EARTHSCOPE PLATE BOUNDARY OBSERVATORY IN AK: SCIENCE HIGHLIGHTS, CURRENT STATUS, CAPABILITIES AND FUTURE BEYOND GAGE IN 2018

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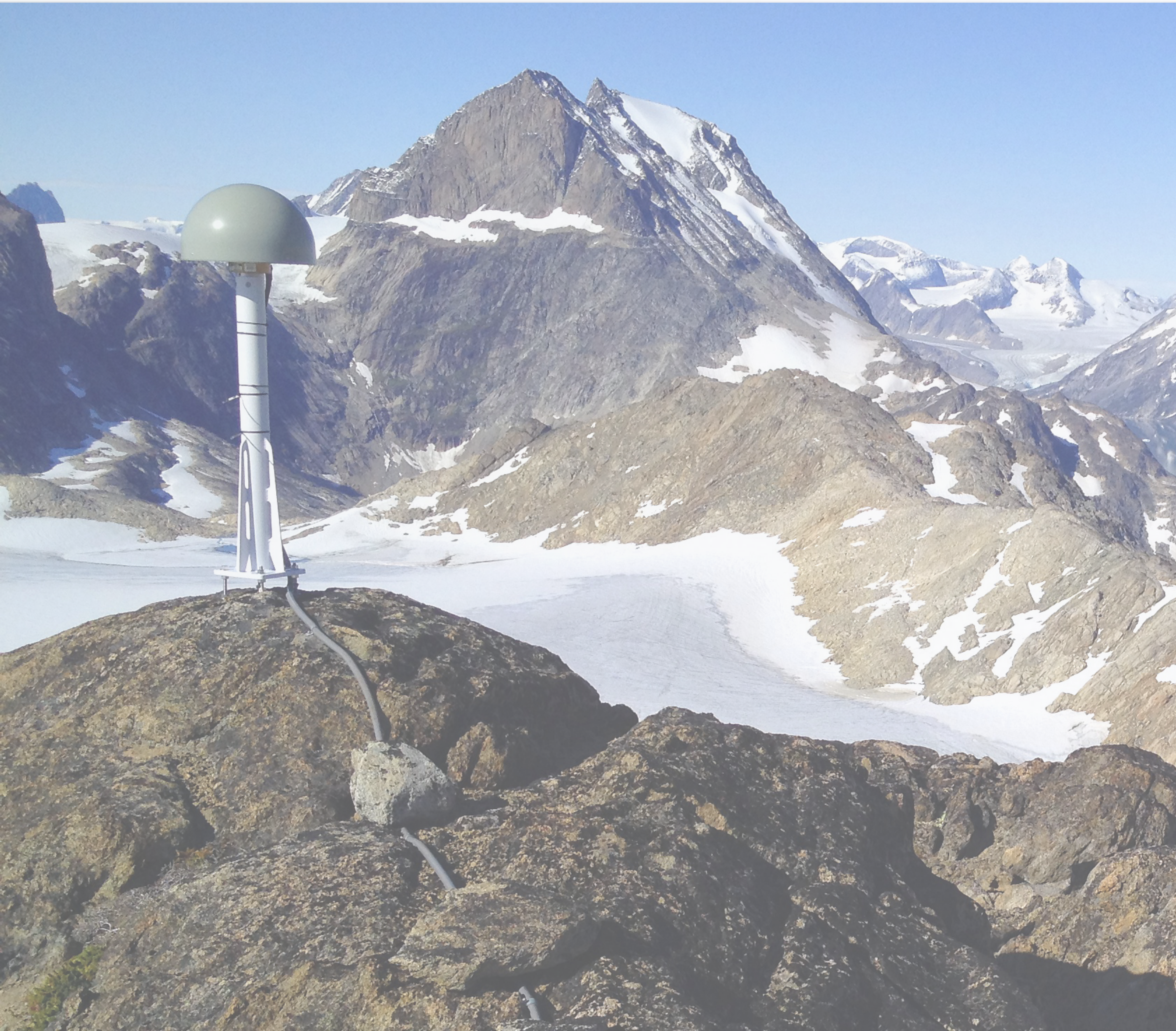
Director of Geodetic Infrastructure and PBO Director

USArray Sustainability Workshop, Nov. 9-10, 2016 - ARCUS, Washington, DC

TALK OUTLINE

- Overview of UNAVCO GI program in NSF GAGE Facility
- EarthScope overview: PBO infrastructure, current status, and data products
- Science Drivers and Value of PBO for earthquake and other studies: some examples from AK
- Vision for the future: PBO as a basis for a multi-hazard network of networks across the Americas - planned upgrades and enhancements (*i.e.* new investments) to PBO?
- Sustainability - Possible Scenarios and Costs: PBO as a platform to support real-time, multi-hazard monitoring for NOAA and USGS, civil infrastructure, and the commercial sector
- Summary and challenges going forward...

GEODETIC INFRASTRUCTURE UNDER NSF GAGE FACILITY (2013-2018)



Geodetic Infrastructure Directorate

- *Community & Continuously Observing Networks*
  - *Plate Boundary Observatory*
    - *GPS/GNSS and Metpack Operations*
    - *Borehole Geophysics Operations*
  - *NASA Global GNSS Network (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*
- *Development & Testing*

HJOR cGPS GNET site - Photo credit: T. Nylen, 2014

The EarthScope Plate Boundary Observatory

- **Funded by NSF**
- **Project started in 2003 - continues through 2018**
- **Total EarthScope Budget: ~$500M over the lifetime of the project**

Focused, dense deployments of cGPS and strainmeter arrays

- 1100 continuous Global Positioning Systems around tectonic clusters
- 78 borehole tensor strainmeters and 3 component short-period seismometers
- 6 long baseline laser strainmeters
- 25 tiltmeters
- 120 meteorological instruments

Portable GPS receivers

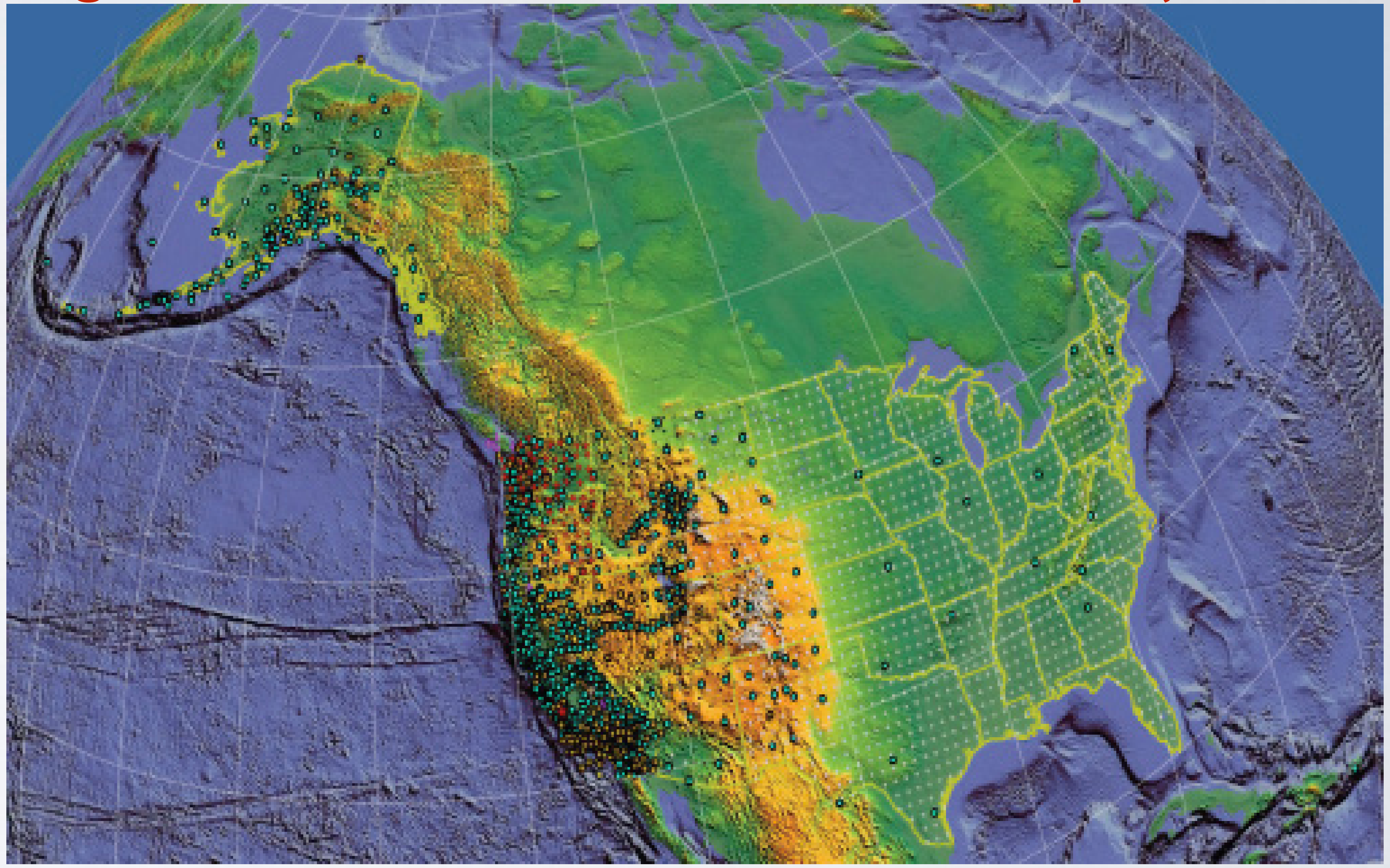
- Pool of 100 portable GPS receivers for temporary deployments to areas not sufficiently covered by continuous GPS

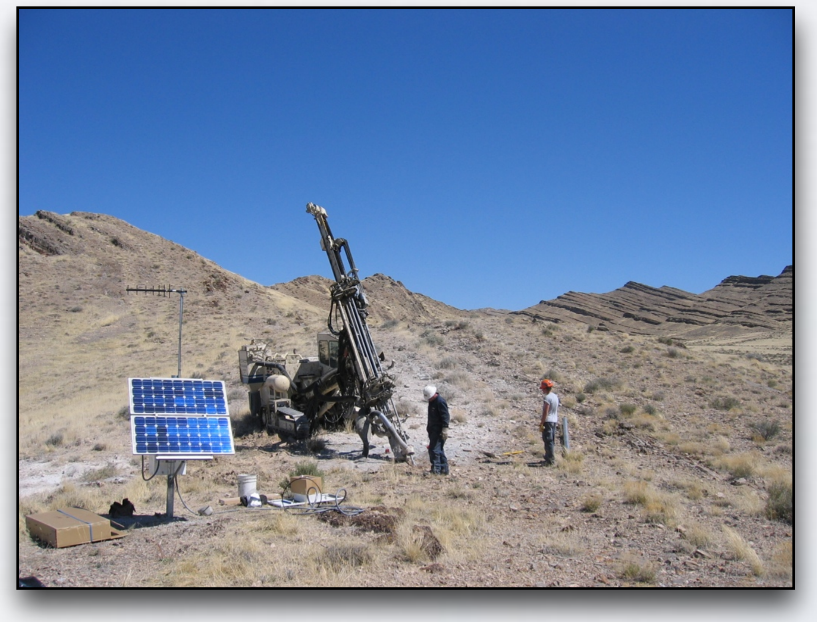
Geo-EarthScope

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

PBO Investment:

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





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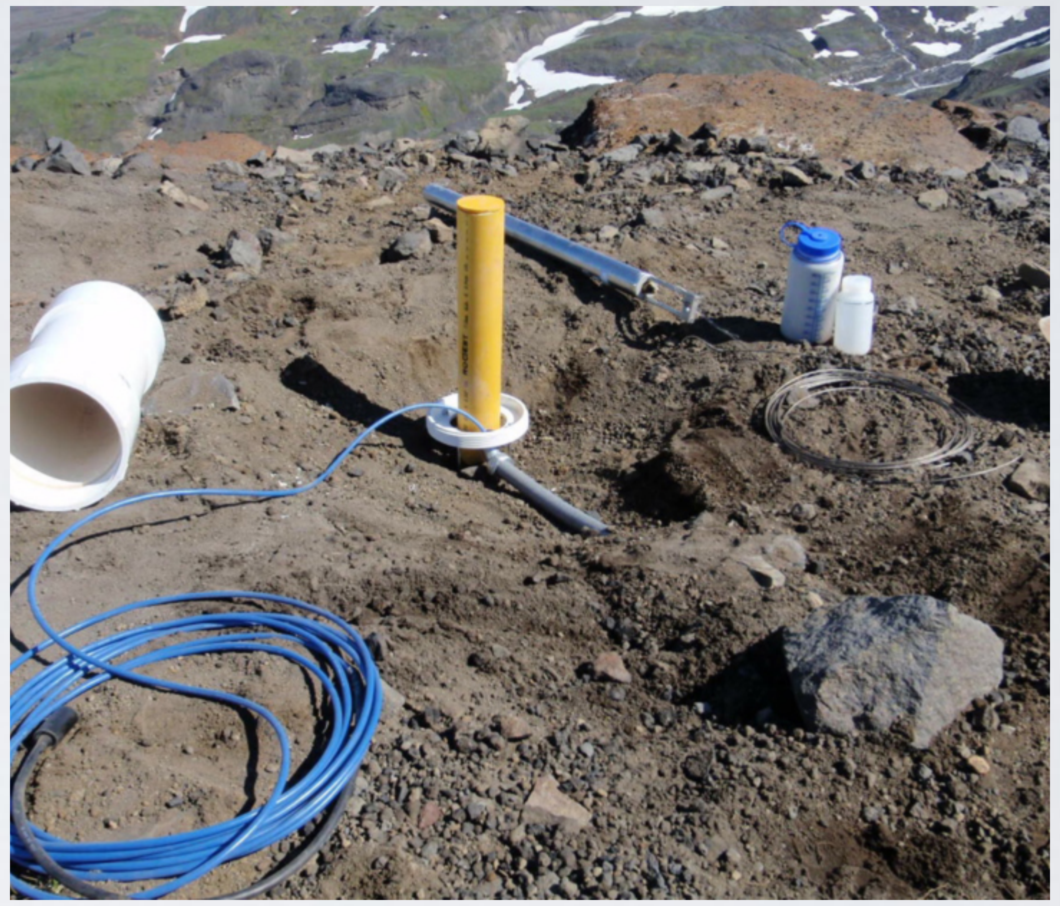
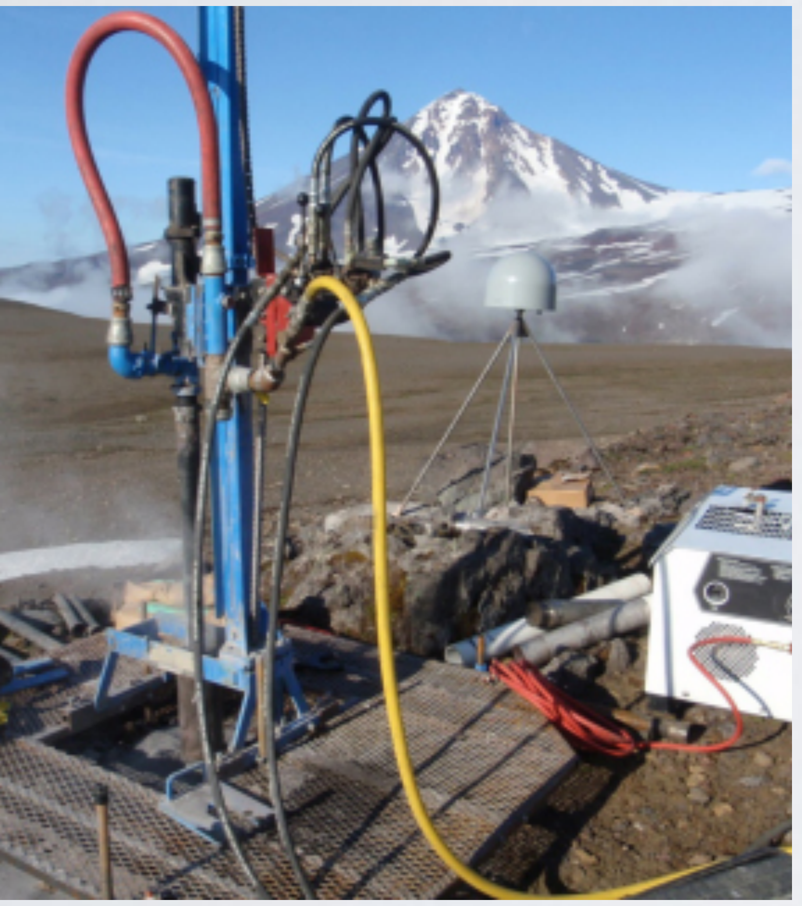
PBO: A NUCLEUS FOR A NETWORK OF GEODETIC NETWORKS




earthscope

PLATE BOUNDARY OBSERVATORY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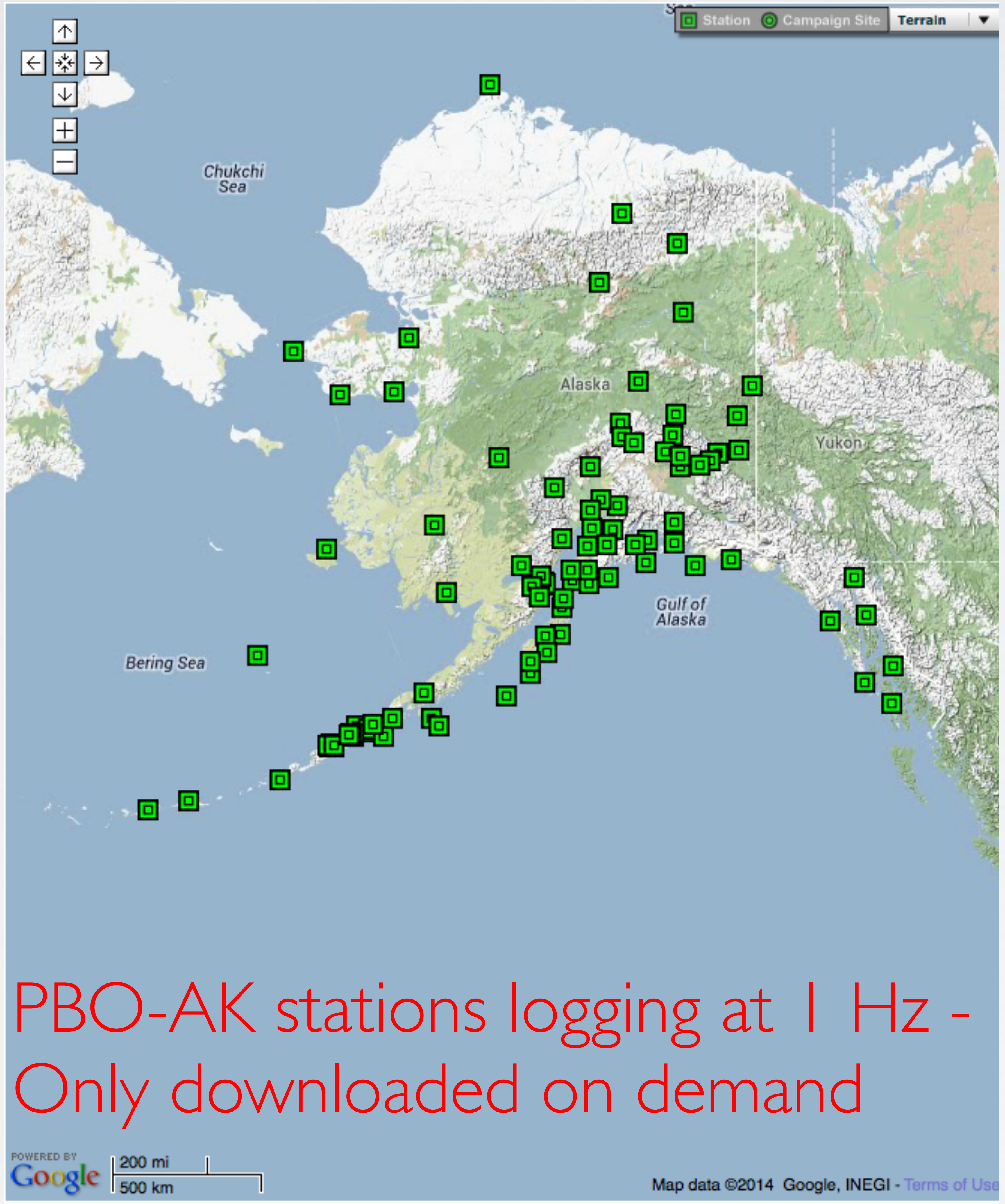
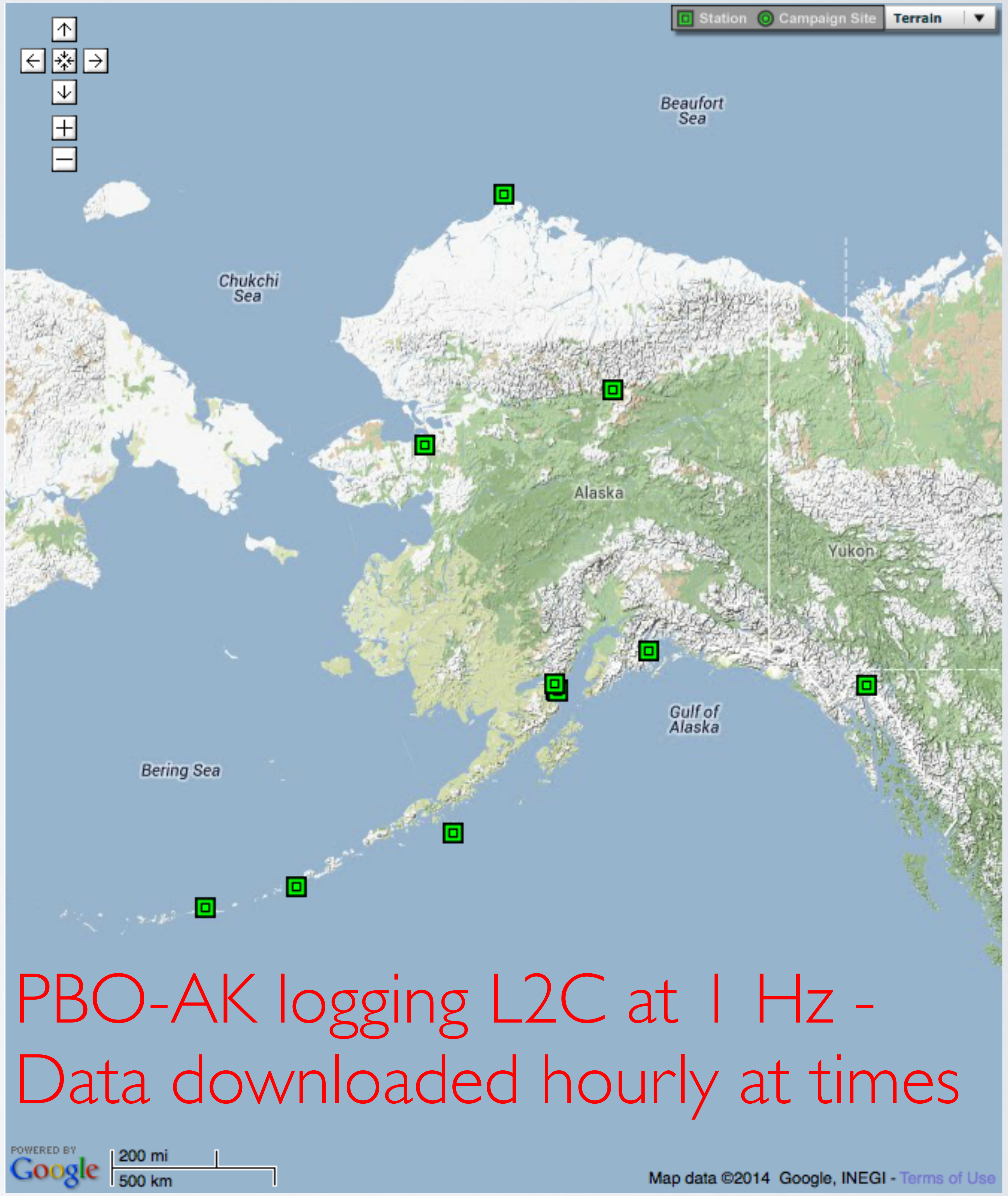
PBO STATION TYPES IN AK

Strong interest in NASA/ USGS/NOAA earthquake, volcano, and tsunami early warning communities **to upgrade** PBO-AK sites to RT-GPS (1 Hz, <1 s latency) with accelerometers (MEMS).

Surveying and AK state-wide spatial reference system could also benefit from these upgrades, but appropriate funding partners have yet to be determined.



PBO-AK stations logging at 1 Hz - Only downloaded on demand



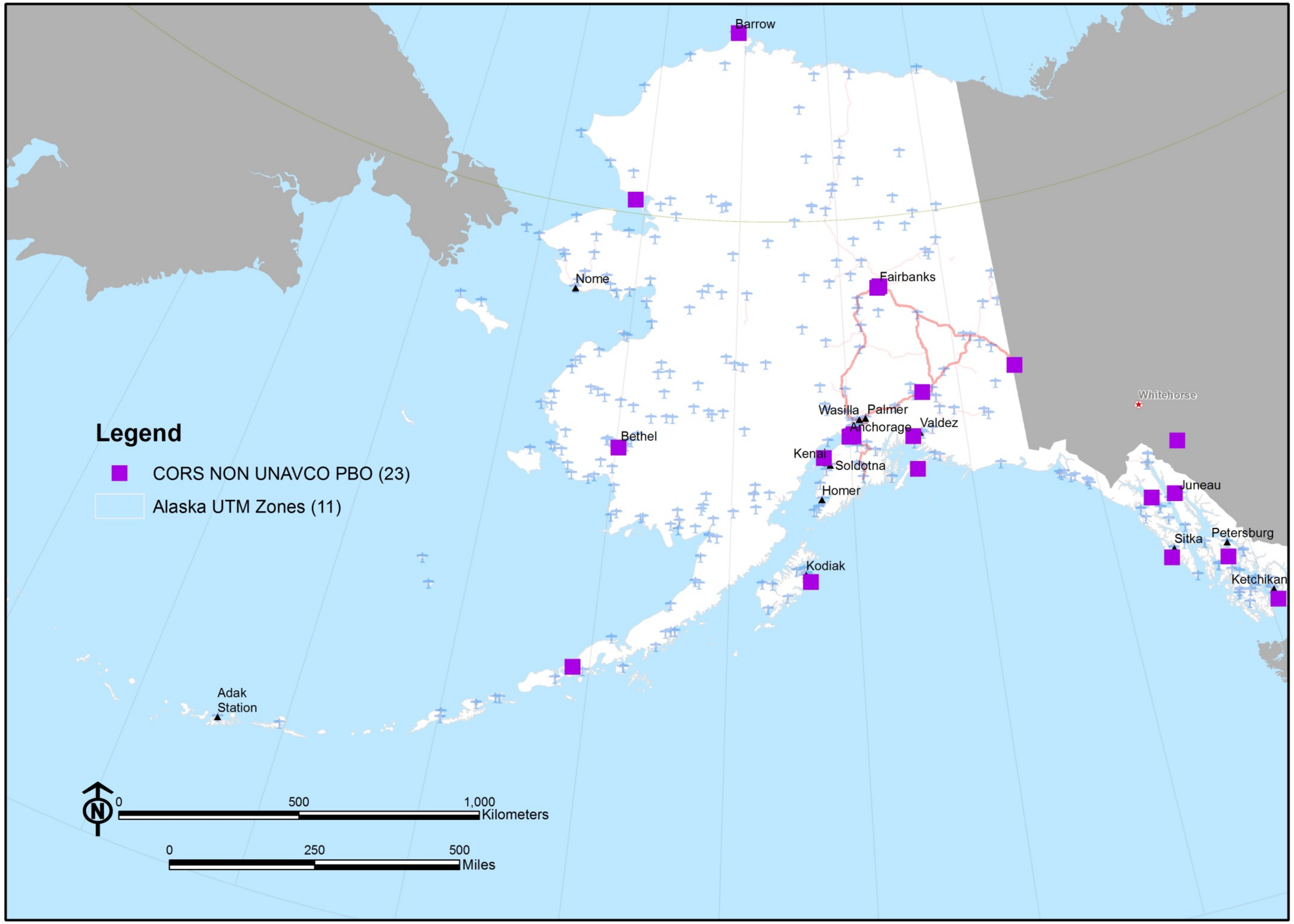
PBO-AK logging L2C at 1 Hz - Data downloaded hourly at times

NON-PBO CGPS ASSETS IN AK

EarthScope PBO geodetic assets make up the vast majority of all cGPS/cGNSS stations in AK.

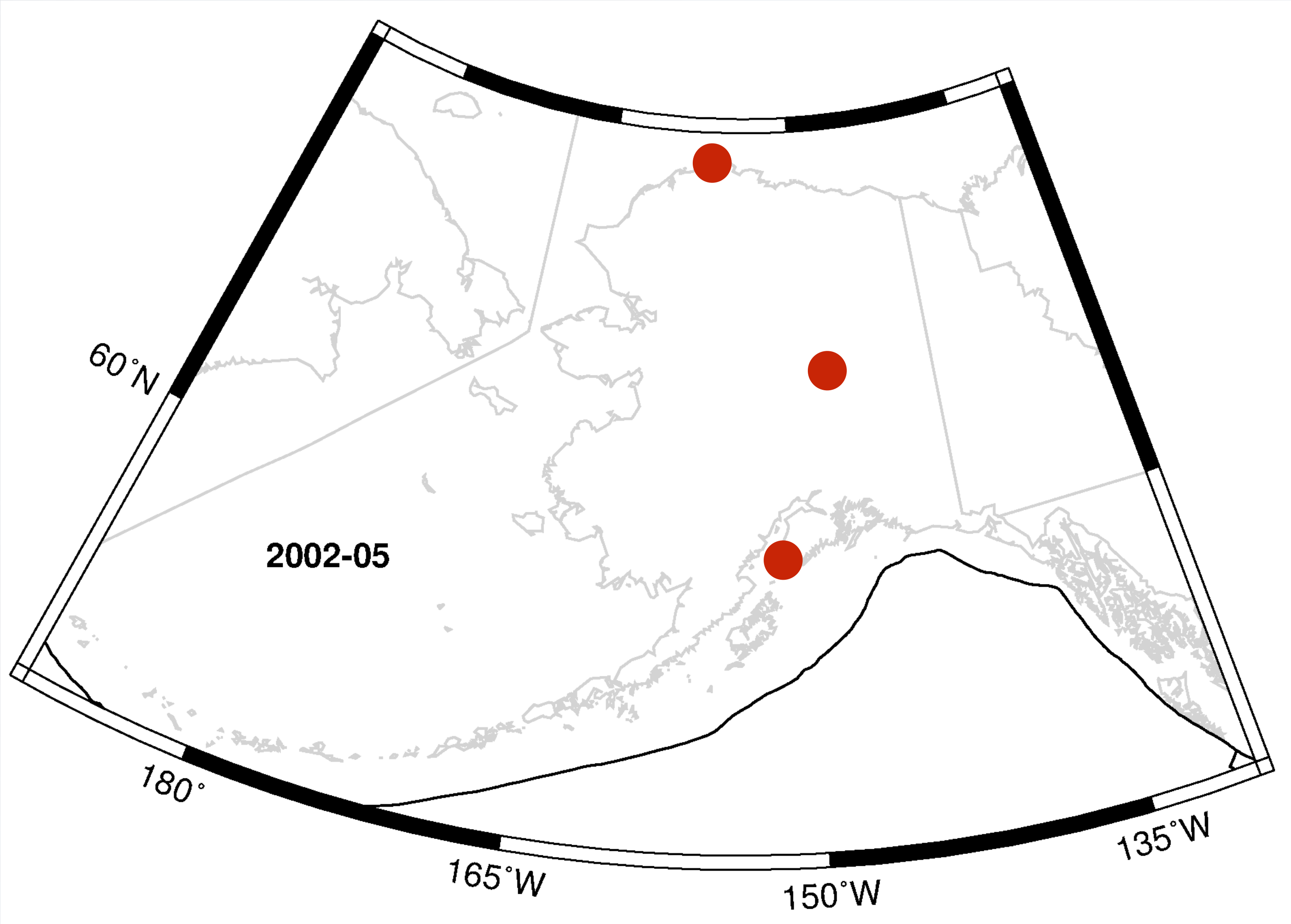
PBO stations are vital for:

1) hazard monitoring and early event characterization
2) civil infrastructure monitoring
3) support of commercial sector for construction, navigation, remote sensing, etc.



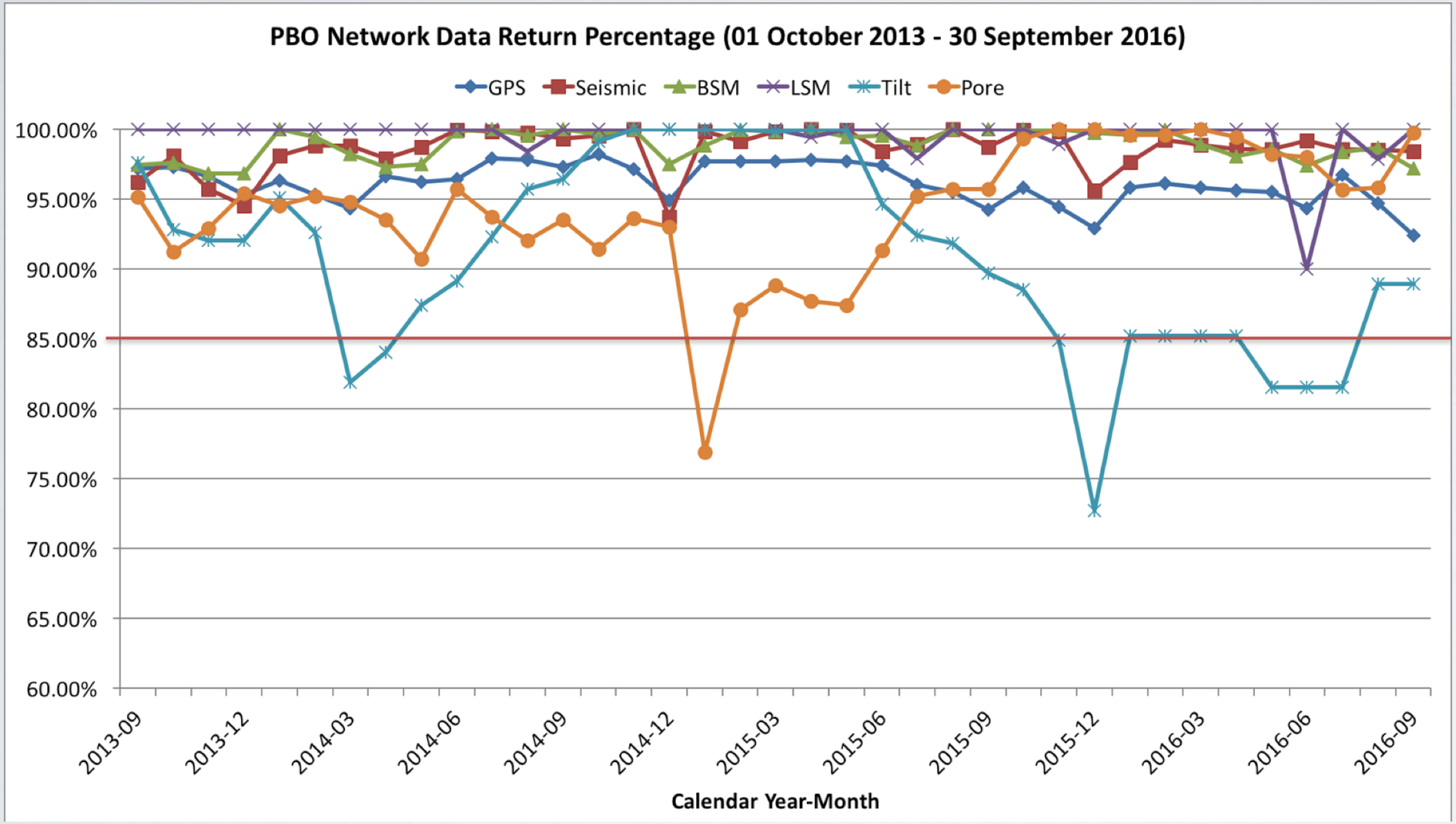
Map Date: 2-12-2015. Author: J.Cusick - NPS. Data - CBS base station list from Trimble 2-1-2015. Modified with CORS MAP. Other data sources - NPS, DOT roads and airports

THE PLATE BOUNDARY OBSERVATORY IN ALASKA
HIGHLIGHTS FROM 2003-2015



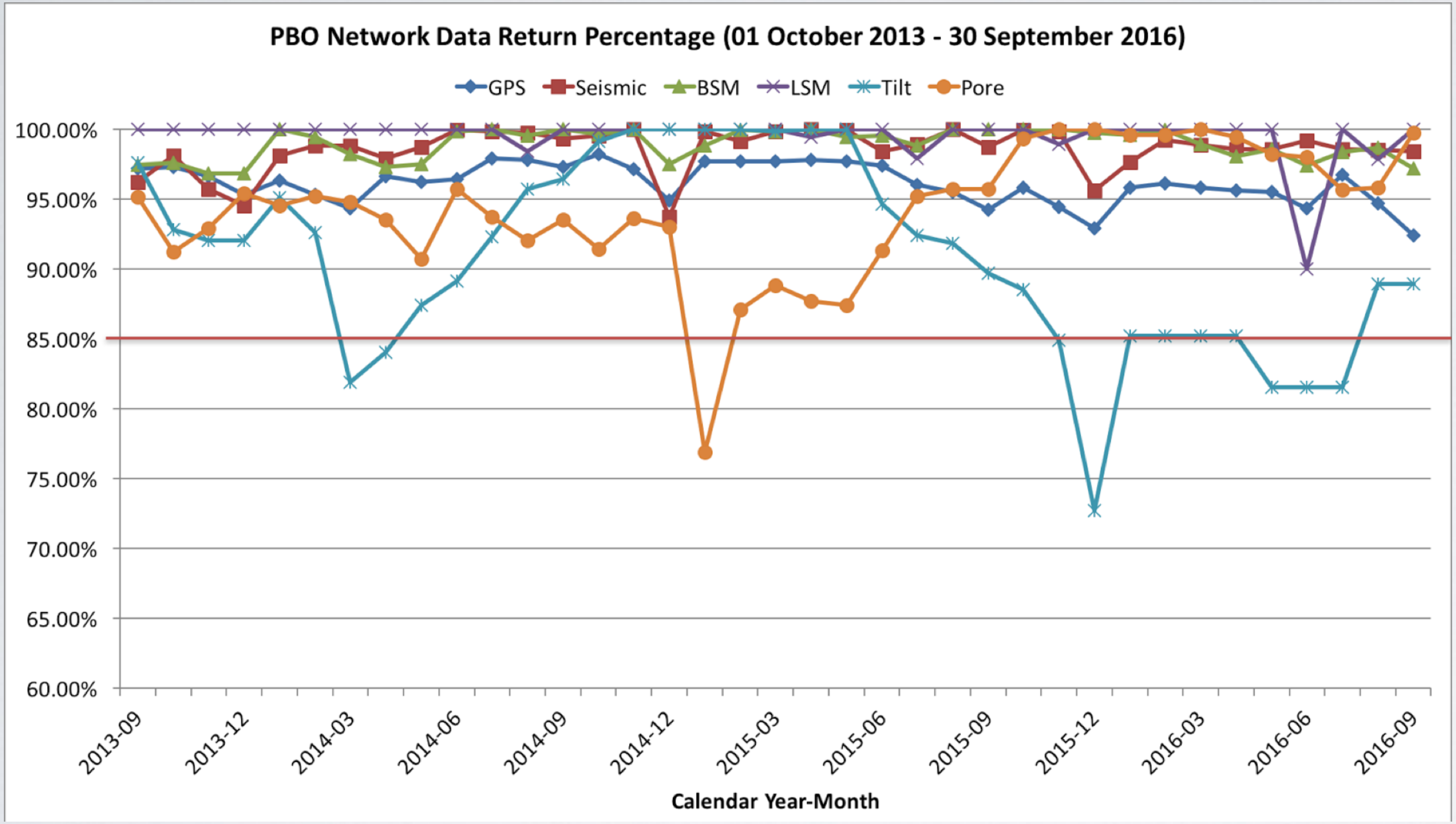
- Before the PBO came to Alaska in 2003, fewer than 5 continuous GPS reference stations were operating in Alaska with reliable telemetry.
- **Today, 140 PBO stations in Alaska provide reliable, continuous access to GPS, tiltmeter, and meteorologic data.**
- PBO sites installed prior to 2006 eruption of Augustine Volcano.
- **Since 2003, UNAVCO has spent $30M on PBO-Alaska network construction and operations/maintenance ($2.5M/yr).**
- Alaska-based UNAVCO staff (currently 3.5 FTE, as many as 6 FTE during construction phase), located in Anchorage and Fairbanks.
- **~80 field visits per year required to maintain the PBO Alaska network.**
- UNAVCO has a proven record of success in Alaska: PBO construction and maintenance has been completed safely, on-schedule, and within budget.

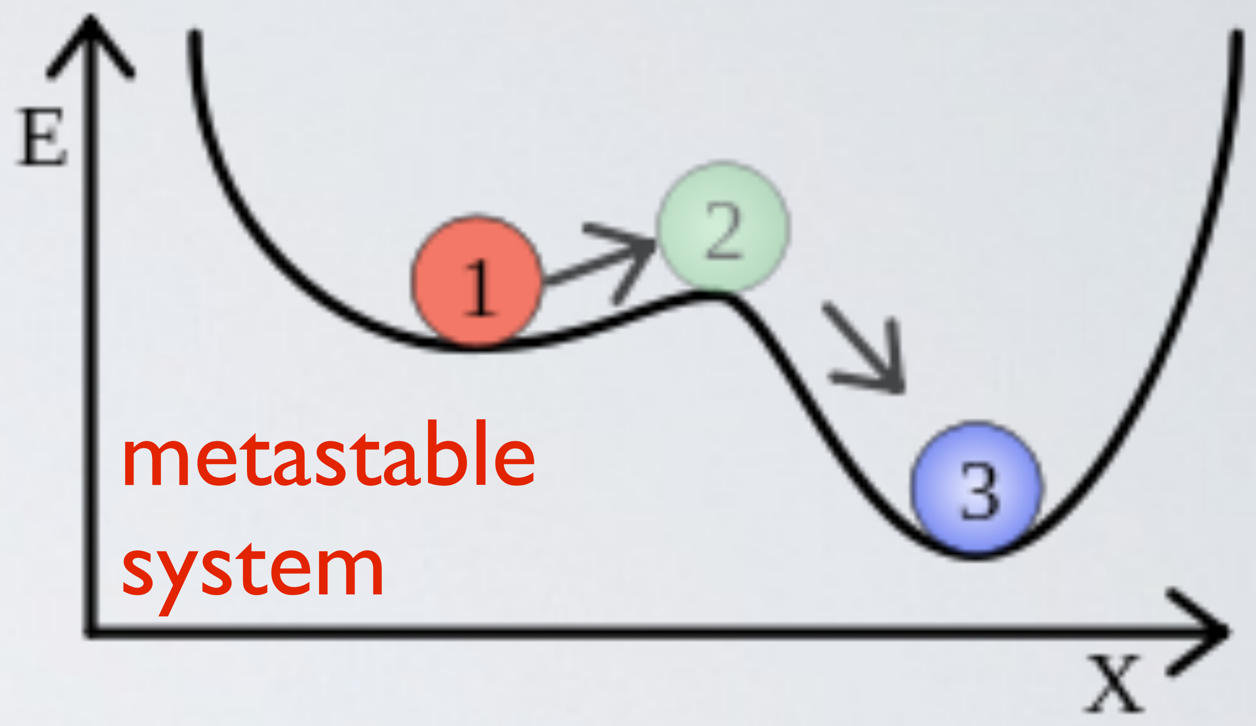
PBO SENSOR DATA RETURN



Metrics complete through September 30, 2016 (Y8Q4 - GAGE Y3Q4)

PBO SENSOR DATA RETURN





Cumulative data return for the PBO network since the beginning of the GAGE O&M period (FY2014) is:

- 96% for GPS/Met
- 99% for seismic
- 99% for BSM
- 100% for LSM
- 94% for pore pressure
- 91% for tilt

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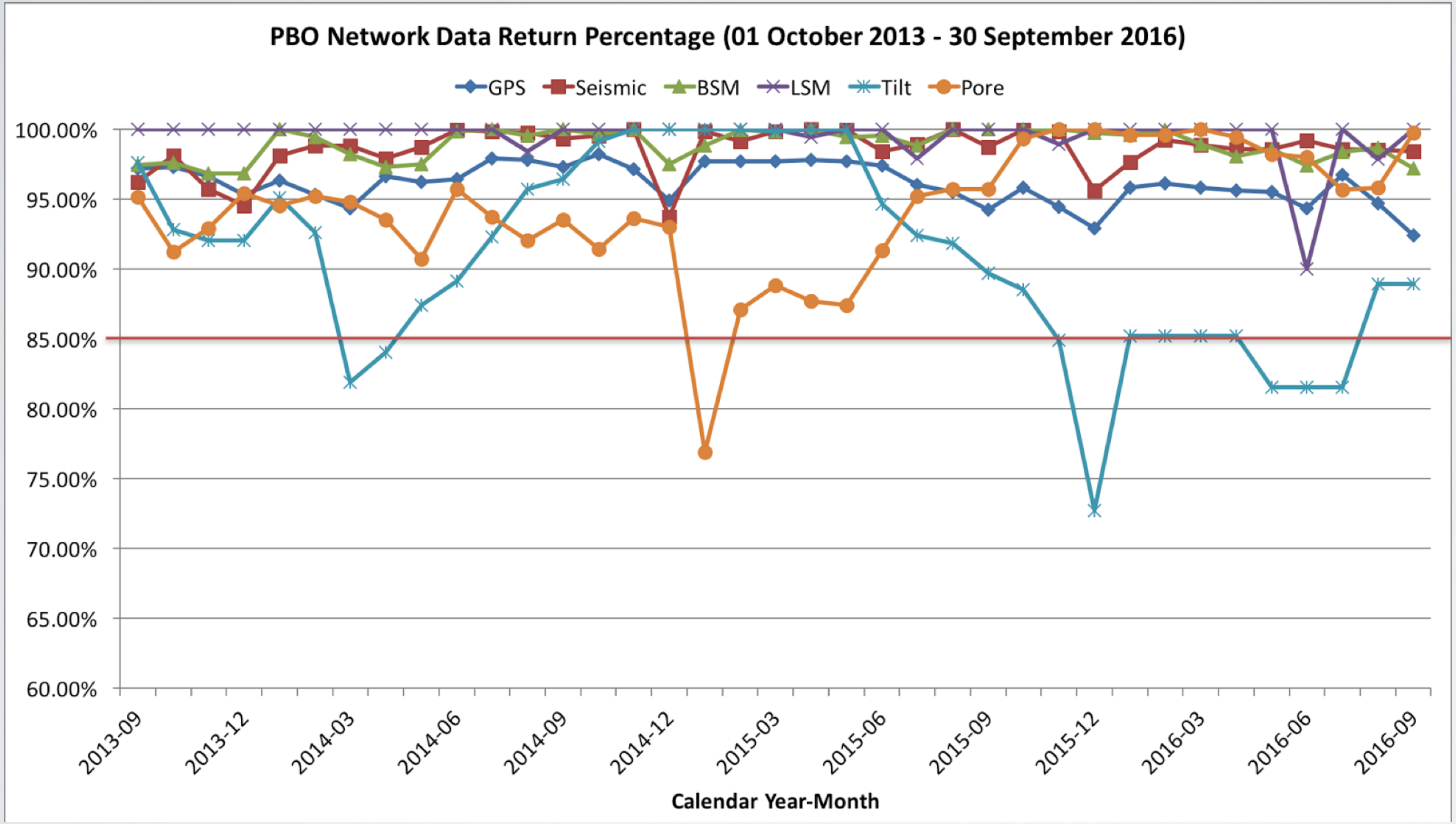
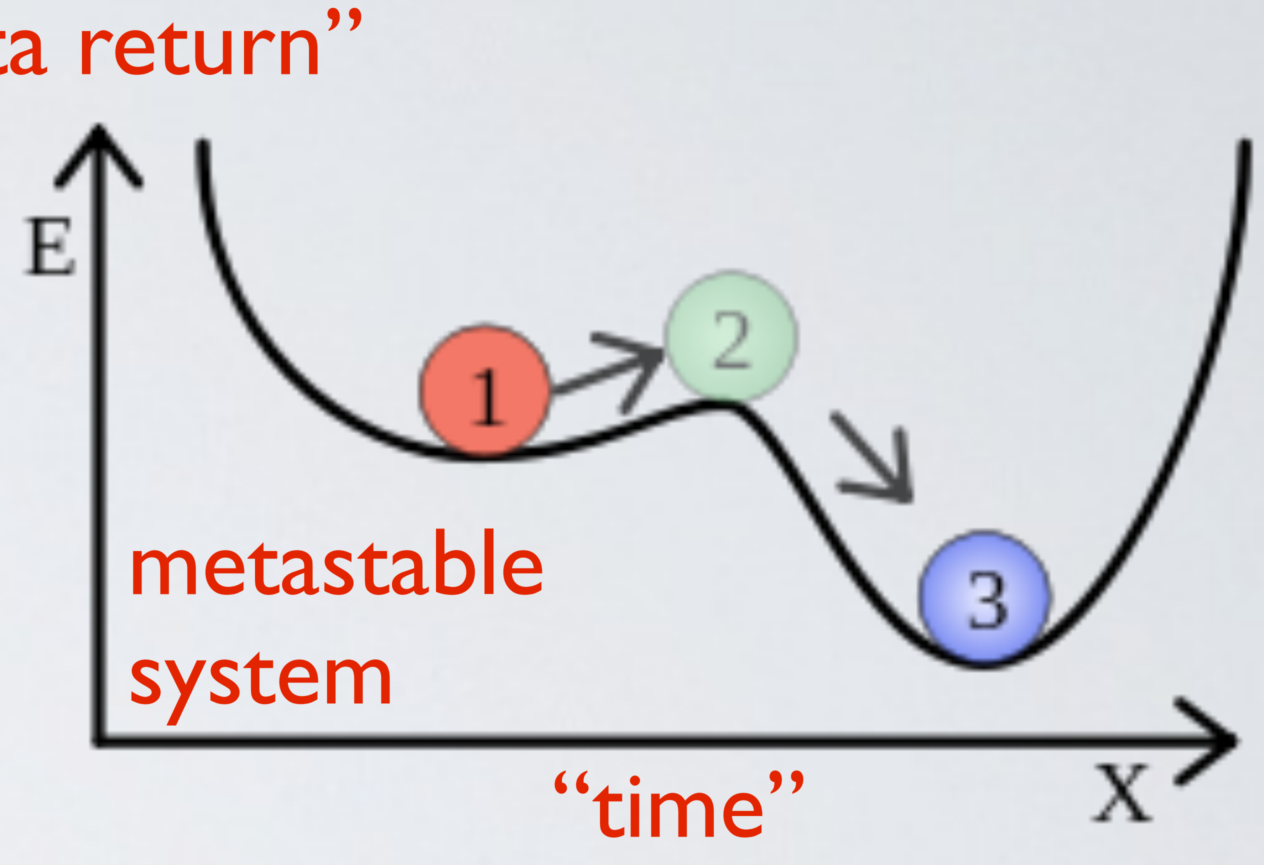
PBO SENSOR DATA RETURN





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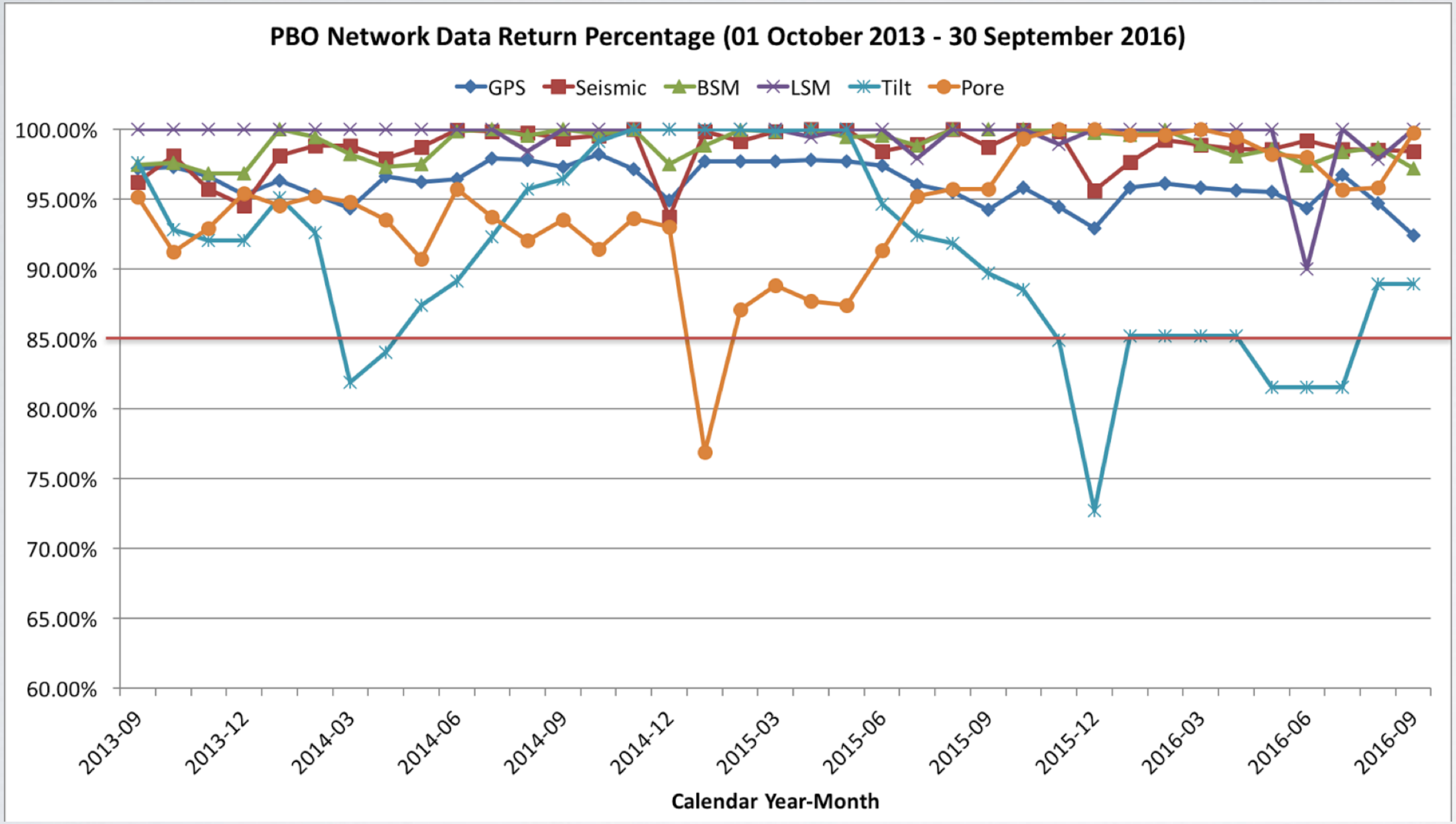

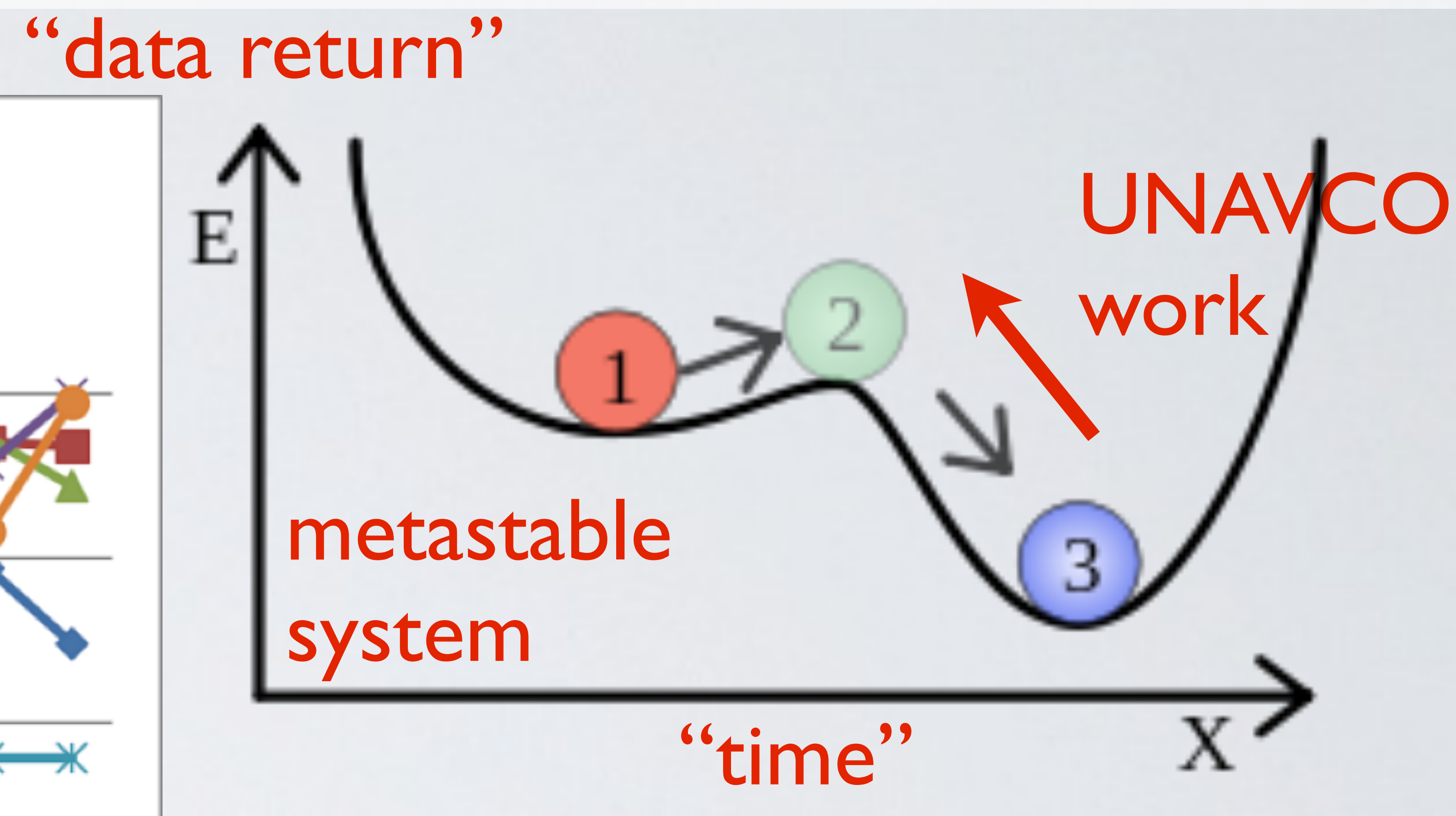

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GAGE Processing Centers - Positioning Data Quality

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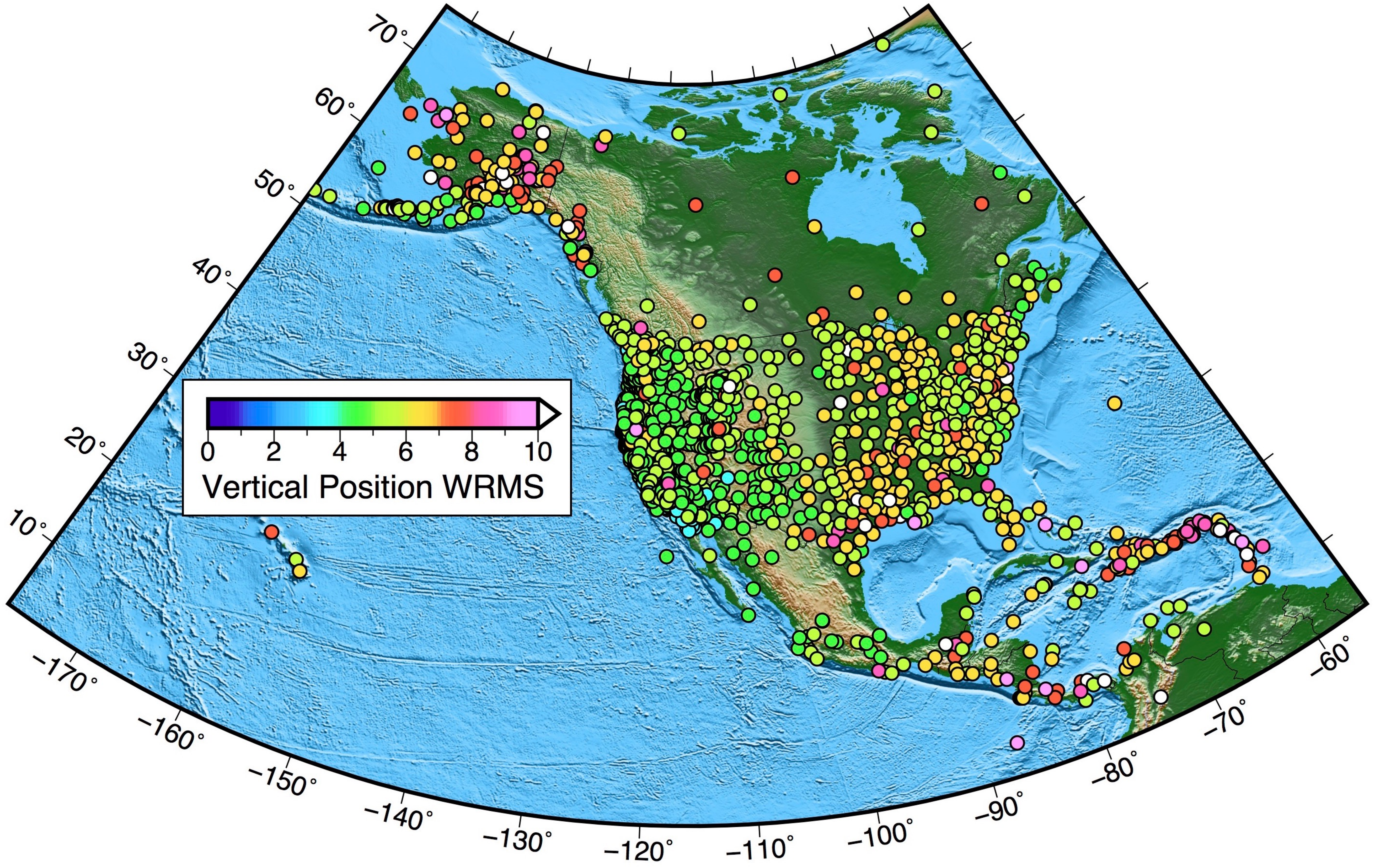

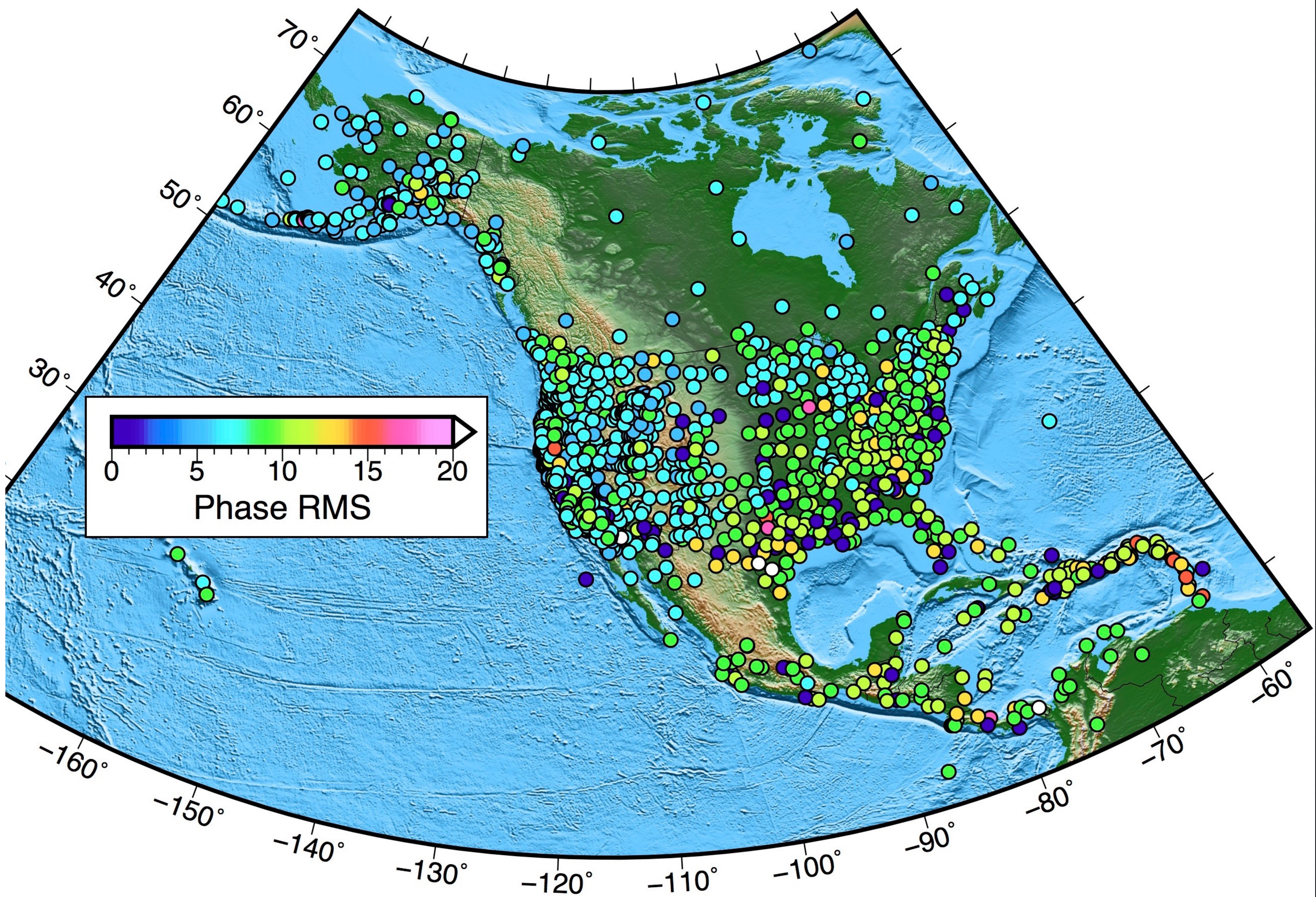

THE PLATE BOUNDARY OBSERVATORY IN ALASKA
SCIENCE AND OTHER DRIVERS

1964 M9.2 4th Ave - Anchorage
Photo source: US Army

2006 Augustine Eruption
Photo source: USGS

- Tectonic block definition and motion - examination of oblique convergence and slip partitioning
- **Strain accumulation and locking along the megathrust interface between NAM-PAC**
- Post-seismic visco-elastic response from the 1964 M9.2 Anchorage and 2002 Mw7.9 Denali earthquakes
- **Static and dynamic forcing of volcanic systems and changes in state of from seismic- and ice-loading**
- Short to medium-term characterization of crustal magma dynamics and volcanic eruptions (e.g. dike intrusion and propagation)
- **Support of hazard missions of USGS and NOAA - EEW/TEW and NGS CORS - PBO AK contributes 76 of ~100 stations**
- With deployment of USArray in AK - integration of crustal and lithospheric structure with surface deformation field

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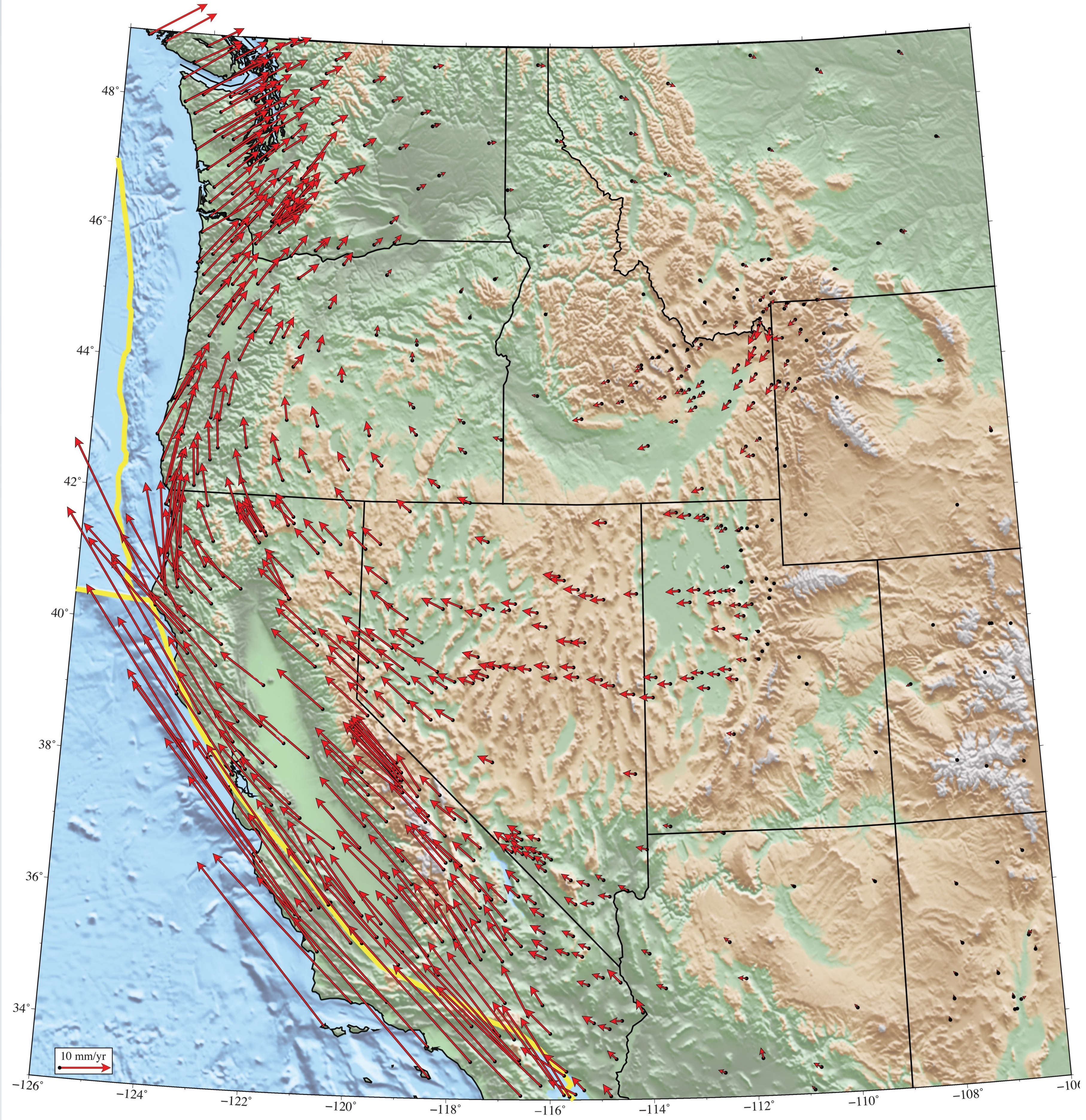
THE PLATE BOUNDARY OBSERVATORY IN ALASKA HIGHLIGHTS FROM 2003-2015

Tectonic Motions of the Western United States



Horizontal velocities for western United States GPS stations whose data are processed by the Geodesy Advancing Geosciences and EarthScope (GAGE) GPS Analysis Centers for the Plate Boundary Observatory at New Mexico Tech and Central Washington University. Velocities are in the North America-fixed reference frame (NAM08) and calculated by the Analysis Center Coordinator at the Massachusetts Institute of Technology. The number of stations shown in California has been greatly reduced to make it easier to see regional motion. For updated velocities, search the web for UNAVCO GPS Velocity Viewer.

For this map and related links, go to unavco.org/velocity-maps

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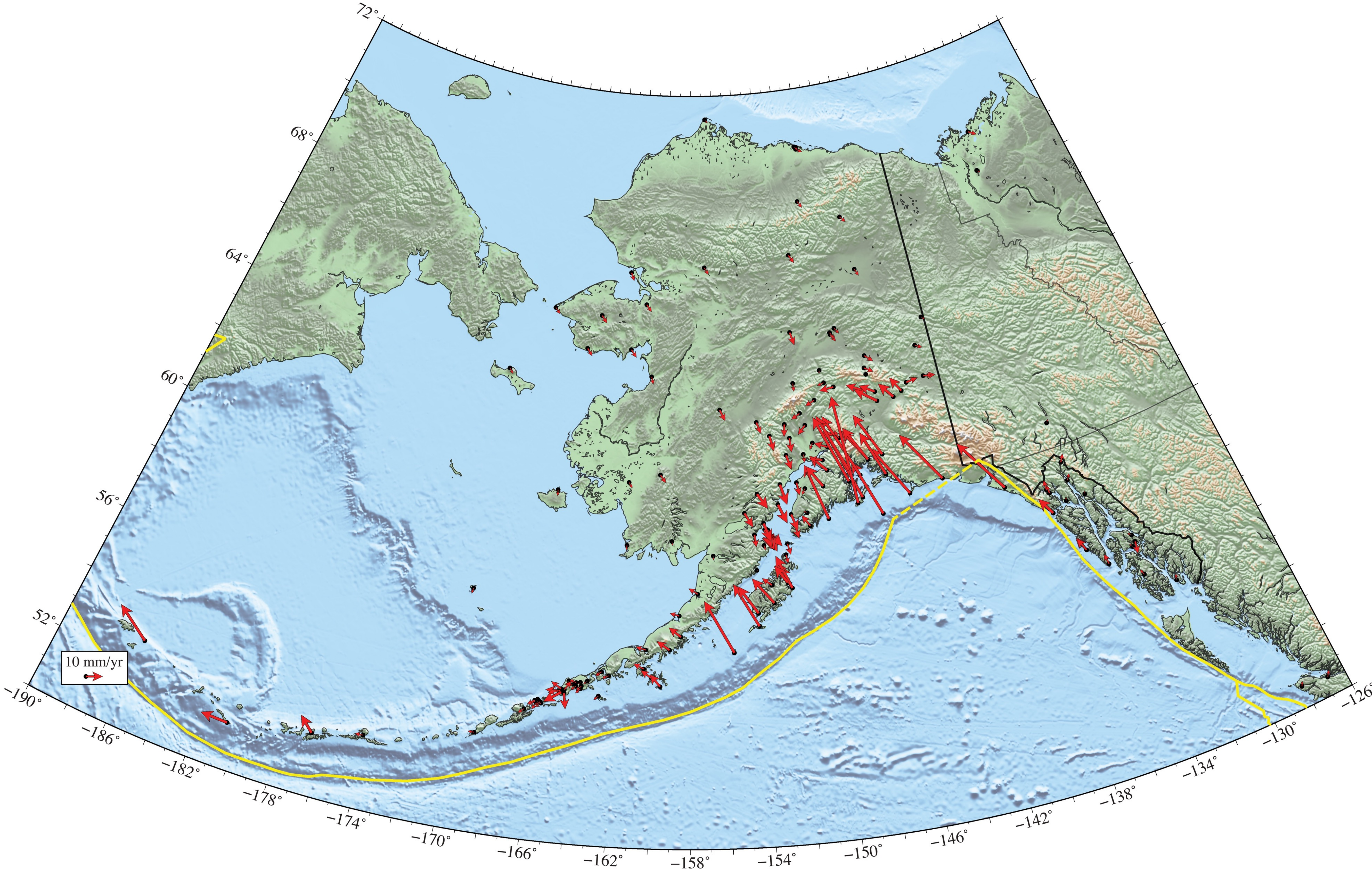
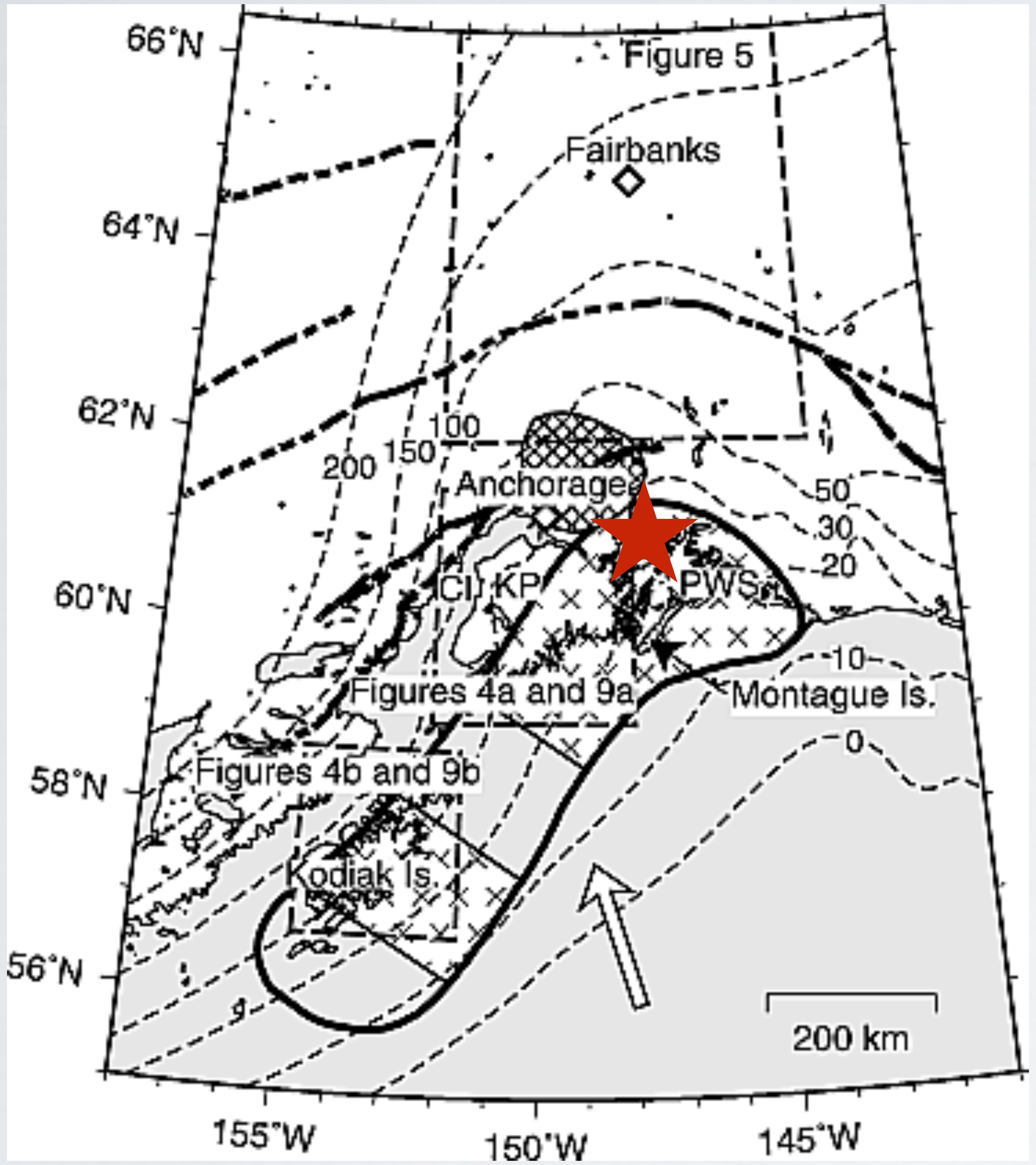
Tectonic Motions of Alaska

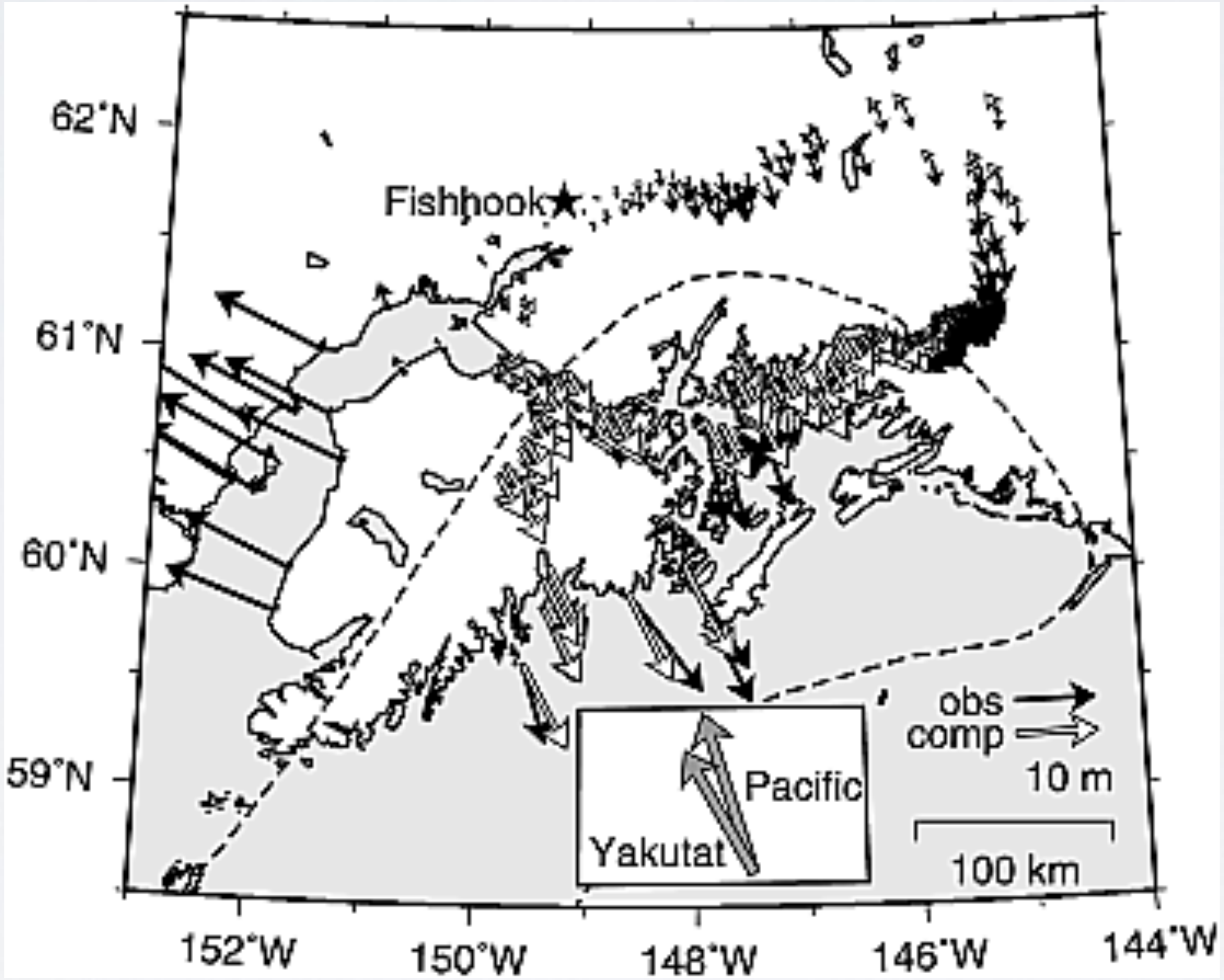


AK SHIELD EXERCISE
REPLAY OF M9.2 MARCH 27, 1964 EARTHQUAKE

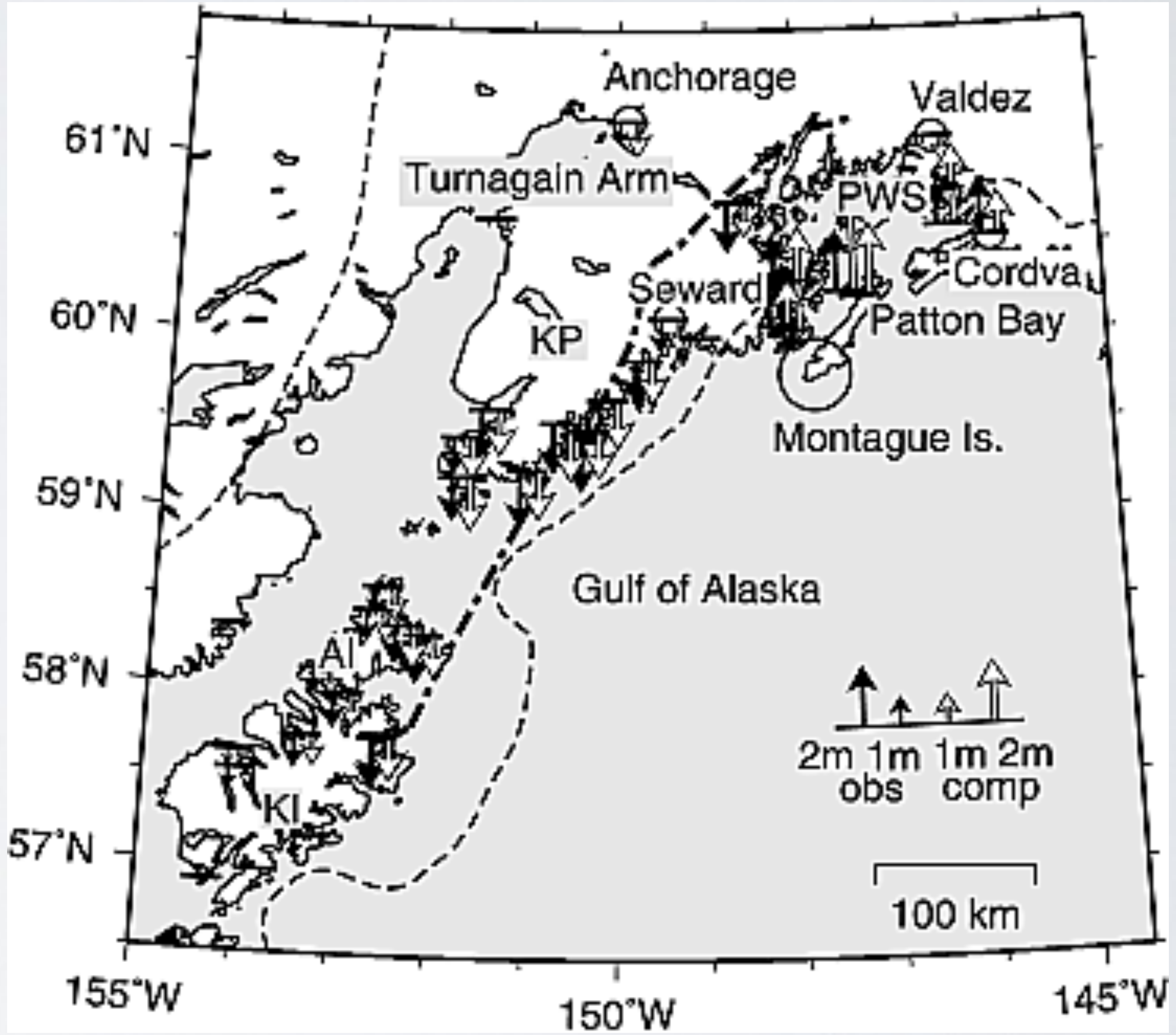
Epicenter and rupture area



Horizontal coseismic



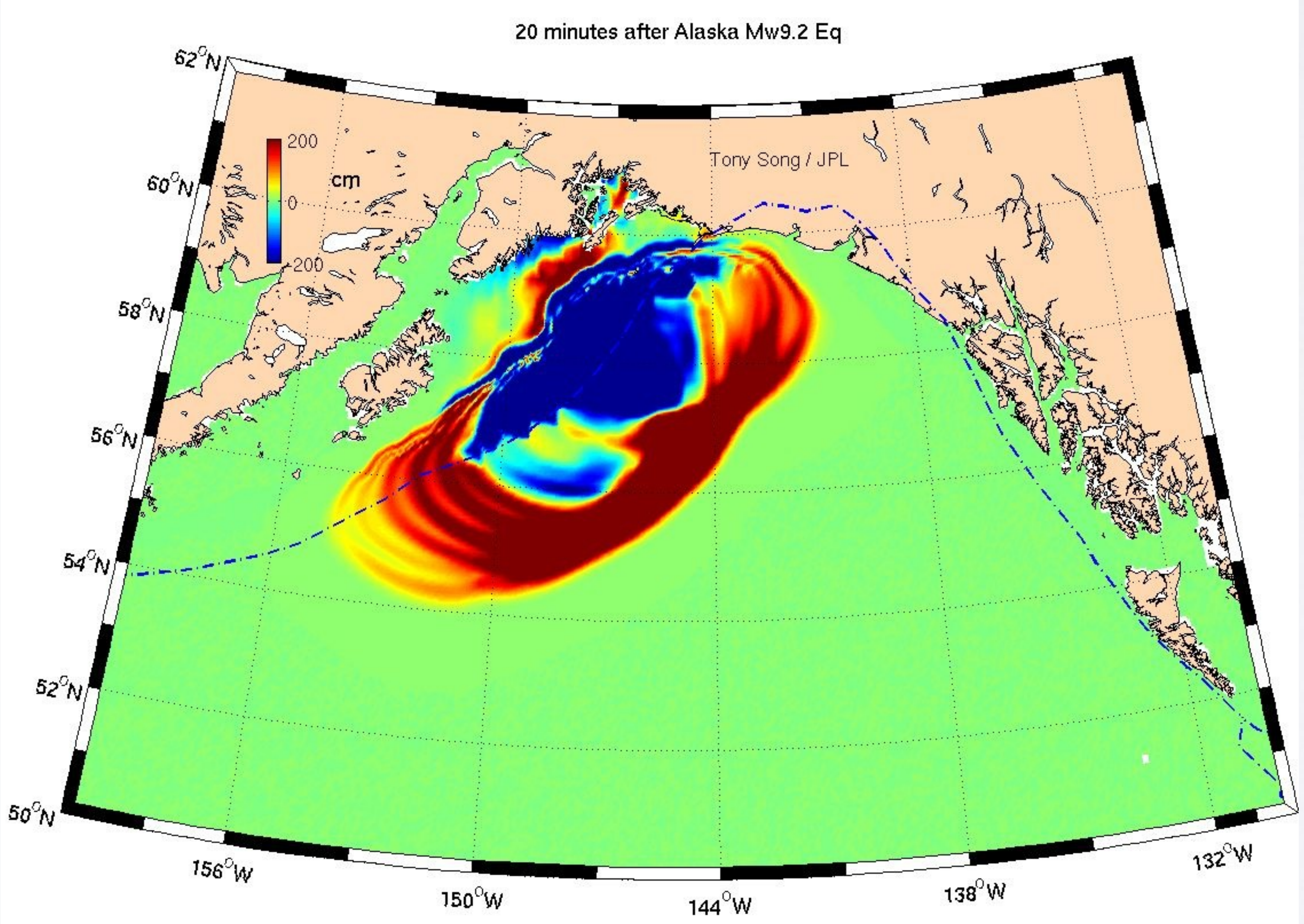
Vertical coseismic

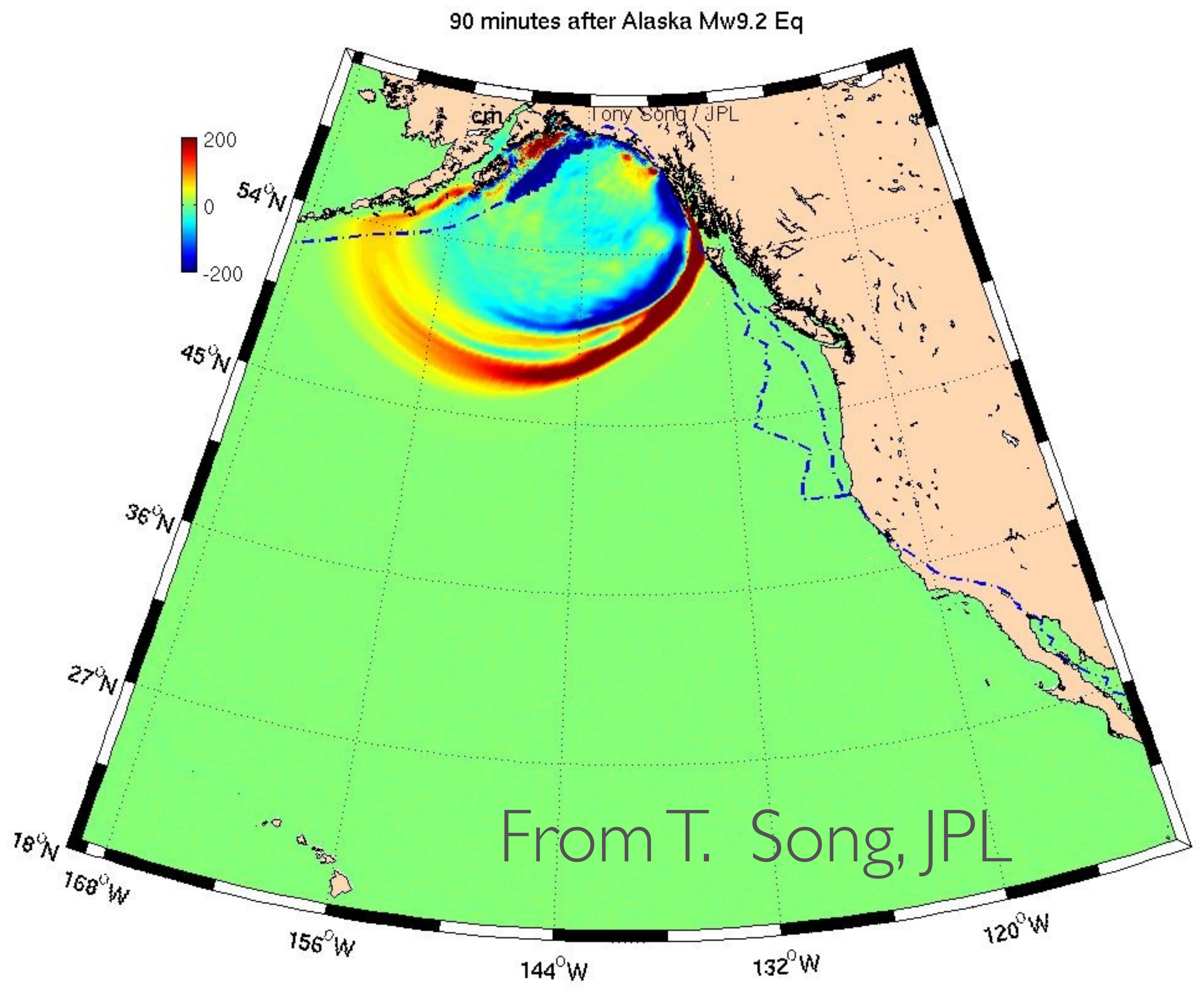


Data from M9.2 1964 event (Suito and Freymueller, JGR, 2009) was used to drive 2014 AK Shield simulation for NASA READI prototype earthquake early warning system

NASA READI TEAM PRODUCTS FOR AK SHIELD

JPL tsunami simulations based on RT-GPS (1 Hz) coseismic displacements for M9.2 1964-type event (FFM of Suito and Freymueller, JGR, 2009





NASA READI team: JPL, UCSD-SIO, CWU with PBO as *key data provider*

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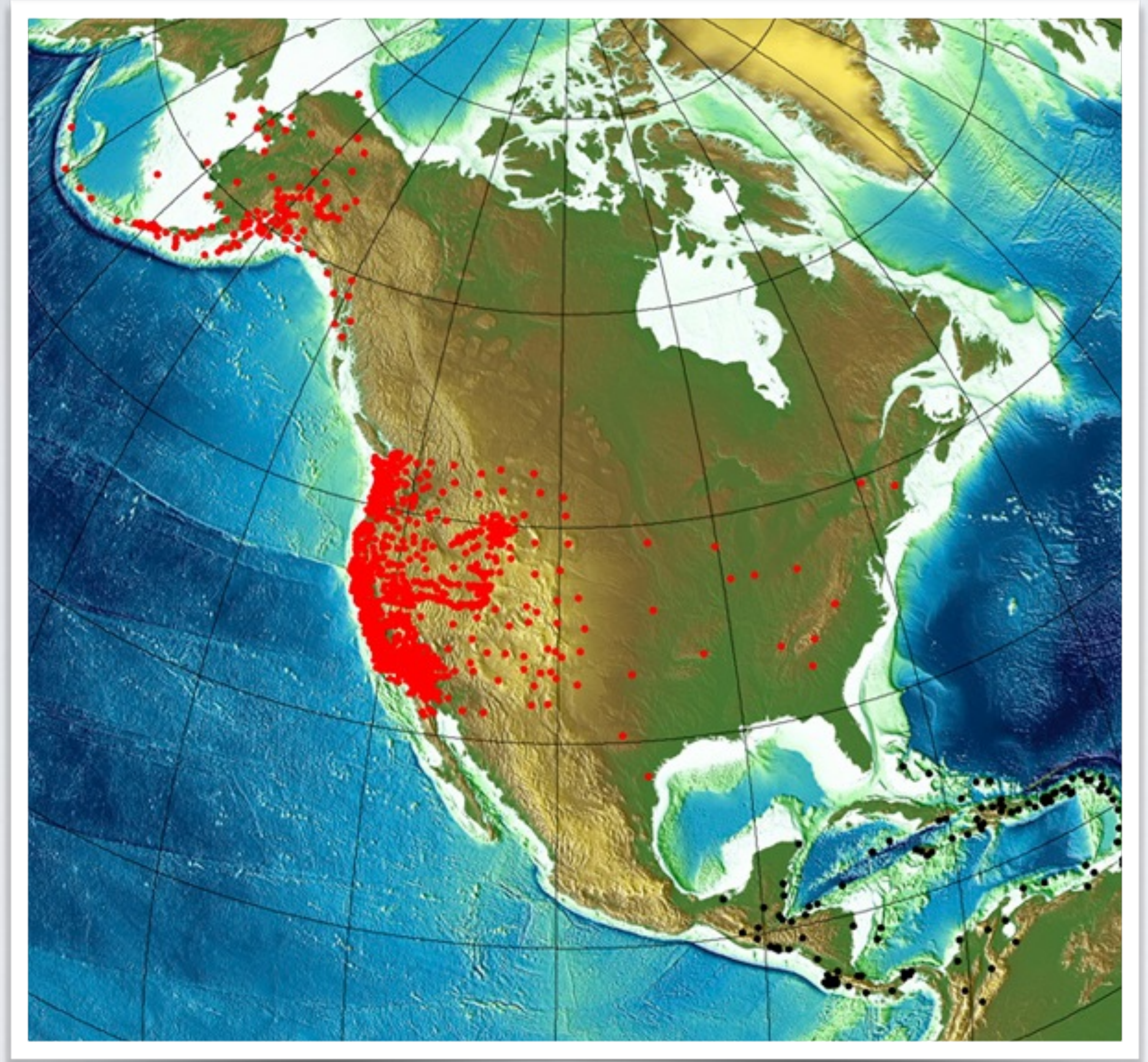
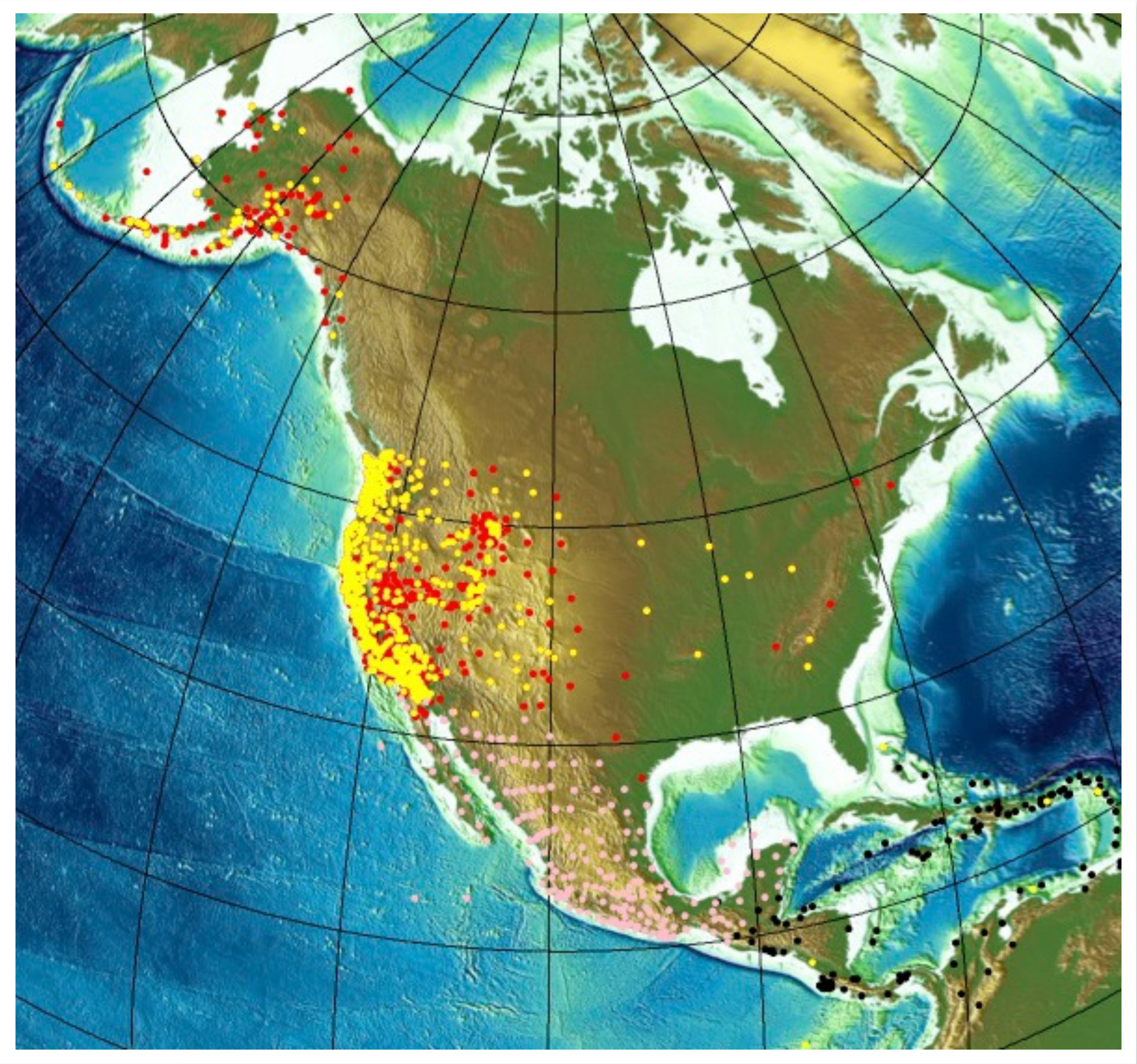
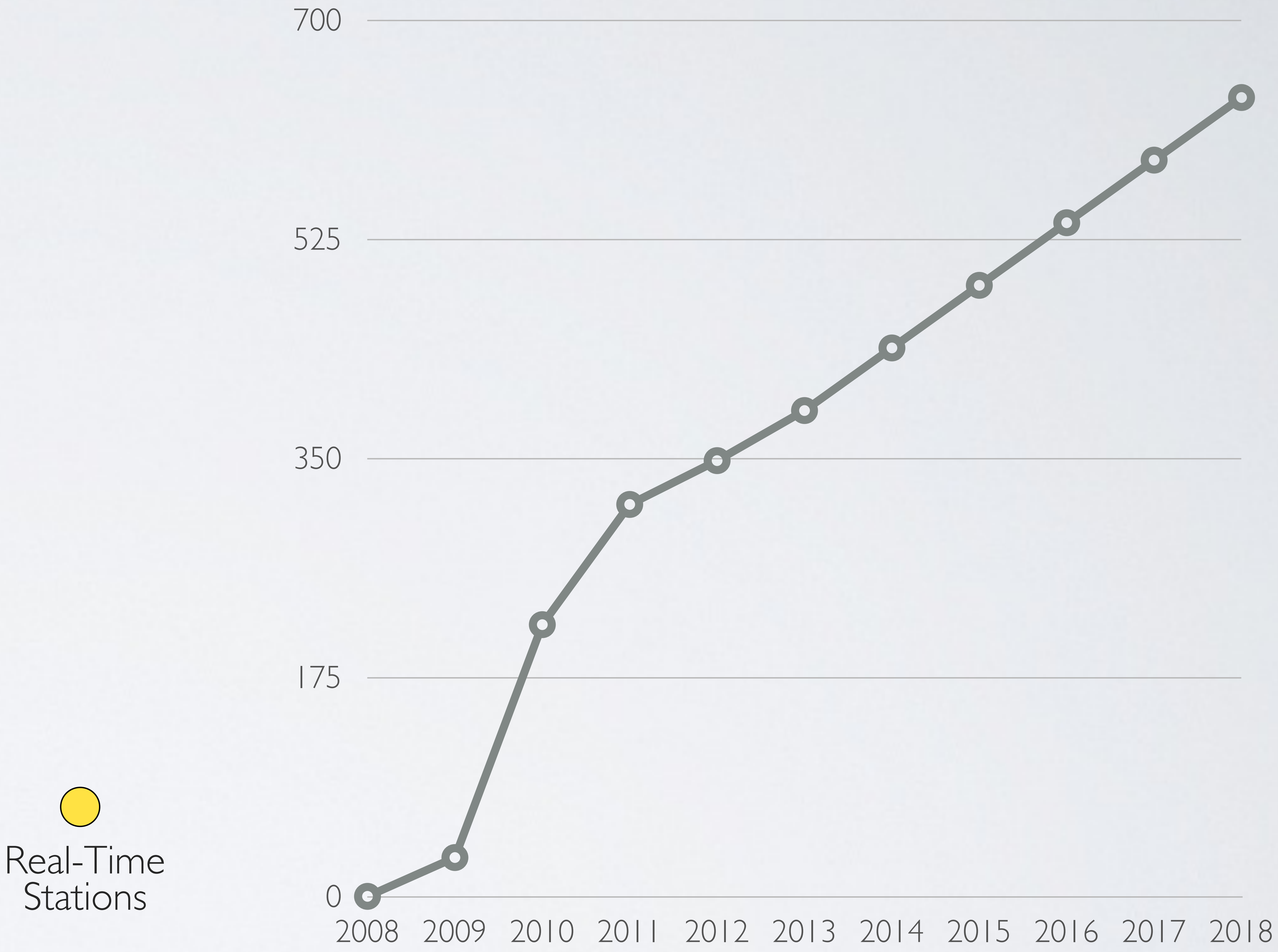
GAGE: RT-GPS/GNSS UPGRADE PLAN



Real-Time Stations

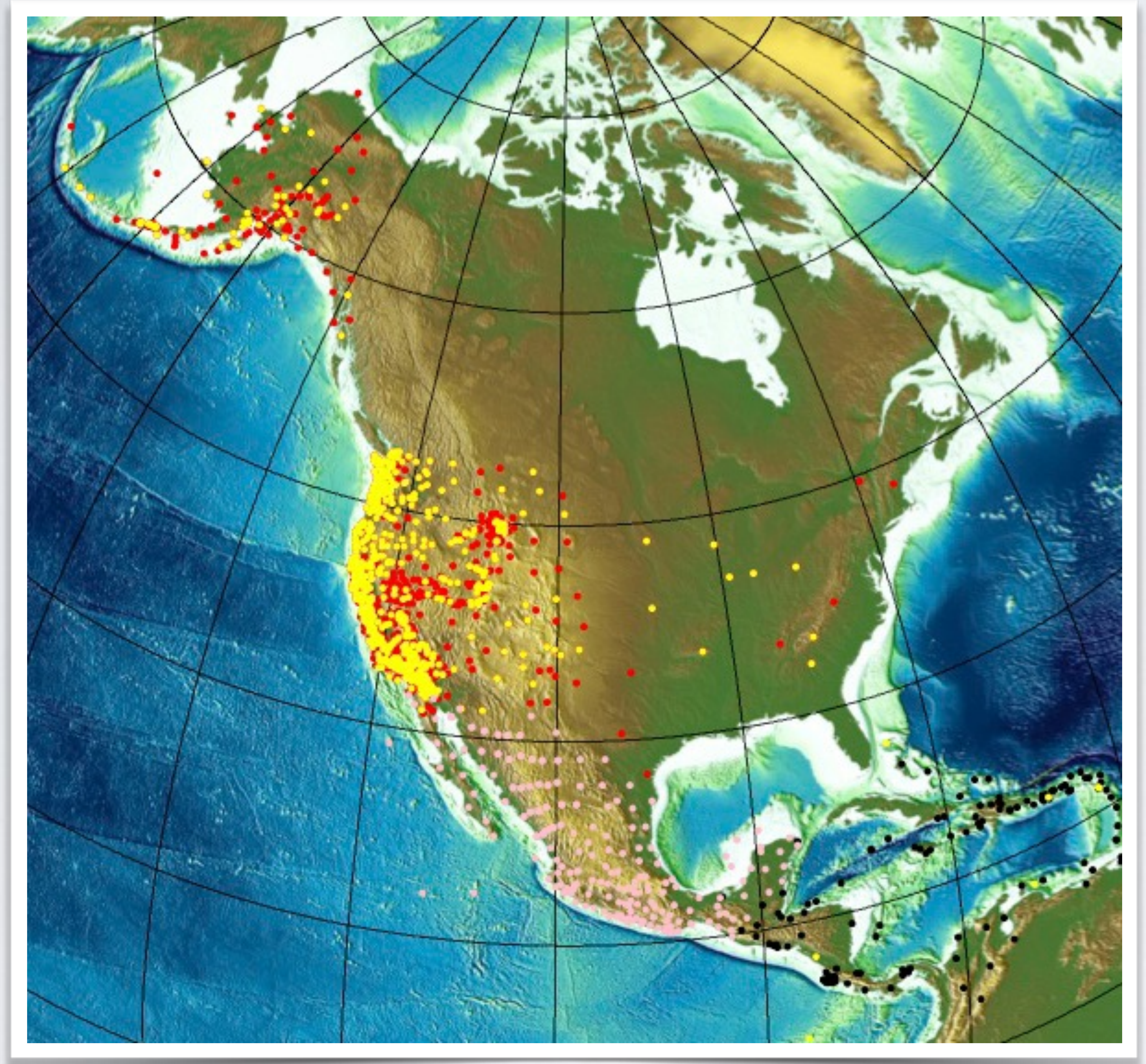
GAGE: RT-GPS/GNSS UPGRADE PLAN

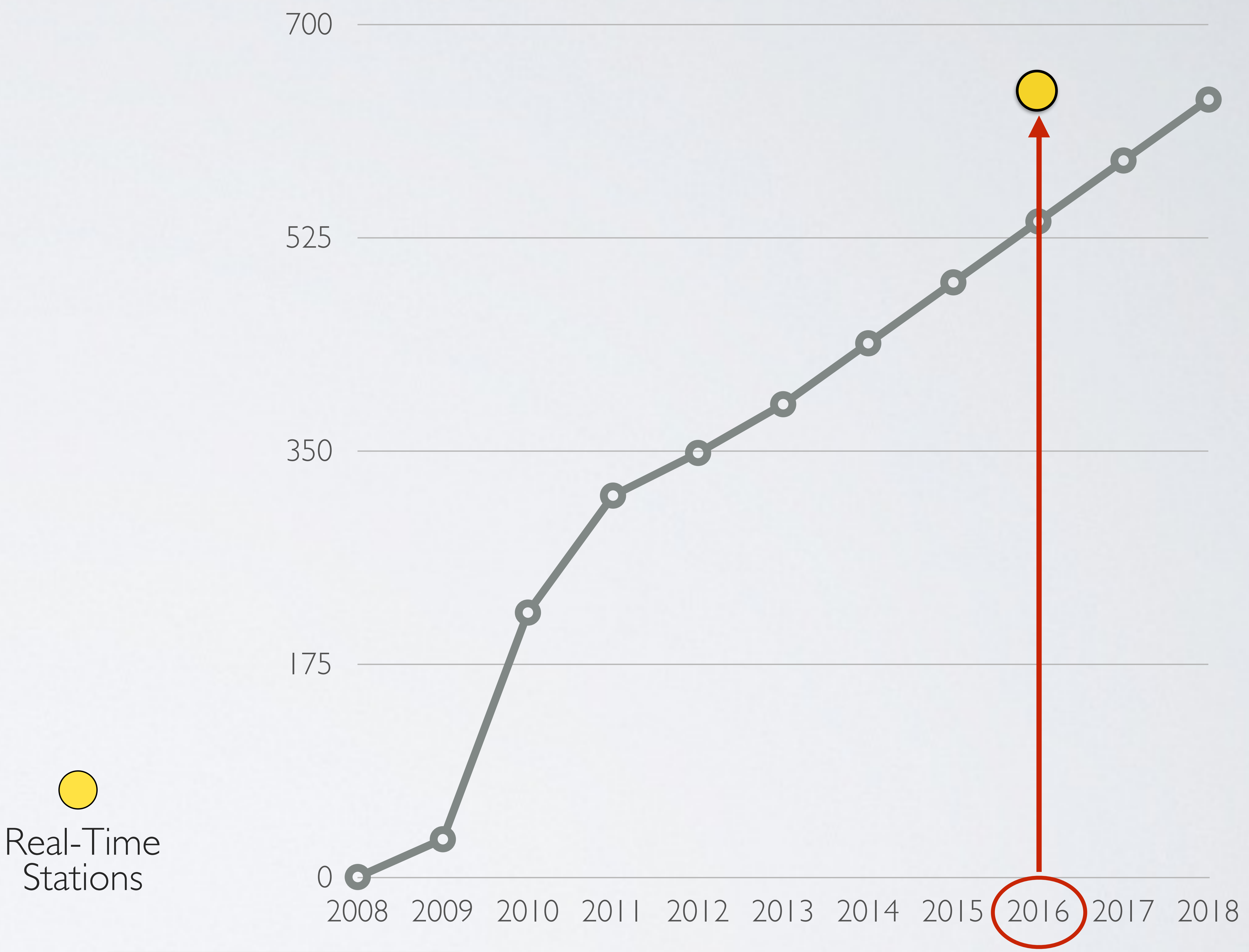




Governance and Community | GAGE Impact | **Geodetic Infrastructure** | Geodetic Data Services | Education & Community Engagement | Beyond 2018

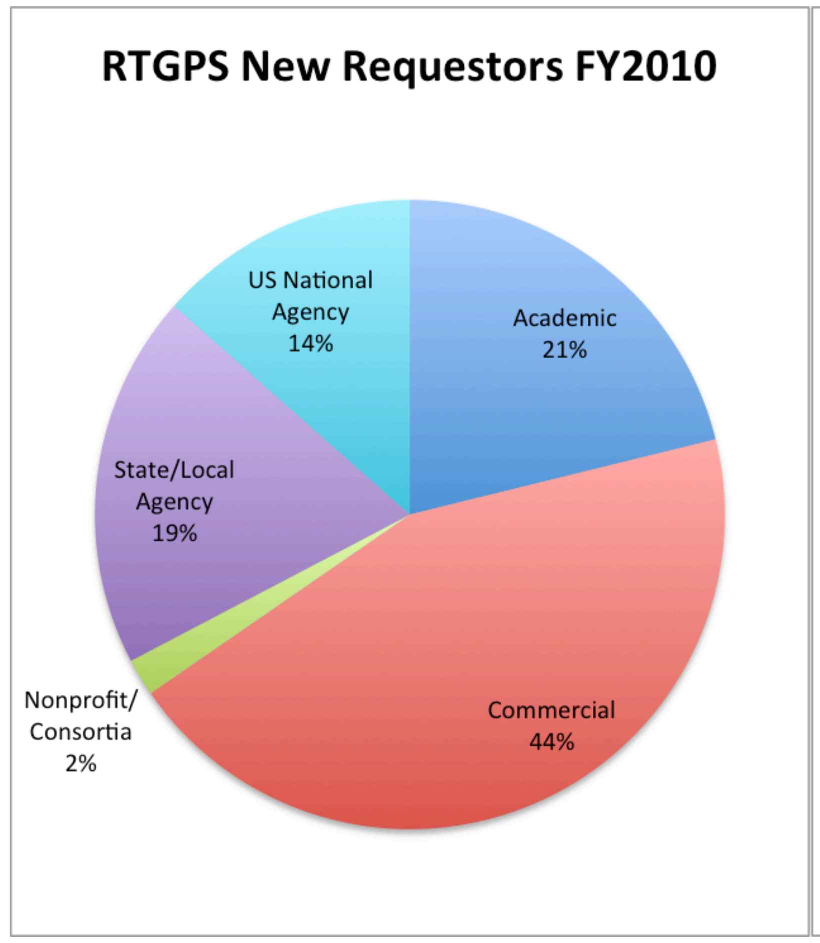
GAGE: RT-GPS/GNSS UPGRADE PLAN

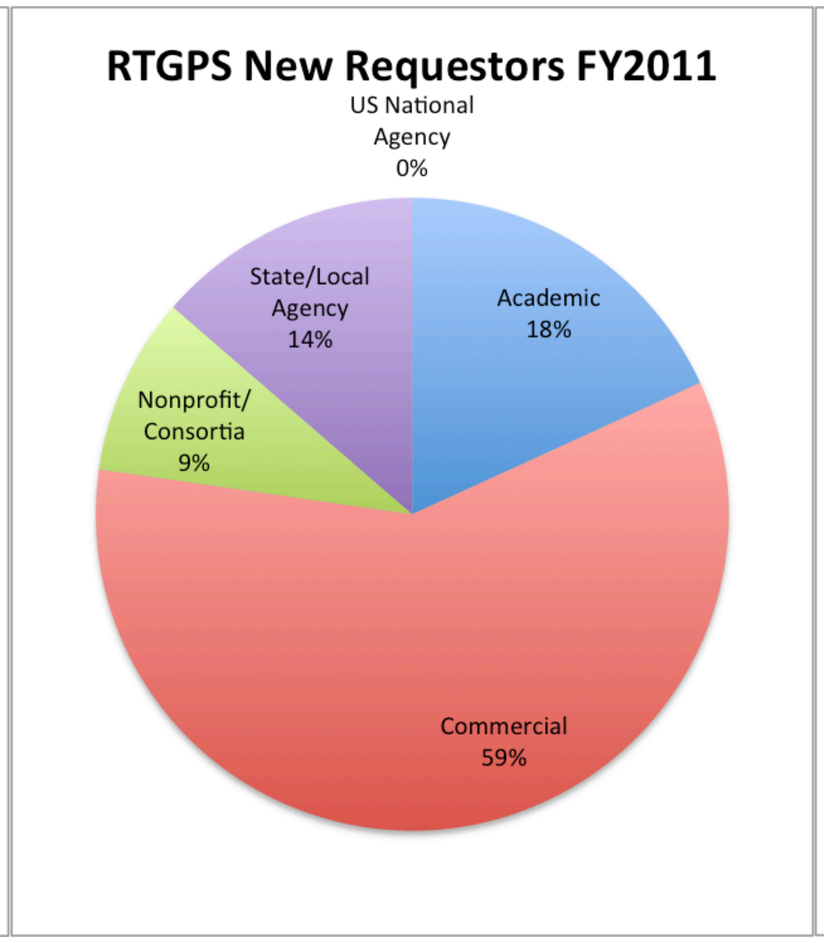


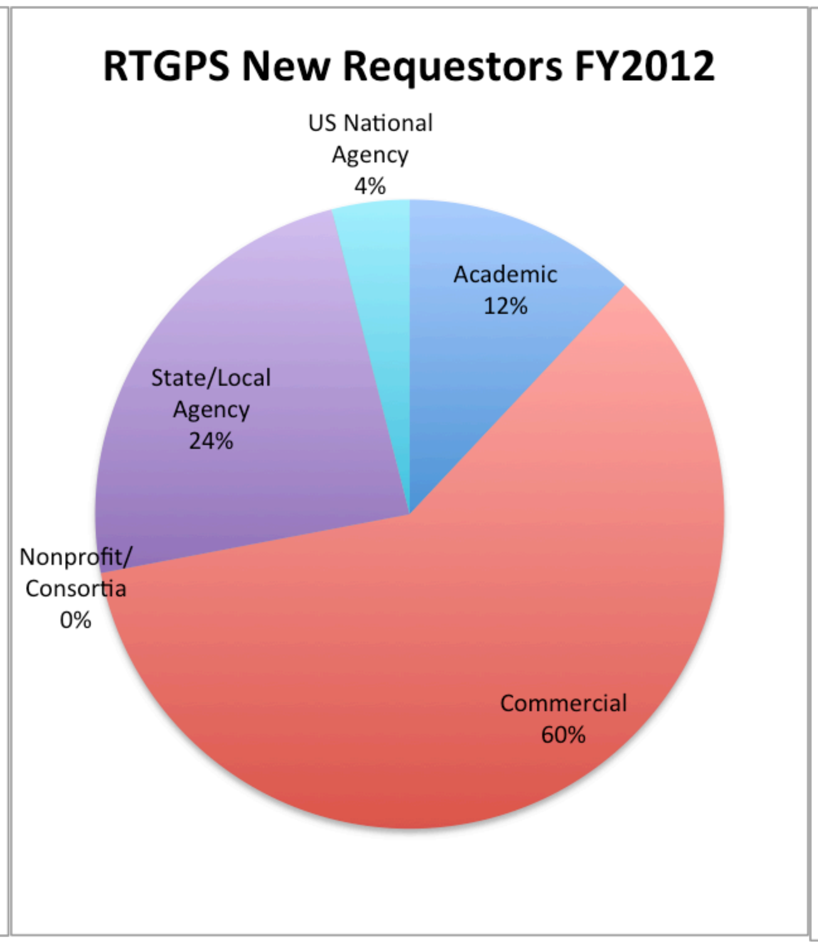


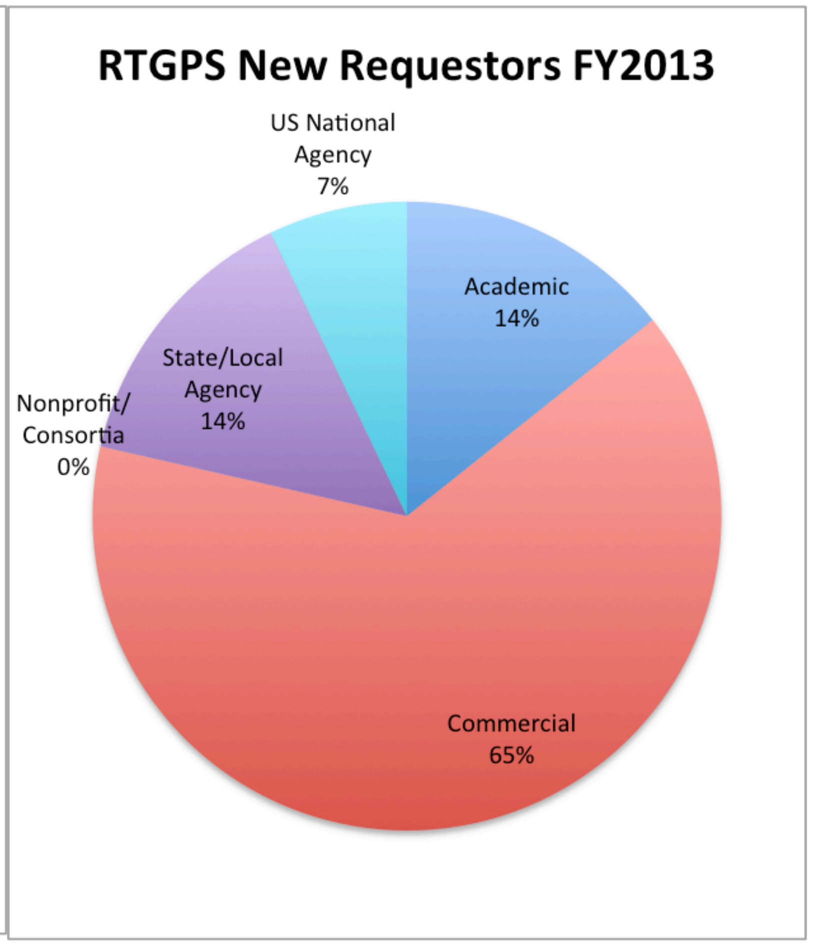
Governance and Community | GAGE Impact | Geodetic Infrastructure | Geodetic Data Services | Education & Community Engagement | Beyond 2018

PBO REAL-TIME GPS/GNSS USERS





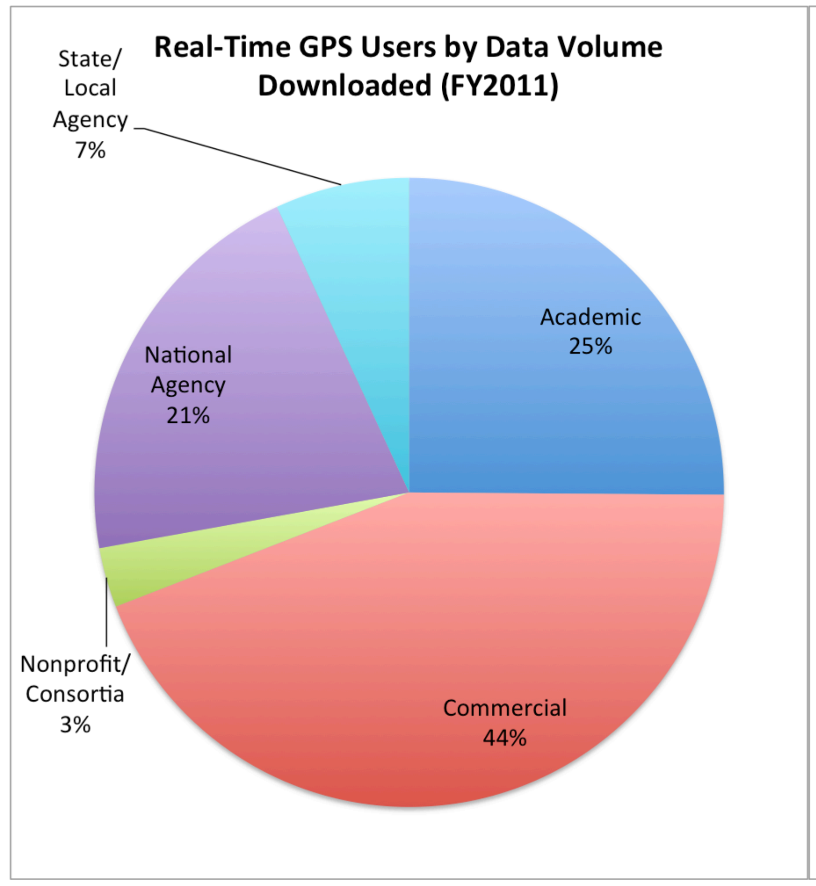


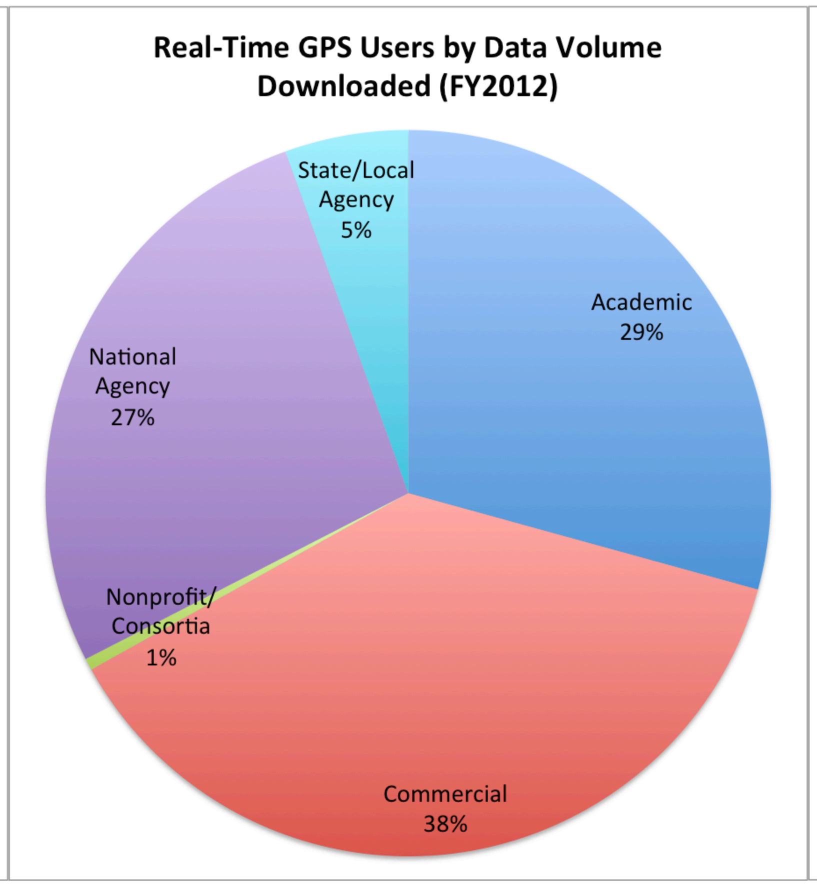


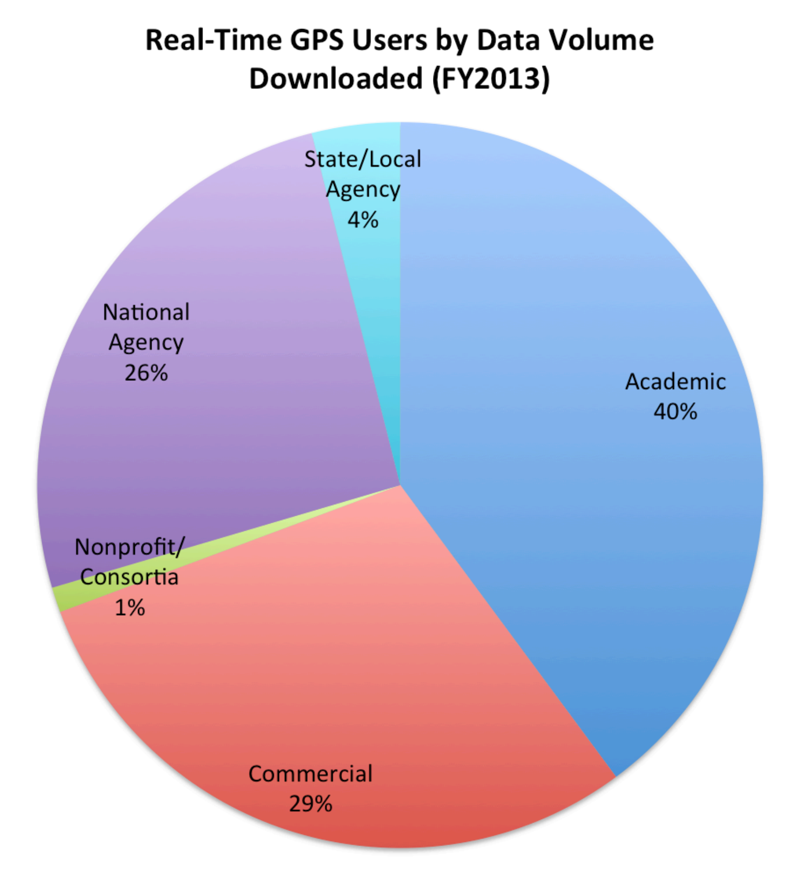
ABOVE: Based on the NUMBER OF NEW USERS (new requestors) per year, the percentage of commercial users relative to academic and agency users has increased consistently over the past four years.

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.





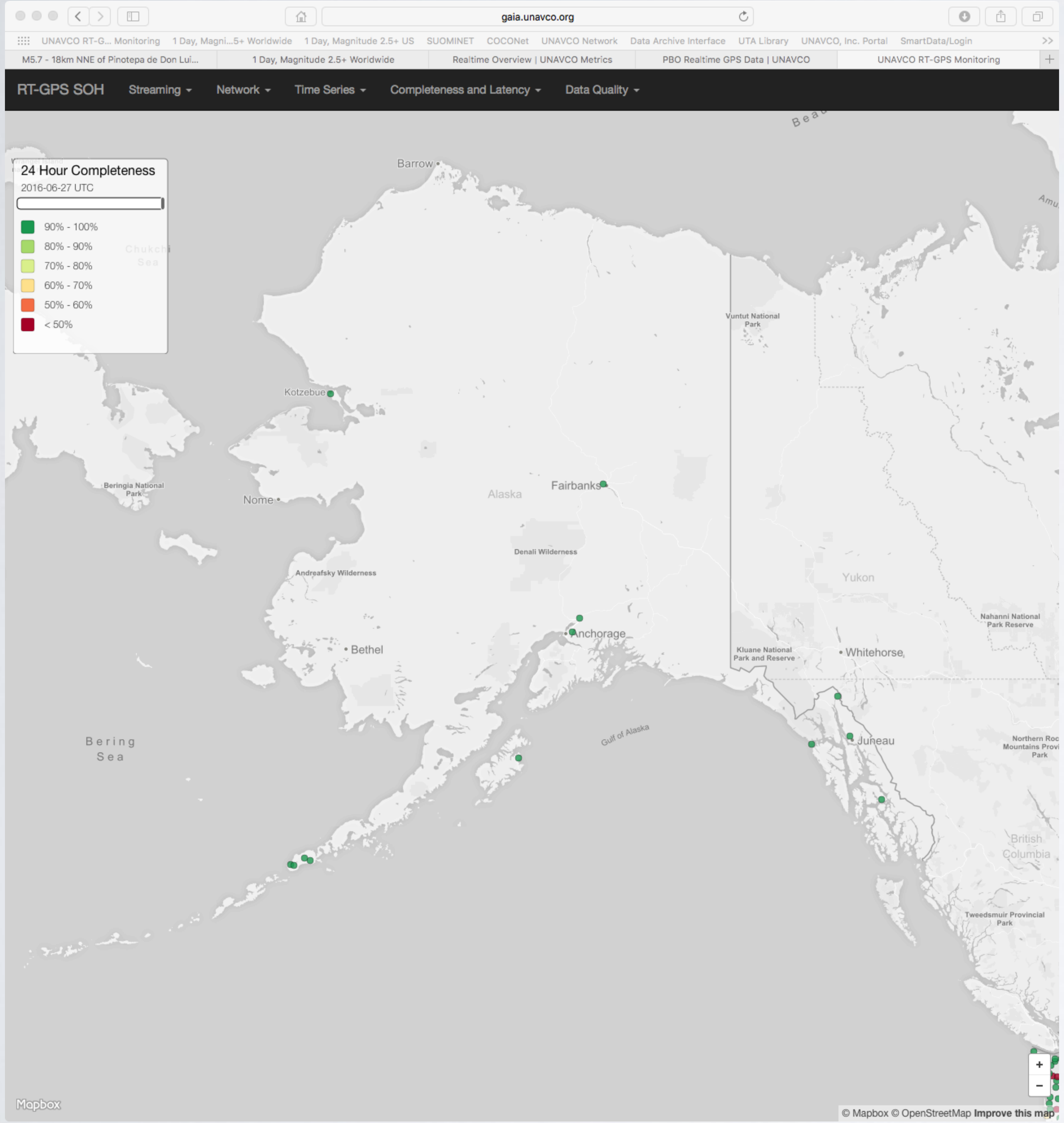


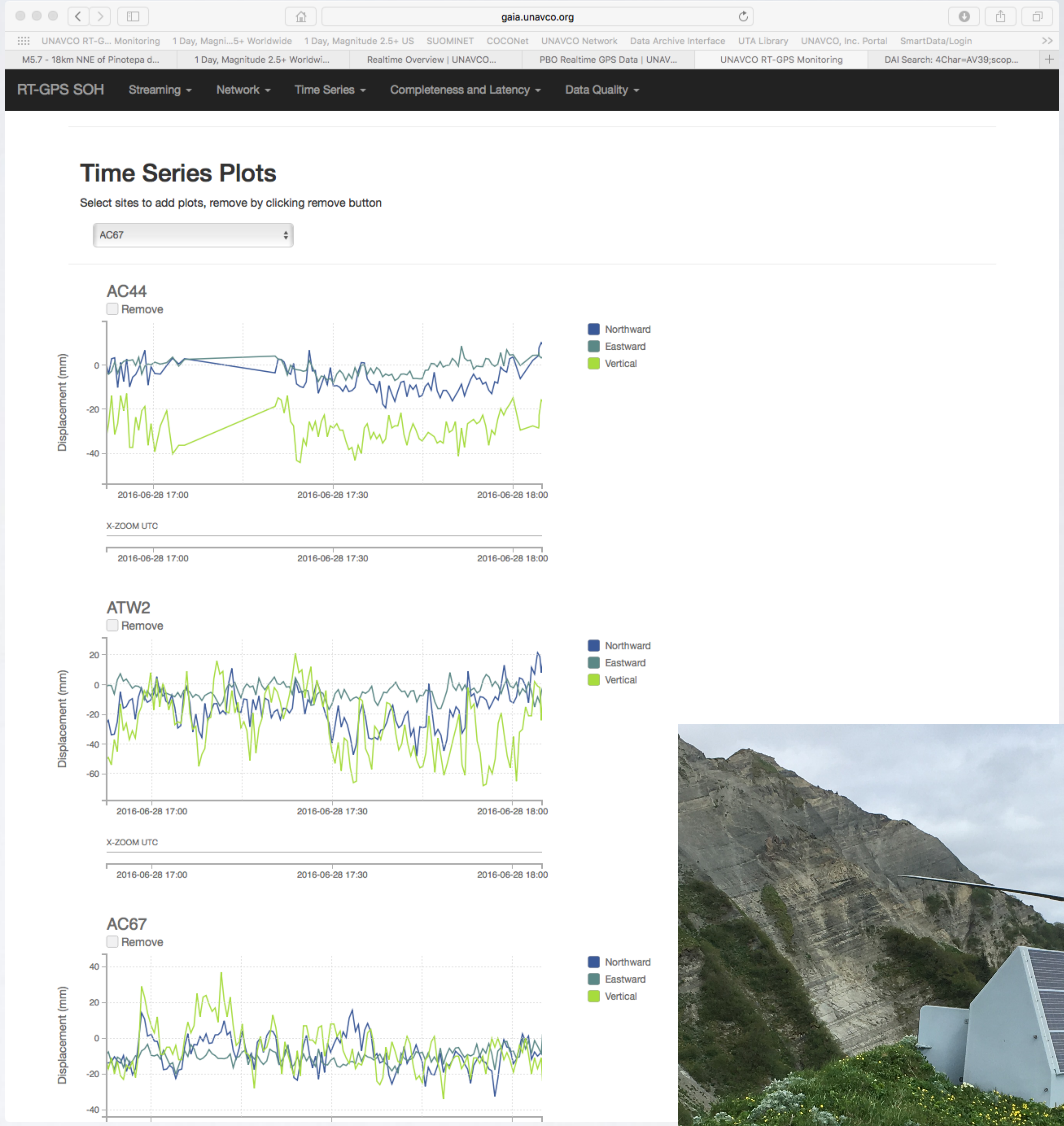
Trends in PBO RT-GPS usage:

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 - CURRENT NETWORK





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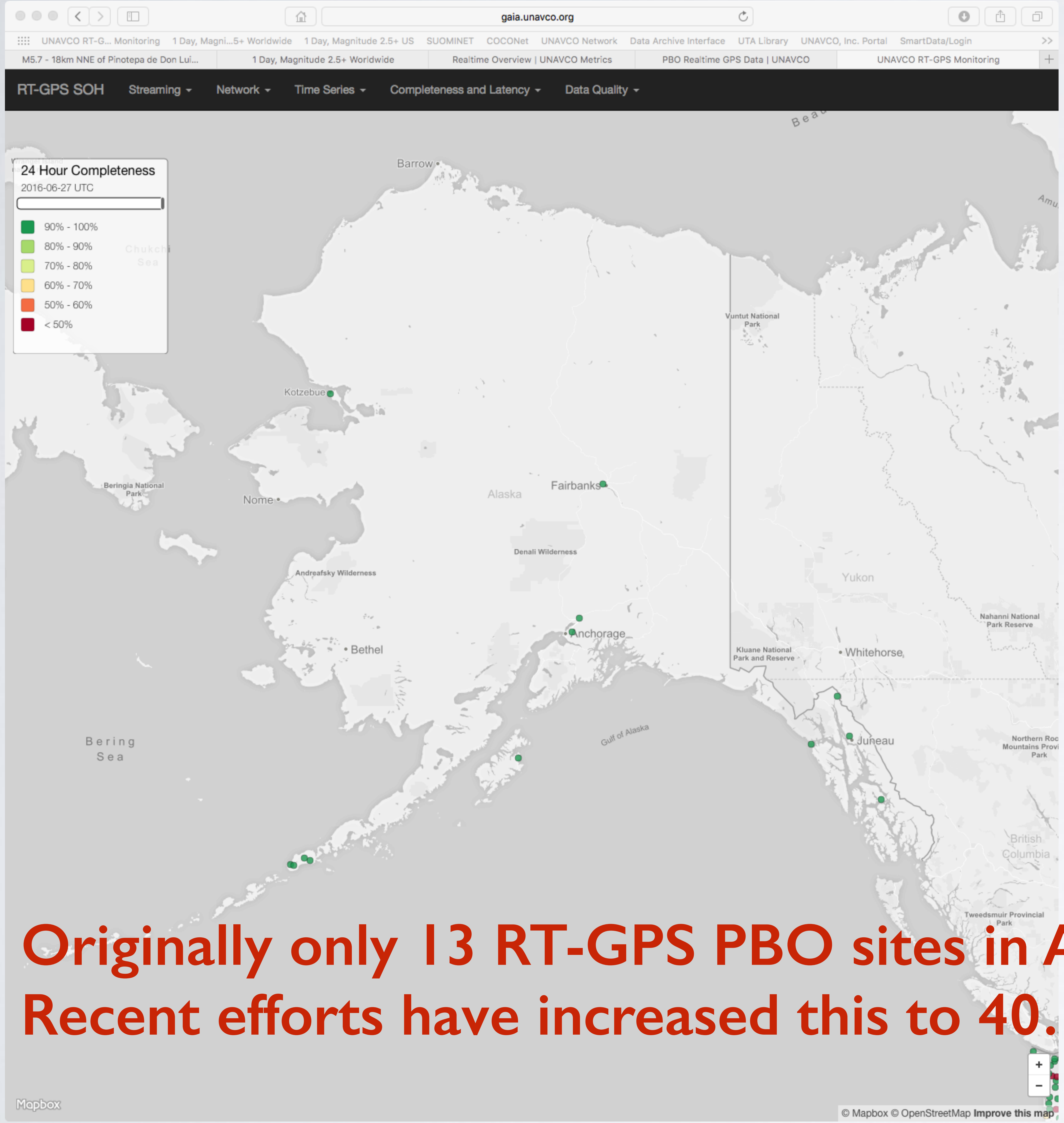
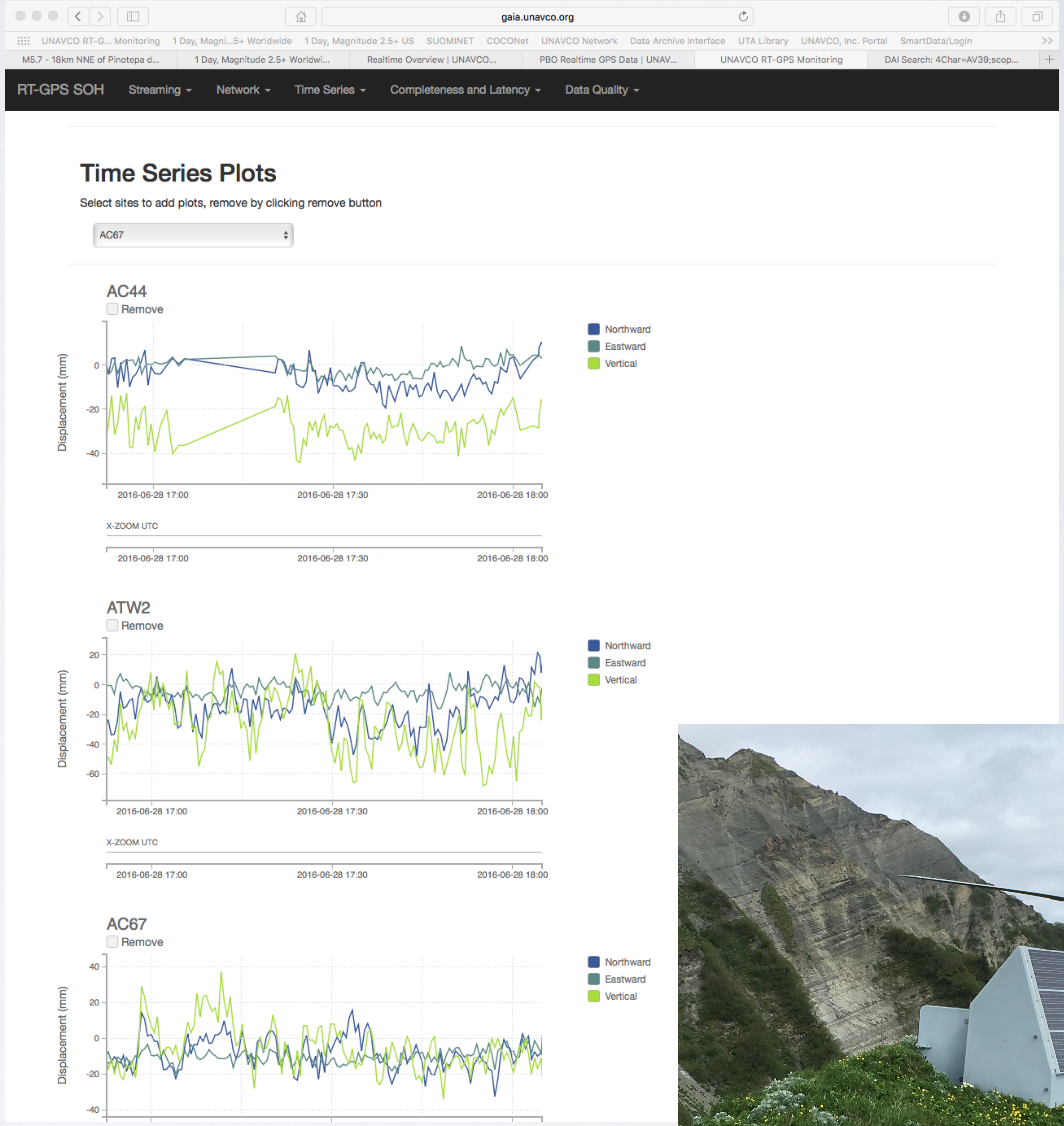
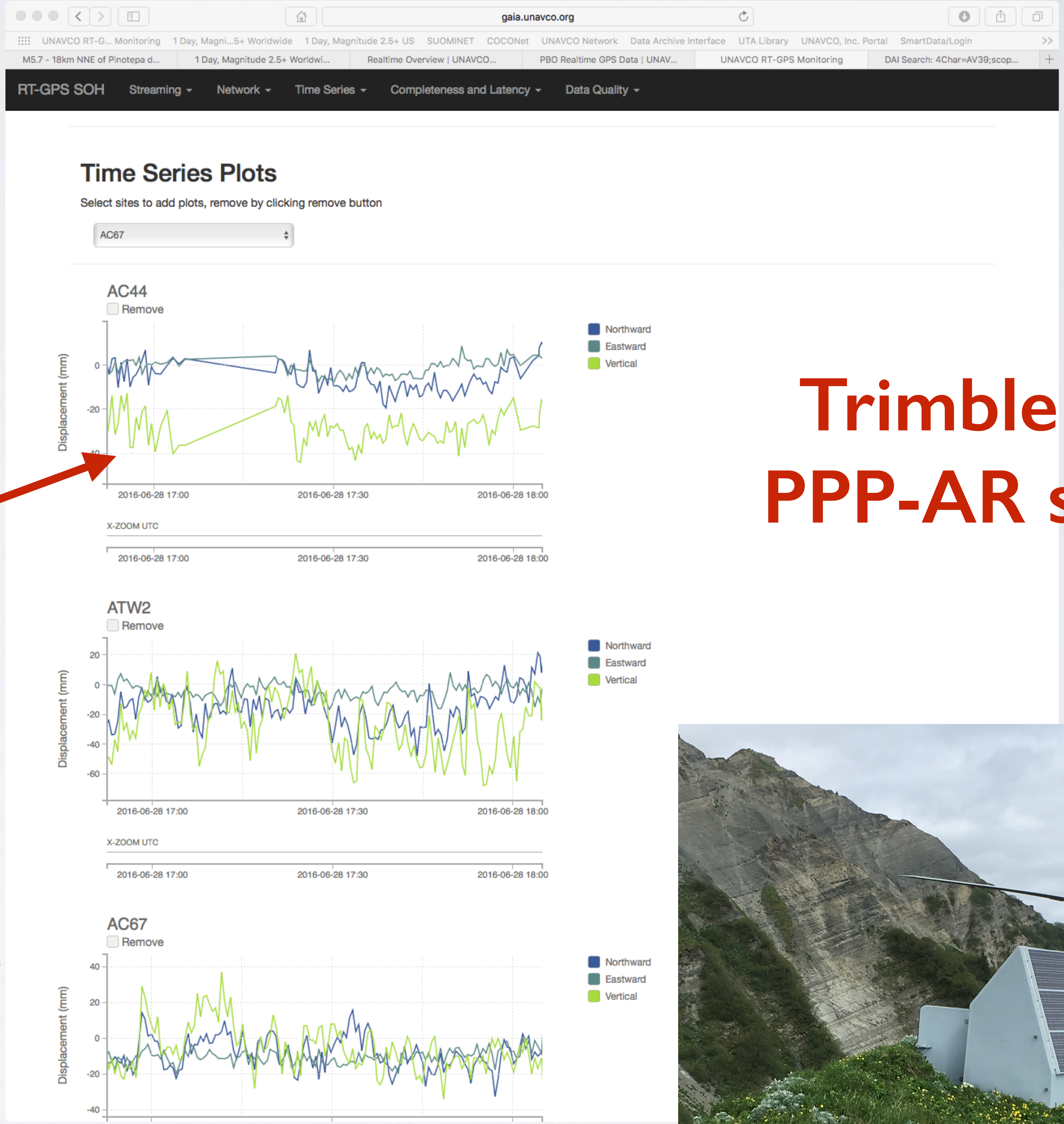


Originally only 13 RT-GPS PBO sites in AK
Recent efforts have increased this to 40…



RT-GPS - CURRENT NETWORK



Trimble PIVOT
PPP-AR solutions

Originally only 13 RT-GPS PBO sites in AK
Recent efforts have increased this to 40…

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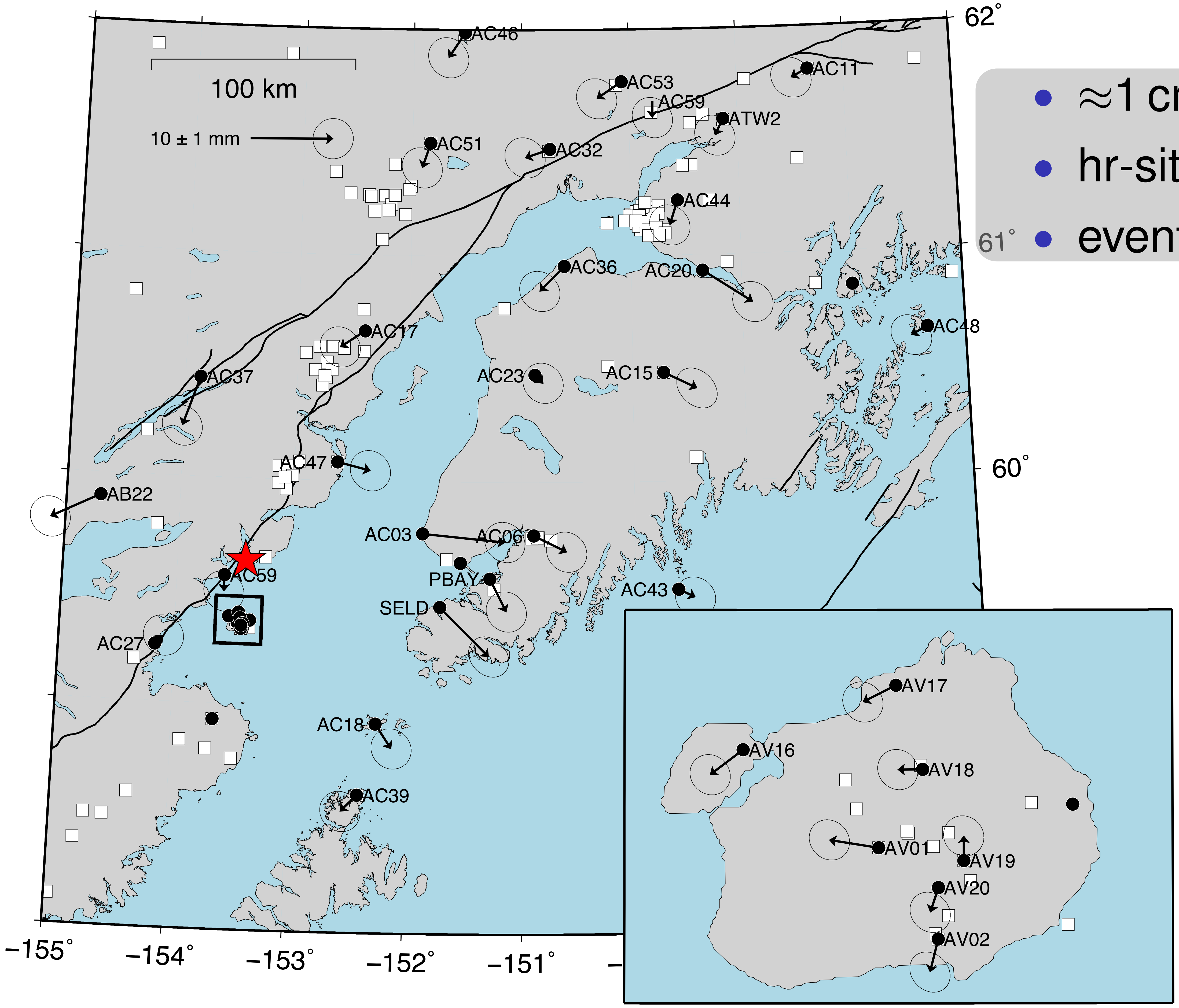
RT-GPS: WHAT *COULD* BE DONE WITH PBO-AK UPGRADES

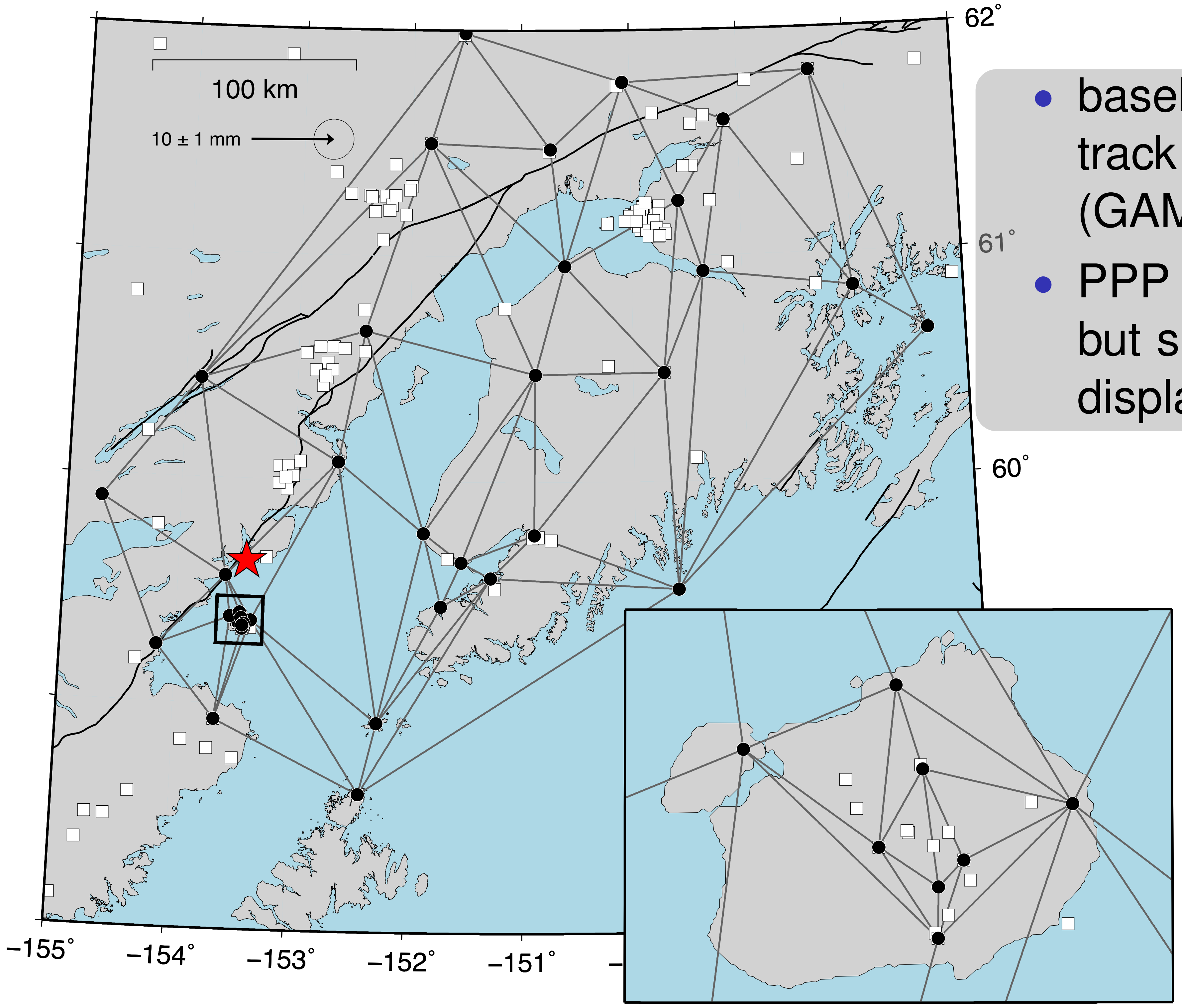
Test Case: 2016 Mw7.1 Iniskin, Alaska
From R. Grapenthin et al. (ms. in prep)

Network Background – Seismic & hr-GPS



- ≈1 cm or less
- hr-sites only
- event at 128 km

Processing Strategy



- baselines w/ track (GAMIT/MIT)
- PPP possible, but small displacements

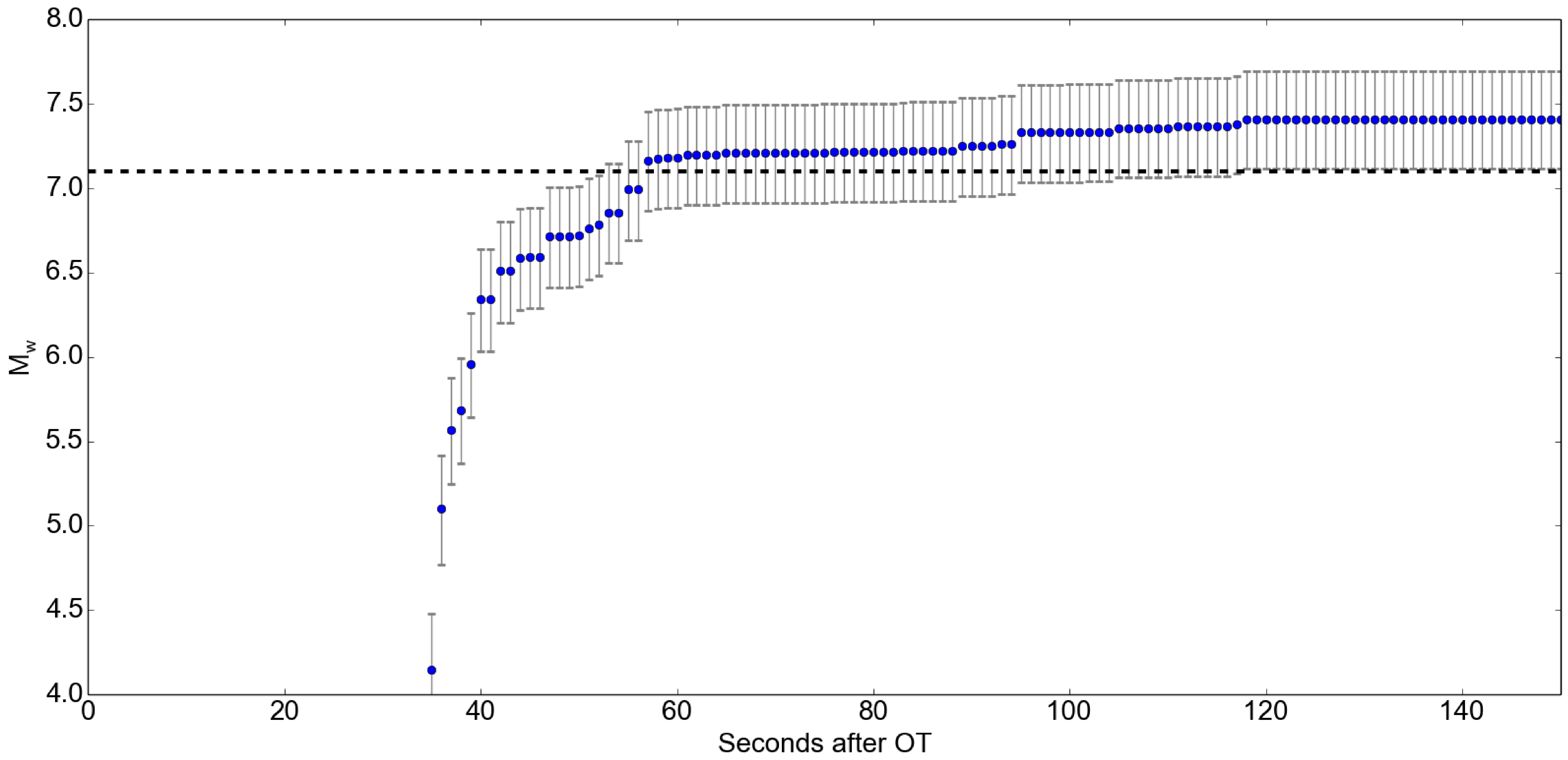
This is GPS only - not a seismogeodetic combination

UNAVCO

RT-GPS: WHAT *COULD* BE DONE WITH PBO-AK UPGRADES

PGD – Magnitude evolution

Better estimate of PGD in ~60 s !

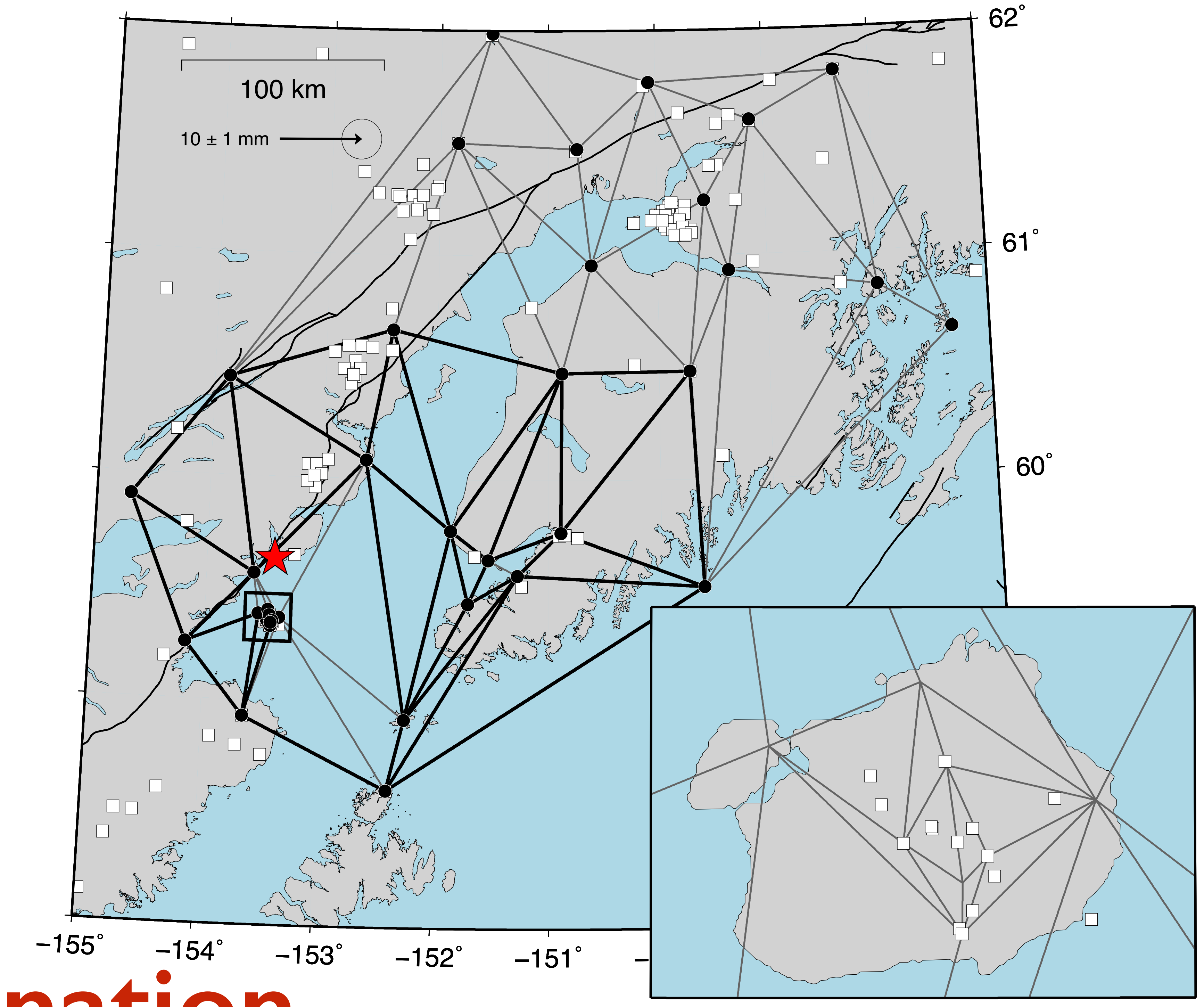


Based on Crowell et al. (2013), Melgar et al. (2015) developed a scaling relationship to infer Mw from PGD & hypocentral distance (R):

$$\log(PGD) = A + B*Mw + C*Mw*\log(R)$$

Test Case: 2016 Mw7.1 Iniskin, Alaska
From R. Grapenthin et al. (ms. in prep)

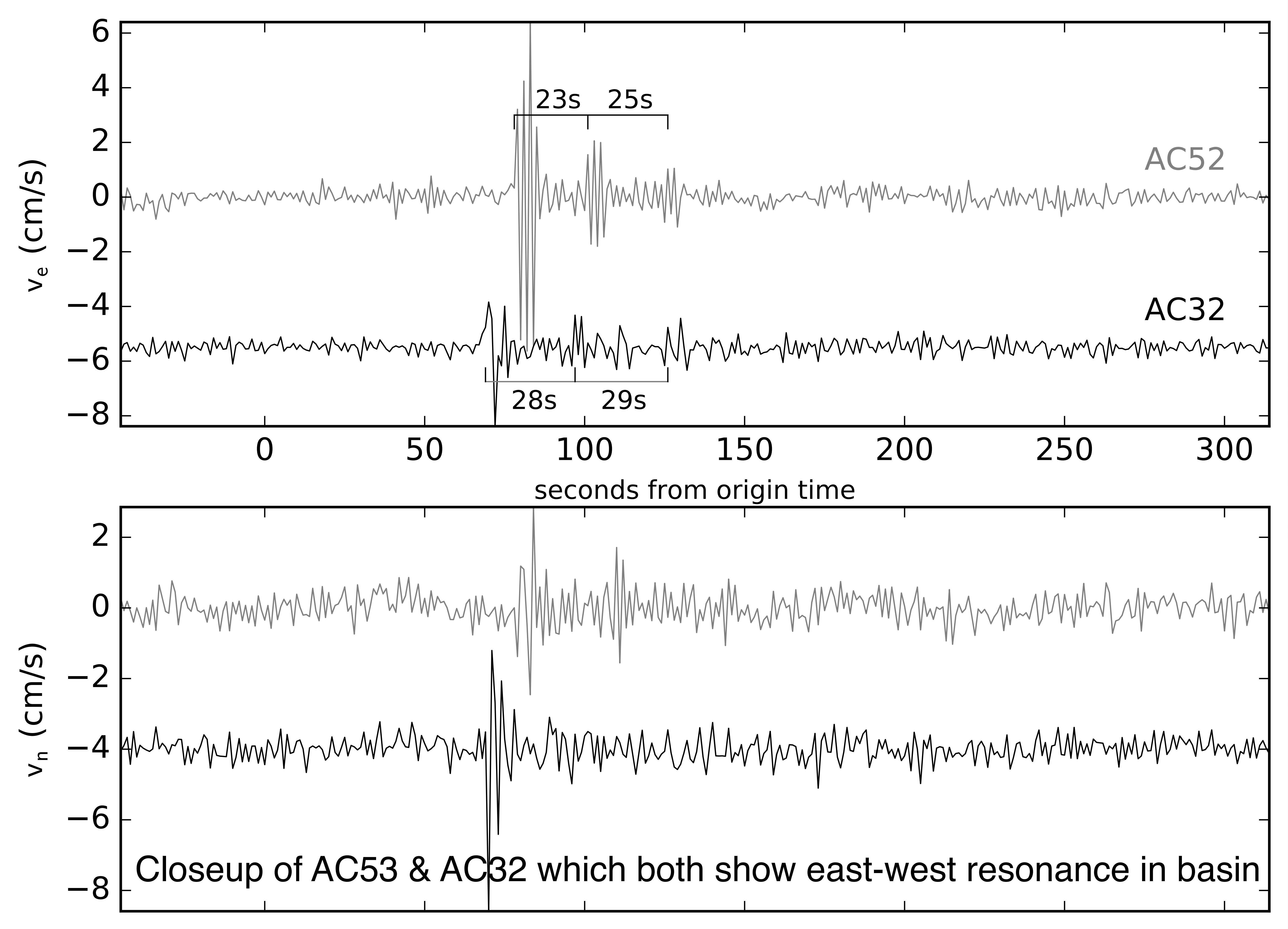
PGD – Subnet



This is GPS only - not a seismogeodetic combination

RT-GPS: WHAT *COULD* BE DONE WITH PBO-AK UPGRADES

Emerging technique exploiting Doppler shift of L1or L2 GPS phase observable to create ***velocigrams*** - no 'positioning' estimation needed…



Test Case: 2016 Mw7.1 Iniskin, Alaska
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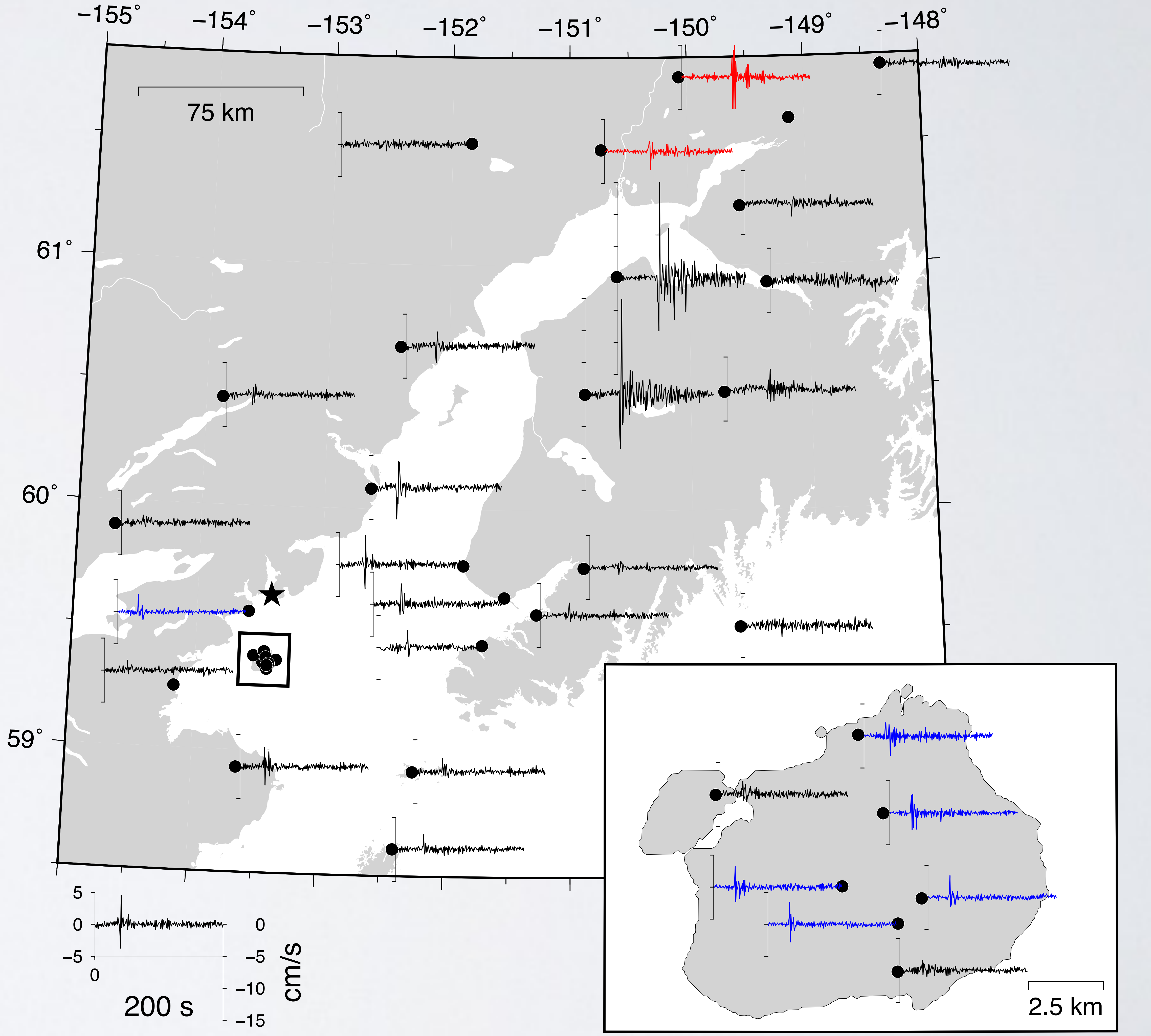


FUTURE GEOPHYSICAL FACILITIES WORKSHOP

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

- Report divides into three components related to US NSF-funded geophysical & seismo-geodetic facilities:

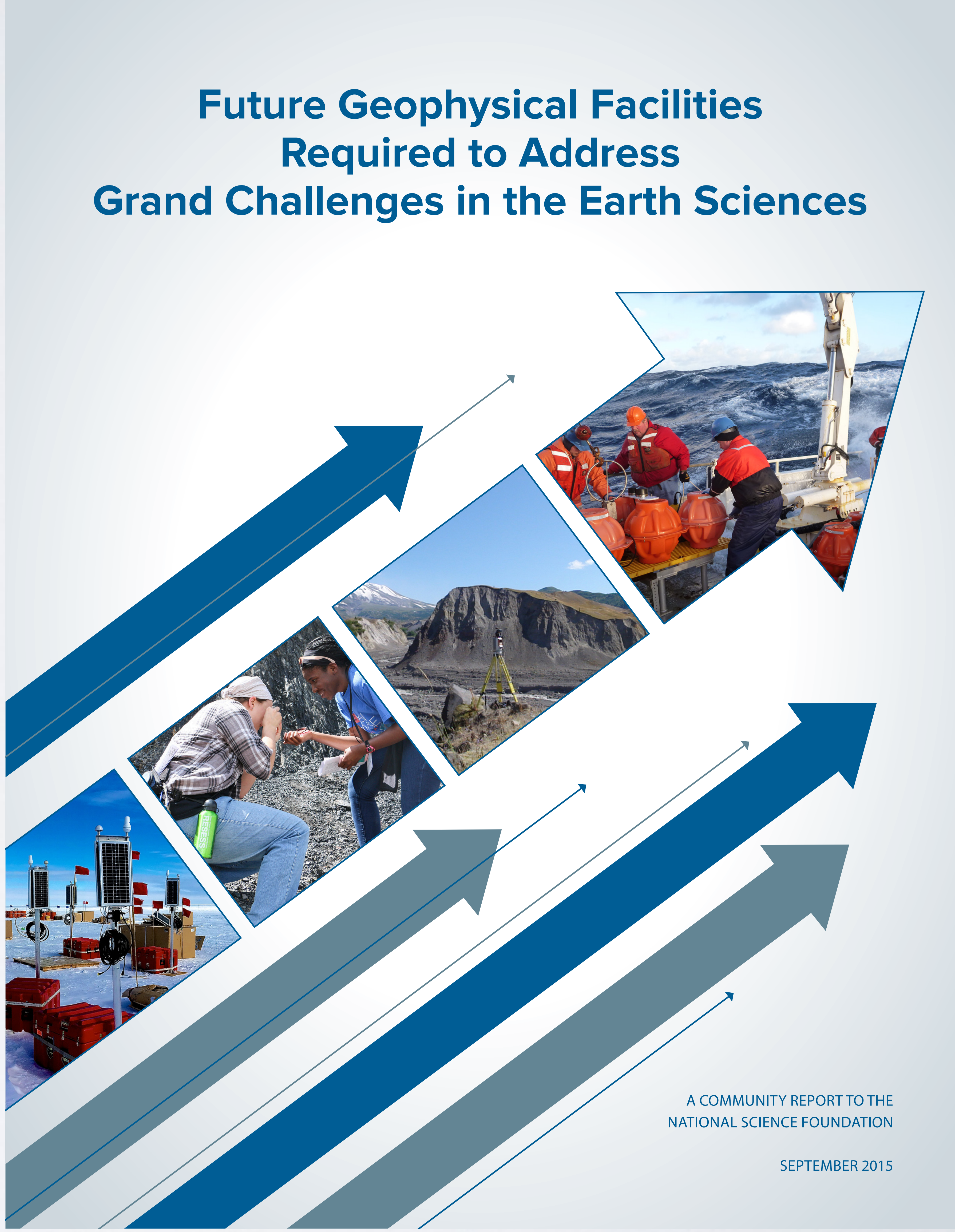
  - **Existing Foundational**

    Maintained permanent seismic, strainmeter, and geodetic networks
    - A global very broadband seismographic network
    - **Permanent and continuously recording GPS (GNSS) networks**
    - **A network of borehole strainmeters**

  - **Emergent Foundational**

    Development of operational RT-GNSS processing at >1 Hz

  - **Frontier**



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POST SAGE-GAGE VISION - SOME KEY PBO ISSUES

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;

(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.

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GPS MODERNIZATION - IMPLICATIONS FOR PBO

- Total of **19 L2C-capable SVs** in orbit now
- Total of **12 L5-capable SVs** in orbit now
- **Block III SVs available for 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
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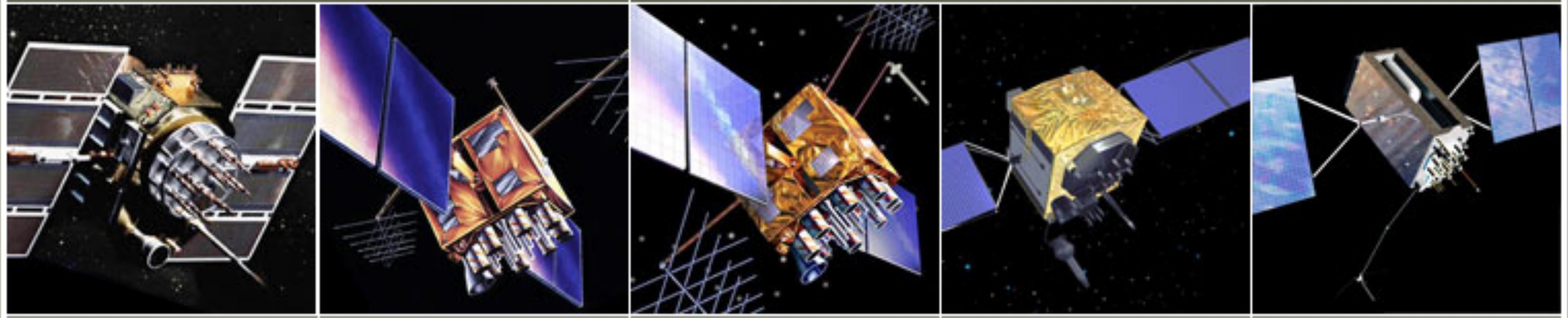

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BLOCK IIA	BLOCK IIR	BLOCK IIR(M)	BLOCK IIF	GPS III
0 operational	12 operational	7 operational	12 operational	In production
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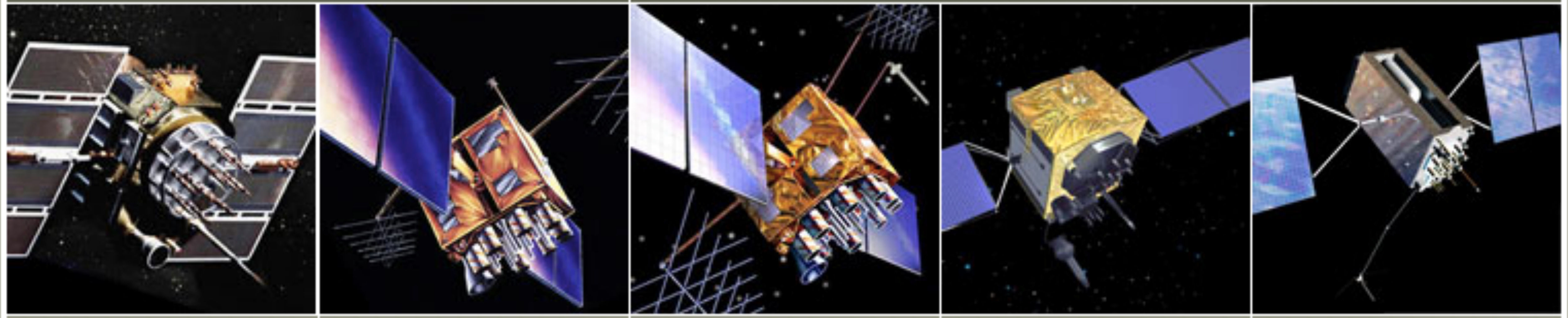

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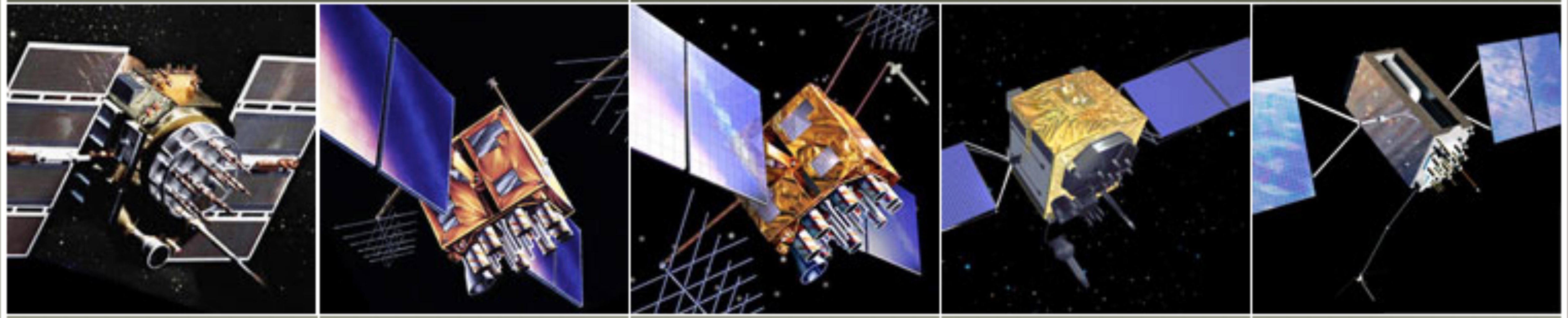

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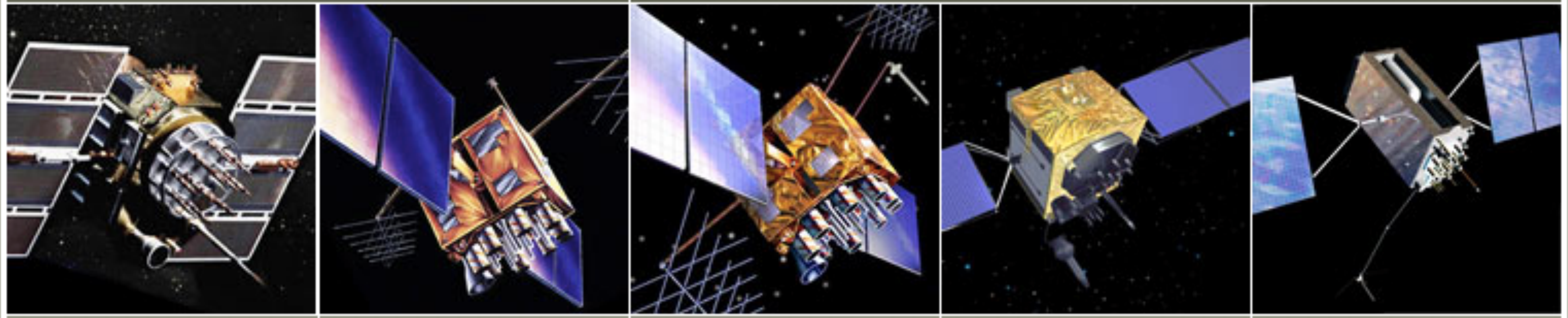

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UPGRADES TO PBO INSTRUMENTS

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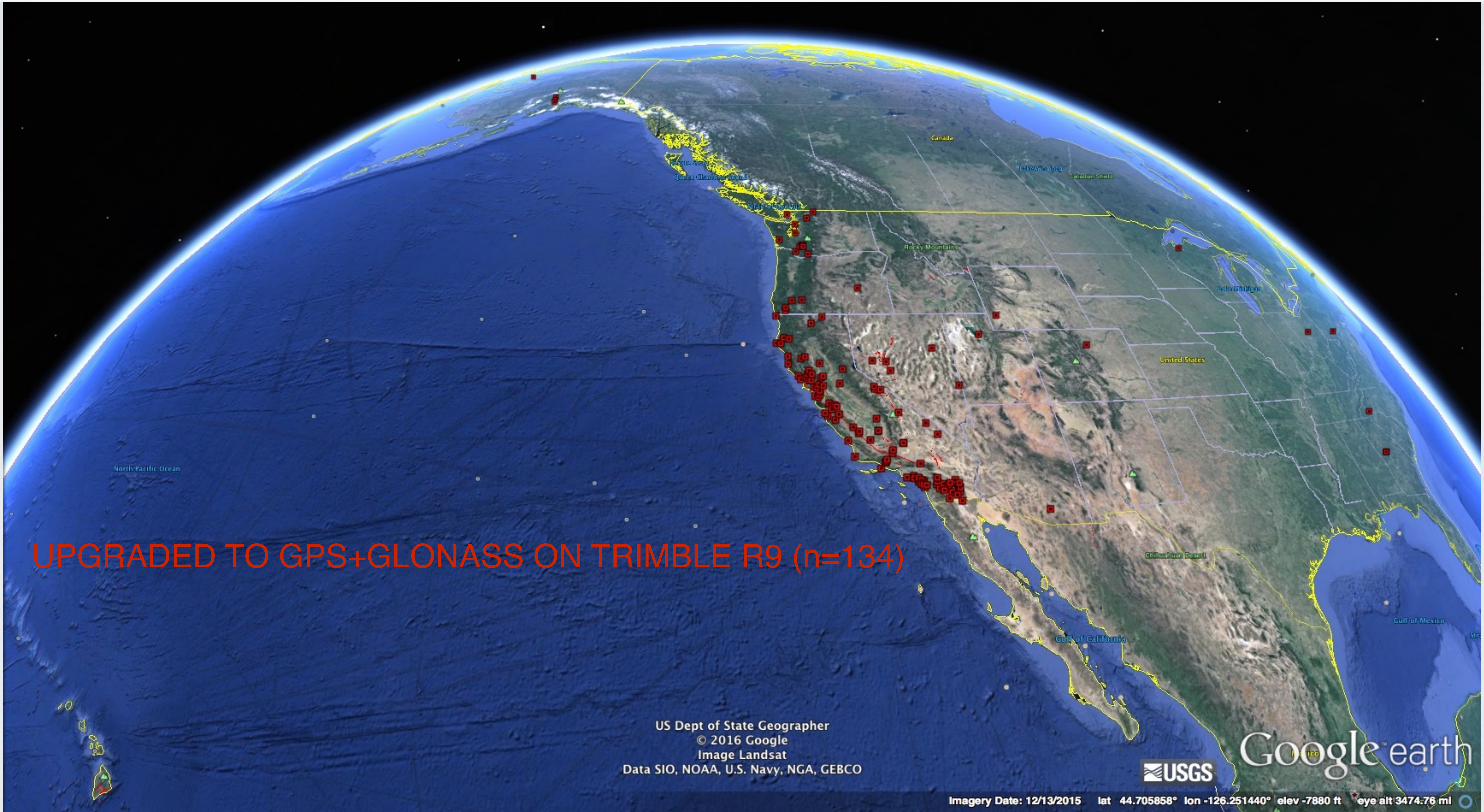

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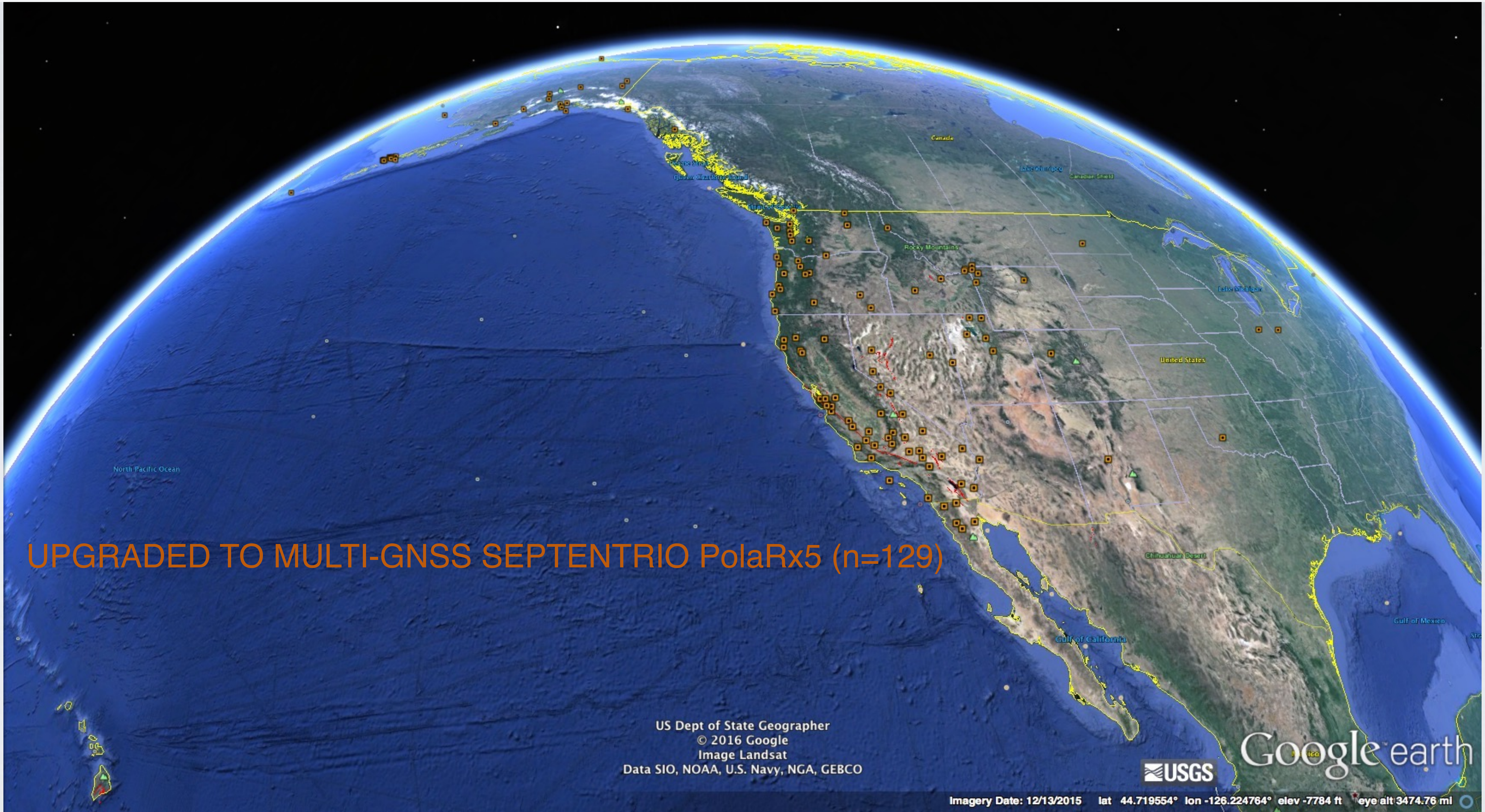

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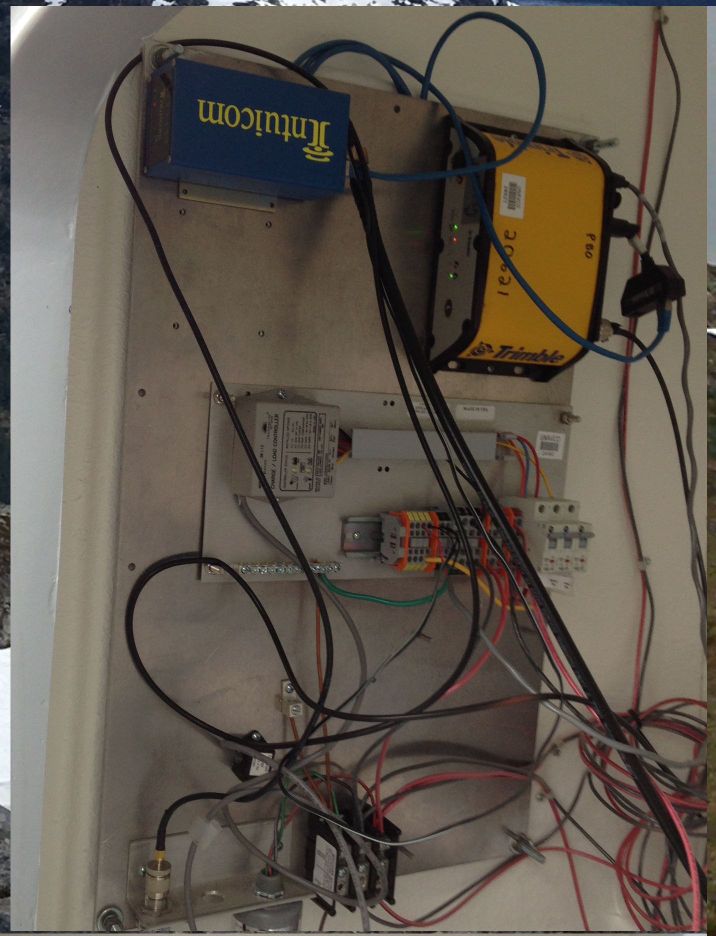
PBO: STATION IN AK - DESIGN AND CHALLENGES

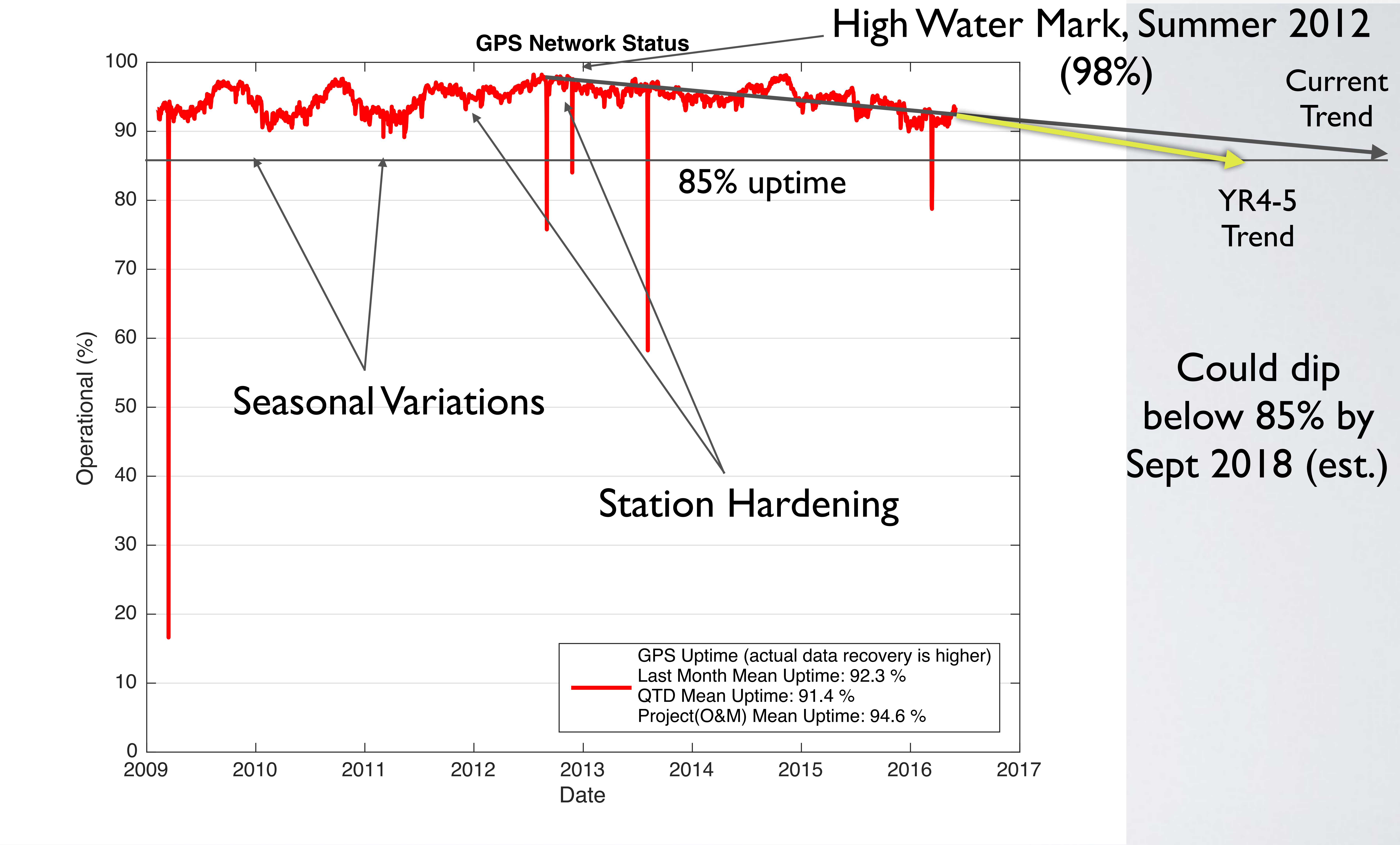
PBO stations are an established, long-term platform for additional sensors!

- DDBM/SDBM - most stable
- Battery/Instrument enclosure
- Solar array
- Telemetry (VSAT/CDMA/microwave)
- Helicopter LZ
- Bears, weather…



GPS NETWORK UPTIME

Operational definition: a GPS station is considered "up" if less than 3 days have passed since data arrived in the UNAVCO archive



Could dip below 85% by Sept 2018 (est.)

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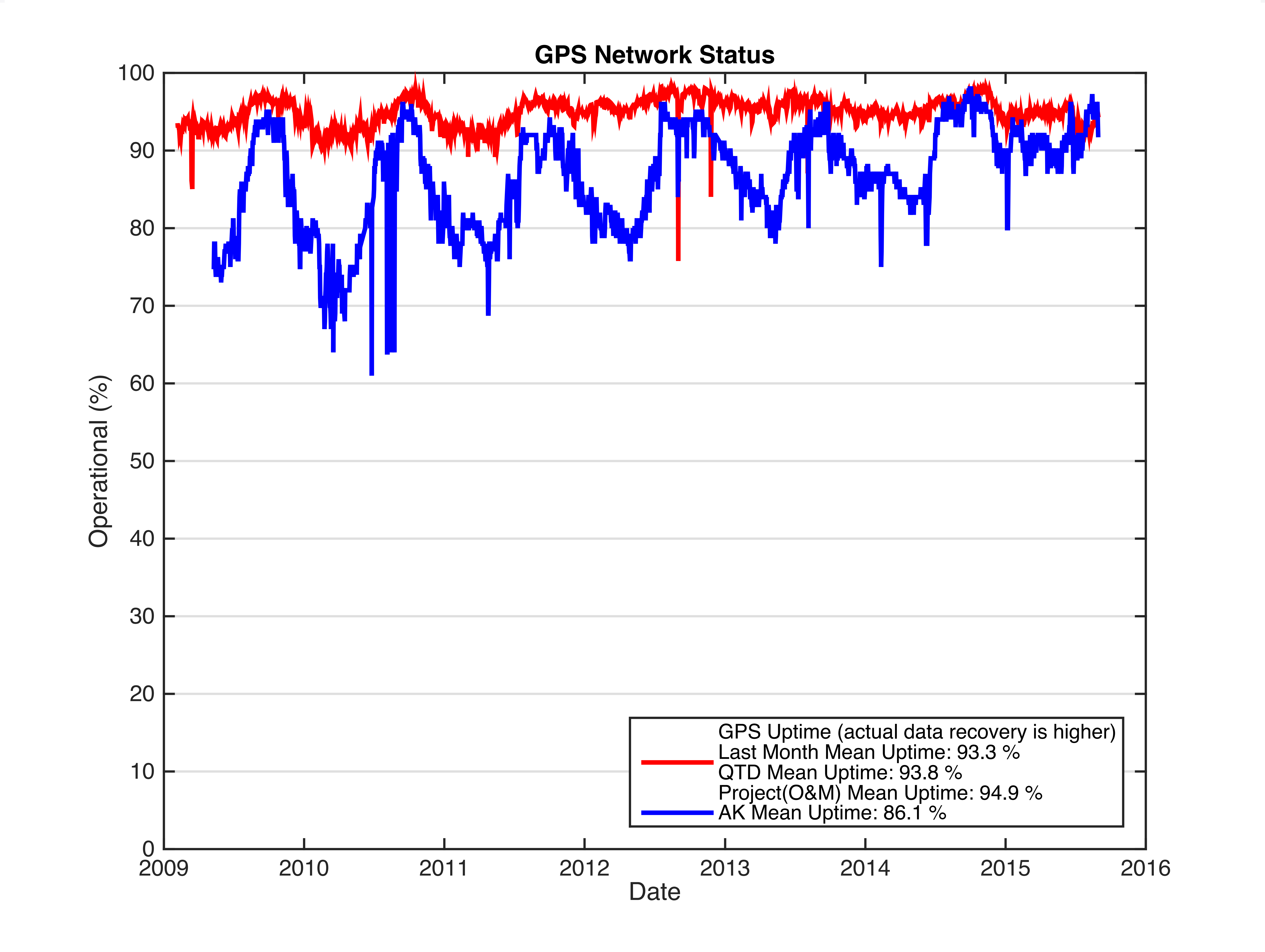


Summer 2012

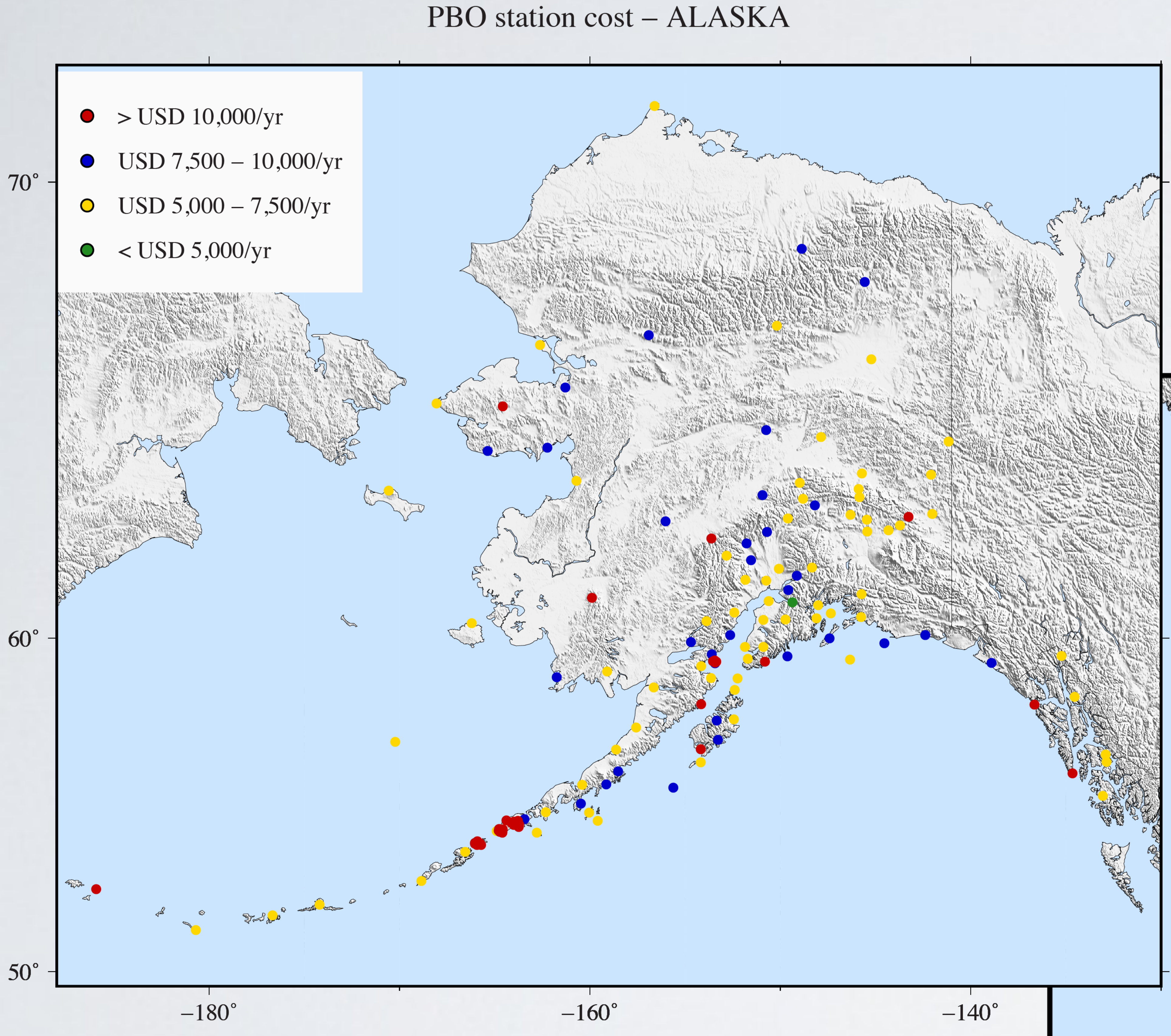
%)

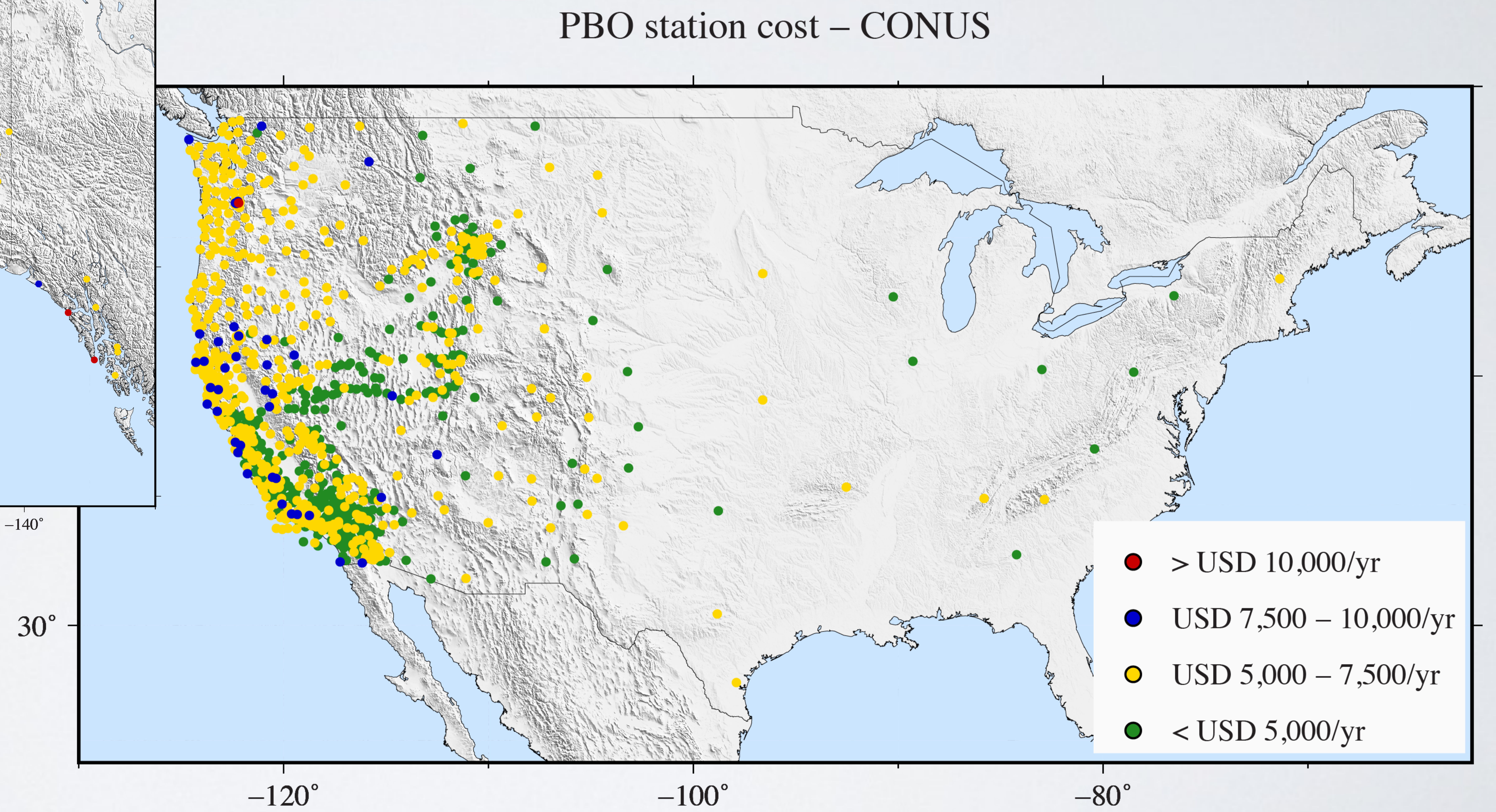
Current Trend

YR4-5 Trend

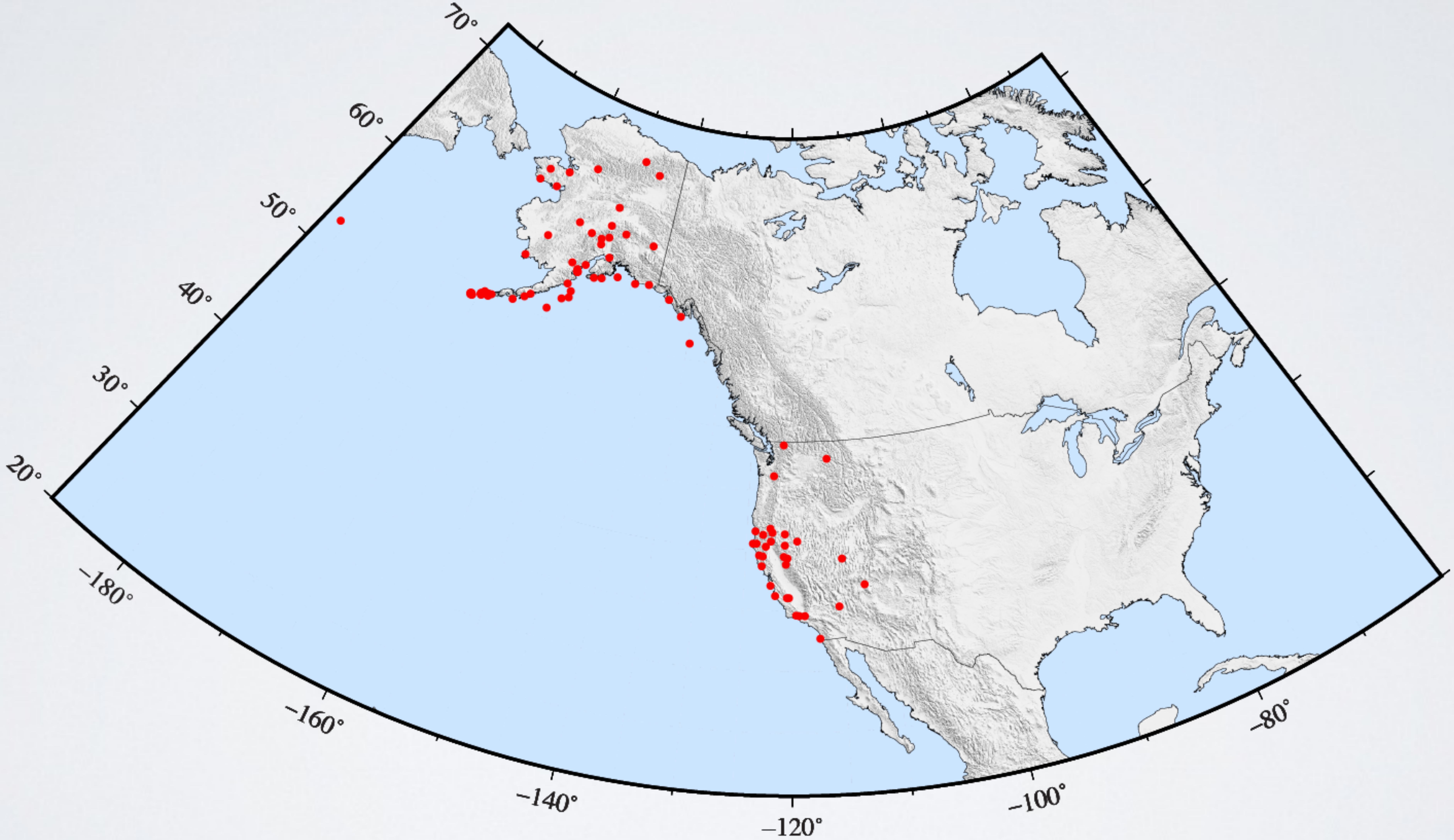
Could dip below 85% by Sept 2018 (est.)

OPERATIONS AND MAINTENANCE COSTS: CONUS AND AK





100 MOST EXPENSIVE STATIONS



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OPERATIONS AND MAINTENANCE: STATION PRIORITIZATION PLAN

GPS/GNSS stations will be prioritized into three categories based on the science goals and the number and diversity of stakeholder interests, guided by advisory committees and community:

1) ***highest*** - problems will receive attention and remediated as rapidly as possible;

2) ***intermediate*** - problems will be diagnosed and will receive attention as resources permit;

3) ***lowest*** - problems will be diagnosed, but any required service will only occur if periodic maintenance is scheduled for that station during the upcoming annual field season.

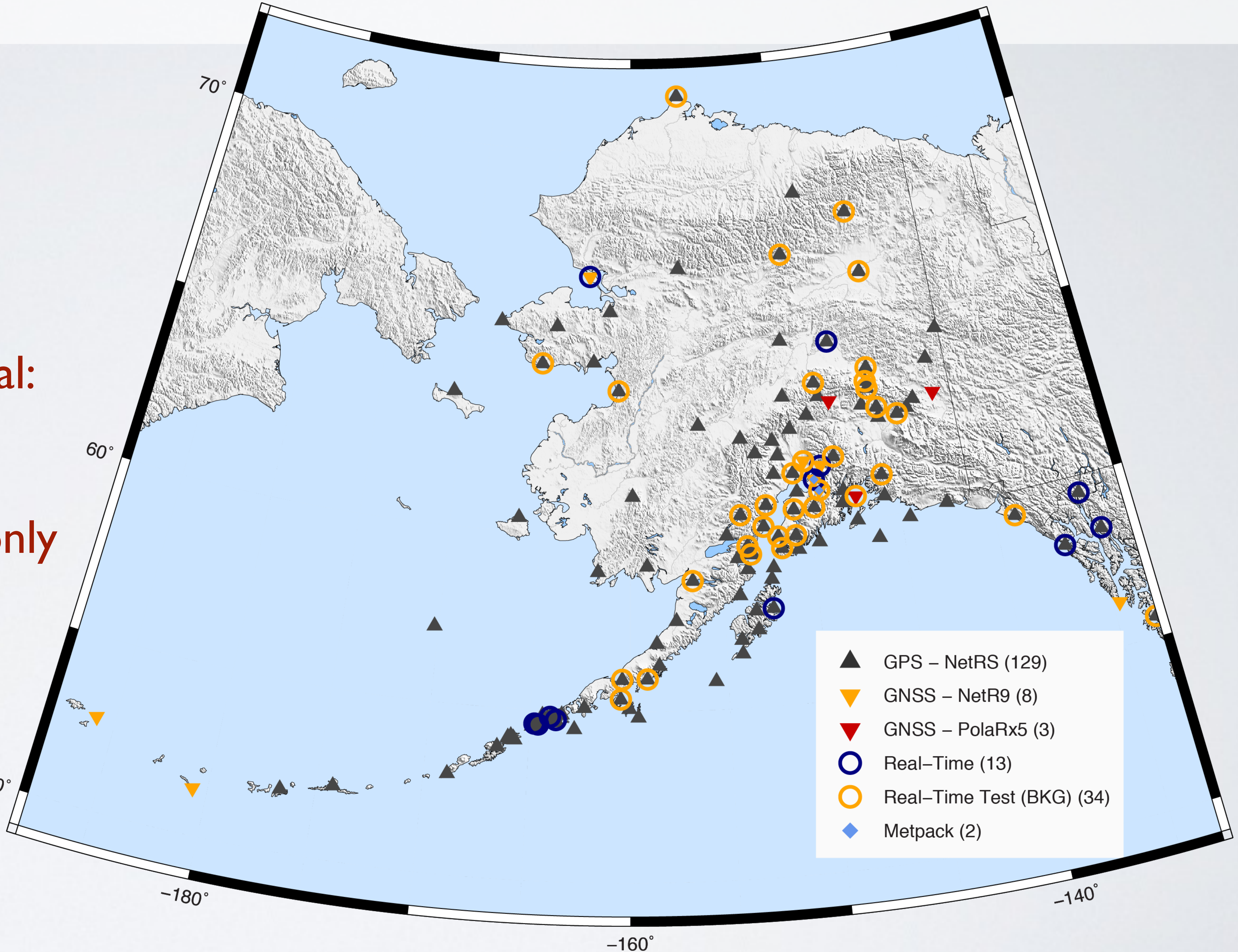
Under GAGE, engineers visited each station approximately every five years for scheduled battery and hardware maintenance and unscheduled maintenance was performed on a best-effort basis. *Our new O&M model will allow more efficient use of available resources*, and most importantly, focus them on the stations that are deemed the highest priority by stakeholders.

CURRENT PBO CAPABILITIES IN AK

NSF EarthScope
Plate Boundary Observatory
Network in Alaska:

Real-time capabilities and potential:

GPS - NetRS (129)
GNSS - NetR9 (8) - GLONASS only
GNSS - PolaRx5 (3) - all SVs
RT - PIVOT (13)
RT - BKG (34)
Metpacks (2)



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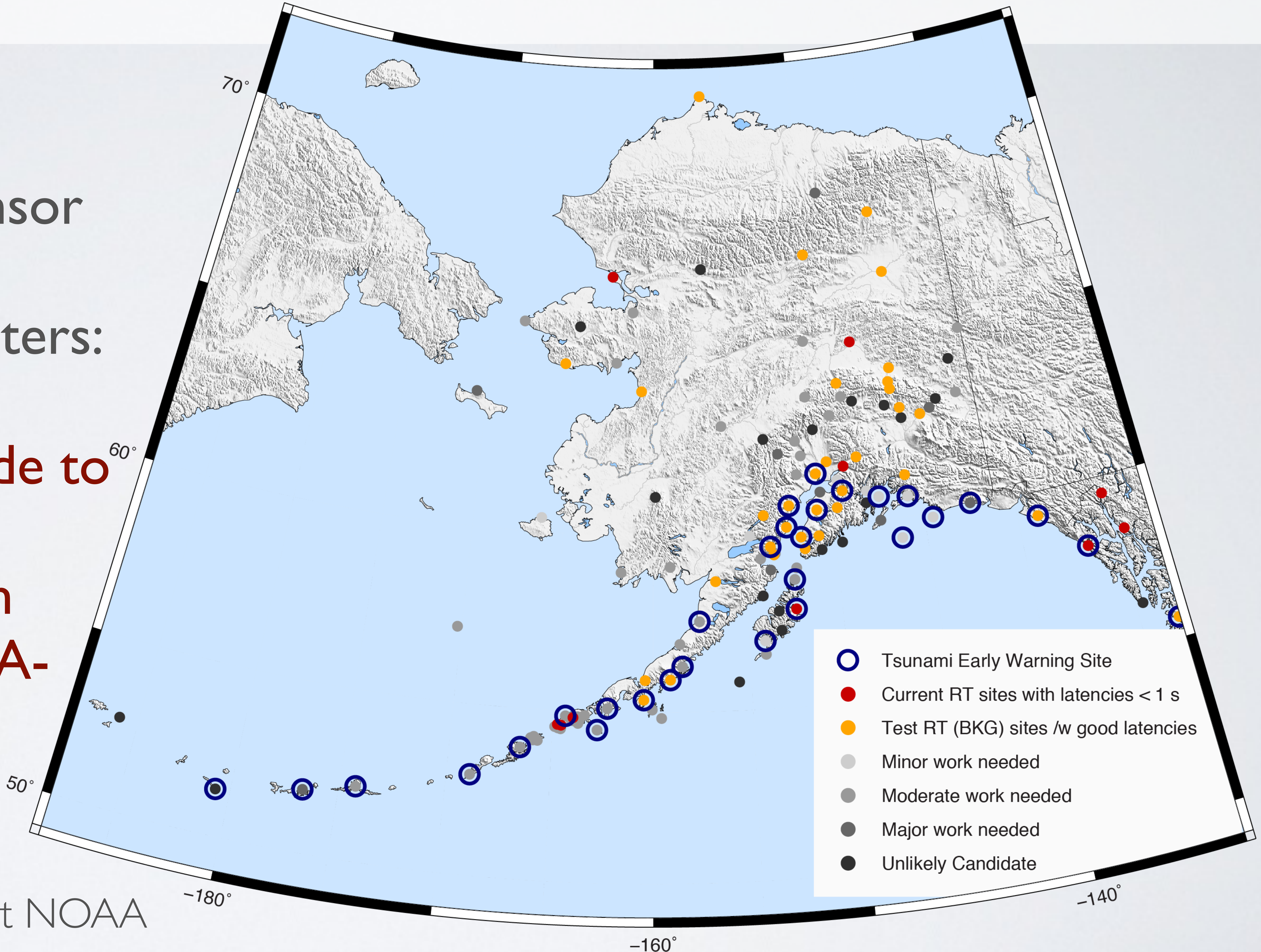
ONE SCENARIO FOR PBO ENHANCEMENT

Example Scenario:
Tsunami Early Warning sensor network for constraining earthquake source parameters:

a straw-man plan to upgrade to 30 real-time stations proximal to the subduction interface to support NOAA-NTWC, USGS, and AEC hazard missions



UNAVCO has a proposal pending at NOAA

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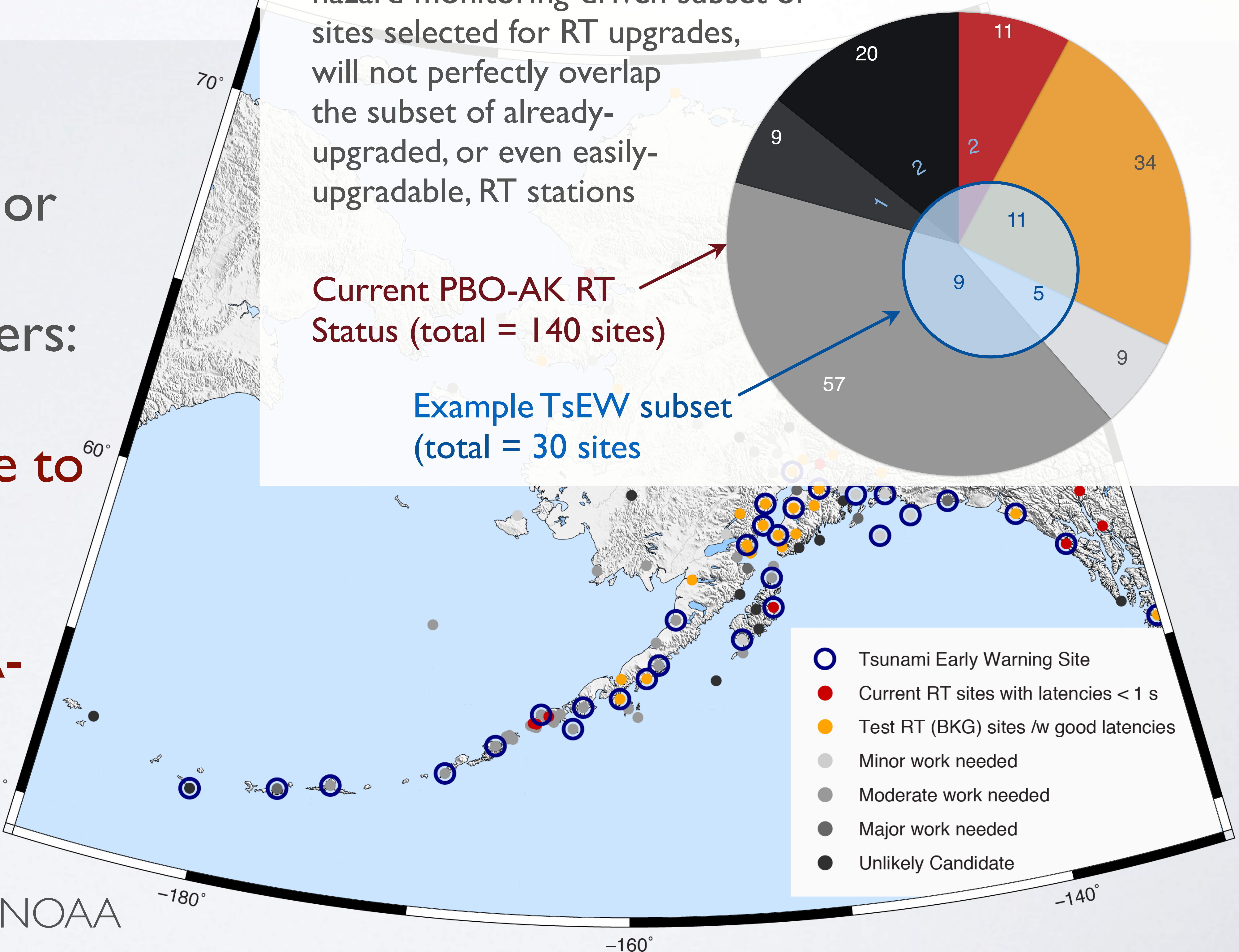
Note that a particular science- or hazard monitoring-driven subset of sites selected for RT upgrades, will not perfectly overlap the subset of already-upgraded, or even easily-upgradable, RT stations

Current PBO-AK RT Status (total = 140 sites)

Example TsEW subset (total = 30 sites



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ONE SCENARIO FOR PBO ENHANCEMENT

- Budget includes one time costs **to upgrade 30 key stations**, staffing and development and set up of local monitoring.
- **Annual costs** include staffing for near-real-time monitoring, triage, and responding to station outages, associated travel, and all recurring communications costs with satellite uplink failover.

	One Time	Annual
Salaries	$328,194	$88,317
Fringe	$189,171	$50,906
Materials/Supplies	$398,820	$10,000
Helicopter Services, etc.	$315,000	$50,000
Travel	$101,003	$20,000
Other Direct Costs	$107,790	-
Communications	$456,000	$456,000
Total Direct Costs	$1,895,978	$675,223
Indirect Costs	$304,494	$108,441
Total	**$2,200,472**	**$783,663**

UNAVCO submitted a proposal to NOAA-NFA-NFAPO-2016-2004791 in May 2016

TYPICAL PBO AK STATION - CURRENT STATE

Standard
PBO
GPS Site

↓

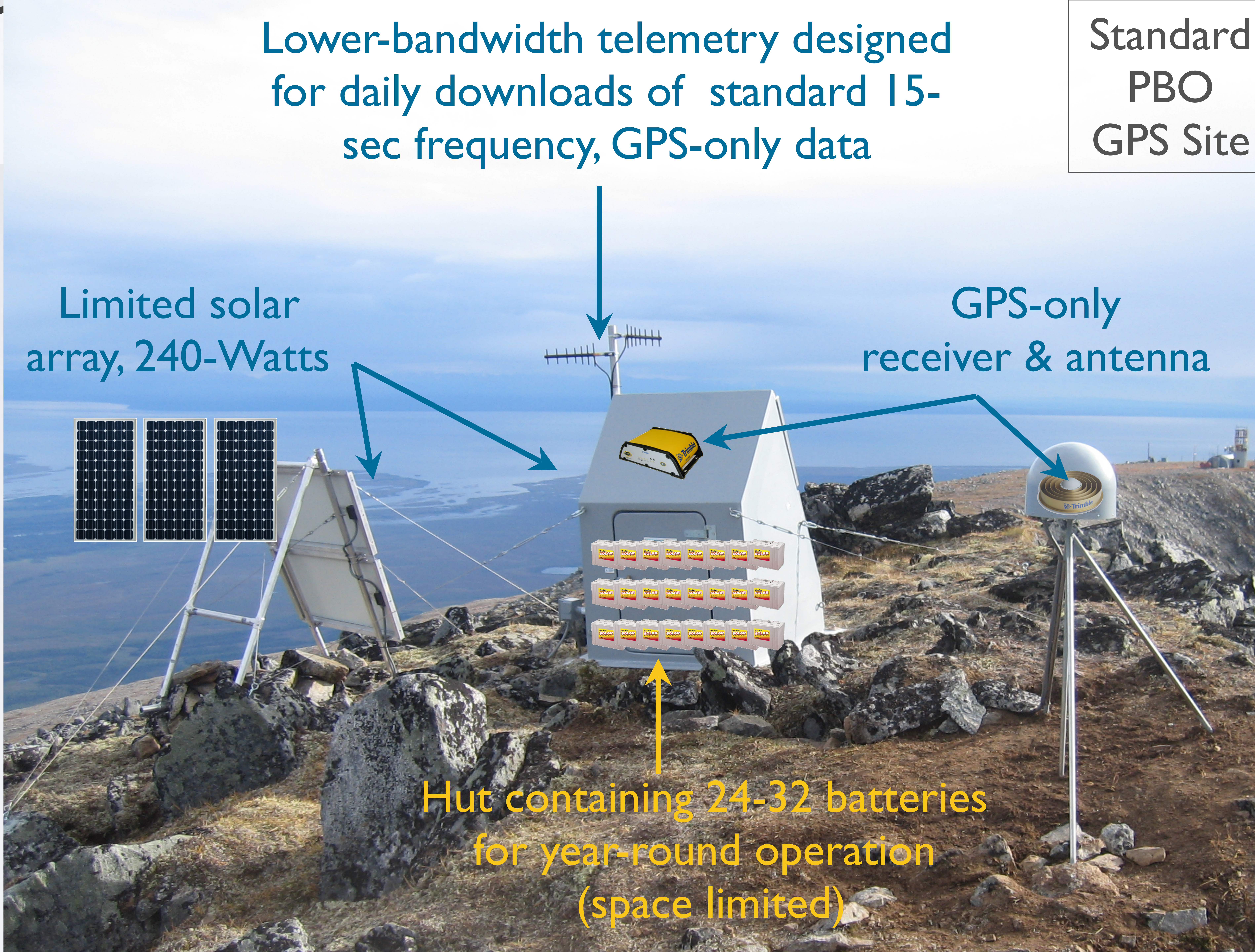
upgrade

↓

Real-time
PBO
GNSS Site

UNAVCO

Current PBO station



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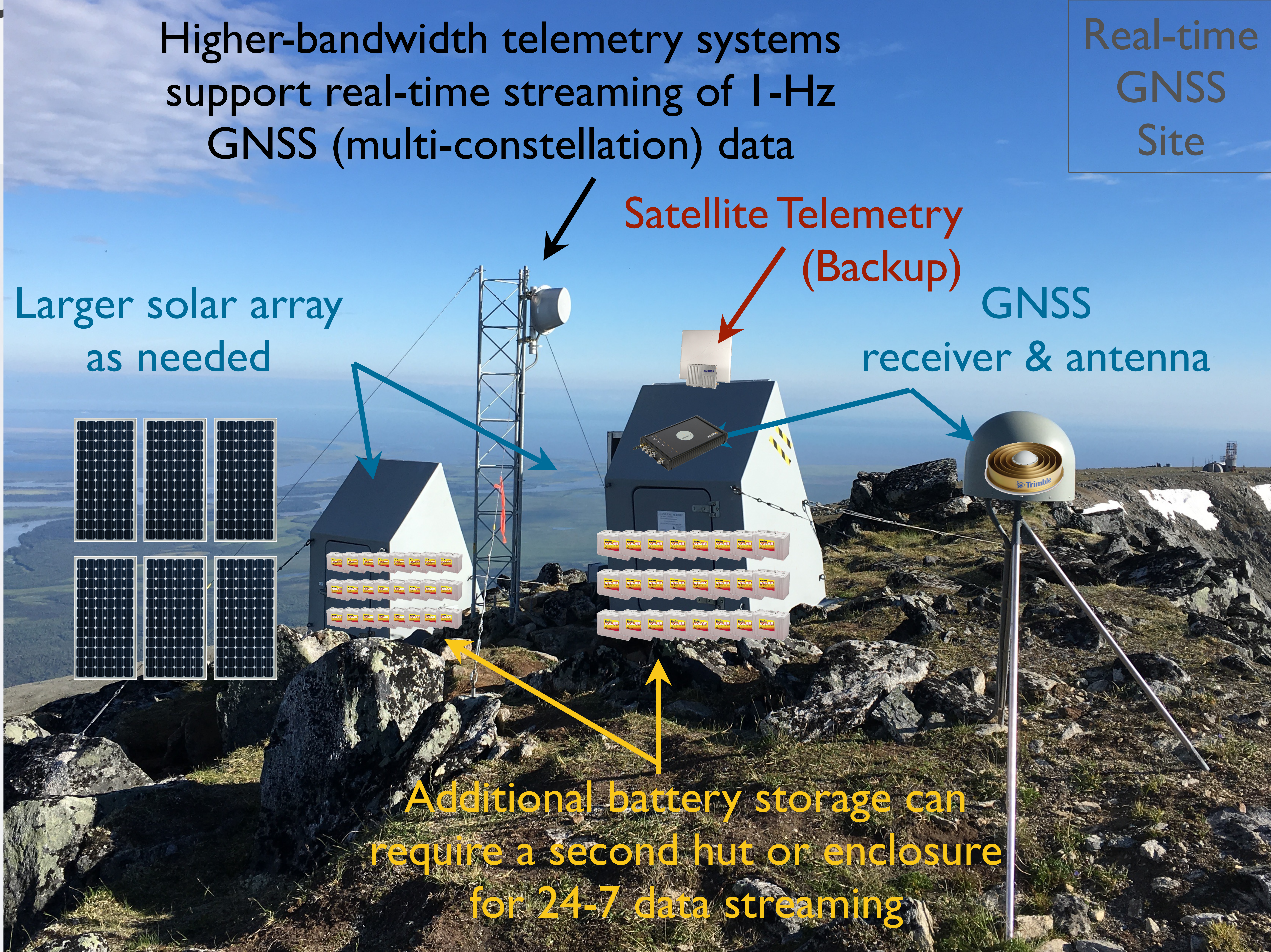
Real-time GNSS Site

Upgraded PBO station



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PBO: A CRITICAL NATIONAL AND AK RESOURCE: SUMMARY OF IMPORTANT CONCERNS

Aging PBO infrastructure - planned replacement in GAGE, not fully possible under current budget scenarios. Many EOL/EOS units 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.** Future post-GAGE (under NGEO) is uncertain…

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 selected PBO-AK stations to real-time would be considerable ($2.2M one-time funds and $0.8M/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 federal and state partners** remains paramount…

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

QUESTIONS?