55th Meeting of the Civil GPS Service Interface Committee

At the Institute of Navigation GNSS+ 2015 Conference
Tampa Convention Center
14-15 September 2015

UNAVCO

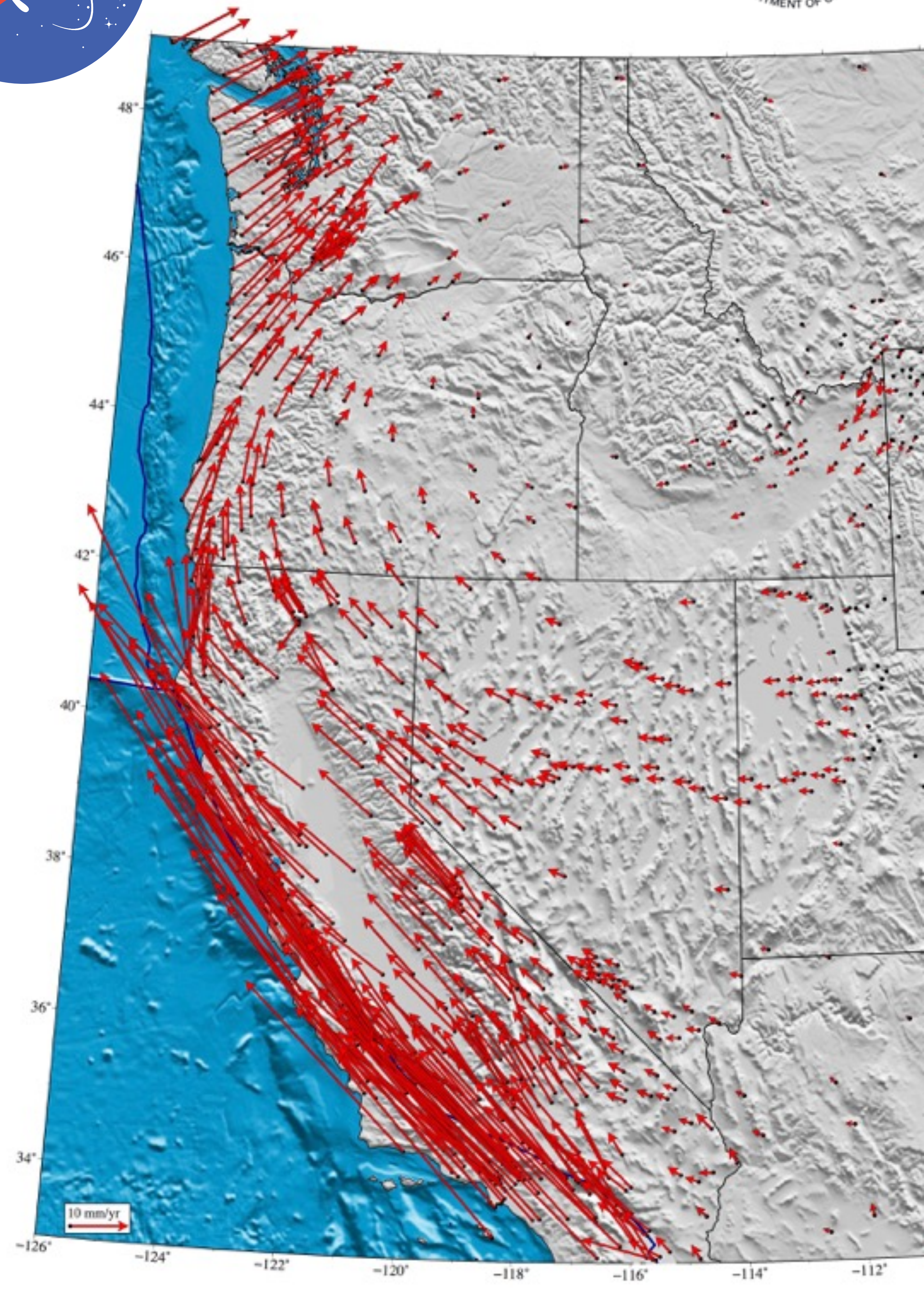
EARTHSCOPE LIDAR & PLATE BOUNDARY OBSERVATORY GPS DATA, PRODUCTS AND SERVICES

David A. Phillips, Ph.D.
Project Manager, Geodetic Data Services

- **Introduction to UNAVCO, EarthScope, PBO, etc.**
- EarthScope airborne LiDAR data.
- Plate Boundary Observatory (PBO) GPS/GNSS network, data and applications.
- Summary.

UNAVCO...

- …is a university-governed **consortium** that advances and supports **geodesy** community science goals.
- …is primarily funded by the National Science Foundation (**NSF**) and operates the National Earth Science Geodetic Facility, known as the Geodesy Advancing Geosciences and EarthScope (**GAGE**) Facility.
- …in collaboration with JPL, is responsible for the operations and maintenance of the 62 permanent GNSS stations that comprise the **NASA** Global GNSS Network (**GGN**).
- …has collaborative partnerships with other federal agencies including the **USGS** and **NOAA**.
- …provides **geodetic infrastructure** and **geodetic data services** that support GPS/GNSS, InSAR, LiDAR and other data by providing instrumentation, engineering, development & testing, data archiving, data products, technical training, community workshops, and **education** resources.



UNAVCO…

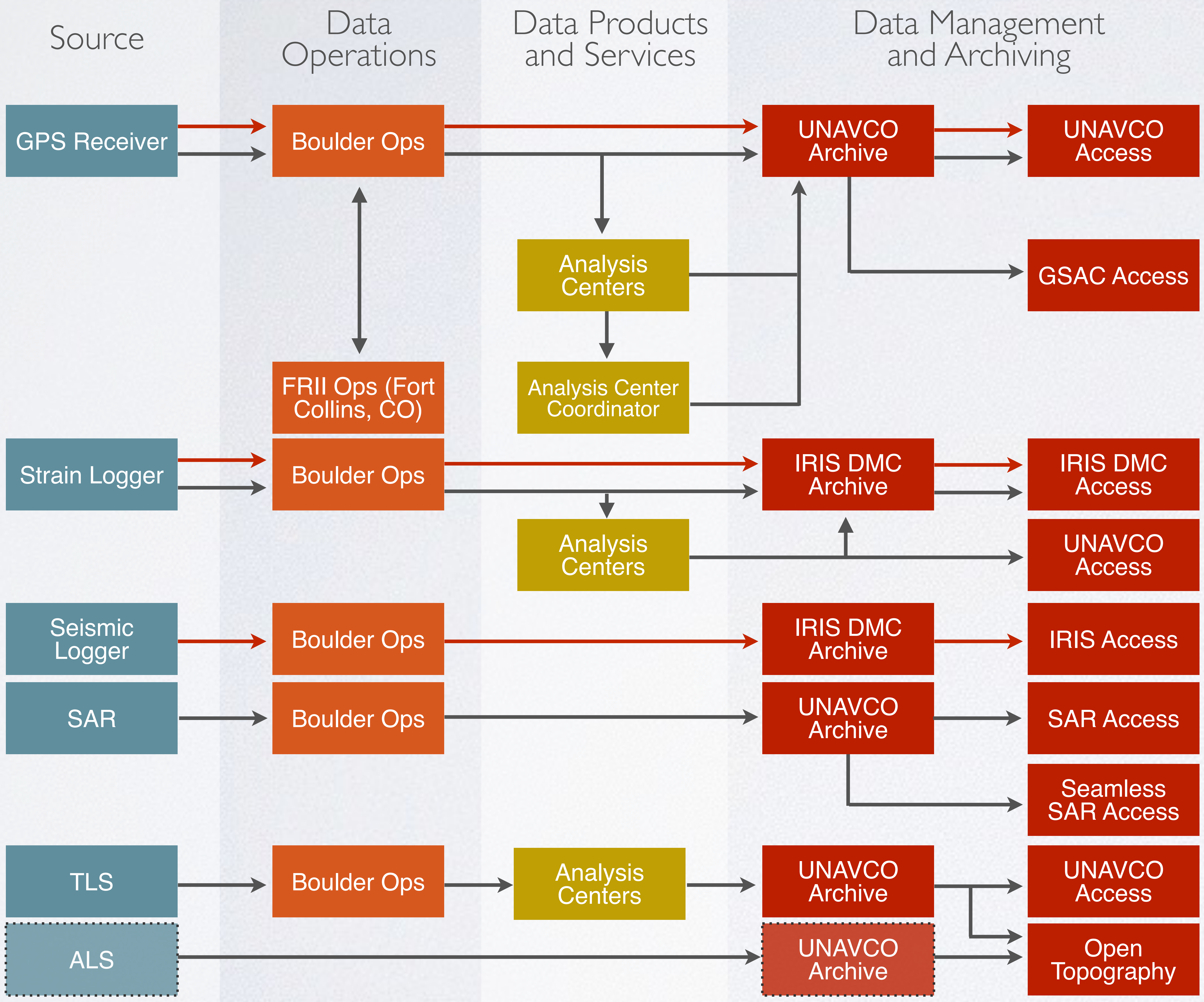
- …operates large scale GPS networks around the world including the Plate Boundary Observatory (**PBO**), COCONET, TLALOCNET, NASA GGN and many others.
- …developed and maintains **TEQC** software
- …supports **event response** activities such as recent earthquakes in Nepal, Japan, Chile, Haiti.
- …works to promote a broader understanding of Earth science through **education** and **outreach**.
- …staff are engaged in national and international community efforts including the **IGS** Governing Board.
- …is based in **Boulder**, Colorado.





GEODETIC DATA SERVICES

File-based data
Streaming data



Data Sources to Users

Data Operations

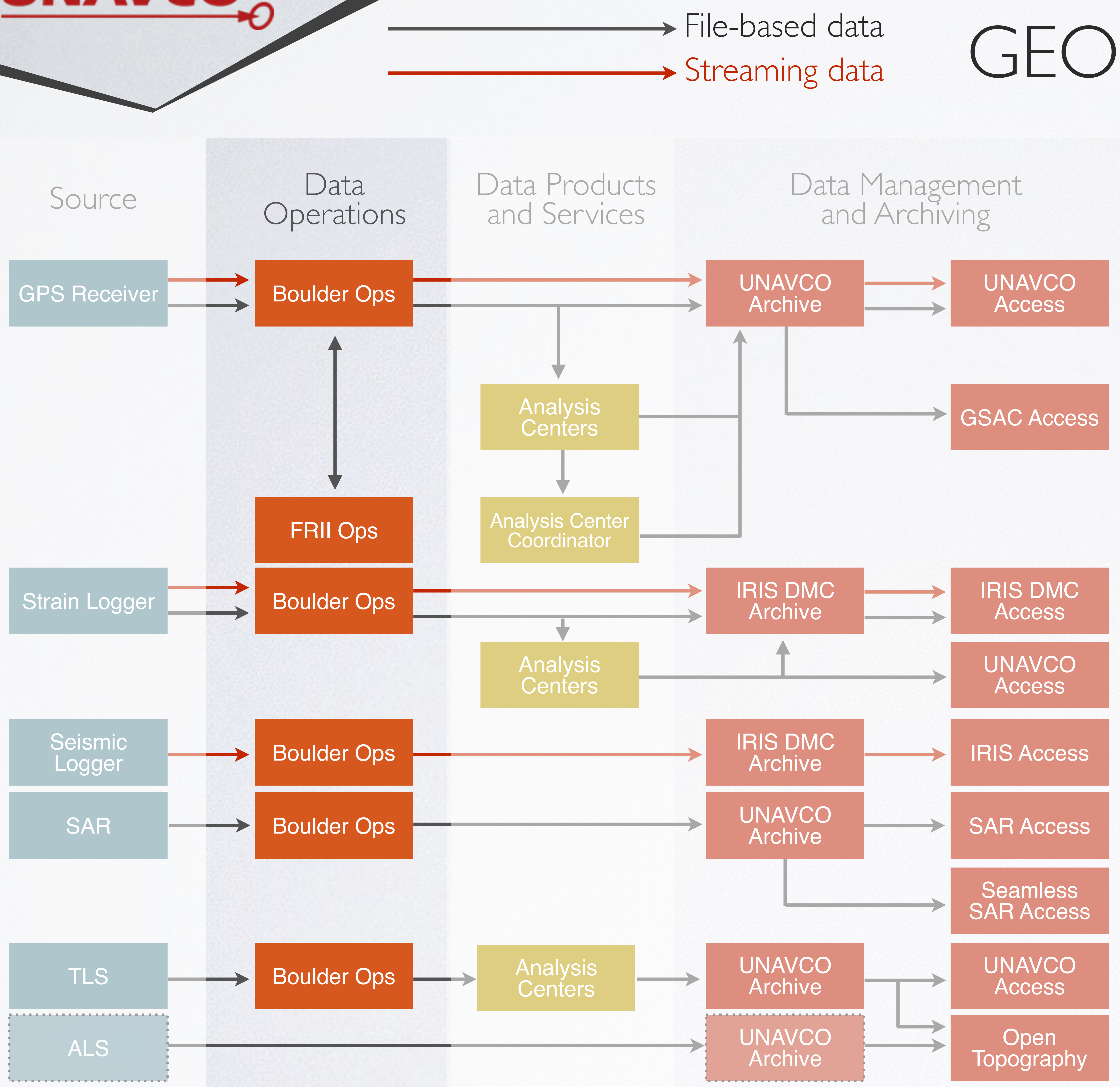
Data Products and Services

Data Management and Archiving

Cyberinfrastructure

- Web Services
- Cloud Storage (Amazon, SDSC)
- Collaborations (EarthCube, COOPEUS, GEO Supersites, IGS)

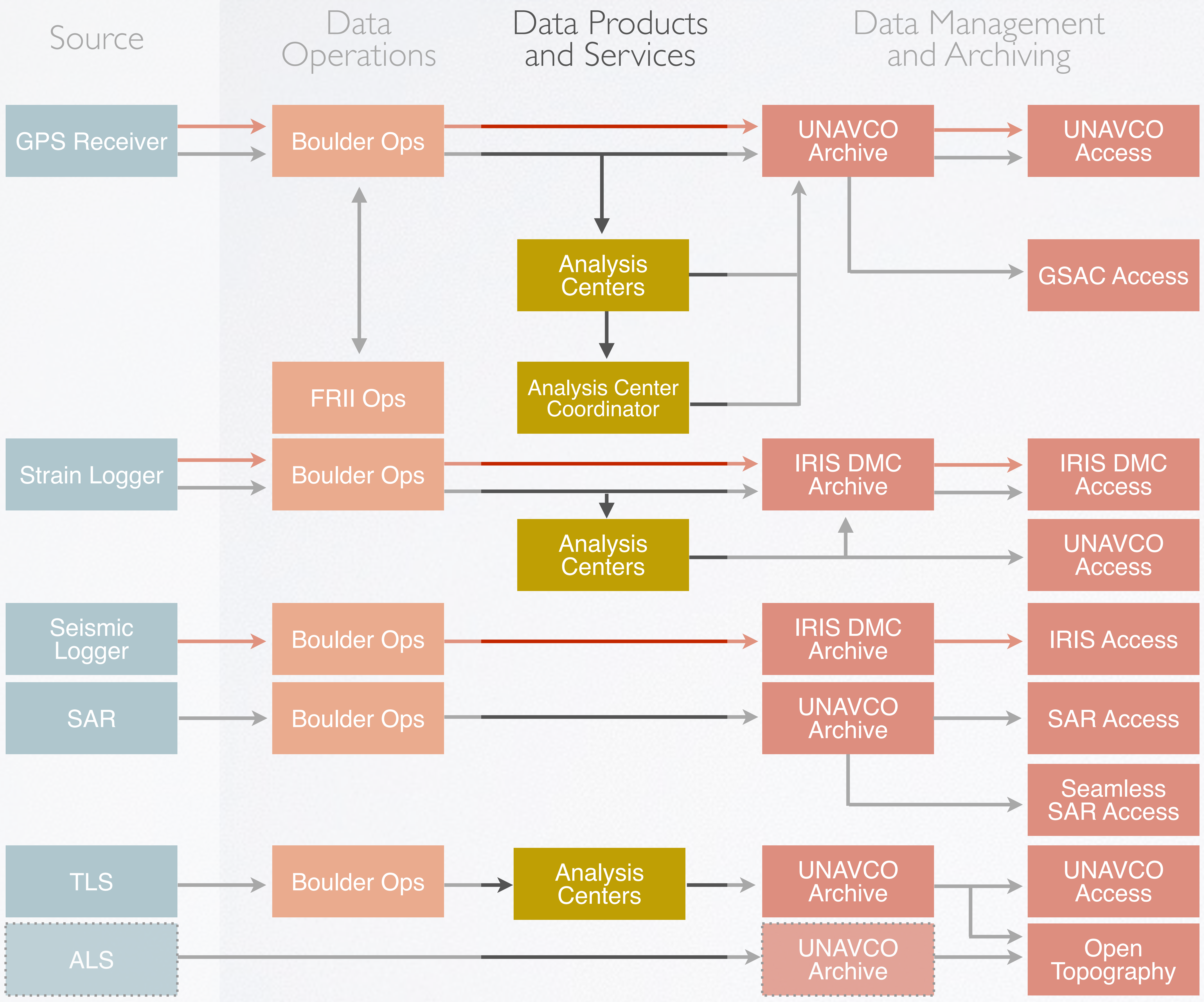
GEODETIC DATA SERVICES



Data Operations

- Acquire data from thousands of globally-distributed sensors (daily/hourly file downloads and continuous streams) and sources
- Sensor Configuration
- Data Communications
- Maintain Accurate Metadata
- Monitor network SOH

GEODETIC DATA SERVICES



Data Products and Services

- Translate raw data to generate higher level data products (e.g. GPS to RINEX)
- Create quality control metrics
- Create processed data products such as GPS time series and ground velocities; cleaned strain products
- Provide training and software tools for translation, processing, analysis

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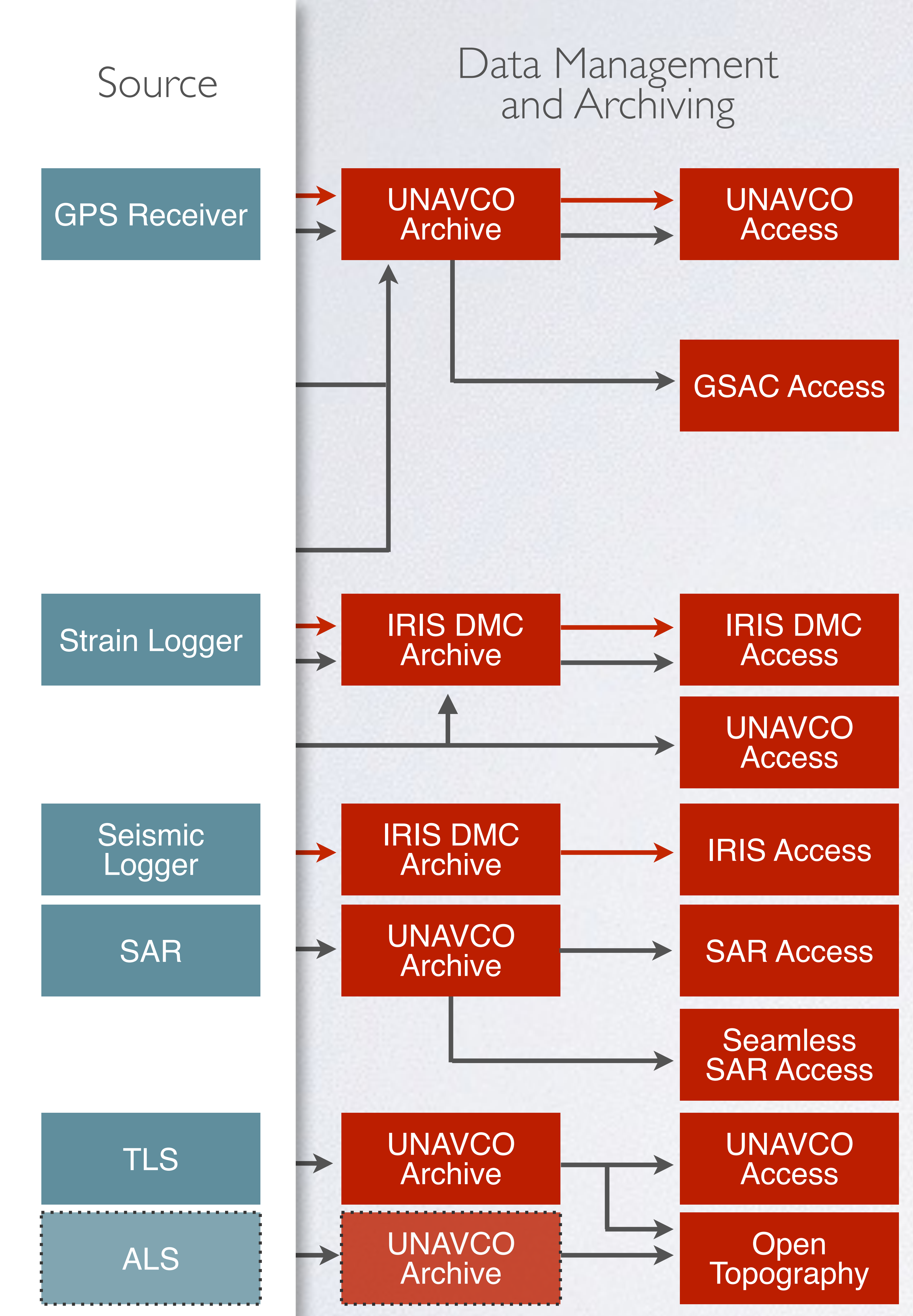
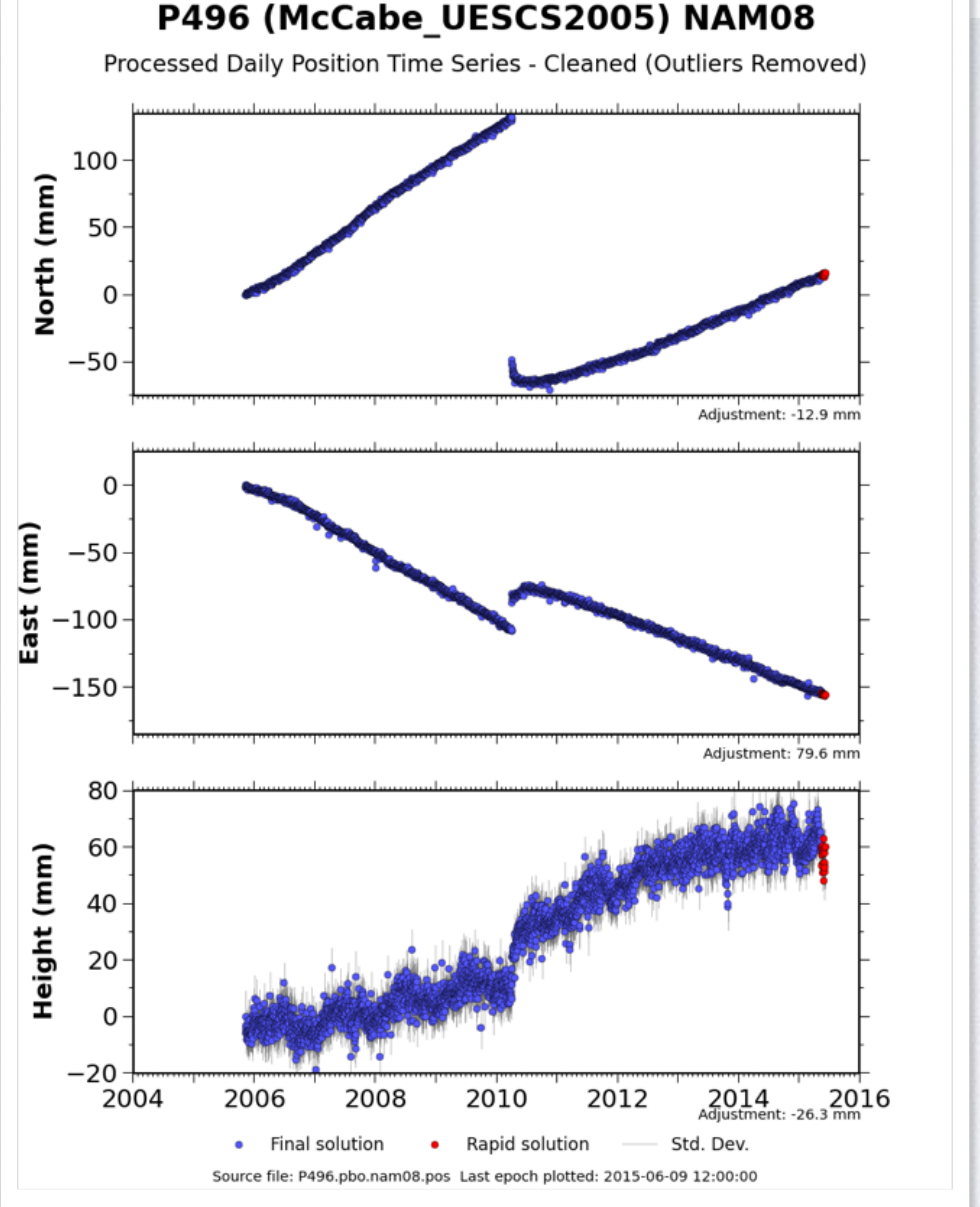
GEODETIC DATA SERVICES

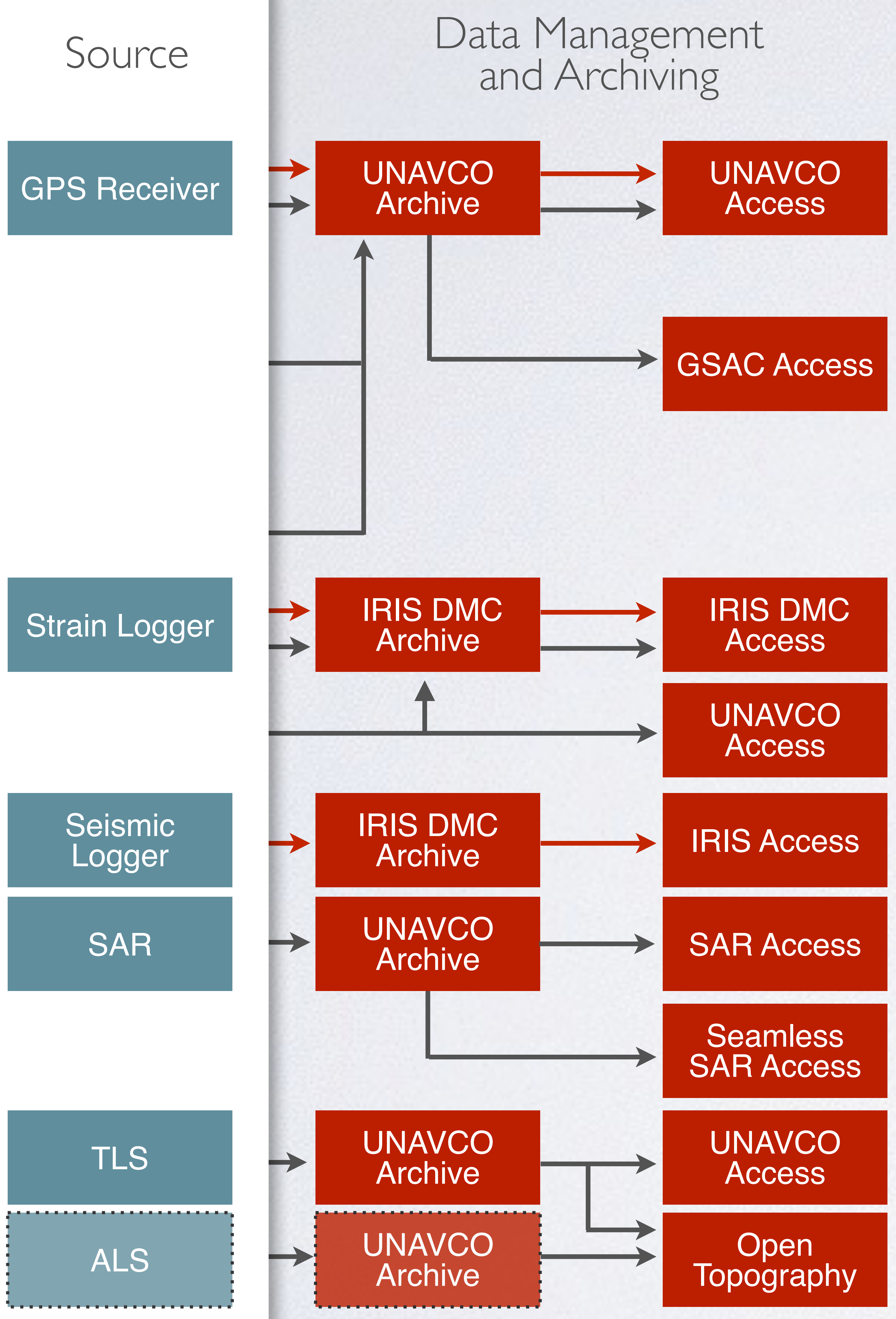


- **GPS Daily Positioning Time Series**



M7.2 El Mayor-Cucapah EQ (4 April 2010)

GEODETIC DATA SERVICES



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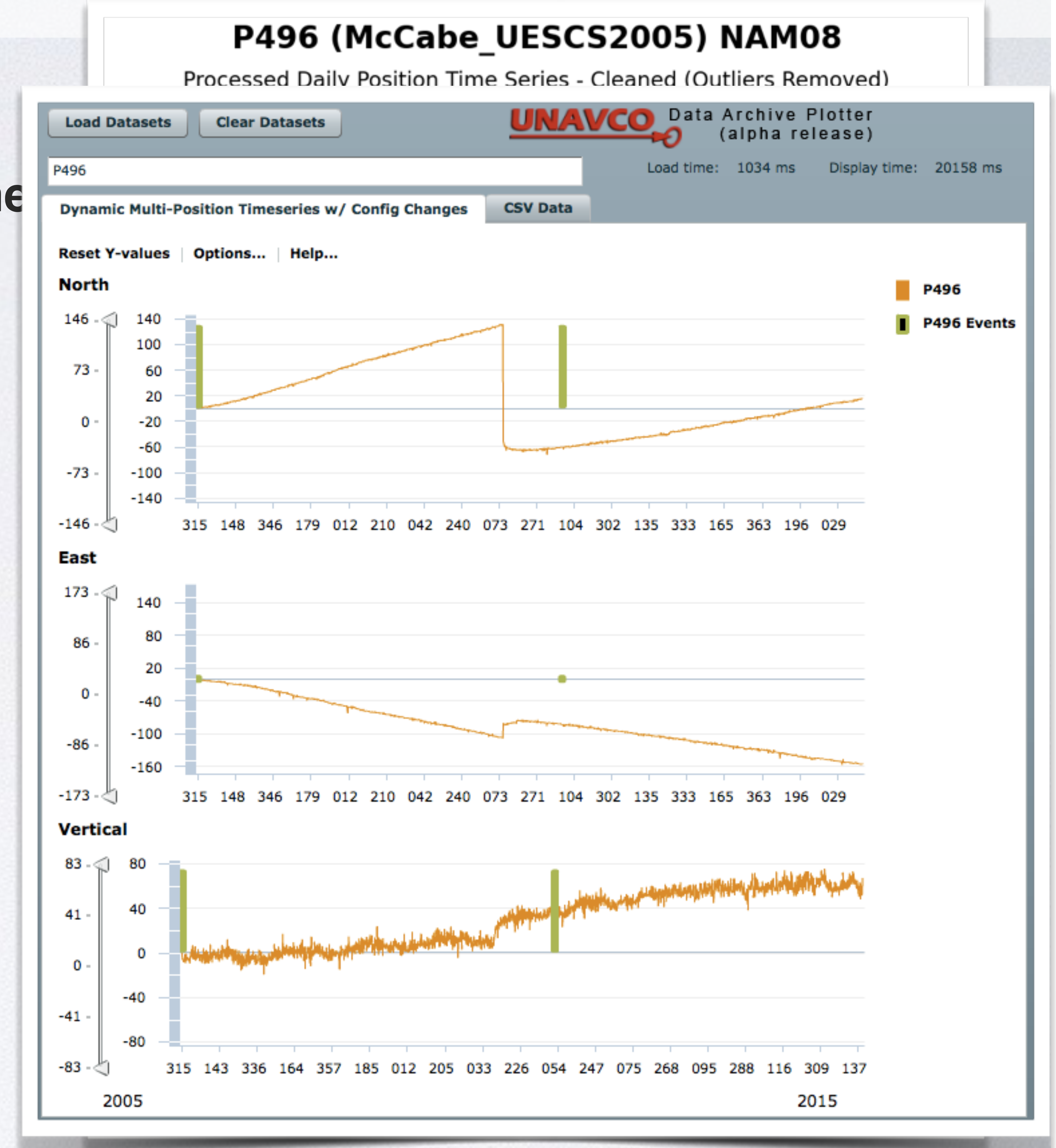

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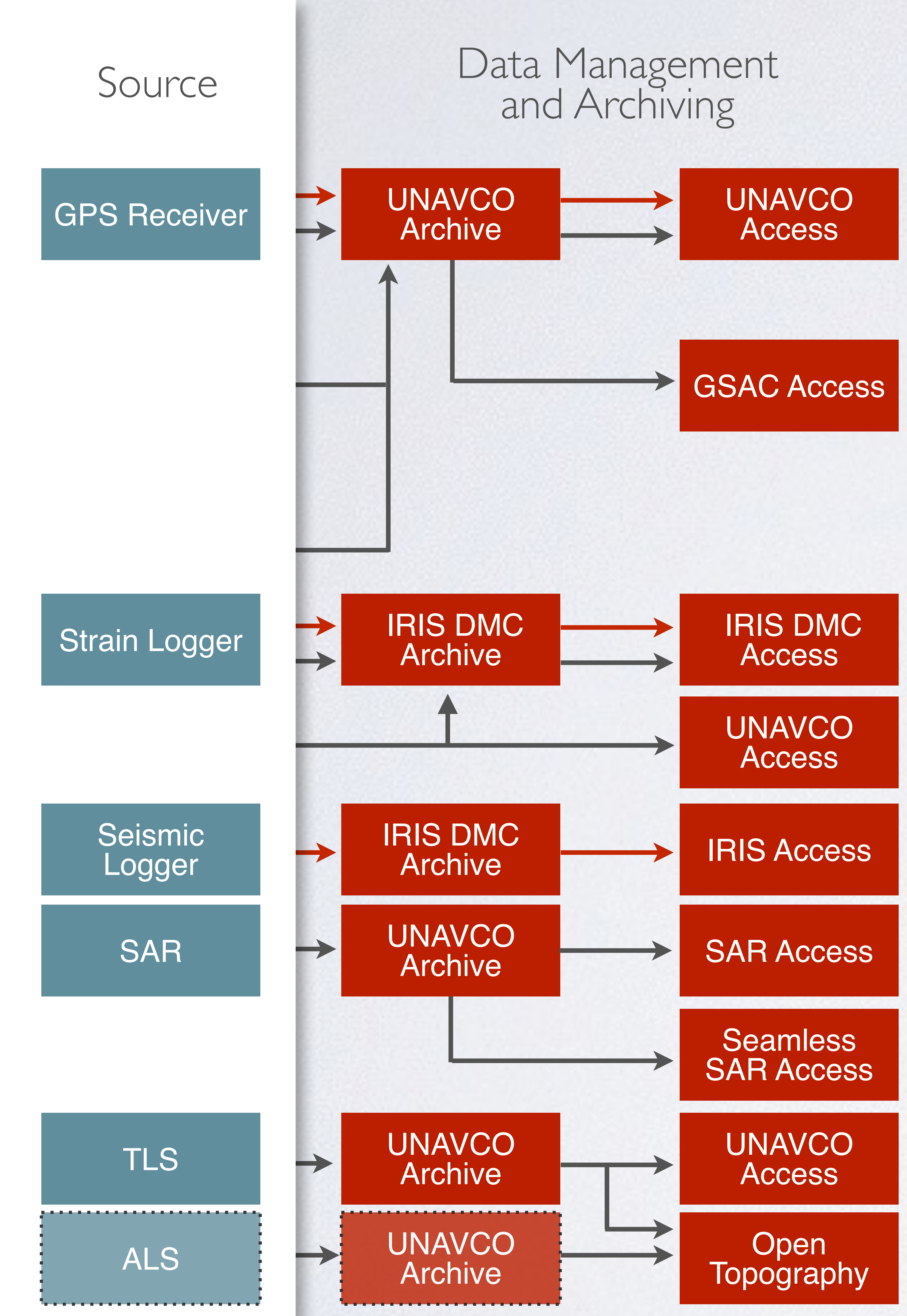

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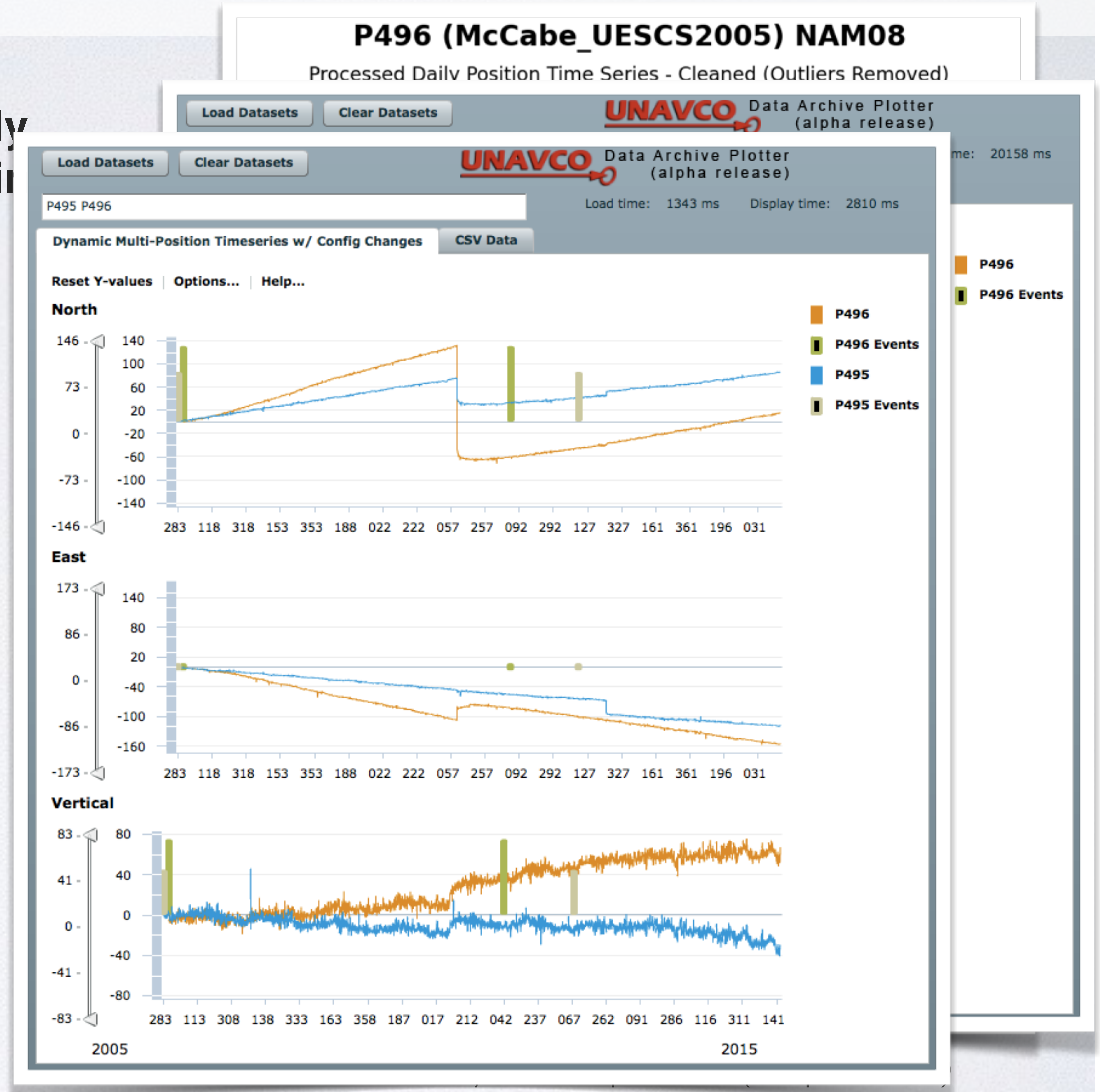

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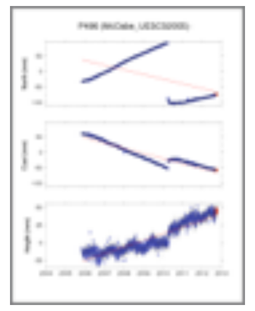
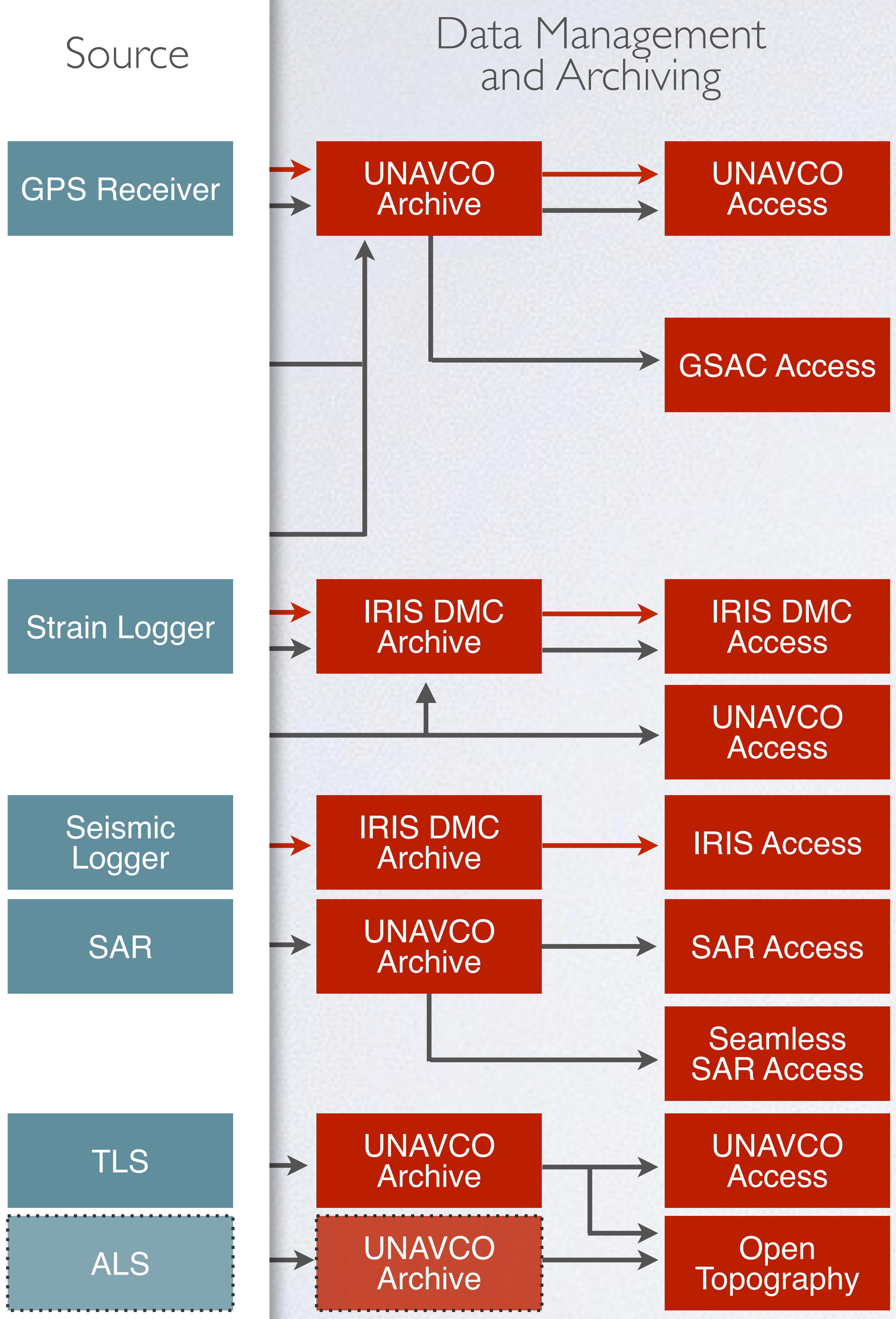
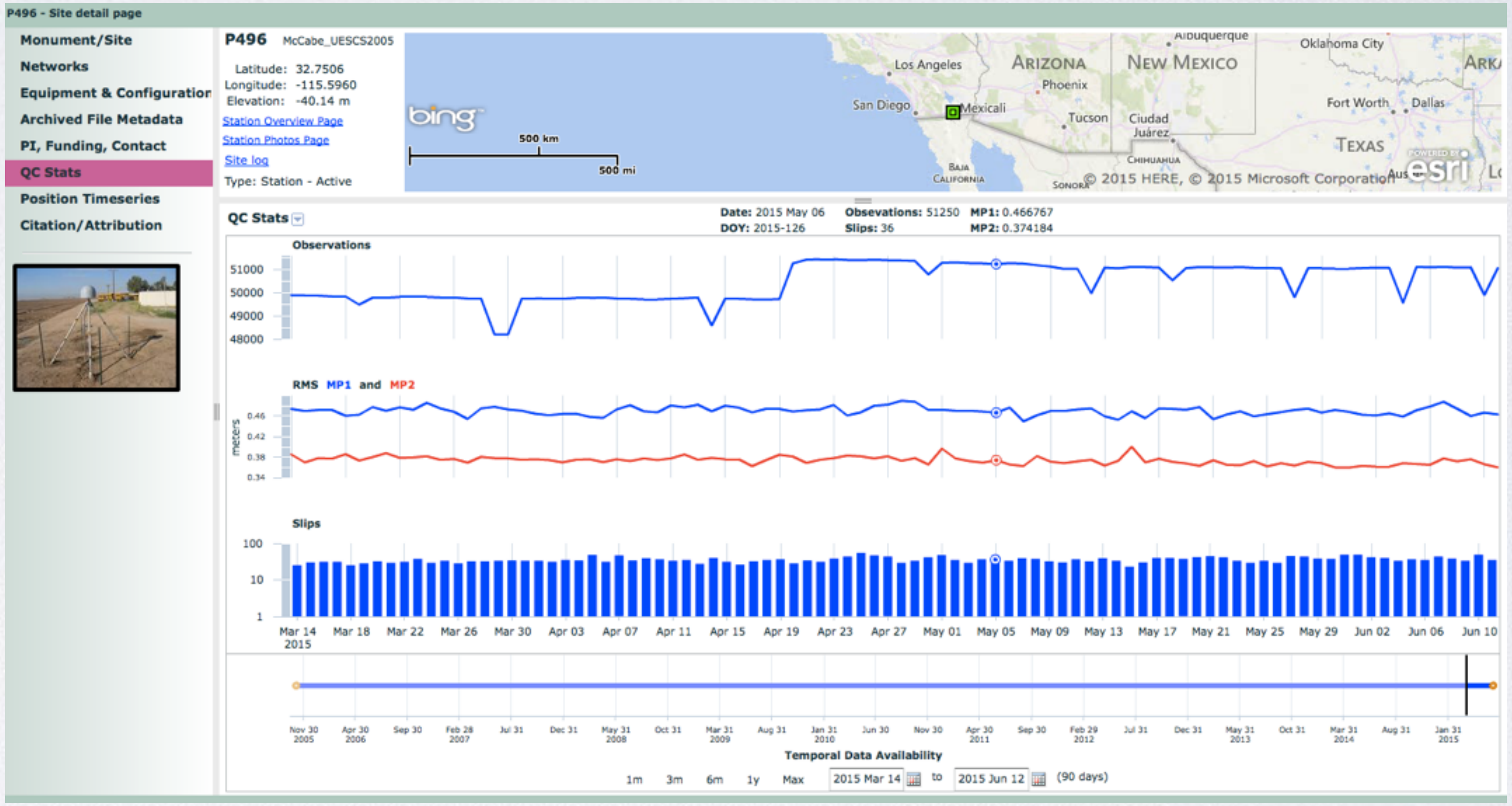




- GPS Daily Positioning Time Series
- **GPS Quality Control Statistics**



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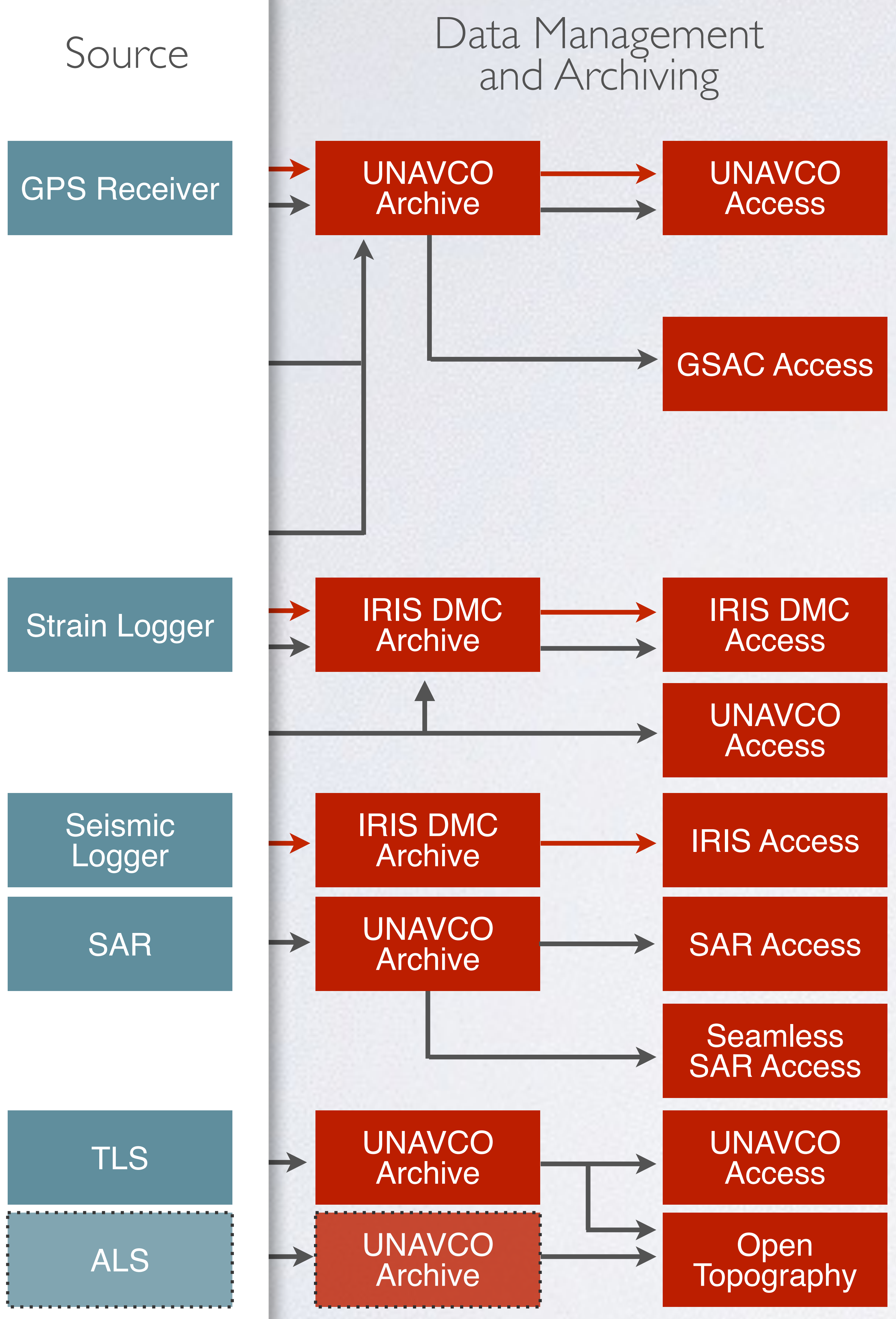

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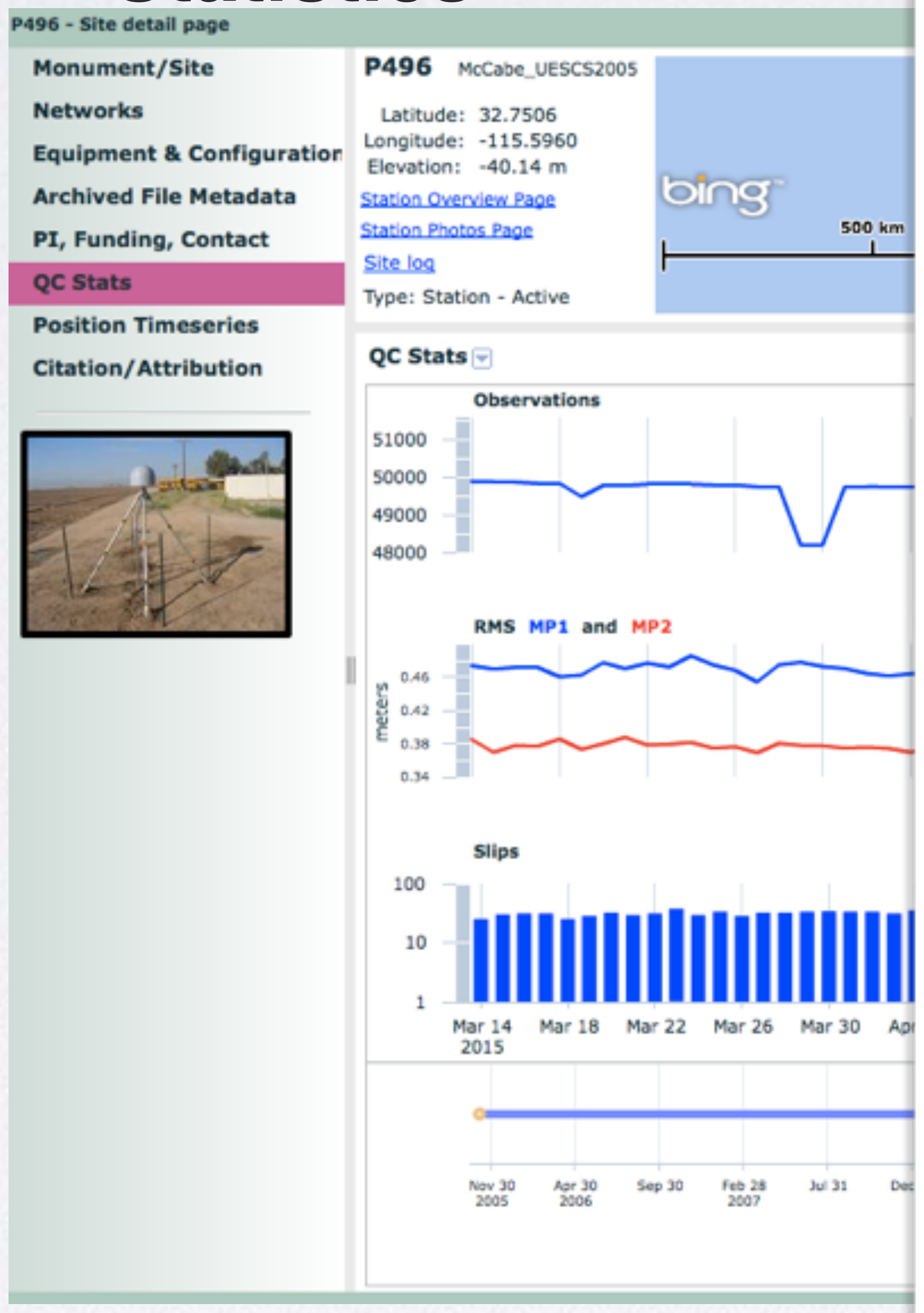

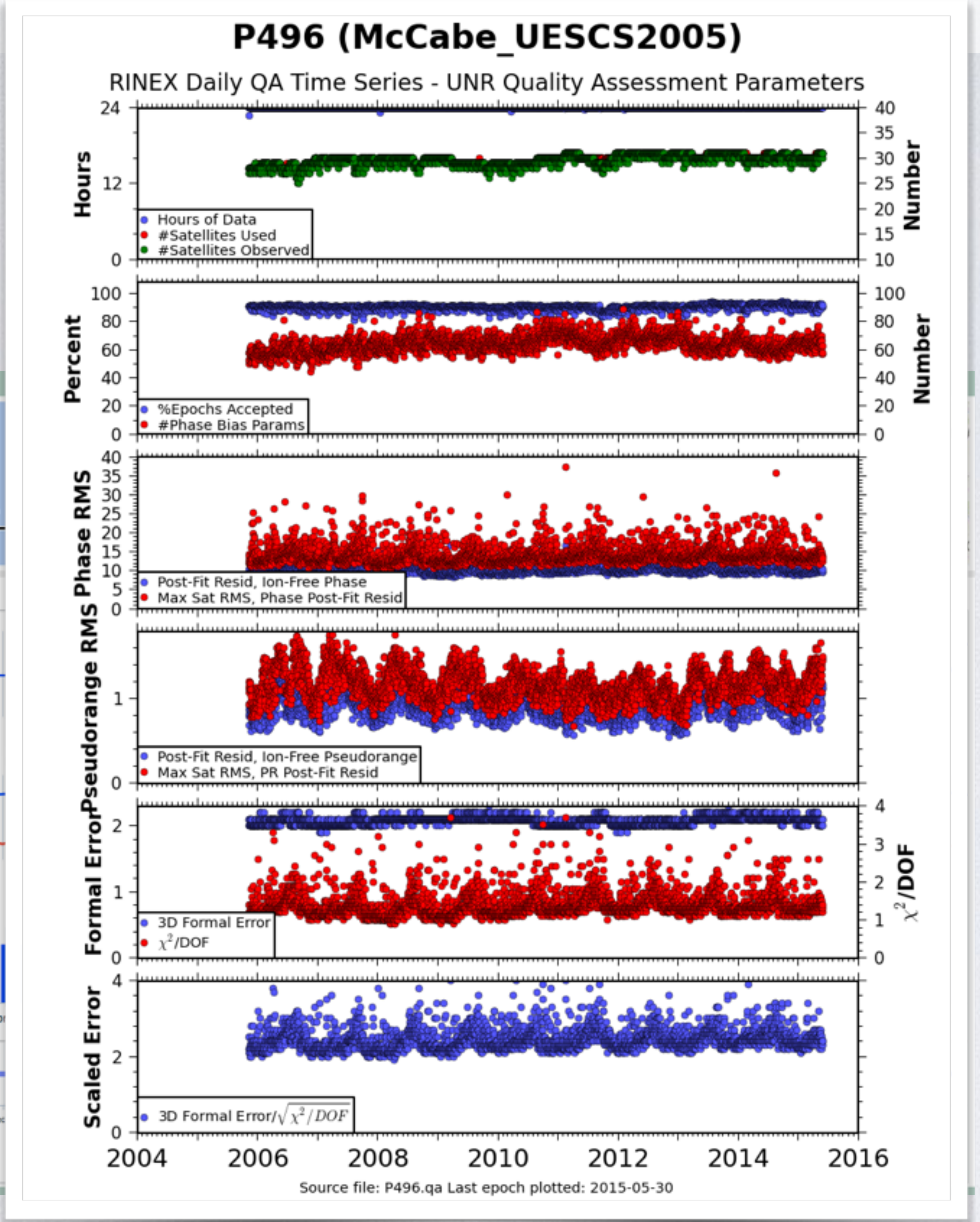

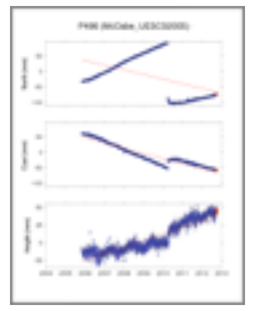

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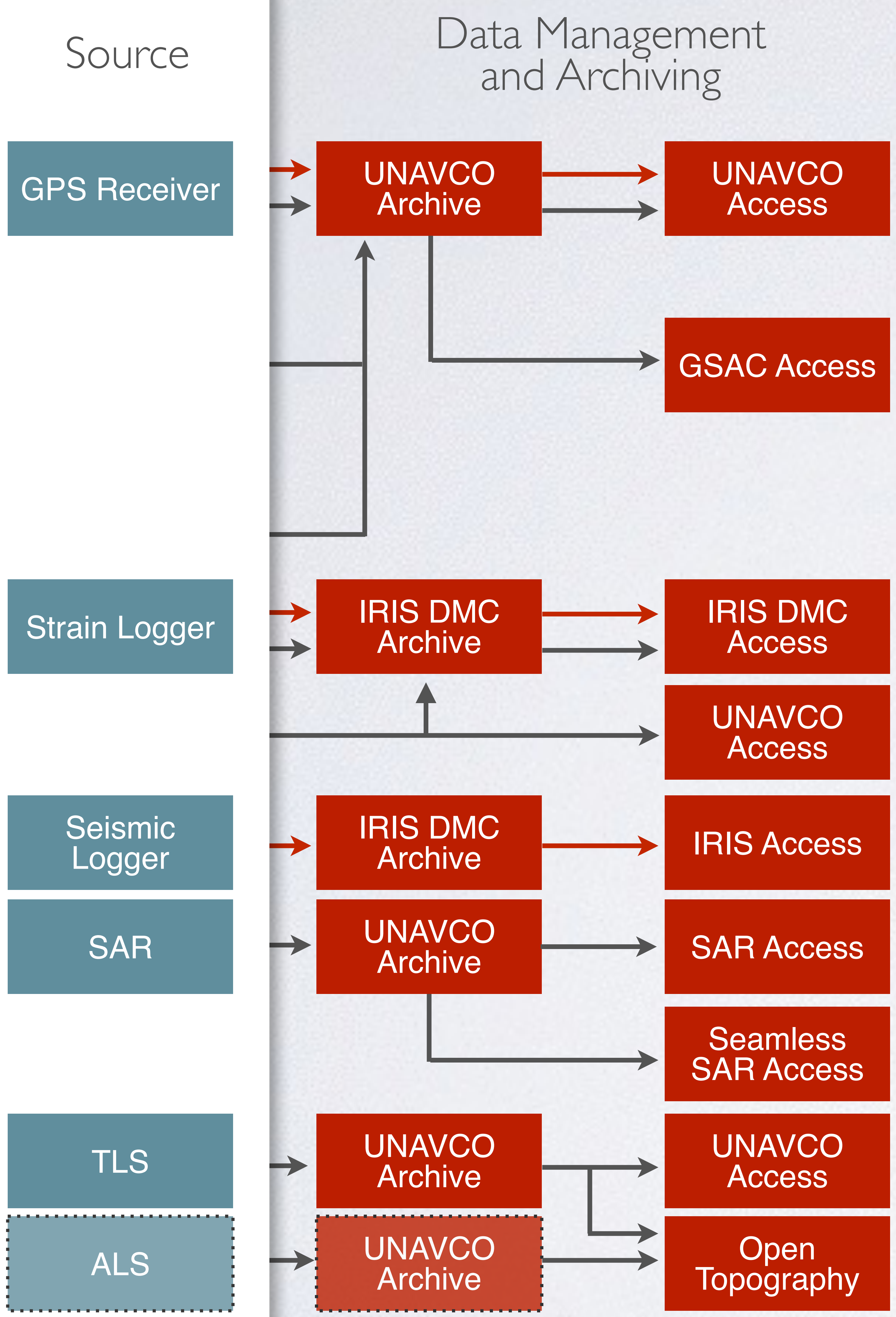
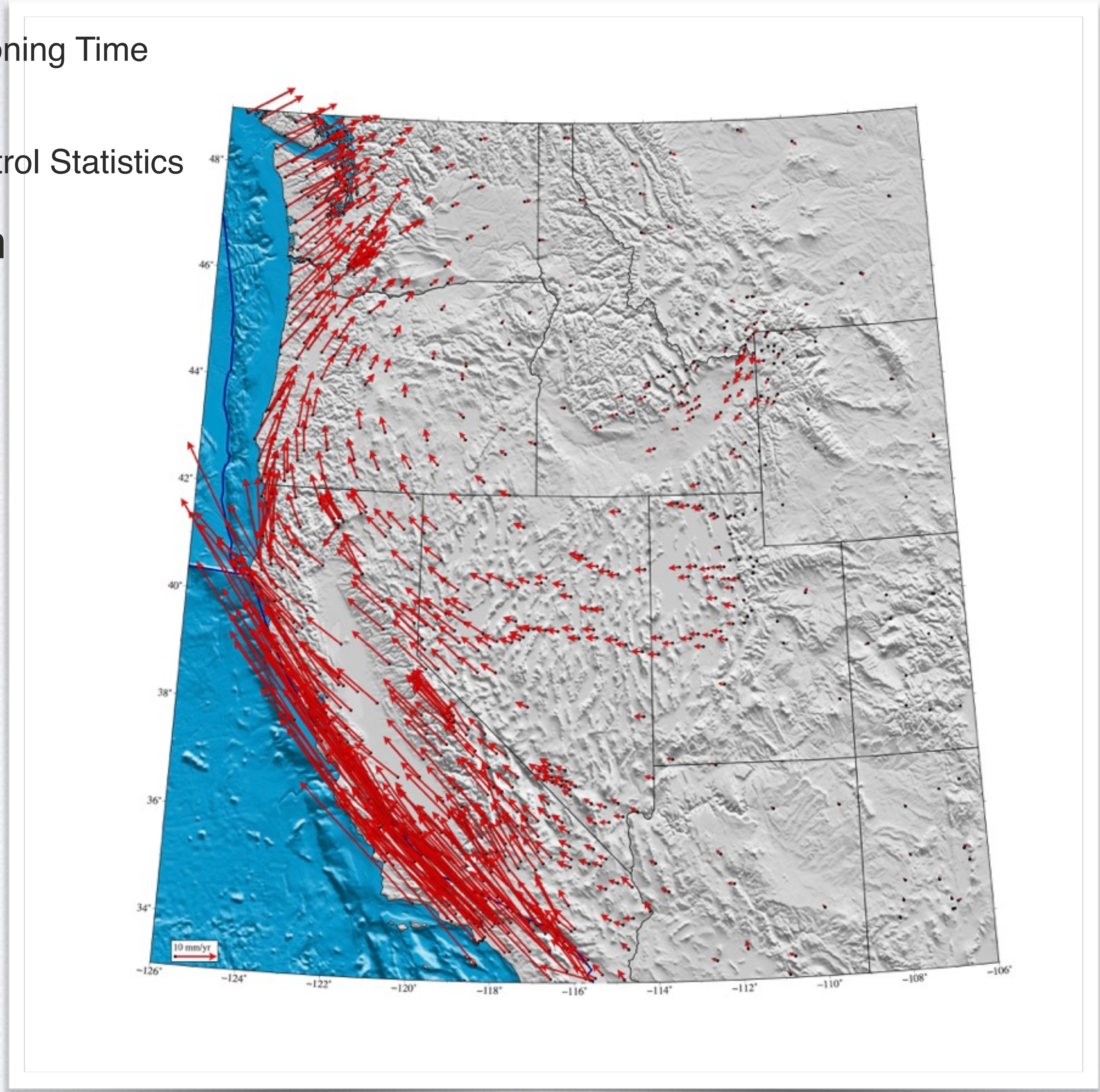


- GPS Daily Positioning Time Series
- GPS Quality Control Statistics
- **GPS Station Velocity**



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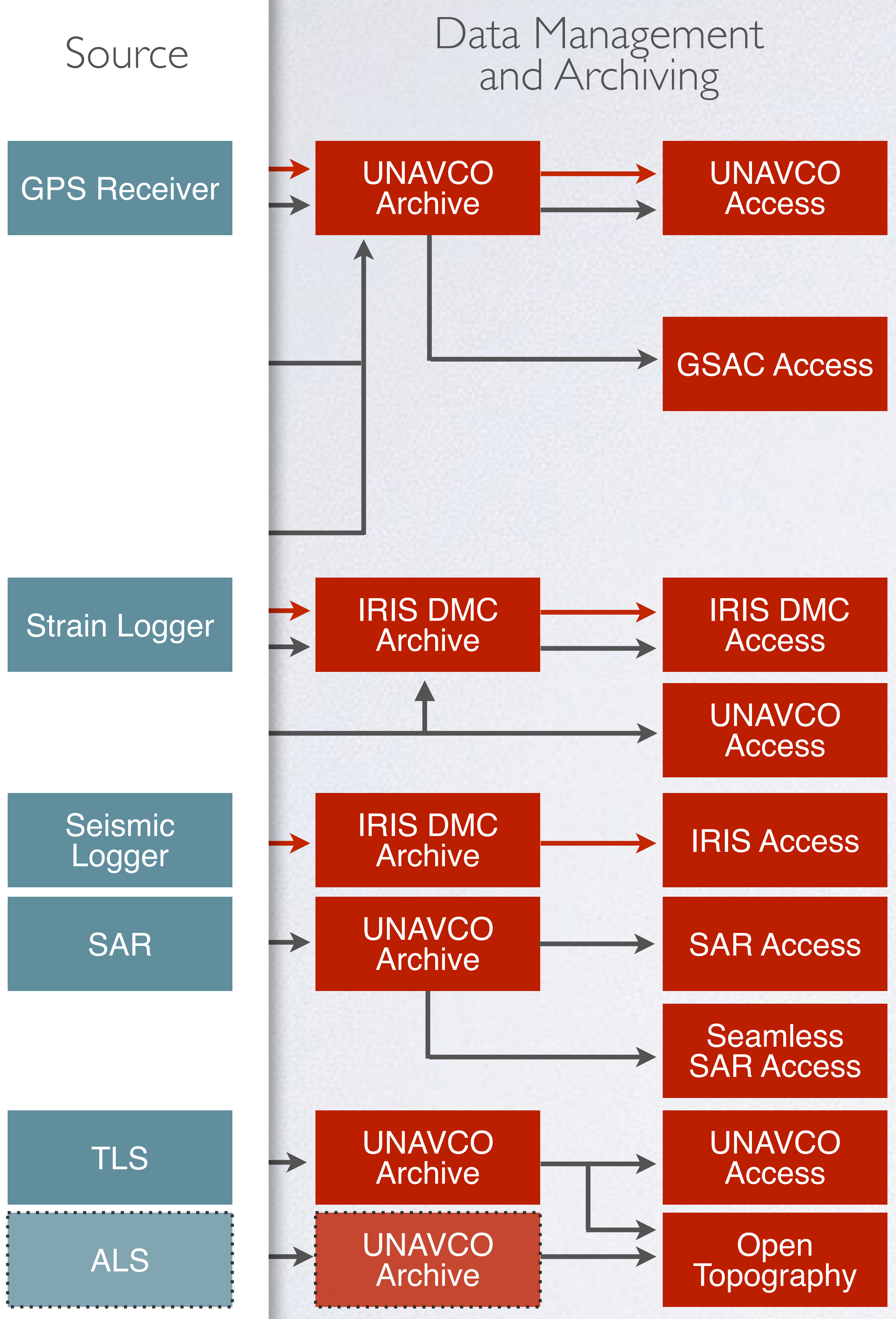
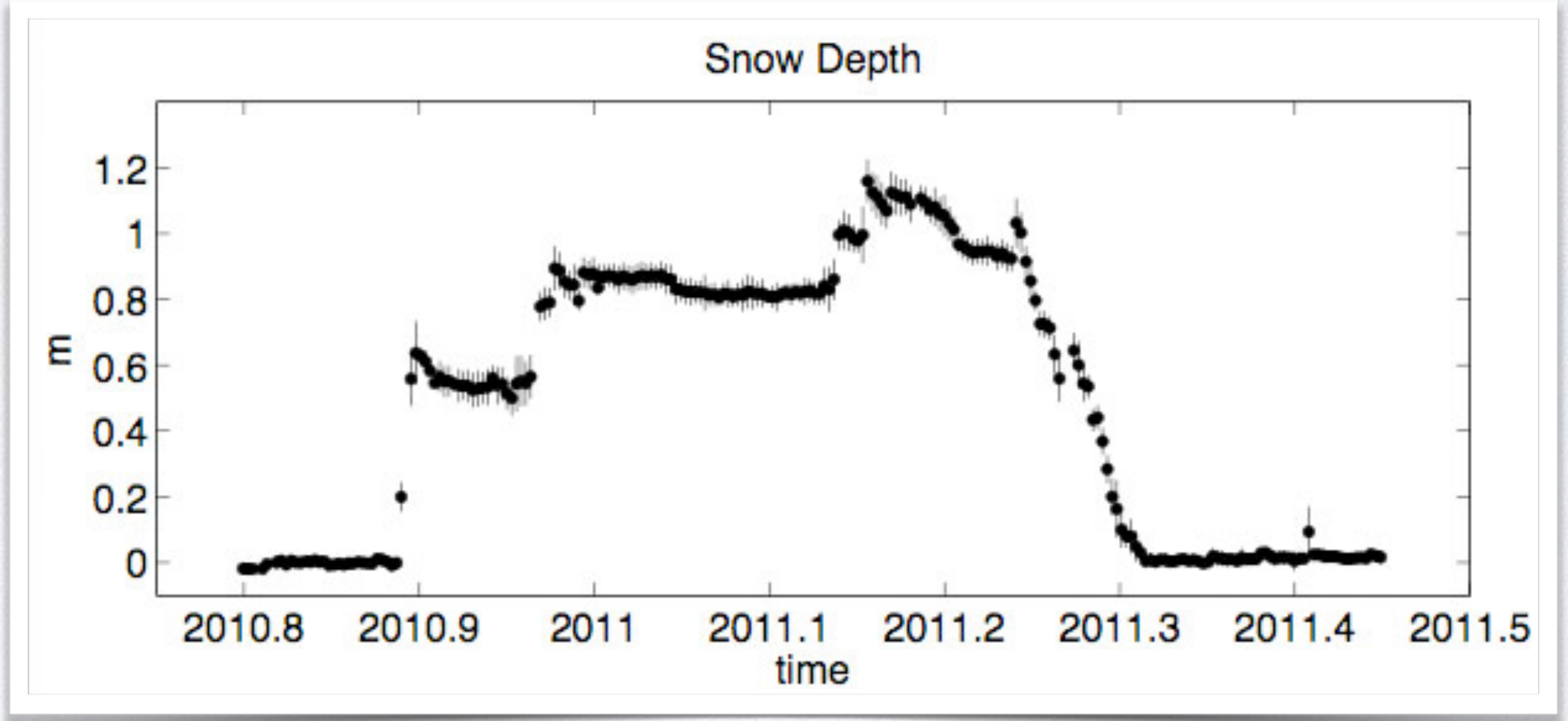
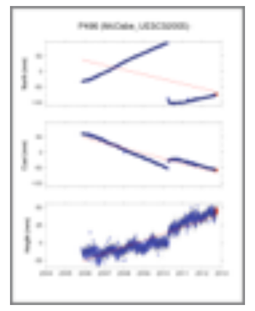


- GPS Daily Positioning Time Series
- GPS Quality Control Statistics
- GPS Station Velocity
- **GPS Reflectometry**





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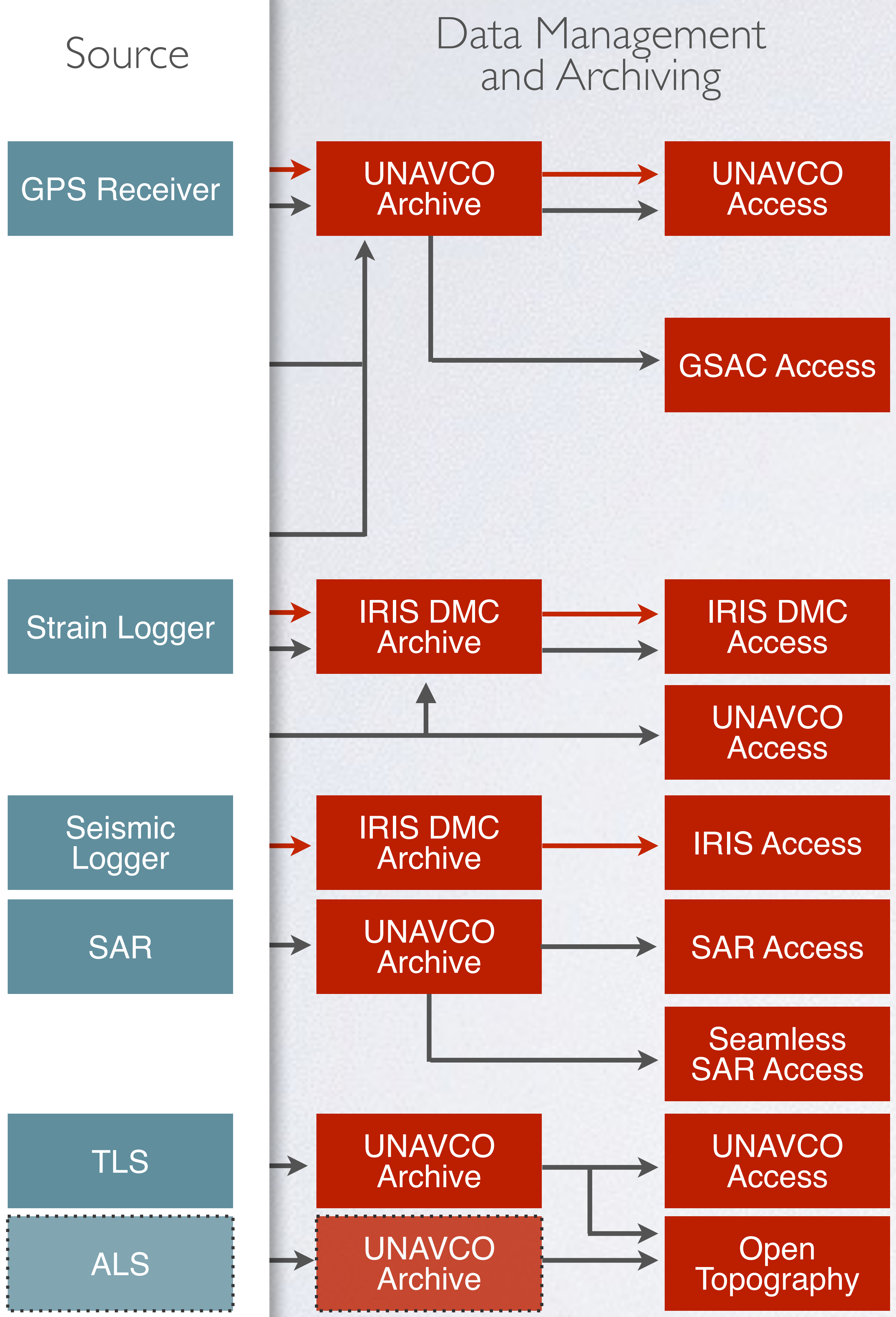
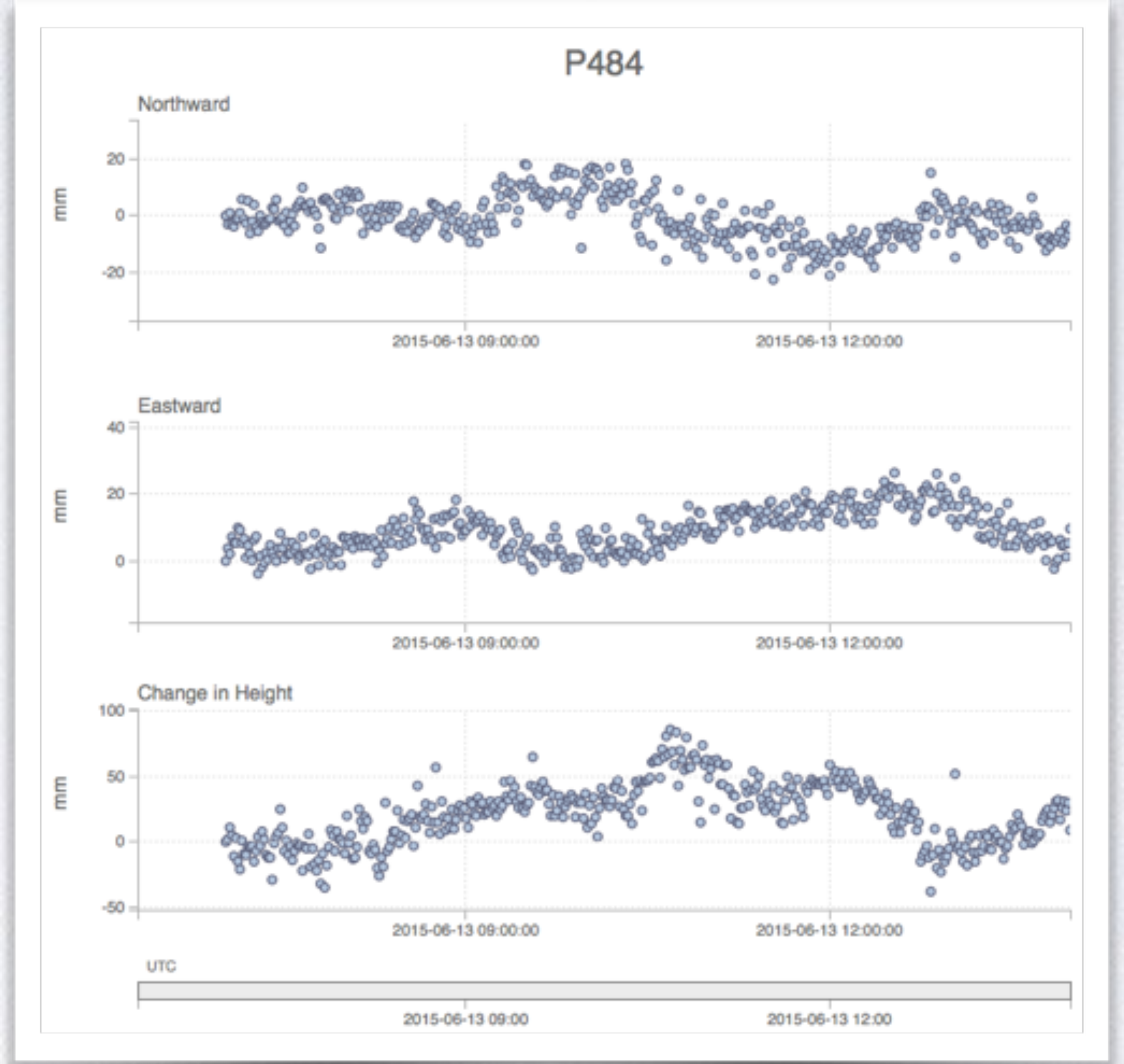
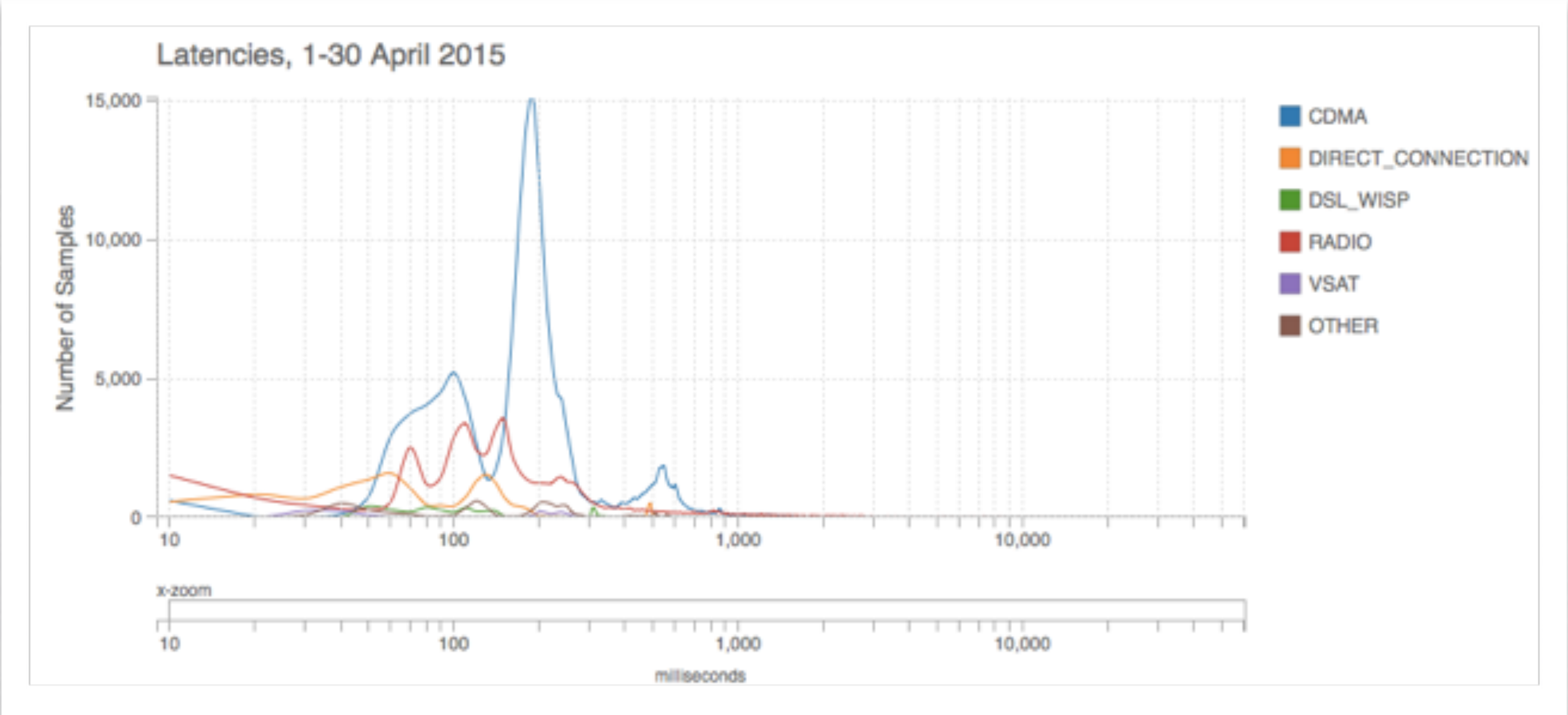
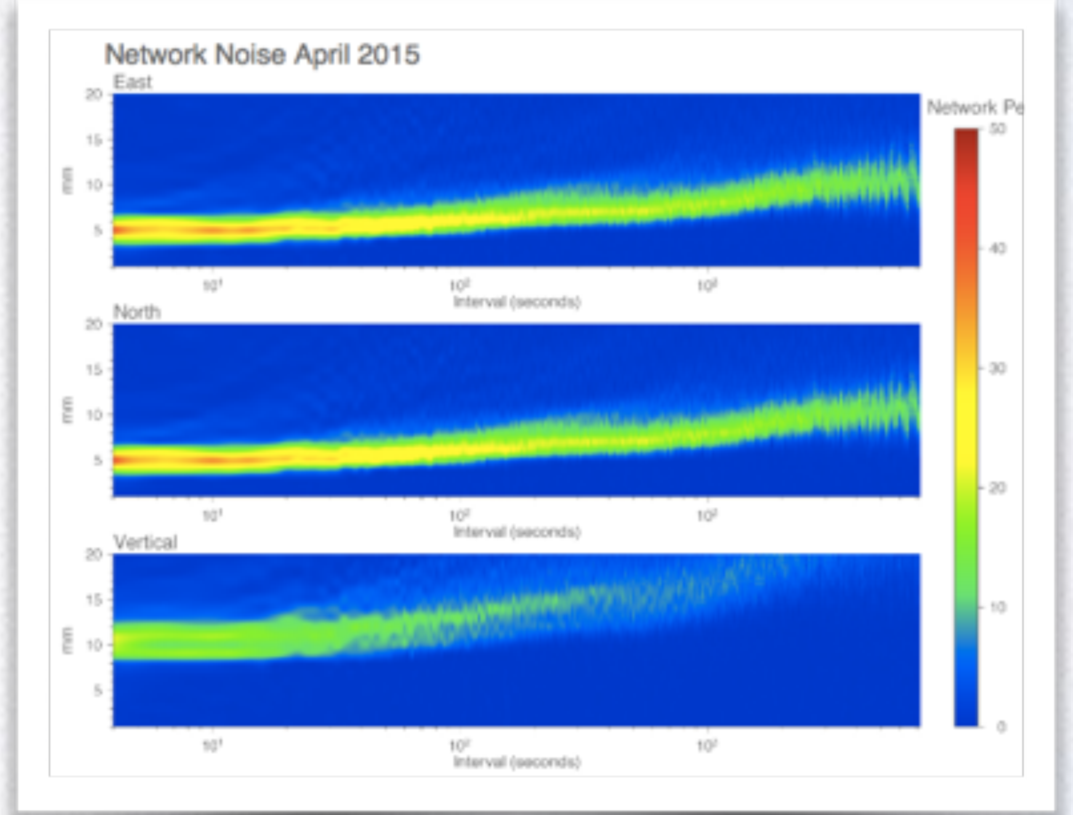


- GPS Daily Positioning Time Series
- GPS Quality Control Statistics
- GPS Station Velocity
- GPS Reflectometry
- **GPS Realtime Position Plots**







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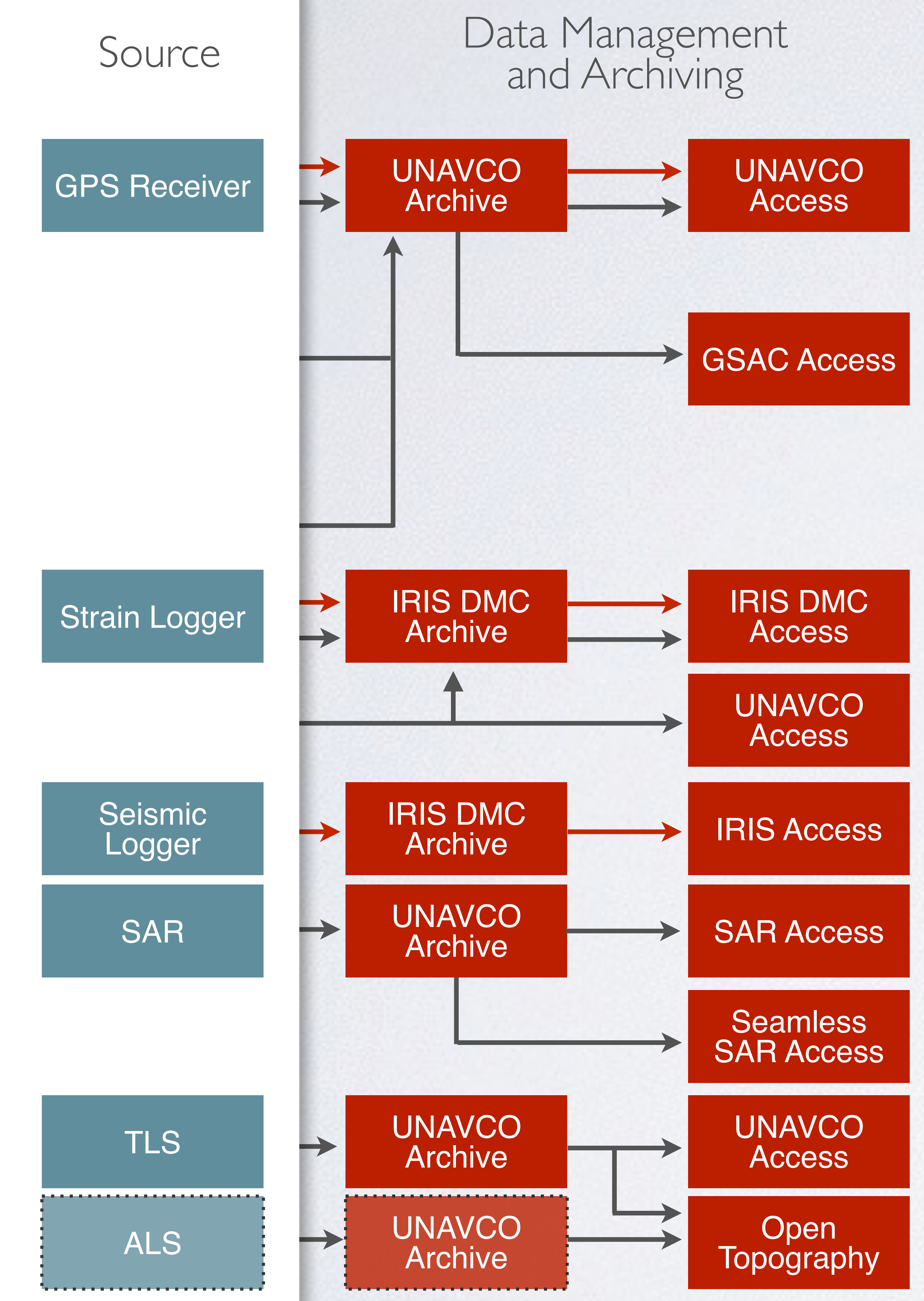
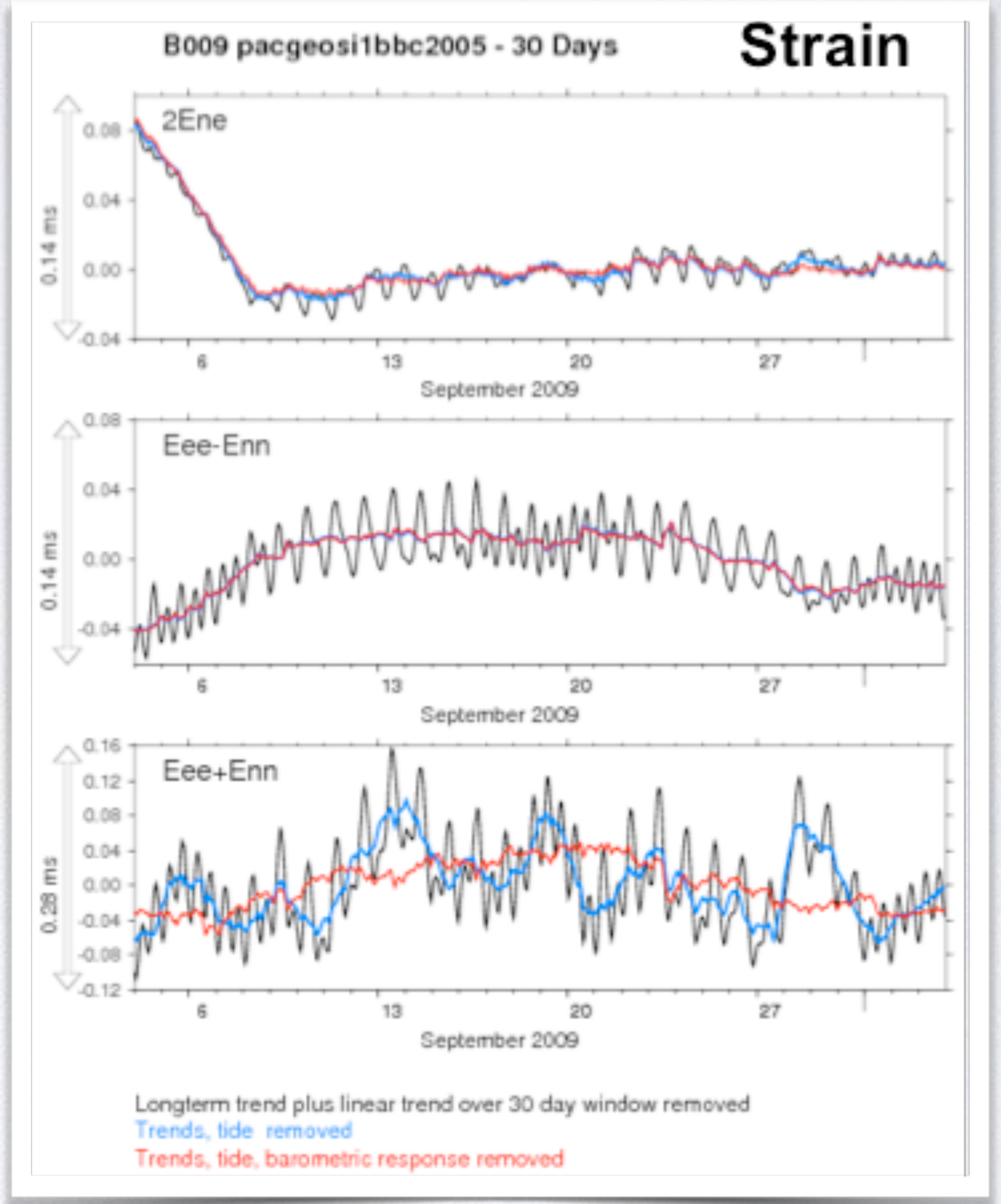
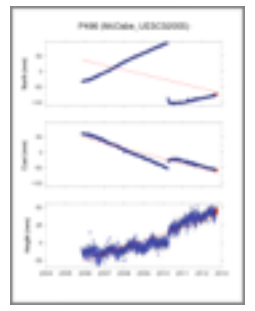
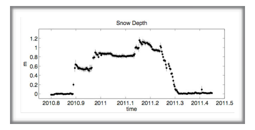


- GPS Daily Positioning Time Series
- GPS Quality Control Statistics
- GPS Station Velocity
- GPS Reflectometry
- GPS Realtime Position Plots
- **Borehole Strainmeter Time Series**







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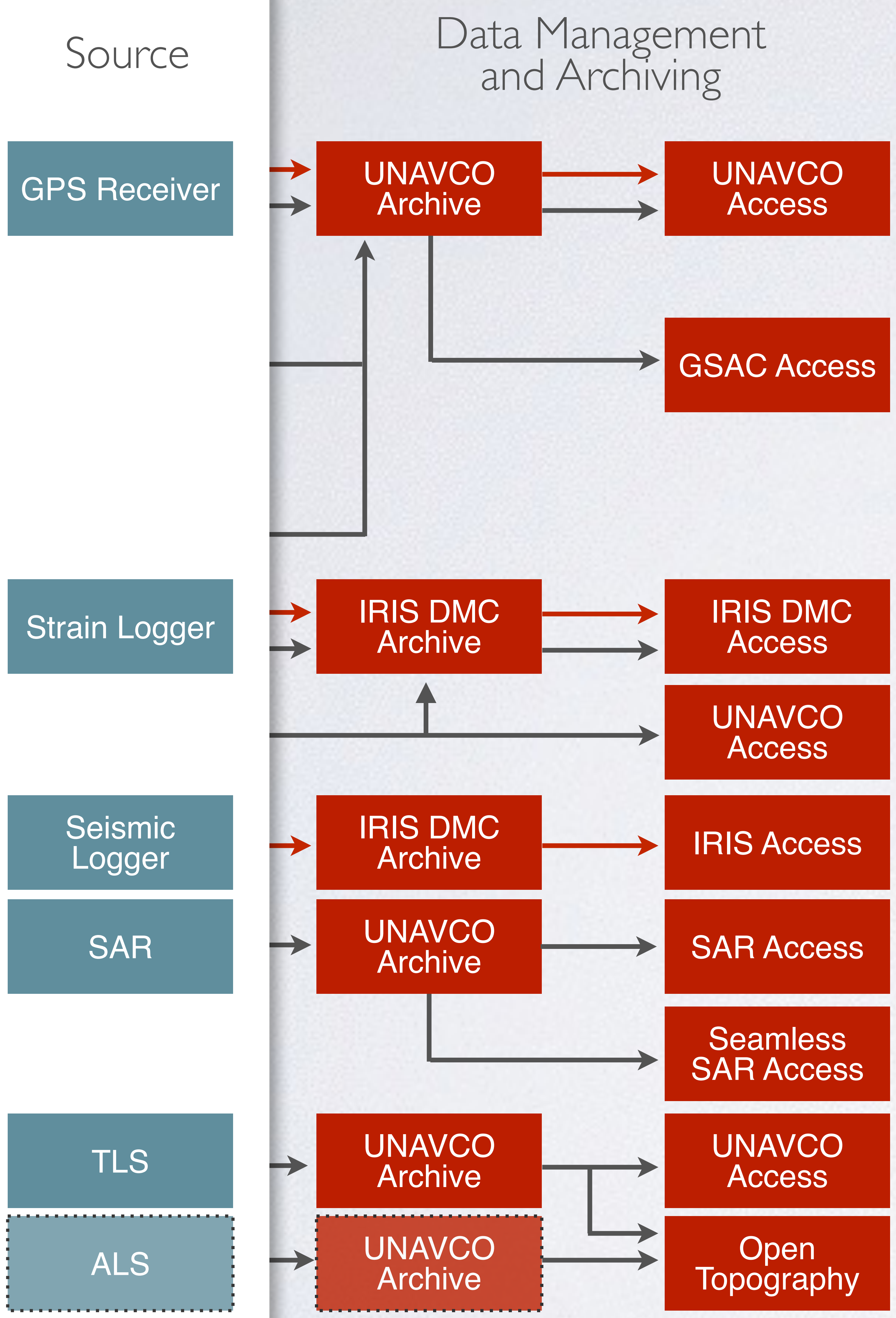
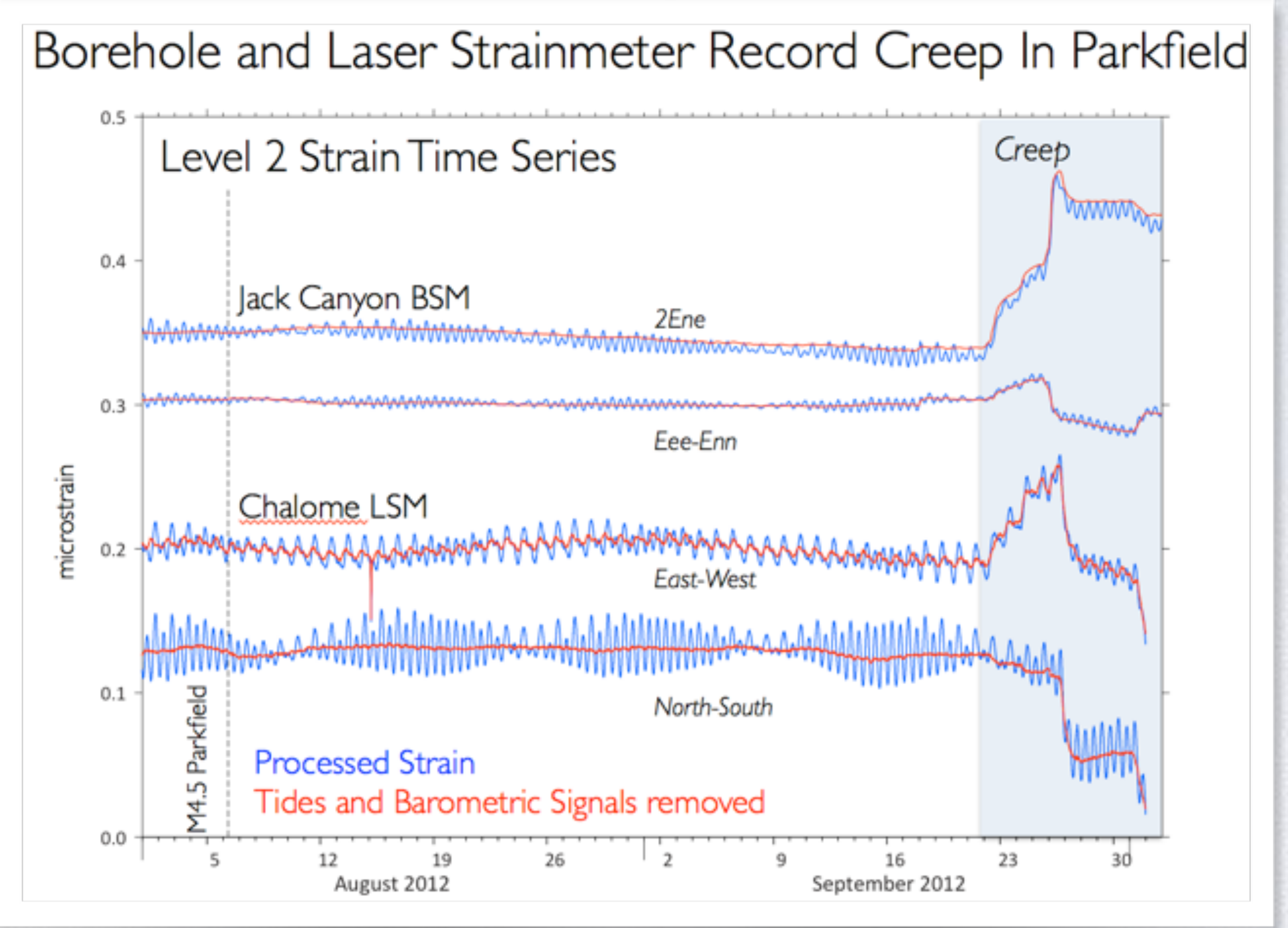
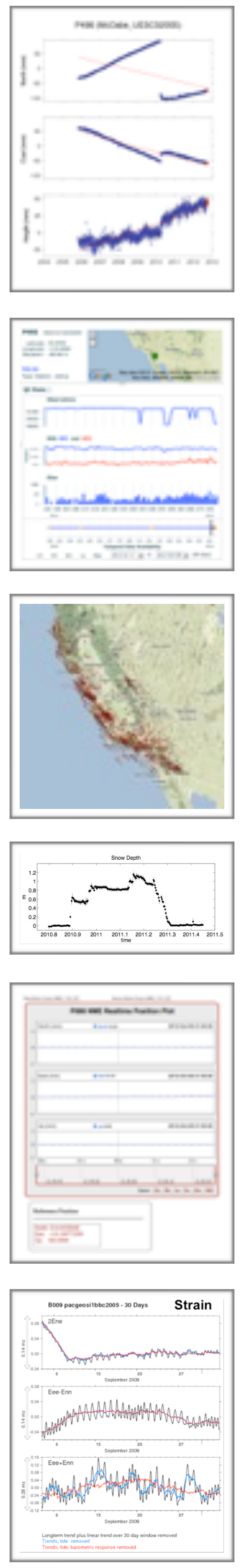


- GPS Daily Positioning Time Series
- GPS Quality Control Statistics
- GPS Station Velocity
- GPS Reflectometry
- GPS Realtime Position Plots
- Borehole Strainmeter Time Series
- **Long Baseline Laser Strainmeter Time Series**





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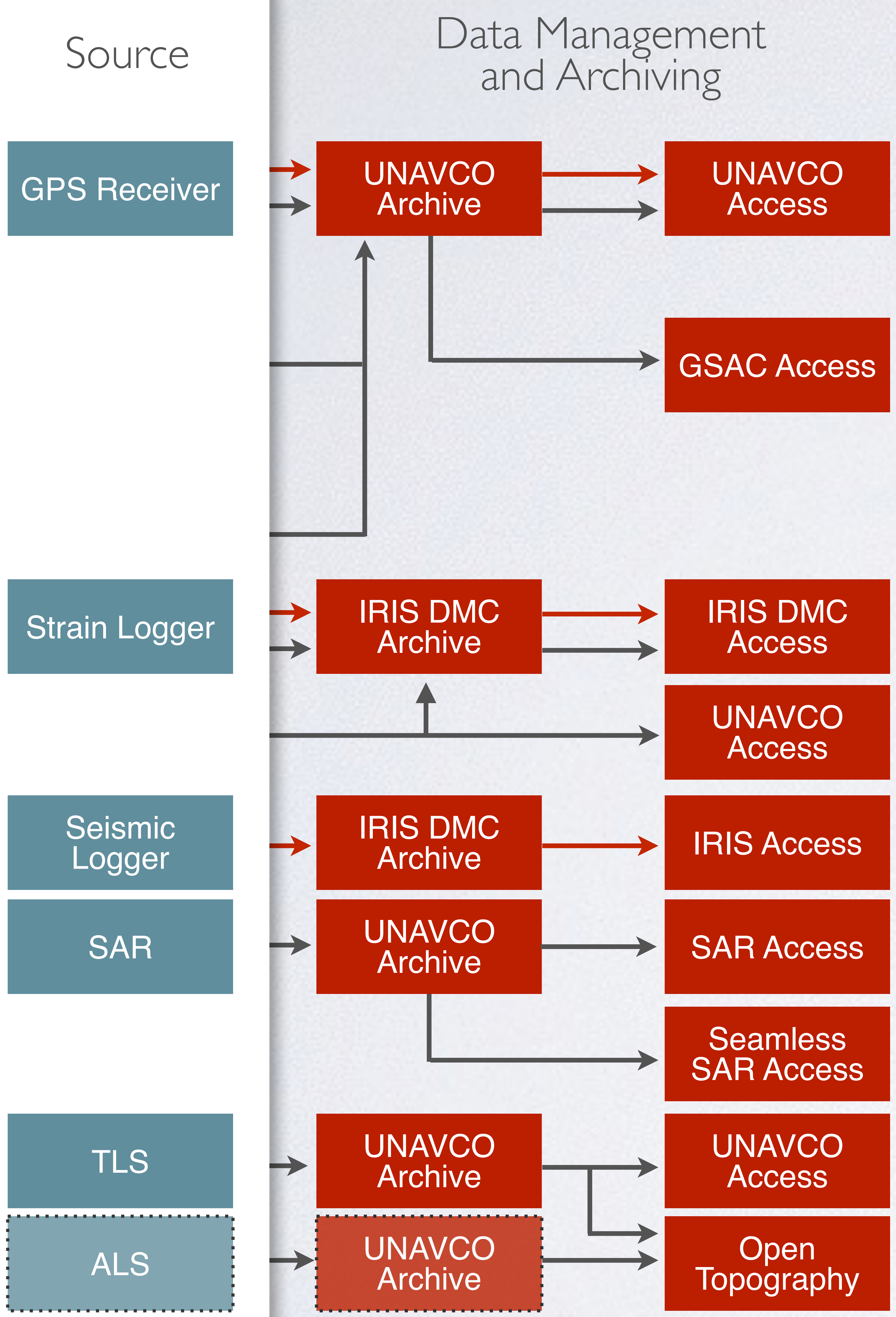

- GPS Daily Positioning Time Series
- GPS Quality Control Statistics
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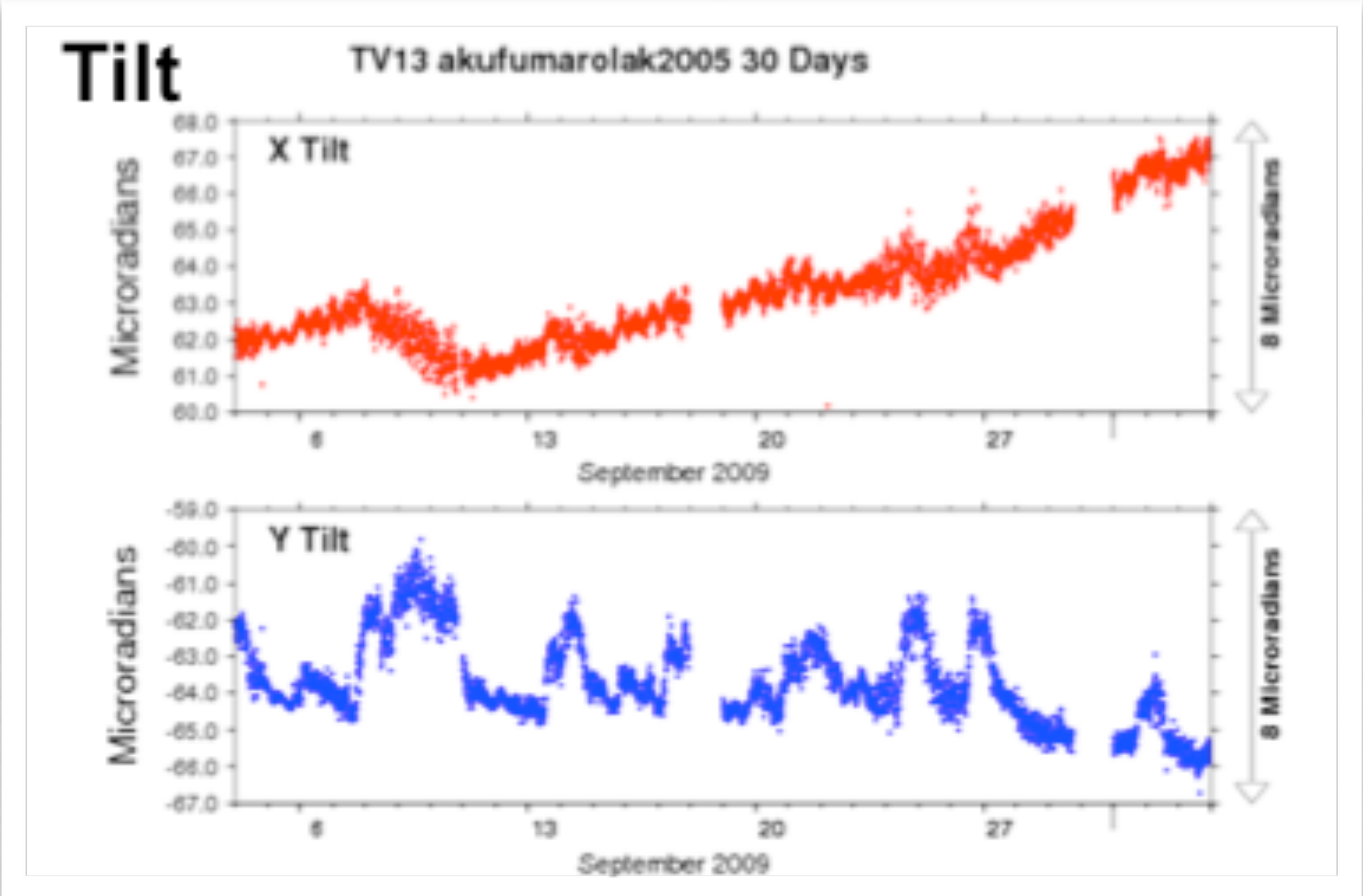
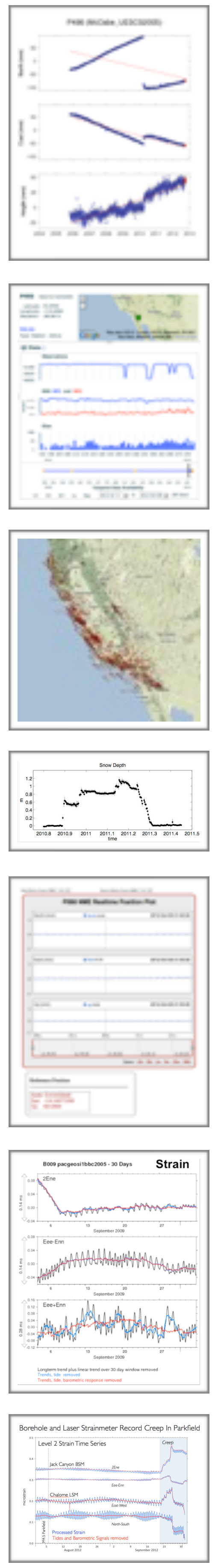
- Borehole Strainmeter Time Series
- Long Baseline Laser Strainmeter Time Series
- **Tiltmeter Time Series**





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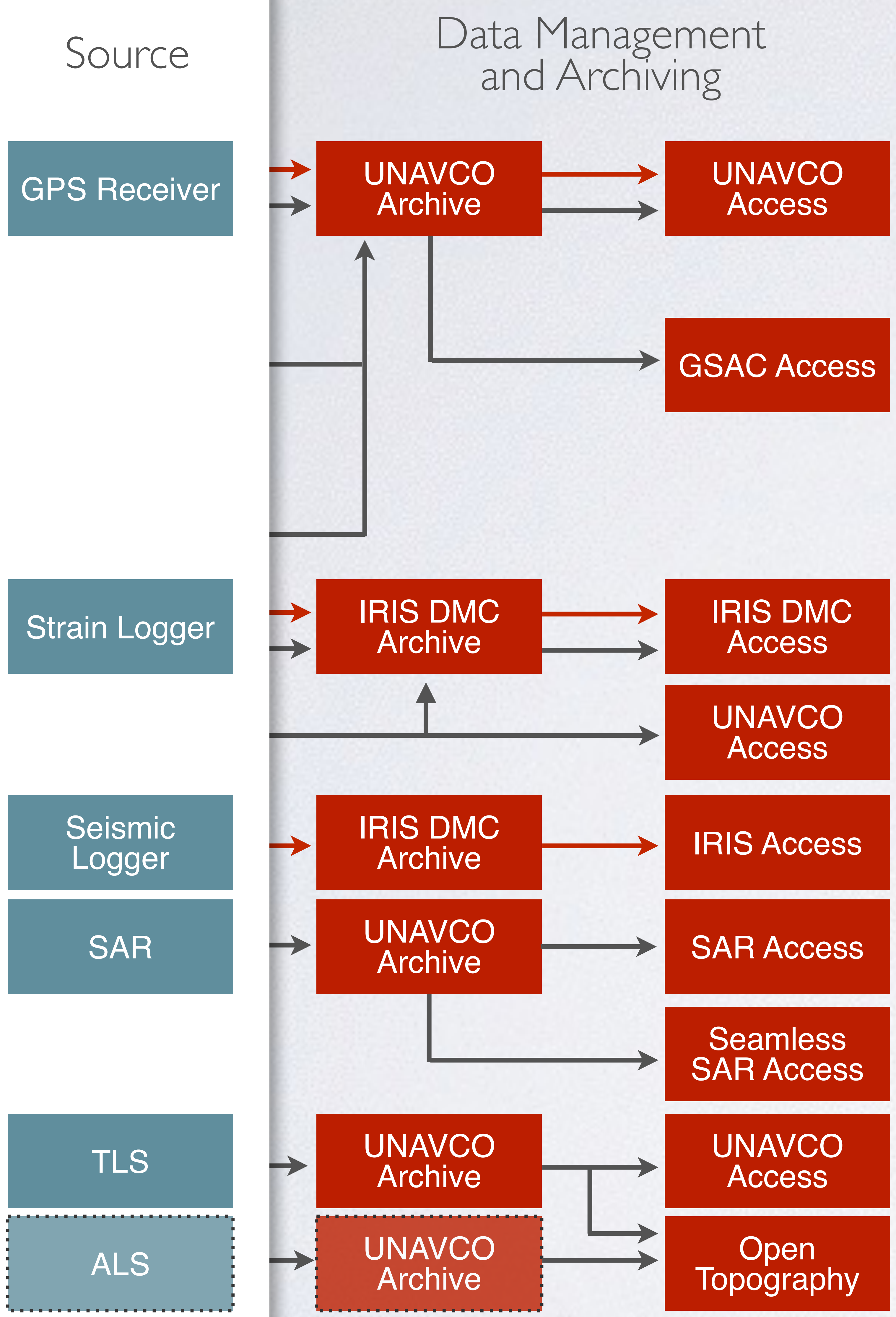
GEODETIC DATA SERVICES



- GPS Daily Positioning Time Series
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- GPS Station Velocity
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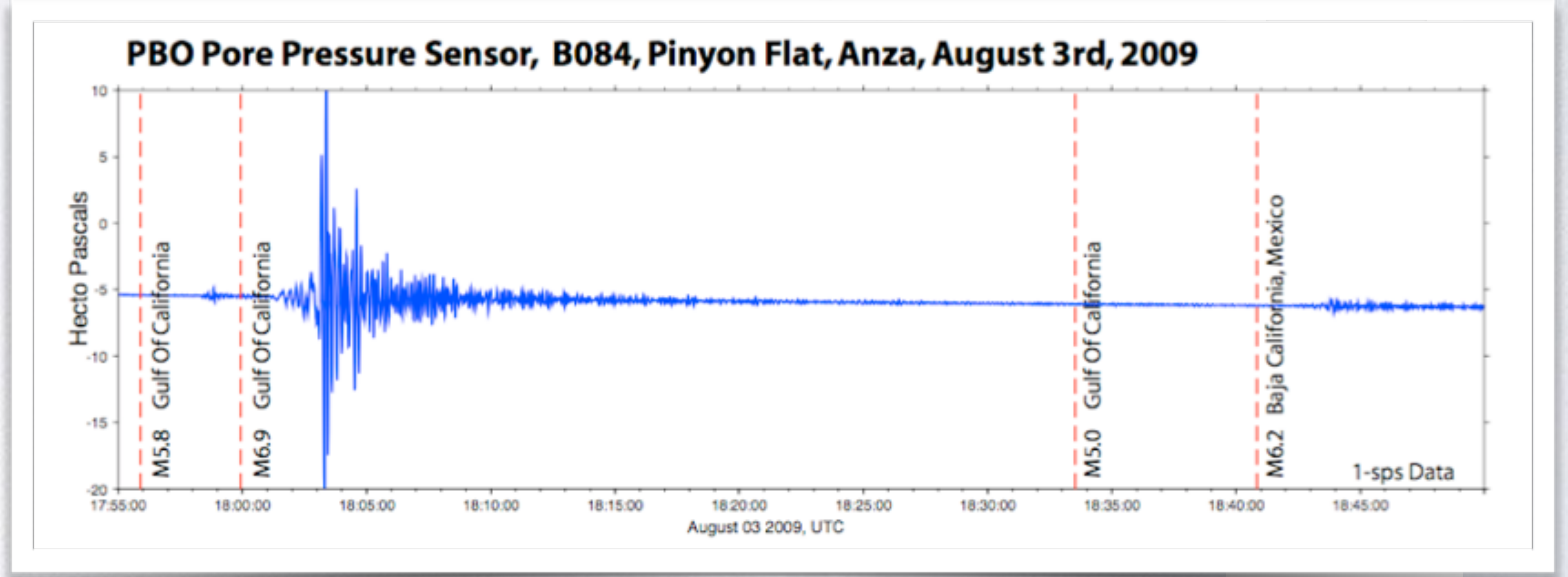
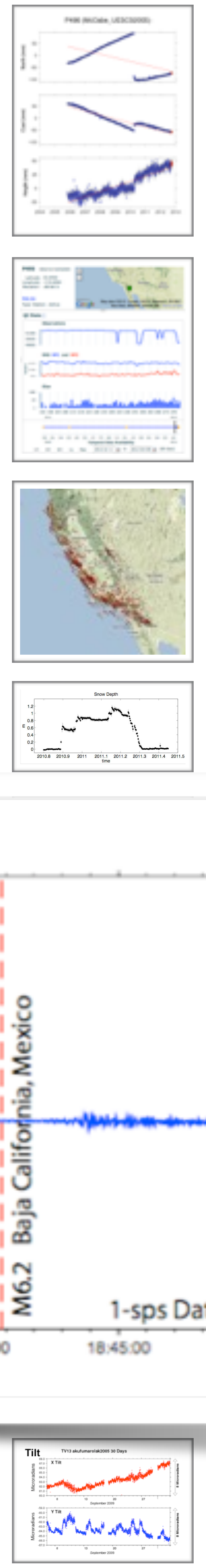
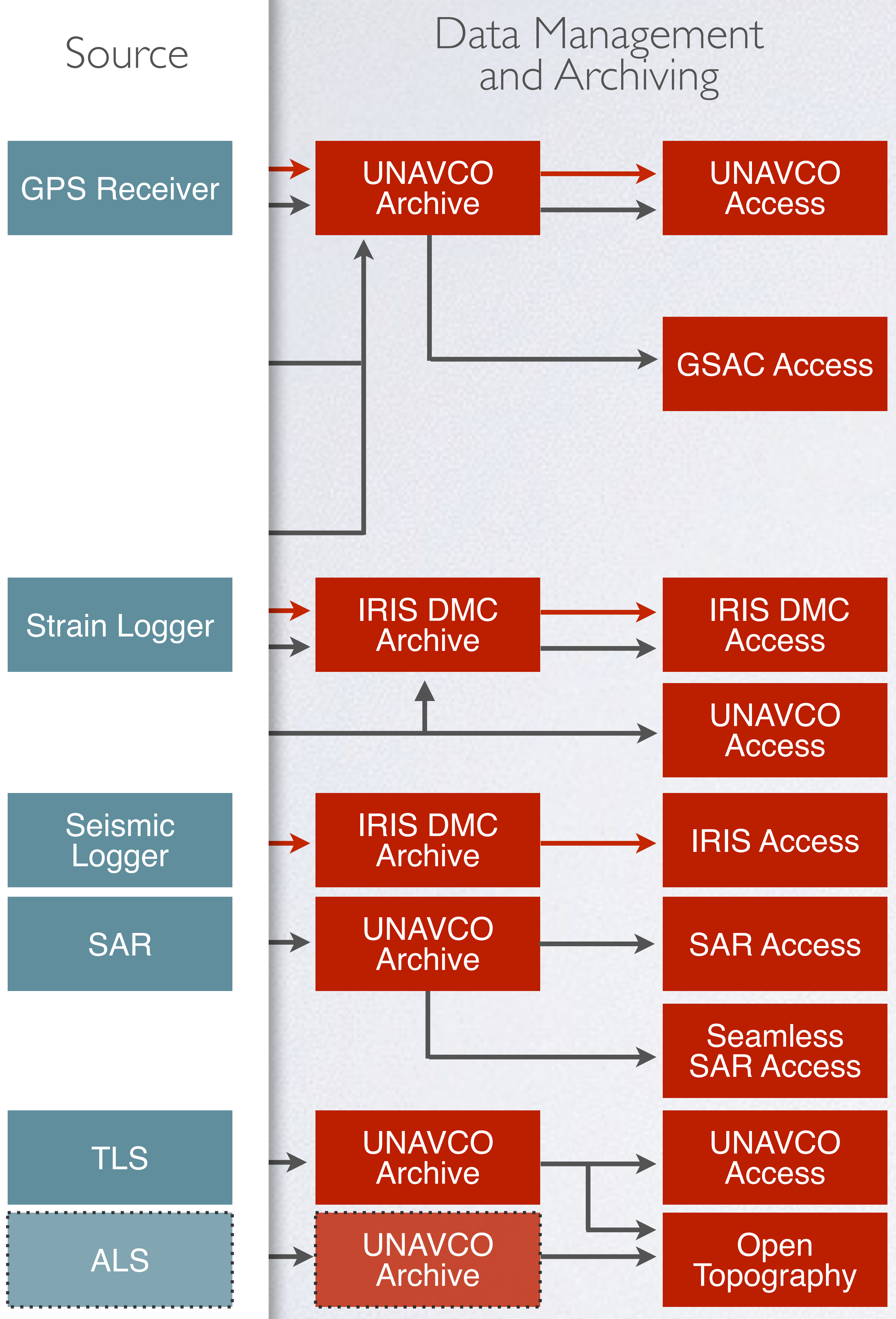
- GPS Realtime Position Plots
- Borehole Strainmeter Time Series
- Long Baseline Laser Strainmeter Time Series
- Tiltmeter Time Series
- **Pore Pressure Time Series**





GEODETIC DATA SERVICES



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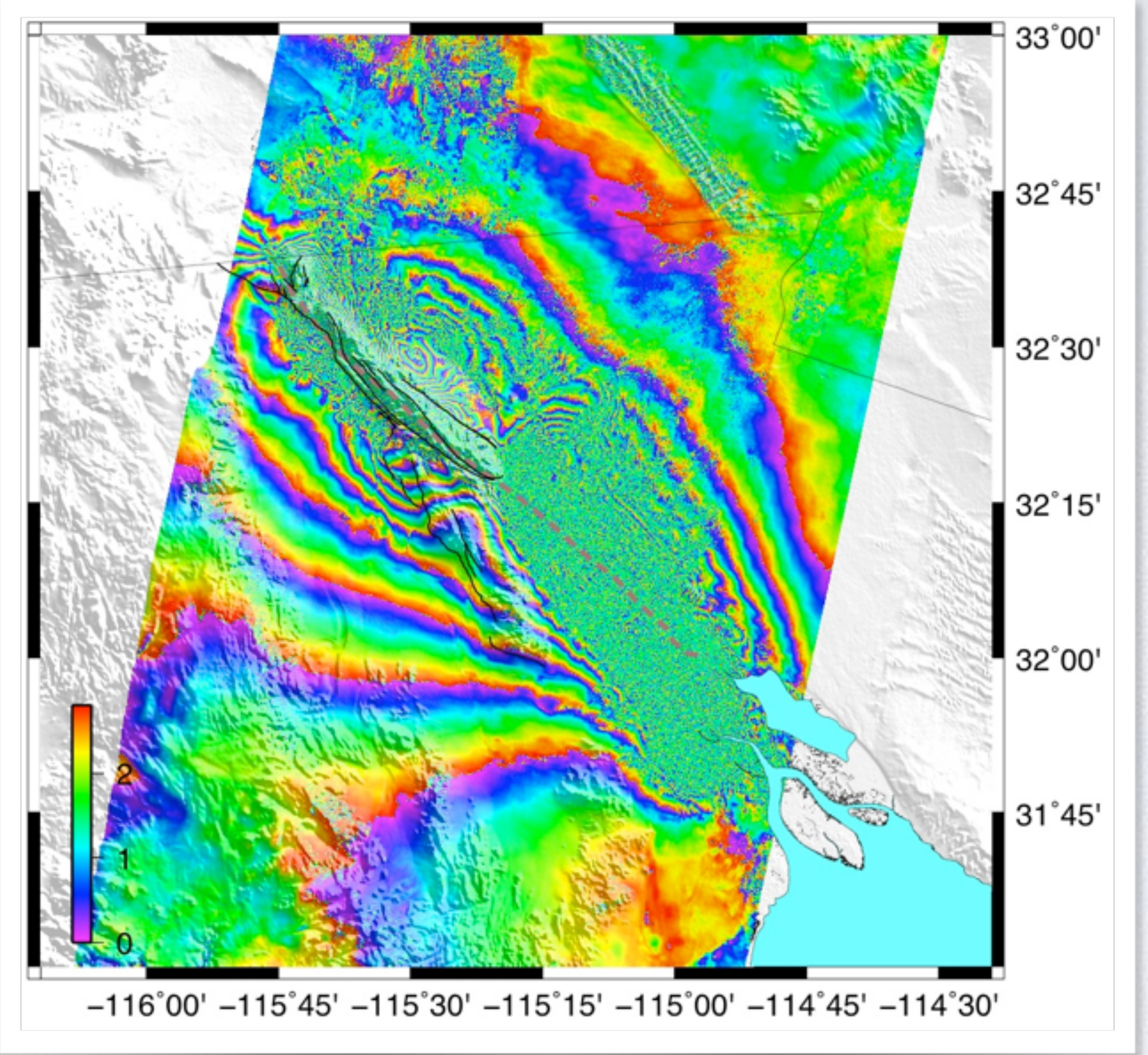
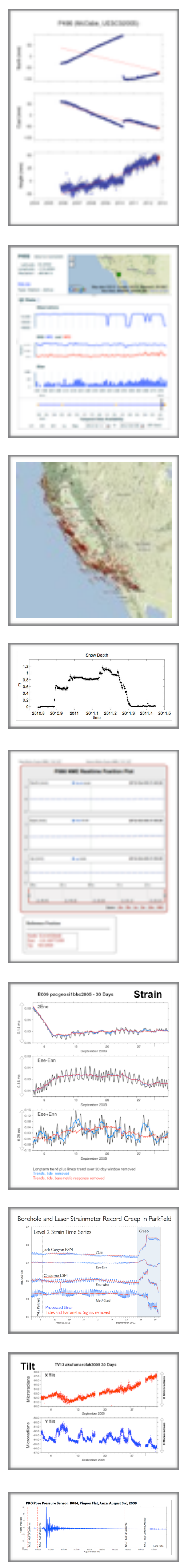
- Pore Pressure Time Series
- **Satellite and Aircraft InSAR Data**





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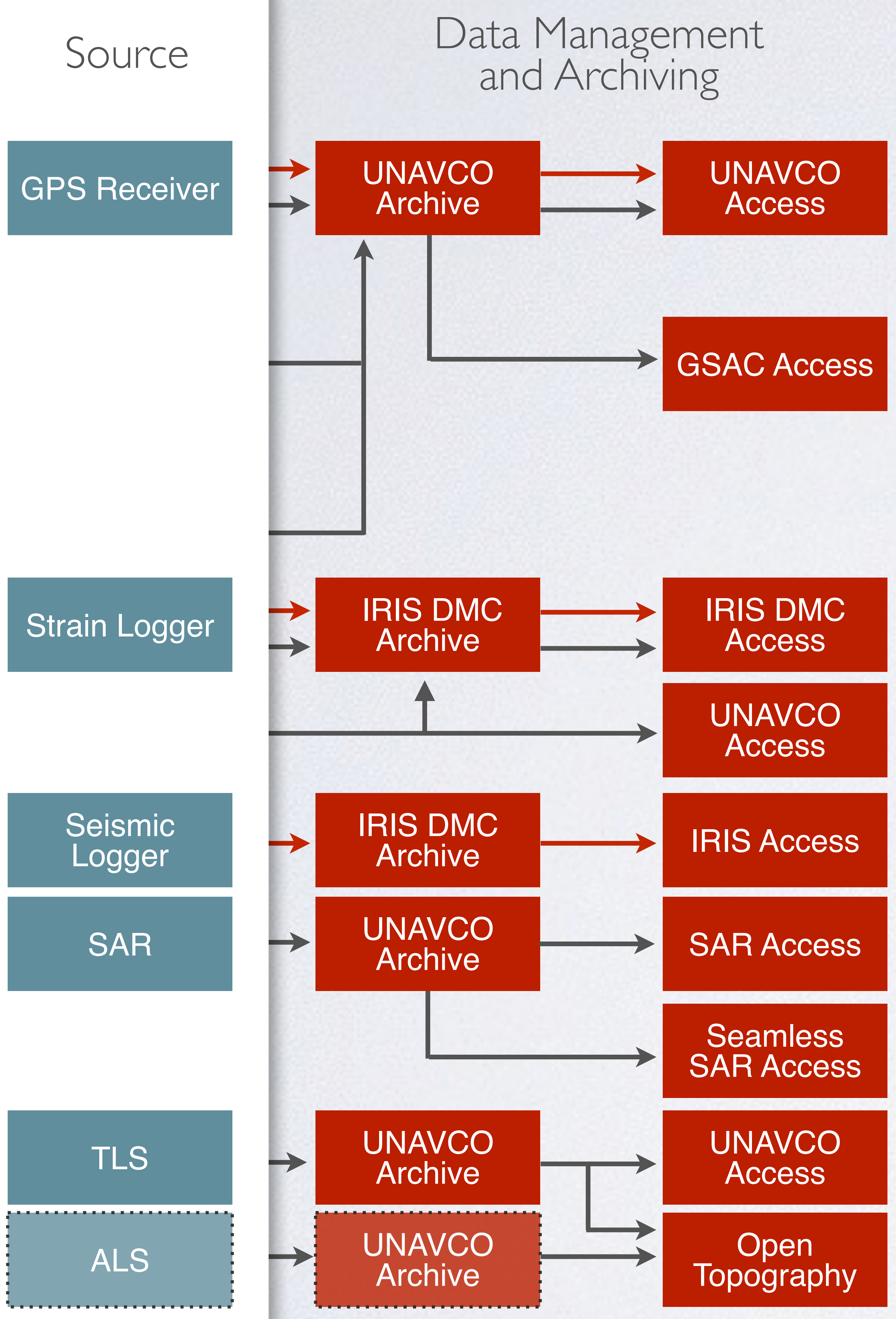

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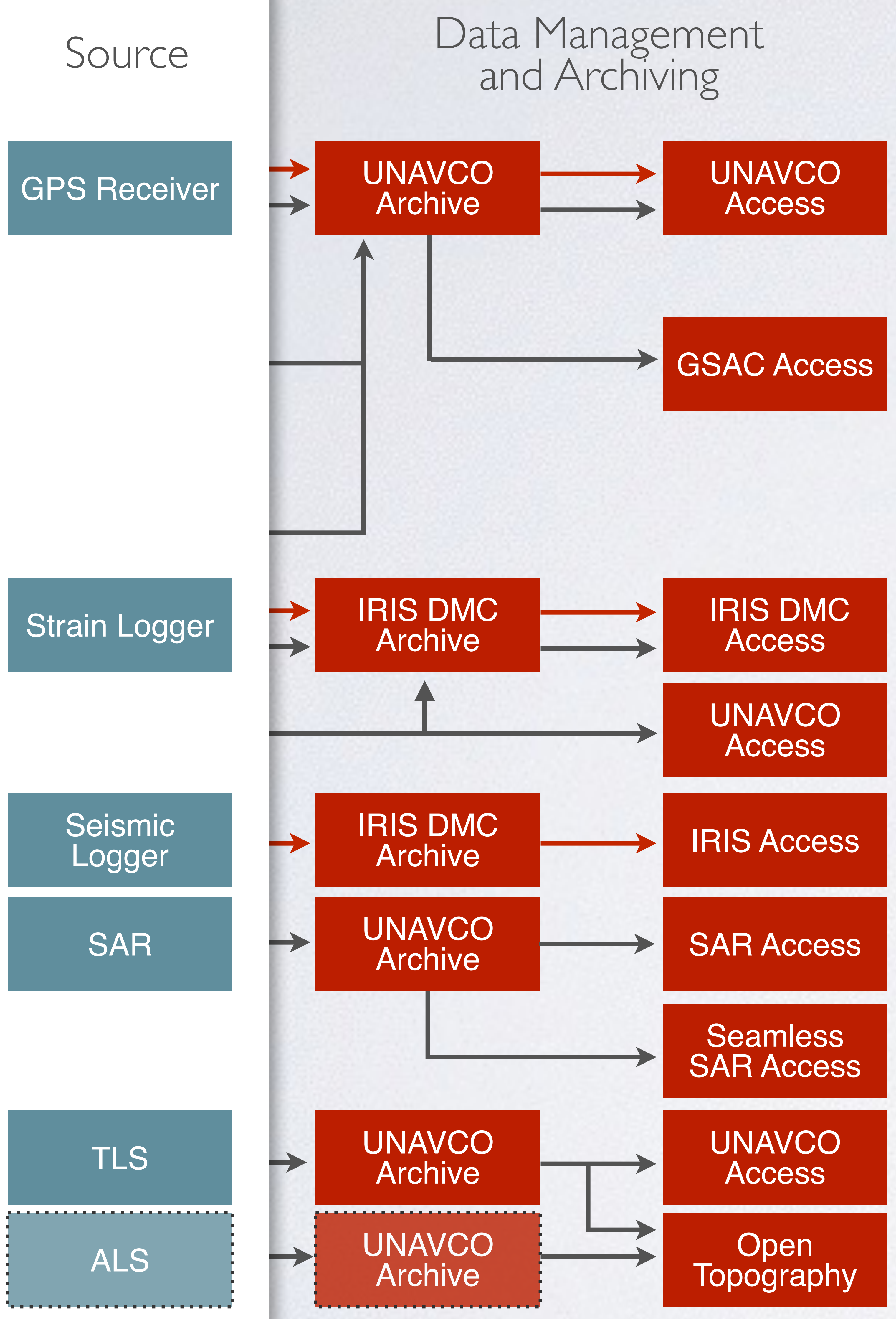
- Satellite and Aircraft InSAR Data
- **Airborne Laser Scanning (Lidar) Data**

GEODETIC DATA SERVICES



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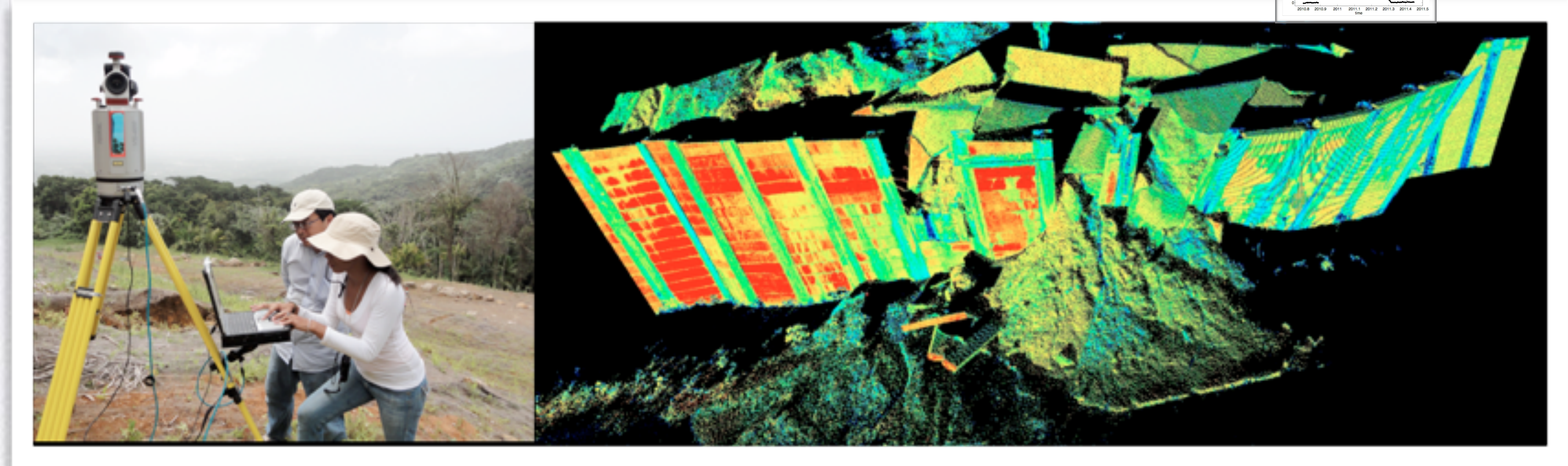
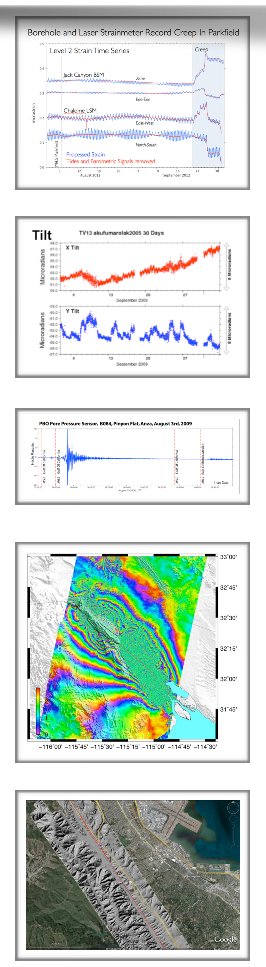
- **Terrestrial Laser Scanning (Lidar) Data**

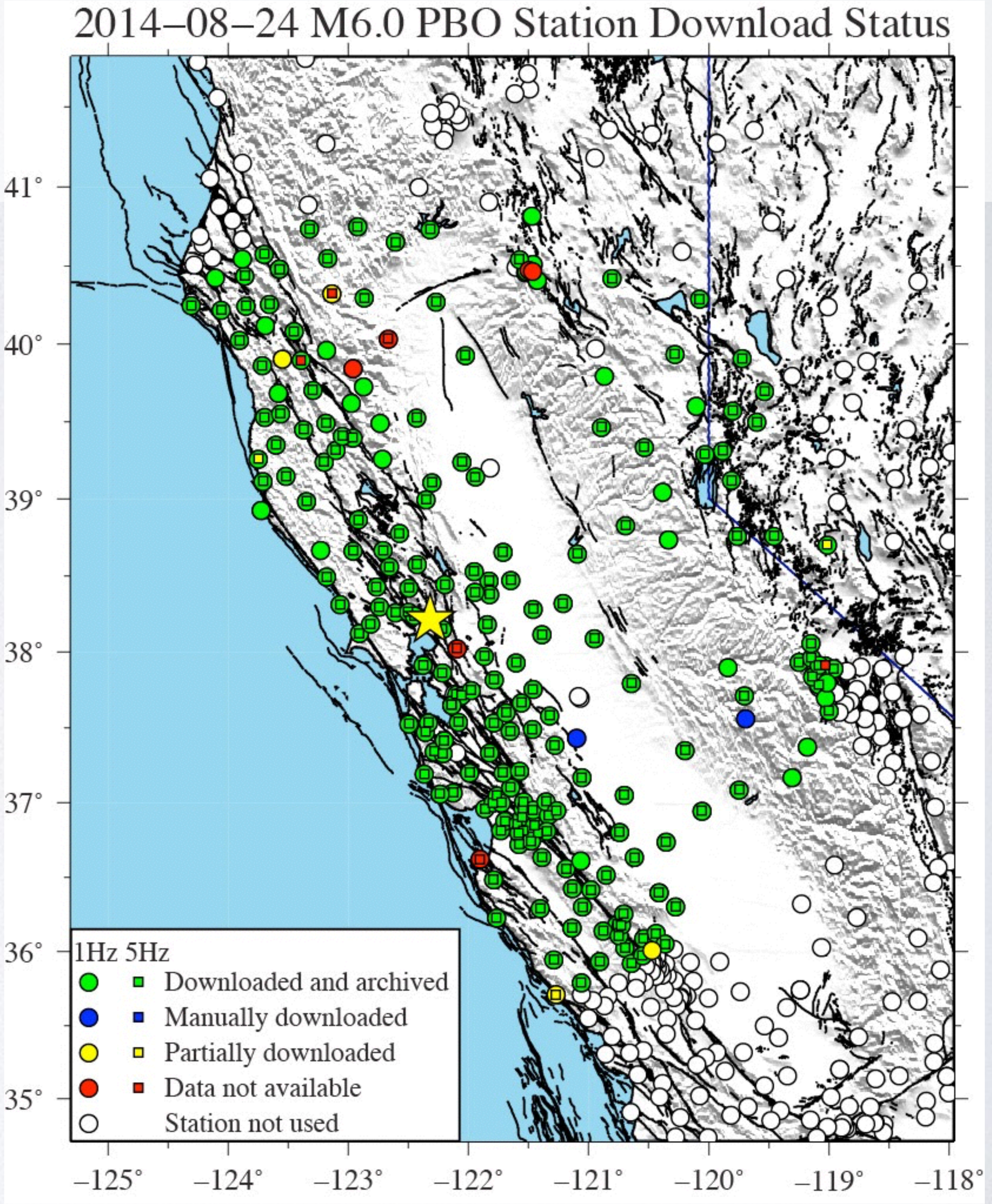




CUSTOM DATA

- UNAVCO provides "custom" data products from PBO stations in addition to "standard" products. Examples:
  - High rate GPS RINEX (1-sps, 5-sps)
  - High rate BSM processed data (1-sps)
- ...For geophysical event response. Recent examples:
  - M8.2 Iquique, Chile 2014-04-01. Full network download (first ever at 5-sps)...1102 stations... 1.6 TB data...160 hours of GDS staff time over 6 weeks.
  - M6.0 American Canyon (Napa) 2014-08-24. All GPS stations within 300 km of epicenter...219 stations total.
- ...For non-event community projects (e.g., airborne LiDAR surveys)
- Custom data requests often epitomize the full suite of UNAVCO staff and services...GI, GDS, ECE...all groups are involved

NAPA EARTHQUAKE RESPONSE ->



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**

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PHOTO GALLERIES

Big Science: The Universe's Ten Most Epic Projects

By Gregory Mone, Brooke Borel, Katherine Bagley and Jennifer Abbasi Posted 7.16.11 at 8:06 pm 12 Comments

IMAGE 10 OF 10

1: The Earthscope

EarthScope

Annual budget: $25,000,000
Construction cost: $197,000,000
Staff: 110
Physical size: 3.8 million square miles
Scientific utility: 10
WIIFY: 10
Wow factor: 10

A telescope to peer deep into the heart of our planet

Designed to track North America's geological evolution, EarthScope is the largest science project on the planet. This earth-sciences observatory records data over 3.8 million square miles. Since 2003, its more than 4,000 instruments have amassed 67 terabytes of data—that's equivalent to more than a quarter of the data in the Library of Congress—and add another terabyte every six to eight weeks

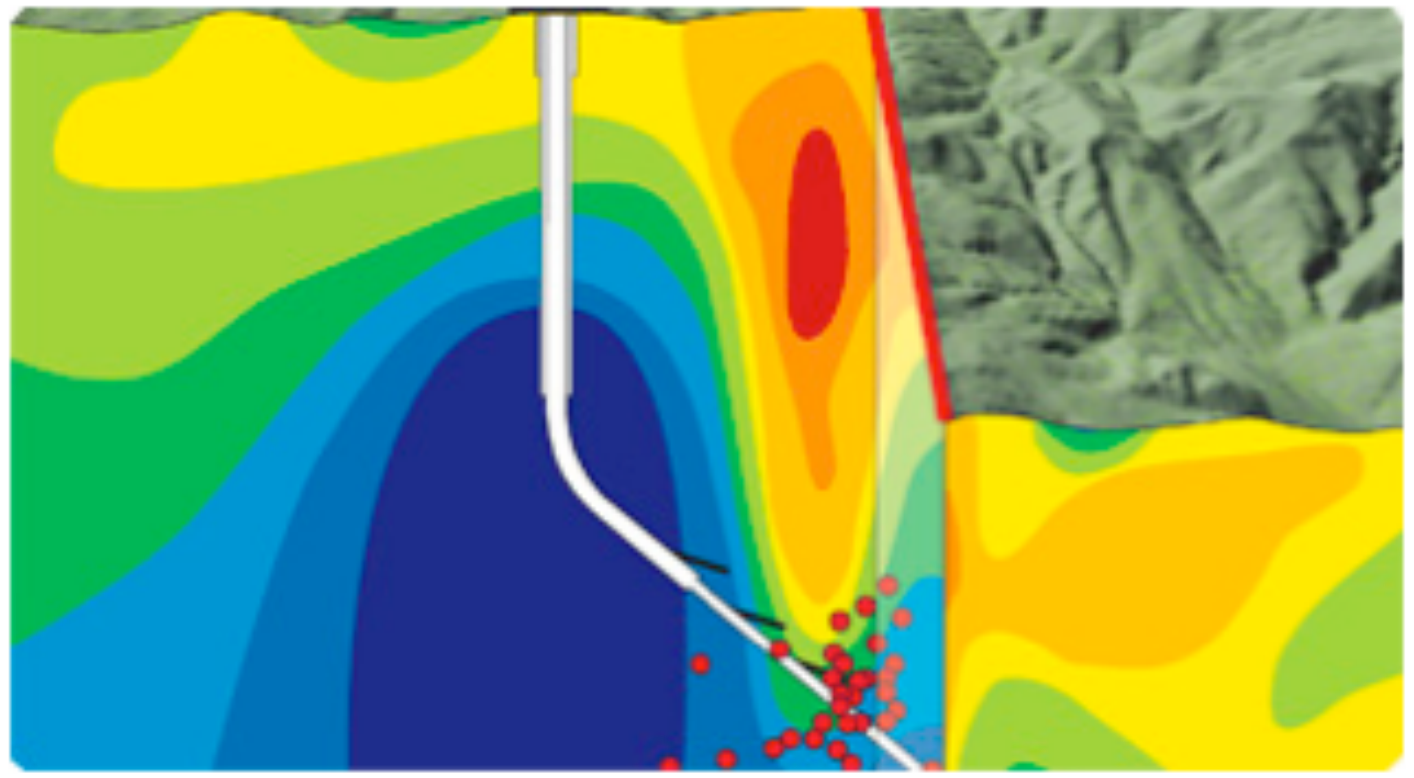
Scientific Utility

Researchers are using EarthScope, which consists of many kinds of experiments, to examine all facets of North America's geological composition. Across the continental U.S. and Puerto Rico, 1,100 permanent GPS units track deformations in the land's surface caused by tectonic shifts below. Seismic sensors next to the active San Andreas Fault in California record its tiniest slips, while rock samples pulled from a drill site that extends two miles into the fault reveal the grinding and strain on the rocks that occur when the two sides of the fault slide past each other during an earthquake. And over the course of 10 years, small crews have hauled a moveable array of 400 seismographs across the country using backhoes and sweat. By the time the stations reach the East Coast next year, they will have collected data from almost 2,000 locations.

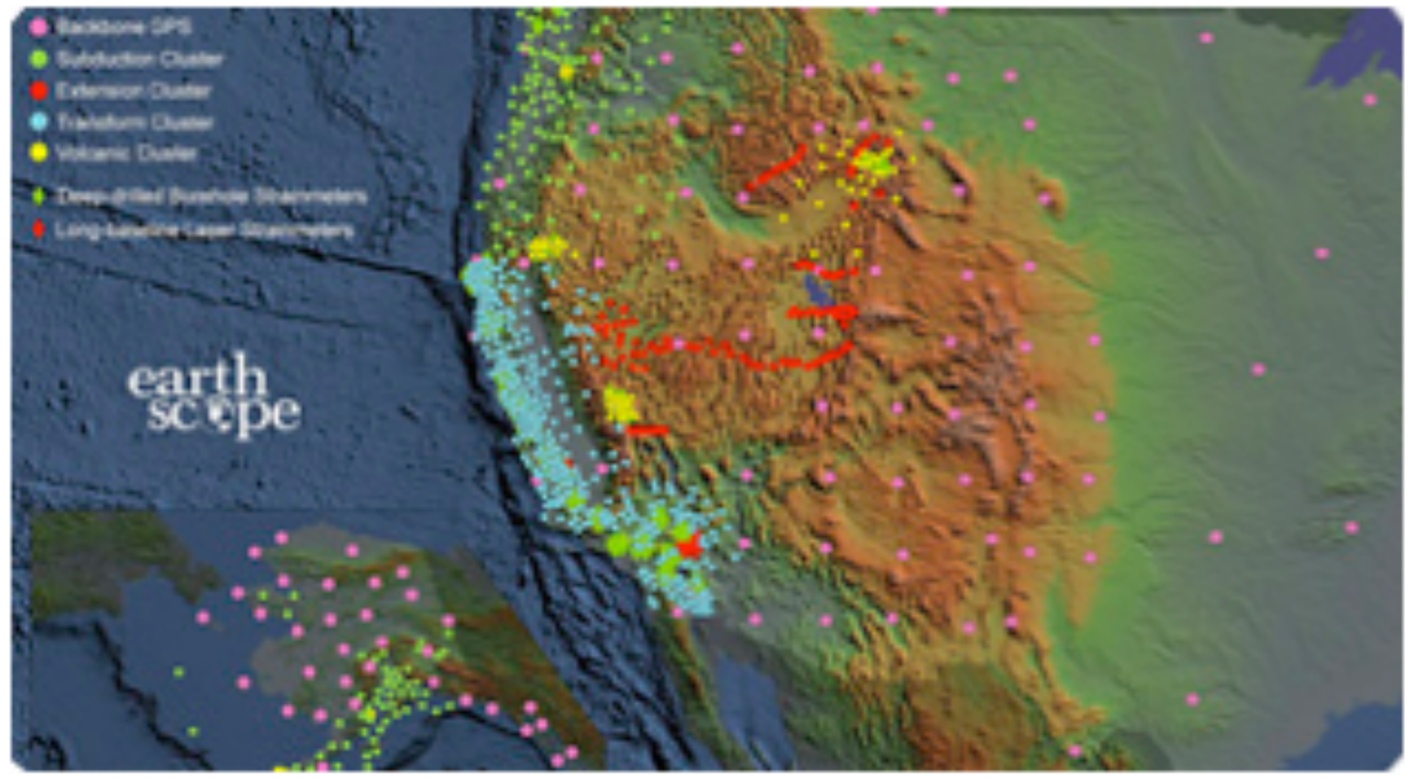
What's In It For You

Collectively, EarthScope's measurements could help explain the forces behind geological events such as earthquakes and volcanic eruptions, leading to better detection. So far, data from the project has shown that rocks in the San Andreas Fault are weaker than those outside it and that the plume of magma under Yellowstone's supervolcano is even bigger than previously suspected.

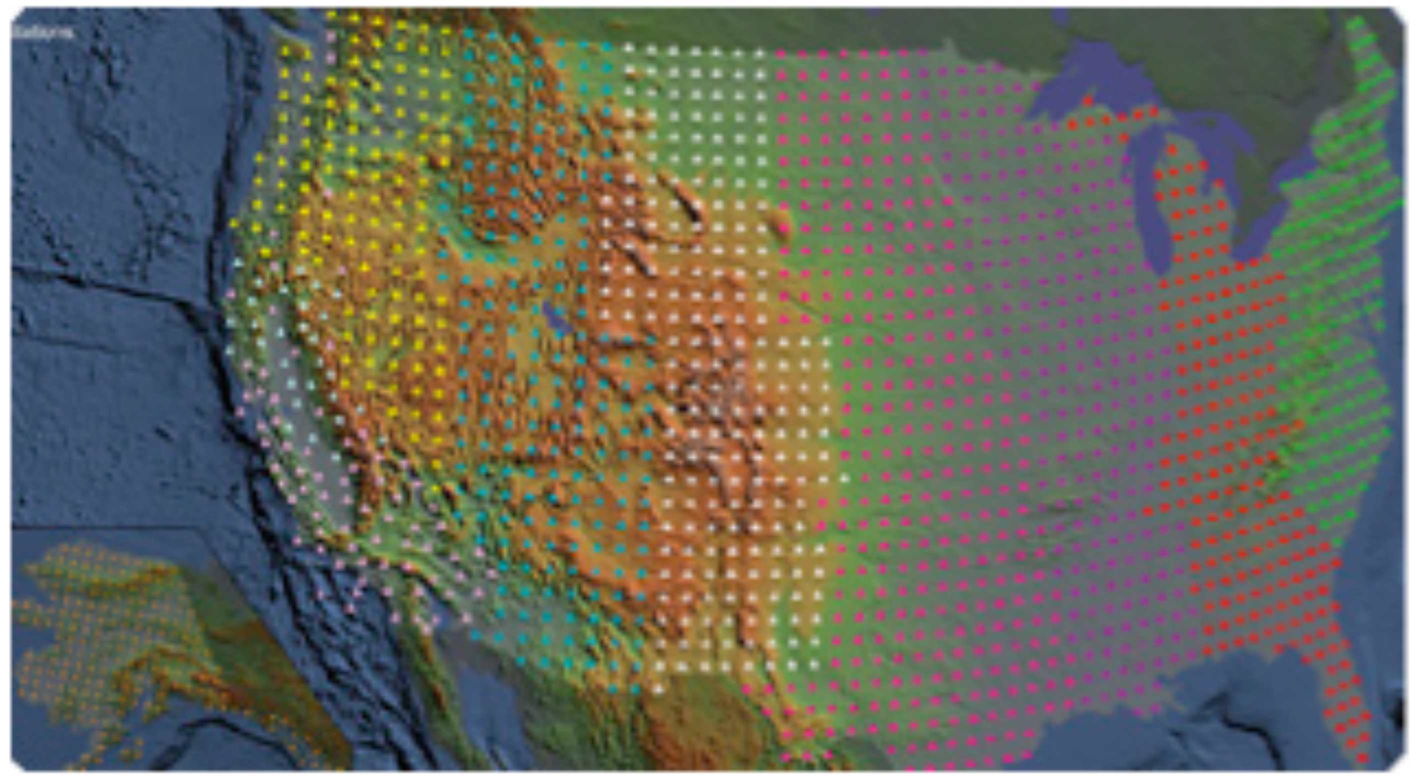
Drilling Component - SAFOD



Geodetic Component - PBO



Seismic Component - USArray



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Designed to track North America's geological evolution, EarthScope is the largest science project on the planet. This earth-sciences observatory records data over 3.8 million square miles. Since 2003, its more than 4,000 instruments have amassed 67 terabytes of data—that's equivalent to more than a quarter of the data in the Library of Congress—and add another terabyte every six to eight weeks

Scientific Utility

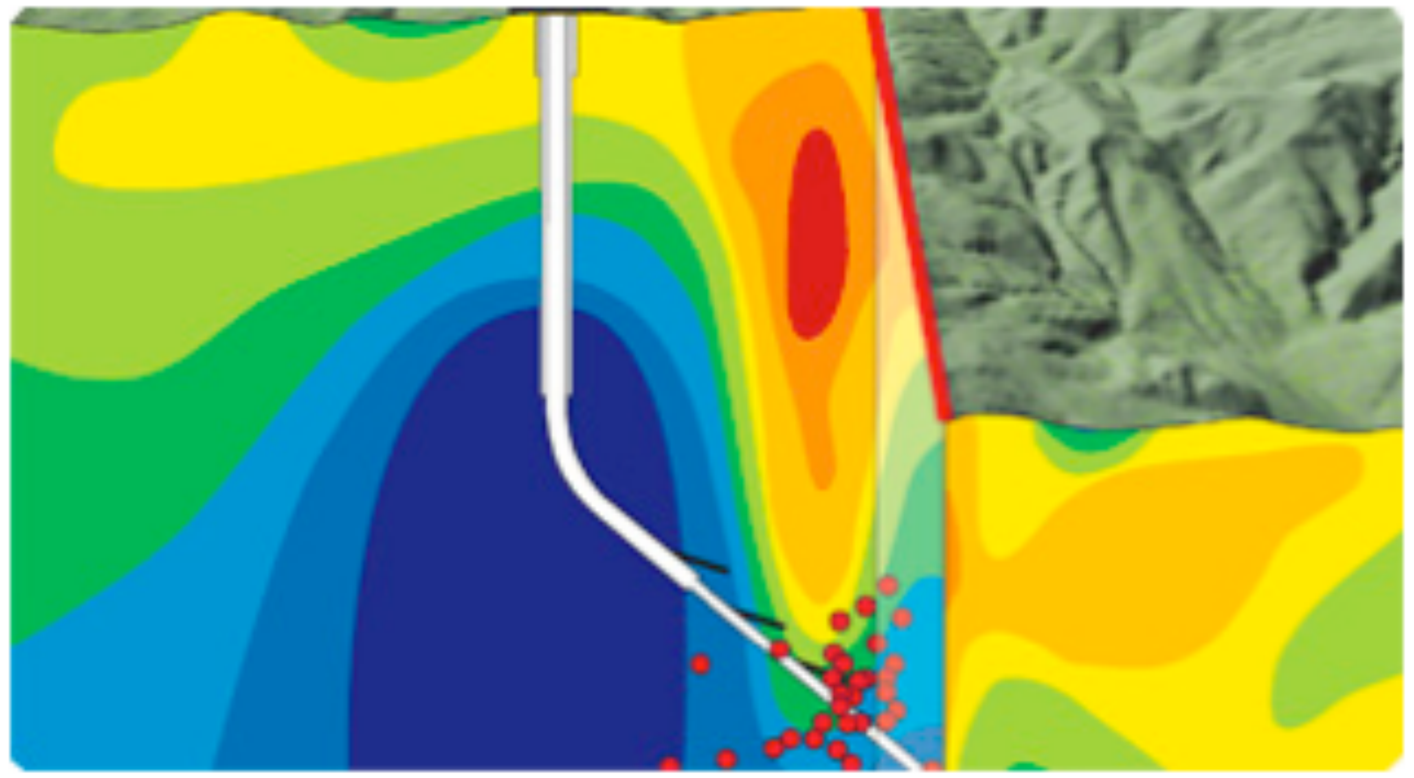
Researchers are using EarthScope, which consists of many kinds of experiments, to examine all facets of North America's geological composition. Across the continental U.S. and Puerto Rico, 1,100 permanent GPS units track deformations in the land's surface caused by tectonic shifts below. Seismic sensors next to the active San Andreas Fault in California record its tiniest slips, while rock samples pulled from a drill site that extends two miles into the fault reveal the grinding and strain on the rocks that occur when the two sides of the fault slide past each other during an earthquake. And over the course of 10 years, small crews have hauled a moveable array of 400 seismographs across the country using backhoes and sweat. By the time the stations reach the East Coast next year, they will have collected data from almost 2,000 locations.

What's In It For You

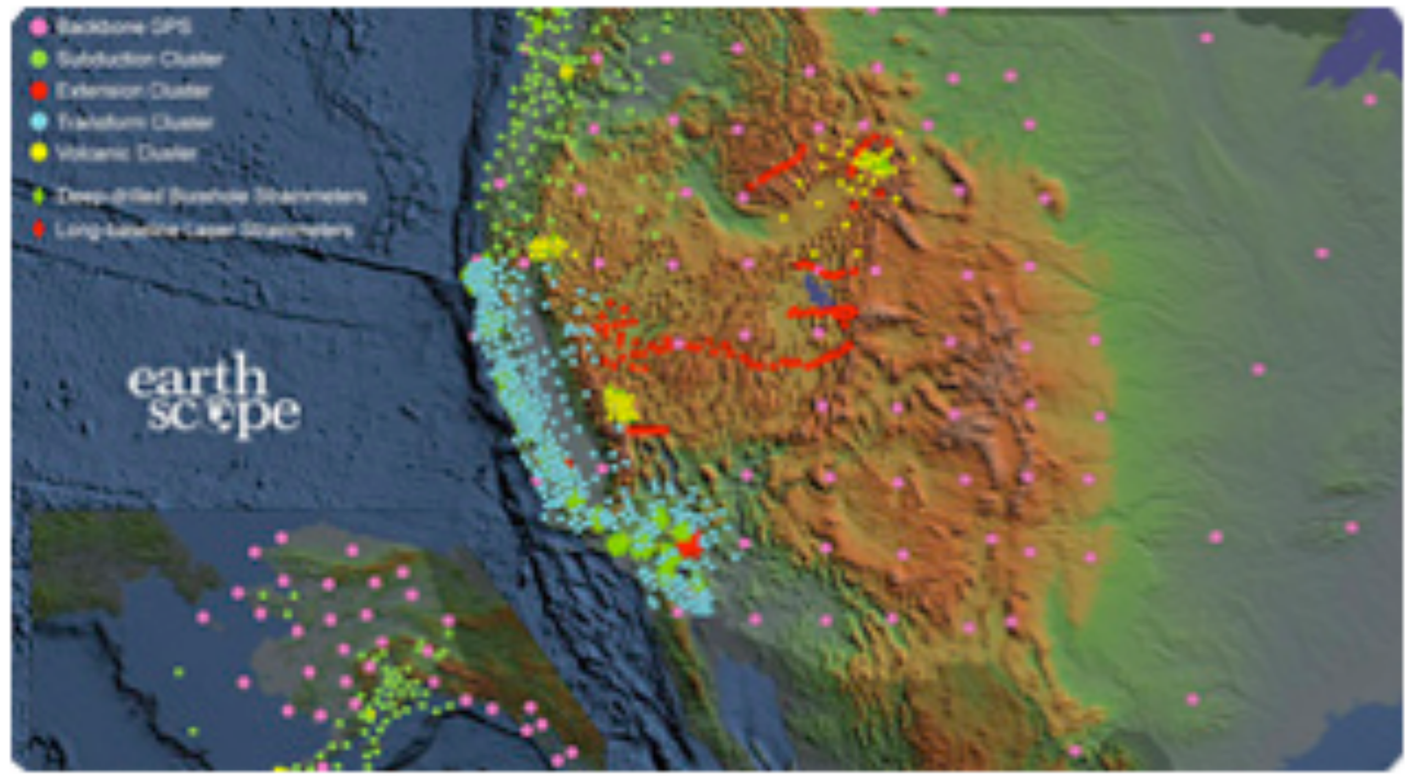
Collectively, EarthScope's measurements could help explain the forces behind geological events such as earthquakes and volcanic eruptions, leading to better detection. So far, data from the project has shown that rocks in the San Andreas Fault are weaker than those outside it and that the plume of magma under Yellowstone's supervolcano is even bigger than previously suspected.

EarthScope Imagery: Satellite InSAR and Airborne LiDAR (“GeoEarthScope”)

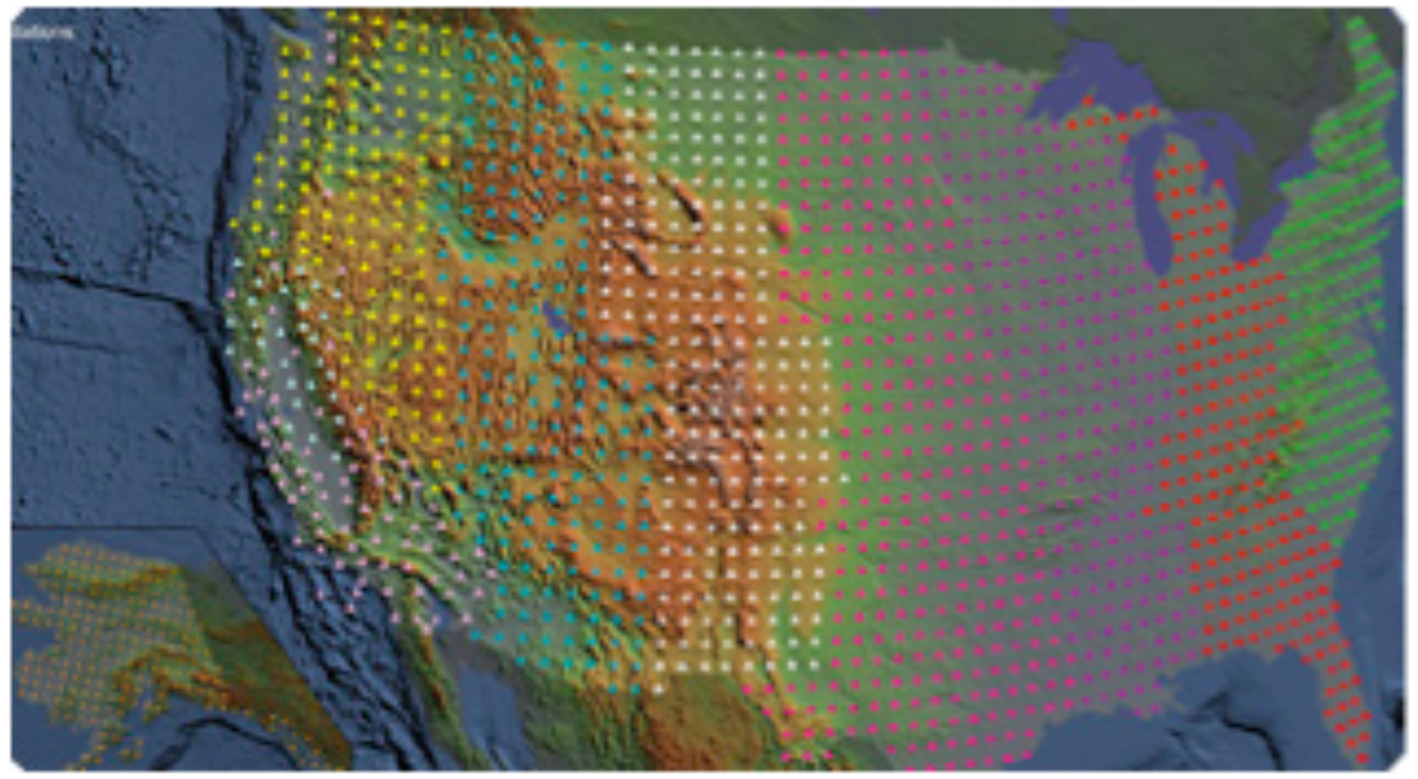
Drilling Component - SAFOD



Geodetic Component - PBO

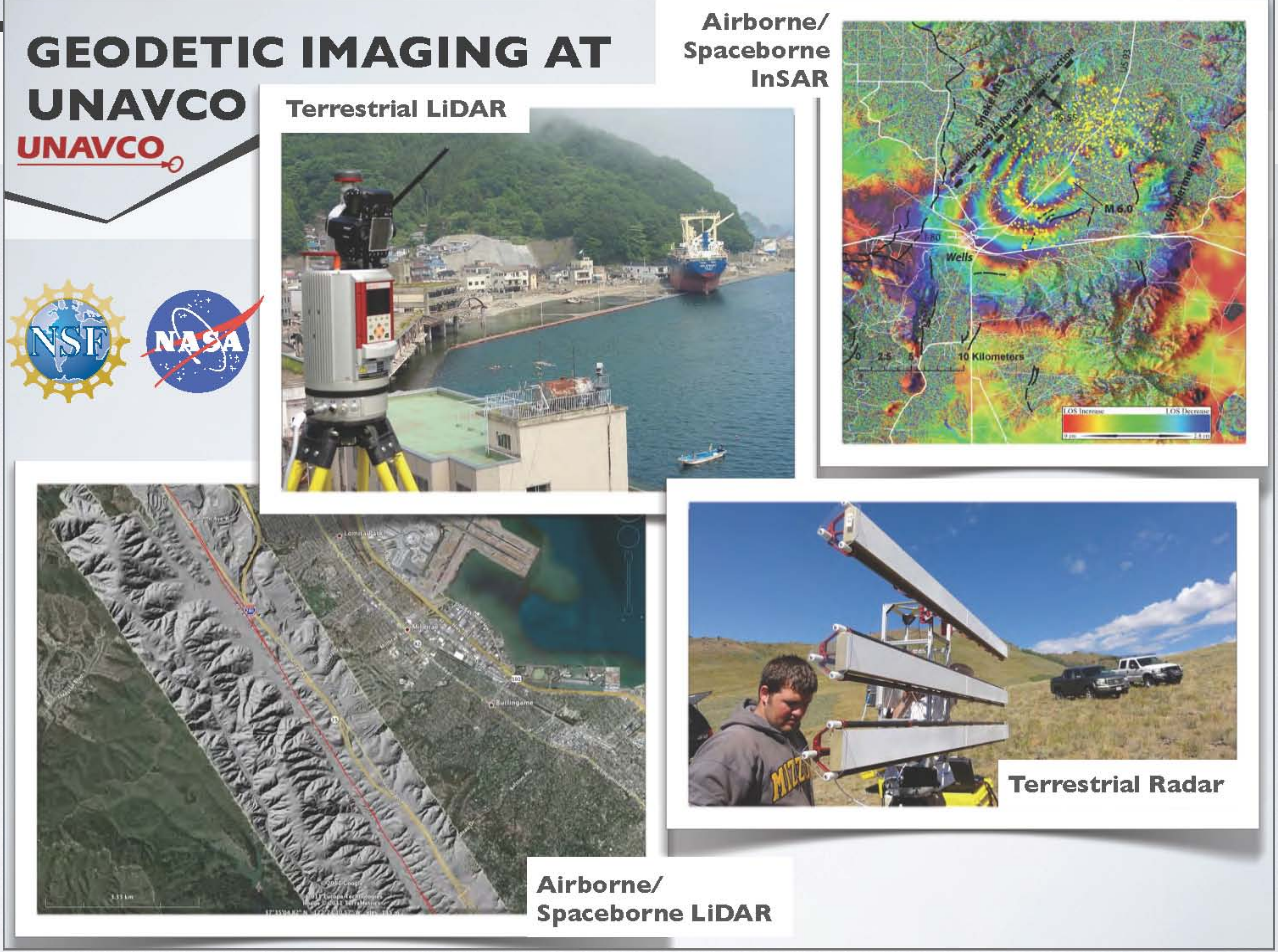


Seismic Component - USArray



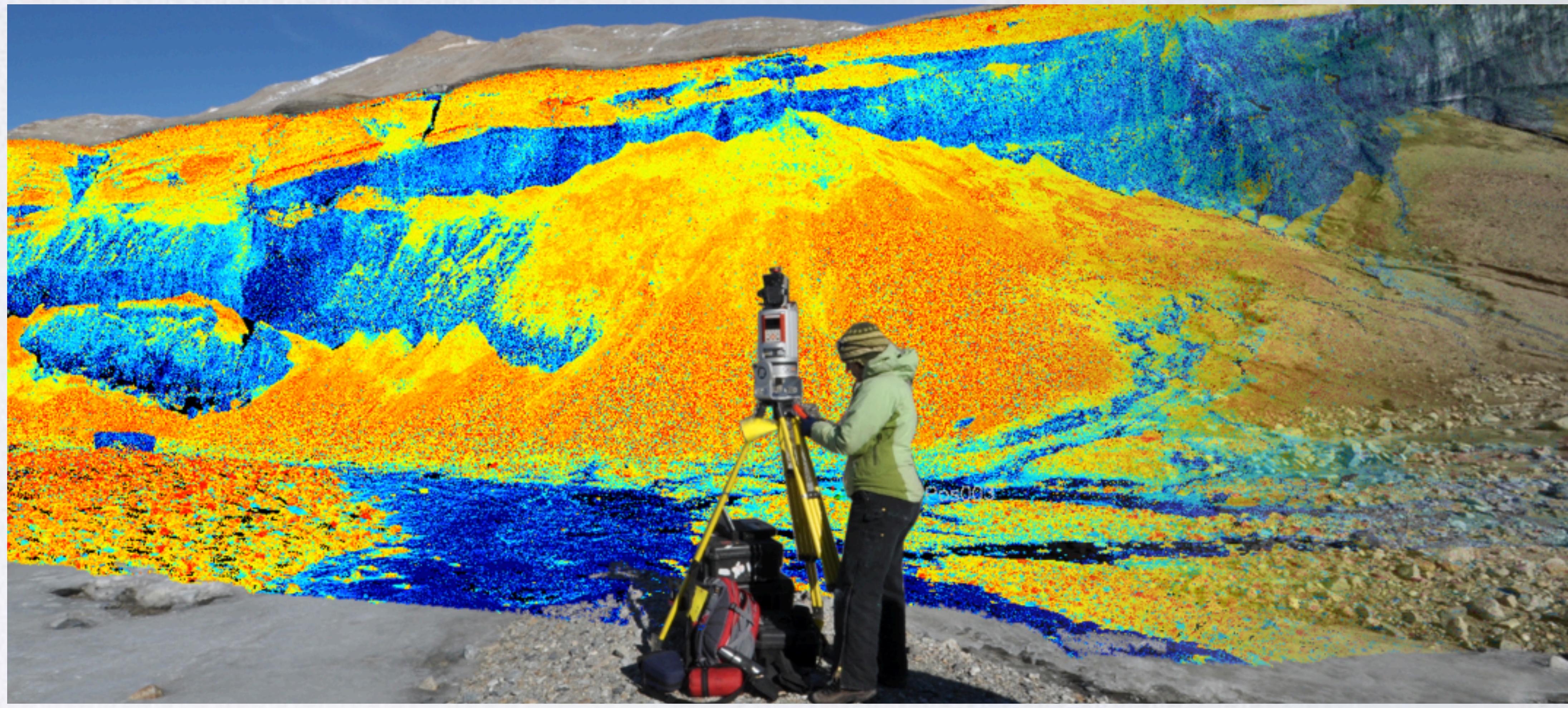
- Introduction to UNAVCO, EarthScope, PBO, etc.
- **EarthScope airborne LiDAR data**
- Plate Boundary Observatory (PBO) GPS/GNSS network and data
- Summary

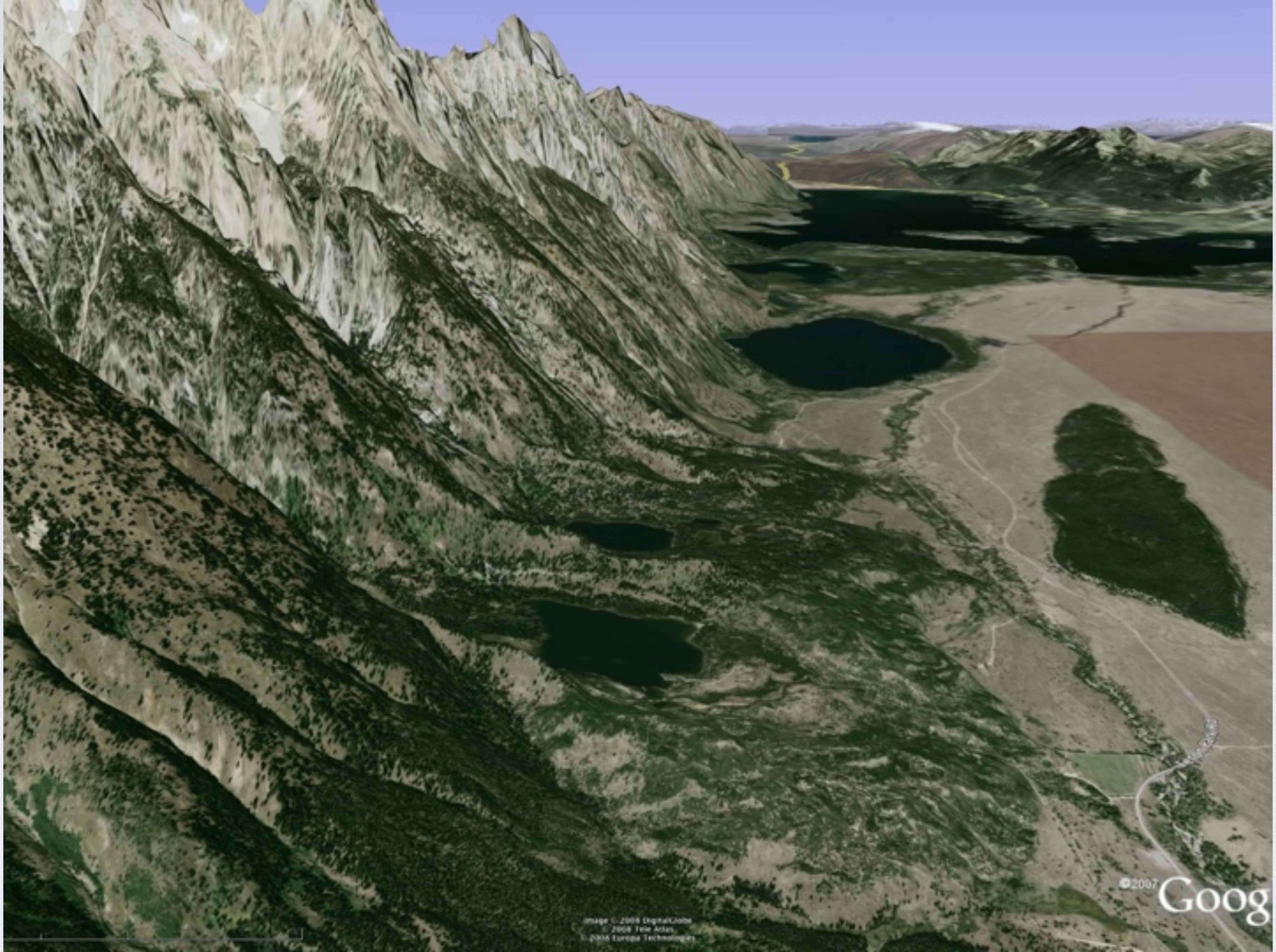
UNAVCO


GEODETIC IMAGING AT UNAVCO
UNAVCO
NSF
NASA
Terrestrial LiDAR
Airborne/ Spaceborne InSAR
Wells
M 6.0
10 Kilometers
Terrestrial Radar
Airborne/ Spaceborne LiDAR

LIDAR, ALS, TLS, ETC.

- LiDAR = Light Detection And Ranging
- Terrestrial Laser Scanning (TLS) = ground based LiDAR measurements. Also called tripod LiDAR or T-LiDAR. UNAVCO provides support for TLS instrumentation, engineering, data processing, archiving, and training.
- Airborne Laser Scanning (ALS) = aircraft based LiDAR measurements. Also called airborne laser swath mapping (ALSM). UNAVCO supports ALS by providing high rate GPS data and project management (e.g. GeoEarthScope).
- LiDAR data discussed here based on Time of Flight (TOF) laser pulse measurements to generate a 3D "point clouds".
- Each measured point has range and intensity values determined by the laser pulse properties plus an X, Y, Z value determined by the scanner's orientation.
  - Scanners can record multiple returns per pulse or even the full waveform which helps LiDAR measure/classify vegetation and ground.
  - Scanner orientation measured by IMU on moving platform.
  - Scanner position measured by (high rate) GPS on moving platform with reference stations on ground.

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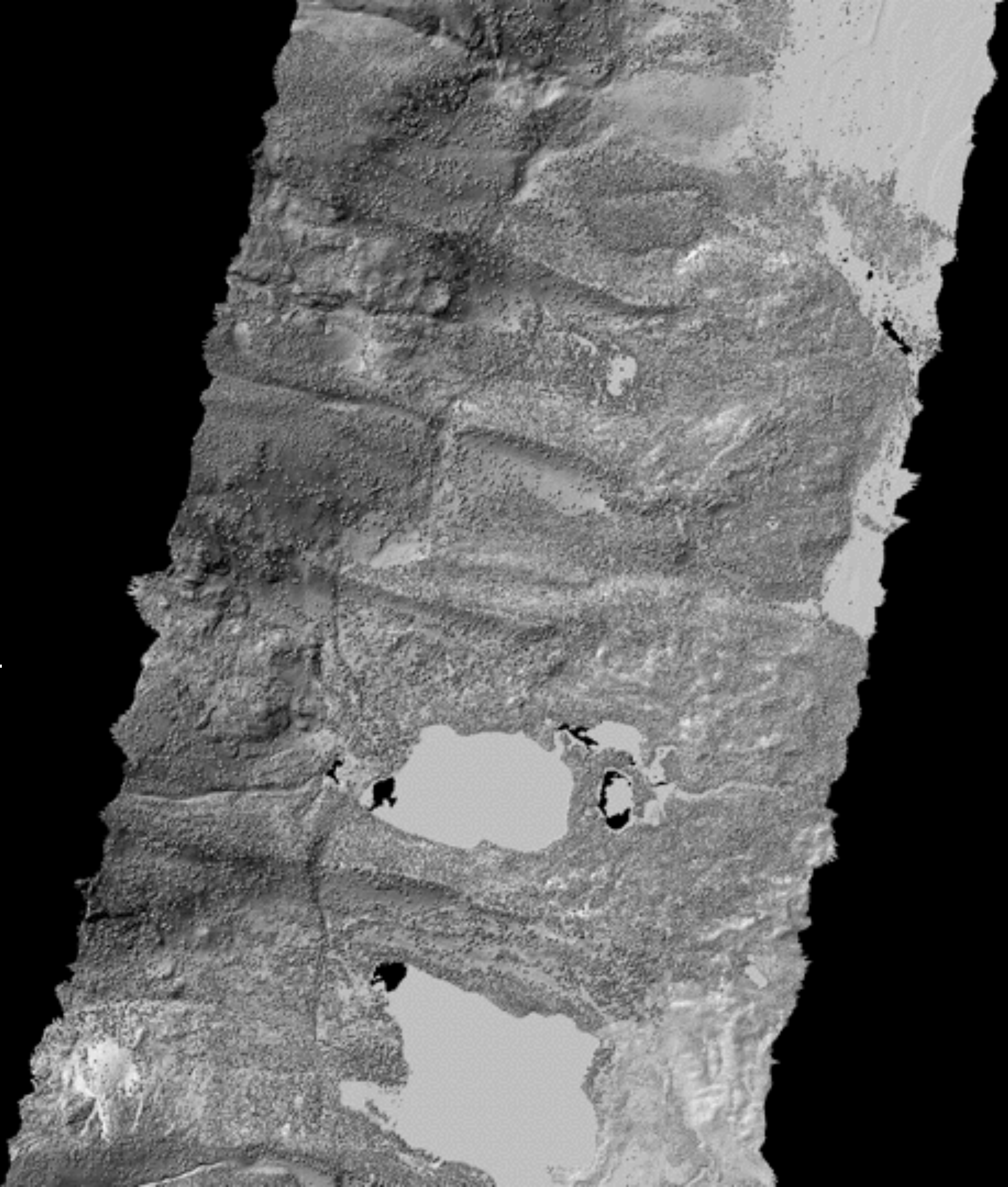
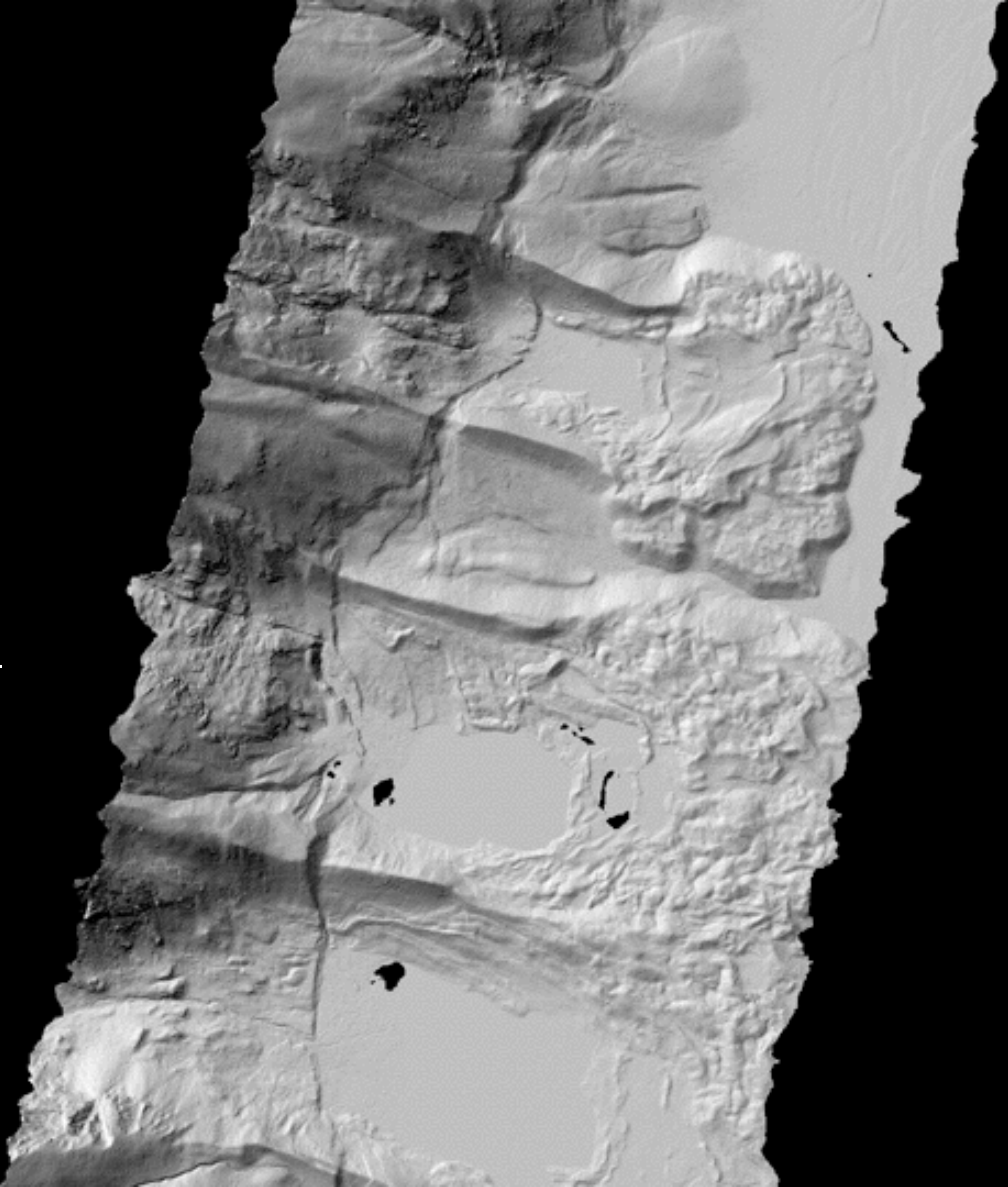
Goog

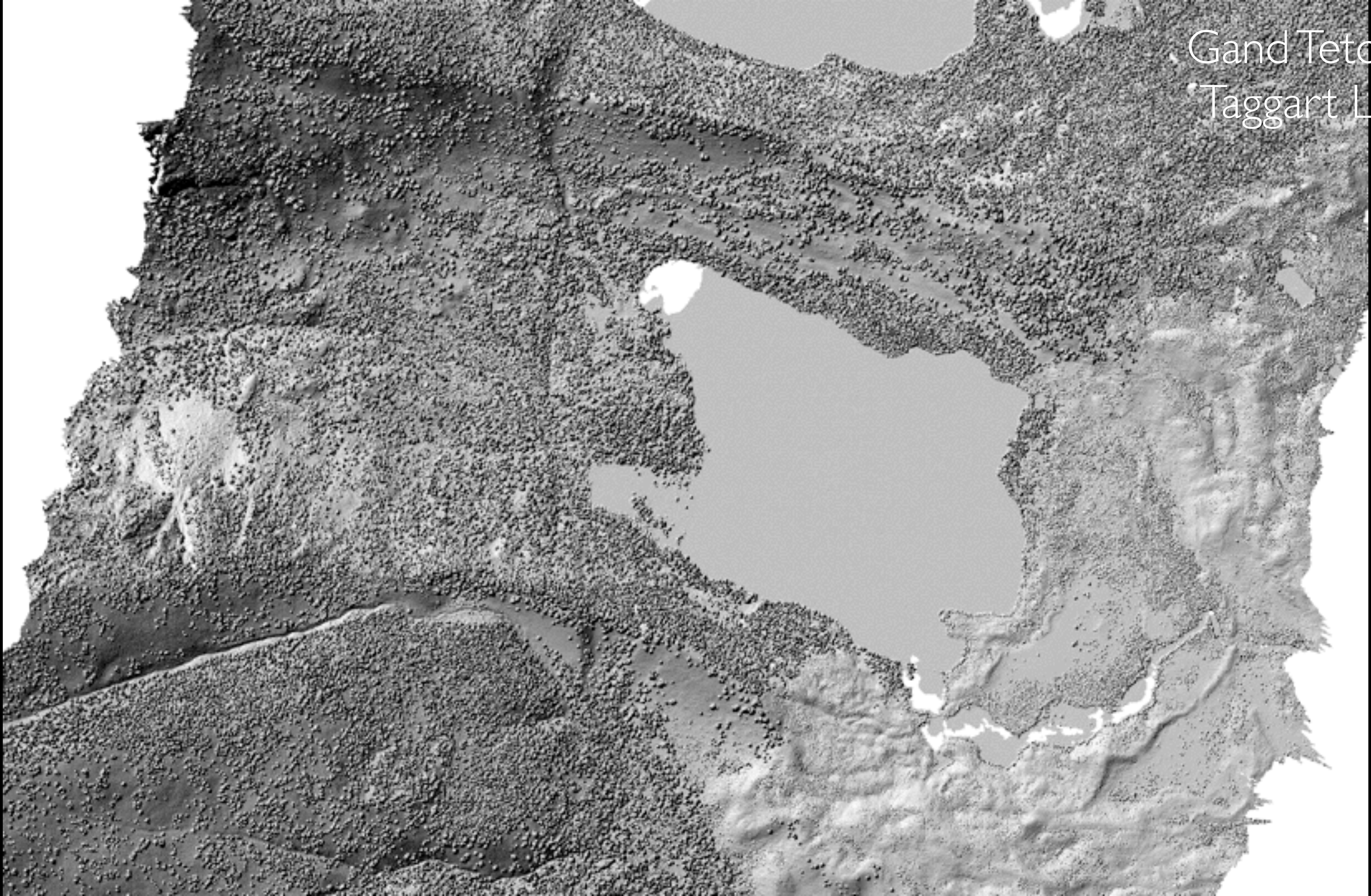
Gand Tetons -
Bradley &
Taggart Lakes



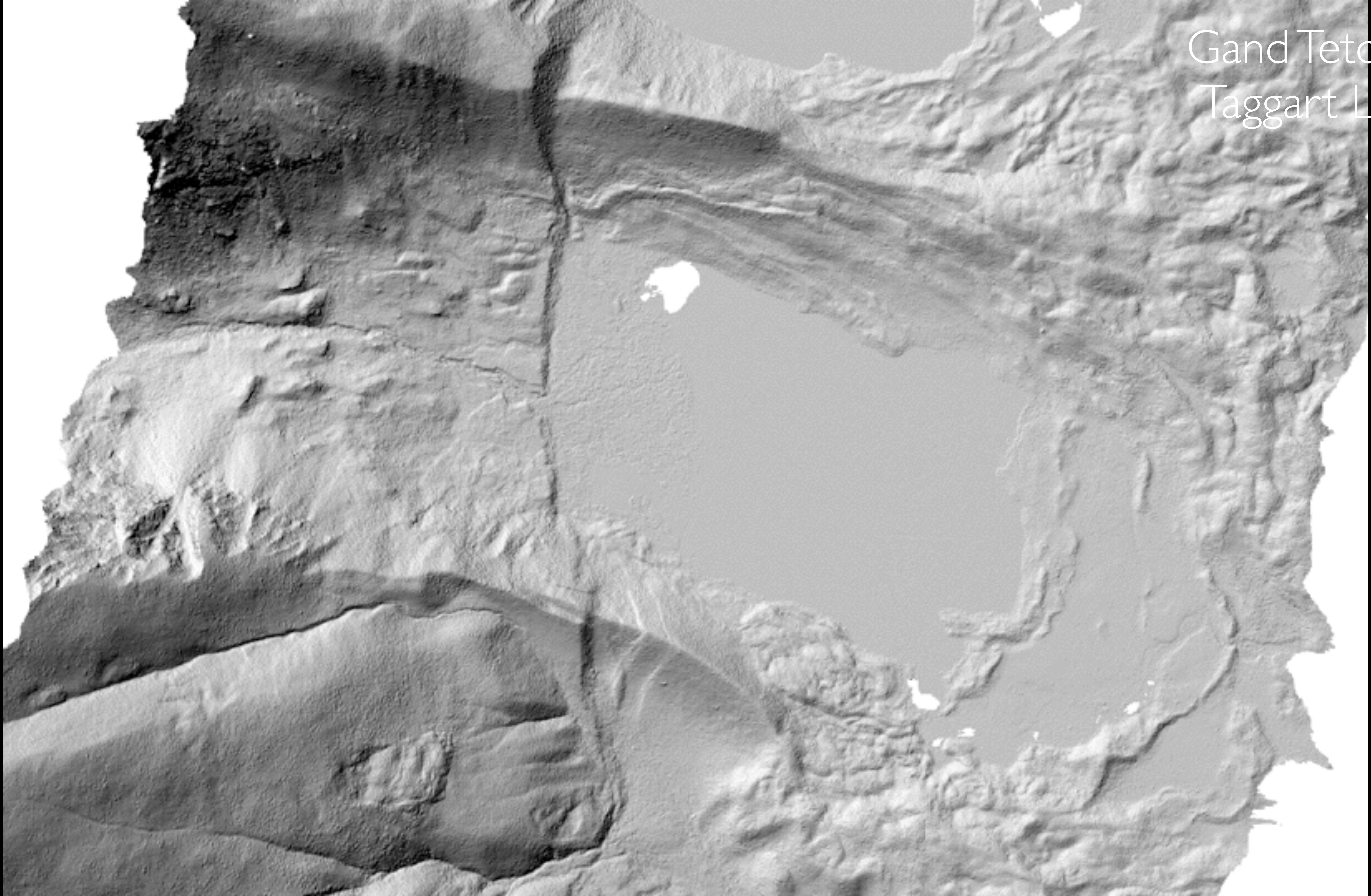
Gand Tetons -
Bradley &
Taggart Lakes



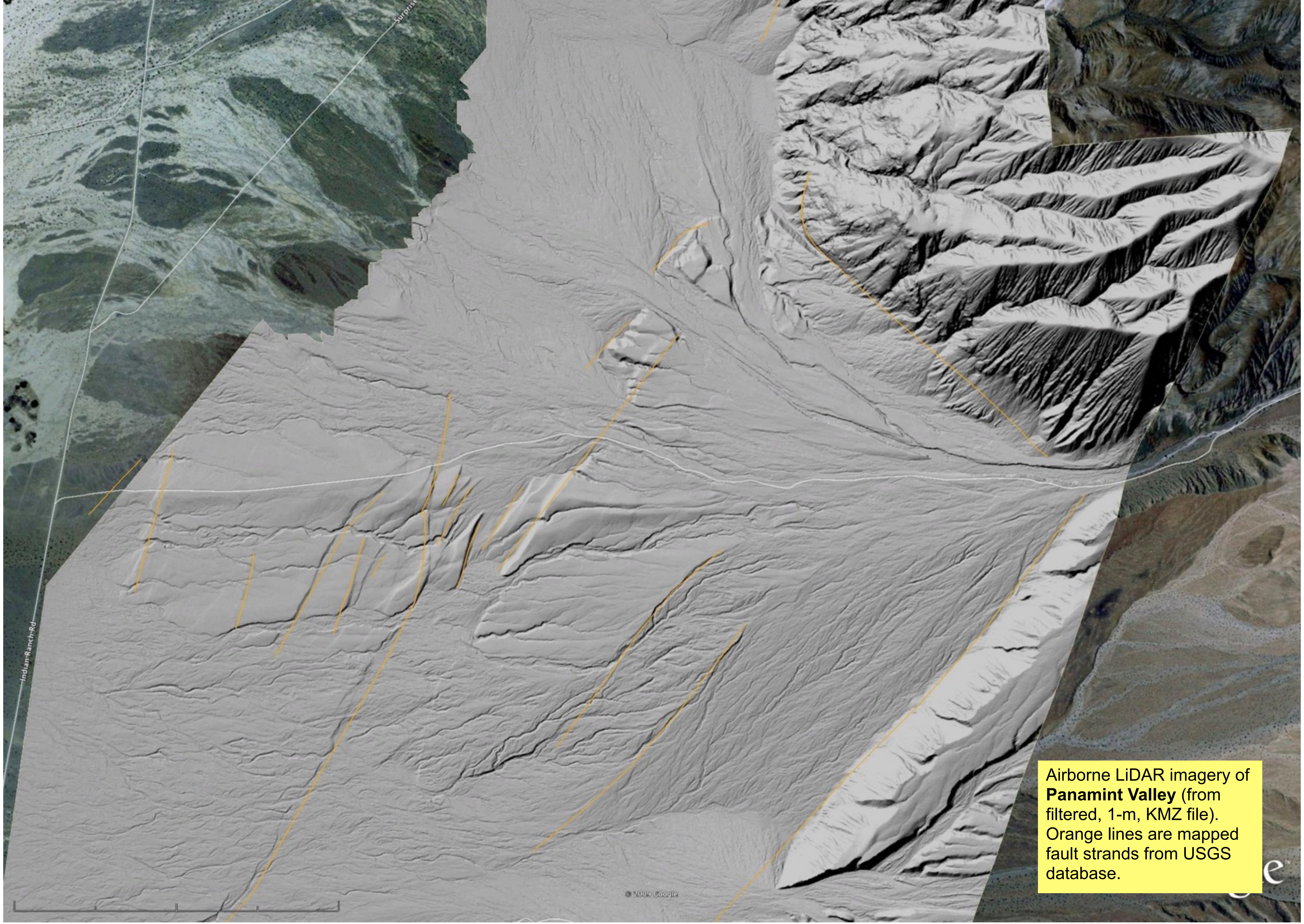
Gand Tetons -
Taggart Lake



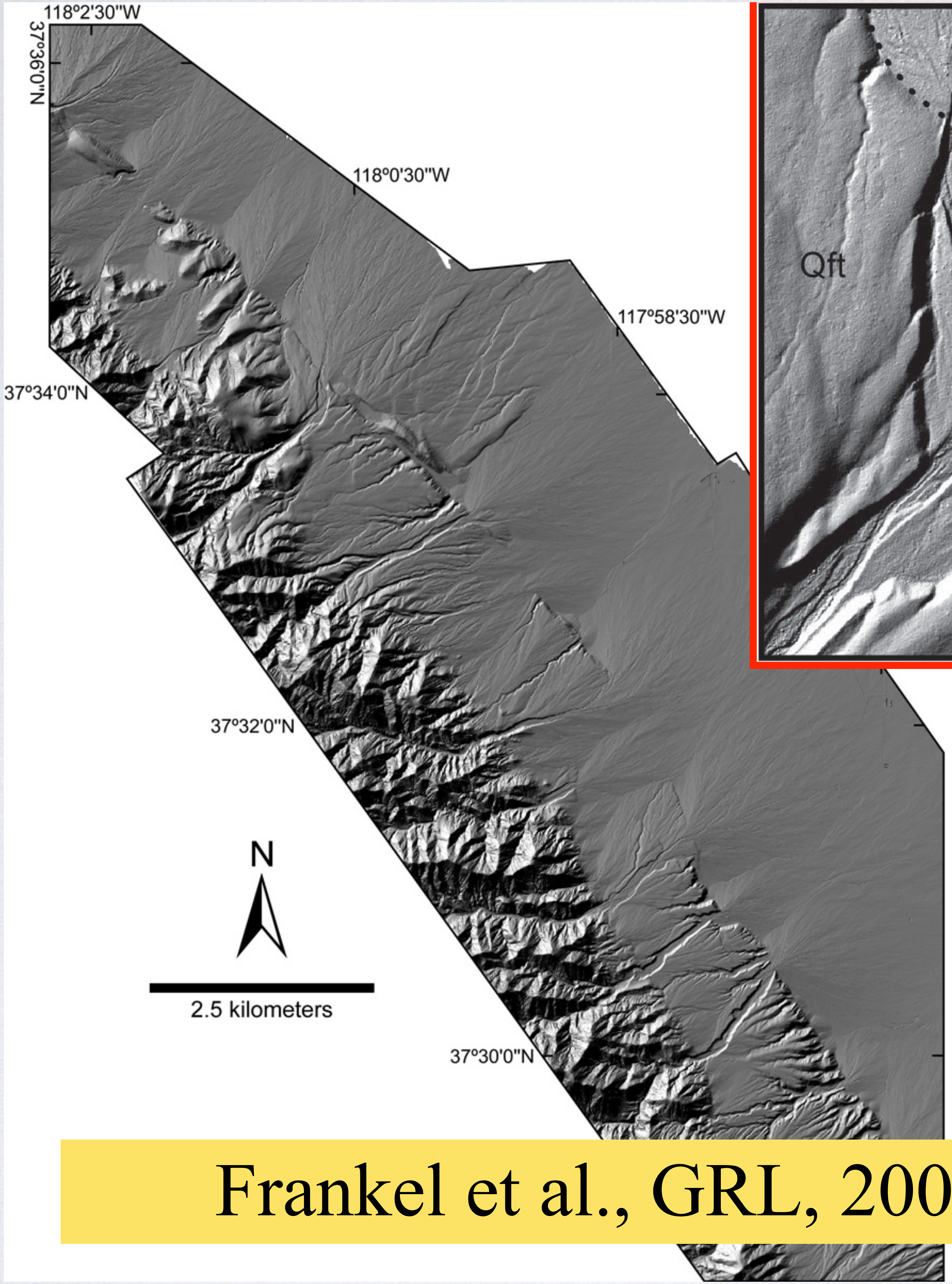
Gand Tetons - Taggart Lake

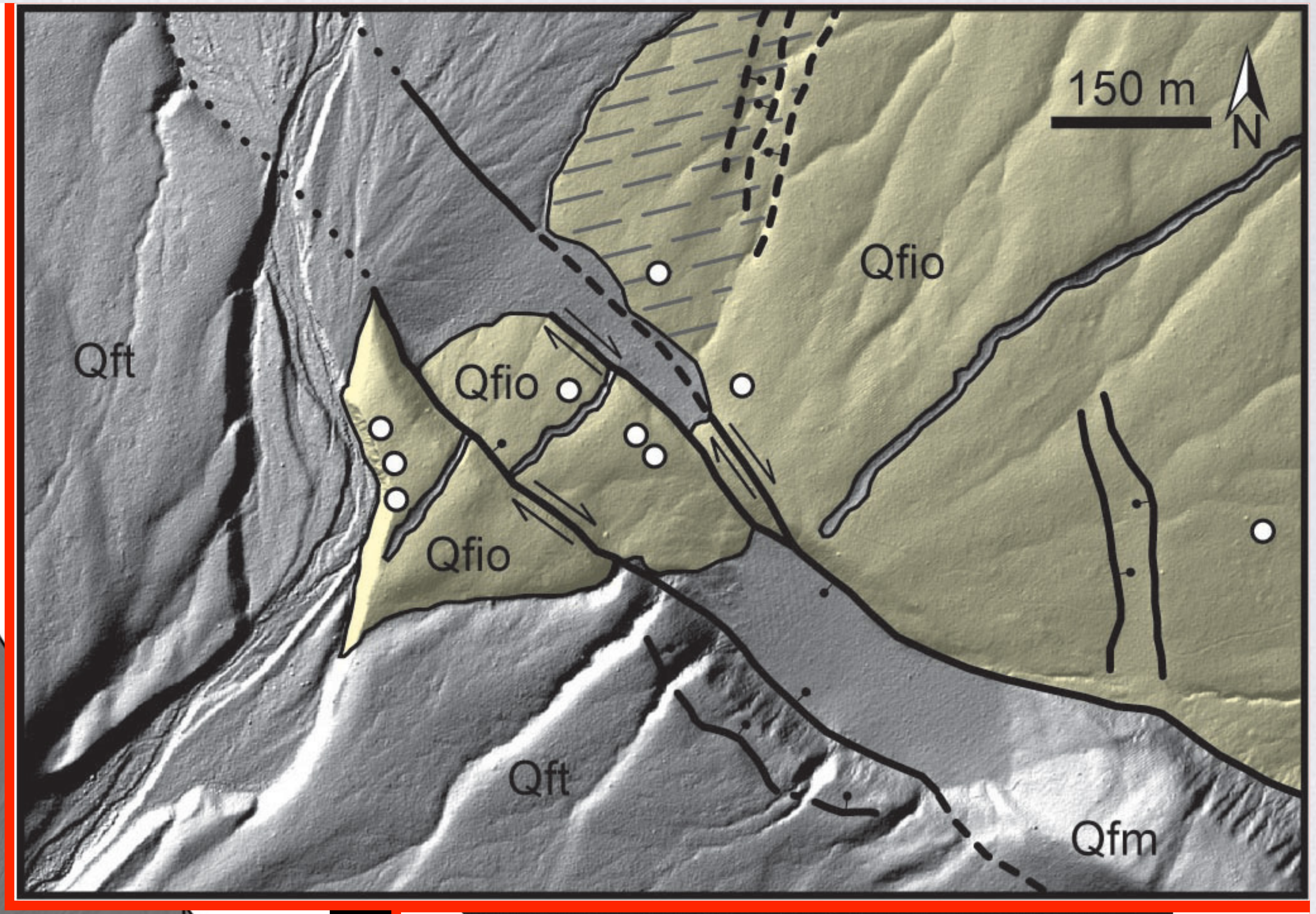


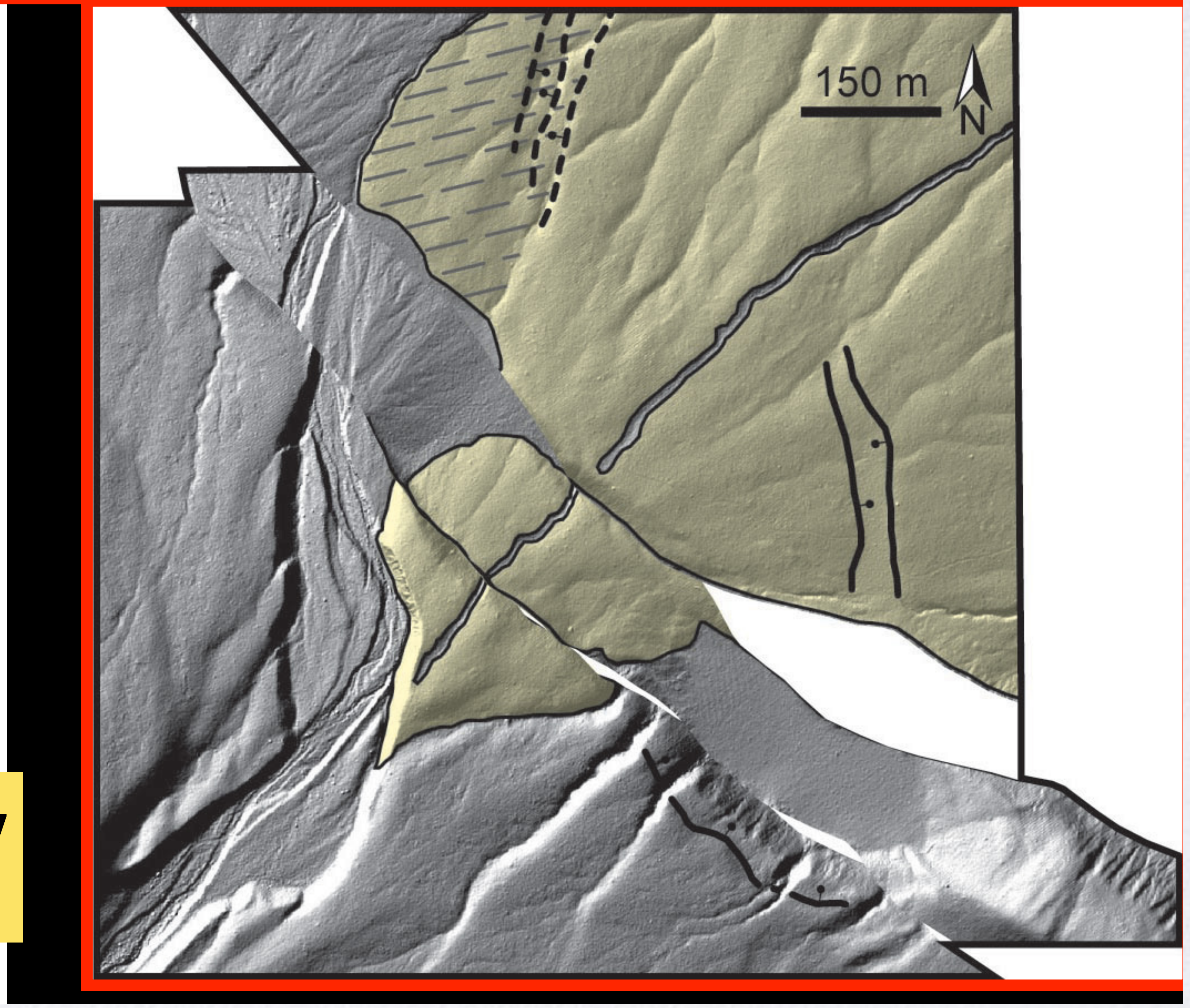
Fort Irwin, eastern Garlock fault



Airborne LiDAR imagery of **Panamint Valley** (from filtered, 1-m, KMZ file). Orange lines are mapped fault strands from USGS database.







Frankel et al., GRL, 2007

The “B4” project

- Led by Mike Bevis (OSU) and Ken Hudnut (USGS)
- LiDAR data collected by NCALM
- GPS data collected by UNAVCO and many field volunteers
- Data collected in 2005
- San Andreas and Jacinto fault coverage from Parafield to Salton Sea

High-resolution LiDAR data rewrites the history of the 1857 Earthquake

Akciz et al., Feb. 2010 *Science*

Zielke et al., Jan. 2010 *Science*

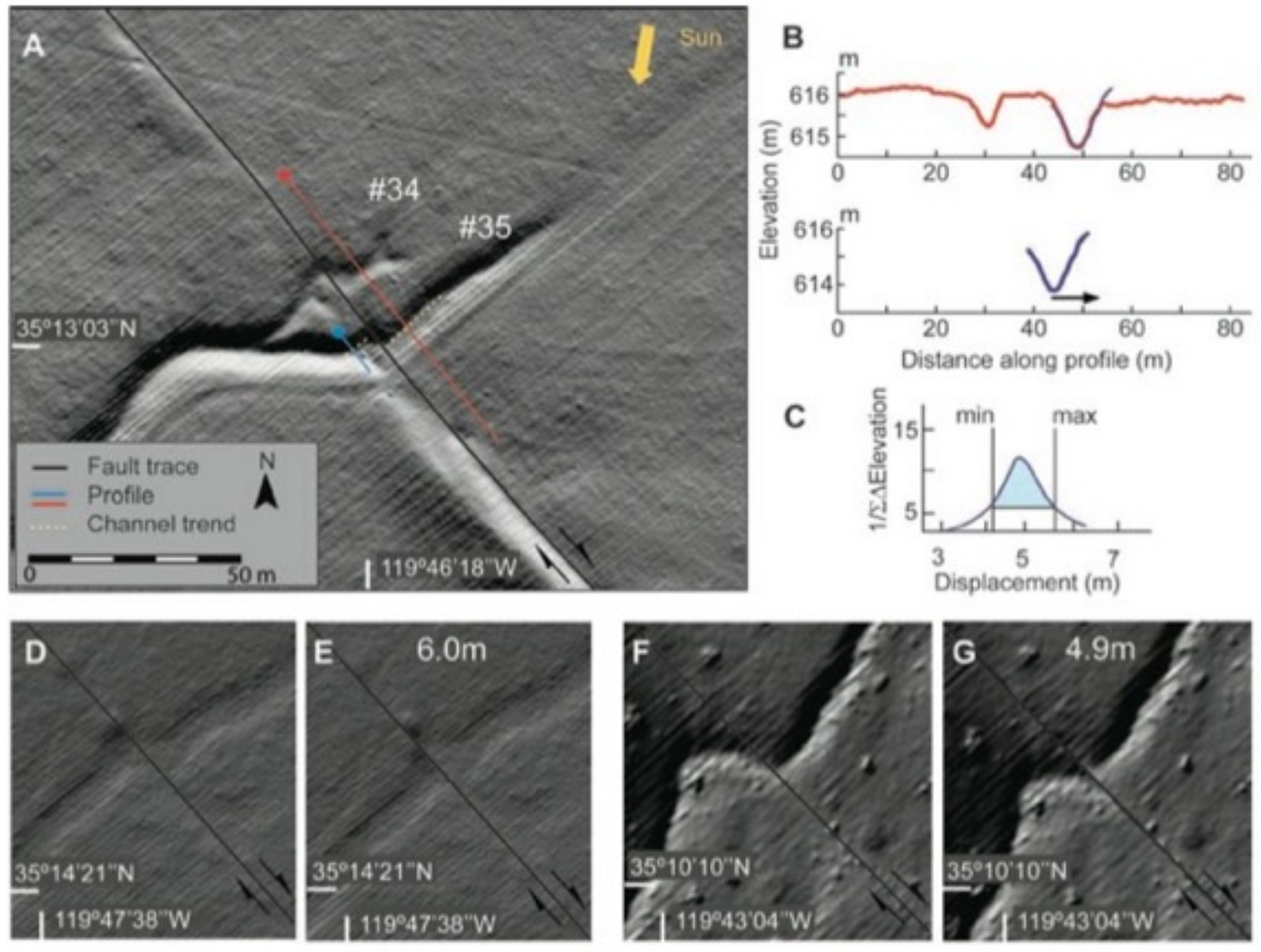


Fig. 2. (**A**) Hillshade map of channels #34 and #35 (5) generated from LIDAR-based digital elevation models. (**B**) Topographic profiles along red and blue lines are projected onto the fault plane based on channel obliquity [yellow dashed line in (A)]. Also shown is the blue profile, back-slipped by optimal offset estimate. (**C**) 1/Σ(Δelevation) is a measure of goodness of fit, calculated for each back-slip increment. (**D** to **G**) Current and back-slipped hillshade plot of two channels in the Carrizo Plain area that intersect the SAF and were offset during the 1857 earthquake (Fig. 1B).

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Press Release 10-011
New Earthquake Information Unearthed by San Andreas Fault Studies

Stream channel offsets features linked to large earthquakes

View of the southeast channel of the Bidart Fan site, Carrizo Plain, looking downstream.
Credit and Larger Version

January 21, 2010

Recent studies of stream channel offsets along the San Andreas Fault reveal new information about fault behavior--changing our understanding of the potential for damaging earthquakes.

The studies were conducted at the Carrizo Plain, 100 miles north of Los Angeles and site of the original "Big One"--the Fort Tejon quake of 1857--by scientists at Arizona State University (ASU) and the University of California at Irvine (UCI).

Applying a systems science approach, the teams report results of a pair of studies in the journal *Science Express* on January 21st. The results incorporate the most comprehensive analysis of this part of the San Andreas fault system to date.

"These research results challenge the widely accepted characteristic earthquake model and could transform our understanding of fault behavior," said David Fountain, program director in the National Science Foundation (NSF)'s Division of

The northwest offset channel of the Bidart Fan, Carrizo Plain, looking downstream.
Credit and Larger Version

Scientists Ramon Arrowsmith/ASU (back, left) and Sinan Akciz/UCI (back, right) in the Carrizo Plain.
Credit and Larger Version

Zielke and Arrowsmith, both of ASU, stand in the bottom of a San Andreas trench.
Credit and Larger Version

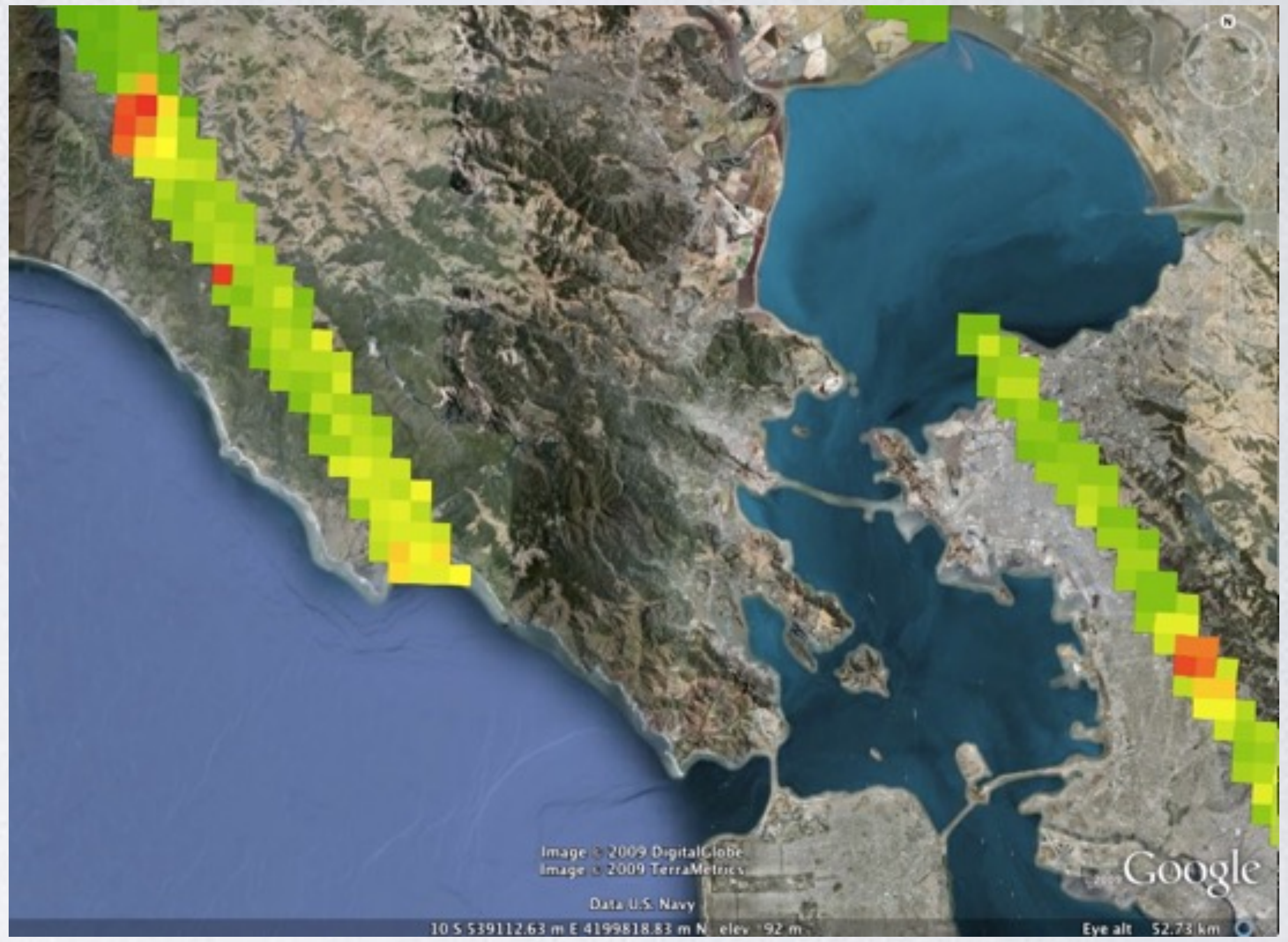
View of an offset stream

UNAVCO

- Acquired ~5,788 km^2 of high resolution airborne LiDAR data as part of NSF EarthScope.
- Primary study regions: Northern California, Southern/ Eastern California, Pacific Northwest, Yellowstone/ Intermountain Seismic Belt, Alaska.
- LiDAR targets in most cases were 1- to 2-km wide corridors centered along active faults.
- Goal: highest data quality possible within scope and budget. Special considerations were given to effective ground point density and geodetic control.
- Goal: data would be available to wide user and application base.
- Goal: a framework for future ALS acquisitions.
- Data were collected and processed by NCALM.
- Data freely available from OpenTopography.

UNAVCO

PROJECT REGION	MAJOR TARGETS	COVERAGE AREA	ACQUISITION DATES
Death Valley – Fish Lake Valley	Death Valley - Fish Lake Valley fault	420 km^2	Nov 2006, Oct 2007
Northern California	San Andreas, Hayward, Calaveras, Maacama, Green Valley, Little Salmon faults, Shelter Cove swath	1960 km^2 (including targets funded by USGS and other partners)	Mar–Apr 2007
Southern/Eastern California	Garlock, Elsinore, Panamint Valley, Ash Hill, Owens Valley, San Cayetano, Calico, Lenwood, Blackwater, Helendale, San Andreas faults	1,995 km^2	Apr 2008
Pacific Northwest	Yakima fold and thrust belt	290 km^2	Apr 2008
Yellowstone / Intermountain Seismic Belt	Yellowstone, Teton fault, Wasatch (Nephi) fault	696 km^2	Jul 2008
Alaska	Denali, Totschunda faults	427 km^2	Jul-Aug 2008
		5,788 km^2	



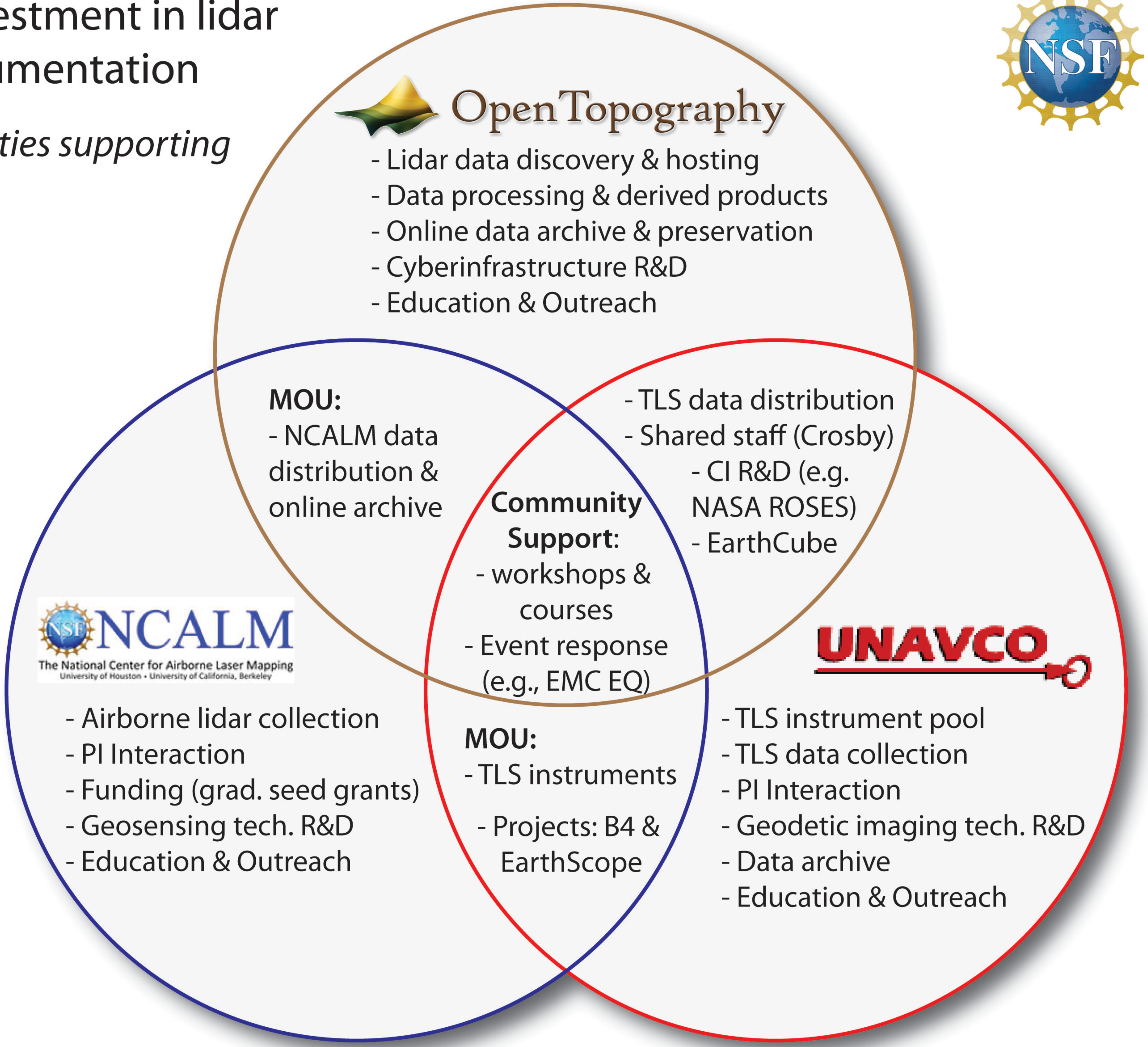
USGS provided funding for Hayward fault coverage - good example of collaborative approach to leverage economy of scale (led by Tom Brocher, Carol Prentice).

NSF EAR IF investment in lidar data and instrumentation

Cooperative facilities supporting NSF earth science

GeoEarthScope goals:

- Collect the highest quality data possible for current and future work
- Make the data truly accessible to a wide range of users with different needs, experience levels and computing resources



GEOES PLANNING

- Target identification and prioritization
  - Defining collection scheme and data product requirements
  - Resolution vs. coverage
  - End use (geomorphology, tectonophysics, etc.)
  - Cost
- Field Logistics
  - Environmental constraints (leaf-off, snow, heat, wind, etc.)
  - Logistical constraints (airfields, fuel, instrument issues, etc.)
  - Permitting
- Data products
  - Data format and metadata standards
  - Data distribution and analysis challenges

UNAVCO

GEOES ALS DATA ACQUISITION

- Spec: data sufficient to generate 0.5 meter DEM's
- Spec: minimum of 4 laser hits per square meter (*4-12+*)
- Spec: data products in absolute reference frame (ITRF2000)
- Data acquisition technology and technique
    - Scanner (Optech GEMINI scanner, laser pulse rate frequencies of *100 KHz open areas, 125 KHz forested areas*)
    - Aircraft position and orientation: IMU accuracy and GPS accuracy (*extensive GPS ground control, suppl. analysis and products*)
    - Swath overlap (*50% minimum*)
    - Flight height (~600m AGL)
    - Field conditions
    - Atmosphere (GPS: water vapor, ionosphere)
    - Flying conditions due to wind, terrain, etc.
    - Topography (esp. challenging in eastern California)
    - Processing methods
- Other issues discovered, etc....

GEOES ALS MANAGEMENT PLAN

- Community led planning
  - Identification and development of project objectives, partners and funding (EarthScope: funding from NSF & USGS, extensive participation/support from NPS, military, universities, local agencies; also PSLC examples).
  - Dedicated working group to identify and prioritize basic targets
  - Data coverage vs. resolution vs. cost vs. time, etc.
- Logistics planning and preparation
  - Refinement of targets (flight lines plotting, etc.)
  - Planning for GPS ground control
  - Airfields, fuel, permits, weather (winds, rain, heat, etc.), etc.
- Data collection
- Data processing
- QA/QC
  - Preliminary data products reviewed by science advisors
  - Metadata reports prepared and reviewed
- Data distribution
  - Open access, multiple formats for different user levels (Open Topography)
- Outreach and Education
  - Short Courses (independent and/or part of national meetings)
  - Dedicated training courses (product or group specific)

Issue with some LiDAR datasets: inconsistent standards; poor QC; specs can be "met" but rigorous vetting of final product not done; incomplete metadata.

DigitalCoast
OFFICE FOR COASTAL MANAGEMENT

About Data Tools

Introduction to Lidar

Contributing Partners: NOAA Office for Coastal Management

Overview

This self-paced, online training introduces several fundamental concepts of how high-accuracy lidar-derived elevation data support natural resource an management applications in the coastal zone. The material provides geospa information needed to understand the characteristics of lidar that have dire and spatial analysis projects. A demonstration is included to show how lida downloaded from NOAA's Digital Coast.

What You Will Learn

After completing this course, participants will be able to

- **Define** lidar
- **Select** types of elevation data for specific coastal applications
- **Describe** how lidar data are collected
- **Identify** the characteristics of lidar data
- **Distinguish** between lidar data products
- **Recognize** aspects of data quality that impact data usability
- **Locate** lidar data sources and additional information resources

Lidar 101:

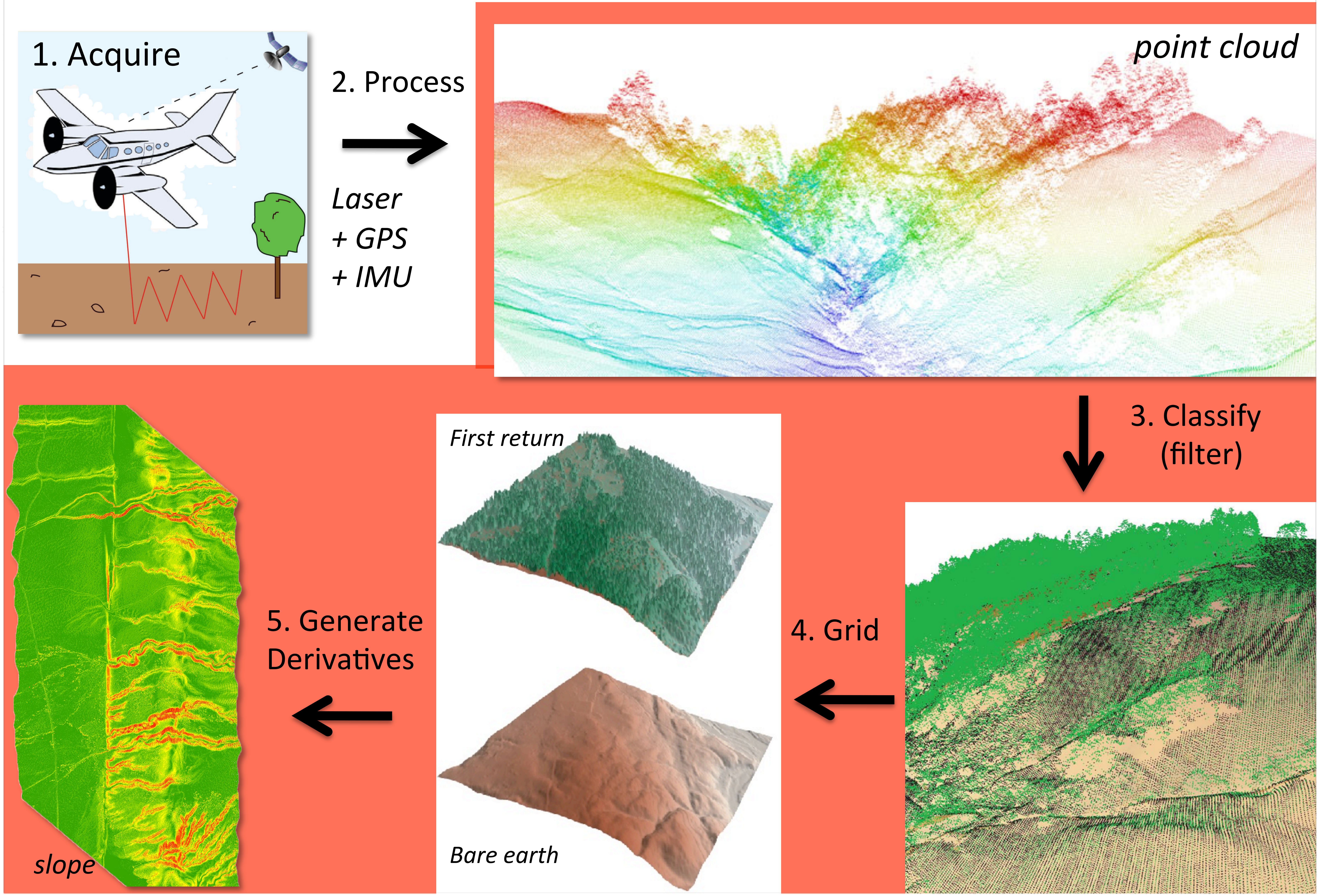
An Introduction to Lidar Technology, Data, and Applications

National Oceanic and Atmospheric Administration (NOAA)
Coastal Services Center

Coastal Geospatial Services Division

Coastal Remote Sensing Program

Airborne Lidar Workflow



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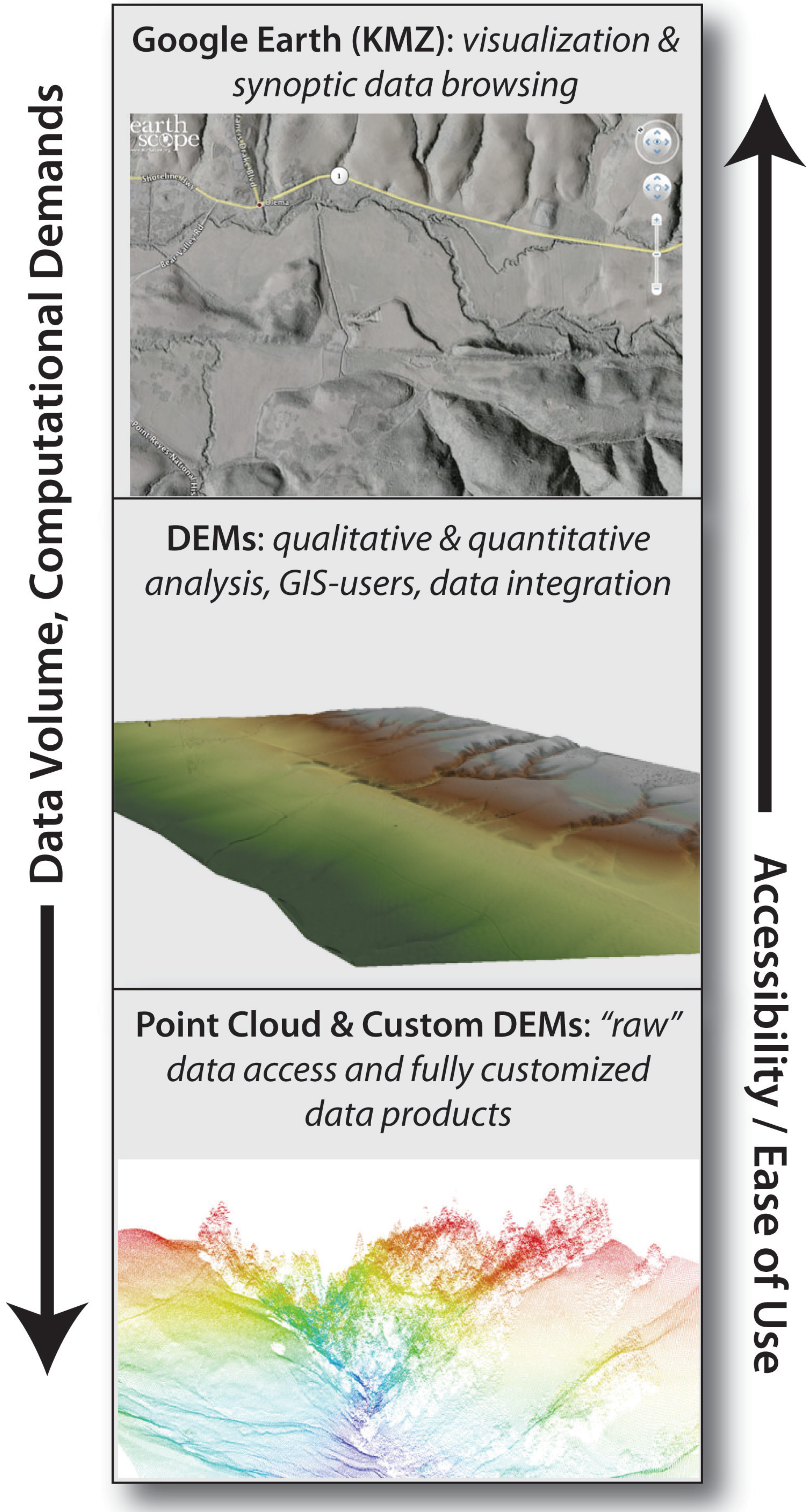
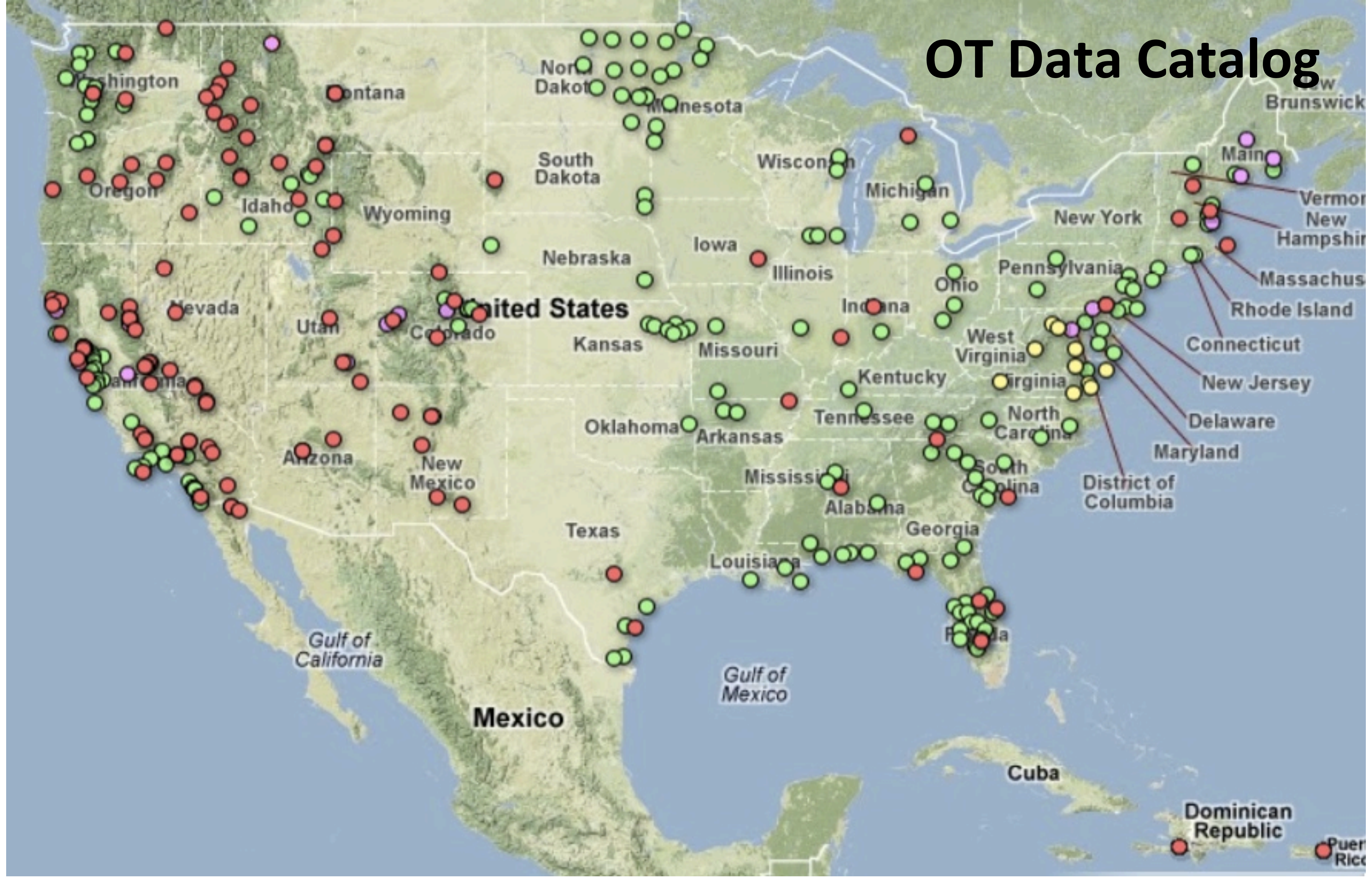
OpenTopography
Multi-Tiered Data Products





- Large user community with variable needs and levels of sophistication.
- Goal: maximize access to data to achieve greatest scientific impact.
- Big data – treat data as an asset that can be used and reused

UNAVCO

Data Status

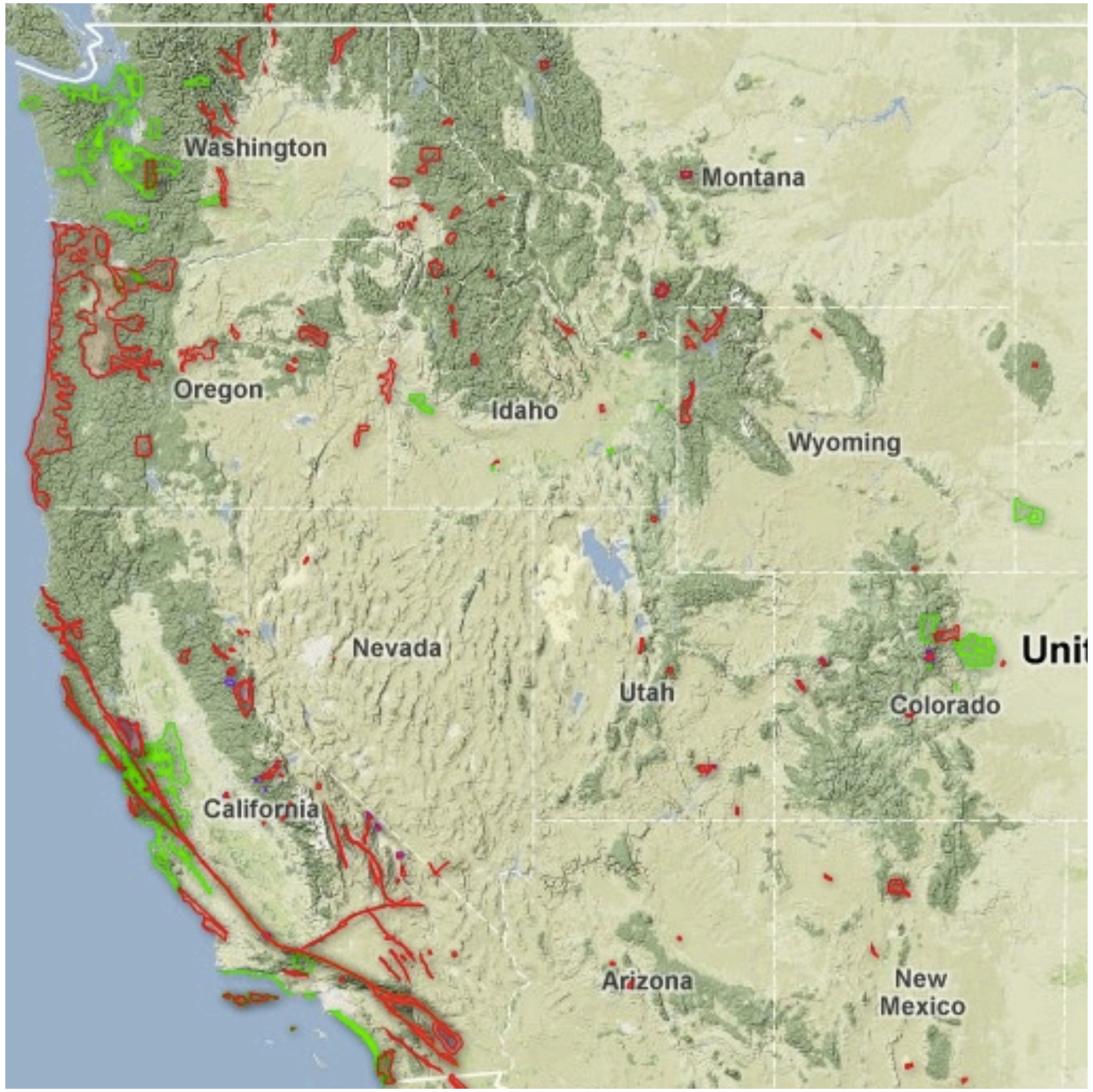
- ~600 billion LIDAR returns
- 158 datasets
- 120,407 km^2

MOUs & Partnerships

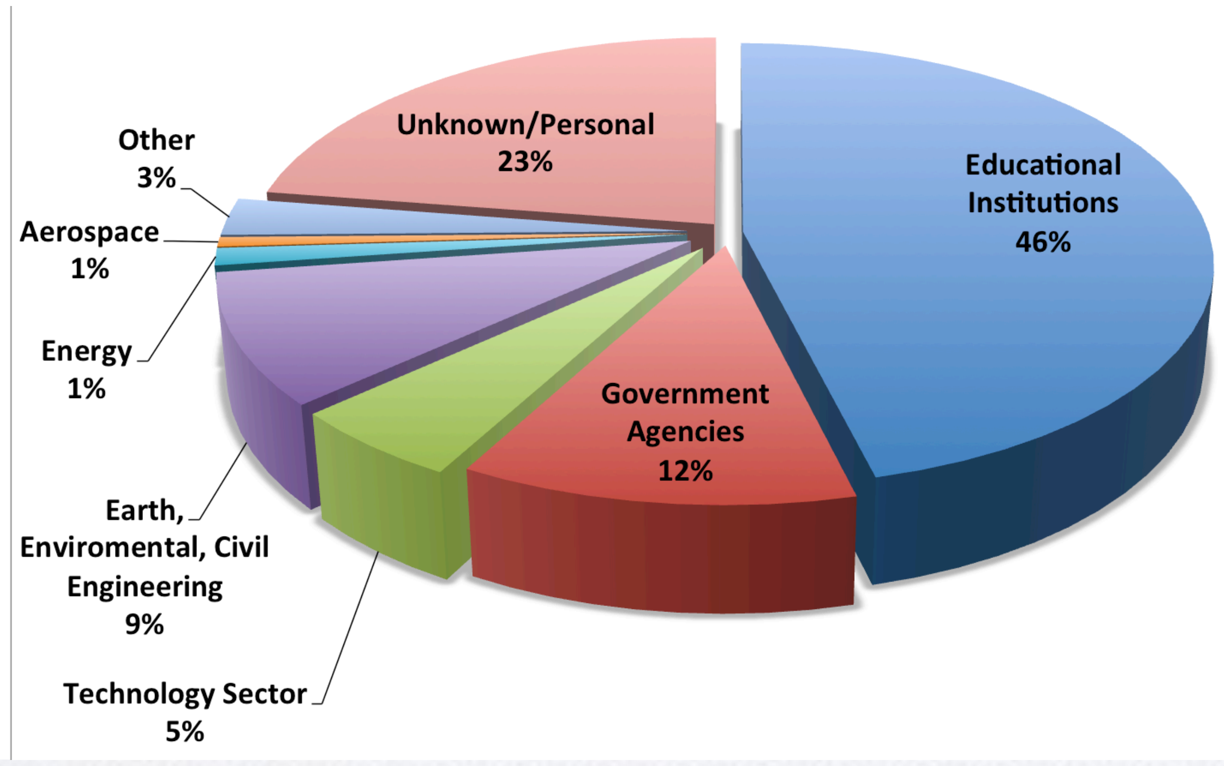
NSF: NCALM, UNAVCO, CZOs, LTER

Other: World Bank, Tahoe Regional Planning Authority, Teton Conservation District, Oregon Lidar Consortium, Idaho Lidar Consortium, …

Service Agreements: State of Indiana Watershed Sciences Inc (for PG&E)



- All datasets receive Digital Object Identifiers (DOI). Attribution and provenance are key aspects of data.
- Quality depends on provider.
- Entire states now in OT.
- SRTM data now available from OT.

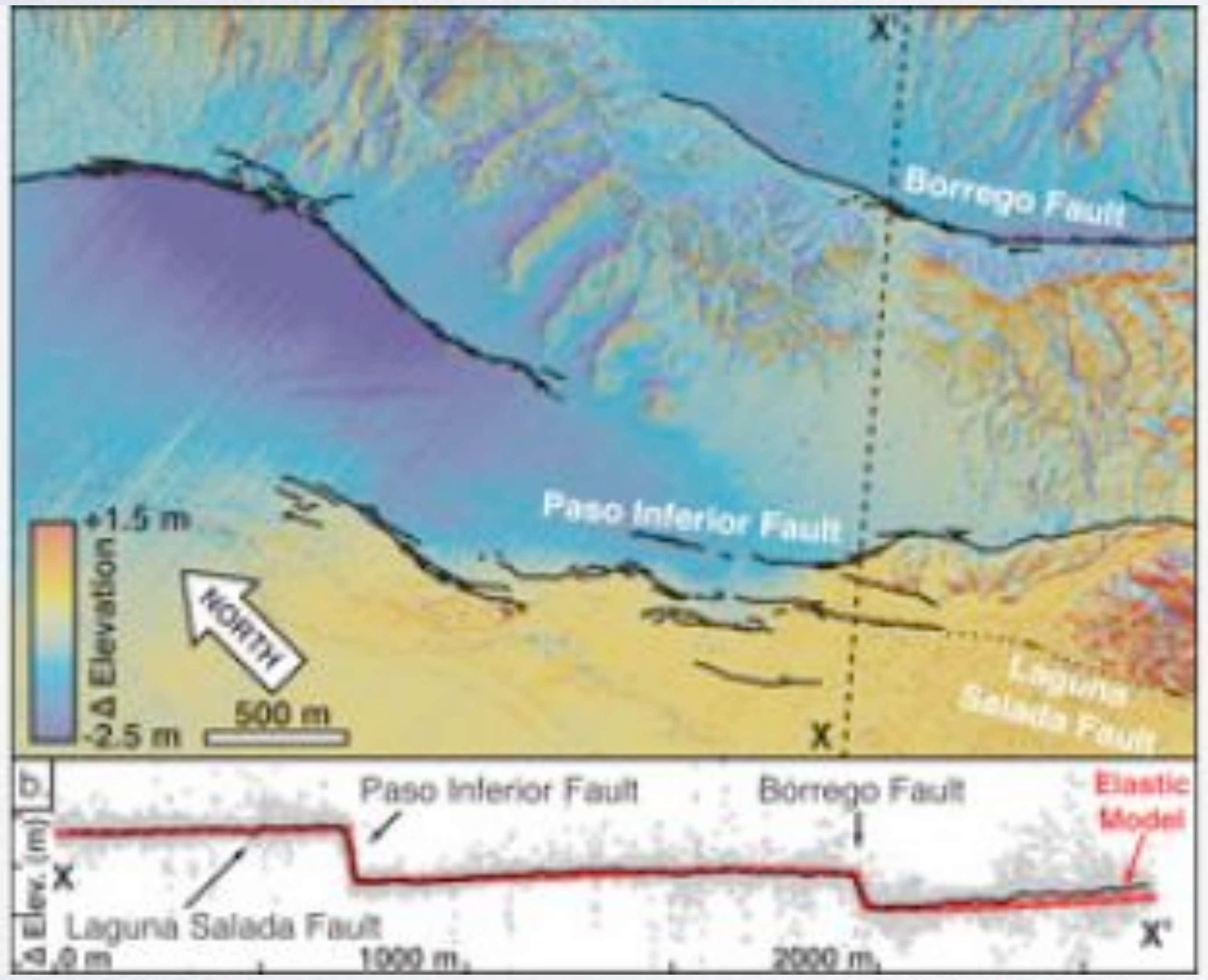


Diverse user base for these data, 3470 registered users, 21,000+ jobs, >30 billion pts/month downloaded.

ASU SDSC NSF

DIFFERENTIAL LIDAR

Eventually it won't just be "B4"…



Differential LiDAR and cross section. Elevation difference map and cross section showing the distributed deformation as slip steps from the NW Borrego fault into the Paso Inferior accommodation zone (from Oskin et al. (2012).

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Science 10 February 2012:
Vol. 335 no. 6069 pp. 702-705
DOI: 10.1126/science.1213778

REPORT

Near-Field Deformation from the El Mayor–Cucapah Earthquake Revealed by Differential LIDAR

Michael E. Oskin[1,*], J Ramon Arrowsmith[2], Alejandro Hinojosa Corona[3], Austin J. Elliott[1], John M. Fletcher[3], Eric J. Fielding[4], Peter O. Gold[1], J. Javier Gonzalez Garcia[3], Ken W. Hudnut[5], Jing Liu-Zeng[6], Orlando J. Teran[3]

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[3]Centro de Investigación Científica y de Educación Superior de Ensenada, Carretera Ensenada–Tijuana no. 3918, Zona Playitas, C.P. 22860, Ensenada, Baja California, México.
[4]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109, USA.
[5]United States Geological Survey, 525 South Wilson Avenue, Pasadena, CA 91106, USA.
[6]National Key Laboratory of Earthquake Dynamics, Institute of Geology, China Earthquake Administration, 1# Huayanli, Dewai Avenue, Beijing 100029.
[*]To whom correspondence should be addressed. E-mail: meoskin{at}ucdavis.edu

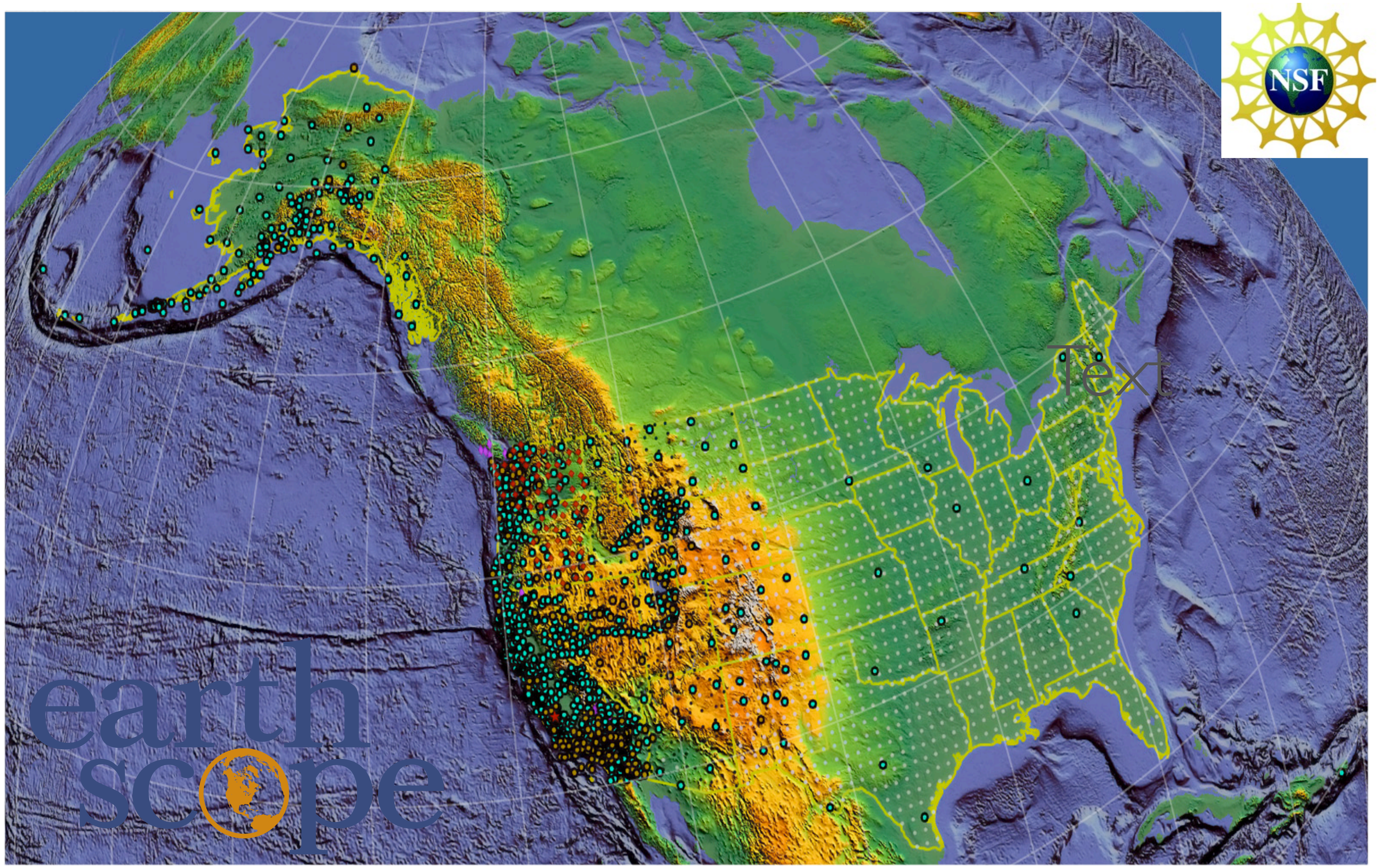
UNAVCO

- Introduction to UNAVCO, EarthScope, PBO, etc.
- EarthScope airborne LiDAR data
- **Plate Boundary Observatory (PBO) GPS/GNSS network and data**
- Summary

EARTHSCOPE: INTEGRATION OF GEODESY AND SEISMOLOGY

Designed as a 15 year experiment set to sunset in 2018

- **Total EarthScope Budget: ~$500M**



PBO is the geodetic component of EarthScope (~$200M)

- 1132 permanent GPS stations (1100 PBO core)
- 75 borehole strain meters
- 79 borehole seismometers
- 23 borehole pore pressure sensors
- 26 shallow borehole tiltmeters
- 6 long baseline laser strainmeters
- 145 meteorological stations (118 core, 27 NOAA)
- 470 real-time streaming GPS stations (422 PBO core)

~ 450 PBO stations are redistributed by NGS as part of the CORS network

PBO: A CRITICAL NATIONAL RESOURCE: SUMMARY OF IMPORTANT CONCERNS

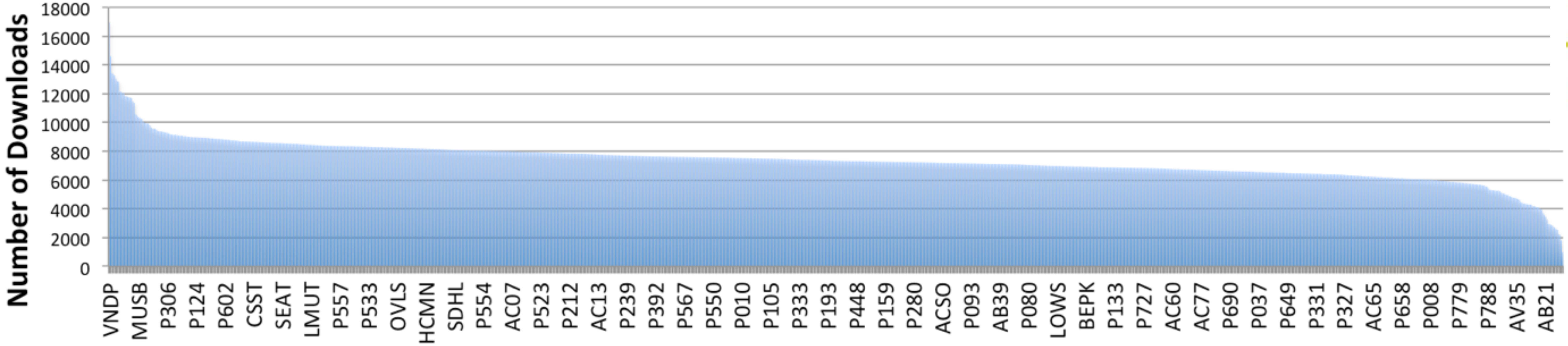
Aging PBO infrastructure - planned replacement in GAGE, not possible under current budget scenarios. **Reduced O&M for PBO means possible loss of data and likely will decrease up-time in long-run.**

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).

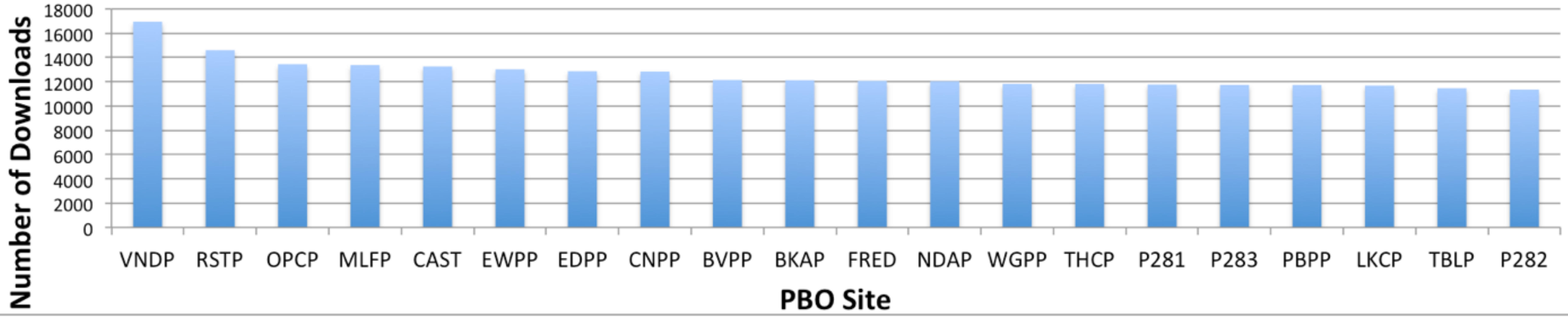
- Geodetic Infrastructure is **vital** to multiple communities and agencies - how will it be sustained?
- NSF (and NASA/USGS to a lesser degree) has made the **initial investment** - but the need for **sustaining partners** remains paramount…

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 needs evaluation and mitigation.

Ranking of All PBO Sites by Number of Downloads (Jan - Aug 2014)



20 Most Used PBO Sites by Number of Downloads (Jan - Aug 2014)



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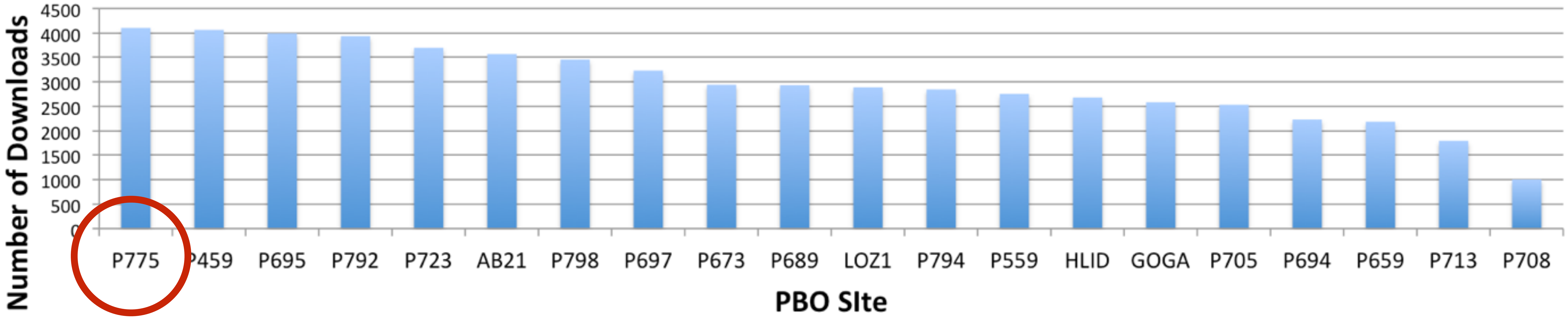
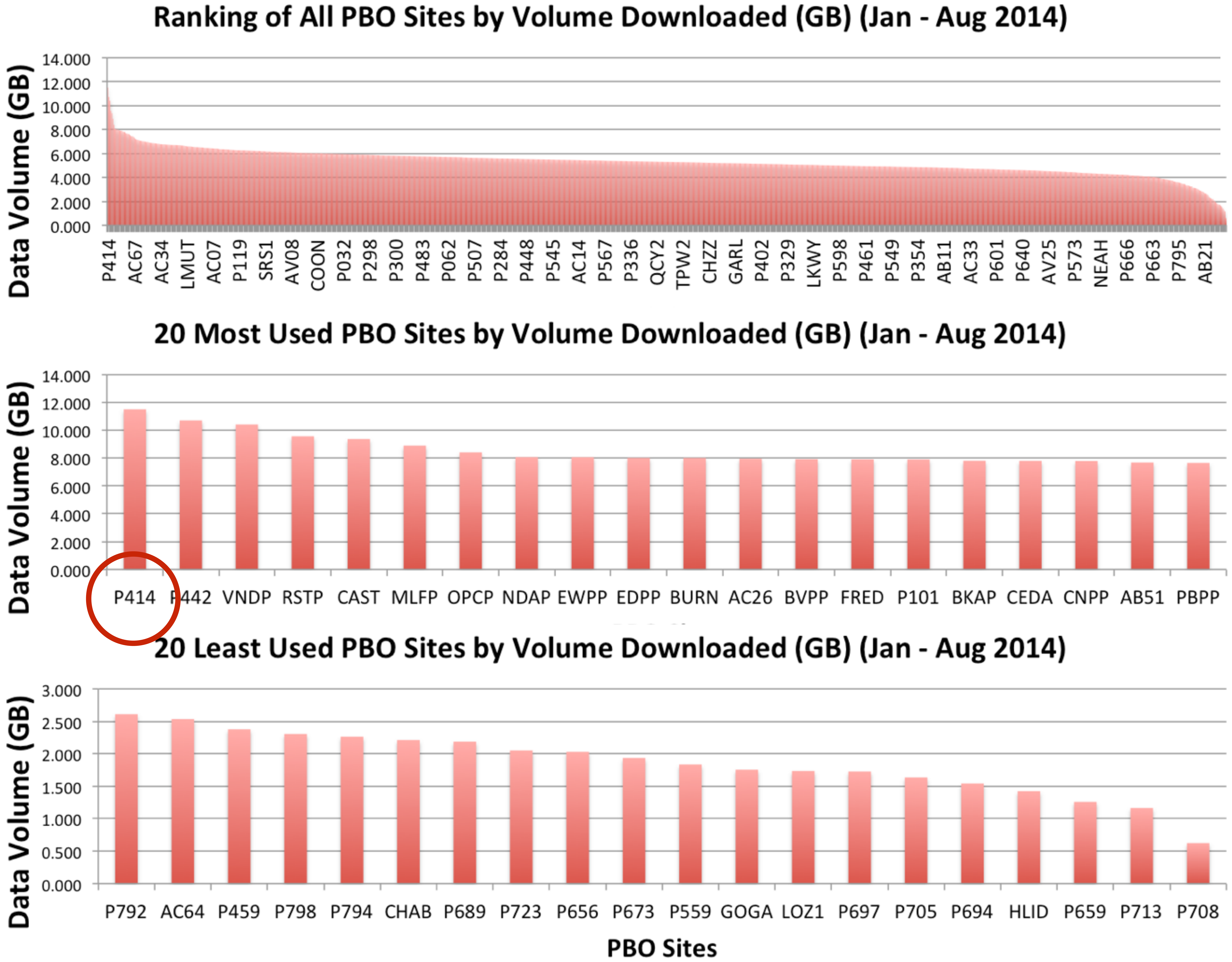


earth scope

UNAVCO



earth scope

UNAVCO

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**

- Analyze user base and station utilization: identify primary users, identify most and least used stations vs. scientific value, etc.

UNAVCO

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** … **ations**

- Make …
- Expa…

For further discussion please contact Dr. Glen Mattioli, Director of Geodetic Infrastructure at UNAVCO

- **Explore adoption of O&M costs or collaborative sponsorship of some sensors or sets of sensors by other entities**

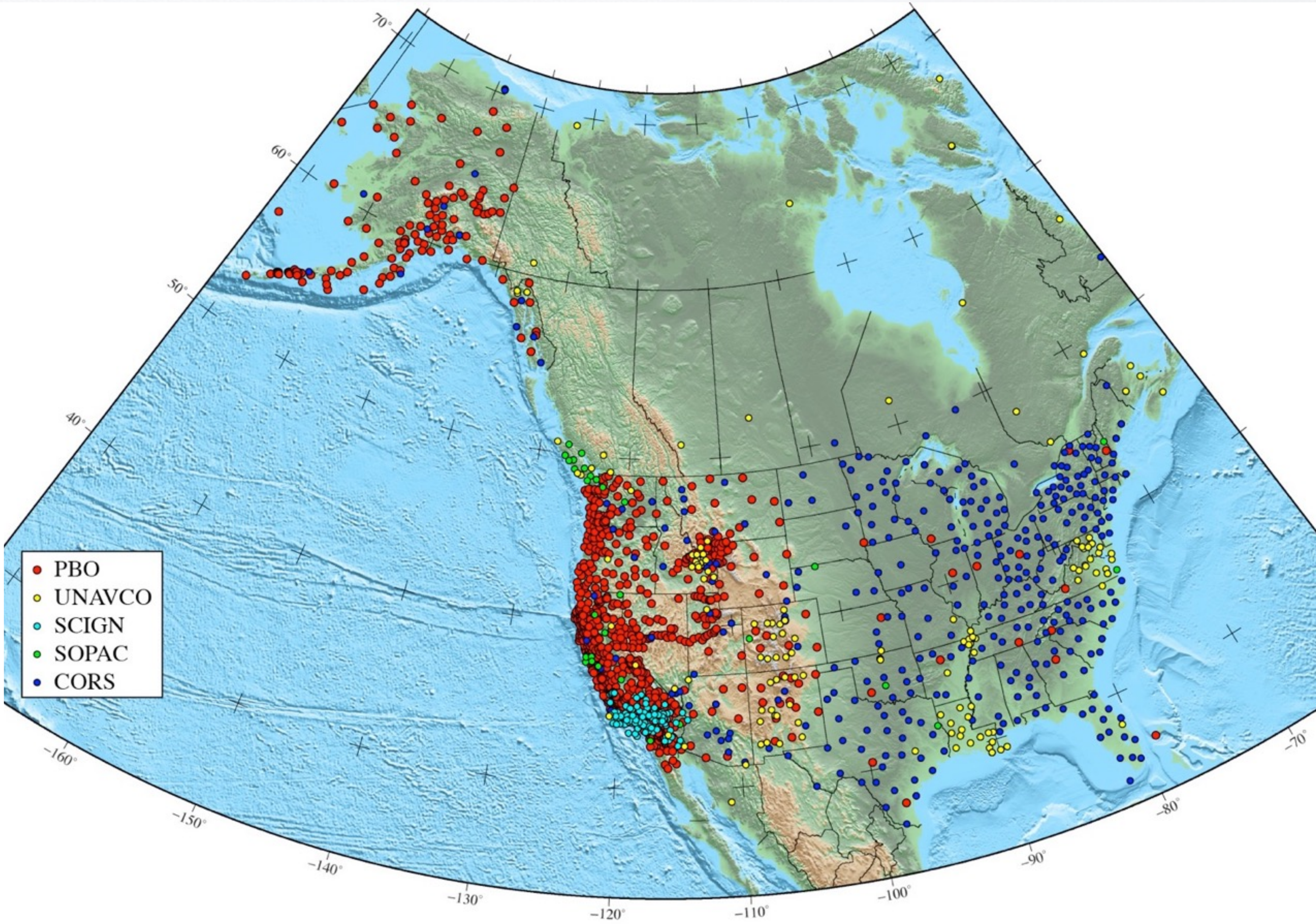
- Leverage ECE to better engage the public and stakeholders in UNAVCO activities

- **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**

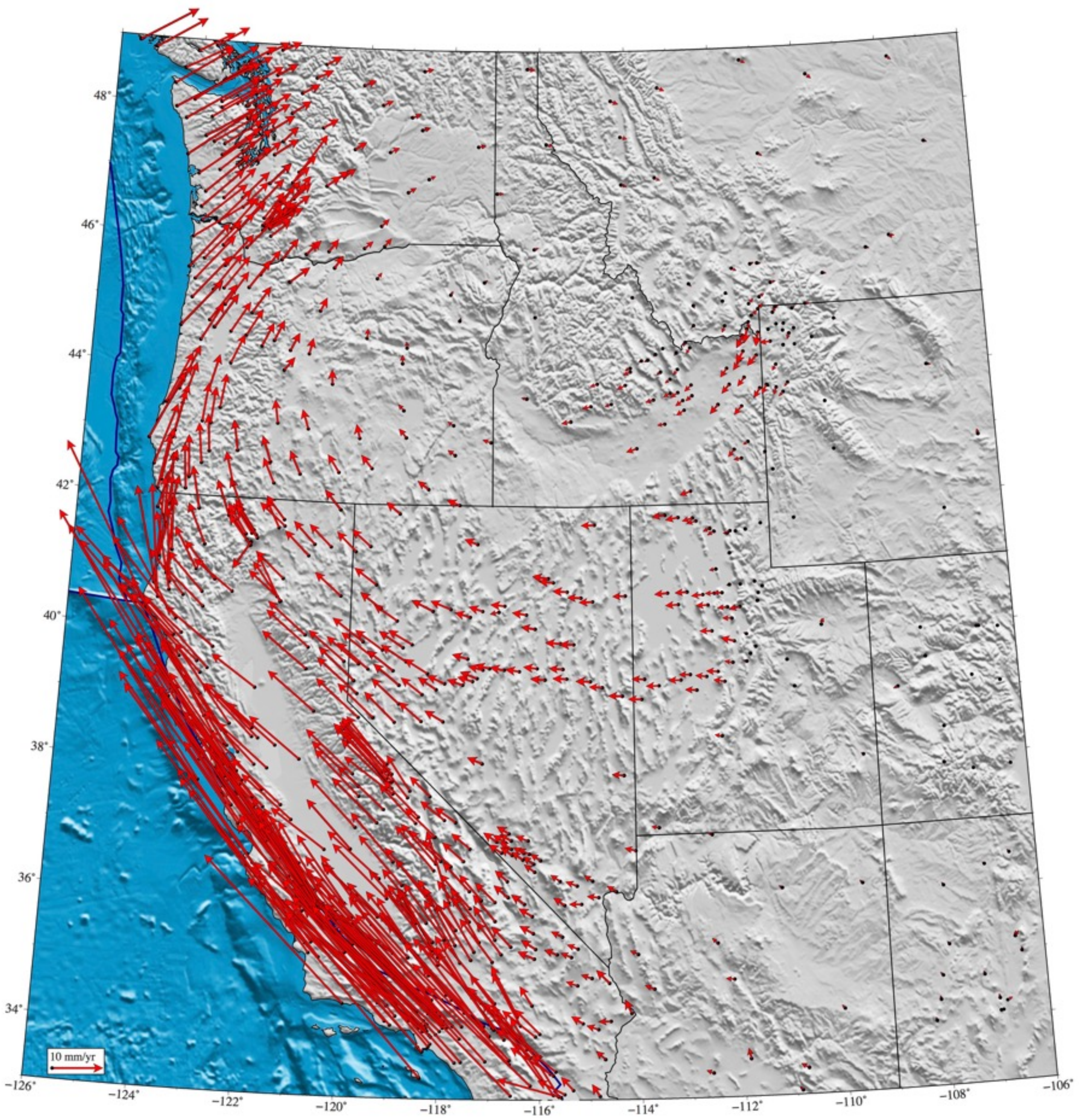
- Defer all maintenance of low-value borehole installations, or divest the sites only producing seismic data to regional seismic networks

GAGE GPS DATA ANALYSIS

- 2,000+ GPS stations analyzed by GAGE Analysis Centers (NMT, CWU) and Coordinator (MIT).
- 1,100 official PBO plus COCONet, SCIGN, and "Expanded Analysis" stations from complementary networks, mostly NGS CORS.
- ACC generates Level 2 products:
  - Daily position solutions
  - Time series
  - Velocity solutions
  - IGS08 and NAM08 frames
  - Coseismic offsets
- .Web Services being developed to provide enhanced user support

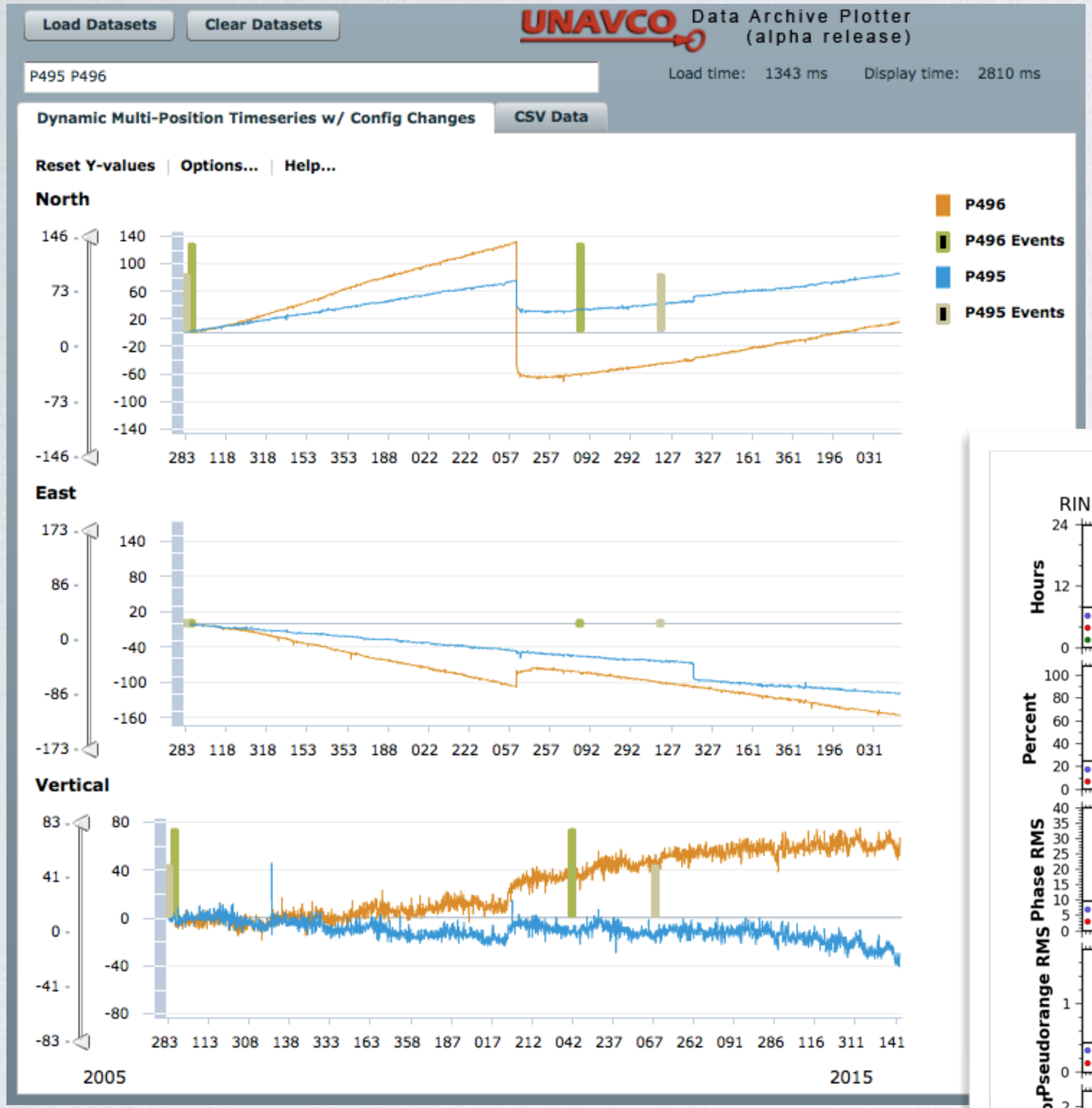


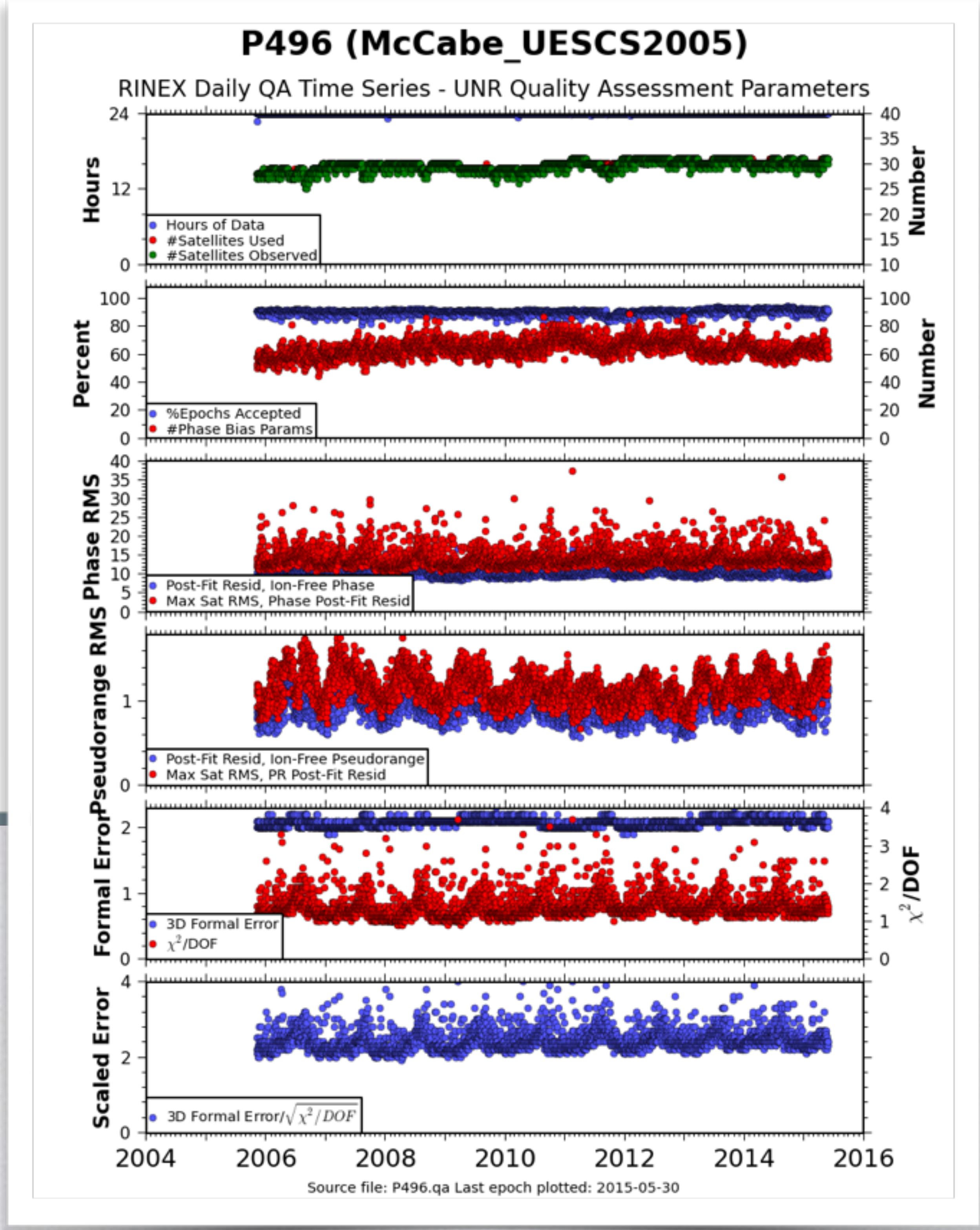
Map of GPS station velocities in NAM08 reference frame. (Not all stations in CA are shown here in order to make individual vectors more visible.)

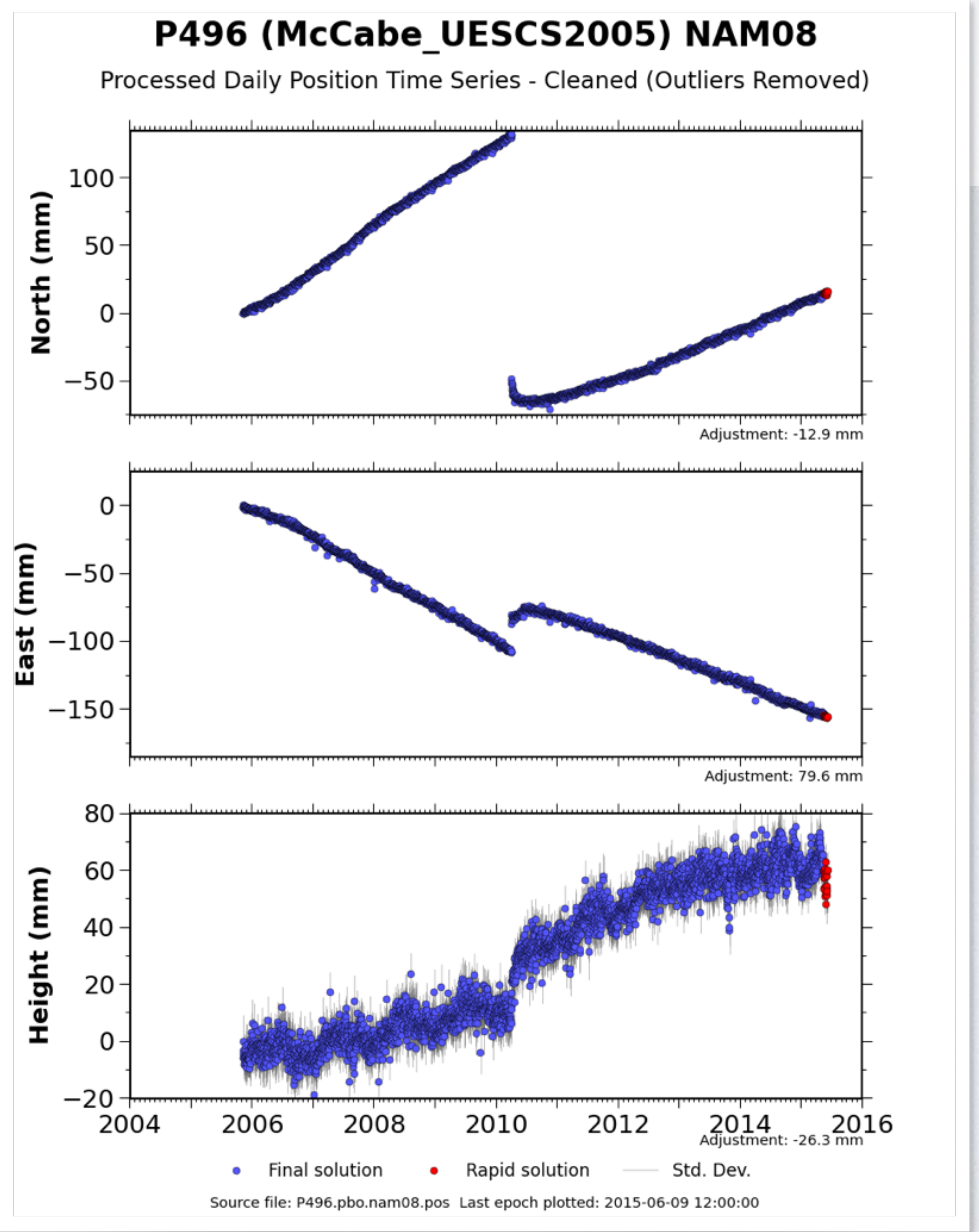


- Network velocity solutions are now generated on a monthly basis. These “SNAPSHOT” velocity solutions are generated by the ACC in a less rigorous way than the annually generated “final” velocity files but their more frequent generation allows the inclusion of recently built stations and analysis of sites with significant temporal velocity changes.
- Two versions of these Snapshot files are provided: a “SNAPS” file that includes all stations and a “SNIPS” file that only only includes stations with velocities that differ significantly from the latest “Final” version, such as due to coseismic effects or station problems.

GPS TIME SERIES: TOOLS, DA







UNAVCO

PBO GPS STATIONS - SIGNALS AND DATA QUALITY

Total GPS station deformation is the sum of many contributing factors including:

- Regional tectonic deformation
- Local site geology
- Co-seismic offsets
- Post-seismic viscoelastic relaxation
- Volcanic inflation/deflation
- Glacial isostatic adjustment
- Ocean and atmospheric loading
- Continental water (surface, ground)
- **Seasonal snow and ice (hydrologic loading)**

- Equipment changes, damage or failure
- Antenna phase center errors
- Metadata errors
- Monument instability
- **Anthropogenic processes such as ground water pumping or water storage in reservoirs**

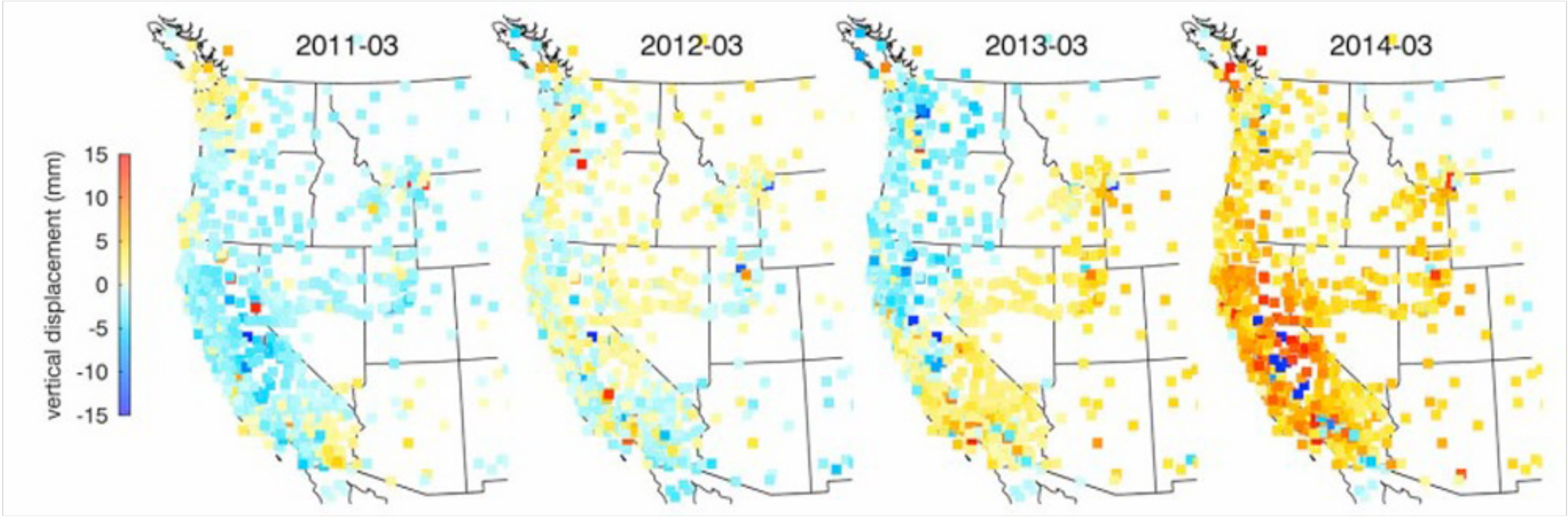
GPS AND HYDROGEODESY

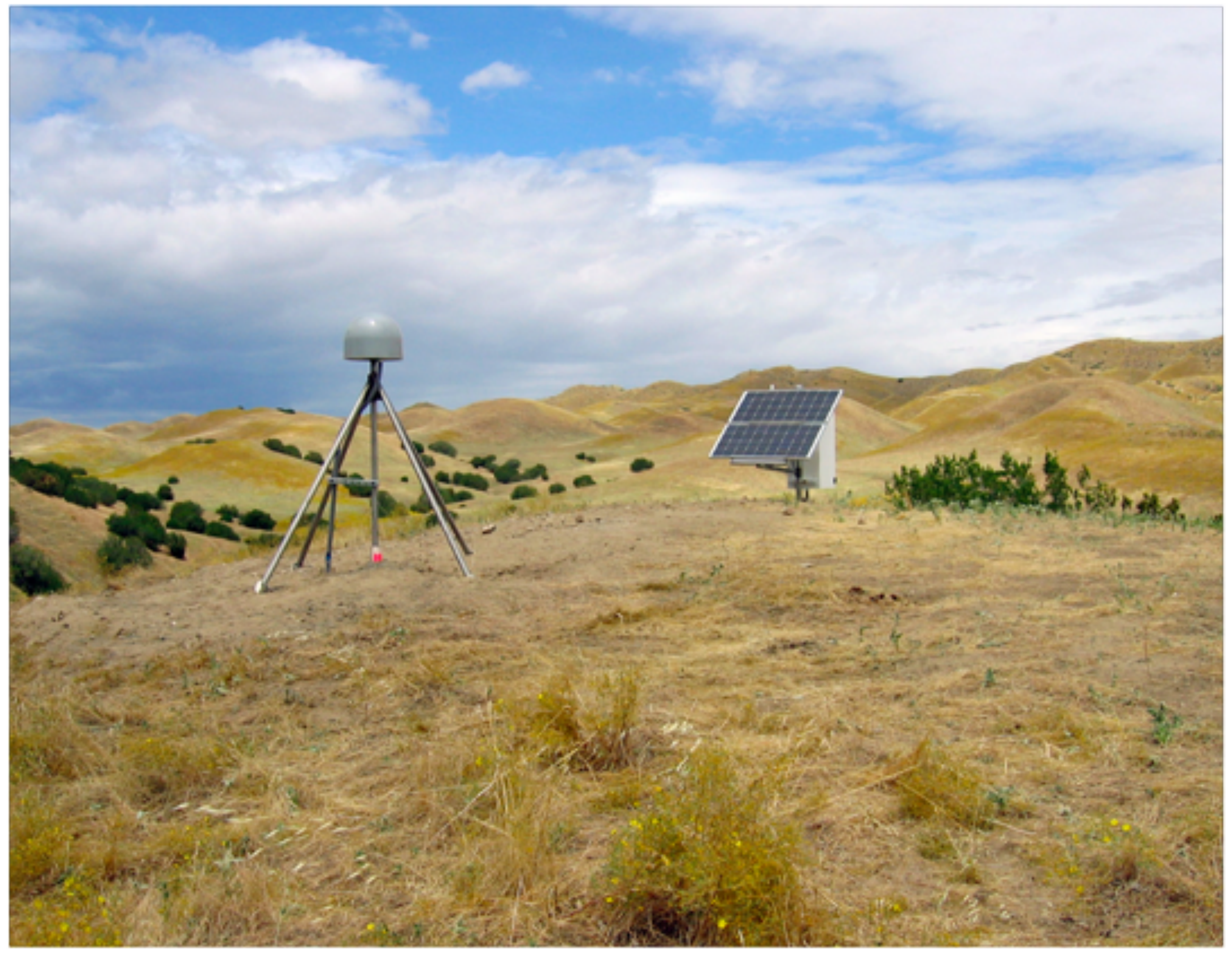
Adrian **Borsa**, Duncan Agnew, Daniel R. Cayan (2014), Ongoing drought-induced uplift in the western United States, **Science**, doi: 10.1126/science.1260279

Uplift and seismicity driven by groundwater depletion in central California, Colin B. **Amos** et al. **Nature**, DOI: 10.1038/nature13275, 2014.

Fu, Y., D. F. Argus, and F. W. Landerer (2015), GPS as an independent measurement to estimate terrestrial water storage variations in Washington and Oregon, **J. Geophys. Res. Solid Earth**, 120, 552–566, doi:10.1002/2014JB011415.

Argus, D. F., Y. Fu, and F. W. Landerer, (2014), Seasonal variation in total water storage in California inferred from GPS observations of vertical land motion, **Geophys. Res. Lett.**, 41, doi:10.1002/2014GL059570.





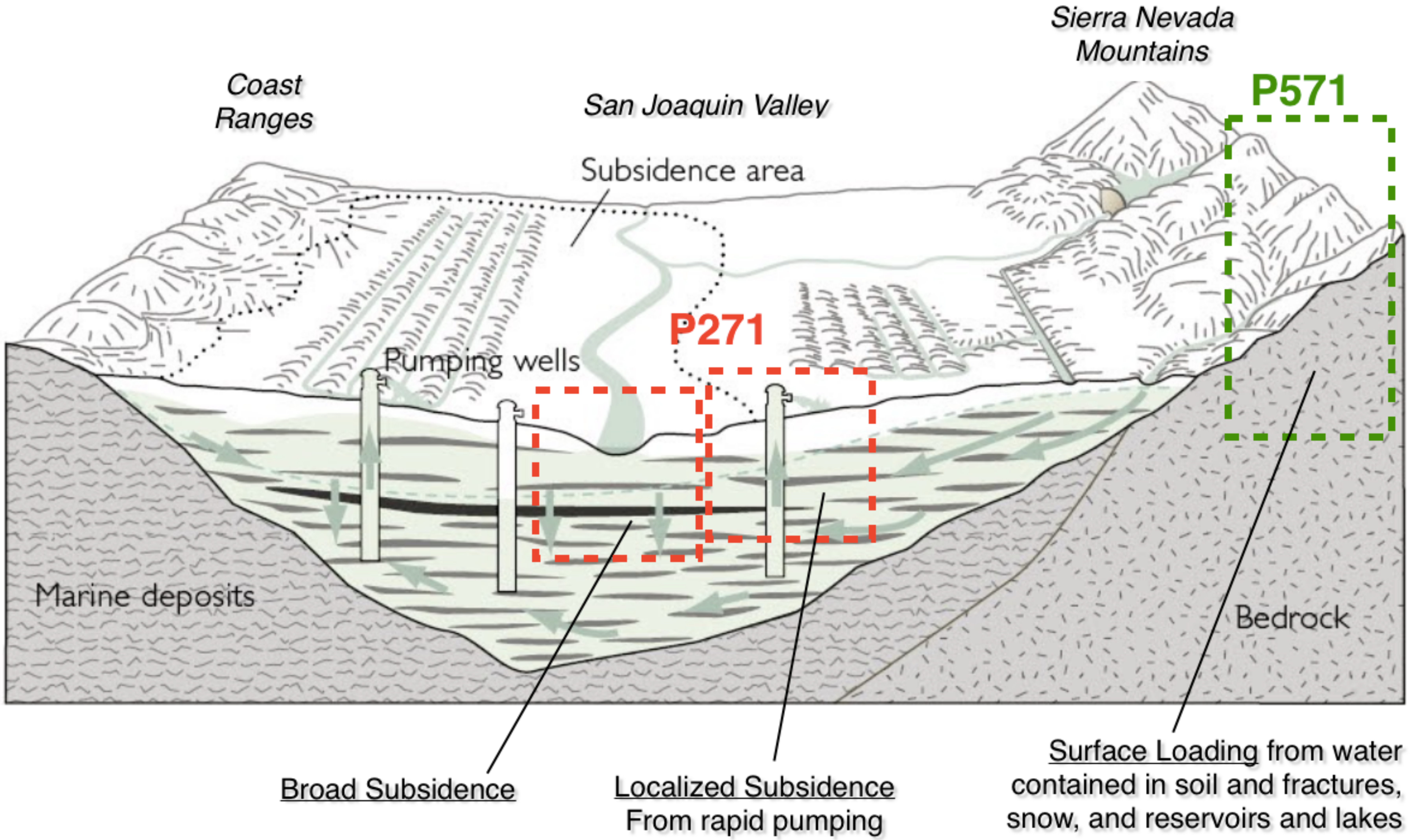
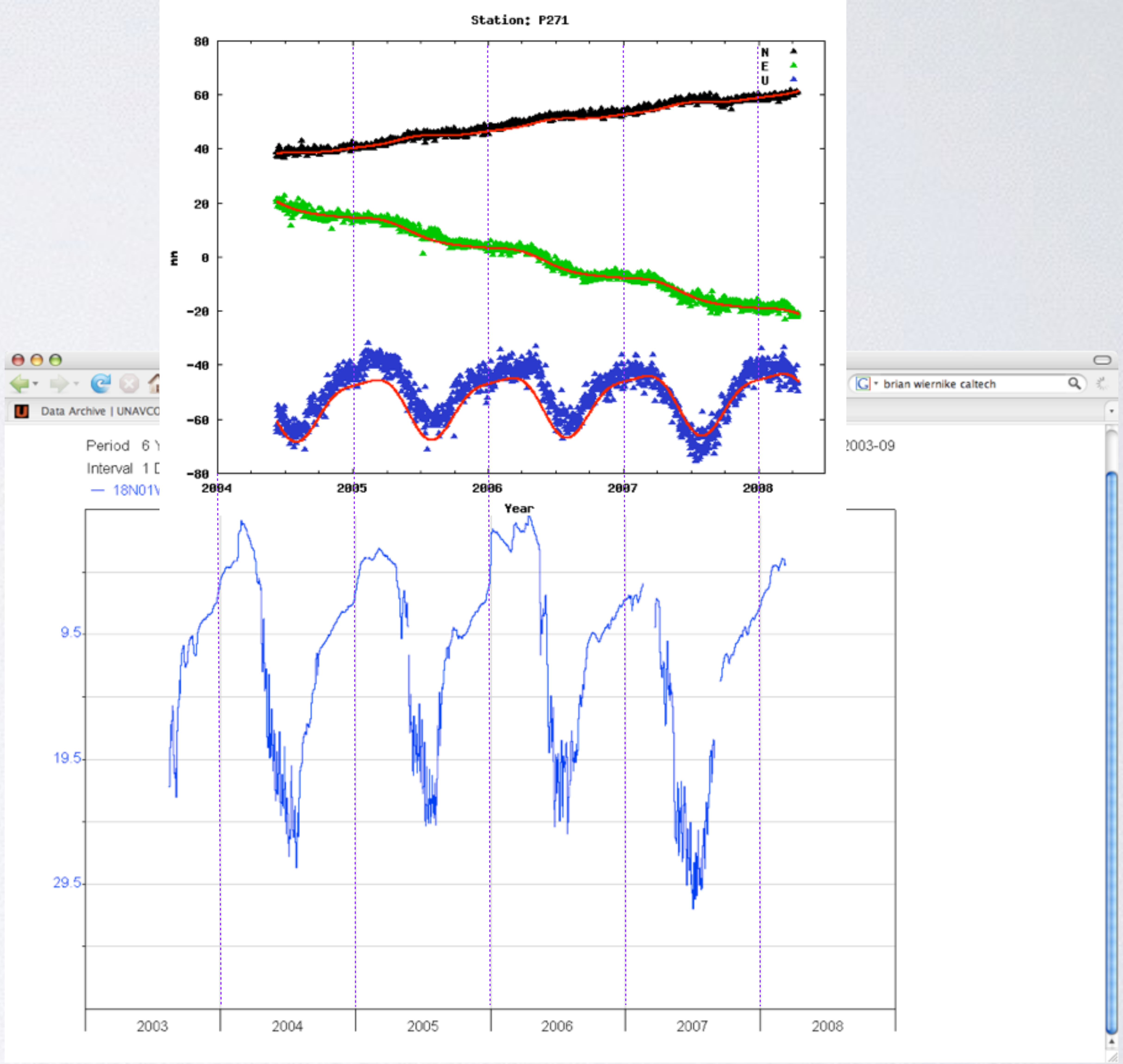


Figure 1-2: Hydrologic Effects in the San Joaquin Valley, California, and relative locations of PBO GPS stations P571 and P271 whose time series are shown below (figure augmented from Galloway et al. (1999)).

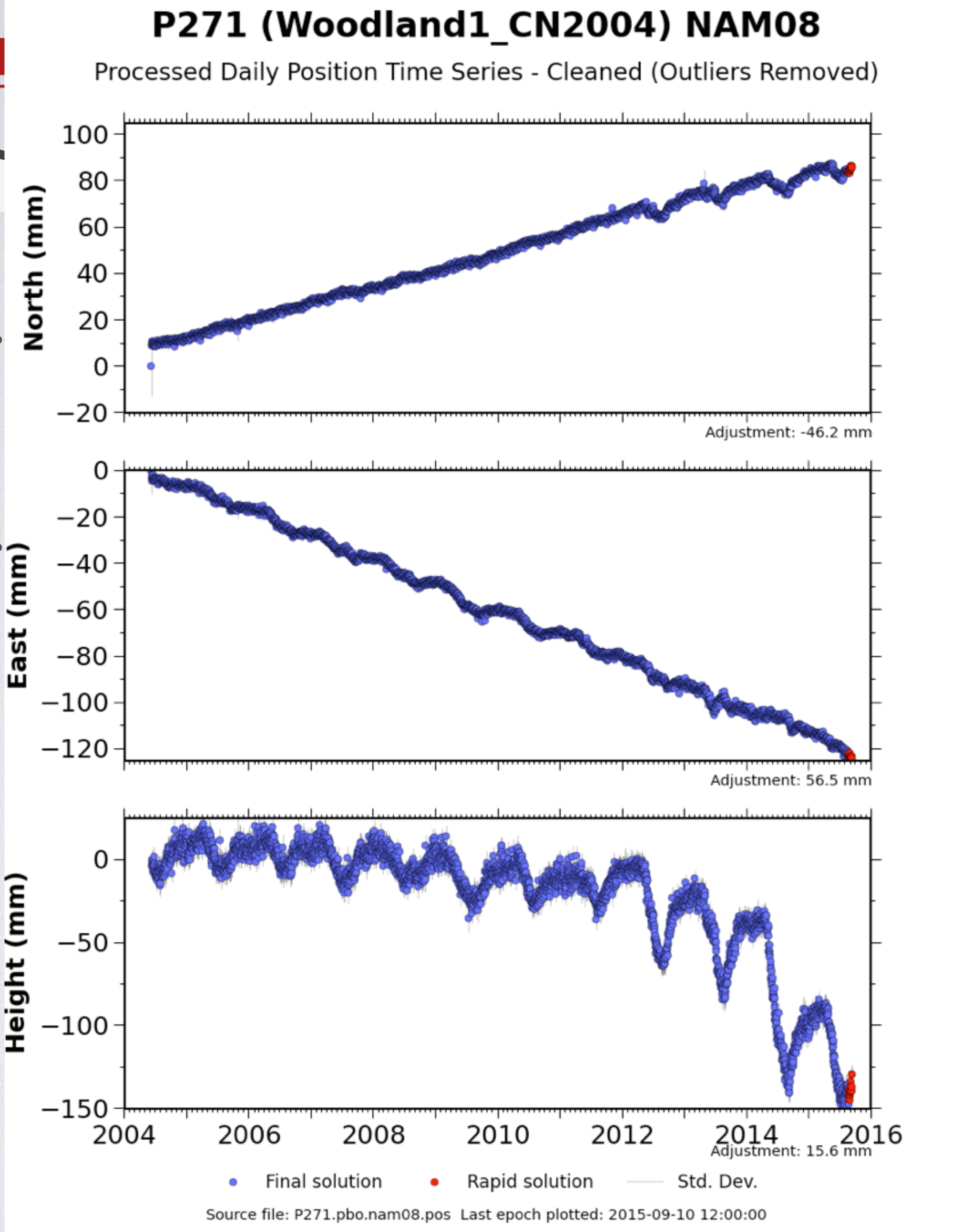
GPS VERTICAL SIGNALS: GROUNDWATER

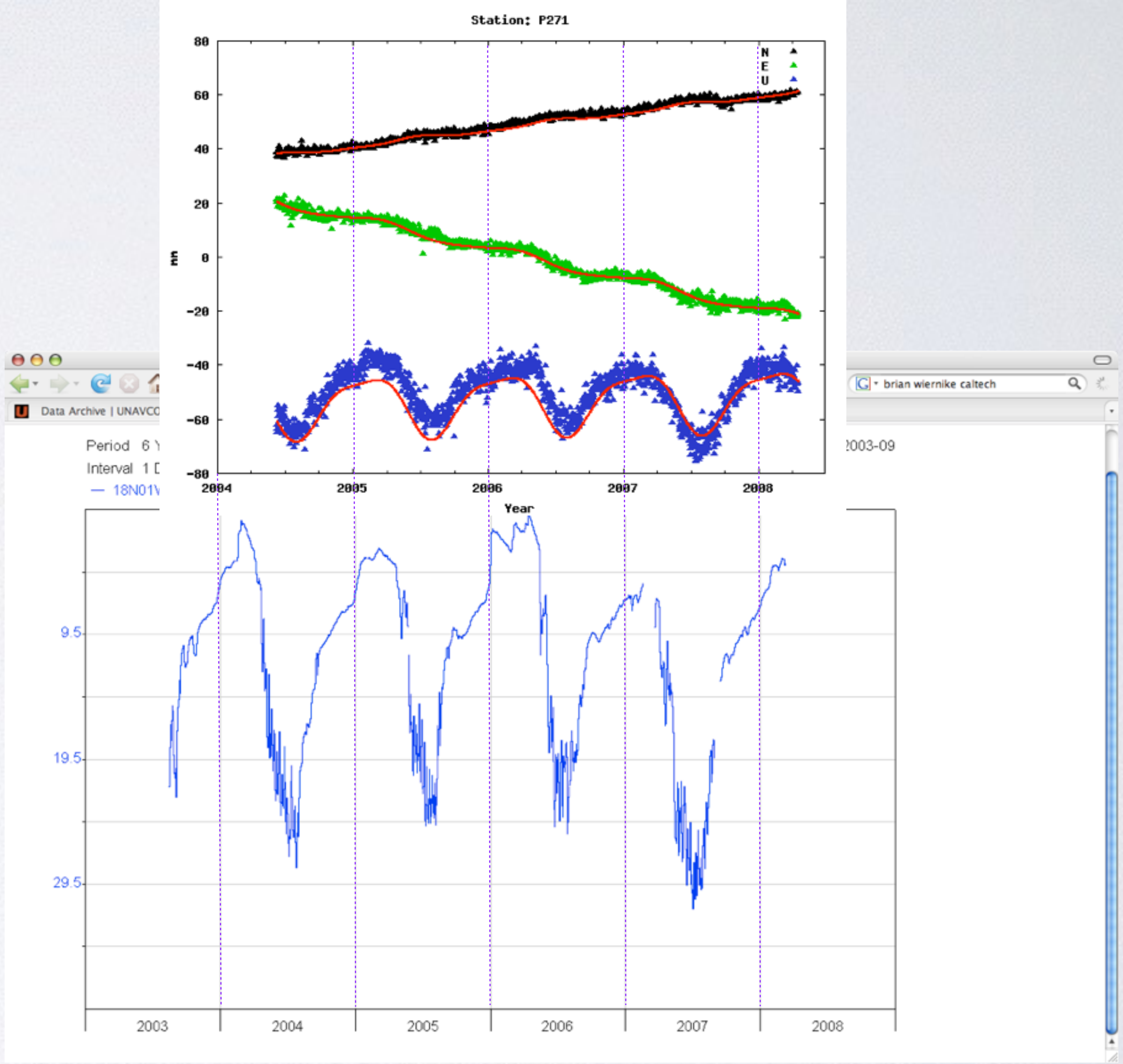
- GPS north, east and up component time series from PBO station P271, located in the San Joaquin Valley of California.

- Water table height time series from nearby well showing annual variations associated with recharge from snowmelt and drawdown from groundwater pumping for irrigation (data reported by California Department of Water Resources). The peak of the annual signal is in March-April and is in phase with water table height. Hydrologic signals at valley sites such as P271 are associated with poroelastic effects and fluctuations in ground water (natural or anthropogenic). Poreoelastic signals can not be modeled using using surface loading models.



IGNALS: GROUNDWATER



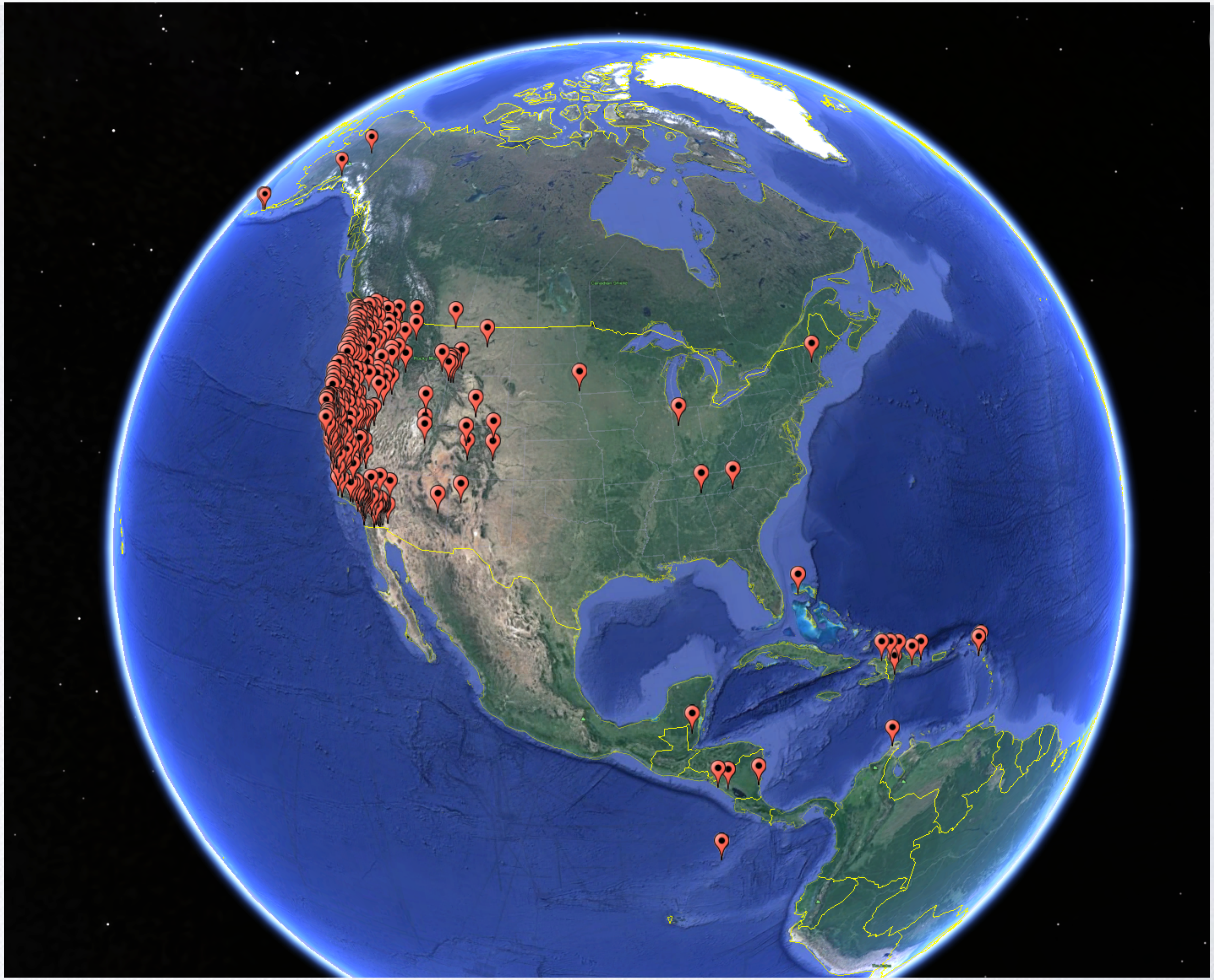


REAL TIME GPS

~ 470 real-time streaming GPS stations

- 422 PBO Core/Cascadia
- 7 TLALOCNet
- 40 COCONet
- 1 Nepal

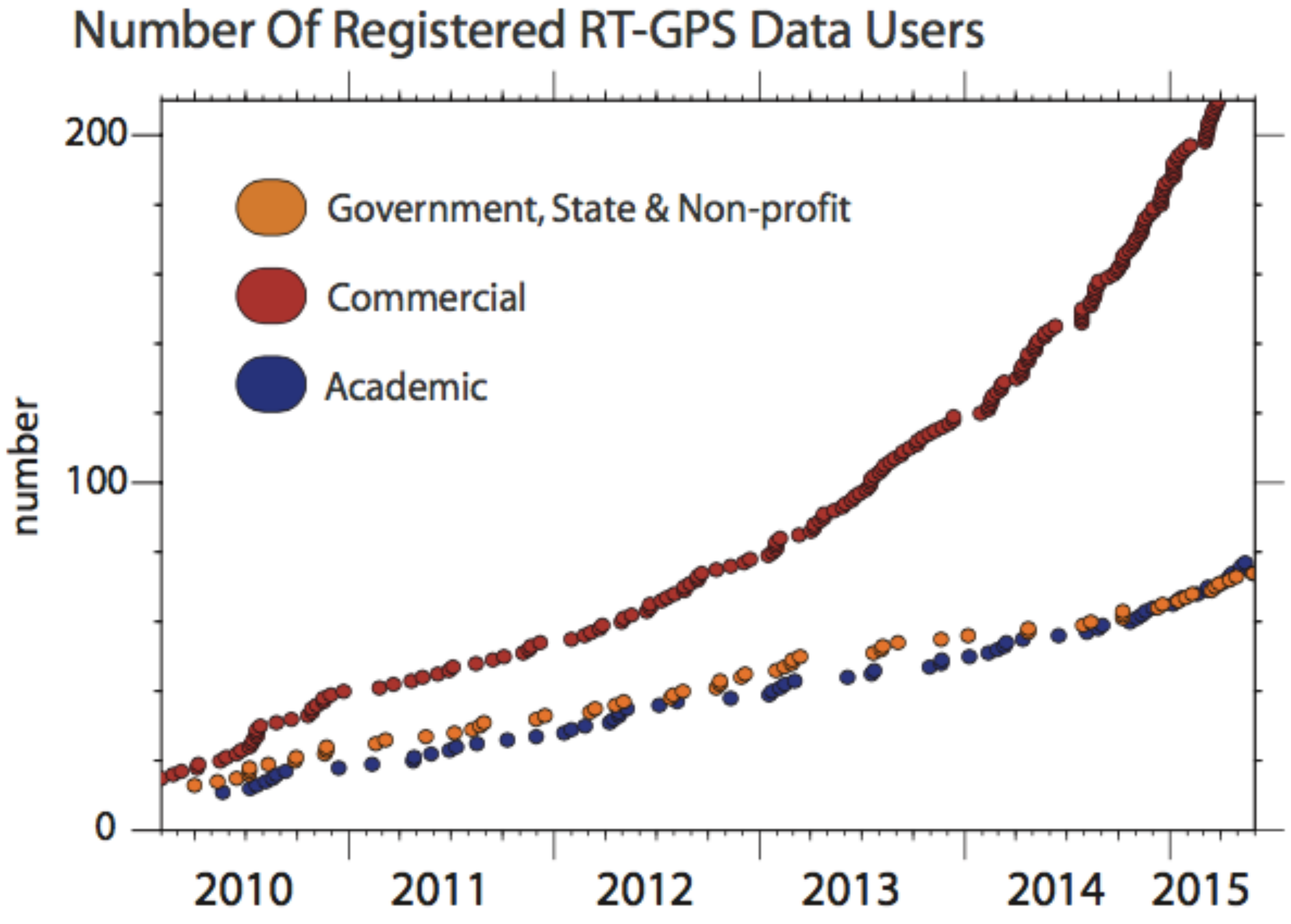
Email "rtgps@unavco.org" for access to streams.

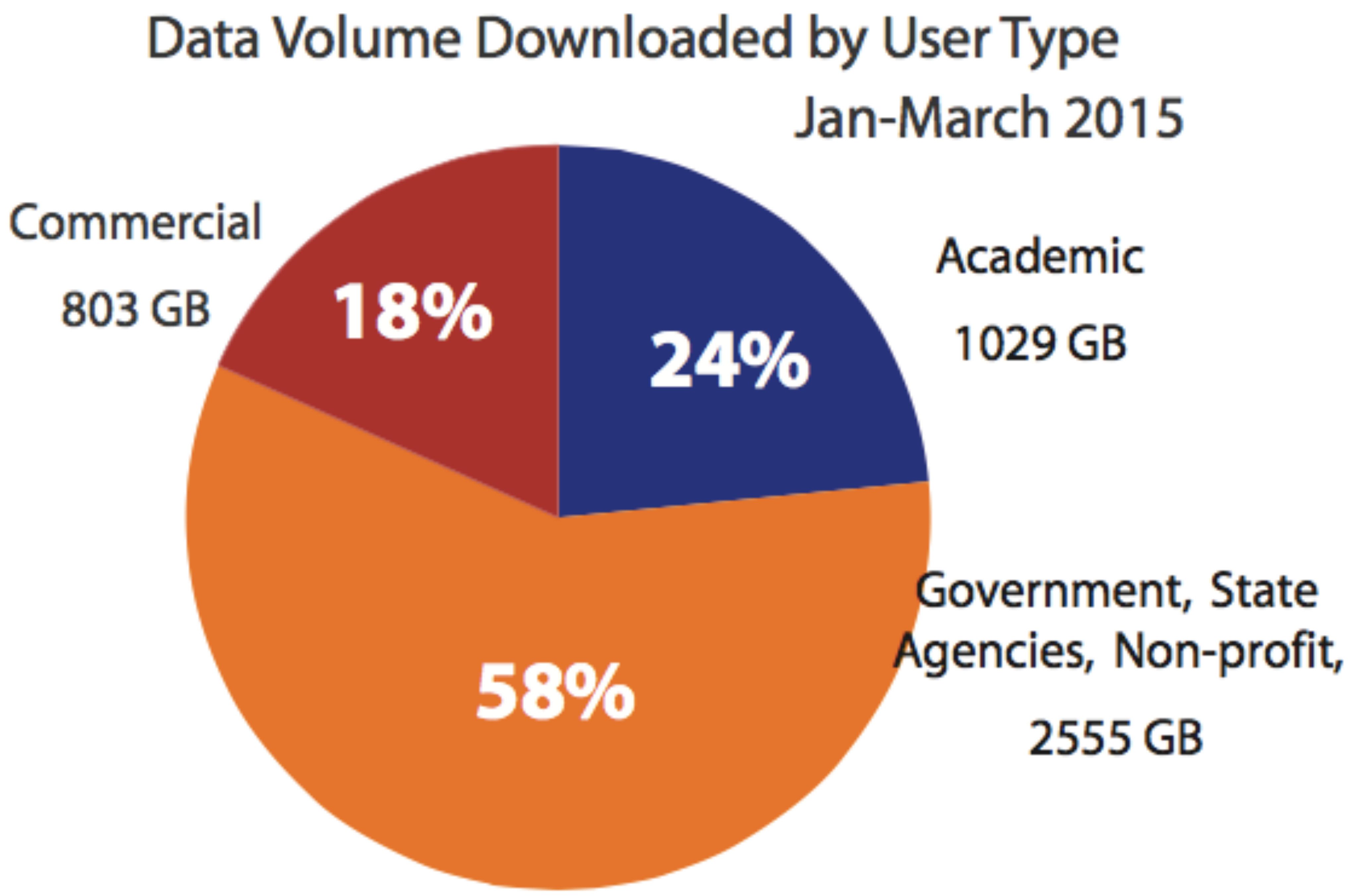


REAL TIME GPS

RT-GPS Data Usage

Data users are divided in to 3 categories: Academic, Commercial and Government, State and Non-profit entities. Although commercial users forms the largest group, the largest volume of data are downloaded through the 2nd quarter of GAGE FY2 were made by Government, State Agencies and non-profit entities.





SUMMARY

- UNAVCO provides the community with a diverse suite of geodetic data, derived products, and user services.
- EarthScope airborne LiDAR data are openly available through OpenTopography. Various data products are available in different formats to serve a broad range of users with different applications, requirements and experience levels.
- GPS/GNSS data from PBO and other networks operated by UNAVCO support research endeavors and contribute to the national infrastructure.
- *Note: a tour of the UNAVCO Facility will take place during the 10th Meeting of the International Committee on Global Navigation Satellite Systems (ICG) in Boulder, Colorado, November 3, 2015.*
- *Note: the 2016 UNAVCO Science Workshop will take place in Broomfield, Colorado March 29-31, 2016.*


I GEODESY
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I like my crust deformed.
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