GGOS Bureau on
Ground Networks and Communications
Position Paper
March 2008

GGOS activities associated with Ground Networks and Communications have been organized under the GGOS Working Group for Ground Networks and Communications. Now that GGOS has been moved from an IAG Project to permanent status, the Working Group will be replaced by the Bureau on Ground Networks and Communications.

The Global Geodetic Observing System is intended to fulfill a range of scientific and societal needs by global, consistent, continuous, and integrated measurements of the shape, gravity field, and dynamics of Earth. GGOS relies on the existence of a global ground network and associated infrastructure through which geodetic data are collected and data products are provided to support Earth observation programs and to provide a better understanding of global change. Through these networks run by the Measurement Services, the terrestrial and celestial reference frames that underlie all GGOS data and products are realized.

GGOS has set stringent accuracy and stability requirements for the reference frame to be used in all activities under its umbrella, the ITRF. The attributes of this frame must be known to better than 1 mm at epoch and be stable at better than 0.1 mm/yr to support geophysical studies of global phenomena as sea level rise, etc. The existing aging networks must be upgraded to meet this challenge and this means changes in both, the deployed equipment as well as the number and physical location of the future sites.

The IAG Services (IVS, ILRS, IGS, IDS, IGFS, IERS, etc) provide the organization, coordination, and standards for each of the measurement techniques (VLBI, SLR, GNSS, DORIS, gravity measurements, etc.). For each technique, the network stations and elements of supporting infrastructure are owned and operated by many different entities, each subject to its own mandates, regulations, constraints or circumstances. The Services ensure that their data and products are provided in a manner that is consistent and responsive to GGOS user needs and that a forum is provided to help optimize the infrastructure for maximum benefit. The success of Services and ultimately of GGOS relies on the mutual cooperation and close coordination of the participants in each of the services.

The GGOS Ground Networks and Communications Bureau should facilitate the communication and coordination among the Services to maximize their present utility and to plan for future networks and network infrastructure that will satisfy the GGOS needs, recognizing that multi-technique co-located stations will form the basis for the GGOS network.

Charter:

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. At the base of GGOS are the sensors and the observatories situated around the world providing the timely, precise, and fundamental data essential for creating the GGOS products. Primary emphasis must be on sustaining the infrastructure needed to maintain the evolving global reference frames, while at the same time ensuring the broader support of the scientific applications of the collected data. Synergistic opportunities to better integrate or co-locate with the infrastructure and communications networks of the many other Earth Observation disciplines organized under GEOSS should be considered and exploited.

Membership:

The IAG services will provide the backbone of the Bureau. The Services should designate representatives to the Bureau to participate in the routine Bureau tasks and activities and to provide two-way communications between the Bureau and the Services and access knowledge and capability. The Bureau should seek representation from other disciplines (measurements/operations, analysis, science) as required and, insure that there is a good distribution of national representation and representation from GGOS management as well.

The current Working Group has accumulated participants as topics have been addressed through its meetings and telecons. All have been considered members of the Working Group; some participate every week; some once in a while; some we don't hear from. Membership has been flexible but a core of members has been identified to oversee the tasks.

Members of the present Working Group are: Zuheir Altamimi, David Arnold, Yoaz Bar Sever, Norman Beck, Dirk Behrend, Wolfgang Bosch, Remi Ferland, Rene Forsberg, Richard Gross, Werner Gurtner, Steve Kenyon, Frank Lemoine, Linling Li, Dan MacMillan, Chopo Ma, Zinovy Malkin, Jan McGarry, Angelyn Moore, Ruth Neilan, Carey Noll, Mike Pearlman, Erricos Pavlis, John Ries, Markus Rothacher, David Rowlands, David Rubincam, David Stowers, Frank Webb, Pascal Willis

Interfaces:

The Bureau must routinely interface with the IAG Services to help facilitate a coordinated approach to network development and an exchange of information so that experience and plans can be shared for common benefit. The Bureau must have a liaison office with major government agencies that traditionally support space geodesy (e.g. NASA, ESA, CNES, ASI, JAXA, RSA, etc.) in order to (a) stay informed of plans for future missions and the associated need for ground network and data communication facilities, and (b) provide these agencies with information on the available infrastructure to facilitate their mission planning activities. The Bureau must be in close contact with the analysis community from all techniques to ensure that analysis and product issues are addressed. Finally,
The Bureau must be responsive as practicable to the Science Committee requirements to ensure that the networks are being responsive to GGOS goals and objectives.

Since ground survey is a critical element in the success of GGOS, the Bureau must work with agencies and associations with ground survey experience and expertise to try to bring the best talent and technologies to support the ground network. Such agencies include the national geodetic surveys such as IGN, NGS, GA, and ASI, as well as international groups such as FIG with well-recognized ground survey engineering expertise.

High Level Tasks:

The Bureau should be flexible enough to address both short- and long-term tasks; the current Working group has the following high-level tasks:

- Promote communication and integration among the Services;
- Develop and maintain ground network station and data product information base;

- Develop a model that predicts the accuracy and stability of the reference frame as a function of the number of co-located SLR, VLBI and GNSS stations, their geographic distribution, and their data quality and yield, to assure that it meets GGOS requirements;
- Estimate the size and distribution of the GNSS network necessary to provide reference frame access globally, commensurate with GGOS requirements;
- Seek an effective way to monitor inter-technique vectors at co-location sites to support the above tasks;
- Identify and facilitate the communications necessary to support data flow from the stations through to archiving of data and data products for the users.

Approach:

Communication and Integration among the Services

The Bureau should hold open meetings biannually to review progress on all of the tasks, status and progress of Service-specific projects, and any other relevant issues; periodic telephone conferences can be used as interim communication of information and status reporting.

The present Working Group holds meetings semiannually (about 3 hours) each year on the occasion of the EGU and AGU (fall) conventions. These meetings are informal; the charts presented are posted in the GGOS website. Telephone conferences are held monthly and more often when necessary to review current issues and projects.

Ground Station Data and Product Information Base

The Bureau should work with the IAG services to maintain lists of network sites and co-location information. Currently, lists of space geodesy (GNSS, SLR, VLBI, and DORIS) sites and co-location information are available, created using metadata in the CDDIS database. These lists are accessible through the INDIGO Web site at http://indigo.nasa.gov/indigo_news.html. These lists should be expanded to include gravity, tide gauge, and other relevant networks, and should be maintained by this Bureau.

The Bureau should maintain a centralized data base of general information about the IAG services, including lists of available data and products. Current compilations are available through the INDIGO Web site http://indigo.nasa.gov/indigo_serva.html. The Bureau will also pursue coordination with other GGOS metadata efforts.

The Bureau should also maintain at all times a best estimate of the anticipated evolution of the measuring capability for each of the techniques associated with the IAG Services and a commensurate prediction of the corresponding accuracy of the resulting ITRF.

Network Design

The development of new equipment implies a totally new observing routine for most techniques, and especially so for SLR and VLBI. Almost 24/7 operations will produce a very different data yield in size and geometric distribution. Near real-time availability of the data implies also that products could be available on a much timelier schedule. New equipment, “Next Generation SLR”, the “VLBI2010” and new GNSS receivers that can track GPS, GLONASS and GALILEO (possibly other GNSS constellations), will produce data with higher accuracy and at much higher rates.

Since the ITRF is based on input from all space geodetic techniques, while each one of these contributes only partial information for its realization, planning the optimal mix of such systems and their optimal distribution on a global scale is fundamental to achieving the GGOS goals. One key aspect of this design is the identification of the sites where multiple techniques will be co-located to ensure the best inter-connection of techniques and the best use of available resources.

The Ground Networks and Communications Working Group (GNC WG) embarked on a study to define the ideal future network from a mix of all space geodetic techniques. As a first step, the study seeks the optimal mix of the two oldest and most expensive (in terms of field equipment) techniques: SLR and VLBI, the rationale being that these two techniques alone can observe and define all of the ITRF attributes, origin, scale and orientation, at a very high level of long-term accuracy albeit with sparse geographic distribution. The network of these two techniques will comprise the "zero-th" order framework from which the other techniques (e.g. GNSS and DORIS) will distribute the reference frame globally in space and time to the user community.

Simulation studies of co-located SLR and VLBI systems are currently utilized to determine the optimal size and distribution of a global network that meets the GGOS requirements. The approach used is limited initially by the computational size of the problem and consists of investigating the results from four globally distributed networks of 8, 16, 24 and 32 sites. The smallest network reflects the current real situation, although due to operational realities, it may often be worse, with only 6 or 7 co-located sites, and the geographic distribution is uneven. Once the initial relationship among the four networks is defined, the effects of system improvements, data taking strategy and data yield, the quality of intersystem vectors, analysis models, etc., will be examined for the effect on the quality of the reference frame. The simulation studies are being conducted with the NASA GEODYN II program.

Global Dissemination of the Terrestrial Reference Frame (GNSS Network)

In order to disseminate the TRF through GNSS with the required accuracy and stability we must verify that the accuracy of the origin and scale is preserved when connected to the GNSS frame through the local ties at co-located sites. At this stage it is imperative that we investigate the weakness that results when local ties are missing, misclosed, or have unmonitored variations.

GNSS delivers its high-accuracy relative positioning and EOP based on precise orbit and clock states for the participating constellations. The accuracy of these states affects directly the accuracy with which GNSS disseminates the ITRF and its products. It is thus important to verify the minimum number of fiducial GNSS-tracking sites through which a tie will be realized to the SLR- and VLBI-based ITRF. This analysis can be performed independently of the SLR and VLBI simulations, with the only input being the size and the distribution of the SLR/VLBI network that will be selected as the one fulfilling our reference frame accuracy goal. Except for potential indirect orbit improvements for the GNSS satellites from possible SLR tracking, it is unnecessary to bring the three techniques together in a grand simulation scheme that would be extremely cumbersome to control and computationally intensive. The possible improvements of GNSS orbits from SLR (even VLBI) tracking can be also assessed from independently run targeted simulations from an already selected optimal network.

Monitoring Inter-technique Vectors at Co-location Sites

There are many obstacles to reaching 1 mm, 3-D intersystem vector results. The ground survey is only one component. Some repeated surveys tend to give fairly consistent results at the few millimeter level yet discrepancies still exist in the reference frame results. Offsets between the reference point modeled in the data analysis and the instrument reference point measured by ground survey are also a major source of error. It will take the combination of surveyors, analysts, and instrument specialists to make the most out of the present network. The achievement of sub-mm intersystem vectors is a very significant task and will likely be achieved in steps as we transition from the current systems to future, better designed instrumentation. The first step should be to identify where resurveys among the most productive stations would provide the most benefit to the reference systems and then work with the appropriate Services and agencies to undertake those surveys.

The Bureau must investigate and propose monitoring procedures of how the reference frame quality depends on the quality of the inter-technique vector and how this monitoring is accomplished in a practical manner. The present technique of using conventional ground survey techniques with visits once every year or two is expensive and gives only a snapshot of the situation. It does not give us any insight into diurnal, seasonal or transient variations. Two approaches that are being studied are Terrestrial Monitoring using some of the newest automated survey equipment and an inverse co-location technique using an array of satellites for ground position navigation with the special provision to carry all space geodetic techniques with an extremely precise connection of their reference points.

Terrestrial Monitoring

The GNC WG investigated some design layouts for optimal measurement of local ties and conducted field demonstrations of some of the state-of-the-art equipment. The Leica Total Station instrument, now used for routine surveys by Geoscience Australia at field stations, shows near mm precision; a demonstration of this system was also conducted by Leica at GSFC. A joint meeting of the GNC WG and the IERS WG-2 was held during the 2007 EGU, in an effort to examine some of the current civil engineering survey techniques that might be applicable. Additionally, a session at the IAG/FIG conference on deformation analysis, measurement, and structural engineering, ("Measuring the Changes“, 12-15 May 2008, Lisbon), is also being organized to examine how the civil engineering community might be able to participate and contribute with new ideas to this activity.

Monitoring of Co-location Vectors using Inverse Co-location (co-location in space)

A mission concept is being developed by JPL in an attempt to solve lingering problems with survey-based approaches to inter-technique ties. One of the prime difficulties in survey-based vector determination between co-located techniques are ambiguities in GNSS antenna phase center location due to instrument calibration uncertainties, local multipath and changing local environment leading to time variability in the baseline vector measurements. Similar issues, if not as complicated, exist with the VLBI antennas in connecting the point to which the collected data refer to a physical point derived from the surveying process.

As envisioned, this approach would co-locate the key geodetic techniques, (GNSS, VLBI, SLR and DORIS) on a well-calibrated and dynamically modelable micro-satellite, specifically designed to support mm-level accurate and stable calibration. The basic approach involves orbit determination by one technique and then the positioning of sites from another technique using this co-location in space, with the intersystem vector being determined within a consistent reference frame. Even if this technique does not prove to be as precise as high-accuracy site monitoring, it has the advantage of providing monitoring of all vector ties in the entire network. Preliminary analysis calls for orbital altitudes in the range of 2000-2500 km, to minimize model errors in atmospheric drag, avoid moving parts on the satellite, optimize solar pressure modeling and provide reasonable satellite lifetime.

Communications

The Bureau should work with the services to identify and facilitate the communications necessary to support data flow from the stations through to archiving of data and data products for the users. Rapid wideband communication, required mainly by real-time e-VLBI, will drive network communications requirements. Although requirements for the other techniques will be less stringent, real-time or near real-time data flow will generally be necessary. In particular there are already GPS stations that are streaming data in real time to analysis centers. SLR presently flows data hourly and is seeking ways to further expedite the process.

To the extent possible, Space Geodesy activities within GGOS should take advantage of communications services that exist for science at low or no cost. The Bureau should be aware of what services exist, how they can be accessed for our users at favorable rates or at no cost, or as a participant in other communities that are already using these services (e.g. IRIS, the seismological network). The Bureau should investigate the use of satellite communication techniques that are now being used at minimal or no cost in other global networks for scientific applications such as seismological networks, tide gauge networks, atmospheric sensing networks, etc. These groups have already well-established procedures that allow their members to gain access to these communication networks. Examples of these systems are the U.S. GOES satellites and the European EUMETSAT network. The Bureau should help broker agreements with such networks in order to provide a standardized approach to economic data and product communication.

The Bureau should establish a standard procedure by which users can be made aware of communication services that are available and receive guidance on determining applicability, how best to gain access, and what technology and procedures are appropriate. It would be very advantageous if participation could be fostered with the UNAVCO group which has considerable expertise in communication and has resolved many communications issues in the past.

It is not intended that the Bureau get involved with the actual use of these networks or satellite links; but rather it should provide the mechanism and procedures to facilitate the process.

Publications:

"GGOS Working Group on Ground Networks and Communications", Pearlman et al., Dynamic Planet (ed. P. Tregoning and C. Rizos), Springer, IAG Symposium. Vol. 130, ISBN 978-3-540-49349-5, p719.

"Global Geodetic Observing System – Considerations for the Geodetic Network Infrastructure", Pearlman et al., Geomatica, Vol 60, No. 2, 2006, p193-204.