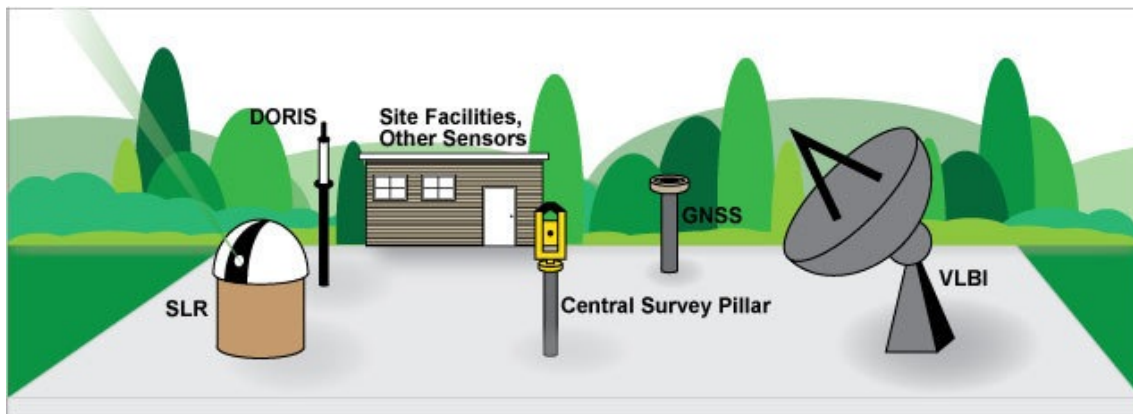


Global Geodetic Observing System (GGOS)

Site Requirements for GGOS Core Sites



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INPE (Nov. 2011) - Review comment 1:

The introduction of a Glossary would help a more transparent understanding of the document.

INPE (Nov. 2011) – Review comment 2:

The text presents in brown letters contents which are being suggested for consideration.

REQUIREMENTS FOR CORE SITES

The Global Geodetic Observing System, an entity under the International Association of Geodesy (IAG), has undertaken the task of defining the geodetic requirements and advocating for the geodetic infrastructure necessary to meet global change and other societal challenges. 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 great 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 evolution of International Terrestrial Reference Frame (ITRF).

INTRODUCTION AND JUSTIFICATION

What is a Core (Fundamental) Site?

A Core Site for geodesy is a geodetic observatory which defines terrestrial reference points in the space and time domain and in the gravity field of Earth. Observational data from complementary instruments are used in a synergetic way, to obtain the most precise global reference frame (see Figure 1).

Nowadays the space domain is dominated by four space geodesy techniques:

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

The use of SLR and VLBI methods require frequency standards like

- Cesium standards and
- Hydrogen-maser.

The time domain is ruled by the local time scale generated by these standards. The reference on the potential level of the gravitational field of Earth is determined by

- absolute gravity meter (AG) and
- Superconducting gravity meter (SG).

These major measuring techniques must be complemented by local sensors such as

- meteorological sensors (for refraction corrections and data reduction),
- hydrological sensors (for data reduction),
- Seismic sensors (for data reduction in time series).

The above listed instruments must be spatially referred to each other. This implies that a local geodetic network and regular local surveys for control are required.

A geodetic observatory is called a Core Site for geodesy, if the co-located instrumentation is

- operated permanently delivering decadal time-series,
- redundant for the detection of system-dependent errors,
- complementary for a synergetic 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 complementing measuring systems is essential for the data quality by tracking down otherwise non-detectable systematic errors. The synergetic use of the advantages of different space-techniques leads to the most accurate reference frame, called ITRF.

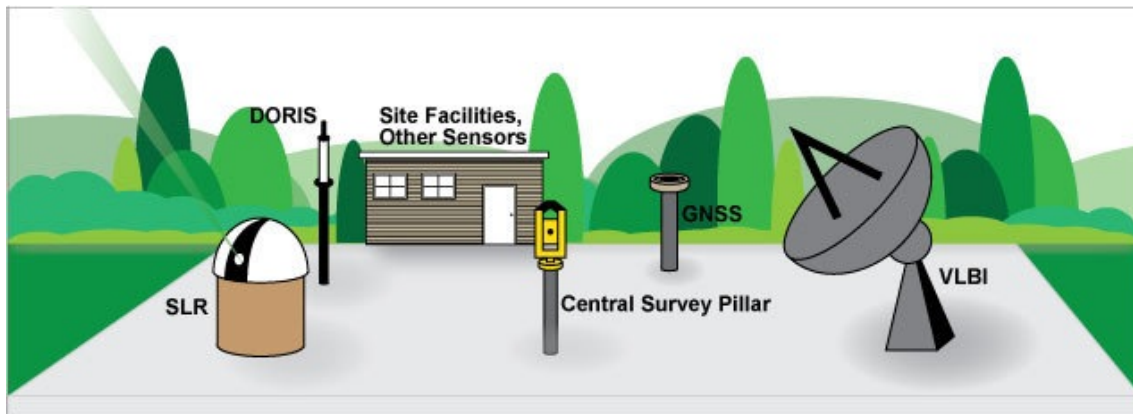


Figure 1. Schematic of a Core Site

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. Co-location is the condition to make the essential connection among the techniques through the measurement of the inter-system vectors to sub-mm accuracy.

Why do we need the Reference Frame?

Reference frames are needed for two purposes:

- **Geoinformation:** Any environmental parameter needs to be mutually georeferenced. Reference frames are basic 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 a 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 hydrology conditions (too much water or too little on the surface 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 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 and 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 reference frame.

The characterization and monitoring of new and the monitoring of existing, important and possibly critical parameters, associated to important and possibly critical aspects of global change which, can be consistently evaluated only if a higher sampling rate of the time series those parameters can be achieved. However higher sampling rates of those parameters demand for higher precision of measurements which, in their turn, can be achieved only if a correlated higher precision can also be assured for the time series which are associated to the IRTF model, therefore, obtained from a correspondingly higher sampling rate.

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) show that we will need a ground network with approximately 30 co-located Core Sites for geodesy. These network stations must provide measurements that are precise, 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 only three fully co-located stations and 8 – 10 stations with co-location of three of the four techniques. The current network has large geographic gaps, few co-locations, and aging technology leading to inadequate data quality 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.

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 a VLBI 2010 concept. The prototype of a new class of radio telescopes is realized with the Twin Telescope at the German observatory in Wettzell. Another prototype for testing new front and back-ends is being built at GSFC. NASA GSFC also has a New Generation SLR (NGSLR) prototype system being built at its optical test site, within a few hundred meters of the new VLBI system. Other groups also have new technology systems underway, for example several groups are now deploying more efficient short-pulse, kHz repetition-rate SLR systems. New GNSS receivers are currently being built to accommodate new additional frequencies and the wider constellation of GNSS satellites. New DORIS ground beacons (V3.1 and V3.2) improve robustness and reliability.

Purpose of this Document

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

More detailed specifications for the DORIS systems can be found at:

ftp://ftp.idsdoris.org/pub/ids/stations/System_Requirements_For_Management_Of_The_DORIS_Station_Network.pdf

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 3 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 3 stations are necessary to capture intra-plate deformation.
- Technique-dependent distribution: Satellite techniques need to observe the complete orbits. 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 full as possible orbit coverage by the 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 a configuration-

dependent systematic. The network configuration of VLBI stations must take care about the ability to cover the entire sky **so that simultaneous,** common views **from** at least a pair of spatially distributed radio telescopes **may be guaranteed.**

The geodetic space techniques are affected by the Earth tides. The models for Earth tides are not yet validated by local measurements with superconducting gravity meters for many **of the existing** sites – especially **for those located** in the southern hemisphere.

Geology

A site located on bedrock is ideal; rock with weathered layers could be satisfactory. A site on sediments is not satisfactory. Any construction should be designed with respect to a ground or soil analysis based on drillings (10-20m depth), and **should also** be away from known faults and regions of local deformation. In areas where this is difficult **to observe**, the surface patterns and activities of nearby faults should be known and mapped. Active faults should not cut through the site. The "slush" zones adjacent to major active faults should also be avoided.

Earthquake regions make up about 30% of the continental surface, **worldwide**. Even in stable "non-earthquake" regions, instabilities may corrupt results at the 1mm position accuracy and 0.1mm/yr velocity accuracy level. Therefore, it is important to have access to data from regional monitoring GNSS networks, which surround the site and, **in this way**, densify the network of **GNSS 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 are **those types of soil that**: slump, creep, slide, or change in elevation, because of variations in ground water level or **in** frost heaving. If hydrological cycles are known to change the reference positions, additional corresponding sensors must monitor the hydrology. Episodic motions must be measured by co-located local sensors.

Site Area (reservation)

The site will require a minimum of 2 -3 hectares with some control over the surrounding region to satisfy horizon and RFI requirements. The VLBI antenna and the SLR telescope will require large reinforced concrete foundations extending as much as 2 meters into the subsurface. 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 **of the** survey monumentation. Deficiencies in the monumentation can corrupt geophysical signal over the lifetime of the platform (>20 years). Core Sites at GSFC, USA and Concepcion, Chile are shown in Figure 2.



Figure 2a. Core Sites at GSFC, USA

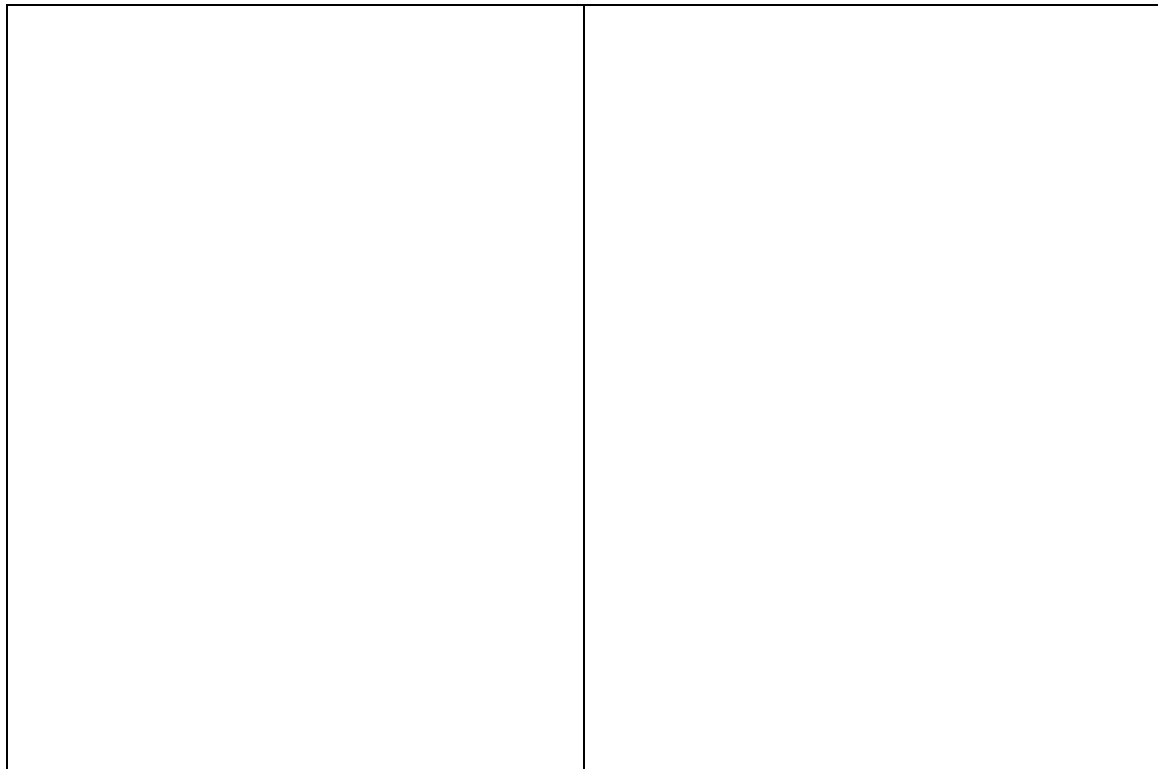


Figure 2b. Core Site at Concepcion, Chile

The site should include room for 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. .

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 a generalized climate condition for Core Sites would likely counteract the global distribution. The ideal meteorological parameter is a clear sky and a dry, local environment.

However, some below-optimal conditions can be considered. This would be the case where, for example, cloud cover is less than 50% during at least 9 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. 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 (SLR, only?) 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 Figure 1). All systems are sensitive to 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. Conversely, the DORIS system is an active producer of RF, and its impact on the other systems on site (and in the wider community) should be very carefully evaluated.

- Interference potential for GNSS (GPS, Glonass, Galileo, and COMPASS) is worst near the L1, L2, L5 operating frequencies in the band of 1.1 – 1.6GHz 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 for VLBI is 2-14 GHz, but the beam is highly directional.

RF site investigation measurements are mandatory 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.

Table 1. Radio Frequencies by Technique

System	Broadcast		Receive	
	Frequency		Frequency	
SLR radar	9.4 GHz	Highly Directional 4 kW peak	NA	NA
VLBI			2 –14 GHz	Highly Directional
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	
COMPASS			1.1 – 1.6 GHz	
DORIS	401.25 MHz 2.036 GHz	Omni-Directional	NA	NA

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

- DORIS transmits 400 MHz and 2 GHz in a hemispherical pattern omnidirectional pattern.
- Most SLR stations use radars operating typically in the regions of 9.4 GHz for aircraft surveillance and safety

Homemade 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. **Therefore**, a combination of: distance, terrain, physical obstructions, and phased operations can be used to mitigate these interference problems.

The laser broadcasts at 532 nm into a narrow beam with divergence in the range of 10 – 30 arcsec. The receiver has a narrow-band filter to delete most

extraneous light. There are two common types of laser transmitters; Legacy systems operating at 5 – 10 Hz, with millijoules (?) output and high repetition systems operating both at milli- and micro- Joule output levels. Human and aircraft illumination must be avoided (see Air Traffic and Aircraft Protection Section below).

Maritime radar systems have a detrimental impact on VLBI-measurements so close proximity to ports and harbors may pose an additional problem. The closeness of highways, main roads with frequent traffic and of railways should be avoided due to the ground noise, which is sensed by gravity meters 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 gravity meter, 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.

Horizon Conditions

The next generation systems will require that the viewing horizon be lowered to 5 degrees to add significant strength to geodetic products. With VLBI, it will allow more distant stations to “connect” to improve inter-station geometry. With SLR, GNSS, and DORIS, it will significantly improve orbital coverage.

Ideally, stations should have 5-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 geodetic receivers 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.

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, use of this 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 will come from eVLBI. A subset of the VLBI stations will be monitoring Earth rotation 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 broad-band 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	10 GBytes/day
VLBI(legacy)	?
eVLBI	4 Gb/sec
GNSS*	130 Mbytes/day
DORIS	General communications
Control and Monitoring	?

Note: *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. 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.

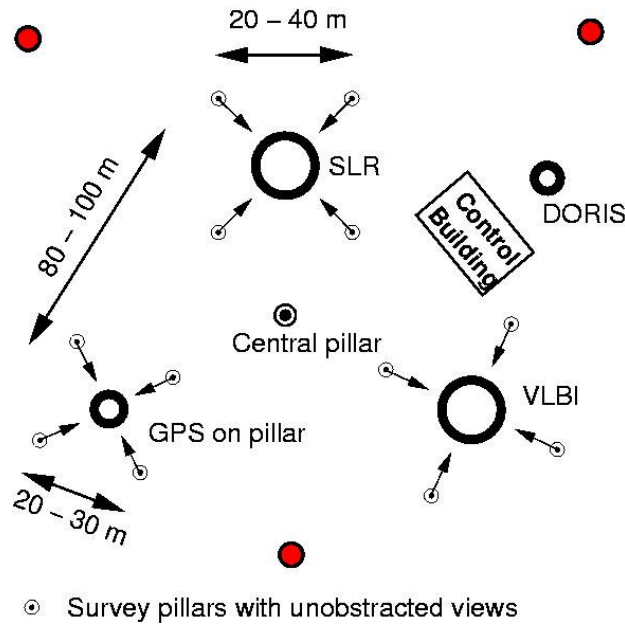


Figure 3. Conceptual Layout of the Local Area Geodetic Markers; dimensions included just to give a rough estimate of scale

(A more complete legend is suggested for the above Figure 3: ex. “red” dots)

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. A key to any locked gate should be readily available to the crew. Trailer weight could be as large as 23,000 kilograms.

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. 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

Typical power requirements for the individual components are shown in Table 3.

Table 3. Electrical Power Requirements

	Power (kW)	Phase Condition	Other Conditions
VLBI	100 kW (?)	3-phase	UPS backup
SLR	30 kW	3-phase	UPS backup
GPS	0.1 kW	2-phase	UPS backup
DORIS	160 W		UPS backup
Control and Local Infrastructure UPS Backup (?)			

As an example the current NASA SLR MOBILAS 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 (2 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.

Site Security and Safety

The station will have valuable equipment and many opportunities for injury for those who are untrained. 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.

Local Commitment

Building and operating a Core Station is a large, long-term commitment. The local agency must be committed to space geodesy and the international space geodesy community to make this endeavor a success. Every well operating station will play a vital role in the GGOS international network.