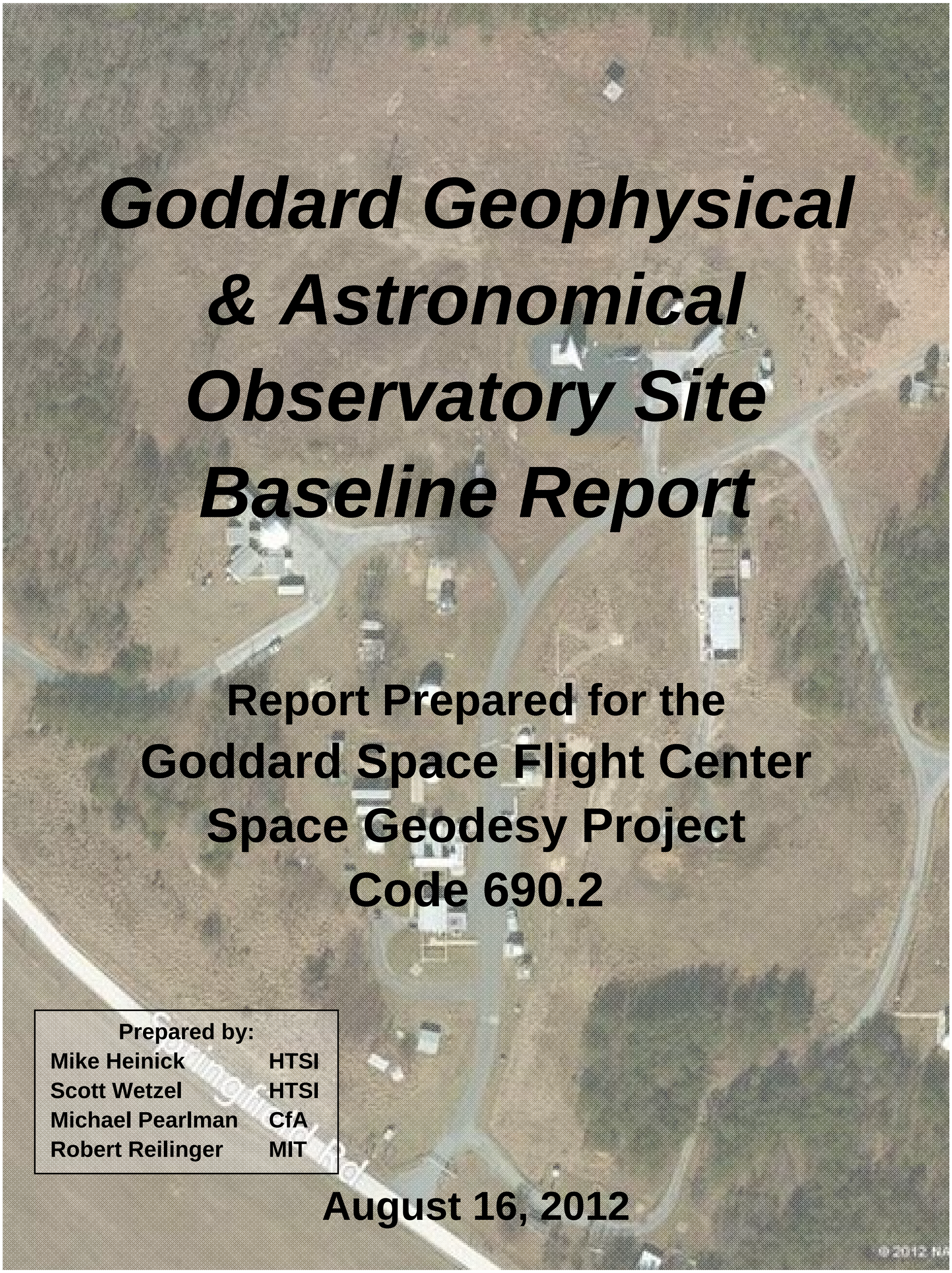

Goddard Geophysical & Astronomical Observatory Site Baseline Report

Report Prepared for the Goddard Space Flight Center Space Geodesy Project Code 690.2

Prepared by:

Mike Heinick	HTSI
Scott Wetzel	HTSI
Michael Pearlman	CfA
Robert Reilinger	MIT

August 16, 2012

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1.0 Acknowledgements

The authors would like to thank the following people for their extensive knowledge and information that contributed to the writing of this report. They include: Julie Horvath and Felipe Hall from Honeywell Technology Solutions Inc., and Michael Floyd and Robert King from MIT.

One component that is necessary for the success of NASA's Space Geodesy Project is the identification of key locations to populate the next generation space geodesy techniques to form a Fundamental Station. As part of the process, a baseline of each occupied NASA SLR and VLBI site and a few key GPS sites will be compared with the site criteria to determine viability for a Fundamental Station. This baseline information will then be used to evaluate other potential sites. With significant help from the above referenced people we were able to accumulate much of this information into a report that will help determine the next NASA Space Geodesy Network.

2.0 Executive Summary

One of the tasks under the NASA Space Geodesy Project (SGP) is to identify candidate locations for the new Fundamental Stations. A Fundamental station is one that ideally consists of the following space geodesy techniques, a next generation satellite laser ranging (NGSLR) ground system, a next generation very long baseline Interferometry (VLBI-2010) system, and an updated Global Navigation Satellite System (GNSS) ground system that has the capability to receive data from all GNSS satellite constellations. If a Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) system is also included, it would be an advantage. The requirements for this Fundamental Station can be found in the document, "*Site Requirements for GGOS Fundamental Stations*, 2011": (http://cddis.gsfc.nasa.gov/docs/GGOS_SiteReqDoc.pdf)

The initial requirement of this project is to baseline the current NASA SLR, VLBI, and select GNSS sites to the requirements stated in the site requirement document. As NASA has a rich history of sites with 1 to all 4 techniques collocated, a baseline of each NASA site will allow for a better understanding of what existing and new sites will meet with the SGP requirements.

The third NASA owned and operated site baselined is the Goddard Geophysical and Astronomical Observatory (GGAO). The GGAO is located as part of the Goddard Space Flight Center (GSFC) in Greenbelt, Maryland, and is known as the birthplace of Satellite Laser Ranging (SLR). Development activities for the current and new prototype SLR and VLBI systems occur at the GGAO through the NGSLR and the VLBI2010 systems, with VLBI2010 development activities also occurring at the MIT Haystack Observatory in Massachusetts.

The GGAO is part of NASA's GSFC facility, Area 200, which is not located on the main campus, but located approximately 2 miles from the campus. The size of the GGAO is approximately 49.75 hectares, with the area of used space for geodesy of approximately 8 hectares. Currently, all space geodesy techniques are collocated at the facility including the existing, operational SLR system, Moblas 7, the existing operational GNSS, GODE, the existing non-operational VLBI system, MV-3, and the existing operational DORIS. Also, currently, the Next Generation SLR (NGSLR) system and the VLBI2010 system are in development at the GGAO along with 3 new GNSS antennas, of which the 2 antennas that were most recently placed in early 2012 will be permanent. In addition, there are 2 older GNSS antennas that were temporarily established to transfer GODE to the new antennas.

Due to site topography issues and the long timeframe of implementing each of the original systems, the layout of this site is not ideal. At issue is poor geometry of each technique (all mostly in a straight North/South alignment), and poor geometry of calibration piers due to site topography. Additionally, it was determined that there were RFI issues between the SLR LHRS radar systems and with the DORIS antennas during the development of the VLBI2010 system. A lesson learned from this development effort is to look for and use natural barriers, or build new barriers, to shield potential local RFI sources from the VLBI2010 system.

Other site infrastructure including power, safety, security, and access are excellent, being part of the GSFC infrastructure. For communications, the GGAO is the facility where e-VLBI was first demonstrated. Local commitment and support are excellent with the GGAO being the center for the development of the SLR and VLBI next generation systems, the proximity to GSFC, and availability of abundant Government, contractor, and other support. As the GGAO is a unique site, it is planned that additional NGSLR systems will be fabricated and tested at the GGAO, and potentially VLBI2010 systems. There is adequate infrastructure to support this development and testing with a greater emphasis for protection for RFI for these other systems considered in the other sites within the GGAO for these SLR and VLBI systems.

Areas of concern in summary for the GGAO include site geometry and weather. The site geometry is not ideal with the existing techniques for the placement of calibration targets for SLR, or for the avoidance of RFI issues for VLBI2010 and DORIS. As for the weather, the GGAO and Maryland region are not ideal areas for SLR with about 50% cloud cover. This value will be confirmed with further analysis of the NGSLR all sky camera, as data was not completely available at the time of this report.

In summary, the GGAO facility has a long time series in SLR, VLBI, GNSS and DORIS. It is a key facility to the ILRS, IVS, IGS, and IDS by its long history in each technique and location. There is excellent infrastructure to support all techniques and strong local commitment with the GGAO's proximity to the GSFC main campus, and access to the development and operational experts in SLR and VLBI. At issue is poor site geometry and poor sky clarity for SLR. It is an excellent choice for a Fundamental Station for the SGP.

3.0 Introduction - GGAO Site Conditions for GGOS

This report describes the current conditions at the Goddard Geophysical & Astronomical Observatory (GGAO) that will determine the suitability of the site as a Fundamental Station for geodesy as described in the paper *Site Requirements for GGOS Fundamental Stations*, 2011. The information provided below will also provide a basis for comparison with other candidate sites during the site selection process.

The key elements that make up a Fundamental Station include a Next Generation Satellite Laser Ranging (NGSLR) system, a broadband capable Very Long Baseline Interferometry (VLBI2010) system and a Global Navigation Satellite System (GNSS) capable system. A DORIS system is desirable to the success of the Fundamental Station but is subject to the plan of the DORIS network.

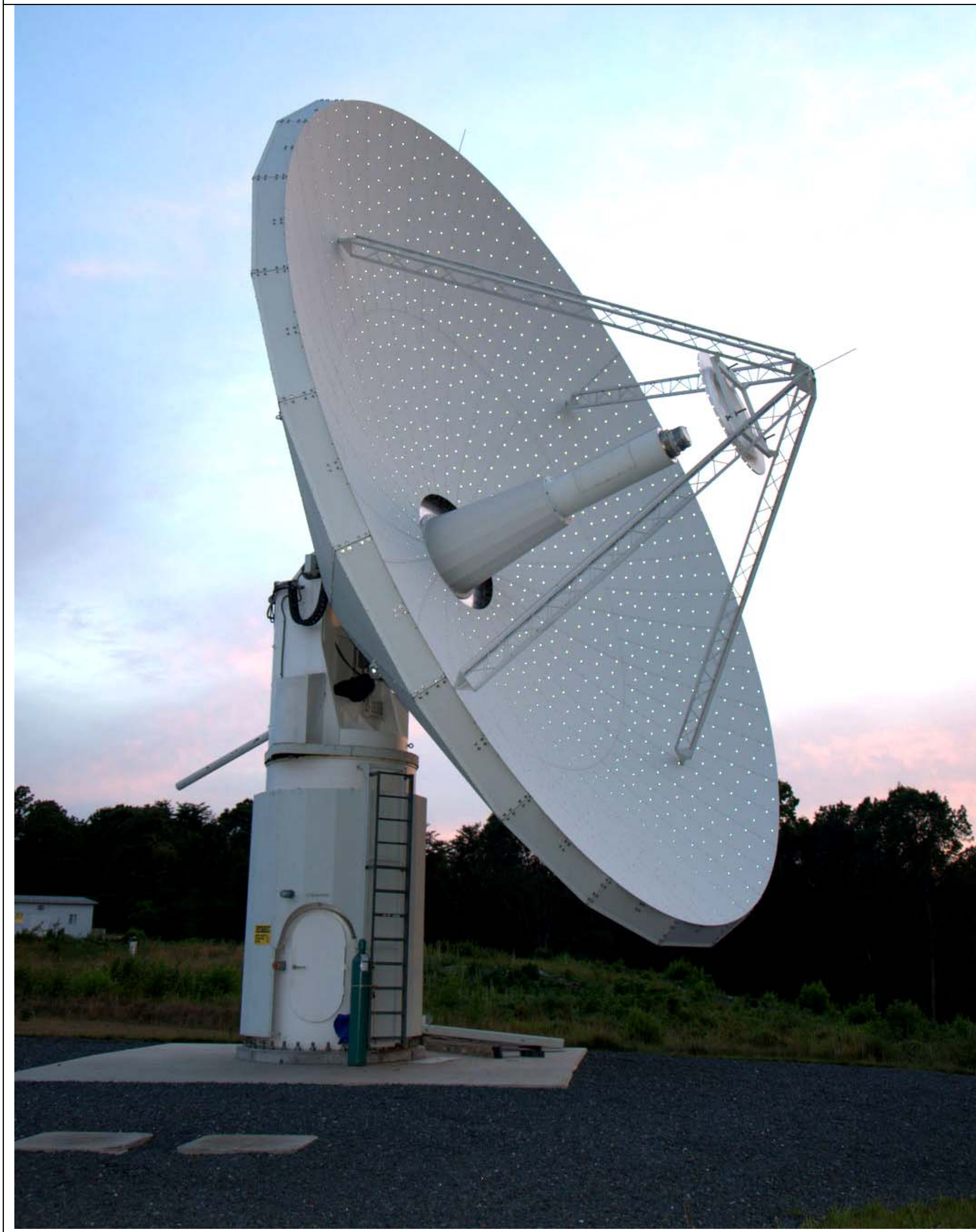
The following sections will examine all of the components of the Site Requirements for a Fundamental Station and will provide a summary of this examination. While NASA has occupied these initial locations by either SLR, VLBI, GNSS, or combinations of 2 or all three techniques, no site is to be considered as an exact candidate for a Fundamental Station. Also, it is understood that none of the existing sites is an exact match to the requirements. Ideally, the requirements within the *Site Requirements for GGOS Fundamental Stations* would make the best site; however, there is probably not an existing NASA occupied site that meets all of the criteria. This report just provides a baseline of the existing sites and allows for an informed decision by the Space Geodesy Project (SGP) to make the next choices for a Fundamental Station.

4.0 Existing Techniques

Techniques currently active at GGAO include SLR, VLBI, GPS, and DORIS.

VLBI – MV-3, a transportable 5-meter VLBI radio telescope, was moved to GGAO in 1991 and has been used as a fixed station. In 2002 the antenna was taken off of the trailer mount and mounted permanently on a pedestal. The VLBI2010 12-meter antenna was completed in October of 2010 and features all electric drives and a Cassegrain feed system.

VLBI2010 12 meter Antenna



VLBI2010 12 meter Antenna

VLBI MV-3 5 meter Antenna

Note: GODE GNSS Station in foreground

GNSS - A GPS antenna JPL 4006 was installed in 1994 at IGS station GODE. Two temporary antennas were installed as part of the transition from GODE. They were installed in 2010. One is located on the VLBI Pier B and the other is located on a temporary structure. New GNSS antennas (GODN and GODS) were installed early in 2012 and are coming on line at the time of this report. They are shown in the following pictures.

VLBI 12 meter, VLBI 5 meter, GODE GNSS

IGS GODE Station

Domes: 40451M123 PID: AA3496 Code: GODE

IGS stations GODE, GODN, GODS, VOBIB and IGSTemp

G

Domes: 40451M123 PID: AA3496 Code: GODE

DORIS –.The Starrec type antenna at geodetic station GREB was installed on June 29, 2000. It was positioned in a manner to reduce RFI to the VLBI systems, at the time MV-3. Work is planned to move the data portion of the DORIS to a new building and to also add a Regina station near the DORIS. This is not part of the SGP effort.

Doris Antenna GREB

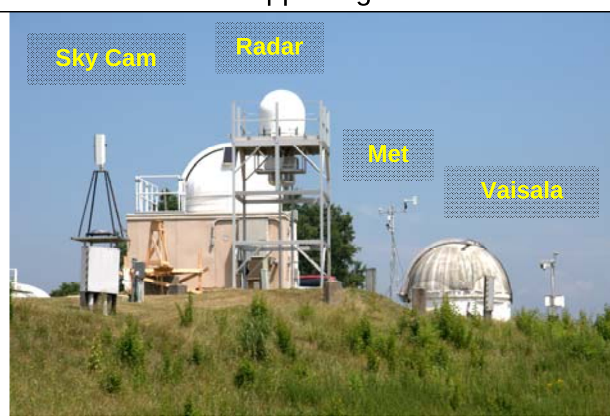
Source: DORIS website http://ids-doris.org/network/sitelogs/station.html?code=GREB

SLR – GGAO has been the primary site for the development of SLR techniques since the 1960s. A number of SLR systems have been developed, built, and collocated at the site, including MLRO for ASI, GUTS for JAXA, and NGSLR for NASA. MOBLAS-7 has been in operation at the site since 1981. NGSLR currently occupies the site with MOBLAS-7.

MOBLAS-7

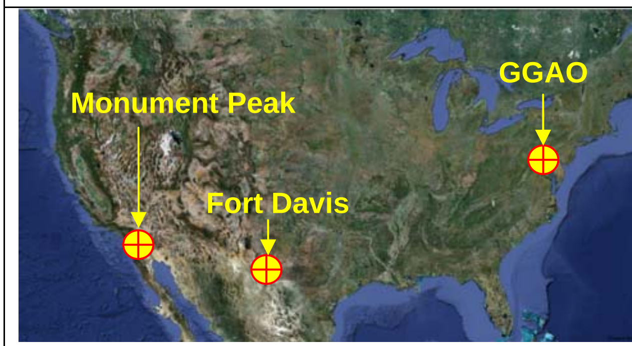
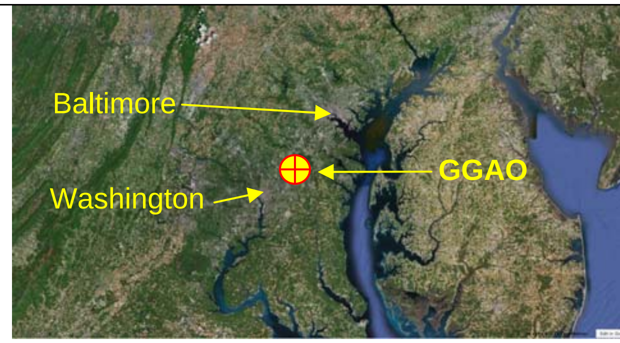
NGSLR

NGSLR Tracking

<table>
<tr><th colspan="2">NGSLR Supporting Instruments</th></tr>
<tr><td>Vaisala</td><td>All Sky Camera</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Met Sensors</td><td>NGSLR & Supporting Instruments</td></tr>
<tr><td></td><td>
</td></tr>
</table>

5.0 Global Consideration for the Location

The GGAO site is located in the Mid-Atlantic region of the North American continent near Washington, D.C. The GODE GPS station at GGAO is located at latitude 39 01' 18" N and longitude 283 10' 23" E (76 49' 37" W).

GGAO on the North American Continent	
SGP Sites in U.S.A.	GGAO Region
	

5.1 Geometrical Distribution

GGAO is one of the original existing network sites and is located near the Mid-Atlantic coast of the United States. For SLR, another existing site on the North American tectonic plate is at Fort Davis, Texas. Farther west, the Monument Peak site near San Diego, California, is located within the eastern boundary zone of the Pacific plate. To the east, there are existing sites in Europe on the Eurasian Plate. Far to the south there is Hartebeesthoek in South Africa on the South African plate.

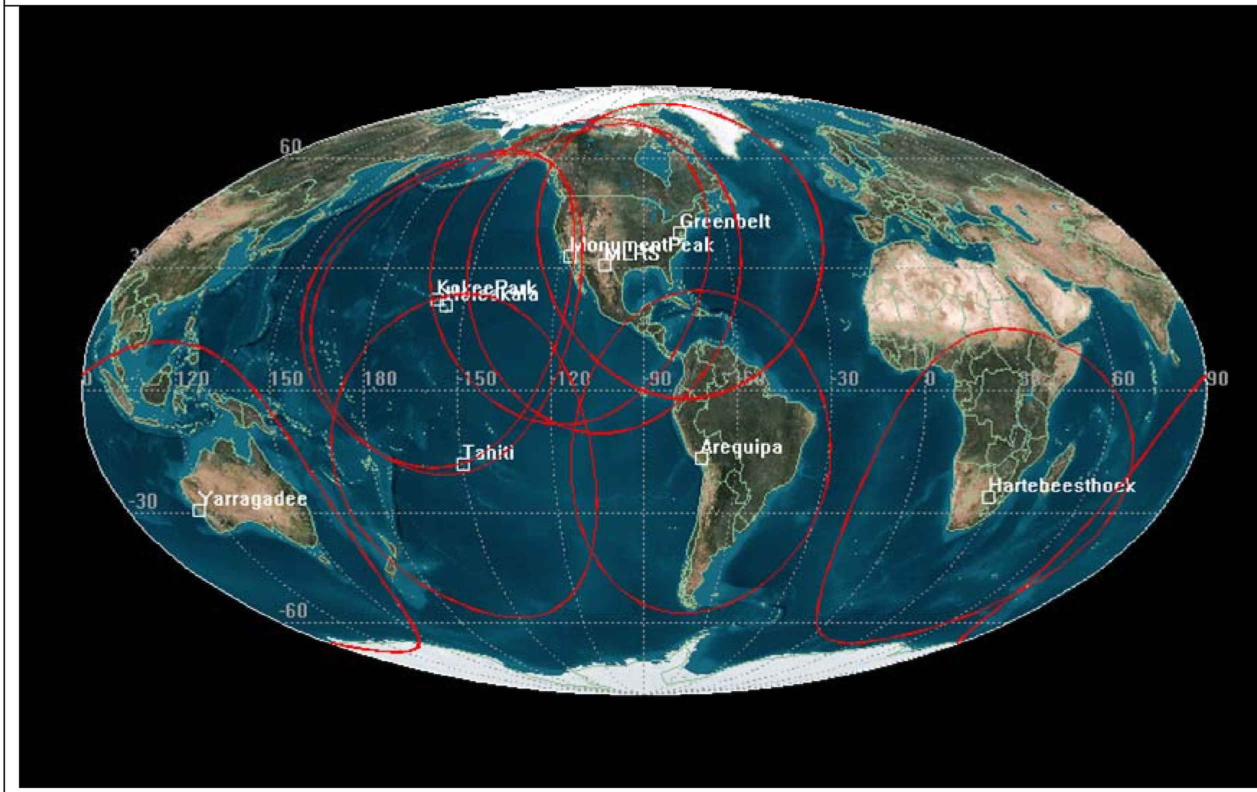
5.2 Technical Distribution

It is desired to have three well distributed stations on each tectonic plate. Another existing site on the North American plate with a long duration SLR occupation is located at Fort Davis, Texas. Another existing VLBI site on the North American plate is located relatively nearby in Westford, Massachusetts. In the past, there have been VLBI occupations at Yellowknife in Canada and Algonquin in Canada. Currently, an occupation at Gilmore Creek in Alaska is being considered and will be subject to a future site selection study.

5.3 Technique Dependent Distribution

VLBI requires simultaneous observations of astronomical targets with at least one other VLBI site. GGAO, at a latitude of approximately 39N, provides access to targets to a declination of 51S when local obstructions and pointing limitations are not considered. For SLR, the location of GGAO on the east coast of the North American continent provides coverage of satellite tracks over the North Atlantic Ocean. The following plot displays the tracking coverage down to 20 degrees elevation for LAGEOS by the NASA SLR sites.

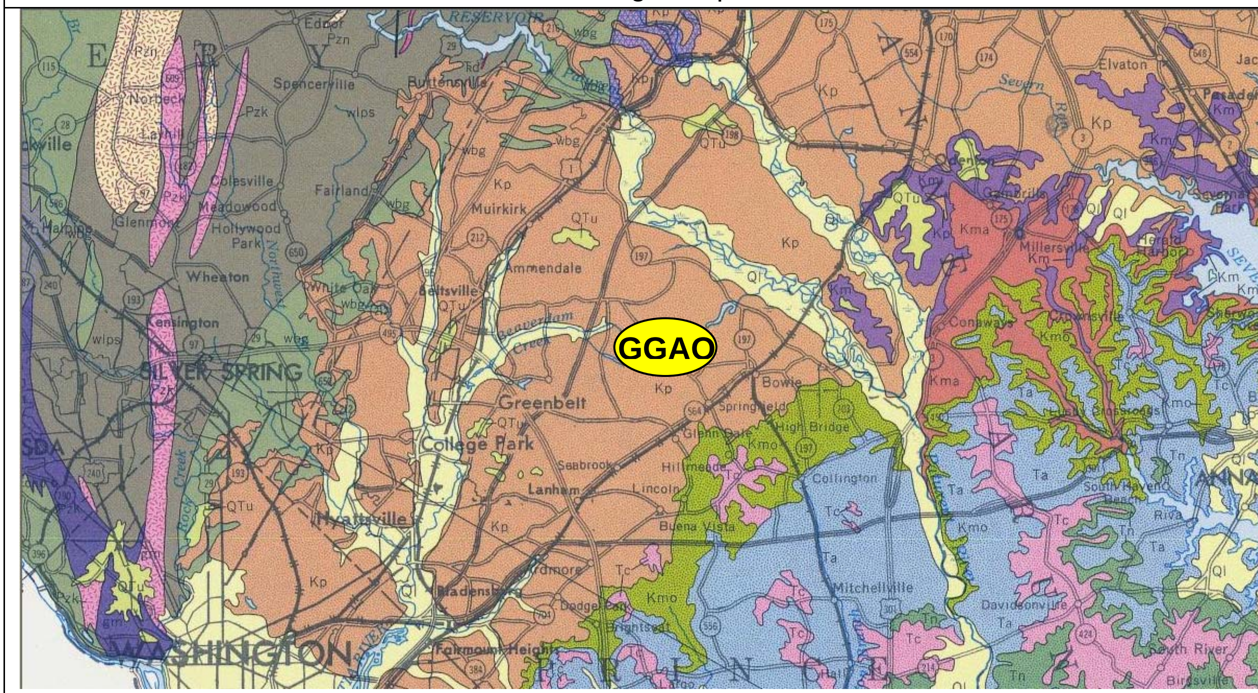
20 Degree Acquisition for Lageos by NASA Sites



6.0 Geology

See the report from MIT on the stability of the GGAO site included at the end of this document in Appendix A.

Geologic Map



Source: http://ngmdb.usgs.gov/ngm-bin/ILView.pl?sid=16548_1.sid&vtype=b

6.1 Substrate

GGAO is on 152m of clay with thin layers of sand that overlay a crystalline basement of gneiss. See NASA Technical Memorandum 82175.

Geologic Map: http://ngmdb.usgs.gov/ngm-bin/ILView.pl?sid=16548_1.sid&vtype=b
Geologic Map of Maryland, Cleaves, E T, Edwards, Jonathan, Jr. and Glaser, J D, Maryland Geological Survey, 1968

6.2 Tectonic Stability

A 5.8 magnitude earthquake occurred on August 23, 2011. The epicenter was located in Mineral, Virginia, and the earthquake was felt across much of the eastern U.S., including GGAO.

A report from MIT on the stability of the GGAO site is included at the end of this document in Appendix A.

7.0 Site Area

GGAO is located in the Mid-Atlantic region of the United States and is part of, and located close to, the Goddard Space Flight Center (GSFC) in Greenbelt, Maryland, which lies between Washington and Baltimore.

GGAO Northeast of the Goddard Space Flight Center (GSFC)

Note: Airfield adjacent to GGAO is abandoned.

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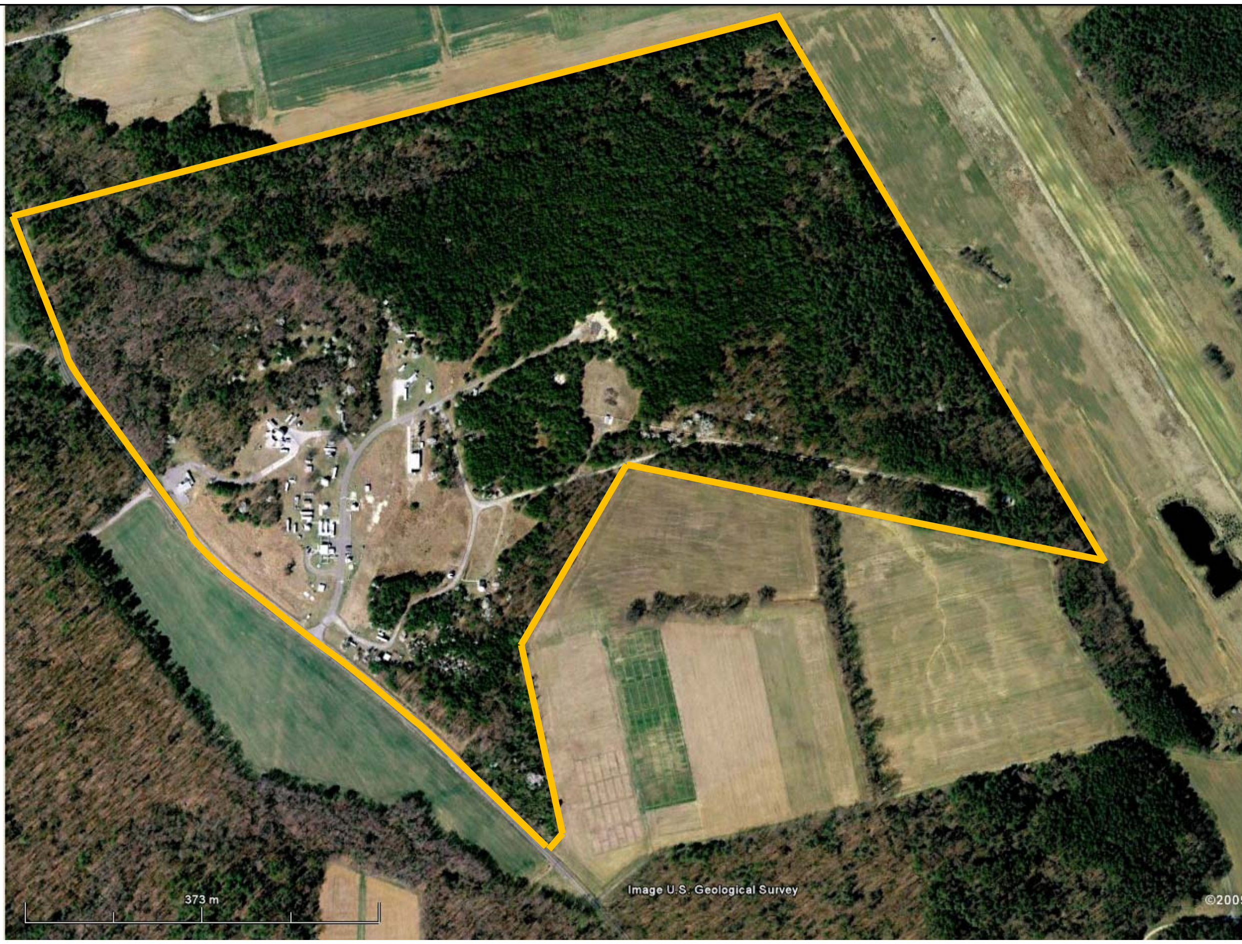
7.1 Local Size

The GGAO site spans an area of ~49.75 hectares surrounded by Beltsville Agricultural Research Center property. Several observatories and facilities occupy the site, primarily near the western side.

GGAO Site Perimeter



GGAO Site

Source: http://www.bing.com/maps/

GGAO Site Layout

Source: http://www.bing.com/maps/

Potential NGSLR Sites

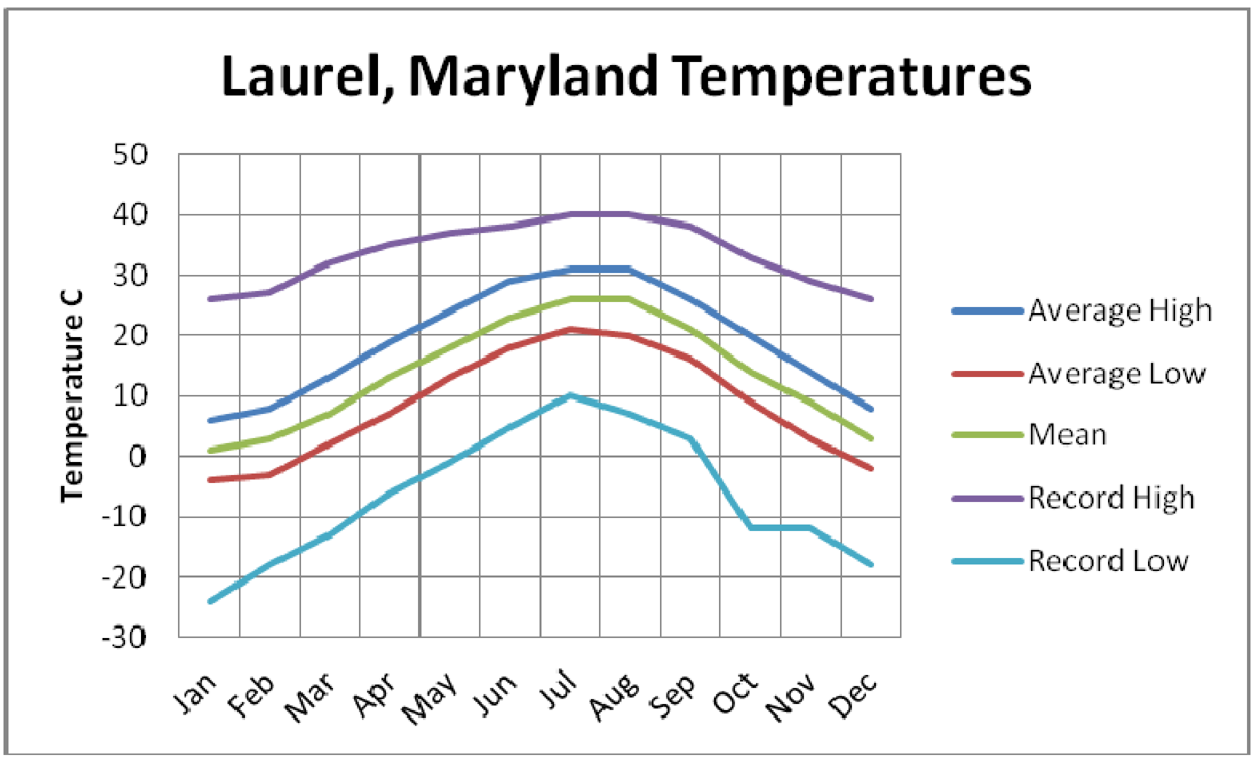
7.2 Weather & Sky Conditions

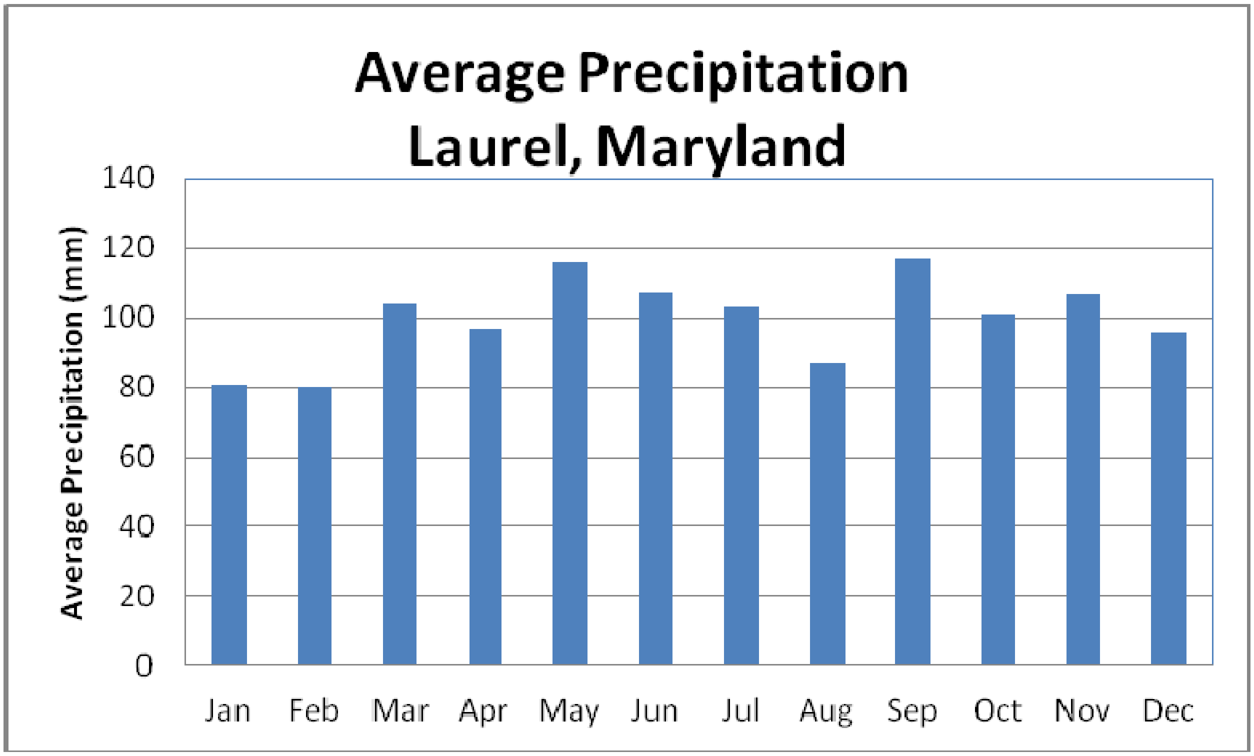
7.2.1 Climate

The climate at GGAO is temperate.

The following table lists monthly temperatures and precipitation amounts for the nearby town of Laurel, Maryland just northwest of GGAO. Plots follow the table.

Month	Average High	Average Low	Mean Temperature	Average Precipitation	Record High	Record Low
January	6°C	-4°C	1°C	80.3mm	26°C (1950)	-24°C (1994)
February	8°C	-3°C	3°C	79.8mm	27°C (2000)	-18°C (1961)
March	13°C	2°C	7°C	104.1mm	32°C (1998)	-13°C (1993)
April	19°C	7°C	13°C	96.8mm	35°C (2002)	-6°C (1997)
May	24°C	13°C	18°C	115.8mm	37°C (1991)	-1°C (1966)
June	29°C	18°C	23°C	107.4mm	38°C (1997)	5°C (1988)
July	31°C	21°C	26°C	102.9mm	40°C (1988)	10°C (1979)
August	31°C	20°C	26°C	87.1mm	40°C (1957)	7°C (1976)
September	26°C	16°C	21°C	116.8mm	38°C (1953)	3°C (1992)
October	20°C	9°C	14°C	101.1mm	33°C (2007)	-12°C (1983)
November	14°C	3°C	9°C	106.9mm	29°C (1950)	-12°C (1976)
December	8°C	-2°C	3°C	95.8mm	26°C (1998)	-18°C (1983)
Source: http://www.weather.com/weather/wxclimatology/monthly/20707						





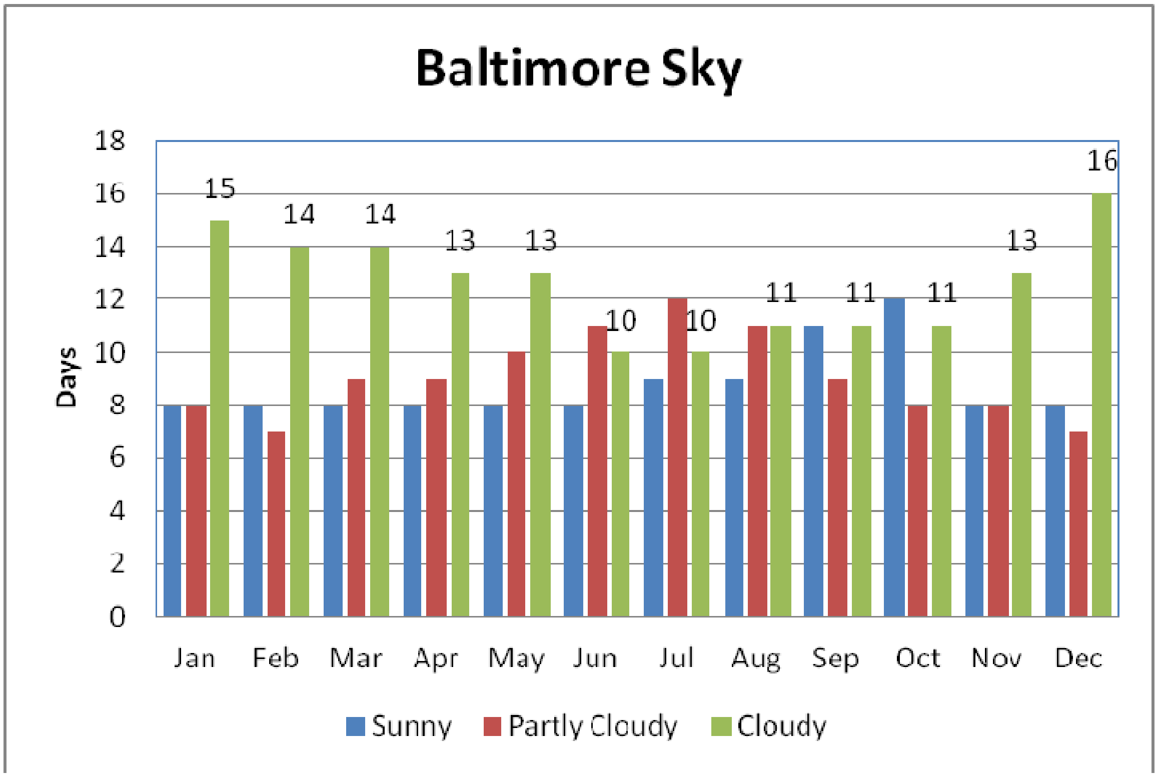
7.2.2 Sky Conditions

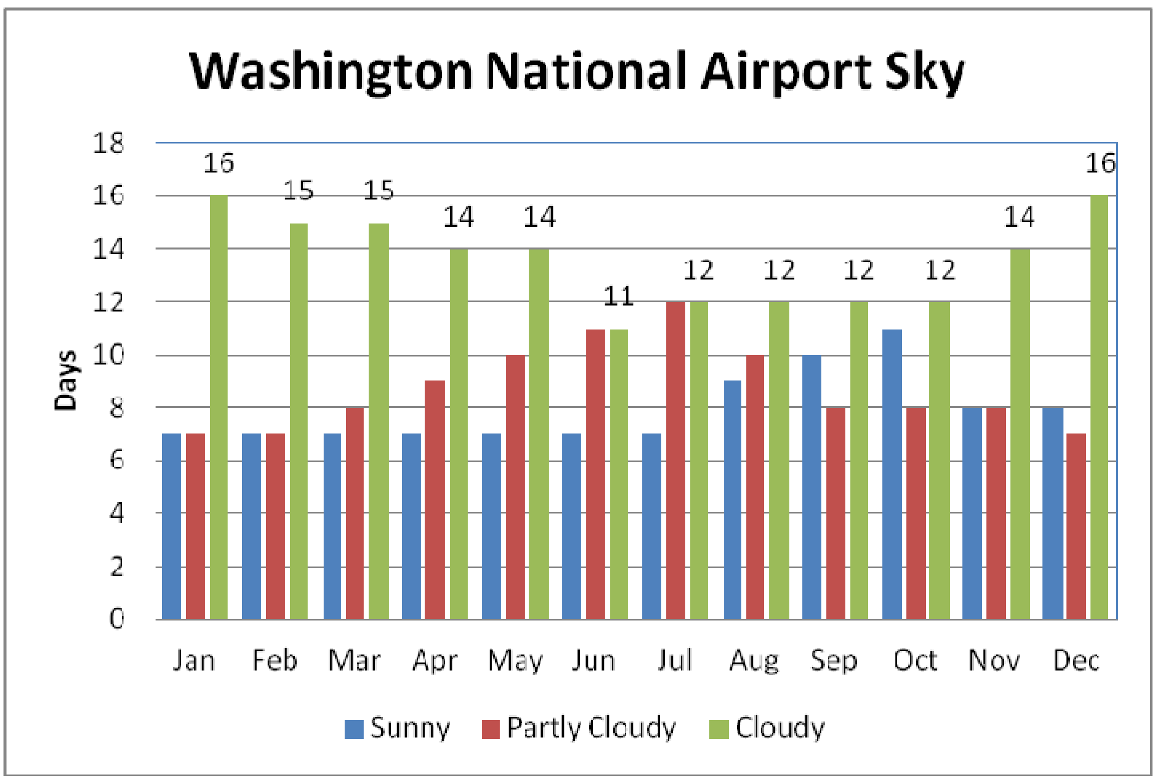
GGAO is located between nearby Washingon, D.C. and Baltimore, Maryland. The following table provides monthly clear, partly cloudy, and cloudy day counts for Baltimore, MD, and Washington, D.C. Plots of the data follow the table.

		Baltimore, MD	Washington Nat'l AP, D.C.
Years		45	48
January	Clear	8	7
	Partly Cloudy	8	7
	Cloudy	15	16
February	Clear	8	7
	Partly Cloudy	7	7
	Cloudy	14	15
March	Clear	8	7
	Partly Cloudy	9	8
	Cloudy	14	15
April	Clear	8	7
	Partly Cloudy	9	9
	Cloudy	13	14
May	Clear	8	7
	Partly Cloudy	10	10
	Cloudy	13	14
June	Clear	8	7

	Partly Cloudy	11	11
	Cloudy	10	11
July	Clear	9	7
	Partly Cloudy	12	12
	Cloudy	10	12
August	Clear	9	9
	Partly Cloudy	11	10
	Cloudy	11	12
September	Clear	11	10
	Partly Cloudy	9	8
	Cloudy	11	12
October	Clear	12	11
	Partly Cloudy	8	8
	Cloudy	11	12
November	Clear	8	8
	Partly Cloudy	8	8
	Cloudy	13	14
December	Clear	8	8
	Partly Cloudy	7	7
	Cloudy	16	16
Annual	Clear	105	96
	Partly Cloudy	108	106
	Cloudy	152	164
Source: http://lwf.ncdc.noaa.gov/oa/climate/online/ccd/cldy.html			

Additional data from the NGSLR all sky camera is still in the process of being acquired and analyzed for a more detailed view of sky clarity. Based on the data above, the GGAO has trackable skies approximately 42% of the time. It is believed, however that this number would increase by a few percent with the all sky camera data.





GGAO experiences occasional ground fog that obscures SLR ground calibration targets.

The NGSLR all sky camera can provide greater detail as to the historical percentage of clear sky at the GGAO. At this time, the data is still being analyzed to produce an accurate value for sky clarity directly at the GGAO.

7.3 RF and Optical Interference

The location of GGAO within a heavily populated region with industrial, aeronautical, and military components raises the possibility of various types and periods of interference from offsite sources.

7.3.1 RF Interference

RFI studies have been ongoing at the GGAO over the past several years. While it is known that the LHRS and DORIS antennas contribute to RFI of the VLBI2010 system, other sources also contribute to the issue, resulting in changes in the way the S-Band data will be acquired. A detailed report on the RFI environment at the GGAO will be forthcoming in the following months, with methods of mitigation that will be able to be used for other sites within the network.

7.3.2 Optical Interference

Night skies at GGAO are never very dark due to the site's location within the heavily populated Washington-Baltimore corridor. Direct lighting from offsite sources is minimal since the immediate area surrounding the site is undeveloped farmland and trees block sources on the horizon.

7.3.3. Other Possible Interference

None are identified at this time.

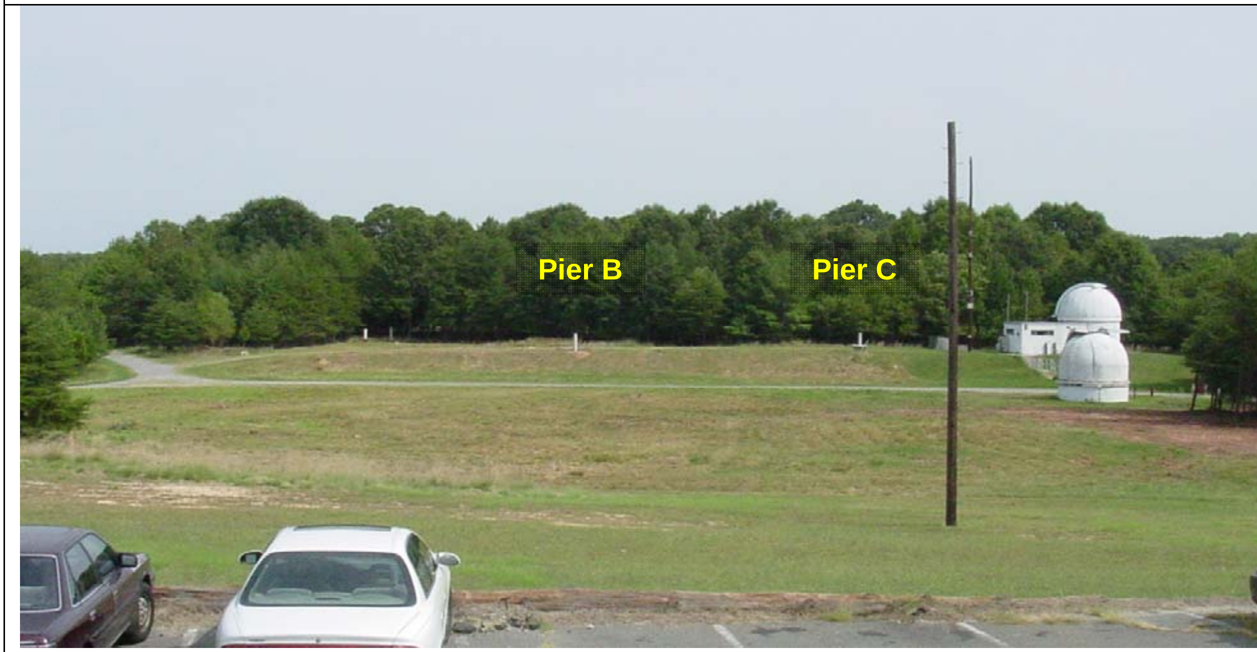
7.4 Horizon Conditions

The *Site Requirements for GGOS Fundamental Stations* document states that, ideally, stations should have an obstruction free view down to 5 degrees elevation over 95% of the horizon.

At GGAO, as with any site, horizon conditions for each technique will vary depending on the location and height of each technique on the site. For SLR, the radar of the Laser Hazard Reduction System (LHRS) used for aircraft protection works best with a clear horizon within 400 meters free of trees, buildings, towers, and other tall objects that would contribute to ground clutter.

GGAO Horizon from NGSLR

Calibration Piers from MOBLAS-7



7.5 Air Traffic

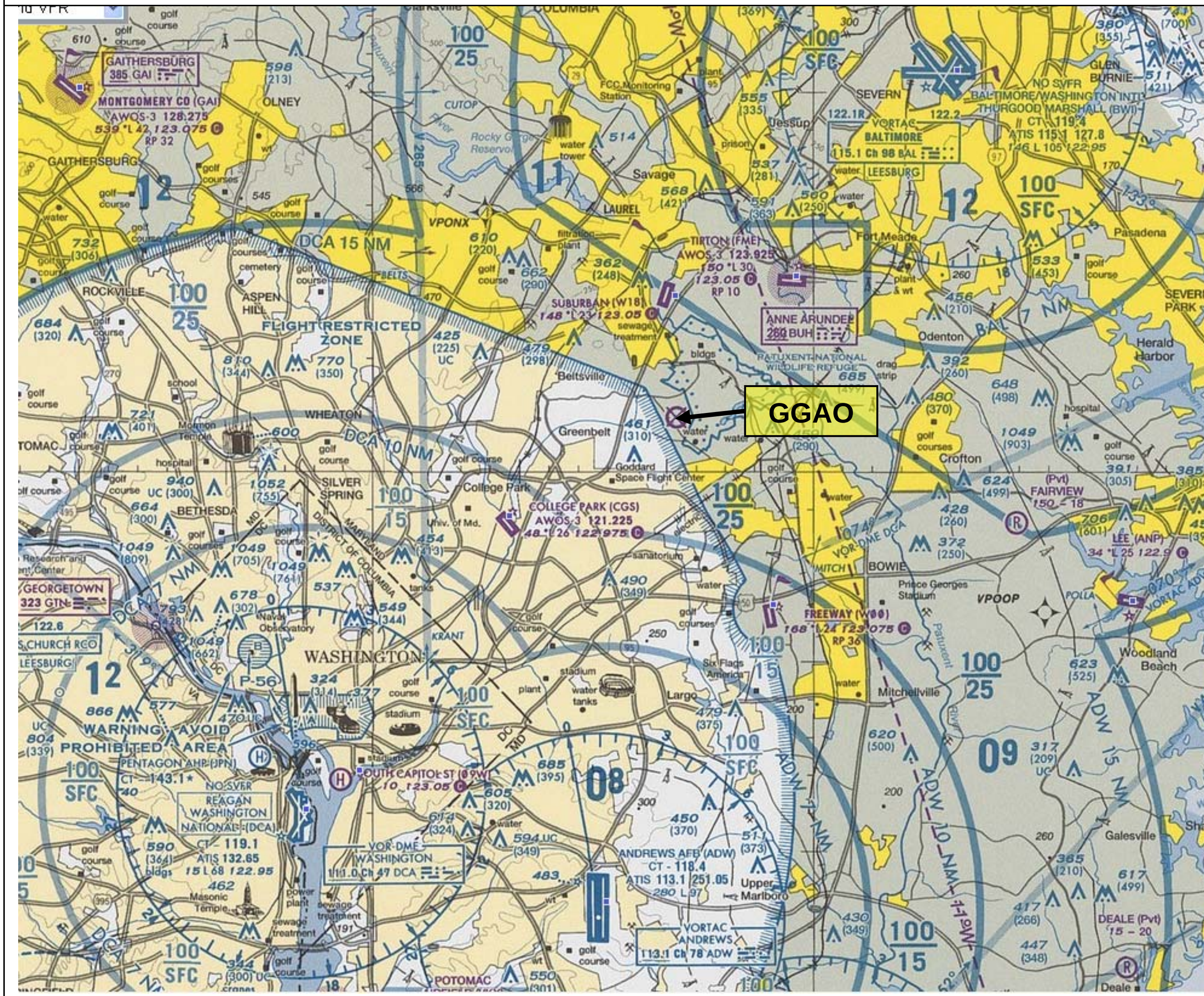
There are three major airfields within 17 miles of GGAO. These include Baltimore-Washington International Airport (BWI), which is the closest to the northeast, Andrews Air Force Base east of Washington, and Washington National Airport just south of Washington. There are also a few small airfields surrounding GGAO at a closer distance.

BWI Air Traffic
http://airnav.com/airport/KBWI

BWI Airport Operational Statistics

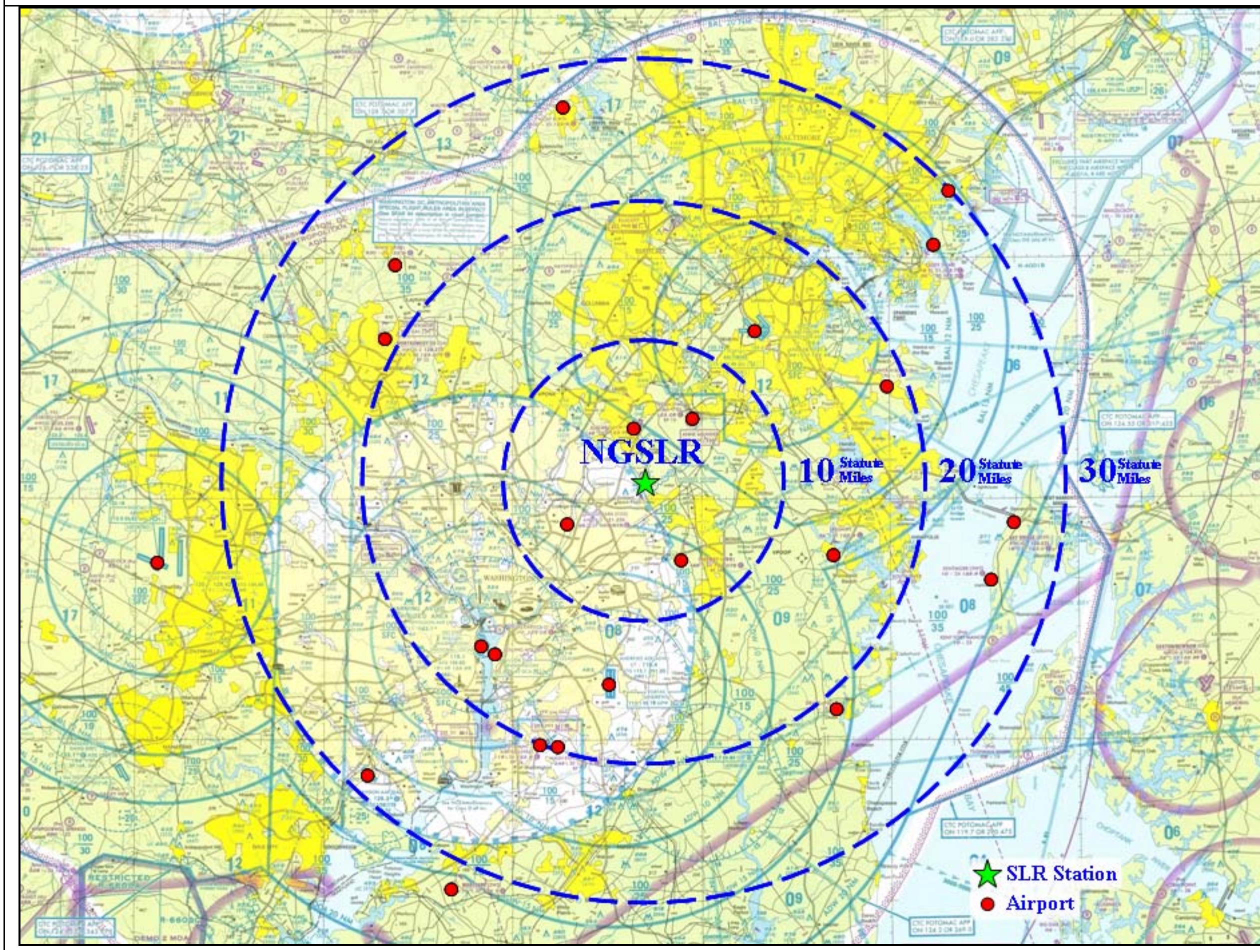
Aircraft based on the field: 73	Aircraft operations: avg 757/day *
Single engine airplanes: 50	76% commercial
Multi engine airplanes: 10	15% air taxi
Jet airplanes: 13	7% transient general aviation
	1% local general aviation
	<1% military
	* for 12-month period ending 31 December 2010

Flight Navigation Chart For GGAO Region



Source: http://vfrmap.com/?type=vfrc&lat=39.175&lon=-76.668&zoom=10

Airports in the GGAO / NGSLR Region



Source: Presentation on the HTSI Laser Hazard Reduction System

7.6 Aircraft Protection

For SLR, a HTSI Laser Hazard Reduction System (LHRS) automatically detects aircraft approaching the laser beam transmit path and blocks the laser transmission until the path is clear of aircraft. It is the current method of aircraft hazard avoidance at the GGAO and at many of the other NASA SLR sites.

7.7 Communications

T1, high speed fiber (~1Gb) is available at the GGAO as well as other voice and data. There is adequate bandwidth at the GGAO to support this effort.

7.8 Land Ownership

GGAO is owned by NASA and is part of the Goddard Space Flight Center.

7.9 Local Ground Geodetic Networks

7.9.1 Local Station Network

DOMES markers at GGAO:

DOMES No.	Description	Code
40451M101	MOBLAS 7101-1977 Standard NASA disk	7101
40451M102	Mobile SLR 7102-1978 Standard NASA disk	7102
40451M103	Mobile SLR 7103-1978 Standard NASA disk	7103
40451M104	Mobile SLR 7104-1978 Standard NASA disk	7104
40451M105	MOBLAS-7 7105-1981 Standard NASA disk	7105
40451M106	Mobile SLR 7100-1977 Standard NASA disk	7100
40451M107	Mobile SLR 7064 Standard NASA disk	7064
40451M110	Greenbelt North GEOS (GSFC) GORF (PID: JV5895)	
40451M111	TLRS 7899-1980 Standard NASA disk	7899
40451M112	STALAS Fixed Laser Standard NASA disk	7063
40451M113	SLR Mark	7106
40451M114	SLR Mark 7125 1985 Standard NASA disk	7125
40451M115	SLR Mark	8213
40451M116	SLR mark 7130 1985 standard NASA disk	7130
40451M117	SLR Mark 7125-B Standard NASA disk	7920
40451M118	SLR mark 7889 1981 standard NASA disk	7889
40451M119	SLR mark 7917 Steel plate SAO-3	7917
40451M120	SLR Mark Standard NASA disk	7918
40451M121	SLR mark standard NASA disk	7919
40451M122	SLR Mark Standard NASA disk	7083
40451M123	GPS Mark East (JPL 4006-1992)	GODE
40451M124	GPS Mark West (JPL 4005)	GODW
40451M125	Mark SGP 7108-1993 VLBI MV3	7108
40451S176	DORIS antenna ref. pt (Starrec type)	GREB
Source: ITRF website http://itrf.ign.fr//site_info_and_select/site.php?SelecSite=404051&begin=1 Note: Several additional markers have been added onsite recently that still need designations.		

Sampling of Geodetic Markers & Calibration Piers

Source of satellite view: http://www.bing.com/maps/

(DOMES information: - *http://itrf.ign.fr//site_info_and_select/site.php*)

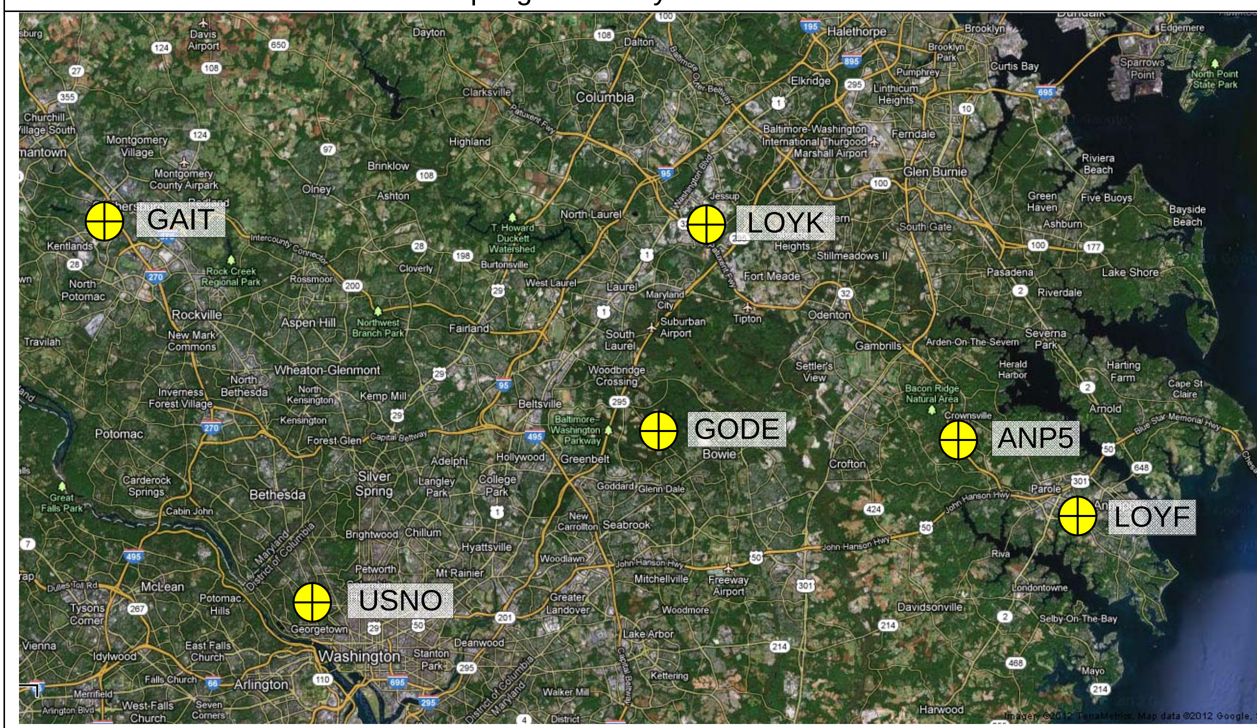
7.9.2 Regional Network

North GEOS Pier (PID: JV5895) is a Federal Base Network Control Station of the National Geodetic Survey.

GODE, mounted on a pier monument, is a CORS station and an IGS reference frame station, DOMES number 40451M123, PID AF9646.

Nearby Offsite DOMES Markers		
DOMES No.	Description	Code
40451M126	Centering Device on roof of Time Service department building	GUSN
40451S003	Roof of USNO Bldg 52/AOAD/M_T(SN#309)/ARP 24-APR-1997	USNO
40451S004	Roof of USNO Bldg 78/3S-02TSADM(SN#12)/ARP 1998-1999	USNX
40451S005	NIMA GPS antenna ASH700936B_M112/ARP	WDC1
40451S006	Roof of USNO Bldg 78/3S-02-TSADM(SN#12)/ARP 21-DEC-2000	USN1
40451S007	USNO Time Service department building roof AOAD/M_T ARP	USN3
40451S008	GPS antenna ASH700936B_M1122/ARP, Roof of USNO building	WDC4
40451S301	USNO-Ashtech Choke ring antenna reference point	NRL1

Sampling of Nearby CORS Stations



Source: http://www.ngs.noaa.gov/CORS/GoogleMap/CORS.shtml

7.10 Site Accessibility

Springfield Road in Prince George's county provides access to the site. Large cranes and other heavy equipment occasionally enter the site to position large components of various GSFC projects.

7.11 Local Infrastructure and Accommodations

The GGAO site is located adjacent to the farm lands of the Beltsville Agricultural Research Center property in Prince George's county, Maryland. Nearby accommodations are in Greenbelt, Laurel, and Bowie, although many of the workers live farther away. For passenger traffic, GGAO is not far from the Baltimore Washington Parkway (trucks are not allowed on the parkway). Typical drive times vary widely from 10-15 minutes from the nearest locations, such as GSFC, on up to 30-45 minutes and beyond from more distant locations depending on the time of day and route selected.

7.12 Electrical Power

GGAO receives its electrical power from the power grid that serves the Baltimore-Washington corridor.

Source of Power - Pepco delivers power to the GGAO site.

Available capacity – Dependent on the supplier to make upgrades to its equipment to support future requirements to meet power needs.

Reliability – There have been power dropouts during periods of exceptionally bad weather such as snow/ice or very high winds, but these are generally short enough to be handled by UPS's. Backup generators can be utilized on site.

7.13 Technical and Personnel Support

GGAO is part of nearby Goddard Space Flight Center with its engineers, technicians, operators, and scientists, many of whom have pioneered the various geodetic techniques.

The level of support suggested by the *Site Requirements for GGOS Core Sites* document is that the site will require a senior technician, eight shift technicians (2 per shift), a logistics and administrative officer, and a custodian.

7.14 Site Security

Site security is managed by the Goddard Space Flight Center (GSFC). A chain link fence with barbed wire at the top surrounds the site. The site has a gate that can open with a badge obtained from GSFC. There is a camera at the gate that can be monitored by GSFC security. There is an additional access point to the GGAO that is locked but can be opened with the support of the GGAO Facility Operations Manager or NASA Security.

Entrance to the GGAO Site

7.15 Site Safety

GGAO, as part of GSFC, a major NASA center, is covered by many NASA safety regulations and practices to prevent injury or fire, and to ensure proper handling and storage of potentially hazardous materials. Procedures are in place to handle emergencies should they occur.

7.16 Local Commitment

GSFC/GGAO is the primary location where various geodetic techniques have been developed, implemented, tested, and continuously operated for close to half a century.

8.0 Concluding Remarks

The long history of technical development, acquisition of geodetic data, and GGAO being part of GSFC with its scientific and engineering talent, make GGAO a very desirable site for a GGOS Fundamental Station. Laser tracking systems at GGAO have been tracking satellites since the 1960's. Satellite laser ranging data has accumulated since the 1970's. VLBI joined SLR at GGAO in 1991 providing a geodetic tie between the two techniques. GNSS and DORIS were added at the site in 1994 and 2000. The site is currently an important site in the networks of each of the techniques.

9.0 Work to be completed

Additional work that needs to be completed for this assessment, include the following:

1. Completion of an RFI Study for broadband.
2. Local hydrology (well levels, aquifer characteristics) and relationship to apparent vertical site stability.
3. Inclusion of a local and regional tie maps.
4. Improved cloud coverage data from the NGSLR All Sky Camera.

10.0 References

Cleaves, E T, Edwards, Jonathan, Jr. and Glaser, J D, Geologic Map of Maryland, Maryland Geological Survey, 1968

Floyd, Michael; King, Robert; Reilinger, Robert; 2012, GGOS Site Stability Investigation

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Appendix A: GGOS Site Stability Investigation From MIT

DRAFT

GGOS Site Stability Investigation (GSFC)

Prepared by: Michael Floyd, Robert King, and Robert Reilinger, DEAPS, MIT (mfloyd@mit.du, rwk@chandler.mit.edu, reilinge@erl.mit.edu)

28 June 2012

Introduction:
Our principal objective is to investigate the level of stability for potential GGOS sites. GGOS requires site stability of 1 mm in 3-dimensions and long-term stability at the 0.1 mm/yr level. Determining whether specific sites meet GGOS stability requirements will require the most precise techniques available to monitor surface motion and very accurate estimates of short period motions due to tidal, loading, and local hydrologic effects as well as modeling systematic errors that can be difficult to distinguish from surface motions. Strain and tiltmeters (in boreholes or caves) and repeated precise leveling are the most precise ground deformation observation techniques on local scales. Leveling provides information only on vertical motions, is time consuming and is primarily useful for relatively local investigations. It also suffers from systematic errors in areas of high relief that need to be modeled. Strain and tilt meters are susceptible to very local conditions and are primarily useful for detecting short period “events” – determining actual ground deformation from strain measurements is non unique and non trivial. InSAR is not sufficiently precise to determine motions at this level of precision.

GPS offers the opportunity to investigate stability on local, regional, and global scales. GPS has demonstrated measurement precision as good as 0.2 mm horizontal and 1 mm vertical on short baselines and 0.5 mm horizontal and 1.5 mm vertical, and long-term stability at the level of 0.2 mm/yr horizontal and 0.5-1.0 mm/yr vertical on a global scale, in principal close to the precision needed to evaluate site stability at the level required by GGOS. To meet this level of precision requires accurate modeling of a range of factors that influence positioning estimates, including tectonic and magmatic deformation and other real surface movements over short time scales (e.g., tidal loading, hydrology) as well as apparent movements due to measurement errors (e.g., multipath changes, water vapor, monument stability).

Our initial investigation focuses on analysis of the GPS time series.

GPS time series analysis:
We did noise analysis for 2 GPS stations operating at GSFC (GODZ, GODE). The attached Figures 1A and B show de-trended time series from the MIT global analysis. Both stations have sufficient data to provide useful results. 1-sigma uncertainties on velocity for both stations (an upper bound on long term stability) are of the order 0.1 mm/yr in horizontal and about 0.4 mm/yr in the vertical. Daily scatter in position (RMS and WRMS) is on the order of 1-2 mm in horizontal and 5-7 mm in the vertical. The

magnitudes of the annual and semi-annual terms are annotated on the figures and are in the range of 0.4 – 0.5 mm in horizontal and 1 - 4 mm in vertical.

These variations reflect un-modeled atmospheric, site [multipath, water table changes, monument stability], tidal [solid, ocean loading], water table variations, instrument/antenna effects, and reference frame instability as well as any possible tectonic motions. Much more detailed analysis of the GPS time series and other relevant data is necessary to estimate the contribution of these different factors before it will be possible to provide more definitive bounds on site stability.

Tectonics/Geology:
GSFC is located on the western edge of the Atlantic Coastal Plain Province about 10 km N or Washington DC. This region has been inactive tectonically since the opening of the N Atlantic in the Mid-Jurassic Period (~160 Ma). Although small to moderate earthquakes occur infrequently along the Coastal Plain, we are not aware of any indications of active faulting near the Facility.

Atmospheric:
The Greenbelt Maryland region receives an average of ~ 112 cm of rain per year, typical for the central US east coast.

Local hydrology: Groundwater levels are monitored throughout Maryland by the USGS. Yearly variations in water levels in the Patuxent Formation Aquifer at an observation well near Greenbelt MD indicate no long-term decline, but fluctuate by ~ 2.5 m on a quasi-annual basis (http://nwis.waterdata.usgs.gov/md/nwis/gwlevels/?site_no=390151076561501). Further study of the aquifer and water utilization is needed to assure water level changes near GSFC do not affect surface motions.

Conclusions/Recommendation for GSFC GGOS site:

GSFC is tectonically stable. The long-term velocity uncertainty of 0.1 mm/yr in horizontal meets first order GGOS standards. The higher vertical rate (0.4 mm/yr) likely reflects measurement errors rather than ground motion. Position scatter is also small, around 1-2 mm in horizontal and 6 mm for the vertical. Again, the higher vertical noise is likely due to measurement error. Any surface deformation that may affect the site will be due to cultural activities, possibly natural changes in soil moisture and groundwater levels, and un-modeled ocean loading. Postglacial isostatic adjustment also contributes to vertical motions at the GSFC location with modeled changes estimated in the range of 1-2 mm/yr (Davis et al., 2008). These long period isostatic motions will need to be carefully monitored. Surface soils and sediments that may be subject to compaction will have to be considered when designing instrument monumentation.

To Do:
Local hydrology (well levels, aquifer characteristics) and relationship to apparent vertical site stability. Network analysis of multiple stations (i.e., differencing station positions may help separate site stability from instrumental/wave propagation effects).

References:

Davis, J.E., K. Latychev, J. Mitrovica, R. Kendall, M.E. Tamisiea, Glacial isostatic adjustment in 3-D earth models: Implications for the analysis of tide gauge records along the U.S. east coast, *J. of Geodynamics, 46*, 90-94, 2008.

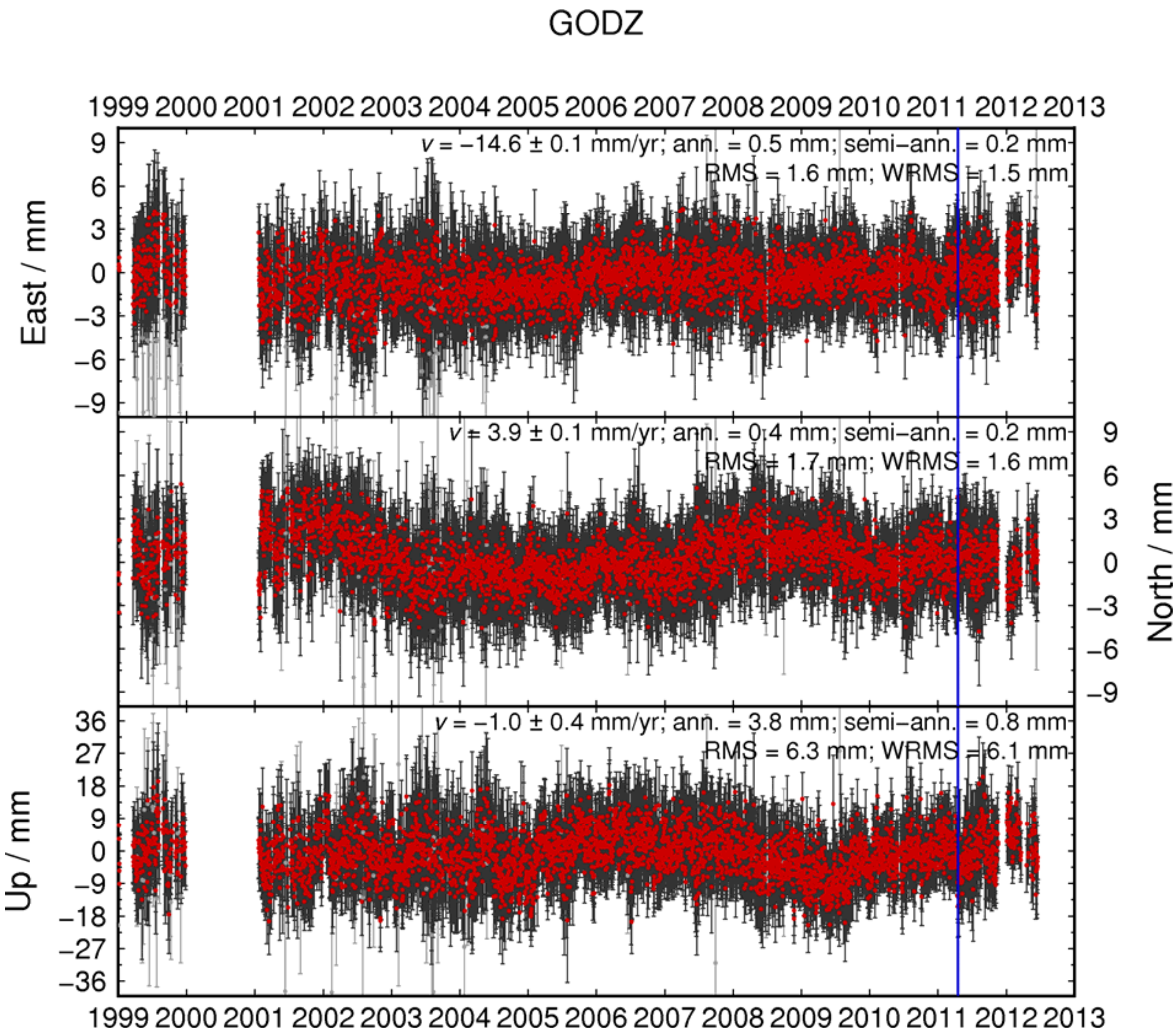

Figure 1 A. GODZ GPS time series and statistics.

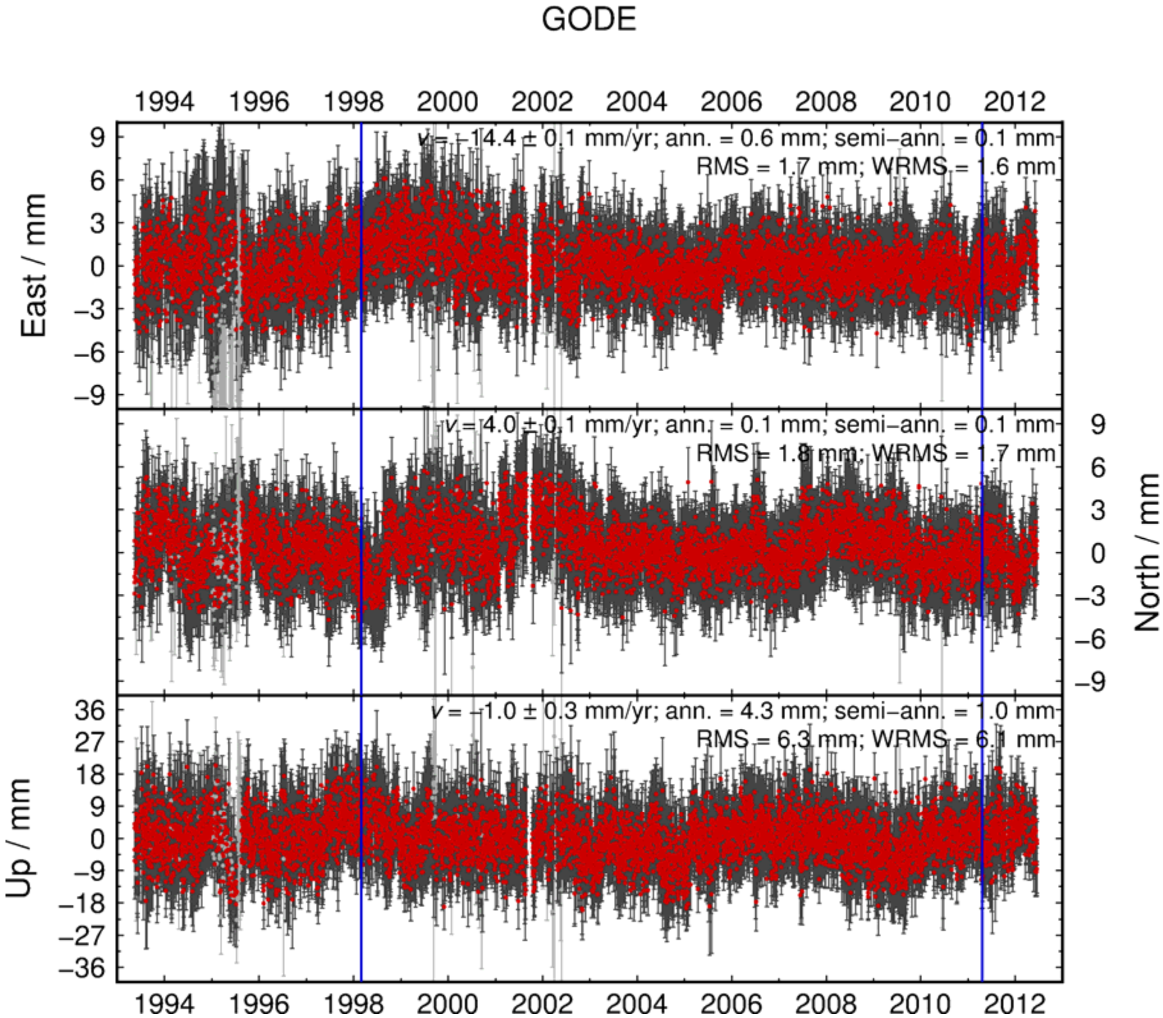

Figure 1B. GODE GPS time series and statistics.

Appendix B: List of Acronyms

DRAFT

AEOS	Advanced Electro-Optical System
ANSS	Advanced National Seismic System
ATST	Advanced Technology Solar Telescope
CORS	Continuously Operating Reference Station
DOMES	Directory of MERIT Sites
DORIS	Doppler Orbitography and Radiopositioning Integrated by Satellite
FAA	Federal Aviation Administration
GGAO	Goddard Geophysical and Astronomical Observatory
GGOS	Global Geodetic Observing System
GNSS	Global Navigation Satellite System
GPS	Global Positioning Satellite
HTSI	Honeywell Technology Solutions Inc.
IAG	International ………………
IDS	International DORIS Service
IfA	Institute for Astronomy
IGS	International GNSS Service
ILRS	International Laser Ranging Service
IVS	International VLBI Service
KPGO	Kokee Park Geodetic Observatory
LAGEOS	Laser Geodynamic Satellite
LCO	Las Cumbres Observatory
LCOGTN	Las Cumbres Observatory Global Telescope Network
LLR	Lunar Laser Ranging
MECO	Maui Electric Company
MIT	Massachusetts Institute of Technology
MOBLAS	MOBile Laser System
MSSS	Maui Space Surveillance Site
NASA	National Aeronautics and Space Administration
SGP	Space Geodesy Project
SLR	Satellite Laser Ranging
TLRS-4	Transportable Laser Ranging System – 4
UoH	University of Hawaii
VLBI	Very Long Baseline Interferometry