The Need for A Precise Space Geodesy Infrastructure

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Global Geodetic Observing System (GGOS)
Networks and Communications Bureau

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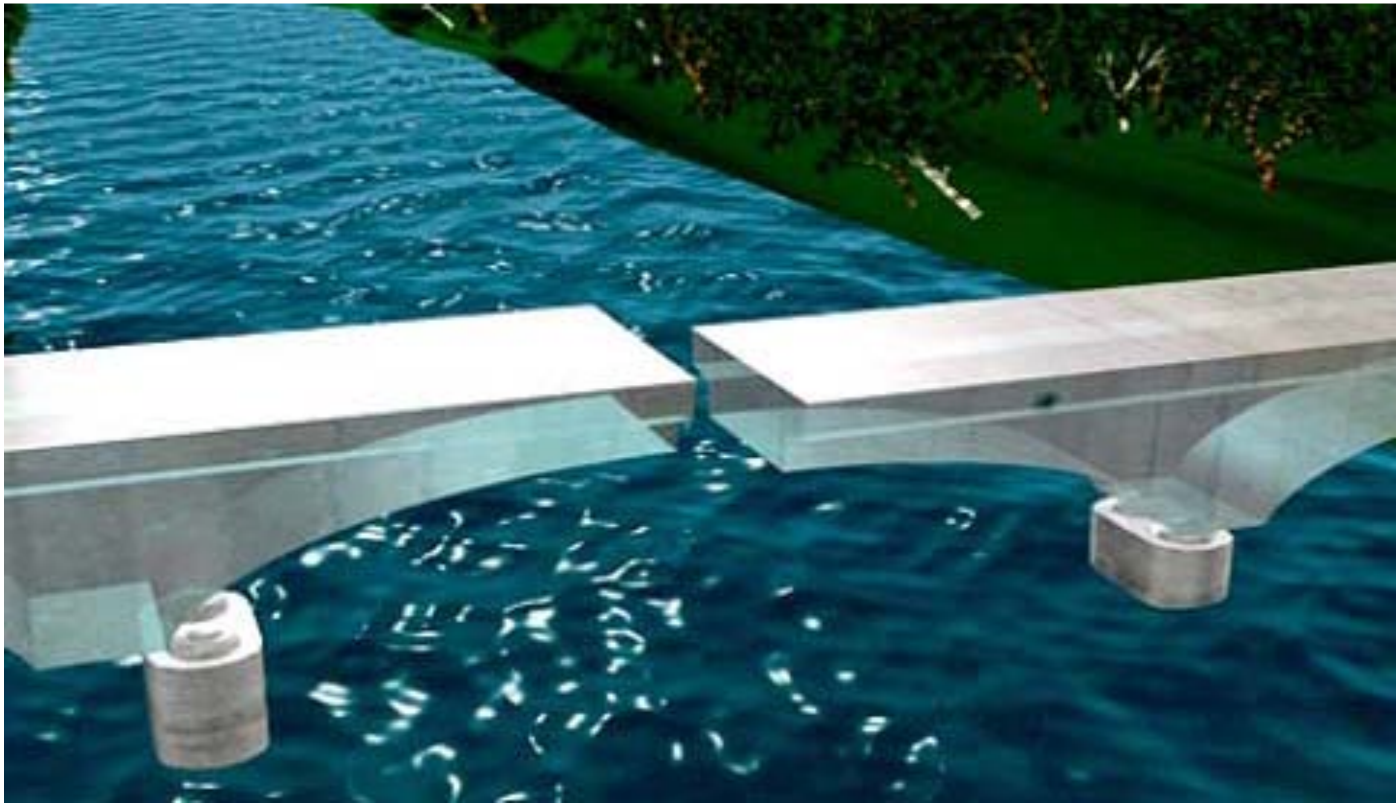
The need for monitoring Earth systems with Space Geodesy Networks

- Earth processes can have a devastating impact on our society and our economies (earthquakes, rising sea level, floods, drought, storms, tsunamis, etc.)
- Monitoring the Earth Systems will help us understand the environmental processes and their interactions:
  - Land, oceans, ice caps, land hydrology, atmosphere, etc.
- Major societal decisions will require many years to implement:
  - Building dikes, moving population, building codes, agricultural strategies, etc.
- Understanding environmental processes will help us make intelligent decisions early enough to have a timely impact
- Space geodesy networks are fundamental to the system to monitor and understand Earth processes for both ground and space measurements
- Space Geodesy networks allow us to integrate national reference systems

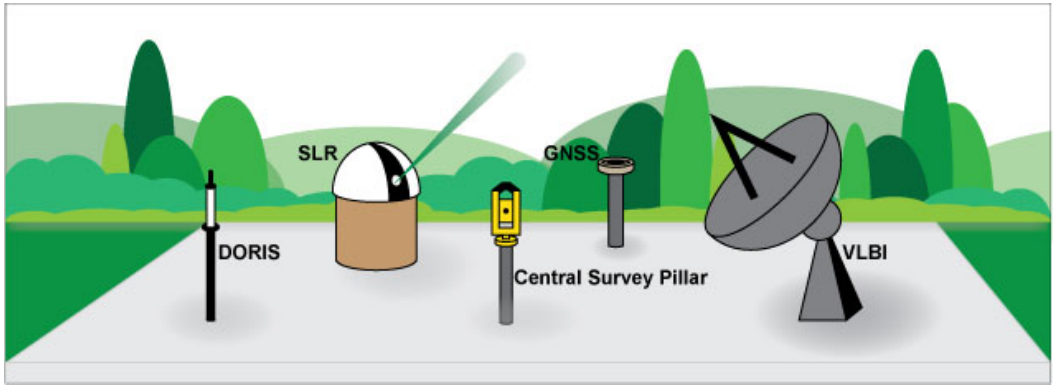
When National Reference Frames are not integrated!



Design error at bridge construction in Laufenburg (2003): During the construction of the bridge across the Rhine river in Laufenburg, a control showed that a height difference of 54 centimeters exists between the bridge built from the Swiss side and the roadway of the German side. Reason of the error is the fact that the horizons of the German and Swiss side are based on different reference frames. Germany refers to the sea level of the North Sea, Switzerland to the Mediterranean. (*Courtesy of Hermann Drewes/DGFI*)

What is a Fundamental Station?

- A ground station with four space geodesy techniques co-located so that the measurements among them can be related to sub-mm accuracy
- The four techniques are:
  - Global Navigation Satellite System (GNSS, e.g., GPS, GLONASS, Galileo)
  - Satellite Laser Ranging (SLR)
  - Very Long Baseline Interferometry (VLBI)
  - Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS)
- Why do we need four 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



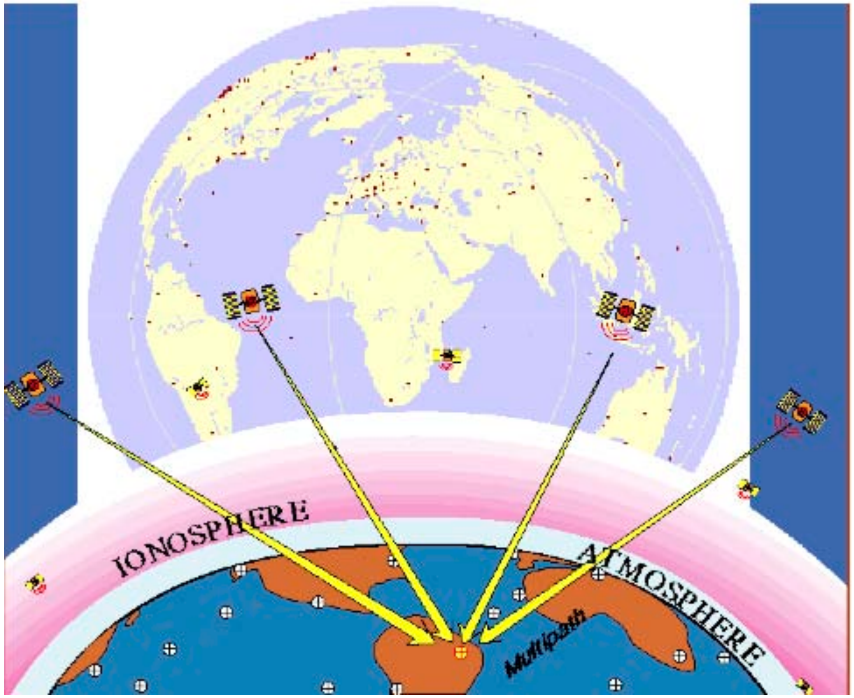
Example Fundamental Station

NASA Goddard Space Flight Center, Greenbelt MD, USA

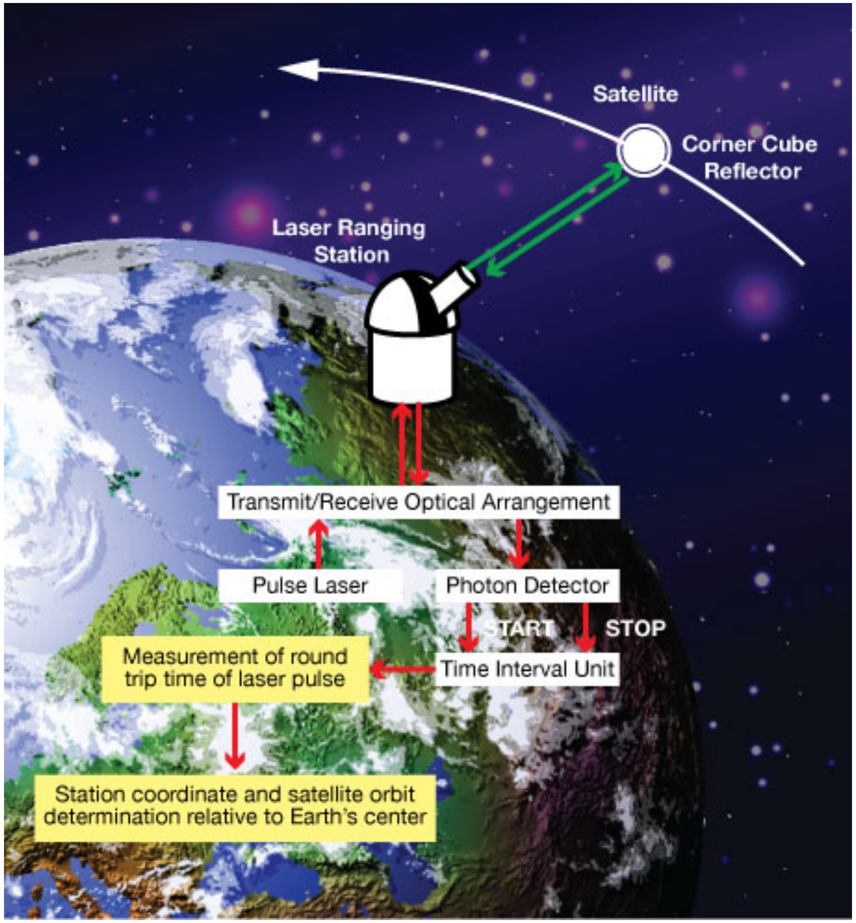
- Goddard Geophysical and Astronomical Observatory (GGAO) has four techniques on site
  - Legacy SLR, VLBI, GPS, DORIS
  - NGSLR semi - “operational”
  - VLBI2010 systems in testing
- GGAO will be the location for the prototype next generation multi-technique station

Global Navigation Satellite Systems (GNSS)

- Space Segment:
  - Satellites (GPS, GLONASS, Galileo, COMPASS, QZS, etc.) equipped with precise clocks transmitting satellite messages such as ephemeris, clock offsets, etc.)
- Ground Segment:
  - Multi-frequency GNSS receiver and antenna
- Measurement:
  - Station to satellite pseudorange, phase delay
- Data Products:
  - Precise distribution of the global reference frame
  - Precise orbit determination
  - Earth orientation and rotation
  - Station and satellite clock solutions
  - Troposphere and ionosphere products
- Characteristics:
  - Comprehensive global network
  - Cost effective and accessible



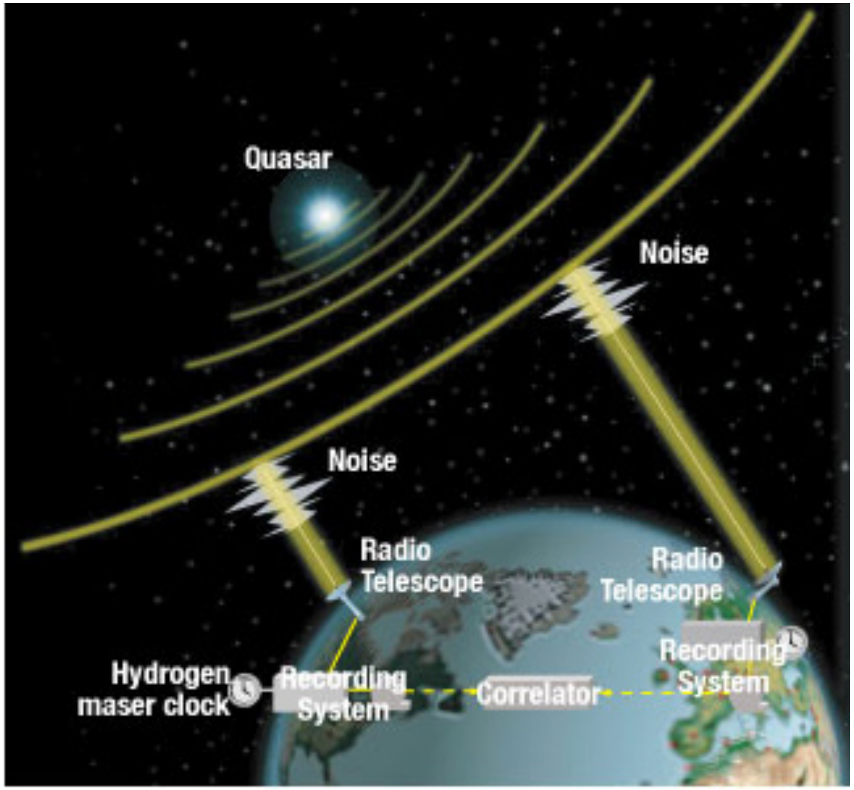
Satellite Laser Ranging (SLR)



- Space Segment:
  - Satellites equipped with corner cube reflectors
- Ground Segment:
  - Short-pulse laser transmitter
- Measurement:
  - Two-way time of flight measurement to the satellite
- Data Products:
  - Station positions
  - Precise orbit determination
  - Earth orientation and rotation
- Characteristics:
  - Most accurate means of measuring satellite position
  - Sole determination of reference frame orientation
  - Passive space segment
  - Least dependent on transmission media
  - Near real-time global data availability
  - Ability to detect variations in long-term trends

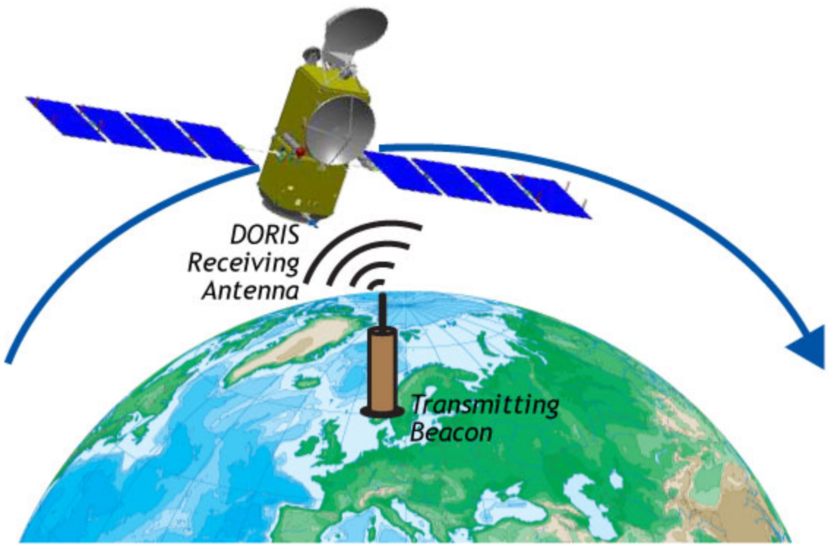
Very Long Baseline Interferometry (VLBI)

- Space Segment:
  - Quasars (microwave frequencies)
- Ground Segment:
  - Radio telescope equipped with wide band receivers
- Measurement:
  - Time difference between arrival of radio wavefront emitted by a distant quasar at two Earth-based antennas
- Data Products:
  - Station positions, velocities
  - Positions of quasars
  - Earth orientation and rotation relative to stars
  - Ionosphere parameters
- Characteristics:
  - Only method linked to the celestial reference frame (stars)
  - Totally passive - radio transmission
  - Large Gbyte data volumes, but moving to wide-band data transmission in near real-time



Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS)

- Space Segment:
  - Satellites equipped with DORIS receiver and uplink hardware
- Ground Segment:
  - Beacon transmitting radiofrequency signals
- Measurement:
  - Doppler shift on radiofrequency signals
- Data Products
  - Station positions and velocities
  - Precise orbit determination
  - Ionosphere parameters
- Characteristics:
  - Global distribution
  - Strong ground system configuration control (single source)



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;*
- *improve the accessibility of geodetic observations and products for a wide range of users; and*
- *improve and maintain the International Terrestrial Reference Frame (ITRF).*

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.

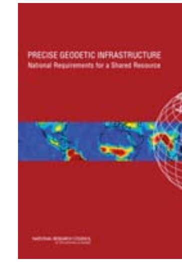
GGOS Bureau for Networks and Communications

- Provide oversight, coordination, and guidance for the development, implementation and operation of the Network of Core (co-location) Sites.
- Develop 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.

Accepted as a Sub-Task under the Group on Earth Observations (GEO)

U.S. National Research Council Report

“Precise Geodetic Infrastructure: National Requirements for a Shared Resource”



(http://dels.nas.edu/Report/Precise-Geodetic-Infrastructure-National-Requirements/12954)

Recognizing the growing reliance of a wide range of scientific and societal endeavors on infrastructure for precise geodesy, and recognizing geodetic infrastructure as a shared national resource, the NRC Study Committee strongly recommends that the U.S. should:

- deploy additional stations to complement and increase the density of the international geodetic network, in a cooperative effort with its international partners, with a goal of reaching a global geodetic network of fundamental stations;
- make a long-term commitment to maintain the International Terrestrial Reference Frame (ITRF) to ensure its continuity and stability;
- assess the workforce required to support precise geodesy in the United States and the research and education programs in place at U.S. universities as part of a follow-up study focused on the long-term prospects of geodesy and its applications.

GGOS Uniform Globally Distributed Network Site Requirements

- Globally distributed network with about 30 fundamental ground stations including at least 4 stations in South America
- Stable geology, away from earthquake regions and regions of local deformation
- Dry, clear weather (for SLR)
- Quiet radio frequency interference conditions
- Clear horizon conditions
- Wide-band communications for near real-time data transfer and instrument control and monitoring
- Site area of at least 10 hectares
- Site accessibility for shipping and personnel
- Local infrastructure (power, roads, etc.)
- Technical and personnel support, etc
- Site security

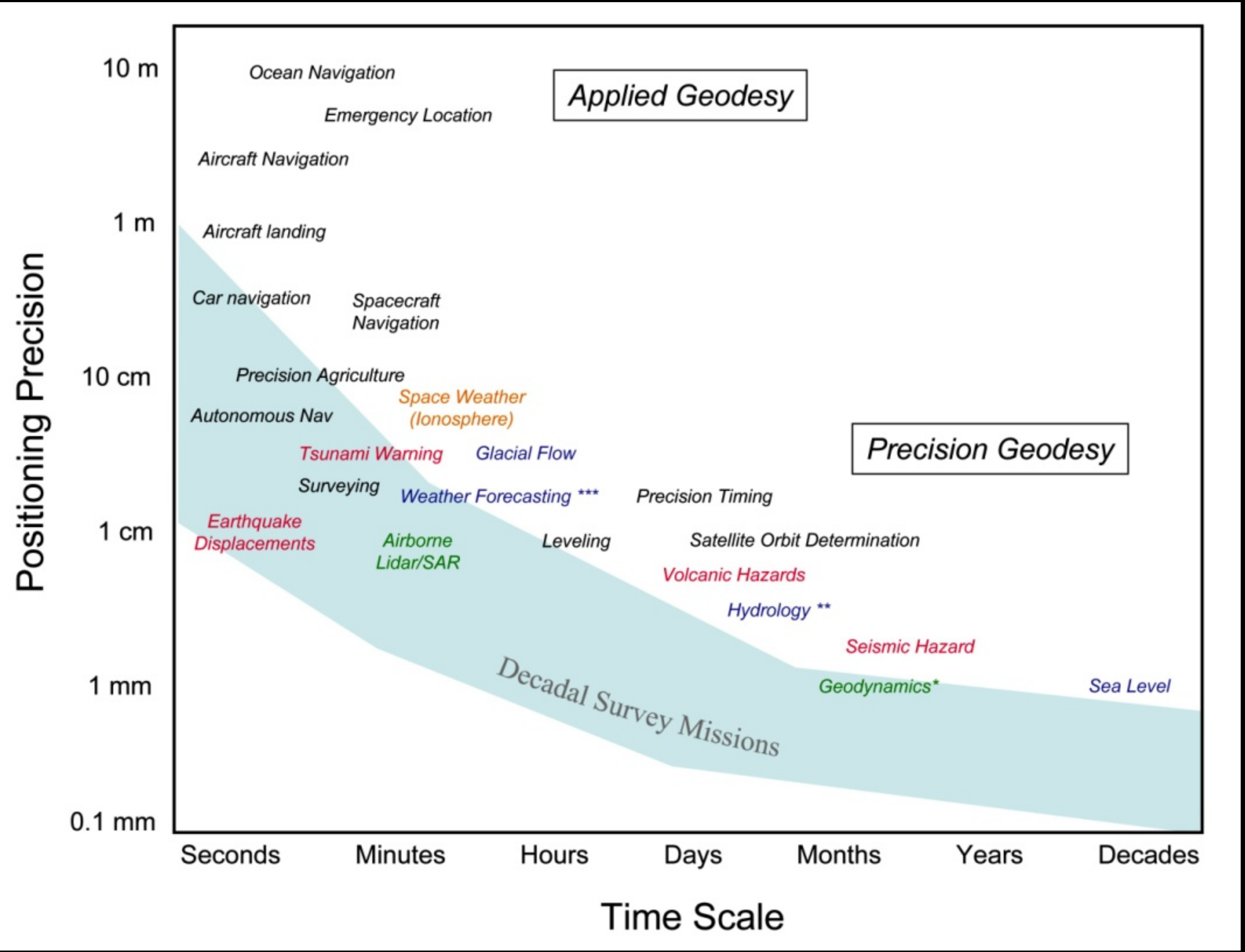
The Need for International Cooperation

- The data products that come from Space Geodesy Programs are based on strong international cooperation, requiring broad international investment
- Internationally, many organizations support ground stations, product development, and analysis:

Each does a part; each benefits from the whole

- Through this model of cooperation the IAG has established its technique services (IGS, IVS, ILRS, and IDS)
- Currently, over 250 institutions in over 90 countries contribute to these IAG services
- Simulation studies show that 30 globally distributed fundamental stations are required to achieve the GGOS requirement for the reference frame
- A denser GNSS network is required to provide global access to the reference frame

The successful implementation of the GGOS network will rely on strong international cooperation and participation



Courtesy of Bernard Minster/SIO
http://dels.nas.edu/Report/Precise-Geodetic-Infrastructure-National-Requirements/12954

National Benefits (why countries are supporting GGOS)

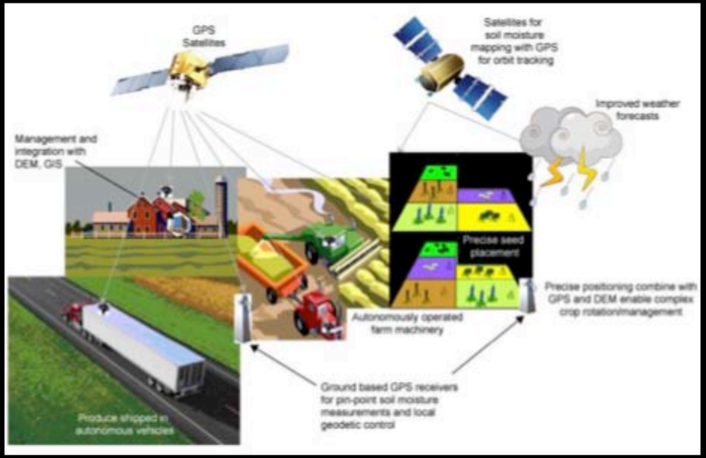
- Monitoring and predicting sea level rise
  - Coastal flooding and erosion
  - Coastal wetland monitoring
  - Tsunami monitoring and warning systems
- Monitoring the ice volume changes
  - Polar ice caps
  - Mountain glaciers
- Developing accurate topography maps
  - Flood plane maps
  - Erosion
  - Infrastructure, engineering, etc
- Hazard Assessment
  - Earthquakes
  - Volcanoes
  - Floods
  - Landslides
  - Wildfire
- Weather
  - Improved numerical weather and ionospheric models
- Understanding changing hydrological conditions
  - Lake and river levels
  - Flooding and drought
  - Water resource monitoring
- Precision agriculture
  - Planting, irrigation, plowing, harvesting, etc.
- Active remote sensing by satellite and aircraft
  - Coastal erosion, highway and border patrol, etc.
- Standardized geodetic reference frame for civil engineering
  - Bridges, tunnels, etc.
- Autonomous navigation
  - Vehicle control
  - Aircraft control
- Education: Earth sciences

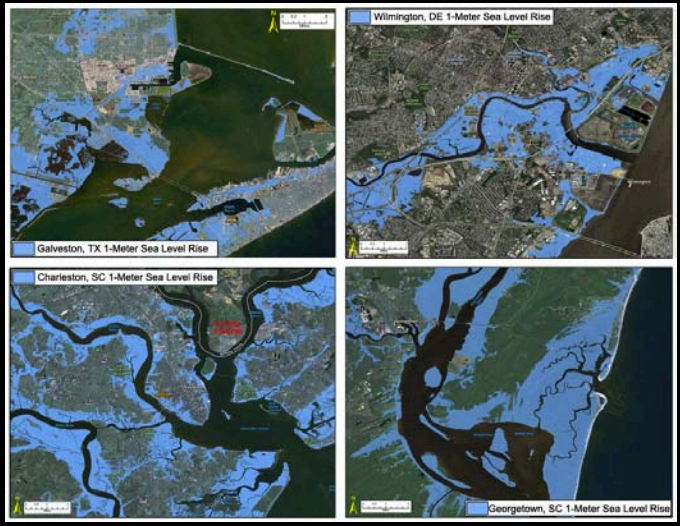
Geodesy for the benefit of society

Research, civil, and commercial areas, e.g.:

- Real time positioning
- Autonomous navigation (roads, sea, air)
- Precision agriculture
- Surveying, floodplain mapping
- Forest mapping, biomass estimation
- Natural hazards monitoring and early warning
- Sea level change

… TIME IS OF THE ESSENCE!





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Earth Science Requirements

Solid Earth Dynamics
- Geodynamics, PGR, EOP

Natural Hazards
- Volcano, Earthquake, Landslide, Flood, Tsunami

Ocean and Cryosphere Dynamics
- Sea Level Rise

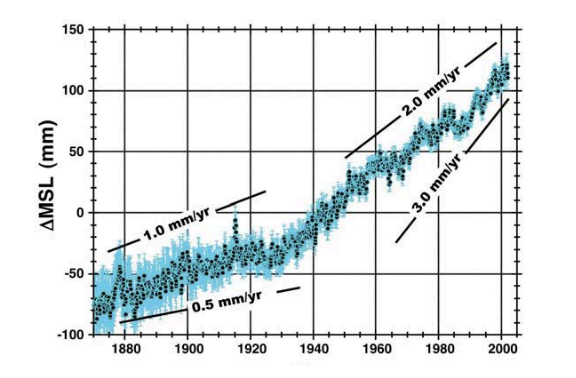
Hydrologic Cycle and Water Resources
- Storage, Subsidence, River and Lake Levels

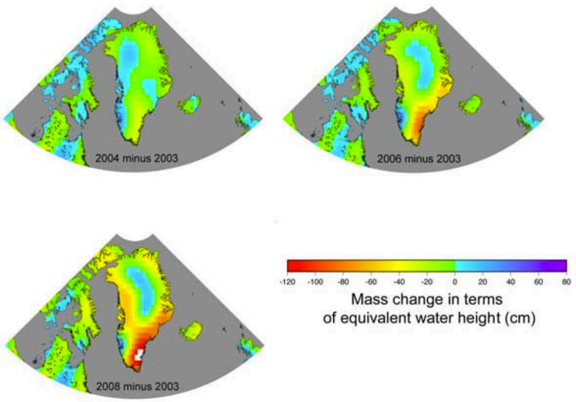
Weather
- Ground- and Based, Space Weather

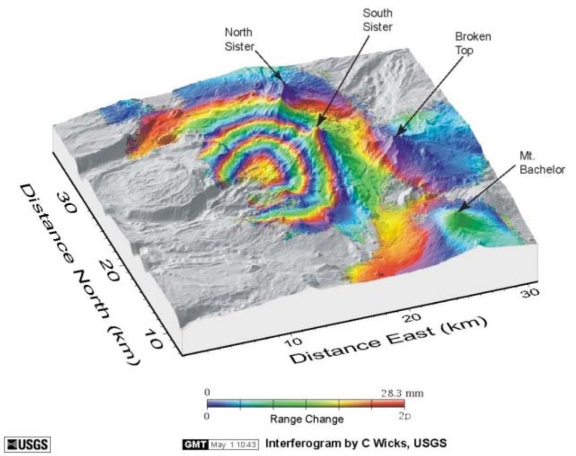
Precision Spacecraft Navigation
- Precision Orbit Determination, Interplanetary Navigation

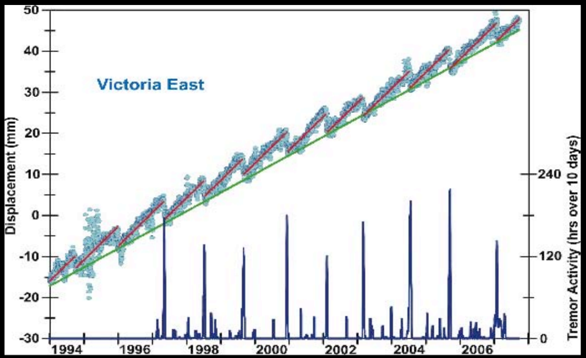
Timing and Time Transfer

Decadal Missions









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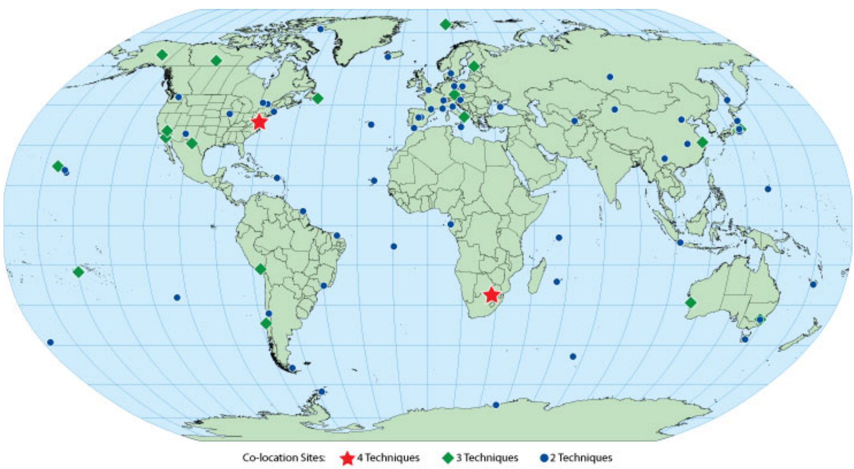
Fundamental Space Geodesy Sites

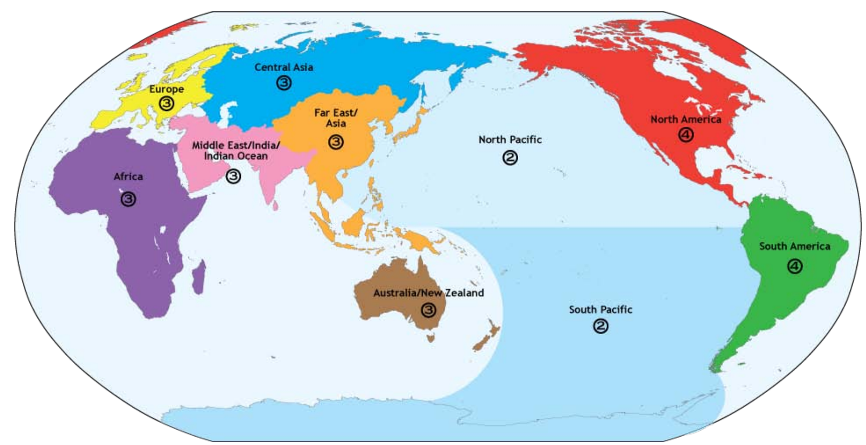
Current space geodesy network co-locations

- 2 sites with 4 techniques
- 16 sites with 3 techniques
- 62 sites with 2 techniques



GGOS conceptual network of fundamental stations

- 30 globally distributed, multi-technique co-located ground stations
- 4 techniques/site



Working Towards a GGOS Network of Fundamental Stations

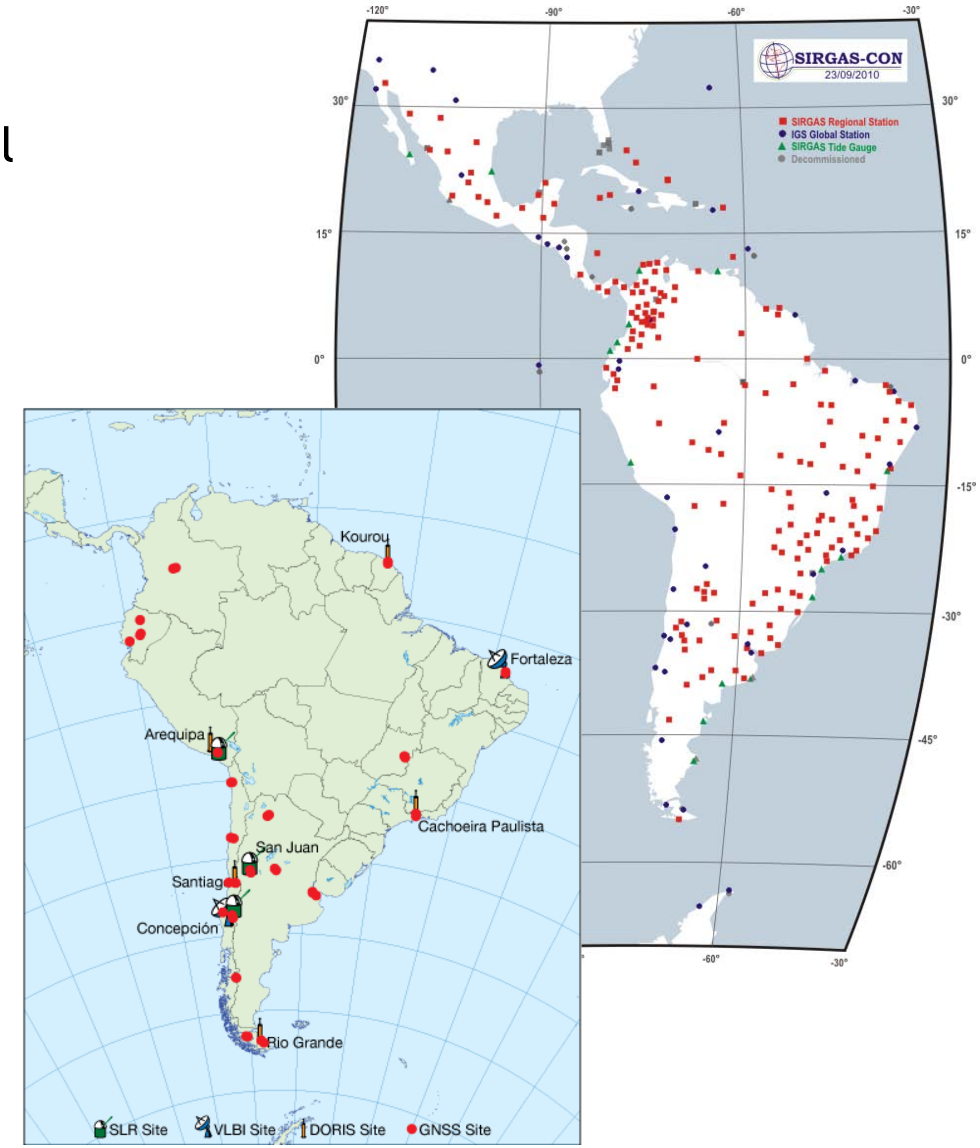
- Time frame: 10-year horizon
- Estimated cost of a Fundamental Station: $10M (U.S.)

Countries with fundamental site activities:

United States	Germany
China	Korea
Australia	Russia
New Zealand	India
Saudi Arabia	South Africa
Spain	

Building the Next Generation Precision Geodetic Infrastructure in South America

- Network in South America no longer optimized to meet societal needs
- Considerable capacity to build upon
- Some of the current stations in South America have inadequate meteorological and geological conditions severely limiting data quality and quantity



Next steps in South America:

- Organize meeting between the IAG, GGOS, SIRGAS, and interested national agencies to discuss opportunities for establishing fundamental sites in South America

For more information contact:

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Chair, GGOS Networks and Communications Bureau
mpearlman@cfa.harvard.edu

Backup Slides

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;
- Separate Proposal for building of first retroreflector array for future GPS satellites
- Project Scientist: Herb Frey/NASA GSFC (Herbert.V.Frey@nasa.gov)
  Deputy Project Scientist: Frank Webb/JPL (Frank.H.Webb@jpl.nasa.gov)
  Project Manager: Ron Zellar/NASA GSFC (ron.zellar@nasa.gov)