AUSLIG GEODESY
TECHNICAL REPORT 3

Accurate Survey Connections between Co-located Space Geodesy Techniques at Australian Fundamental Geodetic Observatories

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1 Abstract

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 accurate connection between the different techniques, commonly referred to as the local tie. As the achievable accuracy of the space geodetic techniques increase, the need for these highly accurate local ties becomes imperative. The observation of the local ties at the 1-2mm level also allows the monitoring of site deformation consequently.

2 Introduction

Australia, due largely to its southern location, is home for the full range of space geodetic techniques, principally located at five sites. Stolz (1998) detailed some of these sites in eastern Australia. AUSLIG maintains the local ties at these five sites throughout Australia. At each of these sites, a network of survey marks allows an accurate and over-determined survey to be observed. The results of these surveys are the vectors between the primary monument and other significant points at each site. In the case of Very Long Baseline Interferometry (VLBI) antennae and Satellite Laser Ranging (SLR) telescopes, the point of interest is referred to as an invariant point (IVP). This invariant point is different for each of the antennae / telescopes and needs to be determined by indirect observation, since generally the IVP is inaccessible. A description of the IVP at each site is given in the result section of this report.

The survey of these local ties generally needs to be repeated on a two yearly basis (International Laser Ranging Service recommendation), depending on the stability of the site. The results listed for Tidbinbilla and Hobart in this report are from observations taken in 1995. Mt Stromlo, Yarragadee and Orroral had observations taken in 1998 and 1999. In the case of Orroral these observations constitute the final survey of the station, since it was decommissioned in November 1998. The Mt Stromlo survey presented here is the first undertaken by AUSLIG for this site. A contractor to Electro Optic Systems (EOS) undertook a previous survey, however the results were never submitted to IERS by AUSLIG. For all five sites, comparisons to previous results are tabulated in the relevant Appendix.

The repeat surveys of these networks allow an estimate of true survey accuracy as well as an indication of site deformation. The surveys described in the report use an observational technique not previously used in the IVP determination at these sites. This technique, which is briefly mentioned in sections headed *Observation of Local Ties* and *Computation of the Telescope / Antenna IVP* of this report, and will be described more fully in a separate publication, has been used in an attempt to obtain a more accurate estimate of the IVP's position.

The *Conclusion* lists a summary of the results at each site. The Cartesian vectors from the primary station in each of the networks to the other monuments in the network is presented along with the associated standard deviations for these vectors. A full description of the monuments connected with a full description of the results is presented in the respective Appendix for each site.

3 Co-location in Australia

The importance of individual space geodetic observing systems has traditionally been based on the determination of some unique product. The emerging importance of the co-location and combination of space geodetic techniques for geodesy and geodynamics is a consequence of the capability of the individual techniques to also provide high quality, common products (Govind et al, 1999). The benefits of co-location and combination are:

- High precision geodetic products are determined in a single consistent solution
- The opportunity to calibrate space geodetic observing systems with respect to each other; distinguishing between technique-specific observation errors and geodynamic signals.

For this purpose the individual observing platforms need to be connected with high accuracy. Generally, this implies that the techniques should be located within several hundreds of metres of each other, allowing terrestrial surveys to be performed at 1-2mm accuracy. Listed in Table 1 are the five Australian sites where co-location occurs. The techniques present at each site are also listed.

Site	Techniques
Orroral	GPS, SLR, DORIS
Mt Stromlo	GPS, SLR, DORIS, Glonass, Absolute Gravity
Tidbinbilla	GPS, VLBI, Absolute Gravity
Yarragadee	GPS, SLR, DORIS, Glonass
Hobart	GPS, VLBI, Absolute Gravity

Table 1 - Australian Geodetic co location site techniques.

Not all space geodetic techniques are currently utilised in Australia. *Table 2* (Govind, 1996) lists the more complete range of techniques that are available for geodetic interpretation. Making each of these techniques unique is the observation type and space segment component of each system. These are also listed in Table 2.

Technique	Observed
Very Long Baseline Interferometry (VLBI)	Quasars
Satellite Laser Ranging (SLR)	Lageos-1 & 2, Ajisai, Starlette, Stella, TOPEX, GPS, Glonass, Etalon 1&2, ERS-1&2, GfZ-1, GFO-1, WestPac, Champ.
Global Positioning System (GPS)	GPS satellites, TOPEX/Poseidon, Ultra Violet Explorer, MicroLab-1, Champ
Doppler Orbitography and Radio Positioning Integrated by Satellite (DORIS)	TOPEX/Poseidon
Precise Range and Range Rate Experiment (PRARE)	Meteor-3, ERS-2
Glonass	Glonass Satellites
Satellite Altimetry	TOPEX/Poseidon, Geosat, Geosat, Seasat (no longer exists), GEOS-3 (mission ended) Geosat-FO
Satellite Gradiometry / Gravity	Aristoteles, Superconducting Gravity Gradiometer Mission (SCGGM), Gravsat. (still to be launched)

Table 2 Space Geodetic techniques and the associated observed platform.

As discussed above the strength of a combined solution is based on the common and unique products each technique can contribute. Table 3 lists the products available from each of the techniques, both unique and common products, and the applications that utilise those products. Clearly, the combination of techniques will allow the common products to be significantly strengthened as a result.

SPACE GEODETIC PRODUCTS:

Technique	Unique Product	Common Product	Geo-science Contribution	Supports
VLBI	Celestial Reference Frame (Source position) Earth Rotation (UT1-UTC) Precession and Nutation	Polar Motion Terrestrial Reference Frame	Plate Tectonics Crustal Deformation Sea Level Monitoring	GPS, SLR, DORIS, PRARE, All Remote Sensing Satellites, All Communications Satellites through the CRF, EOP, Precession, Nutation.
SLR	Static Geopotential Model Dynamic Geopotential Centre of Mass (Geocentric Positions) Orbit Determination (of all satellites equipped with retroreflectors	Polar Motion Terrestrial Reference Frame UT1-UTC	Plate Tectonics, Crustal Deformation Sea Level Monitoring Earth Models (coefficients)	GPS, SLR, DORIS, PRARE, All Remote Sensing Satellites, All Communications Satellites through the TRF, Geopotential Model and EOP, Orbit determination to support Altimeter satellites.
GPS	Orbit Determination of GPS satellites Orbit Determination of other satellites with spaceborne GPS receivers Densification of the TRF	Polar Motion Terrestrial Reference Frame UT1-UTC	Plate Tectonics, Crustal Deformation Sea Level Monitoring GPS Meteorology	Co-location of VLBI and SLR sites Orbit determination to support Altimeter satellites, TRF to support All Remote Sensing Satellites, All Communications Satellites
DORIS	Orbit Determination	Terrestrial reference Frame		Obit Support for Altimetry, Sea Level Monitoring, Ocean Circulation
Altimetry	Global Ocean Tide Models Sea Surface Topography Gravity Anomalies over the oceans Ocean Circulation		Sea Level Monitoring Ocean Tide Site Deformation	Global Geopotential Models Region and Global geoid determination.
Gradiometry	Earth's gravity field		Sea Level Monitoring	Geoids

Table 3 Space Geodesy - Products

Although the combination of techniques does not form part of this report, it is an inherent component of reference frame definition. Readers are referred to Govind (1996), for a more comprehensive discussion of combination techniques and the contribution local ties make to this process.

4 Observation of Local Ties

A Leica TC2003 total station or equivalent (ie TC2001) was used for all horizontal angles, slope distances and Zenith angles. An instrument of this type was required because of its accuracy specifications, ie 1mm + 1ppm for distances and 1” horizontal and vertical angles. Factory calibration tests indicate the instrument actually achieves higher accuracy levels than these standards.

Where Zenith angles were to be used for vertical heighting, the height of the trunnion axis of the total station was determined by observing a levelling staff over a point with known height, with the vertical circle of the total station set to 90 degrees (horizontal). This determined the difference in height between the trunnion axis and the known point. The height of the instrument could then be determined. Further, if the instrument height above the current standpoint was required the difference in height between the current point and the known point used could be determined by differential levelling.

Forced centring was used to eliminate the introduction of setup errors wherever possible. A Zeiss Zenith Nadir Level precise optical plummet was used for all tripod setups, to ensure near zero plumbing errors were achieved. Additionally, wherever possible concrete pillars were used for instrument standpoints. This ensures setup stability during the often long observation periods when observations were taken to the antenna / telescope.

Observations were taken to the SLR telescope / VLBI antenna at a variety of horizontal and vertical settings to determine the location of the *telescope invariant point* (IVP). For the azimuth axis, targets were placed such that as large a radius as possible was achieved from the azimuth axis, and observed at regular intervals as the telescope was rotated through the full 360 degrees (See Figure 1).

For the vertical circle (elevation axes) retro-reflector tape targets were positioned on the side face of the telescope itself in the case of the SLR telescopes and on the bull gear of the VLBI antenna. Observations were taken from at least one instrument standpoint to each of these targets, at a regular interval of vertical rotation of the telescope, with the horizontal direction of the telescope locked perpendicular to the line of sight. The perpendicular setting was only required approximately to allow maximum reflection from the tape retro reflectors used for this survey.

A Leica NA3003 bar-code level and a fibreglass staff was used to carry Orthometric height through the control network. With the exception of the distant SLR calibration pillars at Yarragadee and Orroral, all monuments were levelled. The levelling results, in combination with AUSGeoid98 Geoid – Ellipsoid separations (N values) (Johnston and Featherstone, 1998) were used to transfer ellipsoidal height from the primary GPS monument throughout the network.

GPS baselines between significant and desirable monuments in each network were observed, usually over a five-day period. The baselines were used as a check on network scale and provided network orientation. In order to achieve the optimum level of accuracy, particularly in terms of height, identical antennas were used for all GPS observations, with the exception of the Hobart survey. The Hobart survey was completed using a combination of Leica antennae and a Dorne Margolin T (DMT) Antenna. To compensate for this, the appropriate antenna phase variation models were utilised in the GPS post-processing. Future surveys at this site should be completed with Dorne Margolin T (DMT) or equivalent antenna to eliminate the possibility of heighting errors caused by poor modelling of antenna phase centre variations.

Agreement at the 1mm level was obtained between the GPS baselines and terrestrial observations in the horizontal components. The vertical component usually agreed within 1-2mm, however on longer lines where the Geoid slope causes significant effects, slightly larger miscloses were encountered. The GPS was chosen as the more accurate of the two options in terms of transferring ellipsoidal height over distances greater than 100m.

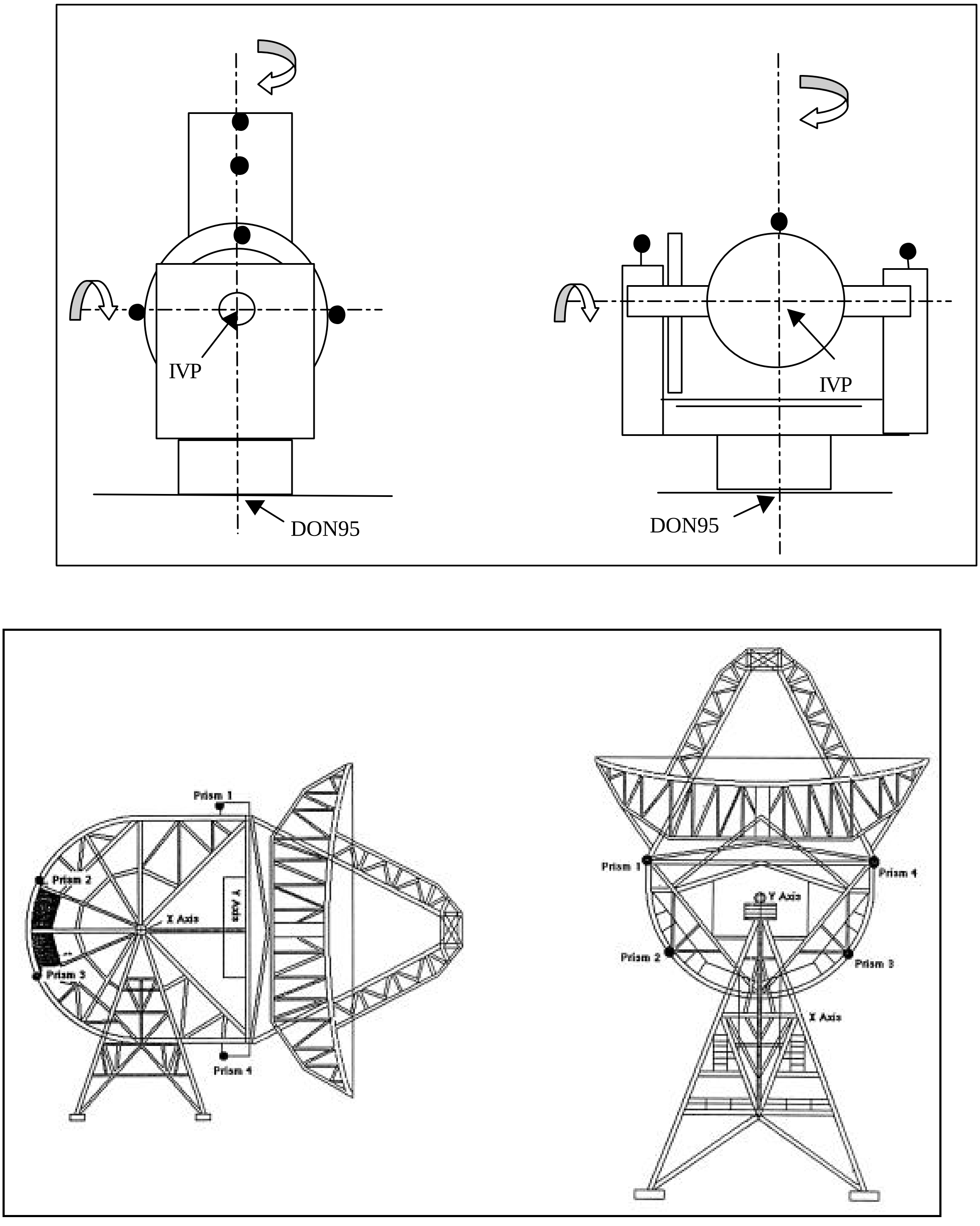

Figure 1 An example of target placement on a telescope and antenna for the IVP determination. The diagram at the top is the Moblas 5 SLR telescope at Yarragadee and Mt Pleasant VLBI Antenna near Hobart at the bottom.

5 Computation of the Telescope / Antenna IVP

Three-dimensional coordinate observations to targets on the structures observed during rotational sequences were used to determine the position and direction of the axes of rotation of the telescope. Each axis of rotation was determined during separate rotational sequences and their intersection point provides an estimate of the invariant point (IVP) of the structure.

A Least Squares method for the computation of the axes of rotation and their intersection was used. No assumptions of axis orthogonality or their precise intersection were made in the implementation of this method. Full variance-covariance information was carried through the computation process and provides a rigorous estimate of the precision of the estimated invariant point position. A separate supplementary publication to this technical report, which will be released later, will provide a full mathematical development of this approach.

6 Results

A comprehensive summary of the results for each site is contained in the relevant Appendix of this report for that site. These results include, for each point surveyed:

- Full point description.
- Latitude, Longitude and Ellipsoidal Height, with the associated standard deviations.
- Earth-centred Cartesian coordinates and the associated standard deviations.
- Three-dimensional Line Error ellipses between the fundamental point at each site and the other significant monuments.
- Comparisons where available, between vectors from this latest survey and previously adopted results at each site.
- Other site-specific information, such as the range to calibration targets etc.

The results listed for all sites are referred to ITRF97 @ 1997.0. This has been achieved by heavily constraining the coordinates for the primary GPS station at each site to the ITRF97 published values at epoch 1997.0.

A tabulation of the Earth-centred Cartesian vectors from the fundamental monument at each site to all other surveyed marks is given in sections 6.1 to 6.5. Also listed is the description of the invariant point of each of the telescopes, which is usually considered to be the fundamental point of each facility, although at Yarragadee it is the mark DON95 underneath the telescope that is actually the fundamental point.

6.1 Orroral SLR Observatory

Mirror 7: NLRS MIRROR 7 CDP 7843 DOMES 50103S007

The coordinated point is a point in space, close to the centre of the 152mm-diameter mirror at the northern end of the horizontal bearing of the telescope. This point is also known as Coude mirror 7. It is 111.2mm perpendicularly above the centre of the circular machined surface defining the lower opening of the mirror 7 housing. (See Appendix A)

From	To	Diff X (m)	Diff Y (m)	Diff Z (m)	Diff X STD (m)	Diff Y STD (m)	Diff Z STD (m)
NLRS Mirror 7	Rock Retro 1998	646.5620	617.3967	-717.9212	0.0128	0.0129	0.0120
NLRS Mirror 7	Pillar 2	20.4126	-2.9796	-13.0445	0.0013	0.0019	0.0011
NLRS Mirror 7	Pillar 3	2.9333	6.9688	13.7809	0.0012	0.0019	0.0011
NLRS Mirror 7	Doris Ground Mark	7.9617	-25.9687	-21.5762	0.0013	0.0018	0.0011
NLRS Mirror 7	Centre Mark Top level	2.6186	-1.5901	-0.6147	0.0013	0.0018	0.0010
NLRS Mirror 7	Dichroic	1.6392	-0.4270	-2.4868	0.0019	0.0020	0.0017
NLRS Mirror 7	Prime Vertical East	0.9452	-4.0590	-0.3905	0.0019	0.0020	0.0017
NLRS Mirror 7	Meridian South	3.9148	-2.3450	-2.7106	0.0014	0.0022	0.0012
NLRS Mirror 7	Prime Vertical West	4.5441	1.9047	-0.3859	0.0013	0.0020	0.0012
NLRS Mirror 7	Meridian North	2.0194	-1.2034	0.3742	0.0014	0.0019	0.0013
NLRS Mirror 7	AU005	-1.9930	-14.4302	-18.8317	0.0012	0.0018	0.0010
NLRS Mirror 7	DATUM LR1	2.4930	-1.4879	-0.3911	0.0014	0.0019	0.0011
NLRS Mirror 7	Spider Retro 1	2.9030	0.7267	-4.6622	0.0020	0.0021	0.0020
NLRS Mirror 7	Spider Retro 2	3.4110	1.3327	-3.6732	0.0021	0.0021	0.0020
NLRS Mirror 7	Centre Ground Mark	6.8525	-4.1416	2.9312	0.0016	0.0030	0.0015
NLRS Mirror 7	DORIS Antenna	6.2605	-24.9485	-23.0195	0.0017	0.0020	0.0015
NLRS Mirror 7	NM C 106	0.2789	-22.2562	-10.4227	0.0012	0.0018	0.0010
NLRS Mirror 7	NM C 107	638.0647	402.6738	-950.6165	0.0013	0.0018	0.0011
NLRS Mirror 7	NM C 107 RM1	639.5941	385.9596	-952.5881	0.0014	0.0030	0.0016
NLRS Mirror 7	NM C 107 RM2	649.5225	395.8997	-956.3844	0.0018	0.0020	0.0026
NLRS Mirror 7	NM C 107 RM3	639.2562	404.5300	-937.3775	0.0018	0.0024	0.0026
NLRS Mirror 7	AU017 (TIDB)	-14519.0412	4430.0674	21807.5599	0.0017	0.0020	0.0014

Table 4 Orroral SLR NLRS Mirror 7

6.2 Mt Stromlo SLR Observatory

IVP Stromlo SLR: Domes 50119S001 CDP7849. The Coordinated point is the intersection of the azimuth axis and elevation axis of rotation of the Mt Stromlo Satellite Laser Ranging telescope. (See Appendix B)

From	To	Diff X (m)	Diff Y (m)	Diff Z (m)	Diff X STD (m)	Diff Y STD (m)	Diff Z STD (m)
IVP	TRIG	-25.6903	-50.8684	-1.3281	0.0008	0.0011	0.0006
IVP	AU017	6067.5192	-477.4043	-7436.3228	0.0017	0.0013	0.0014
IVP	AU045	-10.7687	-22.6353	-0.7403	0.0005	0.0008	0.0005
IVP	AU046	-38.5865	4.9108	57.6658	0.0007	0.0009	0.0008
IVP	AU047	-38.1109	-36.1832	14.3892	0.0006	0.0008	0.0006
IVP	AU048	8.4002	-91.7154	-72.5168	0.0007	0.0009	0.0007
IVP	AU049	44.4050	22.8847	-20.6290	0.0006	0.0009	0.0006
IVP	AU050	-9.0864	-3.7892	10.4865	0.0006	0.0011	0.0007
IVP	AU052	-38.7148	4.9877	57.5612	0.0006	0.0008	0.0005
IVP	AU054	9.9551	15.6292	8.5014	0.0006	0.0008	0.0005
IVP	AU055	-10.4791	0.1841	22.3317	0.0006	0.0008	0.0005
IVP	AU056	3.2893	-1.9767	2.7170	0.0007	0.0008	0.0008
IVP	DORIS	-4.4647	-4.3871	3.3729	0.0007	0.0012	0.0006
IVP	HPGPS	-9.0547	-3.8323	10.1967	0.0006	0.0011	0.0007
IVP	SR1526	7.9789	-3.0233	-2.1831	0.0006	0.0008	0.0005
IVP	GPSTIME	-9.0040	-3.6591	10.2287	0.0006	0.0011	0.0007

Table 5 IVP Stromlo SLR

6.3 Yarragadee SLR Observatory

Moblas 5 IVP: Domes 50107S007. The coordinated point is the intersection of the azimuth axis and elevation axis of rotation of the Yarragadee Satellite Laser Ranging telescope.

DON95 RM4 (YAR1): 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. (See Appendix C)

From	To	Diff X (m)	Diff Y (m)	Diff Z (m)	Diff X STD (m)	Diff Y STD (m)	Diff Z STD (m)
DON95 RM4	Cal Pillar 1	-1421.8020	943.1000	2608.5370	0.0021	0.0036	0.0024
DON95 RM4	Cal Pillar 2	-45.7443	60.0214	133.1289	0.0027	0.0017	0.0007
DON95 RM4	Cal Pillar 3	-21.4081	46.8581	91.2024	0.0017	0.0011	0.0005
DON95 RM4	Cal Target 1	-1421.8414	943.1600	2608.5315	0.0021	0.0036	0.0024
DON95 RM4	Cal Target 2	-45.7764	60.0880	133.1275	0.0027	0.0017	0.0007
DON95 RM4	Cal Target 3	-21.4444	46.9200	91.1955	0.0017	0.0011	0.0005
DON95 RM4	DON95 RM1	8.0603	19.0774	25.3532	0.0004	0.0004	0.0003
DON95 RM4	DON95 RM2	14.0499	15.3224	14.2797	0.0003	0.0004	0.0003
DON95 RM4	DON95 RM3	10.5622	7.0984	3.3079	0.0002	0.0004	0.0003
DON95 RM4	YARR (AU053)	1.0345	-1.5146	-3.4244	0.0002	0.0004	0.0002
DON95 RM4	DON38	65.2076	-10.3828	-70.2796	0.0003	0.0004	0.0003
DON95 RM4	DON95 (7090)	18.6120	12.4676	5.8413	0.0003	0.0004	0.0003
DON95 RM4	DORIS GM	22.4318	21.9883	18.7344	0.0004	0.0004	0.0004
DON95 RM4	DON38 RM1	71.9793	-10.8463	-75.7179	0.0003	0.0004	0.0003
DON95 RM4	DON38 RM2	65.9427	-5.4488	-62.2257	0.0003	0.0004	0.0003
DON95 RM4	DON38 RM3	57.1526	-15.3867	-71.9750	0.0003	0.0004	0.0003
DON95 RM4	DON38 RM4	65.2983	-13.0982	-74.2891	0.0003	0.0004	0.0003
DON95 RM4	DON38_2	101.5231	36.8556	-18.2966	0.0013	0.0005	0.0010
DON95 RM4	GPSTIME	32.8852	19.8346	-1.7300	0.0004	0.0005	0.0007
DON95 RM4	DORIS (A)	21.6385	23.7298	17.6478	0.0004	0.0004	0.0004
DON95 RM4	DORIS (B)	21.5078	23.9381	17.5397	0.0005	0.0005	0.0005
DON95 RM4	Moblas 5 IVP	17.4072	14.9695	4.2896	0.0009	0.0011	0.0009

Table 6 DON95 RM4 (YAR1):

6.4 Tidbinbilla Deep Space Tracking Station

DSS45 IVP, DOMES 50103S010, TIDBINBILLA. A 34 metre Azimuth-Elevation radio telescope. The coordinated point is the orthogonal projection of the vector defining the elevation axes onto the Azimuth axes. The elevation and azimuth axes do not intersect.

AU017, DOMES 50103M108, TIDBINBILLA AFN. A Small drill hole in the centre of the top of a stainless steel pillar plate that is set in the top of a 0.6 metre diameter reinforced concrete pillar. This pillar is set into the ground to a depth of 2.5 metres and protrudes 0.5 metres above ground level. The pillar plate bears the inscription: "TIDBINBILLA SPC-40 GPS STATION MARK JPL 4002-S 1992". (See Appendix D)

From	To	Diff X (m)	Diff Y (m)	Diff Z (m)	Diff X STD (m)	Diff Y STD (m)	Diff Z STD (m)
AU017 TIDB	AU031 NORTH	25.5478	192.5528	114.8709	0.0007	0.0005	0.0006
AU017 TIDB	AU032 SOUTH	124.3695	235.6789	34.2905	0.0007	0.0006	0.0006
AU017 TIDB	DSS45 IVP	60.7284	208.6318	62.4956	0.0034	0.0036	0.0036
AU017 TIDB	NMC 194	-19.3991	162.6994	145.1294	0.0007	0.0005	0.0006
AU017 TIDB	TID M5	-19.9504	-211.4005	-129.8039	0.0061	0.0026	0.0063

Table 7 AU017 TIDB

6.5 Mt Pleasant Radio Telescope Observatory

IVP (Domes 50116S002.). 26m Radio Telescope. The coordinated point is the orthogonal projection of the vector defining the Y-axes onto the X-axes. The Y and X-axes do not intersect.

AU016 (HOB2): Domes 50116M004. The intersection of the top of the stainless steel plate with the vertical axis of a 5/8"*f* Whitworth threaded stainless steel spigot. The pillar plate is set into the top of a 0.5m high concrete pillar 0.6m in diameter. The Dorne Margolin T - GPS antenna currently occupies this monument. (See Appendix E)

From	To	Diff X (m)	Diff Y (m)	Diff Z (m)	Diff X STD (m)	Diff Y STD (m)	Diff Z STD (m)
AU016	IVP	-165.3730	-67.6194	75.8229	0.0024	0.0023	0.0024
AU016	ST55	-4408.4601	-2039.9687	2485.9901	0.0232	0.0131	0.0283
AU016	171/5	-3082.9924	2773.2708	4127.8746	0.0239	0.0159	0.0261
AU016	ST55E	-4407.5631	-2030.7618	2491.5581	0.0231	0.0148	0.0270
AU016	UF003	-185.3269	-54.8709	122.1375	0.0017	0.0019	0.0019
AU016	UF005	-121.5732	-16.5918	84.5781	0.0016	0.0015	0.0016
AU016	498/100	-82.8834	-10.4404	57.7779	0.0018	0.0022	0.0019
AU016	SPRENTRO	635.4320	1161.0876	88.3830	0.0368	0.0235	0.0468
AU016	50116M003	-112.7198	-50.7301	50.1903	0.0007	0.0006	0.0008

Table 8 AU016 (HOB2)

7 Conclusion

The connections between space geodetic techniques at the five Australian geodetic observatories have been completed within the required accuracy standards. Line error ellipses resulting from the GEOLAB adjustments indicate the accuracy estimates are in the order of 1-2mm at 95% confidence. The resultant Solution Independent Exchange Format (SINEX) files for each site have been submitted to the International Earth Rotation Service for inclusion in ITRF2000. These files contain the full three dimensional Earth-centred Cartesian coordinate results for the survey with the associated variance-co-variance information.

In order to monitor the stability of these connections and also obtain an estimate of survey accuracy resurvey of these sites need to be completed in the coming year, particularly Tidbinbilla and Hobart since the observations for the current survey results were taken in 1995. In addition, differences noted in the height difference at Yarragadee between DON95 and DON95 RM4 from the previous survey need to be more closely examined through further survey.

8 References

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9 Acknowledgments

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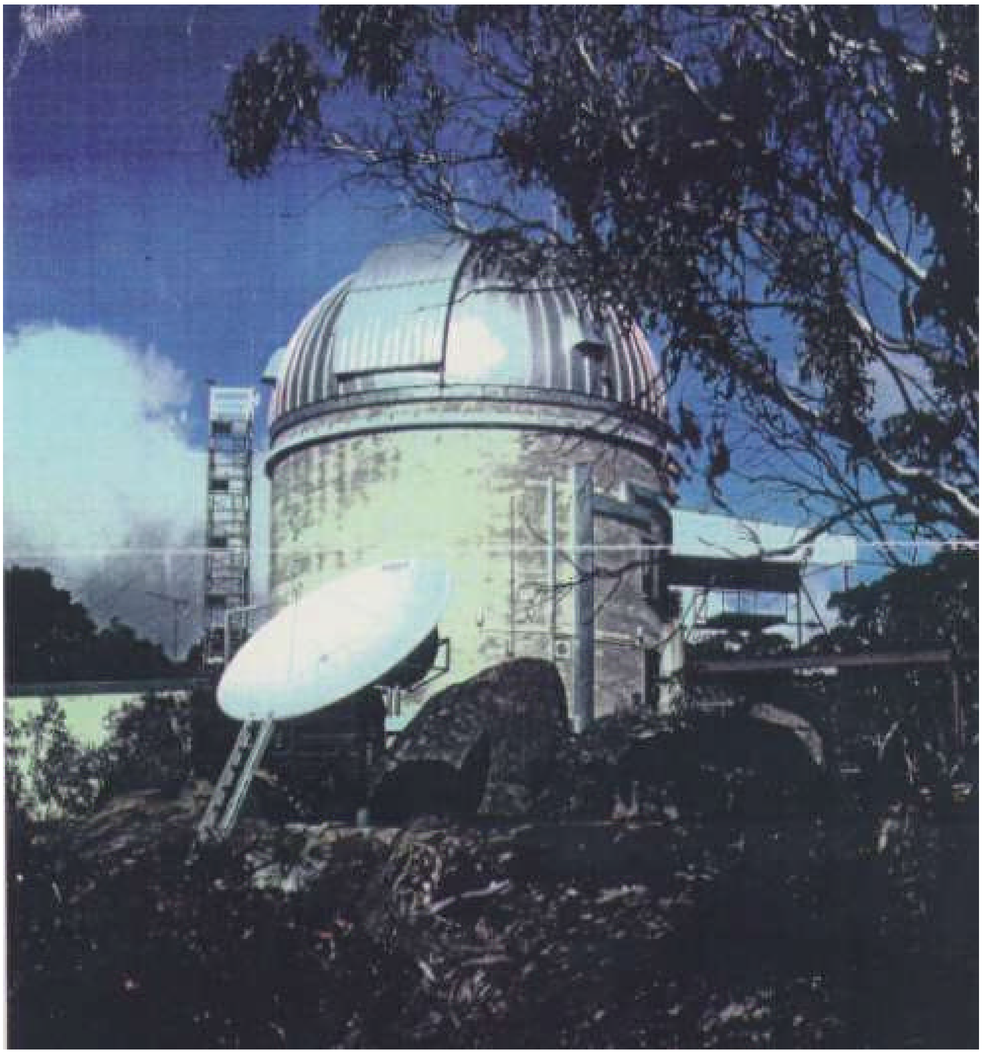
In addition, the contribution of Nick Bowden of the Department of Primary Industries, Water and Land Environment, Tasmania to the 1995 survey of the Mount Pleasant, and on a variety of occasions since, is acknowledged.

We also acknowledge the contribution of Brian Murphy, formerly of AUSLIG, to the surveys of Tidbinbilla and Mt Pleasant.

Appendix A



Orroral Laser Ranging Observatory
Local Tie Survey
September 1998

Introduction

The final local tie survey at Orroral observatory was completed in November 1998. This survey was completed for the purpose of verifying that no local movement has occurred and that the tie between the SLR reference point and the GPS reference point is as published in the IERS local tie files.

Connections to other significant monuments at Orroral have been completed. Not all monuments referred to in the NGDB Orroral facility report have been connected to in this most recent survey. Good agreement at the 1-2mm level was achieved with the previous surveys, by Brian Murphy (1988) and Peter Murphy (1989).

Observations

A Leica TC2003 Total Station was used for all horizontal angles, slope distances and vertical angles. Where vertical angles were used for vertical heighting, the Rueger method (Rueger, J.M., 1996) was used to determine the height of the trunnion axis of the total station. The Rueger method consists of observing a levelling staff, over a point with known height, with the vertical circle of the total station set to 90 degrees (horizontal). These observations were completed in mid October.

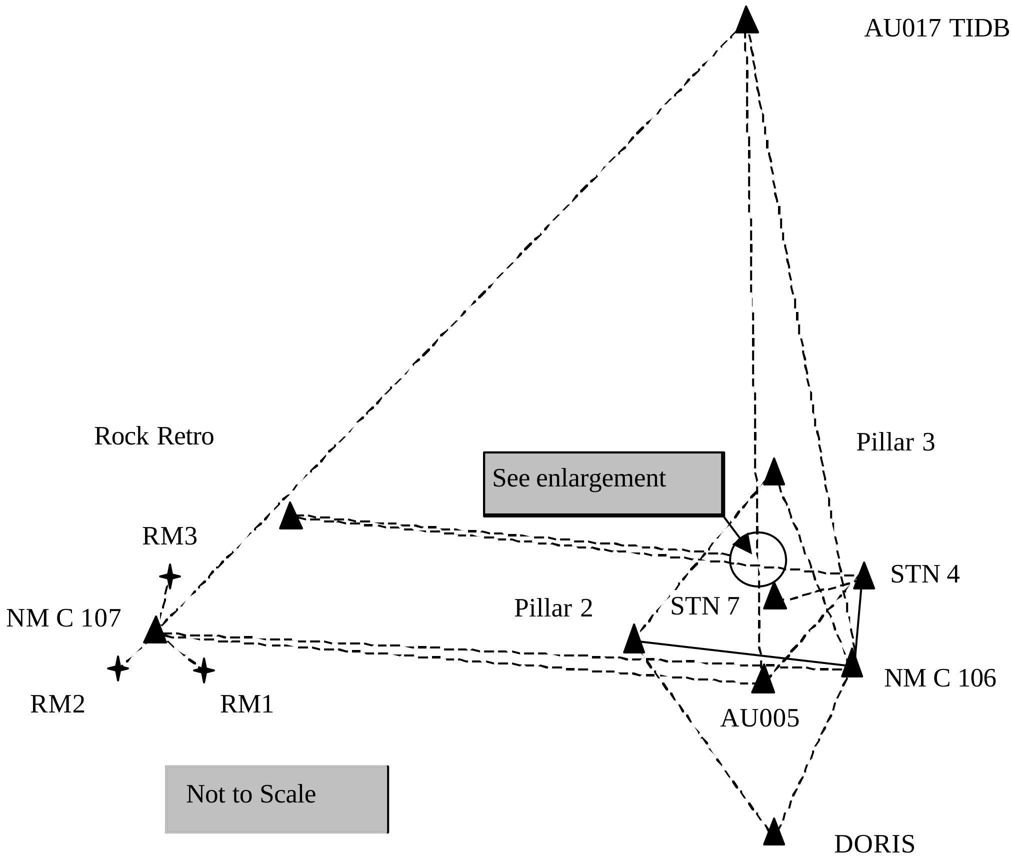
Three independent level runs were completed at Orroral as part of this survey. The first used a Leica NA3003 bar-code level (with aluminium staff) to carry Orthometric height through the control network. It was completed in mid October. Subsequent levelling was carried out using the Topcon DL-101C digital level with fibreglass staff and later with the calibrated invar staves. All three level runs were adjusted using the Topcon TCLEV Leastsquares adjustment software. The adjustment results are attached to file F98/752. The repeat surveys connected to additional monuments and added redundancy to the first.

AU005 (orr1) had an Ashtech Z12 GPS receiver (and Dorne Margolin T antenna) operating on it (see ORRO.log) in a continuous tracking mode. A second Ashtech Z12 GPS receiver and DMT antenna was placed on NMC 107 for one day (day 309 1998) then NMC 106 for another eight days (days 310-318 1998). This data was processed with data from AU017 (TIDB) for the full ten day period (see processing report on file F98/752).

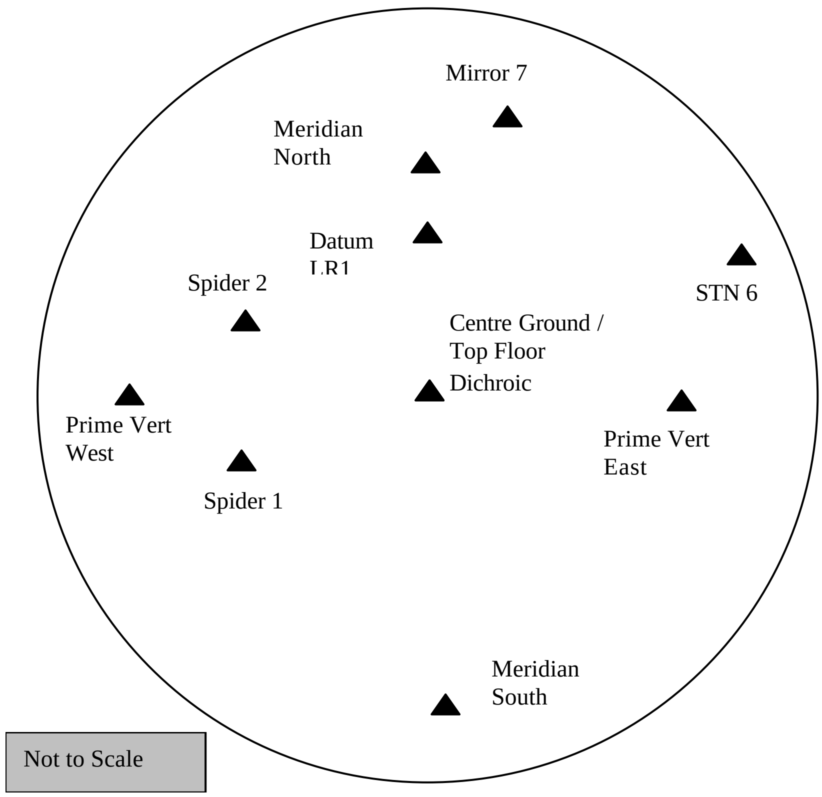
Datum

AU017 (TIDB) has been held fixed at its ITRF97 @ 1997.0 values. The resulting co-ordinates for AU005, NM C 107 and NM C 106 provide orientation for the local terrestrial survey in terms of ITRF97. The GRS80 ellipsoid has been adopted.

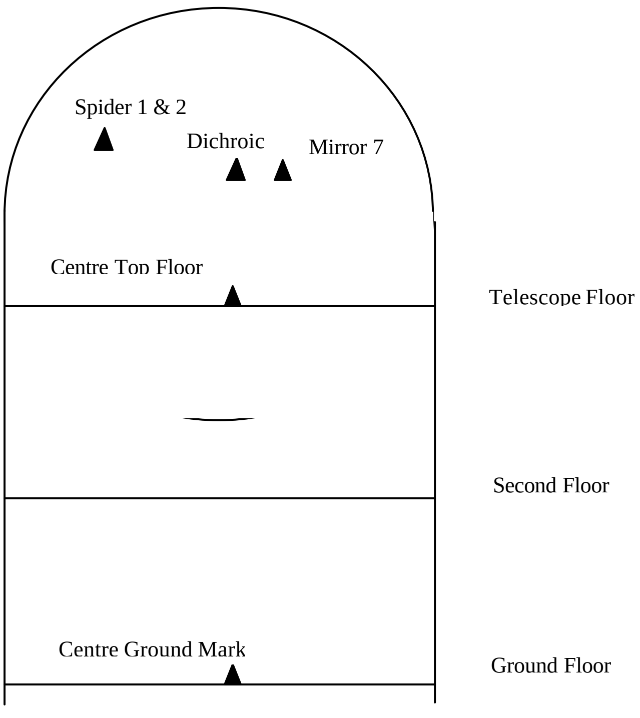
Orthometric heights were calculated at NM C 106 using the ellipsoidal height from the GPS baselines and AUSGEOID98 N values. Orthometric height (see Table A1) was then transferred using the Digital level mentioned above. AUSGeoid98 N values were used at all stations to reconstitute ellipsoidal heights in the adjustment.



Appendix A Figure 1 Orroral Observatory - local tie survey



Appendix A Figure 2 Orroral Observatory - Enlargement



Appendix A Figure 3 Orroral Observatory - elevation

Reductions

All observations were reduced to a grand mean per set and reformatted to the standard GEOLAB format. All distances were reduced for atmospherics (first and second velocity corrections) using the model supplied in the “Supplement to TC2002/T3000 Operator's Manual” as follows:

$$\Delta D_1 = 281.8 - \left[\frac{0.29065p}{(1+\alpha t)} - \frac{4.126 \cdot 10^{-4} \cdot h}{(1+\alpha t)} \cdot 10^{x} \right]$$

Where

$\Delta D_1 =$	Atmospheric correction in ppm
$P =$	Atmospheric pressure (mb)
$t =$	Ambient temperature (°C)
$h =$	Relative humidity (%)
$\alpha =$	1/273.16

$$x = \frac{7.5t}{237.3 + t} + 0.7857$$

They were also reduced for prism offsets, which in the case of the Leica precision prism is 0.000m.

Where height of instrument and/or height of target were not observed these values were calculated to reflect the observed vertical angles.

Observed distances (corrected for atmospherics and prism corrections) have been entered into the GEOLAB data file. No other reductions have been applied i.e. no reductions to the ellipsoid outside the adjustment software. True heights of instrument and target have been used with the associated Orthometric heights of the ground mark in all cases except where short steep observed lines have been observed into the Dichroic mirror, spider retros and mirror 7. These lines are unnecessarily weakened by the software's reduction to ground mark to ground mark observations from instrument to target distances due to the steepness of the lines. In this case, the height of the ground mark is given as being 1.6m above the actual ground mark to minimise this correction.

Problems Encountered

For the long line observations up to NMC 107 and Rock Retro, atmospherics were only recorded at one end of the line, namely at the observatory. It was impractical to observe atmospherics at the other end over a four-day period.

Reciprocal vertical angles were not observed over the long lines to determine the relevant refractive index for vertical heighting. The technique of reciprocal verticals for this purpose is very sensitive to station height errors and should only be used over considerably longer lines. A refractive index of $1+13*10^{-6}$ has been adopted for computation of the height at Rock Retro using single ended vertical angles.

Some discrepancy existed between Leica factory calibration certificates and the results obtained from the Watson calibration baseline. The Leica factory results yield a 0.2mm instrument offset when coupled with Leica precision prisms. The Watson baseline yields a 1.5mm offset and 5ppm scale error. These results are far outside the expected accuracy of the instrument and are most likely caused by incorrect atmospheric reading along the length of the baseline, or baseline deformation. The Watson EDM baseline was re-observed and calibrated in February 1999. After this re-calibration, the results for the TC2003 now agree with the factory results within the standard deviation of the baseline results. The results obtained from the factory have been adopted for this survey.

Station Descriptions

NM C 106: NLRS PILLAR 1 NSW 5662

[NGDB Sequence No.: 12272]

Kern Type 17153A brass centre mark in the form of a cup set in the top of steel encased reinforced concrete pillar. A brass protecting cap covers the centre mark. The co-ordinated point is the centre of the mark and the height refers to the top of the mark, with the cap removed. With the cap removed, the centre mark is 10 mm below the top of the concrete pillar. (See diagram in Attachment 6)

Pillar 2: NLRS PILLAR 2, ORRORAL

[NGDB Sequence No.: 5782]

Kern Type 17153A brass centre mark in the form of a cup set in the top of steel encased reinforced concrete pillar. A brass protecting cap covers the centre mark. The co-ordinated point is the centre of the mark and the height refers to the top of the mark, with the cap removed. (See diagram in Attachment 6)

Pillar 3: NLRS PILLAR 3, ORRORAL

[NGDB Sequence No.: 4417]

Kern Type 17153A brass centre mark in the form of a cup set in the top of steel encased reinforced concrete pillar. A brass protecting cap covers the centre mark. The co-ordinated point is the centre of the mark and the height refers to the top of the mark, with the cap removed. (See diagram in Attachment 6)

Centre Ground Mark: AU 011 DOMES 50103M106

[NGDB Sequence No.: 4934]

Small centre-punch mark in the centre of a triangular copper plate set in the concrete ground floor of the Orroral Geodetic Observatory.

Datum: DATUM LR1, ORRORAL

[NGDB Sequence No.: 8712]

4mm hole drilled in the centre of 15mm stainless steel hexagonal bolt, the top of which is set flush in the concrete top floor of the Orroral Geodetic Observatory. A rectangular aluminium plate (65 x 35 mm) stamped DATUM LR1, is screwed to the floor 40 mm north of this bolt. This point is 2.779 metres vertically below the point known as LLR.

Mirror 7: NLRS MIRROR 7 CDP 7843 DOMES 50103S007

[NGDB Sequence No.: 8713]

1.5 metre X-Y mounted astronomical laser ranging telescope. This facility commenced operation in September 1984. The co-ordinated point is a point in space, close to the centre of the 152mm diameter mirror at the northern end of the horizontal bearing of the telescope. This point is also known as Coude mirror 7. It is 111.2mm perpendicularly above the centre of the circular machined surface defining the lower opening of the mirror 7 housing. (See diagram in Attachment 7)

AU005: AU005 DOMES 50103M107 ORR T2

[NGDB Sequence No.: 23032]

The intersection of the vertical axis of a 5/8" Whitworth threaded steel stub, with the horizontal plane coinciding with the top face of a circular steel mounting plate, to which the steel stub is attached. The mounting plate is attached to the top of the northeastern corner of the truncated collimation tower at the Orroral Geodetic Observatory, and was established in February 1991.

DORIS GM: DORIS GROUND MARK, ORRORAL

[NGDB Sequence No.: 23036]

A Doppler Orbitography and Radar positions Integrated by Satellite (DORIS) antenna is mounted over this mark. Centre punch mark in the top of a 10mm diameter brass rod, set in the top of a large granite boulder.

Dichroic: NLRS DICHROIC 1989, ORRORAL

[NGDB Sequence No.: 40719]

Centre of the tertiary mirror, which is inclined at 45 degrees to the NLRS telescope axes. The position of the Dichroic was measured when the NLRS telescope was pointed at the calibration Retro corner cube reflector. In 1988 John Luck defined the centre of the Dichroic mirror by placing a 2mm white spot at the nominal intersection of the mirror surface and the inner mechanical axis. This white dot was re-observed in 1998.

Meridian North: NLRS MERIDIAN NORTH, ORRORAL

[NGDB Sequence No.: 40727]

Small centre-punch mark in a rectangular aluminium plate (115 x 40 mm) screwed to the top floor of the observatory. The plate is stamped MERIDIAN NORTH.

Meridian South: NLRS MERIDIAN SOUTH, ORRORAL

[NGDB Sequence No.: 40729]

Small centre-punch mark in a rectangular aluminium plate (115 x 40 mm) screwed to the top floor of the observatory. The plate is stamped MERIDIAN SOUTH.

Rock Retro: CALIBRATION RETRO 1989, ORRORAL

[NGDB Sequence No.: 40730]

A solid corner cube retro reflector fixed with epoxy resin to a large granite tor about 1100 metres to the south west of the Observatory. The reference point for the corner cube is the effective point of measurement of the 532nm wavelength used by the NLRS. In 1989, this point was 3.1 mm behind the rear face of the corner cube mount.

Spider Retro 1: NLRS SPIDER RETRO 1, ORRORAL

[NGDB Sequence No.: 40733]

20mm diameter solid retro reflector mounted in a black tube (labelled '1') on the spider vanes which support the NLRS telescope's secondary mirror. The position refers to the effective point of measurement for the 532 nm wavelength, with the NLRS telescope pointing at the Calibration Retro. In 1989, this point was 160.1 mm behind the front face of the removable front cap of the corner cube mount. (See Attachment 2.)

Spider Retro 2: NLRS SPIDER RETRO 2, ORRORAL

[NGDB Sequence No.: 40734]

20mm diameter solid retro reflector mounted in a black tube (labelled '2') on the spider vanes which support the NLRS telescope's secondary mirror. The position refers to the effective point of measurement for the 532nm wavelength, with the NLRS telescope pointing at the Calibration Retro. In 1989, this point was 155.9mm behind the front face of the removable front cap of the corner cube mount. (See Attachment 2.)

DORIS Antenna: DORIS ANTENNA, ORRORAL, DOMES 50103S202

[NGDB Sequence No.: 40747]

Doppler Orbitography and Radar positions Integrated by Satellite (DORIS) antenna.

The DORIS antenna in place at the time of this survey was of “Type B”. The co-ordinated reference point of the antenna is the intersection of the vertical axis of the antenna with the plane marked by a painted ring around the antenna mid way up it vertical extent.

Results

Station	Adjusted Orthometric Heights (m)
CENTRE GROUND MARK	1322.1674
COLLIMATION MARK	1319.7588
DATUM LR1	1328.2510
DORIS GROUND MARK	1326.5216
MERIDIAN NORTH	1328.2541
MERIDIAN SOUTH	1328.2531
MIRROR 7	1330.3824
MIRROR 7 BASE OF HOUSING	1330.2712
NM V C 223	1322.7374
NM V C 224	1321.4047
NM V C 225	1321.2928
NM V C 226	1321.9115
NM V C 227	1321.8854
NM V C 228	1321.8565
NMC 106	1326.9286
NMC 106 PILLAR PLATE	1326.9386
PILLAR 2	1322.5220
PILLAR 2 PLATE	1322.5310
PILLAR 3	1323.2333
PILLAR 3 PLATE	1323.2443
PRIME VERTICAL EAST	1328.2501
PRIME VERTICAL WEST	1328.2426
STAINLESS STEEL BOLT FOR RUEGER HEIGHTS	1328.7507
STATION 4	1324.6747
STATION 6	1328.2562
WALL BRACKET PIN FOR RUEGER HEIGHTS	1328.7507

Appendix A Table 1 Adjusted orthometric heights resulting from levelling observations. The Datum is the ellipsoidal (GRS80) height minus AUSGeoid98 N value at NM C 106.

Station	AUSGeoid98 N Value (m)
All Stations at Observatory	19.553
NM C 107 and RM's	19.563
Rock Retro	19.565
AU017 (TIDB)	19.283

Appendix A Table 2 AUSGeoid98 geoid – ellipsoid separations used in this adjustment.

Station	Lat	Long	Ellipsoidal height (m)	STD LAT (m)	STD Long (m)	STD HEIGHT (m)
Rock Retro 1998	S35 38 33.88022	E148 55 47.25452	1577.0740	0.0139	0.0140	0.0092
Pillar 2	S35 38 11.21060	E148 56 21.21103	1342.0752	0.0004	0.0006	0.0012
Pillar 3	S35 38 10.12335	E148 56 21.23075	1342.7864	0.0007	0.0006	0.0012
Station 4	S35 38 10.57257	E148 56 22.08999	1344.2276	0.0005	0.0003	0.0011
Doris Ground Mark	S35 38 11.45813	E148 56 22.24884	1346.0746	0.0006	0.0003	0.0012
Station 6	S35 38 10.52264	E148 56 21.64719	1347.8093	0.0005	0.0004	0.0011
Station 7	S35 38 10.67029	E148 56 21.68806	1341.7204	0.0007	0.0014	0.0012
Center Mark top level	S35 38 10.58125	E148 56 21.52854	1347.8040	0.0006	0.0005	0.0012
Station 9	S35 38 10.66558	E148 56 21.48731	1349.3040	0.0009	0.0009	0.0012
Station 10	S35 38 10.64448	E148 56 21.44864	1349.3040	0.0008	0.0009	0.0012
Station 11	S35 38 10.60473	E148 56 21.39108	1349.3040	0.0008	0.0009	0.0012
Station 12	S35 38 10.49985	E148 56 21.43763	1349.3040	0.0010	0.0009	0.0012
Mirror 7	S35 38 10.50714	E148 56 21.52810	1349.9357	0.0012	0.0020	0.0014
Dichroic Mirror	S35 38 10.60341	E148 56 21.50903	1350.0643	0.0014	0.0014	0.0013
Prime Vertical East	S35 38 10.57232	E148 56 21.64689	1347.8031	0.0018	0.0017	0.0012
Meridian South	S35 38 10.66486	E148 56 21.52767	1347.8061	0.0011	0.0015	0.0012
Prime Vertical West	S35 38 10.57231	E148 56 21.37010	1347.7956	0.0010	0.0013	0.0012
Meridian North	S35 38 10.54170	E148 56 21.52767	1347.8071	0.0012	0.0011	0.0012
AU005	S35 38 11.11208	E148 56 22.06017	1356.2444	0.0004	0.0002	0.0012
Datum LR1	S35 38 10.57232	E148 56 21.52764	1347.8040	0.0009	0.0011	0.0012
Spider Retro 1	S35 38 10.66996	E148 56 21.44384	1350.9353	0.0021	0.0015	0.0015
Spider Retro 2	S35 38 10.64621	E148 56 21.41279	1350.2597	0.0021	0.0017	0.0015
Station 24	S35 38 10.64276	E148 56 21.58371	1349.3040	0.0011	0.0013	0.0012
Station 25	S35 38 10.56059	E148 56 21.48412	1349.3040	0.0010	0.0011	0.0012
Center Ground Mark	S35 38 10.58119	E148 56 21.52859	1341.7204	0.0015	0.0024	0.0012
Doris Antenna	S35 38 11.45869	E148 56 22.24899	1348.5276	0.0007	0.0003	0.0021
NMC 106	S35 38 11.00348	E148 56 22.27998	1346.4816	0.0004	0.0002	0.0011
NMC 107	S35 38 41.97145	E148 55 54.73765	1628.5383	0.0004	0.0003	0.0012
NMC RM1	S35 38 42.21124	E148 55 55.27523	1621.6133	0.0014	0.0024	0.0012
NMC RM2	S35 38 42.37511	E148 55 54.73326	1621.0833	0.0029	0.0003	0.0012
NMC RM3	S35 38 41.62365	E148 55 54.65003	1620.7722	0.0030	0.0007	0.0012
AU017 (TIDB)	S35 23 57.15172	E148 58 47.98741	665.3657	0.0001	0.0001	0.0001

Appendix A Table 3 Co-ordinates are in terms of ITRF97 at 1997.0 on the GRS80 ellipsoid. Standard Deviations are one sigma.

Station	X (m)	Y (m)	Z (m)	STD X (m)	STD Y (m)	STD Z (m)
Rock Retro 1998	-4445830.5250	2678744.4160	-3696969.1980	0.0128	0.0128	0.0121
Pillar 2	-4446456.6744	2678124.0397	-3696264.3213	0.0009	0.0007	0.0007
Pillar 3	-4446474.1537	2678133.9881	-3696237.4959	0.0009	0.0008	0.0009
Station 4	-4446479.4018	2678111.9068	-3696249.5904	0.0008	0.0006	0.0008
Doris Ground Mark	-4446469.1253	2678101.0506	-3696272.8530	0.0009	0.0006	0.0008
Station 6	-4446476.9143	2678123.4169	-3696250.4262	0.0009	0.0006	0.0008
Station 7	-4446470.9343	2678118.6143	-3696250.5778	0.0012	0.0012	0.0009
Centre Mark Top level	-4446474.4684	2678125.4292	-3696251.8915	0.0009	0.0007	0.0008
Station 9	-4446473.6799	2678126.1657	-3696254.8782	0.0010	0.0010	0.0010
Station 10	-4446473.5023	2678127.1948	-3696254.3497	0.0010	0.0009	0.0010
Station 11	-4446473.3666	2678128.8040	-3696253.3538	0.0010	0.0009	0.0009
Station 12	-4446475.5847	2678128.7724	-3696250.7260	0.0011	0.0009	0.0011
Mirror 7	-4446477.0870	2678127.0193	-3696251.2768	0.0015	0.0018	0.0013
Dichroic	-4446475.4478	2678126.5923	-3696253.7636	0.0015	0.0012	0.0014
Prime Vertical East	-4446476.1418	2678122.9603	-3696251.6673	0.0018	0.0012	0.0017
Meridian South	-4446473.1722	2678124.6743	-3696253.9874	0.0012	0.0015	0.0011
Prime Vertical West	-4446472.5429	2678128.9240	-3696251.6627	0.0011	0.0013	0.0011
Meridian North	-4446475.0676	2678125.8159	-3696250.9026	0.0012	0.0010	0.0012
AU005	-4446479.0800	2678112.5891	-3696270.1085	0.0008	0.0005	0.0007
DATUM LR1	-4446474.5940	2678125.5314	-3696251.6679	0.0011	0.0010	0.0010
Spider Retro 1	-4446474.1840	2678127.7460	-3696255.9390	0.0018	0.0014	0.0019
Spider Retro 2	-4446473.6760	2678128.3520	-3696254.9500	0.0020	0.0014	0.0019
Station 24	-4446475.2827	2678124.2990	-3696254.3065	0.0012	0.0011	0.0011
Station 25	-4446475.2537	2678127.2073	-3696252.2480	0.0011	0.0011	0.0011
Centre Ground Mark	-4446470.2345	2678122.8777	-3696248.3456	0.0013	0.0024	0.0014
DORIS Antenna	-4446470.8265	2678102.0708	-3696274.2963	0.0015	0.0009	0.0013
NM C 106	-4446476.8081	2678104.7631	-3696261.6995	0.0008	0.0005	0.0007
NM C 107	-4445839.0223	2678529.6931	-3697201.8933	0.0009	0.0005	0.0007
NM C 107 RM1	-4445837.4929	2678512.9789	-3697203.8649	0.0011	0.0024	0.0014
NM C 107 RM2	-4445827.5645	2678522.9190	-3697207.6612	0.0015	0.0009	0.0026
NM C 107 RM3	-4445837.8308	2678531.5493	-3697188.6543	0.0016	0.0017	0.0024
AU017 (TIDB)	-4460996.1282	2682557.0867	-3674443.7169	0.0001	0.0001	0.0001

Appendix A Table 4 Earth Centred Cartesian co-ordinates in terms of ITRF97 at 1997.0. Standard Deviations are one sigma.

From	To	Diff X (m)	Diff Y (m)	Diff Z (m)
NLRS MIRROR 7	AU017	-14519.0412	4430.0674	21807.5599
		-14519.0730	4430.0850	21807.5380
NLRS MIRROR 7	NMC 106	0.2789	-22.2562	-10.4227
	1989	0.2790	-22.2570	-10.4230
NLRS MIRROR 7	NMC 107	638.0647	402.6738	-950.6165
NLRS MIRROR 7	DATUM LR1	2.4930	-1.4879	-0.3911
	1989	2.4910	-1.4860	-0.3930
NLRS MIRROR 7	MERIDIAN NORTH	2.0194	-1.2034	0.3742
	1989	2.0180	-1.2020	0.3740
NLRS MIRROR 7	MERIDIAN SOUTH	3.9148	-2.3450	-2.7106
	1989	3.9130	-2.3430	-2.7140
NLRS MIRROR 7	PILLAR 2	20.4126	-2.9796	-13.0445
	1989	20.4120	-2.9770	-13.0480
NLRS MIRROR 7	PILLAR 3	2.9333	6.9688	13.7809
	1989	2.9280	6.9740	13.7780
NLRS MIRROR 7	ROCK RETRO 98	646.5620	617.3967	-717.9212
	1989	646.5870	617.3830	-717.9030
NLRS MIRROR 7	AU005 ORR1	-1.9930	-14.4302	-18.8317
	1989	-1.9940	-14.4230	-18.8400
NLRS MIRROR 7	PRIME VERT EAST	0.9452	-4.0590	-0.3905
NLRS MIRROR 7	PRIME VERT WEST	4.5441	1.9047	-0.3859
NLRS MIRROR 7	SPIDER 1	2.9030	0.7270	-4.6620
	1989	2.9010	0.7310	-4.6640
NLRS MIRROR 7	SPIDER 2	3.4110	1.3330	-3.6730
	1989	3.4090	1.3370	-3.6740
NLRS MIRROR 7	DICHROIC MIRROR	1.6392	-0.4270	-2.4868
	1989	1.6390	-0.4250	-2.4900
NLRS MIRROR 7	CENTRE GROUNDMARK	6.8525	-4.1416	2.9312
	1989	6.8519	-4.1406	2.9304

Appendix A Table 5 Vectors from Mirror 7 to other stations. Values labelled 1989 are taken from the Orroral NGDB facility report, which used results from the 1989 survey. New results are in terms of ITRF97 at 1997.0

FROM	TO	MAJ-SEMI (m)	MED-SEMI (m)	MIN-SEM (m)	DISTANCE (m)	MAJ-SEMI (AZ, VANG)	MED-SEMI (AZ, VANG)	MIN-SEMI (AZ, VANG)
Mirror 7	Dichroic Mirror	0.0023	0.0016	0.0011	3.0089	(90, 0)	(0, 0)	(0, 90)
Mirror 7	Prime Vert East	0.0027	0.0018	0.0009	4.1858	(62, 0)	(152, 0)	(0, 90)
Mirror 7	Meridian South	0.0024	0.0014	0.0009	5.3078	(90, 0)	(0, 0)	(0, 90)
Mirror 7	Prime Vert West	0.0022	0.0013	0.0009	4.9422	(90, 0)	(0, 0)	(0, 90)
Mirror 7	Meridian North	0.0021	0.0015	0.0009	2.3804	(90, 0)	(0, 0)	(0, 90)
Mirror 7	AU005	0.0020	0.0011	0.0009	23.8083	(90, 0)	(0, 0)	(0, 90)
Mirror 7	Datum LR1	0.0021	0.0013	0.0009	2.9295	(90, 0)	(0, 0)	(0, 90)
Mirror 7	Spider Retro 1	0.0023	0.0022	0.0014	5.3973	(90, 0)	(0, 0)	(0, 90)
Mirror 7	Spider Retro 2	0.0027	0.0019	0.0013	5.0387	(53, 0)	(143, 0)	(0, 90)
Mirror 7	Centre Ground Mark	0.0033	0.0016	0.0009	8.5265	(108, 0)	(198, 0)	(0, 90)
Mirror 7	Doris Antenna	0.0020	0.0019	0.0013	34.5184	(90, 0)	(0, 90)	(0, 0)
Mirror 7	NM C 106	0.0020	0.0011	0.0009	24.5774	(90, 0)	(0, 0)	(0, 90)
Mirror 7	NM C 107	0.0020	0.0013	0.0009	1213.649	(90, 0)	(0, 0)	(0, 90)
Mirror 7	NM C 107 RM1	0.0033	0.0013	0.0009	1210.566	(113, 0)	(203, 0)	(0, 90)
Mirror 7	NM C 107 RM2	0.0031	0.0020	0.0009	1222.001	(0, 0)	(90, 0)	(0, 90)
Mirror 7	NM C 107 RM3	0.0034	0.0019	0.0009	1204.562	(161, 0)	(251, 0)	(0, 90)
Mirror 7	AU017	0.0020	0.0014	0.0012	26570.62	(90, 0)	(0, 90)	(0, 0)
Rock 1998	Mirror 7	0.0145	0.0136	0.0091	1146.571	(56, 8)	(326, 1)	(230, 82)
Pillar 2	Mirror 7	0.0021	0.0012	0.0009	24.4072	(90, 0)	(0, 0)	(0, 90)
Pillar 3	Mirror 7	0.0021	0.0012	0.0009	15.7187	(90, 0)	(0, 0)	(0, 90)
Doris Ground Mark	Mirror 7	0.0020	0.0013	0.0009	34.6886	(90, 0)	(0, 0)	(0, 90)
Centre Mark Top Level	Mirror 7	0.0020	0.0011	0.0009	3.1246	(90, 0)	(0, 0)	(0, 90)

Appendix A Table 6 Line error ellipses for the lines listed in Table A4 and Table A6. Station Rock refers to Rock Retro 1989. Error Ellipses are one sigma. A factor of 2.7955 (3D 2 sigma conversion factor) has been used to convert the 95% confidence error ellipses as output from GEOLAB to the above values.

The dimensions of the rock Retro, spider Retro 1 and spider Retro 2 have been adopted from the 1989 Peter Murphy report. These dimensions have been used for the reduction of ranges from the Dichroic mirror to rock Retro, spider Retro 1 and spider Retro 2. No modification or replacement of these reflectors has happened since the Peter Murphy survey. The diagrams for these reflectors as extracted from the 1989-survey report can be found in Attachments 1 and 2.

The calculated ranges and the original (1989) ranges are tabulated below.

From	To	Range (m)
Dichroic	Rock Retro	1144.3236
Dichroic	Rock Retro (1989)	1144.3184
Dichroic	Spider Retro 1	2.6951
Dichroic	Spider Retro 1 (1989)	2.6948
Dichroic	Spider Retro 2	2.6903
Dichroic	Spider Retro 2 (1989)	2.6897
Dichroic	Mirror 7	3.0089
Dichroic	Mirror 7 (1989)	3.0112
Spider Retro 1	Rock Retro	1141.6285
Spider Retro 1	Rock Retro (1989)	1141.6236
Spider Retro 2	Rock Retro	1141.6333
Spider Retro 2	Rock Retro (1989)	1141.6287

Appendix A Table 7 Spatial distances from the Dichroic Mirror to each of the calibration targets. Second sets labelled 1989 are from the 1989 survey. New results are in terms of ITRF97 at 1997.0

The Cartesian (XYZ) co-ordinates (and differences) for the two Spider Retros as listed above refer to the optical zero of the reflector with the telescope pointed at the Rock Retro. The computation outputs, in Attachment 3, show the calculation of these co-ordinates since the GEOLAB adjustment (and field observations) referred to the front lens cap of the reflector. The co-ordinates for the Spider Retros and the Dichroic mirror are of little use since they change as the telescope is moved. The range from the plane of the Dichroic mirror perpendicular to the optical axis of the telescope to the optical centre of the Spider Retros is the value of significance as it does not vary with the movement of the telescope. These values are shown in Table A6.

Similarly, for the Rock Retro the optical zero is 3.1mm behind the physical back of the reflector, which is the point used as reference for the observations. The MATLAB “m” file used to calculate the above offsets can be found in Attachment 4.

SLR reductions at Orroral required corrections to observations so that they referred to the system reference point, Mirror 7. They involved the survey values shown in Table A6, plus the assumed perpendicular distance between the non-intersecting axes of the telescope, 0.498m, obtained from the telescope drawings.

Conclusion

This is the final survey of the SLR reference points at the Orroral Laser Ranging Observatory. The results shown in tables A1, A2 and A3 are from a completely independent survey of the local network at Orroral. No observations from previous surveys have been included in the Geolab adjustment, with the exception of the dimensions of the mirror 7 housing, Rock Retro offsets, and the two Spider Retro dimensions as discussed above.

Good agreements have been obtained between the currently adopted results (1989 survey) and the new survey results, as is demonstrated in the tables A4 and A6.

Appendix B

Mt Stromlo Satellite Laser Ranging Observatory
Local Tie Survey
June 1999

Background

The local tie survey at the Mt Stromlo Satellite Laser Ranging station was performed in June 1999. This survey was completed for the purpose of determining the connection between the SLR reference point and the GPS reference point. It also determines the relationship between the SLR reference point (the telescope invariant point), the four SLR calibration pillars and the surrounding survey monuments. Monuments connected to include AU045 fundamental survey pillar, AU054 west pillar, Mt Stromlo Trig and benchmark SR1526.

A similar survey has been undertaken on one previous occasion by Total Care Surveys under contract for Electro Optic Systems (EOS), in March 1998.

The AUSLIG Space Geodesy Analysis Centre has further processed the results from the AUSLIG survey to determine the intersection of axes of rotation of the SLR telescope, which is the telescope invariant point (IVP).

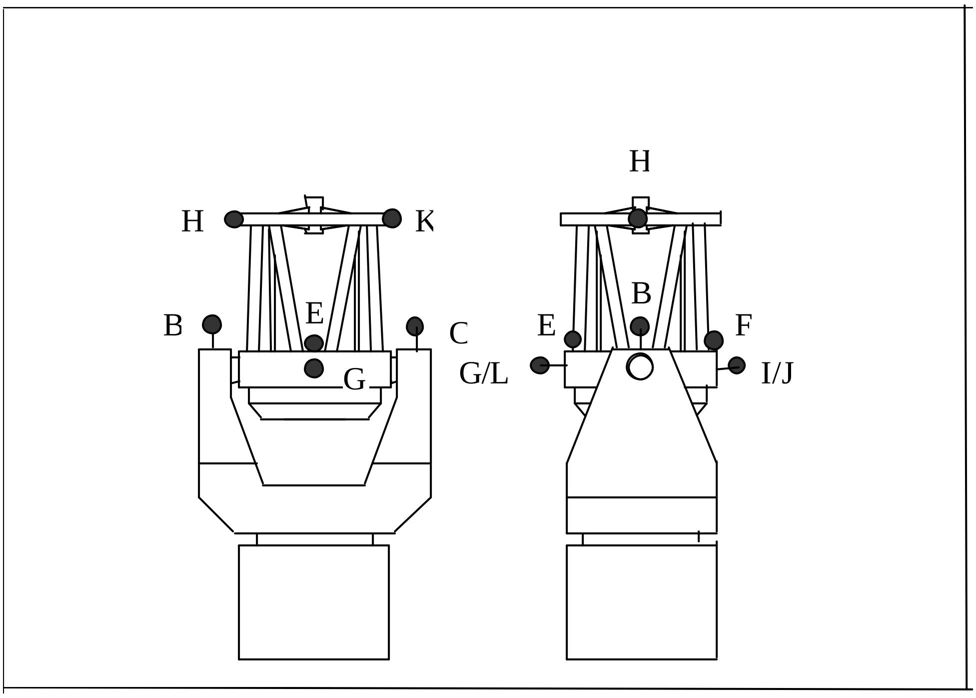
Observations

A Leica TC2003 Total Station was used for all horizontal angles, slope distances and Zenith distances. Where Zenith angles were to be used for vertical heighting, the Rueger method (Rueger, J.M., 1996) was used to determine the height of the trunnion axis of the total station. The Rueger method consists of observing a levelling staff over a known point with the vertical circle of the total station set to 90 degrees (horizontal).

The coordinates of the telescopes invariant point (IVP) were determined from the two independent sets of observations described below, rotating the telescope about its horizontal axis and about its vertical axis. The reductions assumed that the two axes do indeed intersect.

Observations were taken to the SLR telescope with it set at a variety of horizontal and vertical settings. Four targets (B, C, E and F) were placed on the telescope for the determination of the horizontal axis of rotation (see Figure B1). Two prisms (B and C) were mounted on the top of the telescope stanchions. Another two using retro tape (E and F) were mounted on the telescope which was locked in zenith position. Observations were taken from AU045 to all four targets with the telescope set at twenty-degree increments in azimuth (0, 20, 40, etc.) for a full 360 degrees. A second set of observations was taken to the same four targets from AU054 with the telescope again rotated through 360 degrees.

For the elevation axis of rotation three Retro-reflector tape targets were positioned on the telescope. Observations were taken from AU045 to each of these targets (G, H and I) at a ten-degree interval of vertical rotation of the telescope. The horizontal direction of the telescope was locked perpendicular to the line of sight. A second set of observations was taken from AU054 with the telescope now pointed 180 degrees to the first set to another three targets (J, K and L). This perpendicular setting was achieved by lining the two stanchion targets up in a collinear fashion with the line of sight.

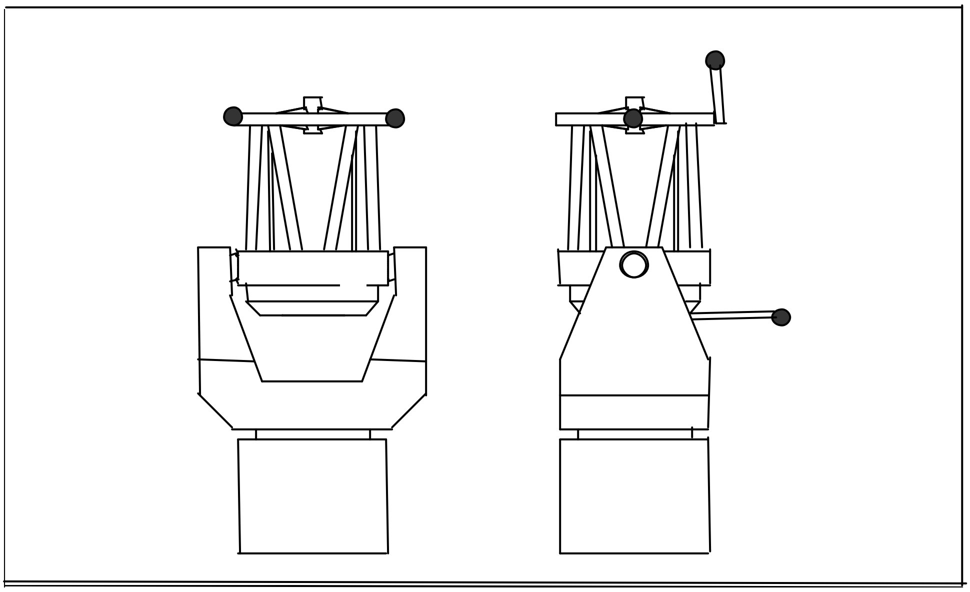


Appendix B Figure 1. **Target locations on the SLR telescope**

A Topcon DL-101 bar-code level was used with calibrated invar staffs to carry Orthometric height through the control network. With the exception of calibration pillars 2, 3 and 4 all monuments were levelled Orthometrically. The levelling results in combination with AUSGeoid98 were used to transfer ellipsoidal height from AU045 through the network.

AU052 (STRO) has a Rogue GPS receiver (and Dorne Margolin T antenna) operating on it (see STRO.log for more detail). A second GPS receiver (Ashtech Z12) and DMT antenna was placed on AU045 fundamental pillar. This data was processed with data from AU017 (TIDB) (see processing report F98/406). These baselines form the basis of datum and orientation for the network.

In December 1999, additional observations were taken for the determination of the elevation axes. The techniques outlined above were again utilised with the targets positioned as shown in Figure B2.



Appendix B Figure 2 Position of the targets for the December 1999 re-survey.

Reductions

All observations were reduced to a grand mean per set and reformatted to the standard GEOLAB format. All distances were reduced for atmospherics (first and second velocity corrections) using the model supplied in the "Supplement to TC2002/T3000 Operator's Manual" as follows:

$$\Delta D_1 = 281.8 - \left[\frac{0.29065p}{(1+at)} - \frac{4.126 \cdot 10^{-4} \cdot h}{(1+at)} \cdot 10^x \right]$$

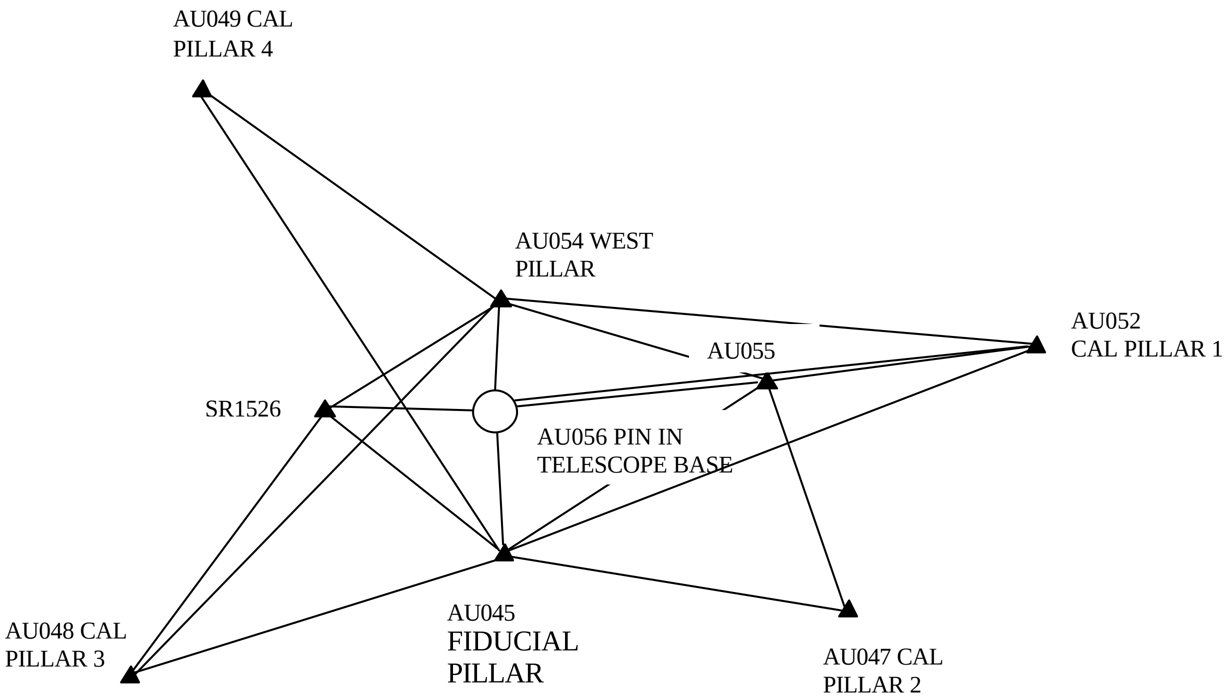
Where

$\Delta D_1 =$	Atmospheric correction in ppm
$p =$	Atmospheric pressure (mb)
$t =$	Ambient temperature (°C)
$h =$	relative humidity (%)
$a =$	1/273.16

$$x = \frac{7.5t}{237.3 + t} + 0.7857$$

They were also reduced for prism offsets, which in the case of the Leica precision prism is 0.000m. The tape retro-reflector has a prism offset of +0.0344m.

The GEOLAB adjustment includes both distance observations and a GPS baseline between AU052 and AU045. Sub millimetre agreement between these techniques was achieved.



Appendix B Figure 3 Stromlo local tie survey network

Mark Descriptions

AU045 (STRO): Domes 50119M001. The intersection of the top of the stainless steel pillar plate with the vertical axis of a 5/8"ƒ Whitworth threaded stainless steel spigot. This pillar plate is set into the top of the fundamental survey pillar at the Stromlo Satellite Laser Ranging station. The Stainless steel pillar plate is inscribed with “AU045 Fundamental Pillar”.

AU046: The intersection of the top of the stainless steel pillar plate with the vertical axis of a 5/8"ƒ Whitworth threaded stainless steel spigot. This pillar plate is fixed on top of North Calibration Pillar 1. The Stainless steel pillar plate is inscribed with “AU046”. This mark is 0.183m below AU052 (STRO).

AU047: The intersection of the top of the stainless steel pillar plate with the vertical axis of a 5/8"ƒ Whitworth threaded stainless steel spigot. This pillar plate is fixed on top of 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"ƒ Whitworth threaded stainless steel spigot. This pillar plate is fixed on top of 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"*f* Whitworth threaded stainless steel spigot. This pillar plate is fixed on top of Calibration Pillar 4. The Stainless steel pillar plate is inscribed with "AU049".

AU052: Domes 50119M002. The intersection of the top of the stainless steel pillar plate with the vertical axis of a 5/8"*f* Whitworth threaded stainless steel spigot The Stainless steel pillar plate is inscribed with "AU052". This pillar plate is bolted on top of the north calibration pillar at the Stromlo Satellite Laser Ranging station, and is 183 mm vertically above a similar mounting which is used for the Laser calibration target. This mounting for the calibration target is known as AU046. For reference in GPS processing, AU052 has the 4-character ID STRO.

AU054: The intersection of the top of the brass pillar plate 0.15m*f* with the vertical axis of a 5/8"*f* Whitworth threaded brass spigot. This pillar plate is set into the top of 0.3m*f* concrete pillar, which is 1.28m high. The Pillar is located to the west of the observatory.

AU055: Centre punch mark on head of brass bolt set with resin in concrete drain directly in front of SLR observatory entrance. Placed such that line of sight into the SLR telescope pillar base ("Fire Place") is possible.

AU056: The intersection of the vertical axis of a 6mm*f* pin, with the horizontal plane coinciding with the concrete base of the mirror 7 mount in the SLR telescope pillar base ("Fire Place"). This pin is directly under mirror 7.

IVP Stromlo SLR: Domes 50119S001. The intersection of the azimuth axis and elevation axis of rotation of the Mt Stromlo Satellite Laser Ranging telescope.

DORIS (MSOB): Domes 50119S002. The intersection of the vertical axis of the DORIS antenna with the plane coinciding with the reference height line marked on the DORIS antenna. The Doris antenna is mounted on a steel stanchion on the roof of the Stromlo SLR observatory. The Doris ground mark (AU051) is the intersection of the top of the steel plate with the vertical axis of a 5/8"*f* Whitworth threaded steel spigot. This point is on top of the steel pole to which the Doris Antenna is attached. It has not been surveyed in this current survey. A connection will be included in future surveys.

AU050: The intersection of the top of the stainless steel pillar plate with the vertical axis of a 5/8"*f* Whitworth threaded stainless steel spigot. This mounting is on top of the north equipment pole protruding from the roof of the observatory.

SR1526: Levelling benchmark at southwest end of the observatory. It consists of a stainless steel rod with a centre punch mark at the top. The mark is under a steel cover plate.

GPS TIME: Coordinates refer to the target fixed to the front face of the pole supporting the GPS timing antenna, adjacent to AU050.

HP GPS: Coordinates refer to the target fixed to the front face of the pole supporting the HP GPS timing antenna, adjacent to AU050.

TRIG: is the original Stromlo geodetic survey mark. It is a .303 cartridge case set in concrete, beneath a steel quadrapod.

AU017, DOMES 50103M108, is the GPS pillar at the Canberra Deep Space Communications Complex at Tidbinbilla. It is a small drill hole in the centre of the top of a stainless steel pillar plate that is set in the top of a 0.6 metre diameter reinforced concrete pillar. This pillar is set into the ground to a depth of 2.5 metres and protrudes 0.5 metres above ground level. The pillar plate bears the inscription: "TIDBINBILLA SPC-40 GPS STATION MARK JPL 4002-S 1992". The pillar is in the centre of a 6 metre square post & rail fence enclosure. The hardwood posts are 200 x 100 mm and the rails 150 x 25 mm. This fence does not obstruct the visibility horizon above 10 degrees elevation.

Results

STATION	Latitude	Longitude	Ellip HT (m)	STD LAT (m)	STD LONG (m)	STD HT (m)
IVP	S35 18 58.12966	E149 00 35.56292	804.0622	0.0004	0.0008	0.0005
TRIG	S35 18 58.24300	E149 00 37.81264	801.4288	0.0003	0.0010	0.0003
AU017	S35 23 57.15172	E148 58 47.98740	665.3657	0.0003	0.0003	0.0023
AU045	S35 18 58.19471	E149 00 36.55048	802.5130	0.0001	0.0001	0.0001
AU046	S35 18 55.93522	E149 00 36.18271	799.7811	0.0007	0.0004	0.0003
AU047	S35 18 57.48539	E149 00 37.56747	807.2008	0.0003	0.0003	0.0002
AU048	S35 19 01.07018	E149 00 38.50393	801.5754	0.0004	0.0004	0.0004
AU049	S35 18 59.16874	E149 00 33.88133	794.5412	0.0003	0.0004	0.0003
AU050	S35 18 57.74254	E149 00 35.87669	802.7640	0.0006	0.0008	0.0002
AU052	S35 18 55.93518	E149 00 36.18272	799.9636	0.0001	0.0001	0.0001
AU054	S35 18 57.91373	E149 00 34.82967	798.7505	0.0002	0.0002	0.0001
AU055	S35 18 57.36820	E149 00 35.77025	798.5600	0.0002	0.0001	0.0001
AU056	S35 18 58.12971	E149 00 35.56295	799.3602	0.0007	0.0002	0.0001
DORIS	S35 18 58.01095	E149 00 35.80278	803.3923	0.0003	0.0009	0.0002
HPGPS	S35 18 57.75114	E149 00 35.87750	802.8913	0.0006	0.0008	0.0002
SR1526	S35 18 58.34494	E149 00 35.50289	798.4728	0.0001	0.0002	0.0001
GPSTIME	S35 18 57.74944	E149 00 35.87059	802.9101	0.0006	0.0008	0.0002

Appendix B Table 1 Geodetic Latitude, Longitude and Ellipsoidal height and the associated standard deviations of the network stations. ITRF97 @ 1997.00 co-ordinates and GRS80 ellipsoid adopted at AU017 (TIDB).

Station	X (m)	Y (m)	Z (m)	STD X (m)	STD Y (m)	STD Z (m)
IVP	-4467063.6474	2683034.4910	-3667007.3941	0.0006	0.0008	0.0005
TRIG	-4467089.3377	2682983.6226	-3667008.7222	0.0005	0.0008	0.0003
AU017	-4460996.1282	2682557.0867	-3674443.7169	0.0016	0.0010	0.0013
AU045	-4467074.4161	2683011.8557	-3667008.1344	0.0001	0.0001	0.0001
AU046	-4467102.2339	2683039.4018	-3666949.7283	0.0004	0.0004	0.0006
AU047	-4467101.7583	2682998.3078	-3666993.0049	0.0003	0.0002	0.0002
AU048	-4467055.2472	2682942.7756	-3667079.9109	0.0004	0.0004	0.0004
AU049	-4467019.2424	2683057.3757	-3667028.0231	0.0004	0.0004	0.0003
AU050	-4467072.7338	2683030.7018	-3666996.9076	0.0002	0.0008	0.0005
AU052	-4467102.3622	2683039.4787	-3666949.8329	0.0001	0.0001	0.0001
AU054	-4467053.6923	2683050.1202	-3666998.8927	0.0001	0.0002	0.0002
AU055	-4467074.1265	2683034.6751	-3666985.0624	0.0001	0.0002	0.0002
AU056	-4467060.3581	2683032.5143	-3667004.6771	0.0004	0.0002	0.0006
DORIS	-4467068.1121	2683030.1039	-3667004.0212	0.0004	0.0009	0.0003
HPGPS	-4467072.7021	2683030.6587	-3666997.1974	0.0002	0.0008	0.0005
SR1526	-4467055.6685	2683031.4677	-3667009.5772	0.0001	0.0002	0.0001
GPSTIME	-4467072.6514	2683030.8319	-3666997.1654	0.0002	0.0008	0.0005

Appendix B Table 2 Earth Centred Cartesian co-ordinates and the associated standard deviations of the network stations. ITRF97 @ 1997.00 co-ordinates and GRS80 ellipsoid adopted at AU017 (TIDB).

From	To	MAJ-SEMI (m)	MED-SEMI (m)	MINI-SEMI (m)	DISTANCE (m)	MAJ-SEMI (AZ,VANG)	MED-SEMI (AZ,VANG)	MINI-SEMI (AZ,VANG)
IVP	TRIG	0.0036	0.0015	0.0014	57.0031	(90, 0)	(0, 90)	(0, 0)
IVP	AU017	0.0066	0.0024	0.0015	9609.4538	(0, 90)	(90, 0)	(0, 0)
IVP	AU045	0.0023	0.0014	0.0012	25.0773	(90, 0)	(0, 90)	(0, 0)
IVP	AU046	0.0025	0.0023	0.0017	69.5584	(90, 0)	(0, 0)	(0, 90)
IVP	AU047	0.0024	0.0015	0.0014	54.4859	(90, 0)	(0, 90)	(0, 0)
IVP	AU048	0.0026	0.0018	0.0017	117.2218	(90, 0)	(0, 90)	(0, 0)
IVP	AU049	0.0026	0.0015	0.0015	54.0470	(90, 0)	(0, 90)	(0, 0)
IVP	AU050	0.0031	0.0021	0.0015	14.3836	(90, 0)	(0, 0)	(0, 90)
IVP	AU052	0.0024	0.0014	0.0012	69.5485	(90, 0)	(0, 90)	(0, 0)
IVP	AU054	0.0024	0.0014	0.0013	20.3875	(90, 0)	(0, 90)	(0, 0)
IVP	AU055	0.0024	0.0014	0.0013	24.6688	(90, 0)	(0, 90)	(0, 0)
IVP	AU056	0.0024	0.0022	0.0014	4.7020	(90, 0)	(0, 0)	(0, 90)
IVP	DORIS	0.0035	0.0015	0.0015	7.1103	(90, 0)	(0, 0)	(0, 90)
IVP	HPGPS	0.0032	0.0021	0.0015	14.1650	(90, 0)	(0, 0)	(0, 90)
IVP	SR1526	0.0024	0.0014	0.0012	8.8073	(90, 0)	(0, 90)	(0, 0)
IVP	GPSTIME	0.0032	0.0021	0.0015	14.1098	(90, 0)	(0, 0)	(0, 90)

Appendix B Table 3 ***Line Error ellipses between the Mt Stromlo IVP and all other network stations at Mt Stromlo, including AU017 (TIDB). Error ellipses are at the 95% confidence level.***

Line	Diff X (m)	Diff Y (m)	Diff Z (m)
Old EOS reflector on AU045 - IVP	10.8426	22.5930	0.8009
	10.8370	*22.5890*	*0.8000*
	0.0056	**0.0040**	**0.0009**
Old EOS reflector on AU045 - Old EOS reflector on AU046	-27.8180	27.5480	58.4070
	-27.8170	*27.5530*	*58.4040*
	-0.0010	**-0.0050**	**0.0030**
Old EOS reflector on AU045 - Old EOS reflector on AU047	-27.3420	-13.5470	15.1300
	-27.3410	*-13.5480*	*15.1330*
	-0.0010	**0.0010**	**-0.0030**
Old EOS reflector on AU045 - Old EOS reflector on AU048	19.1700	-69.0800	-71.7770
	19.1630	*-69.0930*	*-71.7790*
	0.0070	**0.0130**	**0.0020**
Old EOS reflector on AU045 - Old EOS reflector on AU049	55.1760	45.5230	-19.8900
	55.1700	*45.5160*	*-19.8890*
	0.0060	**0.0070**	**-0.0010**

Appendix B Table 4 ***Vectors between the old EOS reflector on the fundamental pillar AU045 and IVP and the Old EOS reflector on the calibration pillars in Earth centred Cartesian components. These differences are from co-ordinates referring to the point of reflection of the old EOS reflectors, which are 0.1045m above the pillar plates according to the Total Care survey. The calibration values for these prisms have been included for the AUSLIG values and are listed in Table B5. The values in italics are the results from the "Total Care" survey of 1998. The values in bold are the differences between the two sets.***

CALIBRATION	AU052 CAL PILLAR 1		AU047 CAL PILLAR 2		AU048 CAL PILLAR 3		AU049 CAL PILLAR 4	
	NEW	OLD	NEW	OLD	NEW	OLD	NEW	OLD
INDEX ERROR (mm)	18.20	-1.30	N/A	-1.40	N/A	-1.40	17.60	-2.40
Note: Old Pillar 1 determined by observations taken in situ.								

Appendix B Table 5 ***Calibration results for the EOS reflectors. Calibration performed using the TC2003 on the Watson baseline. An indicative uncertainty for these results is 0.8mm.***

The calibration of the EOS retro-reflectors was completed at the Watson EDM baseline on the 8/12/99. The results listed in Table B5 are as supplied by ACT Department of Planning and Land Management, Office of the Chief Surveyor.

STATION	X (m)	Y (m)	Z (m)
IVP	-4467063.6474	2683034.4910	-3667007.3941
old reflector on AU045	-4467074.4902	2683011.8986	-3667008.1952
old reflector on AU046	-4467102.3082	2683039.4460	-3666949.7879
old reflector on AU047	-4467101.8327	2682998.3509	-3666993.0652
old reflector on AU048	-4467055.3206	2682942.8186	-3667079.9725
old reflector on AU049	-4467019.3141	2683057.4210	-3667028.0850
New reflector on AU045	-4467074.4810	2683011.9156	-3667008.1939
New reflector on AU046	-4467102.2966	2683039.4442	-3666949.8033
New reflector on AU047	-4467101.8199	2682998.3643	-3666993.0710
New reflector on AU048	-4467055.3217	2682942.8336	-3667079.9602
New reflector on AU049	-4467019.3286	2683057.4107	-3667028.0750

Appendix B Table 6 ***Earth centred Cartesian coordinates for the effective point of reflection of the calibration reflectors placed on the pillars listed. A mean prism offset of 18mm and height of 105mm (as measured by AUSLIG) was used for the new reflectors and the values listed in Table B5 for prism offsets and a height of 105mm (as measured by AUSLIG) was used for the old reflectors.***

Site	East (m)	North (m)	Up (m)	Distance (m)
old reflector on AU045	24.9503	-2.0050	-1.4443	25.0724
old reflector on AU046	15.6584	67.6392	-4.1764	69.5535
old reflector on AU047	50.6426	19.8583	3.2434	54.4935
old reflector on AU048	74.2993	-90.6351	-2.3829	117.2211
old reflector on AU049	-42.4837	-32.0283	-9.4162	54.0309
New reflector on AU045	24.9310	-2.0034	-1.4443	25.0530
New reflector on AU046	15.6539	67.6203	-4.1764	69.5341
New reflector on AU047	50.6245	19.8512	3.2434	54.4741
New reflector on AU048	74.2870	-90.6200	-2.3830	117.2016
New reflector on AU049	-42.4674	-32.0160	-9.4162	54.0108

Appendix B Table 7 ***Topocentric plane East, North and Up coordinates for the Calibration pillars with the IVP as origin (0,0,0). These values are calculated from the Earth centred Cartesian coordinate results listed in Table B6.***

From	To	Diff X (m)	Diff Y (m)	Diff Z (m)	Diff X STD (m)	Diff Y STD (m)	Diff Z STD (m)
IVP	TRIG	-25.6903	-50.8684	-1.3281	0.0008	0.0011	0.0006
IVP	AU017	6067.5192	-77.4043	-7436.3228	0.0017	0.0013	0.0014
IVP	AU045	-10.7687	-22.6353	-0.7403	0.0005	0.0008	0.0005
IVP	AU046	-38.5865	4.9108	57.6658	0.0007	0.0009	0.0008
IVP	AU047	-38.1109	-36.1832	14.3892	0.0006	0.0008	0.0006
IVP	AU048	8.4002	-91.7154	-72.5168	0.0007	0.0009	0.0007
IVP	AU049	44.4050	22.8847	-20.6290	0.0006	0.0009	0.0006
IVP	AU050	-9.0864	-3.7892	10.4865	0.0006	0.0011	0.0007
IVP	AU052	-38.7148	4.9877	57.5612	0.0006	0.0008	0.0005
IVP	AU054	9.9551	15.6292	8.5014	0.0006	0.0008	0.0005
IVP	AU055	-10.4791	0.1841	22.3317	0.0006	0.0008	0.0005
IVP	AU056	3.2893	-1.9767	2.7170	0.0007	0.0008	0.0008
IVP	DORIS	-4.4647	-4.3871	3.3729	0.0007	0.0012	0.0006
IVP	HPGPS	-9.0547	-3.8323	10.1967	0.0006	0.0011	0.0007
IVP	SR1526	7.9789	-3.0233	-2.1831	0.0006	0.0008	0.0005
IVP	GPSTIME	-9.0040	-3.6591	10.2287	0.0006	0.0011	0.0007

Appendix B Table 8 ***Vectors from the IVP to the other network stations and the associated standard deviations.***

Internal Calibration of the "Spider Retro" *(By John Luck, AUSLIG)*

The "Spider Retro" is a masked 2-inch open-faced retro-reflector attached to a secondary spider vane, to provide an internal calibration target. EOS measured the distance from its vertex to the IVP, projected on to the telescopes optical axis, on 29 May 1998. The value, without any glass filters intervening, was 1295.7mm.

Conclusion

This is the second survey of the SLR reference points at the Mt Stromlo Laser Ranging Observatory. The results shown in tables B1, B2 and B3 are from a completely independent survey of the local network at Mt Stromlo. No observations from previous surveys have been included in the GEOLAB adjustment.

Sub centimetre agreements have been obtained between the "Total Care 1998" results and the new survey results (1999), as is demonstrated in the table B4 for a number of the network sites including the four calibration pillars. A re-survey of this network is required to confirm the 1999 results.

Appendix C

Yarragadee Satellite Laser Ranging Observatory
Local Tie Survey
August 1998

Background

The local tie survey at Yarragadee was completed in August 1998. This survey was completed for the purpose of verifying that no local movement had occurred and that the connection between the SLR reference point (later referred to as IVP) and the GPS reference point (DON95 RM4) is as published in the IERS local tie file.

Connections to the significant monuments (see Tables C1, C2 and C3 for the results lists) at Yarragadee have been completed. This survey has been undertaken on three previous occasions. The first was in 1979 by the Australian Survey Office and again in 1987 and 1992 by Brian Murphy of National Mapping and AUSLIG.

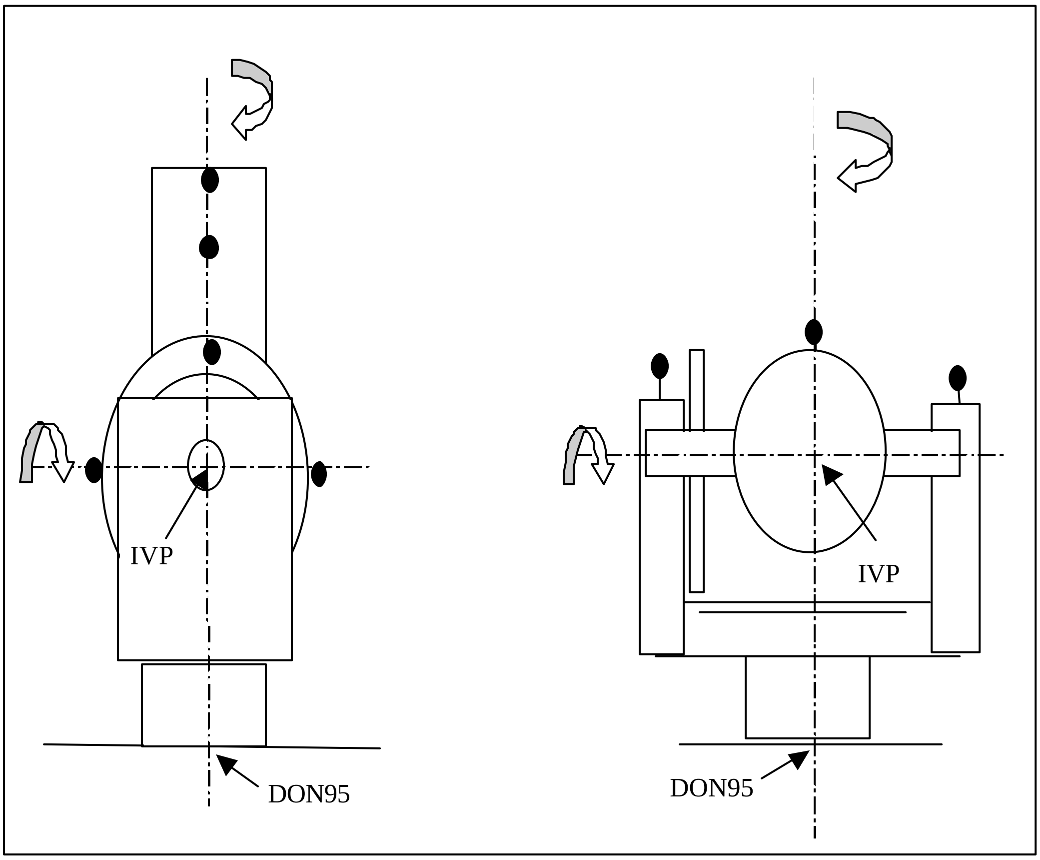
The AUSLIG Geodesy Space Geodesy Analysis Centre (SGAC) has processed the results from this survey in order to determine the intersection of axes of rotation of the SLR telescope. The co-ordinates for the intersection of axis of the telescope, otherwise referred to as the invariant point (IVP), are included in the result section of this report. The vector from Don95 RM4 to DON95 is considered the fundamental local tie information at this site, with the eccentricity from DON95 to MOBLAS 5 IVP being of equal importance.

Observations

A Leica TC2003 Total Station was used for all horizontal angles, slope distances and Zenith angles. Where Zenith angles were to be used for vertical heighting, the Rueger method was used to determine the height of the trunnion axis of the total station. The Rueger method consists of observing a levelling staff over a known point with the vertical circle of the total station set to 90 degrees (horizontal).

Observations were taken to the SLR telescope at a variety of horizontal and vertical settings in order to determine the location of the telescope invariant point (IVP). Three targets were placed on the telescope for the determination of the horizontal axis of rotation (see Figure C1). Two prisms were mounted on the top of the telescope stanchions. A third using Retro tape was mounted near the centre of rotation on top of the telescope, which was locked in a horizontal position. Observations were taken from AU053 to all three targets with the telescope set at twenty-degree increments in azimuth (0, 20, 40, etc.) for a full 360 degrees. A second set of observations was taken to the same three targets from DON95 RM1 with the telescope again rotated through 360 degrees. These observations were at odd twenty-degree increments (10, 30, 50, etc.).

For the vertical circle five Retro-reflector tape targets were positioned on the right hand face (looking down the bore sight) of the telescope itself. Observations were taken from DON95 RM4 to each of these targets, at a ten-degree interval of vertical rotation of the telescope. The horizontal direction of the telescope was locked perpendicular to the line of sight. A second set of observations was taken from DON95 RM1 with the telescope now pointed perpendicular to that line. This perpendicular setting was based on the assumption that the centre of the telescope was approximately over DON95. The perpendicular setting was only required approximately to allow maximum reflection from the tape retro reflectors used for this survey.



Appendix C Figure 1. Location of targets and points of interest on the Yarragadee SLR Telescope.

A Leica NA3003 bar-code level with an aluminium staff was used to carry orthometric height through the control network. With the exception of the calibration pillars, all monuments were levelled. The levelling results in combination with AUSGeoid98 were used to transfer ellipsoidal height from DON95 RM4 (YAR1) through the network.

DON95 RM4 (YAR1) has a Dorne Margolin T (DMT) antenna on it and data is gathered with a Rogue GPS receiver (see yar1.log for more detail). A second GPS receiver (Ashtech Z12) and DMT antenna was placed on AU053 (YARR) then DON38 and CP01 (calibration pillar 1). This data was processed with data from YAR1. These baselines form the basis of datum and orientation for the network. The log sheets for these GPS occupations can be found on AUSLIG internal file F98/406.

Reductions

All angular observations were reduced to a grand mean per set and reformatted to the standard GEOLAB format. All distances were reduced for atmospherics (first and second velocity corrections) using the model supplied in the "Supplement to TC2002/T3000 Operator's Manual" as follows:

$$\Delta D_1 = 281.8 - \left[\frac{0.29065p}{(1+at)} - \frac{4.126 \cdot 10^{-4} \cdot h}{(1+at)} \cdot 10^x \right]$$

Where

$\Delta D_1 =$	Atmospheric correction in ppm
$p =$	Atmospheric pressure (mb)
$t =$	ambient temperature (°C)
$h =$	relative humidity (%)
$a =$	1/273.16

$$x = \frac{7.5t}{237.3+t} + 0.7857$$

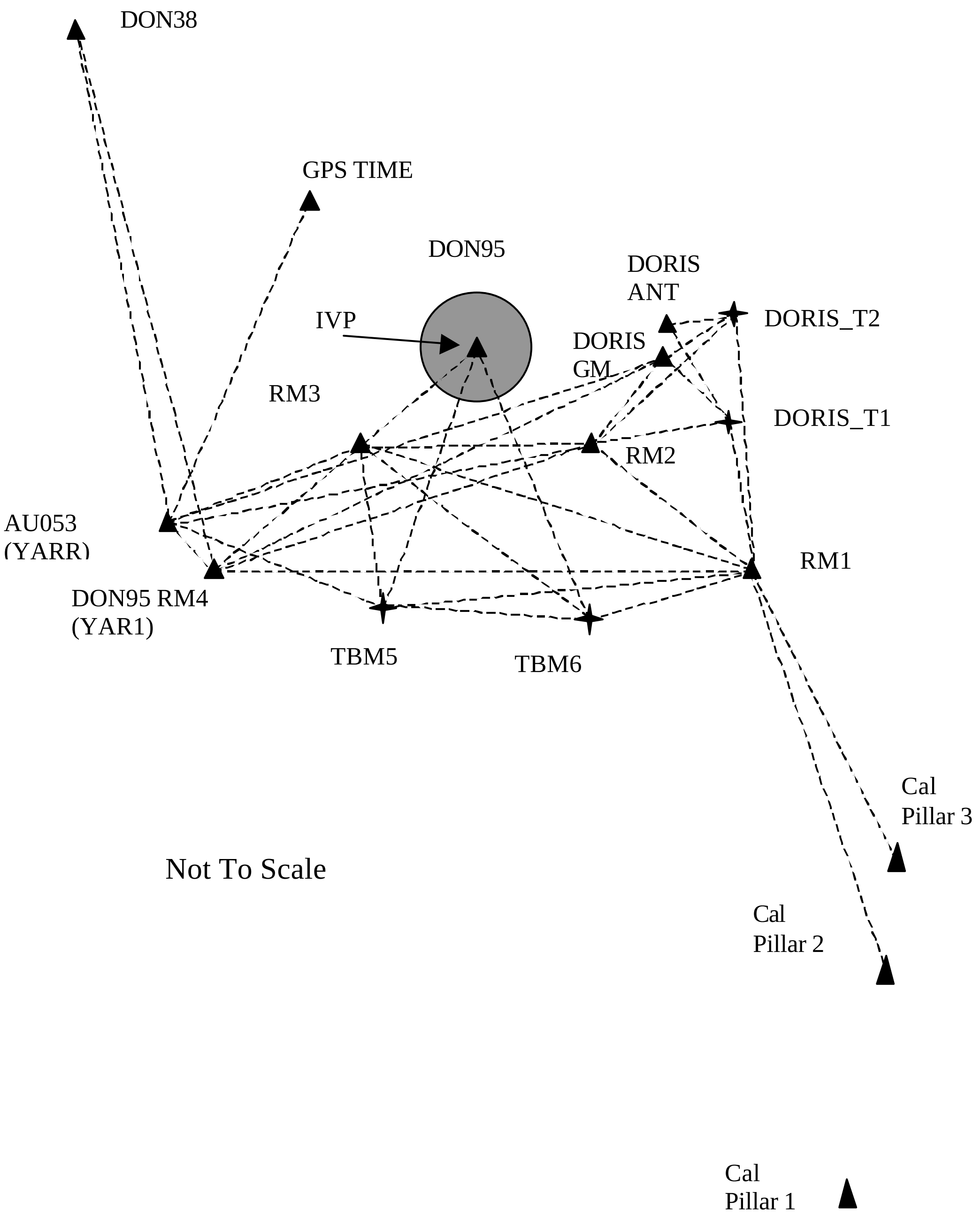
They were also reduced for prism offsets, which in the case of the Leica precision prism is 0.000m. The tape Retro-reflector has a prism offset of +0.0344m. Both prism offsets are caused by a setting of -0.0344m in-built into the instrument to allow for the normal use of the precision prisms. A discussion of this correction is given in the next section. Temperature, pressure and humidity were observed on a half hourly basis during observations.

Where height of instrument and/or height of target were not measured the height of instrument and height of target was calculated to reflect the observed vertical angles, which were inherently observed by the total station. This is necessary for the GEOLAB software to correctly reduce distance observations.

Problems Encountered

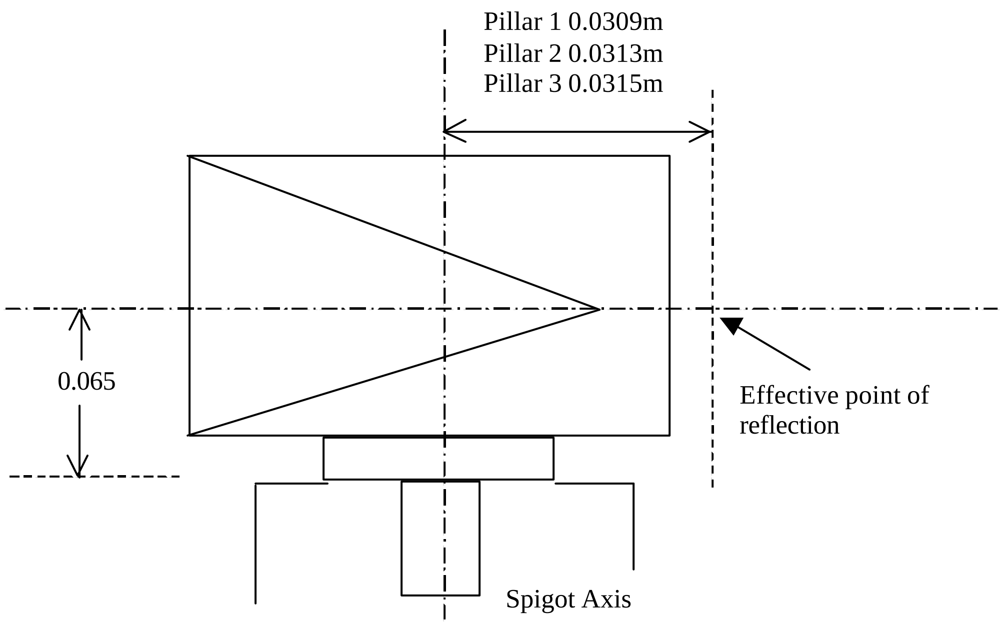
Some discrepancy existed between Leica factory calibration certificates and the results obtained from the Watson (ACT) calibration baseline. The Leica factory results yield a 0.2mm prism offset for the Leica precision prisms. The Watson baseline yielded a 1.5mm offset and 5ppm scale error. These results were far outside the expected accuracy of the instrument and were most likely caused by incorrect atmospheric reading along the length of the baseline, or baseline deformation. The Watson EDM baseline was re-observed and calibrated in February 1999. After this re-calibration, the results for the TC2003 agreed with the factory results within the standard deviation of the baseline results. The results obtained from the factory have been adopted for this survey.

A discrepancy exists between the observed (Orthometric) height difference from DON95 RM4 to AU053 (YARR) and that derived from the GPS reduction. This discrepancy is of the order of 5mm, which is mostly caused by radome effects on height transfer. The radome on the GPS antenna has the effect of causing a phase delay. When a radome is used on one end of the baseline only a height transfer error can occur. The result is an apparent height shift from when the antenna is covered by a radome to when it is not. UNAVCO reports detail this shift to be in the order of 5mm for a non concentric spherical dome (1/4 inch) as is used at YAR1. This confirms the effect noted by our survey. As such the Orthometric height difference has been adopted. This was confirmed by a second occupation where the radome was removed from YAR1.



Appendix C Figure 2 Network layout

The calibration pillars 2 and 3 were both observed in two separate ways. The first way was observations taken to the AUSLIG Leica prisms on a tribrach mount screwed directly onto the 5/8 spigot. The second way was observations taken directly to the SLR reflectors, which screw directly onto the 5/8 spigot. The results for the former are listed as Cal Pillar 2 and Cal Pillar 3 in the result tables. The latter are listed as Cal Target 2 and Cal Target 3 in the same tables. The calibration values listed for the three prisms as determined by BENDIX (1990) and listed in the 1992-survey report have been adopted (see Figure C3). The co-ordinates listed for Cal Target 1, Cal Target 2 and Cal Target 3 refer to the effective measurement point of the reflectors, while Cal Pillar 1, 2 and 3 refer to the intersection of the top of the stainless steel pillar plate with the vertical axis of a 5/8"ƒ Whitworth threaded stainless steel spigot. Calibration pillar 1 was only observed using GPS as it is 3.1 km from the DON95, and the line of sight is now obscured.



Appendix C Figure 3 Retro reflector dimensions on the calibration pillars

Mark Descriptions

Moblas 5 IVP: Domes 50107S007. The intersection of the azimuth axis and elevation axis of rotation 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"ƒ 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 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 (YAR1): 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.

DON38: Mark is a "Lands and Surveys" pre cast SSM stamped DON38. RM's 1,2 and 3 are brass rods set in concrete. RM4 is a steel rod set in concrete.

DON38_2: Don38 PSM2 is brass plaque set in concrete marked P.S.M and stamped "2".

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

DORIS Antenna Type A (YARA): Domes 50107S006. The intersection of the vertical axis of the Alcatel DORIS antenna with the plane coinciding with the bottom of the antenna ground plane.

DORIS Antenna Type B (YARB): Domes 50107S010. The intersection of the vertical axis of the Starec type DORIS antenna with the plane coinciding with the painted reference line midway up the antenna body.

GPSTIME: The intersection of the vertical axis of the support pole for the GPS timing antenna with the base of the antenna itself.

TBM5, TBM6, DORIS Temp 1 and DORIS Temp 2: GI nails driven into bitumen for temporary observation standpoints.

Calibration Pillars 1,2 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"*f* 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 pillar1, 2, and 3.

Calibration Targets 1,2 and 3. The reflective point of the SLR reflectors mounted on calibration pillars 1,2 and 3 respectively as described in Figure C3.

Results

STATION	LATITUDE (DMS)	LONGITUDE (DMS)	ELIP HEIGHT (m)	STD DEV (m)	STD DEV (m)	STD DEV (m)
Cal Pillar 1	S29 1 10.50594	E115 21 21.66599	252.8087	0.0018	0.0016	0.0047
Cal Pillar 2	S29 2 42.66815	E115 20 49.68285	241.2202	0.0008	0.0034	0.0008
Cal Pillar 3	S29 2 44.21049	E115 20 49.07824	242.0676	0.0005	0.0022	0.0007
Cal Target 1	S29 1 10.50499	E115 21 21.66634	252.8736	0.0018	0.0016	0.0047
Cal Target 2	S29 2 42.66702	E115 20 49.68289	241.2854	0.0006	0.0028	0.0008
Cal Target 3	S29 2 44.20955	E115 20 49.07848	242.1336	0.0005	0.0022	0.0007
MOBLAS 5 IVP	S29 2 47.39477	E115 20 48.28626	244.5438	0.0015	0.0010	0.0012
DON95 RM1	S29 2 46.67505	E115 20 48.53348	241.0607	0.0002	0.0004	0.0005
DON95 RM2	S29 2 47.08342	E115 20 48.39282	241.2287	0.0003	0.0003	0.0005
DON95 RM3	S29 2 47.48861	E115 20 48.63945	241.3635	0.0002	0.0001	0.0005
DON95 RM4	S29 2 47.61239	E115 20 49.10458	241.3143	0.0001	0.0001	0.0001
TBM5	S29 2 47.55977	E115 20 48.97643	241.1118	0.0002	0.0002	0.0005
TBM6	S29 2 47.21776	E115 20 48.85875	241.1118	0.0002	0.0002	0.0005
YARB DORIS antenna type B	S29 2 46.91842	E115 20 48.00738	243.6617	0.0005	0.0005	0.0005
YARR (AU053)	S29 2 47.73820	E115 20 49.09399	241.3931	0.0001	0.0002	0.0005
DON38	S29 2 50.19608	E115 20 47.09071	242.8298	0.0002	0.0003	0.0005
DON95	S29 2 47.39450	E115 20 48.28561	241.3628	0.0003	0.0002	0.0005
DORIS GM	S29 2 46.91852	E115 20 48.00736	241.1954	0.0004	0.0003	0.0005
DON38 RM1	S29 2 50.40281	E115 20 46.87185	242.5698	0.0003	0.0004	0.0005
DON38 RM2	S29 2 49.90204	E115 20 46.98809	242.5425	0.0003	0.0003	0.0005
DON38 RM3	S29 2 50.26115	E115 20 47.43896	242.7142	0.0003	0.0003	0.0005
DON38 RM4	S29 2 50.34923	E115 20 47.13065	242.5972	0.0003	0.0003	0.0005
DON38_2	S29 2 48.29202	E115 2045.13021	241.3214	0.0012	0.0013	0.0005
GPSTIME	S29 2 47.60085	E115 20 47.69227	245.5175	0.0008	0.0003	0.0006
DORIS Temp1	S29 2 46.84910	E115 20 48.17132	241.1954	0.0004	0.0004	0.0005
DORIS Temp2	S29 2 46.80455	E115 20 47.99336	241.1954	0.0005	0.0004	0.0005
DORIS antenna Type A	S29 2 46.91920	E115 20 48.00631	243.3958	0.0004	0.0003	0.0005

Appendix C Table 1 Latitude, Longitude and Ellipsoidal height and the associated standard deviation for the network stations. ITRF97 @1997.00 co-ordinates and GRS80 ellipsoid adopted at DON95 RM4 (YAR1).

STATION	X (m)	*Y (m)*	*Z (m)*	STD DEV (m)	STD DEV (m)	STD DEV (m)
Cal Pillar 1	-2390447.3336	5044259.9840	-3075922.2145	0.0023	0.0040	0.0026
Cal Pillar 2	-2389071.2759	5043376.9054	-3078397.6226	0.0029	0.0019	0.0008
Cal Pillar 3	-2389046.9397	5043363.7421	-3078439.5491	0.0019	0.0012	0.0005
Cal Target 1	-2390447.3730	5044260.0440	-3075922.2200	0.0023	0.0040	0.0026
Cal Target 2	-2389071.3080	5043376.9720	-3078397.6240	0.0024	0.0016	0.0007
Cal Target 3	-2389046.9760	5043363.8040	-3078439.5560	0.0019	0.0012	0.0005
MOBLAS 5 IVP	-2389008.1244	5043331.8535	-3078526.4619	0.0013	0.0013	0.0012
DON95 RM1	-2389017.4713	5043335.9614	-3078505.3983	0.0004	0.0004	0.0003
DON95 RM2	-2389011.4817	5043332.2064	-3078516.4718	0.0003	0.0004	0.0004
DON95 RM3	-2389014.9694	5043323.9824	-3078527.4436	0.0003	0.0004	0.0003
DON95 RM4	-2389025.5316	5043316.8840	-3078530.7515	0.0001	0.0001	0.0001
TBM5	-2389022.6591	5043318.9192	-3078529.2368	0.0003	0.0004	0.0003
TBM6	-2389021.9705	5043324.9027	-3078520.0310	0.0003	0.0004	0.0003
YARB Doris Antenna type B	-2389004.0238	5043340.8221	-3078513.2118	0.0005	0.0005	0.0005
YARR (AU053)	-2389024.4971	5043315.3694	-3078534.1759	0.0003	0.0004	0.0003
DON38	-2388960.3240	5043306.5012	-3078601.0311	0.0003	0.0004	0.0003
DON95	-2389006.9196	5043329.3516	-3078524.9102	0.0003	0.0005	0.0004
DORIS GM	-2389003.0998	5043338.8723	-3078512.0171	0.0004	0.0004	0.0004
DON38 RM1	-2388953.5523	5043306.0377	-3078606.4694	0.0004	0.0005	0.0004
DON38 RM2	-2388959.5889	5043311.4352	-3078592.9772	0.0003	0.0005	0.0004
DON38 RM3	-2388968.3790	5043301.4973	-3078602.7265	0.0004	0.0005	0.0004
DON38 RM4	-2388960.2333	5043303.7858	-3078605.0406	0.0003	0.0005	0.0004
DON38_2	-2388924.0085	5043353.7396	-3078549.0481	0.0014	0.0005	0.0011
GPSTIME	-2388992.6464	5043336.7186	-3078532.4815	0.0004	0.0005	0.0007
DORIS Temp1	-2389007.5528	5043337.9111	-3078510.1486	0.0004	0.0004	0.0004
DORIS Temp2	-2389003.4867	5043340.5742	-3078508.9493	0.0005	0.0005	0.0005
DORIS antenna Type A	-2389003.8931	5043340.6138	-3078513.1037	0.0004	0.0004	0.0005

Appendix C Table 2 Earth Centred Cartesian co-ordinates and the associated standard deviation for the network stations. ITRF97 @1997.00 co-ordinates adopted at DON95 RM4 (YAR1).

FROM	TO	MAJ SEMI (m)	MED SEMI (m)	MIN SEMI (m)	DIST (m)	AZ, VANG	AZ, VANG	AZ, VANG
MOBLAS 5 IVP	DON95 RM1	0.0043	0.0036	0.0031	23.4076	(0, 0)	(0, 90)	(90, 0)
MOBLAS 5 IVP	DON95 RM2	0.0043	0.0036	0.0030	10.5450	(0, 0)	(0, 90)	(90, 0)
MOBLAS 5 IVP	DON95 RM3	0.0043	0.0036	0.0029	10.4772	(0, 0)	(0, 90)	(90, 0)
MOBLAS 5 IVP	DON95 RM4	0.0042	0.0033	0.0029	23.3559	(0, 0)	(0, 90)	(90, 0)
MOBLAS 5 IVP	TBM5	0.0042	0.0036	0.0029	19.6533	(0, 0)	(0, 90)	(90, 0)
MOBLAS 5 IVP	TBM6	0.0043	0.0036	0.0030	16.7745	(0, 0)	(0, 90)	(90, 0)
MOBLAS 5 IVP	YARB Doris Antenna Type B	0.0045	0.0036	0.0032	16.5172	(0, 0)	(0, 90)	(90, 0)
MOBLAS 5 IVP	YARR (AU053)	0.0042	0.0036	0.0029	24.4805	(0, 0)	(0, 90)	(90, 0)
MOBLAS 5 IVP	DON38	0.0043	0.0035	0.0030	92.1314	(0, 0)	(0, 90)	(90, 0)
MOBLAS 5 IVP	DON95	0.0043	0.0036	0.0030	3.1810	(0, 0)	(0, 90)	(90, 0)
MOBLAS 5 IVP	DORIS GM	0.0044	0.0036	0.0030	16.8275	(0, 0)	(0, 90)	(90, 0)
MOBLAS 5 IVP	DON38 RM1	0.0043	0.0036	0.0031	100.2286	(0, 0)	(0, 90)	(90, 0)
MOBLAS 5 IVP	DON38 RM2	0.0043	0.0036	0.0030	84.8345	(0, 0)	(0, 90)	(90, 0)
MOBLAS 5 IVP	DON38 RM3	0.0043	0.0036	0.0030	91.2002	(0, 0)	(0, 90)	(90, 0)
MOBLAS 5 IVP	DON38 RM4	0.0043	0.0036	0.0030	96.2079	(0, 0)	(0, 90)	(90, 0)
MOBLAS 5 IVP	DON38_2	0.0065	0.0036	0.0028	89.8033	(38, 0)	(0, 90)	(128, 0)
MOBLAS 5 IVP	GPSTIME	0.0048	0.0036	0.0030	17.3053	(0, 0)	(0, 90)	(90, 0)
MOBLAS 5 IVP	DORIS Temp1	0.0043	0.0036	0.0031	17.4111	(0, 0)	(0, 90)	(90, 0)
MOBLAS 5 IVP	DORIS Temp2	0.0044	0.0036	0.0031	20.1060	(0, 0)	(0, 90)	(90, 0)
MOBLAS 5 IVP	DORIS Antenna Type A	0.0044	0.0036	0.0030	16.5254	(0, 0)	(0, 90)	(90, 0)
Cal Pillar 2	MOBLAS 5 IVP	0.0099	0.0046	0.0041	150.3907	(98, 0)	(188, 0)	(0, 90)
Cal Pillar 3	MOBLAS 5 IVP	0.0067	0.0044	0.0038	100.3860	(90, 0)	(0, 0)	(0, 90)
Cal Target 1	MOBLAS 5 IVP	0.0137	0.0065	0.0052	3116.8660	(0, 84)	(180, 6)	(90, 0)
Cal Target 2	MOBLAS 5 IVP	0.0083	0.0046	0.0041	150.3931	(90, 0)	(0, 0)	(0, 90)
Cal Target 3	MOBLAS 5 IVP	0.0067	0.0044	0.0038	100.3843	(90, 0)	(0, 0)	(0, 90)

Appendix C Table 3 Three-dimensional line error ellipses from MOBLAS 5 IVP to all other network stations. ITRF97 @1997.00 co-ordinates adopted at DON95 RM4 (YAR1). The three axes are Semi-Major, Semi-medium and Semi-Minor. The associated azimuth and zenith angles of these axes are also listed. A 95% confidence level has been adopted.

STATION	Diff X (m)	Diff Y (m)	Diff Z (m)	Distance (m)
MOBLAS 5 IVP	0.0000	0.0000	0.0000	0.0000
DON95	1.2048	-2.5019	1.5517	3.1810
DON95	*1.2060*	*-2.5010*	*1.5530*	*3.1814*
	0.0012	**0.0009**	**0.0013**	**0.0020**
DON95 RM1	-9.3469	4.1079	21.0636	23.4076
DON95 RM1	*-9.3460*	*4.1070*	*21.0670*	*23.4101*
	0.0009	**-0.0009**	**0.0034**	**0.0036**
DON95 RM2	-3.3573	0.3529	9.9901	10.5451
DON95 RM2	*-3.3560*	*0.3550*	*9.9950*	*10.5494*
	0.0013	**0.0021**	**0.0049**	**0.0055**
DON95 RM3	-6.8450	-7.8711	-0.9817	10.4772
DON95 RM3	*-6.8400*	*-7.8700*	*-0.9760*	*10.4726*
	0.0050	**0.0011**	**0.0057**	**0.0077**
DON95 RM4	-17.4072	-14.9695	-4.2896	23.3559
DON95 RM4	*-17.3990*	*-14.9720*	*-4.2820*	*23.3500*
	0.0082	**-0.0025**	**0.0076**	**0.0115**
DON38	47.8004	-25.3523	-74.5692	92.1313
DON38	*47.8030*	*-25.3420*	*-74.5590*	*92.1216*
	0.0026	**0.0103**	**0.0102**	**0.0147**
DORIS GM	5.0246	7.0188	14.4448	16.8274
DORIS GM	*5.0240*	*7.0200*	*14.4500*	*16.8322*
	-0.0006	**0.0012**	**0.0052**	**0.0054**
DORIS Ant (A)	4.2313	8.7603	13.3582	16.5254
DORIS Ant (A)	*4.1990*	*8.7630*	*13.3790*	*16.5354*
	-0.0323	**0.0027**	**0.0208**	**0.0385**

Appendix C Table 4 Vectors from MOBLAS 5 IVP to the other network stations listed in the 1992 report. 1992 results (shown in *italics*) are in terms of WGS84 and the current results are in ITRF97 @ 1997.00. The results in bold **type are the differences between the 1992 results and those of this survey.**

STATION	Range from IVP (m)	Diff Distance (m)
MOBLAS 5 IVP	0.0	
Cal Target 1	3116.8975	
Cal Target 1	**3116.9047**	**-0.0072**
Cal Target 2	150.4229	
Cal Target 2	**150.4245**	**-0.0016**
Cal Target 3	100.4137	
Cal Target 3	**100.4185**	**-0.0048**

Appendix C Table 5 Range from the IVP to the effective measurement point of the calibration reflectors. Results shown in Bold **are from the 1992 survey.**

Conclusion

This is the third survey of the SLR reference points at the Yarragadee Laser Ranging Observatory. The results shown in tables C1, C2 and C3 are from a completely independent survey of the local network at Yarragadee. No observations from previous surveys have been included in the GEOLAB adjustment.

Two to three millimetre agreements have been obtained between the currently adopted results (1992 survey) and the new survey results, as is demonstrated in the tables C4 and C5 for a number of the network sites including the eccentricity from DON95 to MOBLAS 5 IVP. The agreement between DON95 and DON95 RM4 (YAR1) is not as encouraging showing a misclose in the order of 11mm. This is predominantly seen in the height difference between these two marks. A subsequent re-survey of this network is planned for sometime during 2001 to confirm the 1998 results. The discrepancy between these two stations directly effects the local tie information used by IERS.

Appendix D

Tidbinbilla Deep Space Tracking Station

Local Tie Survey

September 1995

Introduction

The local tie survey at the Tidbinbilla (DSS45) 34m VLBI telescope was completed in September 1995. This survey was completed for determining the geodetic tie between the telescope invariant point (IVP) and the GPS reference point at AU017 (TIDB).

This survey was undertaken by B Twilley, B Murphy and others.

The AUSLIG Geodesy Space Geodesy Analysis Centre has further processed the results from this survey in order to determine the intersection of axes of rotation of the VLBI telescope.

Observations

A Leica TC2002 Total Station was used for all horizontal angles, slope distances and vertical angles. Where vertical angles were to be used for vertical heighting, the Rueger method was used to determine the height of the trunnion axis of the total station. The Rueger method consists of observing a levelling staff, over a point with known height, with the vertical circle of the total station set to 90 degrees (horizontal).

Observations were taken into the telescope from two total station standpoints. The first, AU031 (TIDN), being a concrete pillar 65m to the north of DSS45. The second, AU032 (TIDS), being a concrete pillar 74m to the south of DSS45. Both concrete pillars have stainless steel pillar plates with 5/8 spigots.

Observations were taken to the VLBI telescope at a variety of horizontal and vertical settings. Three targets were placed on the telescope for the determination of the horizontal axis of rotation. Two targets were mounted on the top of the telescope near the end bearings of the vertical axis. A third target was mounted near the centre of rotation on top of the telescope, over a centre punch mark. Observations were taken from AU031 to all three targets with the telescope set at approximately twenty-degree increments in azimuth for a full 360 degrees. A second set of observations was taken to the same three targets from AU032 with the telescope again rotated through 360 degrees.

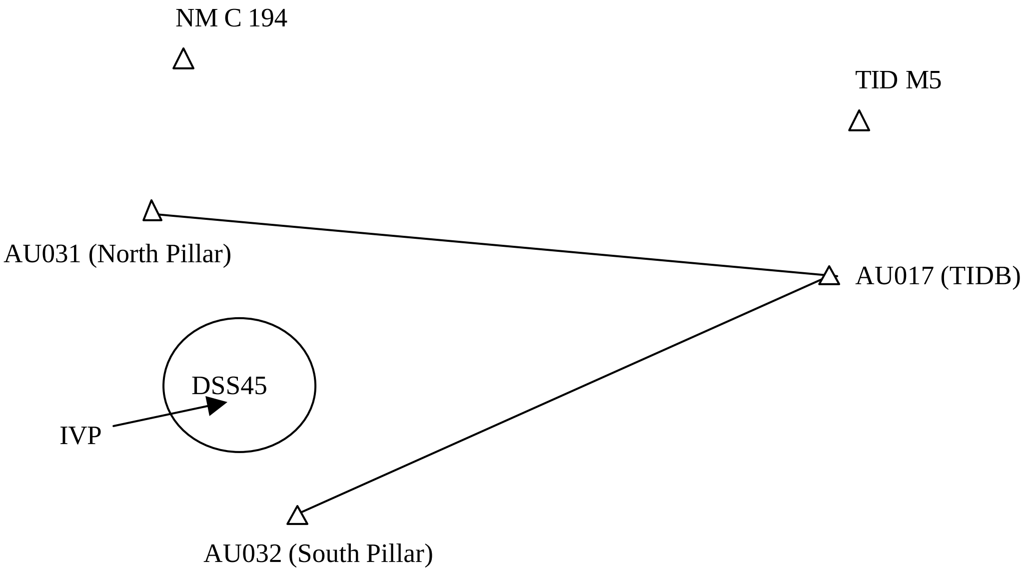
For the vertical circle four Retro-reflector tape targets were positioned on the right hand face (looking down the bore sight) of the telescope bull gear. Observations were taken from AU031 to each of these targets at a variety of elevations setting of the telescope. The elevation settings were chosen to maximise the visibility of the targets. The horizontal direction of the telescope was locked perpendicular to the line of sight. A second set of observations was taken from AU031 to another four targets placed on the opposite side of the bull gear with the telescope now pointed 180 degrees from its previous setting.

AU017 (TIDB) had a Rogue GPS receiver (and Dorne Margolin R antenna) operating on it (see TIDB.log). An Ashtech Z12 GPS receiver and DMT antenna was placed on AU031 for four days and a second equivalent set was placed on AU032 for the same four days. Five days GPS observations were also taken at NM C 194 using a Rogue GPS receiver and DMT antenna. All three data sets were processed with data from AU017 (TIDB) using the BERNESE GPS Processing Software Version 4.0. An L1&L2 solution with no tropospheric delay parameters was used to determine the co-ordinates of the three stations and their associated VCV's.

Datum

AU017 (TIDB) has been held fixed at its ITRF97 @ 1997.0 values. The resulting co-ordinates from the GPS processing for AU031, AU032 and NM C 194 provide orientation for the local terrestrial survey in terms of ITRF97. The GRS80 ellipsoid has been adopted.

Orthometric heights were calculated at all marks by using the ellipsoidal height from the GPS baselines and AUSGEOID98 N values.



Appendix D Figure 1 The general Layout of the Tidbinbilla network.

Reductions

All observations were reduced to a grand mean per set and reformatted to the standard GEOLAB format. All distances were reduced for atmospherics (first and second velocity corrections) using the model supplied in the "Supplement to TC2002/T3000 Operator's Manual" as follows:

$$\Delta D_1 = 281.8 - \left[\frac{0.29065 p}{(1+at)} - \frac{4.126 \cdot 10^{-4} \cdot h}{(1+at)} \cdot 10^x \right]$$

Where

$\Delta D_1 =$	Atmospheric correction in ppm
$p =$	Atmospheric pressure (mb)
$t =$	Ambient temperature (°C)
$h =$	Relative humidity (%)
$a =$	1/273.16

$$x = \frac{7.5t}{237.3 + t} + 0.7857$$

They were also reduced for prism offsets, which in the case of the Leica precision prism is 0.000m.

Observed distances (corrected for atmospherics and prism corrections) have been entered into the GEOLAB data file (Distances from Height of Instrument to Height of Target are entered in to GEOLAB). No other reductions have been applied ie. no reductions to the ellipsoid outside the adjustment software. True heights of instrument and target have been used with the associated Orthometric heights of the ground mark in all cases.

D5. Station Descriptions

AU017, DOMES 50103M108, TIDBINBILLA AFN [NGDB Sequence No.: 23041] Small drill hole in the centre of the top of a stainless steel pillar plate which is set in the top of a 0.6 metre diameter reinforced concrete pillar. This pillar is set into the ground to a depth of 2.5 metres and protrudes 0.5 metres above ground level. The pillar plate bears the inscription: "TIDBINBILLA SPC-40 GPS STATION MARK JPL 4002-S 1992". The pillar is in the centre of a 6 metre square post & rail fence enclosure. The hardwood posts are 200 x 100 mm and the rails 150 x 25 mm. This fence does not obstruct the visibility horizon above 10 degrees elevation.

DSS45 IVP, DOMES 50103S010, TIDBINBILLA [NGDB Sequence No.: 7263] 34 metre Azimuth-Elevation radio telescope. The orthogonal projection of the vector defining the elevation axes onto the Azimuth axes. The elevation and azimuth axes do not intersect.

NM C 194, NSW 7276, TIDBINBILLA [NGDB Sequence No.: 9567] Centre-punched steel picket, driven to refusal and set in concrete. A small rock cairn covers the mark.

M 5, TIDBINBILLA [NGDB Sequence No.: 7554] Intersection of lines scribed on a 63 mm diameter brass cap, braised to the top of a 50 mm diameter steel pipe 3.3 metres long, set in concrete. The cap is stamped DISF 42 BM 5. The height refers to the top of the screw in the cap.

AU031, North Pillar. The intersection of the top of the stainless steel pillar plate with the vertical axis of a 5/8"ƒ Whitworth threaded stainless steel spigot. This pillar plate is set into the top of the concrete survey pillar 65m to the North of DSS45.

AU032, South Pillar. The intersection of the top of the stainless steel pillar plate with the vertical axis of a 5/8"ƒ Whitworth threaded stainless steel spigot. This pillar plate is set into the top of the concrete survey pillar 74m to the South of DSS45

Results

STATION	LAT	LONG	Ellipsoidal HEIGHT (m)	STD LAT (m)	STD LONG (m)	STD HEIGHT (m)
AU031 NORTH	S35 23 52.66029	E148 58 40.92711	661.8674	0.0004	0.0004	0.0009
AU032 SOUTH	S35 23 55.96524	E148 58 37.44460	657.6299	0.0005	0.0004	0.0009
DSS45 IVP	S35 23 54.45631	E148 58 39.66269	674.3853	0.0027	0.0032	0.0045
NMC_194	S35 23 51.42530	E148 58 42.85869	663.1969	0.0004	0.0003	0.0009
TID_M5	S35 24 2.31065	E148 58 55.57367	665.6957	0.0068	0.0032	0.0051
AU017 TIDB	S35 23 57.15172	E148 58 47.98741	665.3657	0.0001	0.0001	0.0001

Appendix D Table 1 Latitude, Longitude and Ellipsoidal height and the associated standard deviations for the network stations. ITRF97 @ 1997.00 co-ordinates and GRS80 ellipsoid adopted at AU017 TIDB.

STATION	X(m)	Y(m)	Z(m)	STD X (m)	STD Y (m)	STD Z (m)
AU031 NORTH	-4460970.5804	2682749.6395	-3674328.8460	0.0007	0.0005	0.0006
AU032 SOUTH	-4460871.7587	2682792.7656	-3674409.4264	0.0007	0.0006	0.0006
DSS45 IVP	-4460935.3998	2682765.7185	-3674381.2213	0.0034	0.0036	0.0036
NMC_194	-4461015.5273	2682719.7861	-3674298.5875	0.0007	0.0005	0.0006
TID_M5	-4461016.0786	2682345.6862	-3674573.5208	0.0061	0.0026	0.0063
AU017 TIDB	-4460996.1282	2682557.0867	-3674443.7169	0.0001	0.0001	0.0001

Appendix D Table 2 Earth Centred Cartesian Co-ordinates and the associated standard deviations for the network stations. ITRF97 at 1997.00 co-ordinates adopted at AU017 TIDB.

From	To	MAJ-SEMI (m)	MED-SEMI (m)	MINI-SEMI (m)	DISTANCE (m)	MAJ-SEMI (AZ,VANG)	MED-SEMI (AZ,VANG)	MINI-SEMI (AZ,VANG)
AU031NTH	DSS45 IVP	0.0123	0.0093	0.0070	65.1105	(202, 82)	(112, 0)	(22, 8)
AU032STH	DSS45 IVP	0.0123	0.0094	0.0071	74.6810	(204, 82)	(114, 0)	(24, 8)
DSS45 IVP	NMC_194	0.0128	0.0093	0.0071	123.9297	(202, 83)	(112, 0)	(22, 7)
DSS45 IVP	TID_M5	0.0220	0.0187	0.0099	468.9513	(204, 6)	(24, 84)	(114, 0)
DSS45 IVP	AU017	0.0125	0.0093	0.0071	226.0993	(203, 83)	(113, 0)	(23, 7)

Appendix D Table 3 Line error ellipses between the DSS45 Antenna IVP and all other monuments included in this survey. Error ellipses are at 95% confidence.

Baseline	Diff X (m)	Diff Y (m)	Diff Z (m)
AU017 – DSS45 (STOLZ)	60.7210	208.6200	62.4880
AU017 – DSS45 (current)	60.7284	208.6318	62.4956
Difference	-0.0074	-0.0118	-0.0076
AU017 – TID M5 (ORRTID93)	-19.9370	-211.4160	-129.7870
AU017 – TID M5 (Current)	-19.9504	-211.4005	-129.8039
Difference	0.0134	-0.0155	0.0169
AU017 – NM C 194 (ORRTID93)	-19.3880	162.6880	145.1390
AU017 – NM C 194 (Current)	-19.3991	162.6994	145.1294
Difference	0.0111	-0.0114	0.0096

Appendix D Table 4 The comparison to the current best-adopted values.

Table D4 lists the current best values adopted for the Tidbinbilla site and the values determined from this survey. Notable differences are seen between the two. ORRTID93 was constrained to a number of sites and used AUSGeoid93 to transfer ellipsoidal height (Steed, pers coms). This may account for the large discrepancies. The published ITRF97 values for DSS45 and AU017 agree with the new survey at the 1-2mm level. This is most probably caused by IERS actually estimating both values rather then holding the previous local tie between both sites tightly constrained, as is normally the case, thus forming a completely independent check on the new local tie results.

Conclusion

This is the first survey of the VLBI reference points at the Tidbinbilla DSS45 telescope that uses this technique. The results shown in Table D1 are from a completely independent survey of the local network at Tidbinbilla. No observations from previous surveys have been included in the GEOLAB adjustment.

Re-survey of this facility is now due for consideration, given that this survey was last completed more than five years ago. This will be the first test of the validity of the current technique since it will give a completely independent estimate of the telescope IVP with a similar accuracy to the first.

Appendix E

HOBART VLBI RADIO TELESCOPE
Local Tie Survey

FEBRUARY 1995

Background

The local tie survey at Hobart was completed through the joint efforts of AUSLIG and the Tasmanian Department of Primary Industries Water and Environment (DPIWE) in February 1995. This survey was completed for the purpose of verifying that no local movement had occurred and that the connection between the VLBI reference point (later referred to as IVP) and the GPS reference point (AU016) is as published in the IERS local tie file.

Connections to the significant geodetic monuments (see Tables E1, E2 & E3 for the results lists) at Hobart have been completed. This survey has been undertaken on previous occasions, Stolz, *et al* (1998), (see table E4 for a comparison between earlier determinations and this survey). However this report outlines the results of the 1995 local tie survey using the described surveying technique, and associated IVP determination.

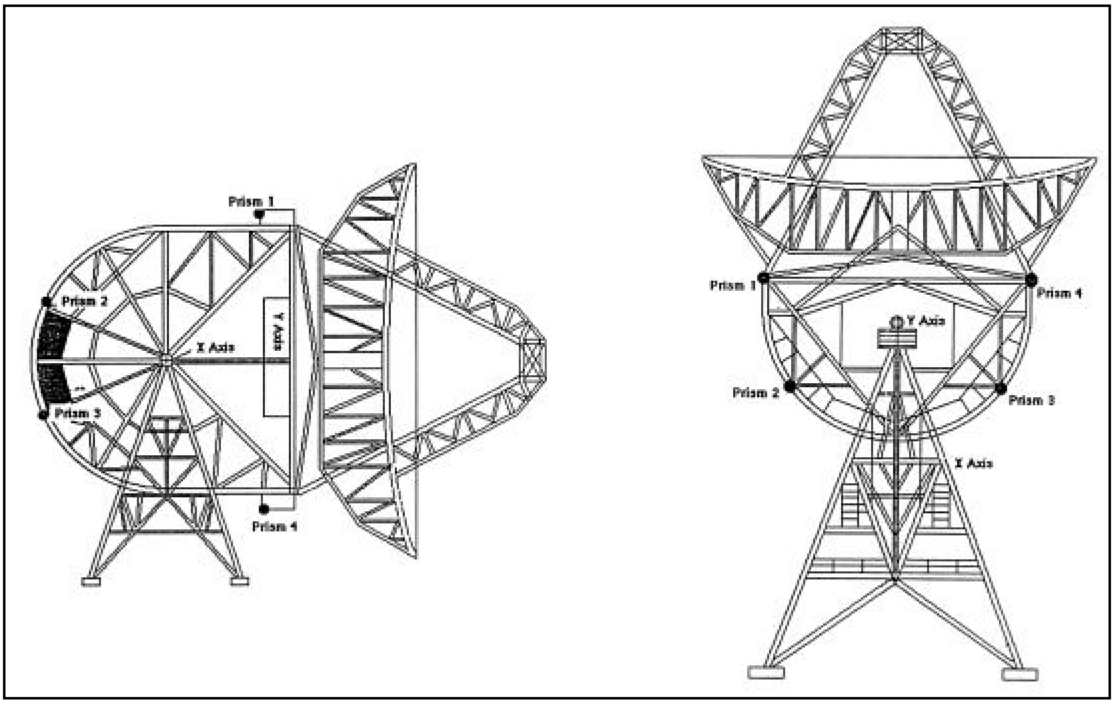
The AUSLIG Geodesy Space Geodesy Analysis Centre (SGAC) has processed the results from this survey in order to determine the invariant point (IVP) of the VLBI telescope. The co-ordinates for the IVP are included in the result section of this report. The vector from AU016 to the VLBI Telescope IVP is considered the fundamental local tie information at this site.

Observations

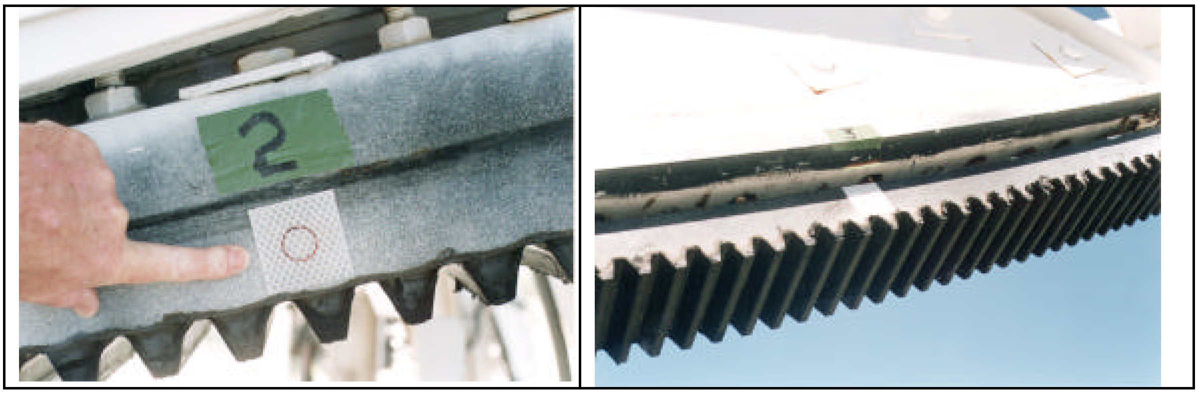
A Leica TC2002 Total Station was used for observations of all horizontal angles, slope distances and zenith distances. Where vertical angles were to be used for heighting, the Rueger method was used to determine the height of the trunnion axis of the total station above the monument reference point. The Rueger method consists of observing a levelling staff, over a point with known height, with the vertical circle of the total station set to 90 degrees (horizontal).

Observations were taken into the telescope from two total station standpoints. The first was UF003 (West Pillar)- a concrete pillar approximately 53 metres to the West of the Telescope. The second, UF005 (North Pillar) - a concrete pillar approximately 70 metres to the north. Both concrete pillars have stainless steel pillar plates with centred 5/8 spigots which are aligned with the extensions of the X- and Y- axes, respectively.

Observations were taken to the VLBI telescope at a variety of horizontal and vertical settings. For both axes, four retro targets were evenly placed along the inside of the telescopes hemispherical bull gear (see figures E1 & E2). Observations were taken from UF003 to all four targets connected to the 'X' axis with the telescope set at approximately twenty-degree increments in azimuth for a full 360 degrees. The targets placed on the 'Y' axis were observed from UF005 with the telescope set at ten-degree increments in elevation. The horizontal direction of the telescope was locked perpendicular to the line of sight.



Appendix E Figure 1 Retro Prism locations for determining telescope axes.



Appendix E Figure 2 Pictures of Retro Targets placed on telescope axes.

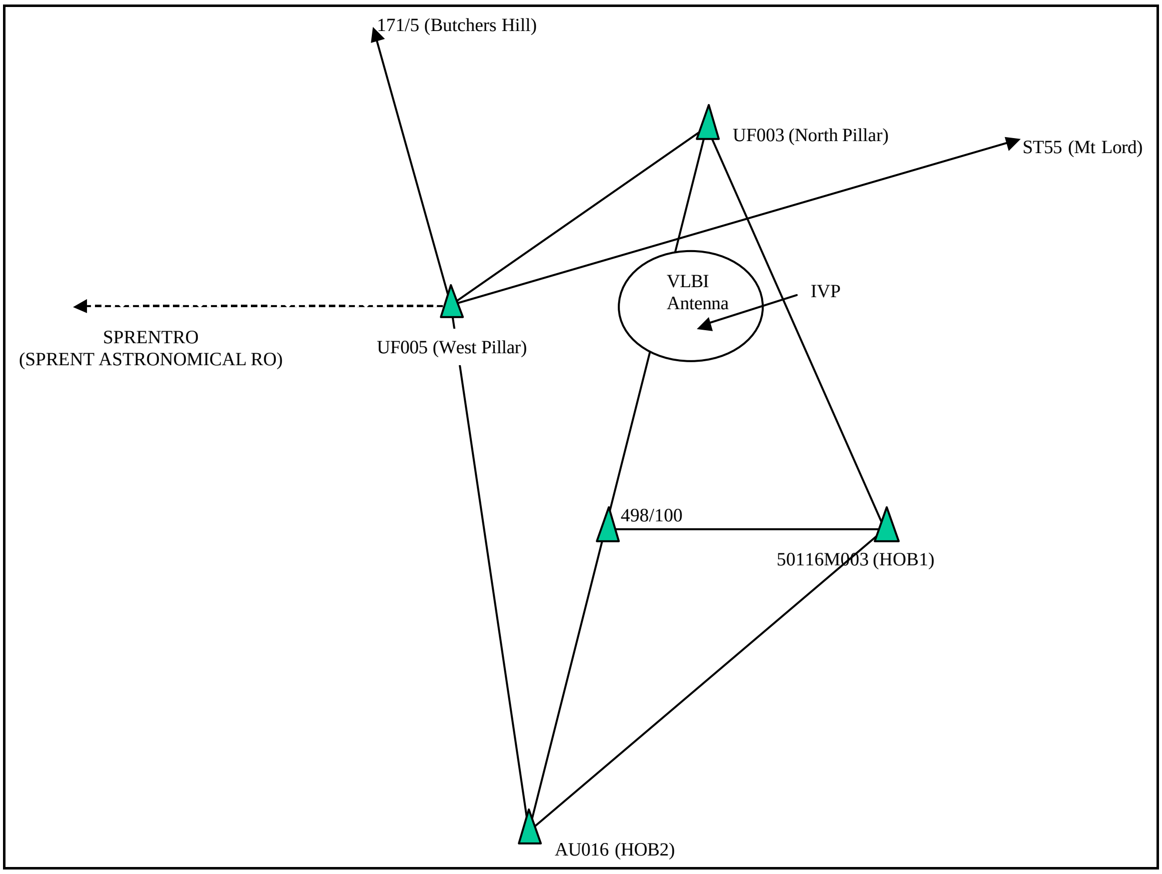
A WILD NA2 bar-code level with an aluminium staff was used to carry Orthometric height through the control network. The levelling results in combination with AUSGeoid98 were used to transfer ellipsoidal height from AU016 (HOB2) through the network.

A number of GPS baselines were also observed during the survey period. GPS data was collected over 3 days, with the observing periods ranging from two to six hours. All GPS data was collected using a Leica200-CR299 Receiver (and Leica Dual frequency geodetic Antenna – SR299GPS). The marks on which data was observed included two sessions at AU016 (HOB2), several hours of data for the Minimac site (HOB1), several sessions for both UF003 (North Pillar) and UF005 (West Pillar), also one and a half hours data at both 171/5E (Butchers Hill Eccentric Mark RM5) and ST55E (Mt Lord Eccentric Mark RM4).

All baseline combinations were processed using the BERNESE GPS Processing Software Version 3.5. The log sheets for these GPS occupations can be found on AUSLIG internal file 95/15.

Datum

AU016 (HOB2) has been fixed at its ITRF97 @ 1997.0 values. The resulting co-ordinates from the GPS processing for UF003, UF005, 171/5E and ST55E provide orientation for the local terrestrial survey in terms of ITRF97. Accordingly the GRS80 ellipsoid has been adopted.



Appendix E Figure 3 The general Layout of the Mount Pleasant network

Reductions

All angular observations were reduced to a grand mean per set and reformatted to the standard GEOLAB format. All distances were reduced for atmospherics (first and second velocity corrections) using the model supplied in the “Supplement to TC2002/T3000 Operator's Manual” as follows:

$$\Delta D_1 = 281.8 - \left[\frac{0.29065p}{(1+at)} - \frac{4.126 \cdot 10^{-4} \cdot h}{(1+at)} \cdot 10^x \right]$$

Where

$\Delta D_1 =$	Atmospheric correction in ppm
$p =$	Atmospheric pressure (mb)
$t =$	Ambient temperature (°C)
$h =$	Relative humidity (%)
$a =$	1/273.16

$$x = \frac{7.5t}{237.3 + t} + 0.7857$$

They were also reduced for prism offsets, which in the case of the Leica precision prism is 0.000m. The tape Retro-reflector has a prism offset of +0.0344m. Both prism offsets are caused by a setting of -0.0344m in-built into the instrument to allow for the normal use of the precision prisms. Temperature, pressure and humidity were observed on a half hourly basis during observations.

Where height of instrument and/or height of target were not measured the height of instrument and height of target was calculated to reflect the observed vertical angles, which were inherently observed by the total station. This is necessary for the GEOLAB software to correctly reduce distance observations.

Mark Descriptions

26 METRE VLBI RADIO TELESCOPE - IVP: Domes 50116S002. 26 Metre Radio Telescope. The orthogonal projection of the vector defining the Y axes onto the X axes. The Y and X-axes do not intersect.

AU016 (HOB2): Domes 50116M004. The intersection of the top of the stainless steel plate with the vertical axis of a 5/8"*f* Whitworth threaded stainless steel spigot. The pillar plate is set into the top of a 0.5 m high concrete pillar 0.6 m in diameter. The Dorne Margolin T - GPS antenna currently occupies this monument.

50116M003 (HOB1): Domes 50116M003, The intersection of the vertical axis of a 5/8"*f* Whitworth-threaded steel stub with the horizontal plane coinciding with the top face of a U-channel support to which the steel stub is attached. The support is mounted on a 1.9 m vertical steel pole that is secured to the roof of the building that houses the hydrogen maser.

UF003 (NORTH PILLAR): Domes 50116M002. The intersection of the top of a stainless steel plate with the vertical axis of a 5/8"*f* Whitworth threaded stainless steel spigot. The pillar plate is set into the top of approx. 1.6 m high concrete pillar 0.4 m in diameter.

UF005 (WEST PILLAR): Domes 50116M001. The intersection of the top of a stainless steel plate with the vertical axis of a 5/8"*f* Whitworth threaded stainless steel spigot. The pillar plate is set into the top of approx 1.6 m high concrete pillar 0.4 m in diameter.

171/5 (BUTCHERS HILL): Is a GI nail set in a precast concrete block.

171/5 RM5 (BUTCHERS HILL): Is a steel bar driven to ground level.

ST55E (MT LORD): Is a steel pin in a concrete block.

ST55E RM4 (MT LORD): Is a steel bar set in concrete.

498/100: Is a Koneo nail in rock.

Results

Station	Latitude (DMS)			Longitude (DMS)			Ellipsoidal Ht (m)	Std dev (m)	Std dev (m)	Std dev (m)
IVP	S42	48	12.91022	E147	26	25.86347	65.1249	0.0025	0.0023	0.0023
ST55	S42	46	20.19939	E147	29	19.42559	274.6526	0.0069	0.0054	0.0379
171/5	S42	45	8.75818	E147	25	49.62161	240.3149	0.0067	0.0048	0.0379
AU016	S42	48	16.98076	E147	26	19.43836	41.0855	0.0001	0.0001	0.0001
ST55E	S42	46	19.97469	E147	29	19.06288	273.9486	0.0058	0.0042	0.0378
UF003	S42	48	11.28765	E147	26	25.86320	51.0277	0.0020	0.0016	0.0019
UF005	S42	48	12.91022	E147	26	22.93335	52.2399	0.0015	0.0013	0.0019
498/100	S42	48	14.19256	E147	26	21.78880	48.9547	0.0018	0.0021	0.0019
SPRENTRO	S42	48	12.90790	E147	25	21.32077	46.7180	0.0637	0.0050	0.0024
50116M003	S42	48	14.29670	E147	26	23.98992	56.6516	0.0005	0.0004	0.0010

Appendix E Table 1 Latitude, Longitude and Ellipsoidal height and the associated standard deviation for the network stations. GRS80 ellipsoid and ITRF97 @1997.00 co-ordinates adopted at AU016 (HOB2).

Station	X(m)	Y(m)	Z(m)	Std dev (m)	Std dev (m)	Std dev (m)
IVP	-3950236.7330	2522347.5756	-4311562.5631	0.0024	0.0023	0.0024
ST55	-3954479.8201	2520375.2263	-4309152.3959	0.0232	0.0131	0.0283
171/5	-3953154.3524	2525188.4658	-4307510.5114	0.0239	0.0159	0.0261
AU016	-3950071.3600	2522415.1950	-4311638.3860	0.0001	0.0001	0.0001
ST55E	-3954478.9231	2520384.4332	-4309146.8279	0.0231	0.0148	0.0270
UF003	-3950256.6869	2522360.3241	-4311516.2485	0.0017	0.0019	0.0019
UF005	-3950192.9332	2522398.6032	-4311553.8079	0.0016	0.0015	0.0016
498/100	-3950154.2434	2522404.7546	-4311580.6081	0.0018	0.0022	0.0019
SPRENTRO	-3949435.9280	2523576.2826	-4311550.0030	0.0368	0.0235	0.0468
50116M003	-3950184.0798	2522364.4649	-4311588.1957	0.0007	0.0006	0.0008

Appendix E Table 2 Earth Centred Cartesian co-ordinates and the associated standard deviation for the network stations. GRS80 ellipsoid and ITRF97 @1997.00 co-ordinates adopted at AU016 (HOB2).

From	To	Maj semi (m)	Med semi (m)	Min semi (m)	Dist (m)	Az,vang	Az,vang	Az,vang
IVP	ST55	0.1063	0.0176	0.0145	5263.3503	(146, 84)	(349, 5)	(259, 2)
IVP	171/5	0.1058	0.0190	0.0138	5744.7614	(311, 90)	(180, 0)	(90, 0)
IVP	AU016	0.0069	0.0064	0.0064	194.0869	(0, 0)	(0, 90)	(90, 0)
IVP	ST55E	0.1057	0.0163	0.0121	5261.7376	(174, 88)	(11, 2)	(281, 1)
IVP	UF003	0.0074	0.0055	0.0038	52.0166	(146, 0)	(236, 0)	(0, 90)
IVP	UF005	0.0054	0.0053	0.0038	67.8151	(0, 0)	(90, 0)	(0, 90)
IVP	498/100	0.0080	0.0076	0.0065	101.9783	(90, 0)	(0, 0)	(0, 90)
IVP	SPRENTRO	0.1775	0.0145	0.0092	1466.6858	(0, 0)	(90, 0)	(0, 90)
IVP	50116M003	0.0069	0.0064	0.0063	60.9478	(0, 0)	(90, 0)	(0, 90)

Appendix E Table 3 Three-dimensional line error ellipses from VLBI Telescope IVP to all other network stations. GRS80 ellipsoid and ITRF97 @1997.00 co-ordinates adopted at AU016 (HOB2). The three axes are Semi-Major, Semi-medium and Semi-Minor. The associated azimuth and zenith angles of these axes are also listed. A 95% confidence level has been adopted.

STATION	Diff X (m)	Diff Y (m)	Diff Z (m)	SOURCE
50116M003	*0.0000*	*0.0000*	*0.0000*	
AU016	112.720	50.730	-50.190	AUSLIG, 2000
AU016	*112.713*	*50.732*	*-50.200*	*Coleman, 1994*
	0.0070	**-0.0020**	**-0.010**	
IVP	-52.653	-16.889	25.633	AUSLIG, 2000
IVP	*-52.658*	*-16.891*	*25.627*	*DELM, 1995*
	-0.005	**-0.0020**	**-0.006**	
AU016	*0.0000*	*0.0000*	*0.0000*	
IVP	-165.373	67.619	-75.823	AUSLIG, 2000
IVP	*-165.370*	*-67.616*	*-75.820*	*Coleman, 1994 & DELM, 1995*
	0.0030	**0.0030**	**0.0030**	

Appendix E Table 4 Vectors from 510116M003 (HOB1) & AU016 (HOB2) to the VLBI Telescope IVP as determined by DELM, 1995, Coleman 1994 & AUSLIG, 2000. The 1994 &1995 results (shown in italics) are in terms of WGS84 and the current results are in ITRF97 @ 1997.00. The bold results are the differences between the 1994 & 1995 results and those of this survey.

Conclusion

There have been a number of attempts over a ten year period to determine the local ties between the three geodetic reference marks at the University of Tasmania's Mt. Pleasant Observatory (Stolz *et al*, 1998). This report outlines the current method used by AUSLIG to reduce existing raw field observations, adjust the local network and subsequently determine the telescope IVP.

The comparisons between the previous best determinations and this current method are shown in Table E4. A 3 mm agreement was obtained between AU016 (HOB2) and the IVP. However an agreement in the order of 10 mm was achieved between 50116M003 (HOB1) and the other two marks, AU016 (HOB2) and the IVP.

In order to confirm the results of this determination a subsequent re-survey of this network is required. In any case it is now over 5 years since the last observation.

ATTACHMENTS

1. **Rock Retro- Reflector Diagram**

2. **Spider Retro- Reflector Diagram**

3. **Outputs from calculations**
   - **Rock Retro**
   - **Spider Retro 1**
   - **Spider Retro 2**

4. **MATLAB "mfile" used for Spider calculations**

5. **Orthometric Height Transfer Adjustment File**

6. **NM C 106 Pillar with reference points**

7. **Mirror 7 housing diagram**

8. **DORIS antenna diagram with reference points**