NASA's Next Generation Space Geodesy Program

M. R. Pearlman[1], R. S. Gross[2], F. G. Lemoine[3], L. M. Hillard[3], J. L. Long[3], C. Ma[3], J. F. McGarry[3], S. M. Merkowitz[3], C. E. Noll[3], E. C. Pavlis[4], D. A. Stowers[2], and F. H. Webb[2]

[1]Harvard-Smithsonian Center for Astrophysics, Cambridge, USA
(mpearlman@cfa.harvard.edu, 001 617 4960121)
[2]Jet Propulsion Laboratory and California Institute of Technology, Pasadena, United States
[3]NASA Goddard Space Flight Center, Greenbelt, USA
[4]University of Maryland. Baltimore, USA

NASA Space Geodesy Project

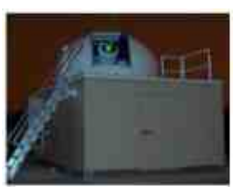
- Provide NASA's contribution to a worldwide network of modern space geodesy Core Sites;
- Phase 1 Proposal developed for a 2–year activity:
  - Complete network simulations to scope the network and examine geographic, operational and technical tradeoffs based on LAGEOS and GNSS tracking with SLR;
  - Complete the prototype SLR (NGSLR) and VLBI (VLBI 2010) instruments;
  - Co-locate these instrument with the newest generation GNSS and DORIS ground stations at NASA Goddard Space Flight Center;
  - Implement a modern survey system to measure inter-technique vectors for co-location;
  - Develop generalized station layout considering RFI and operations constraints;
  - Undertake supporting data analysis;
  - Begin site evaluation for network station deployment;
  - Develop a full network implementation plan;
- Follow-on phase for deployment of 6 - 10 stations;

Motivation for the NASA Space Geodesy Project

- Requirements for the ITRF have increased dramatically since the 1980's
  - Most stringent requirement comes from sea level studies:
    - "accuracy of 1 mm, and stability at 0.1 mm/year" (GGOS 2020)
  - This is a factor 10-20 beyond current capability;
  - Measurement of Sea Level is the prime driver, but other appications are not far behind;
- Simulations show the required ITRF is best realized from a combination solution using data from a global network of ~ 30 integrated stations having all available techniques with next generation measurement capabilities
  - The current network cannot meet this requirement, even if it could be maintained over time (which it cannot).
- NASA is a major participant in the Space Geodesy Network;
- The current core NASA network is deteriorating and inadequate.
- The path forward on much of the technology is known.

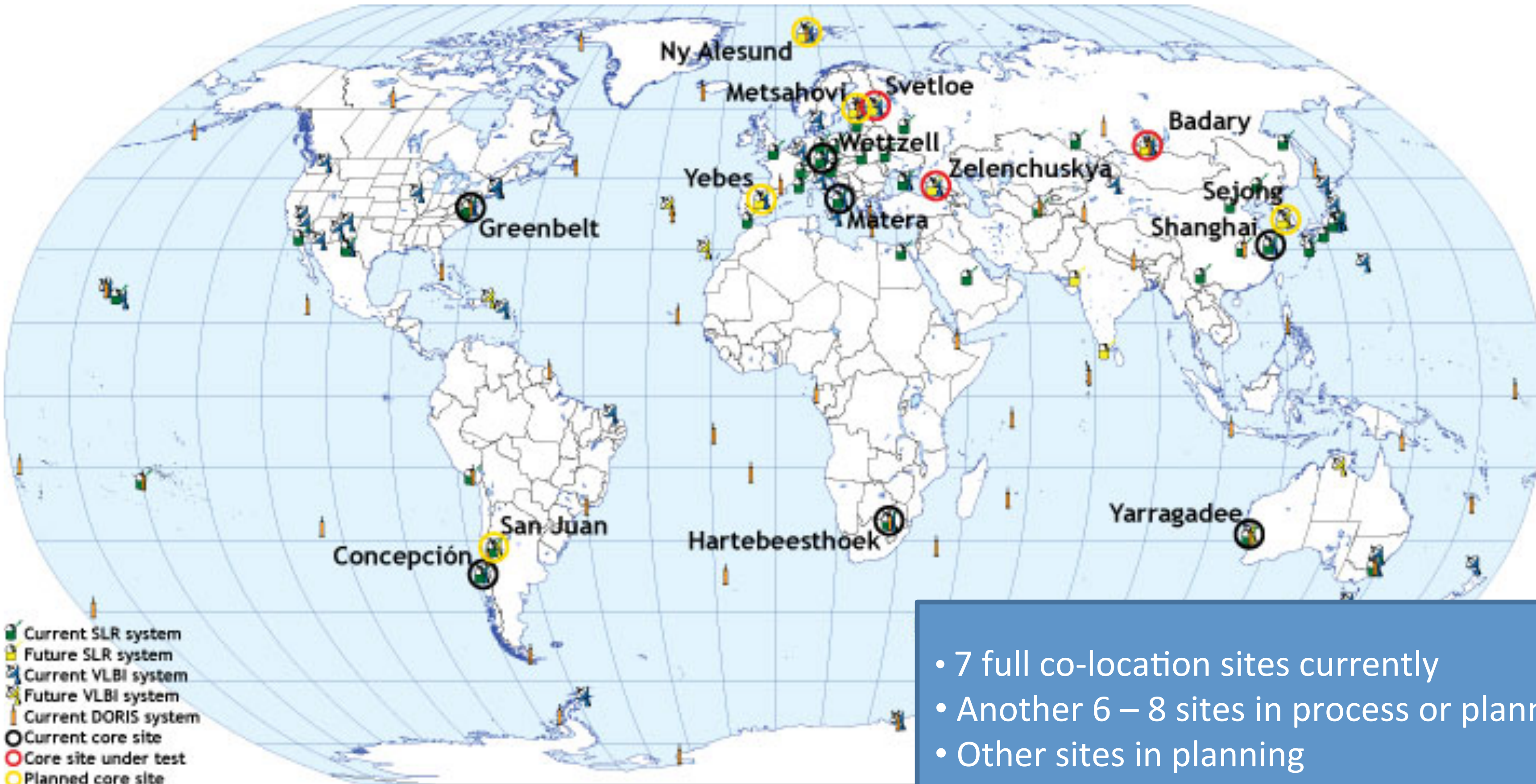
The Space Geodesy Project

- New initiative started at the end of FY11. Part of the Earth Science Decadal and the National Research Council study “Precise Geodetic Infrastructure.”
- Goddard/JPL partnership with participation from Smithsonian Astrophysical Observatory and the University of Maryland.
- Goals:
  - Establish and operate a prototype next generation space geodetic site with integrated next generation SLR, VLBI, GNSS (and DORIS) systems, along with a system that provides for accurate vector ties between them.
  - Develop a Project Implementation Plan for the construction, deployment and operation of a NASA network of similar next generation stations that will become the core of a larger global network of modern space geodetic stations.

VLBI	NGSLR	GNSS	DORIS	Vector Tie
				

Co-located VLBI, SLR, GNSS

(Some with DORIS)

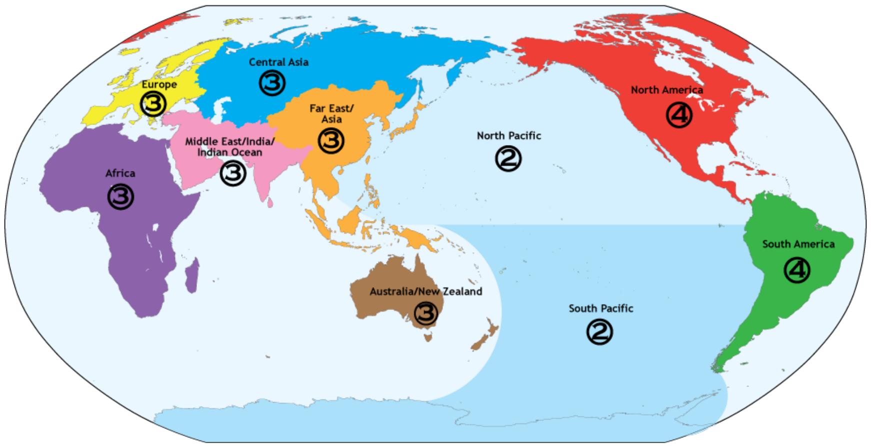


- 7 full co-location sites currently
- Another 6 – 8 sites in process or planned
- Other sites in planning
- Many regional voids in the network
- Many site have older less reliable technology

Simulation Studies to Scope the Network

(Erricos Pavlis)

- **First Phase completed**
  - **~30 globally distributed, well positioned, co-location Core Sites with proper conditions;**
  - **16 of these Core Sites must track GNSS satellites with SLR to calibrate the GNSS orbits;**
- **Follow-on Phases (Impact on the ITRF)**
  - **Sensitivity to intersystem vector accuracy**
  - **Phased deployment; evolution of the products**
  - **Impact of errors and outages;**
  - **Additional space objects**
  - **Tracking scenarios**
  - **Impact of GRASP**

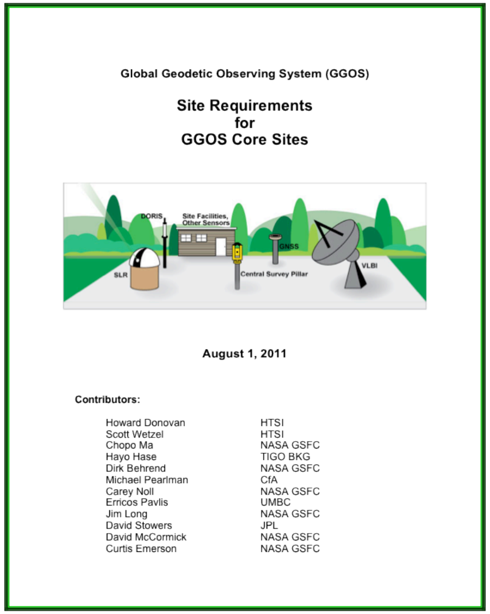


Current focus:

- sensitivity of data products to the accuracy of the inter-system vectors at co-location sites
- benefit of having co-location using a multi-technique, satellite-based target Geodetic Reference Antenna in Space (GRASP)

GGOS Site Requirements Document

(http://cddis.gsfc.nasa.gov/docs/GGOS_SiteReqDoc.pdf)



Global Geodetic Observing System (GGOS)

Site Requirements
for
GGOS Core Sites

August 1, 2011

Contributors:

Howard Donovan	HTSI
Scott Wetzel	HTSI
Chopo Ma	NASA GSFC
Hayo Hase	TIGO BKG
Dirk Behrend	NASA GSFC
Michael Pearlman	CfA
Carey Noll	NASA GSFC
Erricos Pavlis	UMBC
Jim Long	NASA GSFC
David Stowers	JPL
David McCormick	NASA GSFC
Curtis Emerson	NASA GSFC

- Introduction and Justification
  - What is a Fundamental Station?
  - Why do we need the Reference Frame?
  - Why do we need a global network?
  - What is the current situation?
  - What do we need?
- Site Conditions
  - Global consideration for the location
  - Geology
  - Site area
  - Weather and sky conditions
  - Radio frequency and optical Interference
  - Horizon conditions
  - Air traffic and aircraft Protection
  - Communications
  - Land ownership
  - Local ground geodetic networks
  - Site Accessibility
  - Local infrastructure and accmmodations
  - Electric power
  - Site security and safety
  - Local commitment

- Rewriting underway in site stability and system descriptions
- General cleanup

NASA's Next Generation Satellite Laser Ranging System (NGSLR)

- High repetition rate laser
- Single photon detection
- Modular construction
- Commercially available components
- Tracking from 300 km to 20000 km
- Day and Night-time operation
- Eye-safe operation replaced by radar due to changing requirements (FAA)

Achievements & Status:

- Daylight ranging to GLONASS-109 and -115
- LEO, LAGEOS 1 & 2, and GNSS have all been successfully tracked in both daylight and night.
- New narrow pulse (50 ps) laser system being added
- Starting intercomparison testing with MOBLAS-7.

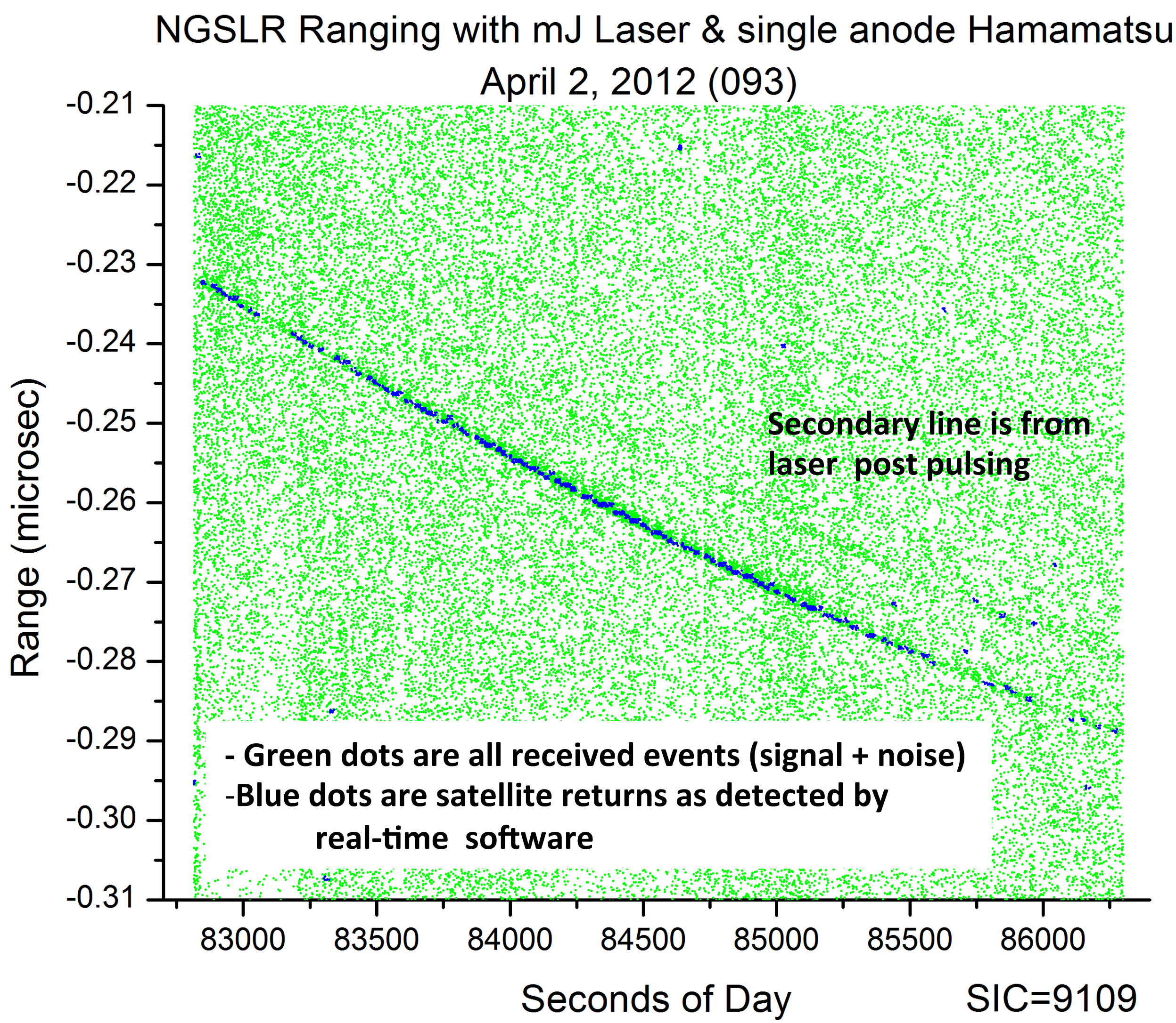
Demonstration of concept

System Features:

- 1 to 2 arcsecond pointing/tracking accuracy
- Capable of 24/7 operation
- Reduced ocular, chemical, electrical hazards
- Semi automated tracking features
- Small, compact, low maintenance, increased reliability
- Lower operating/replication costs

Daylight Ranging to GNSS

Measured Minus Station Predicted Ranges



VLBI 2010

Specifications:

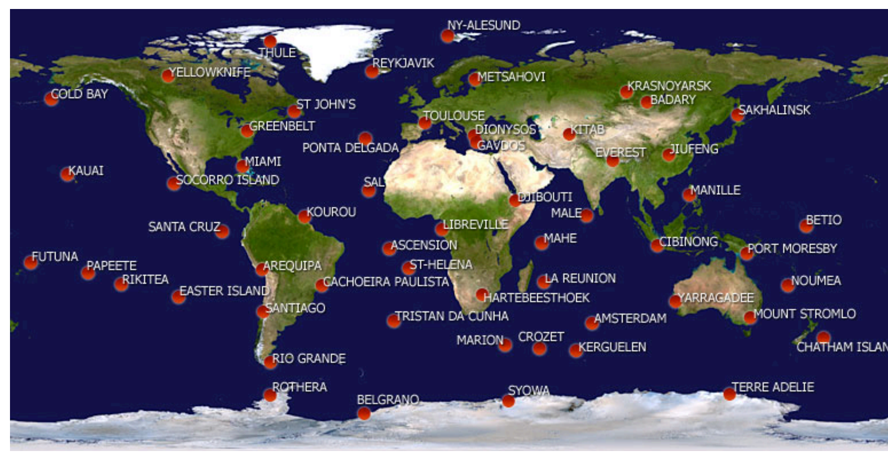
- Smaller antennas (~12m), fast moving, operating unattended, mechanically reliable, economically replicable – more observations for troposphere and geometry – Patriot antenna
- Broad continuous frequency range (~2-12 GHz) using multiple bands – smaller observation error and interference avoidance – QRFH feed
- Higher speed recording, increased sensitivity – Mark 5C recorder
- Transfer data with combination of high speed networks and high rate disk systems

Status

- 12m antenna implemented with the full VLBI2010 signal chain.
- The Westford 18m implemented with the same electronics but a prototype feed
- Four hours of data were taken with electronics set to record four contiguous bands spanning 2 GHz: 6.4 – 8.4 GHz.
- RMS delay difference between the independent polarizations less than 1 picosecond over an hour.

Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS)

- GGAO DORIS beacon is part of a global network of ~57 stations since June 2000.
- DORIS receivers are used on altimeter (TOPEX, Jason1, Jason2, ENVISAT, Cryosat-2) and remote sensing (SPOT) satellites;   Future Missions: Jason-3, SWOT & SENTINEL-3, GRASP.
- GSFC maintains the archival and distribution of the worldwide DORIS geodetic data using the Crustal Dynamics Data Information System (CDDIS).



GNSS Installation at GSFC

- Joint GSFC/JPL project with long-term goal of building, deploying, and operating a next generation NASA Space Geodetic Network (NSGN) consisting of GNSS, VLBI, SLR, and vector tie systems at globally distributed sites in collaboration with the international Space Geodesy community
- January 9-13, 2012:

  Two deep-drilled braced monuments installed

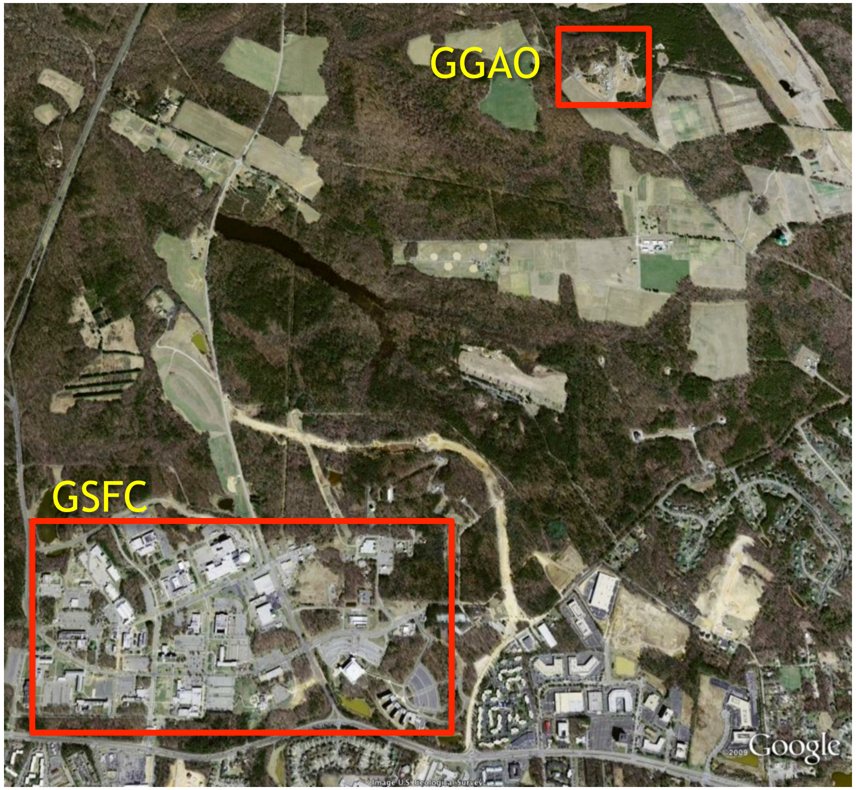
  Cables installed in conduit after trenching.

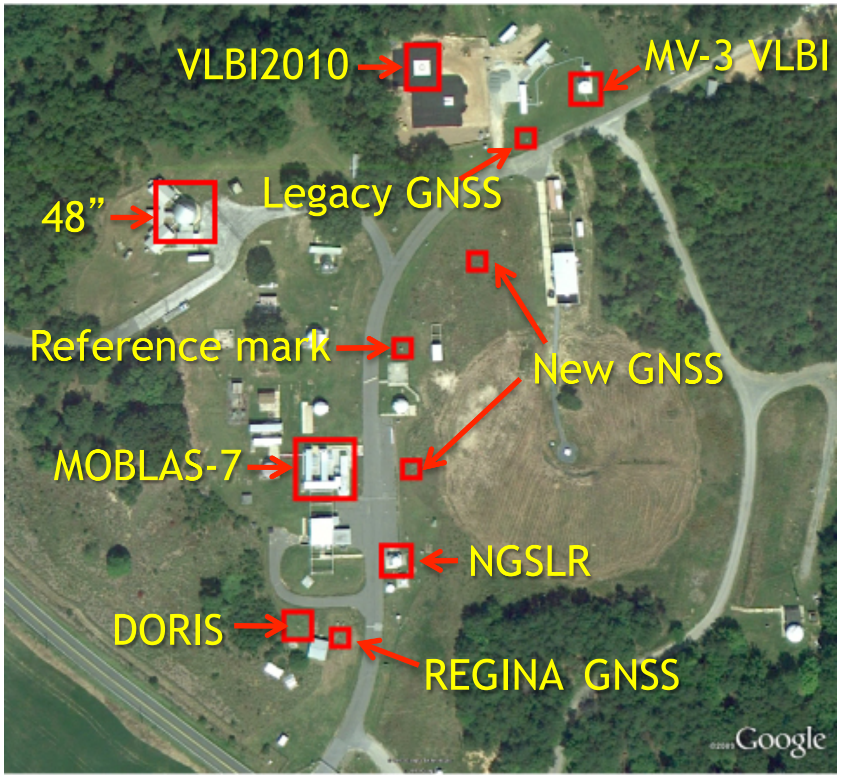
  Multi-constellation (GPS, GLONASS, Galileo) antenna receiver pairs installed and collecting data.
- Data publicly available from CDDIS as sites GODN and GODS
- Existing GPS site to remain operational


GODE
GODN
GODS
DORIS
Deep drill braced monuments
Antenna cable trench
© 2011 Europa Technologies
©2011 Google
8/28/2010
1993
39°01'15.18" N 76°49'36.27" W elev 159 ft

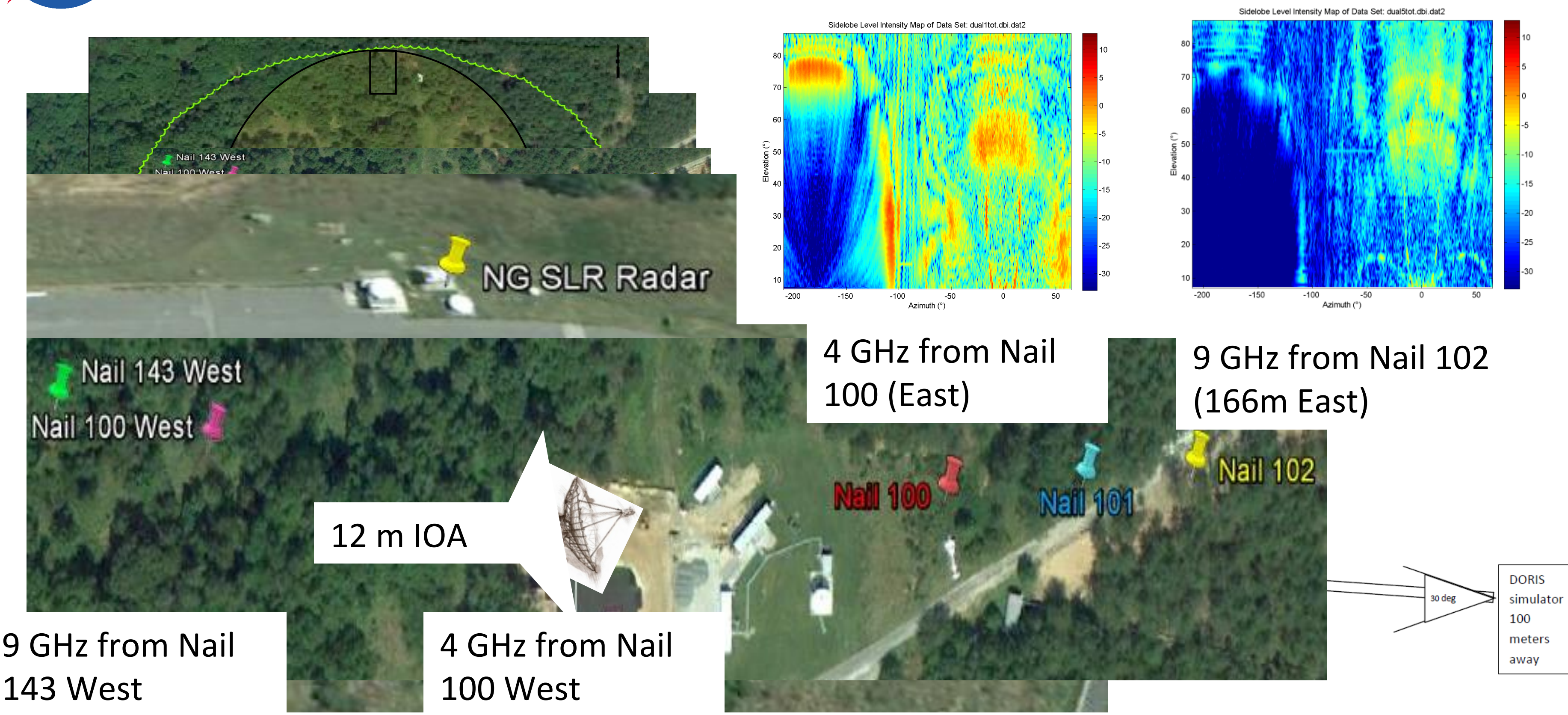
Goddard Geophysical and Astronomical Observatory (GGAO)

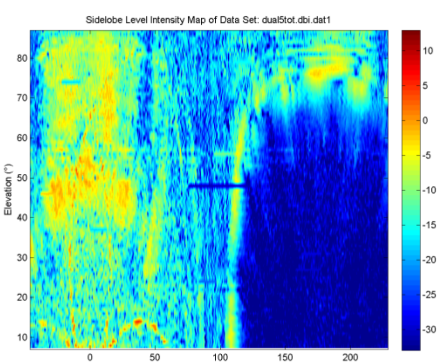
- Located 5 km from Goddard Space Flight Center in the middle of the Beltsville Agricultural Research Center.
- One of the few sites in the world to have all four geodetic techniques co-located at a single location.

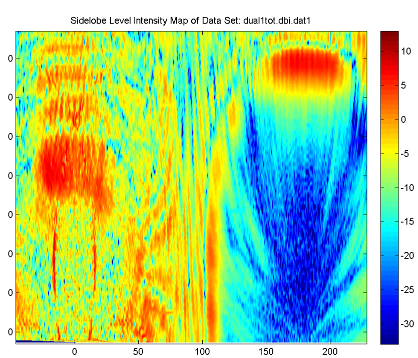




Space Geodesy Project Approach to RFI



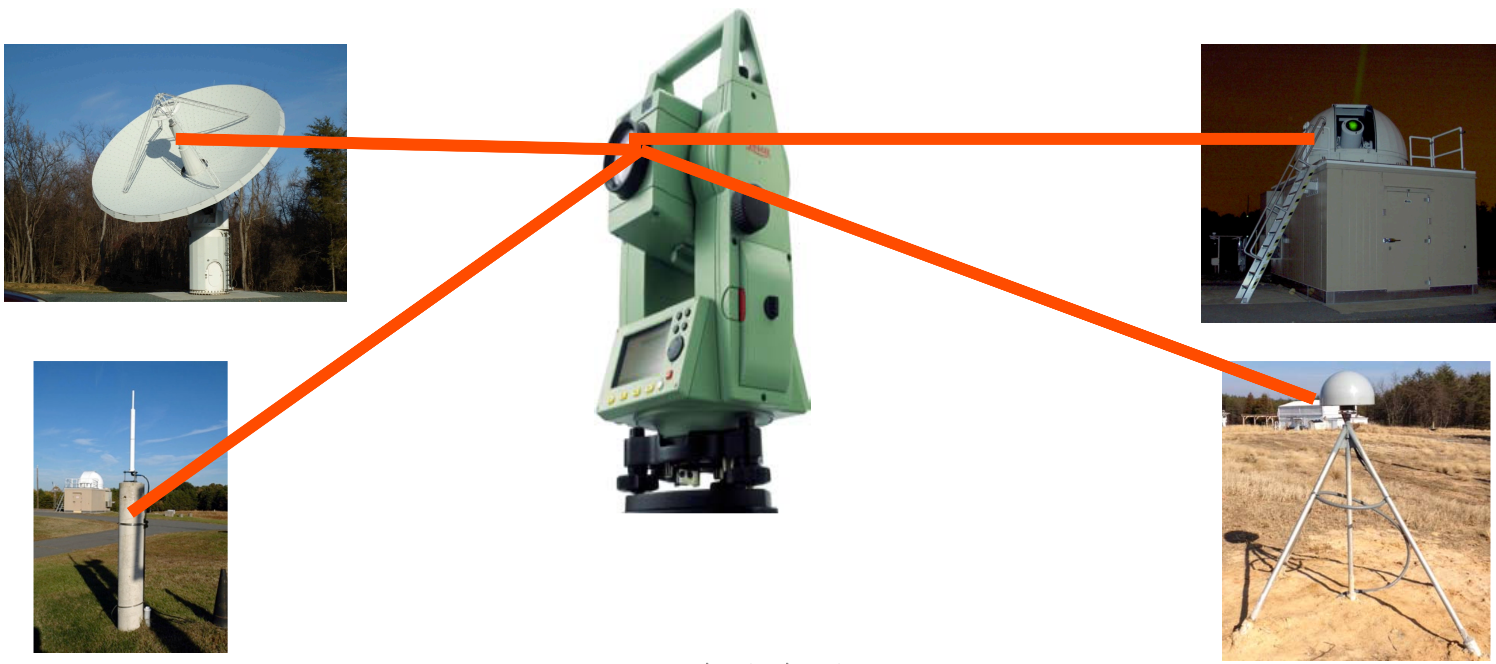




- Modeling the GGAO environment and VLBI2010 susceptibility before & after the trees came down
- Measuring the DORIS Beacon, and the NGSLR radars in South , radar masks & DORIS path loss provide mitigation
- Measuring 12m side lobes with a standard gain horn simulator ≥100m away
- Mitigate RFI with masks, filtering, and shielding

Major Challenge
Co-location Intersystem Vectors

- Automated measurement of inter-instrument vectors is an essential aspect of an integrated space geodesy station.
- Measurements provide closure between terrestrial reference frames derived from different space geodesy techniques.
- Tests of technologies and currently available systems underway at GGAO.
- BIG CHALLENGE: How do we extrapolate measurements to the "electronic or optical" reference point on each instrument?



Project Status Summary

- Prototype station is currently on-budget and on-schedule for a July 2013 completion.
- An implementation plan is currently being developed to upgrade the current NASA sites and establish new sites with our international partners.
- Evaluate current NASA Sites as candidate Core Sites;
  - Current year: GSFC, Monument Peak, Mt. Haleakala, Kokee Park, McDonald, Arequipa, Yarragadee, Hartebeesthoek, Tahiti, Fortaleza
- On-going discussions with existing and potential international partners, including Brazil, Columbia, Norway, South Africa, Australia, and France.
- If additional systems are built, they could be deployed as a full station or perhaps as a system contribution in a partnership.

Global Geodetic Network