The NASA Space Geodesy Network

Stephen Merkowitz

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UAW

Remembering James Leroy Long (1955 - 2019)

Decadal Survey Missions Dependent on Space Geodesy

Extreme weather prediction

Ocean topography, mean sea level

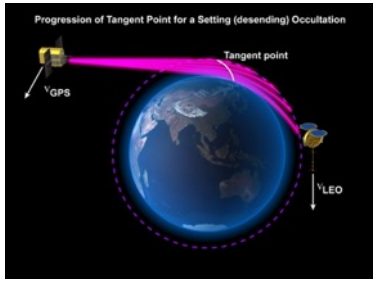
SWOT: Surface waters, ocean topography

Polar Ice Sheet and Glacier changes, sea-ice thickness, Vegetation canopy ht.

3D-Vegetation canopy structure; Forest carbon sources & sinks; Surface topography

Ice-sheet collapse; Ecosystem disturbances; Natural Hazards (Volcanos, earthquakes, landslides)

Mass change (cryosphere, hydrology, solid earth, oceans)



GNSS RO satellites: Weather forecasting; Climate studies; Global ionosphere models

All these missions have Precision Orbit Determination and geolocation requirements that depend on accurate Terrestrial Reference Frame and Earth Orientation Parameters. Most of these also depend on SLR tracking.

Current NASA Space Geodesy Network (NSGN)

- 7 legacy Satellite Laser Ranging (SLR) stations
- 2 legacy Very Long Baseline Interferometry (VLBI) stations
- 3 VLBI Global Observing System (VGOS) stations
- Co-located Global Navigation Satellite Systems (GNSS) stations

McDonald Laser Ranging Station (MLRS)

- The MLRS first started operating in 1982 and quickly became a premiere satellite and lunar laser ranging station. Data from this station was used for the most stringent tests of General Relativity, studies of the interior structure of the moon, and countless other geodetic and spacecraft tracking applications.
- Lightning struck MLRS on September 12, 2019 rendering it inoperable.
- NASA is currently building a next generation SGSLR station next to the MLRS, and has decided to not repair the 37-year-old MLRS.

Next Generation NASA Systems

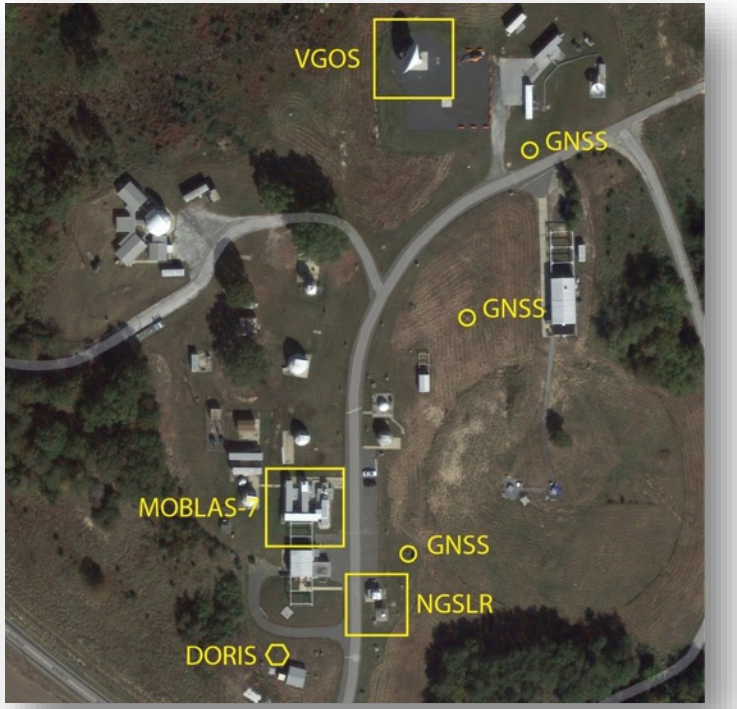
- The VLBI Global Observing System (VGOS):
  - 1 mm measurement accuracy on global baselines,
  - Small, fast, efficient antennas,
  - Broadband (2-14 GHz),
  - Fast data recording rates (2-16 Gbps).
- NASA's Space Geodesy Satellite Laser Ranging (SGSLR) System:
  - 24 hour tracking of LEO, LAGEOS & GNSS satellites,
  - 1 mm normal point precision on LAGEOS,
  - Stability at the 1mm level over one hour,
  - Calibrated against the network standard,
  - kHz pulse rate laser with single photon detection system,
  - Automated operations.
- Collocated with multi-constellation GNSS and DORIS stations.
- Local tie definition and monitoring at 1mm accuracy or better.

Next-Generation NSGN Site Requirements

- Stable geology located away from known active faults and volcanic activity, ideally with bedrock outcrops
- The area surrounding the site shall be largely unaffected from loading transients
- Cloud Cover <= 50% average per year
- Atmospheric particulate content shall not interfere with the laser signal
- Located away from air traffic corridors and airports to protect aircraft from the SLR laser beam and minimize operational disruptions.
- Located away from RF emitters to minimize RFI
- Clear view down to 10 degrees elevation over 95% of horizon
- Available electrical power and broad-band internet

Prototype Next-Generation Site

- The Goddard Geophysical and Astronomical Observatory (GGAO) in Greenbelt, MD is one of the few sites in the world to have all four geodetic techniques collocated at a single location.
- Demonstration of next generation prototypes completed in 2013.
- GGAO is the basis for upgrading and expanding NASA's global Space Geodesy Network.



SLR

VGOS

GNSS

DORIS

NSGN Deployment Tiered Approach

- Network deployment is grouped into tiers based on *four main factors*:
  1. Domestic station replacement priority
  2. ITRF and EOP contribution based on simulated network performance
  3. Legacy station operational performance (data yield)
  4. Legacy station failure risk.
- The Tiers are as follows:

  Tier 1: Sites that already have advanced plans and budget for near-term implementation.

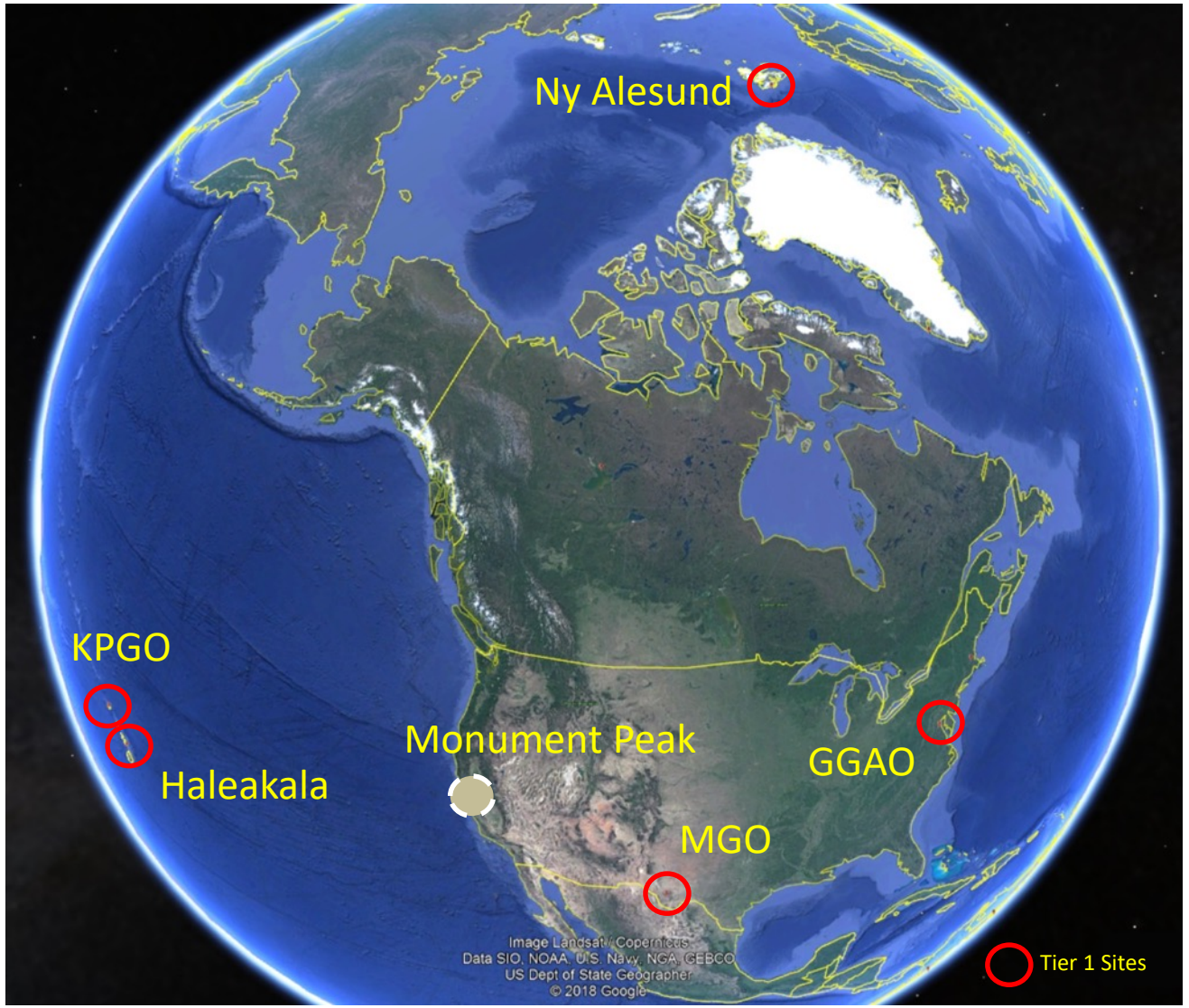
  Tier 2: Replacement of remaining NASA legacy stations.

  Tier 3: Expansion of the NASA network to locations under discussion with partners.

  Tier 4: Completion of the extended network (either by NASA or others).

Merkowitz, S.M., *et al.,* J Geod (2018). https://doi.org/10.1007/s00190-018-1204-5

NSGN Tier 1 Sites



- Replaces all US domestic NASA stations:
  - Greenbelt, MD
  - Fort Davis, TX
  - Kōkeʻe Park and Haleakala, HI
- Also includes a NASA SLR station in Ny-Ålesund, Svalbard.
- Monument Peak is planned for decommissioning once Texas SGSLR is operational as network simulations show that Texas station will provide sufficient SLR coverage over western United States.

NSGN – Tier 2 Sites

- Tier 2 Sites are those for which discussions have already started, and replace NASA Legacy stations. Sites currently under consideration include:
  - Brazil
  - Australia
  - Tahiti
  - South Africa
- NASA plans to continue supporting its legacy Peru SLR station for at least 5 more years.

NASA VGOS Deployment

- Goddard prototype station operational
- Hawaii Kōkeʻe Park Geophysical Observatory (KPGO) station operational
- Texas station installed and being commissioned, with full operations anticipated by January 2020.
- Planning for new site in Tahiti underway with CNES
- Planning underway to replace legacy station in Brazil

Goddard Geophysical and Astronomical Observatory

Kōkeʻe Park Geophysical Observatory, Hawaii

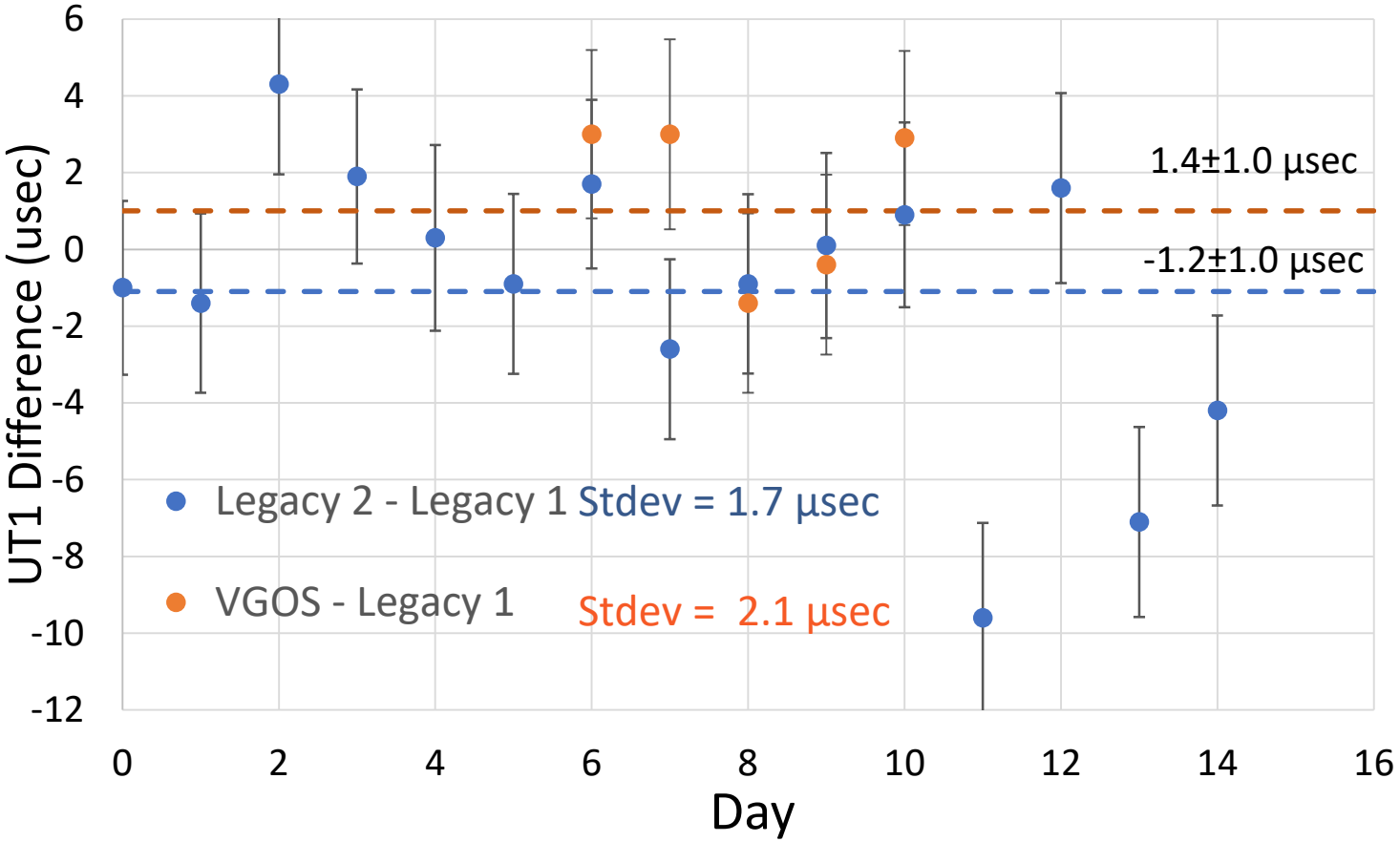
McDonald Observatory, Texas

Tahiti

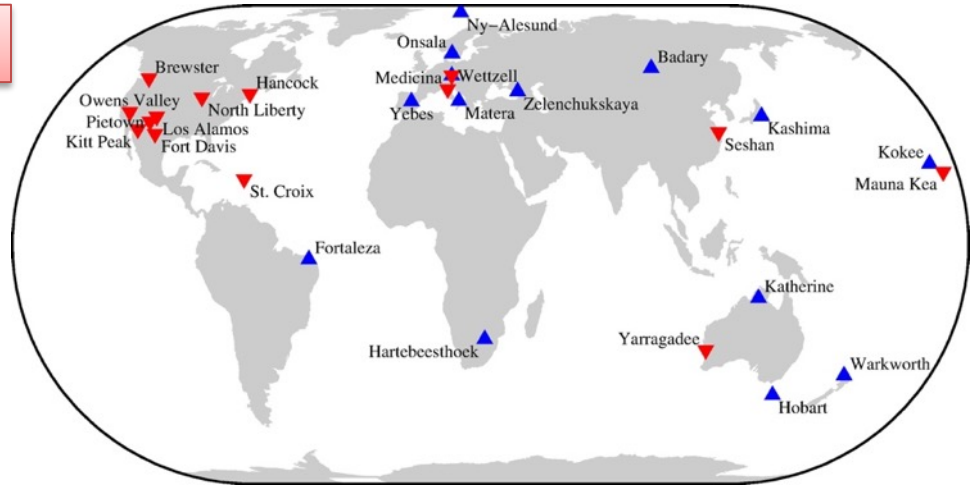
Brazil

VLBI CONT17 Campaign Results

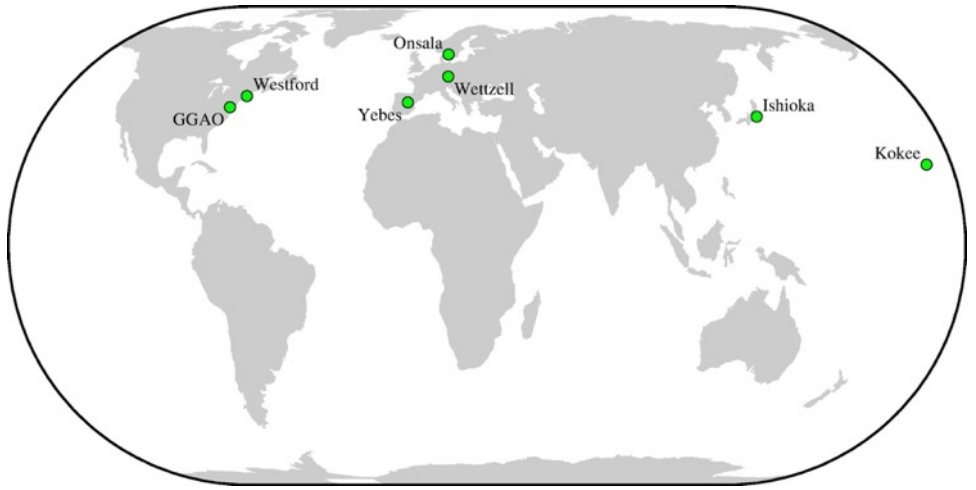
VGOS shown to have comparable uncertainties for UT1 as legacy network!



CONT17: Continuous VLBI campaign from 11/28/17-12/12/17
Journal of Geodesy Special Issue in works



Legacy-1: 14 IVS network stations
Legacy-2: 10 VLBA stations plus 4 IVS network stations

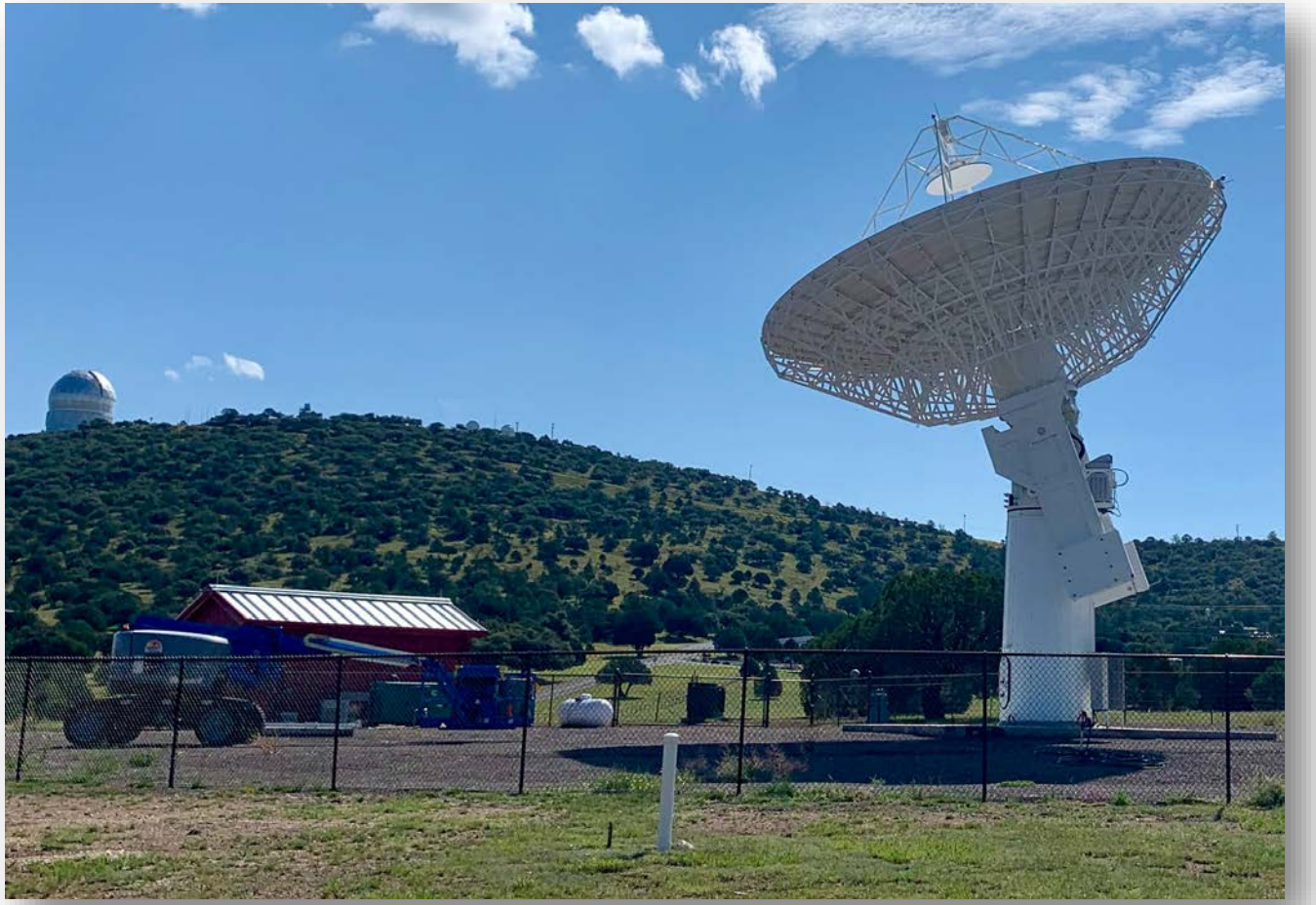


VGOS Network

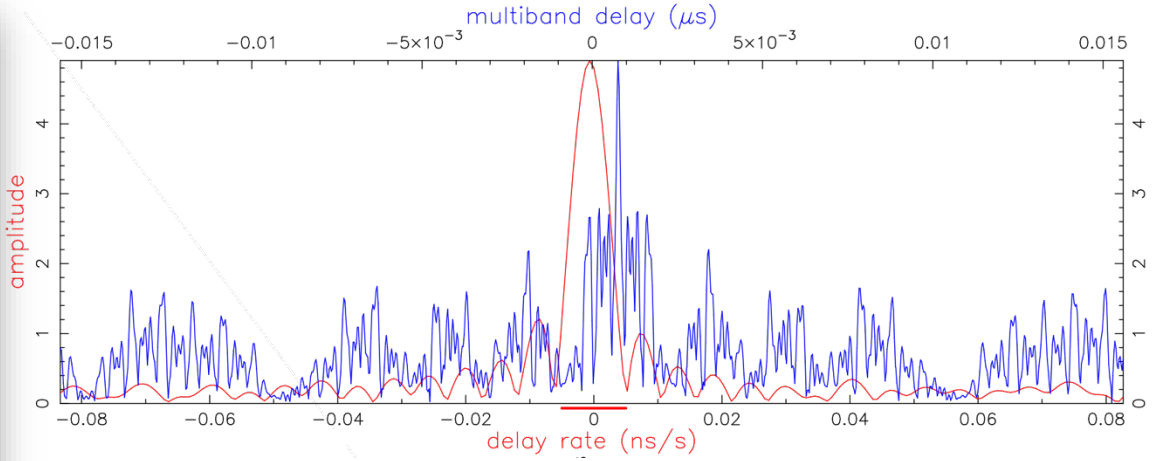
Kōke‘e Park Geophysical Observatory (KPGO) in Hawaii

- KPGO host both legacy VLBI and VGOS stations
- VGOS station observed first light on February 1 and participated in world's first 3-way broadband VLBI measurement on February 5, 2016
- Both stations are currently operational
- Initiating pilot project to begin VGOS intensive sessions

Texas VGOS Station Implementation



New VGOS station was successfully deployed to the McDonald Observatory in Texas and immediately obtained “first light” after completing integration on July 19, 2019.



First interferometric fringes were obtained between the new station and the Goddard (Maryland) and Westford (Massachusetts) stations observing quasar 0059+581.

Milestone	Date
Antenna PDR	✓ 9/12/2017
Antenna CDR	✓ 12/6/2017
Signal Chain CDR	✓ 12/8/2017
Antenna SAT	✓ 2/20/19
ORR	1/2020

NASA SLR Deployment

- Based on NGSLR prototype at Goddard
- Long-lead items for first 3 stations currently being manufactured.
- Texas SGSLR build progressing
- Work on Ny-Ålesund SGSLR station also underway

Goddard Geophysical and Astronomical Observatory

McDonald Observatory, Texas

Ny-Ålesund, Norway

Haleakala Observatory, Hawaii

Texas SGSLR Station Implementation

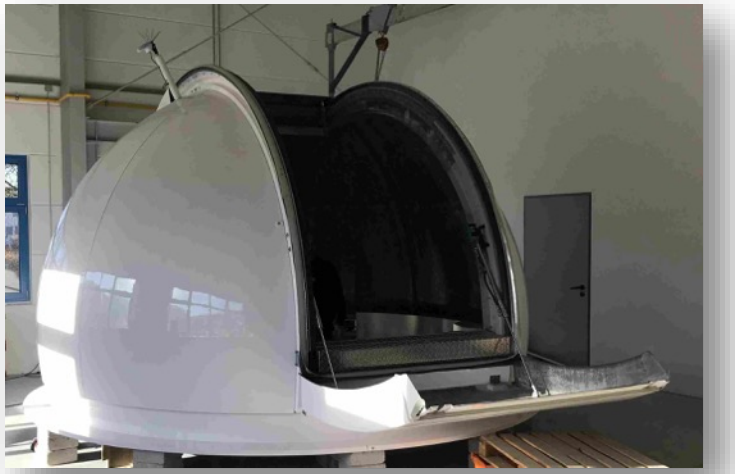
Milestone	Date
SGSLR PDR	✓ 4/7/2016
GTA CDR	✓ 5/12/2017
SGSLR CDR	✓ 9/5/2018

Photonics Industries Laser

McDonald Observatory Infrastructure Improvements

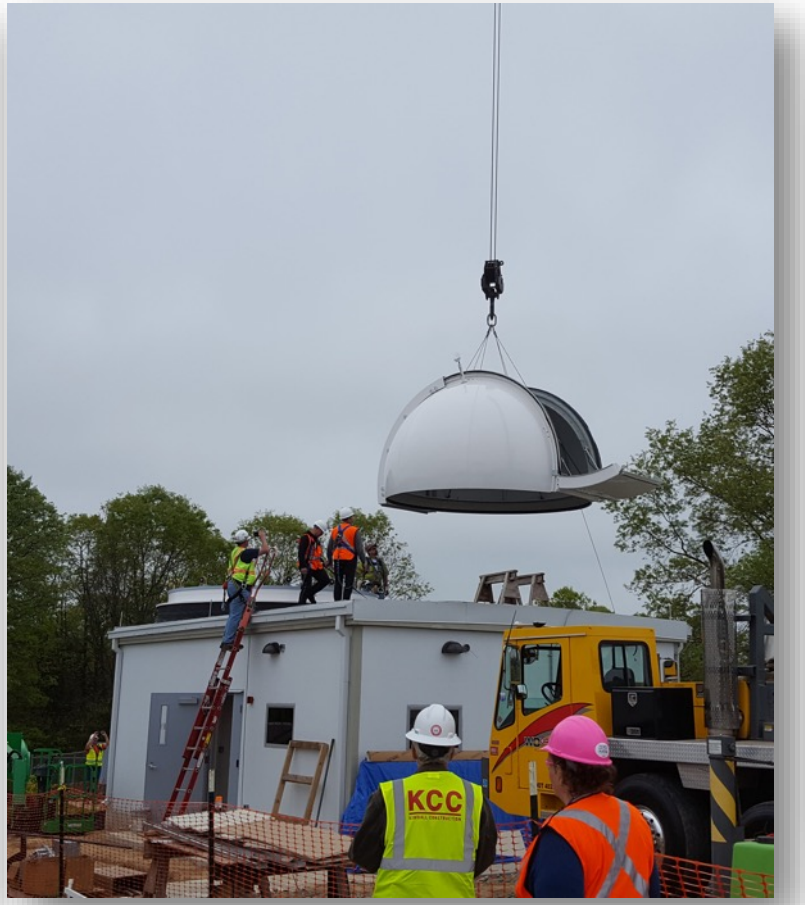
Cobham Gimbal and Telescope Assembly

Baader Planetarium Dome



Sigma Space Receiver

GGAO SGSLR Integration and Test Facility Complete



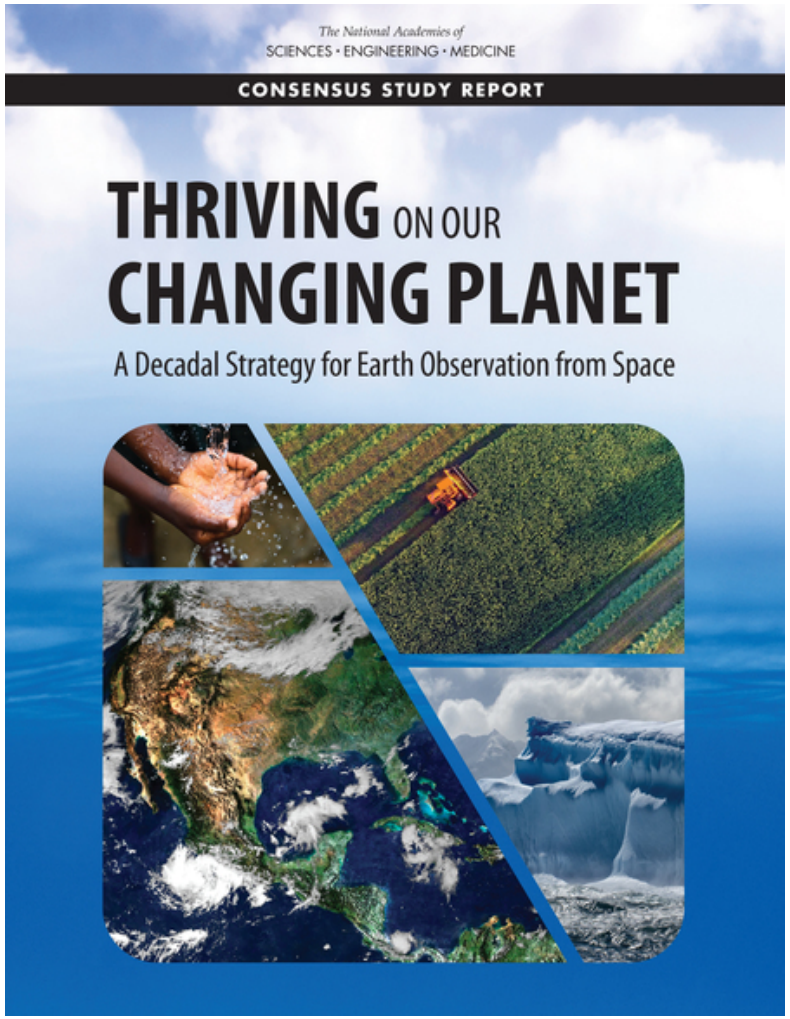
First Gimbal Installed at GGAO

- Norwegian Mapping Authority (NMA) is building a new site in Ny-Ålesund with co-located VLBI, SLR, and GNSS stations
- NASA-NMA partnership to implement SGSLR station

Decadal Survey Responsive Plan

"Recommendation 4.4: NASA should complete planned improvements to its Global Geodetic Observing System (GGOS) sites during the first half of the decadal survey period as part of its contribution to the establishment and maintenance of the International Terrestrial Reference Frame (ITRF)."

- Space Geodesy Project developed a plan that includes completion of the Tier 1 and 2 stations on an accelerated timeline that maintains the current ITRF quality and makes an incremental improvement towards the decadal survey goals.
- NASA is currently developing a comprehensive response to the decadal survey that factors in the proposed network deployment acceleration whose timeline will be driven by available funding.



http://nap.edu/24938

Summary

- NASA successfully demonstrated next generation SLR, VLBI, and GNSS using the GGAO prototypes.
- Tier 1 deployment of next generation stations is underway:
  - KPGO (Kokee Park, Hawaii) VGOS station operational.
  - VGOS station at McDonald Observatory, Texas nearly operational.
  - Build of long-lead items for first 3 SLR stations underway.
- Planning and discussions with international partners for Tier 2 deployment underway.
- Plan for Decadal Survey responsive deployment acceleration under review by NASA.