

**The Role of Core and Co-location Sites and the Activities Underway to Improve the  
Global Space Geodesy Network  
(Abstract 3044)**

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The Global Geodetic Observing System (GGOS) was established by the IAG to integrate the three fundamental areas of geodesy (Earth's shape, gravity field, and rotation) and to monitor geodetic parameters and their temporal variations in a global reference frame with a target relative accuracy of 10E-9 or better (See GGOS 2020). The goals were 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 long-range decisions. GGOS is constituted mainly from the Services (IERS, IDS, IGFS, IGS, ILRS, IVS, etc.) and its main focus at the moment is the International Terrestrial Reference Frame (ITRF), but we expect other data products requiring multi-technique observations will emerge.

The reference frame is the basis upon which we measure change over space, time, and evolving technology. The geometric techniques used to observe the geodetic properties of Earth provide the basis for the ITRF, which is the fundamental reference for virtually all airborne, space-based, and ground-based Earth observations and it is also uniquely important for Earth-based interplanetary spacecraft tracking and navigation.

Studies such as those performed by the US National Research Council (Minster et al., 2010) argue that the most stringent requirement for the reference frame is the measurement of sea level rise, which will require a reference "accuracy of 1 mm and stability at 0.1 mm/yr.", a factor 10-20 beyond current capability. The requirements for many other applications are not far behind and as our understanding of Earth System processes increases, so do the accuracy requirements. To fulfill its role, the reference frame must be accessible 24 hours/day, worldwide so that users anywhere on Earth can use it to position their measurements in a common reference system.

The space segment used to define the reference frame includes the LAGEOS and ETALON "cannonball" satellites (with SLR retroreflectors), the GNSS constellation(s), the DORIS-equipped satellites in Low Earth Orbit, and distant quasars. The ground segment is a globally distributed network of "modern technology", co-located SLR, VLBI, GNSS, and DORIS

systems with local site-ties to accurately relate the measurements from these co-located instruments (Pearlman et al., 2002; Schlueter and Behrend, 2007; Dow et al., 2009; Willis et al., 2009). Co-location in space also plays an important role in connecting the techniques and helping provide an accurate distribution of the reference frame globally. One idea that is being developed at JPL is the Geodetic Reference Antenna in Space (GRASP) concept that would carry a space segment for all of the techniques on a single well-calibrated spacecraft to support site tie calibration (see [http://ilrs.gsfc.nasa.gov/docs/GRASP\\_COSPAR\\_paper.pdf](http://ilrs.gsfc.nasa.gov/docs/GRASP_COSPAR_paper.pdf)).

Stations with co-located SLR, VLBI and GNSS are termed Core Sites. Sites that have only two of these techniques are called Co-location sites. DORIS is included where possible, but we recognize that the DORIS program has its own location requirements and may only be included at some of the Core Sites.

Simulation studies at the University of Maryland (Pavlis, 2008 and Pavlis, and Kuzmich-Cieslak, 2009) show that we will need about 32 globally distributed, well-positioned, new technology Core Sites to properly define and maintain the reference frame. Ideal sites would have stable ground conditions (no episodic events or non-linear motion), clear skies (less than 50% cloud cover over the year), sufficient local infrastructure to support operations, and sufficient land area and terrain to separate or shield instruments to avoid RF interference with other instruments on site or with local services.

Each of the technique communities is expanding its capabilities. Figure 1 shows the current distribution of SLR and Lunar Laser Ranging (LLR) sites and where new site installations are in progress (e.g., Havana, Cuba; Mount Abu and Ponmuda, India) and other sites being planned. The network still has large geographic gaps, an anachronistic mix of new and legacy technologies, and some non-uniformities in procedures, but many groups are now implementing and planning new site and technology upgrades including higher pulse repetition rate lasers (kHz) for faster data acquisition; smaller, faster slewing telescopes for more rapid target acquisition and pass interleaving; ranging from LEO to GNSS satellites for improved coverage, more accurate pointing for link efficiency; narrower laser pulse width (10–30 ps) for greater precision; single photon detection for greater accuracy, and more automation for greater temporal coverage and economy (24/7).

Laser ranging is the only space geodetic technique that measures range directly and unambiguously; the others all measure range differences or rates. The range data are used for Precision Orbit Determination (POD) and a time history of station positions and motions. With the geodetic constellation of high mass to area satellites, SLR is used to generate long-term stable orbits for studies of long-period perturbations. It uniquely ties the ITRF to Earth's center-of-mass (both SLR and VLBI independently determine the scale). Contributions to other geophysical products include plate tectonics and crustal deformation, static and time-varying gravity field components, polar motion and length of day, orbits for calibration and validation of altimetry missions (oceans and ice), support for space science and engineering missions, and studies of relativity and lunar science.



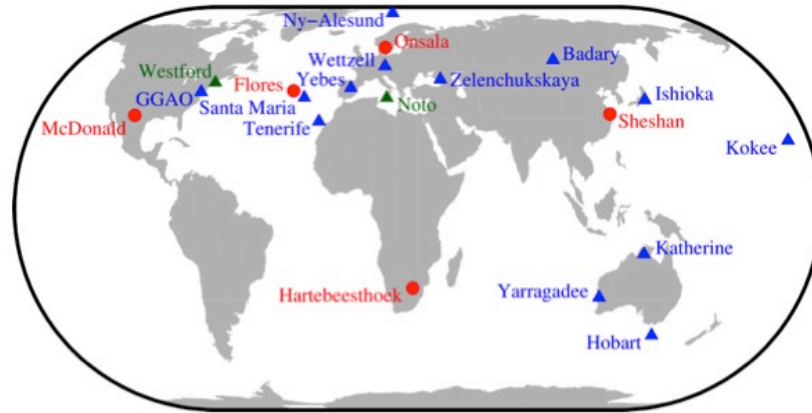
Figure 1. Projected SLR Network (late 2014)

VLBI is a geometric technique that measures the difference between the times of arrival at two Earth-based antennas of a radio wave front emitted by a distant quasar. Using large numbers of time difference measurements from many quasars observed with a global network of antennas, VLBI determines the quasi-inertial reference frame defined by the quasars and simultaneously, the precise positions and velocities of the antennas. Since the antennas are fixed to Earth, their locations track the instantaneous orientation of Earth in the inertial reference frame. Relative changes in the antenna locations from a series of measurements indicate tectonic plate motion, regional deformation, and local uplift or subsidence. The VLBI network, like the SLR, is similarly going through a transition (see Figure 2 and Table 1). New stations are being planned and legacy stations are in the process of upgrading to the VLBI Global Observing System (VGOS class) including smaller and more agile telescopes (12–13 m diameter dishes, 12°/s and 6°/s slew speeds); wide bandwidth (2–14 GHz), flexible frequency allocation, and dual linear polarization detection. These properties enable denser sampling of the atmosphere and as many as two scans per minute (2880/day).

The GNSS network is moving to multi-constellation receivers (GPS, Galileo, GLONASS, BeiDou/COMPASS, etc.) for better geometry and deep-drilled braced monuments for better antenna stability. The DORIS network is moving to the new multi-channel spacecraft receivers for enhanced data quality and increased ground beacon coverage (Auriol and Tourain, 2010). The DGXX receiver on the Jason-2, Jason-3, and Cryosat-2 spacecraft can track up to seven DORIS beacons at one time. Both the GNSS and DORIS networks strengthen the reference frame and provide the essential global coverage. The GNSS co-located instruments provide the tie between techniques with currently limited participation in Core sites. Furthermore, their orbital products are used to disseminate the ITRF to the wider user community who have limited physical access to Core and Co-located sites. The DORIS network serves as a direct tie to Earth Observing altimetry missions (such as Jason-2, Cryosat-2, and Saral), providing POD in the

ITRF frame and for the more recent missions, on-board versions of the orbit for operational purposes and quick-look product development.

## VGOS: VLBI Global Observing System



VGOS progress:    ▲ hardware work in progress  
                          ● funding approved  
                          ▲ legacy upgrade in progress

Figure 2. VLBI Network

**Table 1. VLBI Activity Underway**

Station	Recent Milestone	Broadband Readiness
<b>GGAO</b>	Test observations	Now on fast RT
<b>Westford</b>	Test observations	Now on legacy RT
<b>Wettzell</b>	Receiver tests	Early 2015
<b>Yebes</b>	First fringes on X-band	Late 2015
<b>Noto</b>	Receiver under construction	End 2015 on legacy RT
<b>Ishioka</b>	First fringes	End 2016 (initial S/X/Ka)
<b>Santa Maria</b>	RT constructed on site	2016
<b>Badary</b>	RT constructed on site	2015 (S/X/Ka)
<b>Zelenchukskaya</b>	RT constructed on site	2015 (S/X/Ka)
<b>Kokee Park</b>	RT being assembled at factory	2016
<b>AuScope</b>	Funding for upgrade secured	2016 on fast RTs
<b>Tenerife</b>	RT assembled at factory	2017
<b>Ny Alesund</b>	Civil construction underway	2018

Several initiatives are underway to help expand these networks. The Russian Space Agency and the Russian Academy of Sciences are expanding their overseas SLR and GNSS network to support both GLONASS and GGOS. An SLR station is now operational in Brasilia, Brazil. A second one will be operational in Havana, Cuba in early 2015, and sites for four additional stations are being sought, some in co-location with VLBI. About 50 Russian GNSS receivers are

also planned for deployment in co-location with the SLR instruments and at other sites. NASA's Space Geodesy Project is developing both, a new-technology SLR and a VGOS-class network with the deployment of up to 10 sites to help upgrade and fill gaps in the global core network. Decisions have already been made for sites at McDonald, Texas and Hawaii (in partnership with USNO), and discussions are underway on possible partnerships in Yarragadee (Australia), Hartebeesthoek (South Africa), Tahiti, Brazil, Colombia, Kenya, and Nigeria.

Other Core Sites are presently underway at Sejong (Korea), Ny Ålesund (Norway), Yebes (Spain), Metsahovi (Finland), Urumqi, Changchun, and Kunming (China), and San Juan (Argentina). An optimistic projection on what we might expect for a network of Core Sites over the next decade is shown in Figure 3. The circles highlight suggested NASA/NASA partnership Core Sites. Some would be upgrades from legacy technology. Some would be new sites to fill geographic gaps.

It would of course be very presumptuous to assume that all of these will come to fruition as full Core Sites.

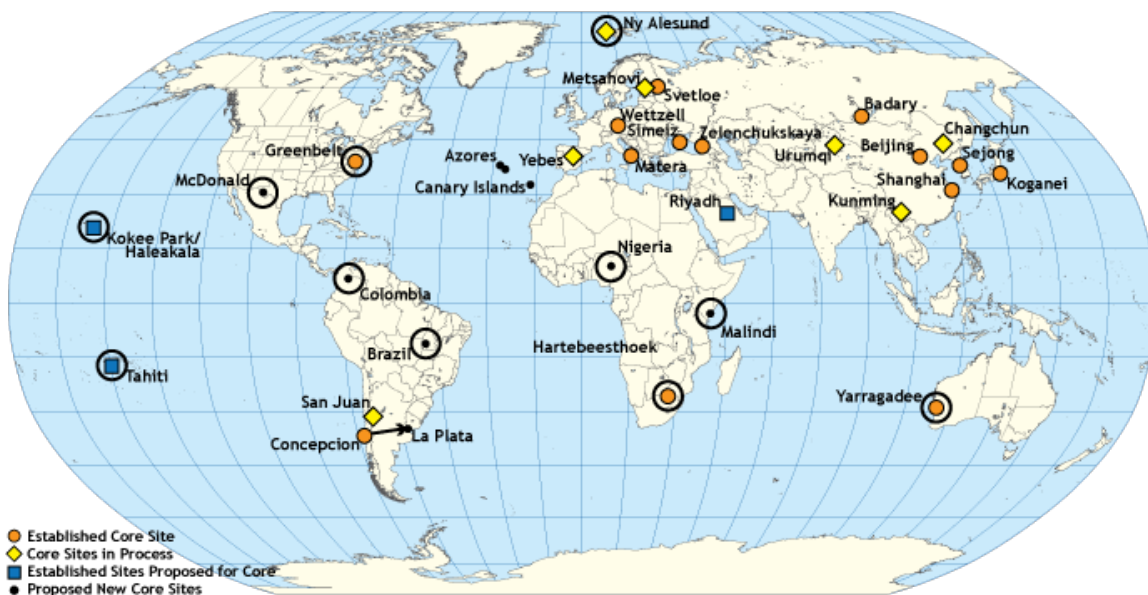


Figure 3. Current, Projected, and Potential Core Sites

We have discussed the ideal situation above, but we need to recognize that even if 32 Core Sites are realized, many sites will not be at ideal locations nor have ideal conditions. Some new technology stations are being deployed, but not co-located with the full suite of a Core Site. Core Sites will be deployed over many years. As a result we will have a mix of new and legacy technologies for many years, and co-location sites (non-Core Sites) will continue to play a vital role in our data products for a long time. The quality of our products will be the result of a convolution of data from networks of Core Sites, co-location sites, a mix of technologies and adherence to proper operational and engineering procedures, and making best use of the data once it leaves the field.

Under GGOS we model the anticipated evolution of the network using current and projected configurations provided by the stations. This information is being used to project forward the expected future capability of the network in +5 and +10-year intervals.

The build-out and upgrade of the network will be a major challenge, requiring careful planning, time, significant resources, and strong international participation. It also means that we need to carefully address the systematic errors in each technique, which if left unaddressed, will degrade our results. It is encouraging to see that many groups are taking the initiative to join the GGOS network, build new stations, upgrade others, and implement programs to better understand their system's performance.

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