Establishing a Modern Ground Network for Space Geodesy Applications

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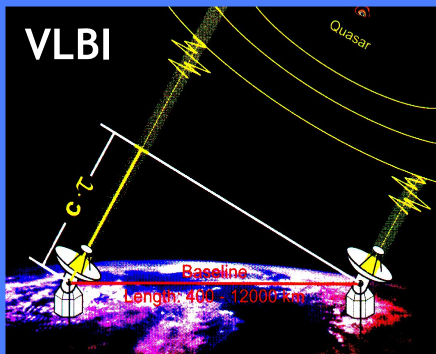
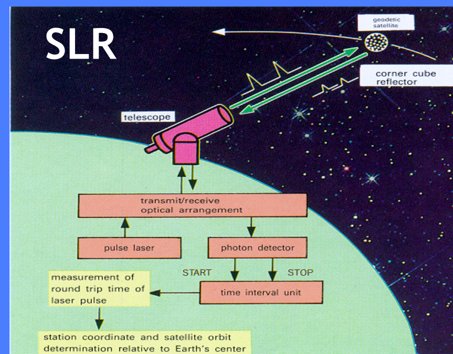
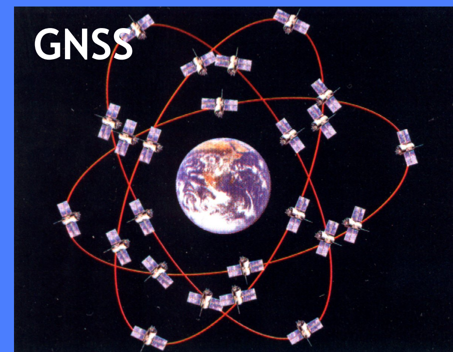
Space Geodetic Techniques



Very Long Baseline Interferometry

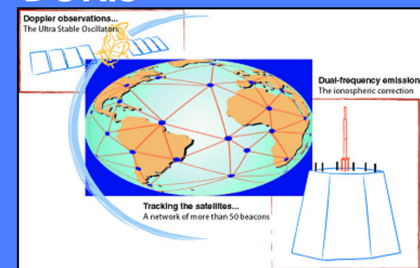


Satellite Laser Ranging



Global Navigation Satellite System

DORIS



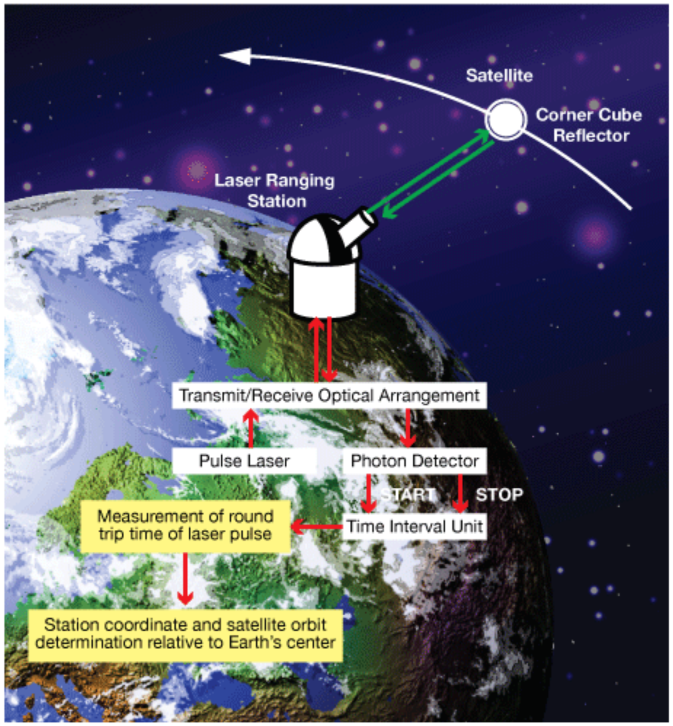
Doppler Orbitography and Radio Positioning Integrated by Satellite

- **Space geodetic systems provide the measurements that are needed to define and maintain the International Terrestrial Reference Frame (ITRF)**
- **Each of the space geodetic techniques has unique properties that bring unique strengths to the reference frame:**
  - Radio verses optical
  - Terrestrial (satellite) verses celestial (quasar) reference
  - Broadcast up verses broadcast down
  - Range verses range difference measurements
  - Geographic coverage

Satellite Laser Ranging Technique

Precise range measurement between an SLR ground station and a retroreflector-equipped satellite using ultrashort laser pulses corrected for refraction, satellite center of mass, and the internal delay of the ranging machine.

- Simple range measurement
- Space segment is passive
- Simple refraction model
- Night/day operation
- Near real-time global data availability
- Satellite altitudes from 400 km to synchronous satellites, and the Moon
- Centimeter satellite orbit accuracy
- Able to see small changes by looking at long time series



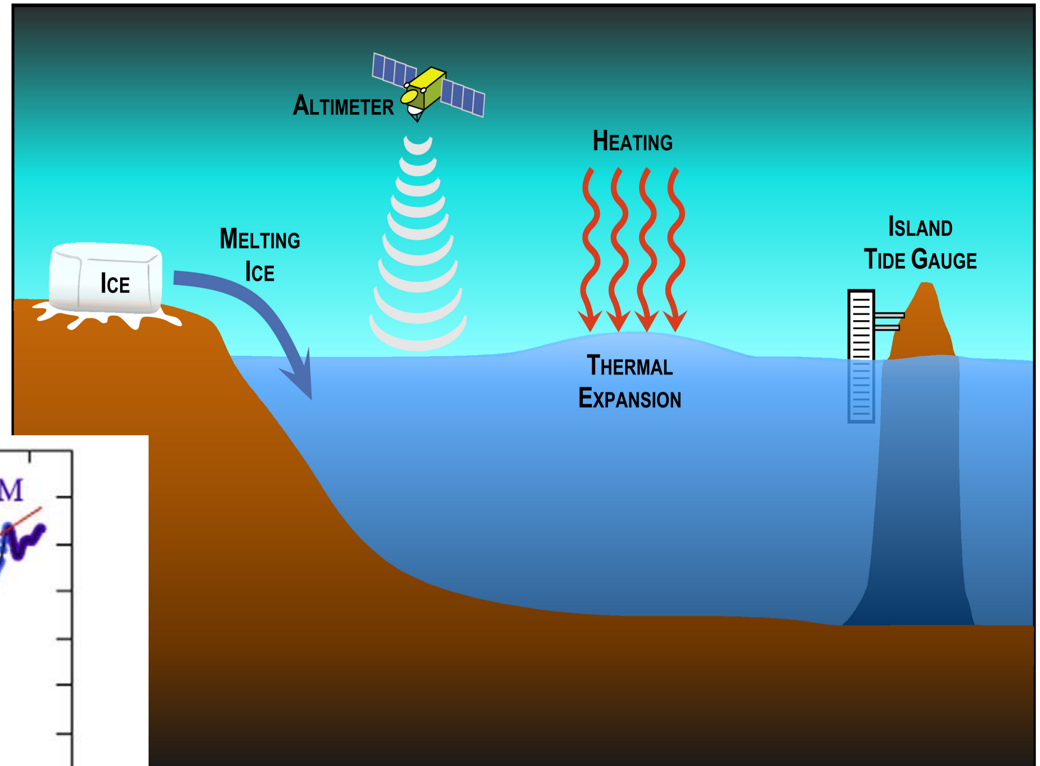
- Unambiguous centimeter accuracy orbits
- Long-term stable time series

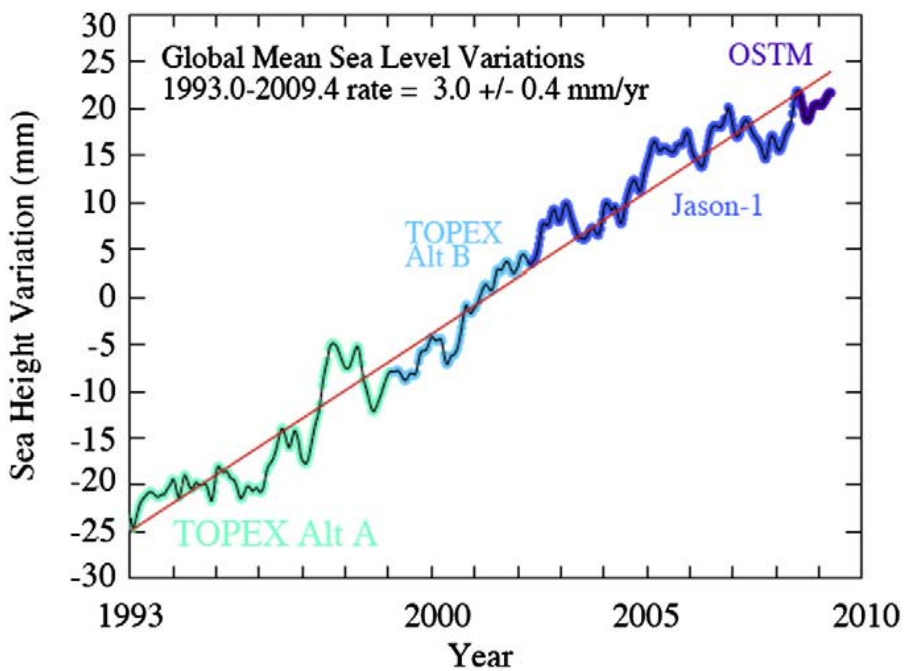
International Terrestrial Reference Frame (ITRF)

- 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, and worldwide.
- Must be robust, reliable, geographically distributed
  - proper density over the continents and oceans
  - interconnected by co-location of different observing techniques
- Established and maintained by the global space geodetic networks.

Why the ITRF Matters

Global mean SSH variations from TOPEX, Jason-1, Jason-2 with respect to 1993–2002 mean, plotted every 10 days using the NASA GSFC orbits from Lemoine et al. (2010), and the latest GDR releases and corrections for the altimetry.





Source: Lemoine, F.G., et al. Towards development of a consistent orbit series for TOPEX, Jason-1, and Jason-2. J. Adv. Space Res. (2010), doi:10.1016/j.asr.2010.05.007

Global Geodetic Observing Systems 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.

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.*

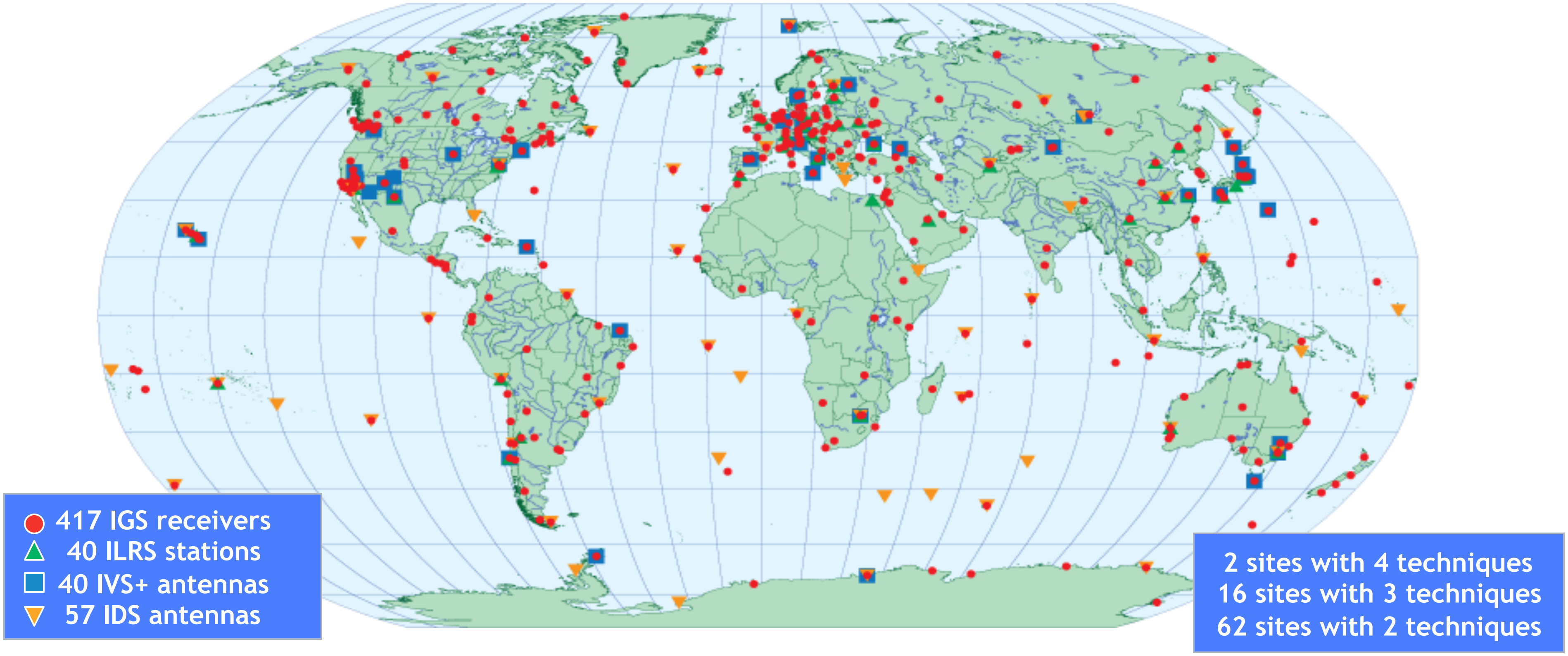
Role

- **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 GGOS Network of Core 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.

Current Global Space Geodesy Network



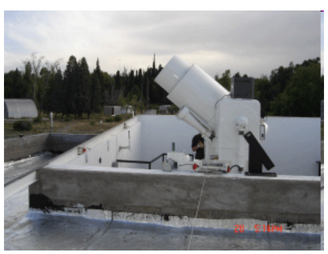
- Insufficient co-locations
- Although all of the Services have gaps in geographic coverage, the geographic gaps in SLR and VLBI are of particular concern.
- All of the networks are an anachronistic mix of legacy systems (in some cases decades old) and modern systems.
- Performance differences between stations and system deterioration over time have seriously compromised overall network performance.

Space Geodesy Stations in South America

- 1 station with SLR/VLBI/GNSS
- 1 station with VLBI/GNSS
- 1 station with SLR/DORIS/GNSS
- 4 stations with DORIS/GNSS

- Stations crowded together
- Some of the stations have inadequate conditions





Concepción

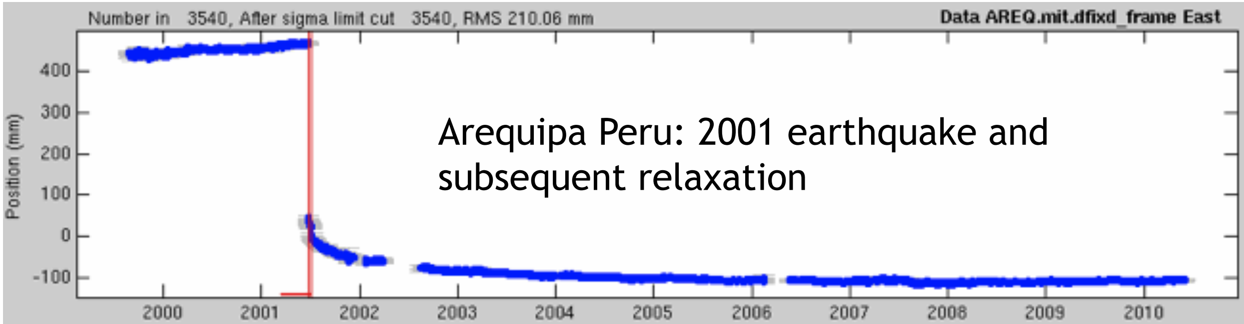
The Right Station in the Wrong Place for ITRF

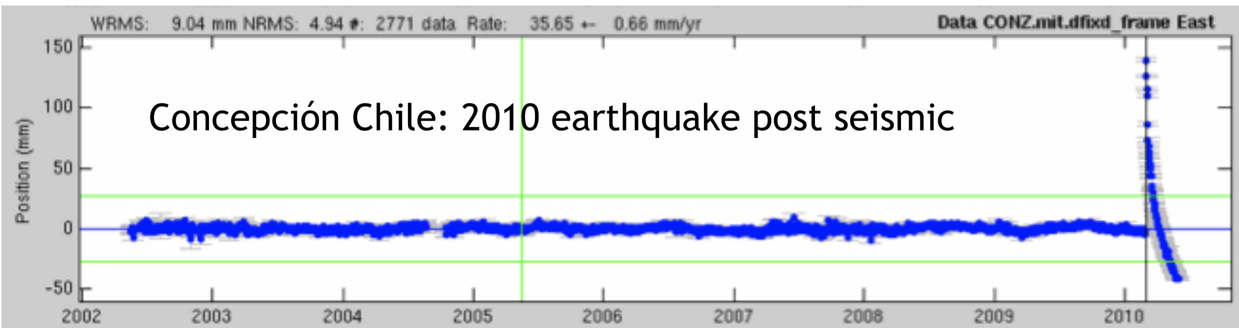
Concepcion earthquake horizontal displacements

Figure courtesy of DGFI

Time History of Station Positions

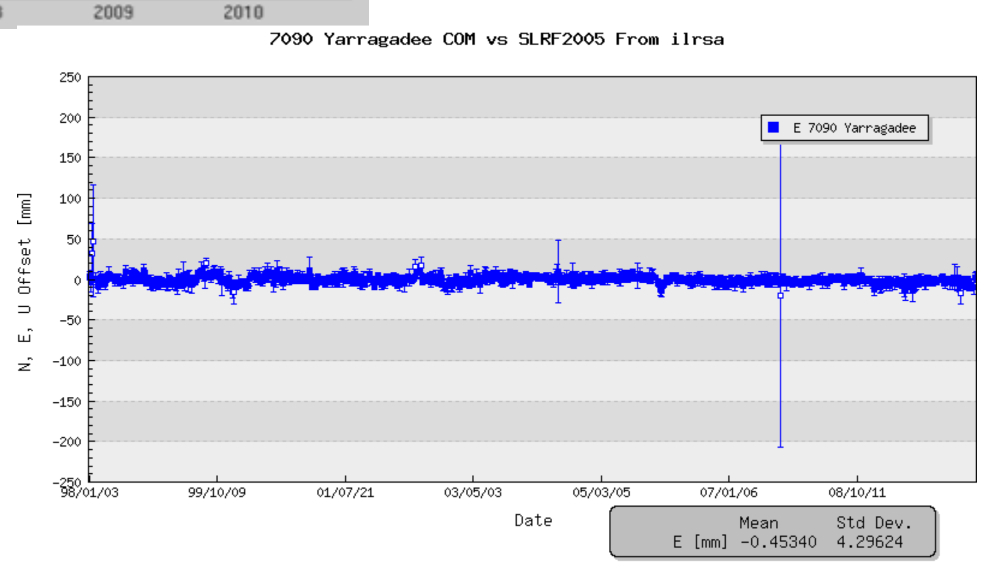
Examples of Local Stability





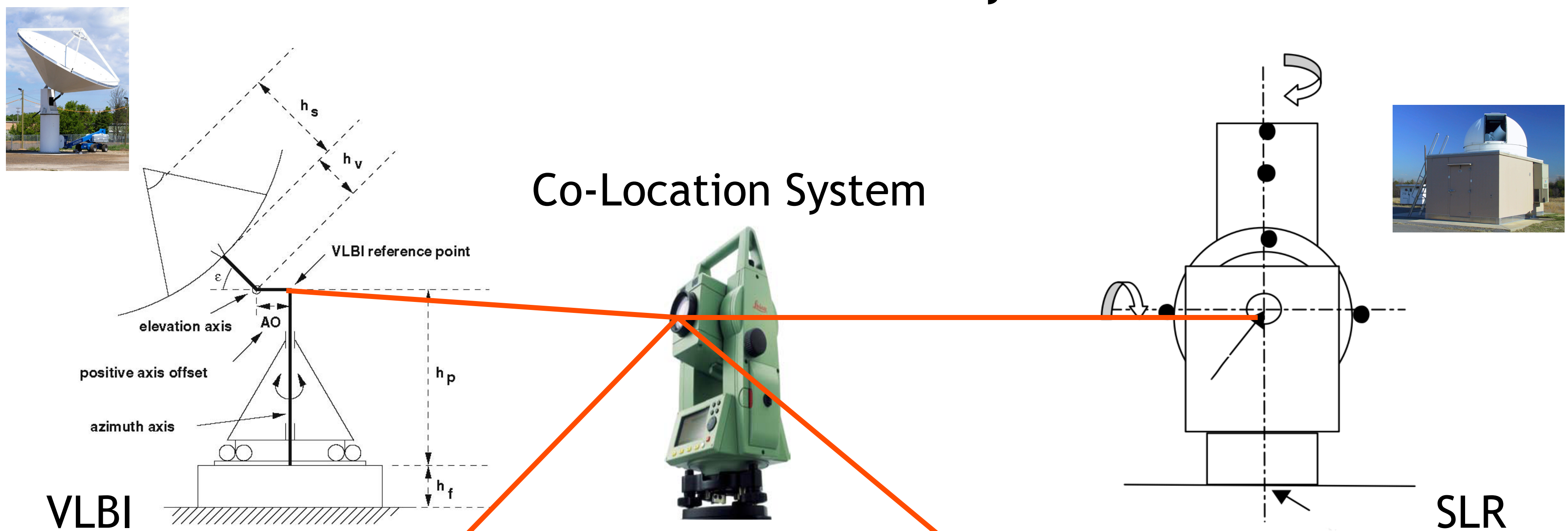
Arequipa and Concepción plots courtesy Tom Herring/MIT

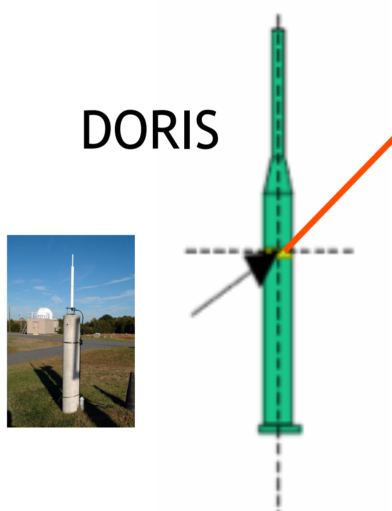
Yarragadee Australia: stable site



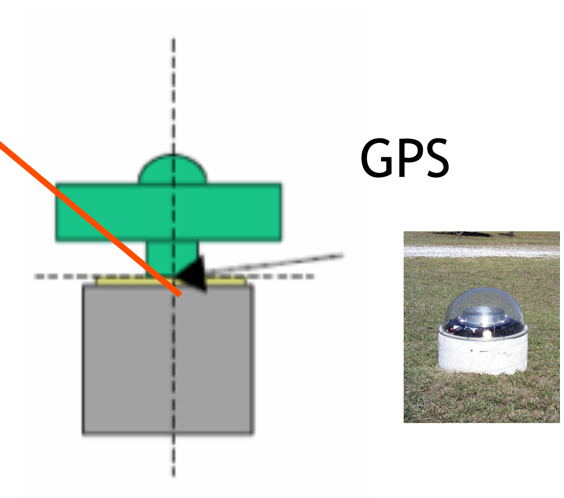
Fundamental Station Ground Co-location

and the essential role of the intersystem vector

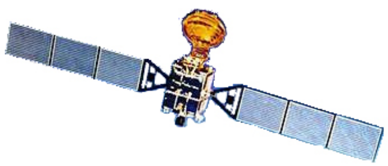




- GNSS and DORIS reference points
  - Extrapolate to measurement phase center
- VLBI and SLR reference points
  - Extrapolate to measurement phase center
  - RP through indirect approach
  - Targets mounted on system structure
  - Rotational sequence about axes of space geodetic instrument
  - Model to determine axes location



Co-location in Space

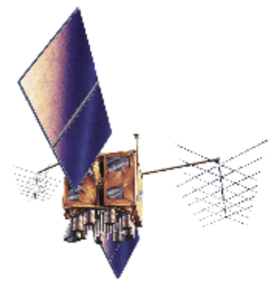


Compass

GNSS/SLR

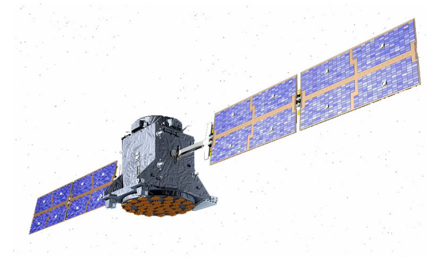
GLONASS

GNSS/SLR



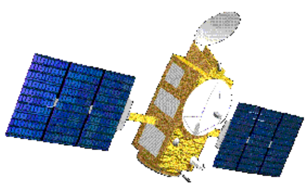
GPS

GNSS/SLR



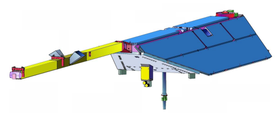
GIOVE/Galileo

GNSS/SLR



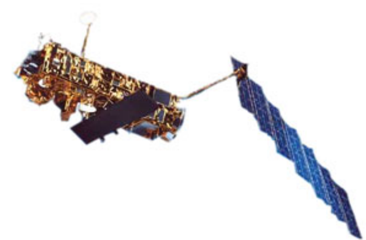
Jason

DORIS/GNSS/SLR



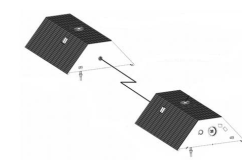
CHAMP

GNSS/SLR



Envisat

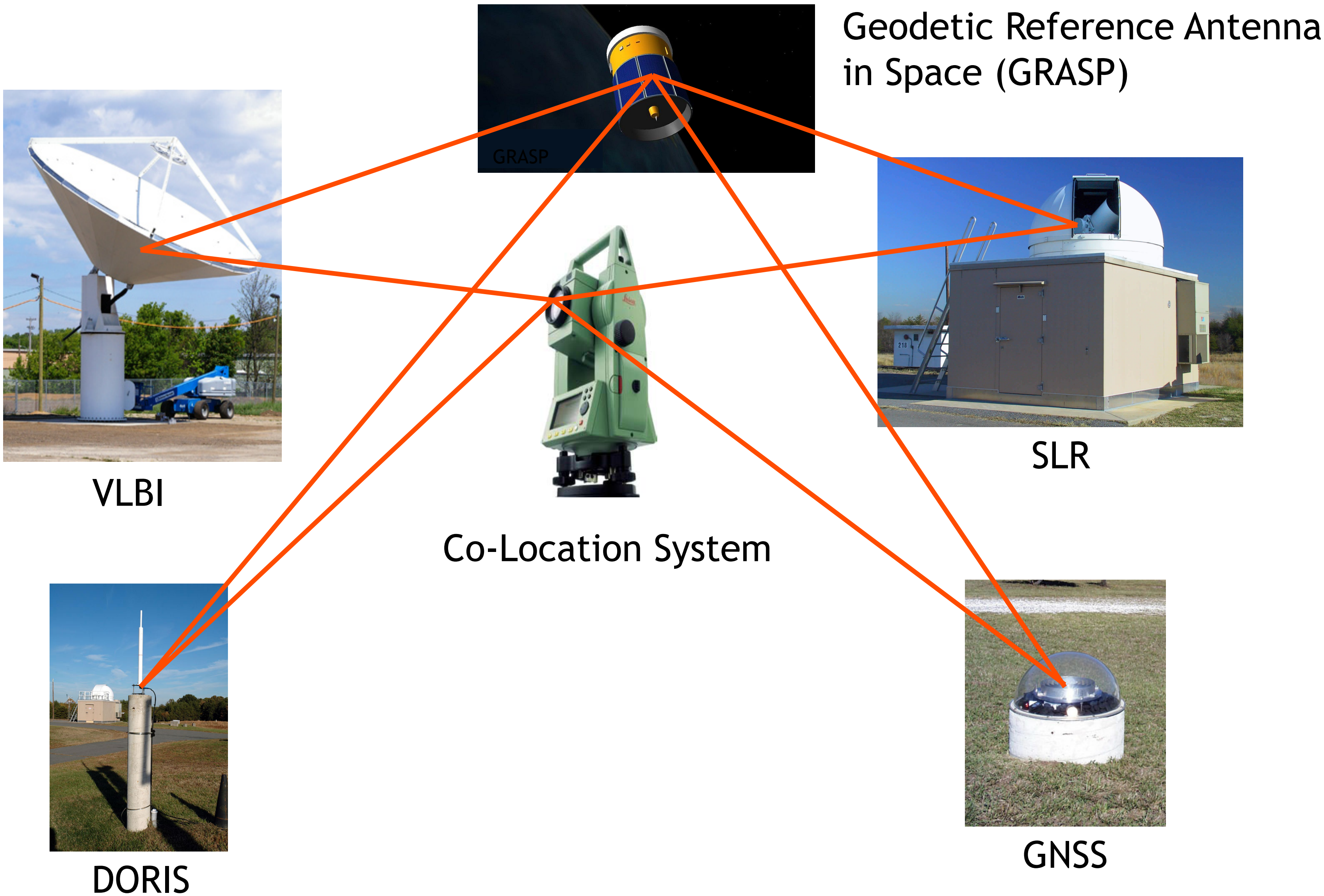
DORIS/SLR



GRACE

GNSS/SLR

Fundamental Station Space Co-location

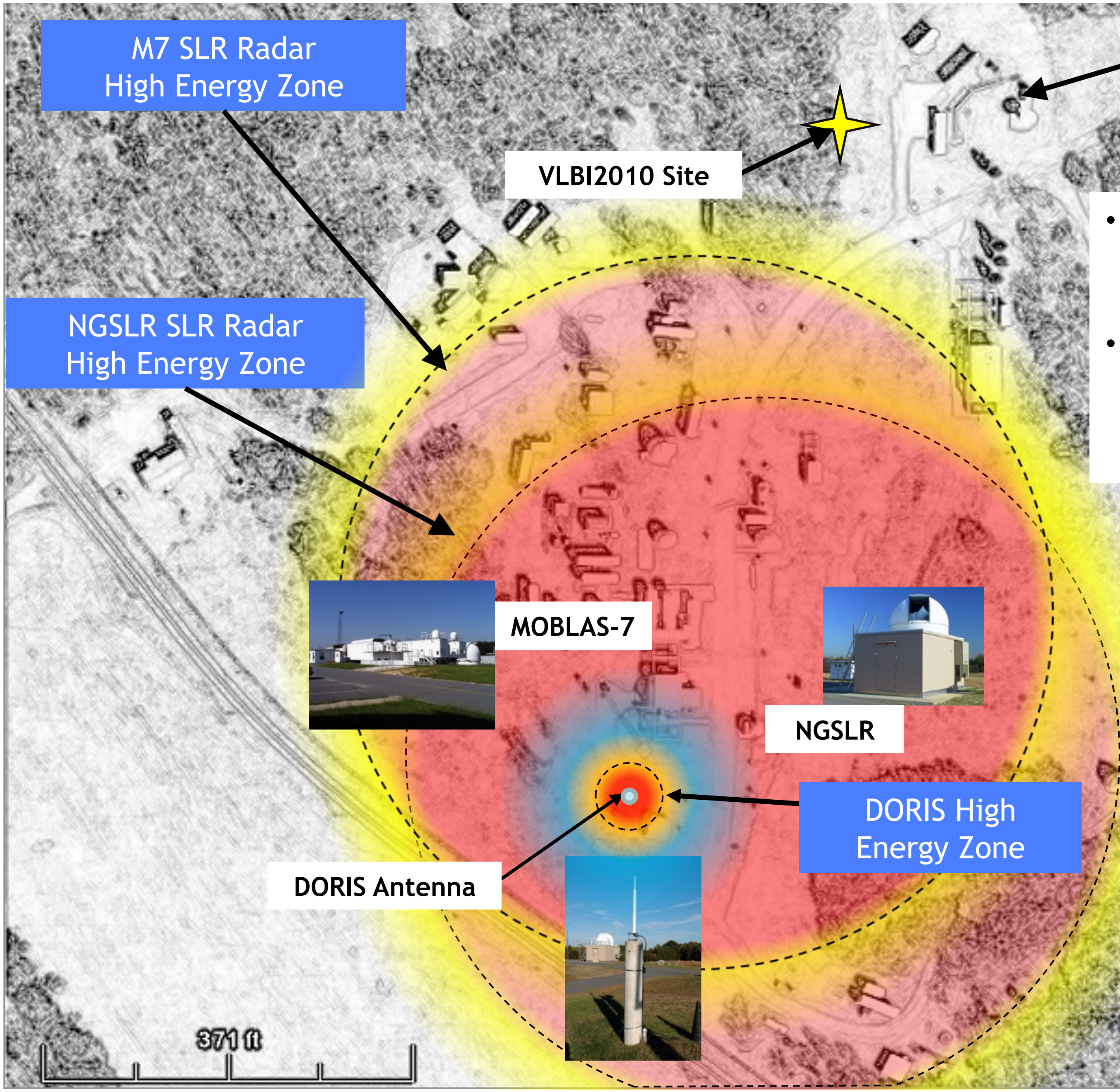


Considerations for Site Locations

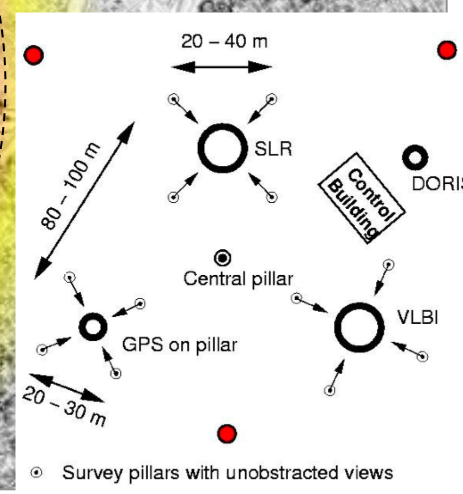
- Geographic locations (globally distributed network)
- General and local geology (geologically stable)
- Weather (SLR)
- Accessibility and shipping constraints
- Local topography and land constraints
- Local infrastructure (power, communications, roads, etc.
- Technical and personnel support, communications, etc
- Site security
- Political considerations (can do business in a practical manner)

- Preference to stations already established

Co-located Station Layout



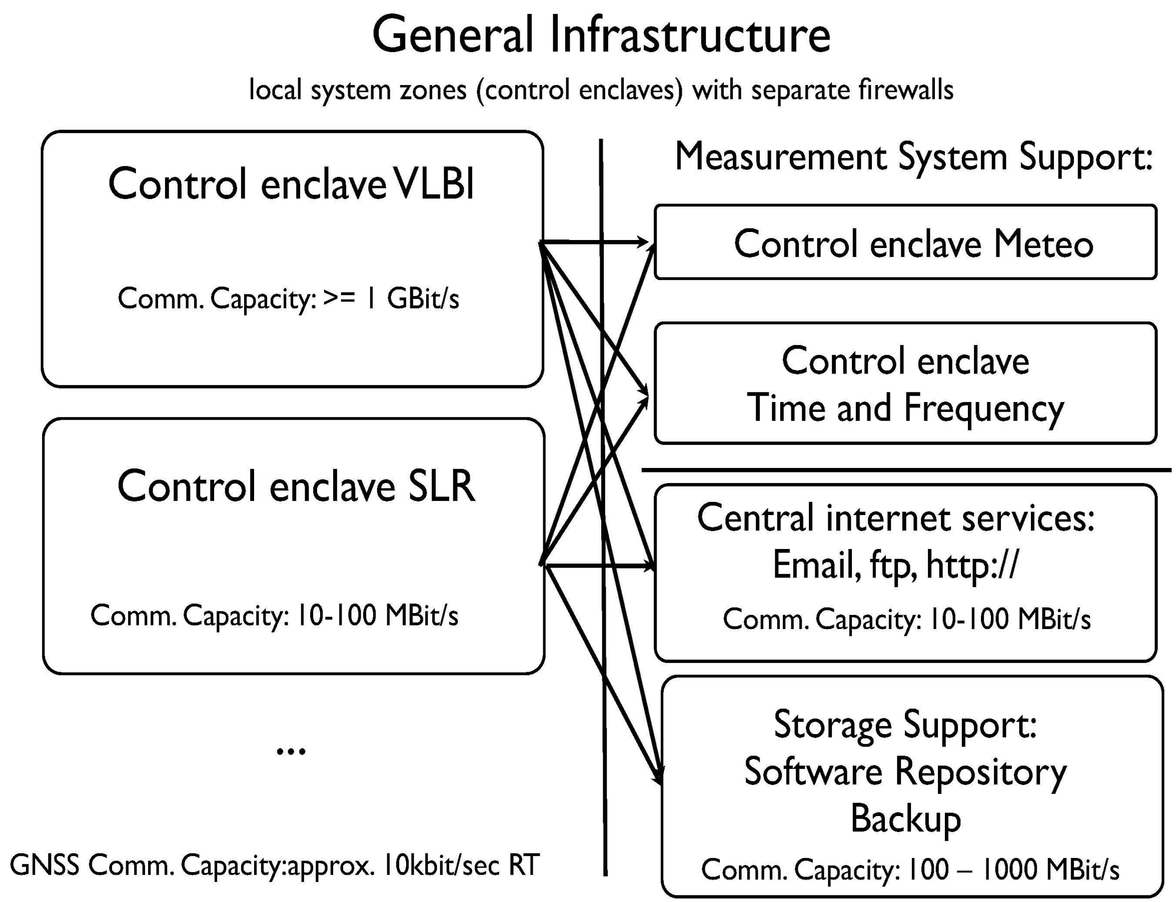
- Studies underway to examine optimum station layouts
- RFI issues influence the relative placement of the instruments at the co-location site



NASA Space Geodesy Project (NSGP)

- 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;
- Separate Proposal for building of first retroreflector array for future GPS satellites

Space Geodesy Network Communications



Friday, 4 June 2010

The Earth Sciences Decadal Survey (Space Studies Board, 2007) made the following strong statement:

"The geodetic infrastructure needed to enhance, or even to maintain the terrestrial reference frame is in danger of collapse ... Investing resources to assure the improvement and the continued operation of this geodetic infrastructure is a requirement of virtually all the missions for every Panel in this study ... "

... and NASA responded, leading the way to meet the GGOS requirements!