NASA's Next Generation Space Geodesy Network Typical Core Site Requirements and Layout

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Abstract

NASA's renewed commitment to the deployment of a new network of "core" space geodetic sites requires careful planning and consideration for location selection, instrument and facility layout, and required infrastructure. Following on National Research Council (NRC) recommendations [1] to upgrade U.S. stations with modern SLR, VLBI, and GNSS systems, and make a long-term commitment to maintaining the ITRF (among others), the Space Geodesy Project (SGP) at NASA Goddard has been defining the exact requirements and layout for a "typical" geodetic site, which includes Satellite Laser Ranging--SLR, Very Long Baseline Interferometry--VLBI, Global Navigation Satellite System--GNSS, and Doppler Orbitography and Radiopositioning Integrated by Satellite--DORIS stations (French system provided by CNES, France) tied together with a Vector Tie System (VTS), utilizing a Robotic Total Station (RTS). Within programmatic constraints, Core Site (CS) identification follows a systems engineering process where site characteristics are evaluated against identified requirements. Taking into consideration site stability, radio-frequency interference, infrastructure, and a host of other requirements this paper describes the process leading to identification, and it will illustrate the generic layout of an idealized CS with unencumbered terrain.

Site Selection Background

There are two high-level objectives driving SGP's direction, and documented in the following "level-0 objectives": 1. SGP shall continue to operate, maintain, and where applicable, upgrade the current NASA Space Geodesy Network; 2. SGP shall contribute to building, operating, and maintaining a *new* global network of *integrated* geodetic stations. These two basic elements lead to a series of derived requirements that flow-down to a "mission" implementation approach. Figure 1 shows the top "level 1" requirements that ensue the programmatic objectives envisioned.

- **SGP0.1**: SGP shall continue to operate, maintain, and where applicable, upgrade the current NASA Space Geodesy Network.
- **SGP0.2**: SGP shall contribute to building, operating, and maintaining a new global network of integrated geodetic stations.

- **SGP1.1**: SGP shall ***contribute to a stable Terrestrial Reference Frame*** (TRF) that meets the needs of NASA's Earth orbiting missions, Earth Surface and Interior Program, and deep space navigation.
- **SGP1.2**: SGP shall ***contribute to measurements of Earth orientation parameters*** (EOP) that meet the needs of NASA's Earth orbiting missions, Earth Surface and Interior Program, and deep space navigation.
- **SGP1.3**: SGP shall ***contribute to determining accurate precision orbits*** to meet the needs of NASA's geodetic, Earth observation, navigation and space science missions.

Figure 1: SGP top-level objectives and derived requirements

Continuing with a defined system process, requirements are identified that lead to the most stringent science performance that the new network of sites must satisfy: support for the measurement of regional and global sea level change. This imposes requirements onto the International Terrestrial Reference Frame (ITRF), which must achieve an accuracy of $\leq$ 1 mm (1-Sigma) in Cartesian coordinates X,Y,Z (on a decadal scale), and a stability of $\leq$ 0.1 mm/year [2]. Figure 2 shows the formal requirements flow-down.

SGP1.1.1: SGP shall support the measurement of regional and global sea level change.

PRIB3.1 (Baseline Requirement TRF): Co-located global geodetic network shall permit the realization of the ITRF with the following attributes *Accuracy*: ≤ 1 mm (1-Sigma) in X,Y,Z (decadal scale); *Stability*: ≤ 0.1mm/yr (annual scale).

Figure 2: Most stringent requirement for SGP sites and global network is derived from the measurement of global sea level change, but many other applications follow closely behind.

In order to achieve the expected performance, simulations were carried out that identified a general distribution of 32 geodetic "core" sites (comprising VLBI, SLR, GNSS, and DORIS stations) that would satisfy the SGP requirements (see Figure 3a). This also supports the goals of the Global Geodetic Observing System (GGOS), with which NASA is working very closely. The current distribution of CS and sites under consideration are shown in Figure 3b.

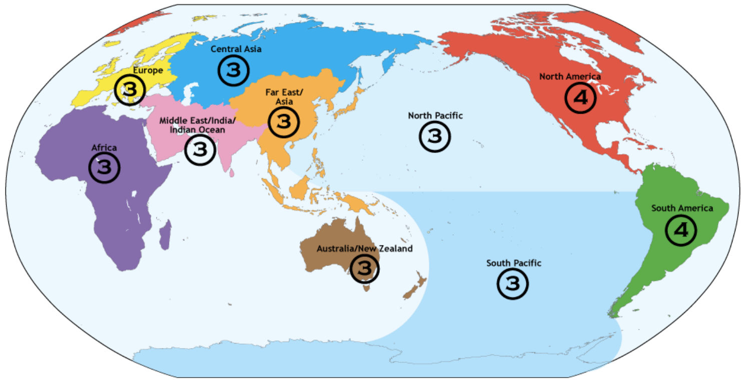


Figure 3a: Simulation results show a general global distribution of Core Sites that will satisfy the SGP Program requirements

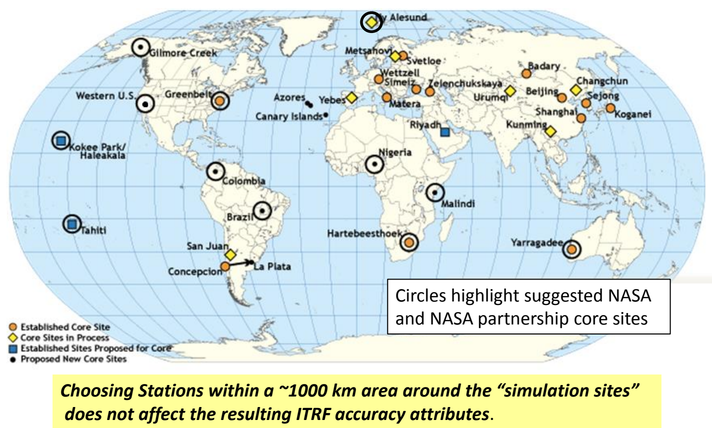


Figure 3b: Current distribution of Core Sites and sites under consideration to achieve the required ITRF performance improvement.

Development of specific requirements on GGOS sites was started by some of the authors in this paper and others, and documented in reference [3]. A formal systems engineering process was used to further focus and fine-tune metrics in the identification and selection of NASA SGP sites, whether in the continental US or abroad.

Site Identification and Assessment Process

Site characterization and identification must follow a system process by which requirements are used as actionable metrics that relate back to the SGP goals. In particular, derived requirements are developed that relate to site identification. Four major groups are defined: 1. Site stability/continuity; 2. NASA Space Geodesy Network (NSGN) site data acquisition; 3. Site infrastructure; and 4. Non-ITRF NASA science requirements. These groups and their derivatives are summarized in Figure 4. The location of NASA and NASA partnership sites must also take into consideration location of current and planned CS by other overseas groups.

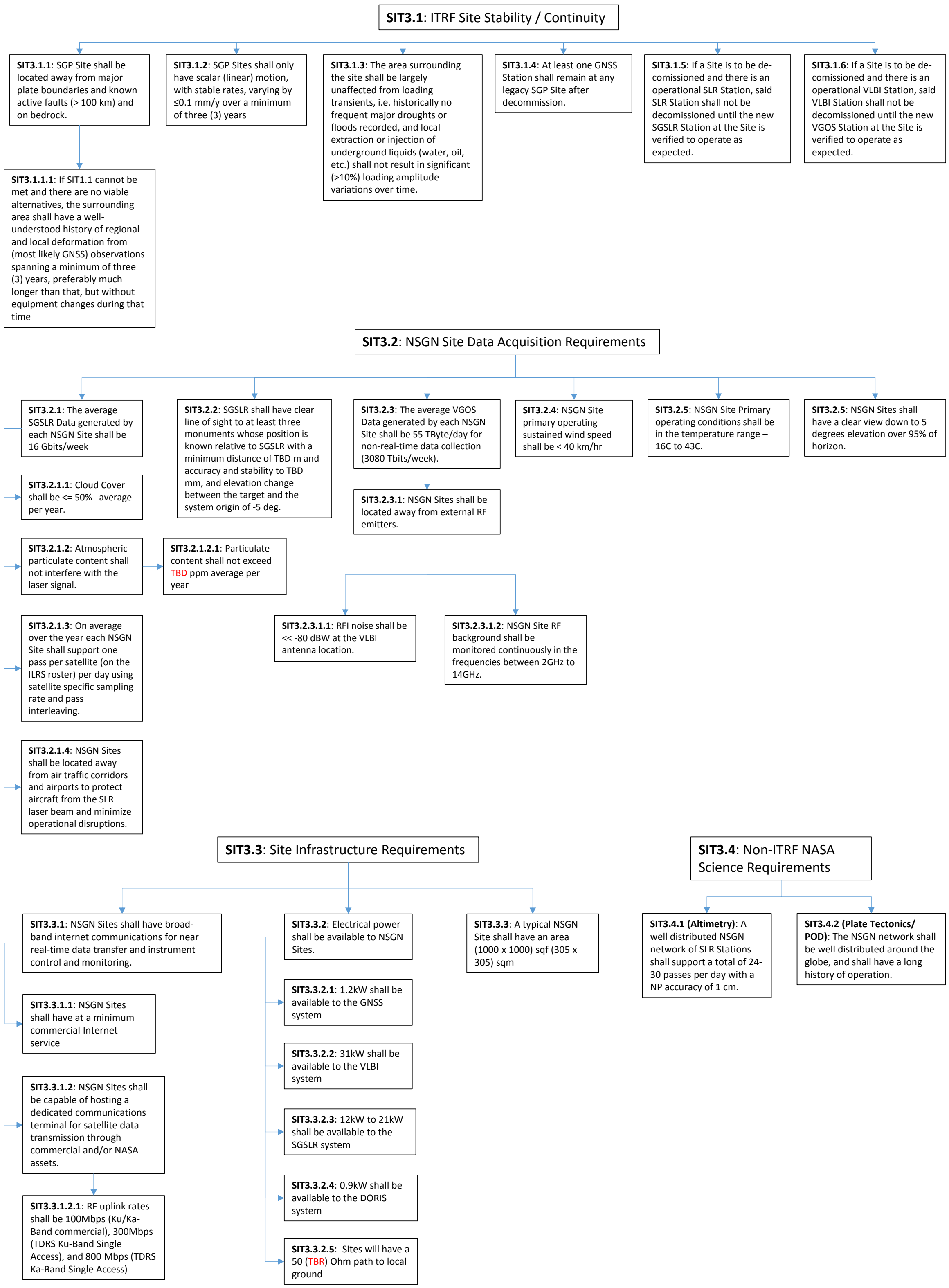


Figure 4: Site identification requirements follow actionable metrics

The identification of a prospective geodetic site is iterative, and includes a process of elimination. As an example, the western US site at McDonald Observatory (MCD) was chosen after comparing competing sites against each of the relevant requirements given in Figure 4. Scores were given for compliance, non-compliance, and “indeterminate”, meaning more information was necessary to verify or deny compliance. In the end, the site with the highest score was selected. Sites of interest are shown superimposed on a seismic hazard map in Figure 5. Programmatic factors (expense, accessibility, security, etc.) are intangibles that influence the selection. Some of this information is intrinsically contained within the requirements (e.g., sites having as a “minimum” commercial internet service factors into infrastructure costs), and some (such as “security”) factor after the top selections are made, as final pragmatic considerations.

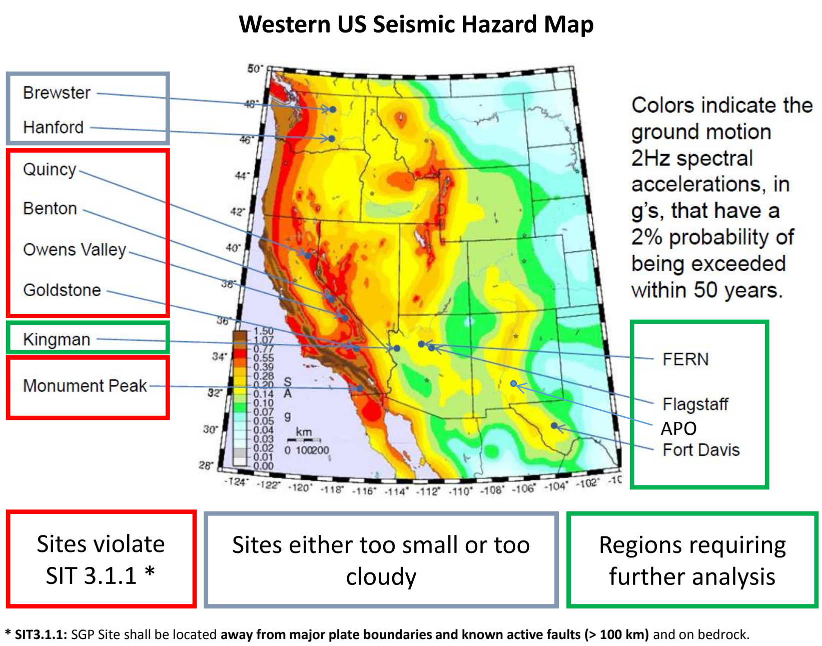


Figure 5: Initial step in site identification example for the western US.

It is important to methodically go through each of the requirements listed in Figure 4. As shown in Figure 5, seismic information is of importance within the “site stability” requirements. Other considerations such as cloud cover, useable site area, and horizon visibility are important. For instance, Hanford was ruled out because of persistent cloud cover, whereas Brewster was ruled out because of inadequate area to host a full CS. Once the most promising sites are selected, site visits are necessary in order to gather missing information, and/or fine-tune and verify existing data. The prospective site for the MCD VGOS antenna was selected for instance, after such a visit. Initial information on the site relating to horizon visibility is shown in Figure 6, and illustrates the type of detail needed of a “first visit”. Infrastructure (electricity and communications) was shown to be within reach of the location. Radio Frequency Interference (RFI) was not known however, so a campaign to monitor any sources of interference was planned.

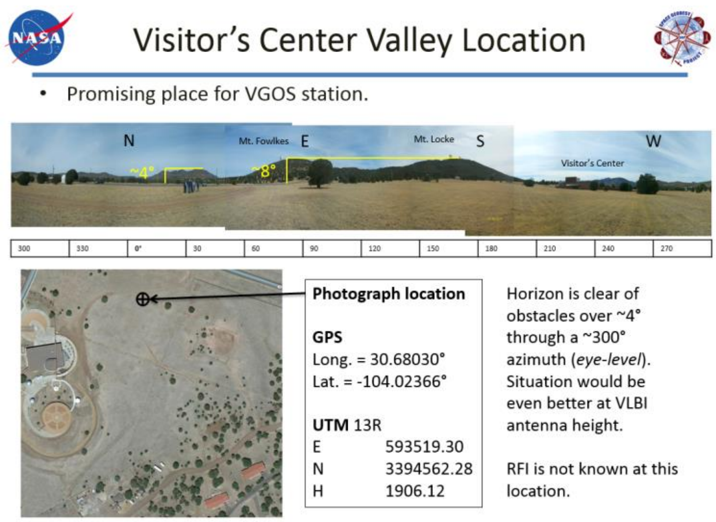


Figure 6: Site visit initial physical survey example for MCD.

A summary of the site selection and assessment process is shown in Figure 7.

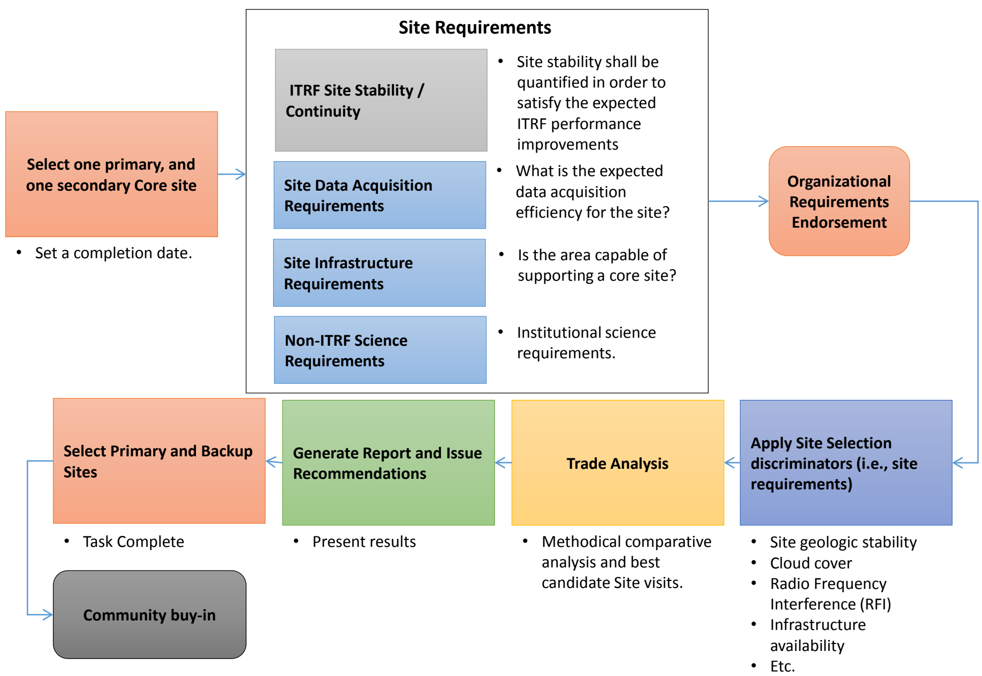


Figure 7: Sites are selected and assessed based on actionable requirements.

Site Preparation – *Technical*

Once a candidate site is identified, there is a need to assess its suitability in more detail. For this, the following steps must occur:

- Prepare a detailed engineering requirements report
- Carry out soil borings and prepare a geotechnical report
- Perform a detailed topographic survey
- Civil engineering design/preparation of construction documents
- Competitive bids/award construction contract
- Construction activities
- Site occupancy review and acceptance

Additional site visits are required to define the exact location of instrumentation. A 3-dimensional (3-D) topographic model is useful, but not required to scope the site layout. Figure 8 shows a 3-D topographic model of MCD, which served to assess the initial instrument locations.

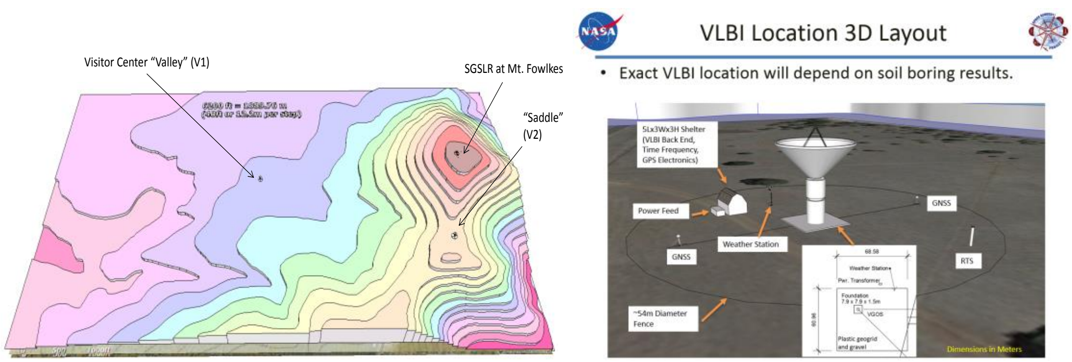


Figure 8: 3-D topographic model aids in selection of station configuration and site layout.

Site Preparation – *Programmatic*

Programmatic considerations factor into the steps necessary to finalize a site and ultimately ascertain its feasibility as a NASA SGP location. There are a series of requirements that must be satisfied, both for national as well as international sites. For US national sites, the National Environmental Policy Act (NEPA) requires the decision maker to consider environmental impacts as one factor along with technical and economic factors in the decision to implement an action. In addition to that, site ownership (private/public land) and historical preservation must be considered, and any required agreements developed.

International Sites with NASA participation require the following steps to be completed:

- Approved agency-to-agency agreement(s)
- Initial site assessment
- Compliance with US Executive Order 12114 - Environmental effects abroad of major Federal actions, http://www.archives.gov/federal-register/codification/executive-order/12114.html

Site Definition – *Technical*

Information on equipment and facilities that will be needed in a CS are outlined. Figure 9 shows the typical block diagram of a NASA CS. Blocks are meant to define not only functional but also physical location of components. Location of specific instruments will change depending on a particular site layout and topographic restrictions, but the blocks and interfaces shown in Figure 9 may very well represent an ideal "start-up" site with no restrictions.

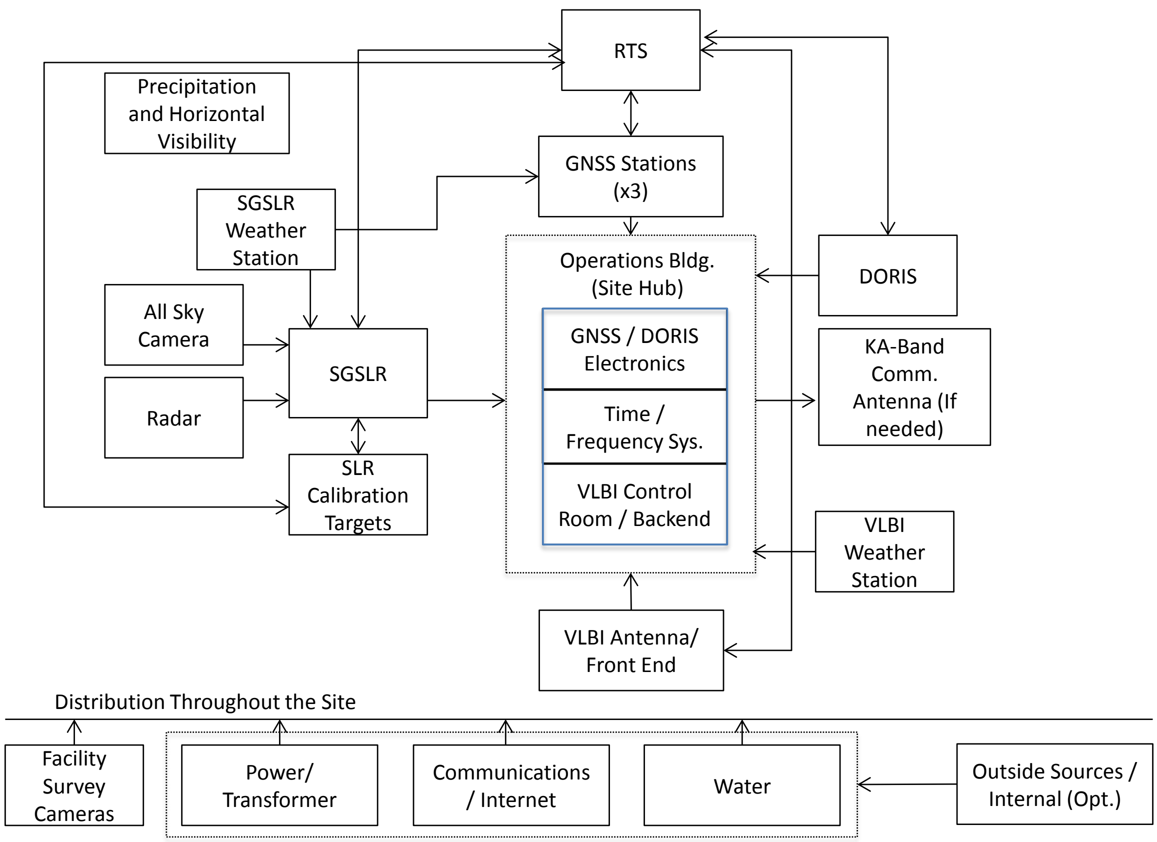


Figure 9: Typical NASA SGP Core Site Block Diagram

Site infrastructure and facility specifications are shown in Figure 10. The approximate power needs per station assumes a nominal 240V supply. Power supply frequency is 50 or 60 Hz. Power conversion is carried out at the individual stations, unless noted otherwise.

Core Site *optional instrumentation* includes components that would enhance the applicability of SGP Sites in support of NASA science, but are not considered essential to the operation of the geodetic techniques. They include *tilt meters*, *seismometers*, *water vapor radiometer*, and *gravimeters (absolute and/or superconducting)*.

Item	Description / Infrastructure	Qty	Unit *
	GENERAL SITE WORK		
1	Security Fence	4000	LF
2	Access road, asphalt, 1000' x 20'	2222	SY
3	Site Road, asphalt, 1000' x 18'	2000	SY
4	HV Overhead Power & Xfmr	1	LS
5	Underground Power on Site	1000	LF
6	Underground Communications Duct	1500	LF
7	Water Distribution on site	300	LF
8	Septic Tank and Drain Field	1	LS
9	Operations Building, 25' x 40'	1000	SF
	VGOS VLBI Site		
1	Earthwork	1	LS
2	Antenna Foundation, 26'x 26' x5'	126	CY
3	Reflector assembly area, access area	5000	SY
4	Power & 480V - 208/120 V Xfmr	1	LS
5	Grounding & lightning Protecion	1	LS
6	Electronics Shelter, 12' x 20'	240	SF
7	Underground conduit	100	LF
	SGSLR Site		
1	Foundation & Pillar for Telescope	4	CY
2	Concrete Pad for Shelter 12’ x 16’ x 1’	7	CY
3	Power 208/120V, 3-ph, 60 Hz, 100 Amp	1	LS
4	Grounding & Lightning protection	1	LS
5	Underground conduit	50	LF
	GNSS Site (x3)		
1	Deep-drilled braced monument	36	SF
2	Underground Conduit	300	LF

Facility	Location
Office space (500 sq. ft. or ½ Ops Bldg.)	Operations Bldg.
Lab/engineering space (500 sq. ft. or ½ Ops Bldg.)	Operations Bldg.
Storage space	Operations Bldg.
Communications (telephone, Internet/LAN)	Site level
Bathroom/kitchen/rest areas	Operations Bldg.
Environmental control (localized)	Site/station level
Backup power/communications system	Site level
Site/station security system	Site/station level
Personal protection system	Site level

Station	Power Needs (kW)
VLBI	31
SGSLR	12 to 21
GNSS	1.2
DORIS	0.9

* LF = Linear Feet; SY = Square Yard; LS = Lump Sum (meaning “a good guess”); SF = Square Foot; CY = Cubic Yard

Figure 10: Basic site infrastructure and facility specifications for a NASA SGP Core Site.

Typical Site Layout: Guidelines and Assumptions

Assumptions used in generating a site-level map are listed here. These are simply a corroboration and expansion of the information presented thus far:

- Overall dimensions are 1000’ x 1000’
  - A controlling dimension is the separation of VLBI antenna and SGSLR radar at 750’
  - Buffer zone of ~200’ between SG instruments and the fence line.
- Layout offers strong geometry for inter-comparison surveys and TRF orientation
  - The four space geodesy techniques form a quad figure of ~500’ per side
  - The three GNSS antennae form an equilateral triangle ~600’ per side
- RTS is near center of site and close to Ops. Bldg. (Site Hub) to minimize cable lengths
- DORIS is near Ops. Bldg. to keep cable lengths short, and located to block line-of –sight to VLBI
- SGSLR has three calibration targets 120 degrees apart at a distance of 250’
- Ops. Bldg. is centrally located: dimensions: 25’ x 40’
- GNSS receivers are located in OPS Bldg.
- VLBI site has a level assembly area constructed of plastic geogrid and gravel; 200’ x 225’

- Pre-fabricated shelter for backend electronics to keep cable length reasonable (~120 feet)
- Antenna foundation is 26’ x 26’ x 5’thick
- Data transmission from antenna to electronics and to the Ops building via fiber optic lines.

◆ Accommodation for septic system, water line, and external power conversion

◆ Accommodation for 3-meter Ka-band antenna for remote Site installations.

- Connected to Ops building via fiber optic lines.

Figure 11 shows the resulting layout based on the aforementioned assumptions.

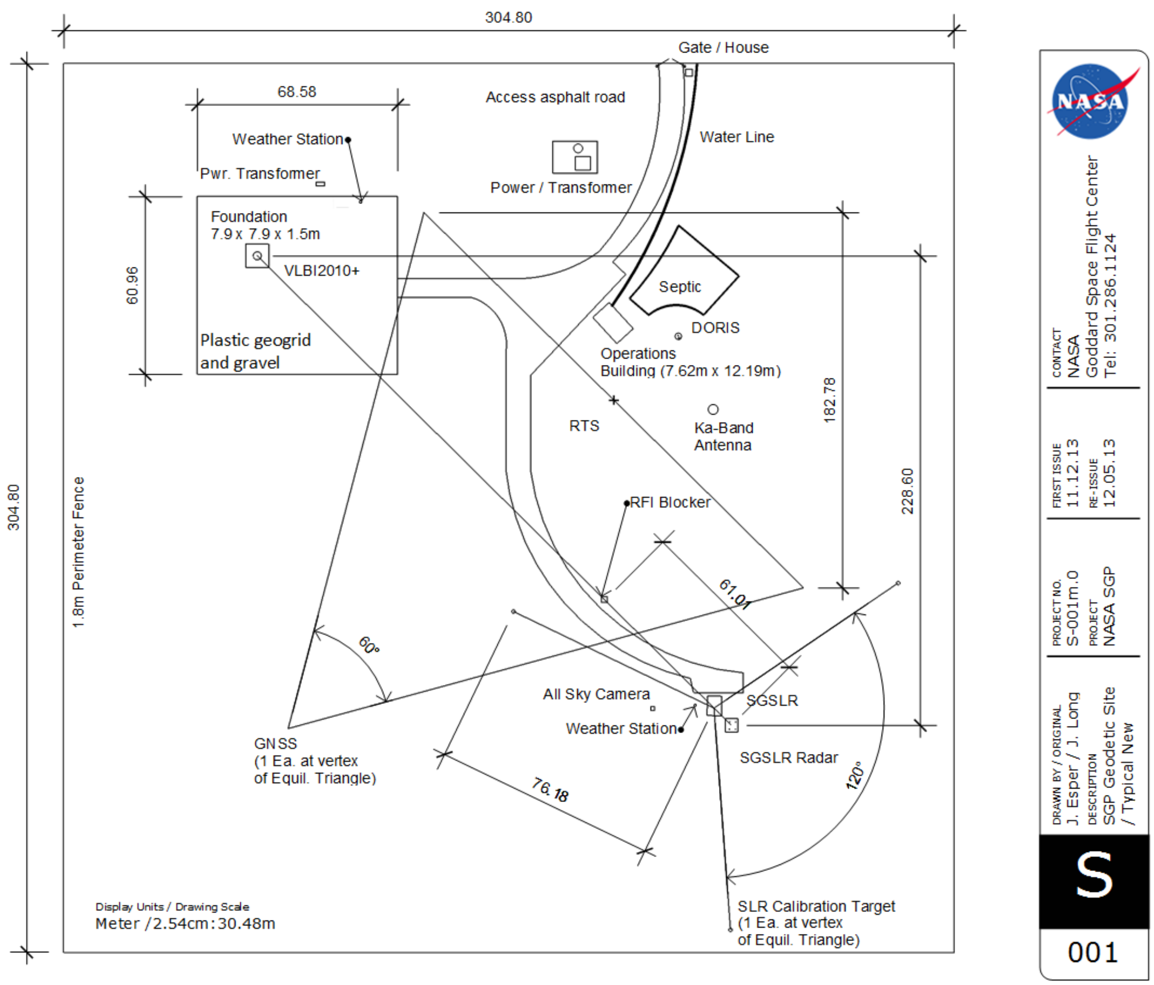


Figure 11: Typical NASA SGP site drawing with unencumbered terrain.

Core Site Visualization

The best way to carry out initial planning for the installation of a CS is to create a 3-D model of the location and instrumentation, including topography. Since topography changes per location, an unencumbered flat terrain model is used for this typical site visualization. For the lack of natural radio-frequency blockers (hills or depressions), a flat terrain requires the fabrication of an artificial barrier to prevent RFI from affecting VLBI observations. This is particularly the case when the SLR is in operation, for which NASA primarily uses a co-located X-Band radar (4 kW at 9.4 GHz) prior to any laser ranging operation as a means of checking for a clear space to target. Other means of aircraft avoidance are being studied, and their use will depend on site location, their viability as a safety system and for some options; the availability of aviation collision avoidance data/signal. Other sources of RFI include the DORIS beacon and local broadcasts (which may be variable, and sometimes unpredictable depending on location).

Figure 12 presents a "bird's eye" view of a complete site, and a perspective from the main entrance gate. Naturally the actual layout will depend upon the terrain and other local conditions and constraints. Figure 13 shows a view from the SLR station, with the RFI blocker (RFIB) in place. Minimum distance between the RFIB and the SLR Radar is 61m. Blocker dimensions for this geometry come out to 4.2m x 3.7m minimum, and 5.9m x 5.4m nominal (including a 20% linear size margin). The goal is to reduce the RFI noise to << -80 dBW at the VLBI antenna location.

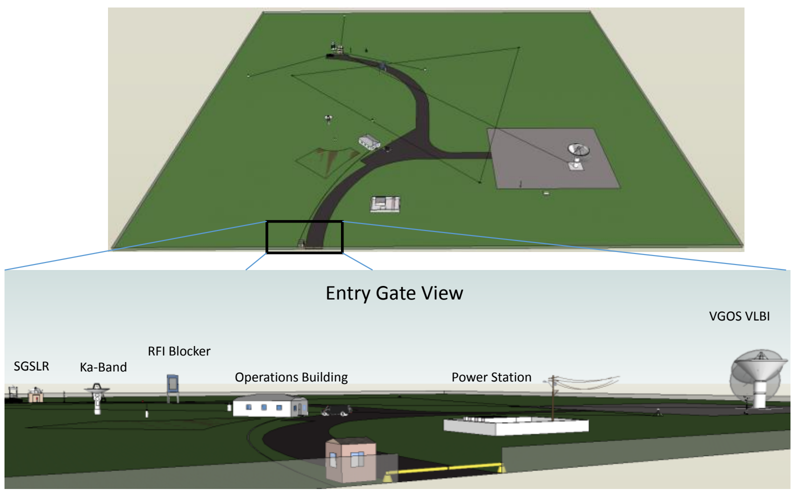


Figure 12: Idealized SGP CS layout and entry gate perspective (assumes flat terrain).

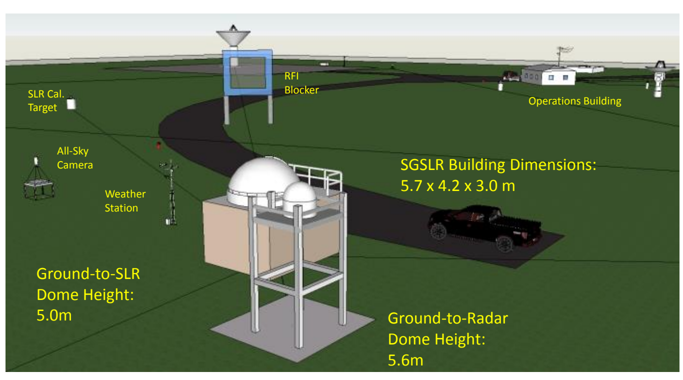
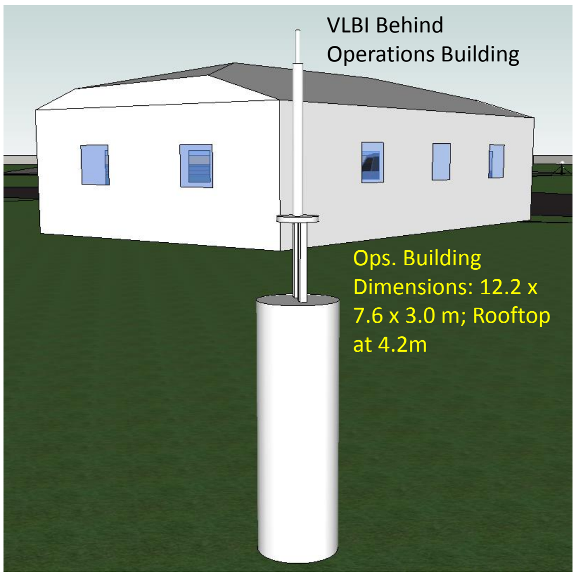


Figure 13: Perspective from SLR station, with RFIB in place.

Figure 14 shows a view from the DORIS beacon. Since DORIS transmits at frequencies of 2GHz and 400MHz, the operations building serves in this case as the RFI barrier for the 2GHz band, which is within the VGOS frequency range (2 to 14 GHz). Care is exercised to locate the building so as not to obstruct DORIS Field of View (FOV), requiring clear 5-deg above the horizon visibility.



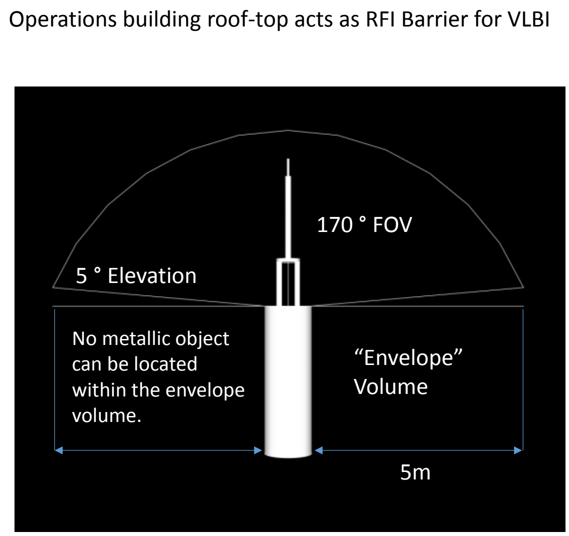


Figure 14: DORIS perspective near the operations building.

Conclusions

A methodical systems engineering approach is necessary to scope and identify NASA Space Geodesy Sites that will service the next generation of space geodetic observations for decades to come. These core sites can be selected based on a series of requirements containing actionable metrics, allowing a qualification and quantification of performance benefits, ranging from scientific to pragmatic considerations. This process was followed in the selection of the McDonald Observatory as the first NASA US continental Core Site. Additional sites will need to be identified as part of the effort of closing gaps in the global geodetic infrastructure needed to meet the most stringent science requirements levied on the International Terrestrial Reference Frame.

References

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[2] "The goals, achievements, and tools of modern geodesy" (2009), in GGOS2020: The Global Geodetic Observing System*,* H.- P. Plag and M. Pearlman(eds.) Chapter 2*,* pp. 24-62, GGOS/IAG, Springer-Verlag, New York.

[3] "Global Geodetic Observing System (GGOS) Site Requirements for GGOS Core Sites (Revision 1a)", Donovan et. al., 2012. Online document http://cddis.gsfc.nasa.gov/docs/2012/GGOS_SiteReqDoc.pdf .