NASA's Space Geodesy Program– An Informal Perspective

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Disclaimers

Although I work at NASA, I am not a NASA employee!

I have worked at NASA since 1985 as a contractor.

Nothing I say is official….

although I do believe it is all true.

Everything I say has been taken from other presentations -- nothing is original.

Overview

- Introduction to NASA's SGP Project
- GGAO Prototype Site
- NASA SGP Site Selection
- Some geodetic VLBI results from GGAO

NASA's Space Geodesy Project

- New NASA initiative started at the end of 2011 in response to the Earth Science Decadal and the National Research Council study "Precise Geodetic Infrastructure." Part of President Obama's Climate Initiative.
- Goddard-led in partnership with JPL and participation from the Smithsonian Astrophysical Observatory and the University of Maryland.
- Goals:
  - Establish and operate a **prototype next generation space geodetic station** with integrated next generation SLR, VLBI, GNSS, and DORIS systems, along with a system that provides for accurate vector ties between them.
  - Plan and implement the construction, deployment and operation of a **NASA network of similar next generation stations (~10)** that will become the core of a larger global network of modern space geodetic stations.
  - **Contribute to a TRF that has an accuracy of 1 mm and stability of 0.1 mm/yr**.

VLBI	NGSLR	GNSS	Vector Tie
			

The Geodetic Measurement System

VLBI
- Orientation of ITRF with respect to ICRF
- ITRF Scale

SLR
- Origin of ITRF (Earth's CM)
- ITRF Scale
- Position spacecraft in ITRF ("Orbits")

GNSS
- Precise monitoring of Polar Motion and Rotation Rate
- Position spacecraft in ITRF ("Orbits")
- Position instruments on Land and Sea (Tide Gauges and Buoys, Geodetic Instruments)

DORIS
- Position spacecraft in ITRF ("Orbits")
- Enhances global distribution of ITRF Station positions and velocities

Technique Connectivity (Station Co-Location)

Fully Define ITRF

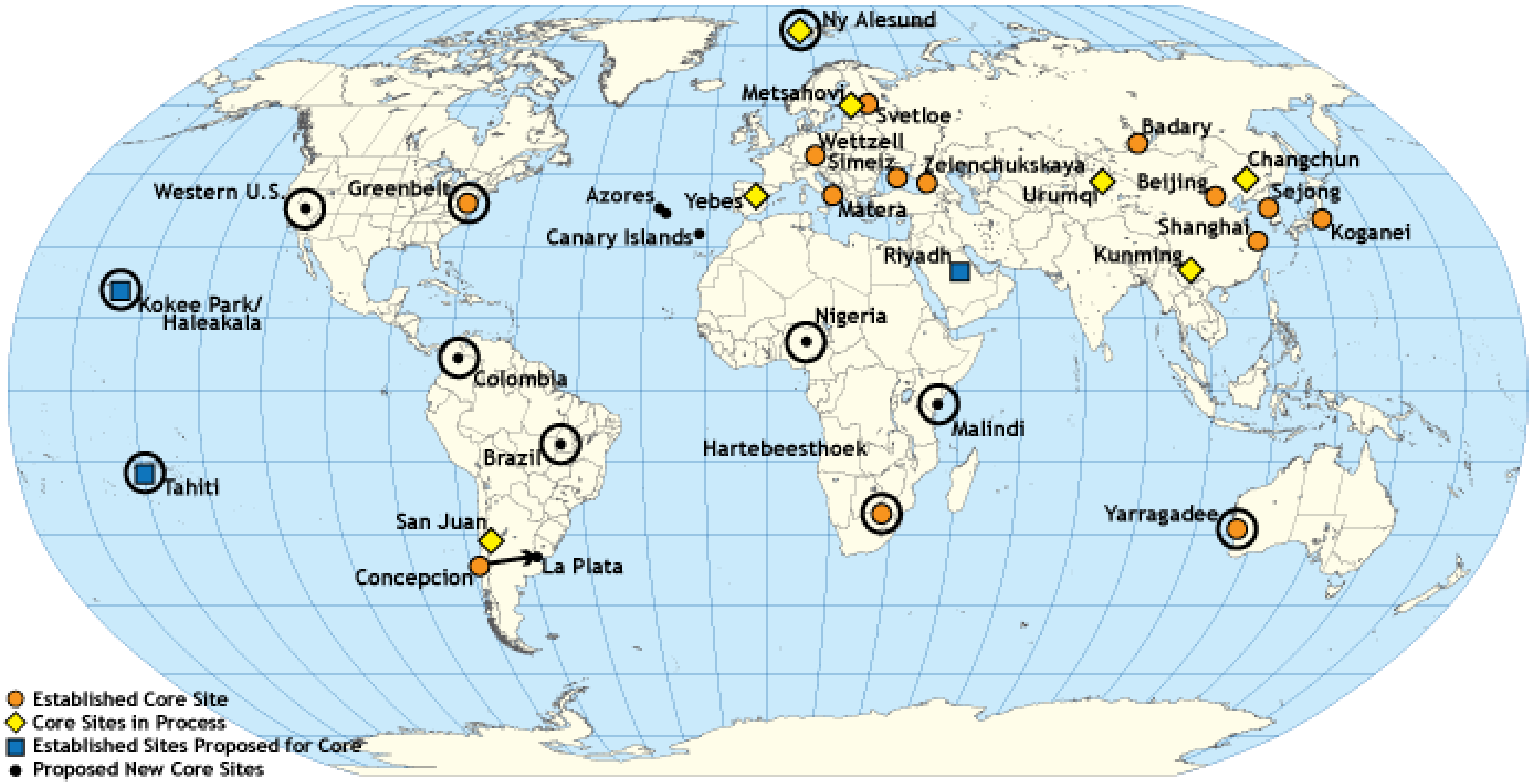
VTS: ITRF Performance Improvement

Origin, Scale, Orientation

Low-Density Global Distribution

High-Density Global Distribution

Possible Distribution of Core Sites



For Illustrative purposes only!

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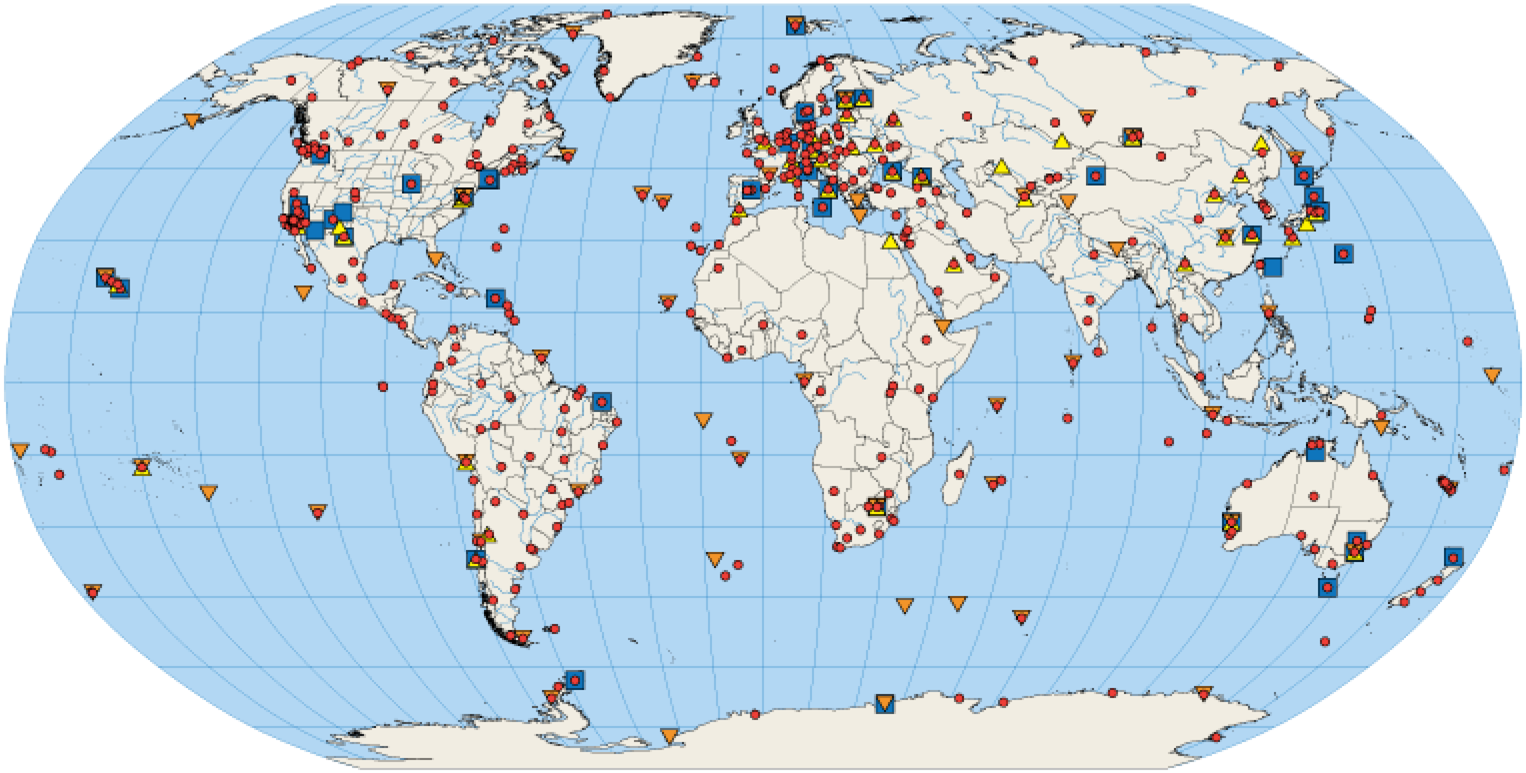
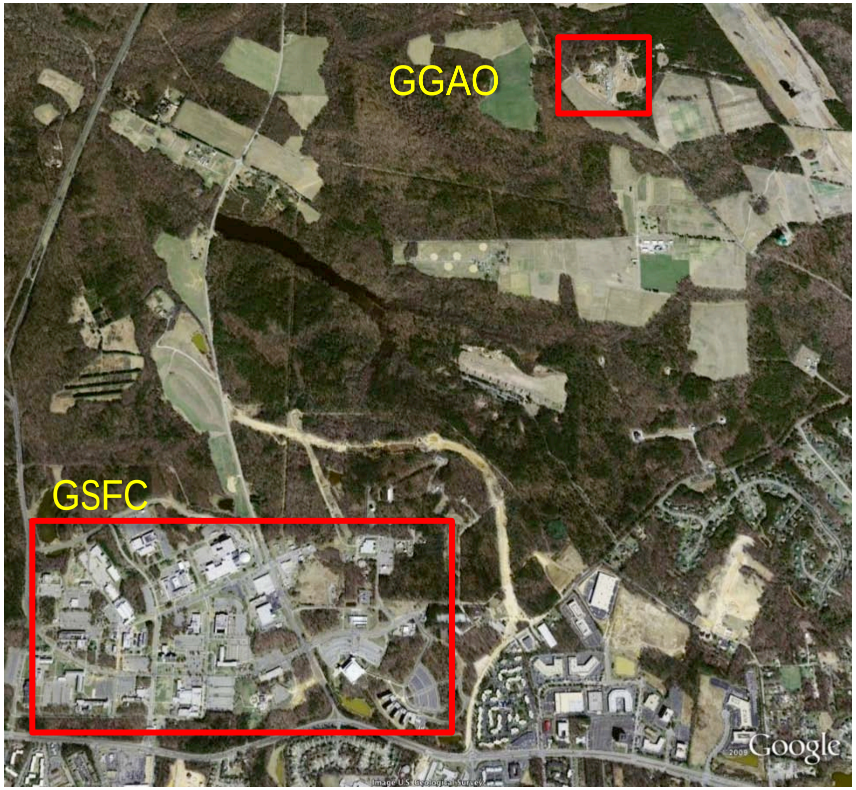
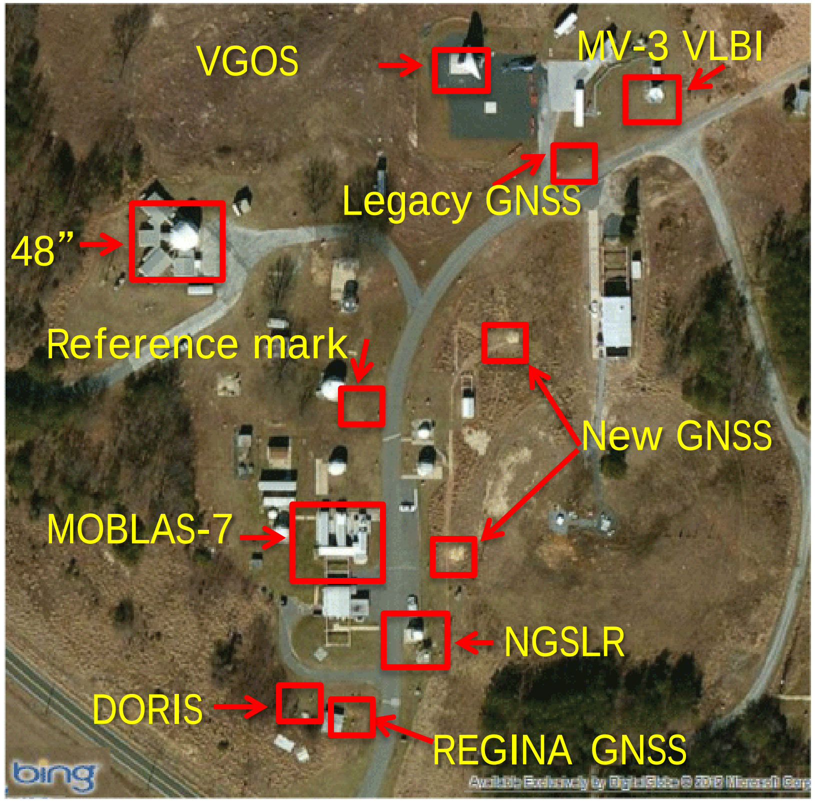
Current IGS/ILRS/DORIS/IVS Stations



Prototype Next Generation Geodetic Site at GGAO

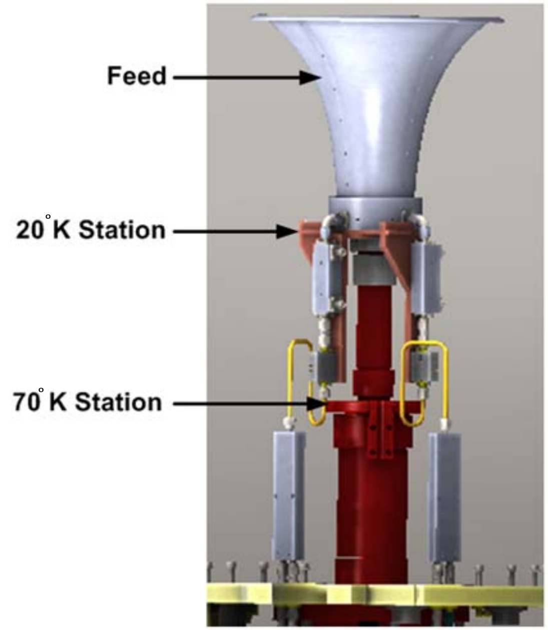
- Goddard Geophysical and Astronomical Observatory (GGAO) is located 5 km from Goddard Space Flight Center in the middle of the Beltsville Agricultural Research Center. GGAO is one of the few sites in the world to have all four geodetic techniques co-located at a single location.



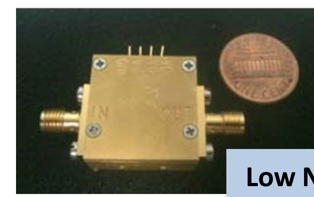


VGOS prototype as built at GGAO

12 meter antenna



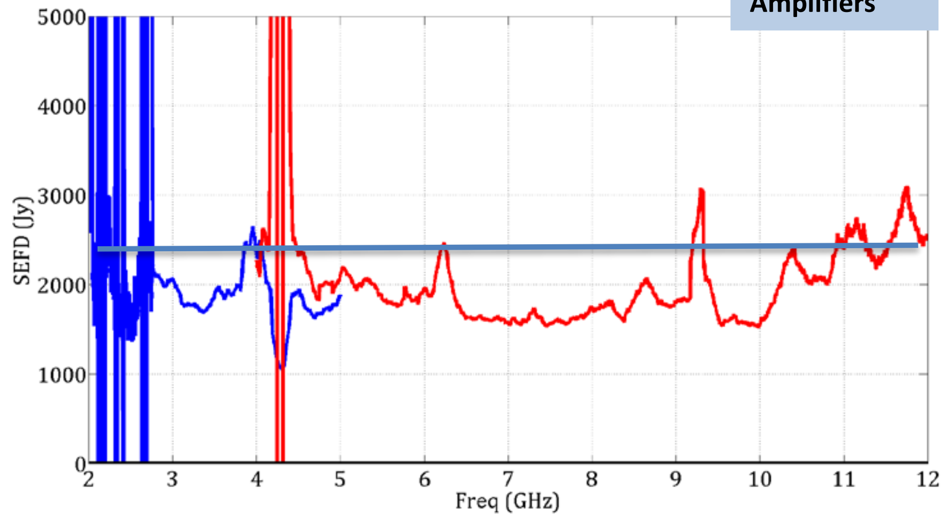
GGAO Cryogenic Front End Components



Low Noise Amplifiers

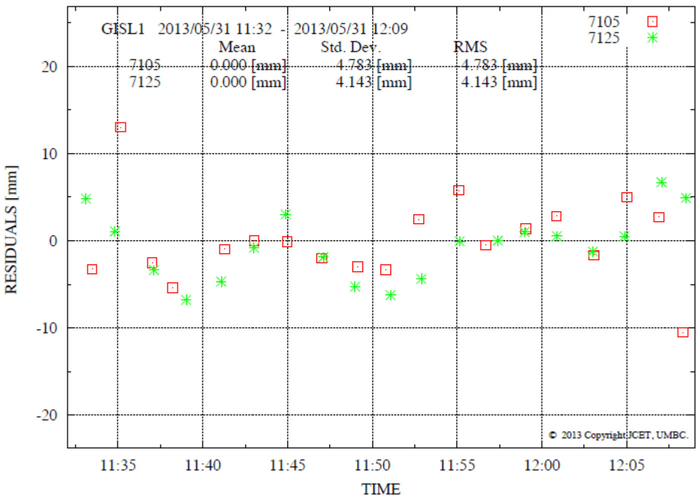
Fully Assembled Rack of Digital Back End Components

Broadband Sensitivity Performance



Next Generation Satellite Laser Ranging (NGSLR)

Demonstrated excellent agreement between **NGSLR** & **MOBLAS-7** tracking the LAGEOS satellites with mm-level precision



NGSLR & MOBLAS-7 simultaneously ranging at the Goddard Geophysical and Astronomical Observatory (GGAO)

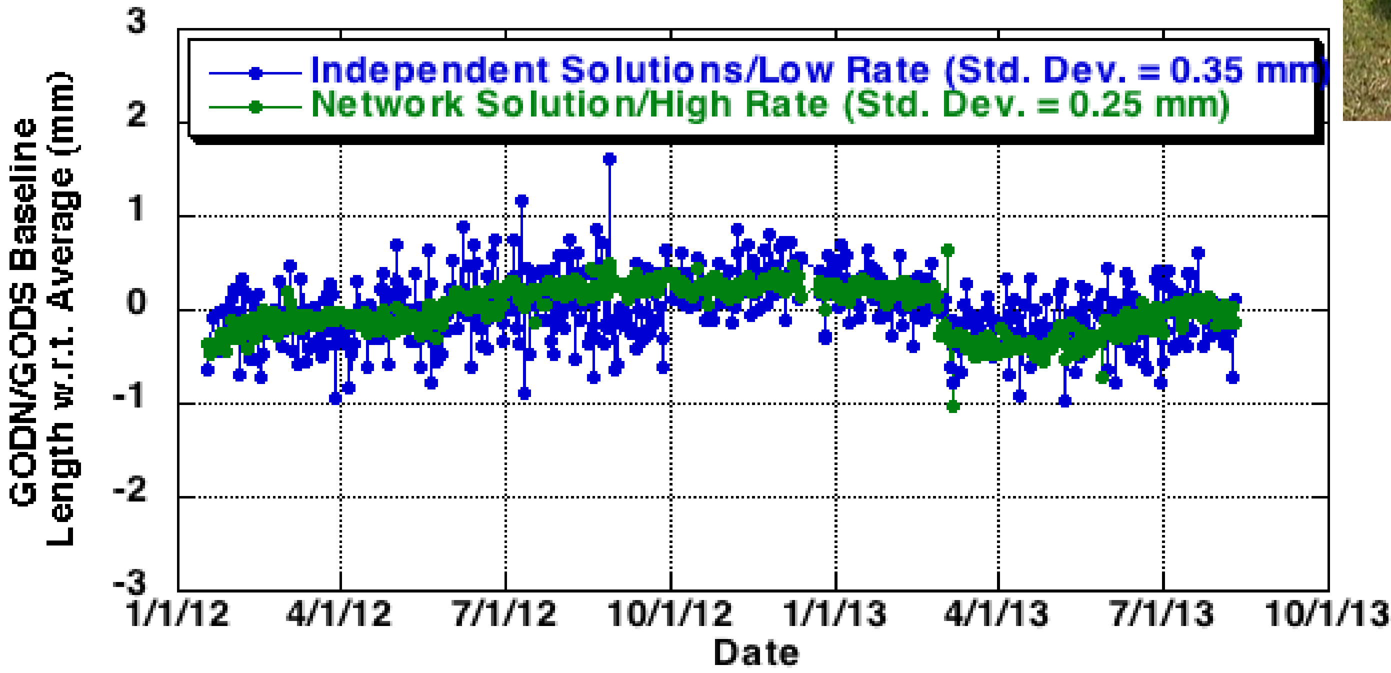
NGSLR successfully completed a 2-year development effort by demonstrating key performance requirements, including:

- LAGEOS normal point precision ~ 1 mm.
- Robust day and night satellite ranging from LEO to GNSS altitudes (up to 22,000 km).
- System stability < 1 mm (RMS) over an hour.
- Semi-automated operations.

NGSLR is now the basis for the new NASA Space Geodesy Network that will consist of up to 10 new stations around the world.

Modern GNSS Stations at GGAO

- Two new GNSS stations installed at GGAO (GODN and GODS):
  - Collecting data since 2012-01-17.
    - Multi-constellation (GPS, GLONASS, Galileo)
- < 1 mm agreement between baseline length from GPS and independent local tie survey.



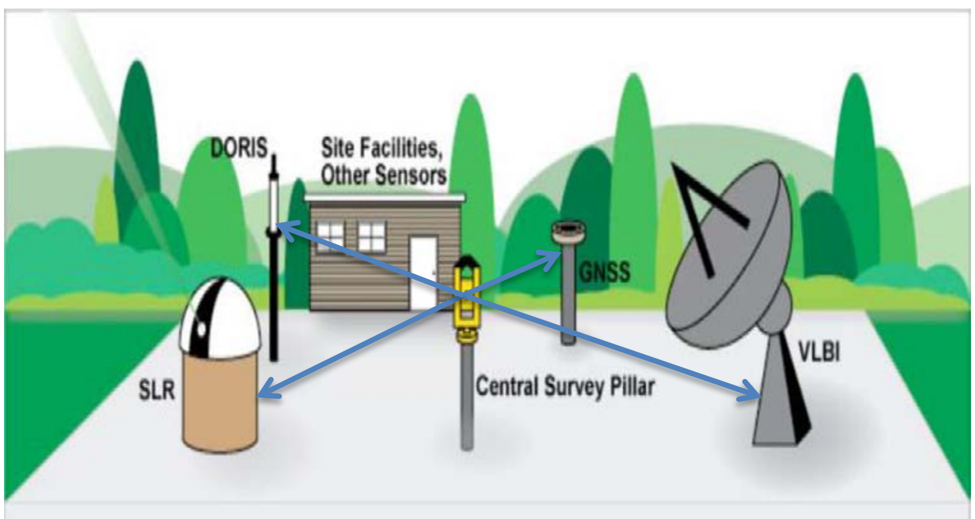
DORIS at GGAO

DORIS Global Network

- GGAO DORIS beacon part of a global network of ~57 stations
- DORIS located at GGAO since June 2000
- Beacons emit at 2 Ghz and 400 Mhz; the observable is dual-frequency 1-way Doppler
- DORIS receivers are located on altimeter satellites (TOPEX/Poseidon, Jason1-2, ENVISAT, Cryosat-2, SARAL) and remote sensing satellites (SPOT-2, SPOT-3, SPOT-4, SPOT-5); future satellites include: Jason-3, SENTINEL-3, Jason-CS & SWOT.

Vector Tie System at GGAO

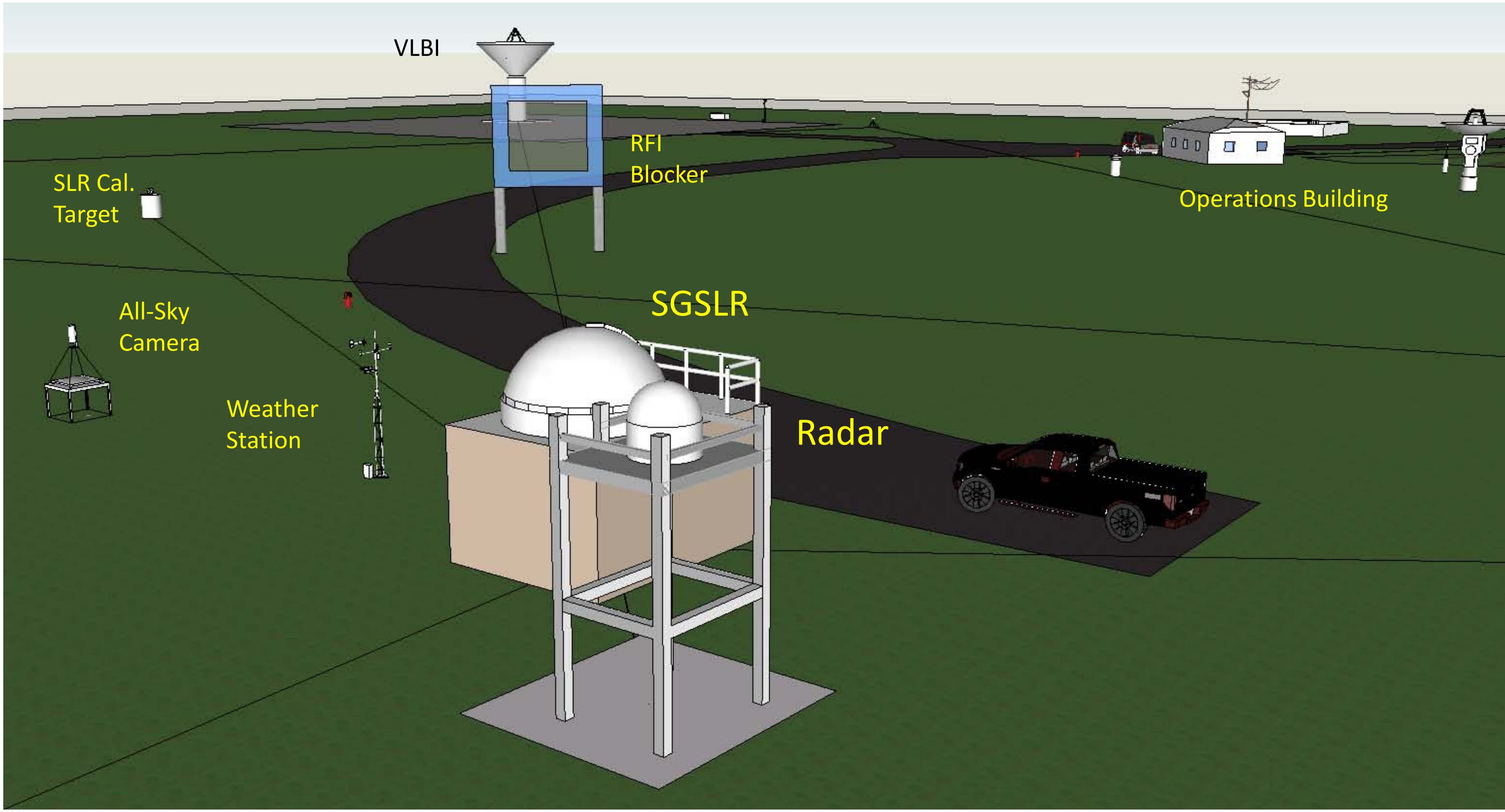
- The Vector Tie System (VTS) is a combination of a precise local-tie survey and a *periodic* monitoring system for measuring site stability.
- Demonstrated sub-mm accuracy at GGAO.
- Demonstrated semi-autonomous operation of monitoring system:
  - Find and identify target prism; verify prism correction,
  - Process distances measurements to correct for atmospheric correction.



Local Reference Frame tie to all geodetic Stations

GGAO Robotic Total (Range) Station

Typical Site Layout



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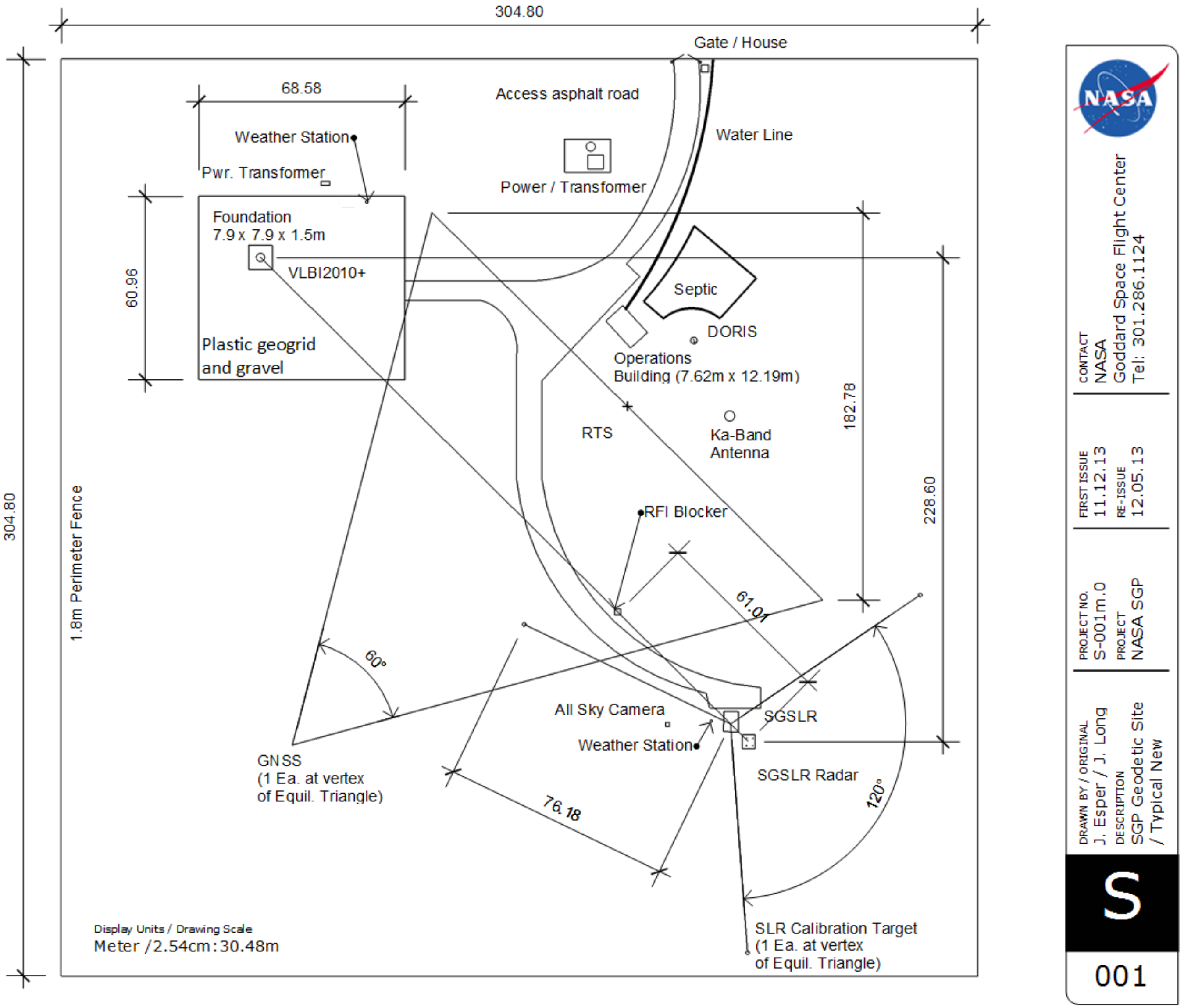
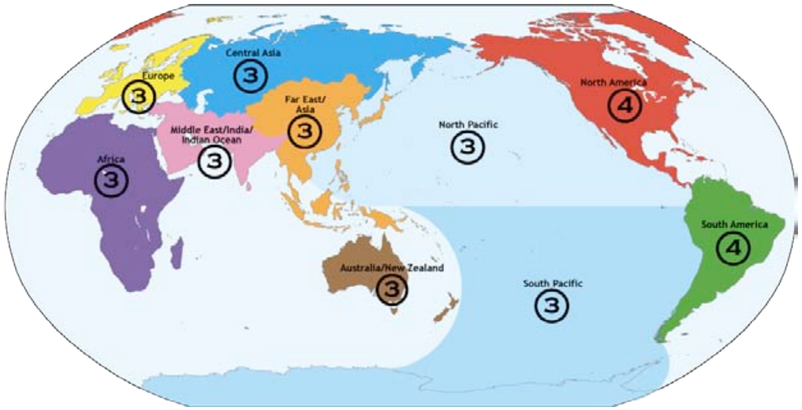
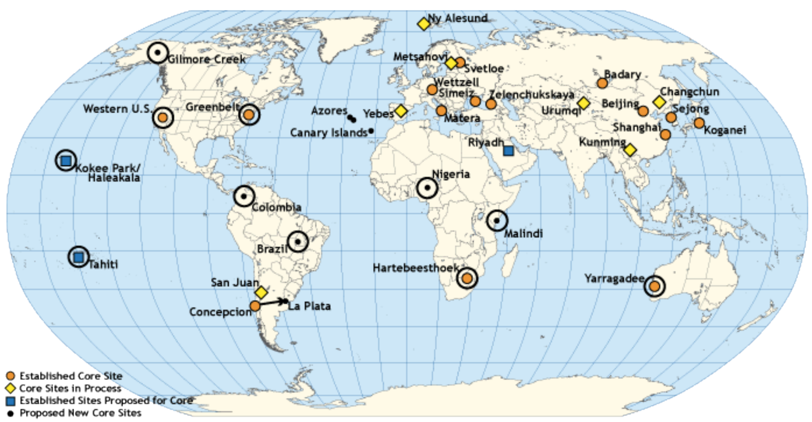


Inputs to the Site Selection Process

Network Simulations



Current and Projected Network Map



August 8, 2011

Call for Participation
The Global Geodetic Core Network: Foundation for Monitoring the Earth System

A Project of the Global Geodetic Observing ***…ition to the Global*** ***…f Systems (GEOSS)***

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… in the development, …ion of the GGOS …Call is being issued by …rks and

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
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Curtis Emerson	NASA GSFC

Selecting sites within a ~1000 km area around the "simulation sites" does not affect the resulting ITRF accuracy attributes.

SGP Site Selection Strategy

- Conceptual global site distribution based on simulation results for a 32 site network as a starting point by regions;
- Recognize existing and projected international sites that other groups plan to bring to new technology status;
- Examine present NASA and NASA partnership sites as potential sites;
- Seek candidate sites in the under-populated regions with a reasonable chance of success.
- For each identified site:
  - Examine value added of the geodetic position,
  - Examine site conditions (cloud cover, ground stability, etc.),
  - Examine human imposed conditions (RF/optical interference, air traffic, etc.),
  - Examine political / programmatic conditions (agreement situation, land ownership and control, partnership arrangements),
  - Examine site accessibility, logistics, infrastructure, security, power, communications).
- Qualify the site (good or bad candidate)

August 8, 2011

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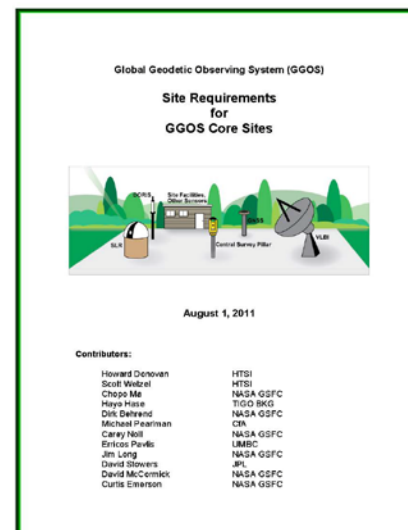
A Project of the Global Geodetic Observing System (GGOS) as a contribution to the Global Earth Observation System of Systems (GEOSS)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Instant Downgrades

- Cloud cover above 50% (SLR)
- Insufficient land (need 10 hectare)
- Unstable ground and long relaxation time
- No option for an agreement (Programmatic)
- Excessive RF conditions (*coming in or going out*)
- Security issues

Reality

Recognizing that:

◆Many sites will not be at ideal locations and nor have ideal conditions

◆Core site deployment will occur over many years

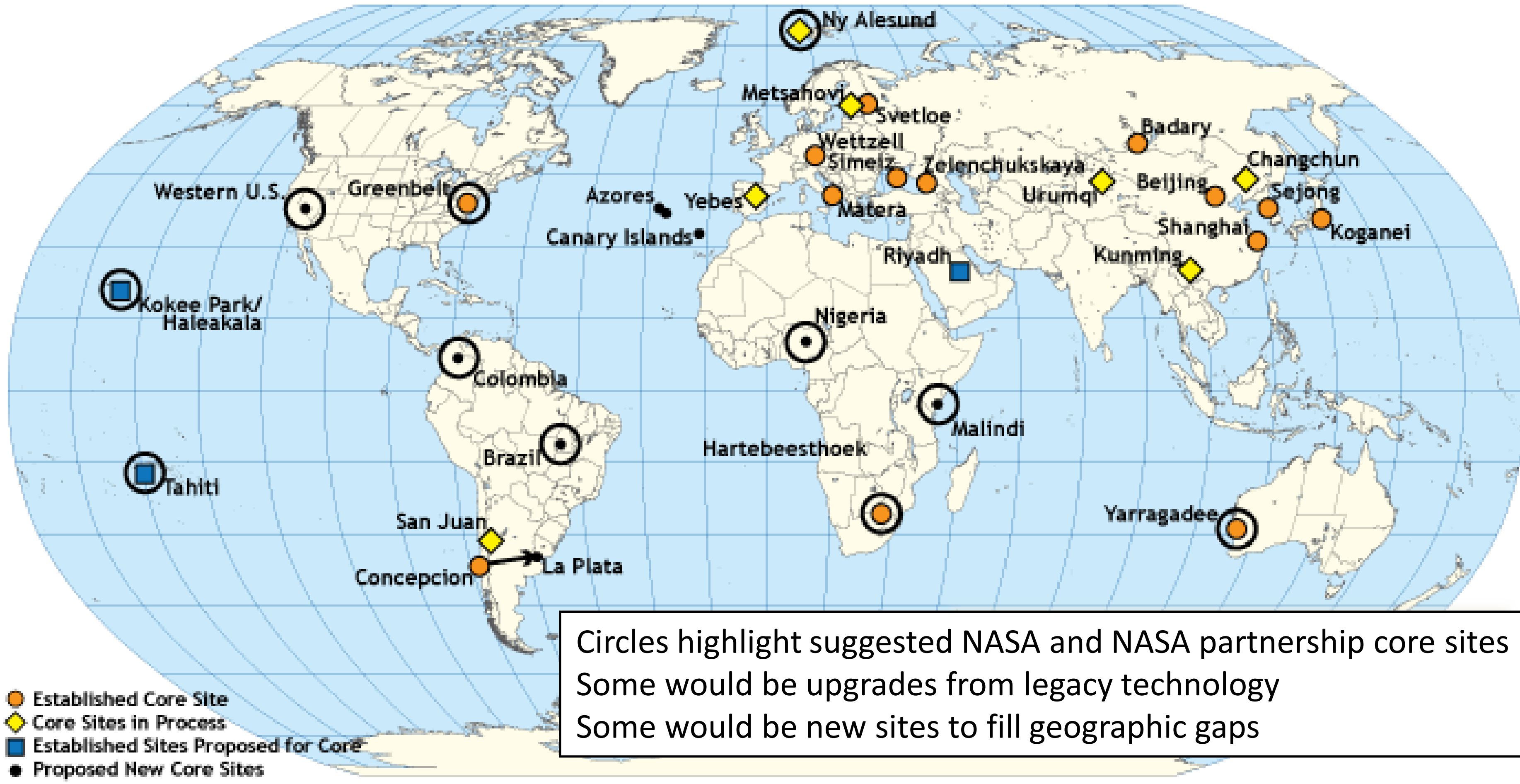
◆We will have a mix of new and legacy technologies for many years

As a result:

◆Co-location sites (non-core sites) will continue to play a vital role in our data products

◆Quality of NASA output will be the product of network Core Sites, co-location sites, mix of technologies, adherence to proper operational and engineering procedures, and making best use of the data once it leaves the field

Current and Candidate Core Sites



Circles highlight suggested NASA and NASA partnership core sites
Some would be upgrades from legacy technology
Some would be new sites to fill geographic gaps

Given programmatic and technical constraints, the NASA SGP core sites (those either wholly owned or supported by NASA) required to cover gaps in the global site coverage are shown here (labeled "Proposed Core Sites")

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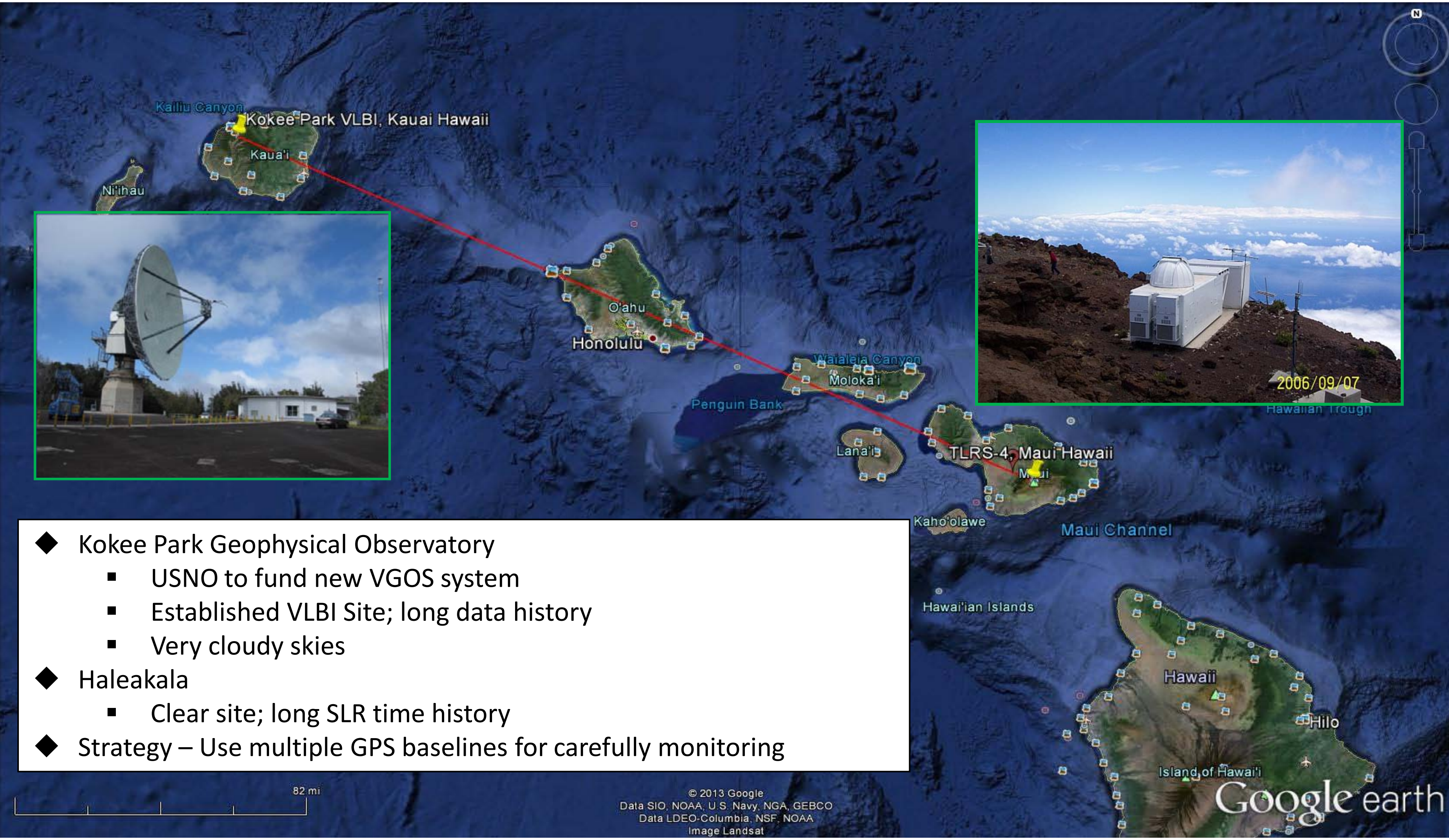
Hawaii – KPGO to Haleakala

(Distance Between Sites is ~380 km)



- Kokee Park Geophysical Observatory
  - USNO to fund new VGOS system
  - Established VLBI Site; long data history
  - Very cloudy skies
- Haleakala
  - Clear site; long SLR time history
- Strategy – Use multiple GPS baselines for carefully monitoring

NASA-USNO Partnership on New Hawaii VGOS Station

- United States Naval Observatory (USNO) has funding to implement a new VGOS station at Kokee Park, Hawaii.
- SGP completed environmental categorical exclusion for 2 potential locations.
- USNO awarded contract for a 12-meter class antenna. PDR held January 28-29.
- USNO requested NASA provide project oversight, site preparation, and signal chain development.
- Station will become an operational VGOS station as part of the new NASA Space Geodesy Network.

Kokee Park Geophysical Observatory on Kauai

Proposed locations for new antenna

NASA-USNO Partnership on New Hawaii VGOS Station

- How will work at Kokee Park is to be organized?
  - 12-m antenna – USNO contract with InterTronic Solutions
  - Pad design – Goddard contractor
  - Pad construction – TBD (NAVFAC or Goddard contractor)
  - Electrical and network installation – Goddard subcontractor
  - Signal chain fabrication, installation, integration and testing – MIT/Haystack Observatory

GGAO VGOS System

A NASA funded collaboration involving employees of:

- NASA (civil servants)
- MIT/Haystack: Hardware, signal chain, correlation
- Exelis: Site support
- NVI, Inc: Scheduling, Field System, Analysis Software

GGAO VGOS Geodetic Sessions

- Geodetic sessions (end-to-end VGOS observations with more than one antenna) were performed with ever increasing realism.

January 2012:
1st 12m broadband observations

April 2012:
1st legacy to broadband observations

May 2012:
1st automated multi-source session (6 hours)

October 2012:
Two 6-hr broadband geodetic sessions.
Use SLR radar avoidance mask.

January 2013:
1st joint broadband-legacy 24 hour session.
1st use of S-Band in broadband front end.

May 2013:
1st 24-hour broadband geodetic session.
1139 30-second scans.

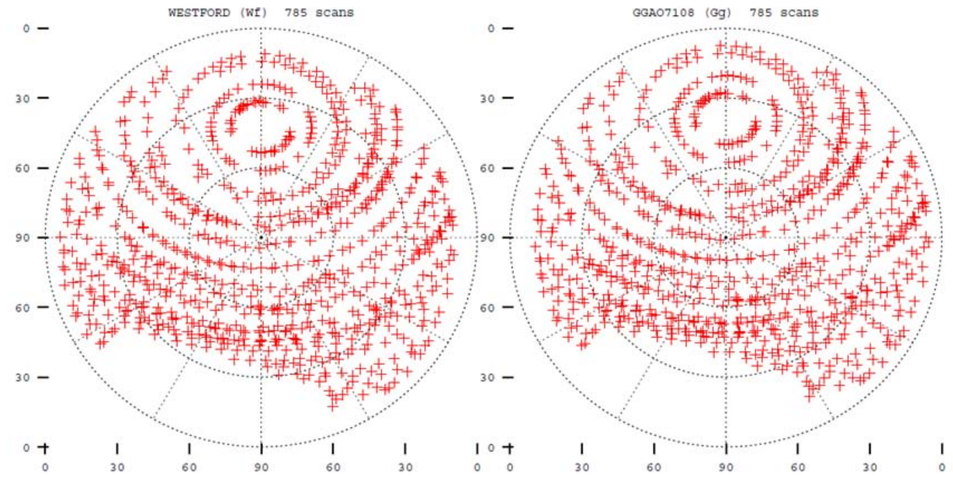
Realism

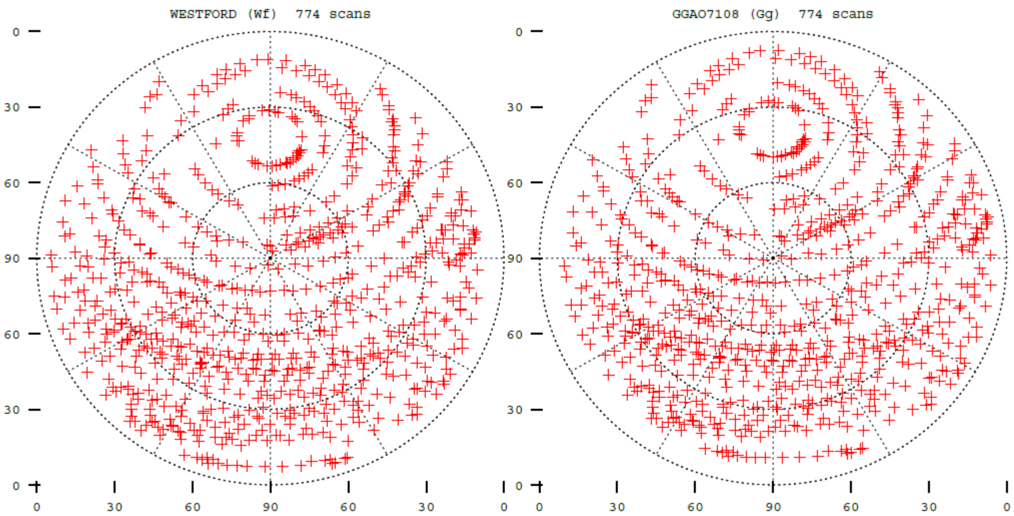
2012 October Observations

- Two six-hour sessions to evaluate repeatability
- First high-scan-rate schedule (~30 scans/per hour)
- Illustrate impact of SLR radar on observations
  - Direction to SLR masked out one day; full sky the other
  - Reduces common visibility in direction of SLR
- Position agreement better than 5 mm
- dTEC (ionosphere delay) in good agreement with GPS

2012 October Observations

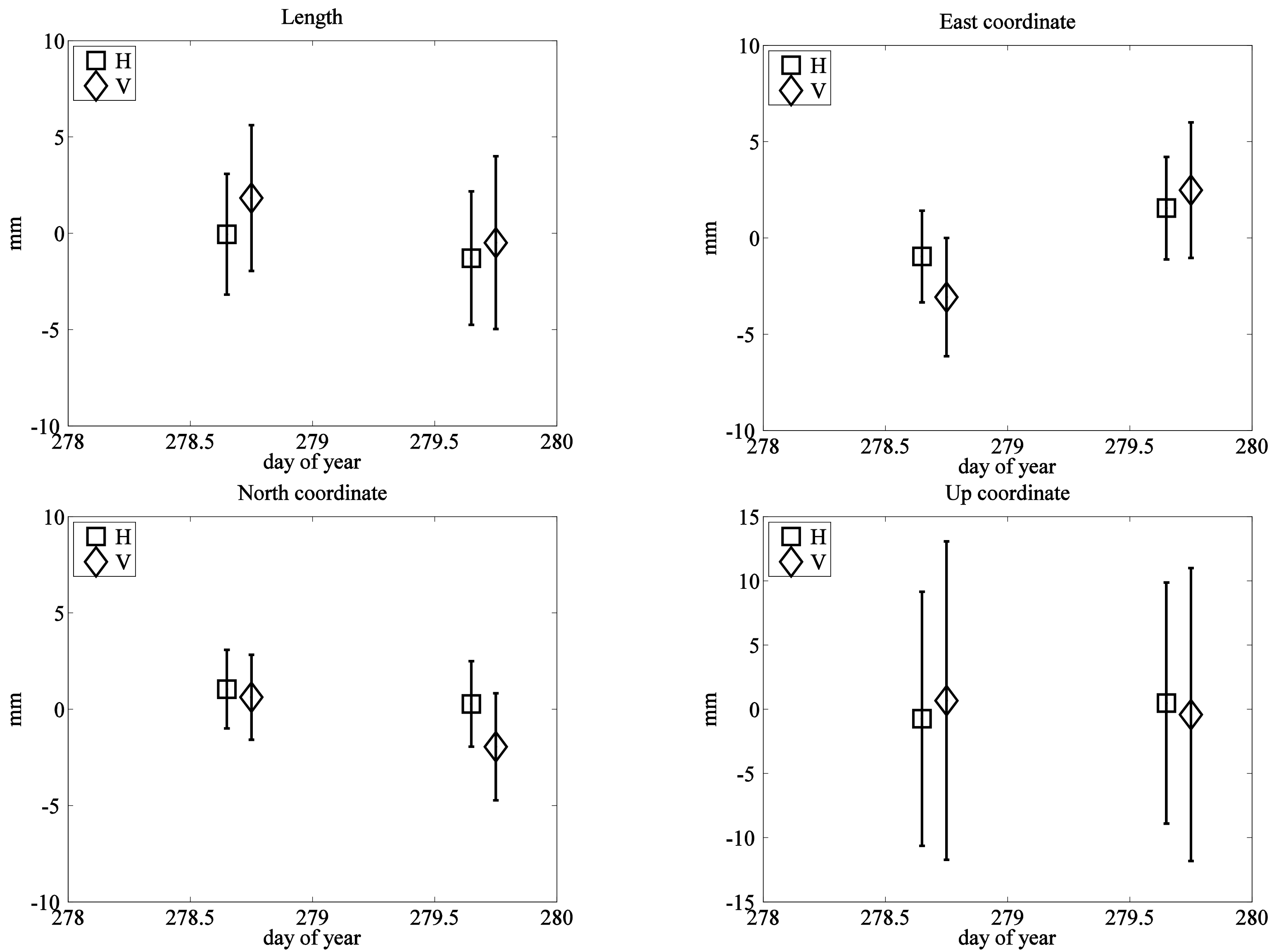
October 4th 2012: This schedule was made to avoid looking at SLR radar





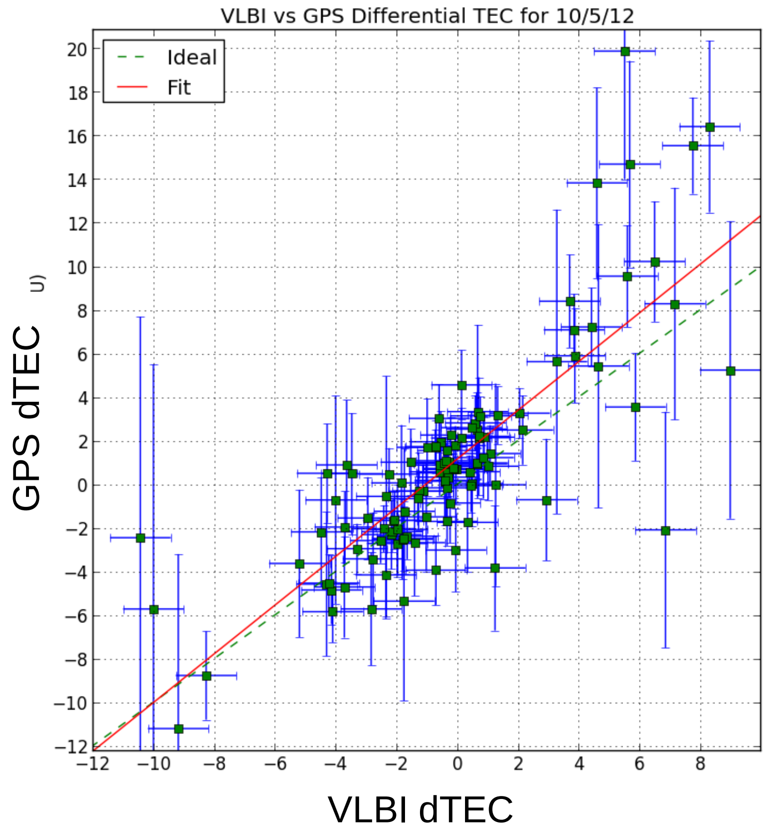
On October 5th the SLR radar was turned off.

2012 October Observations



2012 October Observations

- Comparison of VLBI and GPS derived dTEC
  - Difference the TEC values from collocated IGS GPS
  - Compare with dTEC estimated from VLBI
  - Good agreement
  - GPS could provide apriori TEC for VLBI correlation
  - Will be more important for long baselines



2013 May Goals

- Demonstrate unattended operation
  - Antenna and logging controlled by FS
  - Data acquisition controlled by script
- Evaluate accuracy of Fringe Amplitude Calibration for GGAO-Westford
- Process the data as a geodetic session

2013 May Scheduling

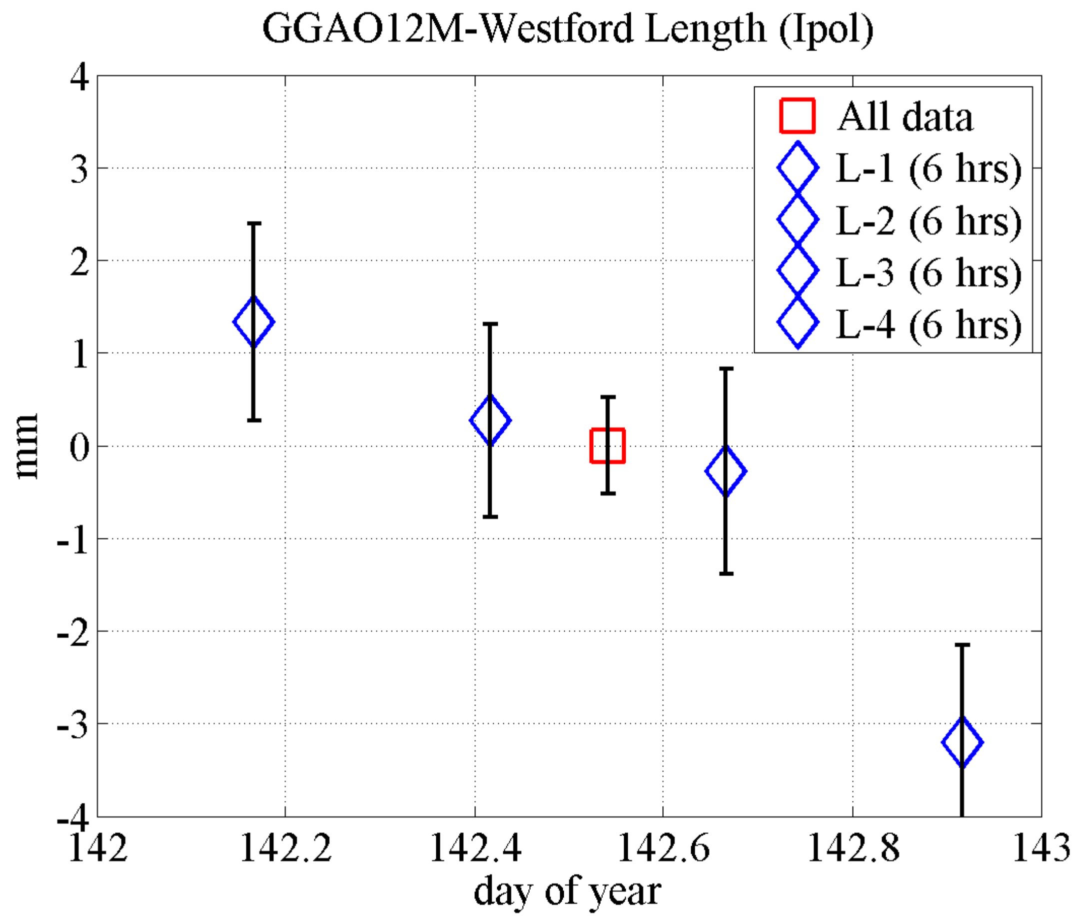
Sked setup:

- Number of sources: 100
- Minimum scan length: 30 sec
- Minimum SNR per band and polarization: 15
- Minimum elevation angle: 5 deg
- SLR radar mask: On
- 512MHz bands at 3.3, 5.3, 6.3 and 8.8 GHz

Achieved:

- Scans/hour: 45 — Now typically ~12
- Observing time 42% — Other: Cal, slewing, idle
- Disk space ~ 36 TB — A lot!

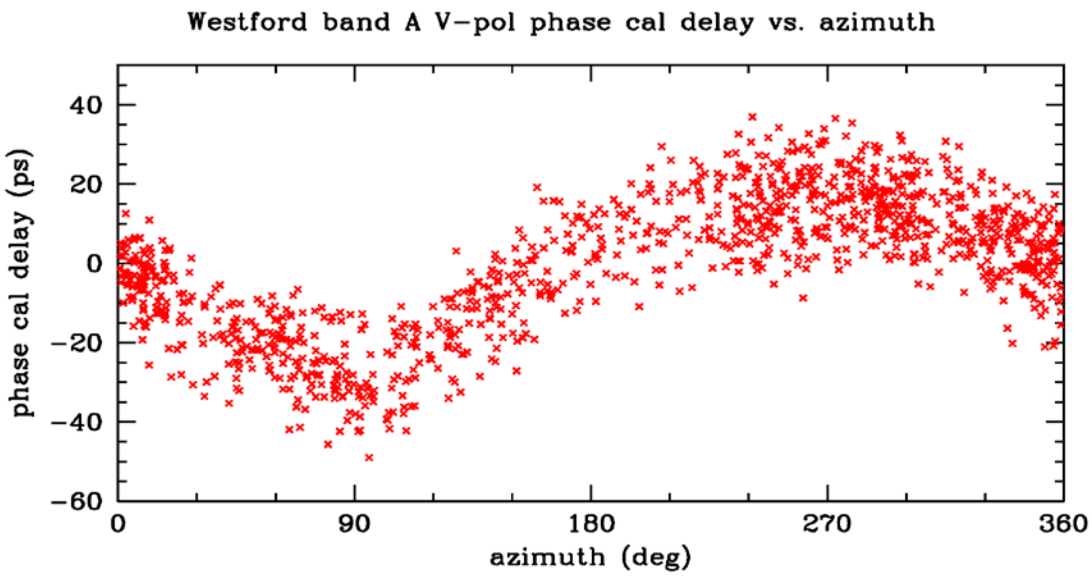
2013 May Results



2013 May Issues

Importance of 5 MHz cable cal delay calibration

- Azimuth dependence of multi-tone phase cal delay
- Probably uncorrected in 5 MHz cable to phase cal



Haystack has designed a new system.

2014 April

First use of single Mark6 for recording 8 Gpbs in one module

Successful use of RDBE-G digital back ends

- Measure internal clock offsets from GPS and maser
- Extract phase calibration signal at the station.
- Use complex samples
- Output in VDIF

The Future

Beginning in 2015 VGOS observing will start ramping up.

Regular observations between Haystack and GGAO.

Other stations will join in as they become available: Ishioka, Kokee, Wettzell Twins, AuScope, RAEGE, NyAlesund…

GGAO (and other VGOS stations) will also participate in mixed-mode observing (VGOS+legacy stations)