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The Importance of Local Surveys for Tying Techniques Together

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Abstract

The synergistic benefits of combining observations from multiple space geodesy techniques located at a site are a main reason behind the proposal for the establishment of the International Space Geodetic and Gravimetric Network (ISGN). However, the full benefits of inter-comparison are only realized when the spatial relationships between the different space geodetic systems are accurately determined. These spatial relationships are best determined and documented by developing a local reference network of stable ground monuments and conducting periodic surveys to tie together the reference points (for example: the intersection of rotation axes of a VLBI antenna) of the space geodetic systems and the ground monument network. The data obtained from local surveys is vital to helping understand any systematic errors within an individual technique and to helping identify any local movement or deformation of the space geodetic systems over time.

1. Introduction

Over the past two decades, the space geodesy techniques, VLBI, SLR, GPS, and DORIS, have developed into very powerful measurement tools for geodetic science, with accuracies of a few millimeters. During this same time period the number of permanent collocation sites with multiple techniques has grown significantly. However, the ability to compare the data from the different techniques is often limited by missing or inaccurate local survey ties. In analyzing geodetic data from the space techniques, it is necessary to separate the tectonic motion from any motion due to locally induced instabilities, such as the settlement of an antenna foundation. This paper will provide a perspective on local surveys within international programs and provide recommended criteria and examples of local surveys from NASA GSFC experience.

Local surveys are very important to the success of the goals of the following two international efforts relating to the intercomparison of space geodesy techniques.

2. The International Space Geodetic Network (ISGN)

The ISGN is being established under the charter of the IAG Commission on International Coordination of Space Techniques for Geodesy and Geodynamics (CSTG) with the goal of improving cooperation between the individual technique services (IVS, ILRS, and IGS) and defining the recommended network station criteria. The accomplishments of the former CSTG Geodetic and Geophysical Sites Subcommission (GGSS), pertaining to site surveys and monumentation are being incorporated as a basis for the ISGN site criteria.

3. The IERS International Terrestrial Reference Frame (ITRF)

The IERS publishes revised ITRF positions on an annual basis for a global network of geodetic stations. The collocated stations offer an extremely valuable opportunity to compare the solutions for the various techniques. However, missing or inaccurate local survey data at some stations significantly impedes this analysis. IERS issues a periodic report to identify problems with local survey ties. The adopted threshold for identifying an uncertainty in a local survey as "imprecise" is 5 millimeters in any component, regardless of length.

In some cases, the accurate survey has been completed, but the data is not transmitted in a usable format, which allows independent evaluation of the data quality. To help alleviate this problem, IERS has adopted SINEX as the format for the submission of local survey data.

4. Description of Model Collocation Site

The following is a description of a model collocation site developed by the NASA/GSFC Space Geodesy Program. The purpose of the extensive set of ground monuments is to facilitate the surveys of the reference point of the different space technique systems and help identify any local instability. The ground monument network should be designed with consideration for geometric strength of figure and inter-visibility between the monuments.

The site should have a central ground monument, to which all other monuments and space systems can be referenced. This central monument may be used in surveys to tie the site to the regional or national, high-accuracy geodetic control networks. The central ground monument is surrounded by three reference monuments at a distance of 25 to 100 meters, in an equilateral triangle configuration. The ground reference monument network is extended as required to enclose the area around all the space geodetic systems. SLR systems often require ground calibration targets, which can be included in the ground reference monument network.

As it is most important that the ground monuments remain stable over a long period of time, they should be designed with consideration of the site specific geological information. Traditionally, the ground monuments have been constructed by excavating a hole, approximately 0.3 meters in diameter and 1 meter deep, filling the hole with concrete, and placing a brass survey disk at the top. A better design is a tall, reinforced concrete pier with a self-centering device, compatible with survey instruments, at the top. The dimensions of the pier are approximately 0.3–0.5 meters in diameter and 1.3–2.0 meters above the ground surface. The depth of the pier into the ground should be a minimum of 2.0 meters, but can vary depending on the geological characteristics of the site. The utilization of the concrete pier eliminates the errors associated with plumbing over a traditional style mark with a tripod.

There should be a network of three or four distant ground monuments, called "footprint" monuments, at a distance of 10 to 25 kilometers from the collocation site. The locations for the footprint monuments must be carefully chosen to select areas geologically stable with the collocation site, but far enough away to avoid local disturbances affecting both the collocation site and the footprint monument. The footprint network will aid in recognizing the difference between local, regional, and tectonic plate motions.

Type of Instrument	Manufacturer's Accuracy	Standard Error Used
Leica THEOMAT 3000 (theodolite)	0.5 seconds	1 mm + 1 second
Leica DI 2002 (distancer)	1 mm + 1 ppm	1 mm + 1 ppm
Leica NA3003 (digital level)	0.4 mm in 1 km (with invar rod)	1 mm
Trimble 4000SSI (GPS)	Horiz.: 5 mm + 1 ppm Vert.: 10 mm + 1 ppm	5 mm + 5 ppm(<1 km) 5 mm + 1 ppm (>1 km)

Table 1. Instrument Accuracy Table

5. Examples of Local Surveys

NASA GSFC has been performing local surveys in support of space geodesy at many sites over a number of years. As the accuracy of the space systems has improved, the survey methods and equipment have been upgraded and improved correspondingly. This experience has resulted in the following recommendations for a high-precision, local survey.

- Utilize the best quality, highest precision equipment available. The type of equipment typically used by the NASA GSFC surveyors is shown in table 1 above. Use conventional survey equipment over short lines (less than 1 kilometer), where there is visibility between the stations.
- Calibrate distance measurement equipment on a regular schedule over an established calibration baseline.
- Measure distances both ways over each line and use two different instruments, if possible.
- Repeat observations (both direct and reverse) for horizontal directions and zenith angles to reduce the effect of pointing errors.
- Measure instrument and target heights accurately to within 1 millimeter.
- Utilize differential leveling methods to measure differences in heights.
- When using a tripod or instrument stand over a monument, utilize a high quality optical plummet and re-plumb tribrachs daily, at a minimum.

The documentation of the survey is also very important. A project file and a brief report should be compiled at the completion of the survey. The report should include the following:

- A narrative description of the project objectives, methods, and conclusions.
- A discussion of the observation plan and equipment utilized.
- A network diagram and sketches of the reference points of the space geodesy systems.
- A summary of the least-squares adjustment and the quality of the survey.

The results of the survey at a collocated site should be submitted to the IERS in the SINEX format.

6. Antenna Survey Procedures

The following is a general description of the procedures used by the NASA GSFC surveyors to perform local surveys at the VLBA antenna sites. The 10 identical VLBA antennas have a 25-meter diameter dish with an elevation over an azimuth wheel and track drive configuration. The elevation axis is offset from the vertical axis by 2.135 meters. None of the antennas are enclosed in a radome.

1. Construct three or four ground monuments in a network around the antenna. These monuments will be used as control points for the antenna survey. At least one of these monuments is a reinforced concrete pier constructed to enable the eventual installation of a GPS antenna on a permanent basis.

2. Perform a precise conventional, electro-optical survey to tie the new ground monuments to previously established survey control monuments. Measurements with GPS are used over long lines and to supplement the conventional measurements.

3. Temporarily mount a specially fabricated, pointed rod survey target at the apex of the antenna quadripod feed support structure. The location of the target should be chosen to optimize simultaneous visibility from the most ground stations and to ensure stability.

4. Mount a survey target, on an X-Y (horizontal motion) translation stage and trivet plate, on a structural platform at the approximate location of the vertical axis of rotation. Using the translation stage, adjust the target to lie on the vertical axis of rotation while viewing the target through a theodolite as the VLBA antenna is rotated in azimuth.

5. Observe directions and distances, from each of the survey reference marks, into the survey target on the vertical axis of rotation.

6. Perform an extensive set of survey observations to position the survey target rod, mounted at the antenna apex, over a wide variety of antenna positions. Observations are made from each reference survey mark that will see the target rod, at each antenna position. Systematically rotate the antenna through 48 point positions (i.e. azimuths: 000, 090, 180, and 270 degrees; elevations at each azimuth: 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120 degrees).

7. Utilize differential level methods and equipment to measure the difference in height between each of the ground monuments and the target located on the vertical axis of rotation.

8. A least squares adjustment program is used to determine the coordinates of each position point for the tip of the target rod. A circle-fit software is used to calculate the center of each of the four circles, as described by the 12 points on the arc at each of the four azimuths. The mean of these four circle centers determines the elevation axis offset.

The NASA GSFC surveyors have used this method (with some minor modifications) at 8 of the 10 VLBA sites, since 1990. The results of the surveys have been consistent and appear to be accurate to within 3 mm. There has been no attempt made to account for antenna structural deflection in this solution, however, this topic may be addressed in the future.

7. International Cooperation

Under the guidance of the ISGN Subcommisson, we hope to promote the idea of an international cooperative team to facilitate local surveys at the ISGN sites. The Subcommission would provide a forum for discussion on survey methods and procedures and encourage their improvement to achieve greater accuracy.

As an example, recently a cooperative survey effort was accomplished in support of the installation of the new Matera Laser Ranging Observatory (MLRO) system at the Italian Space Agency Space Geodesy Center (ASI-CGS) near Matera, Italy. A NASA GSFC surveyor traveled to the site and worked with the ASI-CGS personnel to perform a survey to determine the preliminary coordinates of the MLRO telescope and the ranges to the new calibration targets. In addition, the survey effort was expanded to include the local ties directly to the SAO-1 SLR system and the IGS permanent GPS station. The ground reference marks surrounding the VLBI antenna were included in the survey so that data from a previous survey of the VLBI antenna will be used to determine the tie between the VLBI antenna and the MLRO.

The raw survey measurements were reduced and adjusted by each group, independently. The preliminary results indicate an agreement of around 1 millimeter, in each coordinate, between the two solutions.