Hartebeesthoek Co-location Survey

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1 Introduction

The ITRF is the result of a combination of the different terrestrial reference frames provided by the four space geodetic techniques GPS, VLBI, SLR and DORIS. To perform this combination between independent reference frames, it is necessary to get some co-location sites where the various techniques are observing and whose ties have been surveyed in three dimensions. Many co-location sites have been identified and some of them have missing or inconsistent ties.

In this frame, it has been decided as one of the top priorities to survey Hartebeesthoek co-location site (South Africa). Indeed, this site is one of only two sites where the four techniques are currently observing. Some of ties at Hartebeesthoek were missing, and some others were inconsistent.

This paper briefly presents the local ties survey of Hartebeesthoek site that took place during the summer 2003, from the observations on site to the computation of the SINEX file. All the presented results can not be considered as the final ones, since further improvement has to be developed.

2 Survey description

2.1 Organization

The local ties survey of Hartebeesthoek co-location site is a cooperative project in which the four following agencies participated: Hartebeesthoek Radio Astronomy Observatory (HartRAO), NASA Goddard Space Flight Center (GSFC), Institut Géographique National (IGN) and the South African Department of Land Affairs. The survey team gathered 5 members ; Jim Long coming from NASA GSFC who has experience in numerous local ties surveys ; Valérie Michel, Céline Corbière, and Georgia Roesch from the Special Works unit of IGN, which mainly deals with micro-geodesy and metrology ; and Sean Dane from Surveys and Mapping service of the South African Department of Land Affairs. Also, this project took many benefits of support from the HartRAO personnel and facilities, such as the machine shop.

The survey took place from July, the 22nd to August, the 12th 2003. The meteorological conditions have been very appropriate for such a fieldwork since it was sunny almost everyday and all the outside work was easy to plan, even if in a topometric sense the bright sun is not always an advantage during the measurements. Furthermore, in planning the survey work, it was necessary to coordinate with the astronomic observations planning for the VLBI and SLR.

2.2 Site

The Hartebeesthoek co-location site is located in the Gauteng province, in a valley in the Magaliesberg hills, 50 km west of Johannesburg, South Africa. Hartebeesthoek co-location site can be divided into two sub-sites. These sites are each cover an area around 300 meters, on a side and about 3km apart.

For each subsite, a local control network was set up, from which the instruments were observed and tied together with GPS observations.

The first subsite is on HartRAO site. On this site, one can find a 26-meters VLBI radio telescope, a 30-inch diameter SLR telescope (MOBLAS-6) and the IGS GPS station (HRAO). The site is organized such that 7 reinforced concrete piers surround the space geodetic instruments. These piers are 1.2m to 3m high and their diameter is 0.5m. They are all equipped with self-centring devices and are mostly used for SLR calibration targets what gives an explanation about the tall height of the piers.

The second subsite is on the Satellite Application Centre (SAC) site. A DORIS antenna is implanted, very close to another IGS GPS permanent station (HARB). Three pillars equipped with self-centring devices have been set up around this site.

2.3 Equipment

All the topometric survey instruments and equipments belong to IGN or NASA and had been temporarily imported for the needs of the survey.

2.3.1 Instruments

Leica total stations (TC2002 and TDA5005) were used. Those total stations, which are regularly calibrated at IGN's calibration unit, have a standard deviation of 0.15mgon about angles and 1mm+1ppm about distances. Two Leica accurate corner cube reflectors (GPHP1P), which are calibrated with the total stations were used to determine distances.

For the altimetric observations, an electronic level (Leica NA3003) and invar bar code staffs were used. This equipment, regularly calibrated at IGN's calibration unit, has a resolution of 0.01mm.

For the GPS observations, four Leica SR530 receivers with Leica AT504 choke ring antennas were used.

All these instruments allowed the observations be recorded electronically on PCMCIA cards or REC modules and are then downloaded to laptop PC for processing.

2.3.2 Equipment and accessories

Several very useful accessories have been also brought for this type of fieldworks. These accessories included such items: as heavy tripods, in order to ensure the stability of temporary stations; a translation stage in order to centre a target on a rotation axis; 0.5m, 1.8m and 3.0m long Invar staffs that are all calibrated and associated to each other; calibrated trefoils targets, prisms and tacheometers; trivet plates and tribachs regularly calibrated.

2.4 Observations

2.4.1 Terrestrial observations principles

All the visible lines of sights have been observed with the tacheometers described in 1.3.1.

Horizontal directions and zenith distances were observed in sets, with each set consisting of one reading in both direct and reverse telescope positions. Any observed angle was rejected if the difference between the two circles was greater than 1mgon. Distance measurements were observed over each line one time in both direct and reverse positions. Meteorological data (atmospheric pressure and temperature) were recorded at the beginning of each station.

All the piers are concrete piers with forced-centring devices imbedded in the top. During the observations, Wild or IGN trivet plates were used, which ensured that the targets and total stations were always on the same planimetric position. On each pier, two different total stations have been set up and two different operators observed, in order to avoid any systematic effect. The heights above the reference point of each monument were measured after each set up on three different points with a calliper rule.

As far as direct levelling is concerned, a forward run and a backward run were observed between each benchmark. Before each workday, the instrument collimation was checked. The electronic level instrument was set to perform two readings on bar code staff, and that measurement was rejected if the difference between the two readings was greater than 0.04mm. In the same way, if the difference between the two runs was greater than $0.1\text{mm}\sqrt{n}$, with n is number of traverse legs, a third run was completed.

Some of the piers of the ground control networks were too high to be levelled by direct levelling. Therefore, indirect levelling was done between the benchmark installed on the pier and a target on the top of the pier.

2.4.2 HartRAO polygon

This control network polygon includes 6 concrete piers, the SLR telescope (a total station has been set up on the top of the telescope right on the vertical axis), the IGS GPS antenna (which has been intersected). The VLBI can also be included in this polygon, since a particular moving point has been observed using the 6 piers.

a. S.L.R.

DOMES NUMBER : 30302M003

Global view of the telescope

The SLR measurements refer to a point in the telescope optics where the two rotation axes intersect.

In a first time, the SLR vertical axis rotation was determined. From one total station set up on a heavy tripod, a target on the translation stage was sighted and the direction recorded. The SLR has been rotated 180° around the vertical axis, and the same target sighted again. Then the translation stage was adjusted of half the difference of the two directions. The same thing was done with the SLR telescope oriented at 90° from the original position. This operation was repeated until the target doesn't move, when sighted with the total station, regardless the direction the SLR is pointing.

In a second time, this rotation axis, determined as described above, was marked on the brass disk of the ground mark. Two different methods were used and they agreed to less than 1mm:

Target and translation stage on top of the telescope

Eccentricity measurement above the brass ground mark (IGN method)

- NASA-GSFC method : using 3 total stations in 3 different directions, the operator sighted the target on the top of the SLR, and went vertically down to the ground mark. The point was then determined using graphical method.
- IGN method : using 3 total stations in 3 different directions, the operator sighted the target on the top of the SLR, and went vertically down to a target on a translation stage above the brass part. By iteration, the target was brought to the SLR axis. A needle took the place of the target on the translation stage and stuck the brass disk.

The horizontal axis was not determined during this survey. The previously determined value of 0.489m was used for the offset from the top of the SLR telescope to the horizontal axis of rotation.

b. IGS station HRAO

DOMES NUMBER : 30302M004

ChokeRing antenna of HRAO IGS station

In order to find the planimetric position of the antenna, the directions tangent to the left hand side and the right hand side of the choke ring antenna were observed from all the stations of the polygonation from which the antenna was visible, i.e. 6 stations. In the adjustment, the mean direction of the two observations from a same station, was used to process the planimetric position.

The antenna height was measured by direct levelling on three different points on the top of the choke ring antenna. The mean of the three observations was corrected to account for the difference in height from the top of the choke ring to the ARP. The antenna height of the HRAO log sheet was used to get the altimetric reference point.

c. VLBI

DOMES NUMBER : 30302S001

Global view of the VLBI antenna

For the VLBI antenna, the measurement data is received at the phase centre of the receiver feed horn. The VLBI reference point is generally described as the point where the two rotation axes intersect. But for this antenna type the rotation axes do not intersect, and in this case the VLBI reference point is described as the point represented by the intersection of the fixed axis (Hour Axis) with perpendicular plane containing the moving axis (Declination Axis).

A special target was installed on the apex of the antenna quadripod, to be visible from as many survey control monuments as possible. The hour / declination mount of this antenna made the observation of the antenna difficult since the dish of the antenna hides much of the structure form view when rotating around one of the axis. The apex was the only point that could be observed from three piers during the whole required rotations of the antenna. Indeed, this target was determined by intersections from three piers with three different total stations.

The antenna was rotated around the axis to be determined, in increments of about 10 degrees, then the target described an arc of a circle around the axis of rotation. Several arcs for each axis (3 around declination axis and 2 around hour angle axis) were observed. At each increment, horizontal directions and zenithal distances were measured.

The declination axis has been observed in three different hour angle positions by rotating the antenna around the declination axis. The hour angle wheel (big wheel) was in position 0°, and the declination wheel (small wheel) went

from southern limit to northern limit by step of 10°, 14 points were observed (-85° to +48°). The same operation was done with the hour angle wheel at +19° west and –25° east.

In the same idea, the hour angle axis has been observed by rotating the antenna around the hour angle axis in two different declination positions. The declination angle was held fixed on the position where zenith is achievable, and the big wheel went from western limit to eastern limit by step of 10°, 17 points were observed (+85° to –85°). This operation was repeated with declination angle set at 50°.

2.4.3 SAC polygon

This control network polygon includes 3 concrete piers, one temporary station on a heavy tripod, the DORIS pillar and the one IGS GPS antenna on a steel tower.

a. IGS station HARB

DOMES NUMBER : 30302M009

The directions tangent to the left hand side and the right hand sides of the choke ring antenna were observed from all the polygonation stations from which the antenna was visible, ie. 4 stations. In the adjustment, the mean of the two observations from a same station, was used to process the planimetric position.

The antenna height was measured by direct levelling on three different places under the chokering antenna using reverse rod. Then, the mean of the three observations was corrected to account for the difference in height between the top of the choke ring and the ARP. The antenna height of the HARB log sheet was used to get the altimetric reference point.

ChokeRing antenna of HARB IGS station

DORIS antenna on its pier

b. D.O.R.I.S.

DOMES NUMBER : 30302S006

The DORIS planimetric point is, for this antenna type 5Starec), a point located 88 cm above the base of the antenna, which was included in the polygonation : a target was installed on the steel pier, instead of the Doris antenna during the polygonation. A GPS antenna was also installed on the steel pier after the polygonation. The different heights were measured to 0.001m.

The DORIS altimetric point is, for this antenna, a red ring mark: 0.390 m above the base. Direct levelling was done using direct inverse rod on 3 three different points on the base of the antenna.

The eccentricity of the planimetric reference point has been also controlled.

2.4.4 GPS observations

In order to tie the two local control networks and to provide orientation, three sessions of 5 hours on three different days with a recording rate of 30s have been observed. During each session, four different stations were set up, 2 on each sub-site and at least 6 satellites were visible. The heights of the antenna were measured to 0.001m.

3 Computations

3.1 On-site validation

3.1.1 Polygon

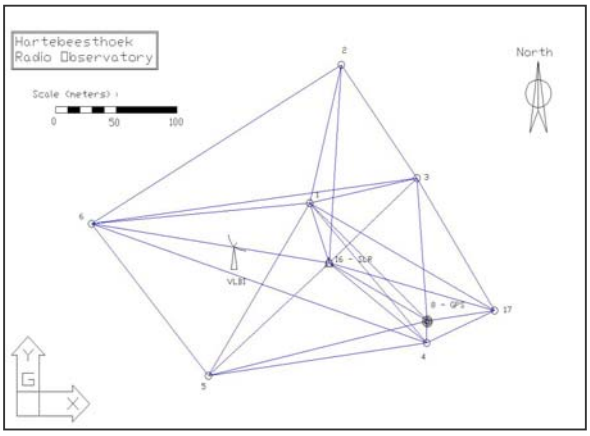
Each local control network has been pre processed on site in order to point out any problems consequently to observations. The observations have been checked in a local coordinate system by a 3D Least Squares Adjustment with the software COMP3D developed at IGN by Y. EGELS.

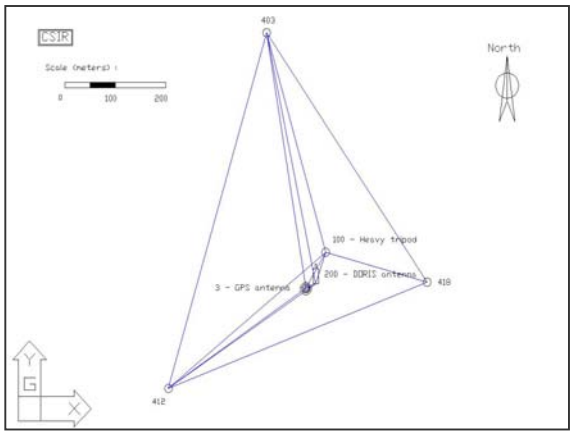
The blunders have been detected and the precision has been estimated in order to check if the requirements of such a survey were achieved.

The a priori standard deviations for the different observations are:

- 0.5mgon for horizontal angles,
- 0.8mgon for vertical angles,
- 1mm+1ppm for distances.

At this step, the confidence ellipsoids had their major semi-axis between 0.5 and 0.9mm for HartRAO polygon, and between 0.5 and 1.8mm for SAC polygon.





3.1.2 Levelling

The levelling network has been also validated on site by compensations between 2 successive benchmarks, then by independent compensations of the 2 subsites and the traverse between the two sites, and finally by a global compensation.

The precision was about 0.5mm for HartRAO levelling network, 0.6mm for SAC levelling network, and the global compensation achieved a 0.63mm precision.

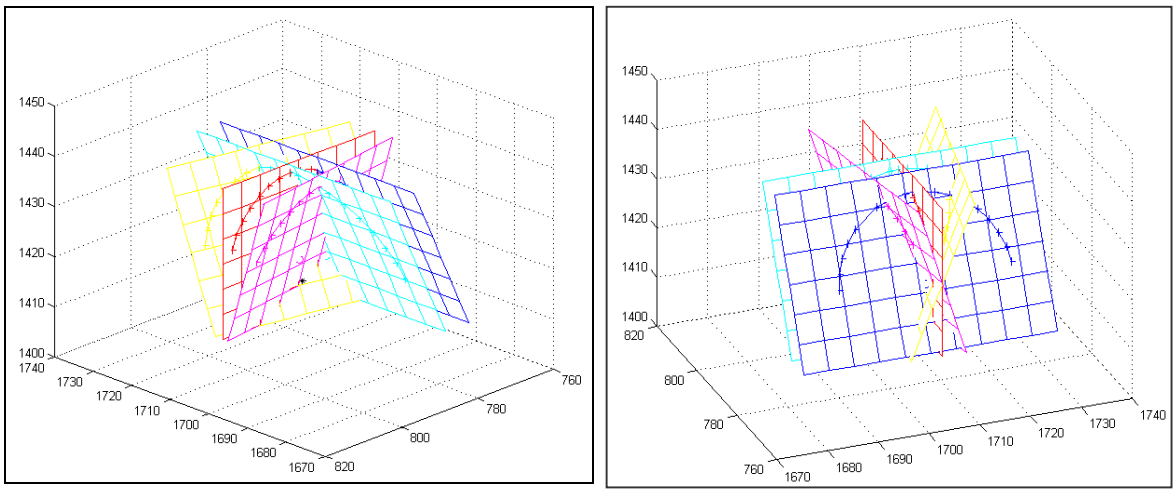
3.1.3 GPS

The GPS baselines have been processed on site to check the ambiguities resolution.

3.2 VLBI reference point

The first computations have been done in the local topocentric network that was defined by the polygon of HartRAO site. By rotating the antenna around one of the axis holding the other one blocked, the target describes an arc of a circle. The plane in which the circle is drawn is normal to the rotation axis around which the antenna is moving. This rotation axis crosses the plane in the centre of the circle.

The 5 plane and circle fittings have been computed by programs developed on the software Matlab 6.1. A first on-site program has been developed in order to check the quality of the target positions determinations and the precision to fitting a circle. Then a more elaborate program takes into account the variances-covariances matrix of the polygon and the target positions to compute the circle fittings.



2 views of the circle and plane fittings for the 5 rotations in the local topocentric network

As far as the primary axis is concerned, one arc lets the axis be determined. The problem is then over-determined since 2 arcs have been observed, which leads to a check and an evaluation of the precision.

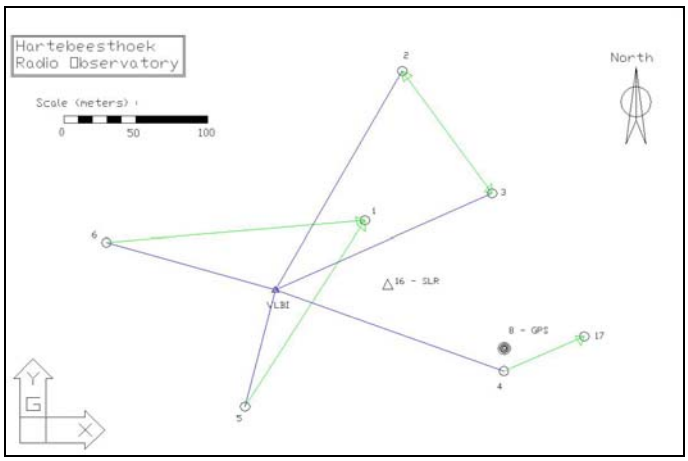
For the secondary axis, each of the 3 arcs defines a position of the secondary axis. However, the angles between each secondary planes to the primary plane have to be constant (and even right angles). Furthermore, the distance between each secondary axis and the primary axis has to be the same. Therefore, a control of the data does exist for the secondary axis too.

The VLBI reference point is the closest point of the primary axis to the secondary axis. The axis offset is the distance between the primary and secondary axis.

In order to get an idea of the precision, a Monte Carlo algorithm has been implemented. This method was used because of the lack of time to develop a full covariance matrix propagation and it gives good preliminary results.

The precision of the reference point estimated by the Monte Carlo method is 0.5mm in x-direction, 1.6mm in y-direction and 1.1mm in z-direction. The axis offset is 6.695m ±2.5mm.

Given the position of the reference point and its precision, a set of fictitious observations have been computed with their associated precision. These fictitious observations correspond to fictitious horizontal and vertical angles that would be measured from the piers of the polygon to the VLBI reference point. They were introduced in HartRAO polygon.

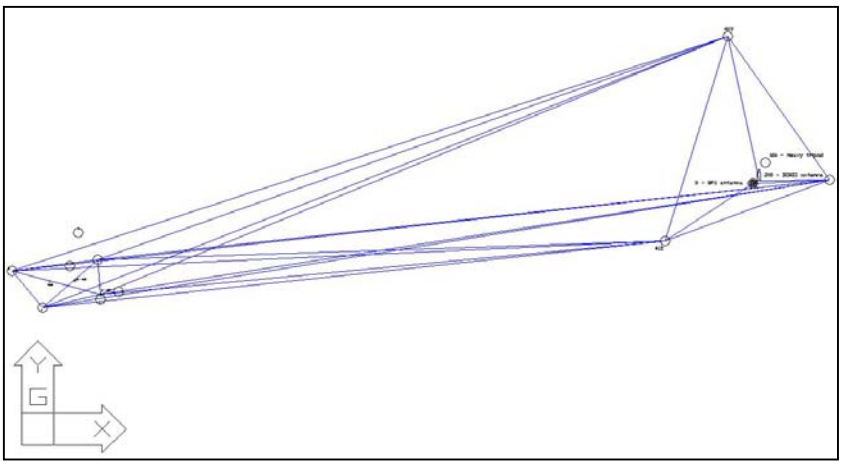


Scheme of the fictitious lines of sight

All this study has been led in HartRAO local topocentric network and Matlab 6.1. was the main developing environment.

3.3 GPS network

The GPS baselines have been processed with BERNESE software version 4.2. The whole GPS network has been then adjusted and a full covariance matrix has been obtained. This GPS network includes 3 sessions of 5 hours. For each session, 6 points are observed at a given time: the 2 permanent stations HARB and HRAO, 2 temporary stations on HartRAO site, 2 temporary stations on SAC site.



4 Results

The whole survey has been adjusted with the software GeoLab Microsearch. The input files for Geolab were developed from all the observations: distances, horizontal and vertical angles, planimetric and altimetric centrings, levelling and GPS baselines. Therefore, all the input data can be sorted as following:

- HartRAO polygon
- HartRAO levelling
- SAC polygon
- SAC levelling
- GPS network

The adjustment has to deal with 684 observations in order to estimate 273 parameters.

Following the discussions during the workshop in Matera, the traverse run by direct levelling between the two subsites was not taken into account. Indeed, the main goal of this traverse is to set up a control network of the whole site when associated with the direct levelling of the 2 sub sites. This ground control network could be re-measured once, twice a year (or more) in order to study the local behaviour of the co-location site.

The results of the adjustment are the coordinates of all the points referring to piers, space geodetic instruments as well as their confidence ellipsoids in the ITRF 2000 at the epoch of the observations. Here is a table with the 3D confidence region at 95% of the 5 points of interest:

```
Microsearch GeoLab, V2001.9.20.0             GRS80       UNITS: m,GRAD Page 0051
================================================================================
3D Station Confidence Regions (95.000 percent):
STATION         MAJ-SEMI (AZ,VANG)    MED-SEMI (AZ,VANG)    MIN-SEMI (AZ,VANG)
------------ -------------------- -------------------- --------------------
HARB               0.0059 ( 28, 90)      0.0001 (210,  0)      0.0001 (120,  0)
VLBI               0.0046 ( 19,  0)      0.0026 (284, 90)      0.0024 (109,  0)
SLR                0.0021 ( 24,  0)      0.0015 (294,  0)      0.0011 (126, 90)
HRAO               0.0032 ( 38, 90)      0.0002 (211,  0)      0.0002 (301,  0)
DORIS              0.0076 ( 55, 89)      0.0034 (234,  1)      0.0021 (324,  0)
```

Furthermore the whole covariance matrix is computed and it is possible to extract covariance submatrix of the only points of interest.

A program has to be developed to express these results in the SINEX format.

This first SINEX file has been introduced into the ITRF 2000 computations by Zuheir Altamimi. The local ties, which were dubious, agree now with the ITRF 2000 solution.