

Role and importance of the International Terrestrial Reference Frame for sustainable development

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Contributors to this report:

Zuheir Altamimi: Institut National de l'Information Géographique et Forestière, France

Tonie van Dam : University of Luxembourg

Hansjörg Kutterer: Federal Agency for Cartography and Geodesy (BKG), Germany

Chris Rizos: University of New South Wales, Australia

Background

The ability to assign time-dependent coordinates to points and objects on the Earth's surface is fundamental for many Earth observation applications. Also important is that these coordinates need to be monitored over time in order to take into account all geophysical changes affecting the Earth's surface. Most areas of science, Earth observation, georeferencing applications, and society at large, today depend on being able to determine positions to millimetre level precision. Point positions, to be meaningful and fully exploitable, have to be determined and expressed in a well-defined reference frame. All current global and regional reference frames rely on the availability of the *International Terrestrial Reference Frame* (ITRF), which is the most accurate realisation of the *International Terrestrial Reference System* (ITRS). ITRS is a system defined by the International Association of Geodesy (IAG – <http://www.iag-aig.org>) and the International Astronomical Union (IAU – <http://www.iau.org>) and endorsed by the International Union of Geodesy and Geophysics (IUGG – <http://www.iugg.org>). ITRF is maintained by the International Earth Rotation and Reference Systems Service (IERS – <http://www.iers.org>), one of the many important IAG services, on the basis of globally coordinated, science-oriented infrastructure committed voluntarily by a large number of national agencies and research institutes. Most regional and global reference frames are today aligned or related to ITRF. Interoperability of georeferenced datasets and services depends on well-defined standards or special agreements for the determination and maintenance of the frames, and the availability of transformations between the different frames. The ITRF, regional and national reference frames, can these days be very easily connected to using the signals from Global Satellite Navigation Systems (GNSS), such as GPS, to determine position with respect to such frames to sub-centimetre accuracy. However, in a hierarchical sense the ITRF is the fundamental frame, being the product of an international, collaborative geodetic enterprise that has been engaged in this task for several decades. All other frames are subordinate, and can (must) be aligned or connected to the ITRF using GNSS.

Reference frames

The positions of the thousands of geodetic stations distributed over the Earth's surface can now be determined with a precision at the level of a few millimetres and their variation over time at the level of, or better than, 1 mm/yr. This performance is only possible as a result of

the tremendous progress made in improving the hardware of the space geodetic techniques and in the high level algorithms and scientific software packages developed by the analysis centres dealing with the geodetic observations accumulated over the last three decades. Continuous geodetic observations have become more and more fundamental for many Earth science applications from the global to the local level: large scale, regional, and local Earth crust deformation, global tectonic motion, the redistribution of geophysical fluids on or near the Earth's surface, including the ocean and atmosphere, cryosphere, and the terrestrial hydrosphere. One of the most demanding applications of these continuous observations is the monitoring of mean sea level and its variability in space and time, given the ramifications of sea level rise with global warming and climate change. All these science applications depend fundamentally on the availability and accuracy of a truly global Terrestrial Reference System (TRS) that only space geodesy can realise [Altamimi et al., 2001, 2002, 2007, 2011]. In addition to these geoscientific applications, a TRS, through its realisation by a Terrestrial Reference Frame (TRF), is an indispensable reference that is required to ensure the integrity and inter-operability of Global Satellite Navigation Systems (GNSS), such as GPS, GLONASS, Galileo, etc.

The International Terrestrial Reference Frame

The implementation of the ITRF is fundamentally based on the rigorous combination of geodetic products of the main space geodetic techniques, through their co-located measuring instruments at a certain number of core sites. The space geodetic techniques that provide measurements for the computation of the ITRF include in addition to the GNSS, Satellite Laser Ranging (SLR), Very Long Baseline Interferometry (VLBI), and Doppler Orbitography Radiopositioning Integrated by Satellite (DORIS). These techniques are organised as scientific services under the umbrella of the IAG: the International Earth Rotation and Reference System Service (IERS – <http://www.iers.org>) [Petit and Luzum, 2010], the International GNSS Service, formerly the International GPS Service (IGS – <http://igs.org>) [Dow et al., 2009], the International VLBI Service (IVS – <http://ivscc.gsfc.nasa.gov>) [Schlüter et al., 2007], the International Laser Ranging Service (ILRS – <http://ilrs.gsfc.nasa.gov>) [Pearlman et al., 2002] and the International DORIS Service (IDS – <http://ids.cls.fr>) [Willis et al., 2010].

However, none of space geodetic techniques is able to provide all the parameters necessary to completely define a TRF (origin, scale and orientation). While satellite techniques are sensitive to the Earth centre of mass (the point around which a satellite orbits; a natural TRF origin), VLBI is not (whose TRF origin is arbitrary defined). The scale is dependent on the modelling of some physical parameters, and the absolute TRF orientation (unobservable by any technique) is arbitrary or conventionally defined through specific constraints. The utility and value of multi-technique combinations is therefore recognised for the reference frame implementation, and in particular for an accurate TRF definition. In principle, the particular strengths of one observing method can compensate for weaknesses in others if the combination is properly constructed, suitable weights are found, and accurate local ties in co-location sites are available.

The key element of a multi-technique combined frame, as used for the ITRF, is the availability of a sufficient number and globally distributed co-location sites. A co-location site is defined by the requirement that two or more space geodetic instruments are operating at the same location or at locations very close to one another, which are very precisely surveyed in three dimensions, using geodetic classical surveys or the GPS technique. Classical surveys are

usually direction angles, distances, and spirit levelling measurements between instrument reference points or geodetic markers. Adjustments by least squares of local surveys are generally performed by national geodetic agencies operating space geodesy instruments, yielding differential coordinates (local ties) connecting the co-located instrument reference points.

Currently, IVS is managing a network of 42 radio telescopes, ILRS 32 laser telescopes, IDS 52 beacons, and IGS more than 400 GNSS permanent, continuously operating receivers/antennas. Figure 1 illustrates the current distribution of the total number of VLBI SLR and DORIS sites, as well as the IGS/GNSS co-located sites. All in all there are 82 co-located sites, 40 of which are GNSS-DORIS co-locations. There are only 8 sites where VLBI and SLR are co-located, a rather low number for ensuring optimal connection between these two techniques. In the ITRF combinations, GNSS plays a major role connecting the three other techniques, given the fact that almost all SLR and VLBI sites, as well as 40 DORIS sites are co-located with permanent IGS stations. The drawback of this situation is that if there is any GNSS-related bias, this will contaminate the parameters that define the ITRF, primarily the origin and the scale that are determined by SLR and VLBI. Unfortunately more than half of the VLBI and SLR instruments are old generation systems. As a consequence, the underlying geodetic infrastructure of ITRF is in urgent need of upgrading for next generation instrumentation, particularly for the large number of aging VLBI and SLR instruments. This is an important goal of GGOS, and will be discussed further in the next section.

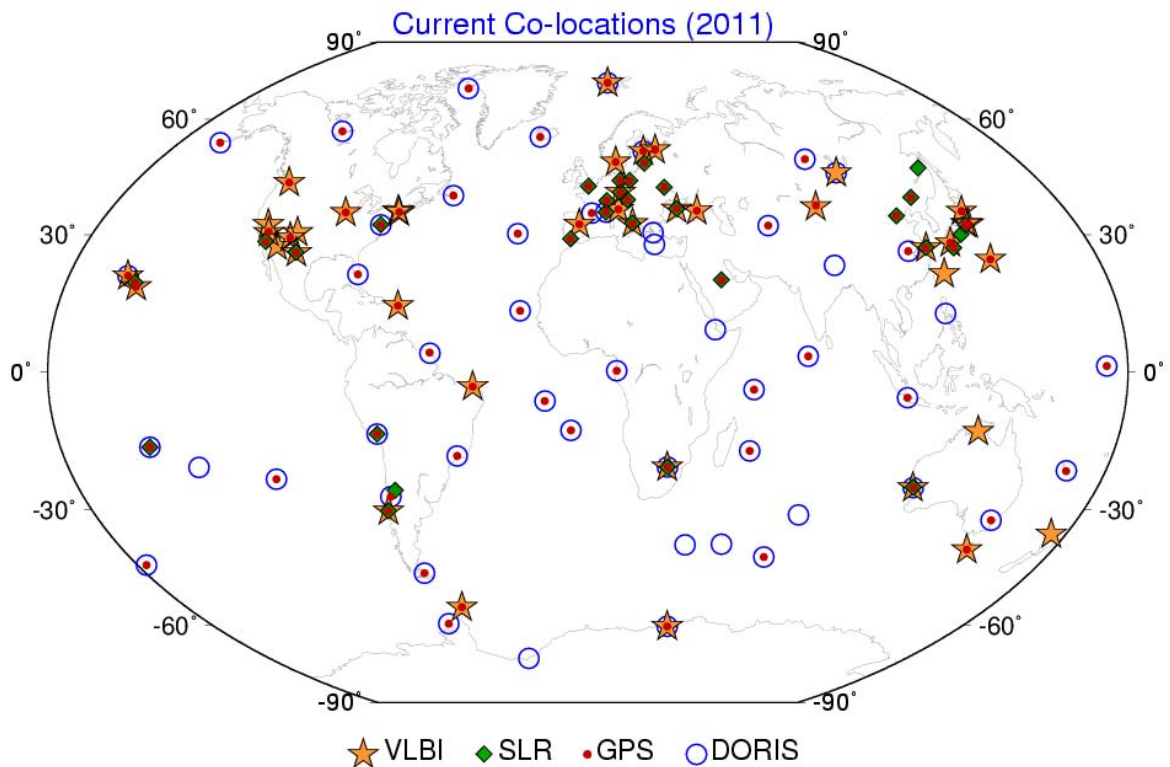


Figure 1: VLBI, SLR and DORIS current site distribution and their co-location with IGS/GNSS(GPS) sites (2011)

GGOS as a paradigm for improving the geodetic infrastructure

From a broader perspective, geodesy is based on three “pillars”: geometry, gravity field and Earth rotation. These pillars present different geodetic perspectives on processes within the “System Earth” which, however, are linked through common parameters. These parameters can be observed by different space geodetic techniques. Some of these techniques are fundamental for the ITRF, as already mentioned. Other techniques are needed for the determination of the gravity field of the Earth. The task of the Global Geodetic Observing System (GGOS) of the IAG is the consistent combination of analysis outputs from all geodetic techniques. Hence, the overall goals of GGOS are:

- 1 mm position and 0.1 mm/yr velocity accuracy on global scales for the ITRF,
- continuous measurements (time series of Earth orientation parameters, station positions, etc.),
- measurements in “near” real-time,
- highest reliability and redundancy,
- low cost for construction and operation of geodetic infrastructure.

As far as the IAG is concerned, GGOS coordinates with the Services, provides new impetus on standardisation activities, and promotes outreach both to science and society. A comprehensive volume describing GGOS is available [Plag and Pearlman, 2009].

Concerning the abovementioned goals, the infrastructure of GGOS has to be considered as comprising both the observation network and the data infrastructure. From Figure 1 it can be seen that the present network has to be upgraded and extended due to the small number and suboptimal geographic distribution of the fundamental observation stations. Figure 2 shows a target design for the terrestrial observation network of GGOS which would improve the present situation significantly. In parallel, there are ongoing initiatives such as VLBI 2010 which proposes several technological innovations such as the VLBI twin telescope technology; and the IGS Multi-GNSS Experiment (M-GEX) which seeks to expand the IGS analysis capabilities beyond GPS and GLONASS, to embrace the future GNSSs from Europe and China.

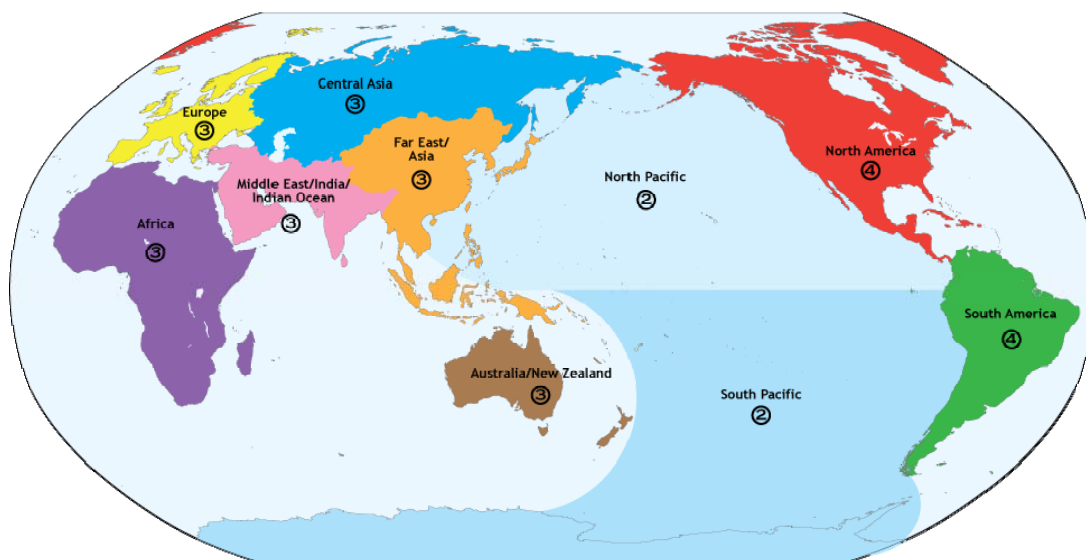


Figure 2: Target observation network of GGOS

The GGOS data infrastructure is based on the IAG services which operate successfully in their particular fields; see Figure 3. GGOS products are provided through a GGOS portal. The respective work is organised within the IAG and relies on national contributions such as from national mapping agencies, research institutes or national space agencies.

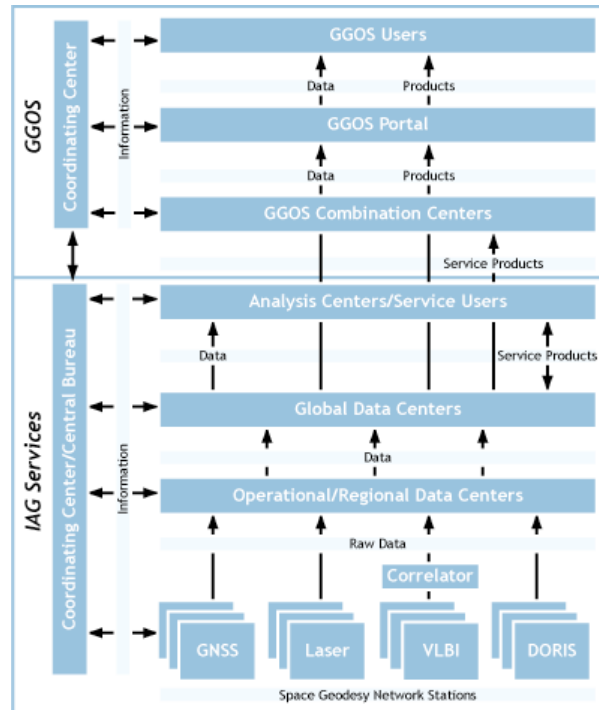


Figure 3: GGOS data infrastructure

ITRF and the GNSS associated reference frames

In order to ensure the integrity of any GNSS system and to precisely determine satellite orbits of its constellation, an associated and well-defined reference frame has to be maintained over time. The current GNSS systems/frames in existence are WGS84 for GPS, PZ-90 for GLONASS, CGCS2000 for COMPASS, GTRF for Galileo and JCS for QZSS. Although these systems/frames are more or less connected to one another or are related to the ITRS/ITRF, it is essential for users of multi-GNSS positioning to be able to position precisely their locations in a unique terrestrial reference frame. In an effort to ensure the interoperability of geodetic references among the different GNSS systems, Working Group D of the International Committee on GNSS (ICG) is actively interacting with the GNSS Providers toward a more rigorous and accurate alignment of the GNSS frames to the ITRF.

ITRF and regional reference frames

The structure of IAG Commission 1 (Reference Frames) includes a Sub-commission 1.3 dealing with the definitions and realisations of regional reference frames and their connection to the global ITRF. The commission offers a home for service-like activities addressing theoretical and technical key common issues of interest to regional organisations. Six regional organisations are part of IAG Sub-commission 1.3, distributed to cover all continents (AFREF for Africa, NAREF and SIRGAS for North and South Americas, EUREF for Europe, APREF for Asia and Pacific, and SCAR for Antarctica). Regional reference systems/frames are

defined with respect to the ITRS/ITRF, realised and maintained by these regional entities; the most known and advanced ones are ETRS89 for Europe, NAD83 for North America, and SIRGAS for South America. In addition, many countries have already redefined or are in the process of redefining their geodetic systems, directly connected to the ITRF, using their national permanent GNSS networks.

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