The NASA Space Geodesy Network

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Abstract

The NASA Space Geodesy Network 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, measurements 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 in the process of building and deploying co-located next generation geodetic stations to new and existing sites around the globe. NASA completed the first phase of this deployment in 2013 with the demonstration of the prototype core site at NASA's Goddard Geophysical and Astronomical Observatory in Greenbelt, Maryland. At the beginning of 2016, NASA completed the implementation of a new broadband VLBI station in Hawaii. Development of a core site in Texas is also underway along with planning for new geodetic stations at other US and international sites. In this article, we discuss recent accomplishments on the network deployment along with the plans for future NASA sites. We also introduce NASA's plans for centralized and automated operations of the new NASA network.

Introduction

The global geodetic infrastructure is comprised of several networks and individual ground stations for: Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging (SLR), Global Navigation Satellite Systems (GNSS), and Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS). NASA's Space Geodesy Program contributes to the global infrastructure through the deployment, operation, and maintenance of two coordinated networks: the NASA Space Geodesy Network (NSGN) of collocated VLBI, SLR, GNSS, and DORIS stations, and the NASA Global GNSS Network. The data produced by these networks are used for a variety of products, including: the definition of the International Terrestrial Reference Frame (ITRF), measurement of the Earth Orientation Parameters, and satellite precision orbit determination. The data and products from these networks are also used to support a broad range of scientific and societal applications in areas such as Earth observations, positioning, navigation, and timing [1].

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" [2]. NASA and many other international government agencies are responding to this warning by making new investments to modernize and expand their geodetic infrastructure.

The Space Geodesy Program 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 NSGN. The Space Geodesy Project (SGP) deployment strategy is guided by the recommendations of the NRC Committee on the National Requirements for Precision Geodetic Infrastructure [1], as well as the plans of other nations for contributing to the Global Geodetic Observing System (GGOS). One of the main objectives of the SGP is to produce the necessary observations to realize a 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 an order of magnitude improvement over the current capability.

Taking into account the NRC recommendations, the results of extensive site assessments, and network simulations [3], the SGP decided that the first two NSGN sites should be located in Hawaii and the western continental United States. Kōke‘e Park, Hawaii was selected as a VLBI site as part of a partnership with the United States Naval Observatory (USNO). Haleakala Observatory was selected 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 United 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 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 progress with the international partners.

Station, Site, and Network Architecture

The new NSGN will be comprised of integrated, multi-technique next generation space geodetic observing systems, as the core contribution to a global network designed to produce the higher quality data required to maintain the Terrestrial Reference Frame and provide information essential for fully realizing the measurement potential of the current and coming generation of Earth Observing spacecraft. To achieve the desired level of accuracy and stability, the NSGN Sites will co-locate 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[1], but are not part of the baseline NSGN architecture. 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, ensuring available and timely site-tie updates (a key issue with the current system of spot surveys).

The functional design of NASA's next generation stations and sites is based on the prototype core site located at NASA's Goddard Geophysical and Astronomical Observatory (GGAO) at the Goddard Space Flight Center (GSFC) in Greenbelt, Maryland. A block diagram of a typical NSGN based on the GGAO site is shown in Figure 1.

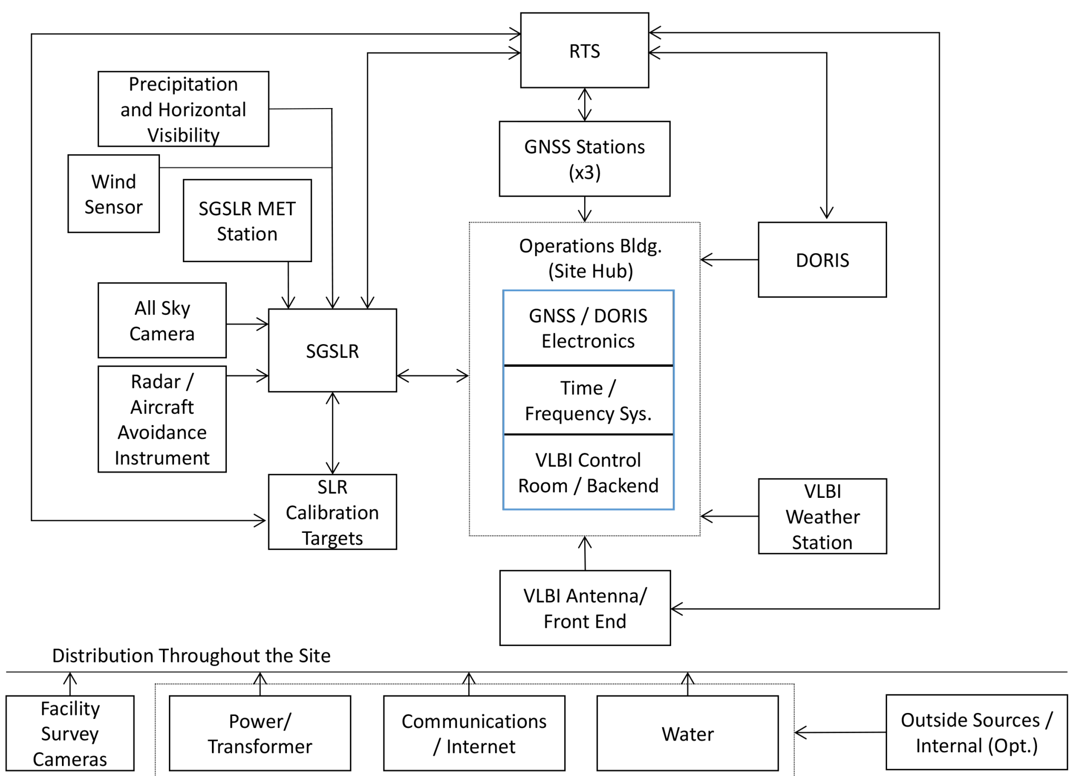

Figure 1: Typical NSGN Site Block Diagram

[1] 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.

The Next Generation SLR (NGSLR) prototype was originally built for eye-safe automated laser ranging [4]. The development was originally focused more on saving operational costs than on increasing 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 1 mm level over hour, and daylight tracking of GNSS satellites. A month-long collocation campaign with MOBLAS-7 was completed in June 2013 [5].

Figure 2: NGSLR prototype system at GGAO.

The Space Geodesy Satellite Laser Ranging (SGSLR) systems that will be deployed as part of the NSGN are based upon the NGSLR design with modifications for full automation and incorporation of lessons learned from the prototype development, testing, and operations. Significant changes from the NGSLR prototype are: (1) full automation, (2) use a standard on-axis Cassegrain telescope (rather than the off-axis optical system used on NGSLR), (3) purchase the telescope and gimbal from the same manufacturer and let the single vendor be responsible for meeting all gimbal/telescope requirements, (4) simplify the design where possible, and (5) modify the optical configuration to improve in-field system troubleshooting, operational performance, and minimize the stray light backscatter.

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 [6, 7]. In May 2013, a 24-hour observing session was performed with the 18-meter Westford antenna at the Haystack Observatory in Massachusetts (also outfitted with a broadband signal chain) to demonstrate its operational capabilities and performance. The analysis of this first two-way VLBI2010 Global Observing System (VGOS) geodetic session successfully produced millimeter-level baseline lengths between GGAO and Westford [8]. Future NSGN VGOS stations will be based on the GGAO architecture, with changes addressing lessons learned, technology obsolescence, and potential antenna manufacturer changes.

Figure 3: Prototype VGOS 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 (tilt meters, etc.) for measuring the site stability. 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. The VTS implementation at new sites will be tailored for the specific site layout.

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. New GNSS stations at NSGN sites will also be modern commercially available multi-constellation systems that meet the IGS standards.

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. The implementation of DORIS beacons at NASA sites will depend upon the requirements of the DORIS network and coordination with the French Centre National d'Études Spatiales (CNES) and National Institute of Geographic and Forest Information (IGN).

Figure 6: The DORIS beacon at GGAO.

The NSGN systems are being developed with a goal of greater than 10 years of operation. The modular designs enable ease of maintenance and technology upgrades. A virtual Network Operations Center (NOC), as shown in Figure 7, is under development to take advantage of the high level of automation of the new systems and provide for centralized network operation. An initial demonstration of centralized monitoring was performed using the GGAO systems in 2014.

Significant efforts were also made at GGAO to mitigate the impact of Radio Frequency Interference (RFI) on the broadband VLBI measurements from the DORIS signal and the SLR radar through strategic placement of RF shielding/blocking material and pointing avoidance masks for the SLR radar and the VLBI antenna [9].

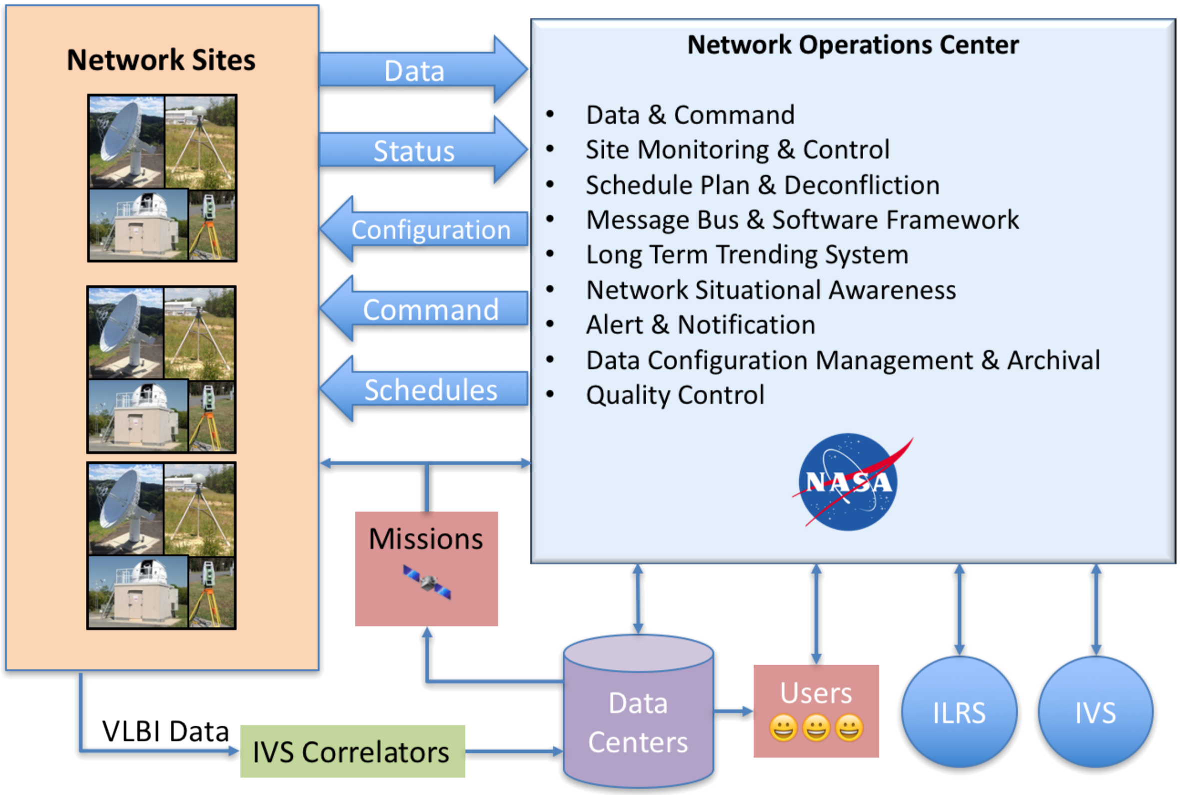

Figure 7: A virtual Network Operations Center will take advantage of the high level of automation of the new systems and provide for centralized network operation. The system will also provide various levels of access for users, the International Laser Ranging Service (ILRS), and the International VLBI Service for Geodesy and Astrometry (IVS).

Hawaii Deployment

The joint USNO-NASA Hawaii VGOS station is located at NASA's Kōke'e Park Geophysical Observatory (KPGO) on Kauai, 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 VGOS station was developed and implemented at KPGO based upon the GGAO prototype design with modifications from the lessons learned. On February 5, 2016, the KPGO antenna was used to make the world's first 3-way broadband measurement using the antennas at Westford in Massachusetts and GGAO. This was followed by a series of VLBI observations between the old and new antennas at KPGO that were taken to define the geodetic tie between the two systems before the 20m main bearing was replaced.

The KPGO VGOS station will be in its commissioning phase through the first part of 2017 to address any issues with the system and to gain operational experience. A series of 24-hour test sessions were performed throughout 2016 to establish the operational setup and procedures.

The NASA broadband stations are now being used to support compatibility testing with other international stations as they come on-line. Broadband fringes in all four bands for GGAO, Westford and Wettzell were measured on June 9, 2016. Verification of all four signal paths for Yebes was achieved on June 9, 2016. Broadband fringes in all four bands for GGAO, Westford and Ishioka were achieved on September 21, 2016. On September 20, 2016, the first VGOS

Trial Campaign of bi-weekly 24-hour sessions began using several of the blue network stations shown in Figure 8. The campaign will be repeated in 2017 and then shift to daily multi-hour sessions.

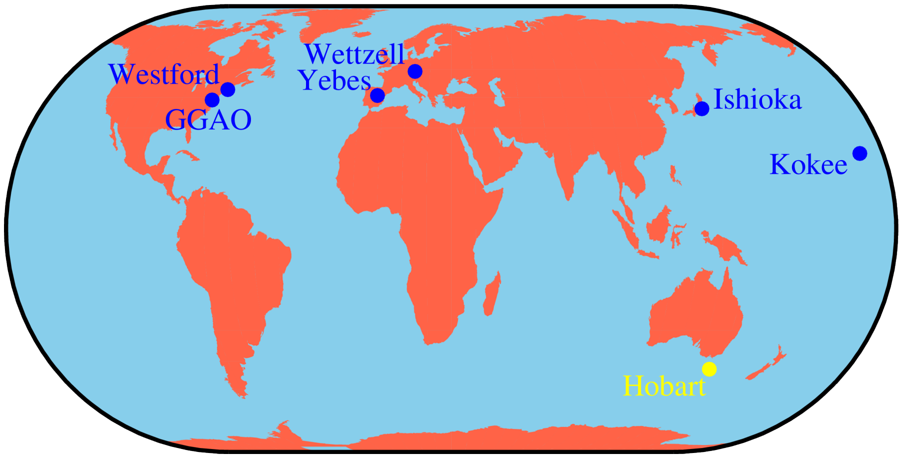

Figure 8: The NASA VGOS stations are being used to support compatibility testing with other international stations as they come on-line. The northern hemisphere stations shown in blue have performed trial runs with the NASA stations. The station at Hobart (yellow) has also performed successful tests with Ishioka.

Unfortunately, KPGO typically has very cloudy skies making it a poor candidate for hosting a SLR station. Therefore, the Haleakala Observatory on Maui was selected as the Hawaii SGSLR 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. A tentative location for the new SLR station has been selected as well as spots for additional GNSS stations. Given the distance between KPGO and Haleakala, it will not be possible to implement the VTS in the same manner as at the GGAO. The VTS will rely heavily on the use of the GNSS stations to tie the stations together into a "single" Hawaii core site. The new Haleakala SLR station is slated for implementation after the Texas SGSLR station is complete.

Texas Deployment

The Texas NSGN site will be located at the McDonald Observatory near Fort Davis, 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 VGOS antenna due to the low radio frequency interference environment and its proximity to the National Radio Astronomy Observatory in Fort Davis.

Several possible sites for new VGOS, SGSLR, and GNSS stations are being considered within the McDonald Observatory. The leading candidate layout places the VGOS antenna in the valley area near the visitor center and the SGSLR 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 initial operations expected to begin as early as the end of 2018.

In order to make the final selection for the VLBI site, an RF survey was performed from July 21-22, 2016. The intent of the survey was to determine where and how strong RF frequencies from outside sources are at the proposed VLBI site. The test used an omnidirectional RF antenna placed on a tripod and adjusted to about 2 m height as shown in Figure 9. The antenna was attached through a co-ax cable to an Anritsu spectrum analyzer. A laptop computer was used to setup the analyzer operational parameters and save the spectra as they are taken. Observations were made from 1.9 GHz to 14.1 GHz. No RFI was detected that would cause saturation of the VGOS antenna.

The SGSLR location on Mount Fowlkes is about 100 meters above and 800 meters east (about 8° in elevation) of the VLBI location near the visitor center. This difference in elevation makes it unnecessary to implement pointing masks since the SGSLR radar will never point down the hill.

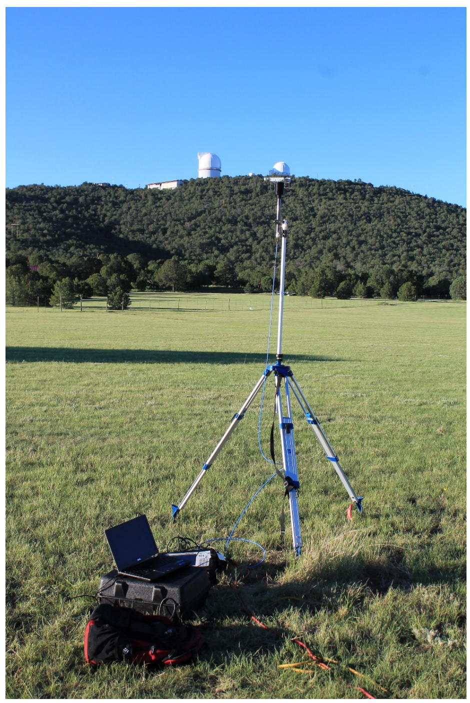

Figure 9: A RFI monitoring station was deployed to MCD to assess the RF environment at the VLBI site. No RFI was detected at the planned location that would cause saturation of the VGOS antenna.

Summary

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. With the completion of the prototype core geodetic site at GGAO and the VGOS station at KPGO, NASA is preparing to deploy a new network of operational next generation geodetic stations. The NASA network of three broadband VLBI stations have demonstrated the viability of VGOS and are being used to ensure the compatibility of new international stations. The next major step is the implementation of a core geodetic site in Texas that is scheduled for completion by the end of the decade.

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