Developing and Deploying NASA's Space Geodesy Satellite Laser Ranging (SGSLR) Systems (Abstract 3018)

Jan McGarry[1] (Jan.McGarry@nasa.gov), Stephen Merkowitz[1], Mark Shappirio[1], Shawn Butani[2], Jack Cheek[3], Bart Clarke[4], John Degnan[3], Bud Donovan[4], Felipe Hall[4], Julie Horvath[4], Doug Lamb[2], Tony Mann[4], Joe Marzouk[3], Alice Nelson[4], Don Patterson[4], Randy Ricklefs[5], Mark Torrence[6], Tom Varghese[5], Scott Wetzel[4], Justine Woo[2], Tom Zagwodzki[5]

[1]NASA Goddard Space Flight Center, Greenbelt, Maryland 20771
[2]Exelis Incorporated, McLean, Virginia, 22102
[3]Sigma Space Corporation, Lanham, Maryland 20706
[4]Honeywell Technology Solutions Incorporated, Columbia, Maryland 21046
[5]Cybioms Corporation, Rockville, MD 20850
[6]Stinger Ghaffarian Technologies, Greenbelt, Maryland, 20770

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Abstract

NASA will be building up to ten new operational Satellite Laser Ranging systems in the coming decade to be co-located with Very Long Baseline Interferometry (VLBI) antennas and Global Navigational Satellite System (GNSS) stations. The first two of these new SLR systems will be deployed to McDonald Observatory in Texas and Mount Haleakala in Hawaii. These Space Geodesy Satellite Laser Ranging (SGSLR) systems will be based upon the Next Generation Satellite Laser Ranging (NGSLR) design with modifications from the lessons learned during the NGSLR development, testing, and operations. An overview of the design changes will be presented in this paper, along with the expected performance and deployment strategy.

Background

NASA's Space Geodesy Project (SGP) is responsible for coordinating the collection of NASA's space geodetic science measurements which are used in the generation of the International Terrestrial Reference Frame (ITRF). An increasingly accurate ITRF will be needed to meet future mission science requirements [1]. To improve the accuracy of the ITRF while reducing the cost of operating the current Network of stations, SGP is implementing a Next Generation Network of up to ten globally distributed sites with co-located Satellite Laser Ranging (SLR), Very Long Baseline Interferometry (VLBI), and Global Navigational Satellite System (GNSS) stations.

The Space Geodesy Satellite Laser Ranging (SGSLR) systems are based upon the NGSLR prototype system [2]. NGSLR's performance was verified through simultaneous ranging with the NASA legacy SLR system MOBLAS-7 in the summer of 2013 [3]. NGSLR demonstrated close to 1 mm precision on LAGEOS normal points, 1 mm stability over an hour, and successful day and night ranging to satellites from 300 km to 22,000 km. Analysis of the NGSLR ranges showed these matched MOBLAS-7's ranges to within a few millimeters of theory. Over a year period NGSLR's long term range stability was determined to be about 1.7 mm.

Figure 1: NGSLR prototype system at Goddard's Geophysical and Astronomical Observatory

SGSLR overview

The Next Generation SGP Network has new data measurement requirements that push the state of the art in many ways. For SLR, this means millimeter or better precision for normal points, millimeter or better stability over an hour, and better than two millimeters over the long term (one year). SLR systems must be able to operate continuously (24 x 7) day or night and track satellites from below 300 km to geosynchronous altitudes. The amount of ranging data from each station is important, and data volume requirements similar to those of the current best stations in the ILRS Network have been placed on the SGSLR systems. Since the cost of operating the systems must also be reduced, remote operation, and eventually full automation, is a further requirement. Reliability and ease of system maintenance is critical, therefore the SGSLR systems are being designed to allow for remote diagnostic capability and modular component replacement, with parts being selected to support long lifetimes.

Lessons learned from NGSLR are being incorporated into the SGSLR design and parts of the design are being simplified since SGSLR is not required to be eye safe as was required for the original version of NGSLR. Included in the changes are (1) use a standard on-axis Cassegrain telescope (rather than the off-axis optical system used on NGSLR), (2) purchase the telescope and gimbal from the same manufacturer and let the single vendor be responsible for meeting all gimbal/telescope requirements, (3) simplify the design where possible, and (4) modify the optical configuration to improve in field system troubleshooting, operational performance and minimize the stray light backscatter. To support the determination of the system origin (invariant point of the gimbal az/el axes) at the millimeter level, as well as to ensure good system performance over the entire operational range of the system, we will use a Finite Element Model (FEM) and analysis of the gimbal/telescope assembly, as well as an improved set of in-situ measurements.

SGSLR will be deployed to places around the globe where the weather conditions can be harsh. The system must be able to operate in temperatures from roughly -30°C to +45°C, in humidities from 10 % to 100%, over a wide variation in barometric pressures, and with winds up to 40 mph or greater. In addition, the system will need to survive snow, ice, blowing dust and very high winds. Since most of the electronics will be in the shelter, the ability to operate over this wide range of conditions falls on the GTA and the dome, making both of these subsystems extremely critical to SGSLR's success. Survival will be the responsibility of the shelter, the dome, and the backup power system. We are working toward a single system design to handle all potential environments.

SGSLR will use much of the software developed for NGSLR with additional functionality added in areas such as closed loop tracking and system self-awareness [4]. The optical bench design was simplified with the goal of reducing backscatter, making alignment easier, and ensuring that the system is very stable. The receiver subsystem is being redesigned to build in closed loop tracking capability while ensuring the system meets the high precision and stability requirements. We are also looking at alternate methods of aircraft avoidance to replace the current SLR radar in order to avoid potential electromagnetic interference with VLBI, and to accommodate future sites (e.g. Haleakala) where radars are not permitted. Finally, while we believe the NGSLR type roll-back shutter slit-type dome will work well for most sites, we are also investigating a closed dome for some of the sites with the harshest environments.

NASA's new SGSLR sites

The first two SGSLR sites will be at (1) McDonald Observatory in Texas (near the current MLRS site) and (2) Haleakala in Hawaii (not far from the current TLRS-4 site). The SGSLR site will be similar in layout to that of NGSLR and will include weather instrumentation, GPS receivers, security cameras, aircraft avoidance instrumentation, and ground calibration piers. Where possible, there will be three ground calibration piers located approximately 120 degrees apart from each other as viewed by SGSLR. Ground calibrations taken at different azimuth angles provide insight into any angular dependence of the system delay.

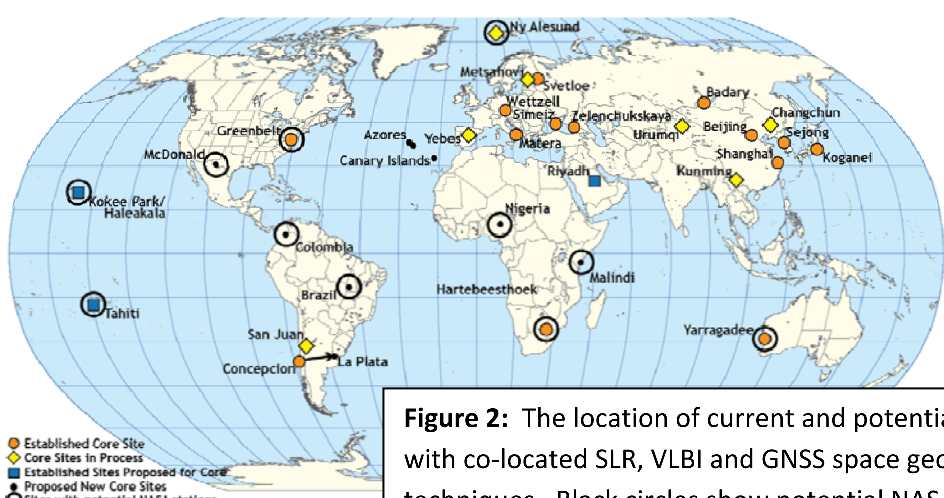


Figure 2: The location of current and potential future sites with co-located SLR, VLBI and GNSS space geodetic techniques. Black circles show potential NASA stations.

At McDonald Observatory, the VLBI system will be located approximately 800 meters from the SGSLR system. GNSS receivers at both technique locations will help tie the systems together along with one or more Robotic Total Stations (RTS). The RTS unit provides an accurate vector tie between the origins of the two stations through the use of automated survey techniques. An aircraft avoidance radar, similar to what is being used at NGSLR, is planned for this site.

At Hawaii, the VLBI system will be located on the island of Kauai, approximately 400 km away from SGSLR on its sister island, Maui. Multiple GNSS receivers at both sites will provide the ties between the VLBI and the SGSLR systems.

We are in discussions with the Norwegian Mapping Authority to place the third SGSLR at Ny Alesund. Future systems will replace existing NASA SLR stations and occupy new sites in South America.

We expect the first two SGSLR stations to be operational in 2018, with additional stations becoming operational at about one per year, subject to funding availability.

SGSLR design details

SGSLR is comprised of ten major subsystems: (1) Telescope, (2) Gimbal, (3) Optical bench, (4) Range Receiver, (5) Laser, (6) Laser Safety, (7) Time and frequency, (8) Meteorological, (9) Shelter and dome, and (10) Computer and Software.

The gimbal and telescope subsystems point the laser at the targets and collect the receive light. These two subsystems together are called the Gimbal/Telescope Assembly (GTA). The GTA is the backbone of an SLR system and must provide accurate pointing and tracking for satellites from LEO to GEO over a long lifetime (30+ years). The accuracy of the GTA pointing and tracking directly affects SGSLR's ability to fulfill its data volume requirements. Procurement of the GTA is underway for SGSLR systems 1 and 2.

The optical bench interfaces the laser and detector to the GTA. The optical bench is located in the environmentally controlled shelter and provides the ability to change the laser divergence, change the receiver field of view, change the ND filters, and change the configuration between satellite tracking, ground calibration, and star calibration. This is all automated, with control and monitoring from the software.

The range receiver records the time of both transmit and receive events. A range gate provides temporal filtering on the receive light and a variable iris changes the receiver field of view and provides spatial filtering. In addition, a three Angstrom daylight filter can be moved into and out of the path by the software. Two Neutral Density (ND) filter wheels, each with the capability of continuous 0 to 2 NDs, can be used to provide up to 4 NDs of attenuation for the incoming laser light from the external ground calibration pier(s). For SGSLR, we are also looking into the possibility of performing internal ground calibrations.

The laser currently used at NGSLR is a Photonics Industries RGL-532-2.5 with 2 kHz repetition rate, a 50 ps pulsewidth, and the ability to transmit up to approximately 2.5 mJ per pulse at 532nm. At the moment, we have not found a laser that we believe is better, but we continue to survey the market for new products.

The SGSLR laser safety system is an extension of the system designed for NGSLR. It consists of two parts. The first is the aircraft avoidance sensor. For NGSLR and the legacy NASA systems, this is a Honeywell Laser Hazard Reduction System (LHRS), a 9.4 GHz radar which has the capability of detecting 20 sq-meter targets out to 40 km. The propagated beam is 3 degrees in diameter and is centered about the laser beam. When an aircraft is sensed, a signal is sent to the back end electronics. The back end, or second part of the laser safety system, consists of an electronics chassis which interfaces with beam blocks and ND filters on the optical bench. An aircraft detect will cause the laser safety system to bring the blocks into place to prevent the laser beam from leaving the system. The software is interfaced to the laser safety electronics and is aware of everything that is happening and can shut off the laser. We are currently investigating the possibility of replacing the front end of the laser safety system with a transponder based aircraft detection sensor [5] or a radar with a 17 GHz frequency.

The station timekeeping is currently planned to be a Microsemi XLi GPS steered rubidium oscillator that has a stated accuracy of 30 ns to UTC. Its 10 MHz frequency is planned to be used for the external frequency to the timing electronics. At sites where the VLBI system is close to SGSLR, the VLBI maser's 10 MHz may be used, as it provides a smooth frequency without the jumps due to the GPS steering.

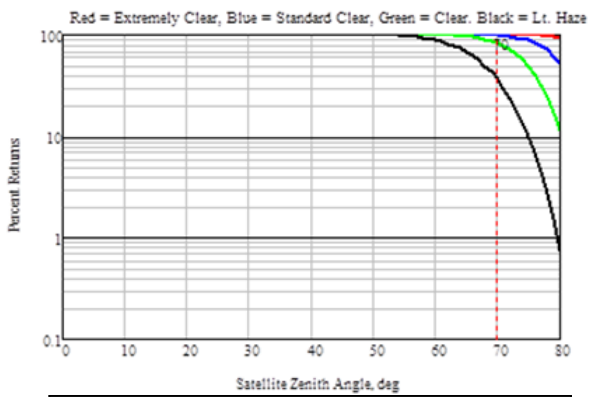
A Paroscientific temperature, pressure and humidity monitor will be used at SGSLR as it was at NGSLR. The station will also have a Vaisala precipitation and horizontal visibility monitor. A wind sensor like the Belfort/Young model used at NGSLR will also be used for SGSLR. A cloud monitor will be needed to determine where in the sky viable tracking is possible. It is unclear at this time whether or not we will continue the in-house built model of the All Sky Camera and we are looking for a viable commercial alternative.

The shelter will be similar to what was used at NGSLR but will be larger and will have a separate clean-room for the optical bench supporting the laser and detector. A separate room for the electronics will allow for control of dust and dirt and provide a more tightly controlled temperature. The dome design is still under investigation.

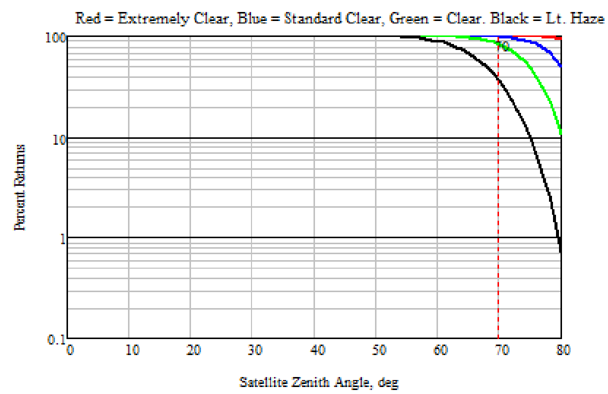
Most of the NGSLR software will be used in SGSLR. Changes will be made based upon lessons learned from NGSLR operations and new requirements. Software changes are needed to implement automation, interface with new hardware, run with the new OS (real-time Linux instead of LynxOS), improve robustness, and increase communication with the SGP central facility.

SGSLR expected performance

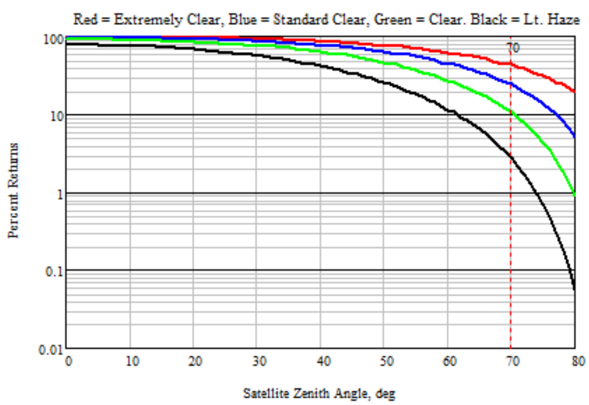
Link analysis [6] for the current design of the SGSLR system shows a robust return rate with close to 100% expected returns from LEOs to LAGEOS for all elevations above 20 degrees except in the worst atmospheric conditions, and > 10% for GNSS above 20 degrees elevation except in the worst atmospheric conditions. Geosynchronous return rates are also strong.



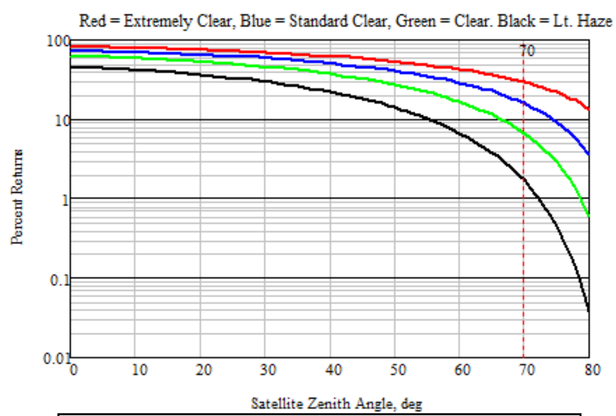
STARLETTE return rate from link analysis



LAGEOS return rate from link analysis



GNSS return rate from link analysis



GEOSYNC return rate from link analysis

Figure 3: Link analysis based upon SGSLR design shows high return rates for all satellites. System characteristics used: laser divergence = 7 arcseconds for LAGEOS, GNSS and GEO, and 12 arcseconds for STARLETTE; per pulse transmit energy = 1.5 mJ; telescope aperture = 0.5 m. No pointing error. Curve colors represent atmospheric clarity: RED is extremely clear; BLUE is standard clear; GREEN is clear; BLACK is light haze.

The data quality of SGSLR is expected to be as good or better than that of NGSLR. Normal point precision of 1 mm or better on LAGEOS should be attained in much less than the ILRS prescribed 2 minutes for most atmospheric conditions, and for STARLETTE 1 mm precision normal points should be achieved in less than the allocated 30 seconds. The long term stability is expected to be better than that of NGSLR which was 1.7 mm over one year. In addition, the data volume for SGSLR, assuming that we track down to 10 degrees elevation, has been estimated at an annual rate of 200,000 LEO normal points, 18,500 LAGEOS normal points, and 26,000 GNSS normal points. These estimates were made assuming no interleaving for any of the satellite passes, a 14% weather outage (such as seen at Yarragadee) and a 15% outage due to problems and other non-weather issues. This is approximately the number of normal points collected annually from MOBLAS-5 in Yarragadee.

Concept of Operations

SGSLR will be capable of both remote operation and eventually autonomous operation [7]. Full automation is expected to be completely implemented after the third system has been in place for one year. Because of the automation goal, there is a great need for communication between the systems and the central SGP facility currently called the Integrated Geodetic Science Operations Center (IGSOC). The Normal Point data and system status will flow to the IGSOC and will be monitored, archived, and forwarded to the appropriate locations. The science data will be handled in the same way as current NASA stations, with the data finally going to the ILRS Data Center, CDDIS and EDC, for archiving [8]. The status information from the sites will be monitored for alerts and alarms, with emails and text messages going out as appropriate for human intervention. Monitoring of the data from anywhere in the world will be available so that engineers can review the stations' current status from their homes. Analysis and trending software will also be available to engineers, analysts and managers via the internet. In addition, remote diagnostic capability will be designed into the systems and will become an important engineering tool to allow for quick problem diagnosis. An onsite technician will be available to perform routine maintenance, limited trouble-shooting and parts replacement, but the engineering expertise will reside at Goddard. It is anticipated that much of the problem diagnosis will happen remotely by the engineering experts. Travel by the Goddard engineers to the sites will occur only when a problem can't be diagnosed remotely or by the onsite technician, or when problem resolution can't be handled by the onsite technician.

Coexisting with VLBI

The broadband frequency range used by the new VGOS (VLBI2010) systems includes the 9.4 GHz frequency used by the current NASA radars. While the NASA SLR radar was in use prior to the design and development of VLBI2010, it is now the responsibility of both SLR and VLBI to ensure that the radar does not damage the VLBI detector. The current method, successfully in use at the Goddard Geophysical and Astronomical Observatory since

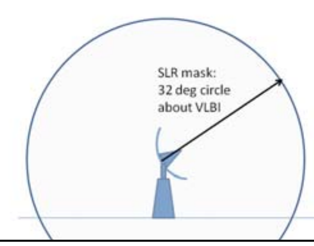


Figure 4: SLR pointing exclusion mask to prevent damage to VLBI from SLR radar.

late 2011, is to employ pointing masks at both the VLBI and the SLR stations. These masks ensure that the radar does not point within 64 degrees of the VLBI detector. Half of the pointing mask is at the VLBI end and the other half at the NGSLR end. From NGSLR the mask is a 32 degree radius circle in the North with the VLBI2010 system located at the center (as shown in figure 4). Similarly for VLBI the mask is a 32 degree circle to the South with NGSLR at the center. The problem with this solution is that it removes a significant fraction of the sky from SLR tracking and from VLBI observations. We have started discussions between the two techniques to develop a real-time communication scheme that will allow both systems to know where the other is pointing. With lots of redundancy in place and careful design of this real-time point-to-point communication, we hope to be able to remove the masks and allow tracking and observations in the areas that are currently masked off.

Summary

NASA will build and deploy a network of up to ten SGSLR systems in the coming decade. The SGSLR design will be based upon the prototype NGSLR system with upgrades to the design based upon new requirements and lessons learned. These new systems will have state of the art performance, designed to provide the accuracies needed for the ITRF to support future NASA missions. These systems will also be fully automated in the coming years, achieving both NASA's required performance and the needed reduction in operating costs.

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