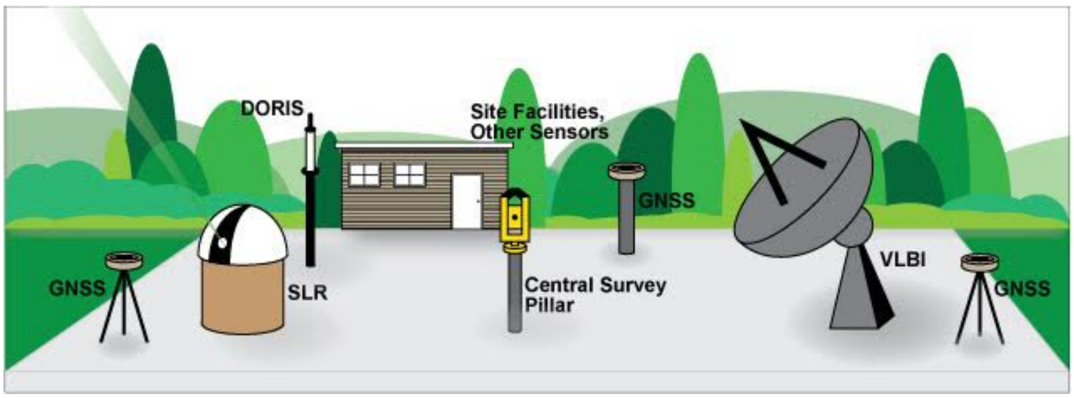
Global Geodetic Observing System (GGOS)

GGOS Requirements for Core Sites

(Revision 2)



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REQUIREMENTS FOR CORE SITES

The Global Geodetic Observing System, an entity under the International Association of Geodesy (IAG), has undertaken the task of advocating for the geodetic infrastructure necessary to meet global change and other societal challenges, and defining the requirements for the geodetic observatories that constitute it. In this role, GGOS will work with the IAG Measurement Services, the scientific community, and national and international agencies to bring a combined effort to bear on these areas of international concern. A major task within this effort is the upgrading, expansion, and maintenance of the global ground network of co-located Core Sites for geodesy to enable the realization and maintenance of the International Terrestrial Reference Frame (ITRF), Earth orientation parameters and precision orbits to meet the needs of Earth orbiting missions, Earth surface and interior programs, and deep space navigation.

GGOS and the geodetic Core Sites should be compliant with the UN-resolution from Feb 26, 2015. See http://www.unggrf.org/. This Site Requirements Document outlines what is needed for that compliance.

INTRODUCTION AND JUSTIFICATION

What is a Core (Fundamental) Site?

A Core Site for geodesy is a geodetic observatory that defines terrestrial reference points in the space and time domain and in the presence of the Earth's gravity field. Observational data from complementary co-located instruments are used in a synergistic way, to obtain the most accurate global reference frame (see Figure 1).
Currently the space domain is dominated by four space geodesy techniques:

- Global Navigation Satellite Systems (GNSS, e.g., GPS, GLONASS, Galileo, BeiDou, QZSS, IRNSS, etc.)
- Satellite Laser Ranging (SLR)
- Very Long Baseline Interferometry (VLBI) and
- Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS).

The deployment of SLR and VLBI instrumentation require highly-stable frequency standards such as that provided by

- Cesium standards and
- Hydrogen-maser.

The time domain is defined by the local time scale generated by these standards.

The reference on the potential level of the gravitational field of Earth can be determined with Absolute Gravimeters (AG) and its variations can be monitored with Superconducting Gravimeters (SG). The SG monitors very precisely the time variation of the local gravity field and periodic AG measurements provide the absolute calibration. It is strongly recommended that core sites incorporate gravimeters into their instrument complex.

These major measuring techniques should be complemented by local sensors such as:

- Meteorological sensors (for atmospheric delay corrections and data reduction),
- Hydrological sensors (for data reduction)
- Seismic sensors (for data reduction of time series) are also very desirable.

To help monitor and model local geodetic signals, the reference points of the above listed instruments must be spatially related to each other. This implies that a local geodetic network and regular local surveys for control are required.

A geodetic observatory following the above outlined design is called a Core Site for geodesy, if the co-located instrumentation is:

- Operated permanently delivering decadal time-series,
- Redundant for the detection of systematic errors per technique,
- Complementary for a synergistic use, and
- Tied together by a local survey.

Each technique makes its measurements in a different way, providing different observables with unique capabilities; together the techniques provide cross validation and increased accuracy. The combination of complementary measuring systems is essential for ensuring data quality by tracking down otherwise non-detectable systematic errors. The synergistic use of the advantages of different space-techniques leads to the most accurate reference frame, called ITRF.

The ultimate strength of the reference frame is established by satisfying the underlying physical model, the theory of general relativity, which unites space, time and gravitational field by the co-location of instruments and the combination of their different observables. Close co-location is the essential condition that makes possible the measurement of the inter-system vectors to sub-mm accuracy in order to provide a robust connection among the techniques.

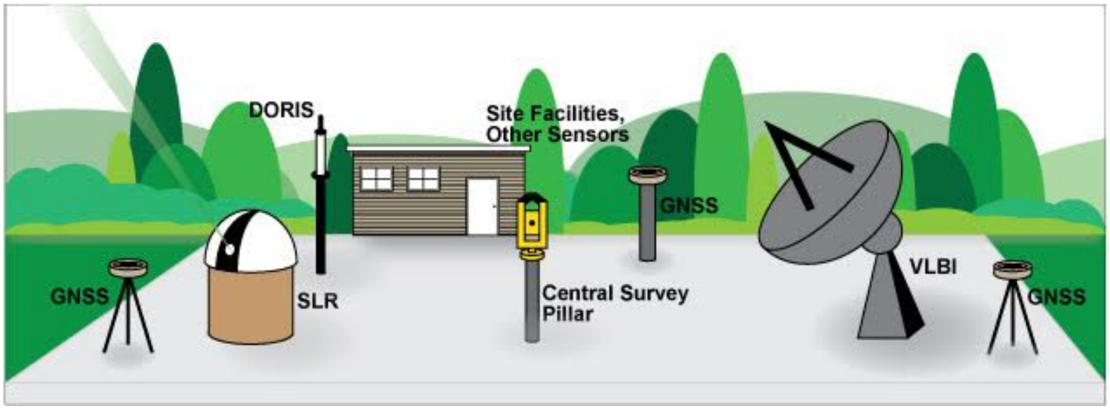


Figure 1. Schematic of a Core Site

Why Do We Need the Reference Frame?

Reference frames are needed for two purposes:

- **Geoinformation:** Any environmental parameter needs to be rigorously geo-referenced. Reference frames are fundamental on a global, continental, national, regional and local level for political decisions, land management and administrative purposes. Reference frames are a (global) infrastructure and part of our quality of life.

  Example: Space agencies have launched and will continue to launch missions that provide accurate positioning and baseline measurements, altimetry, gravity field measurements, synthetic aperture radar and InSAR, and atmospheric and ionospheric measurements. Many of these depend on a highly accurate and stable geodetic reference frame within which to interpret the data and understand trends in the processes of change. The reference frame is the basis upon which we measure change over time (decades), space (thousands of kilometers) and evolving technology. We need to recognize that the way we will measure things 25 years from now will certainly involve new and better technology, but the time history of the measurements must be seamless.

- **Science**: Changes in the reference frame itself are the result of geophysical phenomena, which require permanent monitoring in order to understand our system Earth.

- **Example:** We measure and monitor the Earth's environmental system (its oceans, ice, land, atmosphere) not only to understand the processes of global change, but also to enable us to make educated decisions on how to cope with these changes. It can take a decade or even a generation or more to build a dike, move resource-delivery systems, move neighborhoods, or make other societal or infrastructure changes to limit future disasters due to global change. Changes in hydrological conditions (too much water or too little on or under that surface) are probably one of the most imminent problems that we face today.

Why Do We Need a Global Network?

The reference frame is maintained through a global network of ground stations, many with some co-located techniques, and is realized as the international standard through the International Terrestrial Reference Frame (ITRF). The reference frame is the foundation for virtually all space-based and ground-based metric observations of the Earth. However, the global distribution of contributing network stations is imbalanced due to the geographical distribution of the continents and oceans and also due to different priorities in different nations.

Requirements for the ITRF have increased dramatically since the 1980s. The most stringent requirement comes from critical sea level programs where a global accuracy of 1.0 mm and 0.1mm/yr. stability is required and with other applications are not far behind (Plag and Pearlman). ***This requirement is a factor of 10 to 20 beyond current capability***. Current and future satellites will have ever-increasing measurement capability that should lead to increasingly sophisticated models to explain the sea level trend. Yet the current ground network is far from adequate in terms of both: individual station capability and network distribution to support the ability to obtain the necessary high–quality reference frame.

The integrated network must provide an accurate, stable set of station positions and velocities, with sufficient global distribution to characterize the position and motion of the Earth system with sub-mm accuracy. Simulations (Pavlis et. al) demonstrate the need of a ground network with approximately 30 co-located geodetic Core Sites with a uniform global distribution. These network stations must provide measurements that are precise, accurate continuous, robust, reliable, and geographically distributed (worldwide). Network measurements must be interconnected by co-location of the different observing techniques.

What is the Current Situation?

The current reference frame is maintained by global networks of VLBI, SLR, GNSS, and DORIS stations. There are presently four fully co-located sites (four techniques) and 8 – 10 stations with co-location of VLBI, SLR, GNSS or DORIS. We recognize the DORIS has been deployed to satisfy its own programmatic requirements and will overlap with these sites to the extent practicable. The current network has large geographic gaps, few co-locations, and aging technology leading to inadequate data quality, quantity, and frequent outages.

What Do We Need?

Integration of the different techniques to improve the reference frame requires a globally distributed network of ~30 co-located stations with sufficient global distribution, modern technology, and adequate local conditions to meet the needs of the reference frame and accurate orbit determination for active missions (altimeter, gravity field, GNSS, etc.).

New technologies are now available to replace and upgrade the legacy systems for all of the techniques and as a result, some current systems are slowly being upgraded or replaced. All of the techniques have new generation prototypes underway. As an example, the VLBI community (coordinated through the International VLBI Service for Geodesy and Astrometry) has developed the VGOS design concept. The prototype of this new class of radio telescopes is realized with the Twin Telescope at the German observatory in Wettzell. In addition VGOS radio telescope projects are underway in Japan, China, Australia, Russia, Norway, Sweden, Portugal, South Africa and the US. New generation SLR systems with higher repetition rates, short pulse lasers have been deployed at Herstmonceux, Wettzell, Zimmerwald, and sites in Russia and China, and at GSFC. Russia and China are deploying systems overseas, attempting to fill gaps in geodetic coverage. Other groups have new VGOS and SLR technology systems in planning. New GNSS receivers are currently being deployed to accommodate additional frequencies and the wider constellation of GNSS satellites. DORIS is deploying new ground beacons (V3.1 and V3.2) that have improved robustness and reliability.

Core Site Description

The GGOS Core Site should have the following systems in place:

- VLBI

  The VLBI systems should be compatible with VGOS (formally VLBI 2010), which have already been implemented or are in process in 14 radio telescopes, with the following performance characteristics:

  - Slew/track cycle: 20 sec. slew, 10 sec. on source observation; this requires slew rates of 12 deg/sec in azimuth and 6 deg/sec in elevation. Slower slew rates may not fully satisfy all observation requirements;
  - Antenna SEFD <2500 Jy from 2 - 14 GHz;
  - Flexible placement of multiple 1 GHz bands from 2 - 14 GHz;
  - Recording rate up to 4 Gbps for each band;
  - Hydrogen maser frequency standard;
  - Remote monitor and control capability;
  - Broadband internet connection for data transfer to a correlator;

- Modeling or monitoring of signal path length variation< 1mm;
- Extrapolation to the instrument reference point <1 mm;
- Continuous operation capability.

For more details see:
http://www.haystack.mit.edu/geo/vlbi_td/2010/index.html

- Satellite Laser Ranging

Satellite Laser Ranging Systems are not standardized, but should be built with the following performance characteristics:

- Capable of ranging to satellites from LEO to synchronous altitudes;
- Capable of night-time and daytime ranging;
- Normal point precision to geodetic satellites < 1mm;
- Normal point epoch timing accuracy to GPS time < 50 nsec;
- Capable of pass interleaving;
- Robust, consistent, verifiable calibration <1 mm;
- Capable of acquiring 350 passes each on LAGEOS-1 and -2 during the course of a year:
- Capable of tracking an average of 3 pass segments with 3 normal points each segment on LAGEOS passes;
- Rapid data transmission upon completion of a session;
- Modeling or monitoring of signal path length variations to < 1mm;
- Extrapolation to the instrument reference point < 1mm.

For more details see:
http://ilrs.gsfc.nasa.gov/network/system_performance/index.html

- GNSS

The GNSS installation should be a multi-constellation system comprising a minimum of three permanent antennas with:

- Properly anchored ground-based (deep-braced quatropod antenna) installation;
- Extrapolation to the instrument reference point < 1mm.

For more details see:
http://igscb.jpl.nasa.gov/network/guidelines/guidelines.html

- DORIS (where available)

  The DORIS system should be the latest multi-satellite ground station, securely based with the standard DORIS ground interface. For more details see: http://ids-doris.org/network/station-management.html

- Time and Frequency

  Geodetic measurements are related to time intervals. Therefore stable frequency standards must be present at a GGOS Core Site. As changes of the oscillation can be detected locally only by a continuous comparison among similar devices, redundancy of the equipment is important.

  The site should have:

  - H-Maser (short-term stability 10^{-15});
  - Cesium frequency standards (long-term stability 10^{-13}) with 1 pps output (can be provided by external modules);
  - 1 dual-frequency GNSS timing receiver with external oscillator input and calibrated antenna cable length;
  - Multichannel time interval counter (or switchboard for automated time interval measurements among standards and/or clocks);
  - Frequency distribution system to supply the station reference frequency and epoch 1pps to VLBI, SLR, GNSS, gravimetry;
  - Uninterruptable power supply (as standards to avoid power outages).

  Some sites may elect to have independent timing systems for each instrument and then a means of monitoring the relative offsets. In any event, monitoring relative offsets at key locations around the local network instruments is good practice and can save aggravation later in system performance and malfunction diagnoses.

  As an example of a comprehensive on–site timing environment, the Wettzell Site and the AGGOO observatories which contribute to the generation of Universal Time by the Time Section of the Bureau International de Poids et Measures in Paris, host a temperature-stabilized timing laboratory with considerable redundancy:

  - 3 Cesium frequency standards (long-term stability 10^{-13});
  - 2 H-Maser (short-term stability 10^{-15});
  - 1 dual-frequency GNSS receiver with external oscillator input and calibrated antenna cable length;
  - Clock modules with 1pps output (if not present in frequency standards);

- Time interval counter;
- Switchboard for automated time interval measurements among normals and/or clocks;
- Control and monitor computer;
- Frequency distribution system to supply the station reference frequency and epoch 1pps to VLBI, SLR, GNSS, gravimetry;
- Uninterruptable power supply to avoid power outages to timing standards.

- Ground station configuration and local reference system

  The major instruments should be within 200 meters of each other (if possible) and in mutually clear view to readily permit mm accuracy ground-based surveys. The minimum inter-system separation has to be determined by Radio Frequency Interference (RFI) conditions, especially between VLBI and DORIS.

  The local reference system should be:

  - Oriented in the GNSS reference frame through permanent GNSS antennas;
  - Realized through terrestrial measurements to high-grade retroreflectors mounted coaxially with the GNSS antennas;
  - Monitored in a programmed manner to account for local site motions to < 1mm;
  - Include a geodetic marker that represents the whole site, ideally positioned on a rock outcrop;
  - Utilize stable ground pillars with at least two lines of sight to all instrument reference point manifestations (i.e., retroreflectors);
  - Site plans and instrument designs should envelop all the space geodetic instruments.

  The site should have at least additional three GNSS receivers near (encompassing) the major instruments to provide the local station network:

  - Receivers should be commonly visible and visible to each of the other space geodetic instruments;
  - Proper ground-based (tripod) installation.

Purpose of this Document

This document delineates the requirements for the network stations that will meet the reference frame and the other projected requirements. Listed below are criteria to identify (new) sites with ideal conditions.

SITE CONDITIONS

Global Consideration for the Location

The site must be located optimally in relation to other existing or planned sites in the global network. “Optimally” refers to:

- Geometrical distribution: A homogeneous distribution of reference points requires equidistant spatial separation. The advantage is equal error distribution due to the network configuration. Due to the continent/ocean distribution and the existing network stations the situation can be improved only by smart site selection of new stations.

- Technical distribution: It is desired to have at least three well-distributed stations on each (accessible) tectonic plate. This will allow the monitoring of translation and rotation of the plate. If the plate shows different motion patterns, e.g., South-America due to the subduction zone, more than three stations are necessary to capture intra-plate deformation.

- Technique-dependent distribution: Satellite techniques should observe complete orbits as much as possible. Geometrically, each station can observe only a fraction of the entire orbit. Therefore, the distribution of network stations must be such that it leads to as far as possible full orbit coverage by the network sites. VLBI delivers the Celestial Reference Frame (CRF), which is the basis for Earth orientation monitoring. The CRF itself needs a homogeneous distribution of celestial objects to avoid configuration-dependent systematics. The network configuration of VLBI stations must ensure the ability to cover the entire sky with common views of at least a pair of spatially distributed radio telescopes.

Geology and Site Stability

Obtaining position stability at the 1 mm level is a challenge and will depend on local site conditions and monumentation type. Outcropping bedrock will provide the most stable surface conditions. Among bedrock types, metamorphic and plutonic outcrops will be the most stable in general. Volcanic outcrops can also be extremely stable although some care is needed where volcanic rock overlies less competent materials. Highly consolidated sedimentary rocks can also provide stable conditions, particularly where deep (or deeper) drilled monuments are employed. Less consolidated sediments and soils are the most problematic and may not be capable of meeting the stability requirements, without special attention to monumentation (for instruments and reference markers to monitor system stability) and application of filtering techniques to estimate position noise. Sites with deep soils (i.e., cannot easily access sub-soil bedrock) will most likely not meet site requirements. Final site development should be designed with respect to ground analysis based on drilled cores (10-20 m depths depending on local conditions).

Acceptable sites should be located away from known, active faults, volcanic activity, and regions of local deformation associated with natural or anthropogenic processes. Site motion should be limited to scalar displacement with stable rates, preferably varying by <0.1 mm/year. The area surrounding the site should be largely unaffected by loading transients such as major droughts, flooding, and local extraction or injection of underground liquids (oil, water, etc.). If this cannot be met, and there are no viable alternatives, the regional and local deformation in the surrounding area should be well understood and monitored (most likely through GNSS) for a period of at least three years. In areas where active faults are located less than 100 km from the site, the surface patterns and activities (slip rate and locking depth) of nearby faults should be determined to allow estimation of inter-seismic motion and co-seismic offsets. Earthquake regions make up about 30% of the continental surface. Even in stable "non-earthquake" regions, site offsets > 1mm occur from major events and must be corrected (static co-seismic offsets >1 mm were observed up to 7800 km away from the great Sumatra-Andaman earthquake of 26 Dec. 2004). Therefore, it is important to have access to data from regional monitoring GNSS networks, which surround the site and densify the network of Core Sites.

To support a stable antenna and observatory foundation, sites should be on firm, level, stable material--ideally on hard rock, basement outcrops. To be avoided area soils that slump, creep, slide, or change in elevation because of variations in ground water level or frost heaving. If hydrological cycles are known to change the reference positions, additional corresponding sensors must be installed to monitor the local hydrology. Episodic motions must be measured by co-located local sensors. Gravimeters, especially superconducting instruments, aided by periodic visits of absolute gravimeters, are an excellent way to monitor such motions.

Specific studies needed for estimating site stability include:

1. Analysis of the seismic instrumental record for indications of tectonic activity within 200 km of proposed GGOS sites.
2. Investigation of available neotectonic evidence of faulting within 200 km of the GGOS sites, including historic and paleoseismic evidence from the literature for any potentially active faults identified.
3. Investigation of regional geology/soil maps (soil types and characteristics, and depth to bedrock).
4. Evaluation of available information on the subsurface (drill logs, radar surveys, observations during site construction).
5. Evaluation of time series for any existing geodetic data at the site, and characterization of stability via the variance of the observed apparent changes in position.

6. Investigation of possible correlations between apparent position changes and rainfall that may indicate near-surface motions associated with wetting/drying of surficial materials.
7. Investigation of the amplitude and frequency of variations in apparent site position that may reflect deeper-seated loading responses (snow, ice, surface and sub-surface water, etc.) and/or residual positioning errors.

Final evaluation of specific sites will require subsurface observations in cases where bedrock is not outcropping at the surface.

Geodetic observations are affected by Earth tides, as well as ocean and atmospheric loading. The models for Earth tides are not yet validated by local measurements with superconducting gravimeters for many sites, especially in the southern hemisphere, so consideration should be given to establishing a gravity monitoring capability. This capability should include a superconducting gravimeter with a nearby site to accommodate a visiting absolute gravimeter to remove inevitable drift in the gravity time-series from the superconducting instrument.

Weather and Sky Conditions

In general the instruments need to be designed and built for the intended climate zone. An instrument built for a temperate climate might not work in the Arctic and enforcing a generalized climate condition for Core Sites would likely counteract the desire for global distribution. The ideal meteorological condition that would work for all of the techniques is a clear sky and dry climate. This of course is not sufficiently available, so we must seek the best compromises. Cloud cover should be less than 50% averaged over the year; the site should not suffer from frequent heavy fog, mist, or sand/particulate conditions.

Some below-optimal conditions can be considered; where, for example, cloud cover is less than 50% during at least nine months a year based on a 10-year history at the location. SLR systems cannot operate through clouds, rain, heavy fog, or mist, but these factors do not affect GNSS, VLBI or DORIS. It will therefore be extremely helpful to have available data on average monthly rain and cloud cover when evaluating a site for SLR. Note that sites located near the ocean can be subjected to a high rate of system deterioration due to the salinity of the air and the likelihood for fog or bad weather.

Regions near heavy industry, in particular those causing air pollution (refinery, cement factory, etc.), should be avoided because of both atmospheric transmission issues and instrument deterioration.

Radio Frequency and Optical Interference

All systems either broadcast or receive RF signals (see Table 1). All systems are sensitive to RF Interference (RFI), but GNSS and VLBI being passive systems are the most susceptible. Sites should not be located in the path of, or near the emitters of radio, television, or microwave signals in the sensitive frequency regions.

- Interference potential for GNSS (GPS, GLONASS, Galileo, BeiDou, etc.) is worst near the L1, L2, L5 operating frequencies in the band of 1.1 – 1.6 GHz range; large signals within the entire operating spectrum band-pass can saturate the sensitive receiver and cause tracking problems.
- VLBI is sensitive over the region 2-14 GHz, but the receive beam is highly directional. However a good observatory viewing geometry requires that all sections of the sky including low elevations be observable.

RF site investigation measurements are mandatory in order to understand the RF environment prior to settling on a site. National radio frequency authorities could be very helpful in locating nearby transmitters and relay stations.

SLR and DORIS broadcast RF signals. These can interfere with other systems on–site and with systems outside the station.

- The DORIS system is an active producer of RF, and its impact on the other systems at the site should be carefully evaluated. DORIS transmits at 400 MHz and 2 GHz in a hemispherical, omni-directional pattern, which can interfere with the VLBI reception;
- Most SLR stations use radars operating typically in the regions of 9.4 GHz for aircraft surveillance and safety which can also interfere with the VLBI; other SLR systems may rely on aircraft broadcast beacons or optical sensors, thus avoiding the RF interference issue.
- Off-site broadcast and reception (telephone, TV, radio, communication, etc.) may cause RF interference on site or be subject to interference from instrument on site. (See Radio Frequency and Optical Interference discussion below)

RFI can be produced by the DORIS beacon, the SLR-radar system, local oscillators inside of GNSS antennas, pulse generator of SLR-systems, mobile phones and PC-processors, WLAN, and even bad light bulbs. Care must be taken in the station layout; a combination of distance, terrain, physical obstructions, and phased operations can be used to mitigate these interference problems.

Maritime radar systems have a detrimental impact on VLBI-measurements, so close proximity to ports and harbors may pose an additional problem. Locations near highways, main roads with frequent traffic and railways should be avoided due to RFI and ground noise, which is sensed by gravimeters and seismic instruments. Such noise also can have an impact on optical parts of SLR systems and frequency standards (vibrations). Parking lots and local traffic at the observatory should be kept away from gravimeters, seismic instruments and frequency standards. Wind generators are a known RFI source. High-energy supply line or metal constructions in the air are also sources of RFI and multipath problems.

Table 1. Radio Frequencies by Technique

	Broadcast		**Receive**	
System	**Frequency**		**Frequency**	
SLR radar	9.4 GHz	Highly Directional 4 kW peak	NA	NA
VLBI			2-14 GHz	VLBI needs a hemispherical sky to point at radio sources; highly directional sets of observations within the hemisphere
GPS			1227.6 MHz (L1) 1575.4 MHz (L2) 1176.45 MHz (L5)	Hemispherical (sensitive down to the horizon)
Galileo			1.1 – 1.6 GHz	
GLONASS			1.1 – 1.6 GHz	
BeiDou			1.1 – 1.6 GHz	
DORIS	401.25 MHz 2.036 GHz	Omni-Directional	NA	NA

In selecting a site location, on-site and local RFI can be reduced by use of:

- Local topography and RF blockers blocking structures (including buildings);
- Non-radar techniques such as aircraft beacon receivers and optical sensors for aircraft detection (these may not be sufficient for local authorities in some areas);
- Beam avoidance strategies between the SLR radar and the VLBI;
- Spreading instruments outside the site perimeter (e.g., place the DORIS a short distance (~300 meters away) at a separate but survey accessible site).

NASA studies recommend that RFI should ideally be <<80 dBW at the VLBI antenna location. Studies on DORIS/VLBI compatibility are also underway at BKG; results will be available soon.

The laser broadcasts at 532 nm into a narrow beam with divergence in the range of 10–30 arcsec. There are two common types of laser transmitters: Legacy systems operating at 5–10 Hz, with milli-Joules output and high repetition systems operating both at milli- and micro-Joule output levels. The receiver has a narrow-band filter to delete most extraneous light. Human and aircraft illumination must be avoided (see Air Traffic and Aircraft Protection Section below).

Site Area (Reservation)

Depending upon the instruments on-site and the RFI reducing measures taken, the site will require between 3 and 8 hectares, plus some control over the surrounding region to satisfy horizon and RFI requirements. Core Sites at GSFC (USA) and Wettzell (Germany) are shown in Figure 2a and 2b.

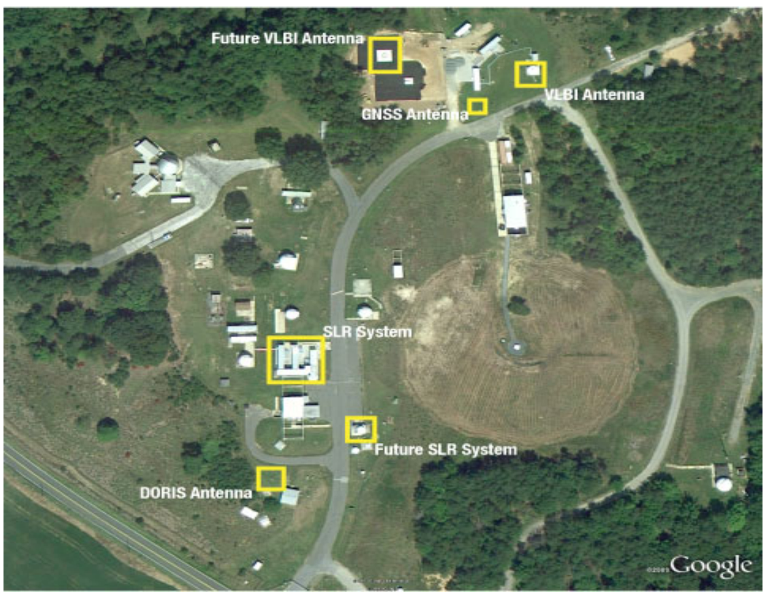


Figure 2a. Core Sites at GSFC, USA

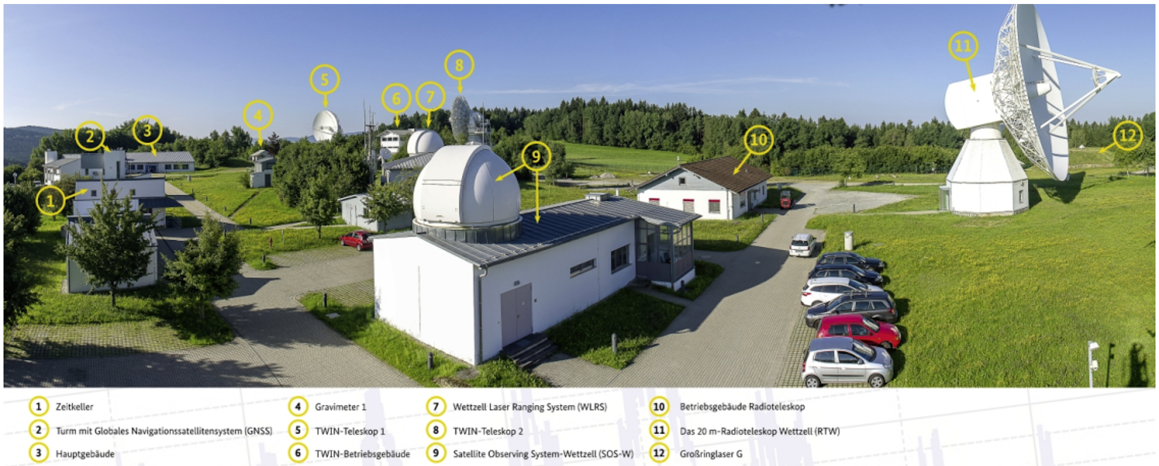


Figure 2b. Core Site at Wettzell, Germany

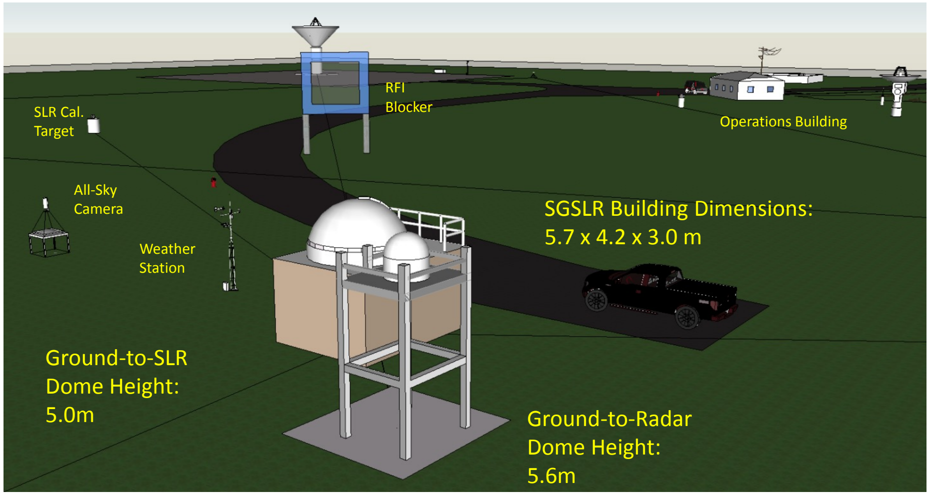
The site might include as part of a control building, a room for an environmentally controlled centralized timing system and other instruments such as gravimeters and seismic measurements, workshop and storage space, and power generators and room for back-up batteries (for example, for a second VLBI instrument). A reinforced concrete pad or solid structure as base will support any additional facility; this design will vary depending on the site; either bedrock or a concrete base at least 2m into subsurface will be required.

The VLBI antenna and the SLR telescope will require large reinforced concrete foundations extending at least two meters into the subsurface, unless bedrock is encountered before. The area around the VLBI antenna should be level and covered with gravel or pavement to provide a stable working surface for aerial man-lifts and cranes. A network of reinforced concrete pillars for survey monuments will be required around the site. Soil borings will be necessary to analyze the engineering characteristics of the soil and ensure stability of the foundations and survey monumentation. Deficiencies in the monumentation may result in seasonal motions that can corrupt geophysical signal over the lifetime of the platform (>20 years).

Figures 3a and 3b show an idealized site configuration depicted by NASA with a site blocker protective screen between the SLR and VLBI to reduce RFI.

Horizon Conditions

The next generation systems will require that the viewing horizon be lowered to five degrees to add significant strength to geodetic products. With VLBI, this configuration will allow more distant stations to “connect” to improve interstation geometry. With SLR, GNSS, and DORIS, it will significantly improve orbital coverage and separation of errors in the estimated station height and systematics in the range measurements.



Approximate building dimensions shown

Figure 3a. Idealized site layout showing Site RF Blocker between SLR and VLBI (Provided by Jaime Esper/NASA)

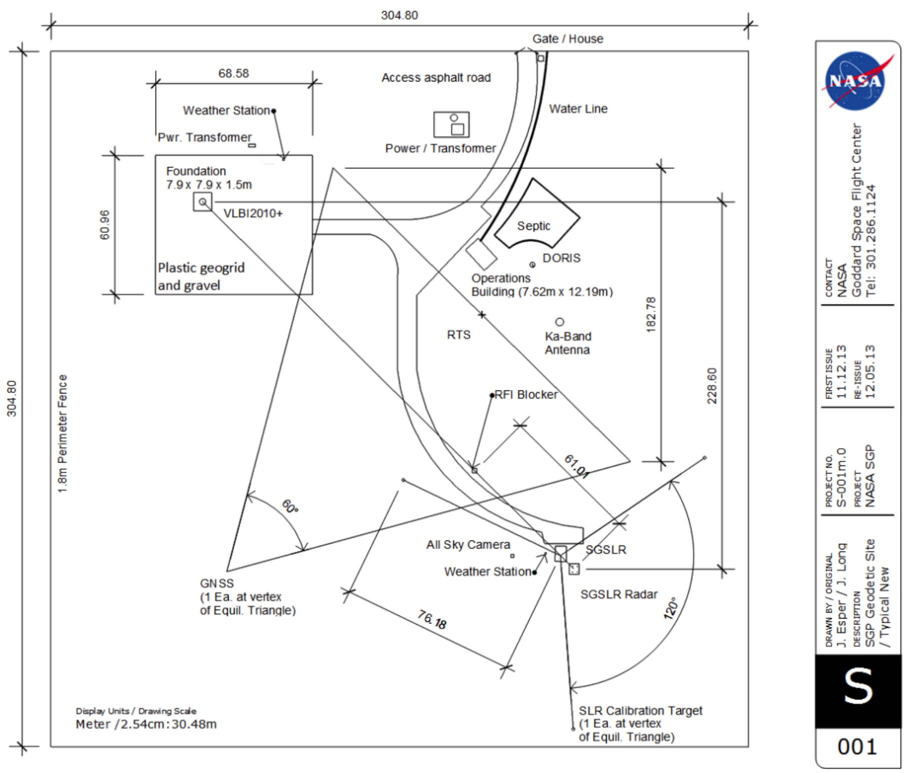


Figure 3b. Notional Site Layout in the NASA Space Geodesy Project Plan highlighting the RF Site Blocking Scheme (Provided by Jaime Esper/NASA)

Ideally, stations should have five-degree elevation, obstruction free view over 95% of the horizon. Minor objects riding above this level may be tolerated, but RF-reflective surfaces, bodies of water, cliffs, walls and metal walls should be avoided. GNSS antennae and to a lesser extent DORIS antennae are subject to multipath interference from structures (particularly metal), including wires separated by 15 to 25 cm and metallic fences, within 100m of the antennae.

Although the SLR systems can track in daylight, they are sensitive to light directed down the receiver path. The site should be located away from sources of high ambient light to maximize system performance.

The SLR should have line of sight to 2–3 carefully surveyed ground targets for calibration, preferably 90 – 120 degrees apart and with precise connection to the local area survey network.

Air Traffic and Aircraft Protection

The laser beam must be steered well clear of aircraft. Illuminating an aircraft is not only dangerous, but may even lead to a complaint to government authorities that could initiate a prolonged ordeal and result in termination of the laser ranging operations. To the extent possible, stations should be selected away from air corridors and airports; planning should be done in consultation with local, regional and national authorities to build healthy, long-term relationships.

Radar is one of the most commonly used techniques to avoid accidental laser illumination of aircraft. The radar system monitors the airspace surrounding the transmitted laser beam and blocks the laser beam should an aircraft enter this airspace. RF sources, RF receivers, tall buildings nearby, etc., could potentially prohibit the use of this protection system. Therefore, the requirement to use a radar system should be included in the site selection process. Use of the radar aircraft detection system will require official permission from local radio frequency authorities.

In addition, local air traffic patterns, SLR system operational hours, minimum transmit elevation angle, laser power and atmospheric conditions are all items that need to be considered in scheduling and planning SLR operations.

Communications

The most demanding communications requirement comes from eVLBI. A subset of the VLBI stations will be observing in an intensive mode for near real-time updates of UT1 and must stream the data electronically for rapid processing. In addition, data volumes with eVLBI will be very large, making disk shipment impractical. Stations without eVLBI will occasionally be required to transmit VLBI data electronically to support special campaigns, systems-testing and diagnostic procedures. All Core Sites, whether deploying eVLBI or not, must have broadband Internet communications for near real-time data transfer and instrument control and monitoring. All stations must have telephone service and in general a robust communication system against power failures.

Table 2. Communications Requirements

System	Data Volume
SLR	3 - 10 GBytes/day
VLBI	5 - 55 TBytes/day*
GNSS**	130 MBytes/day
DORIS	General communications
Site Housekeeping	Small

* Depends upon the amount of data to be delivered electronically.
** Baseline – raw 1s data with current satellites and constellations

Land Ownership

In order to ease permit and access problems, federal, state, county, or city government-owned land is preferable. Next in desirability is land owned by universities or large industries. Least desirable is small, privately owned land. This criterion also applies to access roads to the site and the locations of calibration targets and azimuth posts. Permission must be obtained to clear trees and brush in order to have inter-visibility between monuments, azimuth posts, and target boards.

It should be impressed on the leaseholder that this is a very long-term project and the time period of the original lease or agreement should reflect this. The global aspects of the program and the UN resolution should be reinforced in contracts and agreements.

Rapidly developing areas can pose a problem. The site should be located away from housing development, industrial activity, or heavy agricultural activity and nuclear plants. Operations at several stations in the current global network are now being severely hindered by encroaching construction and industry to the point where long-term viability is in question.

Local Ground Geodetic Networks

Monitoring of ground stability and local motion is essential to the proper interpretation of the space geodesy data. Otherwise, local motions may be aliased into the global reference-frame products. Precise ties within ground survey networks, within the local site, and over a wider regional footprint are required in order to monitor instrument and ground stability.

Local Station Network

At each station there should be a minimum of three ground reference survey pillars (using standard monuments) around each instrument at a distance of 25–100 m, approximately 120 degrees apart. Pillars may serve more than one instrument and be used for the measurements to determine the tie vectors between instrument reference points. There must be mutual line-of-sight visibility among the pillars so that ground-monitoring systems (e.g., a total station surveying system that consists of an electronic theodolite with an integrated Electronic Distance Measurement Instrument) can be used for routine or programmed baseline monitoring to an accuracy of better than 1 mm.

Several of the pillars will also house secondary GNSS receivers to support geodetic monitoring and orientation within the reference frame. Several of the pillars will also house corner-cube targets for SLR calibration.

Regional Network

The local station network must be connected to the regional/national geodetic networks through a regional geodetic “footprint”, monument network over a well designed regional footprint, that can provide robust ties to better than 1 mm, out to 10-30 km. A conceptual layout of the local area network is shown in Figure 4.

Two Total Stations could be positioned to perform intersection measurement to isolate movements/ At least three GNSS antennas are needed to provide the orientation in the GNSS reference frame. The central pillar in this image is in a well-suited position got a site marker.

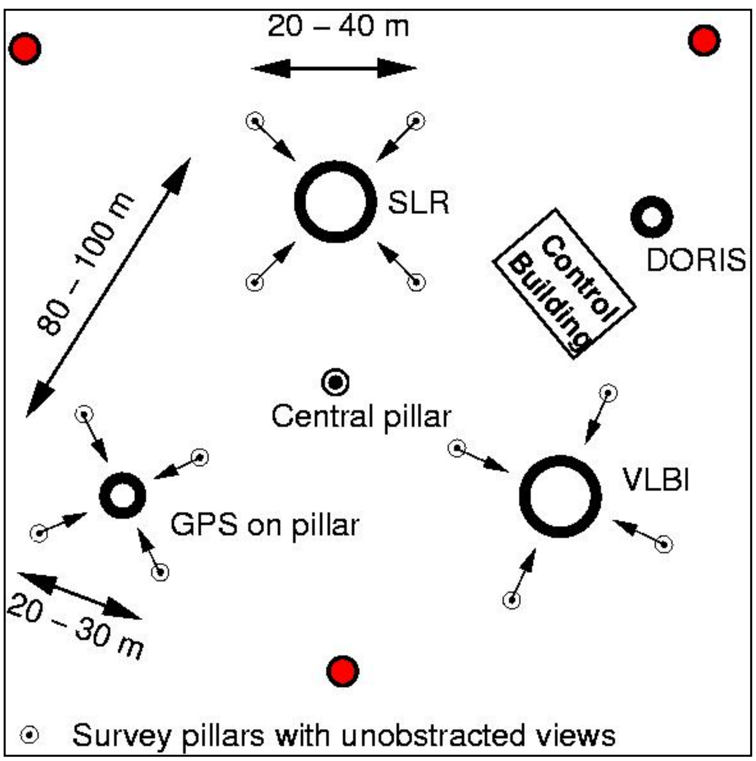


Figure 4. Conceptual Layout of the Local Area Geodetic Markers; dimensions included just to give a rough estimate of scale

Site Accessibility

The station will be operated ideally 24 hours a day, 7 days a week, within local constraints. Station personnel must have access to the station. Personnel who support station maintenance and upgrade, and who may not be based in the country, must have country and site access as needed. Logistical support must be available and components should be delivered to the site within 48 hours from arrival within the country.

Off-highway access roads to the site must be capable of handling the vehicles transporting the observing system to the site as well as the vehicles bringing the crew to and from the site on a daily basis and under nearly all weather conditions. The access roads must be graded and maintained in good condition for the duration of the measurement period. Also, the access road should be able to accommodate the size of the large antenna systems occupying the site; noting that trailer weight could be as large as 23,000 kilograms. A key to any locked gate should be readily available to the crew.

Local Infrastructure and Accommodations

Personnel living accommodations and sources of supplies and fuel should be reasonably near the site (within 25 to 50 km). It is also important, but not crucial, to be near telephone and power lines.

The site should have office and rest quarters with daily personnel working conveniences such as running water and a sewage/septic system and a kitchen. Although remoteness may be good for operations, proximity of living places and services for station personnel is an important consideration.

Electrical Power

The site should have a robust, reliable power system with sufficient backup to keep alive the frequency standards, cryogenic cooling systems and laser oscillator. The power systems should include:

- Clean network power of 120 kW at 50 or 60 cycles
- Alternative power generation for power outages
- Battery backup for frequency standards, cryogenic cooling and the laser oscillator.
- Power distribution in different circuits, separation of switching devices (i.e., aircon) from “clean” network
- Common earth wire for all distributed instruments
- Underground cable guides to avoid impacts or damage by lightening

Power requirements will depend on the particular instruments on site and the site conditions, but typical power requirements are estimated in Table 3.

As an example the current NASA SLR MOBLAS systems require:

- 3 phase power
- 100 amperes per phase
- 120 VAC phase to neutral
- 208 VAC phase to phase
- 60 Hertz
- <25 ohm ground field

Technical and Personnel Support, etc.

The station will require a local team including a senior technician, eight shift technicians (two per shift) a logistics and administrative officer and a custodian. Local operational models may of course depart from this model, particularly if single-manning SLR operations are standard as for many of the current global SLR sites. Operational demands of the other techniques on site, such as VLBI, will also be a factor in assessing the total manning requirements.

Table 3. Electrical Power Requirements

	Power (kW)	**Phase Condition**	**Other Conditions**
Time and Frequency	12 kW	2-phase	UPS backup
VLBI	30 kW	3-phase	UPS backup
SLR	20 kW	3-phase	UPS backup
GNSS	1.0 kW	2-phase	UPS backup
DORIS	1.0 kW		UPS backup
Control and Local Infrastructure	5.0 Kw		UPS backup
Total	~ 70 kW		
Additional Equipment			
Gravimetry	12 kW	2-phase/3-phase	UPS backup

Site Security and Safety

The station will have valuable equipment and many opportunities for injury for those who are untrained. Precautions based on full risk assessment of all operations should be in place and will have to be approved by the local agency. Security would be improved if the station was placed in a remote area or a government installation or otherwise protected area. Several U.S. and foreign sites in populated areas have been compromised by having the survey monuments destroyed, vandalized, or stolen.

Information Technology (IT) security is also dependent upon physical site security. Computers on site are inherently connected to the network and hence to the data centers. Sites must maintain IT security compliance with government standards and industry best practices.

Local Commitment

Building and operating a Core Site is a large, long-term commitment. The local agency must be committed both to space geodesy and to the international space geodesy community to make this endeavor a success. Every well-operated station will play a vital role in the GGOS international network. We mention again that the global aspects and the UN resolution may strengthen our position in dealing with local agencies.