Technical Report On The Ties At Geodetic Observatories In South-Eastern Australia

Art Stolz
School of Geomatic Enginerring University of New South Wales and

Brian Murphy & Jim Steed
Australian Surveying and Land Information Group

ABSTRACT

Finger and Folkner (1991), Ray et al. (1991), Himwich et al. (1993) and Schutz et al. (1993), amongst others, have reported large discepancies between the SLR coordinates of the Orroral geodetic observatory (CDP 7843) and the VLBI positions of the Tidbinbilla DSN sites (CDP 1543 and 1545) when compared via ties determined by a combination of ground survey data and GPS. A systematic study to assess the validity of published ties in the ACT was initiated in response. Susequently, the scope of the study was broadened to include Hobart. An error of 24 cm in the vertical connection between the Hobart VLBI antenna (CDP 7242) and the CIGNET GPS site (HOBA) was made during the initial determination of CDP 7242 by Clayton (1989). Corrections derived by Strong (1991) were promptly communicated to the US National Geodetic Survey but the new results appear not to have been passed on to the IERS. In consequence, this error entered the definitions of both ITRF91 and ITRF93. At Tidbinbilla, the GPS mark AU017 was misidentified by 13 cm in elevation during the levelling run observed to tie this mark to CDP 1543 and 1545 and, although the problem was discovered soon after it occurred, the wrong tie was forwarded to the IERS where it was used to compute ITRF91. We suspect that these two errors explain a large portion of the discrepancies which were found. Table 7 gives the current best determinations of ties. Their accuracy ranges from about 5-10 mm for the shorter connections (< 100 m), to 1-2 cm for those of medium-length (< 1 km), to 3-5 cm for the 26 km-long Orroral-Tidbinbilla tie. Siting of a GPS receiver at Orroral, long observing sessions, careful attention to the modelling of the tropospheric delay, antenna phase centre variations and antenna multipathing should lead to improvements in the accuracy of the Orroral-Tidbinbilla connection.

1. INTRODUCTION

Two reference coordinate systems are required in space geodesy and global navigation: (1) an earth-fixed system to locate the observer and, (2) an inertial or space-fixed system to locate the reference object eg. radio source or earth-satellite. The corresponding reference coordinate systems in current use are the International Terrestrial Reference Frame (ITRF) and the International Celestial Reference Frame (ICRF). The ITRF is defined by a set of coordinates and velocities of space geodetic observatories determined from a combination of SLR, VLBI, GPS and more recently DORIS observations. The ICRF is defined by the directions to compact extragalactic radio sources observed with VLBI. Both the ITRF and ICRF are geocentric, this being achieved by SLR observations from sites used to define the ITRF. The orientation parameters of the ITRF relative to the ICRF are monitored on a regular basis using all of the abovementioned geodetic methods. A practical requirement of the realisation of the ITRF and ICRF is the colocation of observing stations for the different techniques at common sites, either in a permanent mode or by repeated occupations. Obviously, these colocated observatories cannot be the same point and, therefore, they must be linked by ground ties. Terrestrial geodetic methods are used to achieve this, mainly levelling and three-dimensional traverse if the tie is short but for longer ties these measurements are combined with GPS observations. This is the case with colocated geodetic observatories in southeastern Australia which are both in close proximity of one another, within a few hundred metres at Tidbinbilla and Hobart (GPS and VLBI), and widely separated, about 26 km between the SLR site at Orroral and the VLBI antennas at Tidbinbilla. The importance of an accurate global reference coordinate system and, therefore, accurate ties cannot be overestimated. For example, such a reference frame is critical for maximizing the scientific returns from satellite missions such as TOPEX/Poseidon, Icesat and follow-on missions as without an accurate definition of the terrestrial reference frame, it is not possible to compare altimeter estimates of ocean or ice height from separate missions to produce a longer height change record than provided by a single mission. In the absence of other errors, an error in a tie will show up as an unusually large discrepancy between coordinates determined from different methods and compared using this tie. Large discepancies have been reported between the SLR coordinates of Orroral geodetic observatory and the VLBI coordinates of the Tidbinbilla DSN sites by Finger and Folkner (1991) in their determination of the radio-planetary frame tie and DSN station locations, by Ray et al. (1991) when comparing VLBI and SLR geocentric site coordinates, Himwich et al. (1993) in testing the consistency of the scale of the ITRF as estimated from SLR and VLBI data, Schutz et al. (1993) for their Southwest Pacific GPS project and by Watkins and Eanes (1994) in their comparison of SLR and VLBI reference frame positions and velocities. Also, van Hove (personal communication, 1994) found a disagreement of 6-7 cm in the vertical at Tidbinbilla between the ITRF coordinates of DSS45 and the position of the GPS reference mark AU017 prompting her to suggest that the problem may be the ground ties at Tidbinbilla. In response, a systematic evaluation of the validity of published ties between geodetic observatories in Canberra region was initiated by Geoscience Australia with the scope of the study being extended to include the University of Tasmania's VLBI observatory at Hobart. Specifically, the terms of reference of this study were: (1) to analyse the determinations of the tie between the reference point of the SLR systems at Orroral and that of the 34-metre DSS45 VLBI antenna at Tidbinbilla; (2) to analyse the determinations of the tie between the Australian Fiducial Network (AFN) mark AU017 at Tidbinbilla and the reference points of the DSN VLBI antennas DSS42, DSS43 and DSS45; and (3) to analyse the determinations of the ties between the reference point of the 26-metre VLBI antenna at Hobart, the AFN mark AU016 and the CIGNET GPS antenna. We report on our findings below. The GPS, SLR and VLBI reference points at sites in the Canberra region and at Hobart are described. Discussed also are the methods which were used to locate these points and to determine the ties between them. The validity of the ties, particularly those published by the International Earth Rotation Service (IERS), is then evaluated. Finally, we give the current best determinations of the ties.

2. OBSERVATORY REFERENCE POINTS

Figure 1 gives a schematic representation of the major telescope geometries used at space geodetic observatories around the world. The main telescope types are: (i) those with a fixed vertical axis (azimuth-elevation mount); (ii) those with a fixed axis pointing towards the celestial pole (hour angle-declination mount); and (iii) those with a fixed horizontal axis (X-Y mount). Generally, the rotating axes do not intersect, the azimuth-elevation mount being the exception. In VLBI the antenna is symmetric about one of the axes and on this axis lies the phase centre of the antenna feed horn, the point to which the VLBI delay and delay rate observations refer. This point moves as the telescope is rotated and hence is unsuitable as an antenna reference point. Instead, a point on the fixed axis is often used. Usually, this is the intersection of the fixed axis with the plane perpendicular to the fixed axis that contains the moving axis. The delay between the phase centre and antenna reference point is indistinguishable from VLBI clock offsets and secular changes in these offsets and is solved for as such. These offsets do not affect the VLBI baseline measurement. In current SLR systems the reference point is generally a point away from the telecope such as a geodetic marker attached to the observatory or to the ground. This is particularly useful in work involving transportable telescopes which may be placed in slightly different locations each time a site is occupied. The SLR measurements refer to a point within the telescope transmit/receive optics and corrections need to be applied to reduce these measurements to the geodetic marker. These instrumental delays are determined by a careful calibration of each telescope but this is a separate problem and will not be addressed here. The reference mark in GPS is a point on the antenna ground plane or the observatory reference pillar to which the antenna is secured. As for VLBI, the physical centres of typical GPS antennas do not generally coincide with the phase centre, the point at which the signal is received. Furthermore, the phase centres for the L1 and L2 frequencies are independent of each other and will coincide only by chance. Also, the location of the phase centre will vary from one antenna to another, though fortunately, the phase centre for copies of a single antenna model tends to be constant and the effect will largely cancel if the same model is used to measure a baseline. However, the differences in the responses of the various antenna models must be taken into account if data taken by different antenna types are to be combined.

Hobart

There are three geodetic reference marks at the University of Tasmania's Mt. Pleasant Observatory, which is situated about 25 km from Hobart: those of the 26-metre VLBI antenna and, those of the CIGNET and AFN GPS sites. The marks lie within a few hundred metres of one another. The VLBI antenna has an X-Y mount and the antenna reference point is the intersection of the fixed axis (the X-axis, aligned east-west) with the plane perpendicular to this axis and which also contains the moving axis (the Y-axis, aligned north-south). This point is known in the geodetic literature either as CDP 7242 or S002.
Table 1 shows site aliases for geodetic reference points in southeastern Australia. The reference point for the CIGNET GPS site, also referred to as HOBA or HOB1, is the intersection of the vertical axis of a 5/8 in. 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 (Figure 2). The support is mounted on a 1.9 m vertical steel pole which is secured to the roof of the building that houses the hydrogen maser. The reference point for the AFN site AU016, also called HOB2, is the intersection of the vertical axis of a 5/8 in. Whitworth-threaded steel spigot with the horizontal plane coinciding with a stainless steel plate on the top face of the 0.6 metre-high concrete pillar to which the steel plate is attached.

Orroral

An operational SLR site, the National Laser Ranging Station (NLRS), is situated about 60 km from Canberra, approximately 400 m above the floor of the Orroral Valley. A Smithsonian Astrophysical Observatory system (SAO-3) formerly occupied a site in the valley below, about 2 km away. Several GPS sites have also been used at Orroral. Those of interest here are AU005 and NM/C/106. The 1.5 m aperture reflecting telescope of the NLRS has an X-Y mount. However, the reference mark is not a point on the fixed axis; rather it is the centre of the 152 mm diameter mirror which is secured to the observatory structure at the rear end of the horizontal bearing of the telescope. This point, which lies in the optical path of outgoing and returning photons, is known as NLRS Mirror 7 (NLRS-7). The reference point for the SAO-3 is the intersection of the elevation and azimuth axes of the laser telescope. AU005 is the intersection of the vertical axis of a 5/8 inch 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 fixed to the top of the north-eastern corner of the 10 metre-high collimation tower at the observatory. NM/C/106 is a brass centre mark set in the top of one of the steel encased reinforced concrete observatory pillars. A protecting cap covers this mark which is 10 mm below the top of the concrete pillar.

Tidbinbilla

Three of the radio telescopes situated at the Tidbinbilla DSN site have been used for geodesy: the 34-metre DSS42 antenna which has an equatorial mount, and the 70-metre DSS43 and 34-metre DSS45 antennas, both of which have azimuth-elevation mounts. DSS43 and and DSS42 are now used solely for telemetry and astrometry. The reference point for DSS42 is the intersection of the polar-axis with the plane of the declination-axis, in the direction of the polar wheel. The reference point for DSS43 (CDP 1543) and for DSS45 (CDP 1545) is the intersection of the horizontal and vertical planes, respectively containing the centres of rotation in elevation and azimuth of the antennas. The prime GPS sites at Tidbinbilla are called ROGUE GPS 1990/1992 (ROGUE 90/92), ROGUE GPS 1992 and AU017. The ROGUE GPS 1990/1992 site operated from the end of March 1990 until February 1992. The reference point for this site is the centre of the top of the choke rings of the Dorne Margolin R GPS antenna which occupied this mark. The reference point for ROGUE GPS 1992 is the centre of the bottom of the choke rings of the Dorne Margolin R GPS antenna which was placed in this position on 12 May 1992. This point is located 0.092 metres vertically above AU017 which is represented by a small drill hole in the centre of the top of a stainless steel plate set in the top of the reinforced concrete pillar which marks the site.

3. TELESCOPE REFERENCE POINT AND TIE SURVEYS

Harvey (1991) describes some of the methods which are used to determine telescope reference points and to tie these to nearby observatory reference pillars. The discussion focusses on VLBI antennas but the methods which are given apply equally to optical telescopes. One method is to establish a mark directly beneath the telescope reference point with a vertical collimator. The position of the reference point is then usually defined by assuming the telescope to have been built in accordance with design specifications. Lines through doorways, through holes drilled into the observatory structure etc. are subsequently observed to connect this mark to the reference pillars. Several pillars are used to provide redundancy. The vertical distance from the mark to the telescope reference point is determined by levelling, by vertical angle and EDM slant distance, by suspended tape or, to provide a check on this measurement, by a combination of these procedures. Obviously, the connection should be as reliable as any other component of the surveyed network and, with care and appropriate procedures, these can be measured with an accuracy of a few millimetres. At this level of accuracy, it cannot be assumed that construction agrees with design specifications and a better approach is to determine the telescope reference point by ground survey. The method suggested by Harvey (1991) makes use of the fact that, as one axis is rotated about the other axis whilst the latter remains fixed, a point on the moving axis will scribe out a circular path perpendicular to the fixed axis. Measuring the coordinates of this point in three different positions of the telescope allows the direction of the fixed axis and a point on it to be determined. Interchanging fixed and rotating axes determines the direction of the second axis and a point on this axis also. Coordinate geometry yields the position of the telescope reference point. More than three measurements provides redundancy which increases the precision of the determination and is useful for identifying any wobble that may be present. There are two variations of this method depending on whether the ends of the axes are visible or are obscured by structural components. If the ends of the axes can be seen from the ground sighting targets are attached to these points and observed from the surrounding survey network. If they cannot be seen the targets are mounted on the telescope structure some distance from the axes.

Hobart

Figure 3 shows the positions of geodetic marks at Mt. Pleasant Observatory. Clayton (1989) used the second of the abovementioned methods to define the reference point for the Hobart VLBI antenna (CDP 7242) and since the ends of the antenna axes are obscured the targets were mounted on the telescope structure. Four targets were used to determine each axis and these were observed respectively from north pillar (NP) and west pillar (WP) in several antenna locations by theodolite directions, vertical angles and EDM slant distances (Figure 4). These pillars are aligned with the extensions of the X- and Y-axes, respectively. Unfortunately, Clayton neglected to correct the observations made from one of the reference pillars for the effects of instrument height, a distance of 0.240 m, and failed to activate a switch which suppresses small rotations of the antenna X-axis which occur each time it is rotated about the Y-axis (A. Sprent, personal communication, 1994).

Neglecting the instrument height affects mainly the vertical location of CDP 7242 and failure to suppress these small oscillations changes the orientation of the Y-axis and, therefore, the location of the antenna reference point, though only slightly so. In consequence, Strong (1991) using the same control stations and surveying procedures repeated the part of Clayton's survey which was wrong and combined his measurements with those which were correct to obtain a new determination of the coordinates of CDP 7242 in the coordinate system defined by NP and WP. Frost (1991) determined the relative positions CDP 7242, the CIGNET GPS site, WP and NP in the WGS-84 reference system by terrestrial and GPS methods (but see below). Willing (1993) subsequently connected the CIGNET (HOBA) and AFN (AU016) sites separately by GPS and terrestrial measurements. R. Coleman of the University of Tasmania, reobserved the tie HOBA-AU016 with GPS in 1994 over six consecutive days (R. Coleman, personal communication, 1995). Independent determinations of CDP 7242 and the ties to HOBA and AU016 were made in February 1995 by surveyors from Tasmania's Department of the Environment and Land Management (DELM). In this survey, CDP 7242 was located using Clayton's method as well as by measurements to points on both the X and Y axes. The ties WP-HOBA and HOBA-AU016 were obtained by theodolite, EDM and levelling observations and separately with GPS receivers.

Orroral

Networks of eccentric stations surround both the NLRS and the former SAO laser tracking site at Orroral. To define SAO-3, the axes of the Orroral SAO laser tracker were assumed to intersect. The ends of the horizontal axis were visible from ground marks a few metres away, so targets were attached to either end of this axis and to a point on the vertical axis which was a designated distance from the horizontal axis. Horizontal directions, vertical angles and slant distances from the ground marks to the targets were then observed. NLRS-7 and NM/C/106 were connected by precision three-dimensional theodolite, EDM and standardized wire traverse with redundancy in the third dimension being provided by levelling measurements. Two independent surveys were performed, the first by B. Murphy between November 1987 and February 1988 and, the second by P. Murphy, a consulting surveyor, in November 1988. Although the results of the two surveys agree closely the second is considered the more accurate and we confine our discussion to it. Figure 5 is a sketch of the sites used to locate NLRS-7.

We point out that the actual survey was considerably more extensive with many other measurements being made to permit a calibration of the NLRS but this is not of interest here. Point 4 was a tribrach on a steel support secured to the observatory wall. When a theodolite was placed on this tribrach it was possible to observe NM/C/106 and another exterior mark, point 22. Later, after the support had been removed, point 4 was reoccupied and a connection was made through a doorway to a specially machined measuring spike and plate attached to Mirror-7 (Figure 6). The dimensions of the mirror, taken from the design drawings, together with those for the spike and plate, were then used to compute the coordinates of NLRS-7 relative to the reference pillars. The connection between SAO-3 and NM/C/106 is by horizontal directions, vertical angles, a slant distance and precision levelling, while AU005 and NM/C/106 are tied by horizontal directions and a taped height difference.

Tidbinbilla

Figure 7 shows the survey network at Tidbinbilla which was used to define the VLBI antenna reference points and to tie these to the two GPS marks, ROGUE GPS 1992 and AU017. The reference point for DSS42 was defined in the 1960s by the now disestablished Australian Survey Office (ASO). Although we have the results, the records of the survey are unavailable. However, there is a mark (M4) directly below the antenna reference point and we therefore suspect that a collimator or a theodolite may have been used to establish M4 and that the elevation of the telescope antenna reference point above this mark was measured by suspended tape. The reference point for DSS43 (CDP 1543) was determined in October 1986 by B. Murphy from horizontal directions, vertical angles and EDM slant distances observed from stations M4 and M7 to targets placed near the extremeties of the elevation bearing axis when the antenna was set in an azimuth of 0o.001.

Subsequently, the axis of rotation in azimuth was defined to lie exactly mid-way between the vertical planes containing the centres of the outer breather and filler cap insert hole on top of the main antenna bearing (Figure 8). The axis of rotation in elevation was defined as the line joining the centres of the eastern and western extremeties of the elevation bearing axis. By this survey, the western end was found to be 4 mm higher than the eastern end and the elevation of the reference point was taken as the average value of the ends when the antenna was set in the above azimuth.

The survey coincided with the extension of the dish from 64-70 m diameter. The subreflector panels were removed during the construction work exposing a point on the azimuth axis which could be seen by theodolite from survey station PR88 ECCE about 600 m away (Figure 7). Horizontal directions and EDM distances from PR88 ECCE to this point observed for four different azimuth settings of the antenna identified a wobble of radius 0.033 m about the azimuth axis.
However, from these observations, there was no way of deciding, whether this circle was a section of a cylinder, of a cone or of some other figure. This called for a more comprehensive survey which to date has not been undertaken. The reference point of DSS45 (CDP 1545) was determined immediately following the completion of the construction of the telescope in March 1987. During the construction of the antenna a small punch mark, which was visible when the telescope was set in the zenith direction and which was offset by about 34 cm vertically above the elevation axis, was placed on the azimuth axis. Survey measurements from station NM/C/194 were made to specially designed target support systems placed on the punch mark and to marks at each end of the elevation bearing axis as identified from the engineering plans. The measurements confirmed that the punch mark lay exactly half-way between the other two marks. They were also used to locate the horizontal axis of rotation ie. the horizontal line passing through the physical centres of

each end of the elevation bearing axis. CDP 1545 was then defined as the (inaccessible) point of intersection of the vertical through the punch mark and the horizontal plane containing the centres of the elevation bearing axis when the telescope was set in the zenith. In October 1995 Geoscience Australia undertook a more rigorous survey to define CDP 1545 and to redetermine the tie CDP 1545-AU017. Prior to this survey, two concrete survey pillars were constructed close to DSS45. A Leica TC2002 total station was then used to observe to special targets attached to each end of the elevation bearing axis and to reflective tape targets attached to the Bull gear of the telescope. The reflective targets were observed from only one pillar as the telescope was rotated incrementally in elevation with the plane of rotation of the Bull gear set so that it was approximately normal to the line joining the observation pillar and the centre of the telescope. The targets on the elevation bearing axis were observed from both pillars, again while the telescope was rotated incrementally, but this time in azimuth. The abovementioned punch mark was also connected to during this survey. The connections between DSS43, DSS45, ROGUE GPS 1992 and AU017 were determined from horizontal directions, vertical angles, EDM slant distances, precision-levelled height differences and, in some instances, differential GPS measurements. However, DSS43-DSS42 and DSS45-DSS43 were also observed by VLBI. DSS43-DSS42 was measured some time ago by M. Batty with a real time interferometer. Finger and Folkner (1990) give the results. Two VLBI determinations of DSS45-DSS43 were made: (1) with DSS43's subreflector allowed to adjust its focal length automatically as the antenna deformed under gravity loading and, (2) with the focal length of the reflector fixed. The first measurement was experimental, so the latter gives the correct VLBI tie (Jacobs & Reynolds, 1990).

Orroral-Tidbinbilla

Figure 9 shows the regional geodetic network which, together with the two local networks (see Figure 7 and Figure 8), was observed to connect reference points at Orroral and Tidbinbilla. The network and some of the observations date back to the late 1960s when tracking of space objects commenced from sites in the ACT. There are approximately 100 stations in the current network which extends about 85 km north-south and 50 km east-west. The observations comprise horizontal directions, vertical angles, EDM slant distances, levelled and trigonometrically observed height differences, Laplace azimuths and GPS vector baselines.

4. RESULTS AND DISCUSSION

The 26 km-long Tidbinbilla-Orroral tie as well as the shorter local ties were obtained from a single adjustment of the many redundant observations which were made to connect the two sites. Several adjustments were computed at Geoscience Australia over the time the network evolved to the present configuration, the earlier ones in two-dimensions on the Australian Geodetic Datum (AGD-66) and the more recent ones in three dimensions relative to the ITRF. In all of the three dimensional adjustments, the ellipsoidal heights were computed from the trigonometrically observed or levelled height differences and geoid-spheroid separations taken from a model geoid for the region. Only the latest adjustments, all of which are three-dimensional, are of interest here. The first of these, referred to as the OrrTid adjustment, was carried out in 1991 by T. Morrison. This is a free-network solution on the GRS-80 ellipsoid holding fixed the coordinates of NM/C/106 as determined from the then current University of Texas at Austin Center for Space Research SLR long-arc solution for the position of NLRS-7 and the tie between NM/C/106 and NLRS-7 obtained from this same adjustment. The geoid-spheroid separations, interpolated from the AusGeoid91 model (Kearsley & Steed, 1993), were held fixed in the adjustment and only the trigonometrically observed and levelled height differences were adjusted. Two additional adjustments of the Orroral-Tidbinbilla network were computed, this time by J. Steed; OrrTid2 in

1994 and OrTid93F in 1995. In OrrTid2 the ITRF91, Epoch 1988.0, positions of DSS43, DSS45, NLRS-7, ROGUE GPS 90/92 and SAO-3 given in IERS (1992) were held fixed and the geoid-spheroid separations are those of AusGeoid93 computed at Geoscience Australia. OrrTid93F is a free-network adjustment holding fixed the coordinates of NLRS-7 given in IERS (1994). The geoid-spheroid separations for this adjustment were obtained from the ACTGeoid solution which incoporates a digital elevation model to account for terrain and hence is an improvement on earlier geoid models (W. Kearsley, personal communication, 1995). A number of other adjustments were computed by J. Steed in response to requests by the first author. Among these are those called OrrLoc93 and TidLoc93, both of which are free-network solutions, respectively holding fixed the positions of NLRS-7 and DSS45 as given in IERS (1994) with the geoid-spheroid separations taken from the ACTGeoid. These adjustments involved subsets of the data used in OrTid93F. They were performed to identify distortions of the shorter ties which may have been introduced by the regional geodetic network.

Hobart

Clayton (1989) determined the coordinates of CDP 7242 in a local right-handed system centred on West Pillar, with the positive direction of the y-axis pointing towards North Pillar and the positive z-axis aligned with the zenith direction (see Figure 3). These coordinates are:

D x		+40.009	
D y	=	+53.196	m
D z		+12.644	

The azimuth of the y-axis, taken from earlier work by A. Sprent, is 53o 03' 21" ± 7". Rotation through this angle about the z-axis gives the coordinates of CDP 7242 in the topocentric horizon system of WP ie.:

D East		+66.562	
D North	=	-0.003	m
D Up		+12.644	

The components of the vector from the CIGNET site to CDP 7242 in WGS-84 determined by Frost are:

D X		-52.453	
D Y	=	-17.009	m
D Z		+25.846	

Clayton's and Frost's results were communicated to the US National Geodetic Survey (NGS) and published in (1990). Frost (1991) used MiniMac 2816AT receivers and gives the reference point for the CIGNET GPS site as the MiniMac L1-Phase centre. However, subsequent investigation by NGS and Geoscience Australia revealed that the results actually referred to the top of the antenna ground plane (M. Chin, personal communication, 1995). This implies that Frost's determination of HOBA is 0.059 m vertically above the actual point ie. by the thickness of the MiniMac antenna ground plane. A correction to this effect was published by NGS in CSTG (1992). Strong's repeat measurements of HOBA-CDP7242 give (Strong, 1991):

D X		-52.592	
D Y	=	-16.926	m
D Z		+25.684	

NGS was advised accordingly (A. Sprent, personal communication, 1994) but IERS (1993, Table 4) shows that the new figures never filtered through to the IERS. The coordinate differences shown in IERS (1993) are:

D X		-52.490	
D Y	=	-16.986	m
D Z		+25.806	

which are the components of HOBA-CDP7242 given in CSTG (1992) but reduced to the bottom of the MiniMac 2816AT ground plane. Willing (1993) used Turbo Rogue receivers with Dorne Margolin T antennas for his GPS survey but it is not clear to which points these measurements refer. Also, one of the receivers at one stage experienced clock problems (R. Coleman, personal communication, 1995). Hence, we give only his terrestrial connection between HOBA and AU016 ie.:

D x		+4.042	
D y	=	-132.435	m
D z		-15.511	

This connection refers to the local coordinate system used by Clayton. Rotation through the above azimuth angle about the z-axis gives the components in the topocentric horizon system of HOBA ie.:

D East		-103.416	
D North	=	-82.829	m
D Up		-15.511	

The corresponding components in WGS-84 are:

D X		+112.684	
D Y	=	+50.748	m
D Z		-50.231	

which were computed with a WGS-84 latitude and longitude for HOBA supplied by R. Coleman (personal communication, 1995). Correcting the above for a -0.006 m levelling error made by Willing (R. Coleman, personal communication, 1995) gives:

D X		+112.688	
D Y	=	+50.746	m
D Z		-50.227	

The results of the GPS survey carried out in April 1994 by R. Coleman are:

D X		+112.713	
D Y	=	+50.732	m
D Z		-50.200	

Taking Willing's ground survey values from the GPS determinations and transforming the result to the topocentric horizon system of HOBA gives:

East		-0.002	
North	=	+0.000	m
Up		+0.038	

which indicates an error in height in either determination of the tie. Willing's terrestrially determined heights were obtained by precise levelling and it is difficult to imagine, though not inconceivable, that he made an error of -39 mm over such a short distance. Interestingly, the discrepancy of -39 mm in the vertical agrees closely with the height of the Dorne Margolin antenna reference point above the geodetic mark leading us to speculate that these offsets may not have been correctly accounted for at each receiver location. The GPS work carried out by DELM in February 1995 sheds light on the matter. The results of these surveys are:

<u>HOBA - AU016</u>

D X		+112.716	
D Y	=	+50.731	m
D Z		-50.194	

<u>HOBA - CDP 7242</u>

D X		-52.658	
D Y	=	-16.891	m
D Z		+25.627	

<u>AU016 - CDP 7242</u>

D X		-165.370	
D Y	=	-67.616	m
D Z		+75.820	

DELM's terrestrial determinations, moreover, agree with the above GPS figures to within a few millimetres and these in turn are consistent with Coleman's measurements. We conclude that Willing's and not Coleman's results are in error.

Orroral

Table 2 gives the ITRF components of the ties at Orroral published by the IERS and those determined from the abovementioned adjustments while Table 3 shows the origin of the ties. The tie between NLRS-7 and SAO-3, which appears in IERS (1994) and is attributed to J. Luck, originated from the OrrTid adjustment. However, we are unable to trace the source of the ties shown in IERS (1992) and IERS (1993) and, though they are attributed to T. Morrison and were computed at Geoscience Australia, they quite clearly did not emanate from OrrTid (see below). It is instructive to form differences between corresponding ties obtained from the various adjustment schemes. Those computed in OrTid93F are thought to be the most reliable and we subtract these from the others and transform the results to coordinate changes in the topocentric horizon system of NLRS-7.

NLRS7 - SAO3
OrrLoc93-OrTid93F:

D East		+0.013	
D North	=	-0.003	m
D Up		+0.015	

OrrTid2-OrTid93F:

D East		+0.018	
D North	=	+0.025	m
D Up		+0.168	

IERS(1993)-OrTid93F:

D East		+0.012	
D North	=	+0.020	m
D Up		-0.302	

OrrTid-OrTid93F:

D East		+0.001	
D North	=	+0.000	m
D Up		-0.009	

The differences in orientation (1.5") and height (15 mm) for NLRS7-SAO3 obtained from OrrLoc93 and OrTid93F are insignificant. The close agreement in height is not surprising seeing that the sites are connected in the vertical by precision levelling data which was included in both adjustments. However, there are large discrepancies in the connections obtained from OrrTid2 and in those published in IERS (1993), especially in elevation. Two reasons for these discepancies come to mind, (i) differences between the geoid models which were adopted and held fixed in the computations, and (ii) differences in the adjustment schemes which were employed. Table 4 shows the effect on ties of the various geoid models which were used for the ACT. Since the ACTGeoid is an improvement on the other models we analyse departures from this model. As already mentioned, the details of the geoid models and processing methods used to calculate the ties which appear in IERS (1993) are unavailable to us and, therefore, we cannot account for the large discrepancy in the vertical between this tie and that determined from OrtTid93F. However, the large difference in the vertical component of the tie from OrrTid2 and Ortid93F is not explained by differences in the geoids which were used. So, we suspect that they are a direct consequence of holding fixed in OrrTid2 the coordinates of both NLRS-7 and SAO-3 at the values published in IERS (1992). To be sure, any errors in the IERS published ties would reappear in OrrTid2. We return to this issue below in the discussion on the Tibinbilla site.

NLRS7 - NM/C/106
OrrLoc93-OrTid93F:

D East		0	
D North	=	0	m
D Up		0	

OrrTid2- OrTid93F:

D East		0	
D North	=	0	m
D Up		+0.117	

NLRS7 - AU005
OrrLoc93-OrTid93F:

D East		0	
D North	=	0	m
D Up		-0.002	

OrrTid2-OrTid93F:

D East		0	
D North	=	0	m
D Up		+0.121	

The above differences in the vertical again point to problems with the OrrTid2 adjustment.

Tidbinbilla

Table 5 shows the ITRF components of the ties at Tidbinbilla. The terrestrially observed tie DSS43-DSS42 was computed from our connection to M4 and the vertical separation of 15.075 m from this mark to the VLBI reference point as determined by the Australian Survey Office. DSS43-DSS42 and DSS45-DSS43 were also measured by VLBI and these ties appear in IERS

(1993). The tie between ROGUE GPS 1992 and DSS43 published in IERS (1993) and attributed to M. Hendy of Geoscience Australia is not identifiable with any of the known Orroral-Tidbinbilla adjustments and we consider it no further. Forming differences between adjustments as before and transforming the results to coordinate changes in respective topocentric horizon systems gives:

DSS43-DSS42
VLBI-OrTid93F:

D East		-0.026	
D North	=	-0.005	m
D Up		-0.055	

There is a discrepancy mainly in the vertical and on the order of 5 cm between the VLBI and terrestrial determinations of DSS43-DSS42. The VLBI tie, which was observed with a realtime interferometer, is precise to about 1 cm (C. Jacobs, personal communication, 1994). The terrestrial tie is very old and, as we don't know how it was obtained or how accurate it is, we judge it to be unreliable.

DSS45-DSS43
TidLoc93-OrTid93F:

D East		-0.006	
D North	=	-0.002	m
D Up		-0.004	

OrrTid2-OrTid93F:

D East		-0.005	
D North	=	+0.012	m
D Up		+0.051	

VLBI-OrTid93F:

D East		-0.006	
D North	=	+0.010	m
D Up		+0.026	

The results of TidLoc93 and OrTid93F agree at the subcentimeter-level indicating that the approach which was taken to compute this tie from the Orroral-Tidbinbilla network is sound, though perhaps cumbersome. Agreement between OrrTid2 and OrTid93F is not so good but Table 4 shows that a large portion of the discrepancy may be due to the differences in the geoid models. Moreover, it is not inconceivable for the VLBI determination to be in error by 1-2 cm error in the vertical (C. Jacobs, personal communication, 1994) and if the terrestrial survey also has 1-2 cm vertical errors then the error of the difference is on the order of 1-3 cm, which is about what the results show.

DSS43-AU017
OrrTid2- OrTid93F:

D East		+0.007	
D North	=	-0.011	m
D Up		-0.136	

DSS45-AU017
OrrTid2- OrTid93F:

D East		+0.059	
D North	=	-0.037	m
D Up		+0.056	

DSS45-Rogue 1990/1992
OrrTid2-OrTid93F:

D East		+0.017	
D North	=	+0.004	m
D Up		+0.012	

AU017 was misidentified in elevation by 13 cm during the levelling run observed to tie this mark to the surrounding survey network (Figure 9). The error remained in OrrTid but was corrected in OrrTid2. Nonetheless, the wrong tie was communicated to the IERS and subsequently used to compute the ITRF91 positions of all sites (see IERS, 1992). Accordingly, as the IERS (1992) positions of these sites were held fixed in OrrTid2 this error was reintroduced into the adjustment, which accounts for all of the discepancy in the vertical coordinate of DSS43-AU017 and a significant portion of the discrepancy for DSS45-AU017. It also explains the large differences between the OrrTid2 and OrTid93F determinations of the ties at Orroral (see above). The results of the October 1995 DSS45 telescope survey are still being finalized.

Orroral-Tidbinbilla

Table 6 shows the ITRF components of NLRS7-DSS45 for the various adjustment schemes together with those that appear in the literature. The tie attributed to Luck (1993) is cited by Himwich et al. (1993) but is not identifiable with any of the known Orroral-Tidbinbilla adjustments. Manipulation and transformation of this data gives:

Orrtid2-Ortid93F:

D East		-0.003	
D North	=	-0.011	m

D Up		+0.220	

IERS(1993)-Ortid93F:

D East		-0.008	
D North	=	+0.013	m
D Up		+0.000	

IERS(1994)-Ortid93F:

D East		+0.027	
D North	=	-0.001	m
D Up		+0.023	

Luck(1993)-Ortid93F:

D East		-0.006	
D North	=	-0.009	m
D Up		+0.024	

Apart from the differences between the OrrTid2 and Ortid93F adjustments, which we have already explained, the results are not that dissimilar. They agree to within 0.6 parts in 10^6, which is about the accuracy achievable with terrestrial measurements over the 26 km distance and probably of the GPS measurements also. For interest, three additional adjustments were computed, (i) with the terrestrial data alone, (ii) with the terrestrial data and the GPS baseline vector observed between AU005 and ROGUE GPS 90/92 in March 1991, and (iii) with the terrestrial data, the GPS baseline vector observed between AU005 and ROGUE GPS 90/92 in March 1991 and the VLBI measurements made between DSS43 and DSS45 by Jacobs & Reynolds (1990). All are free-network solutions holding fixed the coordinates of NLRS-7 given in IERS (1994) the geoid-spheroid separations taken from the ACTGeoid. The results of these adjustments are:

Terrestrial:

D X		-14 458.324	
D Y	=	+4 638.705	m
D Z		+21 870.049	

Terrestrial+GPS:

D X		-14 458.344	
D Y	=	+4 638.697	m
D Z		+21 870.043	

Terrestrial+GPS+VLBI:

D X		-14 458.333	
D Y	=	-+4 638.694	m
D Z		+21 870.043	

Differencing gives:

Terrestrial-OrTid93F:

D East		+0.004	
D North	=	-0.017	m
D Up		-0.019	

Terrestrial+GPS-OrTid93F:

D East		0	
D North	=	0	m
D Up		0	

Terrestrial+GPS+VLBI-OrTid93F:

D East		+0.000	
D North	=	-0.003	m
D Up		-0.014	

These results do not differ significantly from those of the OrTid93F adjustment. The terrestrial measurements and March 1991 GPS observations together produce a tie which agrees exactly with OrTid93F, implying that the earlier GPS observations have no effect whatsoever and might as well have been omitted. Reassuringly, however, the terrestrial measurements alone give an excellent result, while including the VLBI measurement changes predominantly the vertical component of the tie though only marginally so. Considering that levelling between NLRS-7 and DSS45 is probably uncertain by 5 cm or more and that the GPS measurement is uncertain by about 1-3 cm in the vertical, it is the combination of all three data types which should be taken as the best current determination of this tie ie.:

D X		-14 458.333	
D Y	=	+4 638.694	m
D Z		+21 870.043	

Geoid Modelling Errors

The geoid-spheroid separations were not adjusted in any of the computation schemes though they are clearly not error-free. We briefly address this matter now. The rectangular coordinate of any point in the network in terms of geodetic latitude, f, longitude, l, orthometric height, H, and geoid-spheroid separation, N, is:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} (\nu + H + N) \cos\phi \cos\lambda \\ (\nu + H + N) \cos\phi \sin\lambda \\ [\nu (1-e^2) + H + N] \sin\phi \end{bmatrix}$$

Differentiating and admitting only an error dN in N, gives:

$$\begin{bmatrix} dX \\ dY \\ Dz \end{bmatrix} = \begin{bmatrix} \cos\phi \cos\lambda \, dN \\ \cos\phi \sin\lambda \, dN \\ \sin\phi \, dN \end{bmatrix}$$

The ACTGeoid model probably has relative errors which are on the order of of 3-5 cm for the tie NLRS7-DSS45 (W. Kearsley, personal communication, 1995). Taking the upper bound, substituting this into the previous equation and transforming to topocentric horizon coordinates at the midpoint of the Orroral-Tidbinbilla connection yields:

d East		+0.002	
d North	=	-0.011	m
d Up		+0.049	

As expected, the error maps mostly into the vertical coordinate of position. We note that an error of this magnitude may occur between any pair of the sites of the Orroral-Tidbinbilla network and that the total error, therefore, may be even larger. Accordingly, the accuracy of this tie cannot be improved upon by terrestrial measurements alone eg. reobserving to first-order standards those parts of the levelling connection measured by third-order methods.

Accuracy of Ties

Table 7 gives the current best determinations of ties. We estimate their accuracy as ranging from about 5-10 mm for the shorter connections (&lt100 m), to 1-2 cm for those of medium-length (&lt1 km), to 3-5 cm for the 26 km-long Orroral-Tidbinbilla tie.

8. CONCLUSIONS AND RECOMMENDATIONS

Widening over time of a large crack in the rock on which the NLRS is built indicates that the observatory may be moving locally. The reference network established to monitor such movements, defined by three pillars, is much too small in extent and we recommend that a larger network of sites surrounding the observatory be established and that this be observed at regular intervals ; say, once every 2-3 years. A combination of GPS and terrestrial methods should be employed. The present GPS reference point at Orroral, AU005, is situated on top of a 10 metre-high aluminium tower. The height of the tower fluctuates both diurnally and seasonally by about 1 cm due to temperature variations and the horizontal position of AU005 may be changing due to wind and temperature induced torques. In addition, the site is too close to the observatory dome to be entirely free from antenna multipathing effects. A more suitable GPS site should be found. The Tidbinbilla site is alluvium for depths of 0-6 m and granodiorite from about 6 m on down. The DSS43 antenna foundations extend to a depth of 6 m. Vertical settlement of a few millimetres was expected with almost all of this occurring during construction of the antenna. Further minor settlement was expected in 1987 when the antenna was enlarged to 70 m diameter. However, neither settlement was ever confirmed by observation (C. Jacobs, 1994, personal communication). Settlement does not change the position of the intersection of the antenna axes as the antenna moves in azimuth and elevation during a VLBI observing session and hence it does not need to be modelled in the VLBI observations but the ground ties are affected. Since tie surveys are time consuming and expensive and DSS43 is no longer used for geodesy, we recommend that only the tie from DSS45-AU017 be reobserved from time-to-time, say every 2-3 years. The largest differences between the various determinations of the 26 km-long tie NLRS7-DSS45 occur in the vertical coordinate of position. Likely sources of these differences are errors in levelling, in the GPS measurements and in the geoid models which were used. The accuracy of the levelling could be significantly improved by reobserving to first-order standards those parts of the connection measured by third-order methods. However, there is little point in doing this if the geoid heights are not refined also and since it is doubtful that this is currently (1997) possible we believe that the GPS approach is most likely to produce fruitful results. Longer observing spans, careful attention to the modelling of the tropospheric delay, antenna phase centre variations and antenna multipathing should lead to improvements in GPS vertical accuracy. Therefore, we recommend that a GPS receiver be installed at Orroral, preferably permanently but, in any case, the tie between this point and AU017 be observed regularly and over long periods, say 1-3 months at a time. The unpalatable alternative is to move the NLRS to Tidbinbilla!

ACKNOWLEGEMENTS

We thank Tony Sprent for describing on site the surveys carried out at Mt. Pleasant and Nick Bowden for providing the results of the DELM surveys .

REFERENCES

- Clayton, M., 1989, Determination of the Mt. Pleasant Radio Telescope VLBI Point, Final Year Project Rept., School of Surveying, University of Tasmania, Hobart, unpublished. CSTG, 1990, CIGNET Station Hobart Australia, IAG Comm. VIII, Int. Coord. Space Tech. Geod. Geodynamics, 3 (3), Sept.-Oct., 23-25.
- CSTG, 1992, CIGNET Station Hobart Australia, Revised March 23, 1992, IAG Comm. VIII, Int. Coord. Space Tech. Geod. Geodynamics, 5 (1), Mar.-Apr.,13.
- Finger, M. & W. Folkner, 1990, A determination of the radio-planetary frame tie and the DSN tracking station locations, AIAA/AAS Astrodynamics Conference, 20-22 August 1990, Portland, OR, 335-353.
- Frost, S., 1991, An Investigation of GPS Processing Techniques, Final Year Project Rept., School of Surveying, University of Tasmania, Hobart, unpublished.
- Harvey, B.R., 1991, Telescope axis surveys, Australian Journal of Geodesy, Photogrammetry and Surveying, 54, 1-18.

- Himwich, W.E., M.M. Watkins, C. Ma, D.S. MacMillan, T.A. Clark, R.J. Eanes, J.W. Ryan, B.E. Schutz & B.D. Tapley, 1993, The consistency of the scale of the terrestrial reference frames estimated from SLR and VLBI data, in D.E. Smith and D.L. Turcotte (eds), Contributions of Space Geodesy to Geodynamics: Earth Dynamics, Geodynamics Series, 24, AGU, Washington, D.C., 113-120.
- IERS, 1992, ITRF 91 and its Associated Velocity Field, IERS Tech. Note, 12, Observatoire de Paris, Paris, October 1992.
- IERS, 1993, ITRF 92 and its Associated Velocity Field, IERS Tech. Note, 15, Observatoire de Paris, Paris, October 1993.
- IERS, 1994, ITRF 93 and its Associated Velocity Field, IERS Tech. Note, 18, Observatoire de Paris, Paris, October 1994.
- Jacobs, C.S.& J.E. Reynolds, 1990, Internal consistency of VLBI surveying between DSS43 and DSS45, JPL Astrometric Techniques Group Interoffice Memorandum 335.3-90-xxx, 5 April 1990, 18pp.
- Kearsley, A.H.W. & J. Steed, 1993, AUSGeoid93, International Geoid Service, Bull. 2, December 1993.
- Ray, J., J. Ryan, T. Clark, R. Eanes, M. Watkins, B. Schutz & B. Tapley, 1991, Comparison of VLBI and SLR geocentric site coordinates, Geophys. Res. Lett., 18(2), 231-234.
- Schutz, B., M. Bevis, F. Taylor, D. Kuang, P. Abusali, M. Watkins, J. Recy, B. Perin & O. Peyroux, 1993. The Southwest Pacific GPS project: Results from Burst 1 of the 1990 field campaign, Bull. Géodés, 67, 224-240.
- Strong, S., 1991, On the Calculation of the Mount Pleasant Radio Telescope VLBI Point 1991, Final Year Project Rept., School of Surveying, University of Tasmania, Hobart, unpublished.
- Willing, S., 1993, Integrated GPS/Terrestrial Connections at the Mt Pleasant Observatory, Final Year Project Rept., School of Surveying, University of Tasmania, Hobart, unpublished.

Figures:

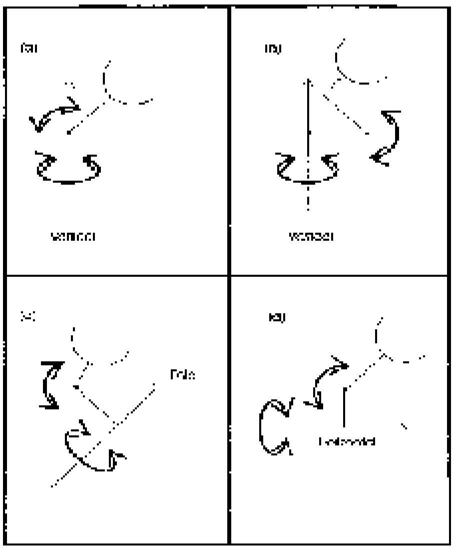


Figure 1. Schematic representation of major telescope geometries: (a) azimuth elevation mount, intersecting axes; (b) same as (a) but with offset axes; (c) hour angle-declination mount, and (d) X-Y mount.

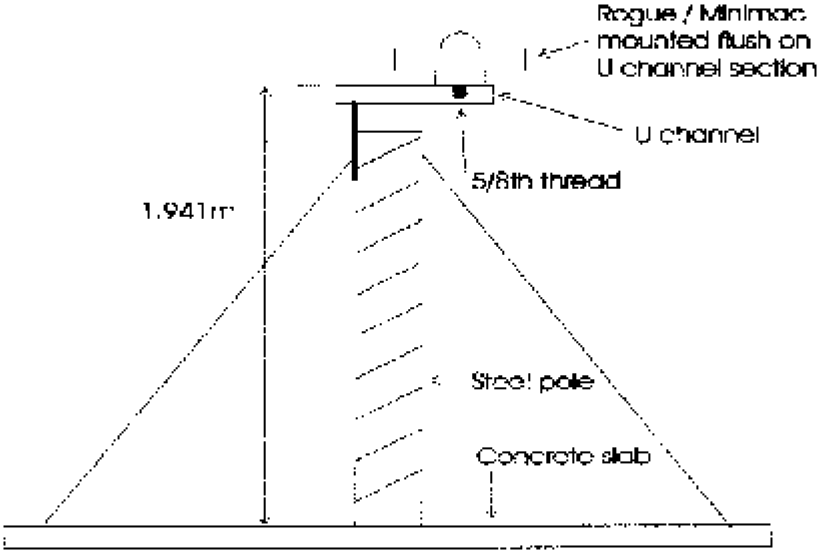


Figure 2. CIGNET site at Mt. Pleasant Observatory, Hobart.

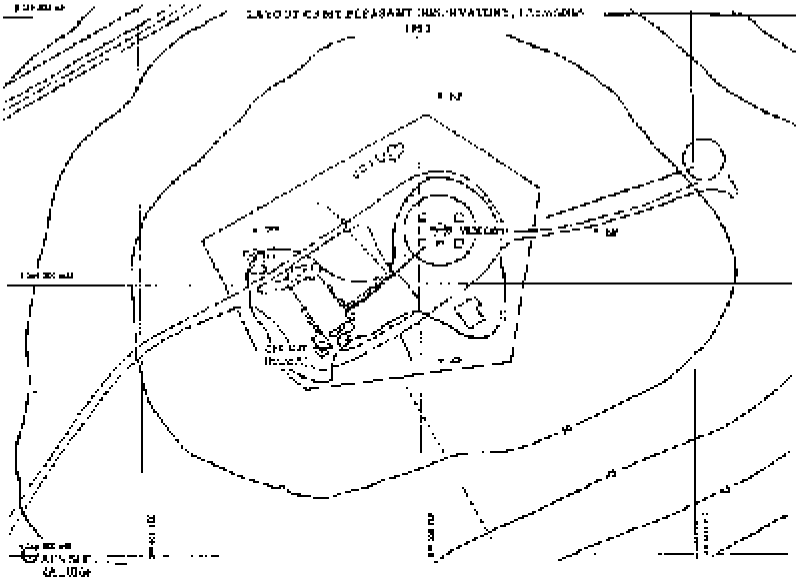


Figure 3. Locations of Geodetic marks at Mt. Pleasant Observatory, Hobart.

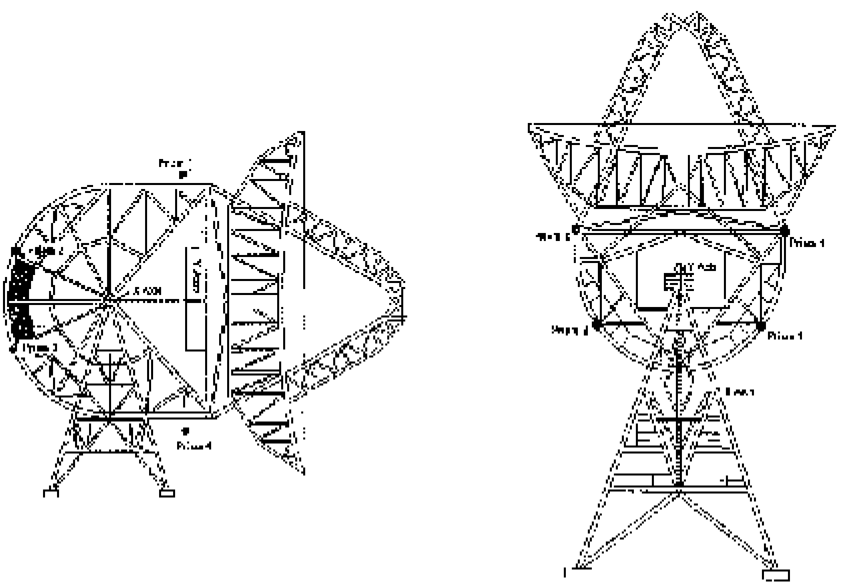


Figure 4. Prism locations for determining telescope axes at Hobart VLBI site

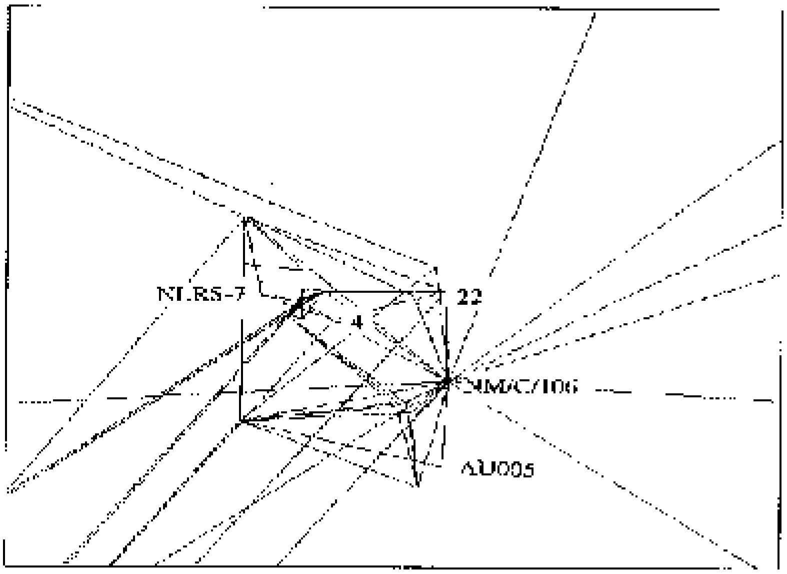
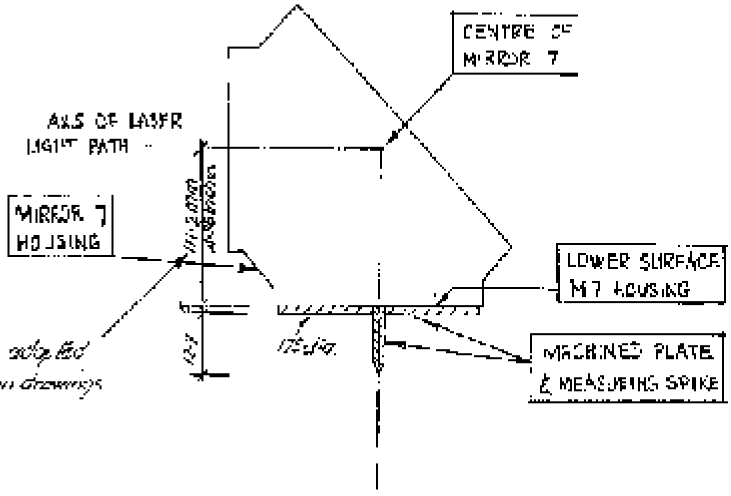


Figure 5. The survey network at Orroral (Scale approx. 1: 1 000).



This figure adapted from design drawings

Figure 6. NLRS Mirror 7 and measuring plate.

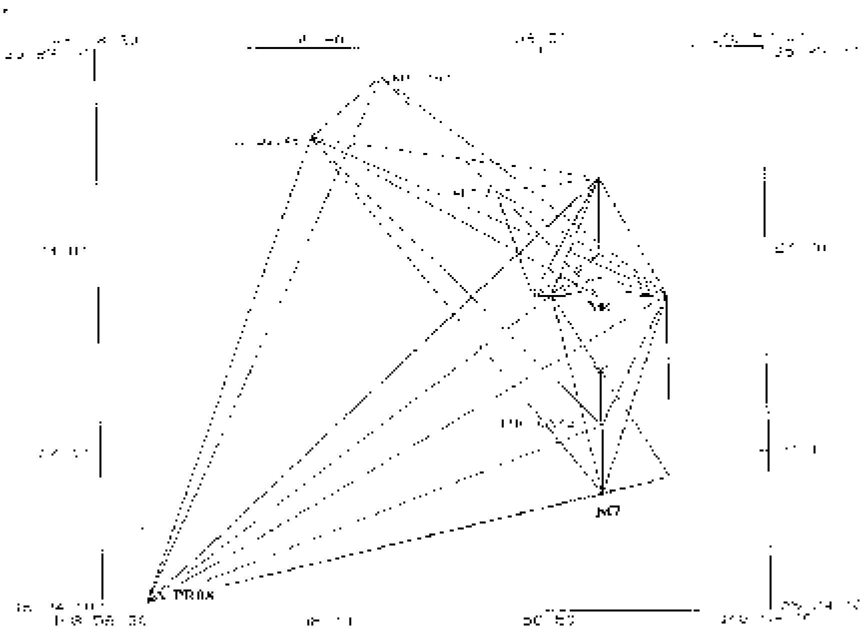


Figure 7. Tie survey network at Tidbinbilla.

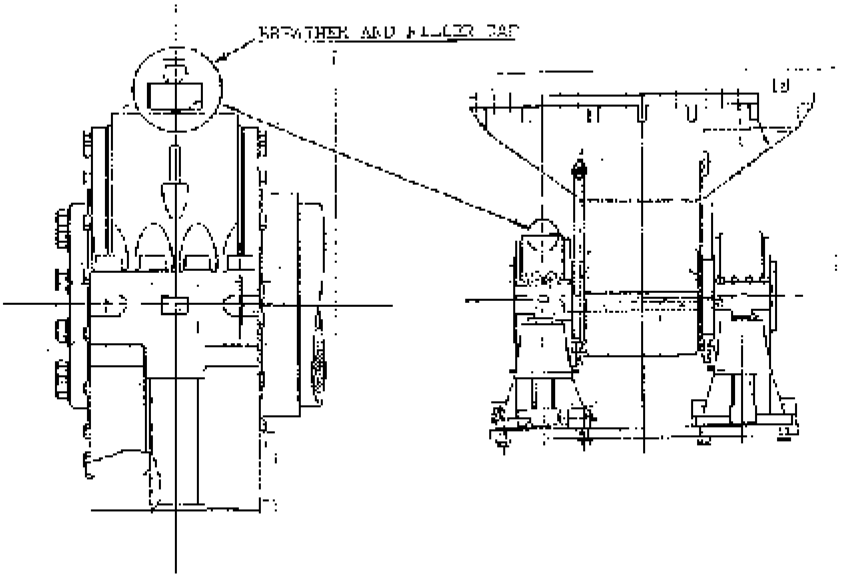


Figure 8. Axes of DSS43 VLBI antenna in relation to observatory structure.

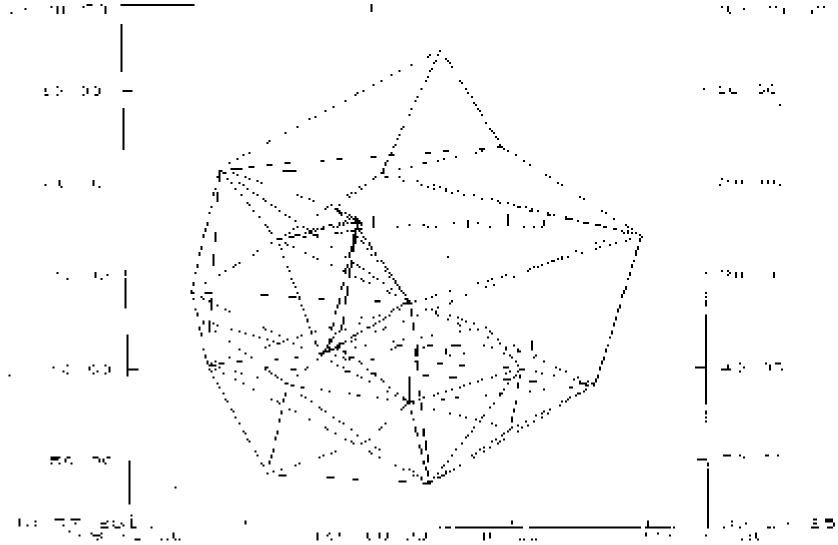


Figure 9. Regional network connecting sites in the ACT.

Tables:

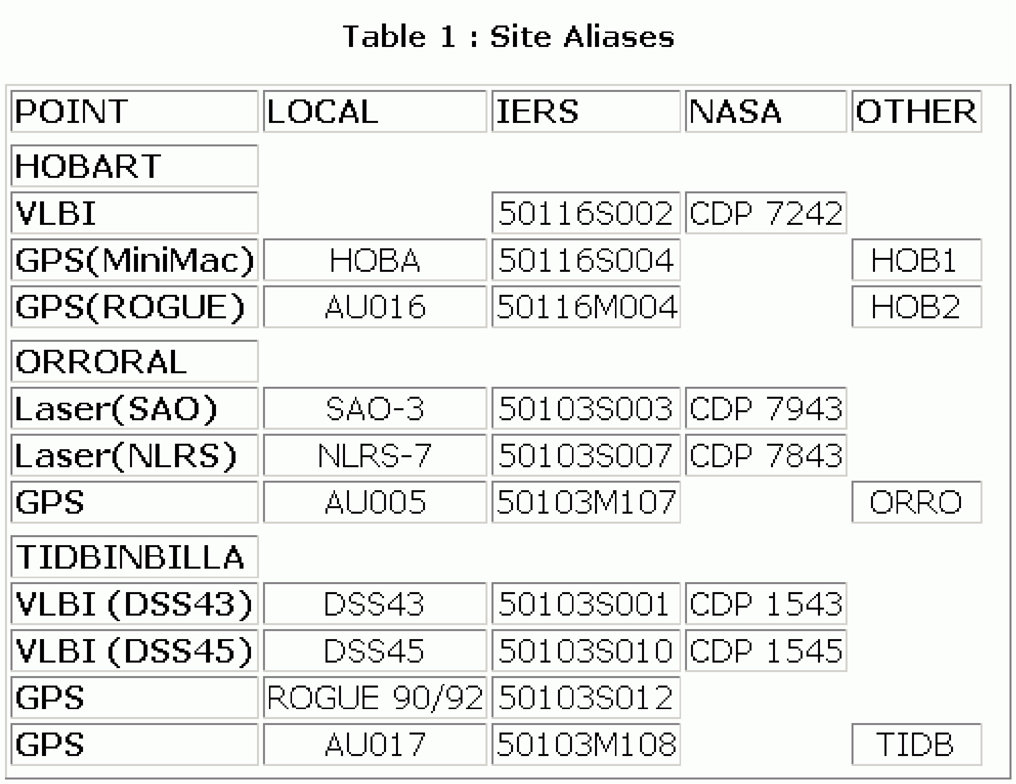


Table 1 : Site Aliases

POINT	LOCAL	IERS	NASA	OTHER
HOBART				
VLBI		50116S002	CDP 7242	
GPS(MiniMac)	HOBA	50116S004		HOB1
GPS(ROGUE)	AU016	50116M004		HOB2
ORRORAL				
Laser(SAO)	SAO-3	50103S003	CDP 7943	
Laser(NLRS)	NLRS-7	50103S007	CDP 7843	
GPS	AU005	50103M107		ORRO
TIDBINBILLA				
VLBI (DSS43)	DSS43	50103S001	CDP 1543	
VLBI (DSS45)	DSS45	50103S010	CDP 1545	
GPS	ROGUE 90/92	50103S012		
GPS	AU017	50103M108		TIDB

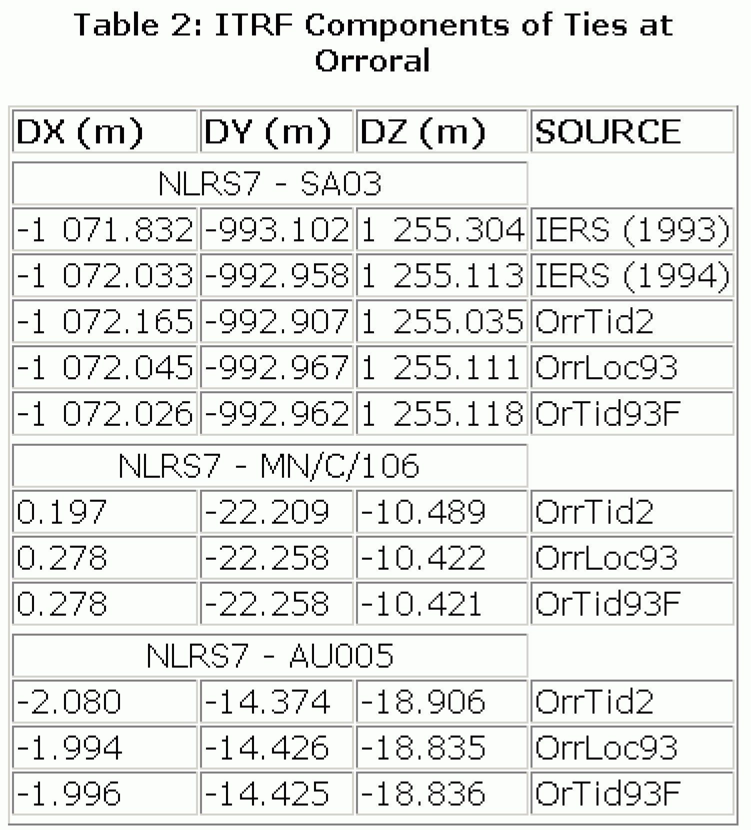
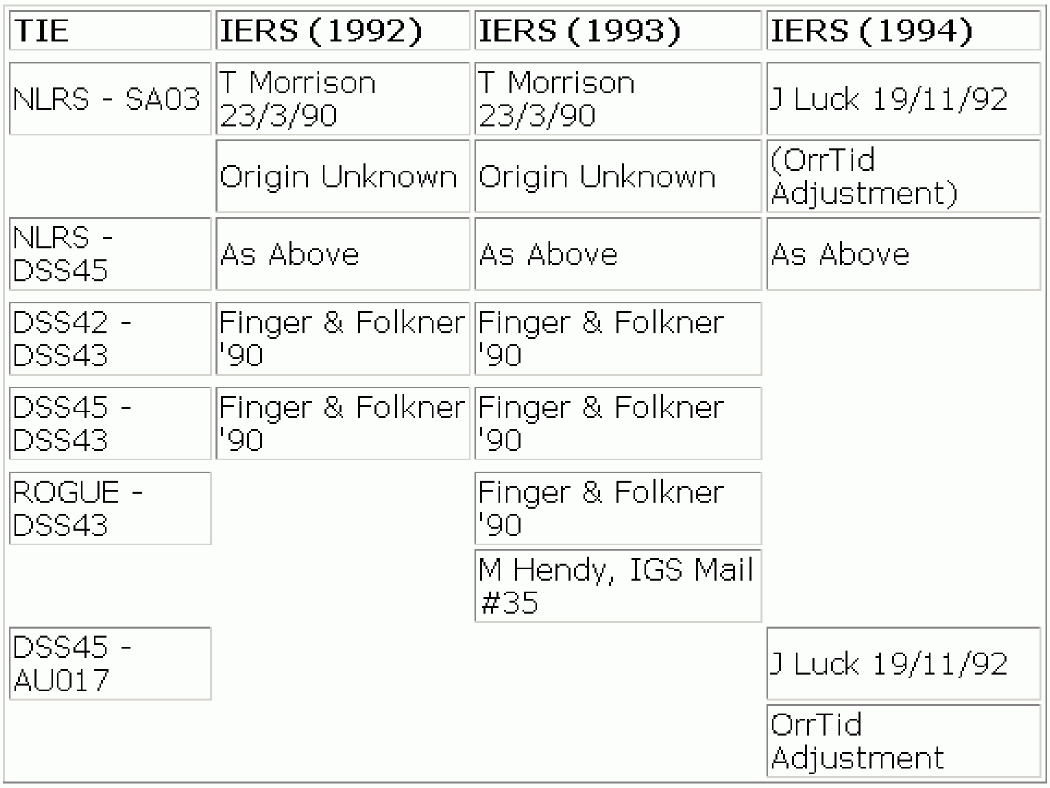


Table 2: ITRF Components of Ties at Orroral

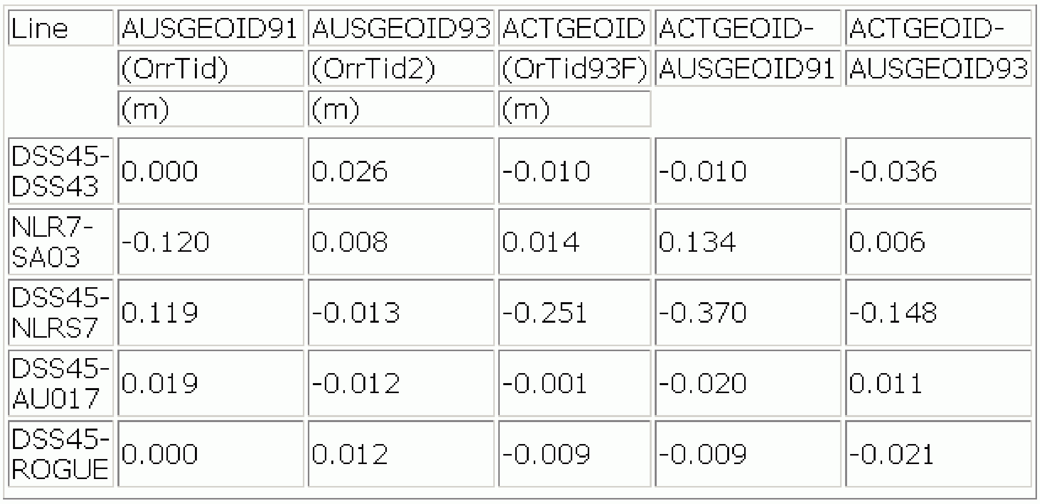
DX (m)	DY (m)	DZ (m)	SOURCE
NLRS7 - SA03			
-1 071.832	-993.102	1 255.304	IERS (1993)
-1 072.033	-992.958	1 255.113	IERS (1994)
-1 072.165	-992.907	1 255.035	OrrTid2
-1 072.045	-992.967	1 255.111	OrrLoc93
-1 072.026	-992.962	1 255.118	OrTid93F
NLRS7 - MN/C/106			
0.197	-22.209	-10.489	OrrTid2
0.278	-22.258	-10.422	OrrLoc93
0.278	-22.258	-10.421	OrTid93F
NLRS7 - AU005			
-2.080	-14.374	-18.906	OrrTid2
-1.994	-14.426	-18.835	OrrLoc93
-1.996	-14.425	-18.836	OrTid93F

Table 3: Origin of Published Ties for Sites in the ACT



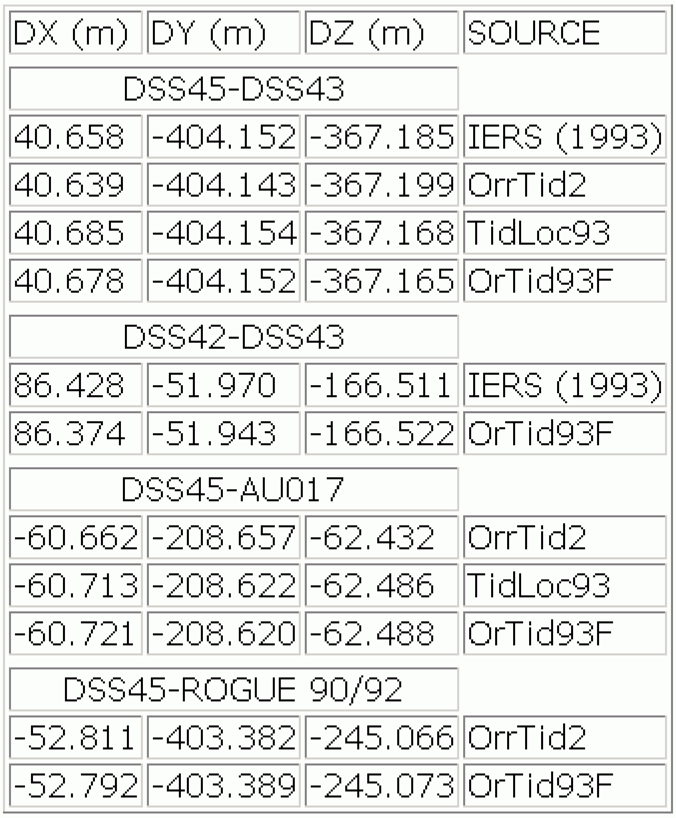
TIE	IERS (1992)	IERS (1993)	IERS (1994)
NLRS - SA03	T Morrison 23/3/90	T Morrison 23/3/90	J Luck 19/11/92
	Origin Unknown	Origin Unknown	(OrrTid Adjustment)
NLRS - DSS45	As Above	As Above	As Above
DSS42 - DSS43	Finger & Folkner '90	Finger & Folkner '90	
DSS45 - DSS43	Finger & Folkner '90	Finger & Folkner '90	
ROGUE - DSS43		Finger & Folkner '90	
		M Hendy, IGS Mail #35	
DSS45 - AU017			J Luck 19/11/92
			OrrTid Adjustment

Table 4: Effect of Geoid Models on the Height Component of Ties in the ACT



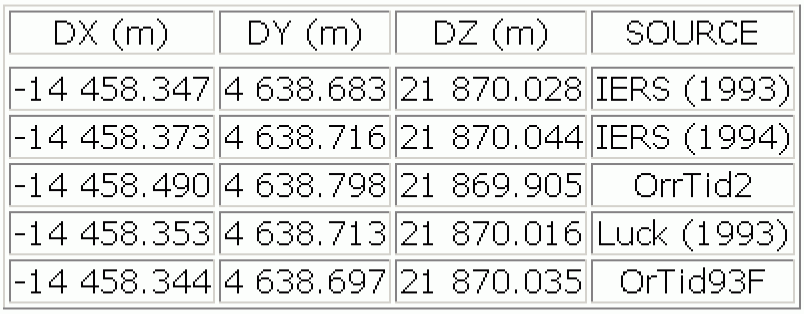
Line	AUSGEOID91	AUSGEOID93	ACTGEOID	ACTGEOID-	ACTGEOID-
	(OrrTid)	(OrrTid2)	(OrTid93F)	AUSGEOID91	AUSGEOID93
	(m)	(m)	(m)		
DSS45-DSS43	0.000	0.026	-0.010	-0.010	-0.036
NLR7-SA03	-0.120	0.008	0.014	0.134	0.006
DSS45-NLRS7	0.119	-0.013	-0.251	-0.370	-0.148
DSS45-AU017	0.019	-0.012	-0.001	-0.020	0.011
DSS45-ROGUE	0.000	0.012	-0.009	-0.009	-0.021

Table 5: ITRF Components of Ties at Tidbindilla



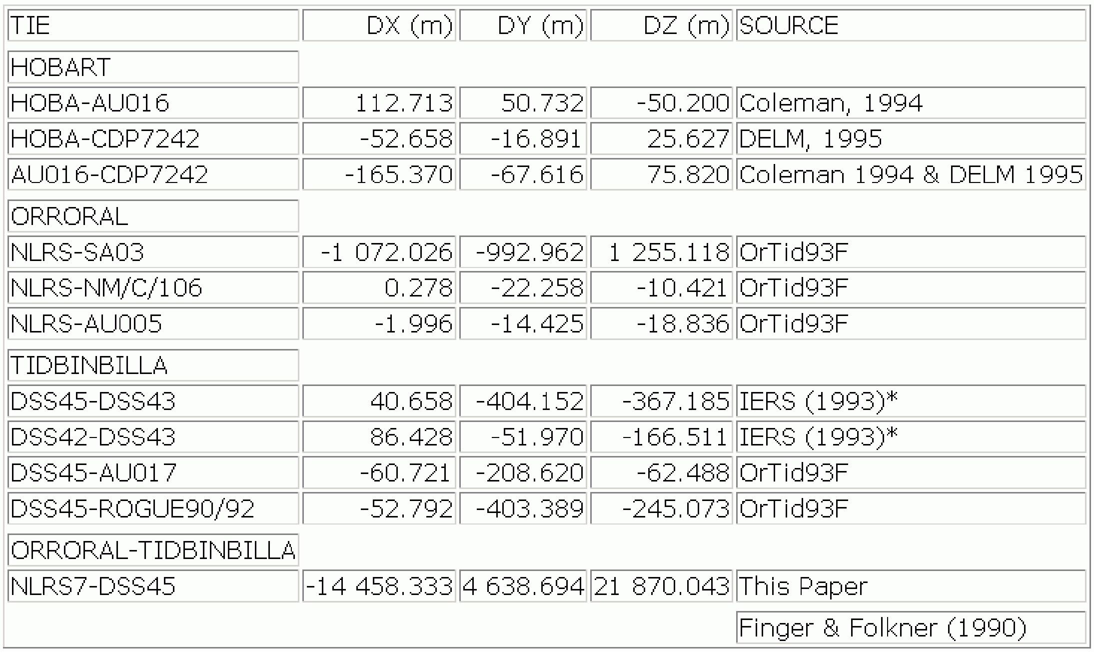
DX (m)	DY (m)	DZ (m)	SOURCE
DSS45-DSS43			
40.658	-404.152	-367.185	IERS (1993)
40.639	-404.143	-367.199	OrrTid2
40.685	-404.154	-367.168	TidLoc93
40.678	-404.152	-367.165	OrTid93F
DSS42-DSS43			
86.428	-51.970	-166.511	IERS (1993)
86.374	-51.943	-166.522	OrTid93F
DSS45-AU017			
-60.662	-208.657	-62.432	OrrTid2
-60.713	-208.622	-62.486	TidLoc93
-60.721	-208.620	-62.488	OrTid93F
DSS45-ROGUE 90/92			
-52.811	-403.382	-245.066	OrrTid2
-52.792	-403.389	-245.073	OrTid93F

Table 6: ITRF Components of NLR7-DSS45 for Various Computation Schemes



DX (m)	DY (m)	DZ (m)	SOURCE
-14 458.347	4 638.683	21 870.028	IERS (1993)
-14 458.373	4 638.716	21 870.044	IERS (1994)
-14 458.490	4 638.798	21 869.905	OrrTid2
-14 458.353	4 638.713	21 870.016	Luck (1993)
-14 458.344	4 638.697	21 870.035	OrTid93F

Table 7: Current Best Determination of Ties in Southeastern Australia



TIE	DX (m)	DY (m)	DZ (m)	SOURCE
HOBART				
HOBA-AU016	112.713	50.732	-50.200	Coleman, 1994
HOBA-CDP7242	-52.658	-16.891	25.627	DELM, 1995
AU016-CDP7242	-165.370	-67.616	75.820	Coleman 1994 & DELM 1995
ORRORAL				
NLRS-SA03	-1 072.026	-992.962	1 255.118	OrTid93F
NLRS-NM/C/106	0.278	-22.258	-10.421	OrTid93F
NLRS-AU005	-1.996	-14.425	-18.836	OrTid93F
TIDBINBILLA				
DSS45-DSS43	40.658	-404.152	-367.185	IERS (1993)*
DSS42-DSS43	86.428	-51.970	-166.511	IERS (1993)*
DSS45-AU017	-60.721	-208.620	-62.488	OrTid93F
DSS45-ROGUE90/92	-52.792	-403.389	-245.073	OrTid93F
ORRORAL-TIDBINBILLA				
NLRS7-DSS45	-14 458.333	4 638.694	21 870.043	This Paper
				Finger & Folkner (1990)