



THE FUTURE OF PLATE BOUNDARY OBSERVATORY (PBO) GEODETIC RESOURCE FROM NOW TO 2028

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Manager

UNAVCO, PBO



56th meeting of the U.S. Civil GPS Service Interface Committee,
Sept 12, 2016 - Oregon Convention Center, Portland, OR

TALK OUTLINE

- **Overview of UNAVCO GI program in NSF GAGE Facility**
- **EarthScope overview:** PBO infrastructure buildout, current status, and data products
- **Science Drivers:** some examples from Cascadia, CA, and AK
- **Codependencies:** NASA READI earthquake early warning project; NOAA NWS-ZWD; NGS-CORS & OPUS services
- **GAGE Budget and Scope:** Plans versus reality in current environment
- **Vision for the future:** PBO as a basis for a multi-hazard network of networks across the Americas - possible refocusing, descoping, or upgrades and enhancements (*i.e.* new investments) to PBO? COCONet science snapshot
- **Preliminary recommendations from the Breckenridge, CO, and Leesburg, VA NSF-funded Community Workshops** - update on re-competition process post-GAGE Facility and EarthScope
- **Summary and challenges going forward**

Geodetic Infrastructure Directorate

Community & Continuously Observing Networks

Plate Boundary Observatory

GPS and Metpack Operations

Borehole Geophysics Operations

NASA GGN

POLENET: GNET & ANET

COCONet, TLALOCNet, and Africa Array

Principal Investigator support

NSF - EAR, PLR funded

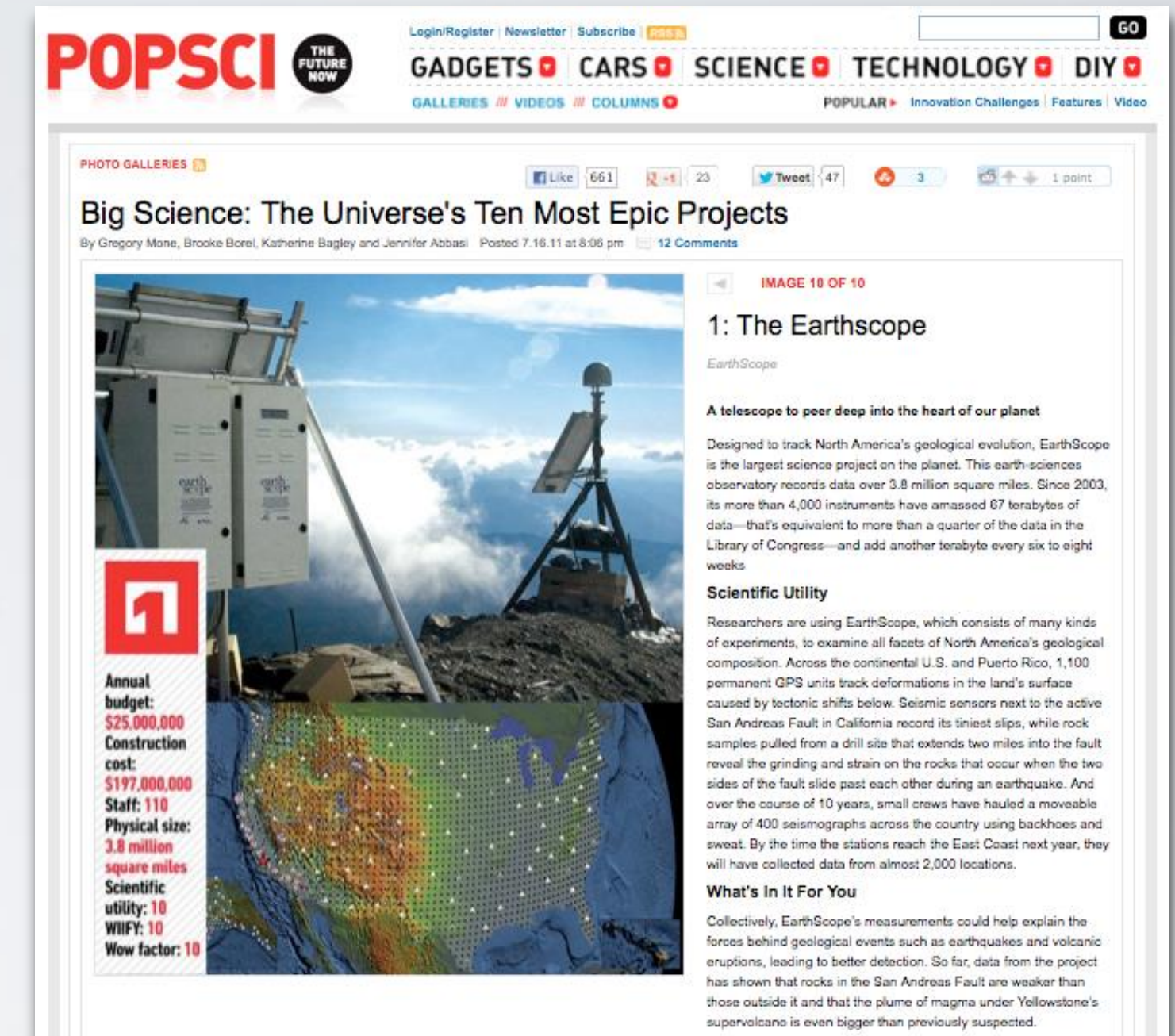
Campaign and longer term GPS deployments

Terrestrial Laser Scanning Projects

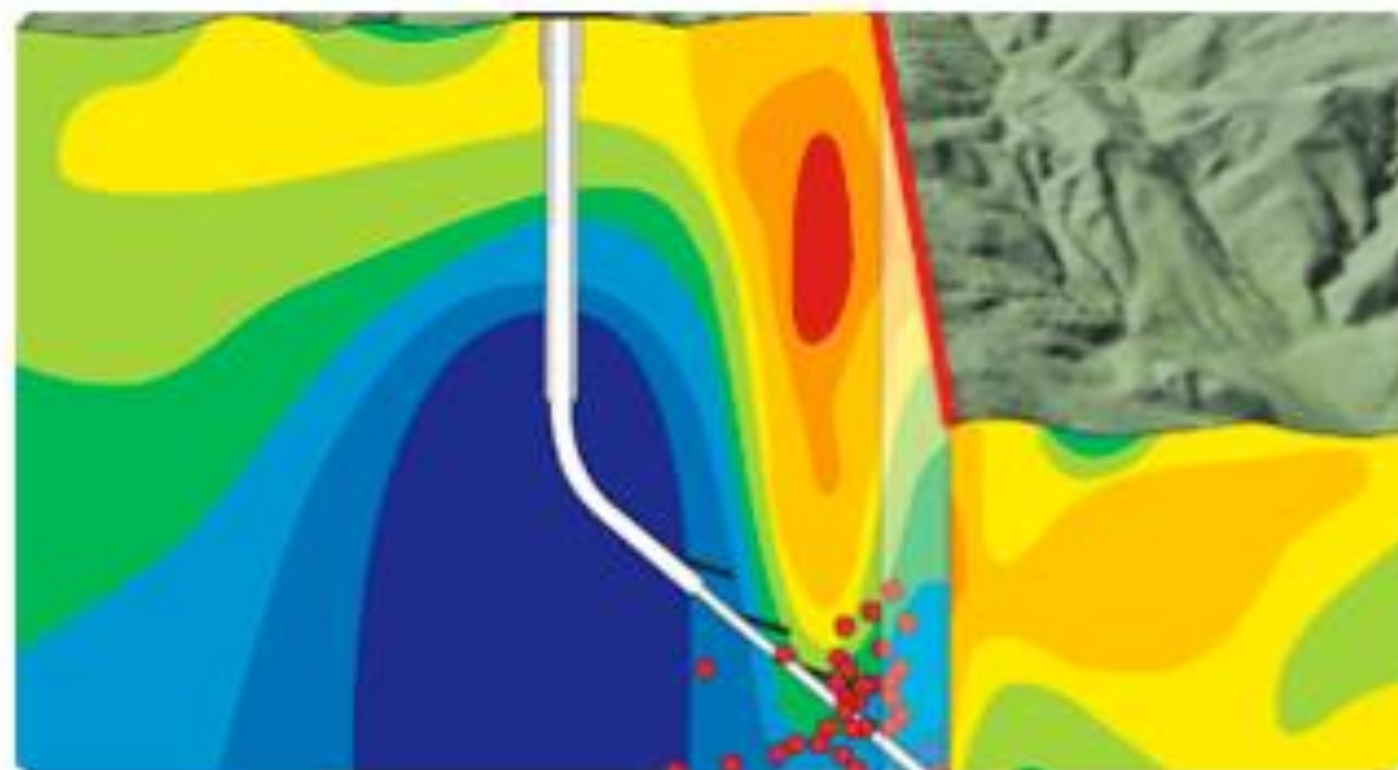
Emerging Imaging Geodesy Tools

EarthScope Background

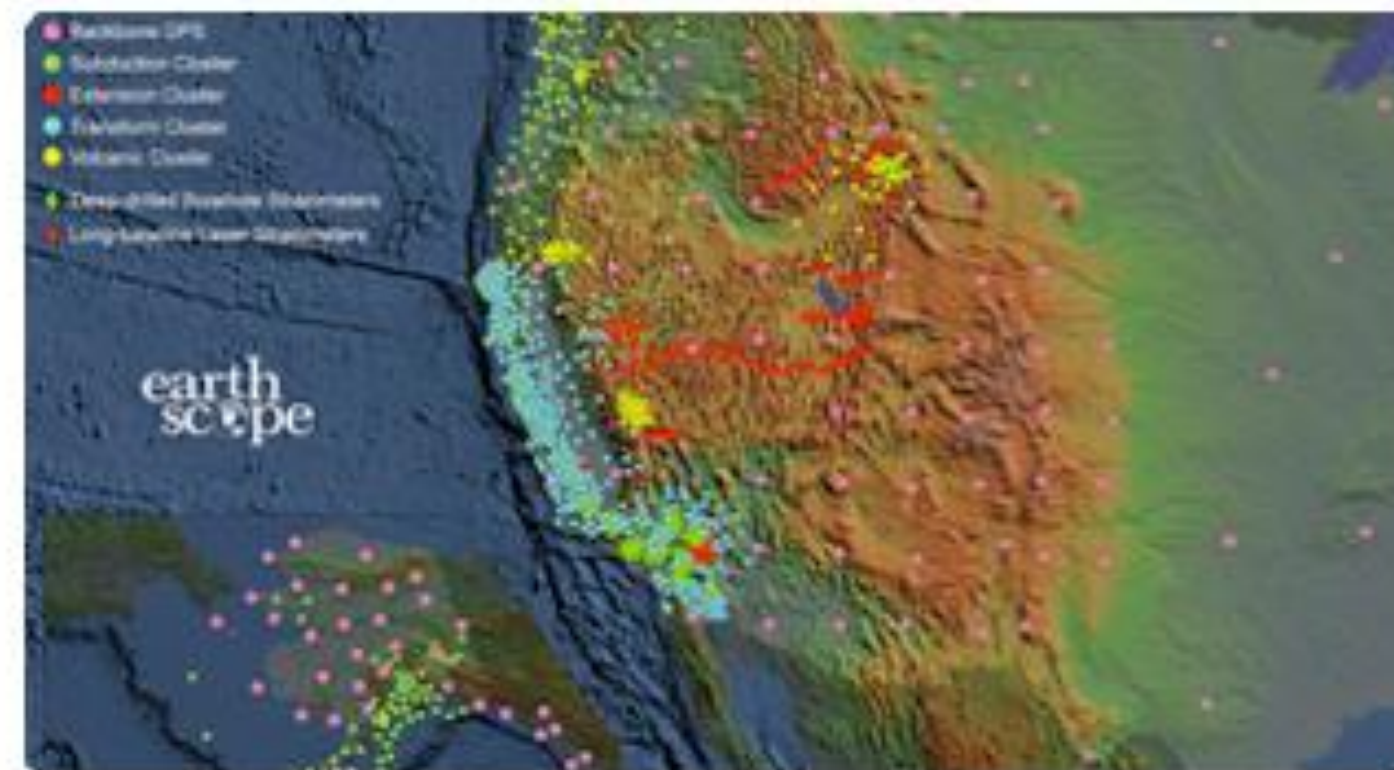
- Funded by NSF
- Project started in 2003 - continues through 2018
- Three Components - Geodetic, Seismic, and Drilling
- Deploys thousands of seismic, GPS, and other geophysical instruments
- Purpose: To study the structure and evolution of the North American continent and the processes the cause earthquakes and volcanic eruptions.
- A collaboration between scientists, educators, policy makers, and the public to learn about and utilize exciting scientific discoveries as they are being made.
- **Total EarthScope Budget: ~\$500M over the lifetime of the project**



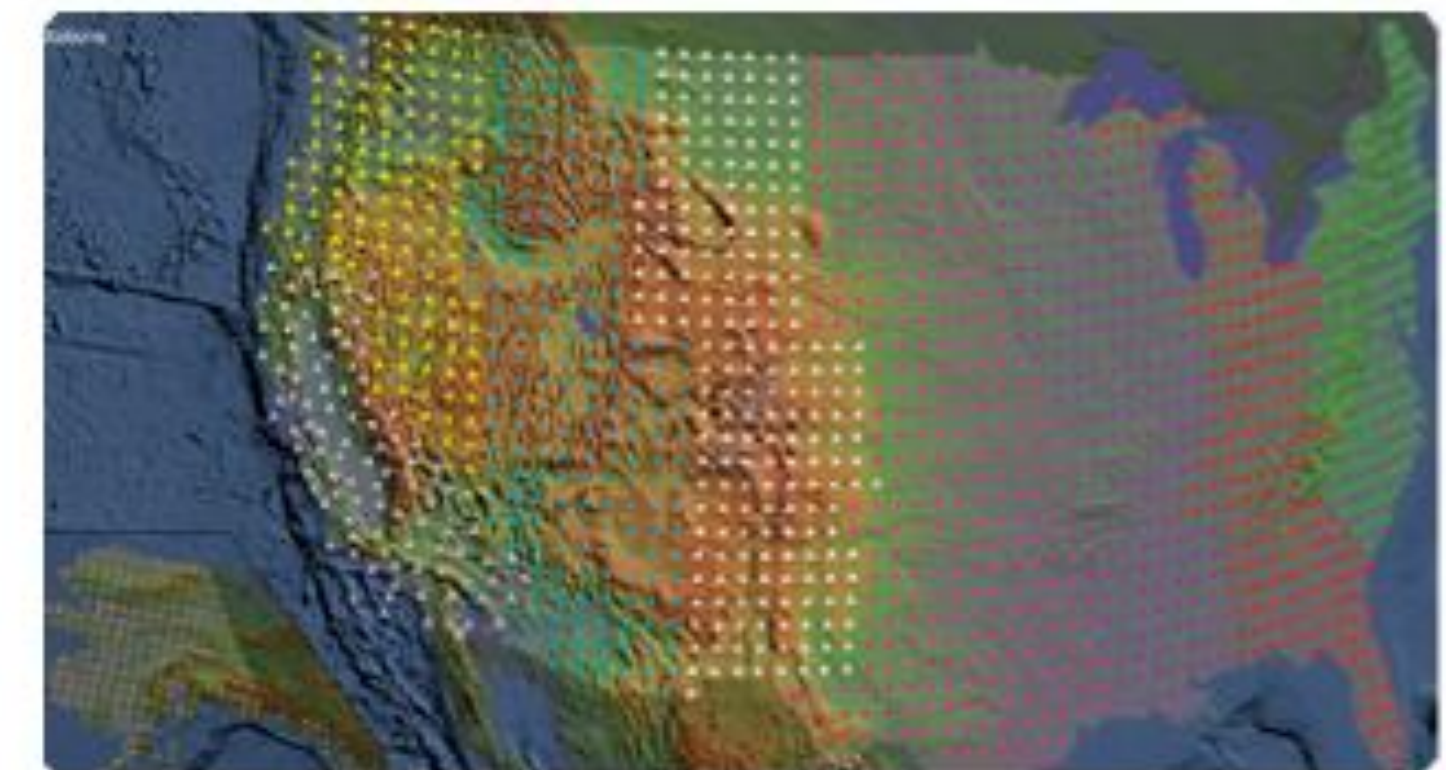
Drilling Component - SAFOD



Geodetic Component - PBO

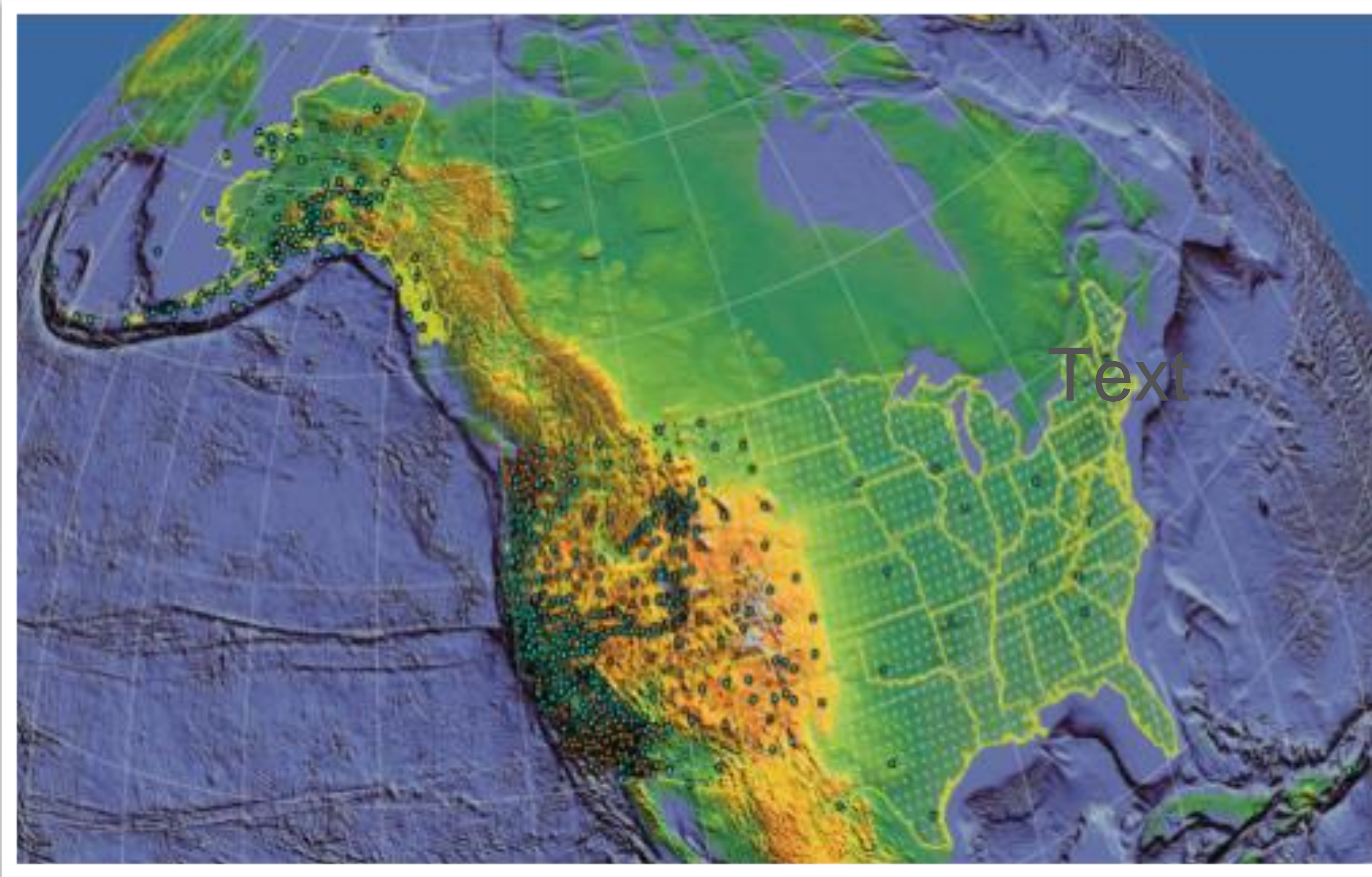


Seismic Component - USArray



EARTHSCOPE: INTEGRATION OF GEODESY AND SEISMOLOGY

Designed as a 15 year experiment will sunset in 2018



Technical advancements:

- community data formats for real-time GPS
- collocation of accelerometers & high-rate GPS
- Cascadia & planned GAGE upgrades
- changes in the landscape with vendors

Integrative science:

- tomography & kinematics for geodynamics
- episodic tremor and slip
- GPS seismology
- Total EarthScope Budget: ~\$500M
- early GPS centroid determination

PBO is the geodetic component of EarthScope (~\$200M):
1100 cGPS, 78 BSM, 6 LSM, 26 tiltmeters



The Plate Boundary Observatory

Focused, dense deployments of cGPS and strainmeter arrays

- 1100 continuous Global Positioning Systems around tectonic clusters
- 78 borehole strainmeters
- 5 long baseline strainmeters
- 26 tiltmeters
- 100 meteorological instruments

Portable GPS receivers

- Pool of 100 portable GPS receivers for temporary deployments to areas not sufficiently covered by continuous GPS

Geo-EarthScope

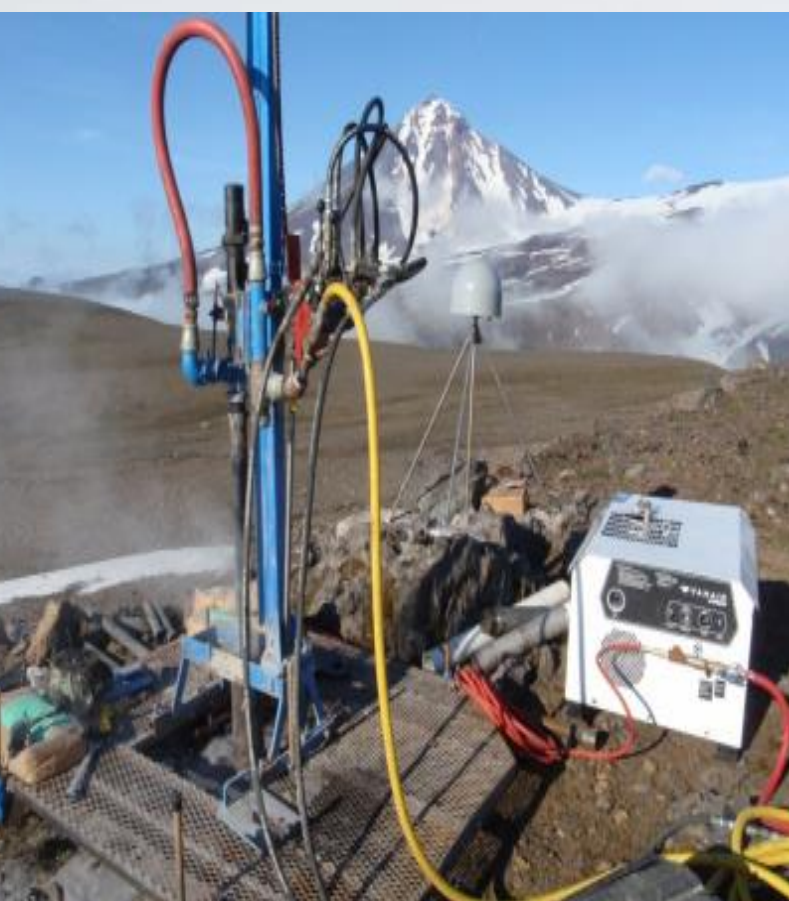
- InSAR imagery covering the western US
- LIDAR imagery covering the northern and southern San Andreas Fault, Yellowstone Caldera, and faults in Cascadia and Alaska

Network Costs

- \$100M - Construction Phase (2003-2008)
- \$54M - Operations and Maintenance Phase 1 (2009-2013)
- \$46M - Operations and Maintenance Phase 2 (2014-2018)



PBO: A NUCLEUS FOR A NETWORK OF GEODETIC NETWORKS



**earth
scope**
PLATE BOUNDARY OBSERVATORY



Governance
and Community

GAGE
Impact

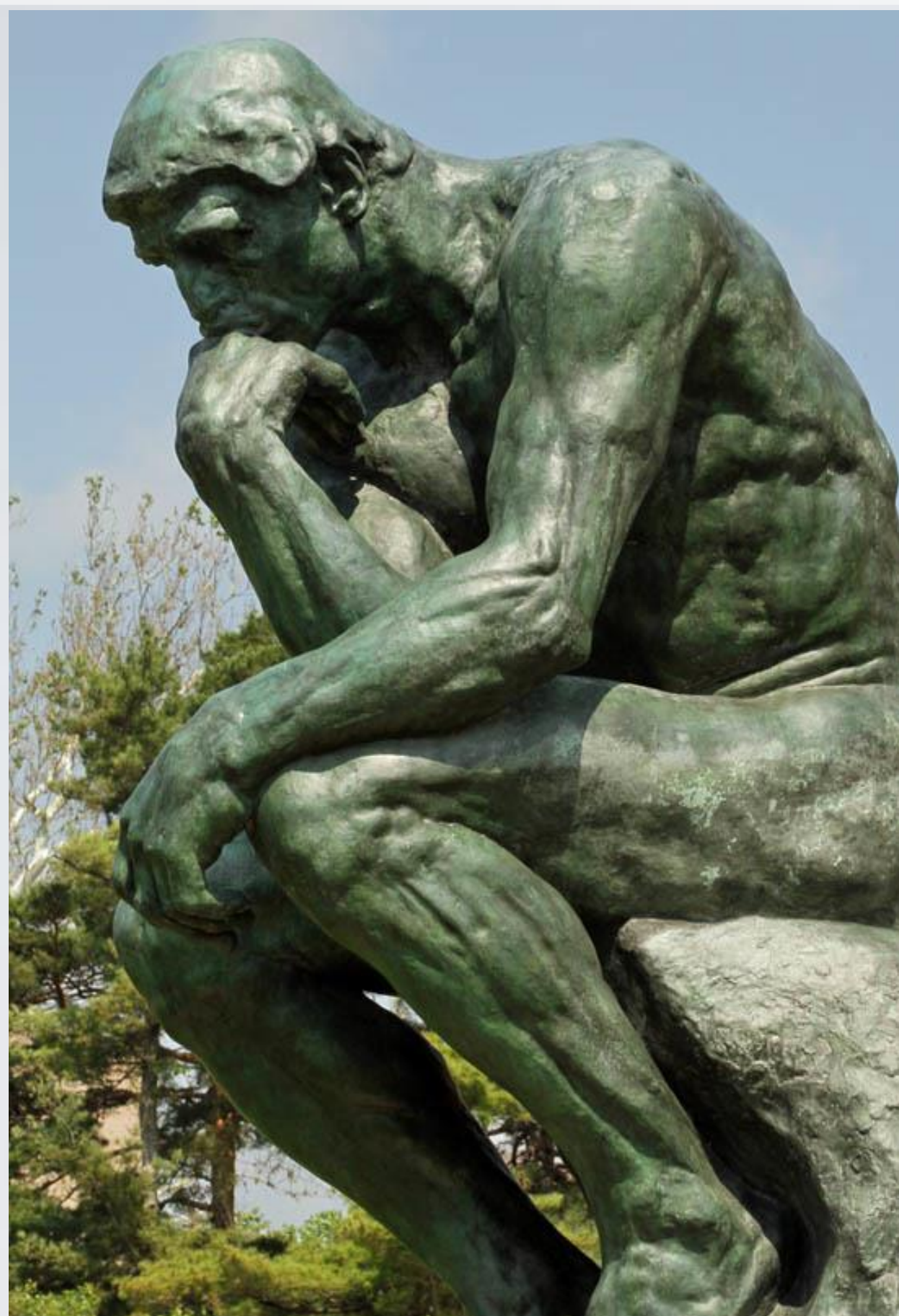
Geodetic
Infrastructure

Geodetic Data
Services

Education &
Community
Engagement

Beyond 2018

PBO FACILITY HIGHLIGHTS

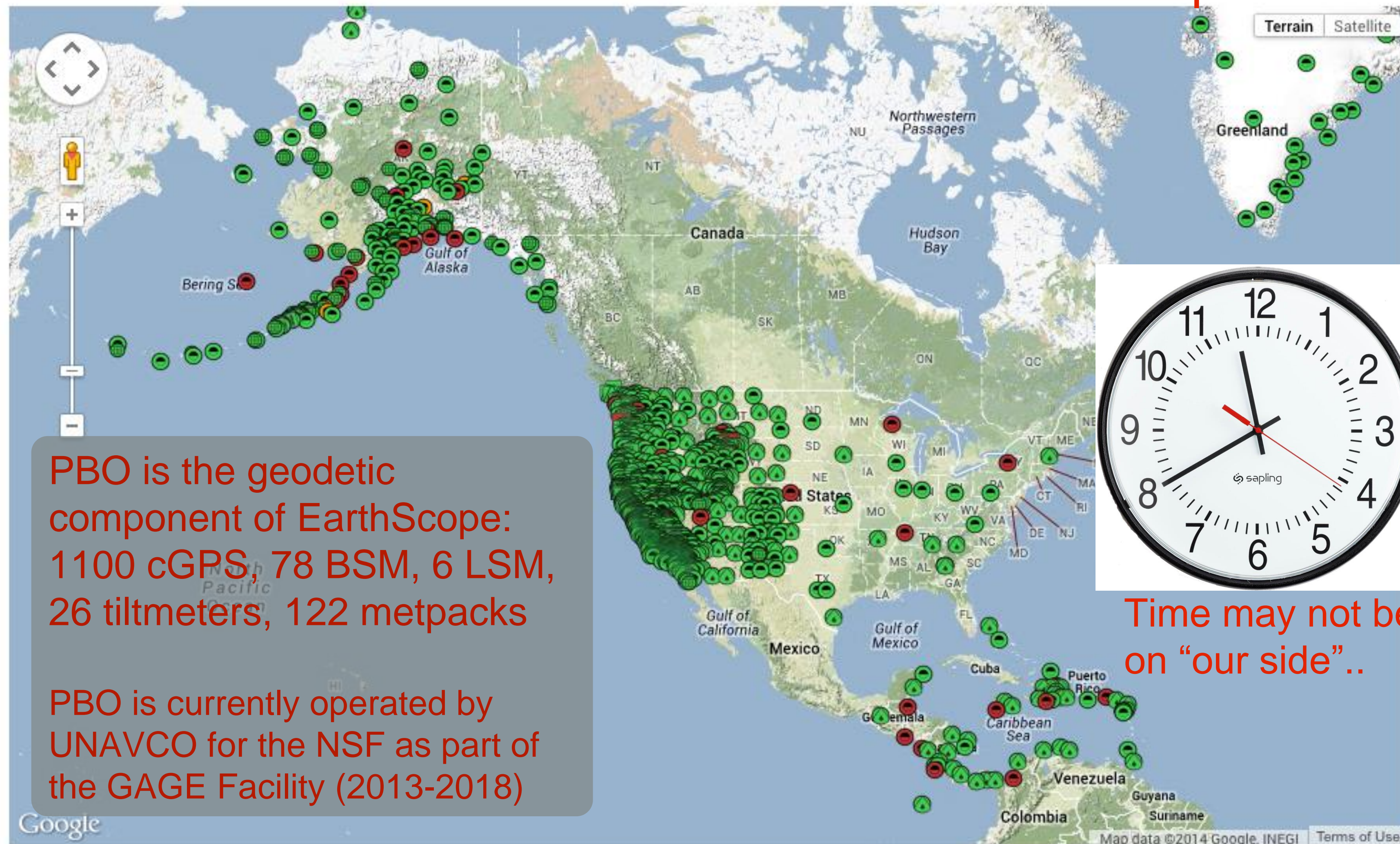


GI AC will use recommendations from NSF Community Workshops to refine and guide UNAVCO going forward...

PBO Station Location Map

Searching Station Meta Data

1100 station cGPS network at ~95% uptime



PBO is the geodetic component of EarthScope: 1100 cGPS, 78 BSM, 6 LSM, 26 tiltmeters, 122 metpacks

PBO is currently operated by UNAVCO for the NSF as part of the GAGE Facility (2013-2018)



Time may not be on "our side" ..

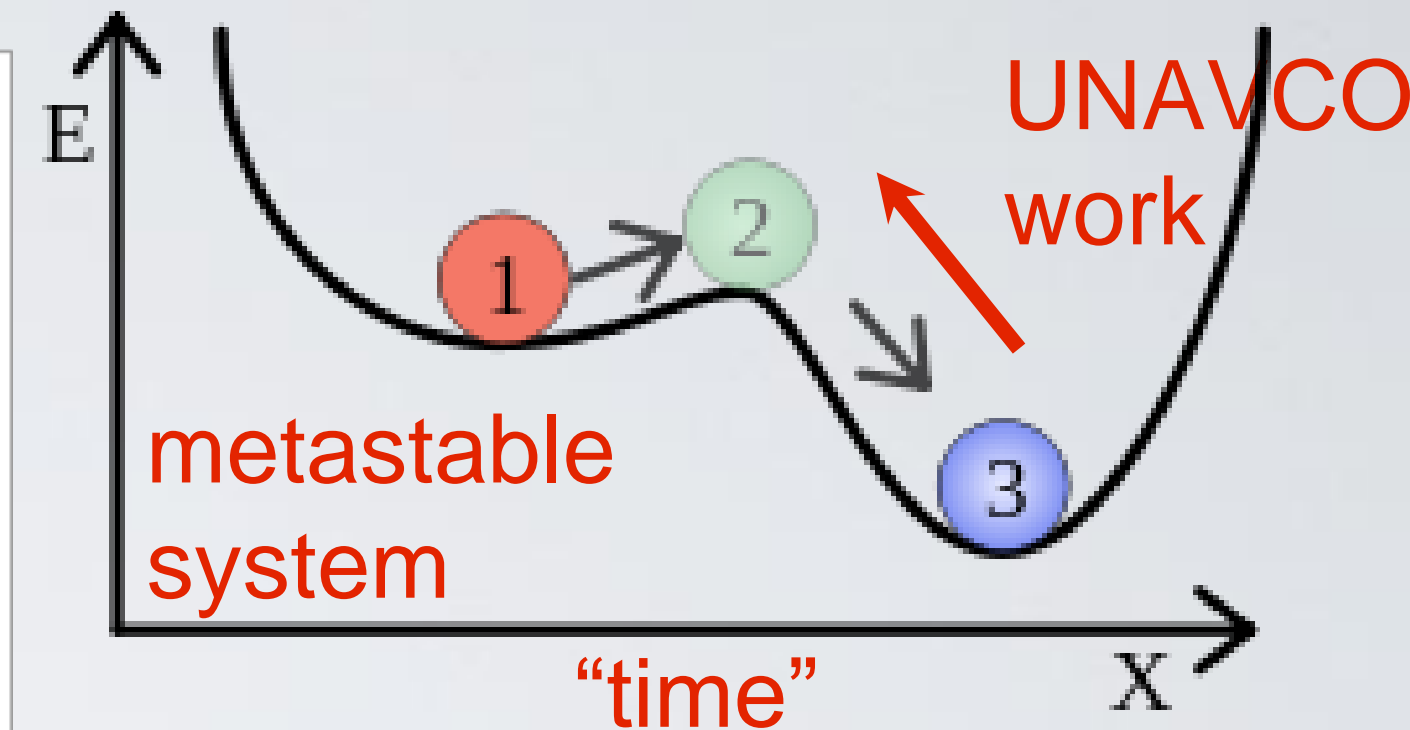
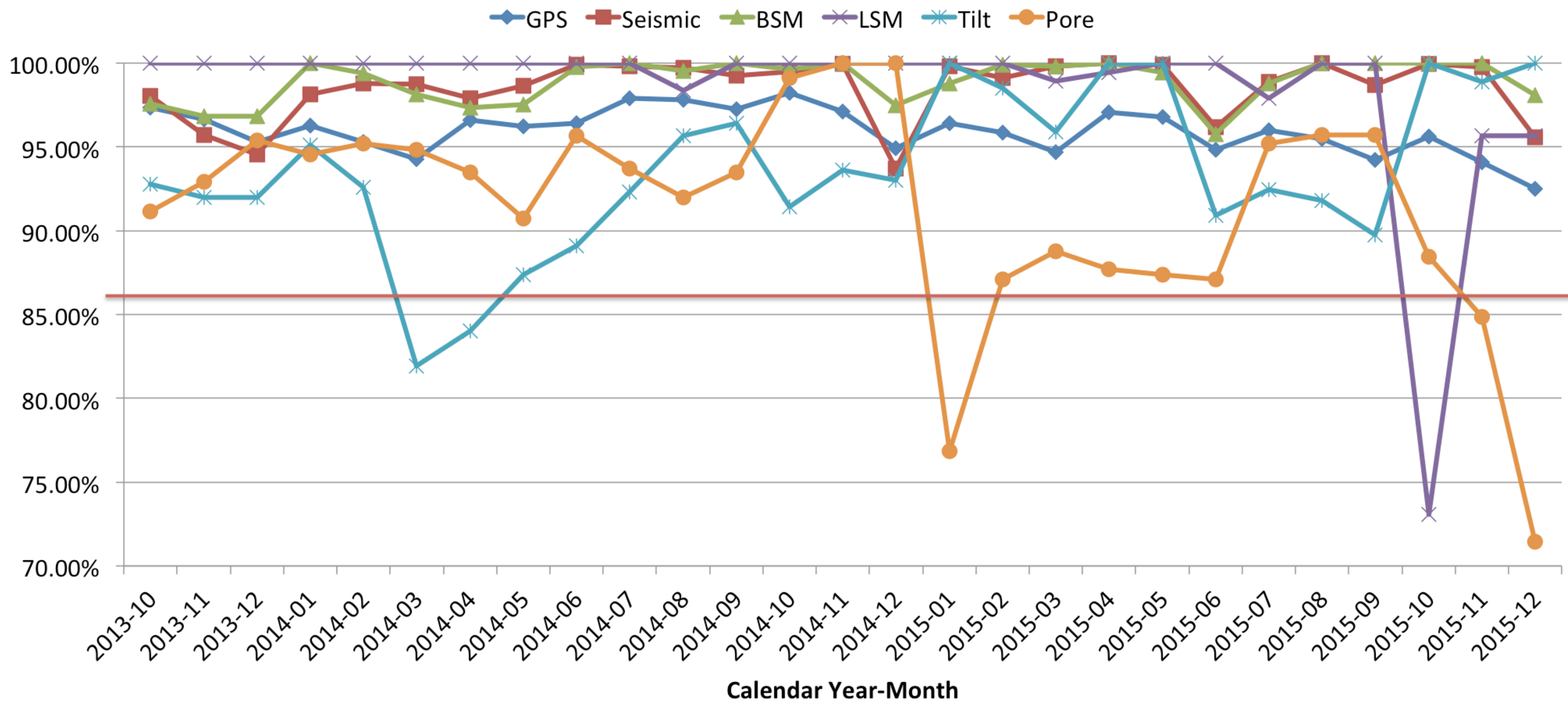


PBO SENSOR DATA RETURN

“data return”

PBO Network Data Return Percentage (01 October 2013 - 31 December 2015)

PRELIMINARY FOR OCT-DEC 2015



Cumulative data return for the PBO network since the beginning of the O&M period (FY2009) is:

- 99% for GPS/Met
- 96% for seismic
- 98% for BSM
- 100% for LSM
- 92% for pore pressure
- 86% for tilt.

Metrics complete through December 31, 2015 (YR8Q1- GAGE YR3Q1)

GAGE-PBO Data Products



GPS data products from PBO, COCONet, other networks

Level 1: RINEX

Level 2: Station positions, time series, velocities (in various ref. frames)

Level 3: Community contributed products such as H2O (K. Larson)

Borehole Geophysics data products (Levels 0,1,2)

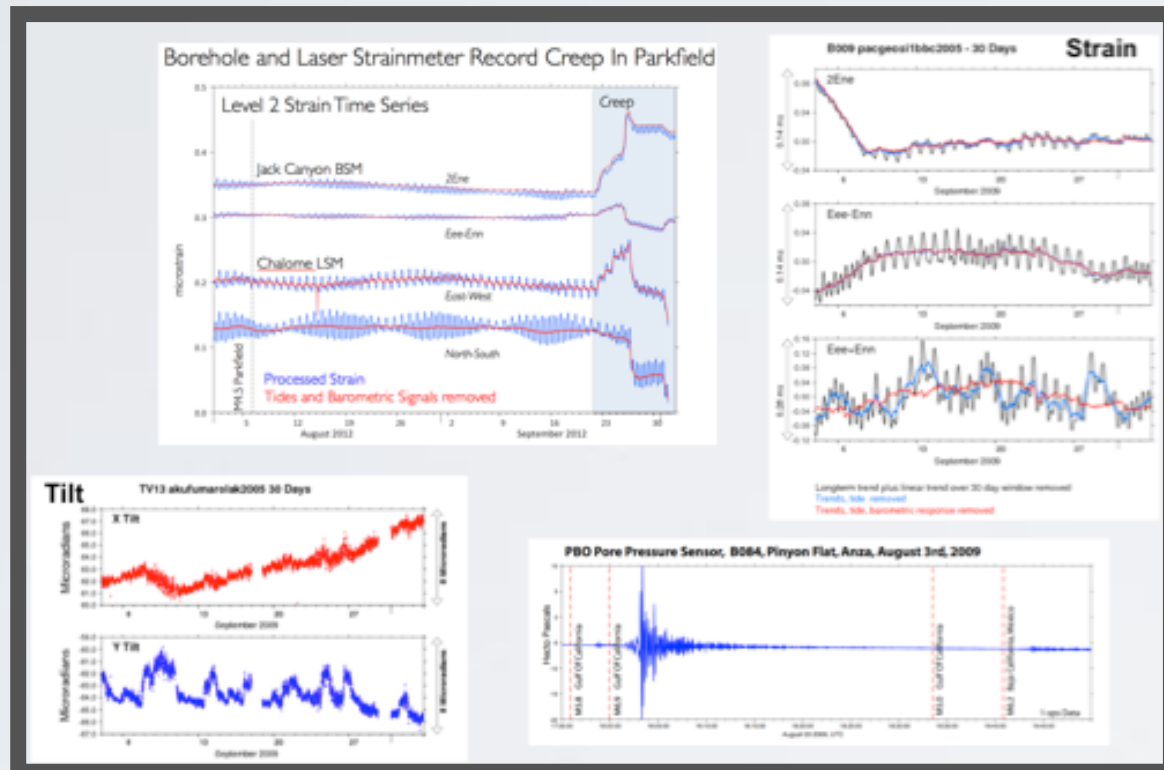
Borehole Strainmeter (BSM)

Laser Strainmeter (LSM)

Tiltmeter (Tilt)

Pore Pressure (Pore)

Seismometer (Seismic)

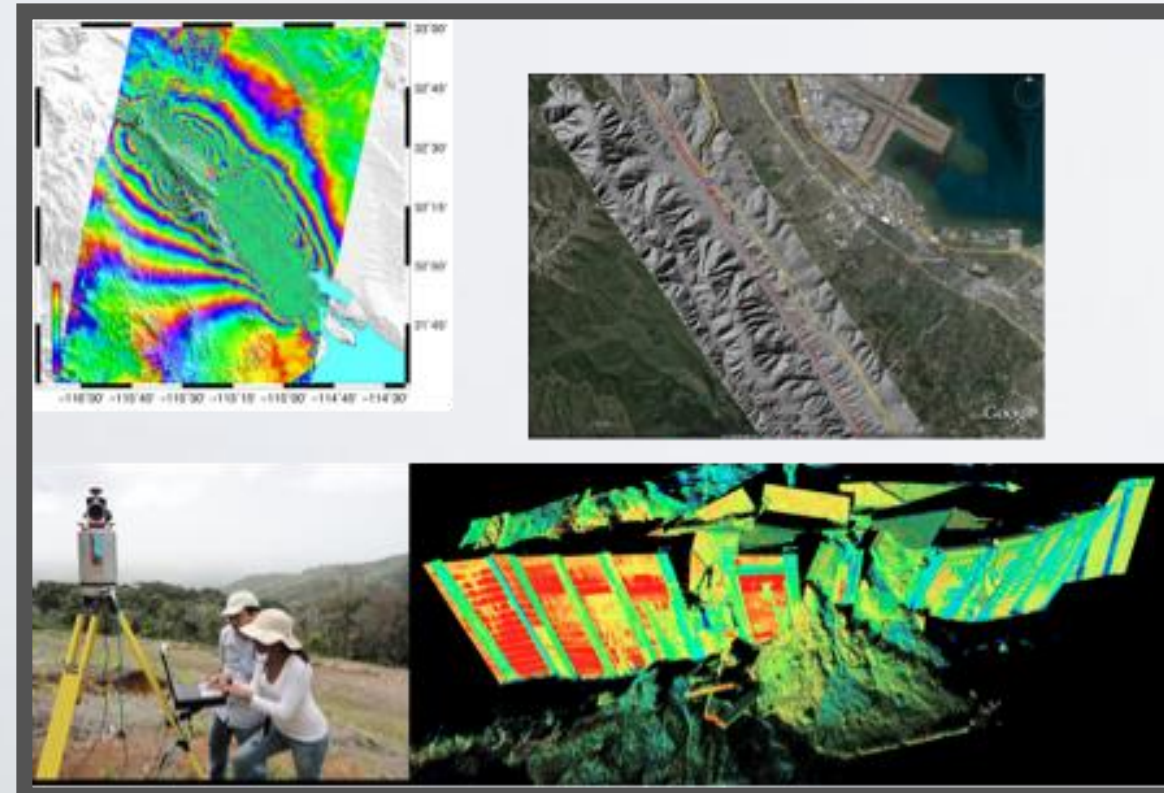


Geodetic Imaging data products

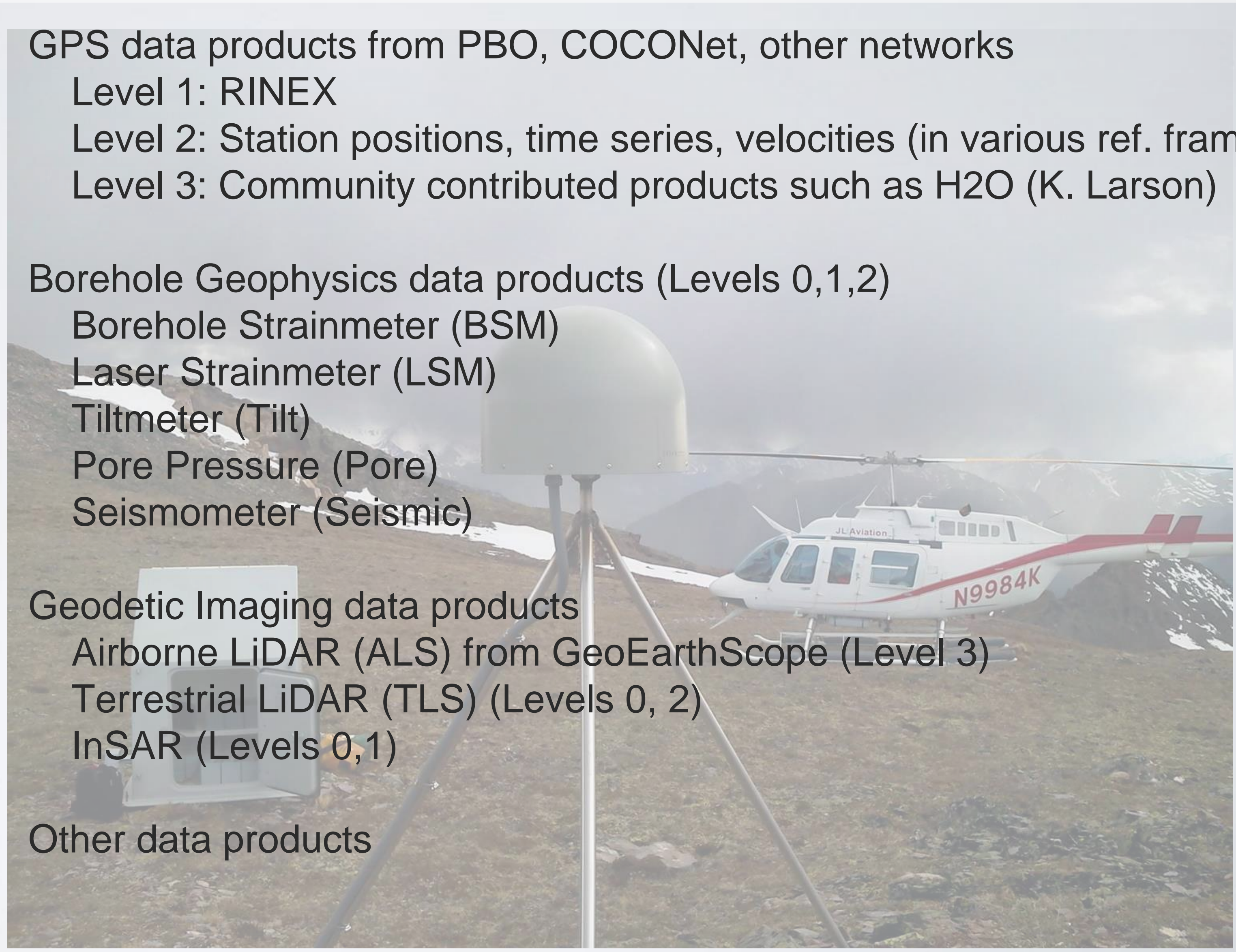
Airborne LiDAR (ALS) from GeoEarthScope (Level 3)

Terrestrial LiDAR (TLS) (Levels 0, 2)

InSAR (Levels 0,1)

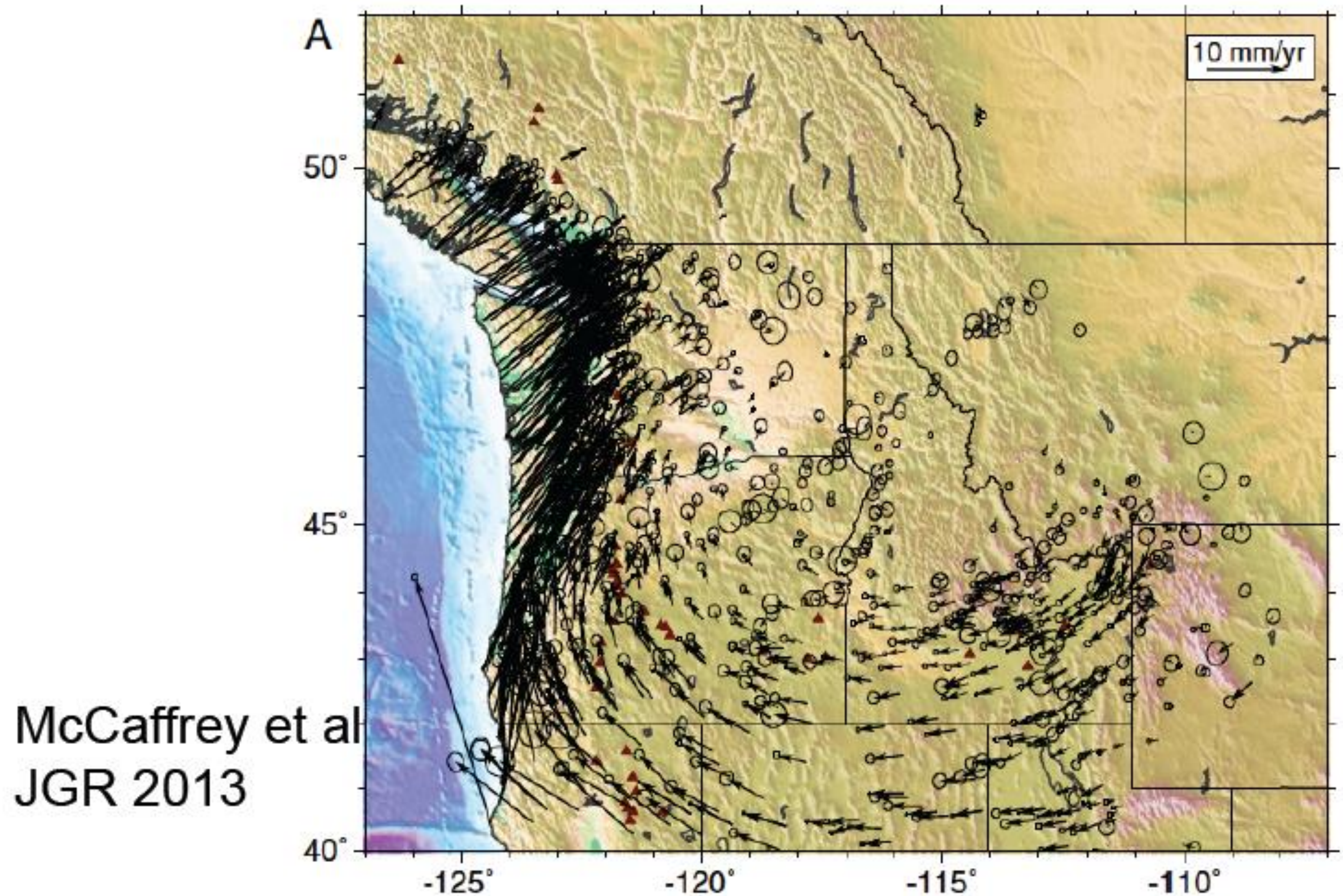


Other data products



PNW block rotation, translation and strain

- Combines cGPS and eGPS measurements
- Uses PBO cGPS data
- Constrains “block” motion and strain/locking along faults



TAKING A BROADER VIEW

Combines cGPS and eGPS measurements

Uses PBO cGPS data

Constrains “block” motion and strain/locking along faults

Kreemer, Hammond, Blewitt, Holland & Bennett, 2012

A Geodetic Strain Rate Model for the Pacific-North American Plate Boundary, Western United States

Corné Kreemer¹
William C. Hammond¹
Geoffrey Blewitt¹
Austin A. Holland²
Richard A. Bennett²

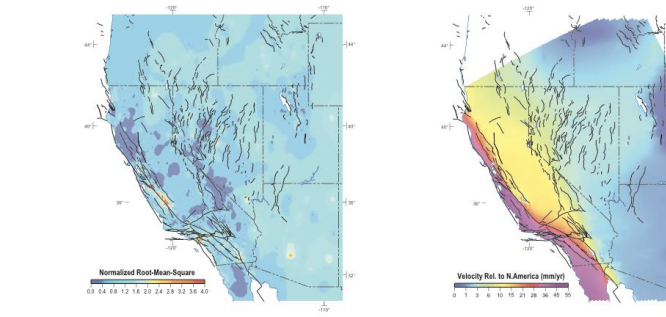
¹Nevada Bureau of Mines and Geology, University of Nevada Reno
²Department of Geological Sciences, University of Arizona
2012

SUMMARY
This map presents a model of crustal strain rates derived from Global Positioning System (GPS) measurements of horizontal station velocities. The model indicates the spatial distribution of deformation rates within the Pacific-North America plate boundary from the San Andreas fault system in the west to the Basin and Range province in the east. As these strain rates are derived from data spanning the last two decades, the model reflects a best estimate of present-day deformation. However, because rapid transient effects associated with earthquakes (i.e., postseismic deformation resulting in curvature of the GPS time-series) have been removed from the GPS data, these strain rates can be considered representative of the long-term, steady-state deformation associated with the accumulation of strain along faults. This model is useful for both seismic-hazard and geodynamic studies to understand the activity rates of known and unknown faults and the plate tectonic boundary and boundary forces that cause the deformation, respectively. In more slowly deforming areas we expect fewer, smaller earthquakes and infrequent large earthquakes will have a much longer recurrence time compared to those in rapidly deforming areas.



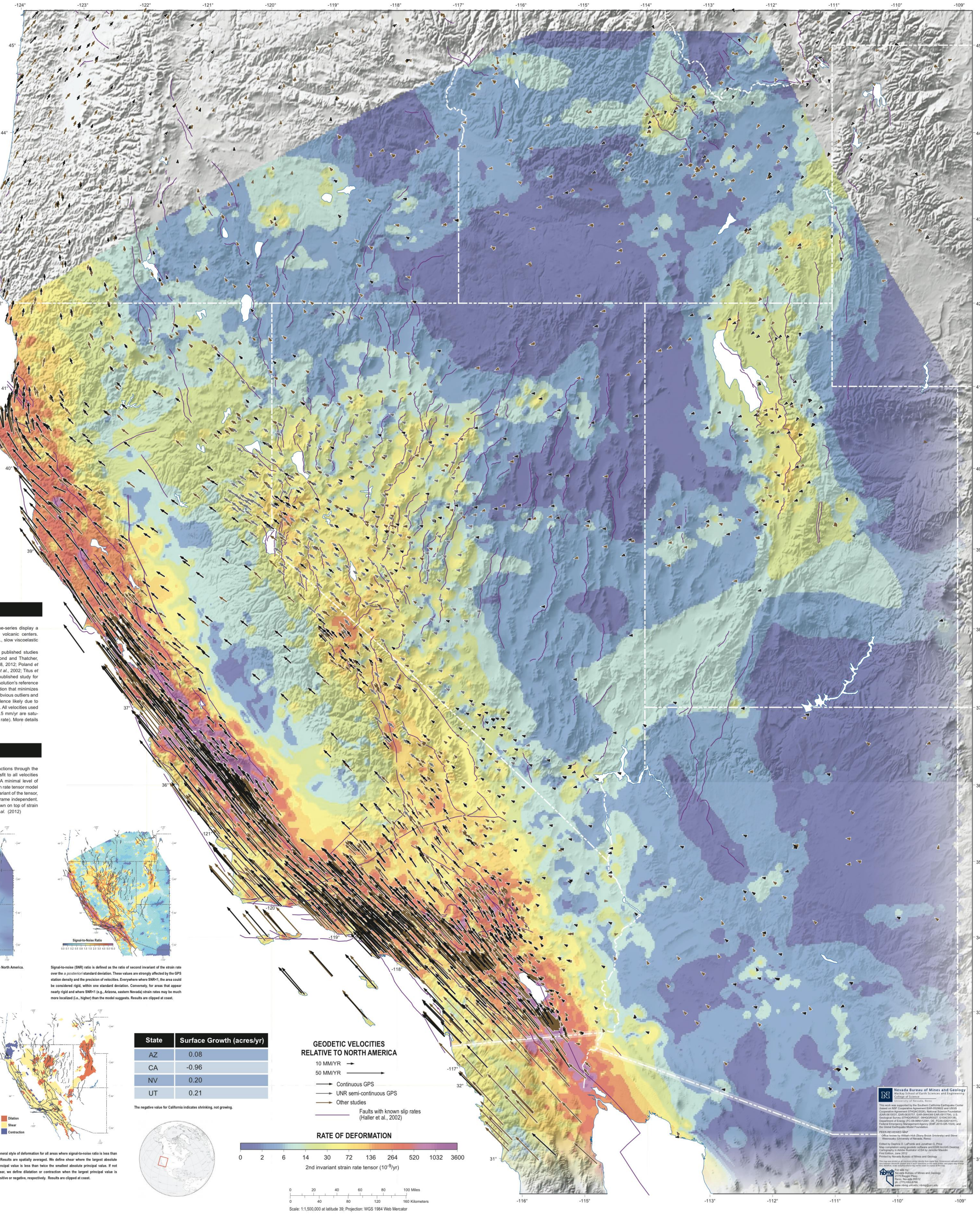
GPS DATA
The GPS velocities were compiled specifically for this study. Of the total 2,840 velocities used in the model, 1,107 were derived by the authors and 1,733 were taken from (mostly) published results. The velocities derived by the authors (the “UNR solution”) were estimated from GPS position time-series of continuous and semi-continuous stations for which data are publicly available. We estimated 1781 2005 positions from 2002 to 2011 using GPS/GNSS II software with ambiguity resolution applied using our custom Ambazip software. Only stations with time-series that span at least 2.5 years were considered. We removed from the time-series continental-scale common-mode errors using a spatially-varying filtering technique. Velocity uncertainties (typically 0.3–3 mm/yr) assume that the time-series contain flicker plus white noise. We used a subset of stations on the stable parts of the Pacific and North American plates (far from the plate boundaries) to estimate the Pacific-North American pole of rotation. The North American 1781 2005 pole was used to rotate our velocities into a North America-fixed reference frame. We did not include parts of the time-series that show curvature due to post-seismic deformation after major earthquakes and we also excluded stations whose time-series display a significant unexplained non-linearity or that are near volcanic centers. Transient effects longer than the observation period (i.e., slow viscoelastic relaxation) were left in the data. We added to the UNR solution velocities from published studies (Chang et al., 2006; Freymueller et al., 1999; Hammond and Thatcher, 2004, 2006, 2007; Lyons et al., 2002; Payne et al., 2006, 2012; Peltzer et al., 2006; Shen et al., 2011; Spitzer et al., 2010; Swarz et al., 2002; Tusa et al., 2011; Williams et al., 2009) and those from an unpublished study for Arizona. The velocities were transformed onto the UNR solution’s reference frame by estimating and applying a translation and rotation that minimizes velocity differences at collocated stations. We removed obvious outliers and velocities in areas that we identified to undergo subsidence likely due to excessive water pumping (e.g., California’s Central Valley). All velocities used in the model are shown on map (velocities less than 4.5 mm/yr are omitted such that the vector field is shown irrespective of rates). More details can be found in Kreemer et al. (2012).

MODELING DETAILS
For the strain rate calculations, we excluded GPS stations with anomalous vertical motion or annual horizontal periodicity, which are indicators of local site instability. First, we used the stations from the UNR solution to create a Delaunay triangulation and estimated the horizontal strain rate components (and rigid body rotation) for each triangle in a least squares inversion using the horizontal velocities as input. Some level of spatial damping was applied to minimize unnecessary spatial variations in the model parameters. The strain rates estimates were then used as a priori strain rate variances in a method that fits continuous bi-cubic Bessel spline functions through the velocity gradient field while minimizing the weighted sum of all velocities (Blewitt and Haller, 2001; Haller and Blewitt, 1993). A minimal level of spatial smoothing of the variances was applied. The strain rate tensor model is shown on the strain map as contours of the second invariant of the tensor, which is a measure of the amplitude that is coordinate-frame independent. Faults with known slip rates (Haller et al., 2002) are shown on map as strain rate contours. More details can be found in Kreemer et al. (2012).



Color map of the estimated maximum shear strain rate between observed and estimated velocities. For all blue colored areas the data are fit within two standard deviations. Areas with large shear strain rate are shown in red. Results are clipped at east.

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Payne, S. J., McCaffrey, R., and King, R. W., 2006. Stress rates and contemporary deformation in the Snake River Plain and surrounding Basin and Range extension. *Journal of Geophysical Research*, v. 111, B06403, doi:10.1029/2005JB003796.
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Tusa, R. L., and Freymueller, G. T., 2006. GPS-derived strain in northeastern California: Implications of the San Andreas fault system and convergence of the Sierra Nevada-Great Valley block to southern Cascade Basin contraction. *Tectonophysics*, v. 413, p. 171–184.



State	Surface Growth (acres/yr)
AZ	0.08
CA	-0.96
NV	0.20
UT	0.21

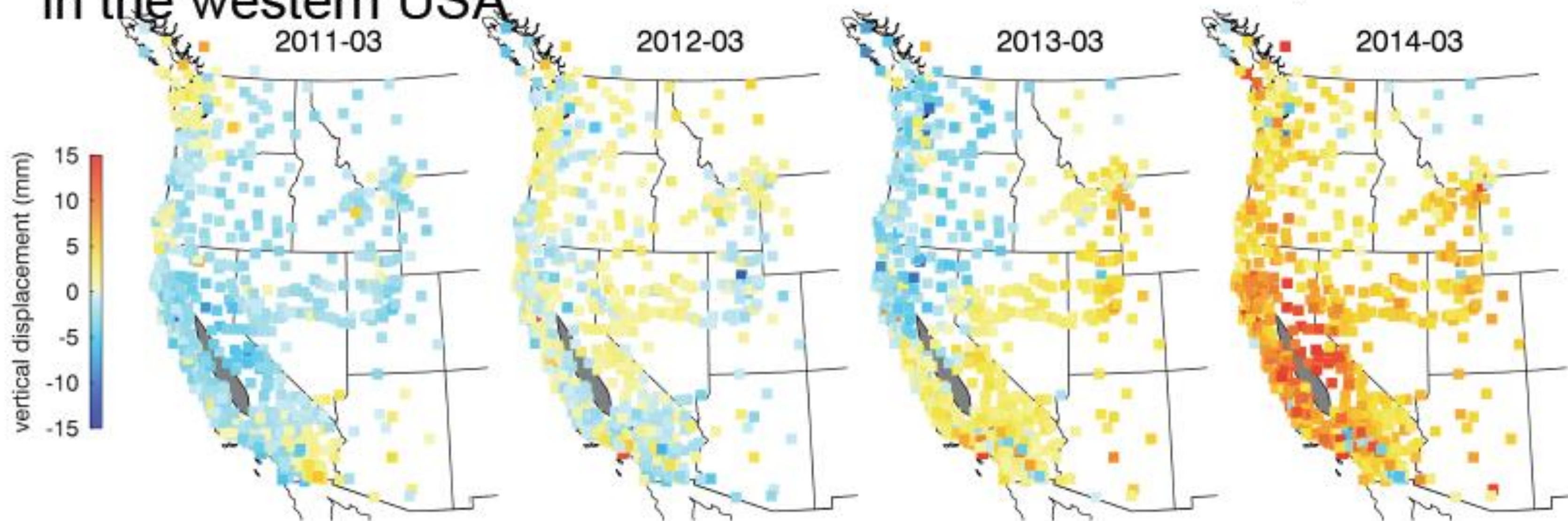
GEODETIC VELOCITIES RELATIVE TO NORTH AMERICA
10 MM/yr
50 MM/yr
Continuous GPS
UNR semi-continuous GPS
Other studies
Faults with known slip rates (Haller et al., 2002)

RATE OF DEFORMATION
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56 58 60 62 64 66 68 70 72 74 76 78 80 82 84 86 88 90 92 94 96 98 100 102 104 106 108 110 112 114 116 118 120 122 124 126 128 130 132 134 136 138 140 142 144 146 148 150 152 154 156 158 160 162 164 166 168 170 172 174 176 178 180 182 184 186 188 190 192 194 196 198 200 202 204 206 208 210 212 214 216 218 220 222 224 226 228 230 232 234 236 238 240 242 244 246 248 250 252 254 256 258 260 262 264 266 268 270 272 274 276 278 280 282 284 286 288 290 292 294 296 298 300 302 304 306 308 310 312 314 316 318 320 322 324 326 328 330 332 334 336 338 340 342 344 346 348 350 352 354 356 358 360

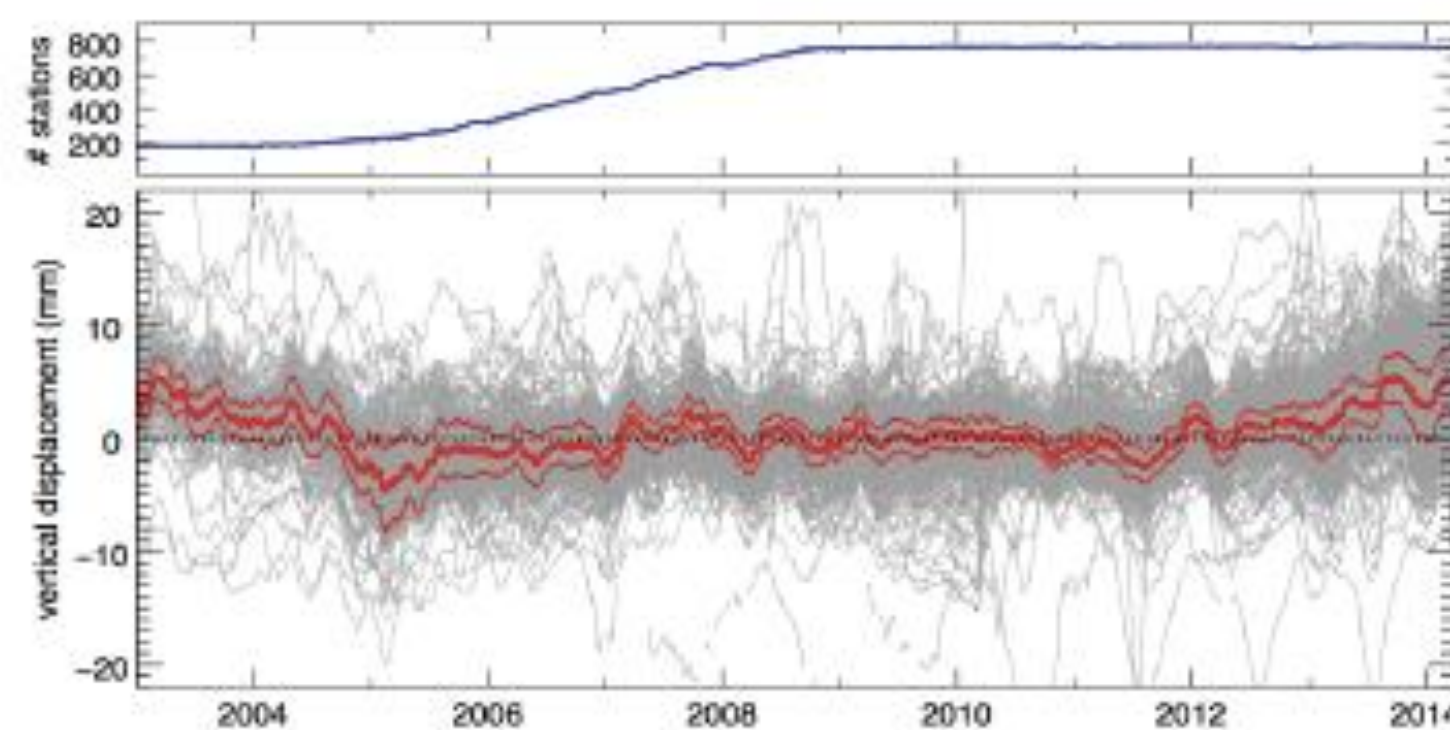
PBO - DROUGHT SENSOR

PBO observations of hydrological loading in the western USA

Borsa, Agnew, Cayan,
Science, 2014

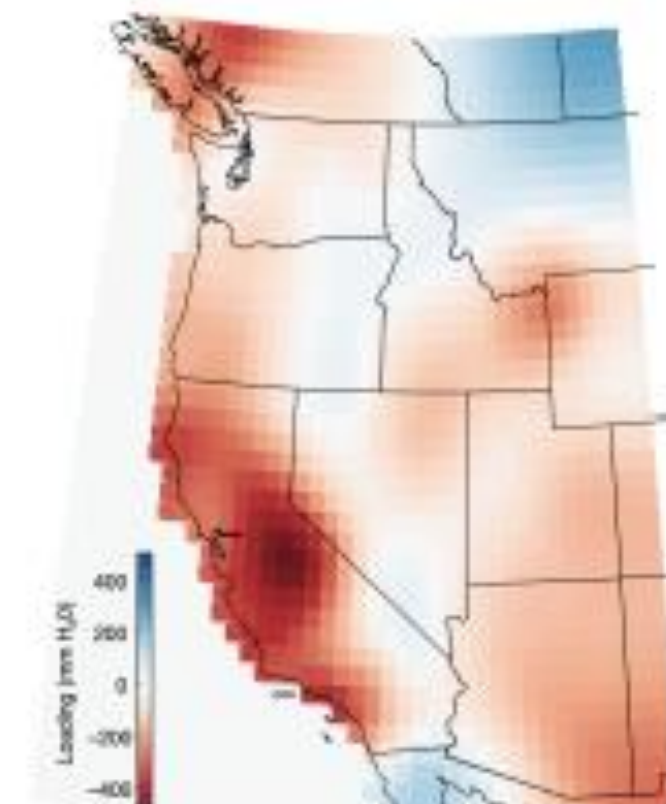


Spatial distribution of the GPS vertical displacements as of March 1 for the years 2011 through 2014. Yellow-red colors indicate uplift; subsidence is indicated by shades of blue. Gray region shows the area of stations excluded in the Central Valley. Water unloading due to the current drought is responsible for the strong uplift observed in 2014-03.

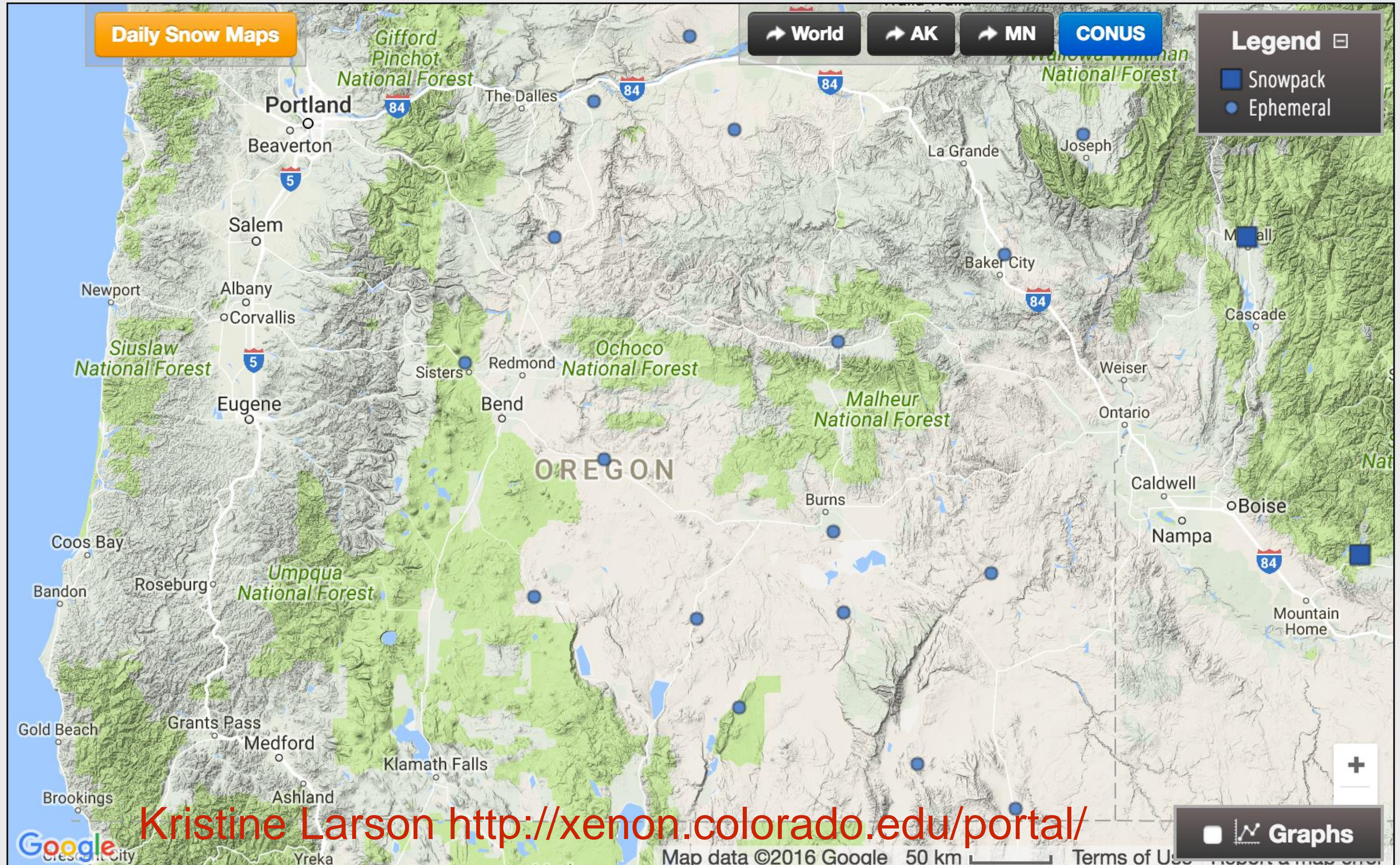


Seasonally-adjusted GPS vertical time series used above.

Water loading model inverted from the 2014-03 panel (above-right) assuming a spherical earth elastic response.



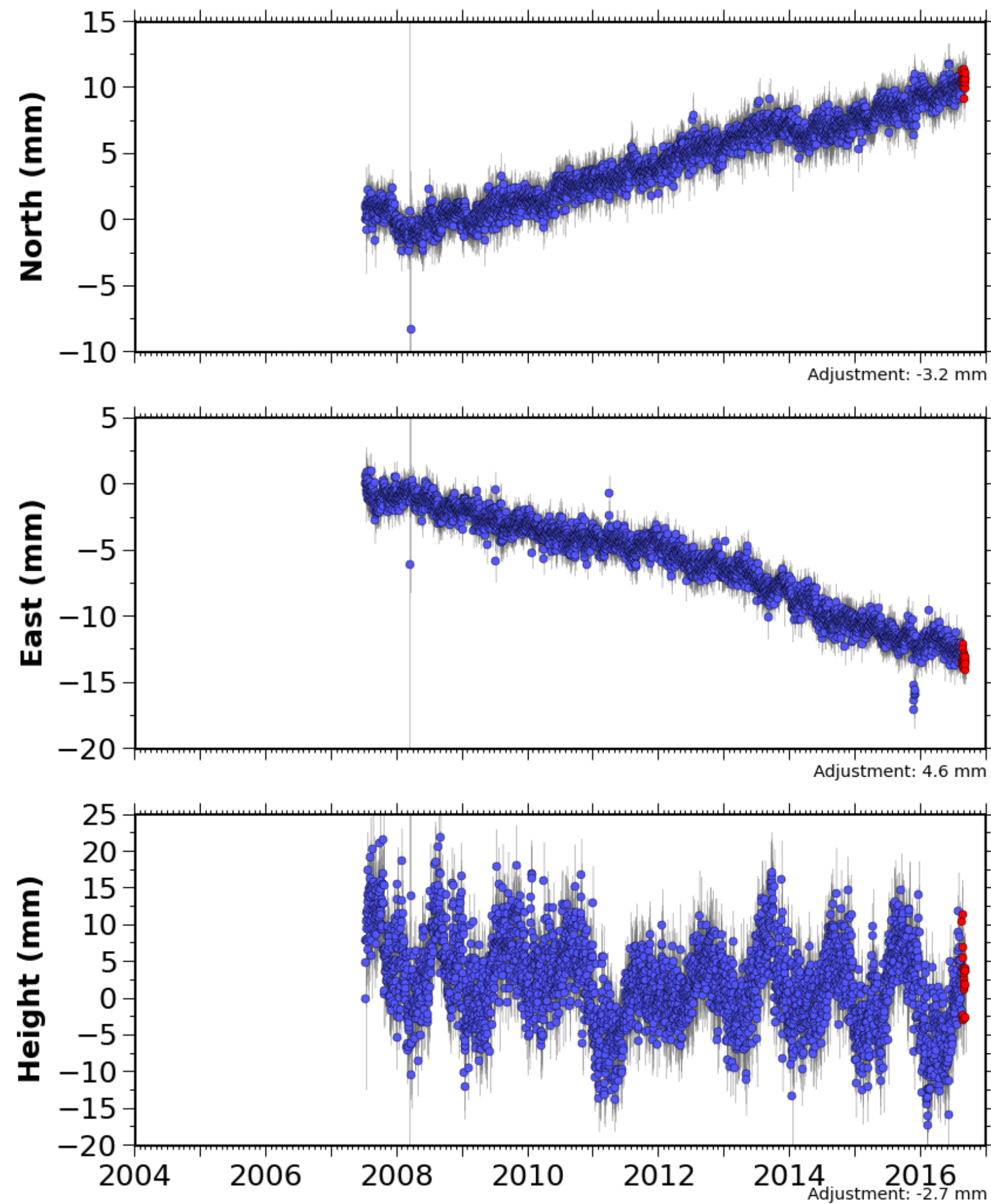
PBO H2O SNOW STATIONS



P392 SNOW DATA

P392 (WrightsPt_OR2007) NAM08

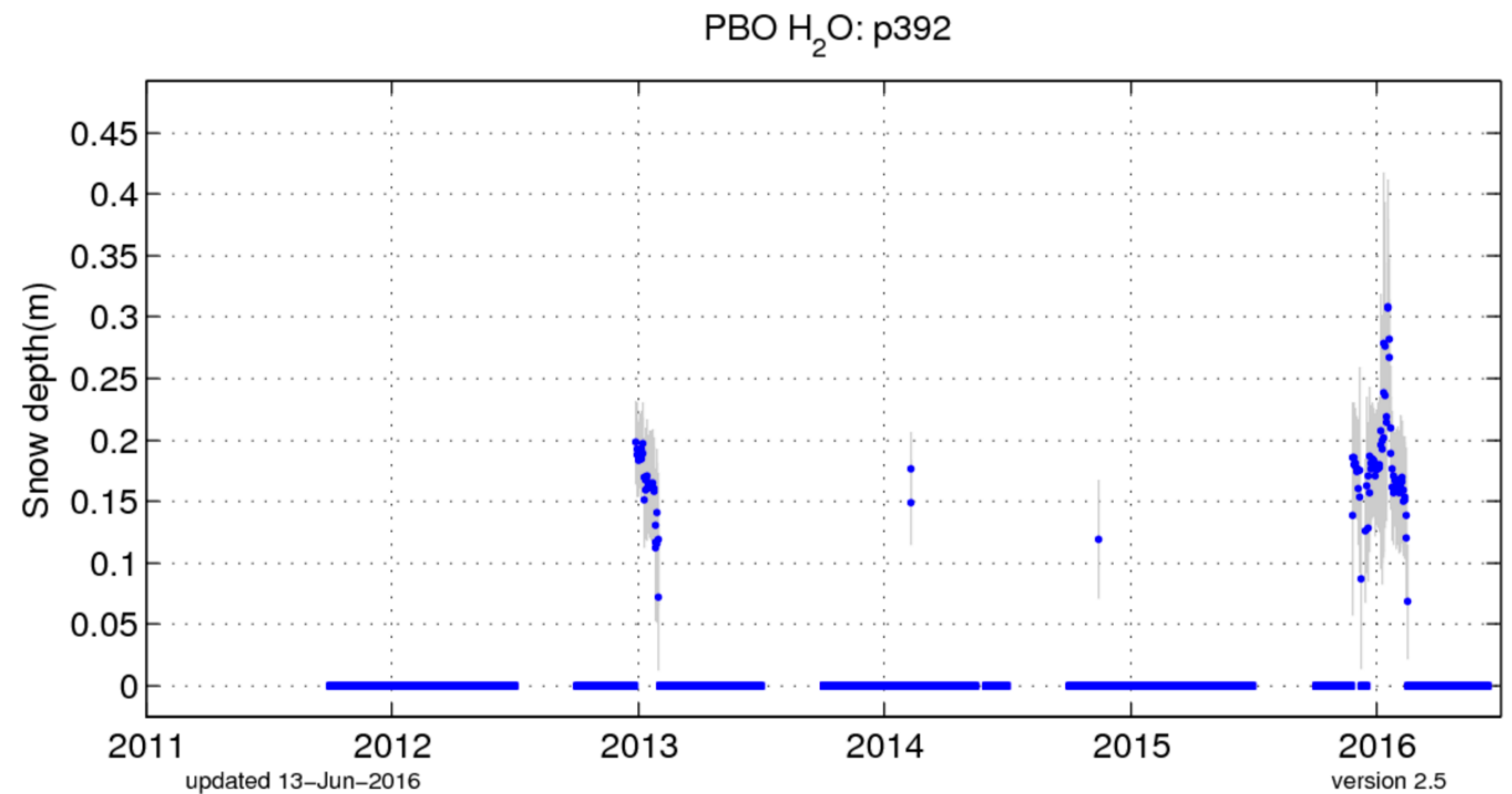
Processed Daily Position Time Series



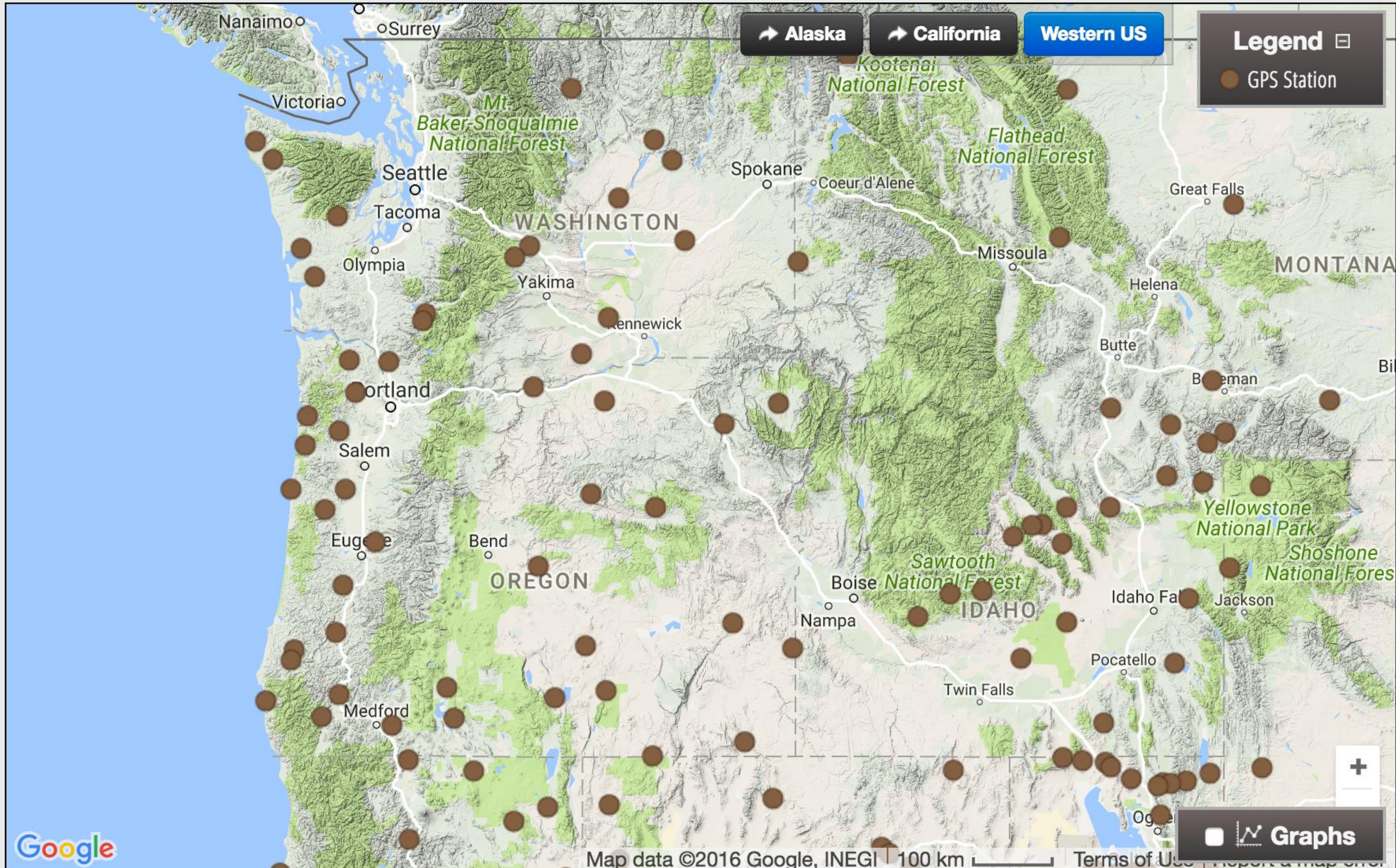
Source file: P392.pbo.nam08.pos Last epoch plotted: 2016-09-08 12:00:00

Station *p392*

Snow Depth

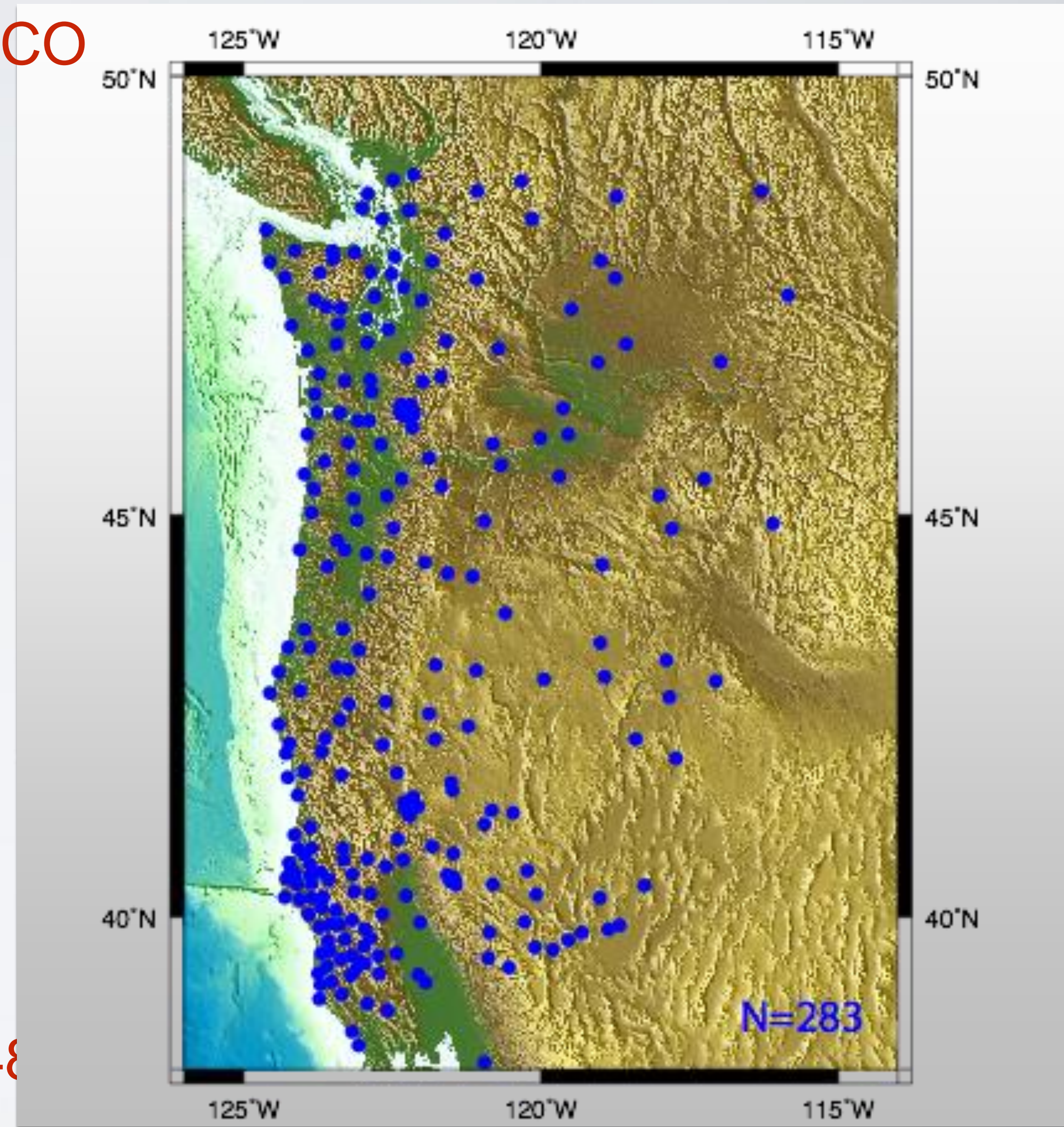


PBO H2O VEGETATION STATIONS



NSF INVESTMENT IN PBO: CA AND CASCADIA

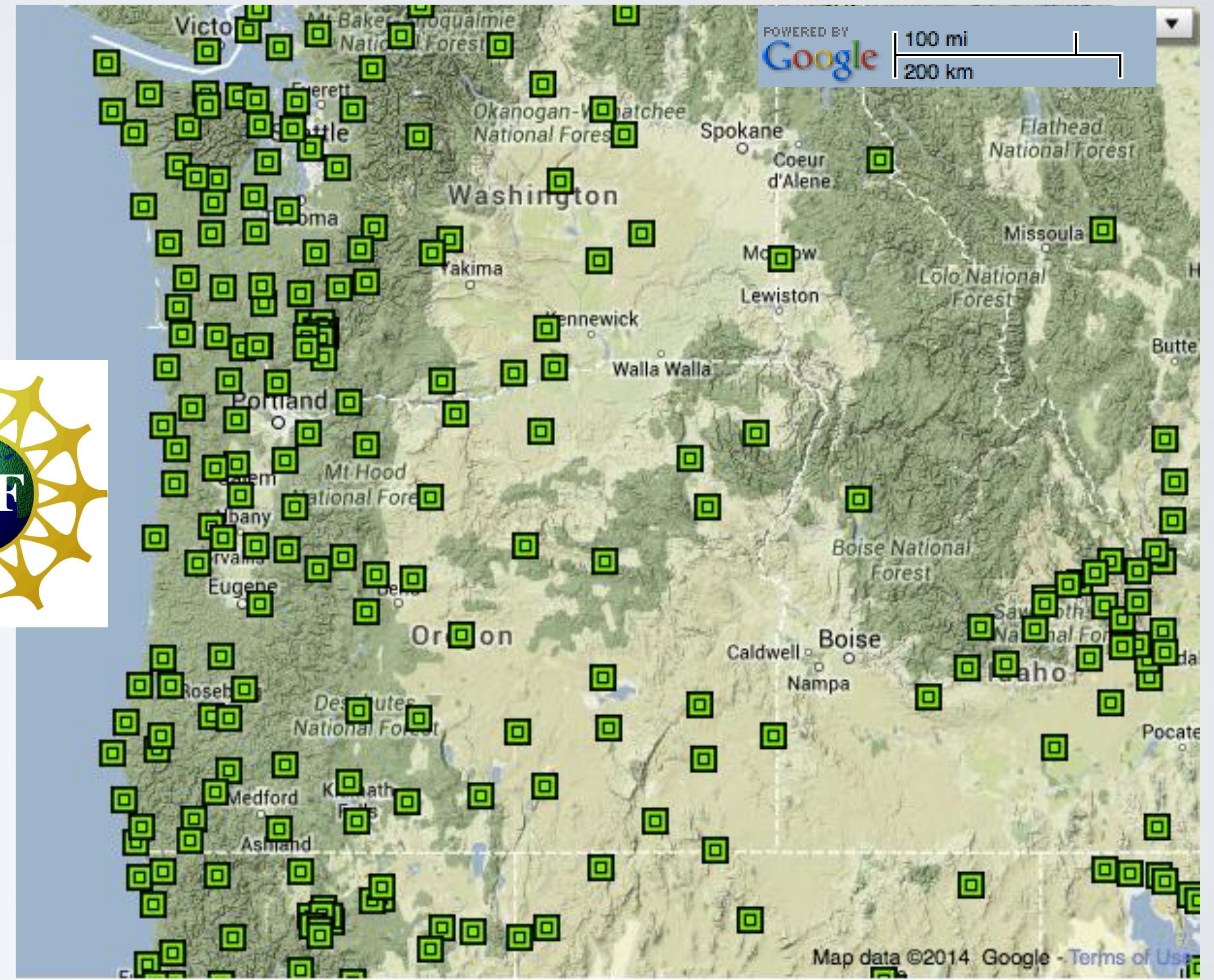
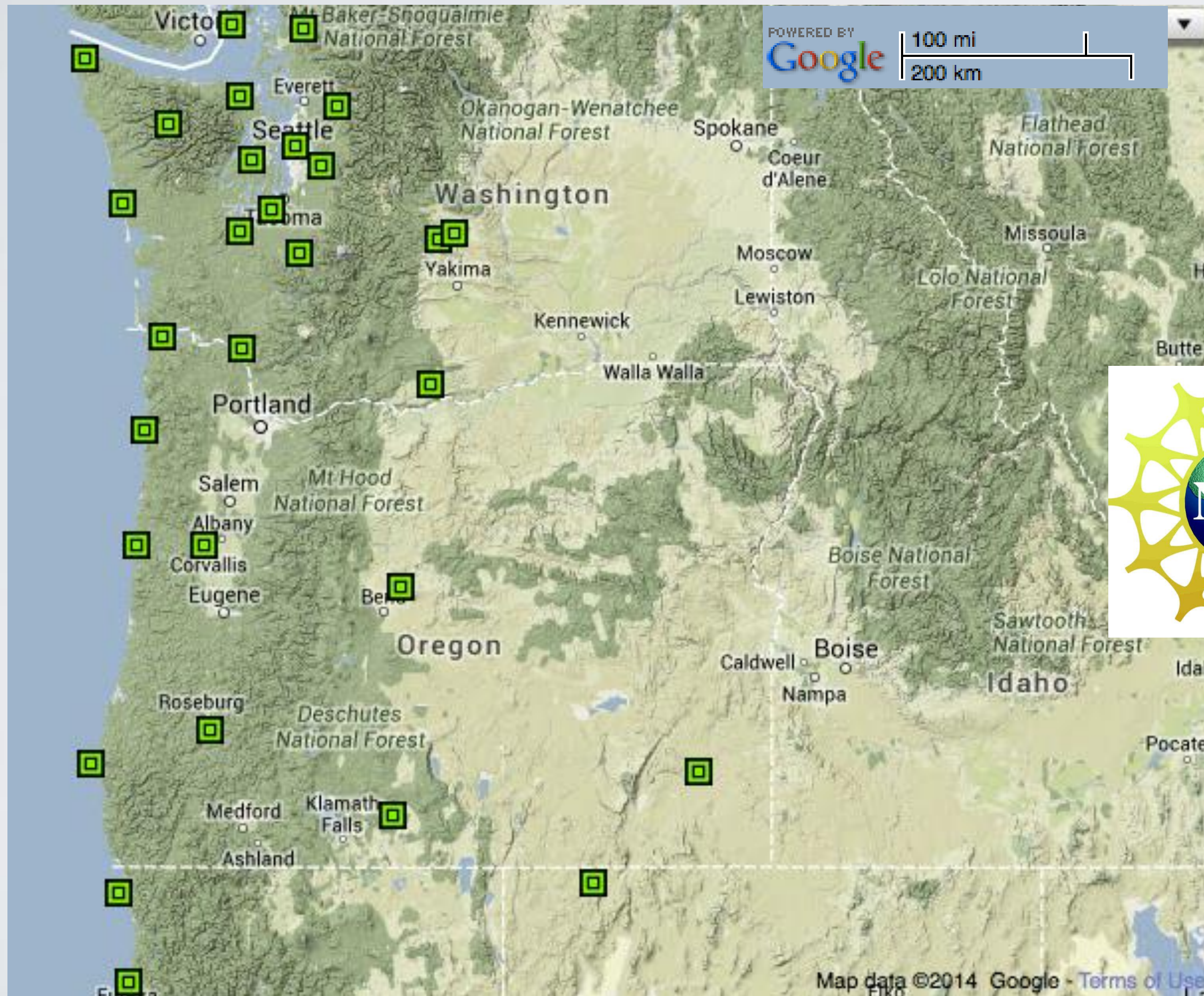
~1632 cGPS (processed and/or maintained) by UNAVCO



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CASCADIA PBO ASSETS: INITIAL AND SUPPLEMENTAL INVESTMENTS

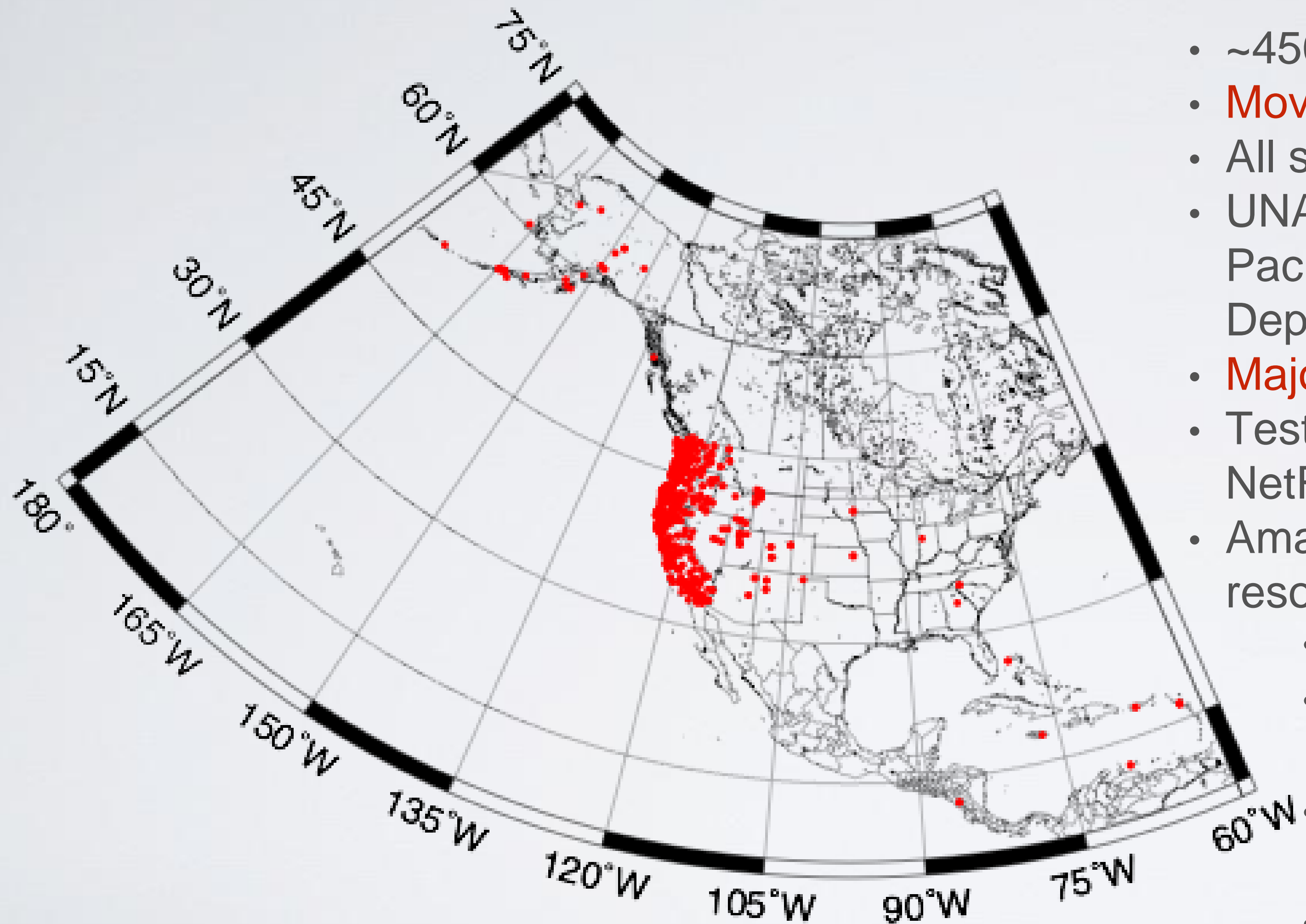
cGPS stations operated, processed, and maintained by UNAVCO



Original 29 PANGA cGPS stations

Current 234 PBO cGPS stations

RT-GPS - CURRENT NETWORK



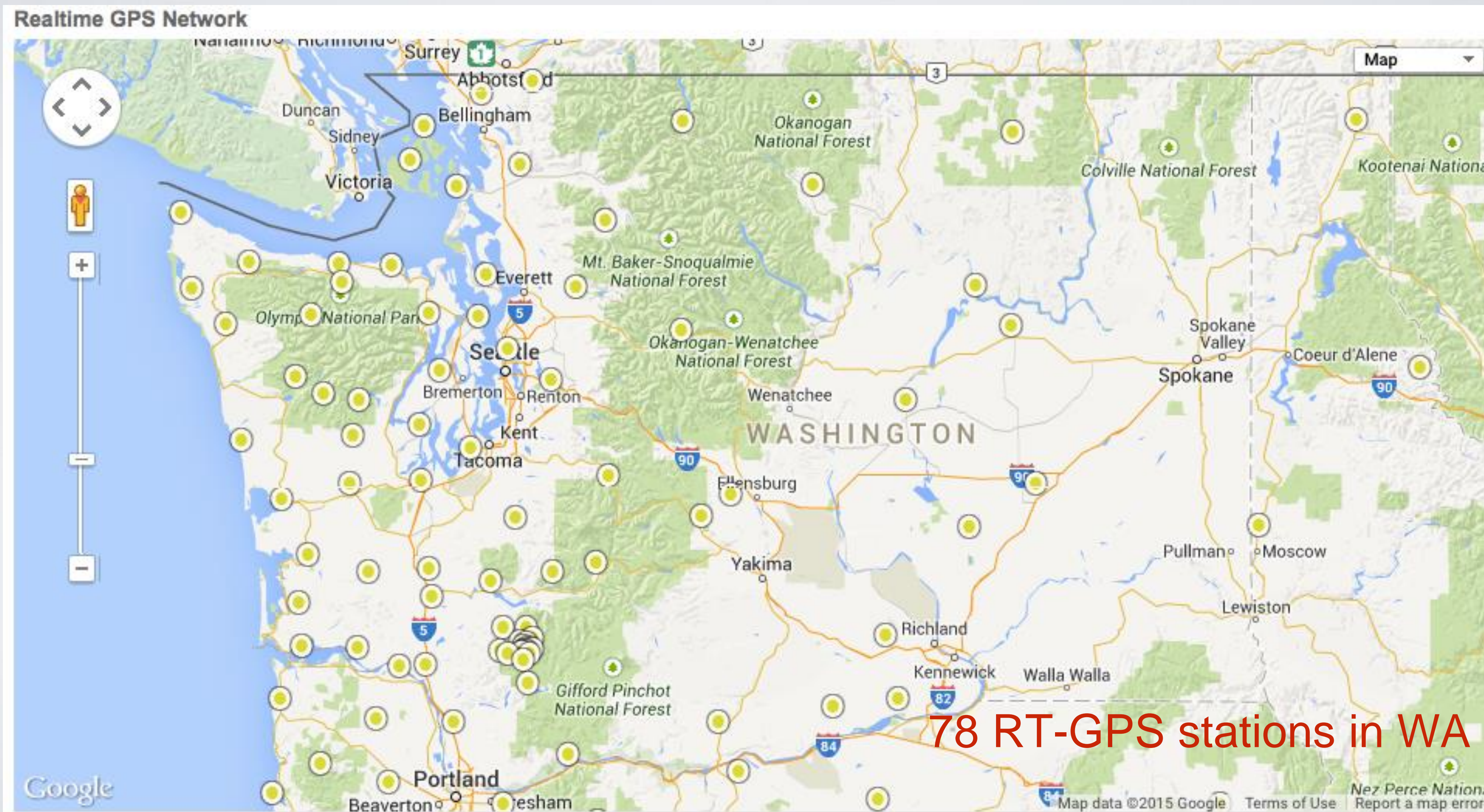
Current Network

- ~450 Real-time stations
- **Moving towards archiving all data at 1 Hz**
- All sites producing RTX point positions
- UNAVCO also participating in initiative for open Pacific wide data, NASA is leading through the State Department
- **Major upgrade to PIVOT is underway**
- Test of archive quality streams in process (limited to NetR9)
- Amazon grant received to test ~250 sites with all resources in the cloud.

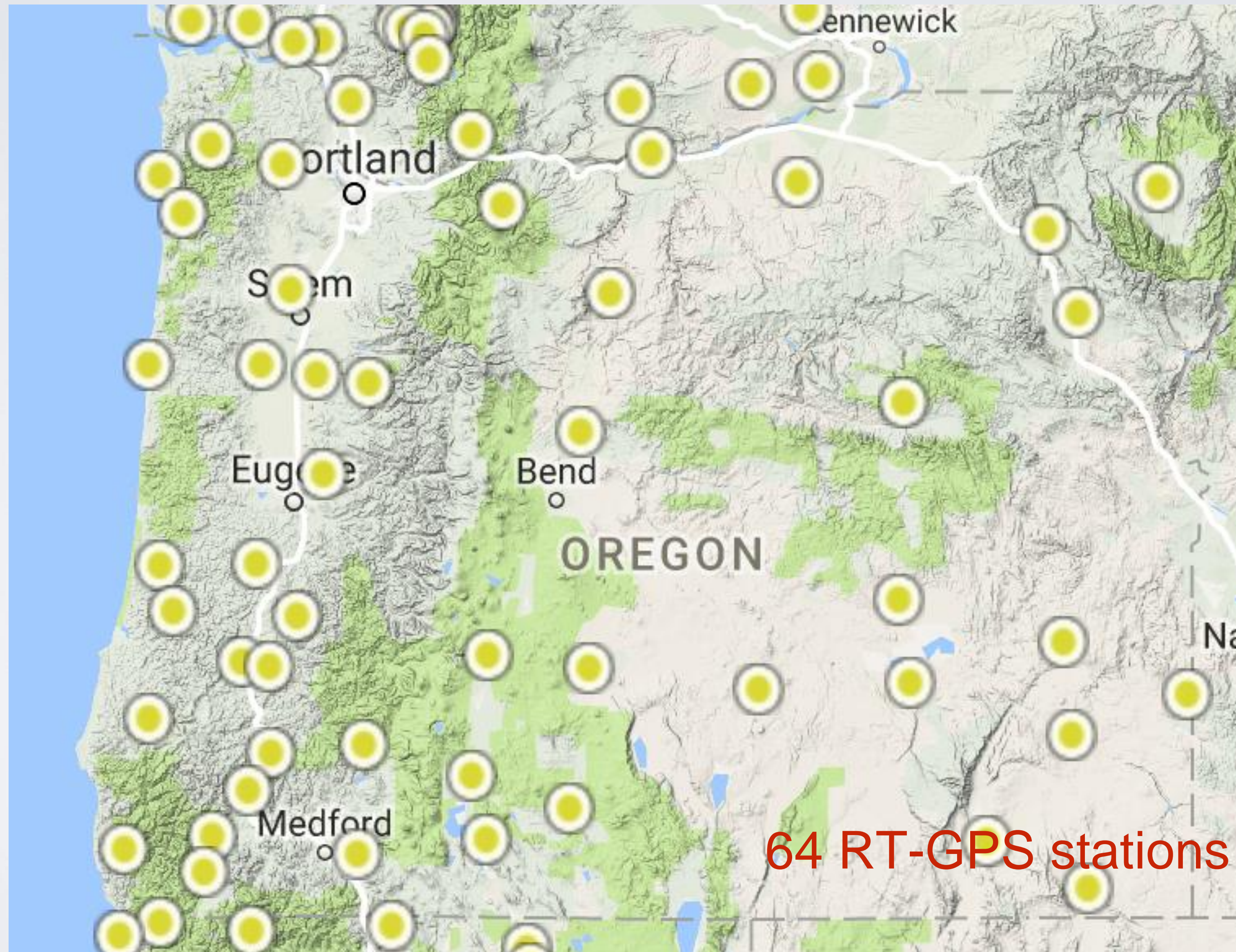
Concerns

- Network side capacity for > 1 Hz data
- Archiving multiple data sets for same sample rate and station. (How to present this).
- **Very low dedicated resources (GAGE YR1 - 1 FTE)**
- Ill defined formats for processed real-time positions (UNAVCO will propose an EYRO/BNX hybrid - still need for SEED analog)

RT-GPS - CURRENT PBO NETWORK IN WA



RT-GPS - CURRENT PBO NETWORK IN OR

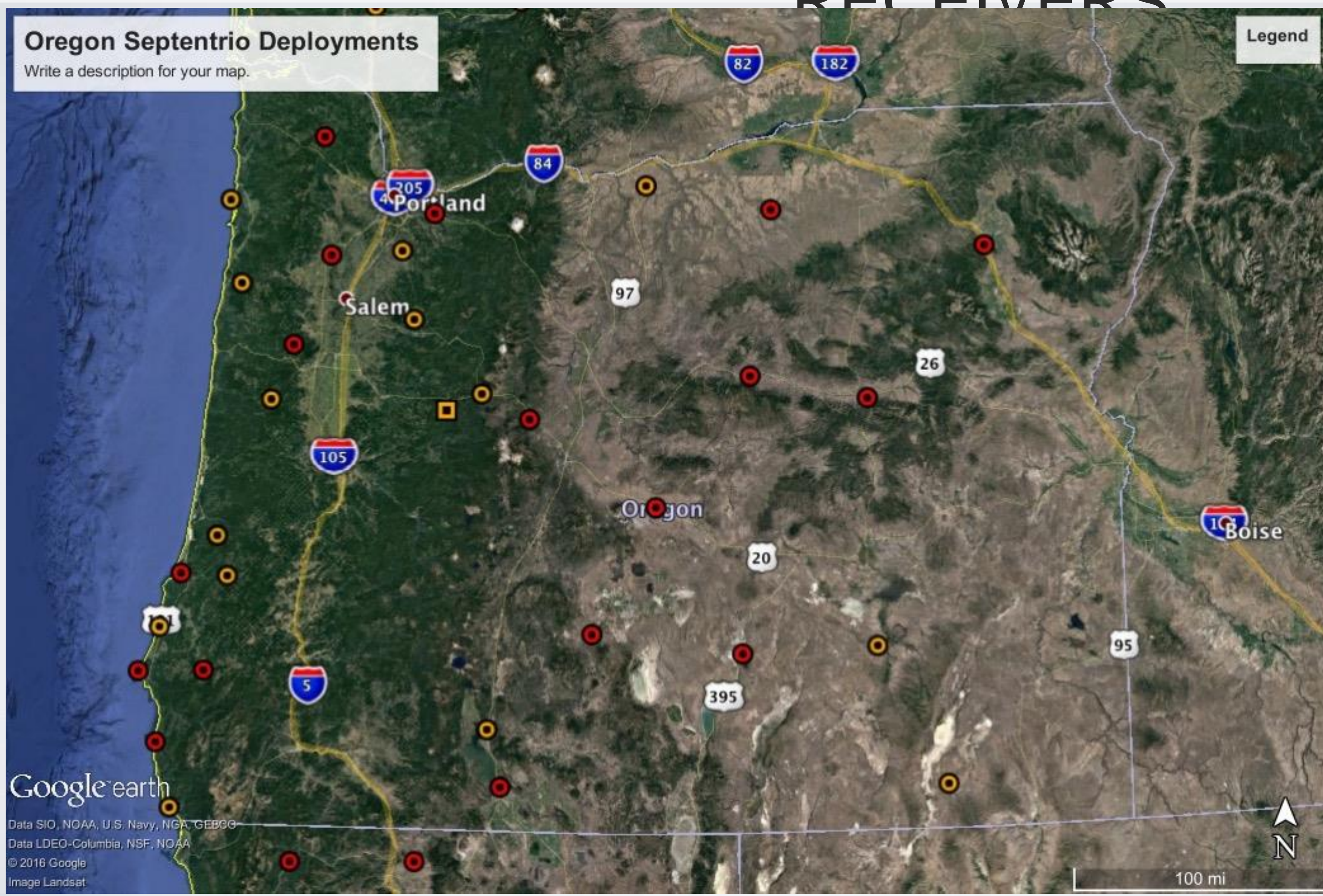


64 RT-GPS stations in OR

100 SEPTENTRIO RECEIVER DEPLOYMENTS



ODOT CONTRIBUTED SEPTENTRIO RECEIVERS

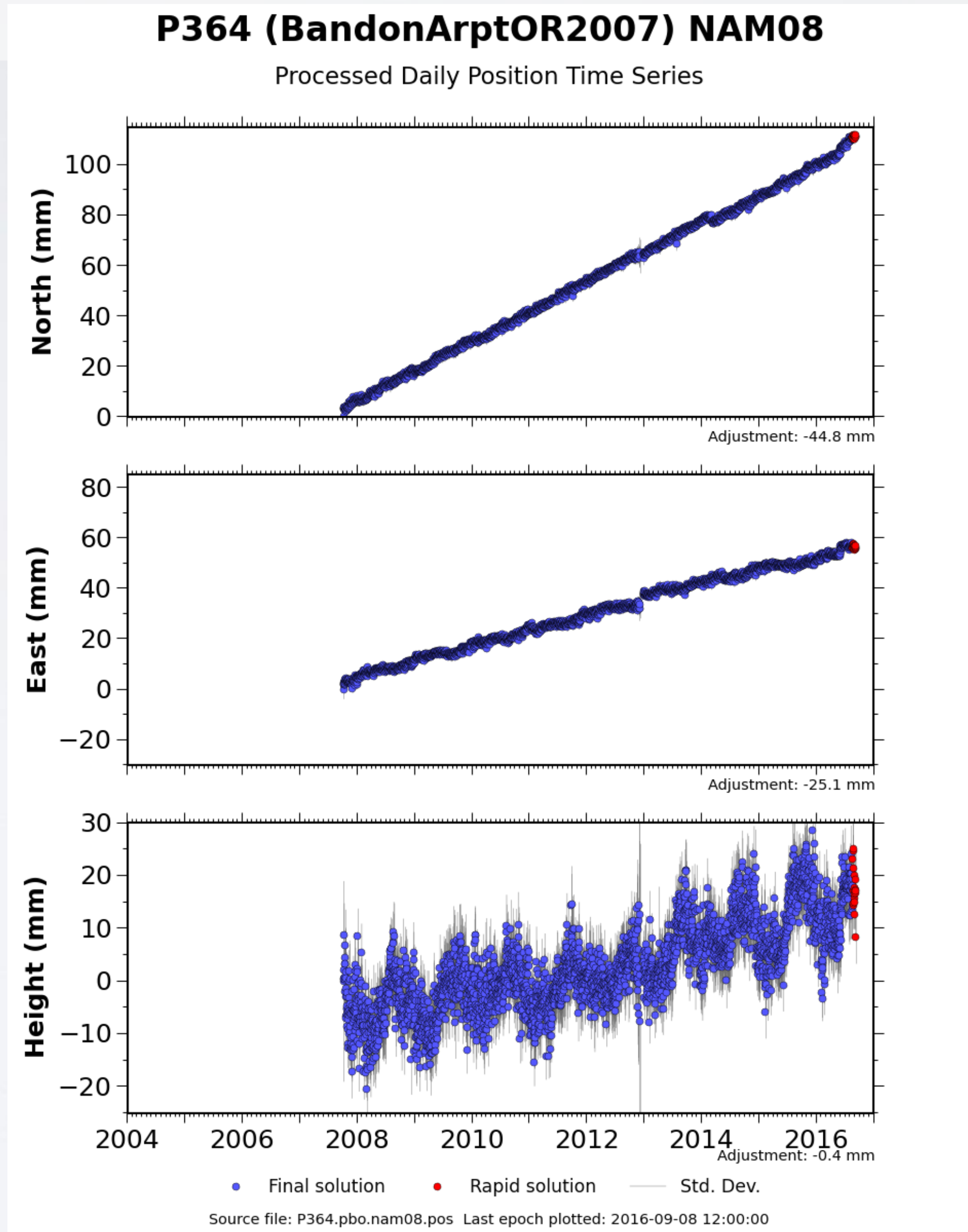
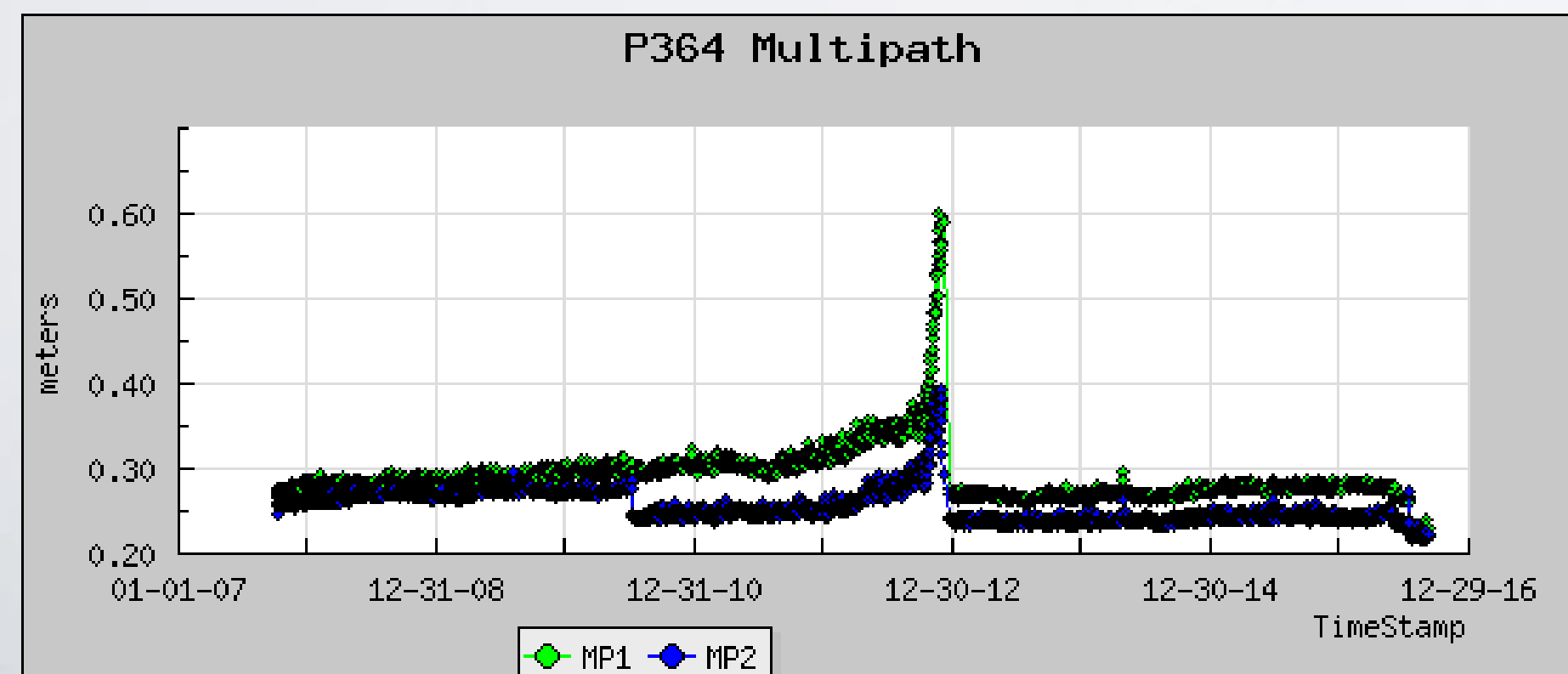
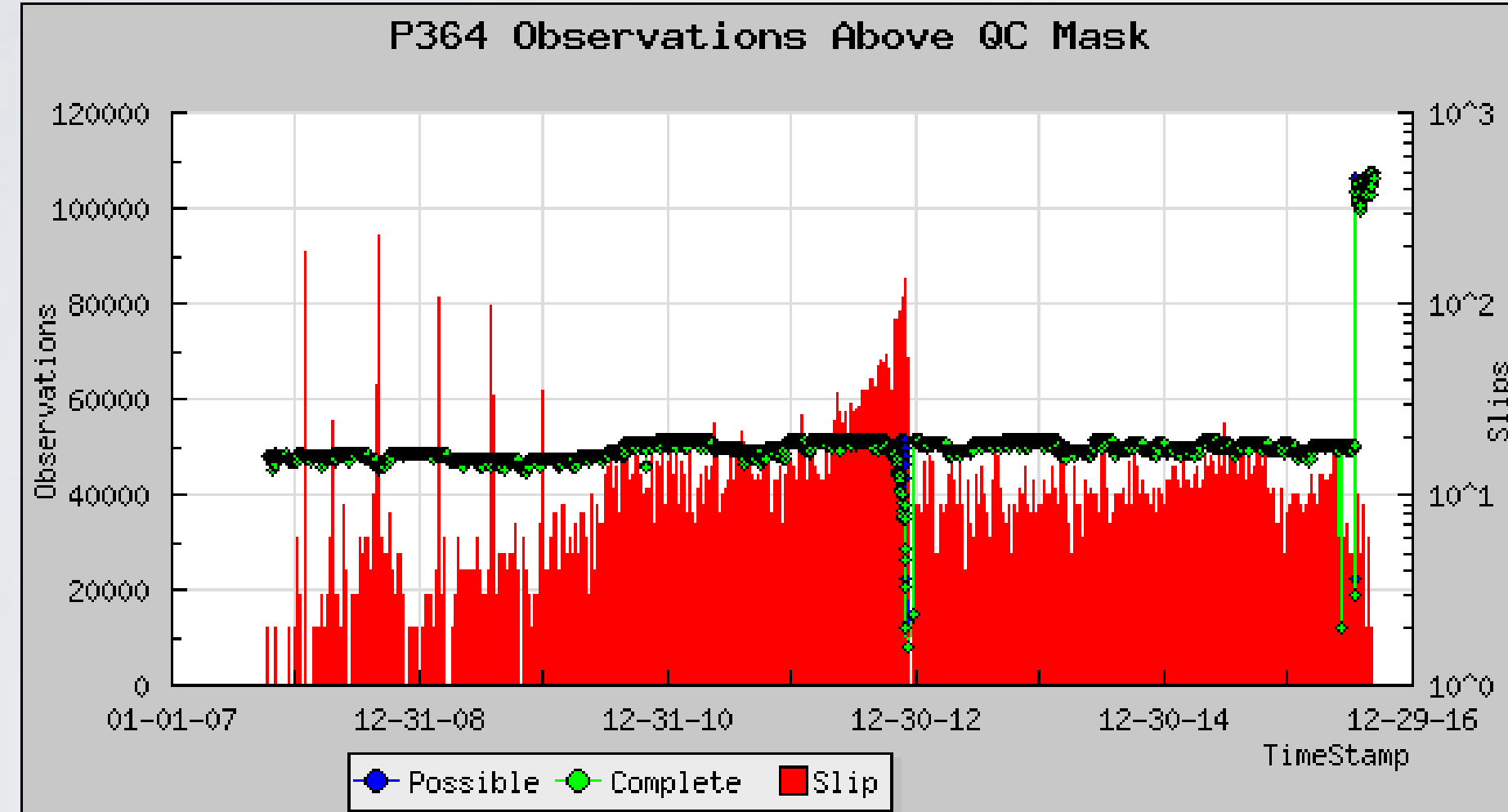
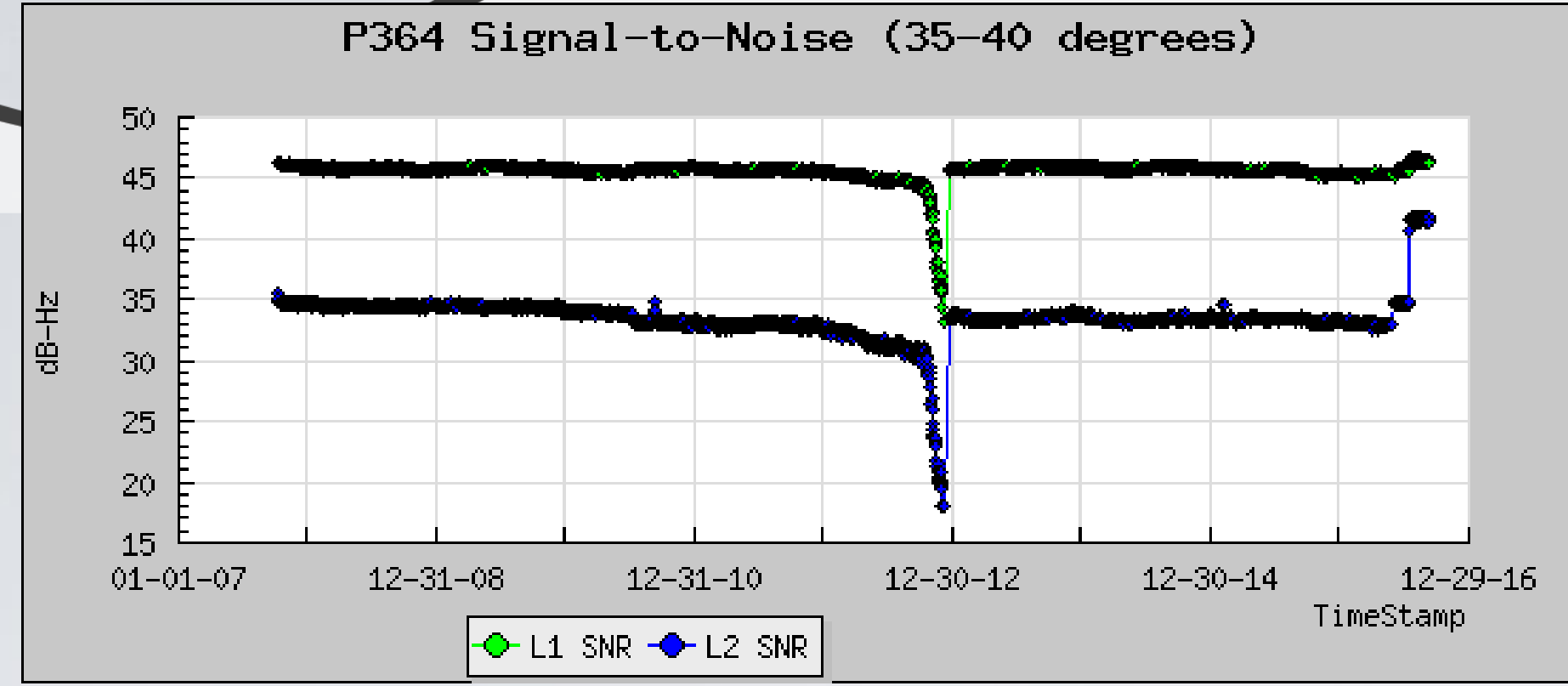


PARTNERSHIPS

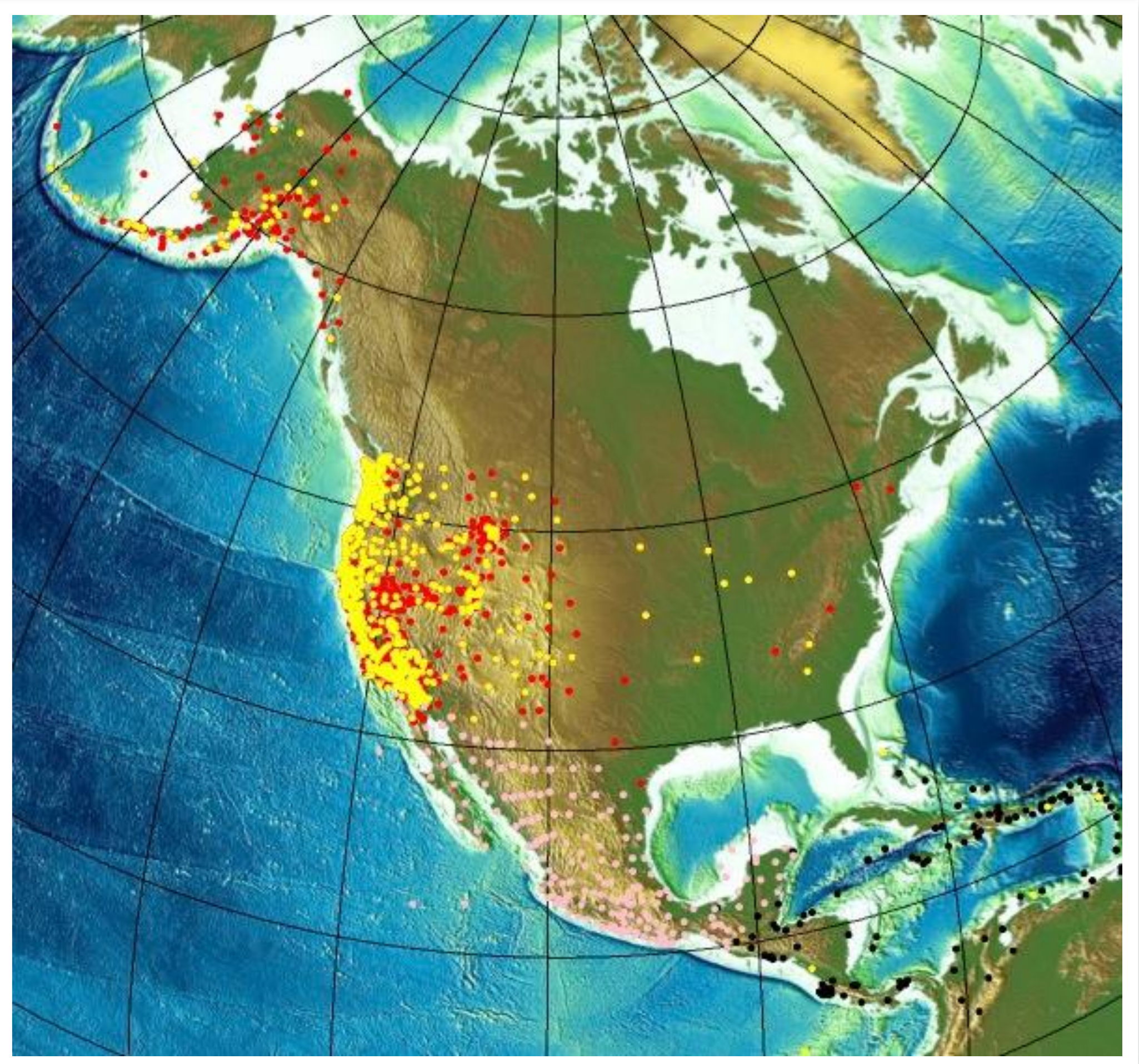
- ODOT Provided 19 Septentrio Receivers
- UNAVCO Provided the Antenna Upgrades



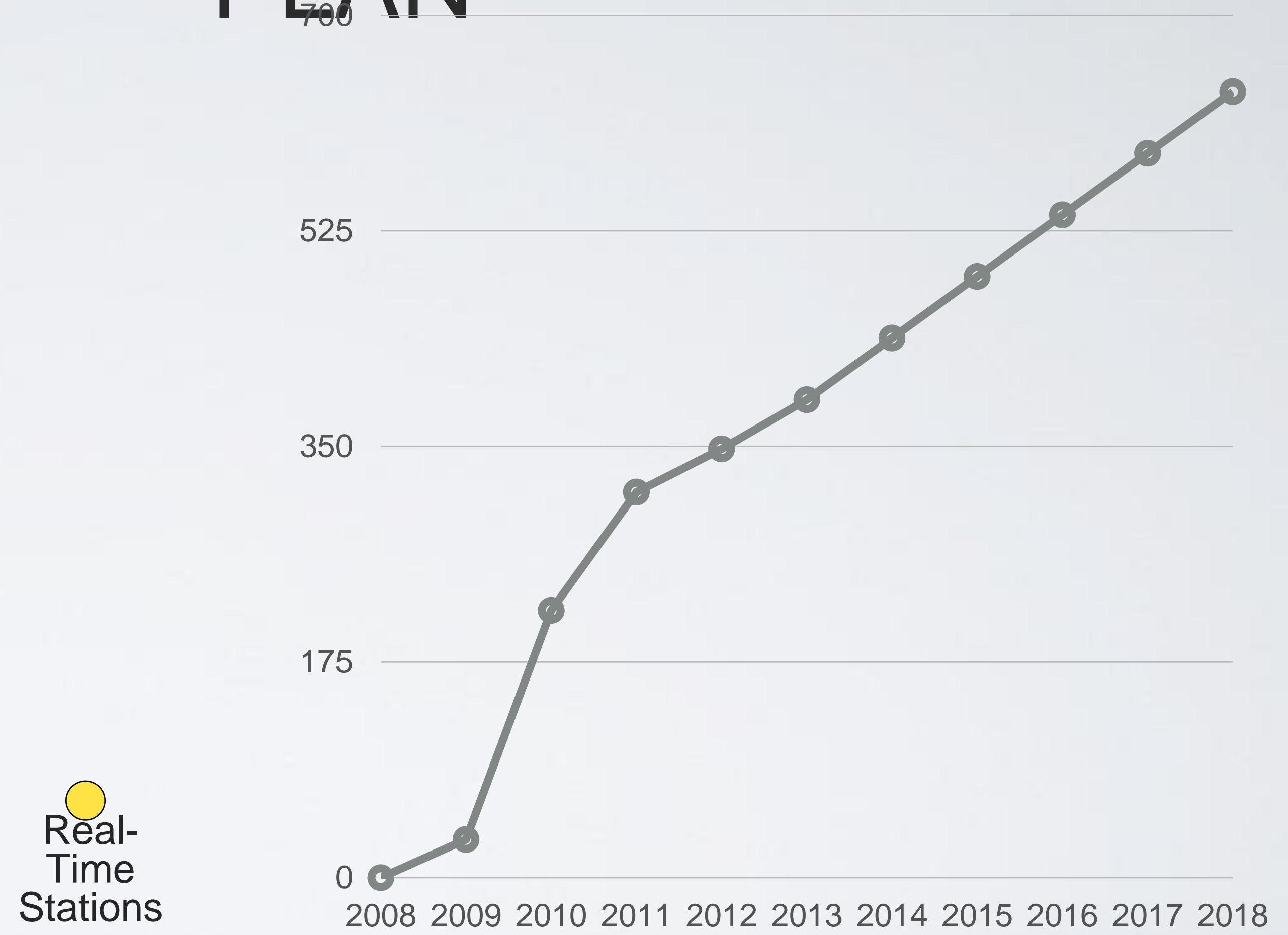
P364 SEPTENTRIO UPGRADE



GAGE: REAL-TIME GPS/GNSS UPGRADE PLAN



PLAN



Governance and Community

GAGE Impact

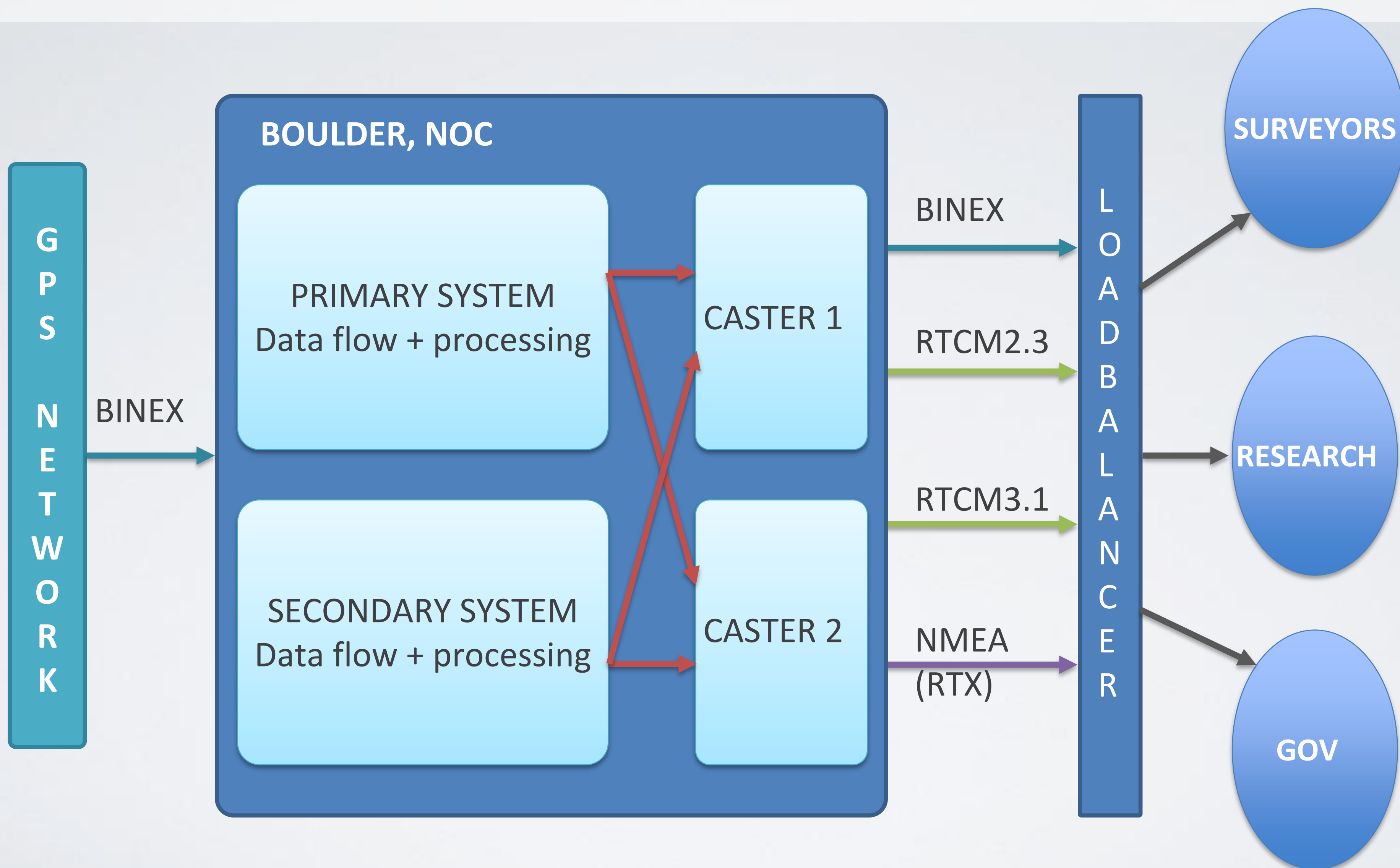
Geodetic Infrastructure

Geodetic Data Services

Education & Community Engagement

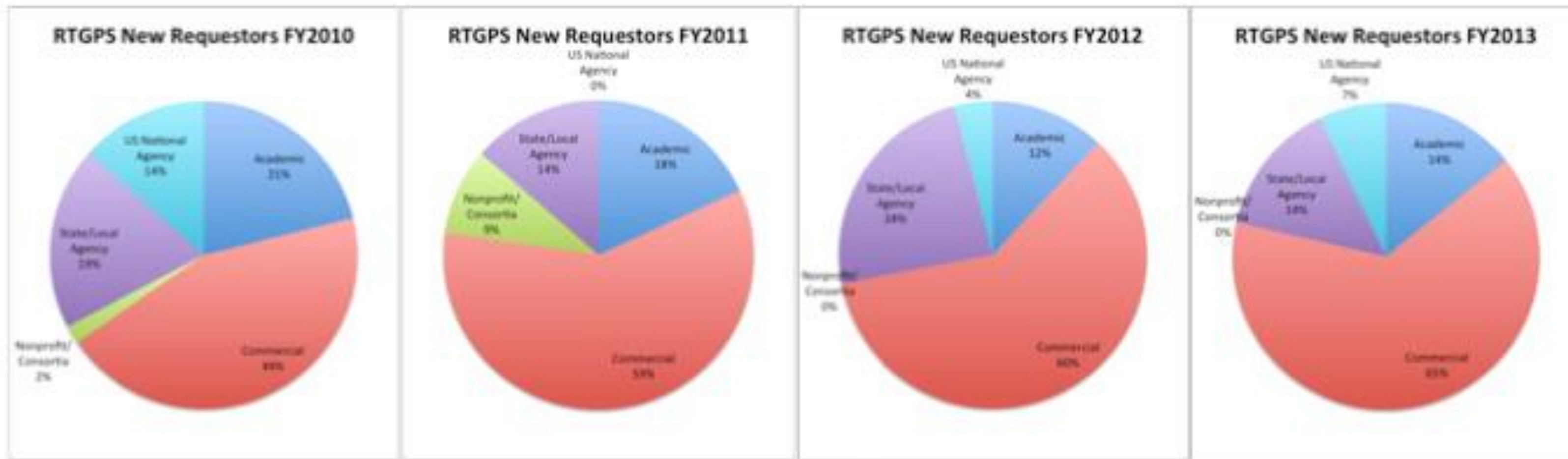
Beyond 2018

REALTIME GPS DATAFLOW AT UNAVCO



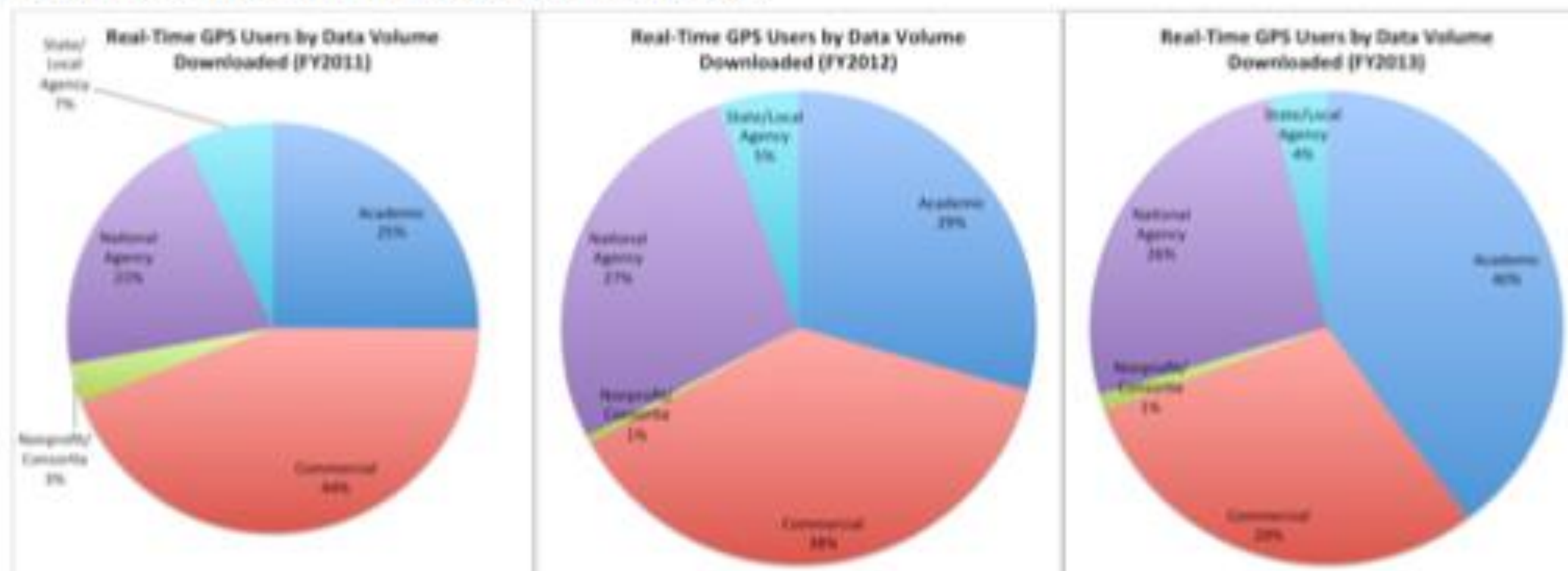
Primary and secondary systems provide redundancy, both run simultaneously

PBO REAL-TIME GPS/GNSS USERS



ABOVE: Based on the NUMBER OF NEW USERS (new requestors) per year, the percentage of commercial users relative to academic and agency users has increased consistently over the past four years.

BELOW: Based on the VOLUME OF DATA DOWNLOADED per year, the percentage of commercial users relative to academic users has decreased consistently over the past several years.



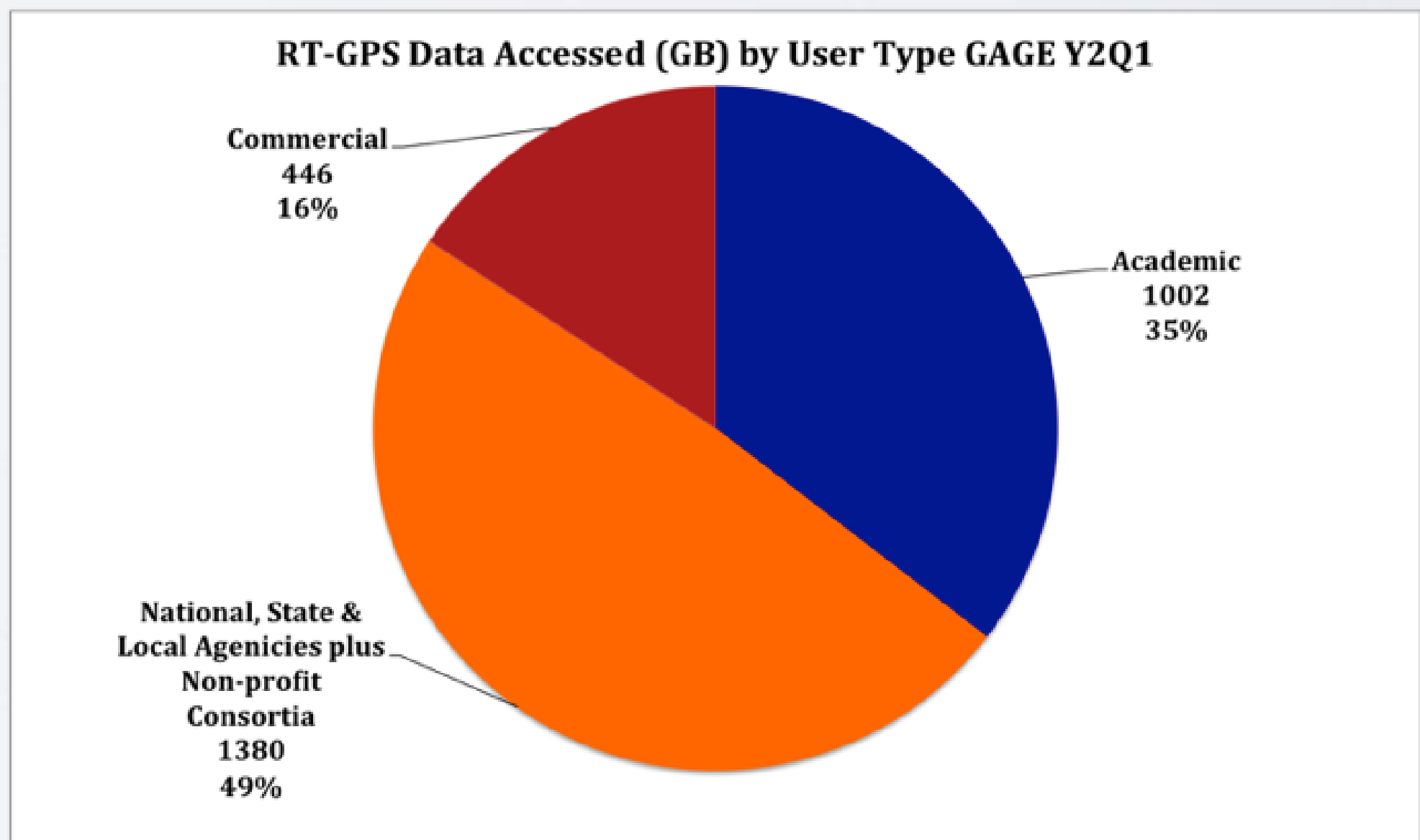
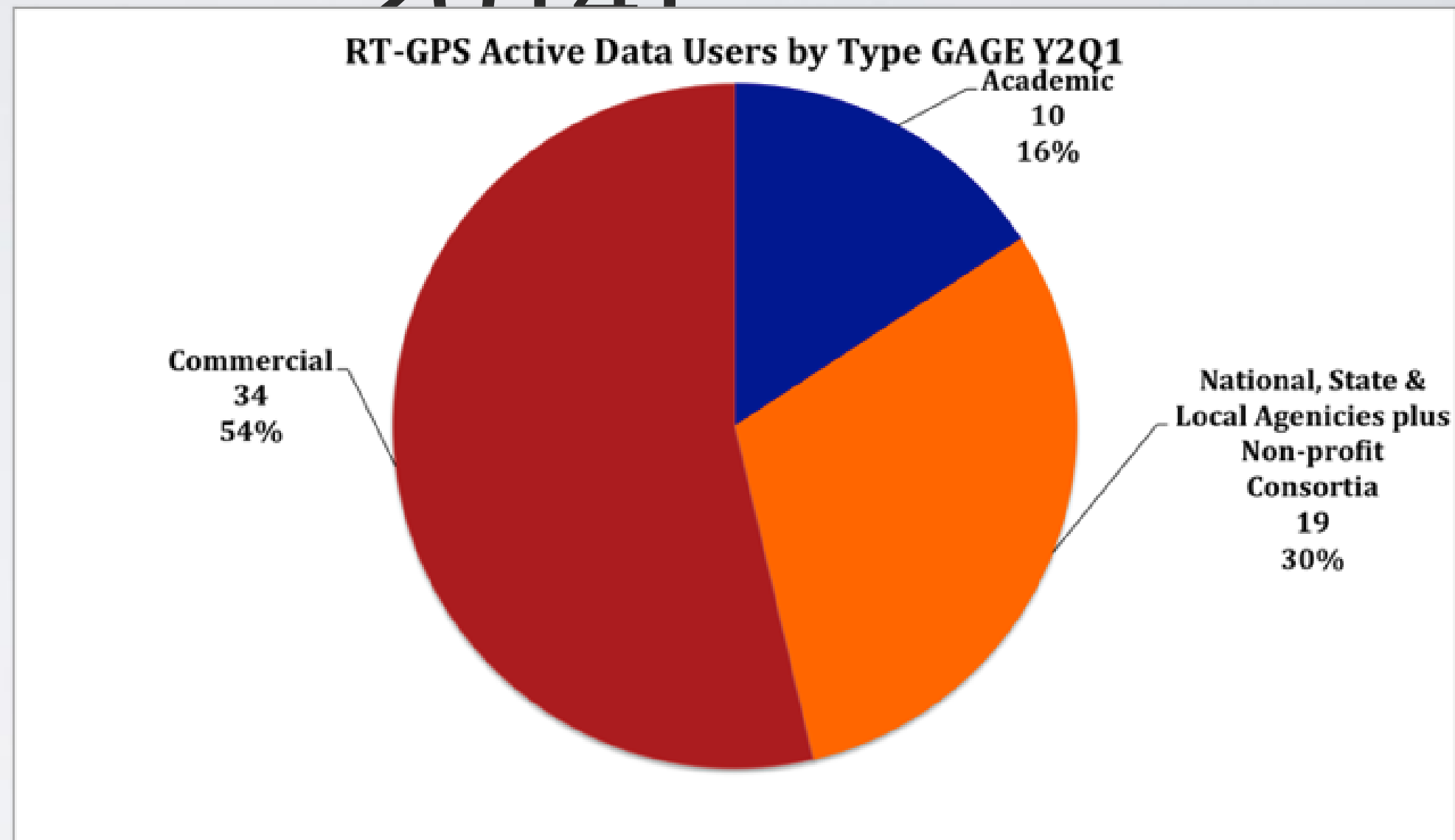
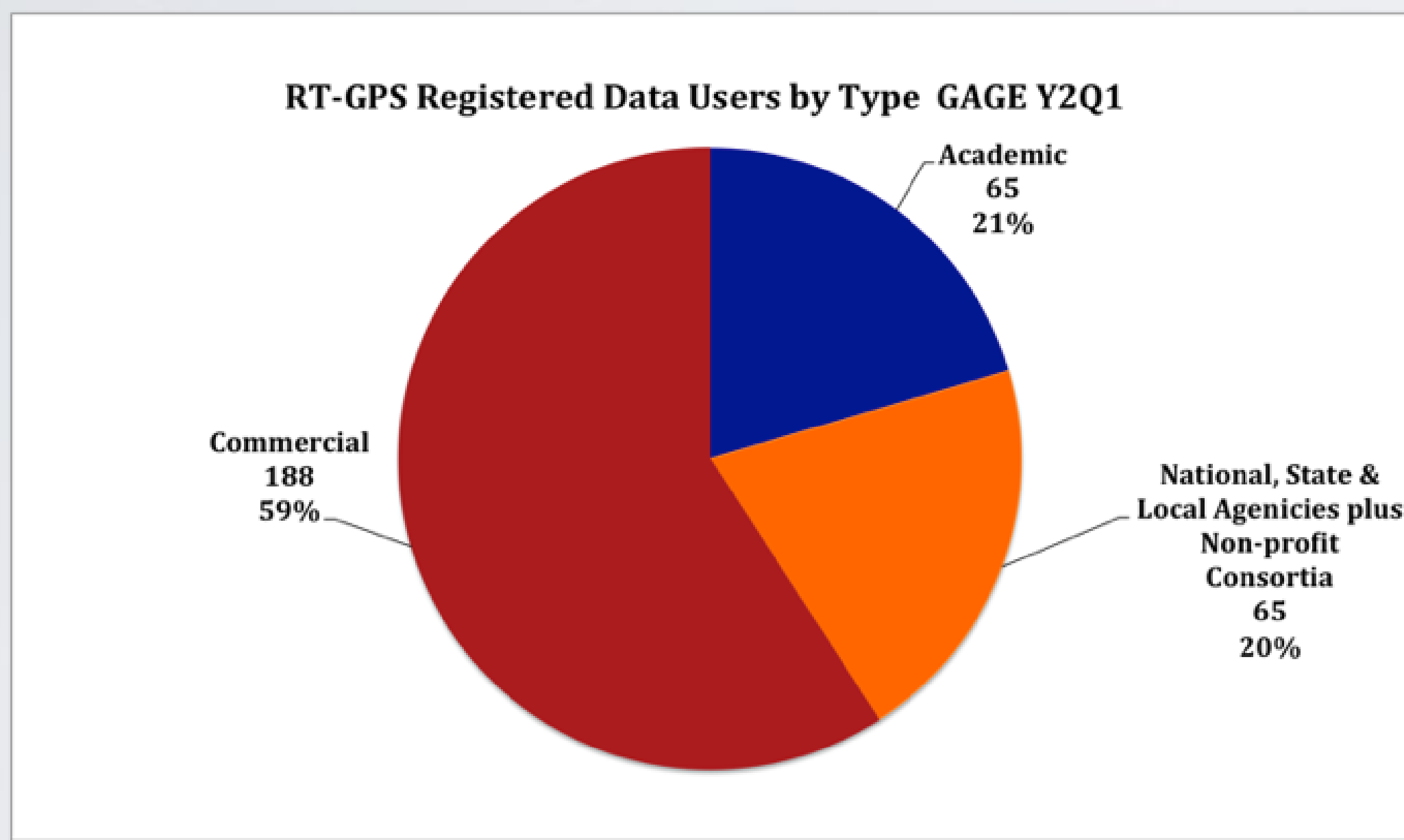
Interpretation: there are more commercial users than academic users of RTGPS data, but academic users access larger volumes of data.

Trends in PBO RT-GPS usage:

Increase in the number of new commercial sector users from 2010 to 2013

Increase in the amount of RT-GPS data downloaded by academic groups

RT-GPS DATA USER METRICS (OCT-DEC 2014)



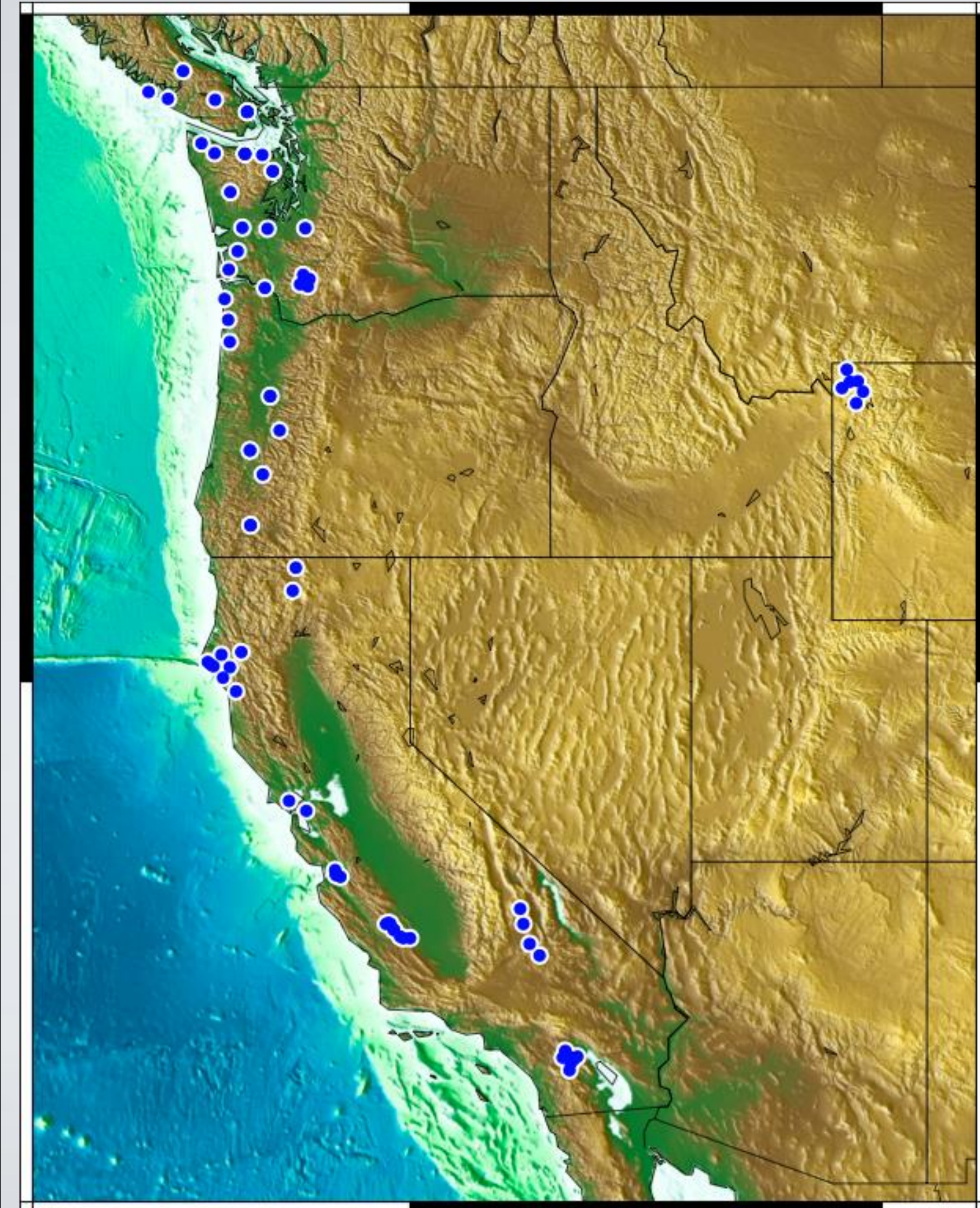
EARTHSCOPE: STRAINMETERS, SEISMOMETERS AND TILTMETERS

Concerns

- Strain workshop identified need for improved data processing outreach (workshops, etc.)
- Need real-time processed strain products (cleaned, translated to SEED).
- Antelope License changes - concern is resources to support multiple concurrent streaming platforms now required.

New Data-Related Initiatives

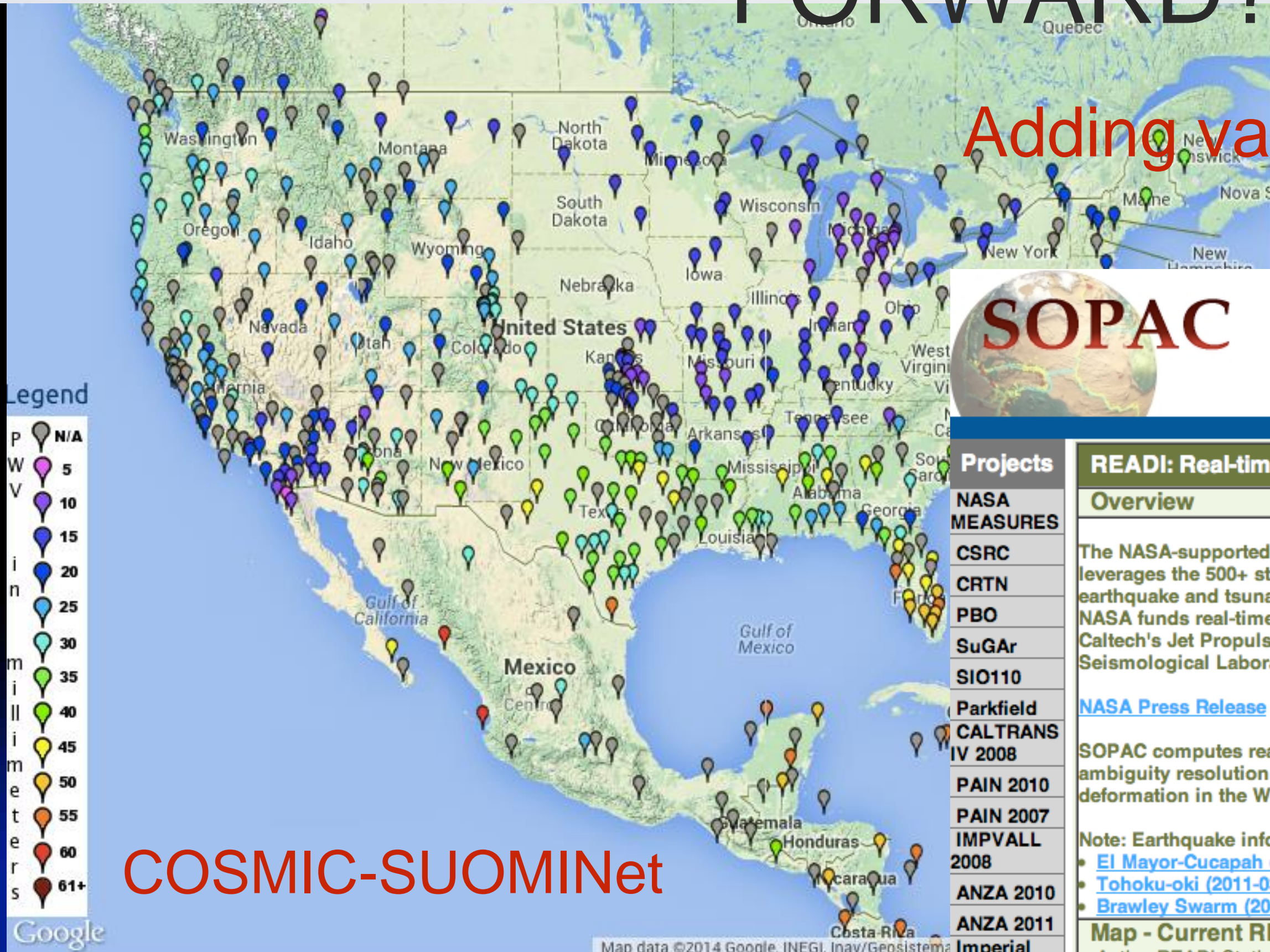
- Realtime strain data (on hold until summer while we focus on RT-GPS)
- Improved strain data quality (review two stations a week with engineers)
- Integration into Web Services (Level 2 Data Products)
- Move streaming data from Antelope to SEEDlink (beta is operational)



DRIVING THE PBO AND OTHER CGPS NETWORKS: MONITORING VS. SCIENCE?

- **What is monitoring and how has it changed over time?**
 - Intermittent observations with single sensors (past); selected continuous observations with selected multiple sensors (current); spatially dense observations over the entire deformation frequency spectrum with validated data available on any platform of choice (future).
- **What are the values and benefits of monitoring?**
 - Validated geophysical “monitoring” data condition “scientific” discovery; new “scientific” models can drive the need for additional “monitoring” data and systems; experimental (physics-based) model may not apply to most geophysical observations - earth system is complex and very interconnected...geohazards and concomitant risks are not constant in space and time!
- **What challenges/opportunities exist in managing, maintaining, and providing access to monitoring data in a ‘real-time’ world, to multiple users?**
 - Continuous (geodetic) sensor observations combined with open data model serves the broadest possible number of stakeholders and applications; but why pay for the cow when you can get the milk for free?

FUTURE OF PBO - HOW DO WE MOVE FORWARD?



Adding value and creating dependency

SOPAC

Home | Site Map | Contacts | Forums

Data Archive | Processing | **Projects** | Sites | Maps | Other

Projects

- NASA MEASURES
- CSRC
- CRTN
- PBO
- SuGAR
- SIO110
- Parkfield
- CALTRANS IV 2008
- PAIN 2010
- PAIN 2007
- IMPVALL 2008
- ANZA 2010
- ANZA 2011
- Imperial Valley 2010
- Ocotillo Wells 2011
- SENDAL 2011
- XML Site Logs
- CCID
- GPS
- Meteorology

READI: Real-time Earthquake Analysis for Disaster Mitigation Network

Overview

The NASA-supported Real-time Earthquake Analysis for Disaster Mitigation Network is a research project that leverages the 500+ station real-time GPS network in Western North America to prototype an accurate and timely earthquake and tsunami early warning system using GPS (GNSS) technology as well as GPS/seismic integration. NASA funds real-time GPS projects at UCSD's Scripps Institution of Oceanography, Central Washington University, Caltech's Jet Propulsion Laboratory, and University of Nevada Reno. Collaborators include UC Berkeley's Seismological Laboratory and Caltech's Seismological Laboratory.

[NASA Press Release](#) | [DataSources](#) | [References](#) | [Western U.S. Map](#)

SOPAC computes real-time GPS satellite clocks and fractional-cycle biases for use in precise point positioning with ambiguity resolution using real-time data from GPS stations in North America (outside the zone of active tectonic deformation in the Western U.S. and British Columbia). See interactive map below.

Note: Earthquake information available in GPS Explorer:

- [El Mayor-Cucapah \(2010-04-04\)](#)
- [Tohoku-oki \(2011-03-11\)](#)
- [Brawley Swarm \(2012-08-26\)](#)

Map - Current READI Status

(Updates automatically every 5 minutes)

Active READI Stations - Dark Blue: up Red: down

Map Tools

Layers

- Base Layers
 - Basic
 - Satellite
 - Terrain
 - USGS Topo Quads
- Overlays
 - Tectonic Plates
 - Fault Lines
 - US Interstates

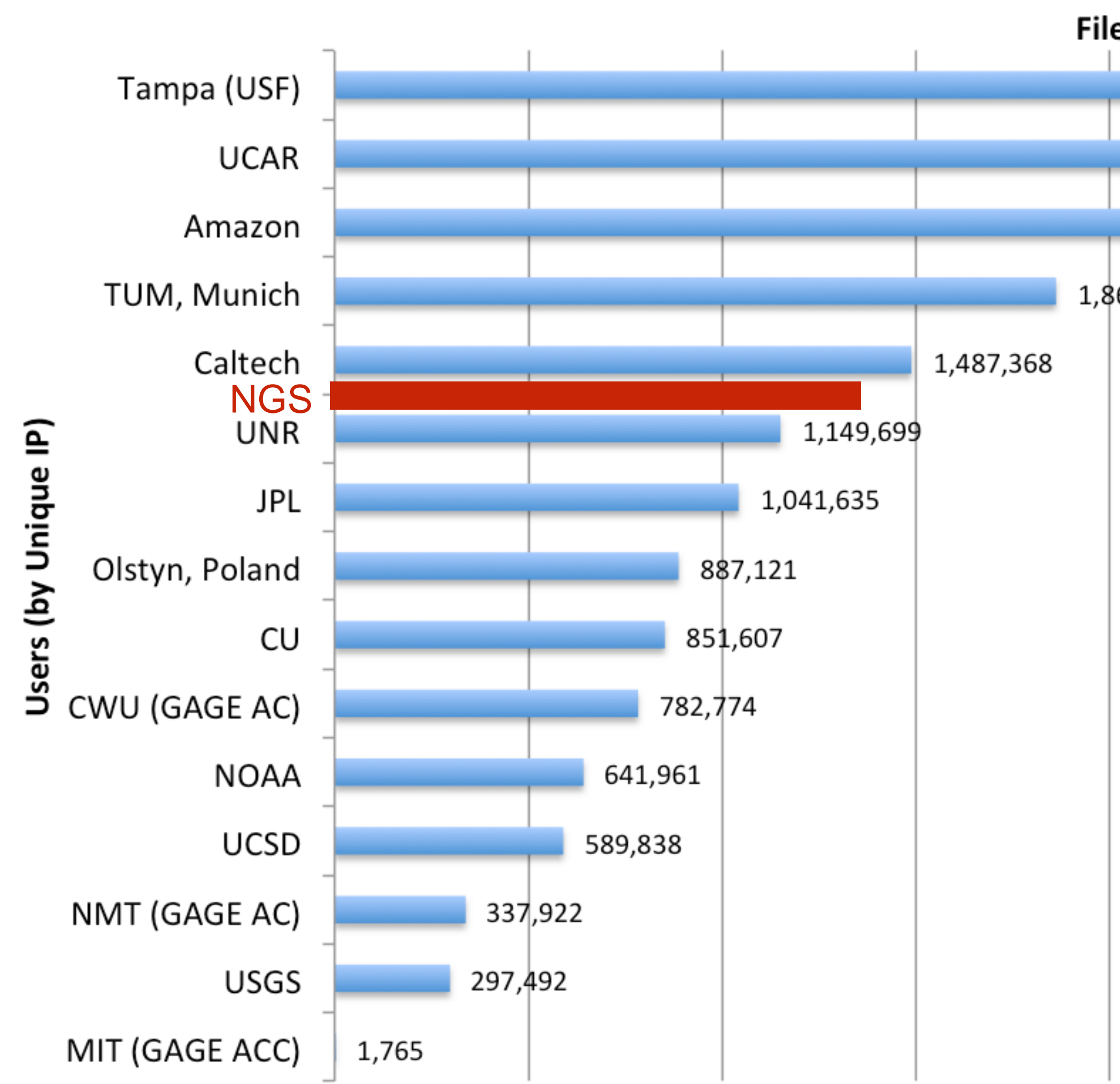
COSMIC-SUOMINet

NOAA and NASA are building systems that depend on PBO, but NSF is not committed to O&M beyond 2018 or upgrades to RT-GPS or GNSS...

SCEC and USGS are operating like PBO is a utility, it will always be on...

NGS - CORS & OPUS: PBO DATA REDISTRIBUTION

Top PBO GPS Data Users by File Downloads (Jan 1 - Sep 17, 2014)



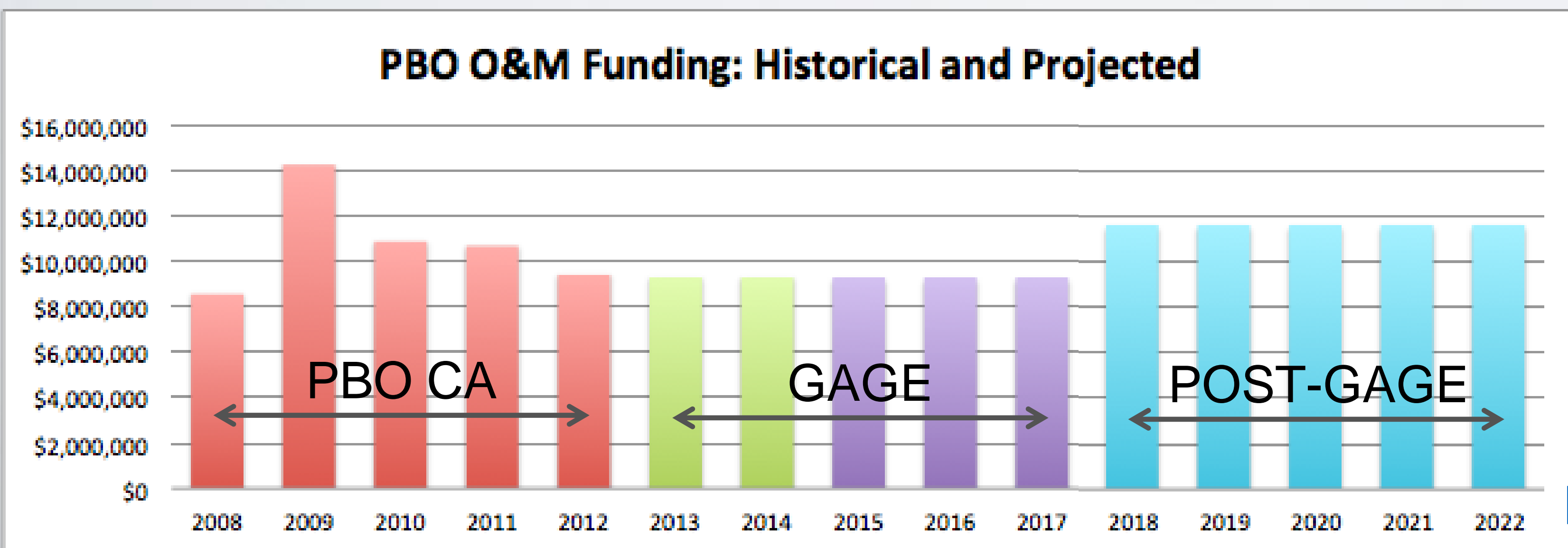
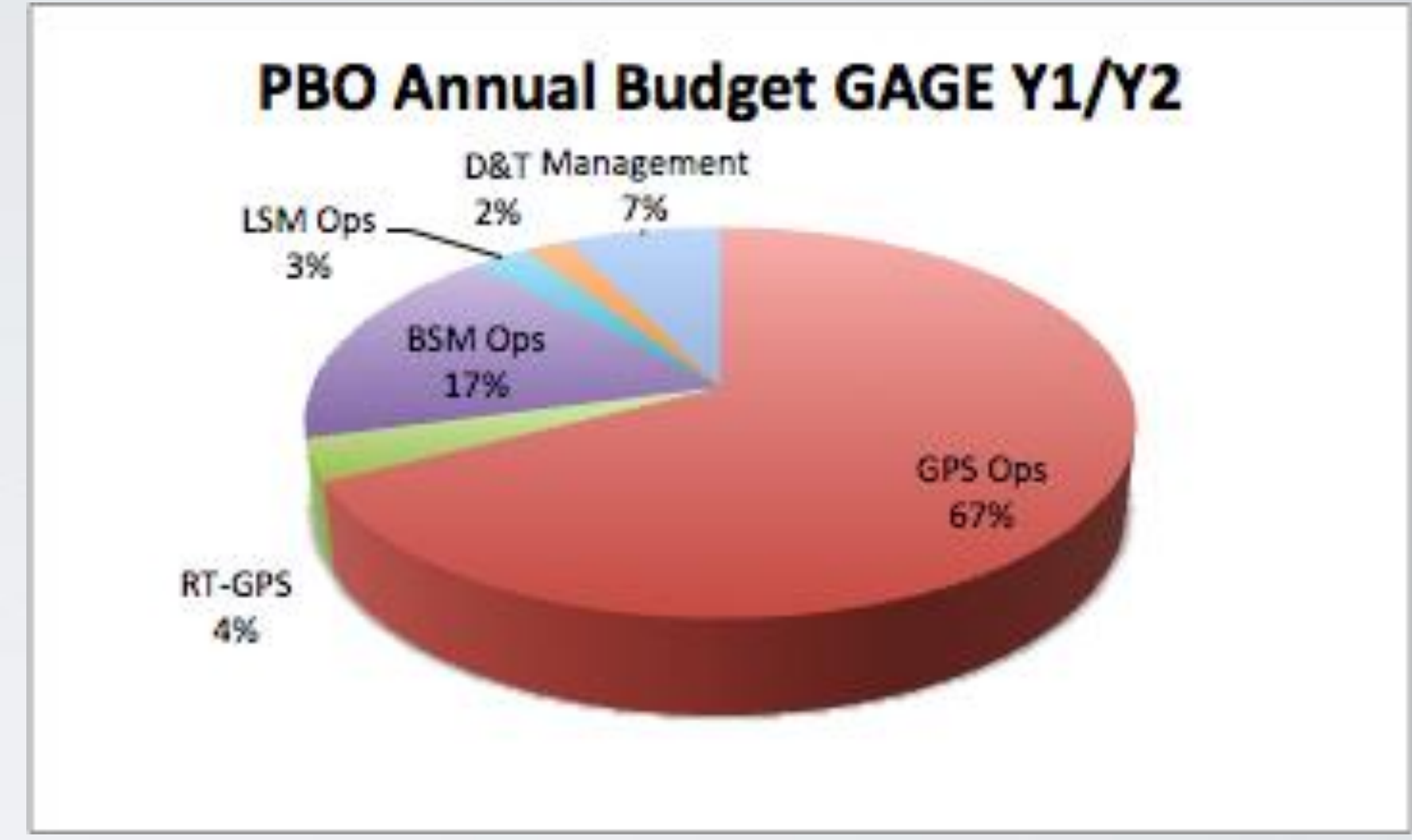
1,217,172 CORS archive via FTP and custom download (UFCORS)





GAGE PBO BUDGET - O&M HISTORY AND YR1&2

PBO Component	GI budget	GI FTE	GDS budget	GDS FTE	Total budget
GPS Ops	\$ 4.55 M	16.20	\$ 1.65 M	7.00	\$ 6.20 M
RT-GPS	-	-	\$ 0.32 M	1.64	\$ 0.32 M
BSM Ops	\$ 1.07 M	3.75	\$ 0.52 M	2.85	\$ 1.59 M
LSM Ops	\$ 0.24 M	1.00	-	-	\$ 0.24 M
D&T	\$ 0.19 M	1.74	-	-	\$ 0.19 M
Management	\$ 0.56 M	2.50	\$ 0.10 M	0.60	\$ 0.66 M
Total	\$ 6.61 M	25.19	\$ 2.59 M	12.09	\$ 9.20 M



PBO CA: \$53.7M; \$10.7M/yr average
 GAGE: \$46.4M; \$ 9.3M/yr average

- POST-GAGE: 25% reduction?
- POST-GAGE: Flat-funded?
- POST-GAGE: 25% increase?

GPS MODERNIZATION - IMPLICATIONS FOR DRO

- Total of **15 L2C-capable SVs** in orbit now
- Total of **8 L5-capable SVs** in orbit now
- **Block III SVs to begin launch in 2016**
- DoD/DoC announced phase-out of civil access to P(Y) on L1/L2 effective 2020 to drive commercial sector to L2C/L5 applications
 - PBO has ~900 Trimble NetRS deployed - only can encode L2C & no GNSS signals (all are EOL/EOS); most EAR/PLR pool receivers are the same vintage technology
 - PBO/COCONet/TLALOCNet has ~250 Trimble NetR9 deployed - can encode L2C, L5, +GNSS
- UNAVCO RFP for new **GNSS receiver preferred vendor** was finalized in June 2015 with Septentrio, Inc. 119 new instruments purchased (19 by ODOT) in 2016 and ~60 deployed to date.

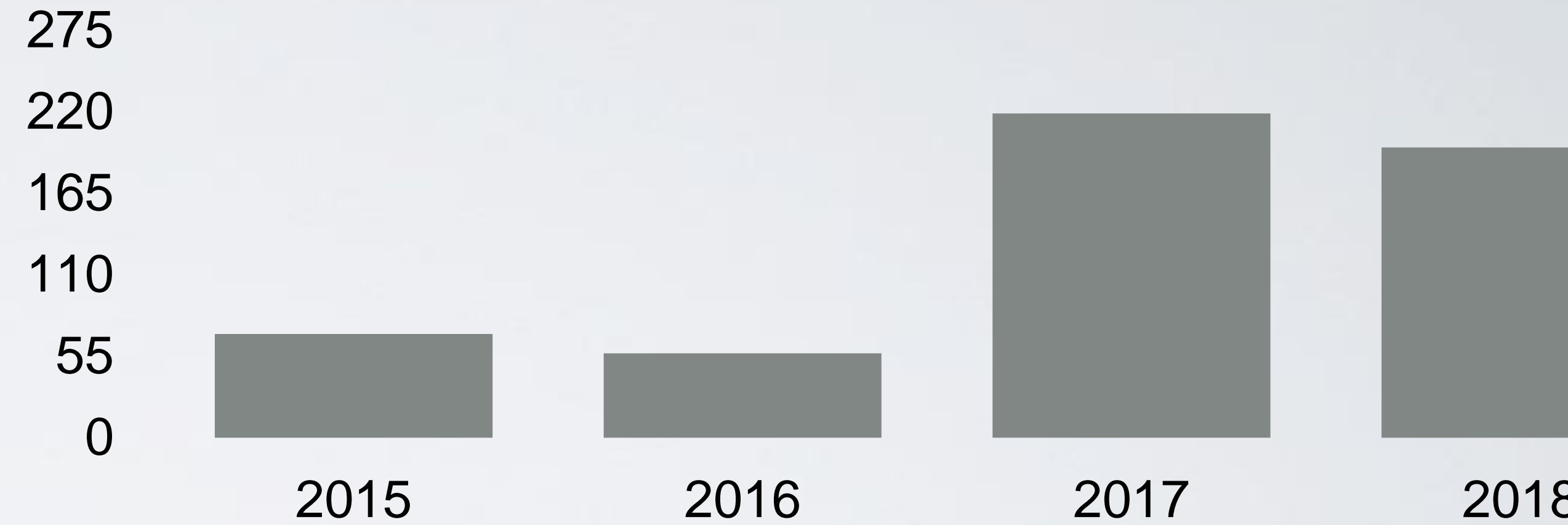
LEGACY SATELLITES			MODERNIZED SATELLITES	
BLOCK IIA	BLOCK IIR	BLOCK IIR(M)	BLOCK IIF	GPS III
3 operational	12 operational	7 operational	8 operational	Now in production
<ul style="list-style-type: none"> ▪ Coarse Acquisition (C/A) code on L1 frequency for civil users ▪ Precise P(Y) code on L1 & L2 frequencies for military users ▪ 7.5-year design lifespan ▪ Launched in 1990-1997 	<ul style="list-style-type: none"> ▪ C/A code on L1 ▪ P(Y) code on L1 & L2 ▪ On-board clock monitoring ▪ 7.5-year design lifespan ▪ Launched in 1997-2004 VIEW AIR FORCE FACT SHEET →	<ul style="list-style-type: none"> ▪ All legacy signals ▪ 2nd civil signal on L2 (L2C) LEARN MORE → ▪ New military M code signals for enhanced jam resistance ▪ Flexible power levels for military signals ▪ 7.5-year design lifespan ▪ Launched in 2005-2009 VIEW AIR FORCE FACT SHEET →	<ul style="list-style-type: none"> ▪ All Block IIR(M) signals ▪ 3rd civil signal on L5 frequency (L5) LEARN MORE → ▪ Advanced atomic clocks ▪ Improved accuracy, signal strength, and quality ▪ 12-year design lifespan ▪ Launched since 2010 VIEW AIR FORCE FACT SHEET →	<ul style="list-style-type: none"> ▪ All Block IIF signals ▪ 4th civil signal on L1 (L1C) LEARN MORE → ▪ Enhanced signal reliability, accuracy, and integrity ▪ No Selective Availability LEARN MORE → ▪ Satellites 9+: laser reflectors; search & rescue payload ▪ 15-year design lifespan ▪ Begins launching in 2016



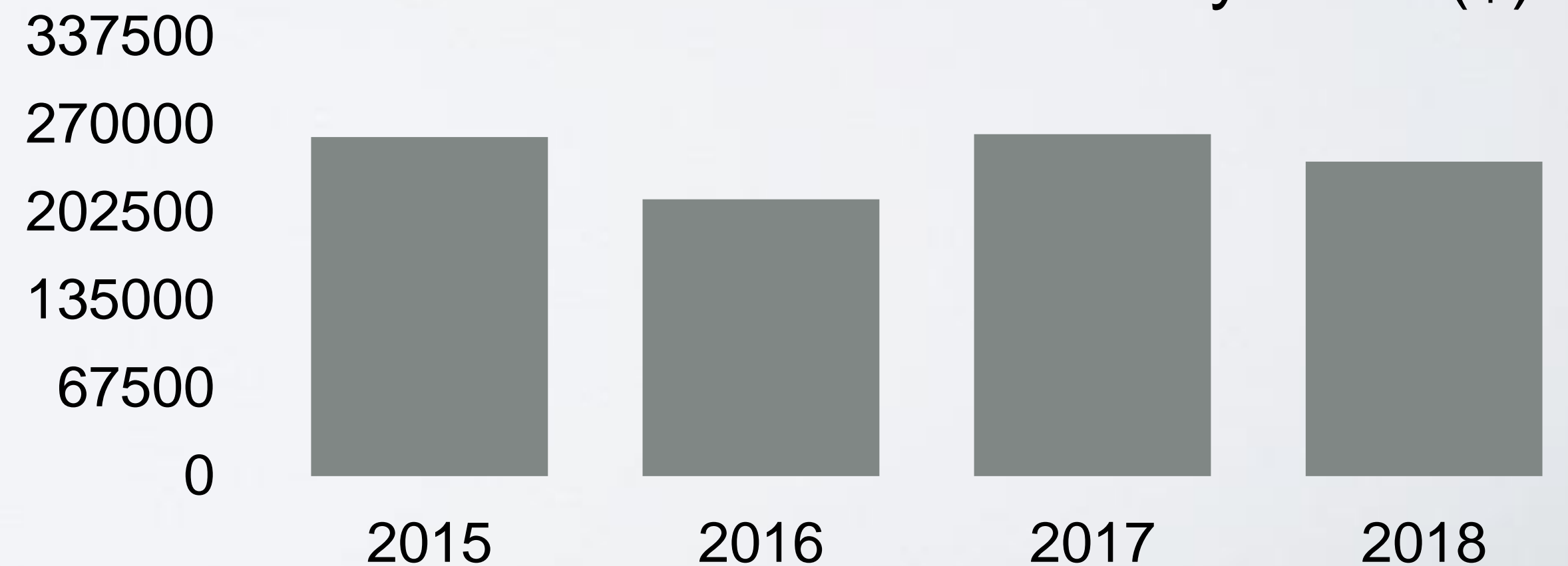
PBO PERMITTING STATUS

- James Downing hired in September, 2014 to manage UNAVCO Contracts and Permitting issues.
- 1.3 FTE currently allocated for the permit renewal process. This is a nearly two-fold increase in LOE from PBO CA and GAGE YR1
- Developed a permitting renewal plan which will require an evenly distributed budget with projections between \$212k and \$262k each year through 2018.
- The number of permit renewals expected in 2017 and 2018 remains high due to clauses that prohibit renewals sooner than 9-12 months before the stated expiration date.

Number of Renewals by Year



Estimated Renewal Cost by Year (\$)



WORKSHOP ORGANIZING COMMITTEE AND TIMELINE

Community Workshop: The future of PBO in the GAGE Facility (2013-2018) and after
EarthScope

Glen S. Mattioli, UNAVCO GI and PBO Director, Chair and PI for NSF Workshop proposal

Rebecca O. Bendick, UNAVCO Board of Directors liaison to the GI AC

James H. Foster, Chair of the GI Advisory Committee

Jeffrey Freymueller, Chair of the PBO Working Group



Proposal submitted to NSF: March 18, 2014

Awarded: June 7, 2014, EAR-1441122; \$60.4K

Workshop announced: June 26, 2014

Workshop convened: September 22-24, Breckenridge, CO

Participants: 66, including 17 UNAVCO staff members and NSF and USGS program managers



RECOMMENDED IMMEDIATE MANAGEMENT ACTIONS

- Regularize maintenance and service schedules in regions where transients are “less likely” (resulting in reduced uptime)
- Identify key regions (Cascadia) for immediate maintenance response where transients are “more likely”
- **Upgrade stations to real-time where cost-effective comms and adequate power are already available**
- **Upgrade a limited number of GPS to GNSS in strategic target areas of high scientific value, large user communities, and D&T**
- Encourage NSF staff to aggressively pursue federal agency cooperation at the highest possible level
- Explore all avenues for “upreach”
- **Seek partnerships to meet additional costs for earthquake early warning and other GNSS-enabled, high-rate, RT applications**
- Make immediate investments in the data management work flow to allow more data integration and sharing
- Expand UNAVCO’s ability to ingest and fully integrate or serve as a portal for data from non-PBO sources
- **Explore adoption of O&M costs or collaborative sponsorship of some sensors or sets of sensors by other entities**
- Leverage ECE to better engage the public and stakeholders in UNAVCO activities
- **Identify sites with the worst data quality and move to other location or decommission as possible (or do not renew permits)**
- **Otherwise, do not decommission GPS sites prior to 2018**
- Defer all maintenance of low-value borehole installations, or divest the sites only producing seismic data to regional seismic networks

SUGGESTED LONG-TERM ACTIONS

Positioning PBO for the future

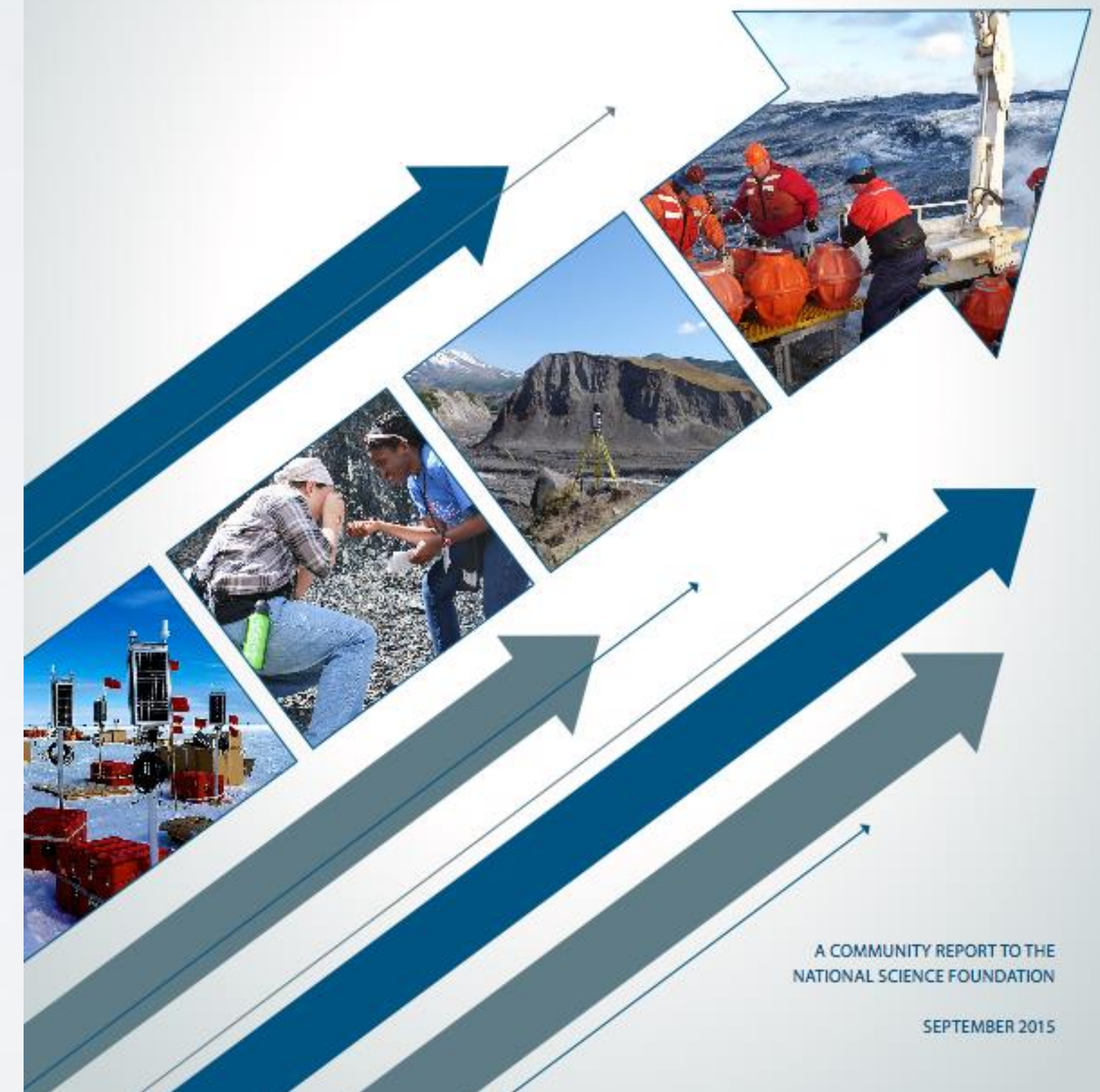
- **Develop a strong GNSS (i.e. GLONASS) + real-time streaming pilot project**
- Develop a strong multi-timescale data products pilot (e.g. Mt. St. Helens)
[multi dataset Google Earth for time series]
- Develop a pilot project to stream multiple sensor outputs and develop a flexible, generic data stream hardware + software system (leverage existing systems developed by Ocean Observing Initiative)
- **Develop pilot data products for nontraditional users**
- Build a management framework for institutionalizing adoption and sponsorship of sensors
- Collaborate with NASA for optimization and validation of NISAR and cal/val for SMAP
- Adopt suggested prioritization for borehole and long baseline laser strainmeters
(after incorporating additional input from the strainmeter user community)
- Explore alternative models for funding the strainmeter network
- Explore and test alternative methods of GPS data transmission and data flow models

FUTURE GEOPHYSICAL FACILITIES WORKSHOP

Workshop held in May 2015 in Leesburg, VA
>100 participants

- Report divides into three components related to seismo-geodetic facilities:
 - Existing Foundational
 - Emergent Foundational
 - Frontier

Future Geophysical Facilities
Required to Address
Grand Challenges in the Earth Sciences



EXISTING FOUNDATIONAL

Capabilities that are fundamental and essential to present and near-term science directions, including the continuation of currently funded NSF projects.

1. Maintained permanent seismic, strainmeter, and geodetic networks
 - A global very broadband seismographic network
 - Permanent and continuously recording GPS networks
 - A network of borehole strainmeters

3. Deployable geodetic observation systems
 - GNSS instrumentation
 - Terrestrial lidar instrumentation
 - Continued installation and occupation of campaign-mode seafloor geodetic monuments

5. Data archiving, quality control, and distribution
6. Hosting of community-provided products and services

9. Workforce development

EMERGENT FOUNDATIONAL

Components that incorporate current technologies would drive significant progress on major science challenges and were judged to be high priority for the 2018–2023 time frame.

12. Instrumentation for rapid response

14. Operational GNSS processing

19. Expanded ocean bottom seismographic and geodetic capabilities

20. High-bandwidth and real-time global telemetry

21. Development of instrumentation and telemetry systems capable of supporting multidisciplinary environmental observatories

Those capabilities that are, to varying degree, nascent, but are of significant interest to the community for their potential to enable transformative science and ensure continued scientific progress.

- 24. Seafloor and free-floating geophysical networks

- 26. Deep borehole access and instrumentation

- 27. Instrumentation for high-risk/high-benefit experiments

POST SAGE-GAGE VISION

For example, the community envisions a future that includes:

- (1) near-real-time and daily maps of deformation derived from integrated seismic, Global Navigation Satellite System (GNSS) instrumentation, and orbiting radar satellite data;
- (2) anchored and drifting seafloor and water column geophysical instrumentation distributed around the globe;
- (3) arrays of fiber optic cables providing spatially continuous high-rate sampling of surface strain;
- (4) aerial and marine drones that can be customized to host and/or deploy a range of instrumentation;
- (5) large instrumentation pools that can be routinely deployed in diverse environments and across a range of scales to record the full spectrum of dynamic events, ranging from coseismic offsets, to slow deformation, to spatially unaliased seismic wavefields;
- (6) global telemetry providing high-rate and low-latency sampling from any number of remote instruments; and
- (7) routine access to high performance computing (HPC) and associated capabilities for data reduction and model inference on an unprecedented scale.

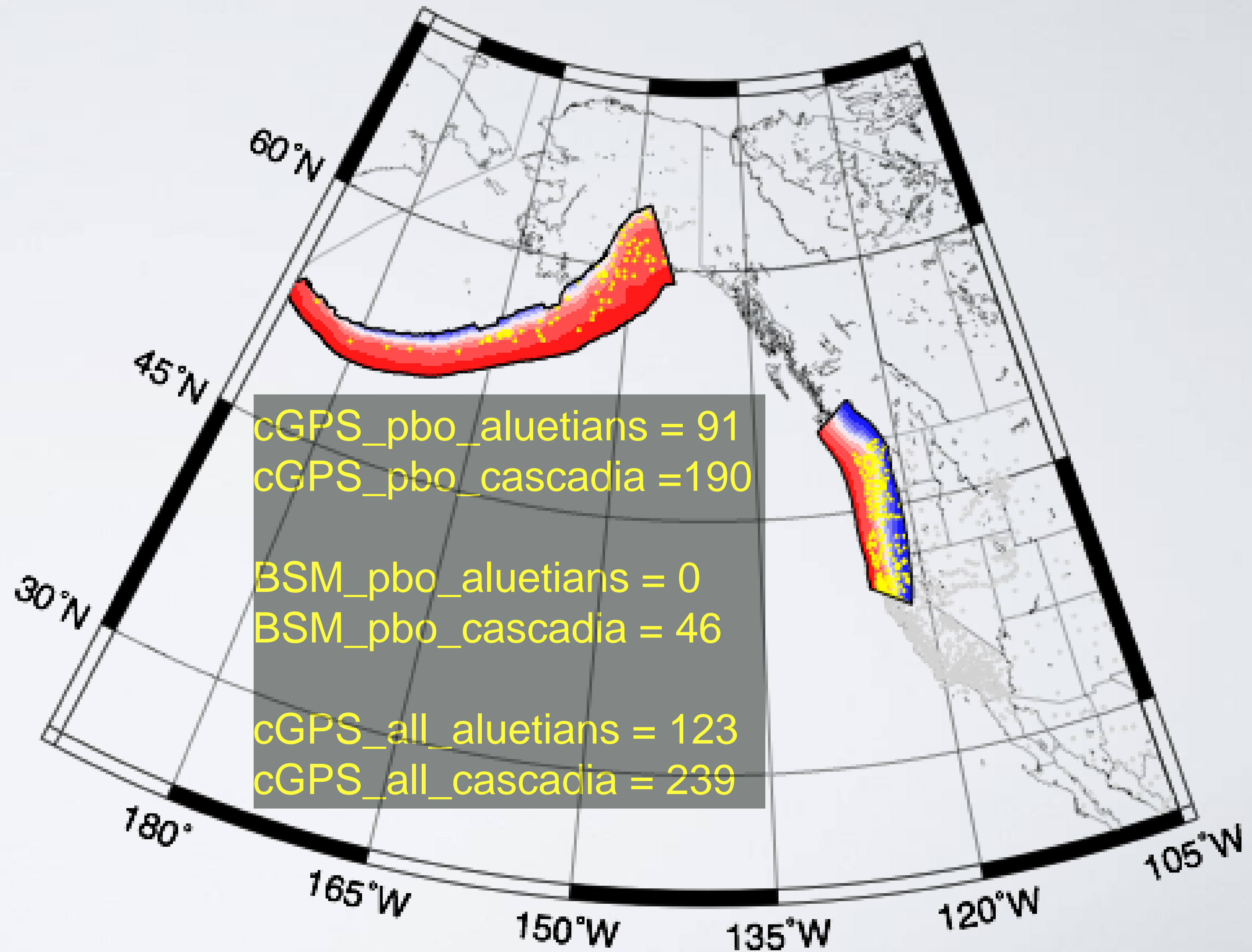
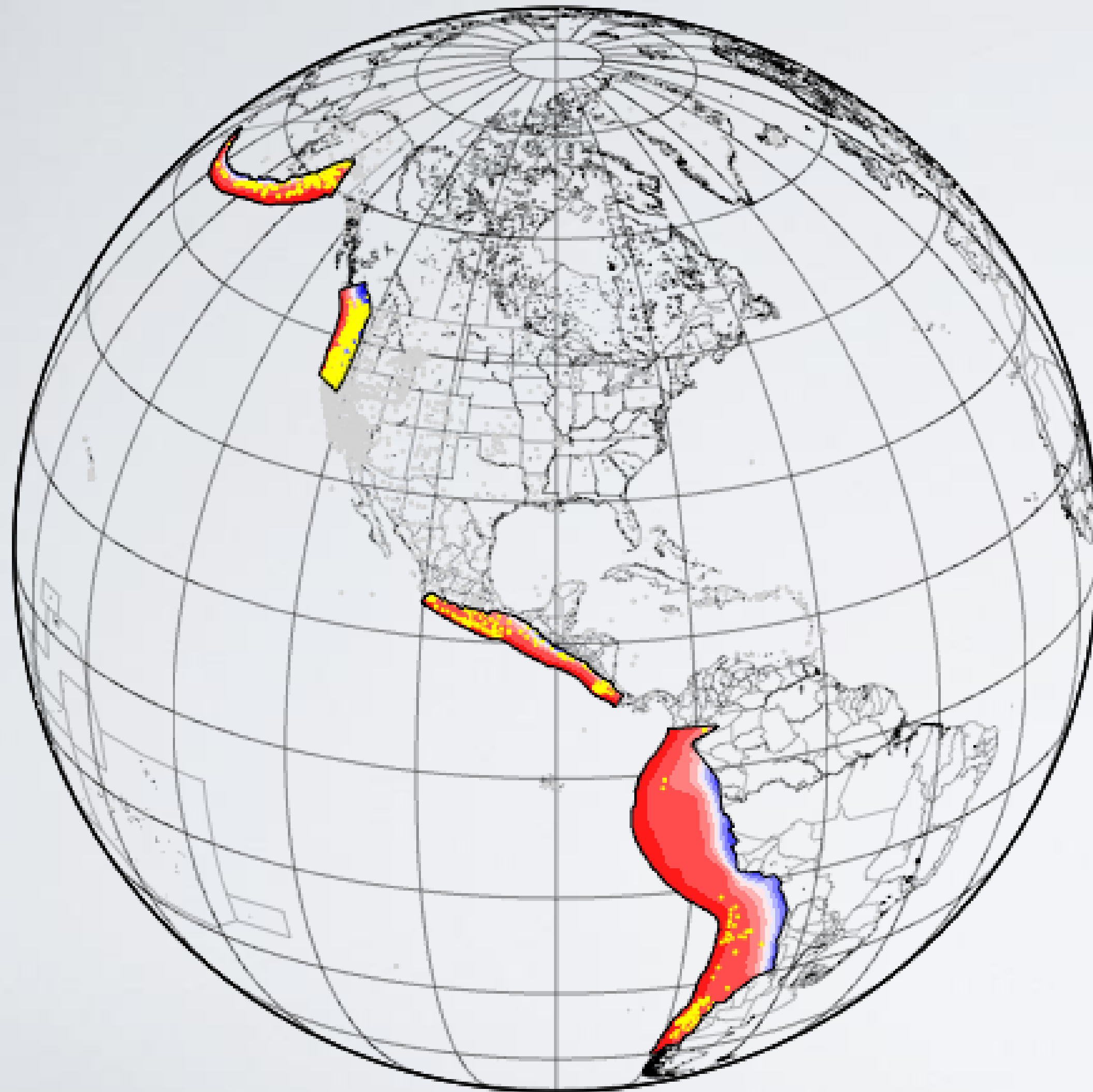
Other Continuous GPS Networks Supported by UNAVCO

- **COCONet** (76 new or upgraded, 61+ existing cGPS/Met stations plus 4 tide gauge stations installed in the Caribbean region)
- **TLALOCNet** (6 new, 18 upgrades to existing cGPS/Met stations in Mexico plus 13 contributed from UNAM)
- **G-Net** (42 cGPS stations in Greenland)
- **A-Net** (42 cGPS/seismic stations in Antarctica)



• **LARISSA** (10 cGPS stations in Antarctica)
Like **PBO** these networks will face critical technological and fiscal hurdles in the near future.

PBO+COCONET+TLALOCNET: A NUCLEUS FOR A NETWORK OF GEODETIC NETWORKS ALONG WESTERN NAM - SUBDUCTION ZONE OBSERVATORY?



GEODESY LANDSCAPE - THE NEXT BIG THING? LOOKING FORWARD ACROSS THE AMERICAS

Interdisciplinary leverage for multi-hazards observatories

Collaborative multi-national efforts

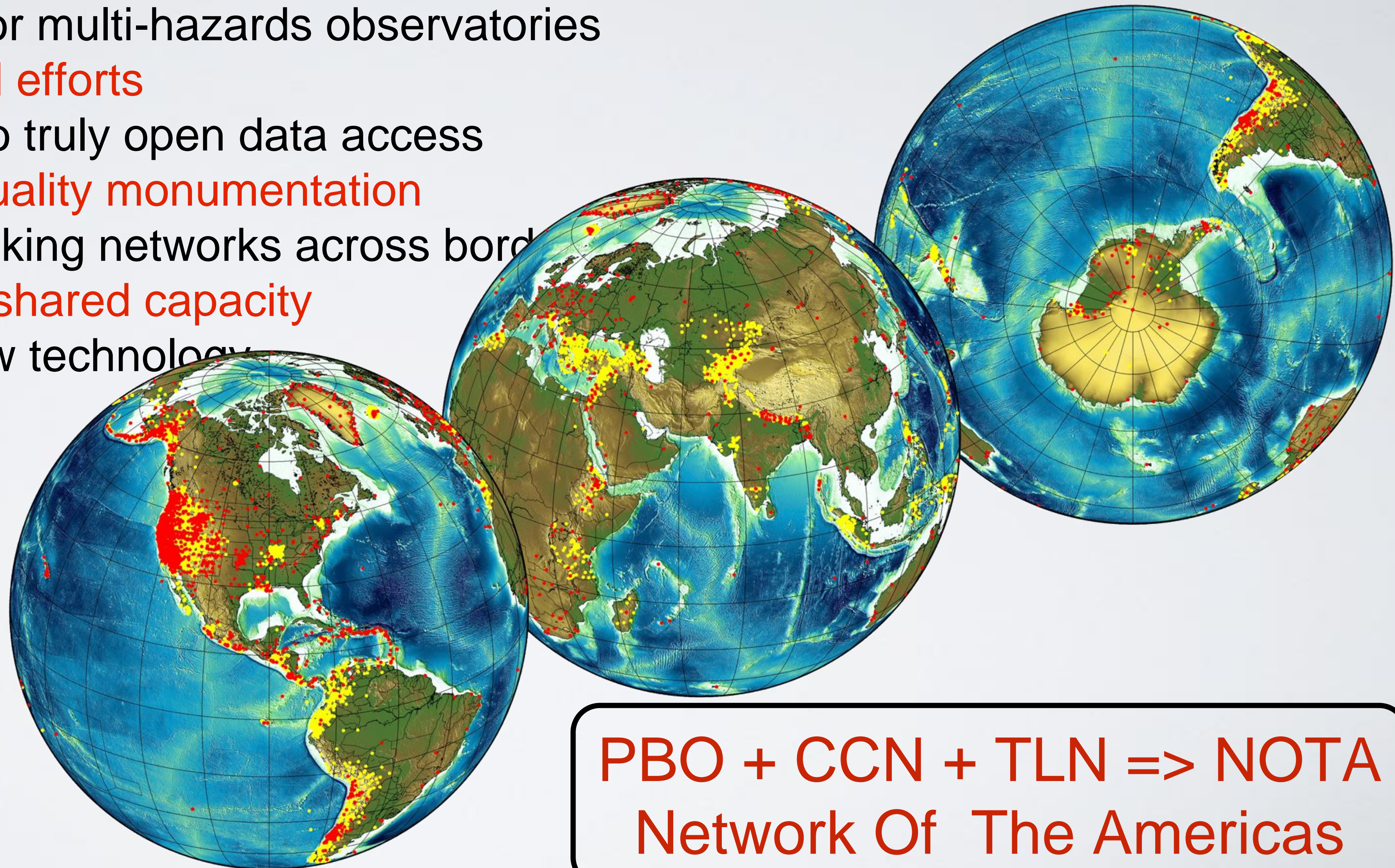
Growing the commitment to truly open data access

Commitment to geodetic quality monumentation

International federations linking networks across borders

Disseminated archives for shared capacity

Driving development of new technology
for sea-floor geodesy



**PBO + CCN + TLN => NOTA
Network Of The Americas**

PBO: A CRITICAL NATIONAL RESOURCE: SUMMARY OF IMPORTANT CONCERNS

Aging PBO infrastructure - planned replacement in GAGE, not fully possible under current budget scenarios. Many EOL Assets will remain in place at close of GAGE Facility. **Reduced O&M for PBO means possible loss of data and likely will decrease up-time in long-run.**

Need for high-rate and real-time data streams and archived products to position UNAVCO for future (NSF and non-NSF) funding and relevance. **PBO is now viewed as a “utility” by many critical stakeholders. Cost to renew and upgrade just PBO-AK stations to real-time would be considerable (\$2.1M one-time funds and \$1.0M/yr ongoing costs using current technologies).**

- Geodetic Infrastructure is vital to multiple communities and agencies - how will it be sustained?
- NSF (and NASA/USGS to a lesser degree) has made the initial investment - but the need for sustaining partners remains paramount...

Impact of loss (descoping NSF project) or degradation of PBO assets (physical and human) on stakeholders are charged with *Safety of Life* warnings, *Initial Crisis Response*, and development and maintenance of state-wide *Spatial Reference Network* systems

