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GGOS Global Space Geodesy Networks and the Role of Laser Ranging

Michael Pearlman (1), Erricos Pavlis (2), Carey Noll (3), Chopo Ma (3), Scott Wetzel (4), Graham Appleby (5), and Ruth Neilan(6)

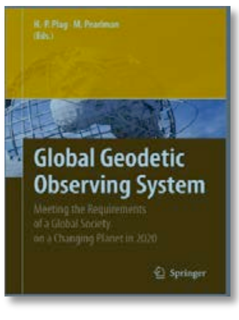
(1) Harvard-Smithsonian Center for Astrophysics, Cambridge, USA
(2) University of Maryland, Baltimore County, Baltimore, USA
(3) NASA Goddard Space Flight Center, Greenbelt, USA
(4) Honeywell Technical Solutions, Inc., USA
(5)Natural Environment Research Council, UK
(6) Jet Propulsion Laboratory/Caltech, USA
mpearlman@cfa.harvard.edu

Abstract

The reference frame is essential to measurements and their interpretation of global change conditions. The improvements in the reference frame and other space geodesy data products spelled out in the GGOS 2020 plan will evolve over time as new space geodesy sites enhance the global distribution of the network, and new technologies are implemented at the sites thus enabling improved data processing and analysis. The GGOS goals include the development of the reference frame to 1 mm accuracy and 0.1 mm stability, an order of magnitude better than the present situation. To achieve the improved reference frame, simulations show that we will need 32 globally distributed core sites with VLBI, SLR, GNSS and DORIS (where available). In addition, co-location sites with less than the full core complement will continue to play a very important role in filling out the network while it is evolving and even after full implementation. The global participation of new technology SLR is a key element to making this work.

Geodesy is the science of Earth's shape, gravity and rotation, including their evolution in time. Techniques used to observe the geodetic properties of Earth provide the basis for the International Terrestrial Reference Frame (ITRF). The ITRF is the foundation for virtually all airborne, space-based, and ground-based Earth observations, and is fundamentally important for interplanetary spacecraft tracking and navigation.

The Global Geodetic Observing System (GGOS) was established by the International Association of Geodesy (IAG) to integrate the three fundamental areas of geodesy (Earth's shape, gravity field, and rotation), to monitor geodetic parameters and their temporal variations in a global reference frame with an accuracy of 10^{-9} or better (See GGOS 2020). GGOS is intended to provide products and services with the geodetic accuracy necessary to address important geophysical questions and societal needs, and to provide the robustness and continuity of service which will be required of this system in order to meet future needs and make intelligent decisions on societal needs. This includes the decisions that we make regarding our national and international resources, our populations, and our environment. GGOS is constituted mainly from the Services (ILRS, IVS, IGS, IDS, and IERS) and although it has a wide spectrum of interest, the main focus at the moment is on the improvement of the ITRF.

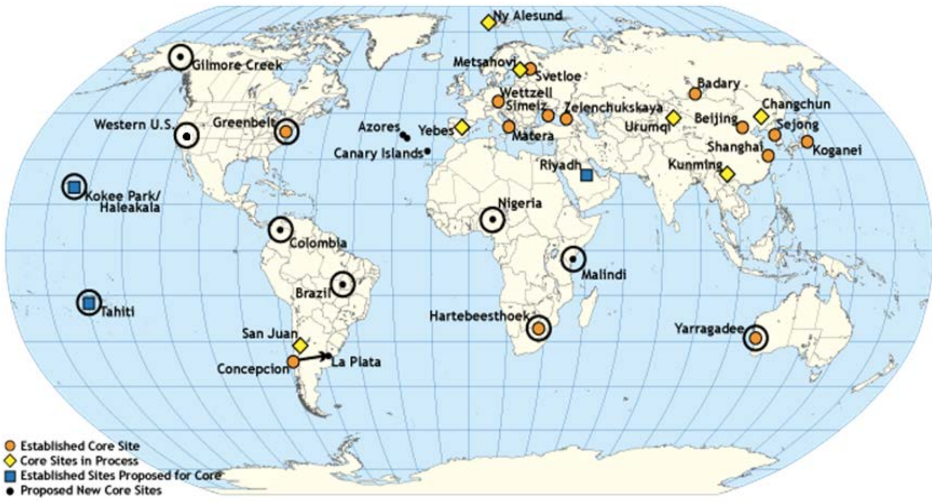


As elucidated in the US National Research Council (NRC) Study headed by Professor Bernard Minster, the most stringent requirement for the ITRF comes from sea level rise currently measured by satellite altimetry to be about 3 mm/year. However, our existing knowledge of the reference frame that is the basis for our ability to connect measurements over space, time, and evolving technology is only at the cm level. Errors in the current reference frame could be aliased into our estimates of sea level rates. It could be larger; it could be smaller. The requirements for a reference frame that would be commensurate with our sea level measurements as recommended by the NRC study are an “accuracy of 1 mm and stability at 0.1 mm/year over 10 years”, which is about a factor of 10-20 beyond current capability. We point out that although sea level is the main driver for the ITRF, many other effects such as seismic hazards and hydrology are not far behind. Since measurements that need to be connected over space and time will be taken all over he world, the ITRF must be accessible 24/7 worldwide, so that users anywhere on Earth can geolocate their measurements in the same, unique, reference frame.

Each of the space geodetic techniques plays an important role in the establishment and maintenance of the reference frame. SLR uniquely defines the Earth’s center of mass and along with VLBI, the scale. VLBI also provides the Earth orientation parameters. The dense global network distribution of GNSS, and to a lesser extent DORIS, provide the global coverage. The space segment is defined by LAGEOS and LARES for SLR, the GNSS constellations, the DORIS satellites, and quasars for VLBI. A globally distributed network of Core Sites, with “modern technology”, co-located SLR, VLBI, GNSS, and DORIS (where available), locally tied together with accurately monitored site ties, define the ground segment. These sites are termed “Core Sites”. In addition, a much denser network of GNSS ground stations is required to distribute the reference frame globally to the users. The sites would be complemented by co-location with other measurement techniques including gravity-monitoring instruments, tide gauges, leveling networks, etc.

Simulation studies performed at the University of Maryland show that about 32 globally distributed, well positioned, new technology, core sites will be required to define and maintain the reference frame, and that about 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. This will be a major challenge, and will require time, significant resources, and strong international participation. A notional depiction of a network distribution is shown here. This is of course the ideal situation and some compromises will have to be made during the actual implementation.

NASA’s Space Geodesy Project is currently building and testing a prototype Core Site at GSFC as a model to be subsequently replicated at several other sites worldwide, as NASA’s contribution to international space geodesy programs and GGOS. These sites would replace legacy equipment in some cases, while some will be located at new sites that would augment or fill gaps in the current network geographically. The site at GSFC is shown with its legacy SLR (MOBLAS -7) and Next Generation SLR (NGSLR), both the legacy VLBI and the new technology VLBI (VGOS), DORIS, and several legacy and new multi-constellation GNSS receivers. Other sites with the three or four techniques are shown on the map below. In general, broadband reception by VGOS is sensitive to RF broadcasts from SLR radars and from DORIS beacons, and therefore careful selection of location and layout will be critical for new technology sites. In addition, great care must be taken to avoid incoming and outgoing interference with external systems such as commercial communication and media transmissions and broadcasts. A map with current core sites, sites planned for upgrade to core status, and sites under consideration for Core status are shown in the map below. The circles denote sites that are under consideration for upgrade or establishment by NASA through partnerships. Many of the Proposed/Suggested Sites were submitted through a GGOS "Call for Participation" offering partnerships. The map does not include six SLR sites that the Russian Space Agency (ROSCOSMOS) and the Russian Academy of Science plan to deploy at sites outside of Russia to enhance tracking on the GLONASS and other GNSS constellations and to support GGOS. Some of the sites under consideration are in Cuba, Brazil, South Africa, Australia, Israel, and Tahiti.



Map showing current established core sites, core sites in process, and sites currently under consideration by NASA (denoted by circles) as either new sites or as site upgrades

A "GGOS Site Requirements" document has been issued to help guide the selection of sites. The document includes an introduction and justification addressing: 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? The document addresses some of the necessary site conditions including: global consideration for the location; geology and ground stability, 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, and local commitment.

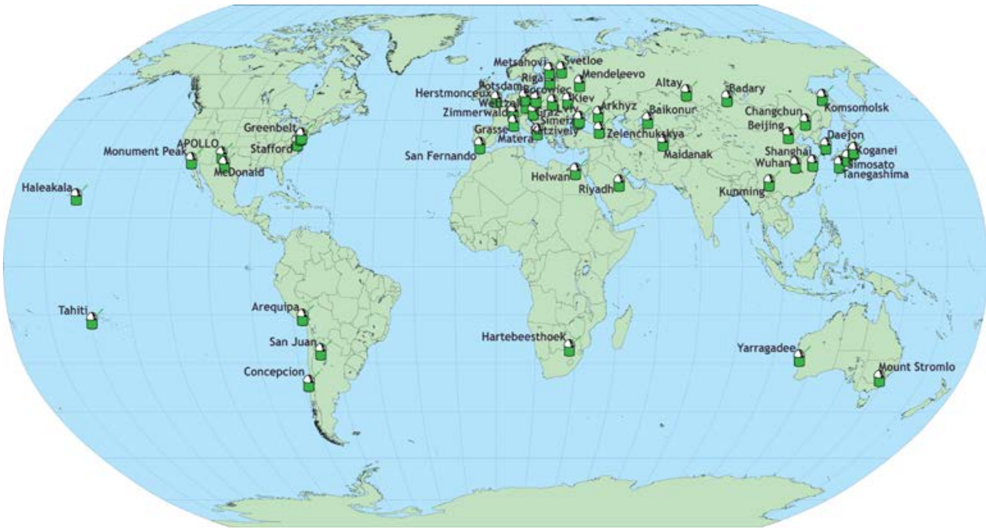
Actions are underway already to enhance the network. BKG (Germany) is moving the TIGO station from Concepcion, Chile to La Plata, Argentina in 2014 to improve ground stability and cloud cover conditions. The Chinese Academy of Sciences is planning to add VLBI to the San Juan (Argentina) site in the 2015-6 timeframe. As a part of its Space Geodesy Project, NASA has discussions underway for possible site locations in South America with the Instituto Geográfico Agustín Codazzi (IGAC) in Colombia and the National Institute For Space Research (INPE) in Brazil. In Africa, NASA also has discussions underway with the Italian Space Agency (ASI) for a possible partnership in Malindi, Kenya and with the National Space Research and Development Agency (NASRDA) in Nigeria for a site in their currently established space geodesy station at Toro.

It will take a long time to achieve the full complement of core sites in the right places, if we ever do achieve it. Even if we have sufficient resources, it’s very unlikely that we will find the full compliment of ideal sites, and some sites will have less than ideal conditions. Aside from core sites, co-location sites with less than the full system complement will continue to be required to augment the core sites and help link the techniques, provide redundancy and alternatives, and enhance global coverage. We expect a mix of new technology and legacy sites indefinitely and our data products will depend on this mix of sites and technology.

SLR has made giant step improvements over the last several years. High repetition systems (0.1 – 2 KHz) are generating normal points (NPs) much faster, enhancing satellite pass interleaving and data yield. Narrow pulse widths are reducing noise; some stations are now operating at near mm NP precision. The addition of the LARES satellite to the reference frame constellation will strengthen the ITRF. Improved arrays, improved data yields, and improved daylight ranging on the GNSS satellites should greatly enhance the role of SLR in navigation satellite data products and allow us to begin testing the GNSS distribution of the reference frame. It should be noted that the GLONASS constellation is fully populated with retroreflector-equipped satellites and offers us an ideal opportunity to press ahead with this concept. Retroreflector arrays will also be placed on the new GPS satellites starting in 2019 further strengthening the GNSS constellations. The network has also had some success with synchronous satellites, most recently the QZSS, the IRNSS, and some of the Beidou spacecraft. Increased automation at the stations is helping to expand temporal coverage and on-site data preprocessing is providing better on-site quality control. In addition we are very pleased that new groups in Korea and Russia are deploying a number of new stations.

We recognize that there are still major challenges even in our current mode of operation. There remain large gaps in our geographic coverage. We have a mix of legacy and new technologies and we will see an evolution as the newer technologies replace the old. Smooth transition is critical to avoid losing the strength of our long-time histories. Some of our current locations suffer from local shortcomings such as poor weather or poor ground stability.

Some agencies such as BKG, NASA, Russian Academy of Sciences and ROSCOSMOS, the National Astronomical Observatories of China and the Chinese Academy of Sciences have deployed sites overseas. This is a trend that we need to encourage. Many of our agencies are running sites in their own back yard, giving us large concentrations in Europe.



Map showing current laser ranging network for SLR and LLR

We also have a number of operational and engineering issues that need to be addressed. Long-term system outages and systematic errors are corrupting our data products. In some cases, long stretches of data from some stations must be discarded from our data products. We need to improve on-site engineering and quality assurance procedures so that the stations can better diagnose their operational problems in real time rather than waiting for data issued a day or days after the fact. We are also implementing better procedures for reporting systems changes, but this only works if stations are conscientious about promptly informing the community of all changes. System changes that may inadvertently introduce systematic ranging error can be carried along for months before they are recognized, or worse, if left unreported, they can be interpreted falsely as geophysical signals.

In summary, we have made very significant progress, but we still have many challenges ahead. We need to put greater care in our data quality through better quality control and reporting procedures. We need to find more partners to help fill out the network and we need to encourage everyone to move to the newer technologies in a systematic fashion to improve our data products while maintaining the integrity of our data record.