velocities, etc.) free of charge. Results are provided with low latency suitable for rapid modeling and analysis of natural hazards from earthquakes, tsunamis, volcanoes, hydrologic changes, and other applications.

UNAVCO, a non-profit, membership-governed consortium, supports and promotes Earth science by advancing high-precision techniques for the measurement and understanding of deformation. UNAVCO also supports education to meet the needs of the community and the public.



Plug and Play GPS Processing

We will provide you with daily and 5-minute position time series and quality control products, with latency between 2 hours and 1 day depending upon data availability. The University of Nevada, Reno (UNR), processes contributed data using products provided by the Jet Propulsion Laboratory (JPL), including ultra-rapid GPS orbits and clock parameters, and JPL's GIPSY/OASIS II software. The processed time series are presented in global (IGS08) and North America (NA12) reference frames.

Participating in Plug and Play

Plug and Play GPS participants submit high quality data and metadata to the UNAVCO Archive where the Data Center services provide data ingestion, access, formatting and cataloging of accurate metadata including proper source attribution. UNR then picks up hourly

Getting Started: How to Contribute Your GPS Data

To get started, fill out a short web form describing your data at http://www.unavco.org/projects/other-projects/plug-and-play-gps/plug-and-play-application.html

Accessing Processed Results

Time series plots and files, and post-processed station quality control factors, are cataloged in a Geodetic Seamless Archive Centers (GSAC) database that is searchable and accessible via web browsers or via newly developed simple RESTful web services. Products themselves are located at the UNR Nevada Geodetic Laboratory (http://geodesy.unr.edu/). To promote open exchange, processed data products are made openly available to all.

UNAVCO

Nevada Geodetic Laboratory

NEVADA

NASA

How To Participate and Sign Up (The ***Play***)

See Previous Data Products Section

- Once in the system all data are brought through to products
- Caveat: MIDAS rates require >1 year of data before they are produced
- (Uplift maps usually need >4 or 5 years)
- But time series should be available very quickly.
- Conceivably within hours of if hourly files are provided.

How To Participate and Sign Up (The *Play*)

What you can do right now

Browse the data products
Use the data products
Incorporate data products into your workflow
Incorporate data products into educational resources
See examples case study on Napa M_W6.0 earthquake

Provide feedback to us!
whammond@unr.edu

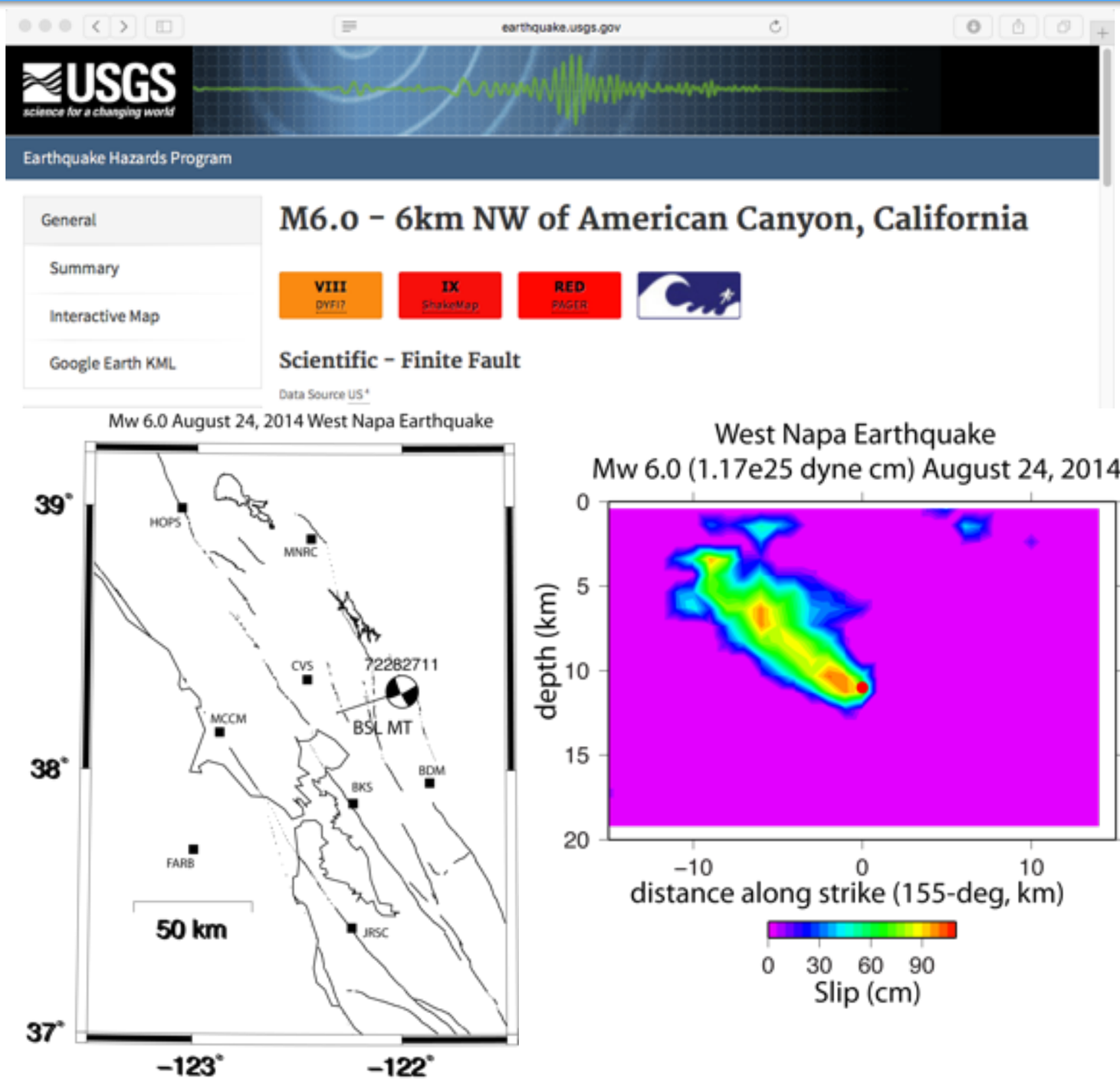
UNAVCO
Nevada Geodetic Laboratory
NEVADA
NASA

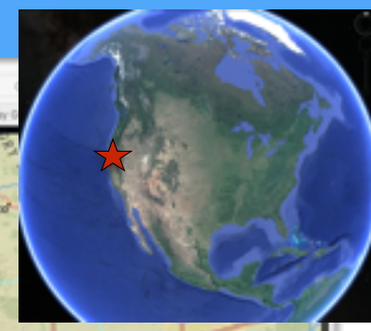
How To Participate and Sign Up (The ***Play***)

Questions?

Case Study: The August 24, 2014 Napa M_W6.0 Earthquake

http://earthquake.usgs.gov/earthquakes/eventpage/nc72282711





UNAVCO

Nevada Geodetic Laboratory

Case Study: The August 24, 2014 Napa M_W6.0 Earthquake

Imagine this happens
And you want GPS solutions.

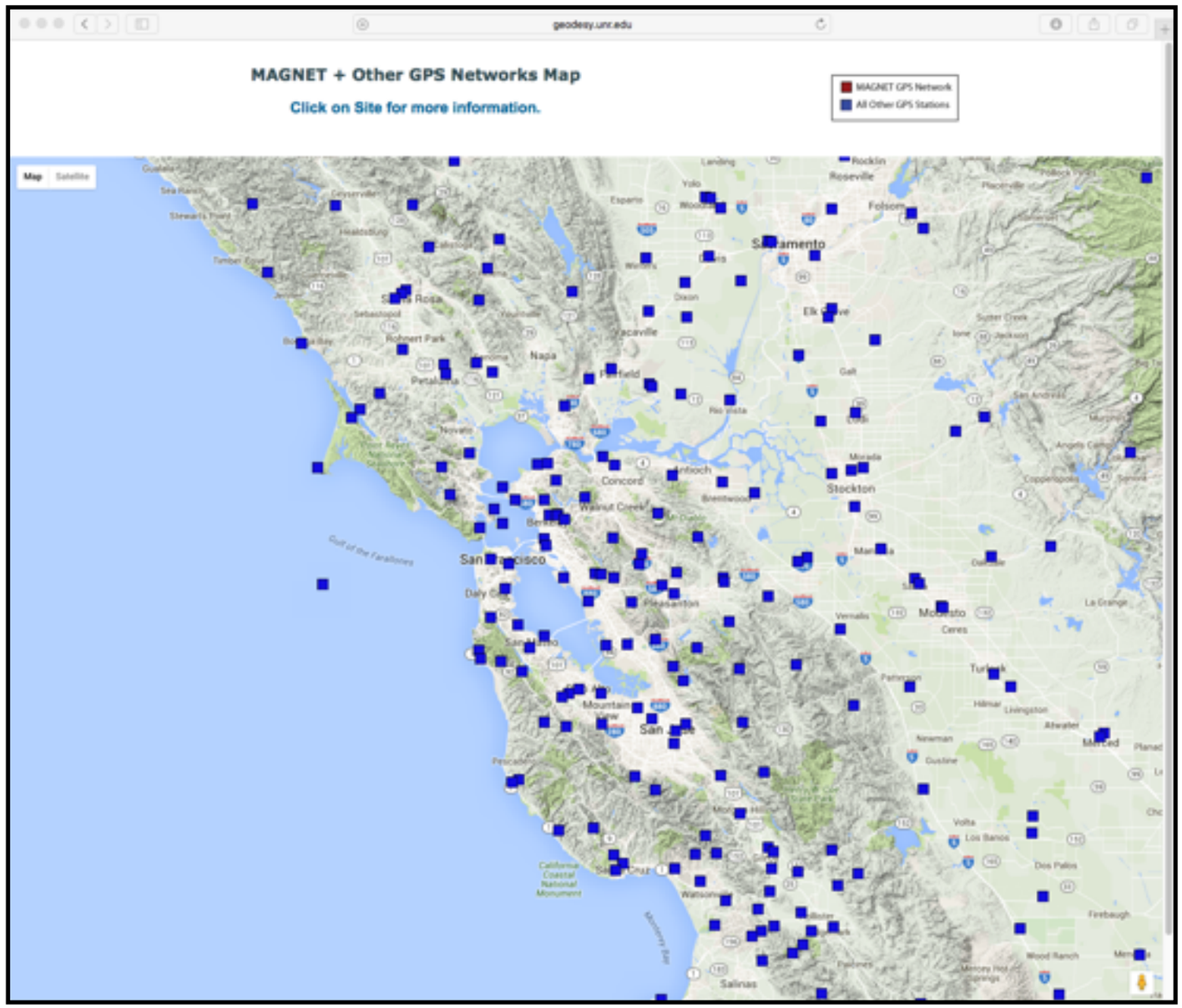
You go to http://geodesy.unr.edu/
You see there are many stations …

You might want an example time series. You might want to grab a couple plots.

Hover you mouse to get station name.

Or if you want everything and you are OK writing scripts you might try the:

- Data Holdings files…
- GSAC search tools…



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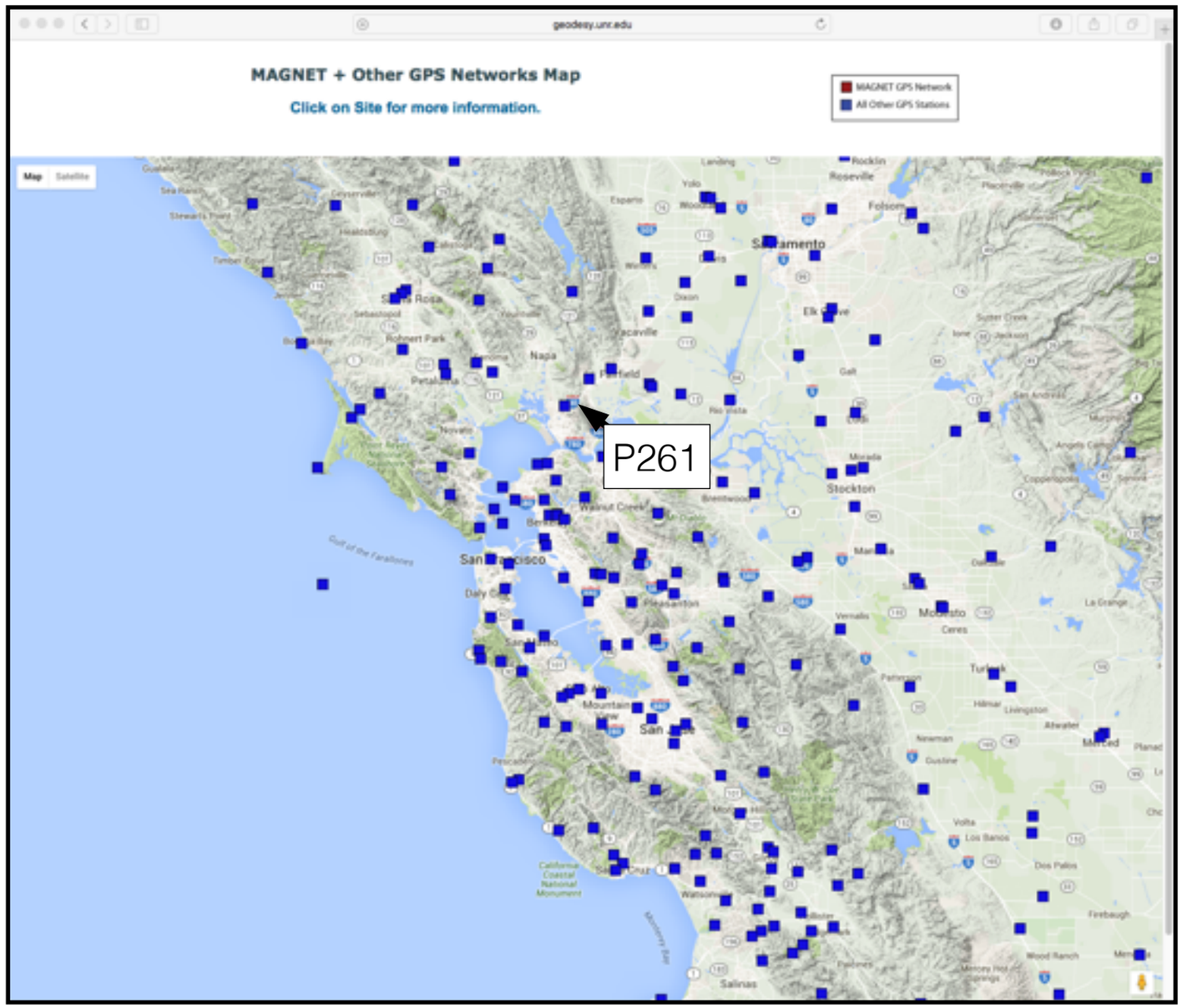

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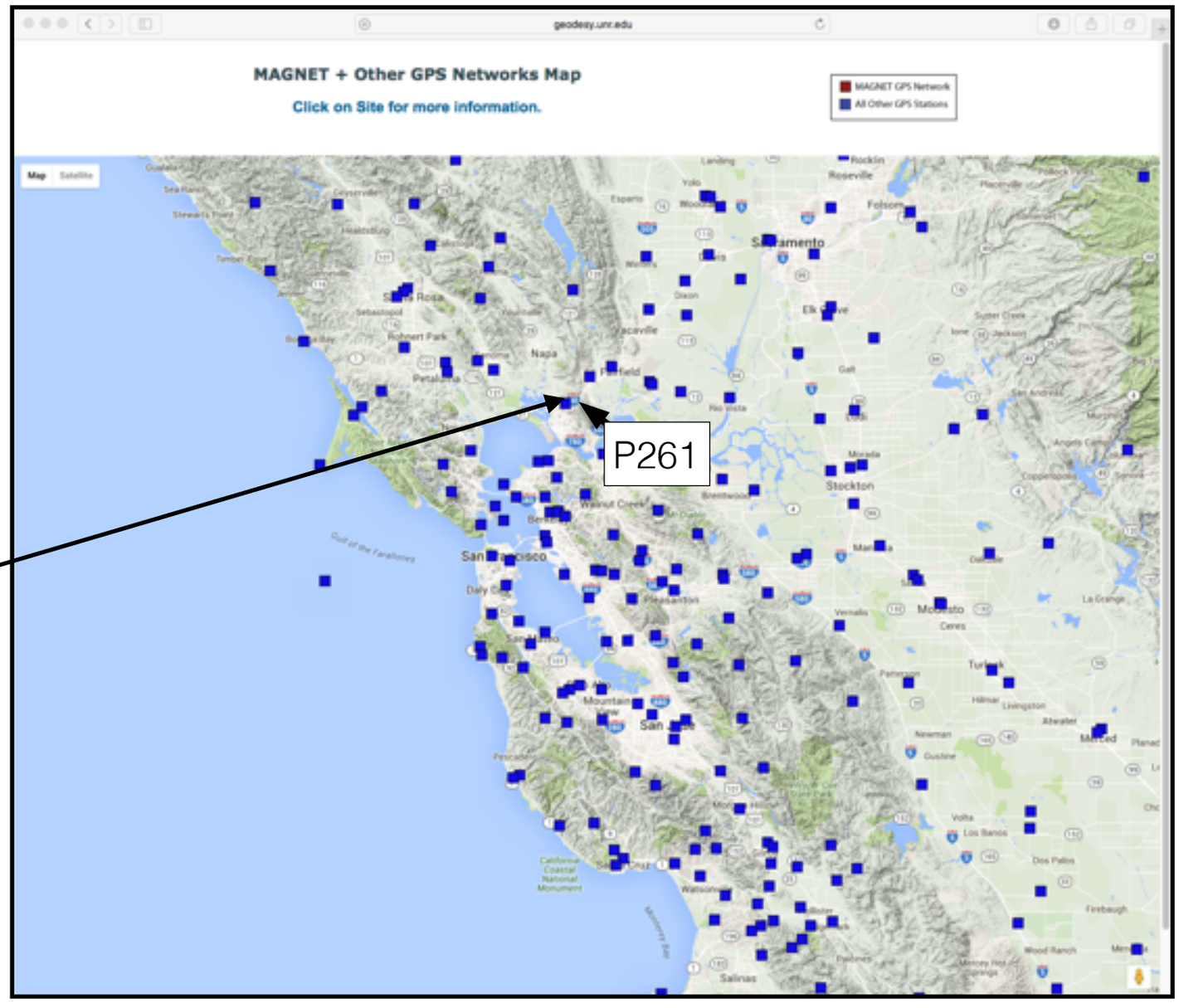

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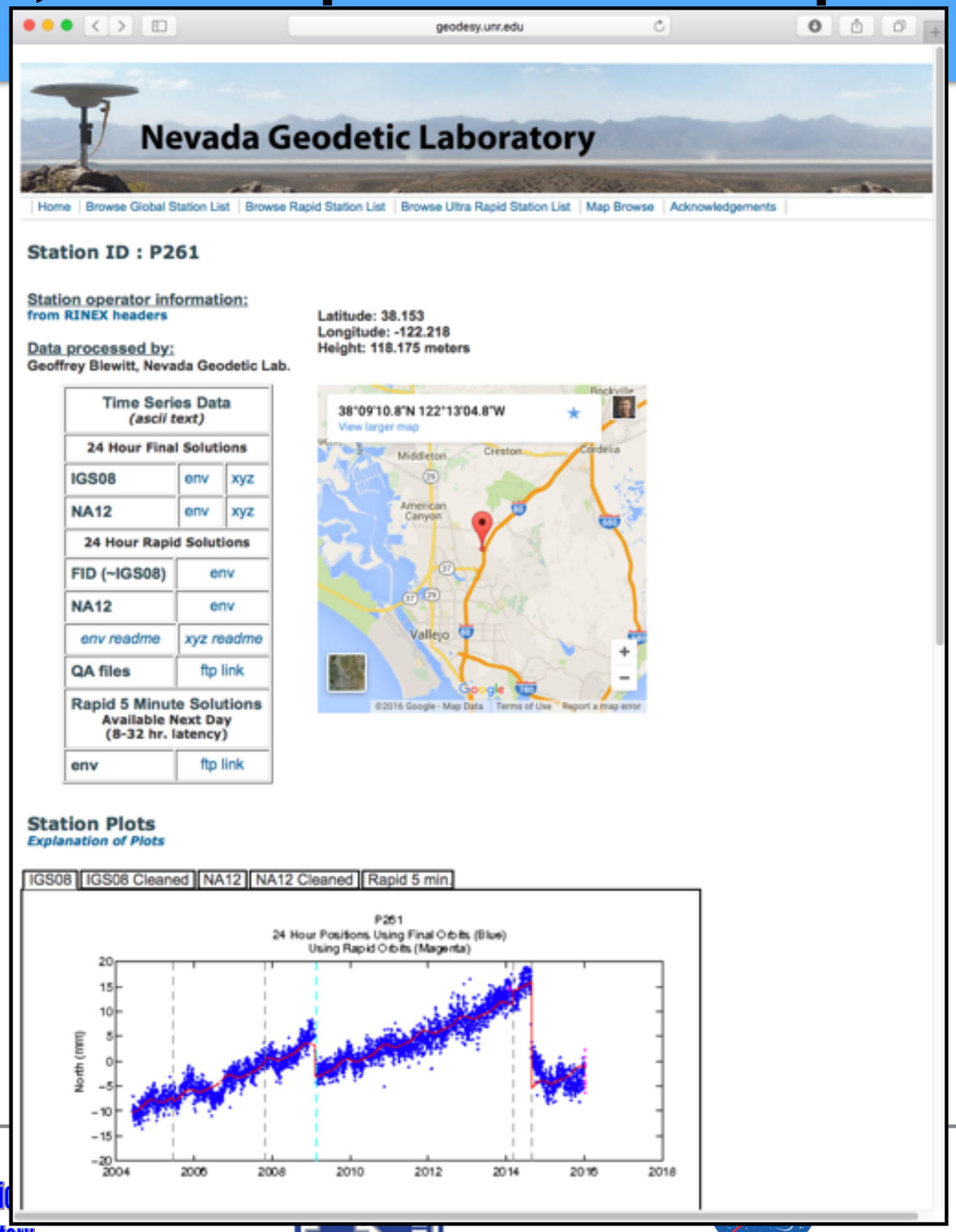

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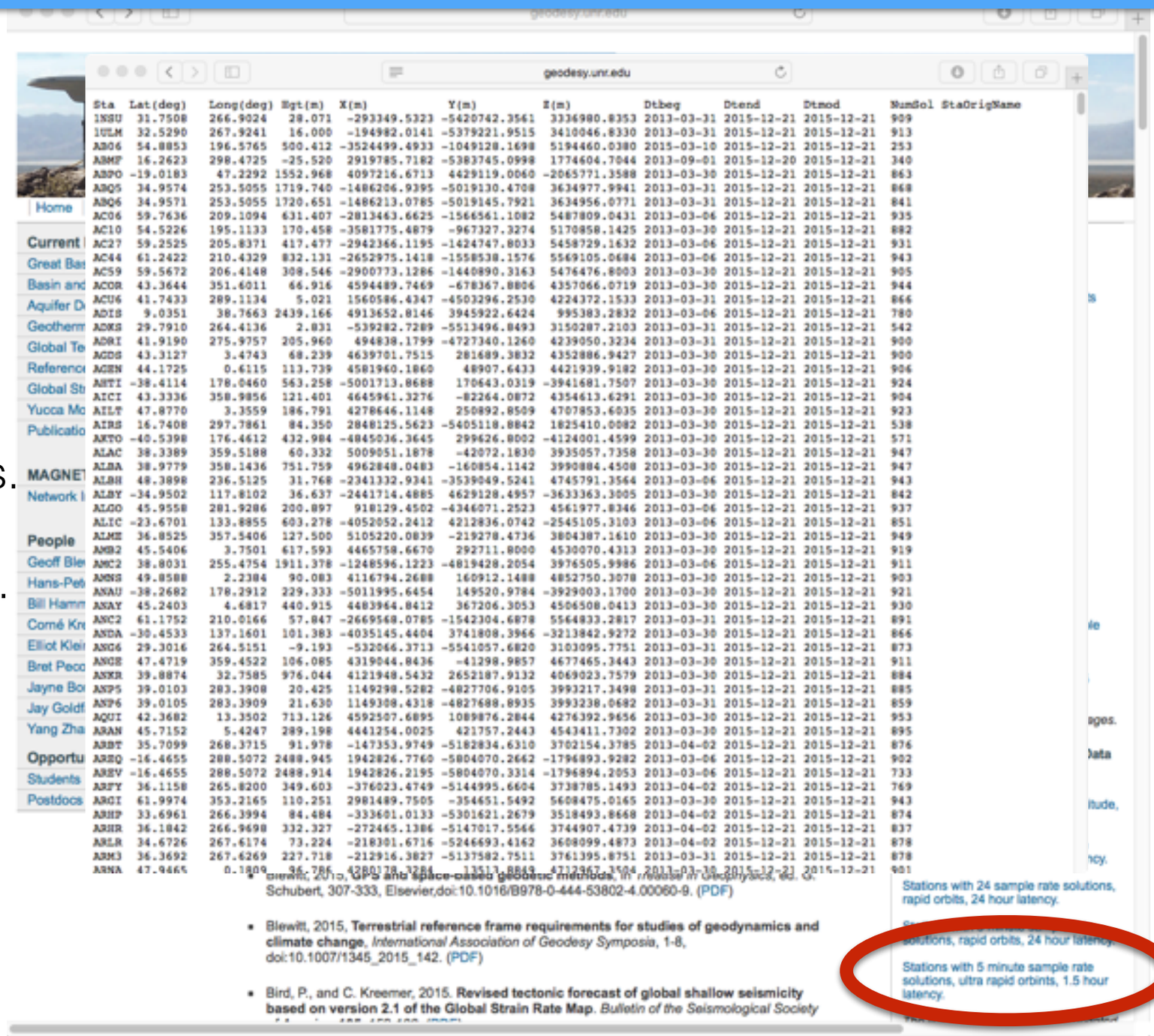

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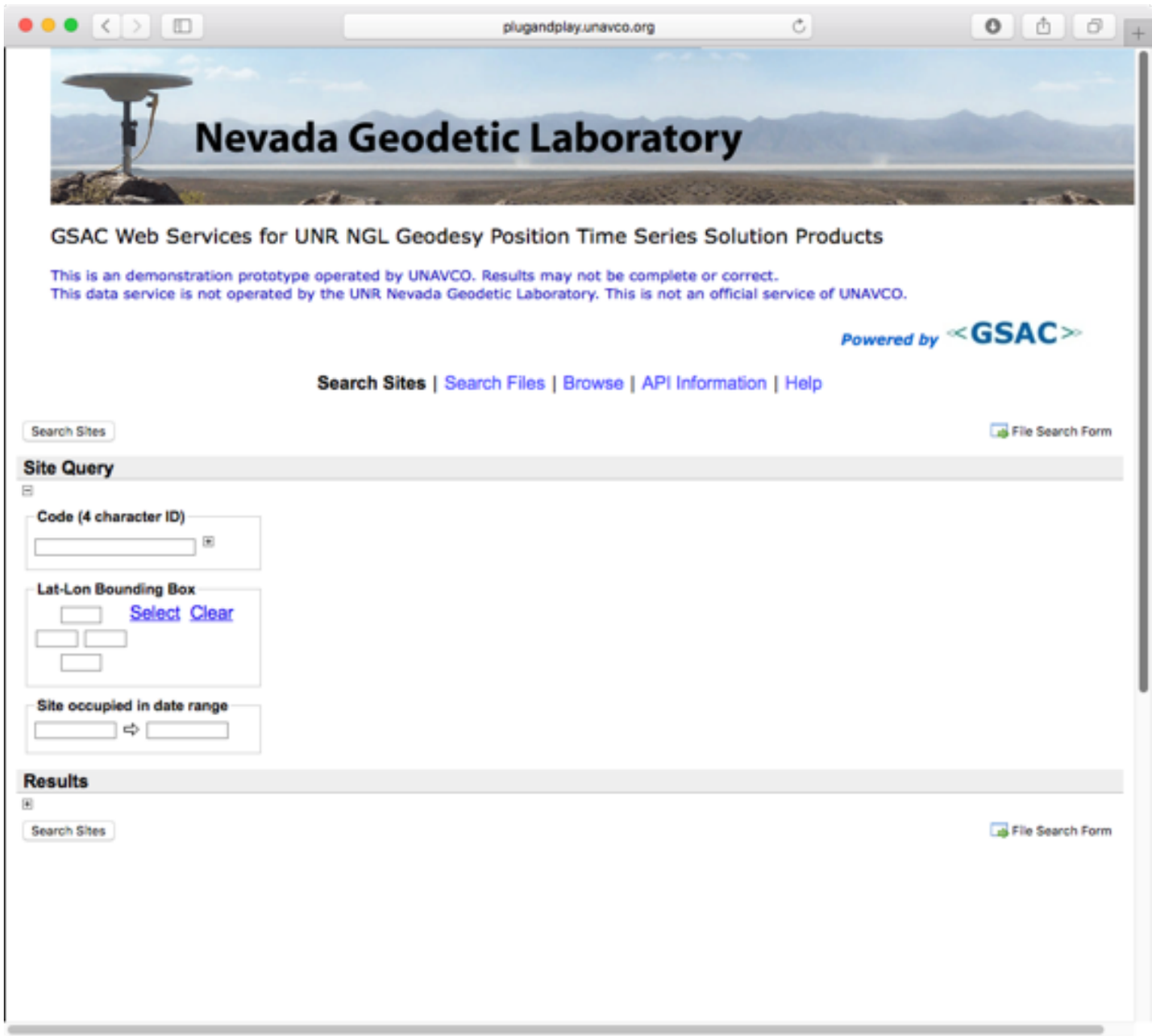

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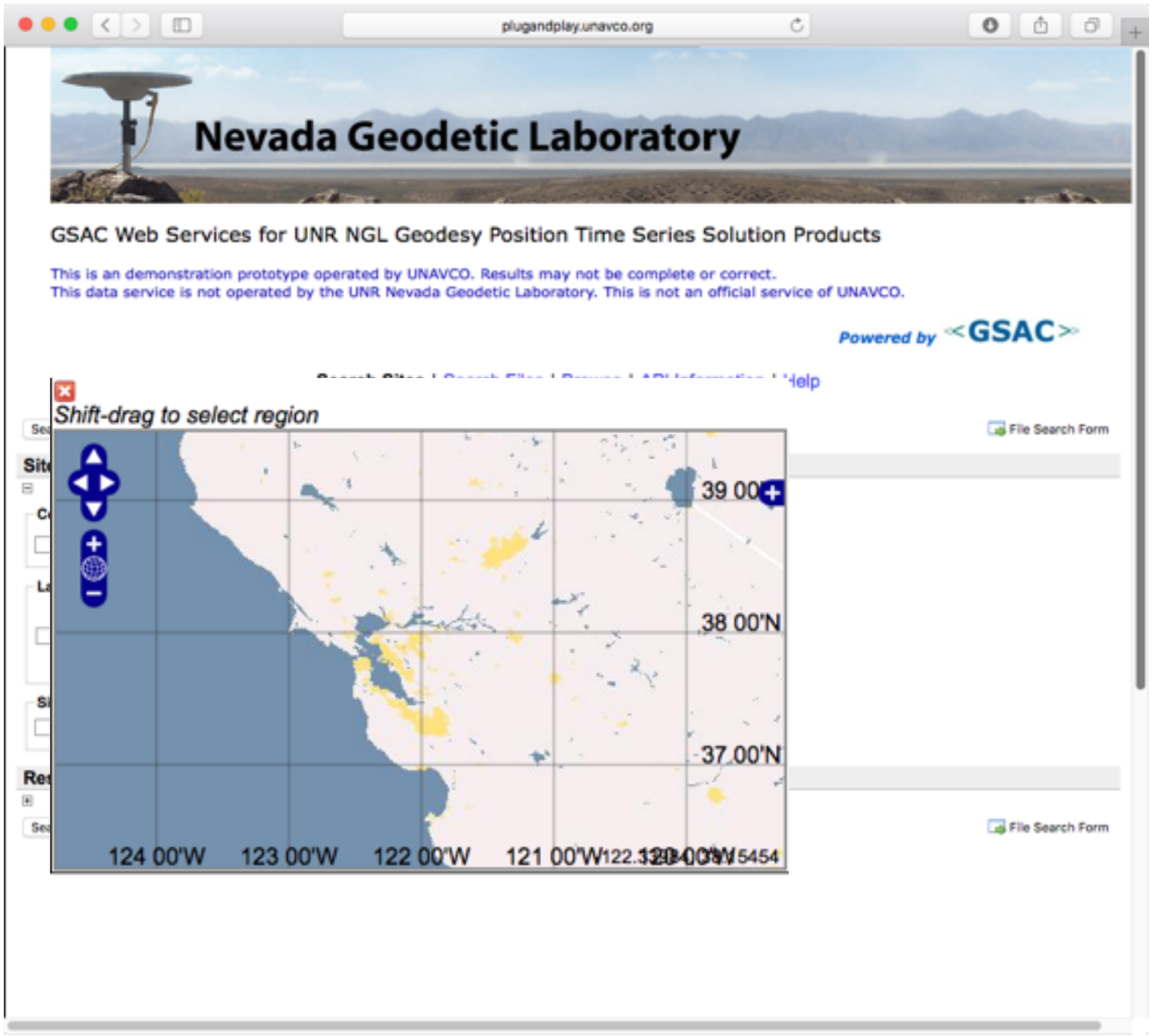

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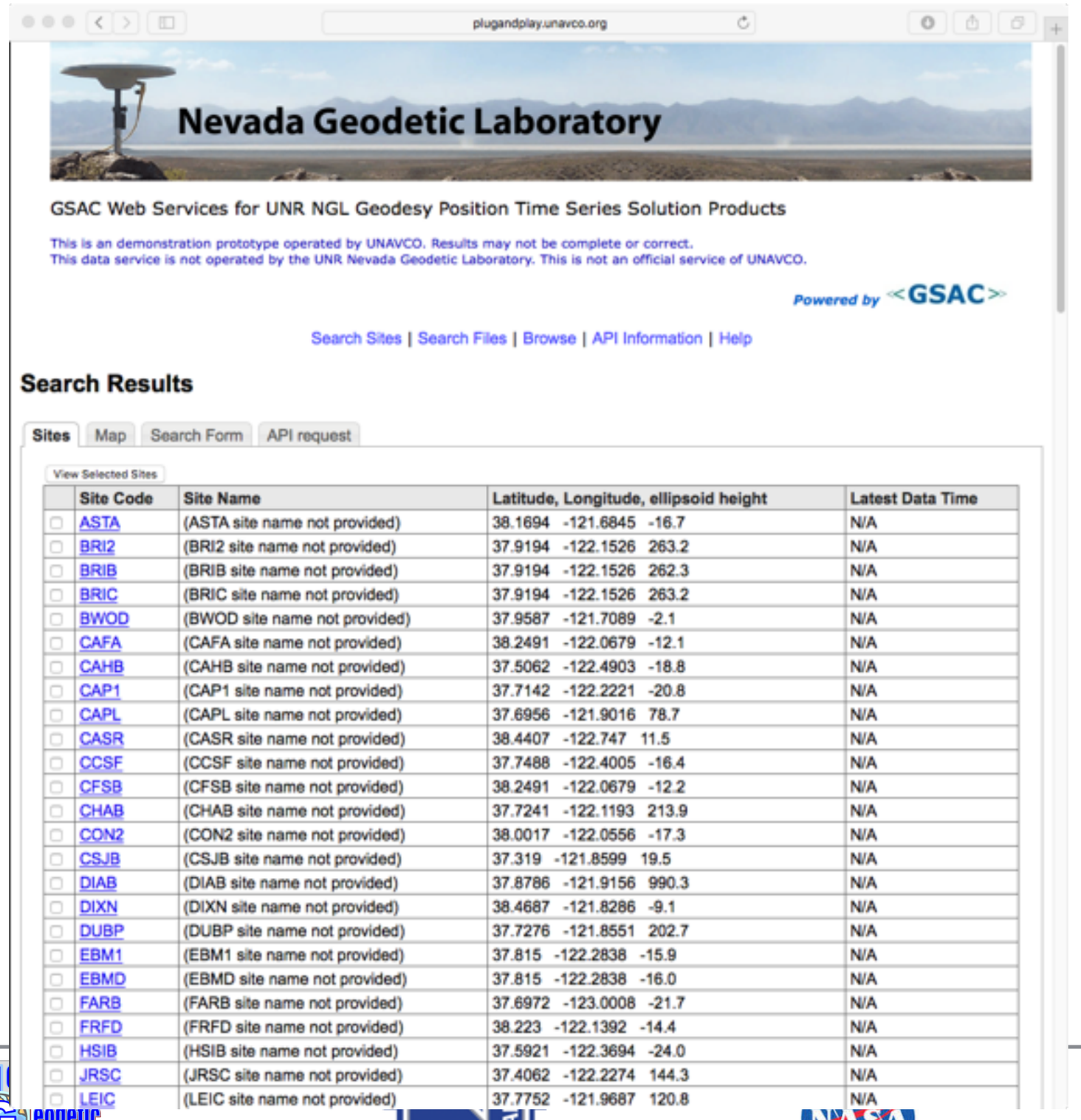

Site Code	Site Name	Latitude, Longitude, ellipsoid height	Latest Data Time
ASTA	(ASTA site name not provided)	38.1694 -121.6845 -16.7	N/A
BRI2	(BRI2 site name not provided)	37.9194 -122.1526 263.2	N/A
BRIB	(BRIB site name not provided)	37.9194 -122.1526 262.3	N/A
BRIC	(BRIC site name not provided)	37.9194 -122.1526 263.2	N/A
BWOD	(BWOD site name not provided)	37.9587 -121.7089 -2.1	N/A
CAFA	(CAFA site name not provided)	38.2491 -122.0679 -12.1	N/A
CAHB	(CAHB site name not provided)	37.5062 -122.4903 -18.8	N/A
CAP1	(CAP1 site name not provided)	37.7142 -122.2221 -20.8	N/A
CAPL	(CAPL site name not provided)	37.6956 -121.9016 78.7	N/A
CASR	(CASR site name not provided)	38.4407 -122.747 11.5	N/A
CCSF	(CCSF site name not provided)	37.7488 -122.4005 -16.4	N/A
CFSB	(CFSB site name not provided)	38.2491 -122.0679 -12.2	N/A
CHAB	(CHAB site name not provided)	37.7241 -122.1193 213.9	N/A
CON2	(CON2 site name not provided)	38.0017 -122.0556 -17.3	N/A
CSJB	(CSJB site name not provided)	37.319 -121.8599 19.5	N/A
DIAB	(DIAB site name not provided)	37.8786 -121.9156 990.3	N/A
DIXN	(DIXN site name not provided)	38.4687 -121.8286 -9.1	N/A
DUBP	(DUBP site name not provided)	37.7276 -121.8551 202.7	N/A
EBM1	(EBM1 site name not provided)	37.815 -122.2838 -15.9	N/A
EBMD	(EBMD site name not provided)	37.815 -122.2838 -16.0	N/A
FARB	(FARB site name not provided)	37.6972 -123.0008 -21.7	N/A
FRFD	(FRFD site name not provided)	38.223 -122.1392 -14.4	N/A
HSIB	(HSIB site name not provided)	37.5921 -122.3694 -24.0	N/A
JRSC	(JRSC site name not provided)	37.4062 -122.2274 144.3	N/A
LEIC	(LEIC site name not provided)	37.7752 -121.9687 120.8	N/A

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Imagine this happens
And you want GPS solutions.

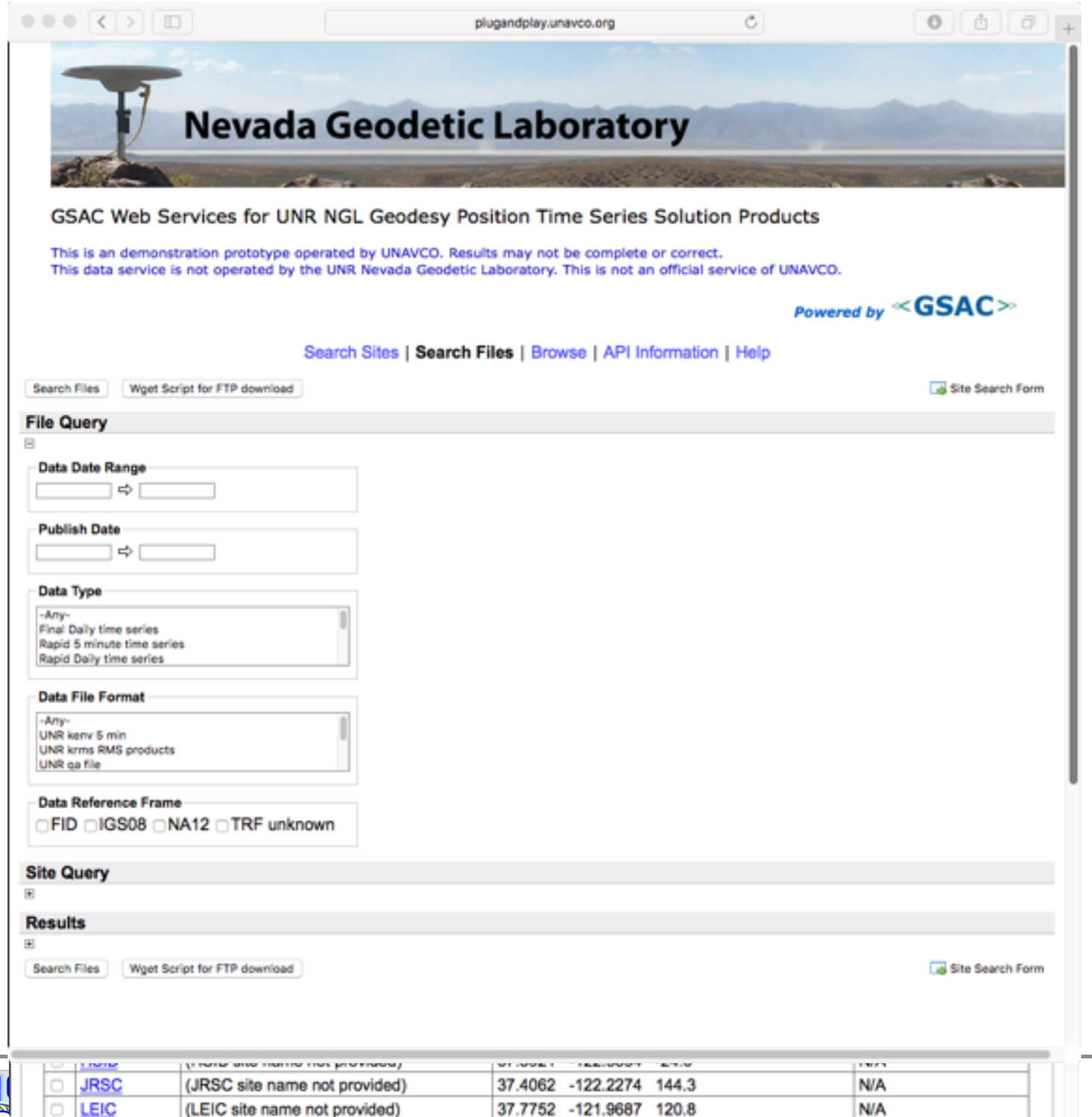
You go to http://geodesy.unr.edu/
You see there are many stations …

If you want an example time series
you might want to grab a couple plots.

Hover you mouse to get station name.

Or if you want everything and you are
OK writing scripts you might try the:

- Data Holdings files…
- GSAC search tools



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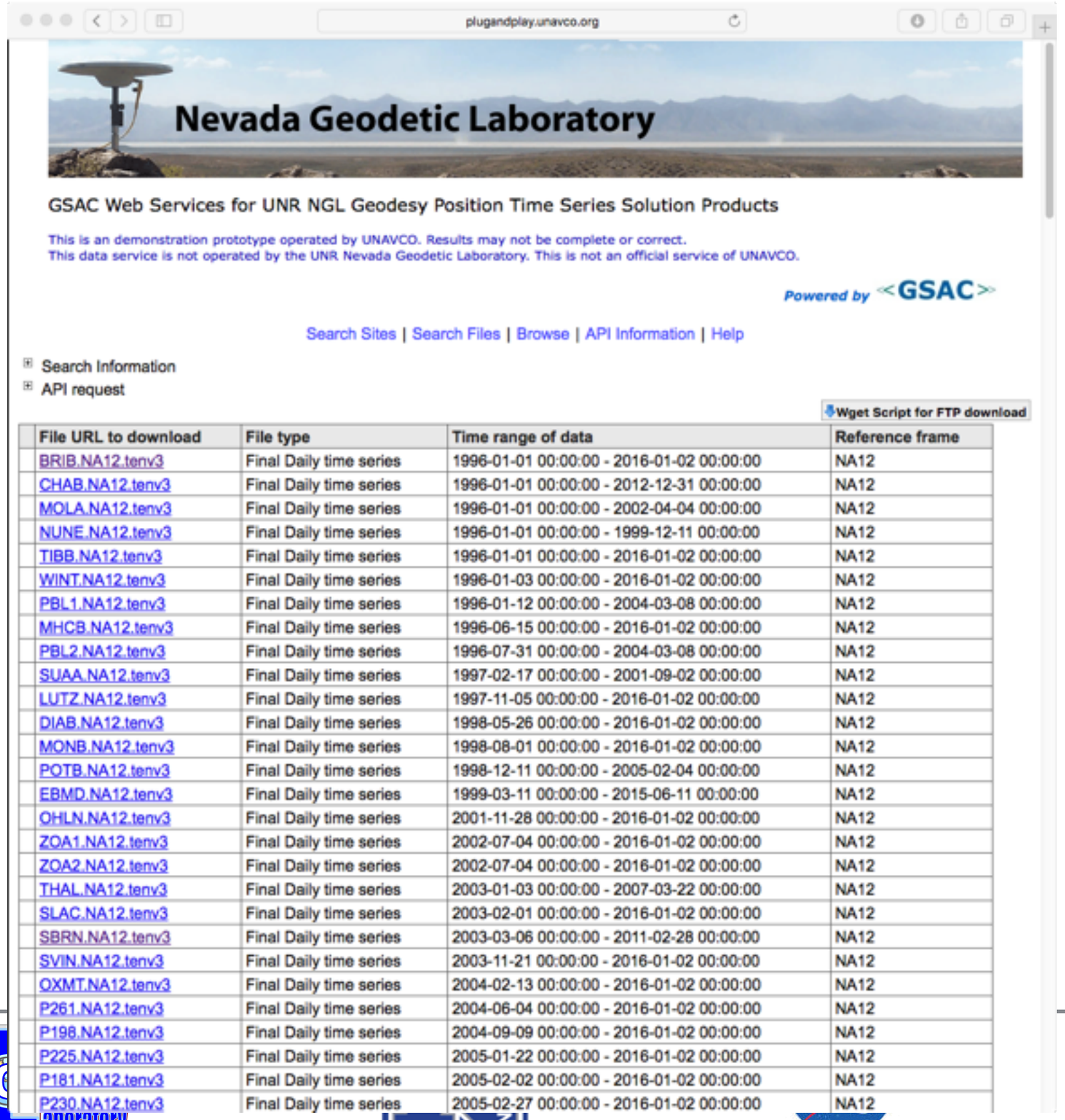

File URL to download	File type	Time range of data	Reference frame
BRIB.NA12.tenv3	Final Daily time series	1996-01-01 00:00:00 - 2016-01-02 00:00:00	NA12
CHAB.NA12.tenv3	Final Daily time series	1996-01-01 00:00:00 - 2012-12-31 00:00:00	NA12
MOLA.NA12.tenv3	Final Daily time series	1996-01-01 00:00:00 - 2002-04-04 00:00:00	NA12
NUNE.NA12.tenv3	Final Daily time series	1996-01-01 00:00:00 - 1999-12-11 00:00:00	NA12
TIBB.NA12.tenv3	Final Daily time series	1996-01-01 00:00:00 - 2016-01-02 00:00:00	NA12
WINT.NA12.tenv3	Final Daily time series	1996-01-03 00:00:00 - 2016-01-02 00:00:00	NA12
PBL1.NA12.tenv3	Final Daily time series	1996-01-12 00:00:00 - 2004-03-08 00:00:00	NA12
MHCB.NA12.tenv3	Final Daily time series	1996-06-15 00:00:00 - 2016-01-02 00:00:00	NA12
PBL2.NA12.tenv3	Final Daily time series	1996-07-31 00:00:00 - 2004-03-08 00:00:00	NA12
SUAA.NA12.tenv3	Final Daily time series	1997-02-17 00:00:00 - 2001-09-02 00:00:00	NA12
LUTZ.NA12.tenv3	Final Daily time series	1997-11-05 00:00:00 - 2016-01-02 00:00:00	NA12
DIAB.NA12.tenv3	Final Daily time series	1998-05-26 00:00:00 - 2016-01-02 00:00:00	NA12
MONB.NA12.tenv3	Final Daily time series	1998-08-01 00:00:00 - 2016-01-02 00:00:00	NA12
POTB.NA12.tenv3	Final Daily time series	1998-12-11 00:00:00 - 2005-02-04 00:00:00	NA12
EBMD.NA12.tenv3	Final Daily time series	1999-03-11 00:00:00 - 2015-06-11 00:00:00	NA12
OHLN.NA12.tenv3	Final Daily time series	2001-11-28 00:00:00 - 2016-01-02 00:00:00	NA12
ZOA1.NA12.tenv3	Final Daily time series	2002-07-04 00:00:00 - 2016-01-02 00:00:00	NA12
ZOA2.NA12.tenv3	Final Daily time series	2002-07-04 00:00:00 - 2016-01-02 00:00:00	NA12
THAL.NA12.tenv3	Final Daily time series	2003-01-03 00:00:00 - 2007-03-22 00:00:00	NA12
SLAC.NA12.tenv3	Final Daily time series	2003-02-01 00:00:00 - 2016-01-02 00:00:00	NA12
SBRN.NA12.tenv3	Final Daily time series	2003-03-06 00:00:00 - 2011-02-28 00:00:00	NA12
SVIN.NA12.tenv3	Final Daily time series	2003-11-21 00:00:00 - 2016-01-02 00:00:00	NA12
OXMT.NA12.tenv3	Final Daily time series	2004-02-13 00:00:00 - 2016-01-02 00:00:00	NA12
P261.NA12.tenv3	Final Daily time series	2004-06-04 00:00:00 - 2016-01-02 00:00:00	NA12
P198.NA12.tenv3	Final Daily time series	2004-09-09 00:00:00 - 2016-01-02 00:00:00	NA12
P225.NA12.tenv3	Final Daily time series	2005-01-22 00:00:00 - 2016-01-02 00:00:00	NA12
P181.NA12.tenv3	Final Daily time series	2005-02-02 00:00:00 - 2016-01-02 00:00:00	NA12
P230.NA12.tenv3	Final Daily time series	2005-02-27 00:00:00 - 2016-01-02 00:00:00	NA12

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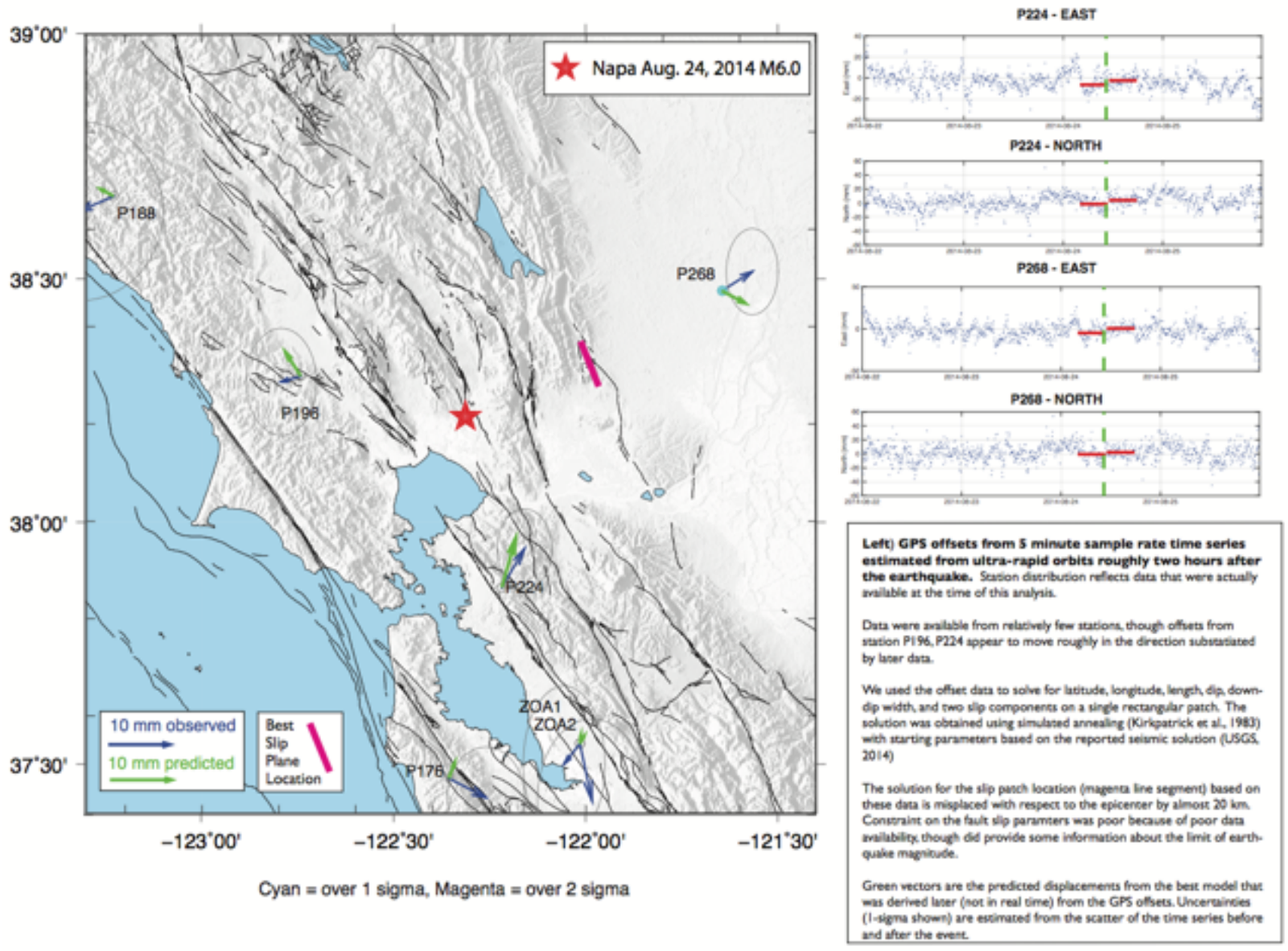
Two Hours After Event: Ultrarapid Orbits

- Not “real time” i.e. 1 Hz with 1 s latency
- From Hourly RINEX
- Not all stations providing hourly
- Working on that
- Offsets detected
- But uncertainties are large
- Inferred source poorly constrained



from Hammond et al., 2014 Fall AGU poster

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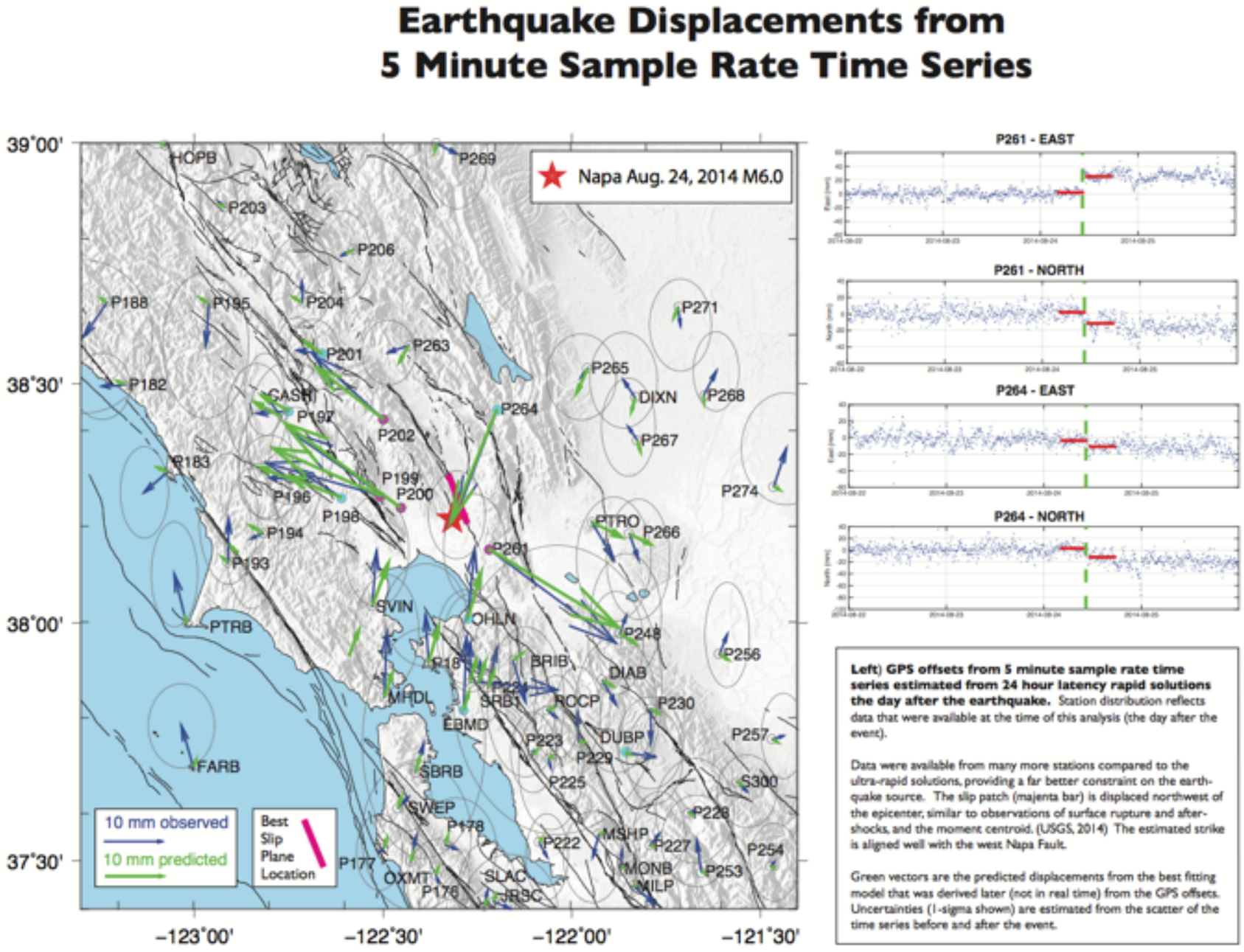
Next Day After Event: Rapid Orbits

- Many more stations contributing
- Time series better behaved
- Offsets show clear strike-slip character
- Significant offsets as far as e.g. south Bay Area
- Source location, style, slip better constrained
- Extent of significant displacement from earthquake more clear



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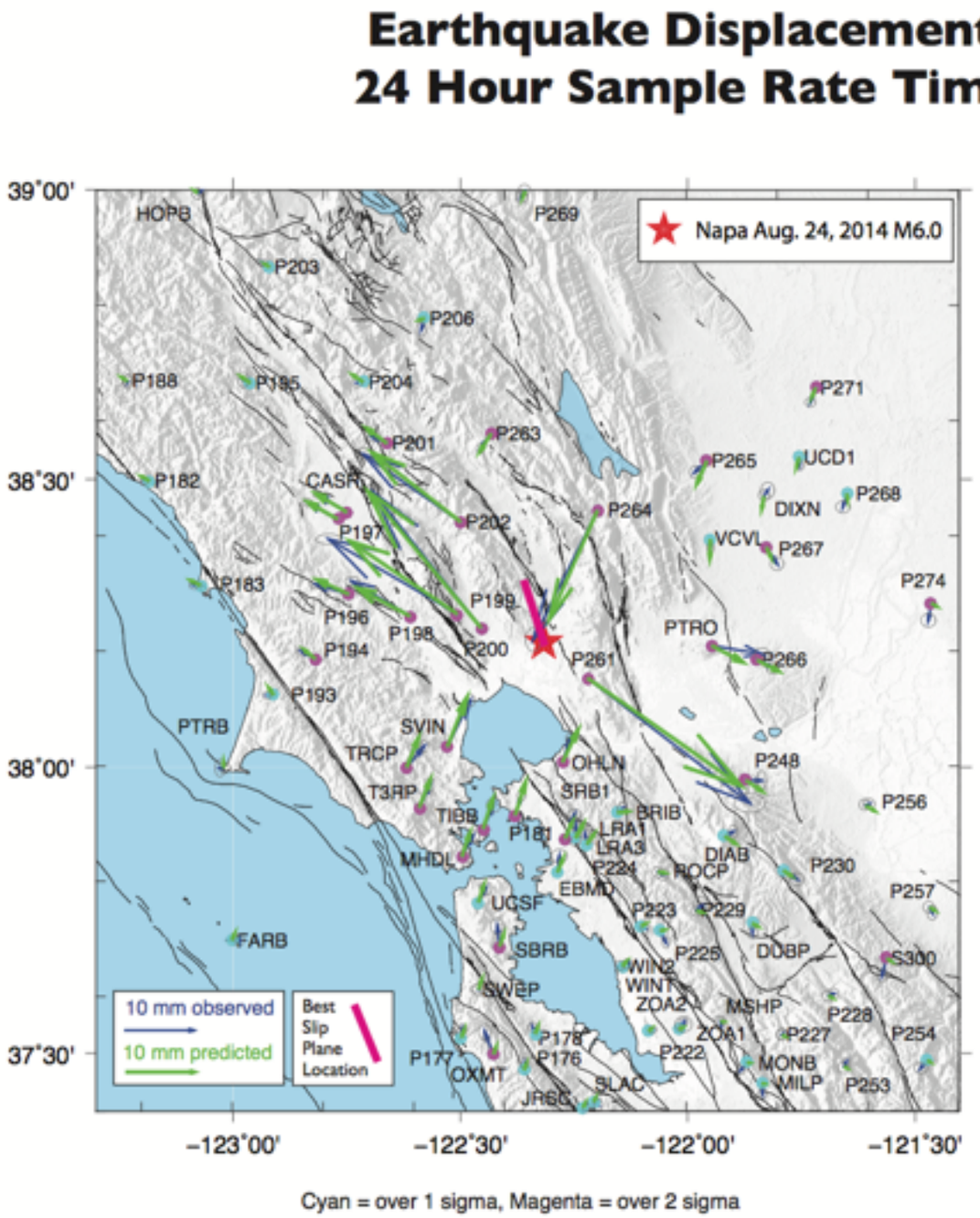
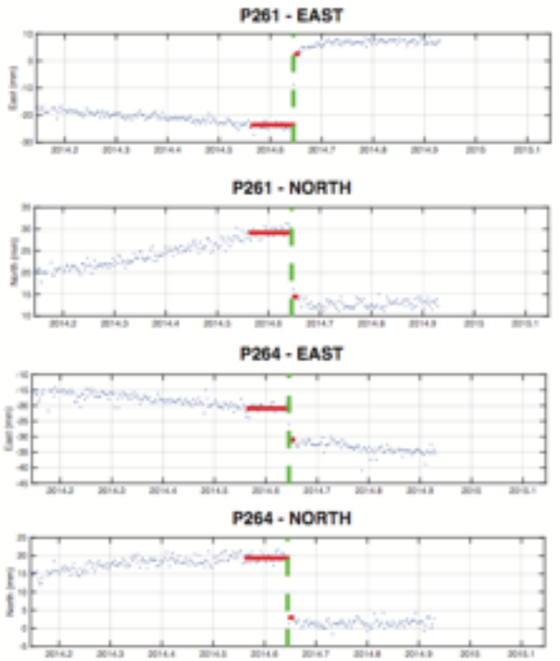
1 Full GPS Day Later: Rapid orbits

- Time series greatly improved, reduced scatter from 24 hour sample rate solutions
- Offsets better constrained
- Dramatically smaller uncertainties
- Inferred source right on top of seismic epicenter





Left) GPS offsets from 24 hour sample rate time series estimated from rapid orbits. These results were available after one full GPS day transpired after the earthquake. The offset is the difference between position during the first full day after the event and the mean of 30 days prior to the event. Station distribution reflects data that were actually available at the time of this analysis.

Compared to the 5 minute sample rate time series, a greater number of GPS stations have provided data and the uncertainties in the displacements are far smaller.

The maximum displacements (29 mm) were at station P261. Marin County moved between 4 and 10 mm northeast.

The model slip patch is located in a similar location compared to the rapid 5 minute solutions, ~5 km northwest of the epicenter. This slip patch is in a similar location to the seismogeodetic solution of Melgar et al., 2014 (see their poster in this session).

Green vectors are the predicted displacements from the best fitting model that was derived later (not in real time) from the GPS offsets. Uncertainties (1-sigma shown) are estimated from the scatter of the time series before and after the event.

from Hammond et al., 2014 Fall AGU poster

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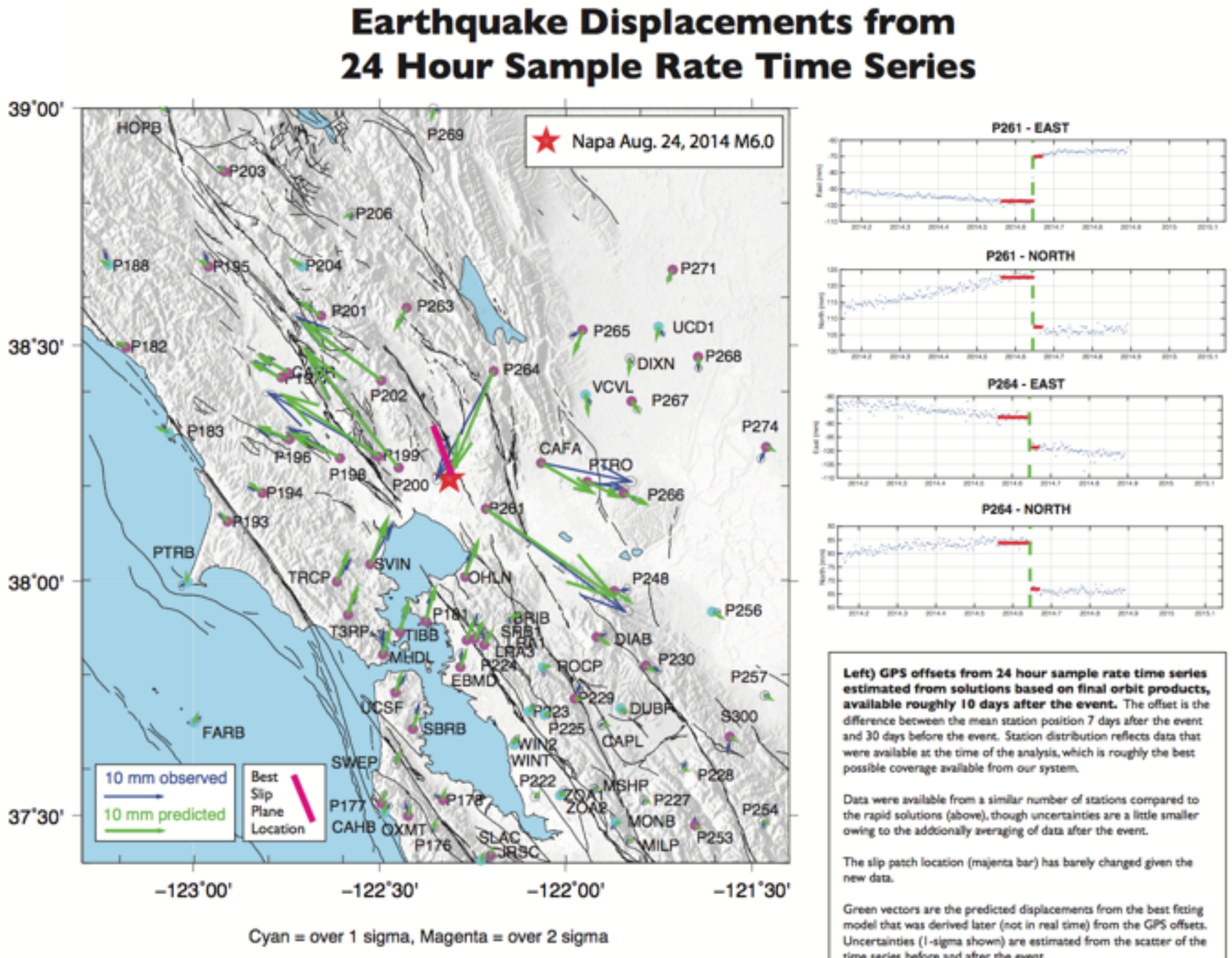
10 Days After Event: Final Orbits

- Moderate improvement over rapids
- Shows stability in solution of source
- Similarity to seismic slip inversions
- Used to benchmark real-time source inversion studies, e.g. Melgar et al., 2015 JGR plus other groups used our rapid-offsets



Left) GPS offsets from 24 hour sample rate time series estimated from solutions based on final orbit products, available roughly 10 days after the event. The offset is the difference between the mean station position 7 days after the event and 30 days before the event. Station distribution reflects data that were available at the time of the analysis, which is roughly the best possible coverage available from our system.

Data were available from a similar number of stations compared to the rapid solutions (above), though uncertainties are a little smaller owing to the addtionally averaging of data after the event.

The slip patch location (majenta bar) has barely changed given the new data.

Green vectors are the predicted displacements from the best fitting model that was derived later (not in real time) from the GPS offsets. Uncertainties (1-sigma shown) are estimated from the scatter of the time series before and after the event.

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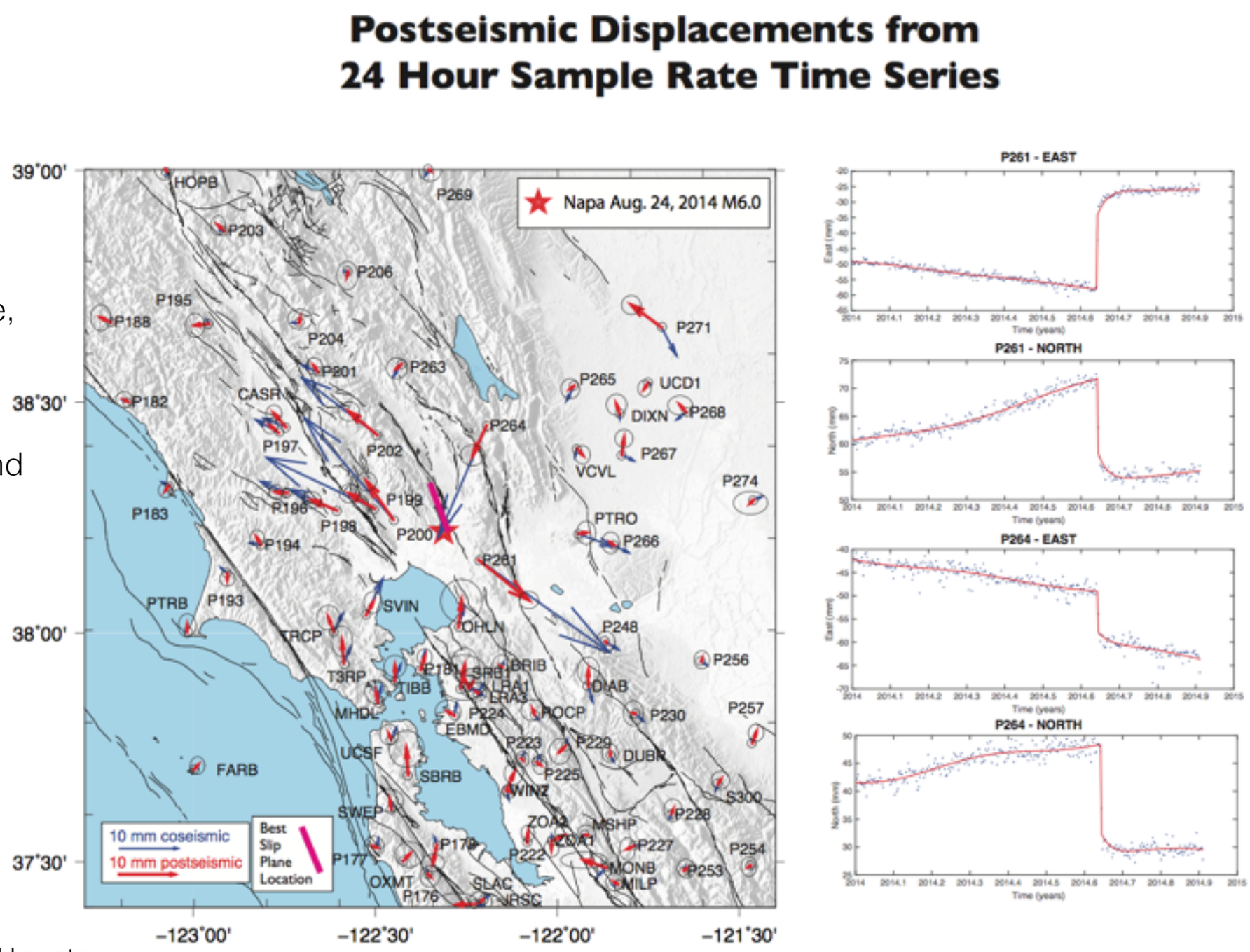
Months After Event: Final Orbits

- Time series modeled with slope, intercept, annual+semiannual terms, step, exponential decay after event
- Clear postseismic afterslip found
- Seen in GPS data and in situ surface observations
- Lasted weeks
- Coseismic M_W=6.07 versus postseismic M_W=5.75
- Clear implications for seismic hazard studies



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Conclusions

- This has been an demonstration of the utility of the Plug and Play system
- Napa earthquake shows how well and how quickly we can do low latency earthquake geodesy
- This example in a tectonically active area with a dense network of continuously recording GPS stations
- Future plans include extending service to automatically and systematically provide offsets (coseismic displacements) for every event over M 5.0.
- In the interim you will need to model steps from time series yourself.

More information on Napa earthquake offsets
http://geodesy.unr.edu/billhammond/earthquakes/nc72282711/nc72282711.html

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Thank you for attending!