

A world map with topographic shading, showing landmasses in various shades of green and brown, and oceans in light blue. The map is centered on the Atlantic Ocean. The title text is overlaid on the map.

Overview and Discussion of Site Requirements

November 8, 2011

Meeting with Brazilian Delegation
NASA GSFC



NASA Space Geodesy Project



- Provide NASA's contribution to a worldwide network of modern space geodesy fundamental stations;
- Phase 1 Proposal developed for a 2-year activity:
 - Complete network simulations to scope the network and examine geographic, operational and technical tradeoffs based on LAGEOS and GNSS tracking with SLR;
 - Complete the prototype SLR (NGSLR) and VLBI (VLBI 2010) instruments;
 - Co-locate these instrument with the newest generation GNSS and DORIS ground stations at GSFC;
 - Implement a modern survey system to measure inter-technique vectors for co-location;
 - Develop generalized station layout considering RFI and operations constraints;
 - Undertake supporting data analysis;
 - Begin site evaluation for network station deployment;
 - Develop a full network implementation plan;
- Follow-on phase for deployment for up to 10 stations;



Global Geodetic Observing System (GGOS)



Official Component (Observing System) of the International Association of Geodesy (IAG) with the objective of:

Ensuring the availability of geodetic science, infrastructure, and products to support global change research in Earth sciences to:

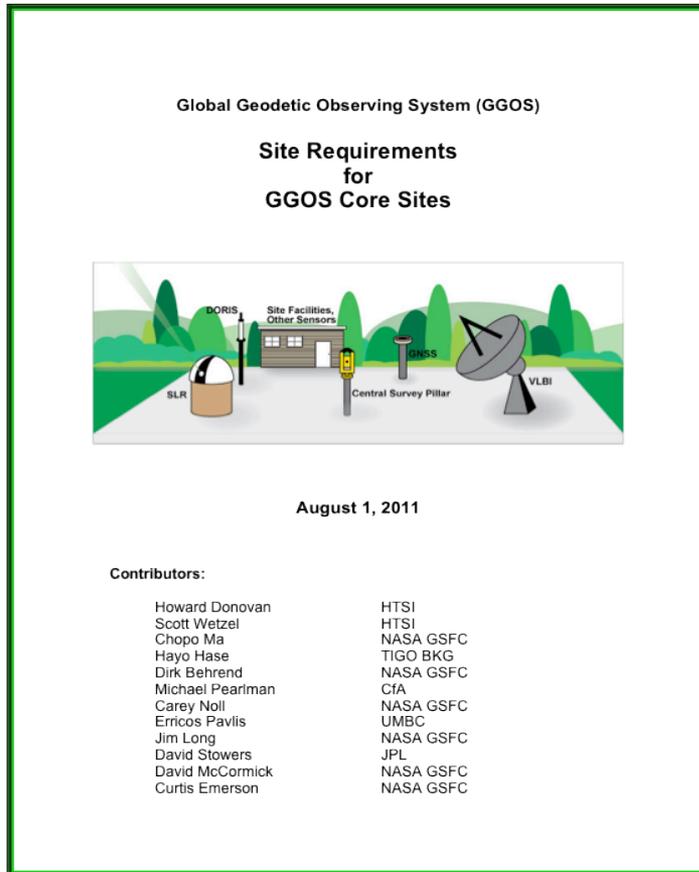
- *extend our knowledge and understanding of system processes;*
- *monitor ongoing changes;*
- *increase our capability to predict the future behaviour; and*
- *improve the accessibility of geodetic observations and products for a wide range of users.*

Role

- **Facilitate networking** among the IAG Services and Commissions and other stakeholders in the Earth science and Earth Observation communities,
- **Provide scientific advice and coordination** that will enable the IAG Services to develop products with higher accuracy and consistency meeting the requirements of global change research.

GGOS Bureau for Networks and Communications

- Provides oversight, coordination, and guidance for the development, implementation and operation of the Network of Core (co-location) Sites.
- Develops a strategy to design, integrate and maintain the fundamental geodetic network of co-located instruments and supporting infrastructure in a sustainable way to satisfy the long term (10 - 20 years) requirements identified by the GGOS Science Council.



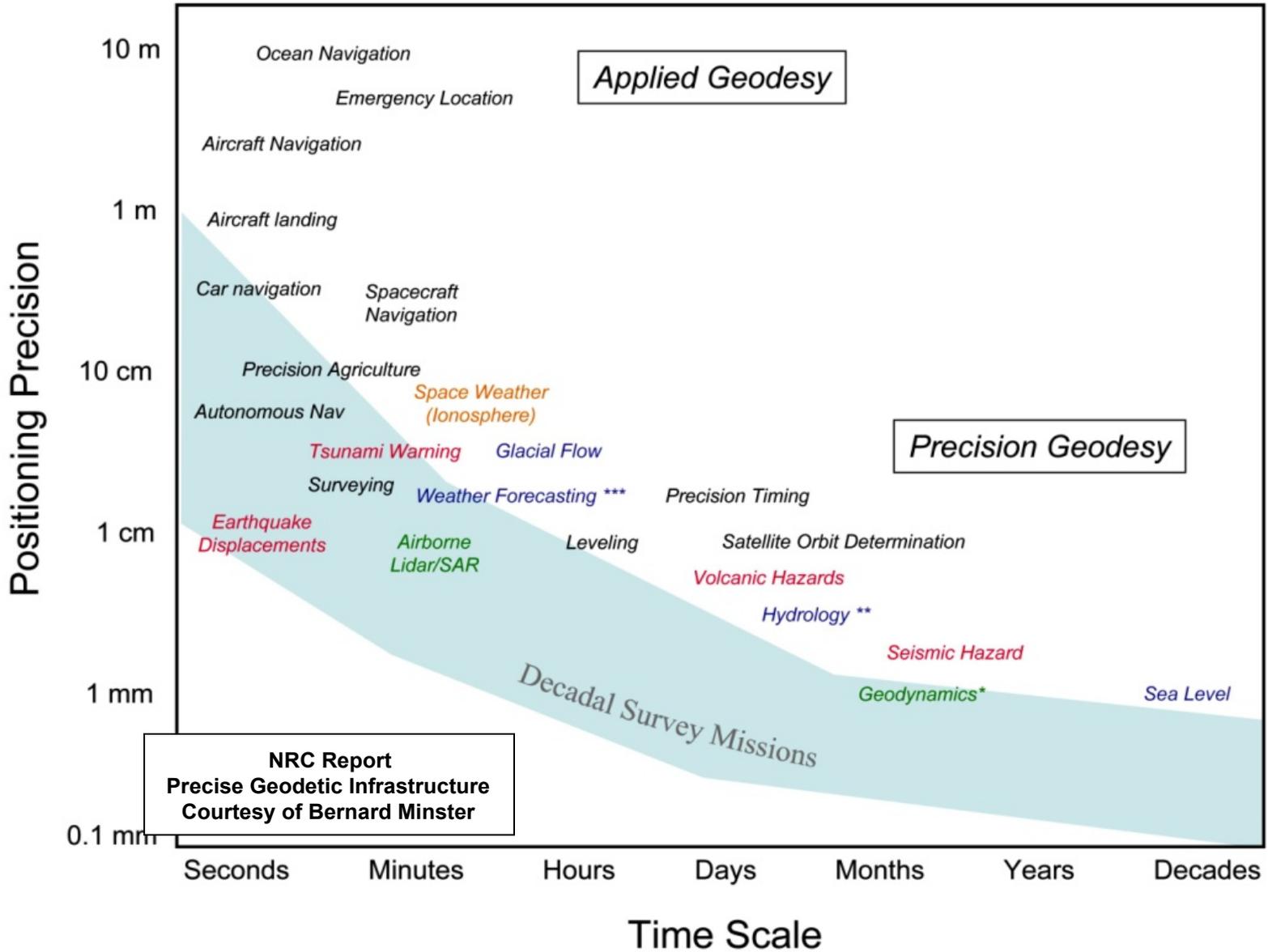
- **Introduction and Justification**
 - What is a Fundamental Station?
 - Why do we need the Reference Frame?
 - Why do we need a global network?
 - What is the current situation?
 - What do we need?
- **Site Conditions**
 - Global consideration for the location
 - Geology
 - Site area
 - Weather and sky conditions
 - Radio frequency and optical Interference
 - Horizon conditions
 - Air traffic and aircraft Protection
 - Communications
 - Land ownership
 - Local ground geodetic networks
 - **Site Accessibility**
 - Local infrastructure and accommodations
 - Electric power
 - **Site security and safety**
 - Local commitment



International Terrestrial Reference Frame (ITRF)



- Provides the stable coordinate system that allows us to measure change (link measurements) over space, time and evolving technologies.
- An accurate, stable set of station positions and velocities.
- Foundation for virtually all space-based and ground-based metric observations of the Earth.
- Established and maintained by the global space geodetic networks.
- Network measurements must be precise, continuous, robust, reliable, and geographically distributed (worldwide).
- Network measurements interconnected by co-location of the different observing techniques





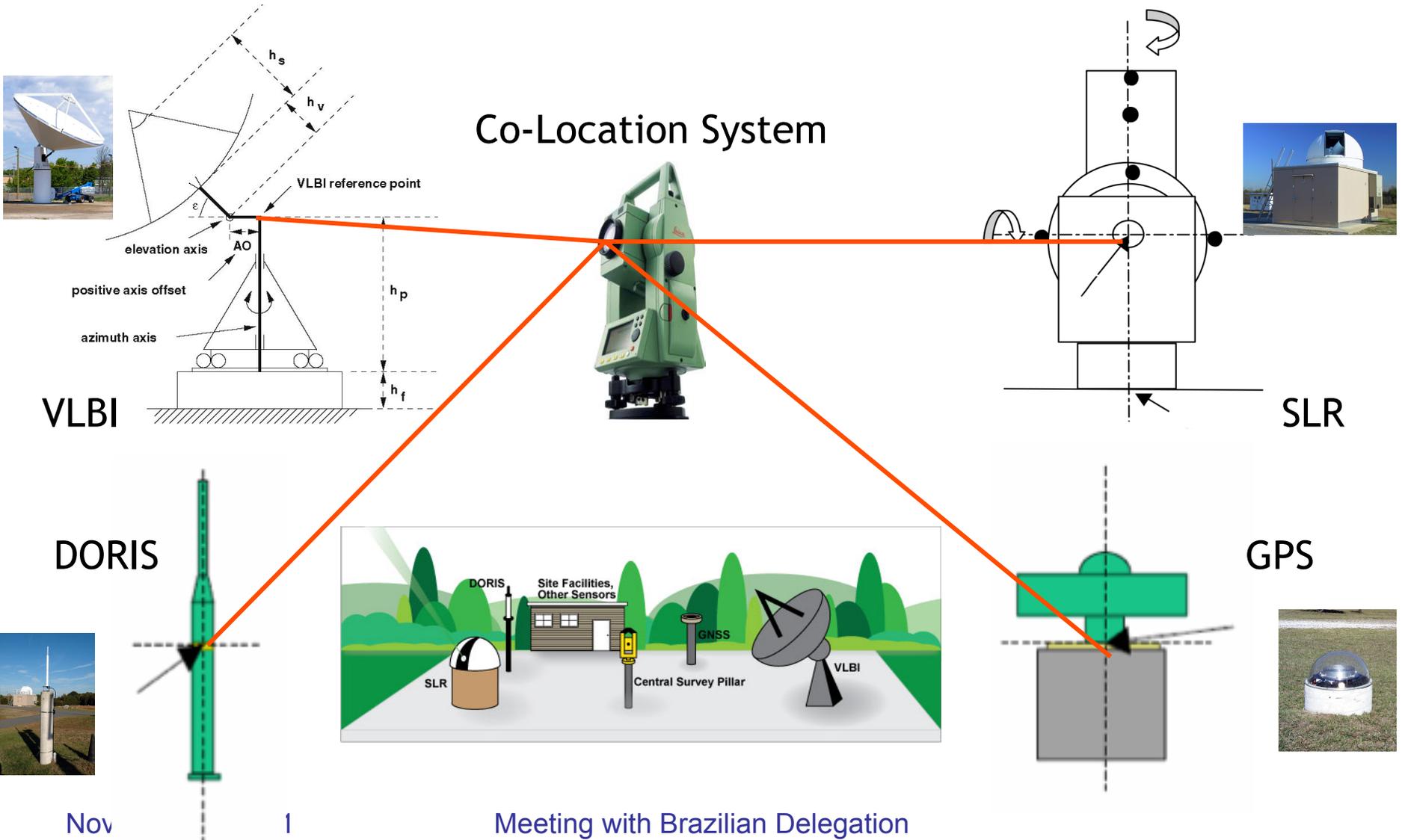
Global Geodetic Observing System Reference Frame Requirement



- Most stringent requirement comes from sea level studies:
 - “accuracy of 1 mm, and stability at 0.1 mm/yr”
 - This is a factor 10-20 beyond current capability
- Accessibility: 24 hours/day; worldwide
- Space Segment: LAGEOS, GNSS, DORIS Satellites
- Ground Segment: Global distributed network of “modern”, co-located SLR, VLBI, GNSS, DORIS stations
- Co-locate with and support other measurement techniques including gravity, tide gauges, etc.
- Simulation studies to date indicate:
 - ~30 globally distributed, well positioned, co-location stations will be required to define and maintain the reference frame;
 - ~16 of these co-location stations must track GNSS satellites with SLR to calibrate the GNSS orbits which are used to distribute the reference frame.

What is a Core Site?

Co-Location System



Nov 1

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Why Do We Need Core Sites? (Terrestrial Reference Frame)



SLR



VLBI

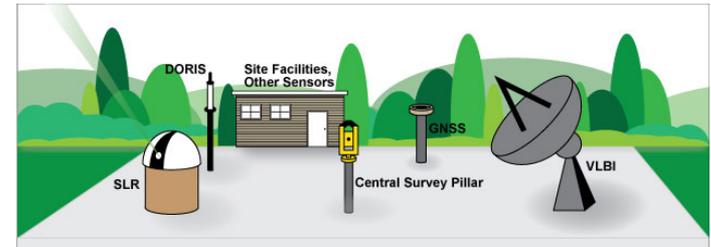


GNSS



DORIS

- **A ground site with co-located SLR, VLBI, GNSS and DORIS (where available) so that their measurements can be related to sub-mm accuracy**
- **Why do we need multiple techniques?**
 - **Measurement requirements are very stringent**
 - **Each technique makes its measurements in a different way and therefore each measures something a little different:**
 - **Terrestrial (satellite) verses celestial (quasar) reference**
 - **Range verses range difference measurements**
 - **Broadcast up verses broadcast down**
 - **Radio verses optical**
 - **Active verses passive**
 - **Geographic coverage**
 - **Each technique has different strengths and weaknesses**
 - **The combination allows us to take advantage of the strengths and mitigate the weaknesses**



GNSS Positioning Systems

(GPS, Glonass, Galileo, COMPASS, etc)

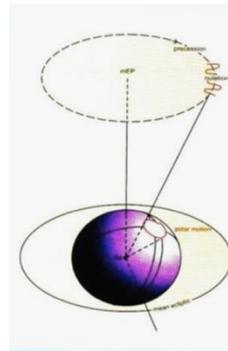
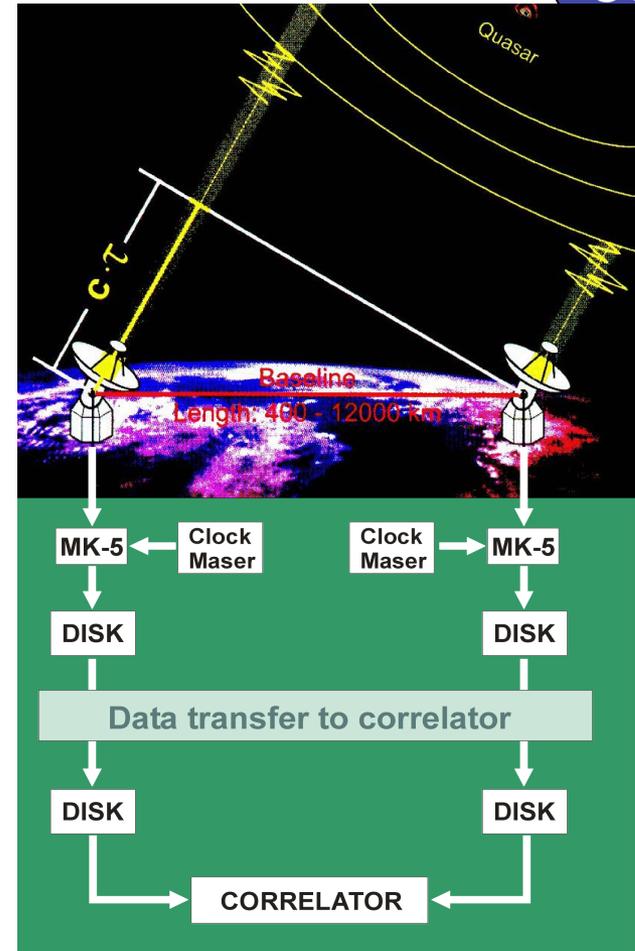


- ✦ The modern navigation tool
- ✦ The satellites broadcast and the ground stations receive to determine position and time ***anywhere*** on Earth
- ✦ Real-time position monitoring
- ✦ Receiver equipped satellites receive for precision orbit determination
- ✦ Navigation, Surveying, Geodesy
- ✦ Understanding complex dynamic processes of the Earth
- ✦ Atmospheric and Space weather

Community is organized under the International Global Navigation Satellite System Service (IGS)

VLBI Observing System

- Radio signals from quasars or radio galaxies
- Signal correlated among stations to extract data products
- Earth Orientation Parameters
 - Precession/Nutation
 - Polar motion; UT1 - UTC
- Positions, Velocities, Time series
- ITRF and ICRF (EOP and Scale)

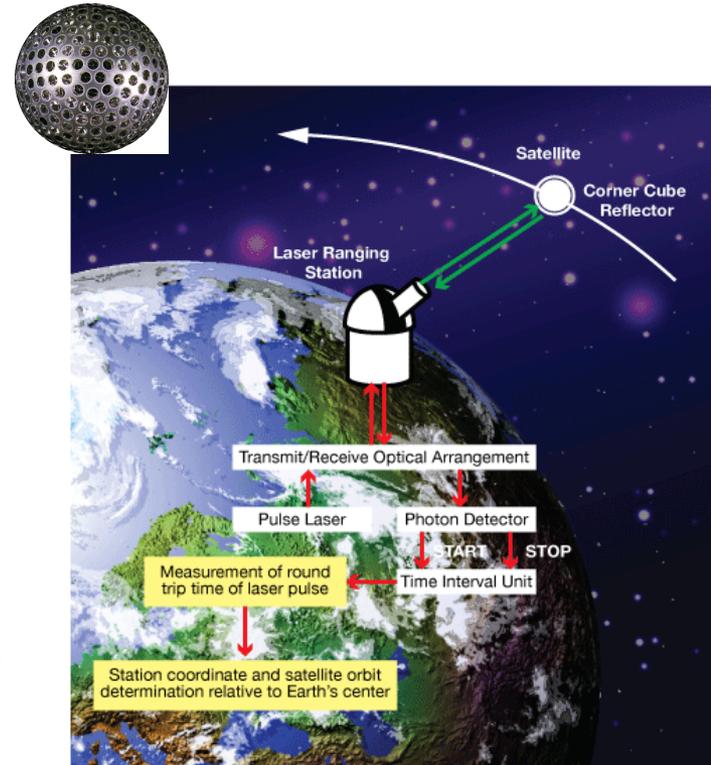


Community is organized under the International VLBI Service for Geodesy and Astrometry (IVS)

Satellite Laser Ranging Technique

Precise range measurement between an SLR ground station and a retroreflector- equipped satellite using ultrashort laser pulses

- Simple range measurement to passive satellite
- Simple refraction model
- Night / Day Operation
- Near real-time global data availability
- From 400 km to synchronous satellites, and Moon
- Reveals small changes over long time series
- Data Products
 - Reference frame (Earth C/M and scale)
 - Position and velocity
 - Static and time-varying gravity field (mass)
 - Polar motion, length of day)
 - Orbits, calibration, and validation of altimetry missions (oceans, ice)
 - Space science, relativity, lunar science



- Unambiguous centimeter accuracy orbits
- Long-term stable time series

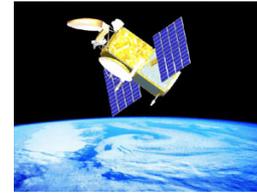
Community is organized under the International Laser Ranging Service (ILRS)



Doppler & Radiopositioning Integrated by Satellite (DORIS).



- **Dual-Frequency Doppler Beacons (2.036 Ghz & 401.25 Mhz), Distributed at Ground Stations Around the World (Global Coverage).**
- **Signals received and recorded on DORIS equipped satellites**
- **Developed by the CNES (Centre National d' Etudes Spatiales) & IGN (Institut Géographique National).**
- **The network was developed to support Precision Orbit Determination (POD) for LEO satellites, such as the SPOT Remote Sensing Satellites & Altimeter Satellites such as TOPEX/Poseidon.**
- **ITRF: Station Position, Velocity, Polar Motion**
- **Gravity field, geoid**
- **On board real time orbit determination for payload products location or platform navigation**



Community is organized under the International DORIS Service (IDS)



Example Core Site

NASA Goddard Space Flight Center, Greenbelt MD, USA

NASA
SGP



- Goddard Geophysical and Astronomical Observatory (GGAO) has four techniques on site
 - Legacy SLR, VLBI, GPS, DORIS
 - NGSRLR semi - "operational"
 - VLBI2010 systems in testing
- GGAO will be the location for the prototype next generation multi-technique station

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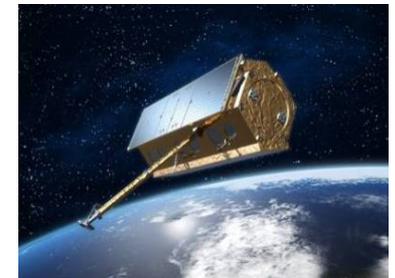
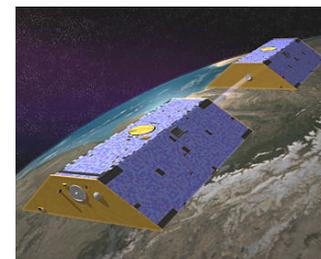
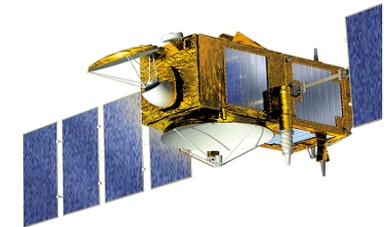
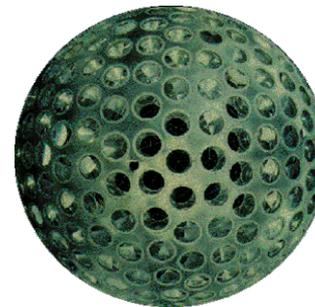
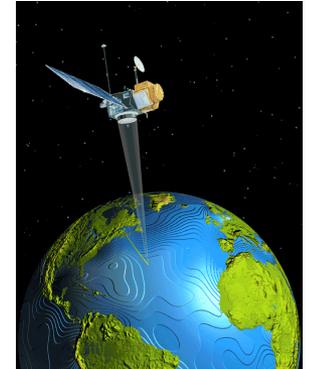
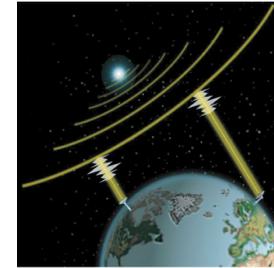
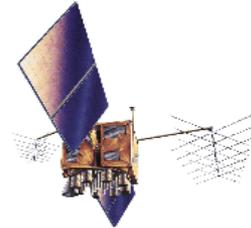
Techniques are moving from Legacy to the Next Generation Technologies



- **Satellite Laser Ranging**
 - Many systems working in the 0.1 – 2 Khz regime;
 - Single photon detection;
 - Increased data yield and daylight ranging on the GNSS satellites;
 - Several new systems in Russia;
 - Progress on the GPS-3 arrays;
- **VLBI**
 - Prototype VLBI 2010 in testing at GSFC and Wettzell;
 - New Systems Systems
 - Tasmania, Katherine, Yarragadee Stations;
 - Wettzell twin telescopes;
- **GNSS**
 - Multiple constellations
 - Additional frequencies
 - New ground stations
- **DORIS**
 - Nearly complete network already
 - Additional satellites
 - New beacons

Space Components

- **Quasars (VLBI)**
 - Positions and velocity
 - EOP
 - Reference Frame
- **Navigation Satellites**
 - Position and velocity
 - Reference Frame (GNSS)
 - Space weather (occultation)
- **Geodynamics Satellites**
 - Positions and velocity
 - Reference Frame (Lageos)
 - Gravity Field (Starlette, Stella)
- **Remote Sensing LEO Satellites**
 - Altimetry (Jason, Envisat)
 - Gravity Field (Champ, Grace)
 - SAR, InSAR (TerraSAR-X, TanDEM-X)



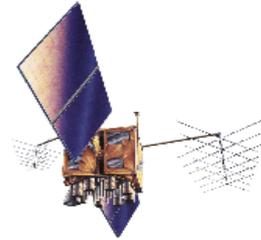
Co-location in Space



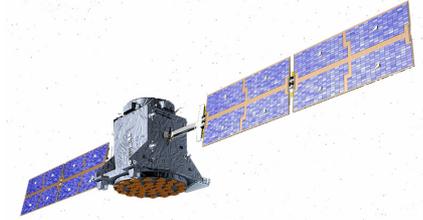
Compass
GNSS/SLR



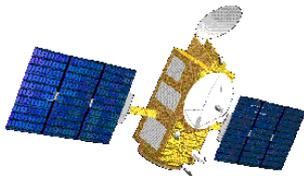
GLONASS
GNSS/SLR



GPS
GNSS/SLR



GIOVE/Galileo
GNSS/SLR



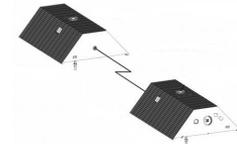
Jason
DORIS/GNSS/SLR



CHAMP
GNSS/SLR

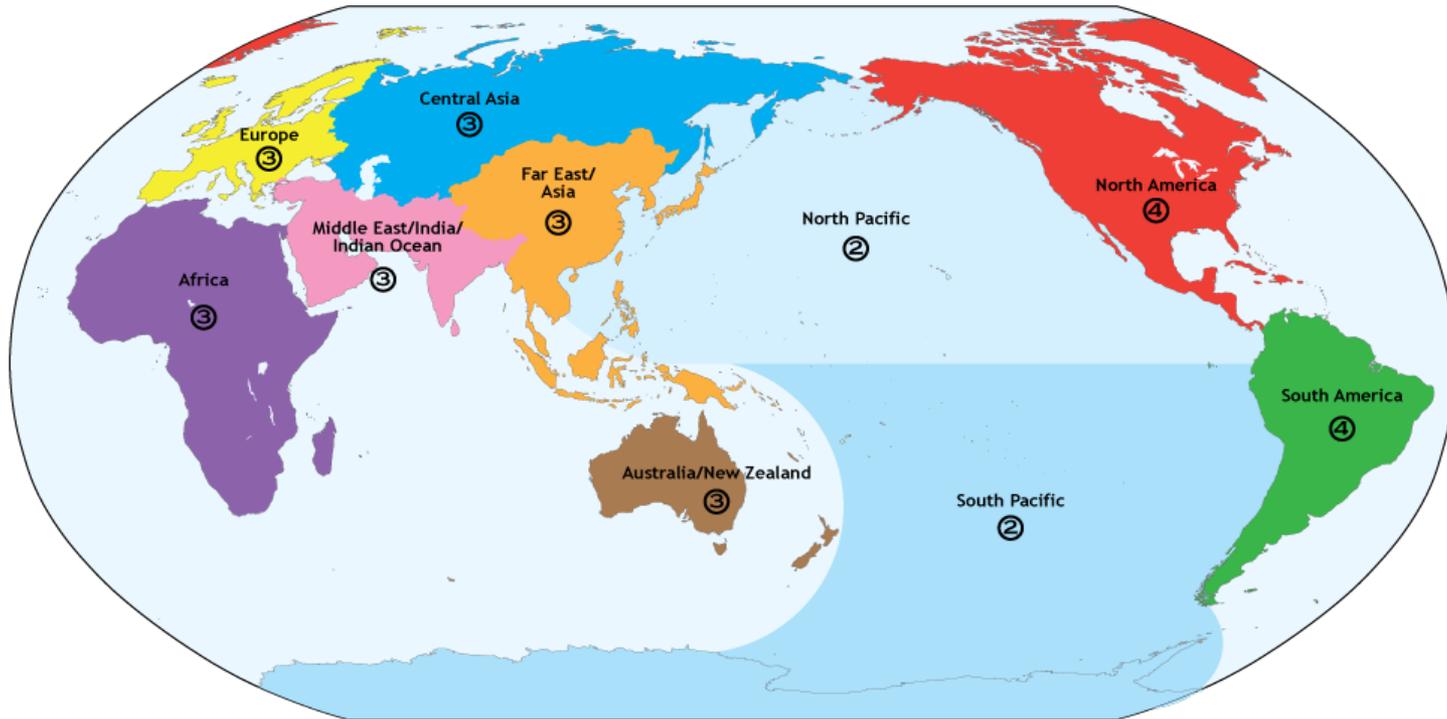


Envisat
DORIS/SLR



GRACE
GNSS/SLR

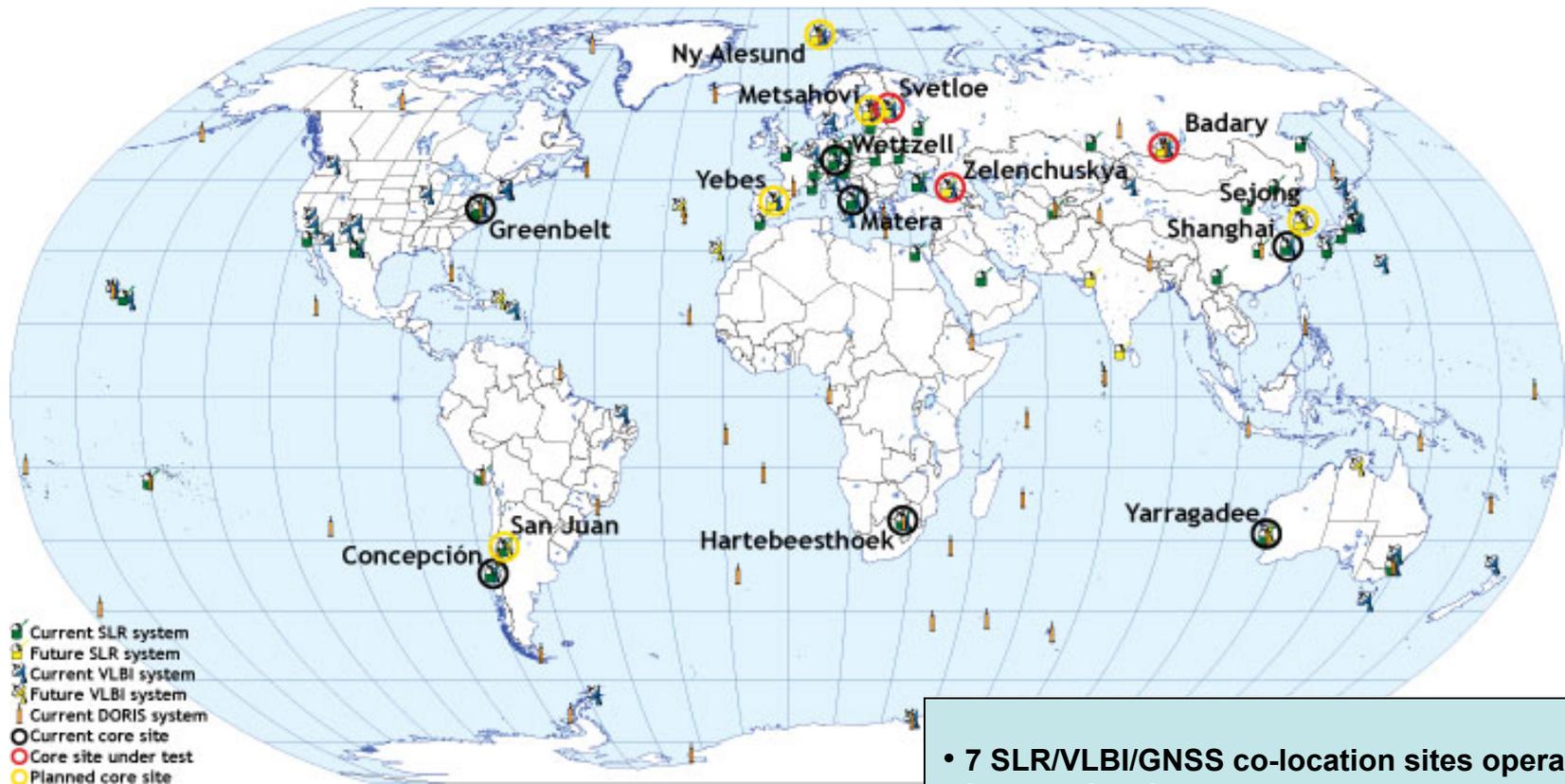
Simulation Studies to Scope the Network of Core Sites (Fundamental Stations)



30 Core Sites required to satisfy reference frame requirements

- Globally well distributed;
- Proper conditions;
- Modern technology;
- Operate routinely;
- Day/Night SLR tracking on GNSS complexes to calibrate the GNSS orbits;

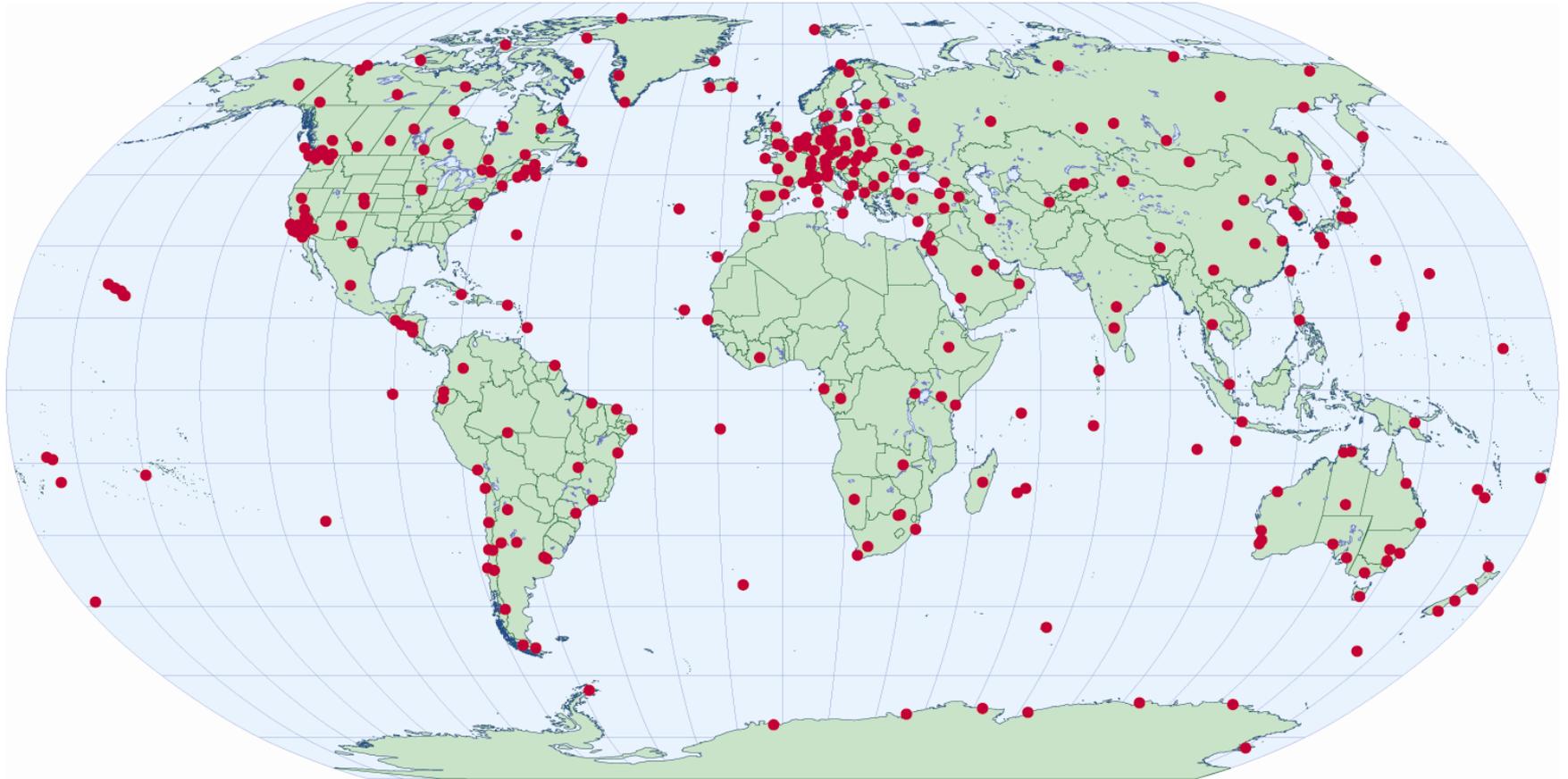
SLR/VLBI/GNSS Colocations (with SLR/VLBI Co-locations noted)



- 7 SLR/VLBI/GNSS co-location sites operating
- 3 more sites in process
- Several more sites in planning
- Essentially all of the sites have legacy technology



GNSS (IGS) Network



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Long Term Stable Terrain

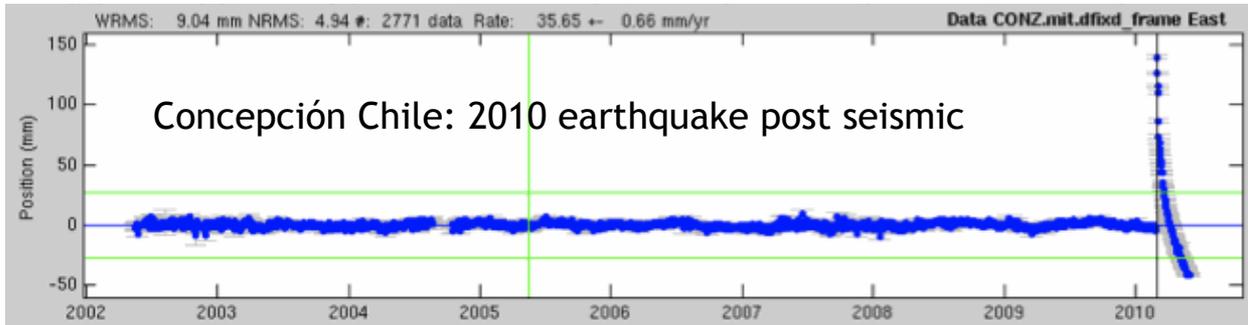
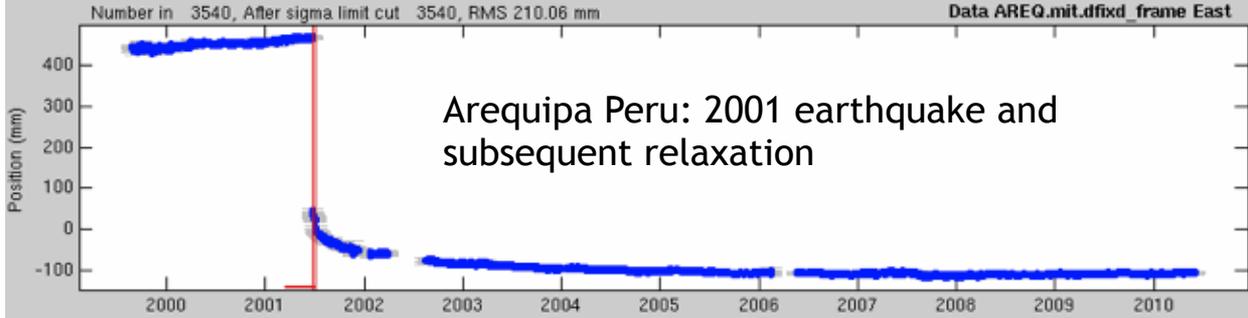
- Bedrock is ideal; rock with weathered layers could be satisfactory;
- A site on sediments is not satisfactory;
- Away from known faults and regions of local deformation;
- In areas where this is difficult, the surface patterns and activities of nearby faults should be known and mapped.
- Earthquake regions make up about 30% of the continental surface. 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 densify the network of Core Sites.

Avoid episodic motion and instability



Time History of Station Positions

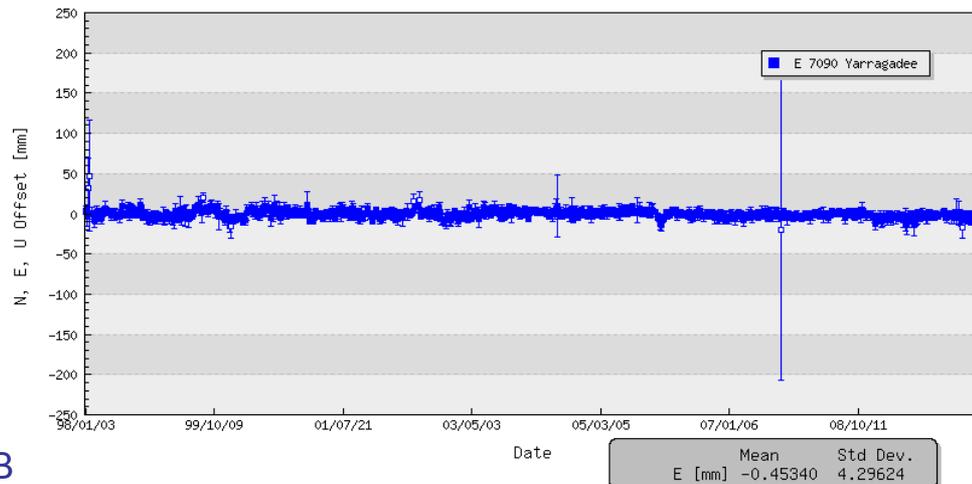
Examples of Local Stability



Arequipa and Concepción plots courtesy Tom Herring/MIT

7090 Yarragadee COM vs SLRF2005 From ilrsa

Yarragadee Australia: stable site



November 8, 2011

August 8 -12, 2010

Meeting with B

The Meeting of the Americas, Foz do Iguaçu, Brazil





Site Reservation

- A minimum of 2 -3 hectares;
- 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.
- 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 can corrupt geophysical signal over the lifetime of the platform (>20 years).
- Include room for other instruments such as gravimeters and seismic measurements, workshop and storage space, and power generators and room for back-up batteries;

A little extra room would be very helpful



Weather and Sky Conditions

- Instruments need to be designed and built for the intended climate;
- Clear and dry sky for optimum laser operations.
- Some compromise will be necessary in particular for seasonal effects; look at the 10-year history of cloud cover, rain fall, fog, mist, etc.;
- Sites 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.
- Avoid sites near heavy industry, in particular those causing air pollution (refinery, cement factory, etc.) to avoid problems with atmospheric transmission and instrument deterioration.



RF, Optical and Mechanical Interference

- All systems are sensitive to RFI, both homemade and externally generated;
- DORIS and SLR aircraft avoidance radars broadcast RF signals which can interfere with the GNSS and VLBI, each instrument has its own frequency sensitivities;
- Avoid close proximity to, and broadcast paths of emitters of radio, television, or microwave signals in the sensitive frequency regions.
- The impact of DORIS on the other systems on site (and in the wider community) should be very carefully evaluated.
- 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.
- 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.
- The lasers broadcast a narrow beam of light at 532 nm; 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 a problem.
- Susceptibility to ground noise and vibration, avoid close proximity to highways, roads with frequent traffic, railways, wind generators, high voltage lines, and large metal structures;

Station layout and location are critical; a combination of distance, terrain, physical obstructions, and phased operations can be used to mitigate interference 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 interstation 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 near by, 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.
- Some groups have success working in real-time with local air monitoring authorities instead of the radar



Communications

- The most demanding communications requirement will come from eVLBI, in particular those engaged in eVLBI;
- Large volumes of data become impractical to ship by disk;
- 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.



Other Issues

- **Local Ground Geodetic Networks**
- **Site accessibility**
- **Local infrastructure and Accommodations**
- **Electrical Power**
- **Technical and personnel support, etc**
- **Site Security and Safety**

Ten Year Plan

- Very ambitious undertaking to move from our present 10 -12 sites with legacy technology to the next generation technology
- Relies on many strong partnerships among international groups and the measurement techniques;
- Will evolve with time
- Must evolve in a seamless manner to avoid discontinuity to the Reference Frame

