The 2006 Mount Stromlo Local Tie Survey

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by

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Executive Summary

THE 2006 MOUNT STROMLO LOCAL TIE SURVEY

The integrity and strengths of multi-technique terrestrial reference frames such as ITRF2000 depend on the precisely measured and expressed local tie connections between space geodetic observing systems at co-located observatories. A local tie survey was conducted at the Mount Stromlo Satellite Laser Ranging (SLR) observatory, in Canberra in August of 2006. The aim of the survey was to precisely measure the local terrestrial connections between the space-based geodetic observing systems co-located at the observatory, which include GPS, GLONASS, SLR and DORIS. In particular, this report documents the indirect determination of the SLR invariant reference point (IVP). Geoscience Australia has routinely performed classical terrestrial surveys at Mount Stromlo, including surveys in 1999, 2002 and 2003 (post-fire). Precise levelling and traverse measurements were made between the permanent survey pillars surrounding the SLR observatory. These survey pillars were monitored to ensure their stability as part of a consistent, stable terrestrial network from which local tie connections were made to the SLR IVP and other observing systems. The relationship between points of interest included the millimetre level accurate connections and their associated variance covariance matrix, and provided an un-broken contribution of the Mount Stromlo observatory to future terrestrial reference frames and other scientific outputs. In this report, observational and analysis techniques are reviewed and results are given.

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Dawson, J., Sarti, P., Johnston, G. and Vittuari, L., 2007. Indirect Approach to Invariant Point Determination for SLR and VLBI Systems: An Assessment, J*ournal of Geodesy, Special Issue VLBI,* June 2007, Vol 81, No. 6-8.

Johnston, G., Dawson, J. and Naebkhil, S., 2004. The 2003 Mount Stromlo Local Tie Survey. *Geoscience Australia Record,* 2004/20, 25pp. *Available online:* <*http://www.ga.gov.au/image_cache/GA5653.pdf*>

Johnston G., and Digney P., 2002. Mt Stromlo Satellite Laser Ranging Observatory Local Tie Survey, Technical Report 9, *Australian Surveying and Land Information Group (AUSLIG) Geodesy Technical Report 9. Available online:* <*http://www.ga.gov.au/image_cache/GA5026.pdf*>

Johnston G., Dawson J., Twilley B. and Digney P., 2000. Accurate Survey Connections between Co-located Space Geodesy Techniques at Australian Fundamental Geodetic Observatories, *Australian Surveying and Land Information Group (AUSLIG) Geodesy Technical Report 3, available online: http://www.ga.gov.au/image_cache/GA5035.pdf*

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 to 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);

High precision geodetic levelling (EDM-Height traversing) between survey marks surrounding the observatory;

Observation of a horizontal geodetic network by application of terrestrial geodetic observations, including distances and directions to survey marks in the vicinity of the observatory;

Observations to a number of targets positioned on the SLR during rotational motion about each of the systems' independent axes (azimuth and elevation). This included zenith angle observations to a staff on a levelled survey mark in the vicinity for precise height of instrument determination;

Reduction of terrestrial geodetic observations, including corrections to observations for instrument and target bias, set reduction and atmospheric effects;

Classical geodetic least squares (minimum constraint) adjustment of all terrestrial geodetic observations, resulting in terrestrial only coordinate estimates and their associated variance-covariance matrix (in the local system) of the geodetic network marks and targets positioned on the SLR;

Invariant reference point (IVP) modelling and estimation as well as estimation of the axes of rotation and associated system parameters such as axis orthogonality and the offset of the axes. This includes readjustment of the terrestrial only network;

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 a priori);

Reduction of the complete solution to stations of primary interest and output of a SINEX format solution file.

1. Site Description

The Mount Stromlo Satellite Laser Ranging (SLR) observatory is located in Canberra in the Australian Capital Territory (ACT) and is co-located with other observing systems including GPS, GLONASS and DORIS. There are a number of survey pillars surrounding the observatory which serve as calibration pillars for the SLR, and instrument locations for the GPS, GLONASS, DORIS and meteorological station on site. It is from this network of survey pillars that terrestrial connections are made to space based observing systems, in particular the SLR.

Table 1: List of globally important survey marks at the Mount Stromlo SLR observatory.

Local Designation	Global/IERS Designation
STR2 (Fundamental Pillar)	STR2 50119M001
STR1 (Stromlo IGS/ARGN GPS)	STR1 50119M002
AU061 (Stromlo DORIS GM)	AU61 50119M004
MSPB (Stromlo DORIS post-fire)	MSPB 50119S004
SLR IVP (Stromlo SLR post-fire)	7825 50119S003

2. Instrumentation

2.1 Tacheometers, EDM, 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”).

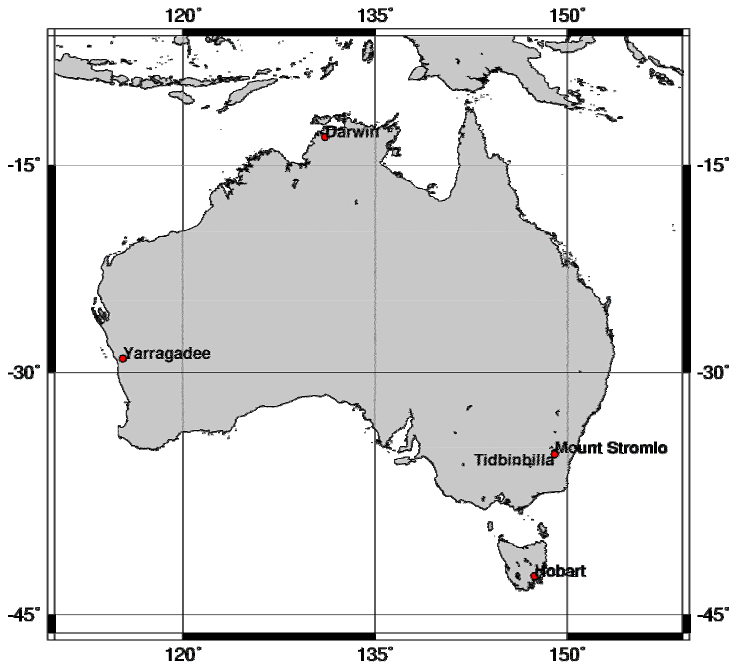


Figure 1: *Mount Stromlo Satellite Laser Ranging (SLR) Observatory. The co-located observatory includes SLR, GPS, DORIS and GLONASS systems.*

2.1.2 Calibration results

Calibration results presented here refer to 2006 survey equipment. For previous survey calibration results refer to Johnston *et al*. (2000) and Johnston and Digney (2002). The *Leica* TCA2003 Total Station calibration was performed by *Leica* Geosystems AG Heerbrugg, Switzerland. Inspection date: 10^{th} 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. All prisms calibrated at the Watson baseline 28/08/06. Approximate prism corrections of 0.0mm applied to observations in data processing.

- *Leica* Precision Micro-Prisms were calibrated at the Watson baseline 28/08/06. Approximate prism corrections of +18.5mm applied to observations in data processing.

- Additive constant for *Leica* Retro-reflective tape is 0.0mm from front face. Correction of +34.4mm applied to observations in data processing.

Staff calibration:

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

2.1.3 Auxiliary equipment

Meteorological observations of temperature, pressure and humidity were recorded using a 4000 Pocket Weather Tracker (SN: 538391). Additional meteorological data supplied from the SLR observatory met station were available.

2.2 GPS Units

GPS sessions were not used as part of this local tie survey. Rather, the baseline computed between STR1 and STR2 for the 2003 local tie survey was adopted to orientate the network.

Figure 2*: Left: Mount Stromlo permanent GPS station STR1 50119M002. Right: Mount Stromlo permanent GPS and GLONASS station STR2 50119M009*

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) and fixed height stainless steel stub (approximately 0.2m in height) with *Leica* bayonet mount 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 were taken to each target eliminating collimation effects. The offset in length between the 1.5m pole and the 0.2m stub used on pillars was determined by observing both on a low mark and calculating the offset. No other pole calibration was required.

2.4 Tripods

Leica GST20/9 heavy duty fixed timber tripod.

2.5 Forced Centering Devices

None.

2.6 Targets, Reflectors

Total station target kits included:

- *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 were included in the ground network:

AU045 (STR2): STR2 50119M001 (sometimes referred to as STRR). The intersection of the top of the stainless steel pillar plate with the vertical axis of a 5/8" Whitworth threaded stainless steel spigot. This is the fundamental survey pillar at the Mt Stromlo SLR observatory. The stainless steel pillar plate is inscribed with "AU045 Fundamental Pillar". The GLONASS antenna is setup over this mark.

AU046: The intersection of the top of the stainless steel pillar plate with the vertical axis of a 5/8" Whitworth threaded stainless steel spigot. This is the north SLR calibration pillar 1. The stainless steel pillar plate is inscribed with "AU046". This survey mark is approximately 0.182m below AU052 (STR1).

AU047: The intersection of the top of the stainless steel pillar plate with the vertical axis of a 5/8” Whitworth threaded stainless steel spigot. This is the north-east SLR calibration pillar 2. The stainless steel pillar plate is inscribed with “AU047”.

AU048: The intersection of the top of the stainless steel pillar plate with the vertical axis of a 5/8” Whitworth threaded stainless steel spigot. This is the south-east SLR calibration pillar 3. The stainless steel pillar plate is inscribed with “AU048”.

AU049: The intersection of the top of the stainless steel pillar plate with the vertical axis of a 5/8” Whitworth threaded stainless steel spigot. This is the south-west SLR calibration pillar 4. The stainless steel pillar plate is inscribed with “AU049”.

AU052 (STR1): STR1 50119M002. The intersection of the top of the stainless steel calibration prism holder with the vertical axis of a 5/8” Whitworth threaded stainless steel spigot. The calibration prism holder is bolted on top of the north calibration pillar. The survey mark is approximately 0.182m vertically above AU046. The Mt Stromlo ARGN GPS antenna is setup over this mark.

AU054: The intersection of the top of the stainless steel pillar plate with the vertical axis of a 5/8” Whitworth threaded stainless steel spigot. The pillar plate is set into the top of a 0.3m concrete pillar, 1.28m in height, which is located to the west of the observatory.

AU060: The intersection of the top of the stainless steel pillar plate with the vertical axis of a 5/8” Whitworth threaded stainless steel spigot. The mounting is located on top of the western equipment pole protruding from the roof of the observatory building. The SLR observatory meteorological equipment is mounted adjacent to this point.

AU061: The intersection of the top of the stainless steel pillar plate with the vertical axis of a 5/8” Whitworth threaded stainless steel spigot. The mounting is located on top of the eastern equipment pole protruding from the roof of the observatory building. The Mt Stromlo DORIS antenna is mounted adjacent to this point.

AU045RM1 AU045RM2, AU046BM: Reference pins close by AU045 and AU046, respectively, which were levelled to and used to determine the precise height of instrument during the survey through application of the Reuger heighting technique.

STR06: The intersection of the top of the stainless steel pillar plate with the vertical axis of a 5/8” Whitworth threaded stainless steel spigot. This pillar is located north of the observatory and was established in August of 2006.

IVP Stromlo SLR: 7825 50119S003. The intersection of the estimated azimuth axis and elevation axis of rotation of the Mt Stromlo SLR telescope.

DORIS (MSPB): MSPB 50119S004. The intersection of the vertical axis of the DORIS antenna with the plane coinciding with the base of the reference height line marked on the DORIS antenna. The DORIS antenna is mounted on a steel stanchion on the roof of the observatory, adjacent to AU061.

TRIG: Original Mt Stromlo geodetic survey mark. A .303 cartridge case set in concrete beneath a steel quadrapod.

1586: Levelling bench mark located to the north east of the observatory. It consists of a stainless steel rod with a centre punch mark at the top.

M1 and M2: The base of the meteorological station barometric pressure sensor box. The meteorological station is mounted on a steel stanchion on the roof of the observatory, adjacent to AU060.
AU046R, AU047R, AU048R, AU049R: SLR calibration targets on pillars **AU046, AU047, AU048, AU049** respectively.

3.1.2 Map of Network

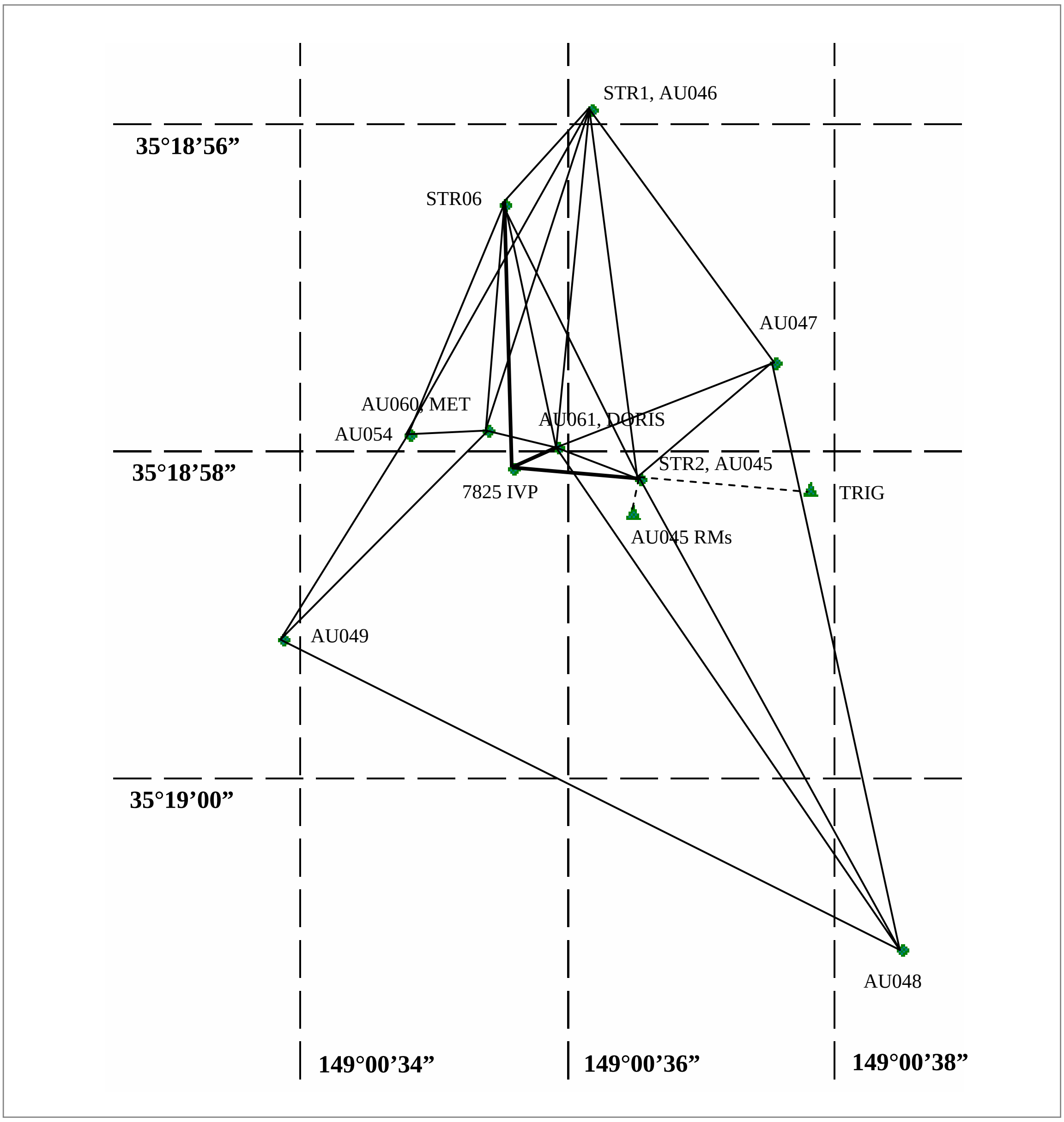


Figure 3: *The Mount Stromlo (2006) terrestrial geodetic network. Terrestrial observations between stations are shown as inter-connecting lines.*

3.2 Representation of Reference Points

3.2.1 VLBI

No VLBI at Mount Stromlo, although Tidbinbilla (***1545 50103S010***) is approximately 20 km away.

3.2.2 SLR

The Mount Stromlo Satellite Laser Ranger (SLR) invariant reference point (IVP) is defined as the intersection of the azimuth axis with the common perpendicular of the azimuth and elevation axes (Johnston et al, 2004). In this survey, an indirect approach to invariant point, or system reference point, positioning was used to measure and thus derive the SLR IVP. This involved the derivation of the independent axes of rotation of the SLR through a process of three-dimensional circle fitting to the three dimensional coordinates of targets observed on the SLR telescope during rotational sequences. In the adjustment process, geometrical models describing target motion during rotation sequences were applied. The geometric models included inter-axis, inter-circle and inter-target conditions. These conditions are critical to the computation of unbiased IVP coordinates at the millimetre level for an SLR with rotational limits in elevation (Dawson et al, 2007).

Targets on the SLR were observed as it was rotated about one axis while the telescope was held fixed in the other axis. This follows that a target located on a rigid body, rotating about one independent axis can be used to express a circle in 3D space. A 3D circle can be described by seven parameters, namely:

Circle centre (3 parameters)
Unit normal vector (3 parameters) perpendicular to the circle plane
Circle radius (1 parameter)

The method of IVP determination applied assumes that, during rotational sequences, targets follow a perfect circular arc in 3D space; that there is no deformation of the targeted structure during rotational sequences, and that the axis of interest can be rotated independently of the other axis. There are no assumptions of axis orthogonality, verticality, horizontality or the precise intersection of axes made using this IVP estimation technique.

The indirect geometrical models describing target motion during rotational sequences include several conditions:

- target paths scribe a perfect circle in 3D space during rotation about an independent axis;
- circle centres derived from targets rotated about the same axis are forced to lie along the same line in space;
- normal vectors to each circle plane derived from targets rotated about the same axis are forced to be parallel;
- orthogonality (or non-orthogonality) of the elevation axis to azimuth axis remains constant over all realisations of the elevation axis;
- identical targets rotated about a specific realisation of an axis will scribe 3D circles of equal radius;
- offset distance between the elevation axis and azimuth axis remains constant over all realisations of the elevation axis;
- distance between 3D circle centres for all realisations of the elevation axis are constant over all realisations of the elevation axis; and

- IVP coordinate estimates remain constant over all realisations (combinations) of the azimuth/elevation axis.

In addition, a constraint that the unit normal vector perpendicular to the plane of the circle must have magnitude one was required, as was a minimum of three rotational sequences to enable the solution of the equation of a circle. Multiple realization of the elevation axis (i.e. observed at multiple azimuths) were observed and computed. A least squares method was used for the computation of the axes of rotation and the IVP

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.

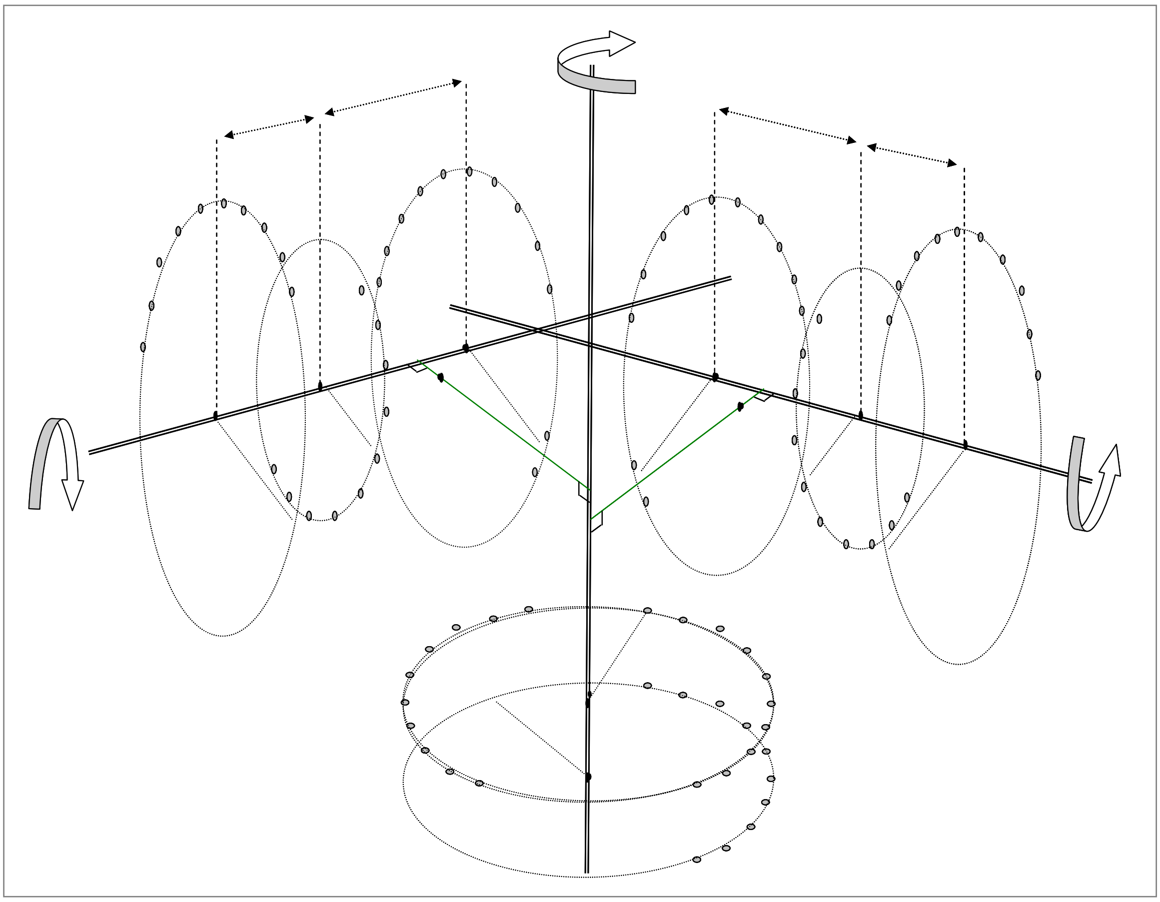


***Figure 4**: IVP model. Circle centres derived from targets observed while being rotated about the same axis are forced to lie along the same line in space. Normal vectors to the circle plane derived from targets observed while being rotated about the same axis are forced to be parallel. Note that 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.

Results from the 1999 survey are detailed in Johnston *et al* (2000). Results from the 2002 survey are detailed in Johnston and Digney (2002). Results from the 2003 survey are detailed in Johnston *et al* (2004).

In order to generate the circles required for IVP determination, measurements were made to a number of targets placed on the SLR as the telescope was rotated through several orientations. In particular, the targets on the SLR were observed from three separate pillars as the SLR was rotated in azimuth (with the elevation set at zero degrees). The targets on the SLR were observed from two different pillars as the telescope was rotated in elevation (with the azimuth set orthogonal to the line of sight of the total station for each set of observations

Table 2: Mount Stromlo 2006 local tie 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 through the full 360° Telescope observed from three standpoints, namely AU045, AU061 and STR06 3 × *Leica* Precision Micro Prisms
Elevation	4	Azimuth axis set orthogonal to line of sight Elevation axis rotated in ~10° increments through 180° Telescope observed from two standpoint, namely AU045 and AU061 4 × *Leica* Precision Micro Prisms

3.2.3 GPS

In the case of Mount Stromlo, the GPS antenna (STR1) was removed during the survey and the monument was observed directly.

3.2.4 DORIS

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

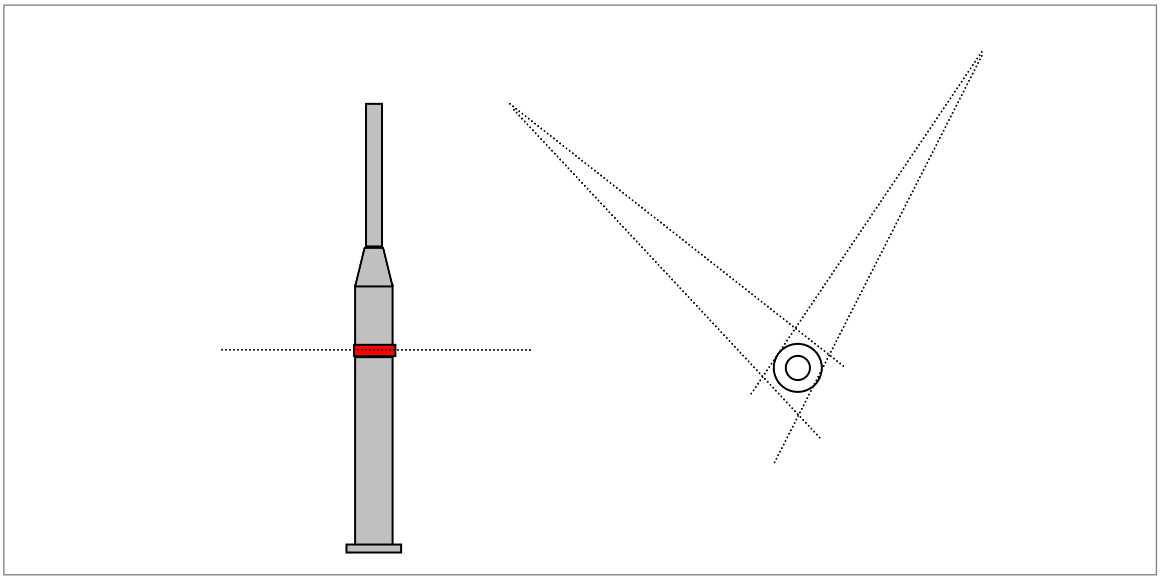


Figure 5*: Horizontal view (left) and plan view (right) of a DORIS antenna reference point (centre of antenna at red mark line).*

3.2.5 GLONASS

In the case of Mount Stromlo the GLONASS antenna (STR2) was removed during the survey and the monument was observed directly.

4. Observations

4.1 Conventional Survey

4.1.1 Network Survey

A terrestrial network survey was conducted between the permanent survey pillars surrounding the SLR observatory. *Leica* Precision-Prisms were measured using the *Leica* TCA2003 total station, which recorded horizontal and vertical directions as well as slope distances. Five rounds of face left, face right observations were taken from each pillar to all surrounding, visible pillars. Approximate target heights and instrument heights were measured with a steel ruler for each set of observations. For each instrument setup, meteorological information (temperature, pressure, humidity) was recorded and was applied, as well as prism offset corrections, to observations as part of data pre-processing. The pillars included in the survey are listed in Table 3.

Table 3: Survey pillars included in the 2006 Mount Stromlo local tie survey

SLR calibration pillars	SLR observation pillars	Other pillars
AU046	AU045	AU060
AU047	AU061	AU054
AU048	STR06	
AU049		

4.2 Levelling

High precision levelling was conducted between the survey pillars and Reuger heighting pins, using the EDM-height traversing technique (Johnston et al, 2002). Height difference observations were made using a *Leica* TCA2003 Total Station sighting to a *Leica* precision prism mounted on a fixed height prism pole (approximately 1.5m in length), or mounting stub (approximately 0.2m in length). The prism pole was used to observe ground marks while the mounting stub was used to observe pillar monuments. The offset in height between the 1.5m pole and the 0.2m stub was determined prior to the survey and applied to level observations made between the two separate mounts.

Levelling loops covering all monuments in the survey network were completed in both directions. Each instrument setup involved recording four rounds of face left, face right observations, to the prism set up over two survey marks. A 50m tape was used to measure between the survey marks so that the total station could be set up approximately half way between points. Temperature, pressure and humidity readings were entered into the total station prior to observing so that the instrument derived parts per million (ppm) values could be applied to measurements. Level run sets were processed through least squares adjustment software, prepared by Geoscience Australia, to derive adjusted height differences between all survey marks.

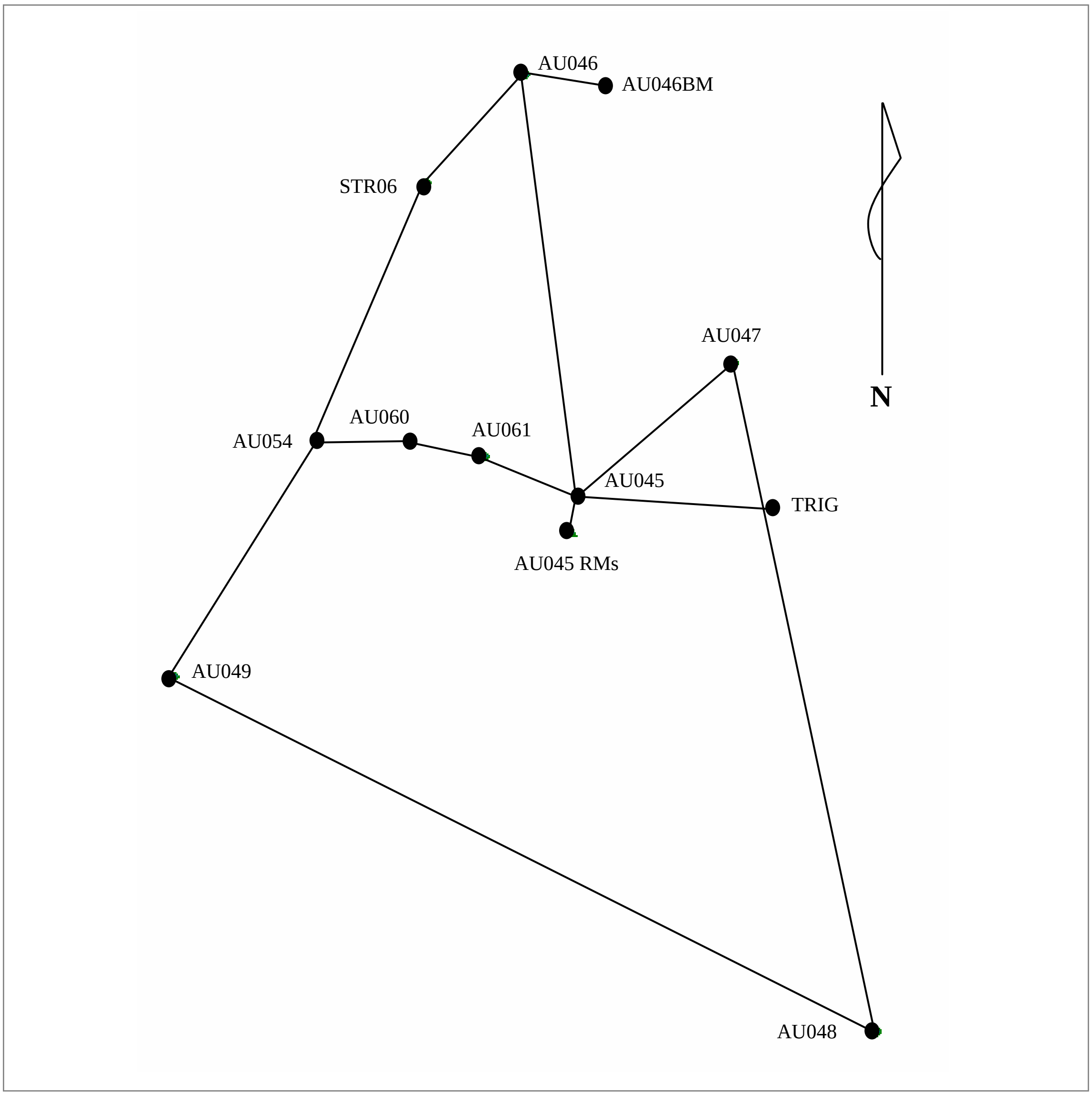


***Figure 6**: Mount Stromlo survey levelling observations.*

4.3 SLR

4.3.1 Azimuth Observations

Observations were taken from three separate survey pillars (AU045, AU061, STR06) to three *Leica* Precision Micro-Prisms, attached to the SLR structure using special magnetic mounts, as the telescope was rotated in azimuth (with the telescope elevation set at zero). Figure 7 shows the positioning of targets on the telescope structure. The telescope was rotated through the full 360 degrees at 20 degree increments. All visible targets were measured with each orientation. It proved difficult to measure all targets at each orientation as targets were often obstructed by the telescope structure. In addition, the SLR dome window had to be re-positioned to allow observation of targets as the telescope was re-positioned.

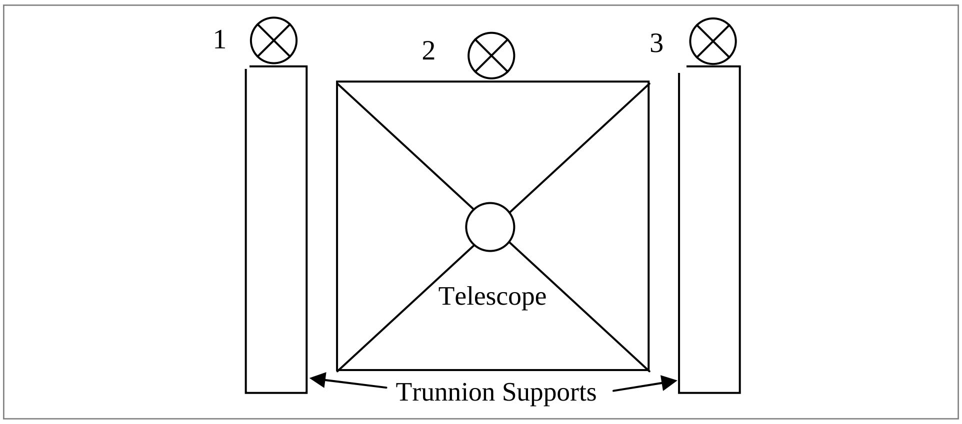
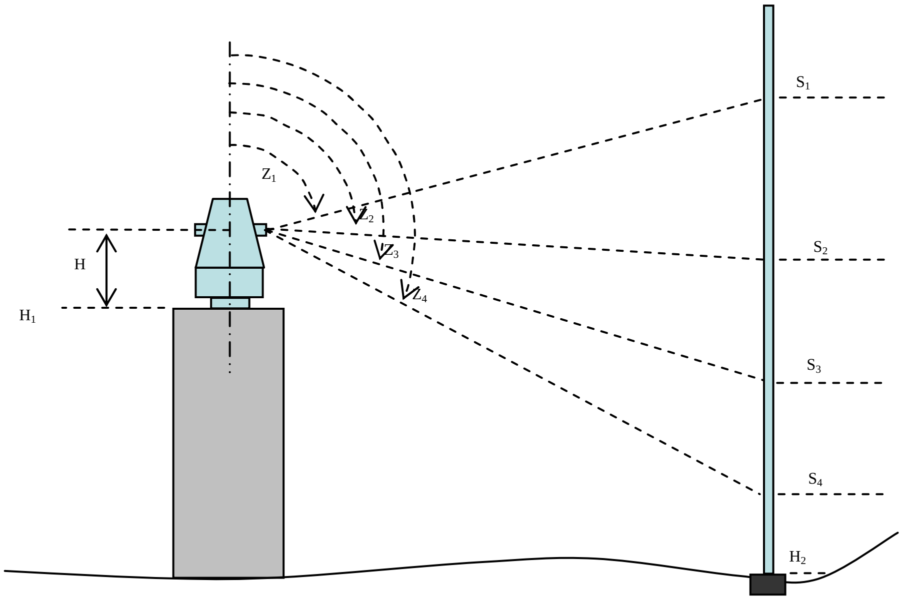


Figure 7: SLR Azimuth rotation - survey target positions on telescope structure

The standard measurement procedure involved setting up on one of the survey pillars. Precision *Leica* prisms were placed on a set of survey pillars (AU045, AU061, STR06, AU048) and five rounds of observations were taken to these targets. A set of observations consisted of a round of face left and face right observations with slope distances and zenith angles recorded with each observation as well. These rounds of observations were intended to strengthen the network between these key survey points. Atmospheric information (temperature, pressure, humidity) was recorded at the start of each instrument setup and was later applied to the observations in post processing using software developed at Geoscience Australia. Target heights were measured at each prism using a ruler as a rough initial guide to target height. These heights were updated later in post processing.

The Reuger heighting technique (Reuger & Brunner, 1981) was applied, at the beginning and end of each observation session, using survey pins located in close proximity to the instrument setup point. This measurement technique involved the observation of one round of FL/FR vertical angles to specific graduations on a levelling staff (0.8m, 1.2m, 1.6m, 2.0m) placed on a levelled survey mark (Figure 8). It is noted that this technique works best when the mid graduation of the levelling staff are approximately horizontal to the instrument trunnion axis (90 degrees) and that this was not sufficiently achieved using the survey pins in the study area. Height differences computed as part of the levelling survey (refer to section 4.2) were utilised to determine the precise height of instrument.



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

Figure 8: *Total station instrument heighting technique, where S_n are staff readings; Z_n are zenith angles (Rueger & Brunner, 1981).*

A distant survey pillar was selected as the back sight for the SLR target survey and a single set of dual face pointings were made to the back sight and as many of the three targets placed on the SLR as visible. Observations were taken to the targets on the SLR when it was positioned at zero elevation and zero azimuth. Observation sets were taken to the SLR targets as the SLR was re-orientated in azimuth at separate 20 degree increments until it had completed a full 360 degree rotation.

4.3.2 Elevation Observations

A similar procedure to that described above was followed for observations to the targets positioned on the SLR as it was rotated through elevation settings. Observations were taken from two instrument set up locations (AU045, AU061) to four micro-prisms placed on the SLR (as shown in Figure 9) as the telescope was rotated in elevation, with the telescope azimuth set on a bearing orthogonal to the total station line of sight. This direction was derived from the final coordinates computed in the previous local tie survey. The telescope was rotated through 180 degrees at 10 degree increments. The SLR was rotated by the computer system until it reached an elevation setting of 90 degrees. For the remaining elevation settings the SLR had to be positioned manually. Wooden blocks were used to chock the SLR at approximate 10 degree increment settings past 90 degrees. Clamps were used to hold the SLR in azimuth. However, it was later found that the telescope orientation changed when it reached 90 degrees. This impeded the proposed ideal circle fitting procedure and meant that circles were fit to quarter arcs of observations, rather than the full 180 degree circle arcs of observations as originally intended.

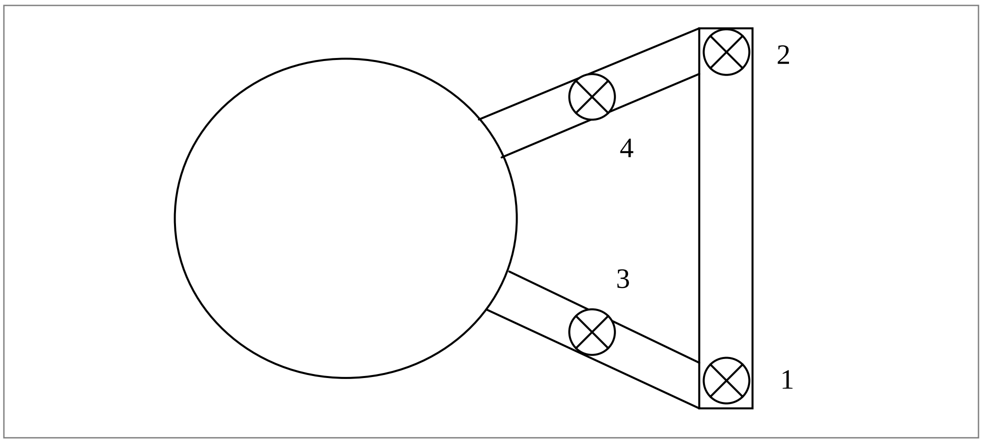


Figure 9: *Elevation rotation - survey target positions on telescope structure*

Three rounds of FL/FR observations were taken to targets on three surrounding survey pillars (AU045, AU061, STR06, AU048) at the beginning and end of the survey. These extra network observations were designed to strengthen the network in regard to these critical points. Reuger heighting observations were taken to the south pin (RM1) and north pin (RM2) at the beginning and end of the survey. These measurements were used to derive the instrument height accurately, which was important for the observation of target elevations. In conducting the survey, a distant survey pillar was selected as the back sight and single sets of dual face pointing were made to the back sight and the four targets placed on the SLR. Observations were taken to the targets at 10 degree increments of the SLR as it was rotated through elevation settings. With each orientation of the SLR the dome window had to be re-positioned to allow observation of targets.

4.4 DORIS and MET Station

Observations were taken to the DORIS and MET station from two survey pillars (AU045, STR06). These two pillars provided a strong geometry as they are approximately perpendicular to each other with respect to the DORIS and MET station. Three rounds of face left, face right observations were taken to *Leica* retro-reflective targets placed on the DORIS and MET station at their respective reference points. Two targets were placed on the MET station, along the base of the sensor box, pointing in the general direction of each of the survey pillars. Two targets were also placed on the DORIS, in line with each of the survey pillars. Additional observations were taken to the left and right sides of the DORIS, along the bottom of the reference line, to support improved centre point positioning of the beacon. The two instrument setup points also served as back sights for the observation rounds during this part of the survey.

4.5 GPS

None.

4.6 General Comments

None.

5. Data Analysis and Results

The flow chart of the analysis process used for the Mount Stromlo survey is detailed in Figure 10. Coordinate solutions are generated in three steps: first at the completion of the classical geodetic adjustment (*Step A*); second 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 third after transformation (*in the case of Mount Stromlo no transformation was undertaken*) of the 'geometrically modified` solution onto the required global reference frame (*Step C*).

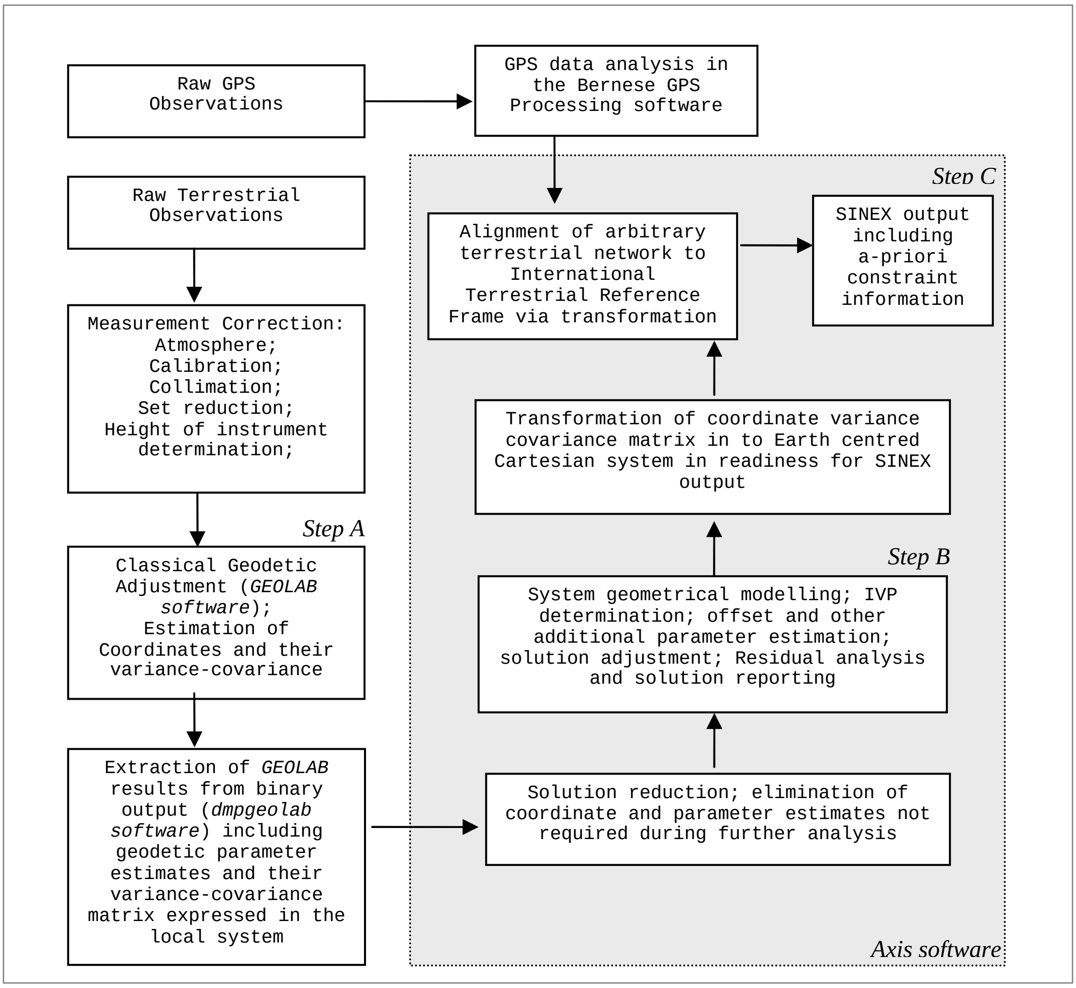


Figure 10*: Analysis process for the reduction of local survey data.*

5.1 Data Pre-processing

5.1.1 Levelling

Levelling GSI files were converted to FLD files using LISCAD SEE software. FLD files were then passed though Geoscience Australia's levelling1.exe software to derive changes in height between survey marks. Levelling misclosures were noted as being well within zero order levelling requirements. Levels were determined for survey marks with AU045 fixed in height as a known point from the previous local tie survey. Orthometric height differences were noted between survey marks for use in the adjustment.

5.1.2 Reuger heighting

Reuger heighting observations recorded during the SLR survey to the survey pins close by instrument stations were extracted from the FLD files and entered into an excel spreadsheet set up to derive instrument heights from vertical angles read to a levelling staff. The mean height of instrument value was computed from a number of observation sets.

5.1.3 Network survey

GSI files were converted to FLD files. Meteorological data and prism correction data were entered into the FLD files. These files were then run through Angles.exe to generate IOB files. The vertical angles and slope distance values were then entered, with heights of instrument computed through the Reuger heighting technique, into a spreadsheet set up to derive heights of targets using these observations. The height of target and height of instrument values were entered into the IOB files for the relevant observation sets. Orthometric height difference values derived through the levelling data processing were added to the IOB file. Measurement precision estimates were also added to the IOB file for each observation type. The precision values entered included:

Slope distance: 0.001m + 1ppm
Horizontal direction: 1 second
Zenith angle: 1 second
Orthometric height difference: 0.0003m

5.1.4 DORIS observations

The horizontal direction to the centre of the DORIS antenna was computed as the average of the observations taken to the left and right of the DORIS antenna along the base of the reference line. The direction measurements were updated in the IOB file. The zenith angle and slope distance observations were adjusted to account for the DORIS antenna radius of 0.027m and the requirement of determining the intersection of the vertical axis of the DORIS antenna with the plane coinciding with the base of the reference height line. The adjusted observations were entered into the IOB file.

5.2 Classical Geodetic Adjustment

Classical geodetic adjustment was undertaken using *GeoLab* version 2.4d geodetic adjustment software. Prior to this, three dimensional coordinates for the fundamental pillar (AU045) and AU046, utilised in the previous local tie survey adjustment, were entered into the IOB file as the primary constraint on the network. A three-dimensional difference vector was created for the 0.1824m vertical offset between AU046 and AU052. The XYZ components of this vector were computed using in-house coordinate transformation software. This vector was constrained strongly. Due to confidence in the height difference observations, derived from the precise total station levelling, the zenith angle measurements between survey pillars were commented out of the IOB file. This placed all emphasis on the levelled, orthometric height differences in determining pillar heights. The IOB file was run through the *GeoLab* version 2.4d geodetic adjustment software until coordinates converged, with derived coordinates repeatedly being added to the IOB file as initial coordinate estimates in the adjustment process. Once convergence was reached, the primary constraint on the network was loosened up to act as a minimum constraint with AU045 held fixed in latitude, longitude and height and AU046 only held fixed in longitude, allowing for movement in the north-south directions and also in height. An appropriate observation variance factor was applied and the final adjustment was run. It should be noted that corrections for the geoid and deflection of the vertical were not applied as part of the classical geodetic adjustment.

5.2.1 Topocentric coordinates and covariances

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

Table 4: Mount Stromlo terrestrial survey results. GRS80 ellipsoid. Heights are ellipsoidal, arbitrary local frame.

STATION	LONGITUDE			LATITUDE			HEIGHT (M)
TRIG	149	0	37.81756	-35	-18	-58.23287	801.4450
1586	149	0	36.25735	-35	-18	-58.28460	797.0327
STR2 50119M001	149	0	36.55558	-35	-18	-58.18199	802.5289
AU046	149	0	36.18783	-35	-18	-55.92246	799.7977
AU047	149	0	37.57255	-35	-18	-57.47268	807.2167
AU048	149	0	38.50903	-35	-19	-1.05746	801.5929
AU049	149	0	33.88642	-35	-18	-59.15600	794.5600
STR1 50119M002	149	0	36.18783	-35	-18	-55.92246	799.9801
AU054	149	0	34.83471	-35	-18	-57.90111	798.7666
AU060	149	0	35.42656	-35	-18	-57.88009	803.4251
AU61 50119M004	149	0	35.93052	-35	-18	-57.97228	804.3348
MSPB 50119S004	149	0	35.92791	-35	-18	-57.98272	804.9614
STR06	149	0	35.54250	-35	-18	-56.50258	799.0843
M1	149	0	35.42655	-35	-18	-57.88703	804.7430
M2	149	0	35.42503	-35	-18	-57.88595	804.7427
AU045RM1	149	0	36.52737	-35	-18	-58.40902	800.9504
AU045RM2	149	0	36.49100	-35	-18	-58.36861	800.9838
1586BM	149	0	36.25736	-35	-18	-58.28460	797.2129

5.2.2 Correlation matrix

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

5.2.3 Reference temperature

No thermal corrections have been applied for structural expansion of the SLR instrument. Since the structure is small and encased in a thermally controlled environment, thermal deformation is ignored.

5.3 IVP Determination

At this stage three dimensional coordinates had been computed for each target at each orientation of the SLR. These points were used to derive three dimensional circles in space, which were used to determine the SLR IVP.

The .par, .con and .inv propriety binary *GeoLab* format files generated from the *GeoLab* adjustment were run through the Geoscience Australia developed *dmpgeolab* software to extract the solution data, including a full variance-covariance matrix, and create an ASCII format .vcv file required for the IVP determination software *axis*, developed by Geoscience Australia. The .vcv file was placed into a directory with the *axis* software along with a setup.axs file. The setup file was edited repeatedly to derive estimates of circle parameters for each target and each rotation sequence. Once initial estimates were refined for all target rotation sequences, geometric constraints were added. Initial constraints introduced included:

- ENORMAL, NNORMAL, UNORMAL – used to constrain normal parameters together;
- TOUCH – used to force two axes to touch each other (in 3D) at some reference point;
- RADIUS – used to constrain circle arc radius parameters together;
- CENTRE – used to constrain together centre to centre distances;
- DELETE – used to omit unwanted target positions from the adjustment procedure.

With updated circle parameter estimates for each target rotation sequence, IVP coordinates were derived. Additional constraints were introduced to constrain separate IVP realisations. Constraints applied included:

- OFFSET – used to constrain the computed offset to be identical for independent IVP estimates;
- ORTHOG – used to constrain the orthogonality between three axes;
- UIVP – used to constrain the individual IVP determination in the up component together.

5.4 Transformation

This procedure produced the final IVP coordinate estimates. The *axis* software was used to transform (through translation and rotation only) the terrestrial network and computed IVP coordinate with the variance-covariance matrix from a local to a global reference frame. Coordinates derived from the previous local tie survey were used to align the survey to the global reference frame. At least three alignment stations with XYZ earth-centred Cartesian coordinates were specified as stations for the local to global transformation.

5.5 SINEX File Generation

A SINEX format solution file was created using the *axis* software. 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 ***AUSSTRO0609GA.SNX***, and can be found at ftp://ftp.ga.gov.au/sgac/sinex/ties/. This file supersedes the SINEX file AUSSTRO0312GA.SNX submitted to the International Earth Rotation Service (IERS).

5.6 GPS

Not applicable. The arbitrary terrestrial network was aligned to the 2003 local tie survey alignment, which was aligned to ITRF2000.

5.7 Additional Parameters

Additional system parameters were computed during the IVP estimation process.

For the IVP ***7825 50119S003*** the azimuth axis deflection from the vertical was estimated as 24.7" at an azimuth of 281° 8' 25.6". The orthogonality (or non-orthogonality) of the azimuth to the elevation axes was estimated to be 90° 0' 29.9". The offset distance between the azimuth and elevation axis was estimated to be 0.7 mm.

Table 5: Mount Stromlo, final results, topocentric vectors between SLR IVP (**7825 50119S003**) and permanently mounted calibration pillar reflectors

Station 2006	East (m)	North (m)	Up (m)	Range (m)
AU046R	15.6561	67.6124	-5.1275	69.5905
AU047R	50.6219	19.8470	2.2914	54.4218
AU048R	74.2853	-90.6156	-3.3338	117.2203
AU049R	-42.4586	-32.0133	-10.3635	54.1755
STR06R	-0.6410	49.7323	-5.8401	50.0781

Table 6: Mount Stromlo, Horizontal and height offsets of EOS retro-reflector targets from pillar reference points, azimuth from pillar reference point to SLR IVP, differences in XYZ from pillar reference point to EOS retro-reflector point.

Reflector	Height	Offset	Azimuth			ΔX	ΔY	ΔZ
AU046R	0.1052	0.0247	193	2	14.8749	-0.0588	0.0418	-0.0805
AU047R	0.1042	0.0244	248	35	30.1899	-0.0568	0.0606	-0.0675
AU048R	0.1040	0.0260	320	39	20.0318	-0.0742	0.0638	-0.0437
AU049R	0.1053	0.0246	52	59	2.9580	-0.0911	0.0318	-0.0488
STR06	0.1042	0.0244	179	15	41.9594	-0.0610	0.0362	-0.0801

Table 7: Mount Stromlo, final results, topocentric vectors between SLR IVP (**7825 50119S003**) and observed points in Mount Stromlo network.

Station	East (m)	North (m)	Up (m)	Range (m)
AU045 (STR2)	24.9523	-2.0070	-2.5005	25.1575
AU052 (STR1)	15.6617	67.6370	-5.0491	69.6099
AU061	9.1612	4.4568	-0.6939	10.2114
DORIS (MSPB)	9.0955	4.1351	-0.0678	9.9916
AU046	15.6618	67.6369	-5.2315	69.6234
AU046R	15.6562	67.6128	-5.1263	69.5909
AU047	50.6444	19.8558	2.1869	54.4416
AU047R	50.6217	19.8469	2.2911	54.4216
AU048	74.3019	-90.6357	-3.4387	117.2495
AU048R	74.2855	-90.6156	-3.3347	117.2205
AU049	-42.4787	-32.0283	-10.4690	54.2204
AU049R	-42.4590	-32.0135	-10.3637	54.1761
AU054	-18.5221	6.6505	-6.2623	20.6522
AU060	-3.5703	7.2984	-1.6039	8.2817
STR06	-0.6412	49.7565	-5.9447	50.1145
STR06R	-0.6408	49.7321	-5.8405	50.0780

5.8 Discussion of Results

Table 8: Mount Stromlo, final results, cartesian coordinates (metres), ITRF2000 at 28 July 2001 and final precision estimates(1σ, metres)

Station	X (m)	σ	Y (m)	σ	Z (m)	σ
IVP (7825)	-4467064.5842	0.6	2683034.9067	0.4	-3667007.6314	1.0
AU045 (STR2)	-4467074.6882	0.4	2683011.8682	0.3	-3667007.8235	0.8
AU052 (STR1)	-4467102.6352	0.8	2683039.4915	0.5	-3666949.5225	1.5
AU061	-4467071.0245	0.5	2683028.0882	0.3	-3667003.5936	0.8
DORIS (MSPB)	-4467071.2691	0.6	2683028.3119	0.9	-3667004.2181	0.9
AU046	-4467102.5076	1.5	2683039.4148	2.2	-3666949.4171	0.8
AU046R	-4467102.5664		2683039.4566		-3666949.4976	
AU047	-4467102.0301	0.8	2682998.3204	1.1	-3666992.6938	1.5
AU047R	-4467102.0869		2682998.3810		-3666992.7613	
AU048	-4467055.5198	2.9	2682942.7882	2.5	-3667079.6000	2.3
AU048R	-4467055.5940		2682942.8520		-3667079.6437	
AU049	-4467019.5169	1.2	2683057.3901	1.8	-3667027.7138	2.5
AU049R	-4467019.6080		2683057.4219		-3667027.7626	
AU054	-4467053.9626	1.0	2683050.1334	0.6	-3666998.5846	1.5
AU060	-4467065.2407	0.8	2683039.4659	0.5	-3667000.7490	1.1
STR06	-4467084.7535	1.5	2683047.7689	1.5	-3666963.5949	1.0
STR06R	-4467084.8145		2683047.8051		-3666963.6750	

Table 9: Mount Stromlo, final results, geographic coordinate, ITRF2000 at 28 July 2001.

Station	Latitude			Longitude			Height
IVP (7825)	-35	18	58.11687	149	0	35.56791	805.0293
AU045 (STR2)	-35	18	58.18198	149	0	36.55561	802.5288
AU052 (STR1)	-35	18	55.92245	149	0	36.18785	799.9806
AU061	-35	18	57.97227	149	0	35.93054	804.3354
DORIS (MSPB)	-35	18	57.98271	149	0	35.92793	804.9615
AU046	-35	18	55.92245	149	0	36.18785	799.7981
AU046R	-35	18	55.92323	149	0	36.18763	799.9034
AU047	-35	18	57.47266	149	0	37.57258	807.2164
AU047R	-35	18	57.47295	149	0	37.57168	807.3206
AU048	-35	19	1.05745	149	0	38.50906	801.5916
AU048R	-35	19	1.05679	149	0	38.50841	801.6955
AU049	-35	18	59.15600	149	0	33.88644	794.5605
AU049R	-35	18	59.15552	149	0	33.88722	794.6658
AU054	-35	18	57.90110	149	0	34.83474	798.7670
AU060	-35	18	57.88008	149	0	35.42658	803.4254
STR06	-35	18	56.50257	149	0	35.54252	799.0849
STR06R	-35	18	56.50336	149	0	35.54254	799.1890

Table 10: Mount Stromlo, final results, cartesian difference vectors (metres). Comparison of 2003 and 2006 results.

FROM STATION		TO STATION	X(m)	Y(m)	Z(m)
2003					
7825 50119S003	-	STR2 50119M001	-10.1064	-23.0391	-0.1933
7825 50119S003	-	STR1 50119M002	-38.0537	4.5839	58.1077
7825 50119S003	-	AU61 50119M004	-6.4437	-6.8202	4.0376
7825 50119S003	-	MSPB 50119S004	-6.6925	-6.5934	3.4105
2006					
7825 50119S003	-	STR2 50119M001	-10.1040	-23.0385	-0.1921
7825 50119S003	-	STR1 50119M002	-38.0510	4.5848	58.1089
7825 50119S003	-	AU61 50119M004	-6.4403	-6.8185	4.0378
7825 50119S003	-	MSPB 50119S004	-6.6849	-6.5948	3.4133

The least squares solution of the SLR IVP position included: 25 targets; 4 IVP estimates (constrained together); 834 pseudo-observations; 227 unknowns; 534 conditions; 57 constraints and 151 additional constraints. The resultant linear system was 1803 x 1803 with degrees of freedom 1349. The computed variance factor was 0.19235. IVP model (circle) fit residuals were 0.3 mm Root Mean Square Error (RMS) for the in-plane residuals and 0.4 mm for the out-of-plane residuals (e.g. Figure 11).

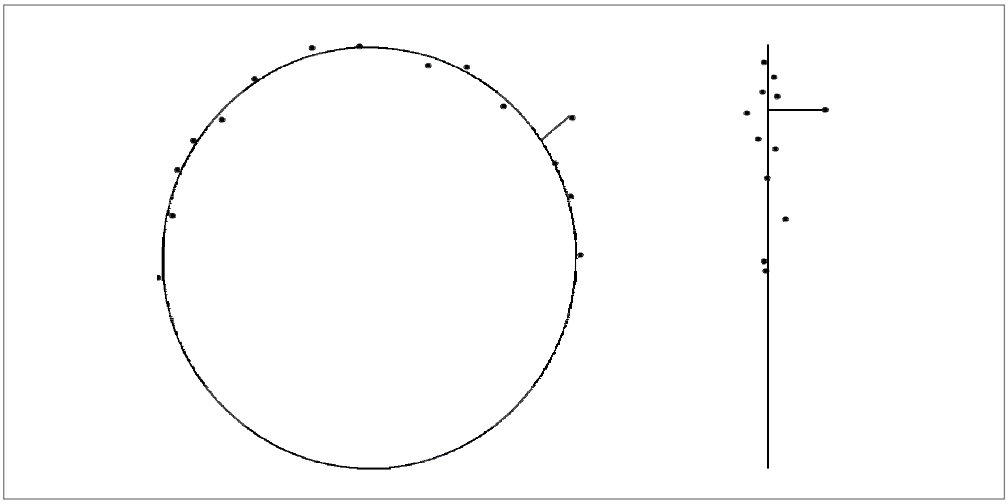


Figure 11*: Circle fitting residuals; left in-plane residuals; right out-of-plane residuals.*

5.9 Comparison with Previous Surveys

In general there is good agreement between the 2003 and 2006 surveys. This indicates reasonable network stability at the site.

Table 11: XYZ Residuals between the 2003 and 2006 surveys.

Station Name	X (mm)	Y (mm)	Z (mm)
AU045	-0.4	-0.5	0.3
AU046	-0.4	0.0	-0.1
AU047	0.5	-0.4	2.4
AU048	-0.9	0.1	2.5
AU049	-2.8	0.7	-1.2
AU052	-0.2	-0.1	0.3
AU060	-1.3	-2.3	-0.6
AU061	0.7	0.8	-0.6
DORIS	4.7	-2.4	2.0
IVP	-2.8	-1.1	-0.9
RMS	2.4	1.4	1.4

Table 12: East, North and Up Residuals between the 2003 and 2006 surveys.

Station Name	East (mm)	North (mm)	Up (mm)
AU045	0.6	0.3	-0.1
AU046	0.2	0.1	0.3
AU047	0.1	1.5	-1.9
AU048	0.4	2.5	-0.8
AU049	0.8	0.6	2.9
AU052	0.2	0.3	-0.1
AU060	2.6	-0.5	0.3
AU061	-1.0	-0.6	0.2
DORIS	-0.4	-1.4	-5.4
IVP	2.4	0.3	2.0
RMS	0.9	1.0	2.1

Table 13: Comparison of X Coordinates for Mount Stromlo points of interest from 2006, Combo, 2003, 2002 and 1999 local tie surveys.

STN	2006	Combo	2003	2002	1999
AU045	-4467074.6882	-4467074.6878	-4467074.6878	-4467074.6878	-4467074.6878
AU052	-4467102.6352	-4467102.6350	-4467102.6353	-4467102.6346	-4467102.6335
AU061	-4467071.0245	-4467071.0252	-4467071.0253		
DORIS	-4467071.2691	-4467071.2739	-4467071.2742		
IVP06	-4467064.5842	-4467064.5814	-4467064.5818		
AU046	-4467102.5076	-4467102.5072	-4467102.5074	-4467102.5066	-4467102.5051
AU046R	-4467102.5664	-4467102.5649	-4467102.5651	-4467102.5643	-4467102.5628
AU047	-4467102.0301	-4467102.0306	-4467102.0294	-4467102.0303	-4467102.0299
AU047R	-4467102.0869	-4467102.0878	-4467102.0866	-4467102.0875	-4467102.0871
AU048	-4467055.5198	-4467055.5189	-4467055.5160	-4467055.5203	-4467055.5198
AU048R	-4467055.5940	-4467055.5938	-4467055.5909	-4467055.5952	-4467055.5947
AU049	-4467019.5169	-4467019.5141	-4467019.5138	-4467019.5152	-4467019.5151
AU049R	-4467019.6080	-4467019.6058	-4467019.6055	-4467019.6069	-4467019.6068
AU054	-4467053.9626		-4467053.9615	-4467053.9612	-4467053.9639
AU060	-4467065.2407	-4467065.2394	-4467065.2397		
STR06	-4467084.7535				
STR06R	-4467084.8145				
IVP03		-4467063.9203		-4467063.9206	-4467063.9196
DORIS03		-4467068.3830		-4467068.3828	-4467068.3934

Table 14: Comparison of Y Coordinates for Mount Stromlo points of interest from 2006, Combo, 2003, 2002 and 1999 local tie surveys.

STN	2006	Combo	2003	2002	1999
AU045	2683011.8682	2683011.8687	2683011.8687	2683011.8687	2683011.8687
AU052	2683039.4915	2683039.4916	2683039.4920	2683039.4914	2683039.4907
AU061	2683028.0882	2683028.0874	2683028.0874		
DORIS	2683028.3119	2683028.3143	2683028.3145		
IVP06	2683034.9067	2683034.9078	2683034.9079		
AU046	2683039.4148	2683039.4148	2683039.4152	2683039.4147	2683039.4139
AU046R	2683039.4566	2683039.4561	2683039.4565	2683039.4560	2683039.4552
AU047	2682998.3204	2682998.3208	2682998.3212	2682998.3204	2682998.3206
AU047R	2682998.3810	2682998.3813	2682998.3817	2682998.3809	2682998.3811
AU048	2682942.7882	2682942.7881	2682942.7898	2682942.7883	2682942.7901
AU048R	2682942.8520	2682942.8525	2682942.8542	2682942.8527	2682942.8545
AU049	2683057.3901	2683057.3894	2683057.3917	2683057.3900	2683057.3898
AU049R	2683057.4219	2683057.4210	2683057.4233	2683057.4216	2683057.4214
AU054	2683050.1334		2683050.1359	2683050.1333	2683050.1332
AU060	2683039.4659	2683039.4682	2683039.4684		
STR06	2683047.7689				
STR06R	2683047.8051				
IVP03		2683034.5043		2683034.5045	2683034.5043
DORIS03		2683030.1159		2683030.1152	2683030.0922

Table 15: Comparison of Z Coordinates for Mount Stromlo points of interest from 2006, Combo, 2003, 2002 and 1999 local tie surveys.

STN	2006	Combo	2003	2002	1999
AU045	-3667007.8235	-3667007.8238	-3667007.8238	-3667007.8238	-3667007.8238
AU052	-3666949.5225	-3666949.5228	-3666949.5217	-3666949.5221	-3666949.5219
AU061	-3667003.5936	-3667003.5930	-3667003.5933		
DORIS	-3667004.2181	-3667004.2200	-3667004.2198		
IVP06	-3667007.6314	-3667007.6305	-3667007.6306		
AU046	-3666949.4171	-3666949.4170	-3666949.4160	-3666949.4166	-3666949.4170
AU046R	-3666949.4976	-3666949.4972	-3666949.4962	-3666949.4968	-3666949.4972
AU047	-3666992.6938	-3666992.6962	-3666992.6964	-3666992.6956	-3666992.6946
AU047R	-3666992.7613	-3666992.7638	-3666992.7640	-3666992.7632	-3666992.7622
AU048	-3667079.6000	-3667079.6025	-3667079.6045	-3667079.6010	-3667079.6020
AU048R	-3667079.6437	-3667079.6467	-3667079.6487	-3667079.6452	-3667079.6462
AU049	-3667027.7138	-3667027.7126	-3667027.7142	-3667027.7137	-3667027.7130
AU049R	-3667027.7626	-3667027.7612	-3667027.7628	-3667027.7623	-3667027.7616
AU054	-3666998.5846		-3666998.5826	-3666998.5830	-3666998.5817
AU060	-3667000.7490	-3667000.7484	-3667000.7487		
STR06	-3666963.5949				
STR06R	-3666963.6750				
IVP03		-3667007.0839		-3667007.0841	-3667007.0835
DORIS03		-3667003.7108		-3667003.7111	-3667003.7168

7. Planning Aspects

The Mt Stromlo SLR facility uses a fully enclosed telescope to avoid dust, pollen and moisture influences on the telescope optics. During the local tie survey a secondary window was removed from the surrounding dome allowing observational access. Care should be taken during the survey to avoid rain or dusty periods. Also, be aware that the telescope cannot be pointed directly at the sun. The survey should be timed to avoid orientations toward the sun.

To improve survey efficiency the two ladders in the SLR observatory workshop should be used during the survey to access AU047 and AU048.

AU048 was selected as the back sight for the surveys from station AU061 as it was the most distant point in the survey area and the DORIS antenna inhibited observation to the other survey pillars in the network. However, there seemed to be some movement detected from physical inspection of pillar AU048 and the total station often returned errors of target movement while trying to take back sight observations. During the survey it was noticed that pillars AU047 and AU048 were not perfectly stable. These calibration pillars are free-standing steel poles with an external steel shroud and were noticed to sway with the wind and movement of the equipment operator during the survey. Pillars AU046 and AU049 were also observed to move slightly but not to same extent as the taller pillars. This could potentially lead to discrepancies in survey observations.

A 5mm allen key was required to dismantle the SLR calibration pillar targets so that GA equipment could be placed over survey marks.

The coordinates of the calibration pillar monuments were derived through the survey process. The computation of the effective point of reflection of the EOS calibration reflectors relied upon the measurement of the prism offset and height external to the survey process. For this survey, prism offset values were extracted from the previous local tie survey in which an external survey was conducted on the Watson EDM baseline, Australian Capital Territory (ACT). In the future more in-depth analysis of these prisms offsets needs to be completed.

The total station was set up on AU061 (the pillar beneath DORIS) to observe the targets on the SLR as it was rotated in azimuth and in elevation. The total station operator connected to the pillar with a band and climbing harness due to the awkward positioning of the pillar on the corner of the building. The operator also tended to lean on the pillar mounts when viewing through the eye piece, due to the height of the pillar and the position of the DORIS. AU061 pillar is in an awkward position, on the corner of the building roof, and is taller than usual, making it difficult to observe through. In addition, the operator sometimes puts weight on the pillar, which could lead to vibration of the pillar. When observing from AU061 into the SLR it is recommended that a safety harness be worn to ensure the safety of the observer. The observer should also stand on a step or rolled up towel to minimise vibration or impact on the roofing through which the pillar passes.

To overcome the problem encountered with the SLR orientation changing during the rotations in elevation, it is suggested that the SLR be moved manually throughout the entire elevation rotation survey. This is in contrast to the SLR being rotated by the computer system from 0 to 90 degrees and then being moved manually through the back arc, which was the procedure employed for this survey. Analysis after the survey showed that the telescope orientation had shifted when it reached 90 degrees, which impeded the proposed ideal circle fitting procedure. It is suggested that in the future the telescope will need to be oriented perpendicular to the observation line of sight and then clamped into position. The telescope can then be moved in 10 degree increments manually using wooden blocks and wedges to chock it in place.

The timing of future surveys needs to be negotiated with the contract operator (EOSSS) to avoid unnecessary negative impact on ranging productivity, especially for high priority satellite missions.

7. References

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7.2.1 Data reduction and classical adjustment

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7.2.2 GPS analysis, IVP determination, alignment and SINEX

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7.3 Location of observation data and results archive

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