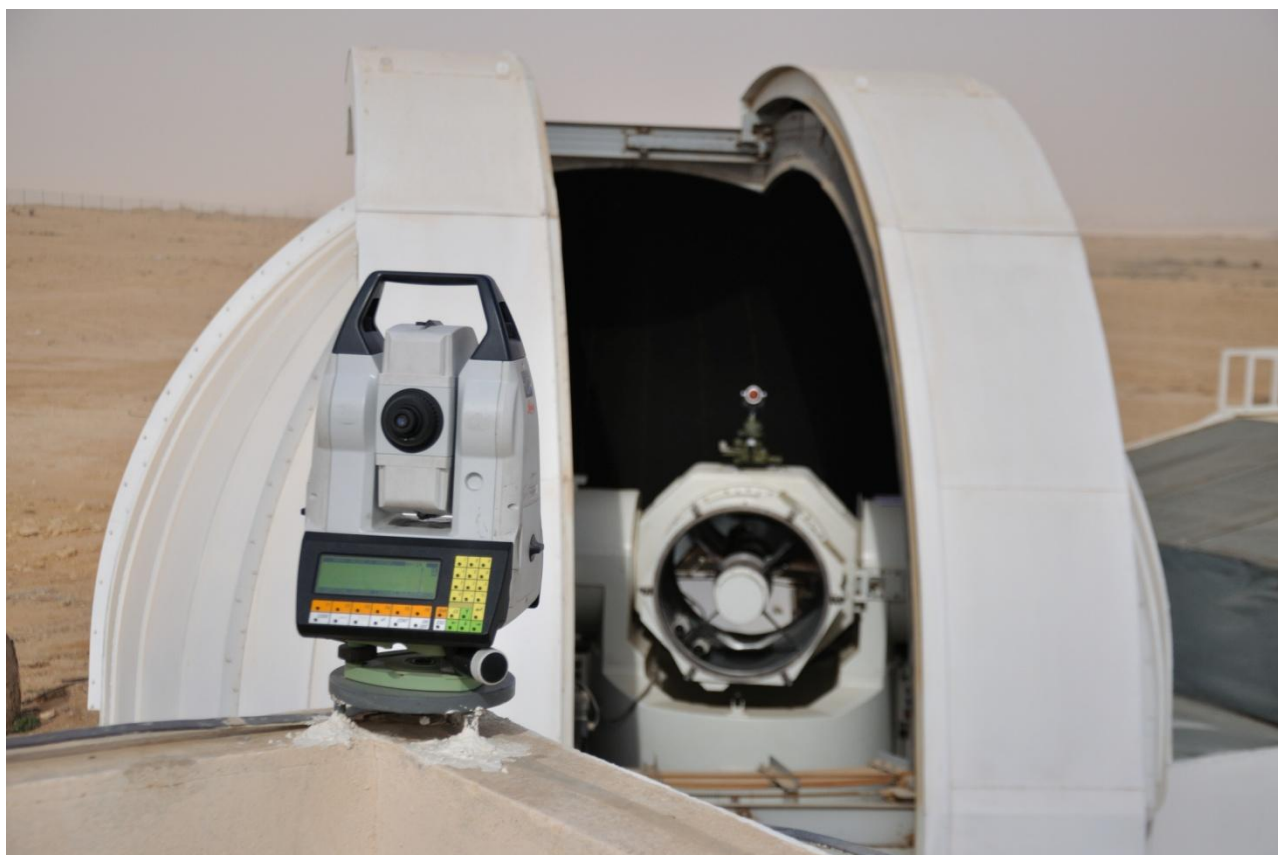


Raphaëlle DELAUGERRE, Damien PESCE

**ITRF Co-location Survey
Saudi Arabian Laser Ranging Observatory
(Saudi Arabia)**



**Rattachement ITRF
au SALRO
(Arabie Saoudite)**

Février 2012

RT/G 141

N° archive 28407

Date de création 09/07/2012

N° de version 1

DIFFUSION LIMITEE

Mots-clé

Rattachement ; Télescope ; Co-localisation ; Co-location ; GNSS ; Riyadh ; Tie survey ; SALRO ; KACST

Résumé

Ce document présente les opérations et calculs du rattachement ITRF entre la station laser et l'antenne GNSS (SOLA) de l'observatoire laser d'Arabie Saoudite (SALRO) près de Riyad.

This document presents the SALRO local tie survey between the SLR and GNSS antenna (SOLA) of the Saudi Arabian Laser Ranging Observatory (SALRO) near Riyadh.

Matériel

Système d'exploitation	Logiciel
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Windows 7 Pro SP1

Microsoft Office Word 2010

Validation

	Fonction	Nom	Visa
Commanditaire	Chef d'unité RSI	Bruno Garayt	03/08/2012 – signé
Rédacteur principal	Technicien de production	Damien Pesce	12/07/2012 – signé
Correcteur	Responsable de production	Jean-Claude Poyard	02/08/2012 – signé
Approbateur	Chef de service	Alain Harmel	07/09/2012 – signé
Vérificateur	Responsable qualité	Thierry Person	31/10/2012 – signé

Diffusion

Organisme / Service	Fonction / Nom	Numérique	Papier
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KACST	Johan Bernhardt	oui	-

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INTRODUCTION

ITRF is the result of a combination of the different terrestrial reference frames provided by the four space geodetic techniques: GNSS, VLBI, SLR and DORIS. To perform this combination between independent reference frames, it is necessary to have 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 of work, it has been decided by Dr Zuheir Altamimi in charge of the ITRS realization at IGN, to survey the SALRO co-location site (Riyadh, Saudi Arabia). Indeed, this site possesses two different space geodetic techniques so the tie between the GNSS antenna SOLA and the Laser Ranging Station (CDP number 7832) was essential.

However, this site is examined to install a DORIS antenna, another space geodetic technique.

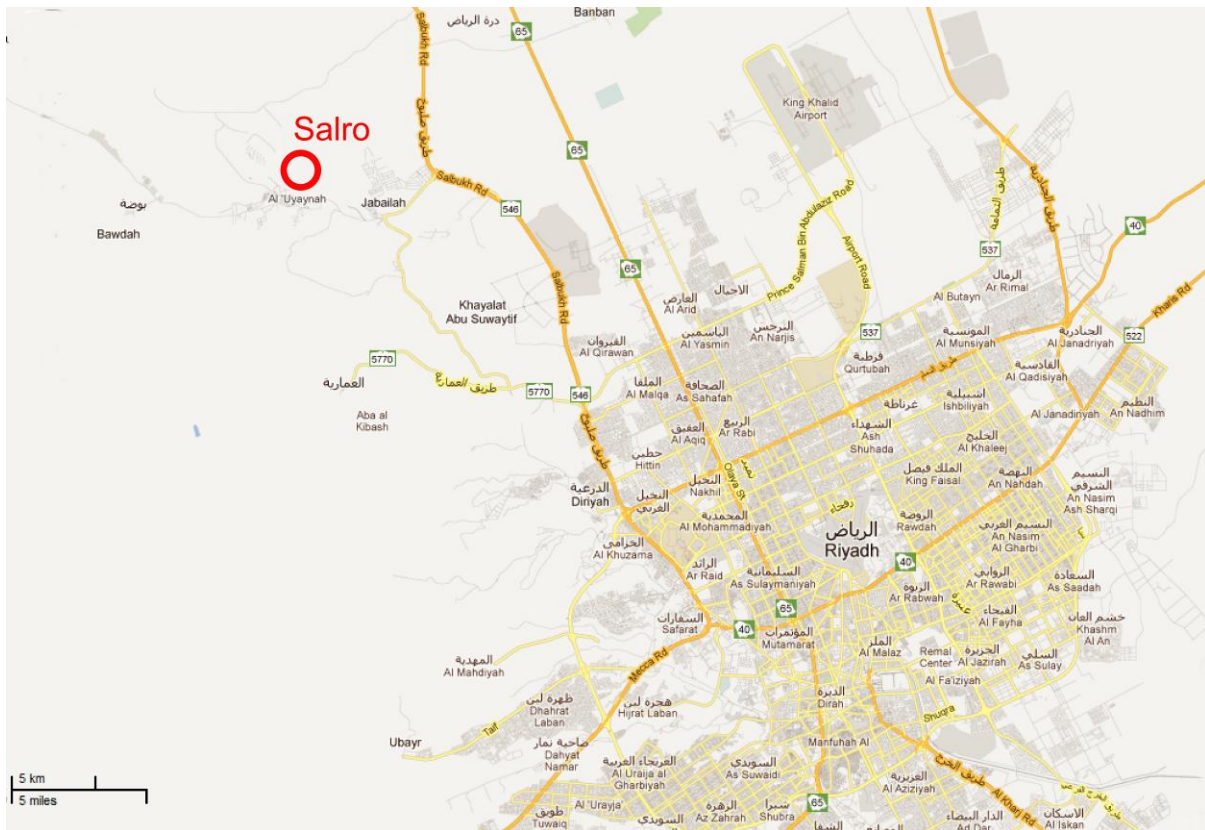
This document presents the SALRO (Saudi Arabian Laser Ranging Observatory) local tie survey which took place in February 2012, from the observations on site to the computation, with as many details as necessary to fully understand what the resulting SINEX file means.

ACKNOWLEDGEMENTS

We would like to express our thanks to Dr Nasr A. Al-Sahhaf and the King Abdulaziz City for Science & Technology (KACST), with a special thanks to Johan Bernhardt and all the team working on the Laser and GNSS stations. Their very nice welcome, their cooperative work on technical and administrative aspects contributed for a great part to the success of this work.

1. CO-LOCATION SITE DESCRIPTION

The SALRO co-location site is located about 40 km north west of Riyadh centre, at the KACST Solar village.



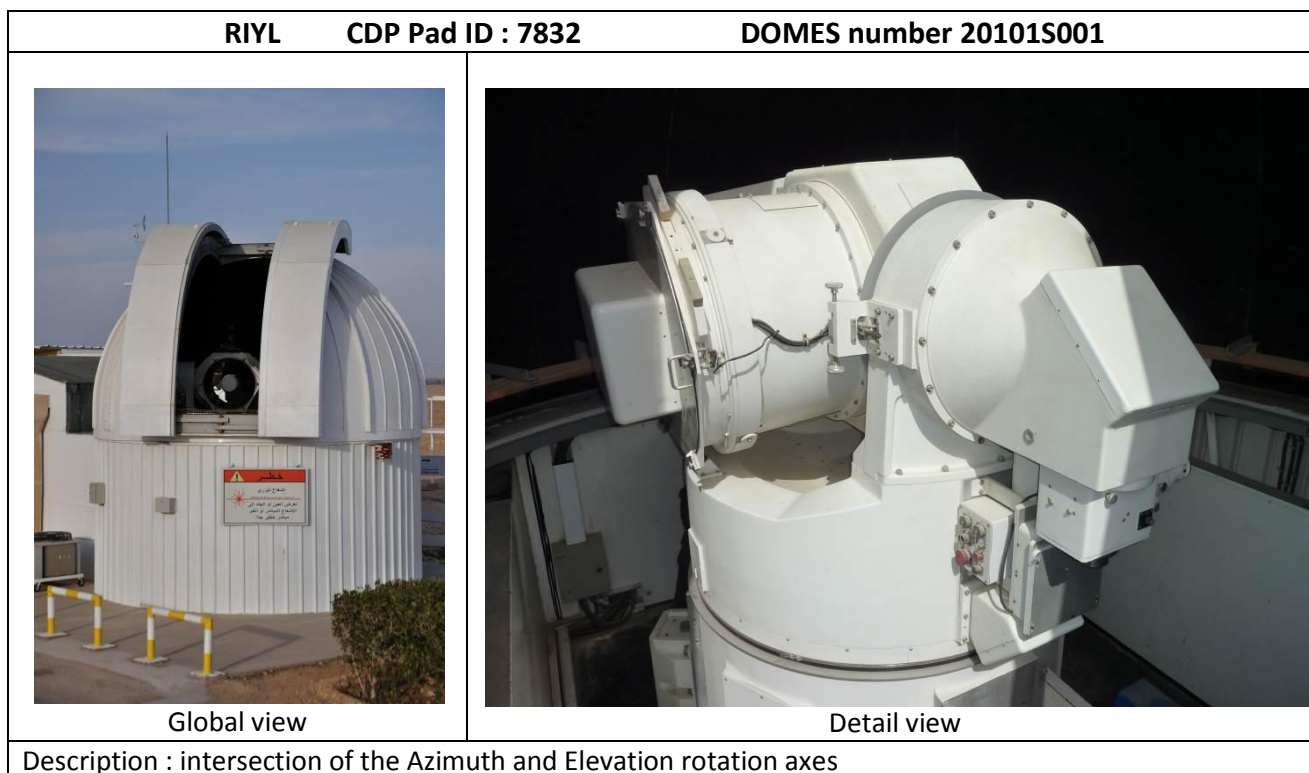
(Extract of Google map)

On this geodetic site, there are a Satellite Laser Ranging (SLR) station, this is « RIYL », a 75 cm aperture telescope, and an IGS permanently operating Global Navigation Satellite System station. This is « SOLA » (GNSS) which is about 25 m apart from the telescope.

The RIYL-SOLA vector has never been measured.

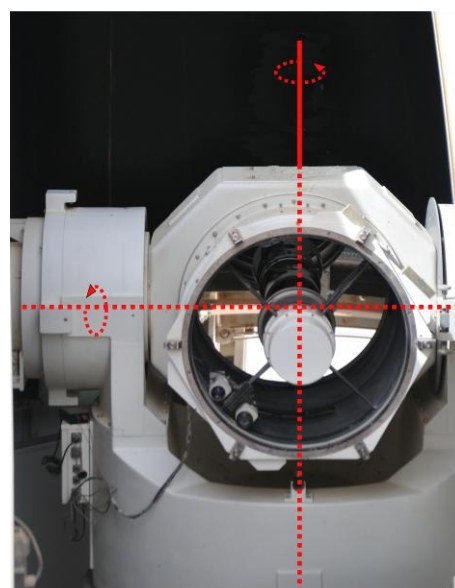
2. ITRF SPACE GEODESY TECHNIQUES

2.1. SLR station

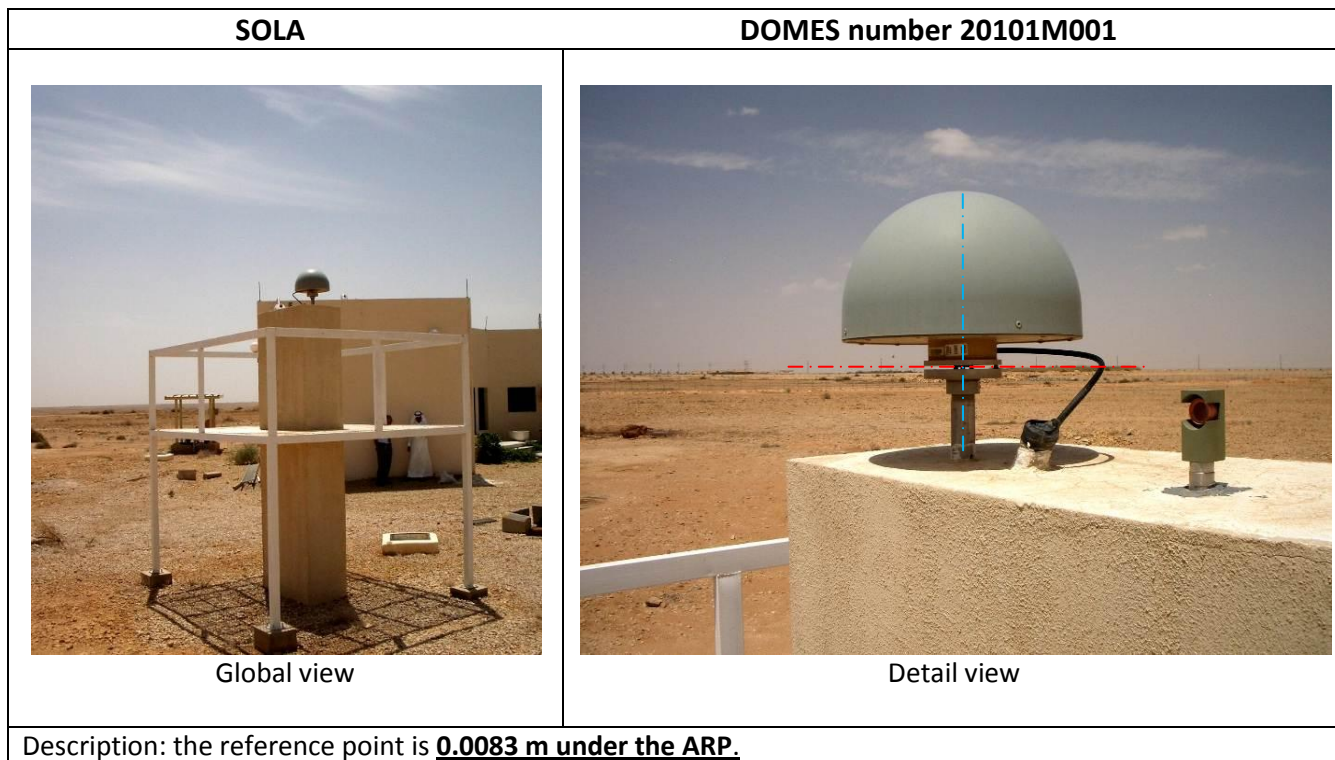


The SLR measurements refer to a point in the telescope where the two rotation axes intersect (it is supposed that the two axes are secant). This System Reference Point (SRP) cannot be materialized.

The site log is presented in Annex 6.1.



2.2. SOLA IGS station



The site log is presented in annex 6.2.

2.3. Other points of interest

2.3.1. SLR Calibration piers

For its calibration, the SLR uses corner cubes (prisms) set up on piers. There are three piers close to the SLR and four further. The first three ones were used for the survey. The tribrachs and their stands were on the fixations of prisms and were not removed during all the survey. SOLA IGS station is fixed on one of these piers next to one calibration prism. The four other piers were only observed from one station to have a distance from the telescope.

We could not centre exactly our instruments on the calibration prism holes (centred at approximately 2mm) but there was no influence for the survey.



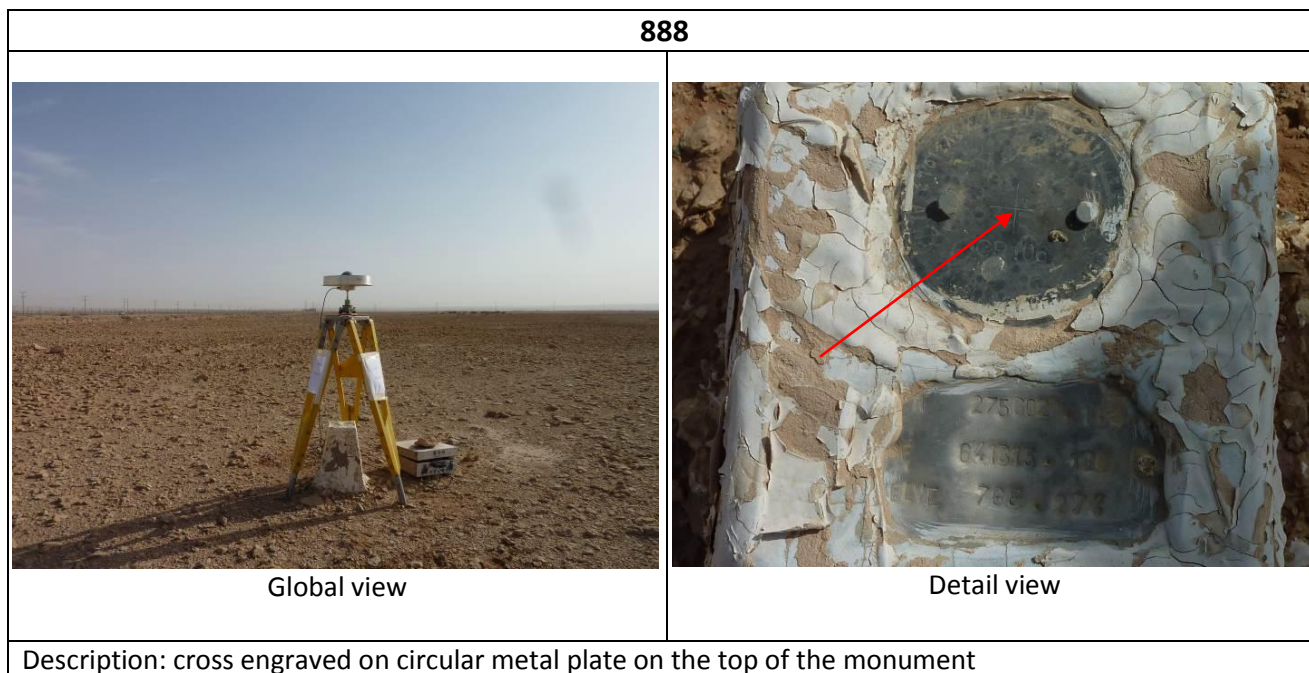
Observations from pier

2.3.2. Temporary stations

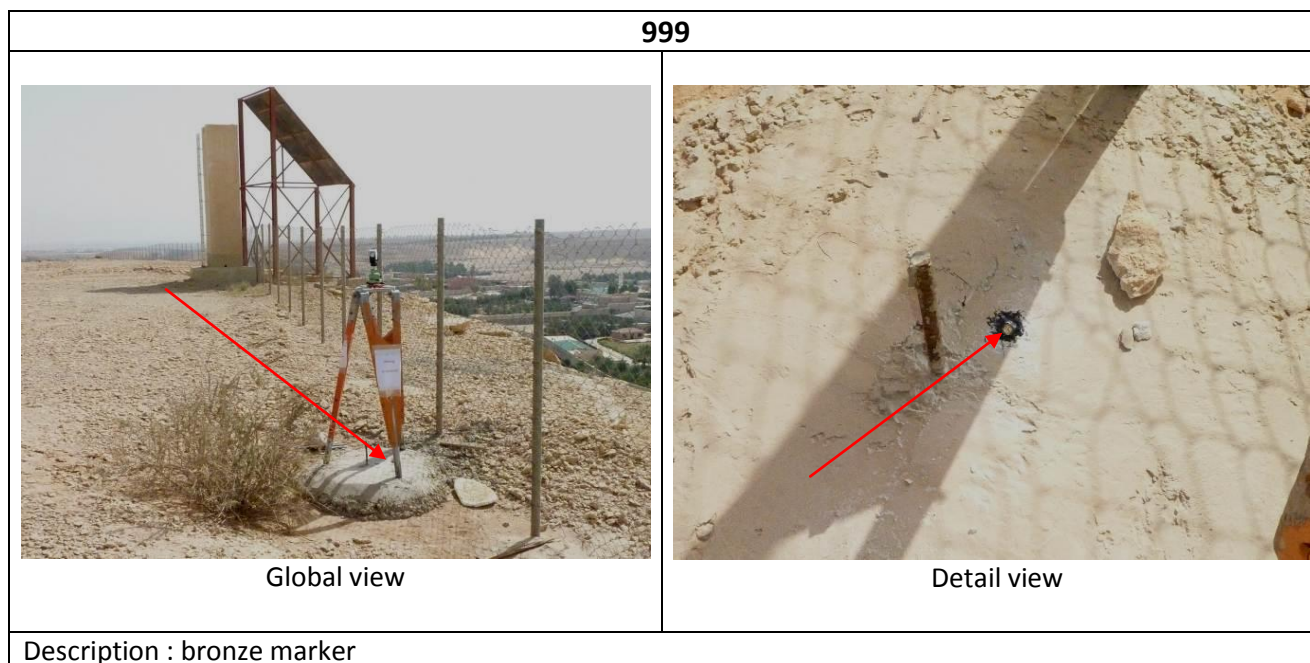
To complete the network, we used temporary stations (without permanent mark). One was fixed on the roof of the main building thanks to a stand and plaster. The second one was setup on a heavy tripod. Two other temporary stations were setup on ordinary tripods to plot several targets on the telescope: one on the roof and the other one on the ground, south to the SLR.

2.3.3. Distant references

To align the network to the ITRF frame, two points far away were setup. One is an existing benchmark (Al Nefesah Survey) about 50 m from the north east pier (415 m from SLR). For the survey, it is called 888. (See description sheet)



The second one is a marker fixed (by IGN team) on a concrete pad near the south pier (794 m from SLR). For the survey, it is called 999.



3. SURVEY DESCRIPTION

3.1. Organization

The local tie survey of SALRO co-location site has been carried out by Raphaëlle Delaugerre and Damien Pesce, with the useful help of the SLR's team. They are both from the Department of Geodesy and Leveling (SGN) of the National Institute of Geographic and Forest Information (IGN) and mainly deal with metrology and micro-geodesy.

The survey took place from the 31st of January to the 7th of February 2012. The weather conditions were ideal during the survey except for some sand winds on the first day.

No SLR observations were planned during these days so that the telescope could be observed in all the positions needed.

3.2. Equipment

All the topometric survey instruments and equipments belong to IGN and have been temporarily imported for the purpose of the survey.

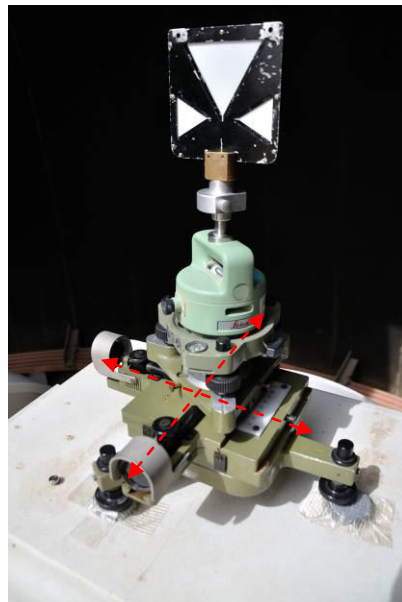
3.2.1. Instruments

Two Leica total stations (TM30 and TDA5005) were used for this work. These instruments, which are regularly calibrated by IGN's metrology unit, were associated with six Leica accurate prisms. They have a standard deviation of 0.15 mgon for horizontal and vertical angles and 1 mm + 1 ppm for distances. The GPS observations were done with a Leica GX1230 receiver and Leica AT504 choke ring antenna. All these instruments allowed the observations to be digitally recorded on memory cards and were then downloaded to a laptop PC for processing.

3.2.2. Equipments and accessories

Several very useful accessories have been also brought for this kind of field work, among which:

- heavy tripods, in order to ensure the stability of the stations
- a translation stage in order to centre a target on the vertical telescope rotation axis (see picture hereafter)



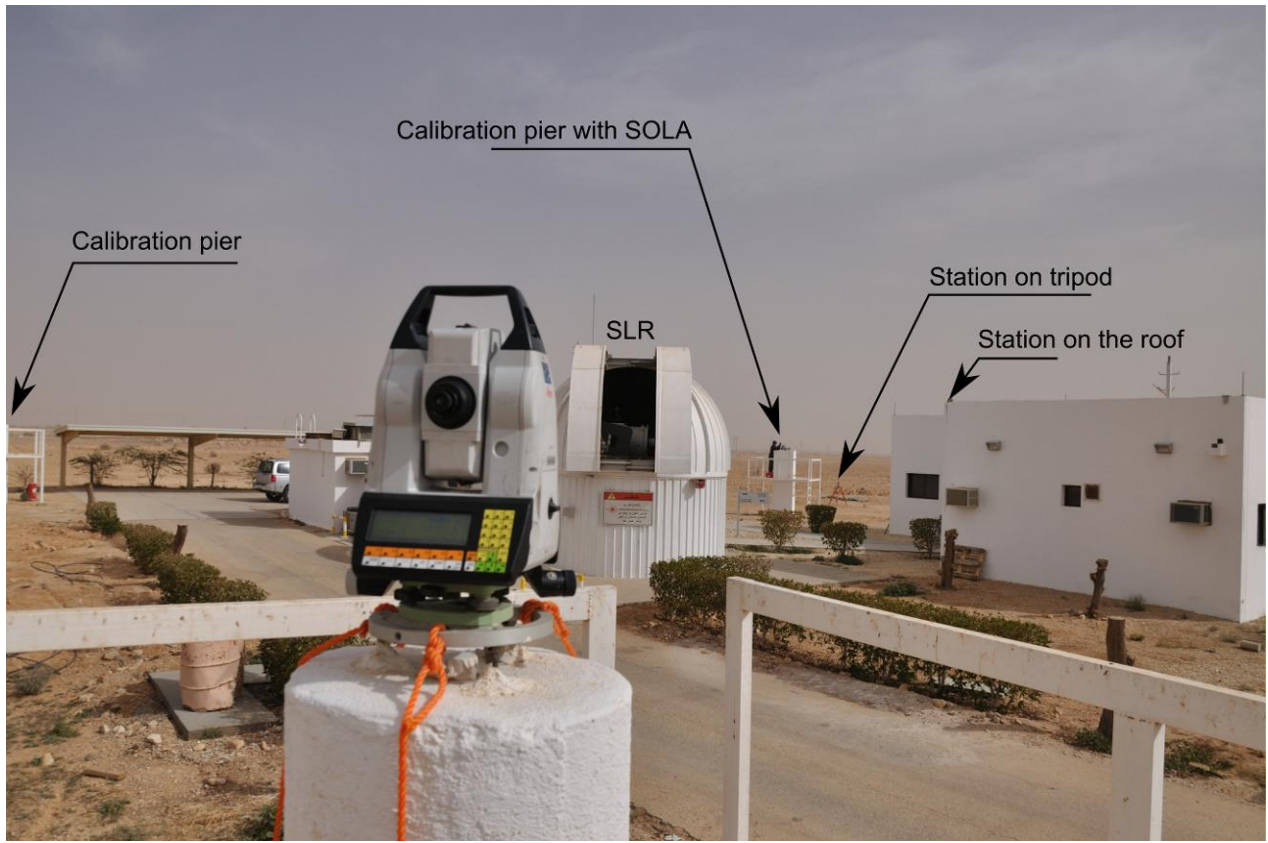
Translation stage

- calibrated trefoil targets and prisms
- regularly calibrated tribrachs

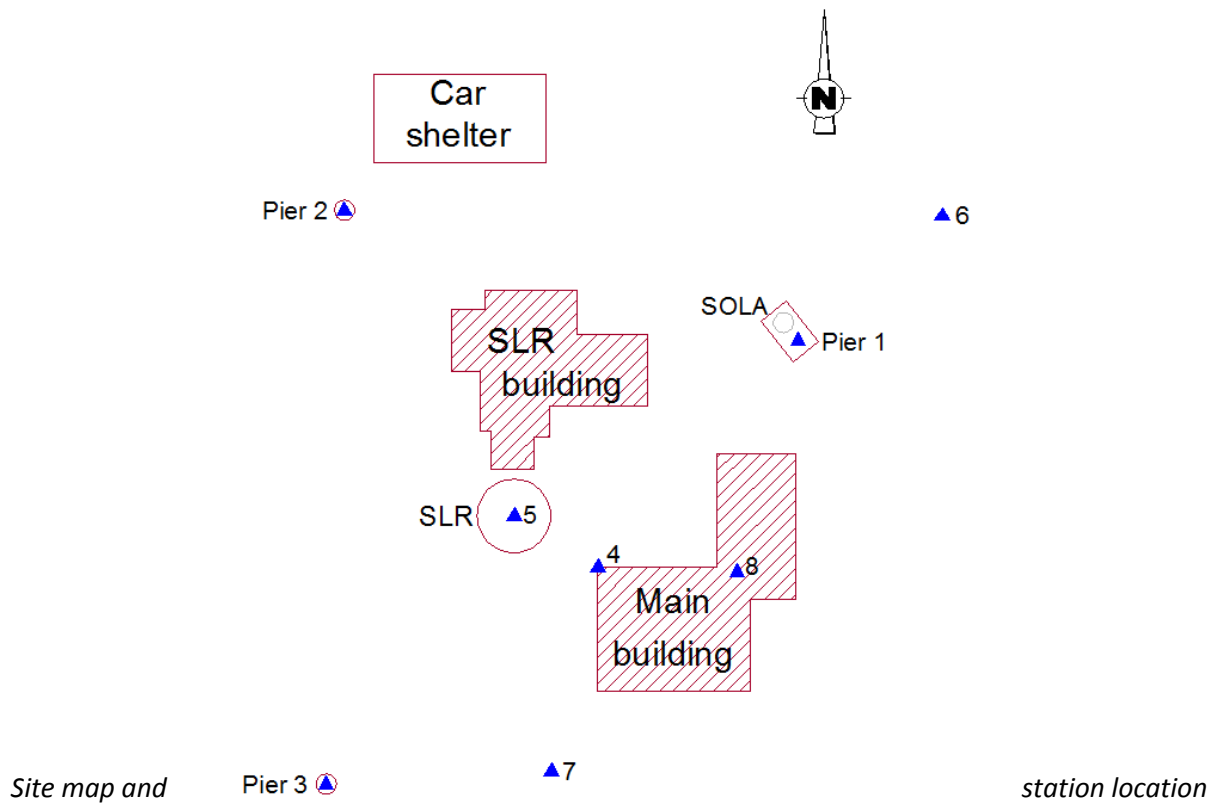
3.3. SALRO observations polygon

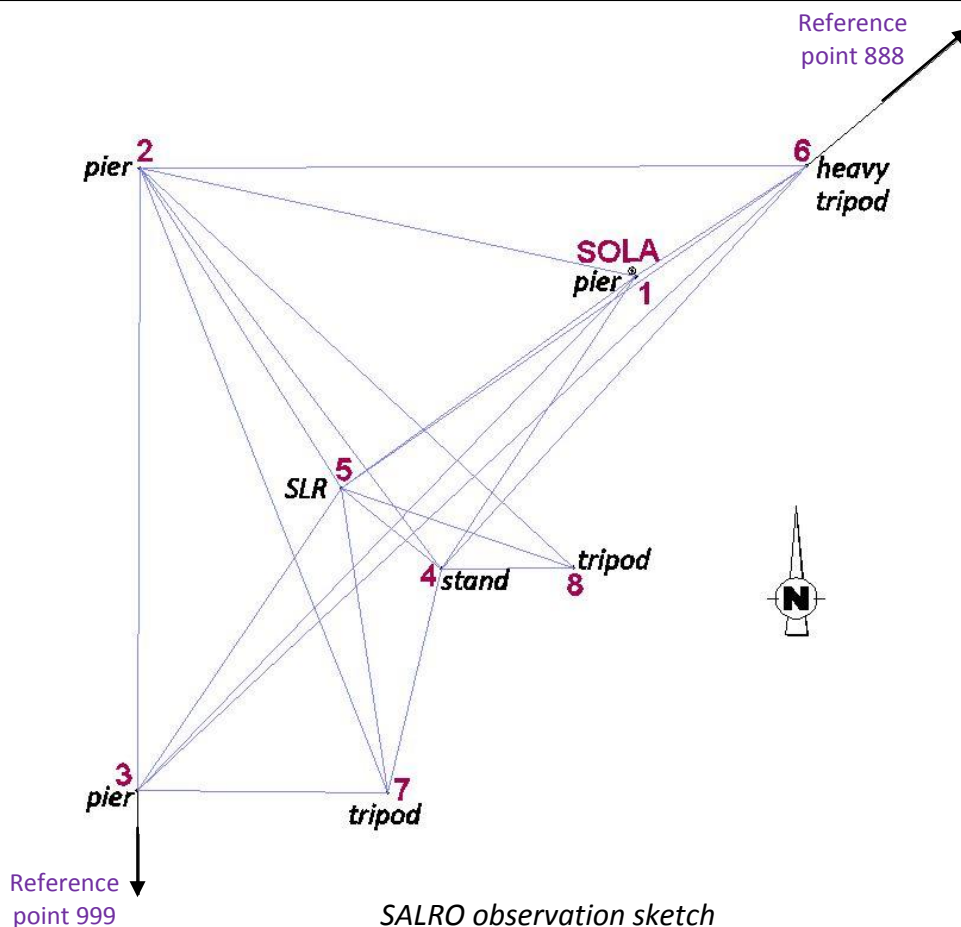
All the survey was conducted in order to provide the highest accuracy in the determination of the 3D vector between the observing instruments.

IGS and SLR stations are quite high above the ground and the opening of the dome is narrow. But thanks to the piers around and a station on the roof, the survey could be carried out in good conditions.



Global view of the network, view from pier 3





3.4. Survey method

All the lines of sight have been observed with the total stations. Horizontal directions and zenith angles were observed in data sets, each set consisting in one reading in both direct and reverse theodolite positions. Any observed angle was rejected if the difference between the two measurements was too high. Distance measurements were observed over each line once in both direct and reverse positions. Meteorological data (atmospheric pressure and temperature) used to correct the distances, were recorded at the beginning of each station occupation.

3.4.1. SLR telescope

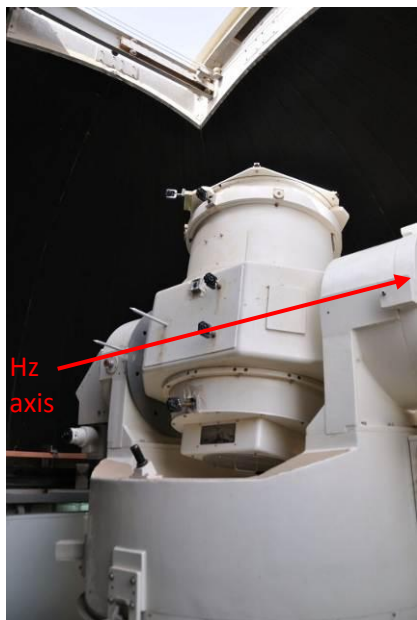
The reference point has been determined in two successive steps: the first one to determine the vertical axis, the second one to determine the horizontal axis.

- *Vertical axis*

The method to find the vertical axis required to level the telescope. The bubbles of the spirit levels of the telescope were out of range. So that is why in a first time, the telescope was leveled. Then, the SLR vertical axis had to be determined. It is supposed perfectly vertical. To measure its position from one theodolite set up on a tripod, a target on the two axes translation stage was seen and the position of the target read on the micrometre. The SLR was then rotated 180° around the vertical axis, and the target rotated towards the theodolite. The target was then shifted using the translation stage, until it was aimed from the same theodolite direction. The new target position was read on the micrometre. Then the translation stage was

adjusted by half the difference of the two readings. The same thing was done with the SLR telescope oriented at 90° from the original position. At last, we checked that the target didn't move when aimed with the theodolite, as the telescope rotated around its vertical axis.

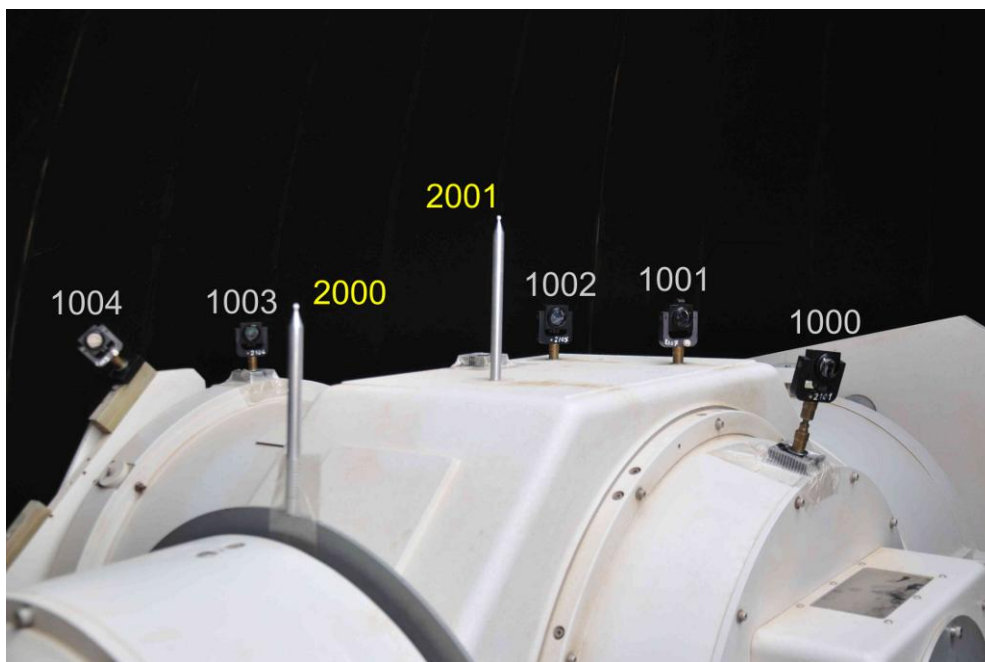
- *Horizontal axis*



To determine the horizontal axis, we have moved the telescope from 0° to 160° in elevation in order to determine circles whose centres are on the horizontal axis. To do so, five prisms and two targets were placed on the telescope and intersected in each position (every 20 degrees) from five stations (stations 1, 3, 4, 7 and 8) for the first three positions ($0,124^\circ$ to $40,190^\circ$) and from four stations (3, 4, 7 and 8) for the last positions ($60,086^\circ$ to $160,122^\circ$).

Telescope with targets in vertical position

Points were numbered as follows: first position ($0,124^\circ$): 1000 to 1004 for prisms and 2000 and 2001 for targets and then increased by 100 for each next positions.



Targets on the telescope

3.4.2. SOLA IGS station

Due to lack of precision, it was not possible to intersect the antenna axis directly. The GPS measurements were stopped during 2 hours to remove the antenna and to intersect the antenna centre support screw (SOLA) from the topometric stations. The height between this screw and the antenna reference point is 8.3 mm (See schemas in annex 6.3 and page 22).

3.4.3. GPS observations

GPS observations have been carried out for more than 24 hours, in order to orientate and reinforce the survey. For SOLA, the IGS data downloaded on site were used. For the other stations, the GPS observations were carried out with the following specifications:

- Cut-off angle 10°
- 30 sec sampling

The following table sums up the GNSS observations.

Point	Start (UT)	End (UT)	Ant. Height (m)	Ant. reference
SOLA	Daily RINEX file DOY 032 to 038		0.0083	ASH701945E_M SCIS
999	DOY 032 12:37	DOY 034 5:26	1.6060	LEIAT504 NONE
888	DOY 035 5:48	DOY 037 11:06	1.0210	LEIAT504 NONE
4 (Temporary point)	DOY 037 11:46	DOY 038 10:01	-0.0503	LEIAT504 NONE

All antenna heights are related to the antenna reference point (ARP).

The point 4 antenna height is negative: That means that the reference point was the rotation axes intersection of the total station, which was 5.03 cm above the ARP.

Due to problems during the process, data of day 032 of the point 999 was not used.

For orientation, remote points from SOLA (i.e. 999 and 888) have been used. Point 4 is too close to be used (only for IGS08 alignment).

4. COMPUTATIONS

4.1. On-site validation

The control network has been pre processed on site in order to point out any problem in the observations. The observations have been checked in a local coordinate system.

The outliers have been detected and the precision has been estimated in order to check if the requirements of such a survey could be met.

4.2. GPS network

The GPS baselines have not been processed on site but at the office with the scientific software Bernese version 5.0 of the University of Berne. This software incorporates the movements of the poles, information on satellites, the ocean overload FES2004 model, as well as specific changes in the position of the phase centres and reference points of antennas and satellite receivers.

4.2.1. ITRF2008

The international reference system for the whole Earth is undoubtedly the International Terrestrial Reference System (ITRS) as defined by the International Earth rotation and Reference systems Service (IERS). ITRS is an ideal reference system defined through theoretical prescriptions and conventions.

The ITRS needs to be realized on the basis of coordinates and velocities of a set of physical earth-related points. Such a realization is the so-called ITRF_{yyyy} (International Terrestrial Reference Frame) where *yyyy* stands for the last year of observations taken into account.

ITRF2008 is the new realization of the ITRS released in May 2010. Following the procedure already used for the ITRF2005 formation, the ITRF2008 uses as input data time series of station positions and Earth Orientation Parameters (EOPs) provided by the Technique Centres of the four space geodetic techniques (GPS, VLBI, SLR, DORIS). Based on completely reprocessed solutions of the four techniques, the ITRF2008 is expected to be an improved solution compared to ITRF2005.

A full description of ITRF2008 is available at http://itrf.ensg.ign.fr/ITRF_solutions/2008.

ITRS is stated to meet the “no net rotation” condition, i.e. the mean displacement due to tectonic plate motion for the whole Earth is zero. Hence, any realization has to provide coordinates and velocities of the involved stations. Therefore a specific epoch must be fixed to express coordinates in an operational geodetic reference set.

4.2.2. IGS08

The International GNSS Service (IGS) is currently maintaining the ITRF related to GNSS stations through a weekly solution. As far as the ITRF alignment is ensured, the main goal is to improve coordinates and velocities as well as to detect possible discontinuities.

The new IGS reference frame, IGS08, was released on April 17th 2011. IGS08 was initially intended to be a direct subset of well performing, stable GNSS stations from ITRF2008 rather than a separate GNSS-only frame solution. But, while the IGS contribution to ITRF2008 was computed using the original set of “absolute” GNSS antenna calibrations (igs05.atx), IGS08 had to be consistent with the latest set of calibrations (igs08.atx) that includes new determinations for some existing antennas. Coordinate corrections due to the antenna calibration updates were thus estimated and applied when possible to the ITRF2008 coordinates of 64 affected stations (out of a total of 232 stations in IGS08).

More details are available in the reference publication : Reischung, P.; Garayt, B.; Schmid, R.; Ray, J.; Collilieux, X.: **IGS08: Elaboration, consequences and maintenance of the IGS realization of ITRF2008**; European Geosciences Union General Assembly 2011, Wien, 07.04.2011 [*EGU2011-6850.pdf* and *igs08_egu11.pdf*].

4.3. Global Adjustment

4.3.1. Terrestrial adjustment

Back at the office, the computation has been carried out by a 3D Least Squares Adjustment with IGN software COMP3D v.4. At a first step, a computation was done only with total station observations in local coordinates system. The input files were created from all the terrestrial observations: horizontal and vertical angles, distances, planimetric and altimetric centrings.

The a priori standard deviations used for the different observations with total stations are:

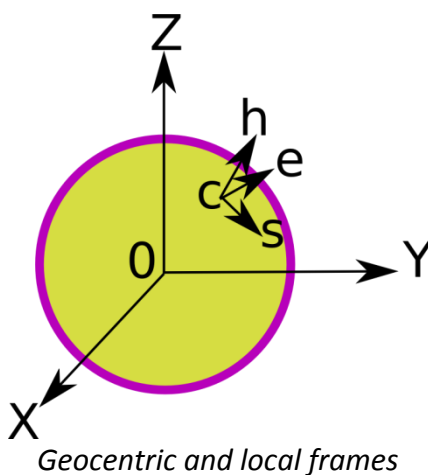
- on precision prism and target:
 - 0.5mgon for horizontal and vertical angles with an accuracy to within 0.1mm on the target definition.
 - 0.5mm for distances.
- on small prism (used for horizontal axis determination):
 - 0.6mgon for horizontal and vertical angles with an accuracy to within 0.2mm on the target definition.
 - 0.8mm for distances.

This adjustment gives us local coordinates and a covariance matrix of all points of the SALRO network.

4.3.2. GNSS orientation

COMP 3D software is a micro-geodesy computation software which works in a local cartesian coordinates system with Z axis along the vertical. This is why 3D geocentric coordinates of the GNSS points have to be transformed into local Cartesian coordinates to be incorporated in COMP 3D computation.

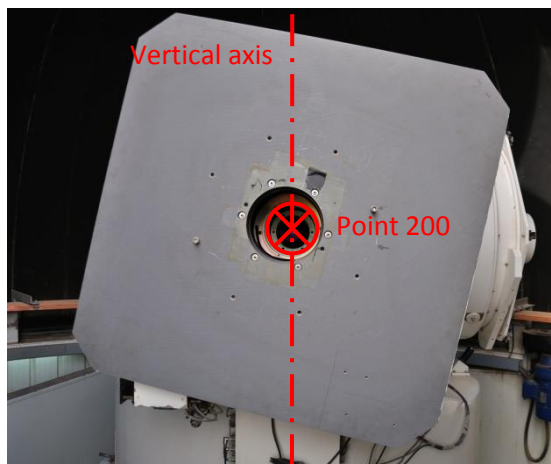
This transformation is simply a rotation and a translation to have X corresponding to the south direction, Y to the east, Z along the vertical and the origin at the centre of the area. The parameters of the transformation are computed for the centre of the GNSS antennas.



All the computations will be done in this frame, using constrains on GNSS stations coordinates to orientate the network. SOLA coordinates will have an accuracy of 0.1 mm and 999 and 888 planimetric coordinates are constrained at 1 cm, in order to express the orientation uncertainty. This process gives covariance matrix useful to create the SINEX file. The resulting coordinates can be changed into geocentric, simply by inverting the transformation.

Problem: At this step of the process, the centre of the telescope (RIYL or 7832) is known in planimetry (vertical axis, point 5) but is not yet processed in altimetry (horizontal axis).

To have a good accuracy on Z component (used for the matrix), a temporary point has been created with planimetric coordinates of point 5 and altimetric coordinate of point 200 (see picture). Centring equation is applied to fix a priori accuracy of 0.5mm (accuracy of the following process) in altimetry and 0.2 mm (accuracy of point 5) in planimetry. At the end, the covariance matrix elements of this temporary point are used for RIYL point.



Side of the horizontal axis of the telescope

4.3.3. SLR reference point

4.3.3.1. Horizontal Axis

To get the horizontal axis parameters, 7 targets have been measured on the telescope in several different vertical orientations.

We used least squares adjustment to estimate the axis position and orientation.

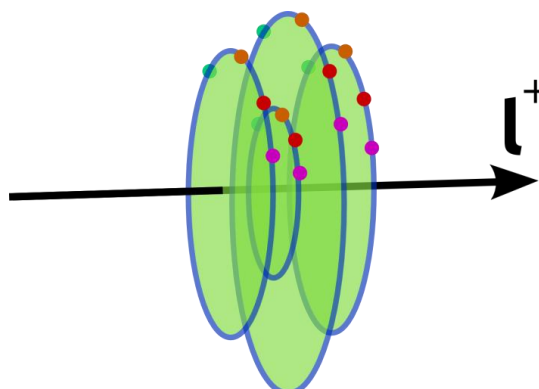
In local frame, the axis parametric equations are:

$$\begin{cases} x = a \cdot l + x_0 \\ y = 1 \cdot l - 100 \\ z = c \cdot l + z_0 \end{cases}$$

for every l in $]-\infty; +\infty[$.

The axis has 4 liberties: a , c , x_0 and z_0 .

The displacement of each target when the telescope moves is a circle, orthogonal to the axis. Two more parameters are needed for each target: the abscissa of the centre of the circle along the axis, and the circle radius.



Definition of the axis using several telescope positions

The observations are the 3d coordinates of the points, with their precisions. The relations between observations and parameters are:

- the distance between a point and the centre of the circle is the radius.
- the vector between the centre and the point is orthogonal to the axis.

The parameters we get are:

$$\begin{aligned}x &= 1.32107761622696e-002 * l - 1.33068765910079e+002 \\y &= 1 * l - 100 \\z &= -9.73702638164107e-005 * l + 2.28682773382609\end{aligned}$$

4.3.3.2. Vertical Axis

The vertical axis is supposed to be strictly vertical. That is why it has been directly measured in one point above the telescope (Point 5).

To find this point a prism has been setup close to the axis. Then the telescope has been turned and its prism has been moved to reach an invariant position for horizontal orientation of the telescope.

The vertical axis parameterization is:

$$\begin{aligned}x &= -132.8344 \\y &= -82.2940\end{aligned}$$

4.3.3.3. Reference point of the Telescope

To check if the axes intersect, the distance between them can be computed. For $y = -82.2940$, what is "x" on the horizontal axis?

$$l = -82.2940 + 100$$

$$x_{\text{hz_axis}} = 1.32107761622696e-002 * l - 1.33068765910079e+002$$

$$dx = x_{\text{hz_axis}} + 132.8344 = 0.0005\text{m}$$

Transformed into the orthogonal distance between the two axis, it gives:

$$\text{distance} = dy * \cos(\text{atan}(\text{abs}(b))) = 0.4\text{mm.}$$

This is consistent with measurement and conception precisions.

We then are able to compute the central point between the two axis:

$$-132.8346 \quad -82.2940 \quad 2.2851$$

The precision is about **0.5mm**.

4.3.4. IGS08 Alignment

Finally the rotation and the translation are applied in the opposite directions for all the points to obtain all points in IGS08 epoch 2012.1.

For the final covariance matrix, the x elements of the matrix are swapped with y elements and vice-versa in a "test-west-up" frame.

4.3.5. Computation Software validation

A second process was done with Geolab 2001 Microsearch software to make a comparison. The a priori standard deviations used for the different observations with total stations are almost the same as Comp 3D process. The results are quite the same around 0.1 mm

5. RESULTS

5.1. Station names

Here is an extract of the calculation input file with the main point description.

*****POINTS DESCRIPTION*****

888 and 999: orientations measured by GPS

888_prism and 999_prism: points at prism height

1, 2, 3, 4, 5, 6, 7, 8: stations

1, 2 and 3: stations on calibration piers

4: station on a stand on the low wall of the roof

5: station on translation stage centred on the vertical axis

6: station on heavy tripod

7: station on normal tripod

8: station on small tripod

SOLA: (DOMES 20101M001) marker of the permanent station antenna (i.e. 0.0083 m below ARP) (see following sheet)

SOLA_prisme: prism on mini centring rod centred on marker (i.e. 0.2 m above SOLA)

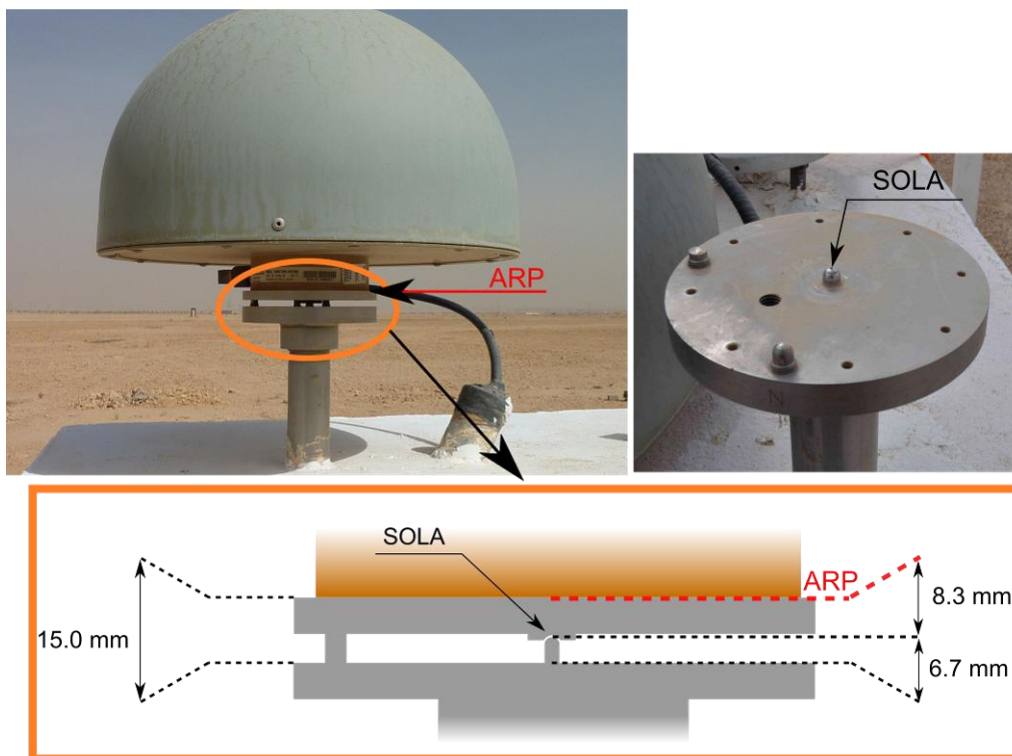
2000 and 2001: targets on the telescope for the determination of the horizontal axis (increased 2100, 2200... for the different positions)

1000 to 1004: small prisms on the telescope for the determination of the horizontal axis (increased 1100, 1200... for the different positions)

200 : centre of the circle hole on a side, hz axis (see picture page 17)

XXX_pier: prisms SALRO on calibration piers (constant = -3.6mm)

7832 or RIYL (DOMES 20101S001): SLR_SRP (= System Reference Point) axis intersection



The following list sums up the most important names used in this process.

Point Description	Used name or code	Computation name
-------------------	-------------------	------------------

SLR station		
<ul style="list-style-type: none"> System Reference Point (SRP) Prism on the translation stage on the vertical axis 	20101S001 / (CDP number 7832)	Centre / RIYL 5
SOLA permanent GPS		
<ul style="list-style-type: none"> SOLA IGS reference point (marker) Antenna ARP 	20101M001 ARP	SOLA

5.2. Adjusted coordinates and confidence regions

The results of the adjustment are the coordinates of all points as well as their confidence ellipsoids in the IGS08 frame at the mean epoch of the observations (i.e. epoch 2012.1).

Hereafter is a table with the 3D coordinates relative accuracy and confidence region at 95% of the 2 main points of interest.

	X (m) / σ_x (m)	Y (m) / σ_y (m)	Z (m) / σ_z (m)
RIYL	3992100.5581	4192172.7109	2670411.1232
	<i>0.0004</i>	<i>0.0003</i>	<i>0.0006</i>
SOLA	3992081.6871	4192182.2506	2670424.0085
	<i>0.00010</i>	<i>0.00010</i>	<i>0.00010</i>

The whole covariance matrix was computed. It was possible to extract from it the covariance submatrix and the vectors (see Annex 6.4) for the following points of interest:

- 7832 reference point 20101S001
- SOLA reference point 20101M001

Vector	X	Y	Z
7832 --> SOLA	18.8710	-9.5396	-12.8853

The 7832(RIYL)-SOLA vector had never been measured before but we can compare the result with coordinates difference from ITRF data.

Station ITRF positions in ITRF2005 Frame at epoch 2012/02/05

ID / Domes nb	X	Y	Z
SOLA / 20101M001	3992081.706	4192182.276	2670424.029
7832 / 20101S001	3992100.576	4192172.728	2670411.134

<i>ITRF2005 epoch 2012.1 Coordinates</i>			
Vector	X	Y	Z
7832 --> SOLA	18.8700	-9.5480	-12.8950

Comparison (mm) with our results

dX	dY	dZ
1.0	8.4	9.7

Then this covariance submatrix has been converted into the SINEX format. The resulting SINEX file (20101_IGN_2012-035_V10.SNX) is presented in annex 6.5.

6. ANNEXES

6.1. RIYL site log

http://ilrs.gsfc.nasa.gov/stations/sitelist/RIYL_sitelog.html

ILRS Site and System Information Form
International Laser Ranging Service

0. Form

Prepared by (Full Name) : John Guilfoyle
Preparer E-mail : vernacular@bigpond.com
Date Prepared : 2002-05-09
Report Type : UPDATE
Format Version : 1.0

1. Identification of the Ranging System Reference Point (SRP)

Site Name : SALRO
IERS DOMES Number : 20101S001
CDP Pad ID : 7832
Subnetwork : WPLTN
Description : AZ EL INTERSECT
Monument Description : N.A.
Monument Inscription : N.A.
Mark Description : N.A.
Date Installed : 1995-08-01
Date Removed : (yyyy-mm-dd)
Geologic Characteristic : BEDROCK
Additional Information : (multiple lines)

2. Site Location Information

City or Town : Riyadh
State or Province : Central
Country : Saudi Arabia
Tectonic Plate : Arabian
Approximate Position
X coordinate [m]: 3992101.1
Y coordinate [m]: 4192172.4
Z coordinate [m]: 2670410.5
Latitude [deg]: 24.9102 N
Longitude [deg]: 46.4004 E
Elevation [m]: 773
Additional Information : (multiple lines)

3. General System Information

3.01 System Name : SALRO
4-Character Code : RIYL
CDP System Number : 55
CDP Occupation Number : 01
Eccentricity to SRP (if Not Identical With SRP)
North [m]: (m +- m)
East [m]: (m +- m)
Up [m]: (m +- m)
Date Measured : (yyyy-mm-dd)
Date Installed : (yyyy-mm-dd)
Date Removed : (yyyy-mm-dd)
Additional Information : (multiple lines)

4. Telescope Information

4.01 Receiving Telescope Type : CASSEGRAIN
Aperture [m]: 0.73
Mount : AZ-EL
Xmitting Telescope Type : CASSEGRAIN
Aperture [m]: 0.75
Tracking Camera Type : ICCD
Model : P49636/A V3
Manufacturer : EEV Photon
Field of View [deg]: 0.07
Minimum Magnitude [mag]:
Transmit/Receive Path : COMMON COUDE
Transmit/Receive Switch : ROTATING MIRROR
Max Slew Rate Az [deg/s]: 10
Max Slew Rate El [deg/s]: 5
Max Used Tracking Rate Az : 10
Max Used Tracking Rate El : 5
Telescope Shelter : DOME
Daylight Filter Type : SPECTRAL FILTER
Dayl. Filt. Bandwidth [nm]: 0.15
Adjustable Attenuation : BOTH
Transmit Efficiency : (0.00...1.00)
Receive Efficiency : (0.00...1.00)
Date Installed : 1992-01-01
Date Removed : (yyyy-mm-dd)
Additional Information : (multiple lines)

[...]

15. On-Site, Point of Contact Agency Information

Agency : Space Research Institute, KACST
Mailing Address : PO Box 6086, Riyadh 11442 Saudi Arabia
Primary Contact
Contact Name : Dr Atteih AlGhamdi
Telephone (primary) : +966 1 481 3325
Telephone (secondary) :
Fax : +966 1 481 3523
E-mail :
Secondary Contact
Contact Name : Turki Al-Saud
Telephone (primary) :
Telephone (secondary) :
Fax :
E-mail : talsaud@kacst.edu.sa
Additional Information : (multiple lines)

6.2. SOLA site log (extract) and diagram

ftp://igs.cb.jpl.nasa.gov/pub/station/general/sitelog_instr.txt

0. Form

Prepared by (full name) : David Maggert
Date Prepared : 2011-08-26
Report Type : UPDATE
If Update:
Previous Site Log : sola_20080703.log
Modified/Added Sections : 3.1, 3.2, 12, 13

1. Site Identification of the GNSS Monument

Site Name : Solar Village
Four Character ID : SOLA
Monument Inscription :
IERS DOMES Number : 20101M001
CDP Number :
Monument Description : CONCRETE PILLAR
Height of the Monument : 4
Monument Foundation : sandstone bedrock
Foundation Depth : 4
Marker Description : SCIGN MOUNT
Date Installed : 2004-02-24T00:00Z
Geologic Characteristic : BEDROCK
Bedrock Type : SEDIMENTARY
Bedrock Condition : WEATHERED
Fracture Spacing : 1-10 cm
Fault zones nearby : NO
Distance/activity :
Additional Information :

2. Site Location Information

City or Town : Solar Village
State or Province :
Country : Saudi Arabia
Tectonic Plate : Arabian
Approximate Position (ITRF)
X coordinate (m) : 3992082.0138
Y coordinate (m) : 4192182.2188
Z coordinate (m) : 2670423.8358
Latitude (N is +) : +245438.4344
Longitude (E is +) : +0462402.0425
Elevation (m,ellips.) : 760.1393
Additional Information :

3. GNSS Receiver Information

[...]

3.2 Receiver Type : TRIMBLE NETRS
Satellite System : GPS
Serial Number : 4646125533
Firmware Version : 1.1-3
Elevation Cutoff Setting : unknown
Date Installed : 2010-02-21T09:55Z
Date Removed : (CCYY-MM-DDThh:mmZ)
Temperature Stabiliz. :
Additional Information :

4. GNSS Antenna Information

[...]

4.2 Antenna Type : ASH701945E_M SCIS
Serial Number : CR620024212
Antenna Reference Point : BPA
Marker->ARP Up Ecc. (m) : 0.0083
Marker->ARP North Ecc(m) : 0.0000
Marker->ARP East Ecc(m) : 0.0000
Alignment from True N : 0
Antenna Radome Type : SCIS
Radome Serial Number :
Antenna Cable Type : Times Microwave LMR-400
Antenna Cable Length : 35
Date Installed : 2004-05-18T12:00Z
Date Removed : (CCYY-MM-DDThh:mmZ)
Additional Information : New antenna section entry reflects the
: addition of a SCIGN short antenna dome.

[...]

11. On-Site, Point of Contact Agency Information

Agency : King Abdullah City for Science and Technology
Preferred Abbreviation : KACST
Mailing Address : Astronomy & Geophysics Research Institute
: Building 17, Laboratory
: Riyadh
: Saudi Arabia

Primary Contact
Contact Name : Dr. Abdullah Arrajehi
Telephone (primary) : 966-5-410-1998
Telephone (secondary) :
Fax :
E-mail : arrajehi@hotmail.com

Secondary Contact
Contact Name :
Telephone (primary) :
Telephone (secondary) :
Fax :
E-mail :
Additional Information :

12. Responsible Agency (if different from 11.)

Agency : Massachusetts Institute of Tech
Preferred Abbreviation : MIT
Mailing Address : ERL/MIT E34-406
: 42 Carleton St.
: Cambridge, MA 02142-1324

Primary Contact
Contact Name : Robert Reilinger
Telephone (primary) : (617) 253-7860
Telephone (secondary) :
Fax :
E-mail : reilinge@erl.mit.edu

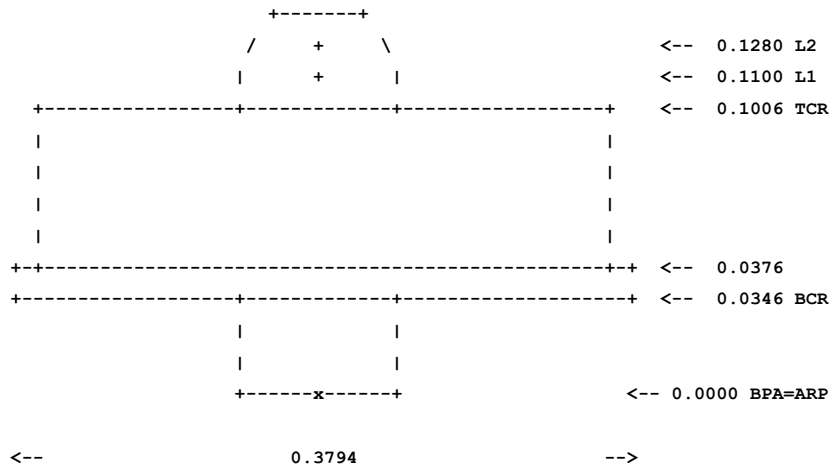
Secondary Contact
Contact Name : UNAVCO
Telephone (primary) : 303-381-7500
Telephone (secondary) :
Fax : 303-381-7451
E-mail : archive@unavco.org
Additional Information :

13. More Information

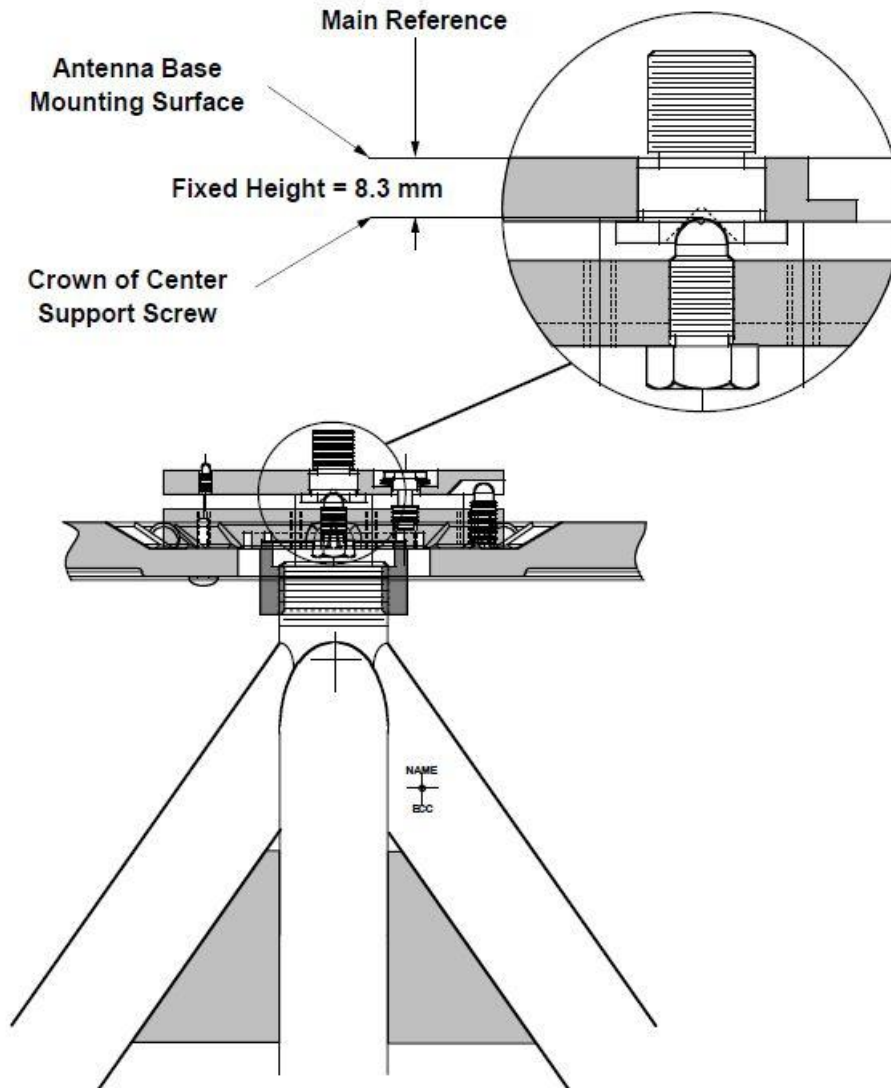
Primary Data Center : UNAVCO

Secondary Data Center : CDDIS (GDC-Global Data Center)
 URL for More Information : <http://www.unavco.org>
 Hardcopy on File
 Site Map : Y
 Site Diagram : Y
 Horizon Mask : Y
 Monument Description : Y
 Site Pictures : Y
 Additional Information :
 Antenna Graphics with Dimensions

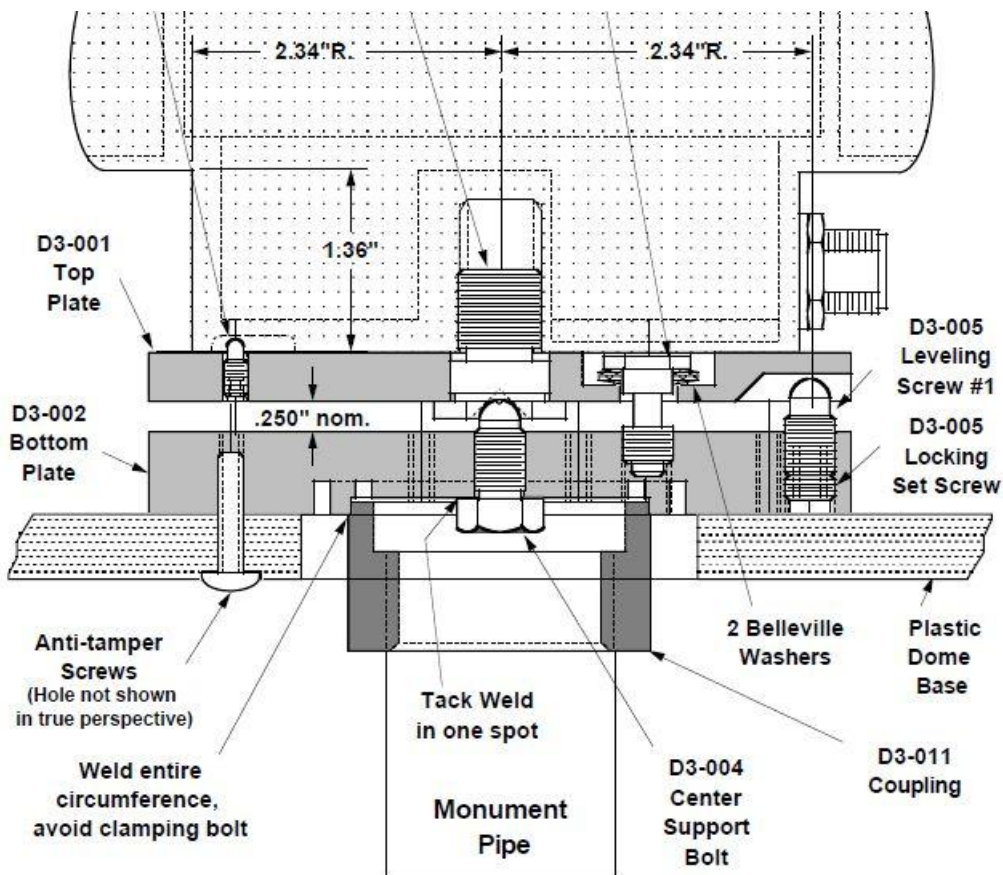
ASH701945E_M



6.3. SOLA antenna mount diagram



University of California IGPP 0225 La Jolla, California 92093		Tolerances +/- (unless specified) x/x .x .xx .xxx angular 1/64" .1" .01" .005" 1deg	
DESIGN 3 GPS Ant. Mount		TITLE Main Reference	
DRAWN BY CBH Do Not Scale This Drawing	DATE 24 Jun, 99 SCALE 1"= 2.5"	DRAWING NUMBER AD3-103	



University of California IGPP 0225 La Jolla, California 92093		Tolerances +/- (unless specified) x/x .x .xx .xxx angular 1/64" .1" .01" .005" 1deg	
DESIGN 3 GPS Ant. Mount		TITLE Cross Section	
DRAWN BY CBH	DATE 8 Sep, 98	DRAWING NUMBER	D3-101
Do Not Scale This Drawing		SCALE	1" = 1"

6.4. Global Covariance Matrix

ITRF08 (IGS08) epoch 2012.1 Cartesian coordinates in metre

	X	Y	Z
7832	3992100.5531	4192172.7057	2670411.1199
SOLA	3992081.6871	4192182.2506	2670424.0085

Covariance Matrix

	7832 X	7832 Y	7832 Z	SOLA X	SOLA Y	SOLA Z
7832 X	1.16E-07	3.24E-08	-1.41E-09	9.89E-09	4.72E-11	7.69E-14
7832 Y	3.24E-08	1.40E-07	1.01E-09	-1.40E-10	1.01E-08	-5.67E-14
7832 Z	-1.41E-09	1.01E-09	3.24E-07	1.95E-13	-1.81E-13	1.00E-08
SOLA X	9.89E-09	-1.40E-10	1.95E-13	1.00E-08	-1.77E-13	3.38E-17
SOLA Y	4.72E-11	1.01E-08	-1.81E-13	-1.77E-13	1.00E-08	1.24E-16
SOLA Z	7.69E-14	-5.67E-14	1.00E-08	3.38E-17	1.24E-16	1.00E-08

6.5. Sinex File

```
%=SNX 1.00 IGN 12:087:00000 IGN 12:032:00000 12:039:00000 C 00006
*-----
+FILE/COMMENT
* Original input files: Comp3d files
* Matrix Scalling Factor used:          1.0000000000
-FILE/COMMENT
*-----
+SITE/ID
*CODE PT  DOMES  T  STATION DESCRIPTION  APPROX_LON  APPROX_LAT  APP_H
SOLA  A  20101M001  20101M001          46 24 02.1   24 54 38.4   760.1
7832  A  20101S001  20101S001          46 24 01.4   24 54 36.7   773.0
-SITE/ID
*-----
+SOLUTION/ESTIMATE
*INDEX TYPE  CODE PT SOLN  REF_EPOCH  UNIT S  ESTIMATED VALUE  STD_DEV
  1 STAX  7832  A    1 12:035:00000  m    2 0.399210055314437E+07  0.32640E-03
  2 STAY  7832  A    1 12:035:00000  m    2 0.419217270569251E+07  0.35880E-03
  3 STAZ  7832  A    1 12:035:00000  m    2 0.267041111985622E+07  0.54590E-03
  4 STAX  SOLA  A    1 12:035:00000  m    2 0.399208168711440E+07  0.95800E-04
  5 STAY  SOLA  A    1 12:035:00000  m    2 0.419218225055390E+07  0.95800E-04
  6 STAZ  SOLA  A    1 12:035:00000  m    2 0.267042400847825E+07  0.95800E-04
-SOLUTION/ESTIMATE
*-----
+SOLUTION/MATRIX_ESTIMATE L COVA
*PARA1 PARA2  PARA2+0  PARA2+1  PARA2+2
  1    1  0.115963765209702E-06
  2    1  0.323923486215995E-07  0.140200727890698E-06
  3    1  -.141395546377018E-08  0.101085970639409E-08  0.324477081476528E-06
  4    1  0.989357096327937E-08  -.140405892478451E-09  0.194558506870848E-12
  4    4  0.999841186767137E-08
  5    1  0.472478492564251E-10  0.100588157668243E-07  -.180949570907515E-12
  5    4  -.177007861732337E-12  0.999809202237547E-08
  6    1  0.768646239720204E-13  -.567397029062965E-13  0.999795947703042E-08
  6    4  0.337603800443642E-16  0.124119058355779E-15  0.999968144538720E-08
-SOLUTION/MATRIX_ESTIMATE L COVA
%ENDSNX
```

6.6. GPS computation report

6.6.1. Introduction

This document describes the process used at the National Institute of Geographic and Forest Information (IGN France) to carry out the determination of the coordinates of 3 GPS points and SOLA IGS antenna. This document is an annex of SALRO co-location survey (Riyadh, KSA) report.

The coordinates are computed in the standard international reference frame (ITRF2008 / IGS08).

The state of the art scientific GNSS software Bernese v5.0 is used to perform the processing steps.

6.6.2. The Processing

The Processing of a GNSS observation campaign in ITRS will be achieved by the use of IGS data and products expressed in ITRF2008 via IGS08 :

- Ephemeris and Earth Orientation Parameters.
- GNSS observations, coordinate and velocities of IGS reference stations. The observation data of at least 10 IGS stations in a 4000 km radius from Riyadh area are available every day.
- Antenna calibration stemming from igs08.atx.

More details about the IGS data and products are available in the reference publication : Dow, J.M., Neilan, R. E., and Rizos, C., **The International GNSS Service in a changing landscape of Global Navigation Satellite Systems**, Journal of Geodesy (2009) 83:191–198, DOI: 10.1007/s00190-008-0300-3.

The processing will lead to coordinates expressed in IGS08 at the mid-epoch of the GNSS observation campaign. (Epoch 2012.1)

6.6.3. Dataset

6.6.3.1. Local stations data

The RINEX observation files correspond to a 30 second sampling rate, 3 station set of GNSS C1/L1/P2/L2 measurements spanning from February 1st to 7th, 2012 (days of year 032 to 038). Rinex navigation files are unnecessary since IGS precise orbits are used in the processing. They were not checked.

The following antenna calibrations / Phase Centre Offset were used (there also is a variable part that we do not copy out here).

Table 1: Antenna Calibration (IGS08).

Antenna IGS Name	Phase Centre Offset (East, North, Up)
ASH701945E_M SCIS	L1 0.0005 0.0001 0.0897
	L2 -0.0006 0.0000 0.1193
LEIAT504 NONE	L1 0.0003 0.0003 0.0913
	L2 -0.0003 0.0001 0.1177

Table 2: Daily files availability. Observation time in hours.

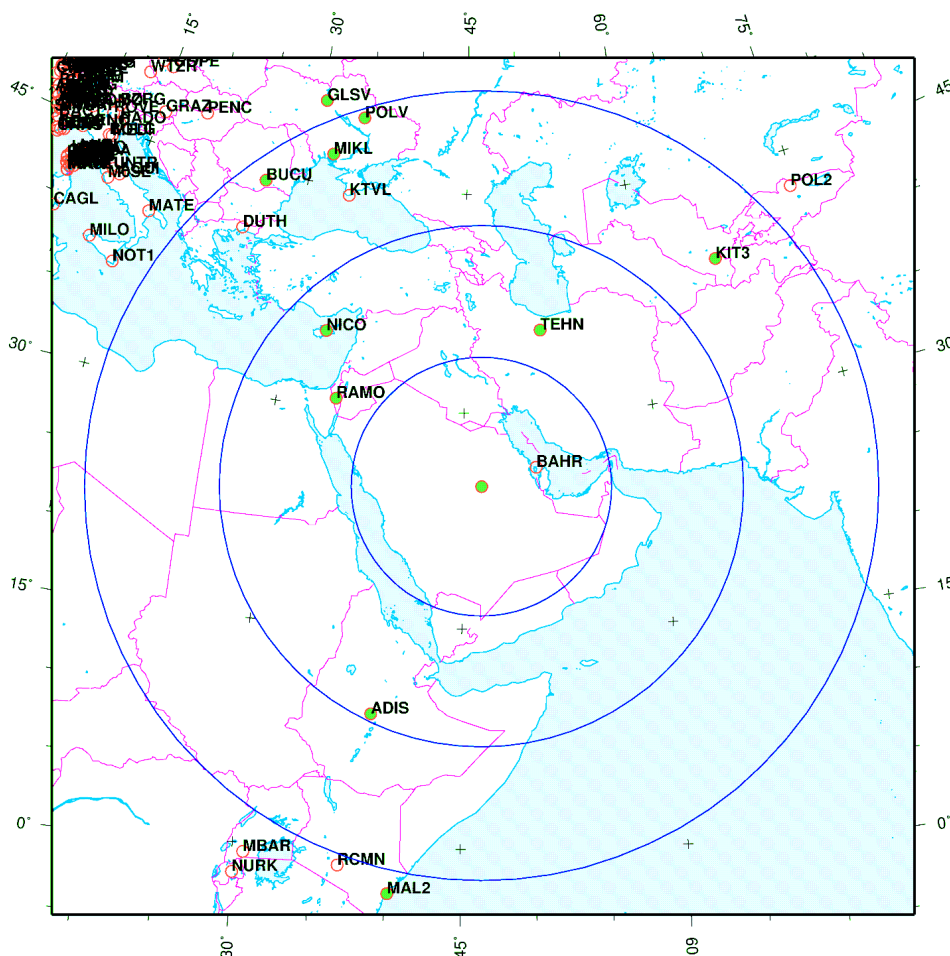
month	2012 February						
day of month	01	02	03	04	05	06	07
day of year	32	33	34	35	36	37	38
SOLA	24.0	24.0	24.0	24.0	24.0	24.0	24.0
999	11.4	29.5					
888				18.1	24.0	11.1	
4						22.2	

The first session of point 999 can't be processed. It was not used, the second session is sufficient enough to achieve the required accuracy and reliability.

6.6.3.2. IGS stations data

The map shows the IGS Reference Frame (RF) stations within a 5000 km radius from the work area used in the processing at least once. The RF stations are a subset of IGS stations selected by the IGS Reference Frame Working Group for the IGS realization of the International Terrestrial Reference Frame (ITRF).

See <http://igsb.jpl.nasa.gov/network/refframe.html>.



Map of IGS08 Reference Frame Stations used in the processing (green points)

6.6.4. Processing

6.6.4.1. Introduction

In a few words, the computation process is twofold: a first step is to provide session (e.g. daily) quasi free network solutions, and the second step is to combine these solutions in order to get final coordinates in the properly defined reference frame.

Attention may be drawn to the daily processing including very distant stations. The use of a high level software such as the Bernese is required with a thoroughly fixed parameterization. The parametrization implemented in our processing suits the processing of mean, long and very long baselines, i.e. between 5 km and 5000 km. The only limitations concerns the duration of observation sessions which must be longer than 2 hours. These baseline characteristics lead to special parametrization in:

- phase preprocessing (L1&L2 combination)
- estimation of troposphere parameters
- ambiguity resolution with the quasi ionosphere-free QIF strategy

In addition, this parametrization is also efficient in case of very short baselines (less than 5 km), if they are mixed with long ones (the duration criterion of 2 hours is still true) to break the correlation between the troposphere parameters and the ellipsoidal heights.

The validation of the computation will be presented in the following way:

- Assessment of the Root Mean Square errors of the combined solution.
- Assessment of consistency between the daily solutions (repeatability).
- Assessment of alignment of the combined solution to the IGS08 reference frame.

6.6.4.2. Sessions Combination

Once all solutions are obtained, related normal equations are merged in a least squares process in order to provide a final reference free combined solution. Moreover, each input normal system is processed with the same options as the combined one. The coordinate residuals of the individual solutions with respect to the combined solution are computed. The Root Mean Square errors and the consistency between the daily solutions (repeatability) are assessed.

6.6.4.2.1. Root Mean Square errors

Table 3 shows the Root Mean Square errors of the combined solution.

Table 3: Station Root Mean Square errors of the combined solution (mm).

Station	E RMS	N RMS	U RMS
ADIS 31502M001	1.1	1.6	2.8
BUCU 11401M001	1.3	1.5	2.7
GLSV 12356M001	1.2	1.8	2.6

Station	E RMS	N RMS	U RMS
KIT3 12334M001	1.8	1.2	2.5
MAL2 33201M003	1.1	2.0	2.3
MIKL 12335M001	1.1	1.6	2.7
NICO 14302M001	1.1	1.2	3.0
POLV 12336M001	1.1	1.7	2.7
RAMO 20703S001	1.1	1.1	3.0
TEHN 20404M002	1.3	1.2	2.9
SOLA 20101M001	1.2	1.1	3.0
888	1.2	1.1	3.0
999	1.2	1.1	3.1
4	1.2	1.1	3.1

6.6.4.2.2. Repeatability

Table 4 shows statistics about shifts between the daily solutions and the adjusted solution.

Table 4: Statistics on daily shifts to the solution (mm in North, East and Up component).

Station	#	Rms N	Min N	Max N	Rms E	Min E	Max E	Rms U	Min U	Max U
ADIS 31502M001	5	0.8	-1.0	1.1	0.7	-1.0	0.7	4.6	-5.0	6.6
BUCU 11401M001	5	1.0	-0.9	1.3	2.4	-2.8	3.0	1.7	-2.1	1.9
GLSV 12356M001	5	0.7	-0.9	0.5	1.6	-1.5	2.2	3.3	-3.7	3.3
KIT3 12334M001	5	2.5	-2.9	3.0	2.6	-2.7	4.2	3.4	-4.3	5.0
MAL2 33201M003	5	1.7	-1.3	2.6	2.7	-3.3	3.1	6.2	-9.0	7.5
MIKL 12335M001	5	0.3	-0.3	0.3	0.9	-1.2	0.9	0.9	-1.4	0.7
NICO 14302M001	5	0.5	-0.7	0.6	0.6	-0.7	0.8	1.4	-1.5	1.7
POLV 12336M001	5	0.8	-0.8	1.1	1.4	-2.0	1.6	2.4	-2.8	3.2
RAMO 20703S001	5	0.3	-0.3	0.3	1.1	-1.7	1.2	1.3	-1.7	2.0
TEHN 20404M002	5	1.0	-1.4	0.8	0.9	-0.9	1.2	2.8	-3.4	3.8
SOLA 20101M001	5	1.1	-1.3	1.4	0.6	-0.7	0.8	4.1	-6.6	3.6
888	3	0.6	-0.6	0.5	0.7	-0.0	0.8	5.9	-5.9	5.5
999	1	0.3	0.3	0.3	0.3	0.3	0.3	3.3	3.3	3.3
4	1	0.8	-0.8	-0.8	1.5	-1.5	-1.5	7.8	-7.8	-7.8

6.6.4.3. IGS08 Epoch Alignment

The combined solution is Helmert-aligned to IGS08 at mid-epoch of observations (2012.1). Residuals are checked to assess consistency of this solution.

Table 5: Helmert Residuals

Station	Residuals in millimetres		
	North	East	Up
ADIS	3.8	0.1	-2.0
BUCU	-3.2	1.8	-2.6
GLSV	2.3	2.4	0.5
KIT3	0.7	8.8	3.0
MAL2	3.7	-1.9	1.2
MIKL	-0.7	-4.5	0.9
NICO	-3.1	-0.9	-3.3
POLV	-0.6	-3.4	4.6
RAMO	-2.4	-1.8	-0.4
TEHN	-3.4	-0.2	-1.9
RMS	2.8	3.7	2.5

6.6.5. Results

GEODETTIC DATUM: IGS08 EPOCH: 2012.10						
Station	CARTESIAN			GEOGRAPHIC		
	X (m)	Y (m)	Z (m)	Lat	Lon	E_h (m)
SOLA	3992081.6871	4192182.2505	2670424.0085	24°54'38.442315" N	46°24'02.051806" E	760.0284
4	3992098.3583	4192180.0555	2670406.6410	24°54'37.794854" N	46°24'01.567698" E	761.6986
999	3992346.4442	4192392.2919	2669688.8535	24°54'12.194673" N	46°24'00.381358" E	753.9790
888	3991785.9688	4192319.3100	2670639.2292	24°54'46.217956" N	46°24'13.050324" E	755.7554