Recent IERS Site Survey of Multiple Co-located Geodetic Techniques by NGS

Kendall FANCHER, Dru SMITH, Steve BREIDENBACH, Jeff OLSEN and Nagendra PAUDEL, U.S.A.

Key words: ITRF, IERS, GGOS, Terrestrial Surveying, Co-location

SUMMARY

A recent terrestrial survey was performed by the United States' National Geodetic Survey (NGS) at the Goddard Geophysical and Astronomical Observatory (GGAO) in Greenbelt, Maryland, U.S.A. The intent of that survey was to determine the geometric vectors between physical reference points on four space geodetic techniques, as well as to re-introduce NGS personnel to the techniques necessary to perform co-location site surveys. This paper discusses the site, and the methods used for performing the survey. Due to the recent nature of the survey, final coordinates are not available at the time of this paper's submission, but will be presented at the FIG conference and ultimately submitted to the IERS for future ITRF combinations.

NGS intends to continue this work, coordinating with the IERS working group on site surveys as well as the GGOS working group on networks and communication, and contributing eccentricity vectors to the IERS for future ITRF combinations, not only at USA sites, but also any global sites when (a) the working group has prioritized the need for a survey and (b) NGS's budget can support such work. A long term goal would be for NGS to work with other international surveying teams and help grow the pool of contributors of site surveys to the IERS.

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1. BACKGROUND

The concept of a 2-dimensional horizontal datum has evolved into that of a 3-dimensional geometric reference system. While the term ”reference system” denotes a theoretical construct, the term ”reference frame” denotes a realization of a reference system in which coordinate values are assigned to given locations. Many countries have officially adopted geometric reference frames that rely (directly or indirectly) upon some realization of the International Terrestrial Reference System (ITRS). For example, both the United States and Canada have jointly adopted a realization of the North American Datum of 1983 (NAD 83) which is defined in terms of a 14-parameter transformation from the International Terrestrial Reference Frame of 1996 (ITRF96) [Craymer et al., 2000]. In the United States, the frame is called NAD 83 (CORS96); in Canada, NAD 83 (CSRS). Both NAD 83 (CORS96) and NAD 83 (CSRS) are related to subsequent ITRS realizations via the composition of the transformation from them to ITRF96 followed by the adopted 14-parameter transformation from ITRF96 to each subsequent ITRS realization.

The work of updating the ITRF ultimately falls under the auspices of the International Earth Rotation and Reference Frame Service (IERS). However, that service is an international voluntary organization of scientists and other professionals. It is therefore incumbent upon national geodetic agencies to perform a variety of tasks within the IERS so that the ITRF, as the foundation of their national datums / reference systems, are robust and capable of serving the ever-greater accuracy needs of the geospatial community.

In the USA, the National Geodetic Survey (NGS) has the mission to define, maintain and provide access to the National Spatial Reference System (NSRS). The NSRS includes the official horizontal and vertical datums of the USA. As such, NGS considers work that contributes in various ways to the IERS to be part of its mission. One new field of contribution, only recently re-started by NGS, is a commitment to perform “co-location site surveys” for the IERS.

2. IERS CO-LOCATION SITE SURVEYS

The latest realizations of ITRF have relied on the combination of four space geodetic techniques: Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging (SLR), Global Navigation Satellite Systems (GNSS) and Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS). While each of these techniques contributes to the final ITRF realization, none of them is capable of defining the ITRF by itself. As such, the combination of these techniques must be performed in some fashion. The most frequent method of combination is through co-locating one or more techniques at the same site on Earth. Unfortunately co-location by itself is not enough for a combination. The actual difference vectors (eccentricities) between the electronic reference points of each technique must be known. These vectors consist of two components – the displacement of each technique's electronic reference point from its physical reference point (such as the phase center variations of GNSS antennas) and the actual geometric 3-dimensional vector tying the physical reference point of one antenna to the physical reference point of another.

The determination of the electronic-to-physical offsets is complicated and generally considered the responsibility of the particular service of the International Association of Geodesy (IAG) which pertains to that technique (being the International VLBI Service or IVS; the International Laser Ranging Service or ILRS; the International GNSS Service or IGS; and the International DORIS Service or IDS). However, the determination of the physical-to-physical offsets can be done with terrestrial surveying techniques, though the party responsible for performing those surveys is not clear. In the case of DORIS, the Institut Géographique National (IGN) both installs the beacons and performs a co-location site survey. Sites without DORIS have been surveyed sporadically and without internationally agreed upon standardized practices for years. Many different groups have performed site surveys, generally for sites of national interest (Johnston et al, 2000; Long et al, 2000; Sarti et al 2004; Shibuya et al, 2005). In fact, NGS was briefly a participant in such surveys (Glover et al, 1994) but only recently has re-engaged in them.

Unfortunately, standardization of surveying techniques is necessary as a number of issues surround such surveys. For example, the stations within a site might move relative to one another (Abbondanza, 2009); the techniques with larger equipment (especially VLBI) may be prone to antenna deformation due to gravitational sag (Sarti et al, 2009a); the sites may be disturbed in some way (destruction of survey marks, replacement of GNSS antennas, removal of GNSS radomes) which cause a change to the eccentricities. In a study of the quality of the intra-site ties, Ray and Altamimi (2005) concluded that many contain residuals too large (1-2 cm) to adequately tie the four space geodesy techniques into a sub-mm accuracy ITRF system. Their recommendation for improved site ties and a more robust VLBI network comes with a warning about the lack of information about unsurveyed biases in the actual electronic-to-electronic eccentricities (such as the impact of radomes) and with the understanding that each service (IVS, ILRS, IGS and IDS) needs to adequately solve and provide the electronic-to-physical eccentricity information. This is especially true in light of the known biases that gravitational deformation have on VLBI antennas (Sarti et al 2009a, Sarti et al 2009b)

3. GGAO

The Goddard Geophysical and Astronomical Observatory (GGAO) is a NASA research facility for laser applications and astronomy. It is located near Washington, DC, in the state of Maryland. The geographical location of GGAO is approximately 39 ° 01'15" N latitude, and 076° 49' 38" W longitude.

GGAO is home to four space geodetic techniques: VLBI, SLR (both MOBLAS-7 and NGSLR), GPS, and DORIS. See figures 1 through 5. It should be noted that the radome on GODE (figure 4) is not calibrated, so that its derived GPS position may well contain a bias. These four geodetic techniques at GGAO are situated all within 250 meters of one another. See figure 6.

Figure 1: The GGAO VLBI Antenna

Figure 2: The MOBLAS-7 SLR system at GGAO

Figure 3: The NGSLR system at GGAO (Photo courtesy of NASA)

Figure 4: The GPS antenna (GODE) at GGAO (Photo courtesy of NASA)

Figure 5: The DORIS antenna at GGAO

Figure 6: Plan view of GGAO showing the four space geodetic techniques: (A) VLBI, (B) GPS (GODE), (C) SLR/MOBLAS-7, (D) SLR/NGSLR, (E) DORIS

GGAO is one of only two sites in the world where all four space geodetic techniques are collocated in close enough proximity to allow for an accurate terrestrial survey tie. Such ties have been made on several occasions in the past (beginning in the 1990's) by NASA contractors. NGS, in collaboration with NASA and the IERS, conducted a new site survey at the GGAO in the Fall of 2009. The goals of the survey included; reintroducing the capability of NGS employees to conduct these type surveys, having an independent check on previously determined ties between the geodetic techniques, and bringing a fresh approach to the methodologies. The NGS used state-of- the- art surveying systems (total station, digital leveling, and GPS) possessing the highest level of measuring capabilities currently available, in an effort to achieve sub-millimeter terrestrial ties between the geodetic techniques.

4. 2009-2010 SURVEY

The local ties survey at GGAO was conducted by NGS with the intent of determining the physical-to-physical eccentricities between the 5 observation systems (2 being SLR). Field measurements were undertaken in stages beginning August 24th, 2009 and concluding on December 2nd, 2009. Although the final coordinates are not available at the time of this paper submittal, they will be available at the FIG conference. The following chapter describes the field procedures established by NGS during the survey.

4.1 Organization

The NGS survey team consisted of Kendall Fancher, Steven Breidenbach, Nagendra Paudel, and Jeff Olsen. Charles Geoghegan provided office support with GPS data reductions.

4.2 Equipment

The following instruments and accessories were used during the site survey.

4.2.1 Instruments

Two Leica TDM5005 total station systems (s/n441698 and s/n441773).
Angular measurement accuracy, σ = 0.5".
Distance measurement accuracy, σ = 1 mm + 2 ppm.
Four Trimble R7 GNSS receivers, part number 50157-00.
Four Javad Ringant-DM GNSS antenna, part number 10-570301-01
Leica DNA03 digital level, part number 723289 (s/n332228).
Height measurement accuracy, σ = 0.3 mm per km double run.
Leica 2-meter invar staff, part number 563660 (s/n30721).

4.2.2 Accessories

Wild NL4 Collimator (s/n40145)
Pointing accuracy, 1: 200,000
Four Leica GPH1P precision reflectors

Centering precision, 0.3 mm
Leica reflector carriers
Tribrach adapters

4.3 Control Network

Numerous survey control stations have been established at the GGAO in support of previous site surveys. For the NGS survey, existing monumentation was utilized for the main scheme network and a combination of existing monumentation and temporary points were utilized as supplemental stations to facilitate the survey. Existing survey monumentation used for this survey included forced centering piers, surface marks, and a deep rod mark. The coordinates of the main scheme stations were newly determined via this survey. See Figure 7. As shown in the network map, the geodetic techniques at GGAO are spread mostly along the North-South direction. The selection of Cal Pier "B3" as a primary control mark in the East-West direction with respect to rest of the marks was strategic. It allowed checks on field observations and subsequent computations. It would have been preferable to have observations between B3 and the north subnet of points, but line of sight between these areas was not possible due to forest separating these areas and prohibiting observations.

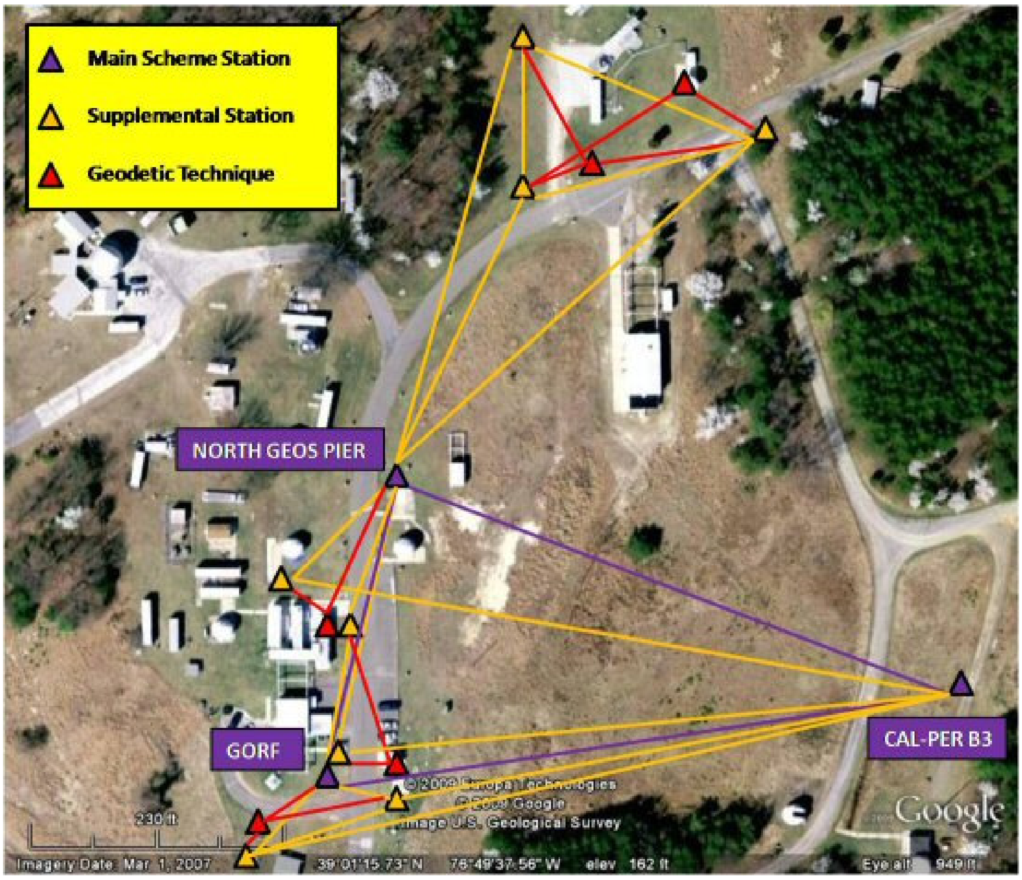

Figure 7: Network design of the NGS site survey at GGAO

4.4 Survey Methodology

The target accuracy for eccentricities in all three dimensions was 1 mm. As such, a variety of very rigorous procedures were followed.

4.4.1 Equipment Setup Procedures

For tripod setups, Wild GDF tribrachs and tribrach adapters were used to support equipment. All tribrachs were plumbed using a Wild NL collimator. A tribrach adjusting cylinder or Leica reflector carrier was used to level all tribrachs. For forced centering pier setups, a Wild GDF tribrach with adapter was threaded directly onto the pier. Tribrachs were precisely leveled as previously described. Collimation and level of equipment were checked before every occupation and verified at conclusion of observations.

4.4.2 Equipment Height Measurement Procedures

A Leica DNA03 digital level instrument and Invar staff were used to measure all GPS Antenna Reference Point (ARP) heights and equipment heights. Equipment heights were checked at the conclusion of observations.

4.4.3 GPS Observations

GPS data were collected for the main scheme network stations during three independent 16 hour (average length) sessions. Data collection began on 24-August and concluded on 26-August. Trimble R7 GNSS receivers and Javad Ringant-DM GNSS antennas were used.

GPS data were post-processed using Trimble Geomatics Office software (version 1.63). All vectors were processed radially, constraining the ITRF2005 (epoch 2009:237) position for the ARP at GODE. The GPS coordinates determined for main scheme network stations, NORTH GEOS PIER, CAL PIER B3 and GORF will be used to translate from the local coordinate system to ITRF2005.

4.4.4 Precise Leveling

A Leica DNA03 digital level and a 2-meter Invar staff were used to determine height differences between network stations. Additionally, the vertical component of the reference points for geodetic techniques DORIS and GPS (GODE) were determined using precise leveling procedures. A collimation check of the level instrument was performed prior to data collection at the beginning of each observing day. The Invar staff level bubble was checked each day prior to data collection. All misclosures between forward and reverse leveling were better than First Order, Class II specifications.

4.4.5 Precise Leveling to Geodetic Technique GPS (GODE)

The GPS antenna on GODE is an Allen Osborne Associates Dorne Margolin T, choke ring (TurboRogue) with a radome. With the radome removed, height differences were measured to three points atop of and along the radius of the inner most ring of the antenna from supplemental station JPL 4005. A vertical offset value of 0.1020m (the mechanical distance from the ARP to the top of the choke ring for this model of antenna, as listed on the IGS website.) was applied to the average of the three measured height differences.

The Jet Propulsion Laboratory (JPL) was notified in advance and permission was granted to remove the radome so that the top of the choke ring of the antenna could be directly accessed. The interruption in service to the GPS, while the radome was removed, was reported to JPL so that the event could be recorded in the site log.

4.4.6 Precise Leveling to Geodetic Technique DORIS

Height differences were measured to three points atop a metal standoff, coincident with the physical bottom of the DORIS, from main scheme station GORF. See Figure 8. A vertical offset value (the mechanical distance from the physical bottom of the DORIS to the "zero" point of the antenna, represented by the center of a red line on the unit) can be applied to the average of the three measured height differences.

Figure 8: Surface to which geodetic leveling was taken at DORIS antenna.

4.4.7 Horizontal Observations to Network Stations

The Leica TDMA 5005 total station surveying system was used for all angular and distance measurements. Leica GPH1P precision reflectors were used for targets. A Tripod Data Systems (TDS) Ranger handheld data collector, with Carlson software, was used to record observations. Angular measurements exceeding 4 seconds from the mean and distances exceeding 1 mm from the mean of their respective data sets were rejected. A data set consisted of 4 horizontal observations (direct and reverse) and 8 distance measurements.

Atmospheric conditions (pressure, ambient air temperature, and relative humidity) were monitored at the height of instrument and entered into the total station system before each set of observations. The total station's onboard software applied atmospheric corrections to each distance measurement.

At station NORTH GEOS PIER, an assumed azimuth and coordinates were used to establish a local coordinate system and stations CAL PIER B3 and GORF were positioned based on this system. Network checks were made between the stations to validate sub millimeter accuracy relative to the main scheme network.

Supplemental stations were established by radial traverse from the main scheme network. Additional observations were made to verify sub-millimeter accuracy relative to the main scheme network.

4.4.8 Horizontal Observations to Geodetic Techniques DORIS and GPS (GODE)

The horizontal reference points of the DORIS and the GPS antenna are invariant. The horizontal reference point is the physical center of these antennae. In order to determine the coordinates for these invariant reference points (IRP), intersection procedures were used.

The horizontal position of the IRPs for geodetic techniques DORIS and GPS (GODE) was determined by intersection from three stations. Tangents to the Doris antenna were measured at three places; near the base, at the midpoint, and near the top of the unit. In the case of geodetic technique GPS (GODE), tangents were measured from three stations to the choke ring antenna, with the radome removed. This method was chosen, so that the GPS antenna would not need to be removed. Tangent observations to the geodetic techniques were later reduced to the center. See Figure 9.

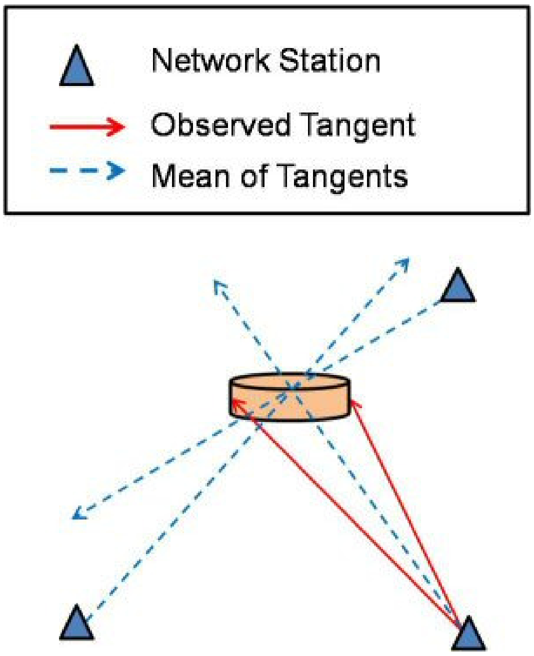

Figure 9: Schematic showing use of three tangent surveys to determine IRP

4.4.9 Measuring to the VLBI, MOBLAS7 and NGSLR

The 3-D positioning of the IRP for geodetic techniques VLBI, MOBLAS-7, and NGSLR involved determining centers of their rotations along the elevation and azimuth axes. The IRP is defined as the intersection of the azimuth axis with the common perpendicular of the azimuth and elevation axes (Johnston et al, 2004). During the processing, NGS intends to solve for the offset between the centers of the two orthogonal axes (in case it is non-zero). In such a case, an offset value will be determined and reported. Observations were taken to each geodetic technique from two stations.

A bar was fabricated to rigidly attach multiple reflectors at a fixed radius from the centers of rotation of the geodetic techniques. The geodetic techniques were rotated at intervals of between 10 to 15 degrees on a single axis, while the opposing axis was held stationary. At each interval, 3-D measurements were taken to the reflectors from a network station after they had been precisely pointed back to the instrument. Along the same axis of rotation, the reflectors were observed from a second station to measure additional points for redundancy.

A circle fit routine in Carlson software was used to reduce observations to the axis of elevation and azimuth rotation. The software generated multiple circles, and then lines through their centers to define the elevation and azimuth axes. See Figures 10 and 11. Given this information the IRP can be determined for each geodetic technique.

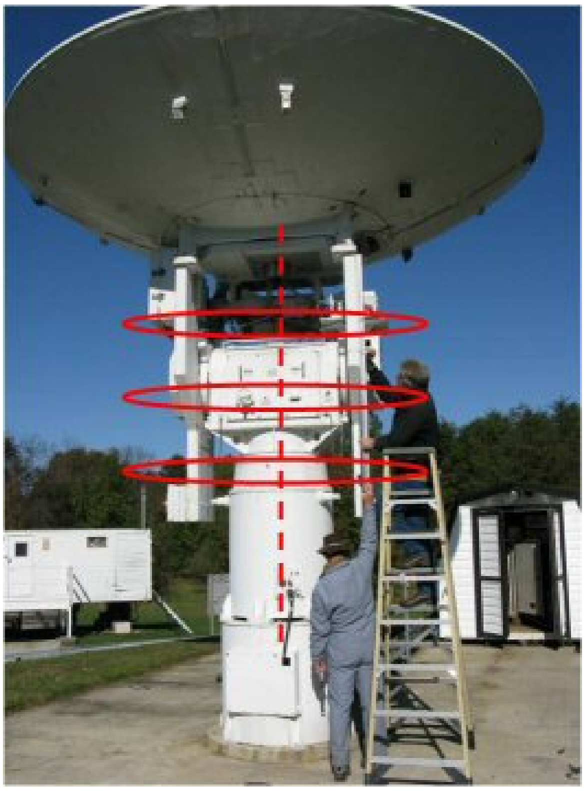

Figure 10: Determination of Azimuth Axis for VLBI

Figure 11: Determination of Elevation Axis for VLBI

5. FUTURE WORK

Ongoing work at NGS includes the final processing of this survey, the computation of coordinates, their translation into the ITRF2005 system and submission of all datasets to the IERS. Additionally, the final computed coordinates will be compared against previous coordinates computed at GGAO from prior (Honeywell) surveys.

However, new technologies were also investigated at GGAO during the performance of this survey. A robotic total station (owned by Honeywell) was demonstrated, and it was concluded that using a robotic total station may allow for less manpower and reduced time required to collect field observations associated with monitoring surveys, allowing for monitoring at more frequent intervals. However, the technology did not appear to be ready for a complete hands-off (remote) approach to performing a co-location survey.

This issue of monitoring the (potentially) dynamic eccentricity vectors between techniques (whether from antenna deformation or intra-site motion) is not easily solved. Robotic total stations are one possible answer to this issue. Repeated surveys are also a possible solution, but the IERS has a significant number of co-location sites that have never been surveyed or have only been surveyed once, and so the concept of repeated surveys becomes an issue of determining the responsible parties for performing the labor.

Because NGS has the capability of performing high accuracy terrestrial surveying, and because its mission relies on an accurate ITRF, NGS has determined that wherever possible, it will perform IERS co-location site surveys. NGS is encouraged by the leading edge work already performed by other countries (Italy, Australia, France and Japan in particular). However, considering the widely distributed number of IERS sites, it is hoped that other countries whose governments support high accuracy surveying would be encouraged to assist the IERS by performing initial, and preferably repeated, co-locations surveys in or near their countries, for submittal to the IERS. With this in mind, NGS intends to eventually assist in training other survey teams, once our own expertise has grown to an appropriate level.

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BIOGRAPHICAL NOTES

CONTACTS

Mr. Kendall Fancher
NOAA/National Geodetic Survey
PO Box 190
Corbin, VA 22446
USA
Tel. + 540-373-1243 phone
Fax. + 540-373-4327 fax
kendall.fancher@noaa.gov
http://www.ngs.noaa.gov/corbin/