# GGOS Working Group on Ground Networks and Communications

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## ABSTRACT


Properly designed and structured ground-based geodetic networks materialize the reference systems to support sub-mm global change measurements over space, time and evolving technologies. Over this past year, the Ground Networks and Communications Working Group (GN&C WG) has been organized under the Global Geodetic Observing System (GGOS) to work with the IAG measurement services (the IGS, ILRS, IVS, IDS and IGFS) to develop a strategy for building, integrating, and maintaining the fundamental network of instruments and supporting infrastructure in a sustainable way to satisfy the long-term (10-20 year) requirements identified by the GGOS Science Council.

Activities of this Working Group include the investigation of the status quo and the development of a plan for full network integration to support improvements in terrestrial reference frame establishment and maintenance, Earth orientation and gravity field monitoring, precision orbit determination, and other geodetic and gravimetric applications required for the long-term observation of global change. This integration process includes the development of a network of fundamental stations with as many co-located techniques as possible, with precisely determined intersystem vectors. This network would exploit the strengths of each technique and minimize the weaknesses where possible. This paper discusses the organization of the working group, the work done to date, and future tasks.


## THE GLOBAL GEODETIC OBSERVING SYSTEM (GGOS)

The International Association of Geodesy (IAG) established the Global Geodetic Observing System (GGOS) project in 2004 to coordinate geodetic research in support of scientific applications and disciplines and as a contribution to GEOS, GEOSS, and IWGEOSS.

### *Role of the Ground Networks and Communications Working Group (GN&C WG)*

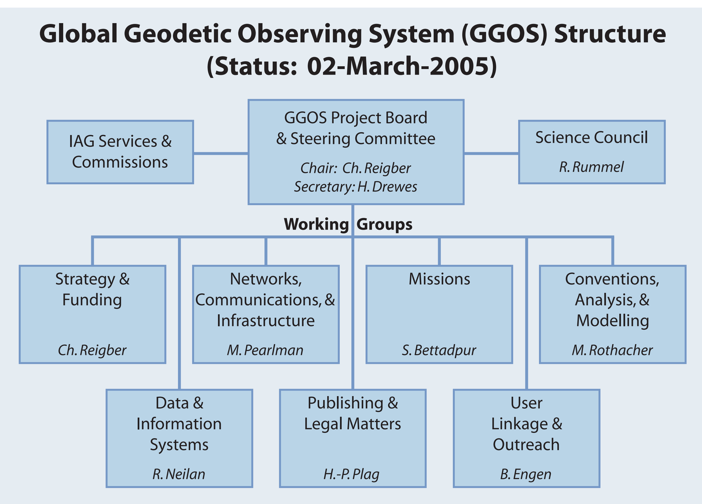
All GGOS data and products emanate from the ground networks infrastructure. The role of the Ground Networks and Communication Working Group (GN&C WG) is to work with the IAG measurement services to develop a strategy to:

- design, integrate and maintain the fundamental geodetic network of instruments and supporting infrastructure in a sustainable way to satisfy the long-term (10-20 years) requirements identified by the GGOS Science Council; and
- include a means of:
  - sustaining the infrastructure needed to maintain evolving global reference frames while at the same time ensuring support to the scientific applications' requirements; and
  - integrating or collocating with the infrastructure and communications networks of the many other Earth Observation disciplines now organizing under the Global Earth Observation System of Systems (GEOSS).

### *Members of the GN&C Working Group*

Membership includes representatives of the measurement services plus other entities that are critical to guiding the activities of the working group:

- IGS: Angelyn Moore, Norman Beck
- ILRS: Mike Pearlman, Werner Gurtner
- IVS: Chopo Ma, Zinovy Malkin
- IDS: Pascal Willis
- IGFS: Rene Forsberg, Steve Kenyon
- ITRF and Local Survey: Zuheir Altamimi, Jinling Li
- IERS Technique Combination Research Centers: Marcus Rothacher
- IAS (future International Altimetry Service): Wolfgang Bosch
- Data Centers: Carey Noll
- Data Analysis: Erricos Pavlis, Frank Lemoine, Frank Webb, John Ries, Dirk Behrend



*GGOS is organized into working groups headed by a Project Board and guided by a Science Council that helps define the scientific requirements to which GGOS will respond.*

## GOALS AND FUTURE REQUIREMENTS OF GGOS

- The measurement requirements for GGOS will be set by the GGOS Project Board with guidance from the Science Council.
- Until requirements are formally specified, we judge the practical useful target for the TRF and space geodetic measurement accuracy to be roughly a factor of 5 to 15 below today's levels.
- Given that the TRF and global geodesy are now accurate to the order of 1 cm (or 5-15 mm for different quantities) and 2 mm/year, we foresee near-term utility in global measurements with absolute accuracies at or below 1 mm and 0.2 mm/year.
- Corresponding levels of improvement are required for Earth orientation and gravity.

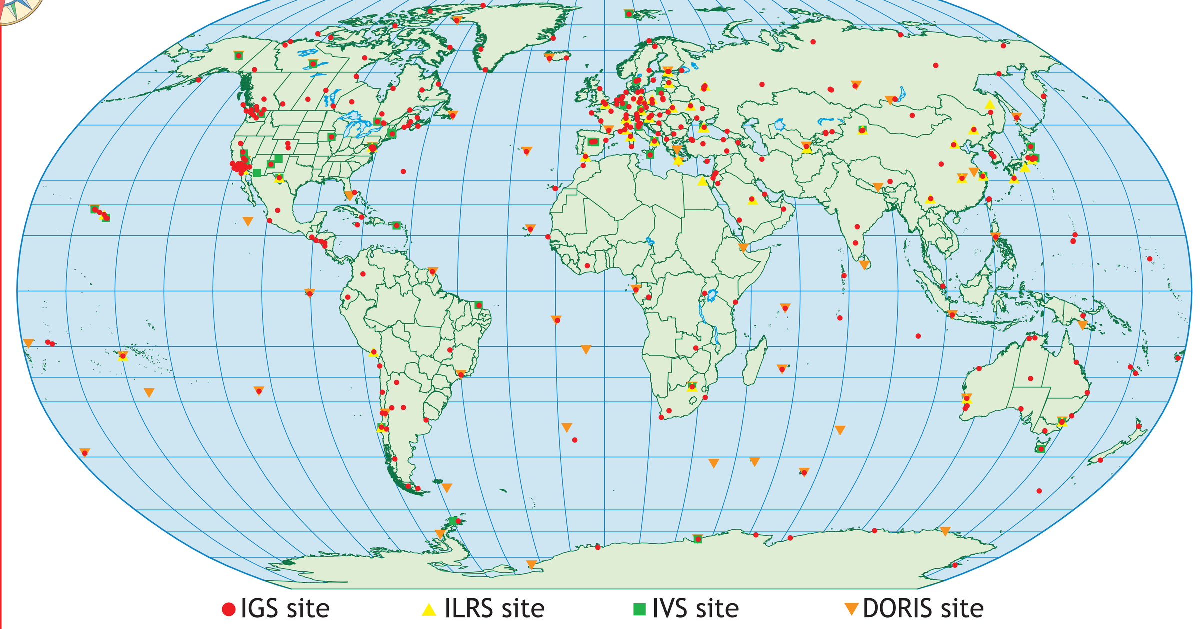
## SIGNIFICANCE OF THE TERRESTRIAL REFERENCE FRAME

Space geodesy provides precise position, velocity and gravity on Earth, with resolution from local to global scales. Through space geodesy, the terrestrial reference system defines the terrestrial reference frame (TRF) in which positions, velocities, and gravity are reported. The task of developing the TRF is complicated by the dynamic character of Earth's surface, which deforms on time scales of seconds to millennia and on spatial scales from local to global.

### *The Terrestrial Reference Frame:*

- links observable quantities, products and geophysical parameters on the Earth;
- is the basis to connect and compare measurements over space, time, and evolving technologies;
- is the means by which observed temporal changes are linked to geophysical signals;
- is the foundation for much of the space-based and ground-based observations in Earth science and global change, including remote monitoring of sea level, sea surface and ice surface topography, crustal deformation, temporal gravity variations, atmospheric circulation, and direct measurement of solid Earth dynamics; and
- is also essential for interplanetary navigation, astronomy, and astrodynamics.

## GLOBAL GEODETIC NETWORK INFRASTRUCTURE




*International Gravity Field Service*

*Laboratory setup of FG5 absolute gravimeter (photo courtesy of Micro-g-Lacoste)*

*International GNSS Service*
*http://igscb.jpl.nasa.gov*

*GNSS station in Thule, Greenland (photo courtesy of F.B. Madsen, DNSC)*

*International DORIS Service*
*http://ids.cls.fr*

*DORIS antenna in Tahiti, Fr. Polynesia (photo courtesy of H. Fagard, IGN)*

*International Laser Ranging Service*
*http://ilrs.gsfc.nasa.gov*

*MLRO SLR facility at Matera, Italy (photo courtesy of G. Bianco/ASI)*

*International VLBI Service for Geodesy & Astrometry*
*http://ivscc.gsfc.nasa.gov*

*32-meter VLBI antenna in Tskuba, Japan (photo courtesy of K. Takashima, GSI)*

## APPROACHES TO NETWORK DESIGN

The final design of the GGOS network must take into consideration all of the applications including the geometric and gravimetric reference frames, EOP, POD, geophysics, oceanography, etc. We will first consider the TRF, since its accuracy influences all other GGOS products. Early steps in the process are:

- define the critical contributions that each technique provides to the TRF, POD, EOP, etc;
- characterize the improvements anticipated over the next ten years with each technique;
- examine the effect in the TRF and EOP resulting from significant changes in the current network or observation program;
- quantify with simulations the improvement in the TRF, EOP, etc. as stations are added and station capability (co-location, data quantity and quality) is improved; and
- explore the benefit of adding new satellite targets (existing and future).

## SYNERGY OF THE OBSERVING TECHNIQUES

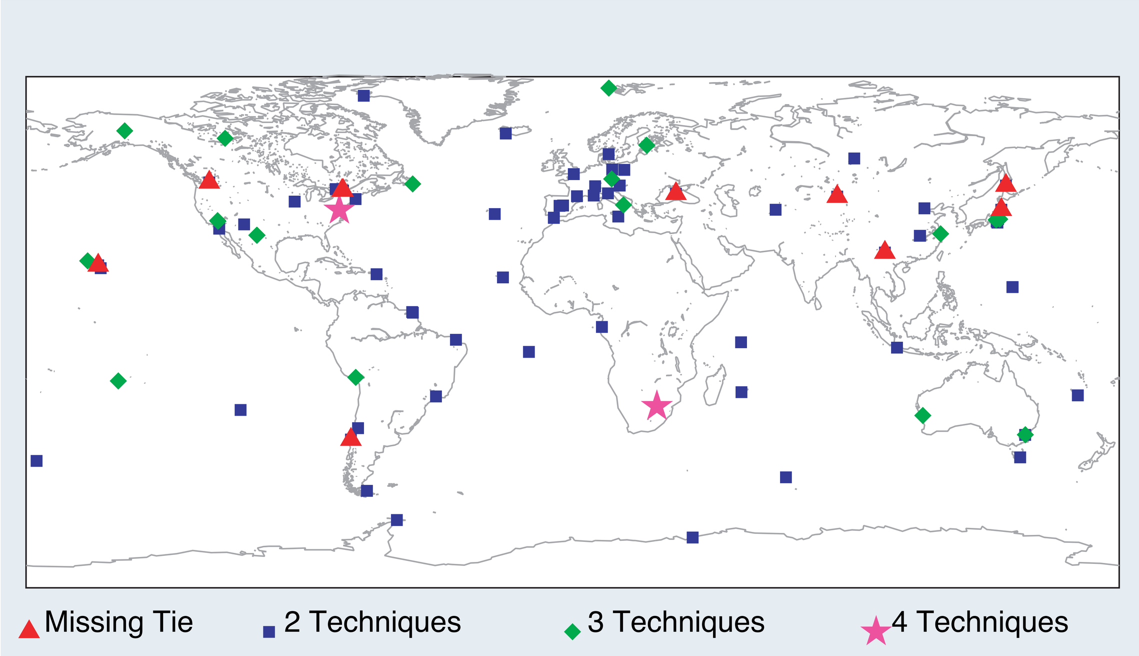
### *The International Terrestrial Reference Frame (ITRF)*

- The ITRF requires multi-technique combination approaches to define all the necessary parameters:
  - SLR defines the geocentric TRF origin (stable to a few mm/decade);
  - SLR and VLBI define the absolute scale to around 0.5 ppb/decade;
  - GNSS provides easy and rigorous TRF access world-wide, using precise IGS products;
  - GNSS facilitates the uniform implementation of the No-Net-Rotation condition;
  - VLBI provides absolute orientation reference; and
  - DORIS contributes a geographically well-distributed network with long-term permanency.
- The TRF is heavily dependent on the quality of each network and suffers with any network degradation over time.

**Co-Location of Space Geodesy Sites**

| Site | GNSS | SLR | VLBI | DORIS |
|---|---|---|---|---|
| ***4 Techniques*** | | | | |
| Greenbelt MD, USA | X | X | X | X |
| Hartebeesthoek, S. Africa | X | X | X | X |
| ***3 Techniques*** | | | | |
| Fairbanks AK, USA | X | | X | X |
| Goldstone CA, USA | X | | X | X |
| Kokee Park HI, USA | X | | X | X |
| McDonald/Ft. Davis TX, USA | X | X | X | |
| Tahiti, French Polynesia | X | X | | X |
| St. John's, Canada | X | | X | X |
| Yellowknife, Canada | X | | X | X |
| Arequipa, Peru | X | X | | X |
| Ny Ålesund, Norway | X | | X | X |
| Metsahovi, Finland | X | X | | X |
| Wettzell, Germany | X | X | X | |
| Matera, Italy | X | X | X | |
| Shanghai, China | X | X | X | |
| Koganei, Japan | X | | X | |
| Mt. Stromlo, Australia | X | X | | X |
| Yarragadee, Australia | X | X | | X |


*Three-technique co-location(left to right: VLBI antenna, GNSS antenna, SLR system) at Hartebeesthoek, South Africa (photo courtesy of M. Gaylard/HartRAO)*



*Distribution of space geodesy co-location sites since 1999. The distribution and quantity of co-location sites (in particular sites with three and four techniques) is sub-optimal. (Figure generated by Z. Altamimi/IGN)*

### *Earth Orientation Parameters (EOP)*

- EOP is required for satellite orbit determination and spacecraft navigation, long-term monitoring of the TRF, monitoring changes in angular momentum in the fluid and solid components of the Earth system.
- EOP relies on a balance of the measurement techniques:
  - VLBI measures celestial pole position and UT1, and defines the ICRF (International Celestial Reference Frame); and
  - Satellite techniques (GPS, SLR, and DORIS) measure variations in polar motion and length of day relative to the orbital planes of the satellites tracked.

### *Gravity, Geoid, and Vertical Datum*

- Gravity:
  - describes how the local vertical changes;
  - defines the datum for height reckoning;
  - provides high resolution global models through spaceborne gravity observations (GRACE, resolution ~200km), complemented by surface gravimetry; and
  - is crucial for determining instantaneous, precise position on Earth or in orbit (precise orbits for near-Earth and interplanetary spacecraft).
- Vertical Datum:
  - provides a common reference for science, engineering, mapping, and navigation problems; and
  - provides a globally consistent vertical datum of very high accuracy that is in reach within the next few years.

### *Precise Orbit Determination (POD)*

- POD provides direct application to many scientific disciplines (ocean and ice topography, sea level and ice sheet change, geo-location in remote sensing).
- POD contributes to estimation of long wavelength static and time-variable gravity field, post glacial rebound, ocean tidal parameters, precise coordinates of tracking sites, geocenter motion, etc.
- POD provides orbit calibration among techniques.

## EVOLUTION OF THE TECHNIQUES

The measurement technique services have each maintained their own networks and supporting infrastructure, routinely producing data. Missions and long-term projects have assumed that the networks will be in place at no cost to them, fully functioning when their requirements need fulfillment. Most techniques require a network expansion while all seek to fill gaps in geographic coverage.

### *GNSS*

- Modernizing for new GPS signal structure, Galileo signals, and GLONASS signals
- Improved handling of calibration issues such as local signal effects (e.g., multipath) and antenna phase patterns, and consolidation of supplementary instrumentation such as strain meters and meteorological sensors

### *Laser Ranging*

- Autonomous operations at kilohertz frequencies, improved pass interleaving and new higher resolution event-timers, and two-wavelength operation for atmospheric refraction delay recovery
- Improved, more compact satellite retroreflector arrays and optical transponders for extended range

### *VLBI*

- Fast slewing, high efficiency 10-12 meter diameter antennas, ultra-wide bandwidth front ends with continuous RF coverage, digitized back ends with selectable frequency segments and improved recording and data transfer techniques
- Near real-time correlation among networks of processors, automated generation of products

### *DORIS*

- Third-generation antennae and improvements to beacon monumentation
- Added DORIS beacons to support altimeter calibration, co-location, and other experiments

### *Gravity*

- Introduction of transportable absolute gravimeters for calibration of superconducting gravimeters
- Airborne and ship campaigns over large areas that are devoid of gravimetric observations
- Development of a method to continuously "map" changes in the field with resolution many orders of magnitude higher than currently achievable from any geopotential mapping mission

## SUSTAINING THE GROUND NETWORKS OVER THE LONG TERM

Missions, long-term projects, and society have tacitly assumed that the networks will always be in place, at no cost to them, fully functioning, to fulfill their requirements.

### *The Problem:*

- Severe budget constraints impact maintenance and data analysis capabilities
- Stable, long-term commitment required from funding agencies for maintenance and operations costs

### *The Challenge:*

- The GGOS community must be proactive in helping to persuade funding sources to
  - provide long-term commitments for stable network evolution and operations;
  - ensure that the GGOS network evolves without data and data product interruption;
  - allow for new and upgraded systems, changes in stations locations; and
  - plan ahead and properly phase-in any changes in the way products are formed.
- The GGOS community must identify network voids and shortcomings, and work with agencies and international organizations toward filling in these gaps.

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