1 INTRODUCTION

1.1 Definition

A local tie survey consists in determining directly or indirectly the relative positions in space of two physical points at a given epoch. It includes several steps from measurements in the field to data processing at the office.

The local tie vectors, as used by the IERS ITRS Centre for the International Terrestrial Reference Frame (ITRF) computations, represent the differential components: dX, dY, dZ between instrument reference points expressed in a geocentric frame, such as the ITRF. They are provided with full variance/covariance information.

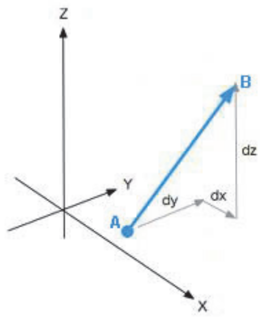


Figure 1: Illustration of a local tie vector between A and B

1.2 Requirements

The ITRF is the result of a combination of different sets of station coordinates provided by the four space geodetic techniques i.e. Global Navigation Satellite System (GNSS), Satellite Laser Ranging (SLR), Doppler Orbitography by Radiopositioning Integrated on Satellite (DORIS) and Very Long Baseline Interferometry (VLBI). To perform this combination of independent reference frames, it is necessary to rely on co-location sites where the various instruments have been surveyed and whose tie vectors between their reference points are available.

In order to continuously improve ITRS realizations, it is fundamental to update, improve and precisely determine new local tie vectors that are included in the ITRF combination.

Although local tie vector accuracy is steadily increasing, the ITRF and Global Geodetic Observing System (GGOS) [Plag and Pearlman, 2009] requirement of 1 mm accuracy of the reference frame is still a challenging target. However, a 1 mm precision of local ties at a reference epoch is probably achievable for physical ground markers, while it is hardly attainable for the electronic instrumental tracking points.

In addition to the ITRF needs, and from a scientific point of view, local ties between co-located tide gauges and GNSS or DORIS stations are of great interest. During local tie survey, additional other specific tasks could also raise, such as SLR distance measurements between calibration targets.

Lastly a permanent site monitoring could also profitably detect, alert and model instrument displacements (local deformation, dish deformation, instrument or support stability).

1.3 Scope of this document

Local tie surveys are generally carried out by agencies hosting different instruments at co-location sites. Although IGN does not directly host multi-technique sites, but as part of the ITRS Centre activities, IGN has decided to perform site surveys at ITRF co-location sites since 2003. In addition, IGN has the responsibility of all DORIS or REGINA[1] site surveys carried out in the framework of the partnership with Centre national d'études spatiales (CNES).

Although every co-location site configuration is different, general principles can be followed to prepare the survey, conduct measurements, process data and prepare deliverables. Thus, deliverables are: set of coordinate differences in a reference frame aligned to ITRF with their full variance/covariance matrix, associated metadata and all related information required to reprocess the local tie survey data if necessary.

This document describes IGN current practices in site surveys and the provision of a local tie dataset to IERS ITRS Centre.

1.4 Local tie survey stages

Figure 2 sums up the various steps, at the office or on the field, from preparation to publication that are necessary to perform a co-location survey.

In this figure, GNSS is used only as a mean to express the local tie vectors or coordinate sets in a global reference frame. Indeed, most of the co-location sites include at least a permanent GNSS antenna with known ITRF coordinates that can be used for georeferencing purposes. While a local tie survey could be made by GNSS only for some specific site configurations (with big coverage for example), this is not a methodology used anymore at IGN due to the strong dependency to the antenna phase center models (not competitive enough in terms of relative accuracy) used in the data processing, not accurately calibrated enough.

[1] REGINA : REseau GNSS pour l'IGS et la Navigation

Within IERS, local tie products are provided in SINEX format (see Chapter 5.4).

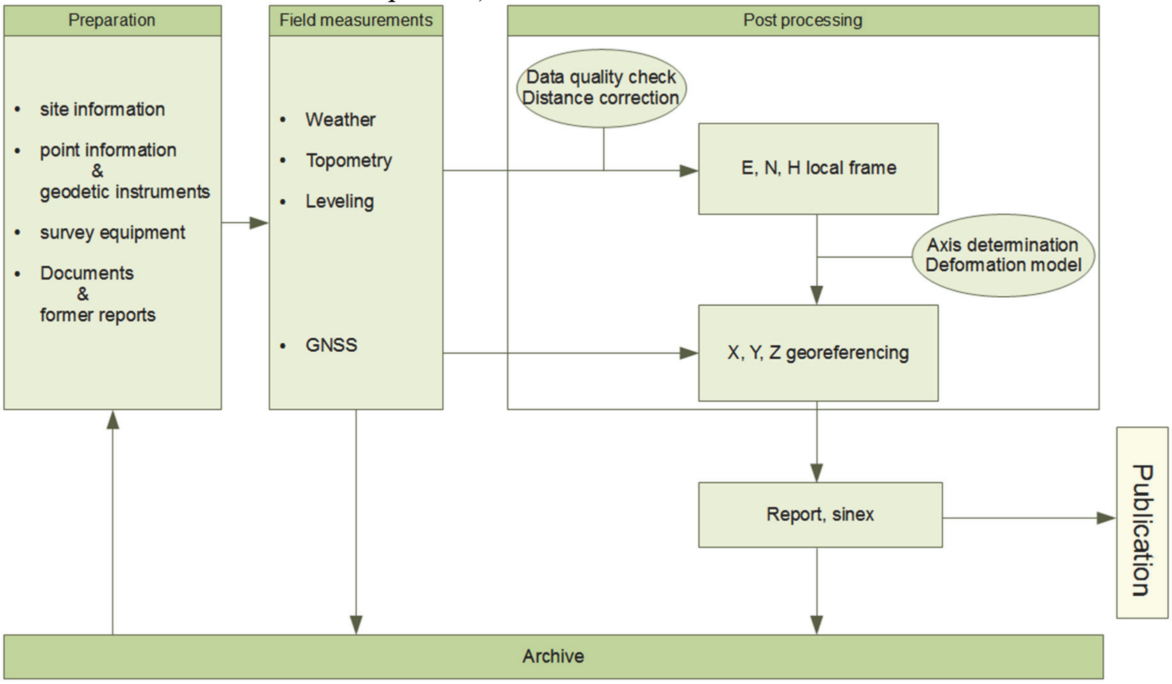


Figure 2: Local tie survey steps

2 SPACE GEODESY TECHNIQUES & INSTRUMENTS

The purpose of this chapter is not to describe the four fundamental space geodesy techniques, namely GNSS, DORIS, SLR, and VLBI, but to define for each technique the conventional reference point (with its particularity and associated issues) which will be tied. Tide gauge and gravimetric reference points are also mentioned.

2.1 GNSS

2.1.1 Conventional reference point

The station reference point is either the antenna reference point (ARP) or a marker (see Section 4 of a GNSS station sitelog).

The ARP is specific to each antenna type (see https://igscb.jpl.nasa.gov/igscb/station/general/antenna.gra); in most cases it is defined as the antenna base and axis.

It is generally associated with two identification codes: an acronym (4-char code) which makes the link with the receiver and the associated observation files, and a DOMES number (see Appendix 3).

Acronym : ROTH	DOMES number : 66007M003
 Global view	 Close-up view (reference point)
Description: axis and base of a 5/8 inch thread on top of a tech2000 mast (UNAVCO). Antenna height is **<u>0.000 m.</u>**	

Figure 3: ROTH GNSS station reference point at Rothera

If the Reference Point is coincident with the Bottom of Pre-Amplifier (BPA) the eccentricity values are set to null. It is mostly the case with the use of a self-centering antenna mount.

If it is defined as a marker or a physical well defined point independent from the BPA, in this case it is not antenna dependent and the eccentricity values are given in the sitelog (Section 4).

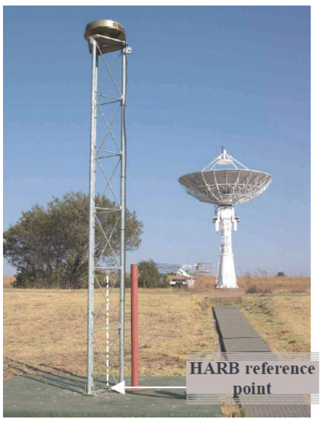
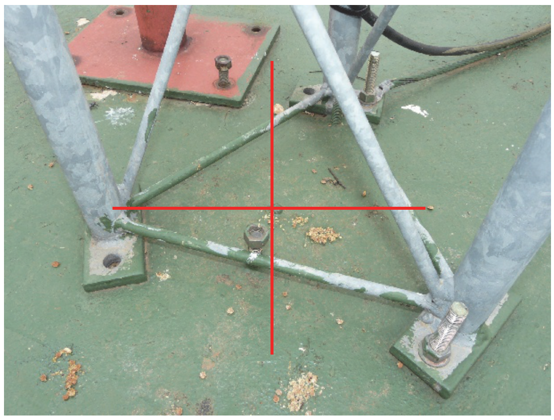
Acronym : HARB	DOMES number : 30302M009
 Global view	 Close-up view (reference point)
Description: top and center of a brass mark on a concrete pad. Antenna height is <u>**3.052 m** (no east and north eccentricity).</u>	

Figure 4: HARB GNSS station reference point

2.1.2 Other issues

Although antenna support is supposed to be stable, tilts have been reported at a few stations. Another possible issue is the thermal expansion of the antenna support depending on the season or time of the day.

Eccentricity values that are reported in the sitelog (Section 4 *GNSS Antenna Information)* have to be checked and updated if necessary although they are not directly concerned with the local tie survey.

Example: NKLG - IGS station at Libreville - Gabon (sitelog extract)

(Since May 3rd, 2010)

```
Marker->ARP Up Ecc.   (m) :  003.043
Marker->ARP North Ecc(m) : -000.0015
Marker->ARP East  Ecc(m) : -000.0025
```

Figure 5: NKLG antenna and support

GNSS antenna manufacturer value & ARP identification

Surveyors have to look closely at the antenna base. Even if the manufacturer asserts that the ARP refers to the lower part of the antenna, any ARP identification problem should be **carefully mentioned in the final report**.

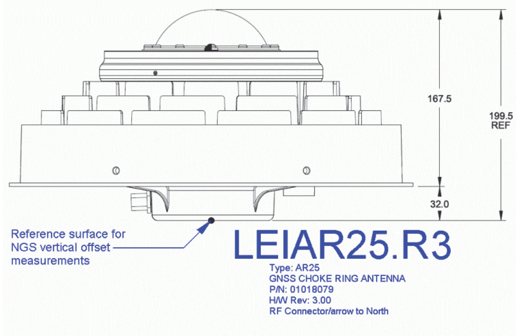


Figure 6: Left) Example of antenna deficiency (AR25) *Right) AR25 manufacturer characteristics (reference point and vertical offsets)*

The above illustration (right) does not mention any gap between the fixing point and the antenna base which is visible on the left (about 1 mm difference).

2.2 DORIS

2.2.1 Conventional reference point

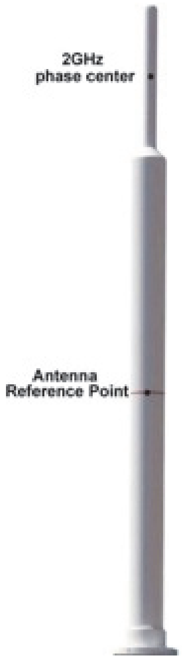


Figure 7: DORIS antenna

For a DORIS antenna raised perfectly vertically, the ARP is defined as the point located 0.390 m above the antenna base-mounting surface on the antenna axis. This is the point DORIS coordinates refer to. A red painted ring on the first section of the antenna (lower tube) roughly indicates it, but that ring center is in no way a metrology mark (Saunier et al., 2016).

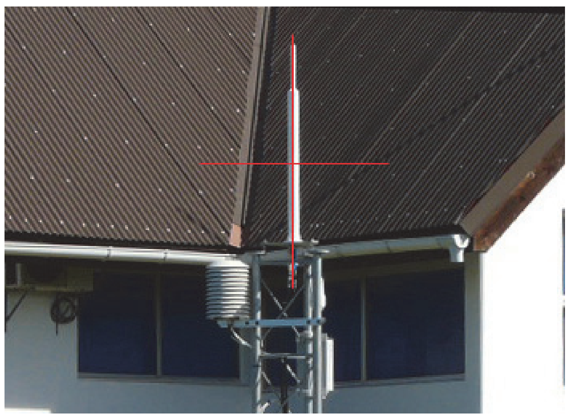
Acronym : RIMB	DOMES number : 92301S004
 Global view	 Close-up view (reference point)
Description: DORIS antenna reference point (Starec type).	

Figure 8: Left) Example of DORIS antenna Right) DORIS antenna reference point

The DORIS reference point differs from a “witness marker”, embedded vertically below the antenna on top of the concrete base. So in case of antenna change or support damage the new ARP could be determined referring to this mark without doing a complete survey.

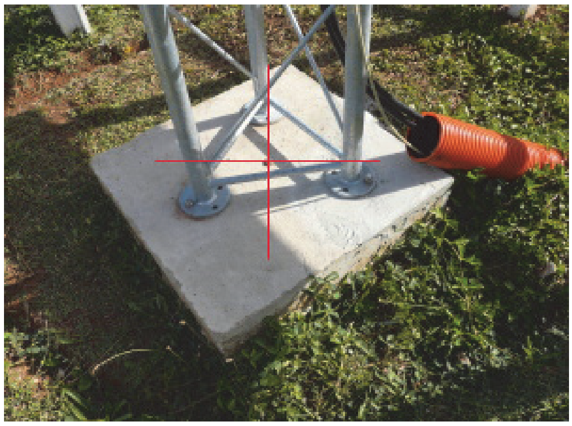
Point name : DORIS mark	DOMES number : 92301M001
 Global view	 Close-up view (auxiliary point or "witness marker")
Description: DORIS domed mark in concrete block.	

Figure 9: Example of DORIS monument marker

N.B.: The DORIS antenna has no need to be oriented (the radiation is symmetric around the antenna axis).

The reference point is not materialized: it can not be directly observed with a total station.

The verticality adjustment of the antenna is performed with 1 millimeter accuracy at the time of its installation.

Figure 10: ARP height above marker

2.2.2 Eccentricities

Eccentricities between the monument marker and the ARP are given in the sitelog at Section 7 *Local site ties* (available on IDS website http://ids-doris.org). An example is reported below:

```
7. Local site ties

7.x
Point description : Domed mark under the DORIS antenna
(RIMB)
DOMES number : 92301M001
Differential components from the current DORIS ref. point
(RIMB)
to the above point (in the ITRS) :
dX (m) : 1.574
dY (m) : 1.579
dZ (m) : 0.968
Accuracy (m) : 0.002
Date measured : 14/03/2009
Additional information : Survey by IGN-F 2009
```

These values must be checked and updated if necessary during the local tie survey.

2.3 SLR

2.3.1 Conventional reference point

Most of the time, SLR ranges refer to a point at the intersection of the telescope axes.

(Always refer to the sitelog at the ILRS website http://ilrs.gsfc.nasa.gov.)

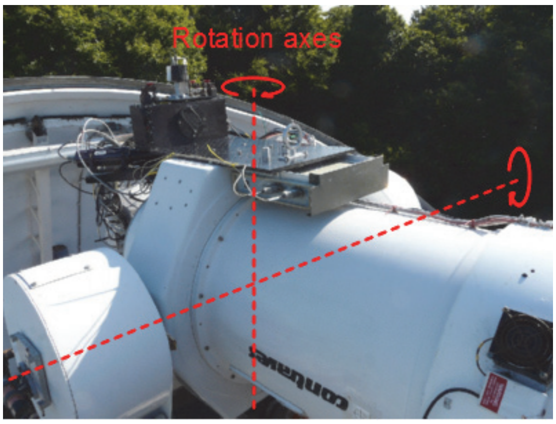
Acronym : HERL / CDP number: 7840	DOMES number : 13212S001
	
Global view	Detailed view
Description: intersection of the Azimuth and Elevation rotation axes	

Figure 11: SLR reference point at Herstmonceux

2.3.2 Specific issue

Of course, this System Reference Point (SRP) cannot be marked. There may be a point as shown on Figure 12 where a sharp metal piece indicates the horizontal axis (elevation rotation axis). It is worth wondering if this piece is really on the rotation axis and if the rotation axes really intersect.

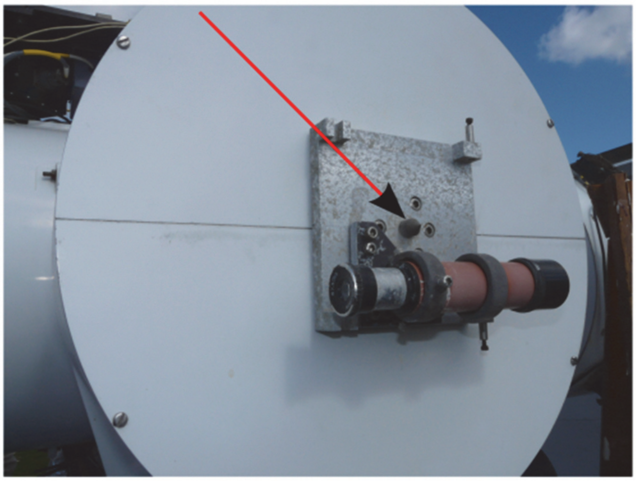


Figure 12: Piercing point on the horizontal axis at Herstmonceux SLR station.

2.4 VLBI

2.4.1 Conventional reference point

VLBI data are captured at the phase center of the receiver feedhorn.

A VLBI antenna reference point (or invariant point) does not change its position under any pointing/tracking conditions. The reference point is sometimes described as the secondary axis projection over the primary axis. For VLBI, there are several types of mountings, mainly azimuthal or equatorial types.

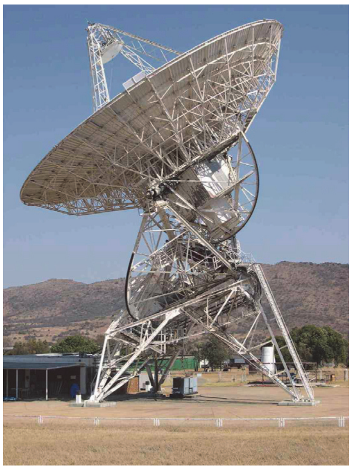
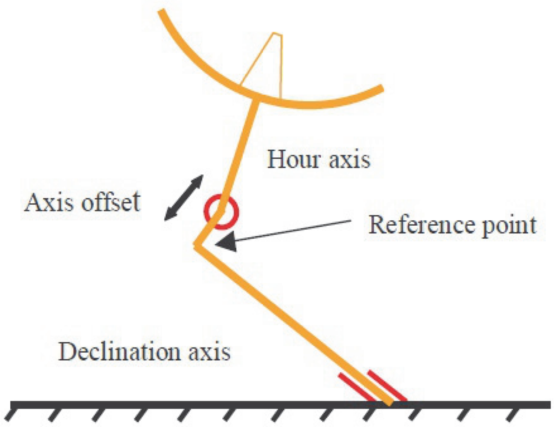
<table>
<tr><th>(Acronym) CDP number : 7232</th><th>DOMES number : 30302S001</th></tr>
<tr><td>
Global view</td><td>

Diagram of the antenna reference point</td></tr>
<tr><td colspan="2">Description: invariant point or intersection of the Azimuth and Elevation rotation axes</td></tr>
</table>

Figure 13: Radiotelescope at Hartebeesthoek

For Hartebeesthoek VLBI antenna type reported in Figure 13, the rotation axes do not intersect. In this case the invariant point is described as the point represented by the intersection of the fixed axis (Hour Axis) with the perpendicular plane containing the moving one (Declination Axis).

For more information see the International VLBI Service website at http://ivscc.gsfc.nasa.gov/stations/.

2.4.2 Specific issue

From a surveyor's point of view one has to find a way to survey a point which is not visible and possibly not materialized.

Studies showed that the antenna dish deforms with elevation (Sarti et al., 2009) and temperature (Nothnagel, 2009). Those deformations lead to an error on the SRP determination by local survey. The issue is to get or to build (if not available) a specific model for each antenna to correct as best as possible coordinates determined during the survey by gravitational as well as thermal effects before fitting the antenna reference point coordinates, see Appendix 7.

2.5 Other points of interest

2.5.1 Tide gauge

Tide gauge observations are referring to a marker. In order to get reliable absolute mean sea level monitoring from such an instrument, it is imperative to link it to a space geodesy technique reference point like GNSS or DORIS.

Tide gauge stations are installed by many agencies. The Intergovernmental Oceanographic Commission or Permanent Service for Mean Sea Level (PSMSL) centralizes information about tide gauge existing networks.

Acronym : tdcu	Benchmark : **BM2** GLOSS number : 266
 Global view	 Detailed view
Description: Ball mark (summit) – tide gauge mark on east pier.	

Figure 14: Example of tide gauge station and reference marker

For more information, see IOC website at http://www.ioc-sealevelmonitoring.org/list.php.

2.5.2 Marker

Geodetic or gravimetric points as pillars or markers can be included in the site survey network as well.

Acronym : HERL / CDP number: 7840	DOMES number : 13212S001
 Global view	 Close-up view (reference point)
Description: marker embedded in concrete (center and top).	

Figure 15: Example of gravimetric marker at Rothera

2.5.3 Prism and calibration distance

At each SLR site, there is at least one corner cube used for SLR distance calibration. The determination of the prism position is relevant for the laser team. It could also be interesting to survey it to constrain the survey sketch of observations.

Figure 16: Calibration target at Herstmonceux

3 METHODOLOGY & GUIDELINES

Various techniques are available to perform a local tie survey. They all have their own distinctive features in terms of results, accuracy and requirements. Levelling, GNSS and the conventional method listed hereafter can be mixed.

3.1 Conventional survey

It consists in measuring horizontal and vertical angles as well as distances. When possible these data are mixed with levelling observations. In any case, a large redundancy of observations is mandatory in order to be able to point out any measurement discrepancy and to provide a quality assessment of the estimated final coordinates. It is worth noting that conventional and levelling observations refer to the geoid vertical which can significantly differ from the ellipsoid vertical.

- Tripod stability

During measurements, one has to deal with weather conditions (wind, sunshine & humidity). The accuracy of the survey is directly related to instrument stability. If possible, the use of pillars or heavy stable tripods is advisable. If standard wood or aluminum tripods are used, reducing the angular set duration and checking the station stability (centering & height) are imperative. For a set of measurements, the angular difference between the aperture and closure values on a reference should be less than 3 milligons.

- Station height

Above a temporary marker, the station height could be set to 0.0 m in the adjustment. To check the stability and to control the height on a permanent marker, it is better to use a rigid gauge or a special device (like Leica GHM007 & GHT196).

- Caliper rule

Some devices require the use of manufacturer value or measurement with a caliper rule (Leica GSL14 mini-pole + GPH 1P prism = 0.2000 m ± 0.0002 m).

- Sighted point

The choice of the element detail targeted with the total station is significant. For example light and contrast are not the same on the left and right sides of an antenna; or the base of a GNSS choke ring antenna is not a circle.

- Weather conditions – temperature stability

Temperature and pressure are essential for distance corrections. As pylon and especially VLBI dish may deform with temperature, it is recommended to measure temperature (and pressure) regularly (twice an hour for example) to enable deformation models to be used. For such models, temperature should be taken several hours before the survey. Ex: 6 h for concrete and 2 h for metal for VLBI thermal deformation models (Nothnagel et al., 2009).

- Vertical and horizontal sets

Even if total stations allow the survey to be recorded with calibration corrections in only one circle, it is advisable to record angular raw data in both right and left circles.

- Prism and tribrach

They should be regularly checked and calibrated. Prisms not closely oriented toward the total station affect the distance accuracy. Recorded distances are generally corrected with the prism calibration value.

Advantage ☺: accuracy

Disadvantage ☹: price, require a lot of equipment and time, survey equipment and personnel availability, equipment shipping, access, duration.

3.2 Levelling

Levelling provides a very good accuracy on the height component. It can be used as an independent set of observations which contain only the height differences (it can confirm the scale factor in case of large height differences between survey points).

- Rod & Level bubbles verticality

Most of the levels are self-levelling instruments but to assure the working range of the compensator, the level bubble should be kept in good adjustment.

Indeed, rod verticality default leads to a systematic error (growing with the height sight).

- Level & Rod stability

The level should be carefully set up. The use of heavy footplates closely settled and self-supporting stands (brace poles) improves the levelling accuracy.

- Temperature stability

Instruments (level, tripod and rods) should be at the ambient temperature. If the temperature difference with the storage room is high, it is good waiting 2 minutes per degree.

- Paired rods

If you switch the rod on a benchmark without moving the level you should get the same height value from the two rods (If not, adopt the right methodology to evaluate and correct the discrepancy).

- Level collimation

The level collimation should be recorded at the beginning of each day (inferior to 15 arc seconds). Most of the time Fortsner method is used at IGN to measure it.

N.B.: On a flat area, this systematic error can be minimized with backsight and foresight distance equality.

- Forward and backward traverse (double run)

The traverse comparison allows validating levelling measurements on the field. If the difference between twin traverse legs is greater than $0.2 \times \sqrt{n}$ (where n = number of traverse legs) in millimeter, a new traverse leg should be observed.

- Refraction

One has to deal with sunshine, temperature and refraction. To avoid a very bad refraction influence, a 0.5 m height line of sight above elements (ground, metallic surface, etc…) is required.

- Level specifications

Respect the maximum sight length from level instrument to the rod (≈35 m) and use a multiple reading option to record every observation (rod reading) with a minimum of 3 readings having a standard deviation of 0.1 mm or less.

Advantage: very good accuracy (1-D value).

Disadvantage: no planimetric position, can not be undertaken alone, requires a lot of equipment (clearance and shipment issue due to the size of the rod).

3.3 GNSS determination

This technique is particularly appropriate if the survey points are too far from each other or if there is no inter-visibility between them.

Some basic rules must be kept in mind for this type of survey:

- Clear sky view;
- Zone without items that may reflect GNSS signals (multi-path);
- Antenna height measurement must be surveyed at the beginning of the session and checked at the end;
- The tripod or support stability is validated by a visual centering check on the mark (possibly a temporary mark) and by checking the equality of antenna height measured at the beginning and at the end of the session;

Figure 17: Example of antenna mount

- Antenna orientation to the True North. Antennas are oriented with a compass to the True North (taking into account the magnetic declination) or with a map or an orthophotography. The orientation is necessary when using GNSS absolute antenna calibration;
- Antenna brand and type must be noticed to allow the use of absolute antenna calibration during GNSS data processing;
- Ideally use an antenna whose individual calibration has been determined.

Advantage: could be done alone, with possible long observation sessions during night, needs a few equipments notably with compact antenna.

Disadvantage: "lower" accuracy than standard survey (particularly on the vertical component).

Orientation of the local tie vector by GNSS

Some points of the network must be observed both by conventional method and GNSS (at least 3 well distributed points). In the case of a flat geoid, the orientation consists in solving for a horizontal angle.

As these observations are used for the azimuth determination at a given epoch, it is very important to ensure a good accuracy of these determinations.

- Session duration > 6h

The final tie vector accuracy is directly dependent on the azimuth accuracy. In most cases the GNSS sessions take place during the survey or at night, so a long operating session duration (30 seconds sampling) of at least 6 hours is easy to perform.

- 2 references

3 GNSS stations including the permanent GNSS produce 2 directions with respect to the permanent station. The second reference validates the first one and increases the orientation accuracy. The more the vector to orientate is long the more the reference GNSS station must be far (the distance between the references and the surveyed points should be at least ten times the longest vector to determine i.e. a distance around 500 m is suitable in most cases, see Figure 18).

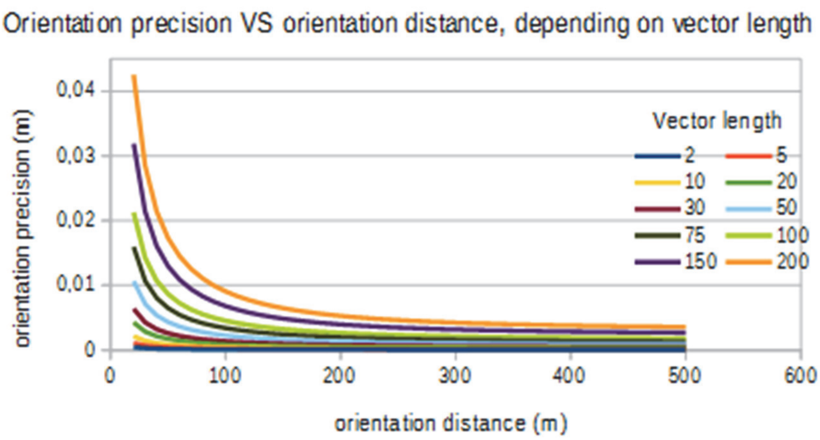


Figure 18: Precision of the orientation in meter as a function of the distance of the GPS station from the vector to orientate.

To build Figure 18, different lines are provided for different vector length in meters using the formula

$$\sigma_{orient\_vector\_m} = dist_{vector\_m} \cdot \sqrt{(\sigma_{tacheometer\_rad}{}^2 + (\sqrt{2} \cdot \sigma_{gps\_hz\_m} / dist_{gps\_m})^2) / nb_{orient}}$$

with

$\sigma_{orient\_vector\_m}$: precision on the orientation in meter

$dist_{vector\_m}$: largest length between vectors to orientate
$dist_{gps\_m}$: distance between points determined by GNSS

$\sigma_{tacheometer\_rad}$: precision of the total station angle measurement in rad

$\sigma_{gps\_hz\_m}$: precision of the hz angle derived from GNSS coordinates

nb_{orient} : number of GNSS orientations

- Do not change the configuration of the existing permanent GNSS station (radome)

Removing the permanent antenna or its radome is not allowed or at least not recommended. We have to keep the same configuration and use the GNSS published observations to fit the realized point from IGS analysis.

Note: For long GNSS sessions without masks, choke ring antennas are not essential as soon as antennas are regularly checked and absolute calibrations are available.

3.4 Example of instrument characteristics

Instrument specifications impact the final accuracy. Examples are provided below:

Total station	EDM st. dev. 1mm + 1 ppm Angular st. dev. 0.15 mgon
GNSS receiver and antenna	Static post-processing accuracies Horiz. 3 mm + 0.5 ppm Vert. 6 mm + 0.5 ppm
Electronic level with invar rod	Accuracy better than 1mm/km
Tripod or pillar stability	–

As a consequence, the survey equipment should be listed in the final report (see example in Appendix 5).

4 LOCAL TIE SURVEY

4.1 Preparation (before field work)

4.1.1 Co-located points list

A co-location site is a place where instruments from different space geodesy techniques are gathered on a limited area.

First of all, all the points to survey need to be identified. Information on points can be found in previous campaign reports, at the website of the international technique service (ex: IGS web site for IGS), in the IERS database available at the ITRF web site (http://itrf.ign.fr), and by request to the local agency (see Appendix 3).

Point information and selection

Points 1-10			ITRF							
Domes	Description	code	93	94	96	97	2000	2005	2008	
92201M003	IGN brass mark	PAMA	⬛	🟥	🟩	🟩	🟩	🟩	🟥	☐
92201M004	DORIS 1 mark (under PAPB)		⬛	🟥	🟩	🟩	🟥	🟩	🟩	☐
92201M006	12 MM DOMED MARK UGP1	TAHI	⬛	🟥	🟥	🟥	🟩	🟥	🟥	☐
92201M007	MOBLAS-8 7124-1997 Standard NASA disk	7124	⬛	🟥	🟥	🟥	🟩	🟥	🟥	☐
92201M008	DORIS 2 mark (under PAPB and PATB)		⬛	🟩	🟩	🟩	🟥	🟩	🟥	☐
92201M009	IGS mark THTI on a terrace roof	THTI	⬛	🟥	🟥	🟩	🟩	🟩	🟩	☐
92201M010	Brass disks cemented in concrete/GPS Station 85414		⬛	🟥	🟥	🟥	🟥	🟥	🟥	☐
92201M011	MARK PAPE ON CONCRETE PILLAR	PAPE	⬛	🟥	🟥	🟥	🟥	🟩	🟩	☐
92201M012	Top and centre of a plate embedded on top of a geodetic concrete pillar	FAA1	⬛	🟥	🟥	🟥	🟥	🟩	🟩	☐
92201M013	NGA GPS tracking station - Top and centre of a brass mark embedded in a concrete block	TAHT	⬛	🟥	🟥	🟥	🟥	🟥	🟥	☐

Figure 19: Summary of registered reference points in the IERS database for Tahiti. Table extracted from ITRF website, http://itrf.ign.fr

4.1.2 Site information

Each survey is different; one must gather information about the site in order to prepare the campaign at best (topography, geology, access, special permit, geodesy points, special request, shipment, clearance, etc).

(see example in Appendix 2)

4.1.3 Survey equipment list

Of course, the list of equipments depends on the site configuration, the number of points and the kind of survey to be done. Custom clearance issues and long-term unserviceability of the equipment have to be considered to minimize the impact of the equipment dispatch.

A list of the most common used equipments is given below:

- receiver GNSS and antenna (with absolute calibration)
- tripod & mini socle
- electronic level
- rod & associated bubble, supporting stands, heavy foot plate
- electronic total station (tacheometer)
- prism (target) & tribrach
- prism mini-pole
- translation stage
- atmospheric station, gauge, special tape, caliper rule
- hammer-drill
- laptop, camera

4.2 Field work

4.2.1 Precise survey principle

Horizontal and vertical angles are recorded as well as distances and mixed with levelling observations if any. A large redundant set of observations needs to be collected in order to be able to point out any measurement discrepancy.

GNSS observations are mainly used to orientate the survey to ITRF and to deal with local vertical deflection (see the discussion in Chapter 3.3). At least 3 stations of the network need to be determined by GNSS (including the IGS/GNSS permanent station if any) to orientate it. The procedure to orientate the final tie vectors is described in Chapter 5.3. More GNSS/levelled points are necessary to estimate the local vertical deflection.

4.2.2 Point measurements

Before defining the polygonation sketch and deciding where to set the survey stations, one has to think how to survey every reference point.

GNSS

Antenna base and axis:

In order to determine the planimetric antenna position, from each station pointing at the antenna, the tangent directions to the left and the right sides of a part of the antenna with circular symmetry are observed (for example a choke ring model in Figure 20). Then in the computation, the mean value of the two angle observations is used to process the geographic position of the antenna. Another way is to find a well defined piercing point along with the centring vertical axis.

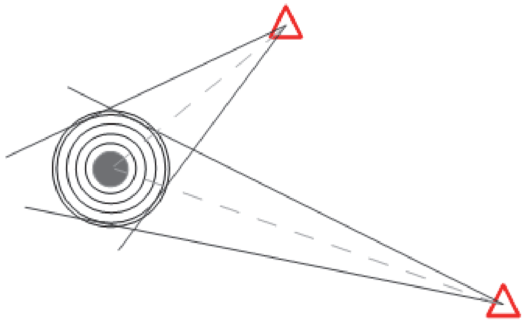


Figure 20: Overhead view of a Choke ring antenna targeted from 2 stations

As far as the altimetric position is concerned, the zenithal angles are measured on a well-defined element of the antenna from which manufacturer antenna quotations are available. This element is chosen regarding brightness and contrast so that it is well defined for the operator. Preferably, it should be located on the antenna vertical axis.

Ideally, if the antenna screw is double-threaded a prism could be added on an in-house prism support for distance measurement, see Figure 21.

Figure 21: Determining antenna direction and distance

N.B.: Unless otherwise stated it is not recommended to move, orientate the antenna, or to remove the radome. This could introduce a discontinuity in the position time series of the station. If such an action is undertaken or if any anomaly is detected, it has to be recorded and the station operator has to be informed.

DORIS

Note: Because of radiation, it is recommended to stop the DORIS transmissions if you work near the antenna (less than 1 m) for a long time. **This action requires the DORIS Network Team authorization**. Please ask procedure and authorization by e-mail at simb.doris@cnes.fr.

The antenna verticality has been adjusted during its installation with a tolerance of one per thousand (difference between axis at top and at base inferior to 1 millimeter i.e. about ± 0.5°).

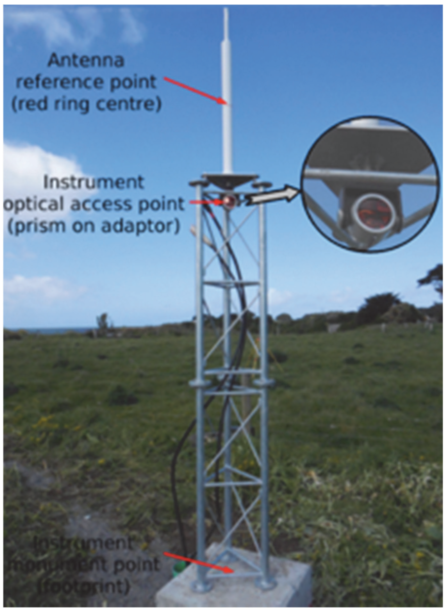


Figure 22: *DORIS points of interest*

First of all, the surveyor must check the antenna verticality and evaluate a possible eccentricity.

This can be done with a theodolite: from a station set at the north or south of the antenna, check if the antenna verticality is correct or not; and then redo it from a second station set at east or west to check the perpendicular antenna direction (see Appendix 6).

Field measurements consist in determining the axis position by sighting left and right sides (as presented in Figure 20 for a GNSS antenna) and by determining the antenna base. The ARP position is defined with respect to the antenna base and axis by applying an up eccentricity of 0.390m.

The determination of the DORIS mark underneath the antenna is also required.

The prism on adaptor under the antenna base (see Figure 22) is used only if you are allowed to disconnect the cables by the DORIS Network Team.

If the antenna is tilted (more than 1 mm), it is recommended to observe in addition the center of the red ring located at the mid height of the antenna lower tube. This point theoretically coincides with the ARP.

N.B.: Unless otherwise stated by the DORIS Network Team, you are not allowed to remove the antenna or disconnect the cables.

SLR

The SLR reference point when it is not a marker is defined as the telescope invariant point when rotating, i.e. as the vertical (azimuthal) and horizontal (elevation) rotation axis intersection. It can be determinated in two successive steps.

Planimetry:

The planimetric position is defined as the one of the vertical axis. From a total station set up on a stable tripod, a target on the translation stage (see Figure 23) is sighted and the direction D_0 recorded. The SLR is then rotated by +180° around the vertical axis, and the same target sighted again and the direction D_0' recorded. Then the total station is set on the mean value i.e. angle $(D_0 + D_0') / 2$ and the translation stage adjusted on this direction. The same procedure needs to be applied with the SLR telescope oriented at +90° and +270° from the original position. This operation has to be repeated until the target doesn't move, when sighted with the total station, independantly of the telescope orientation.

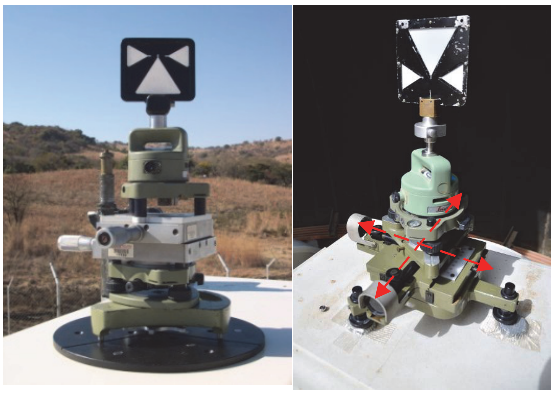


Figure 23: Target on a translation stage

N.B.: Some SLR telescopes have a self-centering device, others require your ingenuity.

A second method is based on distance measurements only. It consists in setting a prism in place of the target. Then orientate one of the translation stage axes (and the telescope) in the direction of the total station. Orientate the prism and record the distance. Next, turn the telescope by 180°, orientate the prism and record the distance. Finally adjust the prism position to the mean value using the micrometer of the translation stage. Repeat the operation for the second translation stage axis with 90° and 270° telescope orientations.

Altimetry:

The vertical position is the one of the elevation axis. Two methods are discussed to determine this position:

Method 1: direct method

This method consists in determining the vertical position of one point at each side of the horizontal orientation axis. By levelling (with the rod sometimes in reverse mode) or classic observations, points are determined around the axis so that the axis is at the middle of these points, see Figure 24. In this method, the telescope doesn't move so there is no deformation. However, the axis is determined in one defined position of the telescope only *(don't forget to report the telescope position)*. This method does not check if the axes really intersect.

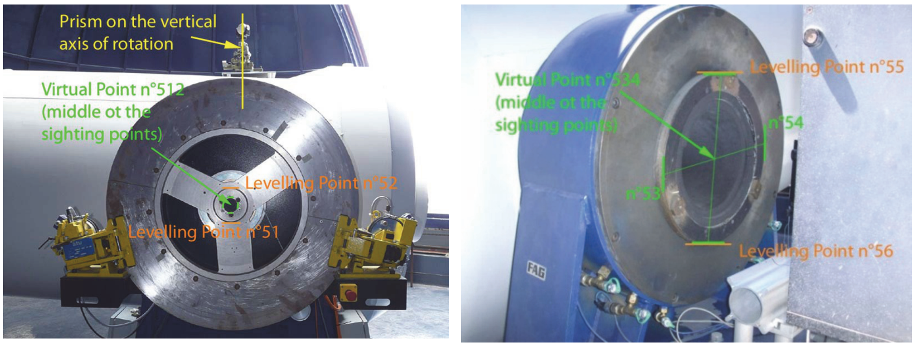


Figure 24: Surveyed points (2009 campaign) on MeO lunar laser at Grasse / Calern

Method 2: indirect method

Several targets or prisms are stuck on the telescope, see Figure 25, and their positions determined from at least one station. Then when staying on the same azimuth the telescope is rotated in elevation and the new prism or target positions are determined again; and so on. Thus, prisms draw circles whose centers are on the requested axis.

For now, this method and especially the number of targets and telescope positions are still under study. It seems that only one azimuth and five targets in five elevation positions provide good results.

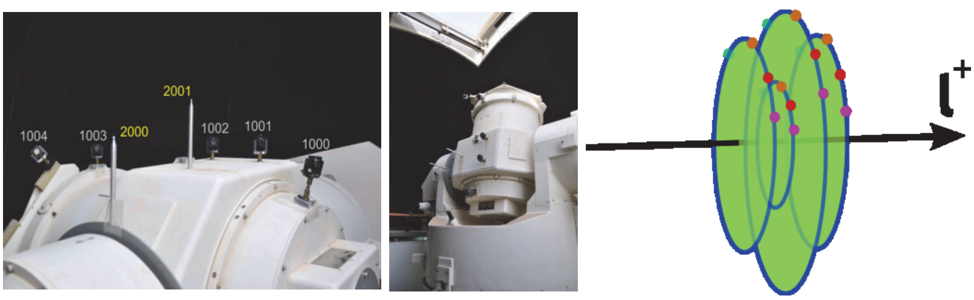


Figure 25: Surveyed points (2013 campaign) on MeO lunar laser at Grasse / Calern

Elevation and temperature variations are recorded on the field but we do not have real feedbacks or model related to telescope deformations.

N.B.: Unless otherwise stated you are not allowed to modify the Laser Ranging Station axes horizontality and/or verticality.

If requested by the SLR team to move the Laser Ranging Station axes (i.e. to level the station) it can be useful to do a survey before and after the adjustment.

Once the two rotation axes are determined, the SRP coordinates can be obtained by calculation. This computation allows deducing if the two axes really intersect or if there is an offset. At last, it is possible to compare results with the manufacturer value.

VLBI

As for SLR elevation axis determination, the reference point is determined by an indirect method. The coordinates of some targets fixed on the dish are determined for several orientations of the two antenna rotation axes. And then, in a post-processing step, the coordinates of the circles centers that are drawn by the targets are determined.

As antenna dish deforms with elevation and temperature, it seems that the antenna top is not the best place for a target (but since the dish hides much of the viewed structure form when rotating around one of the axis, it could be the only place visible from the majority of control stations). If possible, prisms or targets fixed on the edge of the dish or close to the elevation axis seem to be more relevant.

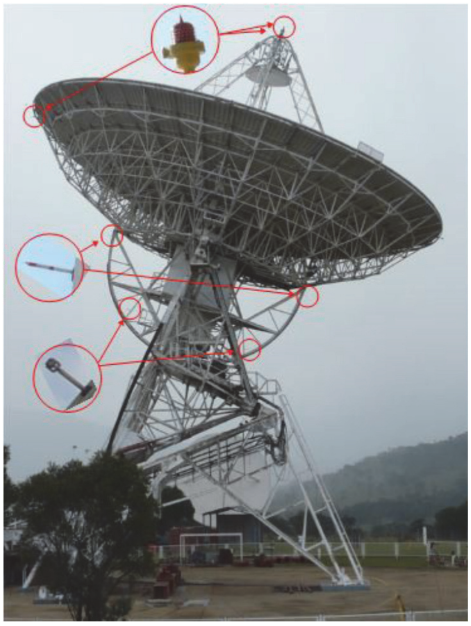


Figure 26: Target types on VLBI

On the field, the antenna is made rotated around the secondary axis, by increments of about 10 degrees. Then targets for each position of the antenna are determined by intersections from as many ground control stations as possible. Then the primary axis is moved and hold fixed when the secondary axis is moved again by increments of about 10 degrees. This operation is repeated so that several arcs for each axis are surveyed.

Time, antenna position and temperature should be recorded. Indeed to be fully exploitable, the measurements should be ideally corrected with an antenna model (Sarti, 2009; Nothnagel, 2009).

Marker

Markers are directly pointed and intersected from the survey stations. A prism can be set up on a mini-pole to allow the distance recording.

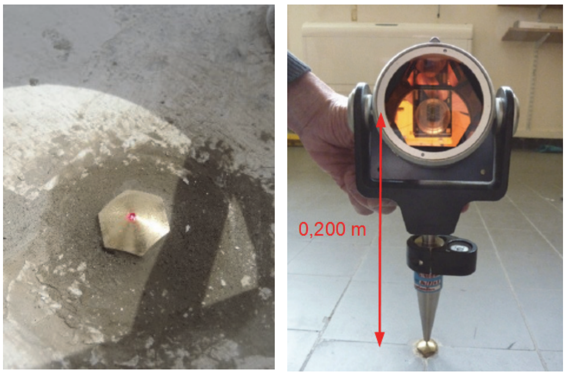
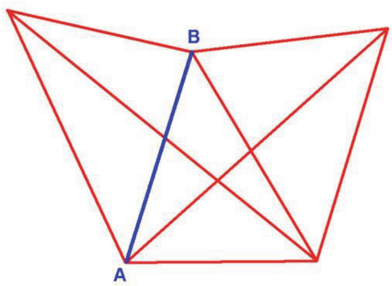


Figure 27: Left) Marker. Right) Prism on Leica GSL14 mini-pole

4.2.3 Polygonation sketch

As far as the survey concerns only two points A and B, one has to decide the best place for setting the surrounding stations.

The location of the surrounding stations (your measuring instrument) should aim at obtaining a balanced polygonation sketch with good intersection of the lines of sights (appropriate distances and angles between the stations and surveyed points).



An adjustment simulation can be processed in order to validate the polygonation sketch, see Figure 28.

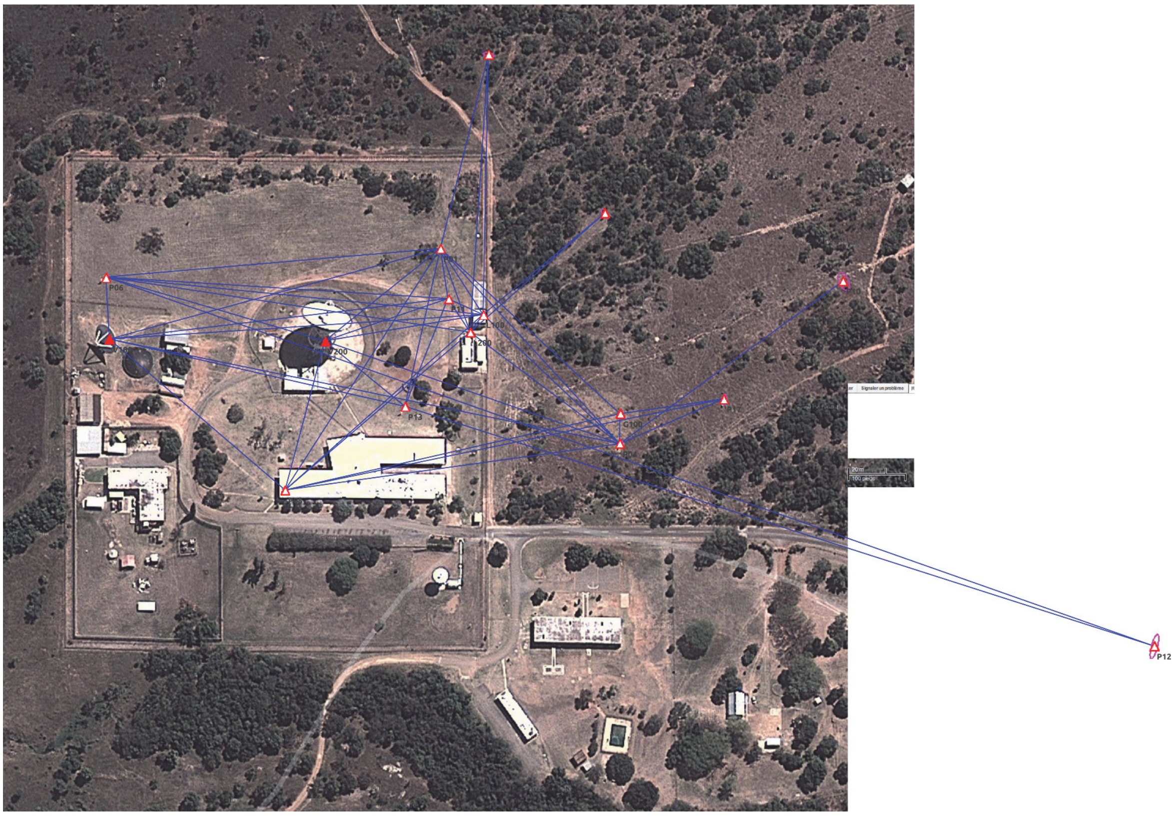


Figure 28: Simulation performed at Hartebeesthoek before the survey

A sketch of observations is shown in Figure 29. It allows a better understanding of the survey.

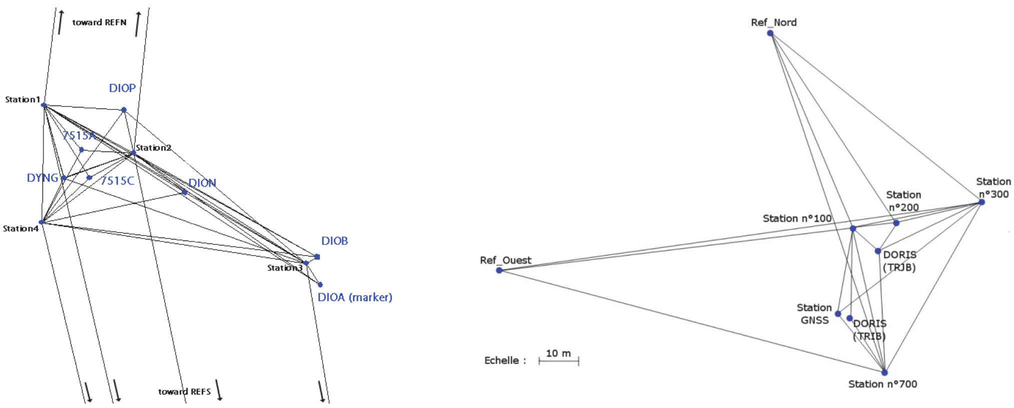


Figure 29: Examples of sketch of observations

5 ADJUSTMENT AND REPORT

5.1 Adjustment software

Many adjustment software packages exist, commercial and in-house, which are used by the organizations to process observations: Starnet-Pro V7, GeoLab, GnuGamma but also HAVAGO, CLEMENT, AXIS, or GSMAT.
(See more on the link http://itrf.ign.fr/splinter_meeting.php.)

As an example, post-processing software packages have been developed to determine reference point positions by indirect methods.

At IGN, final observations computations (i.e. GNSS, levelling, topometry and centering equations) are usually carried out by least squares adjustment software packages like Microsearch GeoLab 2001 or in-house developed software COMP3D.

5.2 GNSS data post-processing

Back at the office, GNSS baselines have to be processed. As baselines are short, there is no need to use scientific software like Bernese, GAMIT, GIPSY or NAPEOS, preferably used for long baselines processing. The surveyed baselines can be processed using manufacturer software like Leica Geo Office or Trimble Business Center.

Even if most of the time only horizontal coordinates are used to compute the azimuths of some points, it is preferable to set the correct antenna heights in the software options (especially in case of 6 parameters adjustment) when the point is levelled.

The GNSS processing software should use both the current precise ephemeris and the current set of absolute GNSS antenna calibrations (currently IGS14 and igs14.atx). At IGN, most of the time, data are processed with Leica GeoOffice and the following parameters: automatic mode, tropospheric model (Saastamoinen) and a 15° cut off angle. The software process report file should be included in the report appendices.

Antenna height and eccentricities:

Height and eccentricities are given in the GNSS sitelog at Section 4 *GNSS Antenna Information*. Note that those values should not be applied during the survey data processing since the marker is to be surveyed.

Absolute antenna calibration:

The IGS atx files associated to the IGS reference frame (currently IGS14) shall be used.

```
LEIAR25.R3      NONE                                            TYPE / SERIAL NO
ROBOT               Geo++ GmbH              20    29-JAN-17 METH / BY / # / DATE
     5.0                                                        DAZI
     0.0  90.0   5.0                                            ZEN1 / ZEN2 / DZEN
     4                                                          # OF FREQUENCIES
IGS14_1930                                                      SINEX CODE
# Number of Calibrated Antennas GPS:      020                   COMMENT
# Number of Individual Calibrations GPS:  040                   COMMENT
# Number of Calibrated Antennas GLO:      020                   COMMENT
# Number of Individual Calibrations GLO:  042                   COMMENT
# GLONASS PCV (metric)                                          COMMENT
#  derived from Delta PCV per 25.0 MHz                          COMMENT
#  for frequency channel number k=0                             COMMENT
   G01                                                          START OF FREQUENCY
     +1.18      +0.31   +161.38                                 NORTH / EAST / UP
   NOAZI    +0.00    +0.22    +0.84    +1.70    +2.59    +3.26    +3.55    +3.35    +2.71    +1.74
+0.65   -0.37   -1.21   -1.79   -2.04   -1.83   -0.94   +0.88   +3.75
     0.0    +0.00    +0.20    +0.82    +1.71    +2.64    +3.35    +3.65    +3.43    +2.73    +1.74
+0.66   -0.31   -1.07   -1.60   -1.88   -1.78   -1.06   +0.57   +3.26
     5.0    +0.00    +0.20    +0.82    +1.71    +2.64    +3.35    +3.64    +3.41    +2.71    +1.69
+0.60   -0.38   -1.15   -1.68   -1.96   -1.86   -1.17   +0.44   +3.09
    10.0    +0.00    +0.20    +0.82    +1.71    +2.63    +3.35    +3.63    +3.40    +2.68    +1.66
+0.55   -0.45   -1.22   -1.75   -2.02   -1.93   -1.24   +0.35   +2.99
    15.0    +0.00    +0.20    +0.82    +1.71    +2.63    +3.34    +3.63    +3.38    +2.66    +1.62
+0.50   -0.51   -1.29   -1.82   -2.08   -1.97   -1.28   +0.31   +2.95
…
…
   355.0    +0.00    +0.20    +0.82    +1.71    +2.64    +3.36    +3.66    +3.44    +2.76    +1.78
+0.72   -0.24   -1.00   -1.53   -1.80   -1.69   -0.94   +0.74   +3.46
   360.0    +0.00    +0.20    +0.82    +1.71    +2.64    +3.35    +3.65    +3.43    +2.73    +1.74
+0.66   -0.31   -1.07   -1.60   -1.88   -1.78   -1.06   +0.57   +3.26
   G01                                                          END OF FREQUENCY
   G02                                                          START OF FREQUENCY
     +0.34      -0.46   +159.00                                 NORTH / EAST / UP
   NOAZI    +0.00    -0.12    -0.46    -0.95    -1.52    -2.13    -2.78    -3.48    -4.17    -4.73
-5.00   -4.83   -4.14   -3.00   -1.52   +0.22   +2.32   +5.07   +8.78
     0.0    +0.00    -0.13    -0.47    -0.96    -1.51    -2.09    -2.70    -3.35    -4.01    -4.57
-4.86   -4.74   -4.12   -3.06   -1.65   +0.02   +2.06   +4.75   +8.46
…
   360.0    +0.00    -0.13    -0.47    -0.96    -1.51    -2.09    -2.70    -3.35    -4.01    -4.57
-4.86   -4.74   -4.12   -3.06   -1.65   +0.02   +2.06   +4.75   +8.46
   G02                                                          END OF FREQUENCY
   R01                                                          START OF FREQUENCY
…
   R01                                                          END OF FREQUENCY
   R02                                                          START OF FREQUENCY
…
   R02                                                          END OF FREQUENCY
                                                                END OF ANTENNA
```

Figure 30: absolute antenna calibrations file (extract)

The absolute antenna calibration file requires antennas oriented to the True North, see Chapter 3.3. This shall be checked on the field using a compass or a map. Then if needed the value of mis-alignment can be recorded in the sitelog at Section 4 *Alignment from True N* by the responsible agency (see sitelog Section 12).

Example: Extract of Section 4 of the GNSS permanent station SEY1 sitelog at Mahe Island (Seychelles):

```
4.6 Antenna Type : ASH701945B_M DOME
Serial Number : CR519993002
Antenna Reference Point : BPA
Marker->ARP Up Ecc. (m) : 1.2065
Marker->ARP North Ecc(m) : 0.0000
Marker->ARP East Ecc(m) : 0.0000
Alignment from True N : -6
Antenna Radome Type : DOME
Radome Serial Number :
Antenna Cable Type : (vendor & type number)
Antenna Cable Length : (m)
Date Installed : 2007-06-29T00:00Z
Date Removed : 2011-08-02T23:59Z
Additional Information : Antenna is aligned to magnetic north.
```

5.3 Orientation of the tie vectors

The local orientation is managed in two steps: a geographic orientation (planimetry) and a vertical orientation (vertical deflection). The stated requirement for the tie vector orientation accuracy is 1 mm or better. Therefore, to transform coordinates from the topocentric frame to a global frame, one has to take into account the geoid undulation (deflection of the vertical – DoV). Indeeed, Geoid slope could be important like at Grasse-Calern (France) where the value is around 6 cm per km. A geoid model (EGM08) can be used in the computation in order to apply the geoid undulation at every point.

- no geoid undulation: one can orientate the observation polygon only in planimetry. The 2 references processed by GNSS are used in the adjustment software. The reference coordinates in current ITRF at the epoch of the survey, the azimuthal values or the GNSS reference vectors are set not fixed but constrained to realistic values (around ~1 cm or with associated realistic accuracies, i.e. multiplied with a suitable factor).
- with geoid undulation: a 6-parameters transformation (3 translations and 3 rotations) has to be estimated. This requires at least 3 points well distributed on the site and determined by GNSS (with distances of typically several hundred meters, see discussion in Chapter 3.3).

For small job the computed heights are orthometric heights. But the best is to apply a 6-parameters transformation.

The geoid undulation can be determined with other methods but they have not been experimented by IGN.

Note: At some sites where the bearing distances can not be as far as several tens of meters, the 1 mm accuracy for orientation can not be achieved easily. A gyroscopic bearing (1 milli-degree precision) seems difficult to implement.

5.4 Report and Results – SINEX file

Report:

One of the purposes of the report is to present the results as clearly as possible and to provide to IERS ITRS Centre a SINEX file for next ITRF realizations. In general, each agency has its own reporting experience.

The report shall allow possible reprocessing of the data or can be used as a basis to redo the survey almost in the same conditions. Some information like surveying point identification (set out unambiguously), pictures, data and metadata and processing parameters are crucial.

Reporting advises are also supplied in section "Reporting" of the IERS Technical Note No. 33 (Richter et al., 2005).

Reports of previous surveys from various agencies can be found at http://itrf.ign.fr/local_survey.php.

Your report as well as your survey results can be made available at this site by contacting itrf@ign.fr.

IERS archive:

IGN decided to create and update a database of local tie vectors and SINEX files.

SINEX file name:

We suggested normalizing the SINEX file name following this example: "10002_IGN_1999-284_v10.snx". It includes the Site ID (5 numbers), the Survey Agency, the mean epoch of observations as year and day of year, and version number. Indeed, if more than one sinex file is made from the same survey (reprocessing), the greatest number is the most recent adjustment.