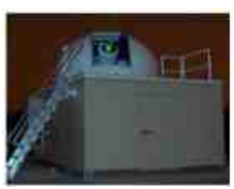
NASA's Next Generation Space Geodesy Program

M. R. Pearlman[1], S. Desai[2], D. 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], D. Murphy[2], 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 County, Baltimore, USA

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.

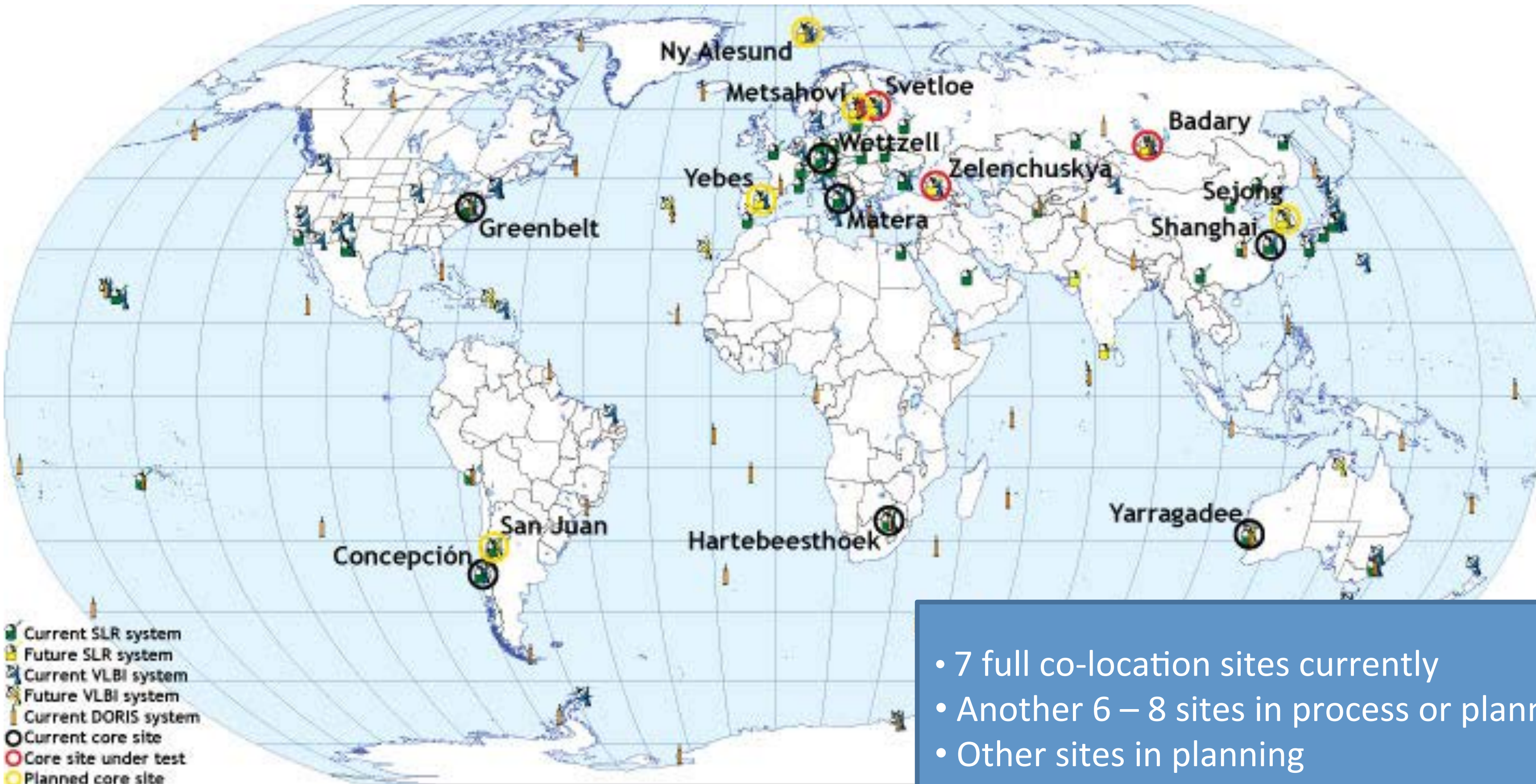
VLBI	NGSLR	GNSS	DORIS	Vector Tie
				

Motivation for the NASA Space Geodesy Project

- Requirements for the ITRF and POD 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 applications 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 (VLBI, SLR, GNSS, and DORIS) 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.

Co-located VLBI, SLR, GNSS

(Some with DORIS)



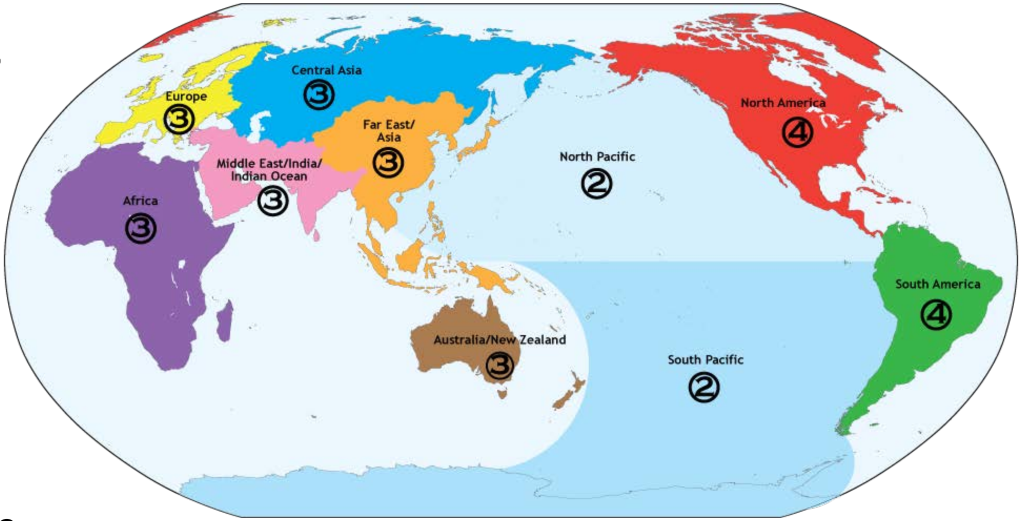
- 7 full co-location sites currently
- Another 6 – 8 sites in process or planned
- Other sites in planning
- Many regional voids in the network
- Many site have older less reliable technology

Simulation Studies to Scope the Network

(impact on the Reference Frame)

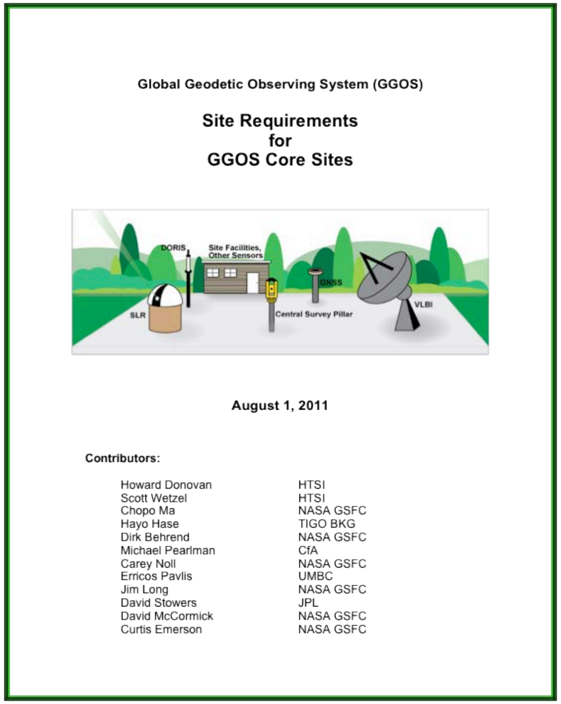
(Erricos Pavlis)

- **Simulations completed**
  - **~30 globally distributed, well positioned, co-location Core Sites with modern technology and proper conditions;**
  - **16 of these Core Sites must track GNSS satellites with SLR to calibrate the GNSS orbits;**
- **Simulations underway**
  - **Sensitivity to intersystem vector accuracy**
  - **Phased deployment; evolution of the products**
  - **Impact of errors and outages;**
  - **Additional space objects**
  - **Tracking scenarios**



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 accommodations**
  - **Electric power**
  - **Site security and safety**
  - **Local commitment**

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

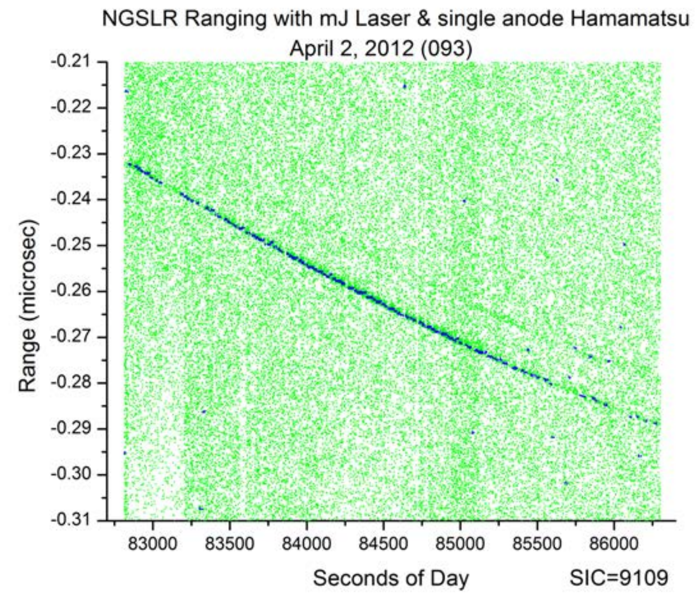
- Higher pulse repetition rate for faster data acquisition;
- Smaller, faster slewing telescope for more rapid target acquisition and pass interleaving;
- More accurate pointing for link efficiency;
- Narrower laser pulse width for greater precision;
- Single photon detection for greater accuracy;
- More automation for economy (24/7);
- Greater temporal and spatial filtering for improved signal to noise conditions;
- Modular construction and more off the shelf components for lower replication/operations/maintenance cost;
- Reduced ocular, chemical, electrical hazards

Intent: Demonstrate the concept for a network

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

- High repetition rate (2 Khz) laser
- New 50 ps pulse width laser being installed
- 1 to 2 arcsec pointing/tracking accuracy
- Day and Night-time operation
- Operating on full range of satellites
  (LEO to GNSS)
- Preliminary inter-comparison testing with legacy system shows good stability.
- Still lots to do

Daylight Ranging to GNSS



VLBI 2010

(Developed within the International VLBI Service (IVS)

Specifications:

- Smaller antennas (~12m), 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
- Higher speed recording (8 Gbps), increased sensitivity – Mark 5C recorder
- Transfer data with combination of high speed networks and high rate disk systems

Features:

- Standardization and commercial off-the-shelf availability of many parts for lower operating and replicating costs
- Selectable RF band placement to better tolerate RF interference and allow better accommodation with legacy (S/X) systems
- Improved group delay to support ~1 mm position determination
- Use of phase delay?

VLBI 2010 Status

- 12m antenna implemented at GSFC with the full VLBI2010 signal chain;
- Demonstrated 5 deg per sec azimuth slew rate
- Demonstrated 60% aperture efficiency
- The Westford 18m implemented with the same electronics but a prototype feed;
- Demonstrated broadband (8 Gbps) data collection and 4 ps group delay on the Haystack-GSFC baseline
- Six hours of geodetic data taken at 3.2, 5.2, and 9.2 Ghz; all bands produced good observations

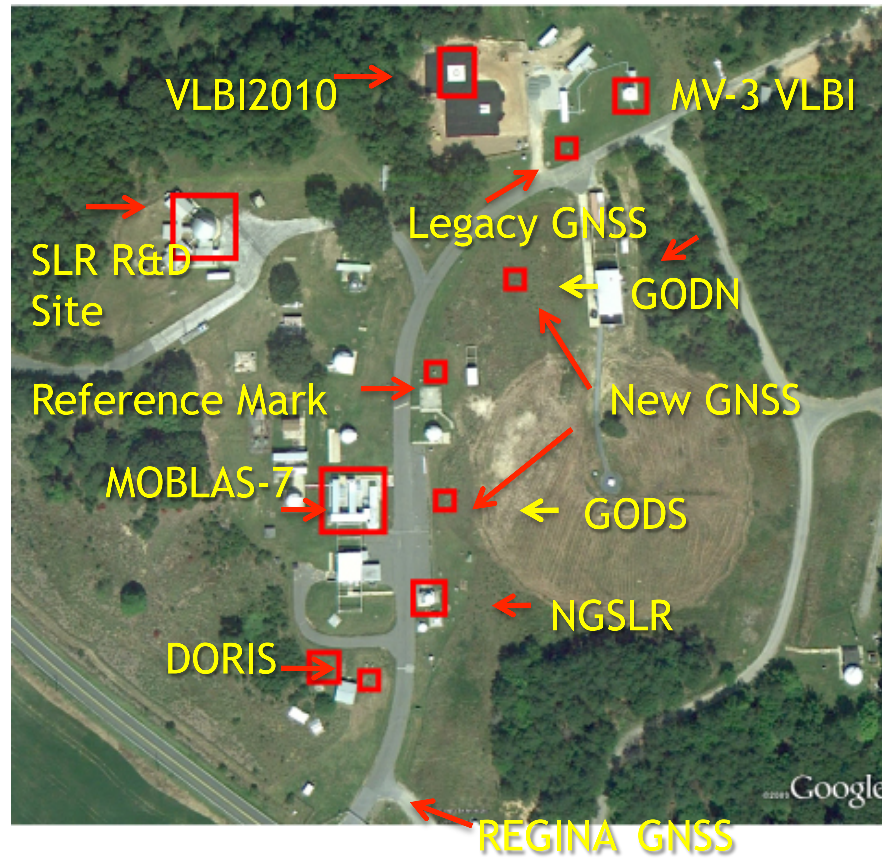
Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS)

- 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

Pair of multi-constellation GNSS (GPS, GLONASS, Galileo) receivers (GODN and GODS) installed with deep-drilled brace monuments; data collecting since January 2012

Existing GPS (GODE) and GPS +GLONASS (GODZ) receivers to remain operational



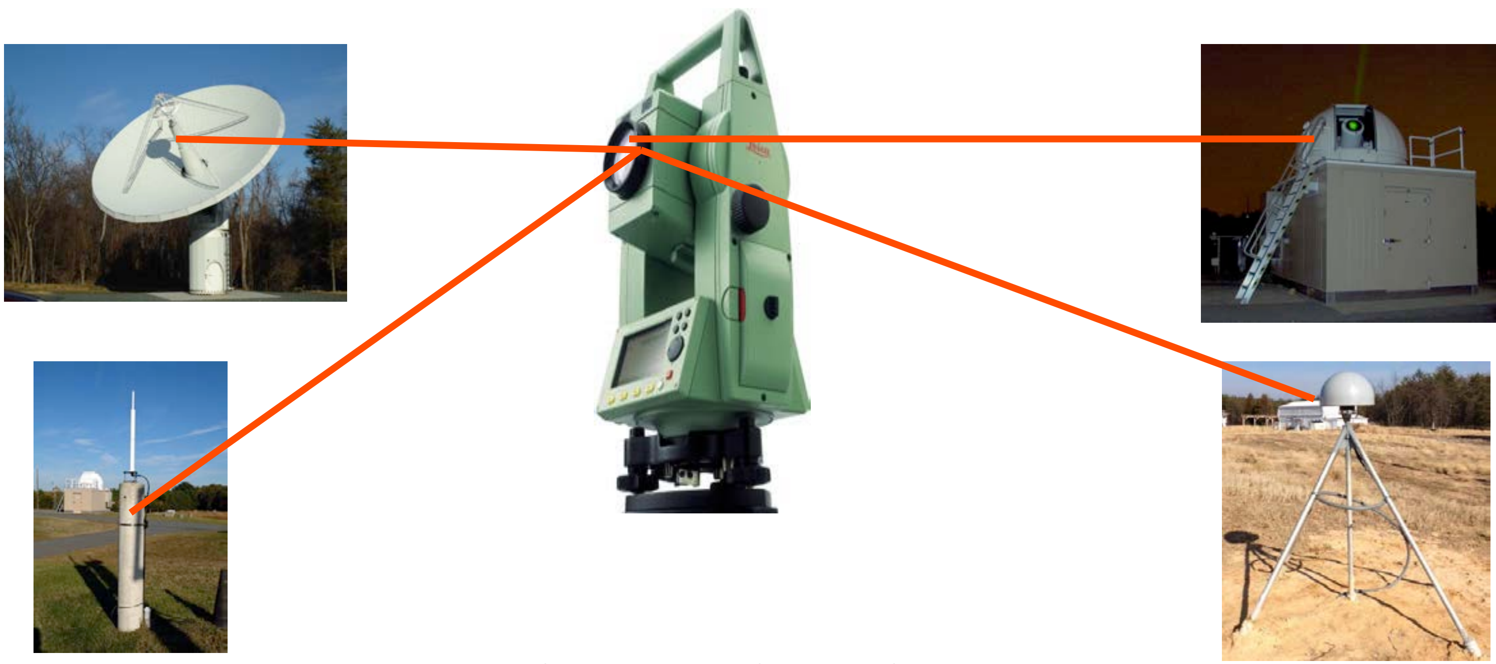
GPS Results at GSFC

- Processed 6 months of GPS data from GODN and GODS
  - Independent daily static point positioning with single-receiver ambiguity resolution using JLP GIPSY/OASIS software
- De-trended time series of independently determined station positions in figure below right;
  - highly- correlated position solutions at GODN and GODS;
  - common mode geophysical signals and systematic errors due to short baseline;
- Time series of GODN/GODS baseline computed from independently determined positions
- De-meaned time series of baseline show standard deviation of

  0.5 mm East, 0.7 mm North, and 2.7 mm up
- Future work
  - Expect factor of 2 – 3 reduction in the standard deviation of the GODN/GODS baseline by simultaneously using L1 only data from both stations
  - Evaluate GPS baselines against ground surveys

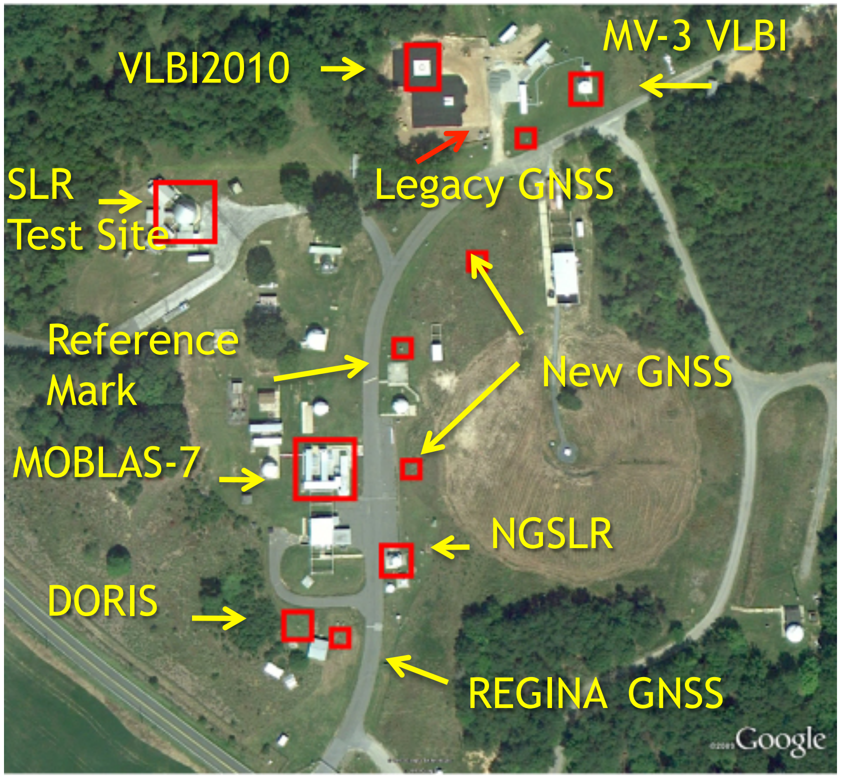
Major Challenge
Co-location Intersystem Vectors

- 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?



Space Geodesy Project Approach to RFI

- Modeling the GGAO environment and VLBI2010 susceptibility before & after tree removal
- 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



Lots of Instruments on the Site

Project Status Summary

- Simulation studies have scoped the size of the full international network required;
- Supported the development of the GGOS Site Requirements Document that defines Core Site and details their ideal condition;
- 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, Gilmore Creek, 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.