NASA's Next Generation Space Geodesy Network

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Abstract

NASA's Space Geodesy Program supports the geodetic needs of current and future Earth Observations by maintaining and operating a global network of Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging (SLR), and Global Navigation Satellite Systems (GNSS) ground stations. Much of the current geodetic infrastructure is decades old and is not capable of meeting future requirements. In particular, measurement of changes in the mean sea level will require a Terrestrial Reference Frame with an accuracy of 1 millimeter and stability of 0.1 millimeters per year, a factor of 10-20 beyond current capabilities. To meet this future need, NASA is implementing plans to deploy a "Next Generation Space Geodesy Network" that will replace the legacy NASA VLBI and SLR networks with up to ten globally distributed sites with collocated VLBI, SLR, GNSS, and Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) stations. NASA recently completed the first phase of this deployment with the demonstration of the prototype core site at NASA's Geophysical and Astronomical Observatory at Goddard Space Flight Center. The second phase is now underway with the development of new multi-technique sites in Texas and Hawaii. NASA is also working with its international partners to develop the plans for implementing additional new international next-generation geodetic sites as part of the new NASA geodetic network and the Global Geodetic Observing System (GGOS).

Introduction

The global geodetic infrastructure is comprised of several networks and individual Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging (SLR), Global Navigation Satellite Systems (GNSS), and Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) ground stations. The data produced by these networks is used for a variety of applications ranging from the definition of the International Terrestrial Reference Frame (ITRF), to satellite precision orbit determination, to sea level change monitoring. However, many of the geodetic stations are decades old and are not capable of meeting future requirements. The US National Research Council (NRC) Committee on Earth Science and Applications from Space warned in 2007 that: "The geodetic infrastructure needed to enhance or even to maintain the terrestrial reference frame is in danger of collapse" [1]. NASA and many other international government agencies are responding to this warning by making new investments to modernize and expand their geodetic infrastructure.

NASA's Space Geodesy Project (SGP) is implementing NASA's response to the NRC warning by sustaining and operating NASA's legacy Space Geodesy Networks while executing the construction, deployment, and operation of the next generation Space Geodesy stations that will be part of a new NASA Space Geodesy Network (NSGN). NASA's deployment strategy is guided by the recommendations of the NRC Committee on the National Requirements for Precision Geodetic Infrastructure [2], as well as the plans of other nations for contributing to the Global Geodetic Observing System (GGOS). NASA is currently planning the construction of up to ten new or upgraded geodetic sites that are chosen to fill in the gaps of the global network. One of the main objectives of the SGP is to produce the necessary observations for realization of the Terrestrial Reference Frame that has an accuracy of 1 mm (decadal scale) with stability at 0.1 mm/year (annual scale). This is an ambitious goal, as it represents a factor of 10-20 beyond the current capability.

To achieve the desired level of accuracy and stability, the NASA sites will collocate and use in unison several key techniques of observation, including: VLBI, SLR, GNSS, and DORIS. Other complementary instruments, such as gravimeters, may also be collocated at the sites (absolute gravimeters allow the independent detection of vertical point displacements or mass variations, caused by tectonically induced movements of the Earth's crust, post-glacial uplifts, or changes in sea level [3]). The measurements derived from the various techniques at each site must be combined to produce the ITRF. To improve this combination, each NASA site will include a Vector Tie System (VTS) that monitors the local-ties (relative positions) between the different geodetic stations. The design of NASA's next generation stations and sites is based on the prototype core site located at NASA's Geophysical and Astronomical Observatory (GGAO) at the Goddard Space Flight Center (GSFC) in Greenbelt, Maryland.

Project Implementation Approach

The mission of the SGP is to implement a flexible and extensible space geodesy ground network to maintain a high-level of service in the future, accommodate new users and capability requirements, and reduce the effort required to operate and maintain the network. The key Project lifecycle activities include: legacy network operations, next generation prototype design and development, concept studies, design, acquisition, implementation through system level test, installation/integration and test at the sites (including phased transition to operations), final acceptance, and operations of the new NASA network. The SGP has completed the prototype development and other formulation activities, and is now beginning the implementation of the new network.

The SGP must accomplish this mission in close cooperation with international partners and without significant negative impact to operations of the existing global network. Accordingly, the key phases of the effort and the project timeline were developed with careful consideration for the ongoing global operations. The decision was made to design, develop and implement an architecture modernization from the ground up, rather than to incrementally upgrade the existing stations. This decision was informed largely by early Project activities as well as studies by the International GNSS Service (IGS), the International Laser Ranging Service (ILRS), the International VLBI Service for Geodesy and Astrometry (IVS), the International DORIS Service (IDS), and GGOS that considered the risks imposed on existing operations by alternative approaches to enhancing the existing legacy stations. The legacy NASA stations will be replaced and/or decommissioned as part of the NSGN modernization.

Taking into account the NRC recommendations, the results of extensive site assessments, and network simulations [4], the SGP decided that the first two NSGN sites should be located in Hawaii and the western continental Unites States. Kōke‘e Park, Hawaii was selected as a VLBI site as part of a partnership with the Unites States Naval Observatory (USNO). Haleakala Observatory is being considered as the Hawaiian site of the SLR station due to its history as a legacy SLR site and good viewing conditions.

An extensive trade study was performed to determine the best site within the western continental Unites States, with McDonald Observatory, TX selected as the primary site. The McDonald Observatory has a long history of lunar and satellite laser ranging, and is close to the VLBA site at the National Radio Astronomy Observatory in Fort Davis that has participated in VLBI campaigns.

Additional partner sites are also being considered and will be assessed as discussions with the international partners progress. Figure 1 shows the current and planned core geodetic sites as described in the responses to the GGOS Call for Participation. Also indicated, are the potential sites for NASA core stations where there are ongoing discussions with the associated international partner agency. The NASA deployment schedule to international partner sites after the completion of the Texas and Hawaii sites in 2018 is estimated to be about 1 new station/year, dependent on many factors, including: partnership arrangements, science impact, and available funding.

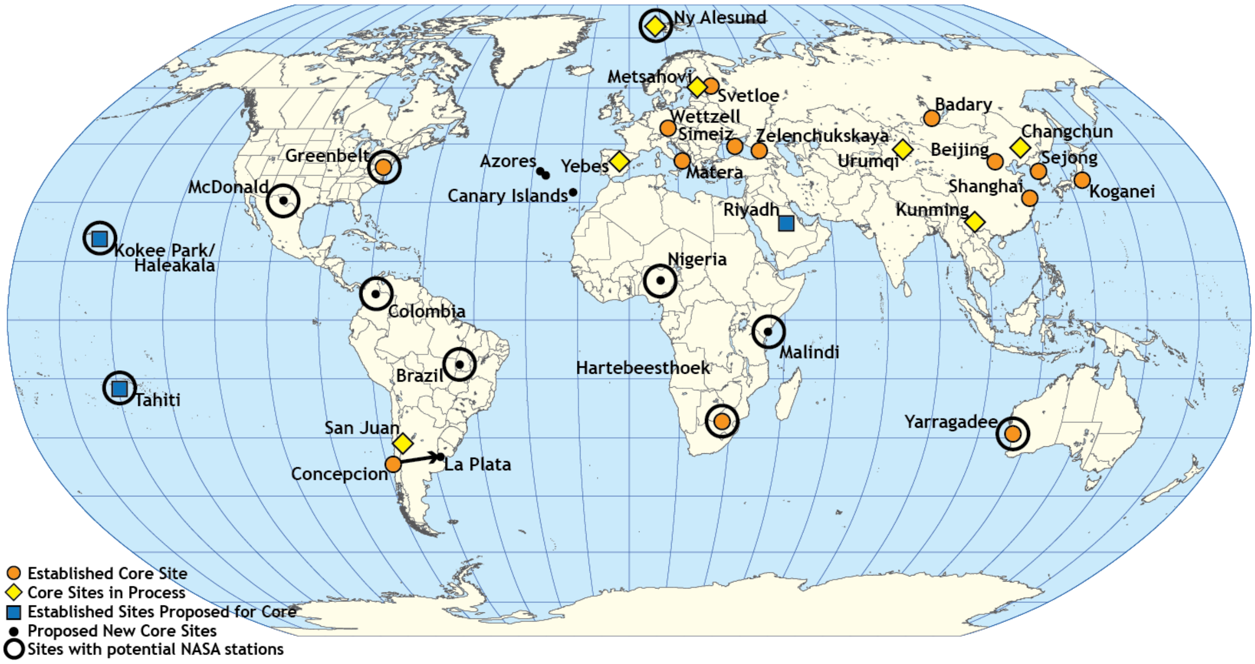

Figure 1: Current and proposed core geodetic sites. International sites marked as having potential NASA stations indicate ongoing partnership discussions with the associated international partner agency.

The GGAO Prototype Core Site

The Goddard Geophysical and Astronomical Observatory (GGAO) is located 5 km from NASA's Goddard Space Flight Center in Greenbelt, MD. GGAO is home to the operational MOBLAS-7 SLR station. Also located at this site is a DORIS antenna, three GNSS antennas with four GNSS receivers, prototype next generation VLBI and SLR stations, and a VTS for monitoring the local-ties between these stations.

The Next Generation SLR (NGSLR) system was originally built as a prototype for an eye-safe automated laser ranging system [5]. The development was originally focused more on saving operational costs than on data quality. Over time, the requirement to track daylight GNSS was added that required laser energies that no longer made the system eye-safe. Millimeter quality requirements were also added to the precision and stability of the system. Modifications to NGSLR for these new requirements were started in 2011 and the new system performance was demonstrated in 2013. Some of the key performance requirements that were demonstrated include: 1 mm normal point precision on LAGEOS, ground calibration stability at the 1mm level over hour, and daylight tracking of GNSS satellites. A month-long collocation campaign with MOBLAS-7 was completed in June 2013 [6].

Figure 2: NGSLR prototype system at GGAO.

A fast-pointing 12-meter VLBI antenna was also installed at GGAO and a broadband signal chain was developed and implemented to meet the VLBI2010 specifications [7, 8]. In May 2013, a 24-hour observing session was performed with the 18-meter Westford antenna at Haystack Observatory, Massachusetts (also outfitted with a broadband signal chain) to demonstrate its operational capabilities and performance. The analysis of this first major VLBI2010 geodetic session successfully produced millimeter-level baseline lengths between GGAO and Westford [9].

Figure 3: Broadband VLBI prototype antenna at GGAO.

The VTS is a combination of precise local-tie surveys and a periodic monitoring system using one or more Robotic Total Stations (RTS) and other instrumentation for measuring the site stability (tilt meters, etc.). The GGAO implementation demonstrated the ability to monitor the site semi-autonomously with sub-millimeter accuracy. This included the ability to find and identify the target prisms, verify the prism correction, and process distance measurements to correct for atmospheric conditions.

Figure 4: The Robotic Total Station at GGAO that is part of the site's Vector Tie System.

Two new GNSS stations, GODN and GODS (Goddard North and South), were also installed at GGAO and have been delivering data since January 2012. The stations are multi-constellation (i.e., they are compatible with GPS, GLONASS, and Galileo). A comparison of the GNSS measured GODN-GODS baseline length to the VTS measurements was found to be in agreement at the sub-millimeter level.

Figure 5: The South GNSS station (GODS) at GGAO.

The DORIS beacon at GGAO has been operating since June 2000 as part of the global DORIS network of ~57 stations. The beacon transmits at 2 GHz and 400 MHz, observable at satellites equipped with DORIS receivers.

Figure 6: The DORIS beacon at GGAO.

Significant efforts were also made at GGAO to mitigate the impact of Radio Frequency Interference (RFI) from the DORIS signal and the SLR radar on the broadband VLBI measurements through strategic placement of RF shielding/blocking material and pointing avoidance masks for the SLR radar and the VLBI antenna.

Texas and Hawaii Deployment

The first two deployed SGP sites will be in Texas and Hawaii. The Texas stations will be collocated at the McDonald Observatory near Fort Davis. This is the current operational site of the McDonald Laser Ranging System (MLRS) [10]. The site has a long history of lunar and satellite laser ranging [11] and is owned and operated by the University of Texas at Austin. The location is well suited for a VLBI antenna due to the low radio frequency interference environment and its proximity to the VLBA site at the National Radio Astronomy Observatory in Fort Davis.

Several possible sites for new VLBI, SLR, and GNSS stations are being considered within the McDonald Observatory. The leading candidate layout places the VLBI antenna in the valley area near the visitor center and the SLR station on Mount Fowlkes near the MLRS. At least two GNSS stations will be operated at each of these two locations. A RTS will also be strategically located at each of the two locations as part of the VTS that will “tie” the stations together. Planning for the stations deployments is underway with operations expected to begin by the end of 2018.

The Hawaii VLBI stations will be located at NASA’s Kōke‘e Park Geophysical Observatory (KPGO) on Kauai. This is the current operational site of the joint USNO-NASA 20-meter VLBI antenna. The site also hosts a DORIS beacon and several GNSS stations. The construction of a new broadband 12-meter VLBI station at KPGO is underway with operations expected to being in early 2016.

Unfortunately, KPGO has very cloudy skies making it a poor candidate for hosting a new SLR station. Therefore, the Haleakala Observatory on Maui was selected as the SGP Hawaii SLR site. Haleakala has a long history of SLR (and lunar laser ranging) and is the current operational site of NASA’s TLRS-4 SLR station. Several potential locations for the new SLR station are being considered along with additional multi-GNSS stations. Given the distance between KPGO and

Haleakala, it will not be possible to implement the VTS in the same manner as at GGAO and at the McDonald Observatory. The VTS will rely heavily on the use of the GNSS stations to tie the stations together into a “single” Hawaii core site. Operation of the new SLR station at Haleakala is expected to begin in early 2019.

Summary

With the recent completion of the prototype core geodetic site at GGAO, NASA is preparing to deploy a new network of operational next generation geodetic stations. The new NASA network is designed to produce the higher quality data required to support the establishment and maintenance of the Terrestrial Reference Frame, and provide information essential for fully realizing the measurement potential of the current and future generation of Earth Observing spacecraft. When fully implemented, this upgraded global network will benefit not only the ITRF, but all other network products (e.g., Earth Orientation Parameters, precision orbit determination, local and regional deformation, astrometry, etc.) that may be improved by at least an order of magnitude, with concomitant benefits to the supported and tracked missions, science projects, and engineering applications. The first NASA sites in Texas and Hawaii are planned to be operational before the end of the decade. NASA will then focus its attention on working with its international partners to expand the network to those regions of the globe that are lacking in adequate geographic coverage and will have the largest positive impact on the improvement of the ITRF.

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