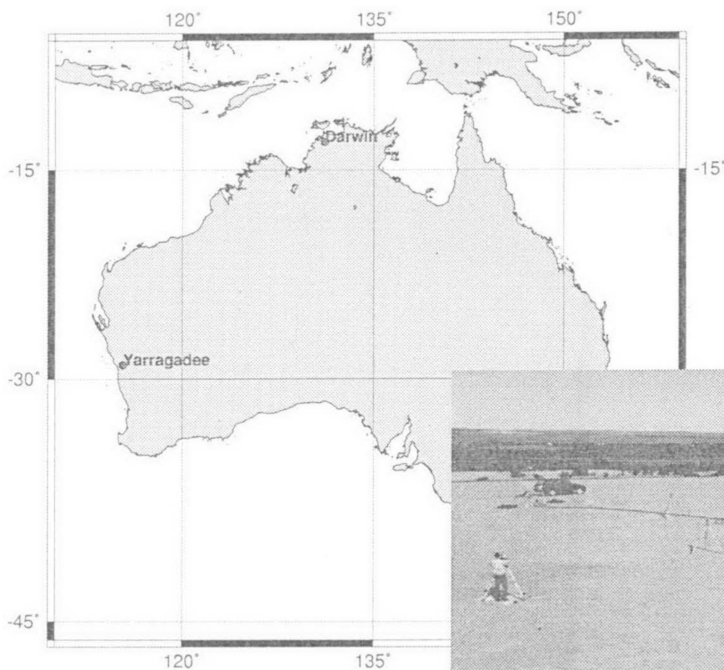
The 2003 Yarragadee (Moblas 5) Local Tie Survey

GEOSCIENCE AUSTRALIA
RECORD 2004/19

by

G. Johnston[1], J.Dawson[1]



Australian Government
Geoscience Australia

1. Geoscience Earth Monitoring Group, Geohazards Division, Geoscience Australia GPO Box 378 Canberra ACT 2601

Geoscience Australia
Chief Executive Officer: Dr Neil Williams

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Contents

Executive Summary

The combination of Space Geodetic techniques is fundamental to the definition of the International Terrestrial Reference Frame (ITRF). An integral component of this combination is the accurately measured and expressed connection between the different space geodetic techniques, commonly referred to as the local tie. Our ambition is to observe each local tie at an accuracy level of 1-2 mm.

The Yarragadee (Moblas 5) Satellite Laser Ranging (SLR) observatory, located in Western Australia, is co-located with permanent GPS, DORIS and GLONASS systems. A local tie survey at Yarragadee was completed over four days, the 24th to 27th November 2003, by specialist Geoscience Australia geodetic surveyors using precision classical geodetic observations and geodetic GPS observations. The purpose of this survey was to repeat the determination of the relationship between each of the observing techniques to the surrounding survey control. This survey also connected the new DORIS antenna position, ***YASB 50107S011***, into the existing control, along with its pillar reference point, ***YASM 50107M007***. This type of local tie survey has previously been undertaken at Yarragadee in 1992, 1999 and 2001.

The 2003 survey results are compared with those observed at Yarragadee in 1999 and 2001. The results indicate a significant movement vertically, 4 to 5 mm, at ***RM3*** and ***YAR2 50107M004*** between the 1999 survey and the 2003 survey. The motion is not present to the same extent between the 2001 and 2003 surveys, indicating the displacement took place between the 1999 and 2001 surveys.

Introduction

This report is not meant to serve as a manual for precision geodetic local tie surveys and it largely assumes that the reader has an understanding of the basic concepts of geodetic surveying. Furthermore, this report does not detail or justify the approach taken, but merely reports the results of each major computation step. However for completeness the steps in our approach for the observation and computation of local ties are as follows:

- *The calibration of all geodetic instrumentation including: total station instruments; levelling staffs; fixed height mounts; and reflectors (targets);*

- *The observation of a vertical geodetic network by application of geodetic levelling (in our case specifically EDM-Height traversing) to all survey marks in the vicinity of the observatory;*

- *The observation of a horizontal geodetic network by application of terrestrial geodetic observations, including angles and distances to all survey marks in the vicinity of the observatory;*

- *The observation of a Global Positioning System (GPS) network on suitable survey marks in the vicinity of the observatory (these marks are included in the geodetic levelling);*

- *The observation of targets located on the observing system (Satellite Laser Ranging or Very Long Baseline Interferometry instrumentation) during rotational motion about each of its independent axes. This includes zenith angle observations to a staff on a levelled survey mark in the vicinity for precise height of instrument determination;*

- *The reduction of terrestrial geodetic observations, including the correction of observations for instrument and target bias, set reduction and atmospheric effects, and includes the height of instrument determination from observations to a staff;*

- *Classical geodetic least squares (minimum constraint) adjustment of all terrestrial geodetic observations, including deflection of the vertical and geoid corrections (derived from the Australian national gravimetric geoid). This results in terrestrial only coordinate estimates and their associated variance-covariance matrix (in a local system) of the geodetic network and targets located on the SLR and/or VLBI instrumentation;*

- *Invariant Point (IVP) modelling and estimation, includes the estimation of IVP, the axes of rotation and associated system parameters such as axis orthogonality and the offset of the axes; Includes readjustment of terrestrial only network;*

- *Analysis of GPS observations. This results in GPS only coordinate estimates and associated geocentric variance-covariance matrix;*

- *Transformation (translation and rotation only) of the readjusted terrestrial network and computed IVP coordinate variance-covariance matrix into a global reference frame including a geocentric variance-covariance matrix (estimated and apriori); The previous GPS analysis is used as the global reference frame realisation; and the*

- *Reduction of the complete solution to stations of primary interest (i.e. those with DOMES) and output of a SINEX format solution file including all apriori constraints.*

1. Site Description

The Yarragadee (Moblas 5) Satellite Laser Ranging (SLR) Observatory, located in Western Australia, is co-located with permanent GPS, DORIS and GLONASS systems.

***Table 1**: List of globally important survey marks (with DOMES) at the Yarragadee SLR observatory.*

Local Designation	Global/IERS Designation
RM4	YAR2 50107M004 YARRAGADEE IGS GPS GM
AU053 (or AU53)	YARR 50107M006 YARRAGADEE GLONASS GM
DON95	7090 50107M001 YARRAGADEE SLR GM
DORIS GM	YARM 50107M005 YARRAGADEE YARB GM
DORISC	YARB 50107S010 YARRAGADEE DORIS/YARB
DORISP	YASM 50107M007 YARRAGADEE YASB PILLAR
IVP-00A-00G	YIVP 50107S007 YARRAGADEE SLR IVP
DORISN	YASB 50107S011 YARRAGADEE DORIS/YASB

A local tie survey at Yarragadee was completed on the 24th to 27th November 2003 by specialist Geoscience Australia geodetic surveyors using precision classical geodetic observations and geodetic GPS observations. The purpose of this survey was to repeat the determination of the relationship between each of the globally important station marks together with the surrounding survey control. This type of local tie survey has previously been undertaken at Yarragadee in 1992, 1999 and 2001.

The previous survey in May 2001 showed some differences from the original 1992 survey, and the 1999 survey, especially in the area of DON95 RM4 (Johnston *et al.*, 2003). This survey also connected the new DORIS antenna position into the existing control, along with its pillar reference point.

2. Instrumentation

2.1 Tacheometers, EDMI, Theodolites

2.1.1 Description

Leica TCA2003 Total Station, SN 439124.

Specification:

- EDM (infrared) distance standard deviation of a single measurement (DIN 18723, part 6): 1mm + 1ppm;
- Angular standard deviation of a mean direction measured in both faces (DIN 18723, part 3): 0.15mgon (0.49").

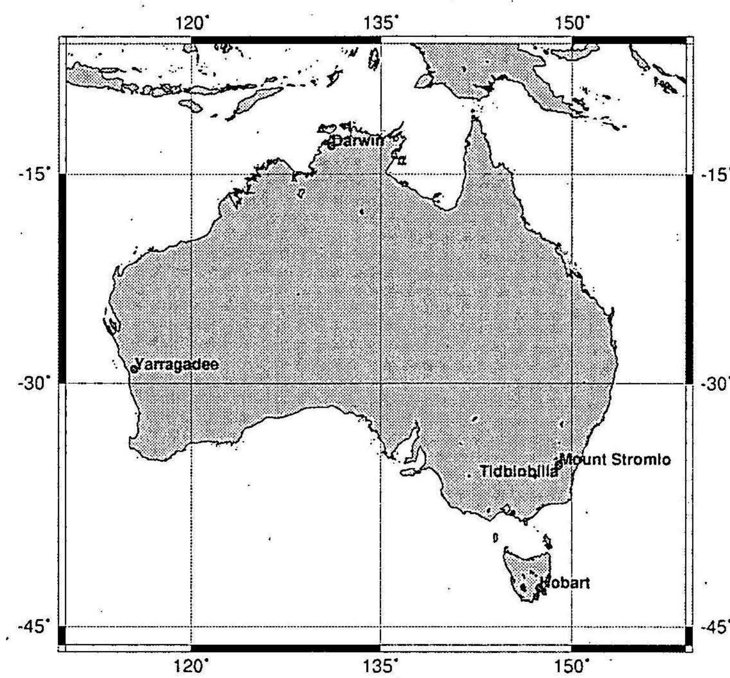


***Figure 1**: Yarragadee (Moblas 5) Satellite Laser Ranging (SLR) Observatory in Western Australia. The co-located observatory includes SLR, GPS, DORIS and GLONASS systems.*

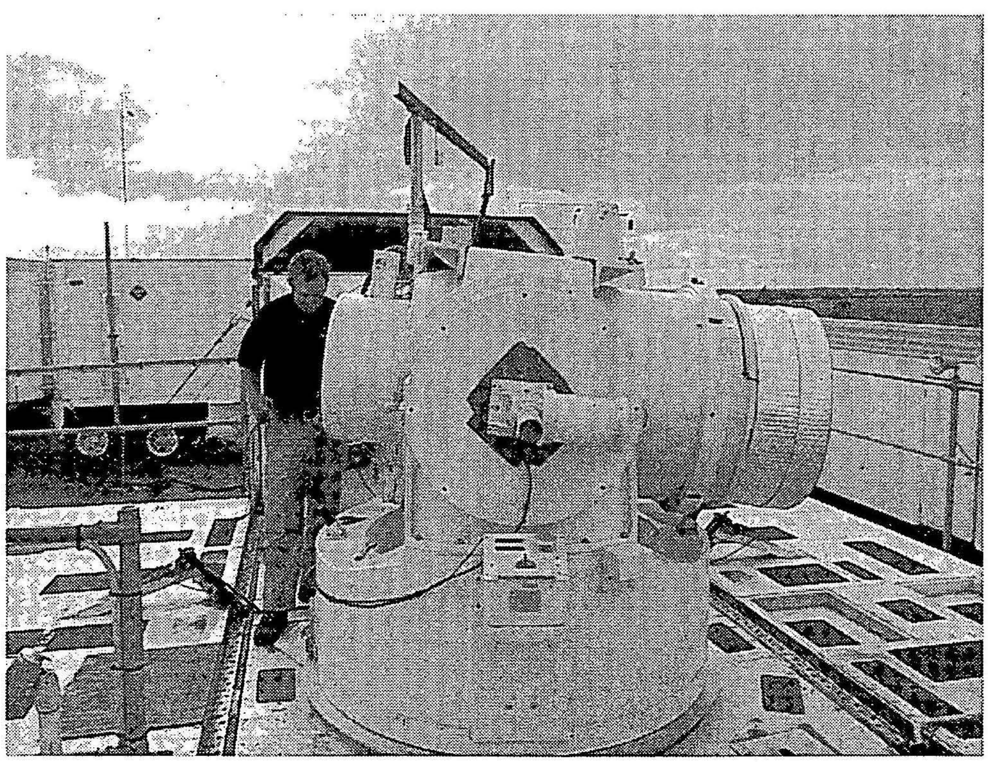


***Figure 2**: Yarragadee Satellite Laser Ranging (SLR) system.*

2.1.2 Calibration results

The Leica TCA2003 Total Station calibration was performed by Leica Geosystems AG Heerbrugg, Switzerland. Inspection date: 10th December 2001:

- EDM (Infrared) distance standard deviation: m_0 = 0.2mm (Distances from 19.5m to 501.5m). Distance linearity: ±0.3mm (Distances from 2.25m to 120m);
- Angular standard deviation horizontal: 0.09 mgon (0.29") and vertical: 0.09 mgon (0.29").

Reflector calibration:

- Additive constant for Leica GPH1P precision prism is -34.4mm which is applied directly in the total station.
- Additive constant for Leica Retro-reflective tape is 0.0mm from front face.

Staff calibration:

- Staff used for instrument heighting (refer section 4.1) compared against a calibrated invar staff by Geoscience Australia.

2.1.3 Auxiliary equipment

Meteorological observations were recorded by the Yarragadee Moblas 5 (SLR) meteorological station.

2.2 GPS Units

GPS observations were made at four monuments in the terrestrial network, namely CAL3, YAR2 (permanent IGS station), YARR (permanent IGLOS station) and AU64 (also known as AU064). The GPS analysis undertaken within the International Terrestrial Reference Frame 2000 (ITRF2000) was used to align the local terrestrial network to ITRF2000.

2.2.1 Receivers

```
+SITE/RECEIVER
*SITE PT SOLN T DATA_START__ DATA_END____ DESCRIPTION
CAL3  A ---- P 03:327:32640 03:327:86369 ASHTECH UZ-12
YAR2  A ---- P 03:327:32640 03:333:86339 AOA ICS-4000Z AC
AU64  A ---- P 03:329:37290 03:330:33149 ASHTECH UZ-12
YARR  A ---- P 03:330:35039 03:333:86339 ASHTECH Z18
-SITE/RECEIVER
```

2.2.2 Antennas

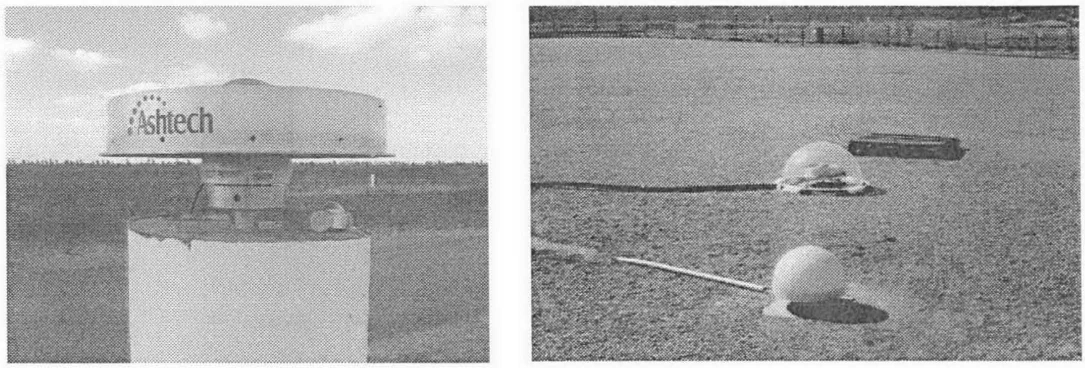


Figure 3: *Left; GPS observations at the Yarragadee SLR calibration pillar (CAL3). Right; the IGS station YAR2 (background) and the IGLOS station YARR (foreground).*

```
+SITE/ANTENNA
*SITE PT SOLN T DATA_START__ DATA_END____ DESCRIPTION
 CAL3  A ---- P 03:327:32640 03:327:86369 ASH701945C_M
 YAR2  A ---- P 03:327:32640 03:333:86339 AOAD/M_T
 AU64  A ---- P 03:329:37290 03:330:33149 ASH701945C_M
 YARR  A ---- P 03:330:35039 03:333:86339 ASH701073.1
-SITE/ANTENNA
```

Please note: the YAR2 and YARR antennas both have domes. All GPS observations were undertaken with the domes on the antenna as per normal IGS and IGLOSS operation. This may be a limiting factor in the comparison of the terrestrial and GPS determined networks.

2.2.3 Analysis software, mode of operation

Refer to section 5.2.1.

2.3 Levelling

2.3.1 Levelling instruments

Leica TCA2003 Total Station, SN 439124.

Specification :

- EDM (infrared) distance standard deviation of a single measurement (DIN 18723, part 6): 1mm + 1ppm;
- Angular standard deviation of a mean direction measured in both faces (DIN 18723, part 3): 0.15mgon (0.49").

2.3.2 Levelling Rods

Fixed height stainless steel rod approximately 1.5m in height with Leica bayonet mount on top for mounting precision prism (refer to section 4.2 for technique details).

2.3.3 Checks carried out before measurement

Multi-set (repetition), dual face observations are taken to each target eliminating collimation effects. The offset in length between the 1.5m pole and the 0.2m stub used on pillars is determined by observing both on a low mark and calculating the offset. No other pole calibration is required.

2.4 Tripods

Leica GST20/9 Heavy duty timber tripods.

2.5 Forced centering devices

Leica Zenith & Nadir Plummet S/N F.NR.272713

2.6 Targets, reflectors

Total station target kits include:

- Leica GDF21 Tribrach;
- Leica GZR3 prism carrier with optical plummet;
- Leica GPH1P precision prism.

3. Measurement Setup

3.1 Ground Network

3.1.1 Listing

The following sites are included in the ground network:

Moblas 5 IVP (YIVP): Domes 50107S007. The intersection of the azimuth axis with common perpendicular of the azimuth and elevation axes of the Yarragadee Moblas 5 Satellite Laser Ranging telescope.

AU053 (YARR): Domes 50107M006. The intersection of the top of the stainless steel plate with the vertical axis of a 5/8" ϕ Whitworth threaded stainless steel spigot. This pillar plate is set at ground level and is embedded in concrete to a depth of 400mm. The GPS – Glonass antenna currently occupies this monument.

DON95: Domes 50107M001, CDP 7090. Punch mark in a circular brass plaque 0.080m in diameter set in concrete. The plaque is inscribed "Australian Survey Office Survey Mark" and is stamped DON 95. This is the primary reference point for the Moblas 5 SLR system.

DON95 RM1: Punch Mark in brass rod 0.010m diameter set in concrete. A brass plaque stamped "RM1" is set is concrete nearby. The Latvian PSLR system (CDP 7847, Domes

50107S009) was temporarily positioned over this mark. The eccentricities to the PSLR are not available as part of this survey.

DON95 RM2: Punch Mark in brass rod 0.010m diameter set in concrete. A brass plaque stamped "RM2" is set is concrete nearby.

DON95 RM3: Punch Mark in brass rod 0.010m diameter set in concrete. A brass plaque stamped "RM3" is set is concrete nearby.

DON95 RM4 (YAR2): Domes 50107M004, AU029. Punch Mark in brass rod 0.010m diameter set in concrete. A brass plaque stamped "RM4" is set is concrete nearby. This mark constitutes the IGS GPS station otherwise known as YAR1.

DON38: Mark is a "Lands and Surveys" pre cast SSM stamped DON38.

D38E2: Mark is a "Lands and Surveys" pre cast SSM stamped DON38 Ecce 2.

DORIS GM (YARM): Domes 50107M005. Ground mark under the DORIS antenna. Mark consists of a punch mark in a brass pin set in concrete.

DORISP (YASM): Domes 50107M007. A Concrete Pillar 0.6m diameter with a stainless steel plate set in the top. The mark refers to the intersection of the top of the stainless steel plate with the vertical axis of a 5/8" diameter Whitworth threaded stainless steel spigot. The mark is also known as AU062.

DORISC (YARB): Domes 50107S010. The reference point on the DORIS Antenna (Type B) in service until the 27th November 2003. The reference point consists of the intersection of the vertical central axis of the antenna with the red painted horizontal reference line. This point is near vertical above DORIS GM.

DORISN (YASB): Domes 50107S011. The reference point on the DORIS Antenna (Type B) in service after the 27th November 2003. The reference point consists of the intersection of the vertical central axis of the antenna with the red painted horizontal reference line. This point is vertically above DORISP.

AU063: Concrete pillar protruding 0.2m above ground level with a stainless steel plate set in the top. The mark refers to the intersection of the top of the stainless steel plate with the vertical axis of a 5/8" diameter Whitworth threaded stainless steel spigot.

AU064: Concrete pillar protruding 0.2m above ground level with a stainless steel plate set in the top. The mark refers to the intersection of the top of the stainless steel plate with the vertical axis of a 5/8" diameter Whitworth threaded stainless steel spigot.

GRAV: Brass domed plaque set in the concrete floor of absolute gravity hut located adjacent to SLR system. It is used for Absolute gravity observations. The reference point is the centre punch point in the middle of the plaque.

USN_GRAV: Brass domed plaque set in the concrete floor of USN building. It is used for Absolute gravity observations. The reference point is the centre punch point in the middle of the plaque.

TBM5, TBM6, TBM-GATE, USN1. Screws driven into bitumen for temporary observation standpoints.

Calibration Pillars 2 and 3: Concrete pillars approximately 0.3m diameter. The mark refers to the intersection of the top of the stainless steel plate with the vertical axis of a 5/8" diameter Whitworth threaded stainless steel spigot. The pillars are used to mount calibration reflectors for the SLR system and are also referred to as Moblas 5 pillar2 (*CAL2*), and 3 (*CAL3*). *CALT2*, *CALT3* refer to the effective point of reflection of the permanently mounted SLR calibration reflectors.

OLD-MET: Meteorological sensor location for the DORIS system prior to the 27th November 2003.

3.1.2 Map of Network

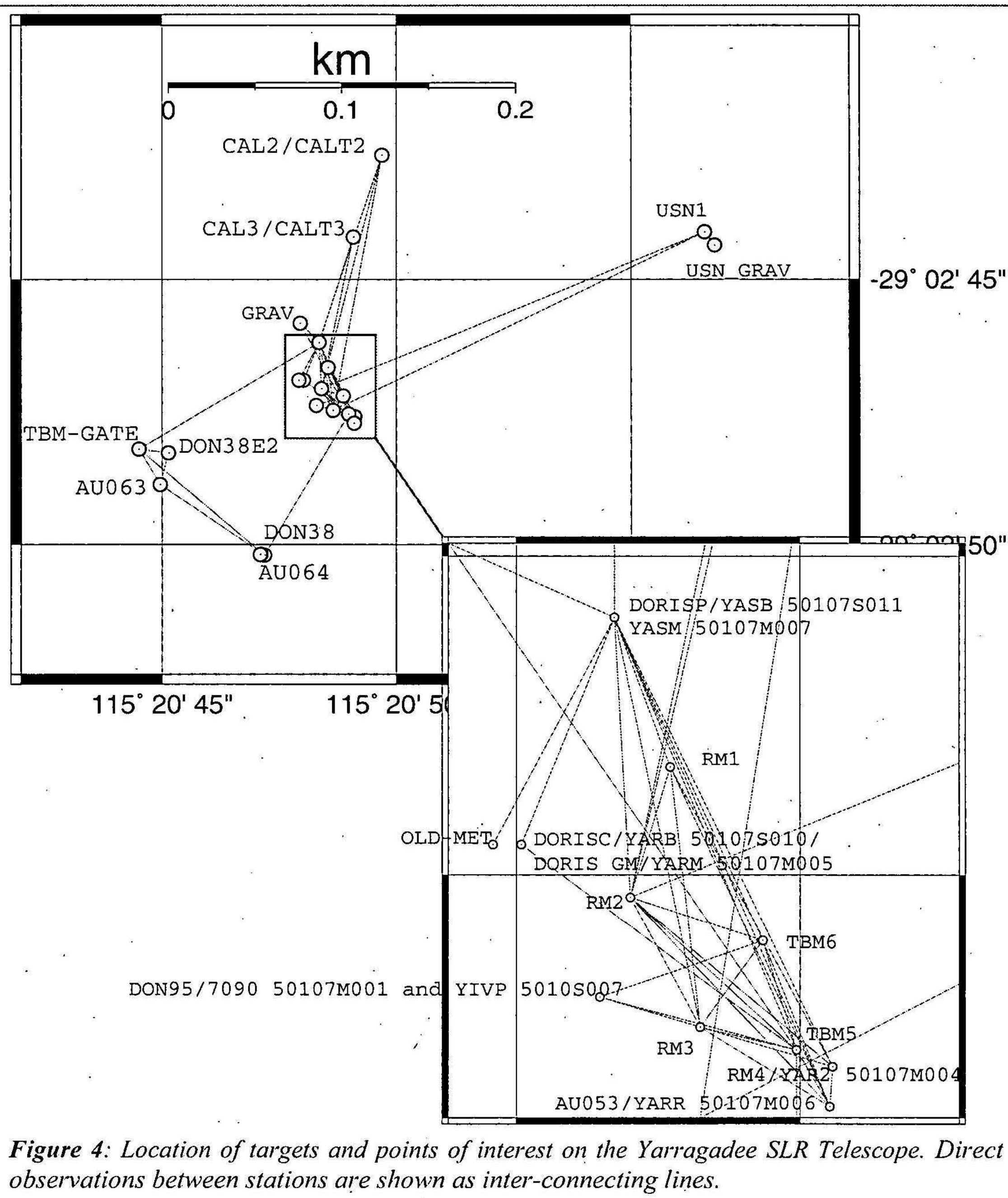


Figure 4: Location of targets and points of interest on the Yarragadee SLR Telescope. Direct observations between stations are shown as inter-connecting lines.

3.2 Representation of Reference Points

3.2.1 VLBI

No VLBI at Yarragadee.

3.2.2 SLR

The Yarragadee Satellite Laser Ranging (SLR) invariant reference point or IVP is defined as the intersection of the azimuth axis with common perpendicular of the azimuth and elevation axes. A method based on 3-dimensional circle fitting is applied as the basis for IVP determination. Three dimensional coordinate observations to targets on the SLR telescope during rotational sequences are used to determine the independent axes of rotation. Multiple realization of the elevation axis (i.e. observed at multiple azimuths) are observed and computed. A least squares method is used for the computation of the axes of rotation and the IVP. A target located on a rigid body, rotating about one independent axis can be fully expressed as a circle in 3-dimensional space. This circle can be described by seven parameters, namely the circle centre (3 parameters), a unit normal vector (3 parameters) perpendicular to the plane of the circle and a circle radius parameter (1 parameter). A constraint that the unit normal vector perpendicular to the plane of the circle must have magnitude one is required, as is a minimum of three rotational sequences to enable the solution of the equation of a circle.

The method makes the following assumptions: during rotational sequence target paths scribe a perfect circular arc in 3D space; there is no deformation of targeted structure during rotational sequence; there is no wobble error; and the axis of interest can be rotated independently of the other axis. No assumptions of axis orthogonality, verticality/horizontality or the precise intersection of the axes are made.

The indirect geometrical model includes a number of conditions, including:

- Target paths during rotation about an independent axis scribe a perfect circle in space;
- Circle centres derived from targets observed while being rotated about the same axis are forced to lie along the same line in space;
- Normal vectors to each circle plane derived from targets observed while being rotated about the same axis are forced to be parallel;
- The orthogonality (or non-orthogonality) of the elevation axis to the azimuth axis remains constant over all realisations of the elevation axis;
- Identical targets rotated about a specific realisation of an axis will scribe 3-dimensional circles of equal radius;
- The offset distance between the elevation axis and azimuth axis remains constant over all realisations of the elevation axis;
- The distance between 3-dimensional circle centres for all realizations of the elevation axis are constant over all realisations of the elevation axis; and
- The IVP coordinate estimates remain constant over all realisations (combinations) of the azimuth/elevation axis;

Because the 3-dimensional circle (described by seven parameters) includes a normal vector to the circle plane, the following constraint is also applied;

- The unit normal vector perpendicular to the circle plane is of magnitude one;

The linearized equations take the form of two sets of equations, namely conditions and constraints with added parameters

$$Av + B\Delta = f$$
$$D_1\Delta + D_2\Delta' = h$$

where v is the parameter vector of residuals of the input classical adjustment results, Δ is the parameter vector of the circle parameters, Δ' is the parameter vector of the parameters associated with the IVP estimates, f and h are the constant vectors associated with the evaluation of the conditions and constraints respectively and A, B, D_1 and D_2 are matrixes of coefficients. The least squares solution is obtained from the following system of normal equations

$$\begin{bmatrix} -W & A^t & 0 & 0 & 0 \\ A & 0 & B & 0 & 0 \\ 0 & B^t & 0 & D_1^t & 0 \\ 0 & 0 & D_1 & 0 & D_2 \\ 0 & 0 & 0 & D_2^t & 0 \end{bmatrix} \begin{bmatrix} v \\ k \\ \Delta \\ k_c \\ \Delta' \end{bmatrix} = \begin{bmatrix} 0 \\ f \\ 0 \\ h \\ 0 \end{bmatrix}$$

where W is the weight matrix of the input coordinates derived from the classical adjustment and k and k_c are vectors of Lagrange multipliers required to satisfy the Least Squares criteria.

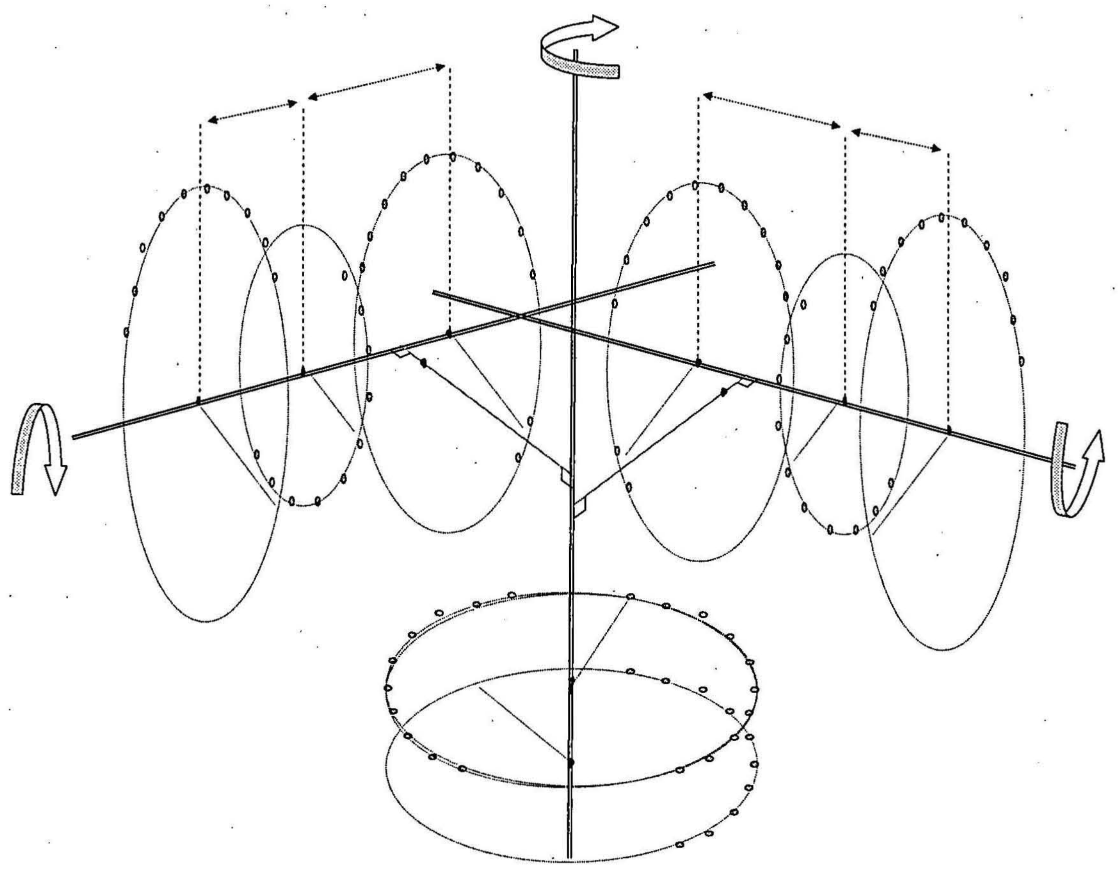


***Figure 5**: IVP model. Circle centres derived from targets observed while being rotated about the same axis are forced to lie along the same line in space; Normal vectors to the circle plane derived from targets observed while being rotated about the same axis are forced to be parallel; Note that to simplify the diagram only two targets are shown on the azimuth axis and three targets are shown on the elevation axis. The two realisations of the elevation axis allow for the constraint of the circle radius parameters, as can the inter-circle centre distances. The angle between the elevation and azimuth axis (i.e. axis orthogonality) should be constant over all realisations of the elevation axis. The IVP estimate should be constant over all realisations of elevation/azimuth axis combinations.*

The solution to the normal equation system is iterated as required for the non-linear condition and constraint equations. An updated estimate of the input coordinates and their variance-covariance matrix is obtained together with an estimate of the IVP coordinate their variance-covariance matrix and the inter-relating covariance matrix.

***Table 2**: Yarragadee 2003 survey IVP determination observations*

Axis	Number of targets	Description/Comment
Azimuth	3	*Elevation axis fixed at 90° from zenith;* *Azimuth axis rotated in 20° increments;* *Azimuth axis can rotate through 360°;* *System was observed from two standpoints, namely YASM A 50107M007 and YAR2 A 50107M004;* *Targets were Leica precision prisms force centred directly onto the top of the telescope.*
Elevation 1st realization	7	*Elevation axis rotated in 10° increments;* *Azimuth axis fixed at bearing 342°;* *Elevation axis can rotate through 185°;* *Elevation axis realized from observations from the DORIS pillar, YASM A 50107M007;* *Targets were retro-reflective tape.*
Elevation 2nd realization	7	*Elevation axis rotated in 10° increments;* *Azimuth axis fixed at bearing 88°;* *Elevation axis can rotate through 185° ;* *Elevation axis realized from observations from a tripod setup over the permanent GPS mark, YAR2 A 50107M004;* *Targets were retro-reflective tape.*

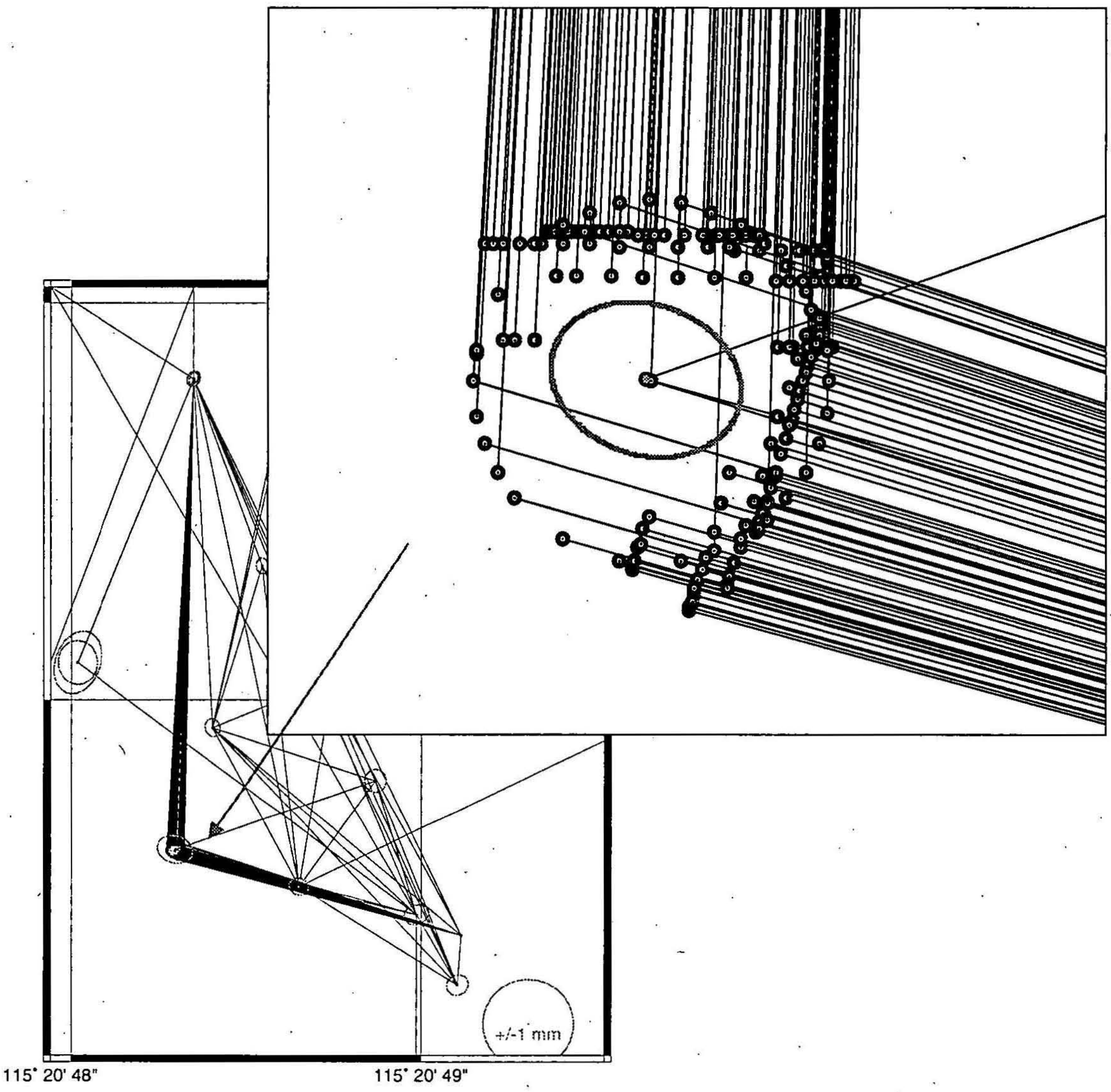


***Figure 6**: Yarragadee Pure Terrestrial Network, error ellipses are 95% confidence. Error ellipses to targets on the Satellite Laser Ranging (SLR) system during rotational sequences are not shown. Direct observations between stations are shown as inter-connecting lines. Inset is close up of observations to SLR system during rotational sequences; observations to determine azimuth axis as seen clearly as a circle of targets, while observations to determine the elevation axis (2 realisations) are seen as straight lines of targets; the target in the centre of the inset is the primary SLR ground mark, DON95 or 7090 A 50107M001 beneath the telescope system.*

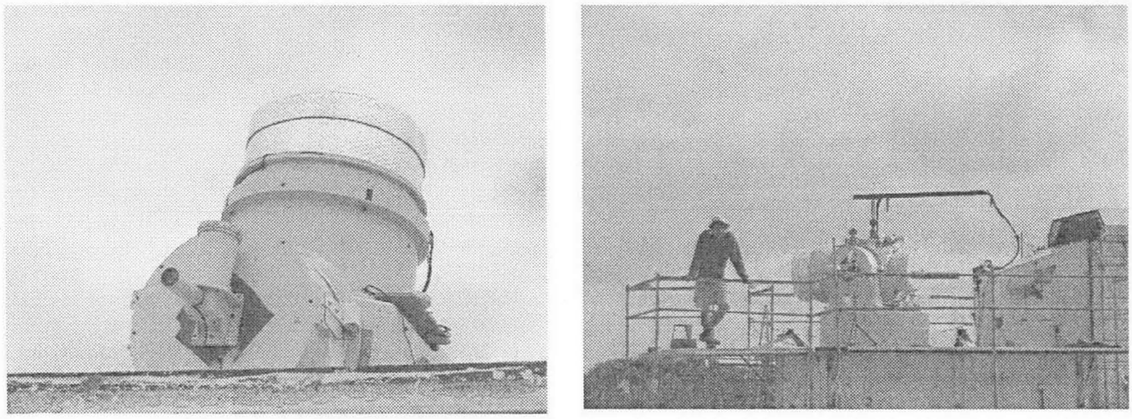


***Figure** 7: Yarragadee SLR telescope.*

3.2.3 GPS

In the case of Yarragadee the GPS antenna is removed during the survey and the monument is observed directly.

3.3.4 DORIS

The position of the DORIS antenna was determined indirectly by observation to the sides of the antenna at the physical red marker line. Observations are reduced by averaging and then intersected in the geodetic adjustment in the conventional manner.

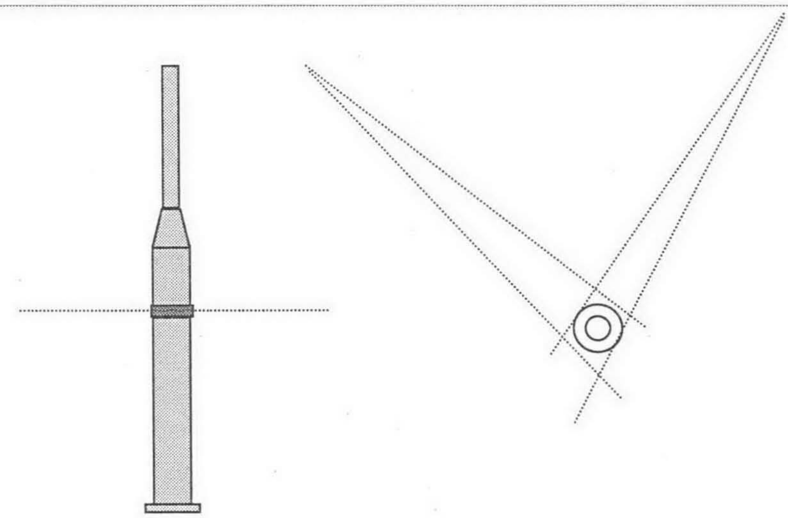


***Figure** 8: Horizontal view (left); and plan view (right) of a DORIS antenna reference point (centre of antenna at red mark line).*

3.3.5 GLONASS

In the case of Yarragadee the GLONASS antenna is removed during the survey and the monument is observed directly.

4. Observations

4.1 Conventional survey

The Figure 4 network diagram illustrates the network observed. At every standpoint (with the exception of DORISP) a tripod was set up over the monument using the Zenith Nadir Plummet. Observations from DORISP were performed with the tribrach mounted directly onto the spigot.

Generally five sets of observations were completed at each standpoint. A set consists of a round of face left observations, followed by the reverse round of face right observations. Slope distances and zenith angles were recorded for each observation as well. Atmospheric corrections were not applied in the instrument, but later applied to distances in post processing using conventional correction formulae and local meteorological observations.

The heights of instrument were observed using the technique illustrated in Figure 10. Vertical angles are observed to graduation boundaries on a normal levelling staff. This technique routinely returns values for height of instrument accurate to 0.1mm. The technique is strongest when the mid height of the levelling staff is approximately horizontal from the instrument trunion axis. The technique relies on the height difference between the ground marks (H_1 and H_2) being determined independently to these observations. In the case of this survey the monuments were included in the levelling survey discussed in 4.2.

Observations into the SLR telescope for the indirect determination of the IVP were performed from two standpoints. For the determination of the azimuth axis three targets were placed on the top of the telecope trunion as illustrated in Figure 9. The three targets were observed as detailed in section 3.2.

For the elevation axis retro-reflective tape targets were placed on the SLR brake ring, which provided a flat surface. The telescope was then positioned near to orthogonal to the line of sight from RM4. Observations were undertaken as described in section 3.2. The telescope was then moved to be near to orthogonal to the line of sight from DORISP. The observation sequence was then repeated.

Observations to the targets during these rotational sequences consisted of a single set of dual face pointings, commencing and terminating on an external reference object (network station) for orientation.

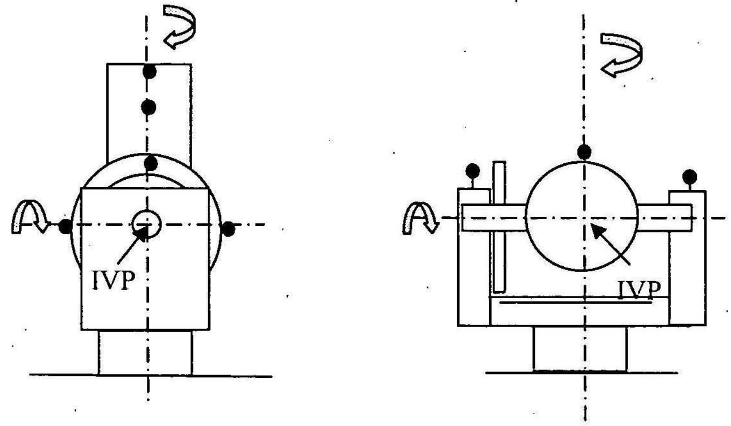
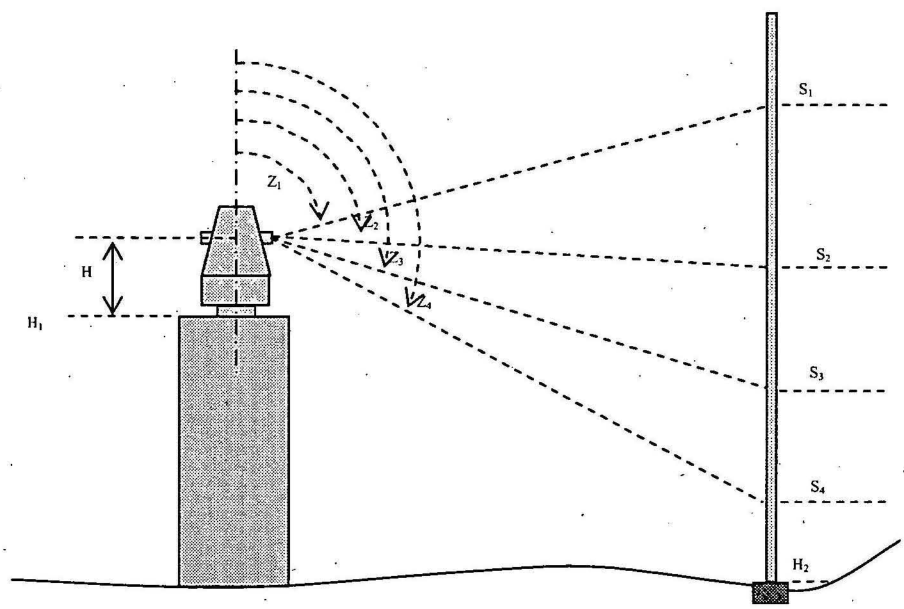


***Figure 9**: Location of targets (indicative only) and points of interest on the Yarragadee SLR Telescope. Left elevation axis determination targets. Right azimuth determination targets.*



$$H = \frac{S_2 \cot Z_1 - S_1 \cot Z_2}{\cot Z_1 - \cot Z_2} - (H_1 - H_2)$$

***Figure 10:** Total station instrument heighting technique, where S_n are staff readings; Z_n are zenith angles (Rueger & Brunner, 1981).*

4.2 Levelling

The levelling for this survey was carried out using the EDM-height traversing technique. It comprises height difference observations to a prism mounted on a fixed height prism pole, which is braced by a bi-pole and placed over the survey mark. Differential heighting can then be achieved. This technique minimises thermal expansion effects and refraction caused by thermal flux since the lines of sight are near to parallel along the ground surface.

Where pillar monuments are used a fixed height prism mounting stub (approximately 0.2m in length) which screws directly onto the 5/8" ϕ Whitworth threaded stainless steel spigot is used.

Figure 11: *Yarragadee levelling; fixed height prism pole braced by a bi-pole used for EDM-height traversing technique.*

Levelling loops covering all the monuments in the network were completed in both directions. The results were then adjusted in the least squares sense giving adjusted height differences between all marks.

4.3 *GPS*

```
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 YAR2  A     1 P 03:327:32640 03:333:86339 03:330:59489
 AU64  A     1 P 03:329:37290 03:330:33149 03:329:78420
 YARR  A     1 P 03:330:35039 03:333:86339 03:332:17489
-SOLUTION/EPOCHS
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4.4 General comments

None.

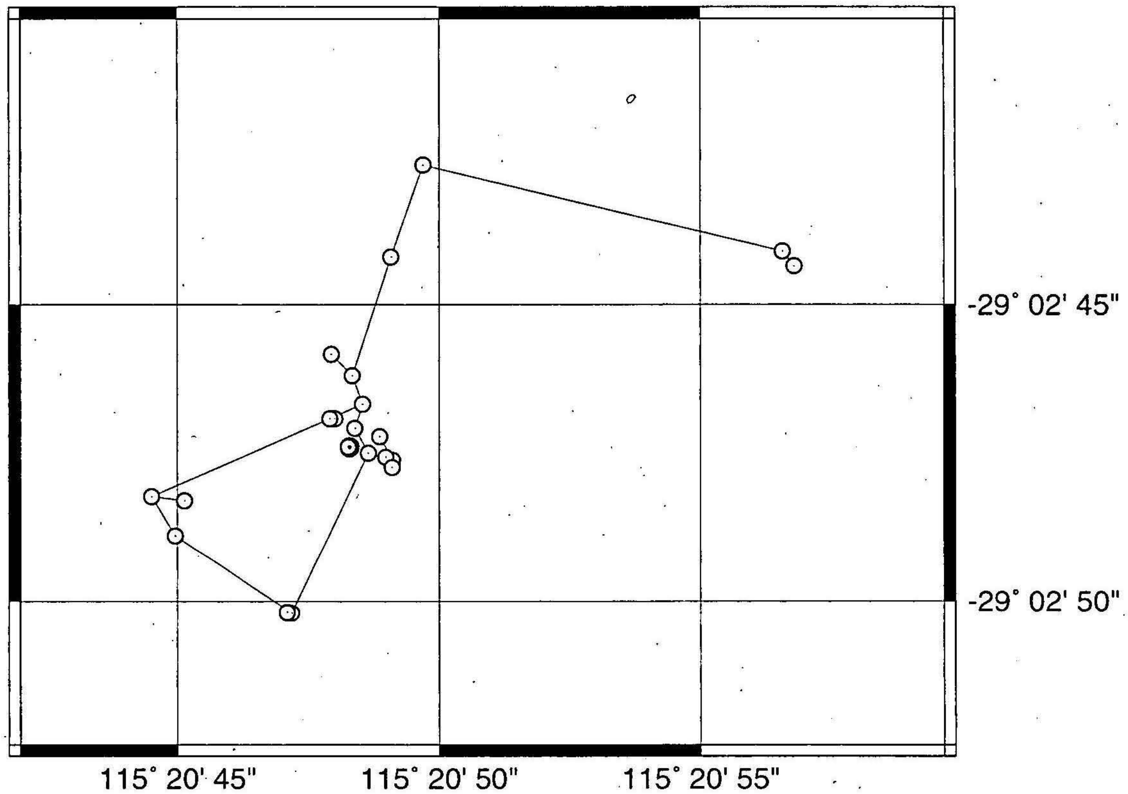

***Figure 12**: Yarragadee survey levelling observations. Direct observations between stations are shown as inter-connecting lines.*

5. Data Analysis and Results

The flow chart of the analysis process used for the 2003 Yarragadee survey is detailed in Figure 13. Coordinate solutions are generated in three steps; firstly at the completion of the classical geodetic adjustment (*Step A*); secondly at the completion of the geometrical modelling where the impact of the geometrical model is propagated throughout the input classical adjustment results (*Step B*); and thirdly after transformation (*rotation and translation*) of the 'geometrically modified' solution onto the required global reference frame (*Step C*). In this report the results of *Step A* are reported in section 5.1.2 and 5.1.3; and the results from *Step C* are reported in section 5.2.2, the results from *Step B* are not reported.

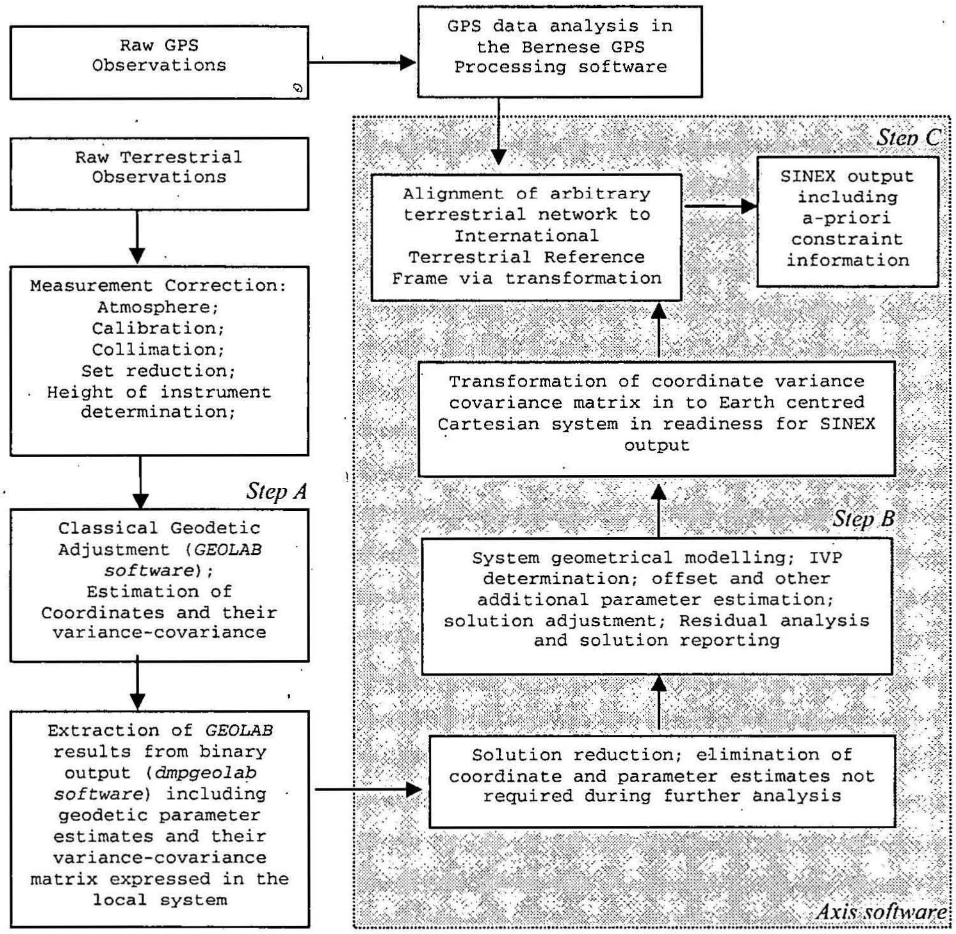

***Figure 13**: Analysis process for the reduction of local survey data.*

5.1 Terrestrial Survey

5.1.1 Analysis Software

Classical geodetic adjustment is undertaken in *GEOLAB* version 2.4d. Deflections of the vertical and geoid undulation corrections were applied using ***AUSGEOID98*** (Johnston & Featherstone, 1998). Extraction of the solution data, including a full variance-covariance matrix, from the propriety binary GEOLAB format into ASCII format is undertaken using the Geoscience Australia developed *dmpgeolab* software (version 0.00). The geometrical modelling, adjustment and transformation processes are undertaken in the Geoscience Australia developed *axis* software (version 1.01).

5.1.2 Topocentric coordinates and covariances

Geodetic coordinates (GRS80 Ellipsoid) provided in the arbitrary local terrestrial system before alignment to the ITRF2000 are given below:

***Table 3**: Yarragadee 2003 terrestrial survey results. GRS80 ellipsoid. Heights are ellipsoidal.*

STATION			LONGITUDE			LATITUDE			HEIGHT (m)
RM1	A	---------	115	20	48.54394	-29	-2	-46.66198	241.0240
RM2	A	---------	115	20	48.40321	-29	-2	-47.07034	241.1932
RM3	A	---------	115	20	48.64975	-29	-2	-47.47551	241.3343
YAR2	A	50107M004	115	20	49.11507	-29	-2	-47.59937	241.2833
CAL2	A	CAL2-----	115	20	49.69350	-29	-2	-42.65514	241.1701
CAT2	A	CALT2----	115	20	49.69401	-29	-2	-42.65410	241.2436
CAL3	A	CAL3-----	115	20	49.08885	-29	-2	-44.19752	242.0241
CAT3	A	CALT3----	115	20	49.08922	-29	-2	-44.19660	242.0952
GRAV	A	---------	115	20	47.94581	-29	-2	-45.83036	240.7497
TBM5	A	---------	115	20	48.98697	-29	-2	-47.54679	241.2710
TBM6	A	---------	115	20	48.86915	-29	-2	-47.20471	241.1663
USN1	A	---------	115	20	56.57365	-29	-2	-44.09985	242.0141
YARR	A	50107M006	115	20	49.10445	-29	-2	-47.72520	241.3601
AU63	A	AU063----	115	20	44.95939	-29	-2	-48.87042	241.2531
AU64	A	AU064----	115	20	47.18702	-29	-2	-50.19992	242.6767
D38E	A	D38E2----	115	20	45.14064	-29	-2	-48.27903	241.2862
DO38	A	DON38----	115	20	47.10120	-29	-2	-50.18311	242.7998
7090	A	50107M001	115	20	48.29603	-29	-2	-47.38144	241.3263
YARB	A	50107S010	115	20	48.01795	-29	-2	-46.90536	243.6203
YASB	A	50107S011	115	20	48.34786	-29	-2	-46.19196	243.0415
YASM	A	50107M007	115	20	48.34786	-29	-2	-46.19196	242.3085
YARM	A	50107M005	115	20	48.01784	-29	-2	-46.90543	241.1582
USNG	A	USN-GRAV-	115	20	56.78793	-29	-2	-44.35818	242.4481

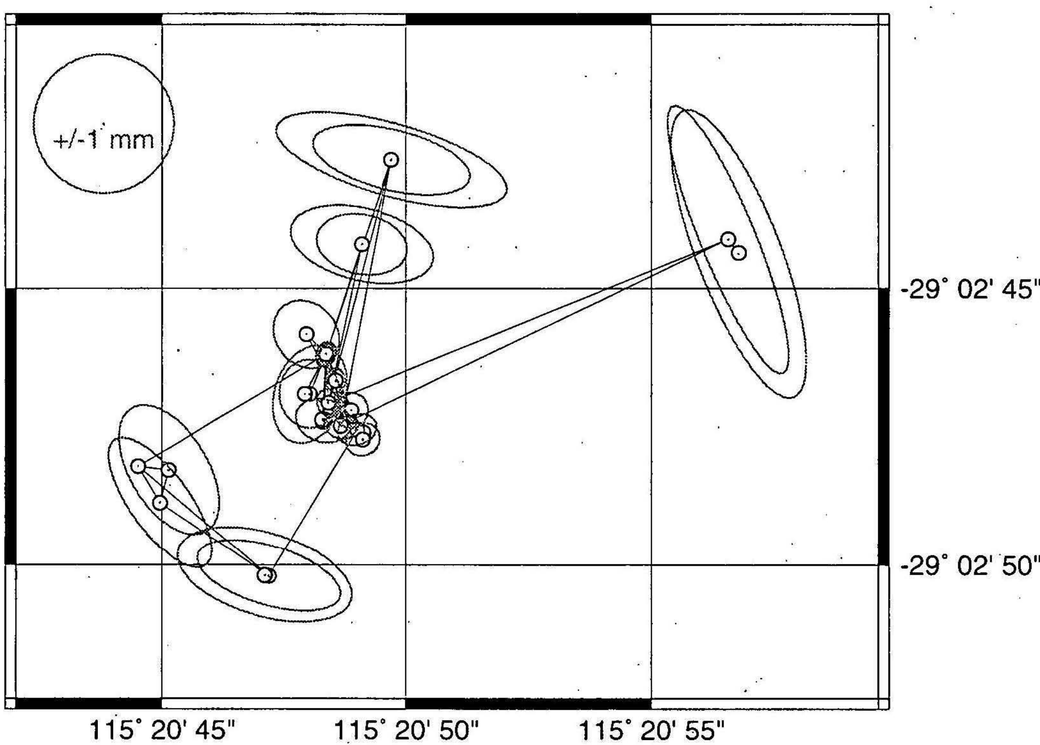

***Figure 14**: Yarragadee terrestrial network, error ellipses are 95% confidence. Direct observations between stations are shown as inter-connecting lines.*

5.1.3 Correlation matrix

The computed correlation matrix is too large to be included in this report, please refer to the SINEX file (see section 5.5) for further information of this type..

5.1.4 Reference temperature

No thermal corrections have been applied for structural expansion of the SLR instrument. Since the structure is small thermal deformation is ignored.

5.2 GPS

5.2.1 Analysis software

The GPS data analysis was undertaken using the Bernese GPS Processing Software Version 4.2 (Hubentobler U., S. Schaer, P. Fridez, Bernese GPS Software Version 4.2, *Astronomical Institute, University of Berne, 2001).* International Terrestrial Reference Frame 2000 (ITRF2000) coordinates of the permanent GPS monument, ***YAR2 50107M004***, were adopted at the epoch of observation. Both L1 and L2 observations were used and no troposphere model parameters were estimated. The observations were processed to a 10° cut-off. Carrier phase ambiguities were resolved to their integer values in all cases. Final International GPS Service (IGS) orbits and Earth orientation parameters were used for computations. IGS recommended constant and elevation dependent antenna phase models were applied.

5.2.2 Results

Table 4*: Yarragadee 2003 GPS survey results, GRS80 ellipsoid. Heights are ellipsoidal.*

STATION			LONGITUDE			LATITUDE			HEIGHT (M)
CAL3	A	---------	115	20	49.08884	-29	-2	-44.19752	242.0285
YAR2	A	50107M004	115	20	49.11507	-29	-2	-47.59937	241.2833
AU64	A	---------	115	20	47.18690	-29	-2	-50.19992	242.6691
YARR	A	50107M006	115	20	49.10445	-29	-2	-47.72519	241.3569

5.3 Additional Parameters

Additional system parameters were computed during the IVP estimation process. The azimuth axis deflection from the vertical was estimated as 55.37" at an azimuth of 99° 57' 22.69". The orthogonality (or non-orthogonality) of the azimuth to the elevation axes was estimated to be 90° 00' 4.5". The offset distance between the azimuth and elevation axis was estimated to be 0.2 mm.

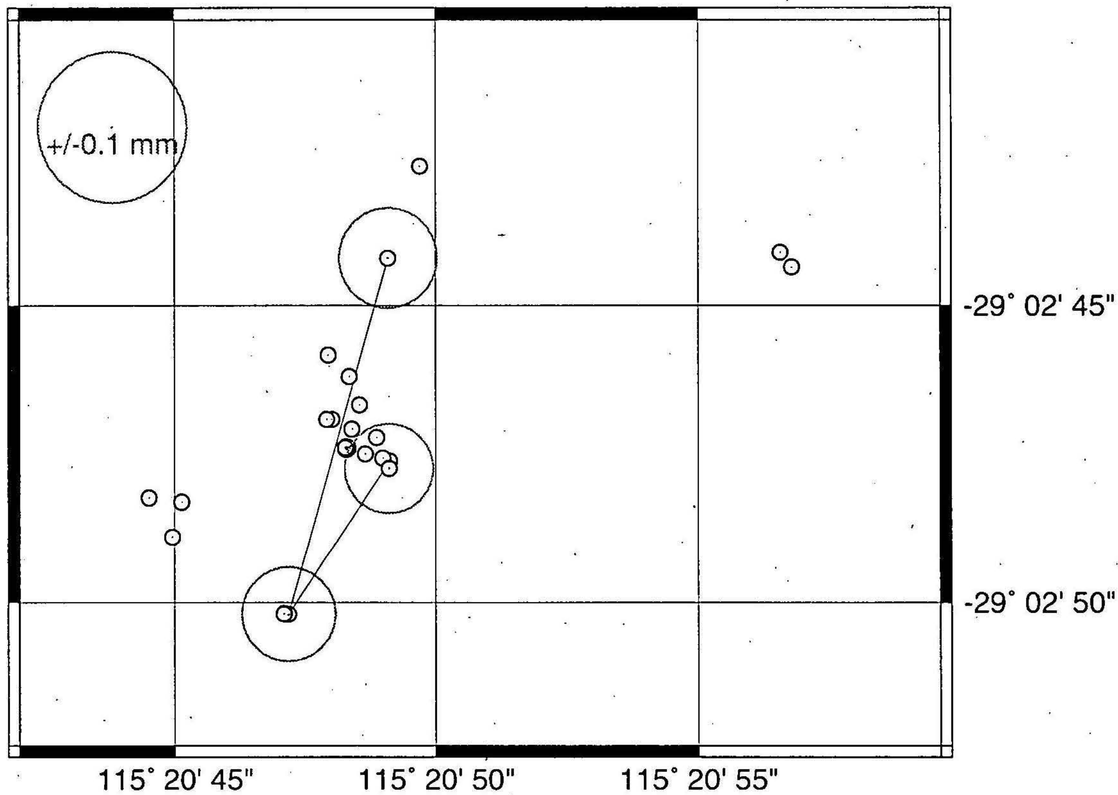

***Figure 15**: Yarragadee GPS Network, error ellipses are 95% confidence. GPS baselines are shown as inter-connecting lines.*

***Table 5:** Yarragadee 2003, final results, topocentric vectors between SLR IVP (from YIVP 50107S007) and permanently mounted CALT2 and CALT3 reflectors.*

	EAST (M)	NORTH (M)	UP (M)	RANGE (M)
CALT2	-37.8065	-145.5579	3.2670	150.4231
CALT3	-21.4428	-98.0662	2.4139	100.4121

5.4 Transformation

The arbitrary terrestrial network is aligned to the International Terrestrial Reference Frame by means of a six parameter transformation, namely three translations and three rotations. This ensures that the scale of the network as realised through the calibrated total station distance measurements is adopted in the final solution.

Table 6: *Yarragadee 2003, local to ITRF2000 alignment results.*

FRAME : GLOBAL (OR REFERENCE SET)
ALIGNMENT STATIONS : CARTESIAN COORDINATES - EARTH CENTRE ORIGIN

SITE	X(M)	Y(M)	Z(M)
CP3	-2389047.2673	5043363.7637	-3078439.1810
RM4	-2389025.8599	5043316.9140	-3078530.3859
AU064	-2388962.5911	5043305.2083	-3078601.0564
AU053	-2389024.8224	5043315.3954	-3078533.8083

FRAME : ARBITRARY
SOLUTION STATIONS : CARTESIAN COORDINATES - EARTH CENTRE ORIGIN

SITE	X(M)	Y(M)	Z(M)
CP3	-2389047.2684	5043363.7651	-3078439.1821
RM4	-2389025.8598	5043316.9140	-3078530.3859
AU053	-2389024.8236	5043315.3976	-3078533.8100
AU064	-2388962.5940	5043305.2073	-3078601.0568

ALIGNMENT RESIDUALS

	UNTRANSFORMED-REFERENCE			TRANSFORMED-REFERENCE		
SITE	X(M)	Y(M)	Z(M)	X(M)	Y(M)	Z(M)
CP3	-0.0011	0.0014	-0.0011	0.0006	0.0003	0.0001
RM4	0.0001	0.0000	-0.0000	-0.0015	0.0008	-0.0007
AU053	-0.0012	0.0022	-0.0017	-0.0002	-0.0015	0.0010
AU064	-0.0029	-0.0010	-0.0004	0.0012	0.0004	-0.0004

	UNTRANSFORMED-REFERENCE			TRANSFORMED-REFERENCE		
SITE	EAST(M)	NORTH(M)	UP(M)	EAST(M)	NORTH(M)	UP(M)
CP3	0.0004	-0.0001	0.0020	-0.0007	0.0001	-0.0000
RM4	-0.0001	-0.0000	-0.0000	0.0010	0.0000	0.0015
AU053	0.0001	-0.0003	0.0030	0.0009	0.0003	-0.0015
AU064	0.0031	-0.0002	0.0005	-0.0012	-0.0004	0.0000

TRANSFORMATION PARAMETERS: ARBITRARY TO GLOBAL (OR REFERENCE SET)

CARTESIAN SYSTEM : CENTROID ORIGIN

VARIANCE FACTOR : 3.22633e-07
SIGMA : 5.68008e-04

TX	TY	TZ	RX	RY	RZ
M	M	M	AS	AS	AS
-0.0011	0.0006	-0.0009	1.30	-0.50	3.19

RESIDUAL SCALE BIAS 8.0 PPM

5.5 Description of SINEX generation

The SINEX naming convention adopted by Geoscience Australia for local survey data is:

XXXNNNNYYMMFV.SNX

where

XXX is a three character organisation designation;
NNNN is a four character site designation;
YY is the year of survey;
MM is the month of survey,;
F is the frame code (G for global frame; L for local frame); and
V is the file version.

The SINEX file corresponding to this report is ***AUSYARR0311GA.SNX***, and can be found at ftp://ftp.ga.gov.au/sgac/sinex/ties/. This file supersedes the SINEX file aus00c04.snx submitted to the International Earth Rotation Service (IERS) in 1999 for the ITRF2000 computation.

5.6 Discussion of results

Table 7: *Yarragadee 2003, final results, geodetic coordinates, GRS80 ellipsoid (degrees, minutes, seconds, metres), ITRF2000 at date of survey.*

STATION			LONGITUDE			LATITUDE			HEIGHT (M)
YAR2	A	50107M004	115	20	49.11503	-29	-2	-47.59937	241.2818
YARR	A	50107M006	115	20	49.10441	-29	-2	-47.72520	241.3584
7090	A	50107M001	115	20	48.29600	-29	-2	-47.38143	241.3239
YARB	A	50107S010	115	20	48.01792	-29	-2	-46.90535	243.6187
YASB	A	50107S011	115	20	48.34784	-29	-2	-46.19196	243.0419
YASM	A	50107M007	115	20	48.34784	-29	-2	-46.19195	242.3089
YARM	A	50107M005	115	20	48.01781	-29	-2	-46.90541	241.1571
YIVP	A	50107S007	115	20	48.29667	-29	-2	-47.38170	244.5059

Table 8: *Yarragadee 2003, final precision estimates of the geodetic coordinates (1σ, metres).*

STATION			LONGITUDE (M)	LATITUDE (M)	HEIGHT (M)
YAR2	A	50107M004	0.0001	0.0001	0.0001
YARR	A	50107M006	0.0003	0.0002	0.0001
7090	A	50107M001	0.0004	0.0003	0.0003
YARB	A	50107S010	0.0004	0.0005	0.0004
YASB	A	50107S011	0.0001	0.0002	0.0002
YASM	A	50107M007	0.0001	0.0001	0.0002
YARM	A	50107M005	0.0005	0.0007	0.0005
YIVP	A	50107S007	0.0001	0.0002	0.0002

Table 9: *Yarragadee 2003, final results, cartesian coordinates (metres), ITRF2000 at date of survey.*

STATION	X (M)	Y (M)	Z (M)
YAR2 A 50107M004	-2389025.8584	5043316.9132	-3078530.3852
YARR A 50107M006	-2389024.8222	5043315.3969	-3078533.8093
7090 A 50107M001	-2389007.2435	5043329.3782	-3078524.5400
YARB A 50107S010	-2389004.3497	5043340.8434	-3078512.8398
YASB A 50107S011	-2389016.7654	5043346.2031	-3078493.3567
YASM A 50107M007	-2389016.4911	5043345.6240	-3078493.0009
YARM A 50107M005	-2389003.4253	5043338.8993	-3078511.6465
YIVP A 50107S007	-2389008.4493	5043331.8808	-3078526.0923

Table 10: *Yarragadee 2003, final precision estimates of the cartesian coordinates (1σ, metres).*

STATION	X (M)	Y (M)	Z (M)
YAR2 A 50107M004	0.0001	0.0001	0.0001
YARR A 50107M006	0.0002	0.0002	0.0002
7090 A 50107M001	0.0004	0.0004	0.0003
YARB A 50107S010	0.0004	0.0004	0.0005
YASB A 50107S011	0.0002	0.0002	0.0002
YASM A 50107M007	0.0001	0.0001	0.0001
YARM A 50107M005	0.0006	0.0005	0.0007
YIVP A 50107S007	0.0001	0.0002	0.0002

Table 11: *Yarragadee 2003, final results, cartesian difference vectors (metres).*

FROM STATION	TO STATION	X(M)	Y(M)	Z(M)
YIVP 50107S007	- YAR2 50107M004	-17.4091	-14.9676	-4.2929
YIVP 50107S007	- YARR 50107M006	-16.3729	-16.4839	-7.7170
YIVP 50107S007	- 7090 50107M001	1.2058	-2.5026	1.5522
YIVP 50107S007	- YARB 50107S010	4.0995	8.9626	13.2525
YIVP 50107S007	- YASB 50107S011	-8.3161	14.3223	32.7355
YIVP 50107S007	- YASM 50107M007	-8.0418	13.7432	33.0914
YIVP 50107S007	- YARM 50107M005	5.0239	7.0185	14.4458

The least squares solution of the SLR IVP position included; 20 targets; 2 IVP estimates (constrained together); 801 pseudo-observations; 140 unknowns; 33 additional unknowns; 518 conditions; 36 constraints and 103 additional constraints. The resultant linear system was 1631 x 1631 with degrees of freedom 1285. The computed variance factor was 0.11437. IVP model (circle) fit residuals were 0.7 mm Root Mean Square Error (RMS) for the in-plane residuals and 0.5 mm for the out-of-plane residuals.

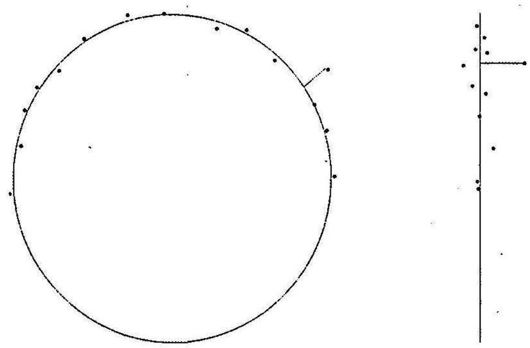

***Figure 16**: Circle fitting residuals; left in-plane residuals; Right out-of-plane residuals.*

The Root Mean Square Error (RMS) of the terrestrial coordinate observations to the IVP model were 0.3, 0.2 and 0.2 millimetres in the east, north and up components respectively. The Root Mean Square Error (RMS) of the terrestrial only coordinate network transformed (3 rotations and 3 shifts) was 1.0, 0.3 and 1.1 millimetres in the east, north and up components respectively. Thus, all indications are that this survey is approaching the 1 millimetre level accuracy, although antenna specific GPS antenna phase centre variations remain un-modelled in this analysis.

5.7 Comparison with previous surveys

The 2003 survey results are compared with those observed Yarragadee in 1999 and 2001, see tables below. The results indicate a significant movement vertically at RM3 and YAR2 between the 1999 survey and the 2003 survey. The motion is not present to the same extent between the 2001 and 2003 surveys, indicating the displacement took place between the 1999 and 2001 surveys. This time period corresponds to when a trench was dug adjacent to RM3 and YAR2 to bury the GPS antenna cable to YAR2. These earthworks may have disturbed the position of these two marks.

***Table 12**: Shows the residuals between the 2001 survey transformed onto the 2003 survey.*

Site	NORTH (mm)	EAST (mm)	UP (mm)
CAL2	1.2	0.4	0.7
CAL3	-0.6	2.2	2.2
RM1	1.1	-0.4	-0.7
RM2	1.0	-1.2	-0.2
RM3	-0.4	-0.2	0.2
YAR2 50107M004(RM4)	1.0	0.1	0.9
GRAV	0.7	-0.4	-0.6
TBM6	0.1	-0.8	0.4
YARR 50107M006(AU053)	-0.0	-0.1	0.4
DON38	-2.9	0.0	2.4
7090 50107M001	-0.8	-0.4	-1.0
YARB 50107S010	-1.4	0.8	0.4
YARM 50107M005	-0.4	-0.2	-4.6
RMS	**1.2**	**0.8**	**1.8**

***Table 13**: Shows the residuals between the 1999 survey transformed onto the 2003 survey.*

Site	NORTH (mm)	EAST (mm)	UP (mm)
CAL2	0.2	0.5	-4.9
CAL3	-1.9	1.2	-1.8
RM1	1.0	-0.2	-0.3
RM2	1.0	-1.6	-0.1
RM3	1.9	-3.4	5.2
YAR2 50107M004(RM4)	-0.2	1.3	4.5
GRAV	-1.1	0.6	2.4
TBM6	-2.4	1.6	-2.2
YARR 50107M006(AU053)	0.4	-0.4	-2.7
DON38	1.1	0.4	-0.1
RMS	**1.4**	**1.5**	**3.2**

6. Planning Aspects

The terrestrial network at Yarragadee is highly over determined. However several very significant monuments are difficult to survey accurately. DON95 is the primary ground reference mark for the MOBLAS 5 SLR system. However, it is physically located under the SLR system in a confined space, which prohibits the use of a tripod and target kit. Its location also heavily restricts the geometry of the observations into it. A special forced centred fixed height prism mount has been constructed for observing to this point. The height of this mount needs to be calibrated in the same manner as the pillar stub discussed in section 2.3.3.

The accuracy of observations taken to retro-reflective tape is highly dependant on the angle of incidence of the observing ray. Future surveys will use magnetic mounted corner cube reflectors, which maintain their accuracy despite non-orthogonality.

The observation of GPS data is a significant component of the overall survey. In this survey two new monuments were placed specifically for GPS observations. The observation of suitable data spans needs to be considered in the context of normal terrestrial survey activities.

While local tie surveys are a significant technique for reference frame definition, every attempt should be made to minimise disruption to normal SLR activities. Observations to the telescope in this survey were generally undertaken in large gaps between satellite passes.

7. References

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7.1 Name of person responsible of observations

Gary Johnston, Geodesist
Geoscience Australia
Cnr Jerrabomberra Ave and Hindmarsh Drive
GPO Box 378
Canberra ACT 2601 Australia
Phone: +61 2 6249 9049
Email: Gary.Johnston@ga.gov.au

7.2 Name of person responsible for analysis

7.2.1 Data reduction and classical adjustment

Gary Johnston, Geodesist, *contact details are as above*

7.2.2 GPS analysis, IVP determination, alignment and SINEX

John Dawson, Geodesist
Geoscience Australia
Cnr Jerrabomberra Ave and Hindmarsh Drive
GPO Box 378
Canberra ACT 2601 Australia
Phone: +61 2 6249 9028
Email: John.Dawson@ga.gov.au

7.3 Location of observation data and results archive

Gary Johnston, Geodesist, *contact details are as above*