Activities of the IERS Working Group on Site Survey and Co-location

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Abstract The objective of the International Earth Rotation and Reference Systems Service (IERS) Working Group on Site Survey and Co-location is to improve local measurements at space geodesy sites. We appointed dedicated Points of Contact (POC) with the four different services of IERS as well as the NASA Space Geodesy Project in order to improve the efficiency of internal communication within the working group. Following the REFAG2014 conference, the POCs agreed on a common and general terminology on local ties that clarifies the communication regarding site surveying and co-location issues between and within the IERS services. We give brief introductions to the different observation techniques and mention some contemporary issues related to site surveying and co-location.

Keywords Site survey, local tie, IERS, co-location

1 Introduction

The combination of space-geodetic solutions is critically reliant on the availability of local tie vectors, which are the relative positions of the reference points of co-located space-geodetic instruments determined by some survey technique. In order to combine the four space-geodetic techniques DORIS, GNSS, SLR, and VLBI, tie vectors enter the combination of space-geodetic solutions effectively as a fifth technique. The tie vectors are not only necessary for rigorous terrestrial reference frame realization but also serve to highlight the presence of technique-specific and/or site-specific biases. With the ultimate objective of improving the accuracy and consistency of space-geodetic solutions through adequate utilization of local measurements, the International Earth Rotation and Reference Systems Service (IERS) Working Group on Site Survey and Co-location (WG Sisuco) provides an authoritative source of surveying methodology advice, promotes technical discussion, provides a forum for the evaluation of existing and new procedures and analysis strategies, and supports the exchange of relevant information across the Global Geodetic Observing System (GGOS) and between the International Association of Geodesy (IAG) technique services. The working group also acts as an entity of the GGOS Bureau of Networks and Observations under the IERS name, as well as of the IAG Subcommision 1.2 as WG 1.2.1.

GGOS is the Observing System of the International Association of Geodesy (IAG). GGOS works with the IAG components to provide the geodetic infrastructure necessary for monitoring the Earth system and for global change research. It provides observations of the three fundamental geodetic observables and their variations, that is, the Earth's shape, the Earth's gravity field, and the Earth's rotational motion. In order to meet the most demanding requirements on GGOS as a whole, the system needs to provide data in a frame that is accurate to 1 mm and stable to 0.1 mm/yr over decadal time scales, which is approximately an order of magnitude better than currently provided. Current tie and space geodesy discrepancies of the ITRF2014 [9] are of the order of 3 mm, which indicates that there is still room for improvement in the treatment of local ties. Here we give examples of recent and current work on:

- the working group's organization,
- adequate terminology when discussing local ties,

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- insights into DORIS, GNSS, and SLR local tie work,
- ongoing IVS activities within the WG scope, e.g., telescope deformation, VLBI–GNSS baseline comparison through automatic reference point determination, and GNSS-based telescope ties.

The WG has existed in various forms for some twenty years and has 36 listed members. In order to advance the speed of constructive communication, a group of dedicated points of contact (POC) has been established among the involved entities: the four IERS services, the IERS surveying entity, and the NASA Space Geodesy Project. These POCs are:

- IDS: Jerome Saunier,
- IGS: Ralf Schmid,
- ILRS: Erricos C. Pavlis,
- IVS: Rüdiger Haas,
- NASA SGP: James L. Long,
- IERS surveying entity: Xavier Collilieux.

The IERS surveying entity, through IGN France, is undertaking an effort to collect and issue its comprehensive experiences from different surveying campaigns for the benefit of improved surveying practices for all.

2 Terminology

As a consequence of the increasing awareness of the geodetic contribution to various scientific fields, e.g., different aspects of climate change, the importance of a coherent combination of space-geodetic techniques is becoming more imminent. In order to improve the information exchange between the different players in the field, the need for a common terminology was accentuated at an open WG workshop in Paris in 2013. The discussion ended up in a combined effort to implement a common terminology, which has been submitted as a resolution to the proceedings of the REFAG2014 conference and published in its submitted form at the WG homepage [1]. The resolution is conformant to the DOMES [10]:

- Each instrument (defined by a DOMES number) has a unique geometric reference point, and it is the task of the services to define these reference points. The term “reference” is reserved for these points.
- Each site should assign a single point or marker to represent the site as a whole. These markers should ideally consist of a brass bolt or something similar and, wherever possible, be attached to the lithosphere.
- Movements of the site should be monitored or modeled in standardized ways.

3 International DORIS Service, IDS

This text is largely taken from [4]. Since 1994, thanks to its network of more than fifty permanent beacons (including three on the African mainland), DORIS has contributed to the IERS activities for the realization and maintenance of the ITRS (International Terrestrial Reference System). On July 1, 2003, the International DORIS Service officially started as an IAG Service. Positions and velocities of the reference sites at the cm and mm/yr accuracy level contribute to scientific studies in the fields of global and regional tectonics.

Locating a satellite in space is complicated by the fact that it is in motion on a trajectory dictated by launch parameters and forces acting on the satellite. Chief among these forces are the pull of Earth’s gravity, which keeps the satellite in orbit, and surface acceleration forces such as solar radiation pressure and atmospheric drag. A good understanding of the Earth’s gravity field and the satellite’s environment is used to calculate the real trajectory with respect to the elliptical orbit described by Kepler’s laws of motion. The DORIS antenna onboard satellites receives signals emitted by the network of terrestrial stations. When the receiver and the source are moving with respect to each other, the receiving wavelength differs from the emitting wavelength through the Doppler effect. The frequency of the signal received by DORIS instruments onboard the satellite is higher than the emitted signal when the satellite moves closer to the emitting beacons and lower when it moves away. On a plot of the frequency received by the satellite as a function of time, the slope of the curve at the point of near maximum (TCA point: Time of Closest Approach) allows calculation of the distance between the beacon on the ground and the transmitting satellite.

The DORIS ground network is now being upgraded, and new definitions have been adapted in line with a WG resolution [14, 13, 1]. The geometric reference point of the Doris ground antennas, the so-called “antenna reference point” (ARP), is the center of a painted ring on the lower part of the antenna radome.

4 International GNSS Service, IGS

The IGS was established in 1994 as the “International GPS Service for Geodynamics” [5]. In view of other global navigation satellite systems (GNSS) evolving, it has been called “International GNSS Service” since 2005. The IGS operates as a voluntary federation of over 200 agencies, universities, and research institutions in more than 90 countries. The basis of all activities is a global network of about 500 stations continuously tracking a variety of GNSS signals. On the African continent, the network is still sparse. Of the approximately 40 available African IGS stations, nearly half are located in South Africa.

Traditionally, carrier frequencies in the L-band ranging from 1176.45 MHz (e.g., GPS L5) to about 1602 MHz (GLONASS G1) have been used for GNSS purposes [8]. The Indian Regional Navigation Satellite System (IRNSS) is the first to transmit signals in the S-band (2492.028 MHz). The primary products of the IGS are orbit and clock information for the GNSS satellites. Whereas the accuracy of the final GPS orbits has reached a level of 2–3 cm, the orbit quality for the new GNSS is substantially lower (due to, e.g., uncertainties in the observation modeling, sparse tracking networks, incomplete constellations affecting the ambiguity success rate, or constellations with geostationary or geosynchronous orbits). Key aspects of the current IGS activities are the transition from a GPS/GLONASS to a multi-GNSS processing and the provision of products in real-time.

The geometric reference point of the receiving GNSS antennas is the so-called “antenna reference point” (ARP). For all antenna types installed within the IGS network, the ARP is defined in the file *antenna.gra* [6] together with the “north reference point” (NRP), which defines the proper orientation of the antenna with respect to the true north direction. Preferably, the ARP is an easily accessible point on the lowest non-removable horizontal surface of the antenna. Typically, it coincides with the axis of attachment of the antenna to the monument.

Several IGS antenna calibration facilities determine elevation- and azimuth-dependent phase center corrections with respect to the ARP. Thus, it is possible to model the position of the phase center where GNSS signals are actually received. However, IGS station coordinates do not refer to the ARP, but to a permanent marker. The IGS Site Guidelines [7] demand that eccentricities from the station permanent position marker to the ARP be surveyed and reported in site logs and RINEX headers to ≤ 1 mm accuracy. Apart from that, the three eccentricity components should not exceed 5 m.

Local ties with respect to a GNSS antenna have to be measured from a co-located instrument to the GNSS station’s permanent marker. The biggest systematic error sources affecting the estimated GNSS station position are probably near- and far-field multipath. However, also the phase center corrections are not free of errors. Calibrations from different institutions do not agree on the 1-mm level, and the resulting error in the phase center position is even amplified by forming the ionosphere-free linear combination. For 6.5% of the IGS stations (status as of January 2016), purely elevation-dependent converted field calibrations are still applied, and about 10.5% of the antennas in the IGS network are covered by uncalibrated radomes. The IGS aims at a network with full coverage of state-of-the-art absolute robotic calibrations.

5 International Laser Ranging Service, ILRS

LAGEOS (short for Laser Geodynamic Satellite) was launched in 1976 and was the first NASA orbiter dedicated to the measurement technique called laser ranging. Laser ranging activities are organized under the International Laser Ranging Service (ILRS), which provides global satellite and lunar laser ranging data and their derived data products to support research in geodesy, geophysics, Lunar science, and fundamental constants. The ILRS was established in September 1998 to support programs in geodetic, geophysical, and lunar research activities and to provide the IERS with products important to the maintenance of an accurate International Terrestrial Reference Frame (ITRF). Satellite Laser Ranging (SLR) and Lunar Laser Ranging (LLR) use short-pulse lasers and state-of-the-art optical receivers and timing electronics to measure the two-way time of flight (and hence distance) from ground stations to retroreflector arrays on Earth orbiting satellites and the Moon. Scientific products derived using SLR and LLR data include precise geocentric positions and motions of ground stations, satellite orbits, components of Earth's gravity field and their temporal variations, Earth Orientation Parameters (EOP), precise lunar ephemerides, and information about the internal structure of the Moon. Laser ranging systems are already measuring the one-way distance to remote optical receivers in space and can perform very accurate time transfer between sites far apart. As with VLBI, the geometric reference point of an SLR telescope is the projection of the secondary axis onto the primary axis.

6 IVS Site Surveying Issues

The IVS was inaugurated in 1999, and the VLBI technique should be familiar to the reader of this publication. As with SLR, the reference point of the telescope is the projection of the secondary axis onto the primary axis. However, there are some issues with VLBI that are more articulated and have attracted some recent attention.

6.1 Telescope Deformation

Large structures such as radio telescopes are subject to external forces and deform, particularly under the influence of temperature and gravitation. Modern surveying systems such as terrestrial laser scanners have been used to determine the shape variation of the reflector and supporting elements [2]. Here, we also take the opportunity to introduce a continuously operating lidar monitoring system that measures selected internal length variations of the Onsala 20-m telescope and provide data in real-time [3].

6.2 VLBI–GNSS Baseline Comparison

One of the main objectives of the WG Sisuco is to resolve technique specific biases. In a recent project [15] in the European Metrology Research Program (EMRP), comparisons of the VLBI and GNSS baselines between the Metsähovi and Onsala sites, together with independent GNSS and terrestrial based local tie monitoring schemes, are made on both sites. The project is presented in some detail in [11].

A customized, VLBI-schedule-adapted terrestrial system called the "High-End Interface for Monitoring and spatial Data Analysis using L2-Norm" (Heimdall) has been developed. It consists of a robotic total station monitoring system adapted to the local observation schedule, and it determines the reference point of the telescope by observing retro-reflecting prisms attached to the structure. Heimdall was operational during the CONT14 experiment. The system is presented in further detail in [16].

With the end objective of observing all techniques in a truly common reference frame, some transfer functions still need to be applied in order to exchange data between different observation frames of the separate techniques. As GNSS coordinates are available everywhere, they have been designated to carry the information between the techniques. A pure GNSS tie has been developed that determines the reference point of the telescope indirectly, through hinge-mounted GNSS antennas on the sides of the telescope.

7 Limiting Factors

As it turns out for most repeated local surveys, the weakest link in the chain is the orientation of the local system with respect to the global terrestrial reference frame. The length of the vector between two reference points surveyed at different occasions is quite often reproducible within 1 mm, which can be justified by control measurements, instrument calibrations, and so on. However, as the vector between the reference points needs to be oriented in the ITRF, and the GNSS point observations that constitute the foundation of these orientations are often perturbed by a series of unknown parameters, the orientation of the local network often varies between surveys.

Furthermore, the evolution and improvement of the space-geodetic techniques have been dramatic, and observations are now being performed on a regular basis at extremely high repeatability within the separate techniques. However, with the objective of improving current performance by an order of magnitude, every opportunity to improve the system has to be evaluated.

Acknowledgements

The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union.

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