







Enabling Discoveries in Multiscale Earth System Dynamics: Geodetic Facility for the Advancement of Geoscience (GAGE)

The role of UNAVCO and the GAGE Facility in Supporting the IGS and Global Geodesy: Current status, Upcoming Changes, and **Ongoing Challenges**

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Organization of Presentation Outline

Presentation in 5 sections:

Section I	UNAVCO Mission, Community Science Vision, and
Section II	UNAVCO and IGS: Support for NASA SGP, GGN,
Section III	Status and future of UNAVCO, the GAGE Facility, a
Section IV	Some Science Snapshots from NOTA
Section V	Challenges Going Forward





GAGE GI Program , and the IGS-CB and NOTA

Section I **UNAVCO** Mission, Community Science Vision, and GAGE GI Program







UNAVCO Mission

To facilitate geoscience research and education using geodesy





UNAVCO Vision



- *To transform the understanding of Earth systems* and hazards using geodesy
- This vision is realized through global leadership and facility operations that integrate innovative geodetic technologies and open observations for geoscience research and education, and for the improvement of the human condition



UNAVCO Facts

- UNAVCO has had a four-decade-long history of providing responsive and innovative facility support to the US and global geodetic community
- UNAVCO is a non-profit university-governed consortium, comprised of 121 U.S. Academic Members, primarily degree-granting institutions, which participate in its governance and science community
- 113 Associate Members include organizations that share UNAVCO's Mission at home and abroad, giving UNAVCO global reach in advancing geodesy
- UNAVCO Membership has increased over 8% since 2016 ٠





GAGE Facility - Geodetic Infrastructure Program

Principal Investigator Support NSF EAR & OPP funded PI and community projects **RAPID** Instrument Response Campaign and long-term GNSS deployments Geodetic Imaging Terrestrial Laser Scanning Projects Emerging Imaging Geodesy Tools (UAV-SfM) **Community & Continuously Observing Networks** EAR: PBO, COCONet, and TLALOCNet >> NOTA GNSS and Metpack Operations **Borehole Geophysics Operations** Multi-constellation GNSS station upgrades OPP: POLENET: GNET (Danish Contract) & ANET NASA: Global Geodetic Network (GGN) Geodetic Instrumentation Testing & Support (formerly D&T)





Section II UNAVCO and IGS: Support for NASA SGP, GGN, and the IGS-CB



NRC Studies: Precise Geodetic Infrastructure (2010)

Evolving Geodetic Infrastructure to Meet New Scientific Needs (2020) PRECISE GEODETIC INFRASTRUCTURE National Requirements for a Shared Resource

NATIONAL RESEARCH COUNC





FIGURE S.1 Illustration of how the geodetic infrastructure is connected to enabled scientific applications. NOTE: DORIS = Doppler Orbitography and Radiopositioning Integrated by Satellite; GNSS = Global Navigation Satellite System; InSAR = Interferometric Synthetic Aperture Radar; SLR = Satellite Laser Ranging; VLBI = Very Long Baseline Interferometry.

- Mass change - Surface and ground water and soil moisture

- Scale - Orientation

> - Experts - Archives

GNSS Signals and **Novel Applications**



GNSS signals sense information

about the atmosphere.

The GNSS satellite signal is delayed by charged particles caused by solar storms; this layer can also be displaced by tsumanis, yielding information for tsunami early warning.

The GNSS satellite signal is delayed by water vapor that can turn into rain. This informs forecasting of flash floods and hurricanes.

Global Distribution of GAGE-supported GNSS Stations and PI Projects



GAGE Facility Campaign GPS/GNSS Data Holdings





International GNSS Service

Mission

The International GNSS Service provides, on an openly available basis, the highest-quality GNSS data, products and services in support of the terrestrial reference frame, Earth observation and research; positioning, navigation and timing; and other applications that benefit science and society.

To learn more about the IGS Mission, and how it is benefitting society, please refer to the IGS Strategic Plan

Vision

A better understanding of the Earth through the application of GNSS.

Organizational Values

Fundamental to the IGS are key values that are shared across the organization, these are:

- Advocacy of an open data policy, with data and products openly available,
- Welcome contributions from and participation with all organizations,
- Effective reliability through redundancy of IGS components,
- Technical evolution through "friendly competition",
- Dedicated engagement with policy entities to raise mutual awareness of IGS and geodesy in general.



International GNSS Service and UNAVCO

- Overlapping Mission and Vision
- Commitment to FAIR data principles and growing global geodesy
- Both organizations grew independently, but in parallel UNAVCO staff have participated in various roles with IGS since the early 1990s
- Primary support and contribution from UNAVCO to IGS is through NASA: Global GNSS Network, Space Geodesy Project, and IGS-Central Bureau
- GAGE final, precise, daily GPS processing used IGS data products in the past when there were two independent processing centers (GIPSY-JPL and GAMIT/GLOBK-IGS)
- NOTA RT-GNSS system is running several processing engines, including one (Wuhan - PRIDE) that uses MGEX products

Global Tracking Network Evolution – IGS 1992





Global Tracking Network Evolution – IGS 2022







Freddy Blume Engineering Manager III

GAGE Facility - GI Senior Staff

NASA Global GNSS Network Geodetic Instrumentation Testing and Support (GITS)

Started at UNAVCO in November 2003 Post-doc at CU Boulder and 10 years in oil exploration in WY

Installation of GGN station in Madagascar and managing **PBO** Nucleus Project

Featured in NOVA's "Deadliest Earthquakes" at a tsunamiravaged house in Dichato, Chile following the Maule M8.8 event

UNAVCO - NASA SGP, GGN, and IGS-CB Support Staff



Kimber DeGrandpre

Engineer II Just started at UNAVCO NASA GGN/SGP





Data Scientist III 23 Years at UNAVCO IGS-CB since 2015



Jacob Sklar

Engineer III 20 Years at UNAVCO NASA GGN/SGP



Engineer Manager II 18 Years at UNAVCO NASA GGN/SGP to 2021

David Maggert

Sarah Doelger

Global Tracking Network Evolution – NASA GGN Today



Global Tracking Network Evolution – Status and Goals

- NASA Space Geodesy Project
 - Completed installation of DDBM monuments and geodetic ties to VLBI/SLR in TX and HI
 - Upcoming fieldwork includes completion of the SGP multi-technique facility at McDonald Observatory in TX – lightning mitigation

NASA Global GNSS Network (GGN) •

- GGN currently operating at \sim 95% uptime with 92% data return in G2Y4Q2
- UNAVCO coordinates O&M and data flow for GGN with JPL
- Recommissioning of Easter Island Station (waiting final signatures on MoU with Government of Chile and others). Field visit earlier this year restored data communications with Harvest Oil Platform.



NASA Space Geodesy Project and GGOS – UNAVCO Role



- 4) Tight co-location of methods to improve POD on LEO/MEOs



Time Scale

SDBM and DDBM monuments – key element in high precision geodetic observations from GNSS

using standard SDBM dimension stainless steel rods for legs, each 4m in length

Each leg is encased in concrete

> 10-15cm diameter holes drilled into soil with a hand auger to approx 3m below the surface



NASA Space Geodesy Project – UNAVCO Role





NASA Space Geodesy Project – UNAVCO Role

Drilled Brace for GNSS (The newly ins

als from several GNSS ONASS, and Galleo





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IGS Participation and IGS Central Bureau Support

- D. Maggert serving as IGS Network Coordinator since 2015
 - Wrangles IGS station metadata and new IGS station applications
 - Coordinates with GNSS equipment manufacturers to get info into IGS system
 - Serves on RT-GNSS Working Group
- F. Blume serves on IGS Antenna Working Group and 2022 IGS Workshop Organizing Committee; previously C. Meertens, F. Boler, L. Estey served on various working groups and Executive Committee
- As part of NASA-GGN (JPL), NSF-NOTA, NGS, and USGS station O&M and data flow management, GAGE Facility provides data from 97/511 IGS stations (~19%), including 15 RT-GNSS streams
- Built and previously maintained IGS Site Log Manager
- Designed, built, and maintained TEQC (RINEX v2.11) development halted and now "dockerized" with retirement of L. Estey. TEQC replacement – GRANITE – to be released later this year.
- Built current IGS Network Page and manage igs.org domain future support is under discussion
- Provided support for various IGS meetings at AGU Annual Meetings

GAGE Facility - Geodetic Instrument Testing and Support (GITS)

- Independent GNSS Receiver Evaluation and Firmware Validation
- GNSS Receiver Performance and Mitigation during RFI
- GNSS Antenna Testing
- GNSS and Data Communication Integration
- Extreme Temperature Testing of GNSS Station Components
- Publication of Results Through an Online Knowledge Base for Global Geodesy Community

GNSS Receiver Evaluation and Firmware Validation



GNSS Receiver Performance during RFI



Results and Information Published in Online Knowledge Base





Iridium Data Transmitters

Asticle (D) 222 | Daties: Usersted | Linet Hedated Mer. New 22, 2015 at 11:00 DM

Section III Status and Future of UNAVCO, the GAGE Facility, and NOTA





EarthScope Background



•Funded by NSF

UNAVCO

•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





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The Earthscope

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What's in It For You

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Seismic Component - USArray

The EarthScope Plate Boundary Observatory

\$200 M (USD) Total Investment by NSF over 15 years

Focused, dense deployments of cGPS

and strainmeter arrays

- II31 continuous Global Positioning Systems around tectonic clusters
- 78 borehole strainmeters
- 5 long baseline strainmeters
- 26 tiltmeters

UNAVCO

• 145 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 I (2008-2013)
- **\$46M** -Operations and Maintenance Phase 2 (2013-2018)







UNAVCO

Network of the Americas (NOTA)

Federation of NSF-funded cGNSS networks across the Americas:

- PBO (2003-2018 ~\$200M)
- TLALOCNet (2015-2018 ~\$2M) • COCONet (2010-2018 ~\$6M)

Currently ~1154 cGNSS/Met stations distributed across 31 countries. 82% uptime.

NSF released a Dear Colleague Letter in 2019 announcing the descoping and decommissioning of ~10% of existing NOTA stations.



Typical NOTA Remote GNSS Station

Typical NOTA GNSS Station

GAGE-NOTA Data Products

GPS data products from NOTA and other networks Level I:RINEX – will now support v2-4 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, I)

Other data products

Increasingly supporting near-real-time and real-time data and products

Campaign vs. Continuous GPS Position Time Series

CRO1 Coordinate changes - CA is fixed stacovs used AMB

GMD 2022 Apr 22 23:15:42 Mattioli/UTA

EarthScope Plate Boundary Observatory (PBO) Velocity Field

Tectonic Motions of the Western United States

Based on combination of JPL and IGS Orbit and Clock Products

ShakeAlert and Real-time NOTA

ShakeAlert: An Earthquake Early Warning System for the West Coast of the United States

Future of GAGE Facility and IRIS and UNAVCO Merger

- In Fall 2019, NSF informed IRIS and UNAVCO boards of its intention to support a *single* geophysical facility after the close of the IRIS-SAGE (seismic) and UNAVCO-GAGE (geodetic) Facilities. Formal DCL announced this in January 2020. Both facilities are funded through 5-year Cooperative Agreements that expire in September 2023
- Joint IRIS-UNAVCO Merger Negotiation Committee established in Fall 2019 to study possible merger and develop draft terms or merger for board and membership consideration
- IRIS and UNAVCO Boards of Directors separately voted to approve the terms of merger in Summer 2020 - Member Representatives from both IRIS and UNAVCO voted to approve the merger in Fall 2020
- Merger Implementation Committee and Programmatic Planning Teams established in Fall 2020
- Based on extensive review of SAGE and GAGE Facilities and an NSF AC-GEO Geophysical Instrumentation Portfolio Review, NSF announces in June 2021 its intention to extend the existing Cooperative Agreements through September 2025. No formal action yet.
- Initial merger of IRIS and UNAVCO into *EarthScope Consortium* will occur in December 2022 with goal of full integration by Fall 2023.
- Expect new NSF solicitation for single, Future Geophysical Facility in early 2024, with decision on new operator by late 2024 or early 2025.

Section IV Science Snapshots from NOTA

GAGE Facility – NOTA Science Snapshots

- Cascadia Episodic Tremor and Slip from GNSS and BSM •
- Crustal Loading from GNSS for Hydrogeodesy
- July 5, 2019 Ridgecrest M7.1 earthquake: applications of **RT-GNSS** for Earthquake Early Warning
- Hurricane tracking improvement from GNSS-derived troposphere estimation

Sauce Barrier

Cascadia ETS

Dragert & Wang, JGR, 2011; Bartlow et al., GRL, 2011

-122"

29

5 September 2010

Hodgkinson et al., 2014, GSA abstract & poster (122-27)

Crustal loading from GPS for hydrogeodesy

Borsa et al., Science, 2014

Crustal loading from GPS for hydrogeodesy

Second Barth

A. Borsa, pers. comm., 2020

Hurricane Isaac (2012)

SuomiNet Precipitable Water Vapor 120823/0045

Black track - best estimate of actual track from NHC Red track - conventional data assimilation Green track - COCONet PWV data added to assimilation

J. Braun, UCAR/COSMIC, pers. comm.

Section V Challenges Going Forward

Some Ongoing Issues and Challenges

- Increasing demand for real-time or near-real-time GNSS streams, advanced and custom data products, and analysis – presents some challenges related to open data access and the balance of basic versus applied science and commercial applications
- Aging geodetic infrastructure (e.g., NOTA) with no long-term commitment to continued technical enhancement and rejuvenation
- Flat or nearly flat funding for a decade despite real and increasing inflation that impacts all aspects of UNAVCO and GAGE Facility operations
- Staff retention and continued growth impacts of remote work and COVID
- Uncertainty and complexity associated with IRIS-UNAVCO merger into *EarthScope Consortium*
- Uncertainty regarding outcome of the re-competition for the *Future Geophysical Facility* after the close of the SAGE and GAGE Facilities

GAGE National Science Foundatio

National Science Foundation's Geodetic Facility for the Advancement of Geoscience

