The 2012 Warkworth Observatory Local Tie Survey

Land Information New Zealand
Record A1387321

Department of Sustainability and Environment
Geodetic Survey, Office of Surveyor-General Victoria

Contents

Executive Summary

The Warkworth Observatory is located near Auckland, New Zealand. A local tie survey was completed between 3-7 December 2012.

The purpose of the survey was to determine the relationship between the permanent GNSS CORS site (WARK A 50243M001) and the invariant reference point (IVP) of the 12 metre radio telescope (7277 A 50243S001), capable of Very Long Baseline Interferometry (VLBI) observations.

The following report documents the technical aspects of the survey.

Acknowledgements

Land Information New Zealand (LINZ) would like to acknowledge Geoscience Australia (GA) and the Department of Sustainability and Environment (DSE), Victoria, Australia for their support and assistance during this local tie survey. The survey would have not been possible without their expertise, time and equipment.

LINZ would also like to thank the Auckland University of Technology (AUT), the owner and operator of the radio telescope, for their assistance on site while completing this survey.

1. Introduction

This report is not written to serve as a manual for precision geodetic local tie surveys and assumes that the reader has an understanding of the basic concepts of geodetic surveying.

Furthermore, this report does not detail or justify the approach taken, but merely reports the results of each major computation step. However, for completeness the steps in our approach for the observation and computation of local ties are as follows:

- The calibration of all geodetic instrumentation including: total station instruments, fixed height mounts and reflectors.
- The observation of a vertical geodetic network by application of geodetic levelling (in our case specifically EDM Height Traversing) to all survey marks in the vicinity of the observatory.
- The observation of a horizontal geodetic network by application of terrestrial geodetic observations, including angles and distances to all survey marks in the vicinity of the observatory.
- The observation of a Global Navigation Satellite System (GNSS) network on suitable survey marks in the vicinity of the observatory.
- The observation of targets located on the radio telescope during rotational motion about each of its two independent axes. This includes zenith angle observations to a staff on a levelled survey mark for precise height of instrument determination.
- The reduction of terrestrial geodetic observations, including the correction of observations for instrument and target bias, set reduction and atmospheric effects, as well as the height of instrument determination.
- Analysis of GNSS observations to derive GNSS only coordinate estimates and associated geocentric variance-covariance (VCV) matrix.
- Least squares (minimally constrained) adjustment of all terrestrial geodetic observations, variance-covariance matrix (in a local system) of the geodetic network and targets located on the VLBI.
- Invariant Point (IVP) modelling and estimation, which includes the estimation of IVP, the axes of rotation and associated system parameters such as axis orthogonality and the offset of the axes.
- Transformation (translation and rotation only) of the readjusted terrestrial network and computed IVP coordinate variance-covariance matrix into a global reference frame including a geocentric variance-covariance matrix (estimated and apriori). The previous GNSS analysis is used as the global reference frame realisation.
- Reduction of the complete solution of stations of primary interest (ie. those with DOMES) and output of a SINEX format solution file including all a priori constraints.

2. Site Description

The Warkworth Observatory is located 60km north of Auckland, New Zealand. The observatory contains two radio telescopes but the Warkworth 12m Patriot Radio Telescope (7277) is the only one capable of VLBI observations in New Zealand. The Warkworth Radio Telescope is owned and operated by AUT.

In 2009 a permanent GNSS CORS station was also established on site and LINZ is in the process of applying for the station to be included into the International GNSS Service (IGS) network.

LOCAL DETERMINATION	GLOBAL/IERS DESIGNATION
WARKWORTH AXIS IVP	7277 A 50243S001
WARKWORTH GNSS CORS	WARK A 50243M001

Table 2.1 List of survey marks with DOMES at Warkworth Observatory

A local tie survey was undertaken by two geodetic surveyors from Land Information New Zealand (LINZ) and Department of Sustainability and Environment, Victoria, Australia (DSE) in December 2012.

3. Instrumentation

The following section provides the specification and calibration procedures of the equipment used in the December 2012 survey.

3.1. TOTAL STATION

3.1.1. Total Station

Leica TCA2003 (S/N 442403)

Specification

- EDM (infrared) distance standard deviation of a single measurement: 1mm + 1ppm;
- Angular standard deviation of a mean direction measured in both faces: 0.15mgon (0.5”).
- Instrument calibrated by the National Measurement Institute, Australia on the 5th of October 2012

3.1.2. Auxiliary Equipment

Delta Ohm meteorological gauge (S/N:09011514) was used to measure temperature and pressure. A Paroscientific MET4 meteorological sensor located at Warkworth Observatory recorded the humidity during the survey.

Specification

- Temperature: Accuracy ± 1 C
- Pressure: Accuracy ± 1 mbar
- Relative Humidity: Accuracy ± 2%

3.2. SETUP AND CENTERING EQUIPMENT

A Leica FG-L30 (S/N: 609030) zenith and nadiar optical plummet was used to centre and level all instruments and target set-ups.

3.2.1. Targets and Reflectors

The standard target kit includes:

6 x Leica Precision Mini Prisms
6 x Magnet targets
5 x Lecia GPH1P Precision Prisms
5 x Lecia Tribrach

5 x Lecia GZR3 Prism Carriers with Optical Plummets

- Precision Mini Prisms have an offset of approximately +0.0180m
- Leica GPH1P prisms have an offset of approximately 0.0000m.
- The precise offset for each targets were applied to the reduced distances.

3.3. LEVELLING

3.3.1. Levelling Instruments

Refer to section 3.1.1 for description of Total Station

3.3.2. Levelling Rods

- A fixed height stainless steel rod with Leica style bayonet mount was used with a bi-pole for stability.
- A stub with an approximate height of 0.2m, with a bayonet prism mount was also used to determine the height of the antenna.
- The levelling pole and stub (named VIC1) offset was measured on 30 June 2009 to be 1.4645m.

3.4. TRIPODS

A single standard Lecia tripod with adjustable legs was used during the precise levelling.

Seven custom built (5 GNS, 2 AUT) towers were used during the EDM traverse and observations to the radio telescope and GNSS antenna.

3.5. GNSS UNITS

Survey grade Trimble NetR9 receivers and Trimble Zephyr Geodetic 2 antennae were used during the survey.

3.5.1. GNSS Receivers

SITE	SERIAL NO.	DESCRIPTION
WARK A 50243M001	5034K69668	TRIMBLE NetR9
WASE	5130K77167	TRIMBLE NetR9
WANW	5133K77662	TRIMBLE NetR9
WASW	5130K77201	TRIMBLE NetR9

Table 3.1: List of GNSS receiver information

3.5.2. GNSS Antennae

SITE	SERIAL NO.	TYPE	DESCRIPTION
WARK A 50243M001	30477149	TRM55971.00	ZEPHYR GEODETIC 2 NONE
WASE	1441137889	TRM55971.00	ZEPHYR GEODETIC 2 NONE
WANW	1441138156	TRM55971.00	ZEPHYR GEODETIC 2 NONE
WASW	1441137986	TRM55971.00	ZEPHYR GEODETIC 2 NONE

Table 3.2 List of GNSS antennae information

4. Network Measurement

4.1. GROUND NETWORK

4.1.1. Listing

SITE	DESCRIPTION
7377 A 50243S001 (IVP)	The intersection of the azimuth axis with the common perpendicular of the azimuth and elevation axes of the 12m Radio Telescope
WARK A 50243M001	The intersection of the top of the 50mm stainless steel centre block with the vertical axis BSW 5/8th inch thread. The centre block is set in a 1.5m high UNAVCO-style deep braced monument. The offset between the ARP and the vertical reference point of the monument (top of centre block) is 0.002m.
WAW1 WARK RM 1	Stainless steel pin set in concrete block reinforced with 4 x 12mm dia SS bars extending 1.5m into subbase.
WAW2 WARK RM 2	Stainless steel pin set in concrete block reinforced with 4 x 12mm dia SS bars extending 1.5m into subbase.
WAW3 WARK RM 3	Stainless steel pin set in concrete block reinforced with 4 x 12mm dia SS bars extending 1.5m into subbase.
WANW	20mm stainless steel pin set in concrete reinforced by galv. iron rods driven 2m in to ground
WASE	20mm stainless steel pin set in concrete reinforced by galv. iron rods driven 2m in to ground
WASW	20mm stainless steel pin set in concrete reinforced by galv. iron rods driven 2m in to ground
WANE	20mm stainless steel pin set in concrete reinforced by galv. iron rods driven 2m in to ground

Table 4.1 Description of network

4.1.2. Map of Survey Network

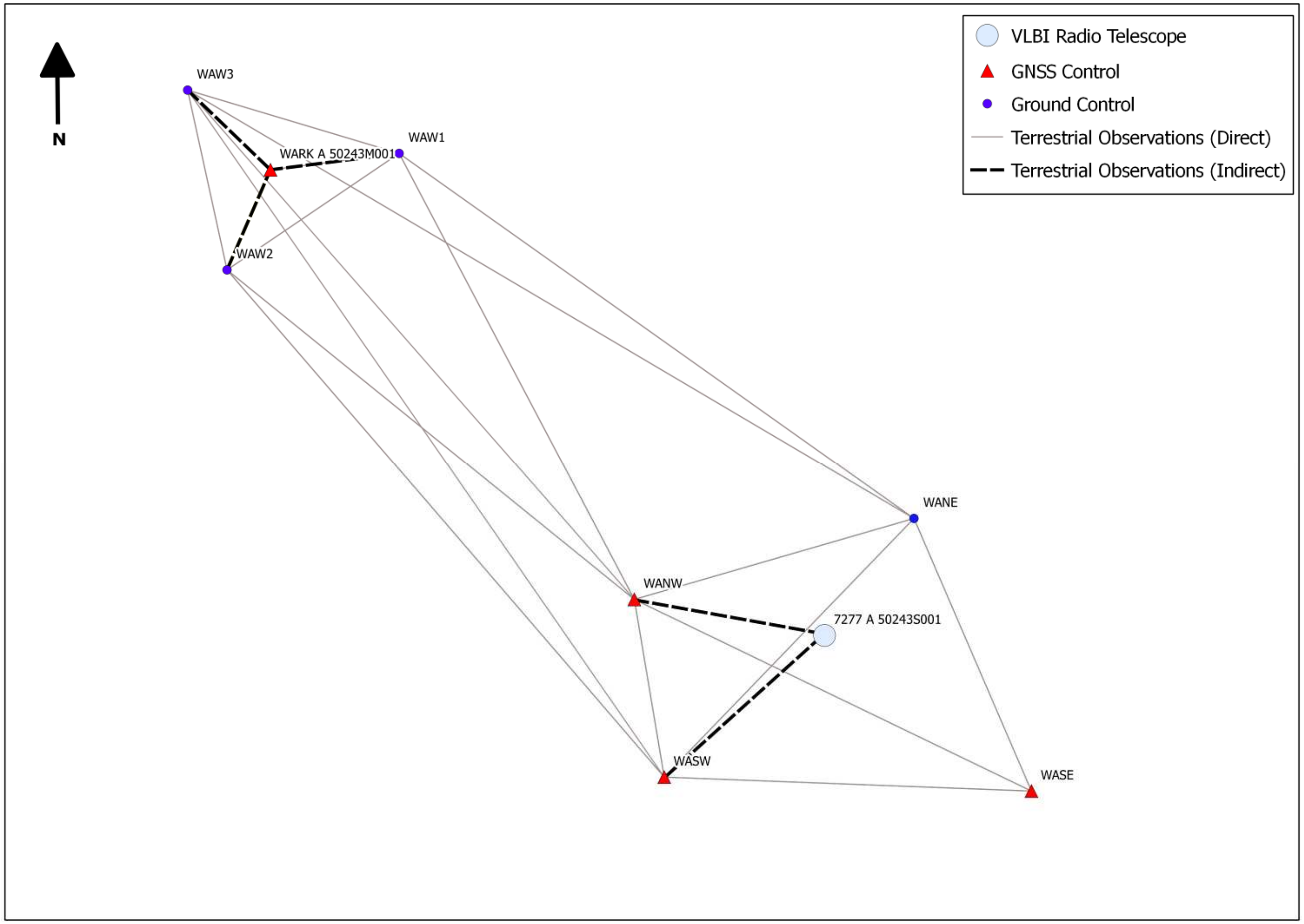


Figure 4.2: The terrestrial network showing the ground control

5. Description of Observing Systems

5.1. VERY LONG BASELINE INTERFEROMETRY (VLBI)

The 12 metre patriot dish was commissioned by Auckland University of Technology (AUT) in 2008. The IVP of this dish is the intersection of the azimuth axis with the common perpendicular of the azimuth and elevation axes.

Just prior to the survey AUT identified a problem with a bearing on the elevation axis. This fault has little impact on the measurements of the dish. The bearing was replaced shortly after the survey.

A least squares method is used for the computation of the axes of rotation and the IVP. The method works on the basis that a target located on a rigid body, rotating about one independent axis can be fully expressed as a circle in 3-dimensional space and described by seven parameters:

- A circle centre (3 parameters).
- A unit normal vector perpendicular to the circle (3 parameters).
- A circle radius (1 parameter).

The method of IVP determination makes assumptions that:

- During rotational sequence target paths scribe a perfect circular arc in 3-dimensional space.
- There is no deformation of targeted structure during rotational sequence.
- There is no wobble error.
- The axis of interest can be rotated independently of the other axis.

No assumptions of axis orthogonality, verticality / horizontality or the precise intersection of axes are made.

The indirect geometrical model includes a number of conditions:

- Target paths during rotations about an independent axis scribe a perfect circle in space.
- Circle centres derived from target observed while being rotated about the same axis are forced to lie along the same line in space.
- Normal vectors to each circle place derived from targets observed while being rotated about the same axis are forced to be parallel.
- The orthogonality of the primary axis to secondary axis remains constant over all realisations of the secondary axis.
- Identical targets rotated about a specific realisation of an axis will scribe 3-dimesional circles of equal radius.
- The offset distance between the primary axis and the secondary axis remains constant over all realisations of the secondary axis.
- The distance between 3-dimensional circle centres for all realisations of the secondary axis are constant over all realisations of the secondary axis.

- The IVP coordinate estimates remain constant over all realisations (combinations) of the primary/secondary axis.

In addition, a constraint that the unit normal vector perpendicular to the plane of the circle must have a magnitude of one was applied and a minimum of three rotational sequences for each target was required to enable the solution of the equation of a circle.

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

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

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

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

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

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

5.2. GLOBAL NAVIGATION SATELLITE SYSTEM (GNSS)

WARK A 50243M001 was not removed from its monument/pillar during this survey to allow the continuation of the data and to avoid the risk of the antenna not being re-centred in the same position which could cause a possible shift in the time series. This abides by IGS guidelines for continuous time series.

An indirect survey of the GNSS antenna was conducted from each of the reference marks evenly space around WARK A 50243M001. To estimate the horizontal position of the antenna sets of angular observations were made to specific symmetrically coupled points on the external profile of the antenna. By making use of the symmetrical properties of the antenna it was possible to intersect the observations and obtain direction observations to the central axis. Using triangulation the horizontal position of the ARP was estimated. To estimate the height of the antenna a precise levelling connection was made to the top of the antenna. Using the height difference precisely levelled between the antenna reference point and the top of the antenna on an identical antenna of the same make and model the height of the ARP was derived (0.0847m). Trimble and NGS have not published this dimension so it was measured on site. It is assumed that the antennas are identical by factory specification.

This method makes the following assumptions:

- The measured Zephyr Geodetic 2 antenna has identical dimensions to the Zephyr Geodetic 2 WARK antenna.
- The antenna has been manufactured to be perfectly symmetrical.

6. Observations

6.1. TERRESTRIAL NETWORK SURVEY

A precise EDM traverse was conducted between all seven ground control marks at the Warkworth Observatory (Figure **4.2**).

Five sets of face left/ face right observations were completed and recorded at each ground control mark. Horizontal angles, slope distances and zenith distances were recorded. Atmospherics were recorded at each setup and corrections were applied during post processing.

6.2. PRECISE LEVELLING

Precise levelling was conducted between all the ground control marks using the EDM Height Traversing technique (Johnston et al, 2002). Height difference observations were made using a Leica TCA2003 Total Station to a prism mounted on a fixed height stainless steel prism pole (approximately 1.5m in height) and to a fixed height stainless steel stub (approximately 0.2m in height). Atmospheric conditions (temperature, pressure, and relative humidity) were recorded and entered into the instrument every 30 minutes.

Levelling loops covering all monuments in the survey network were completed in both directions (Figure **6.1**). Each instrument set-up involved reading five rounds of face left/ face right observations to a single prism set-up over two marks. The levelling observations were adjusted in a least squares sense to derive adjusted height differences between all marks.

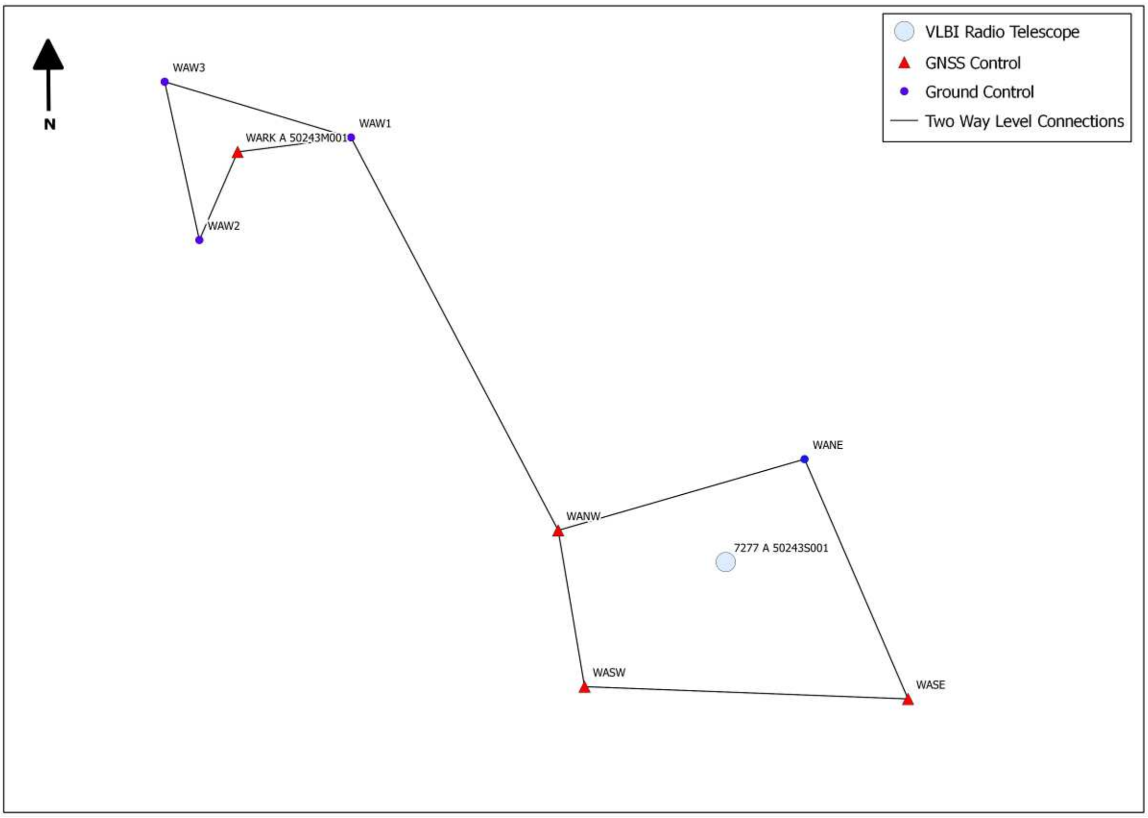


Figure 6.1: Precise levelling network, observed two way height differences

6.3. GNSS

At least 12 hours of GNSS observations were collected at the WARK continuous GNSS station, WANW, WASW and WASE.

6.3.1. GNSS Receivers

SITE	DATA START (YY:DDD:SSSSS)	DATA END (YY:DDD:SSSSS)	DESCRIPTION
WARK A 50243M001	12:308:00000	12:308:86370	TRIMBLE NetR9
WASE	12:308:17100	12:308:68730	TRIMBLE NetR9
WANW	12:308:17550	12:308:69360	TRIMBLE NetR9
WASW	12:308:16950	12:308:69150	TRIMBLE NetR9

Table 6.1: List of GNSS receivers and observation times

6.3.2. GNSS Antennae

SITE	DATA START (YY:DDD:SSSSS)	DATA END (YY:DDD:SSSSS)	DESCRIPTION
WARK A 50243M001	12:308:00000	12:308:86370	ZEPHYR GEODETIC 2 NONE
WASE	12:308:17100	12:308:68730	ZEPHYR GEODETIC 2 NONE
WANW	12:308:17550	12:308:69360	ZEPHYR GEODETIC 2 NONE
WASW	12:308:16950	12:308:69150	ZEPHYR GEODETIC 2 NONE

Table 6.2 List of GNSS antennae and observation times

6.4. INDIRECT OBSERVATION TO TELESCOPE

6.4.1. 12m Radio Telescope

The 12m Radio Telescope was observed indirectly from two standpoints WANW and WASW for both elevation and azimuth. Leica Precision Mini Prisms were mounted onto the substructure for the azimuth axis observations using magnetic mounts. The same Leica precision mini prisms were mounted on to bayonets attached to the telescope dish for the elevation axis observations. The magnetic mounts could not be used on the dish because it is made from aluminium.

<u>Azimuth Observations (5 targets)</u>
The elevation axis was fixed in a vertical setting. The azimuth axis was rotated in 20 degree increments starting from 340 degrees backward through to 0 degrees. One set of observations was completed to all visible targets on the radio telescope for each 20 degree rotation.

Figure 6.2: Target placement on the front (left and top right) and back (bottom right) on telescope for the azimuth observations.

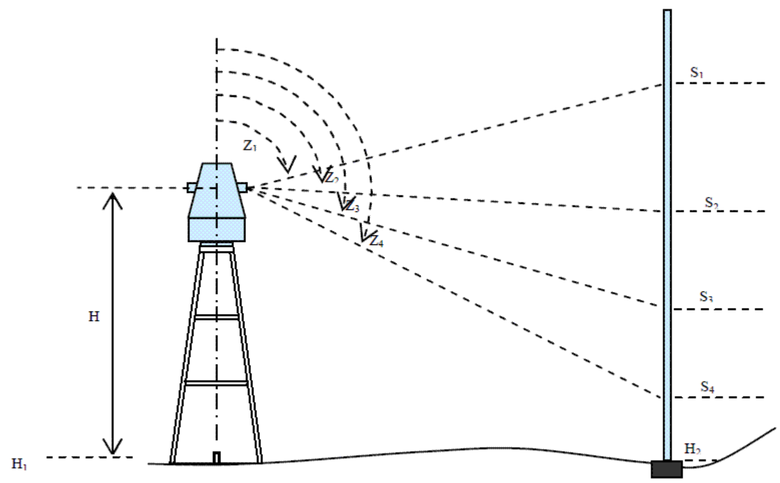
Elevation Observation (4 targets)
The azimuth axis was fixed in a horizontal orientation of 13 degrees and 130 degrees, to be orthogonal to the total station line of sight. The elevation axis was set to 85 (due to the bearing issue could not be set to 90) and lowered in 10 degree increments down to 10 degrees.

Figure 6.3: Placement of targets on dish for the elevation observations

6.4.2. Instrument Height Determination

Obtaining the correct height of instrument was an important step in the survey as any error in this measurement would propagate into the derivation of the IVP.

The heights of instrument were observed using the technique illustrated in Figure **6.4** (Reuger and Brunner, 1981). The technique involves the observation of one round of face left/ face right vertical angles to specific graduations on a levelling staff (in this case 0.8, 1.2, 1.6 and 2.0m) placed on a levelled survey mark. This technique works best when the mid-graduations of the levelling staff are approximately horizontal from the instrument trunion axis. The technique relies on the height difference between the ground survey marks (H1 and H2) which was calculated independently in the precise level survey (Section **6.2**).



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

Figure 6.4: Total station instrument heighting technique where Sn are the staff readings, Zn are the zenith angles (Rueger and Brunner, 1981).

7. Data Analysis and Results

7.1. DATA PRE-PROCESSING

7.1.1. Levelling

The levelling observations were reduced using Geosciences Australia's levelling reduction software to derive the change in heights between survey marks.

7.1.2. Terrestrial data

The horizontal angle, slope distance, and zenith angle observations were reduced using software prepared by DSE to average observation sets and apply corrections for atmospherics and target offsets. This software output the reduced observations into a format compatible with the DynaNet software.

7.1.3. Least squares Adjustment

A three-dimensional least squares adjustment was undertaken in the DynaNet software. The precise levelling observations were combined with the terrestrial traverse observations and all the observations to the targets on the radio telescope. A minimally constrained least squares adjustment was performed, holding the WARK GNSS station and the line from WARK to the WANW ground survey mark constrained. The output coordinates for the ground marks and observed radio telescope targets were output into a SINEX file together with a full VCV matrix.

7.2. GNSS

7.2.1. Analysis Software

The GNSS data analysis was undertaken using the Bernese GPS Processing Software Version 5.0 within the AUSPOS online data processing facility. An International Terrestrial Reference Frame 2008 (ITRF 2008) solution was minimally constrained in a regional solution. Both L1 and L2 observations were used and no troposphere model parameters were estimated. Final IGS orbits and Earth Orientation Parameters were used for computations. IGS recommended constant and elevation dependent antenna phase models were applied.

7.2.2. Results

SITE	LATITUDE	LONGITUDE	ELLIP HEIGHT (M)
WARK A 50243M001	-36 26′ 03.87406″	174 39 46.00833″	111.281
WASE	-36 26′ 05.78899″	174 39 48.35637″	121.255
WANW	-36 26′ 05.19891″	174 39 47.13109″	120.215
WASW	-36 26′ 05.74598″	174 39 47.22339″	120.903

Table 7.1: ITRF 2008 co-ordinates from AUSPOS

7.2.3. IVP Determination

The geometrical modelling, adjustment and transformation processes were undertaken in the Geoscience Australia developed Axis software.

The least squares solution of the IVP for the Warkworth 12m radio telescope included 187 observations to 18 targets. 2 estimates of the IVP where derived and constrained together through 117 constraints. The resultant linear system for the network was 573 x 573 with 922 degrees of freedom. The computed variance factor was 0.6355. The IVP model (circle) fit residuals were 0.2mm and 0.4mm for in-plane and the out-of-plane. The maximum circle fit residual was 1.1mm.

As part of the IVP determination process, the radio telescope offset was estimated to be 0.0010 m ± 0.0002 m.

7.2.4. Correlation matrix

The computed correlation matrix is too large to be included in this report, please refer to the SINEX file (section 5.10) for further information.

7.3. REFERENCE TEMPERATURE

No thermal corrections were applied for the structural expansion of the radio telescope.

7.4. TRANSFORMATION

The derived IVP and ground survey mark coordinates were transformed onto the GNSS derived coordinates listed above, using a seven parameter transformation in the Axis software.

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ALIGNMENT RESIDUALS

CARTESIAN SYSTEM - CENTROID ORIGIN (METRES)

              UNTRANSFORMED-REFERENCE        TRANSFORMED-REFERENCE
       SITE      X(M)     Y(M)     Z(M)        X(M)     Y(M)     Z(M)

       WANW    -0.0002  -0.0008  -0.0005      0.0003  -0.0002   0.0008
       WARK     0.0012   0.0006  -0.0006     -0.0000   0.0003  -0.0003
       WASE    -0.0007  -0.0010   0.0024      0.0001  -0.0009  -0.0008
       WASW     0.0001  -0.0027  -0.0001     -0.0003   0.0008   0.0003

              UNTRANSFORMED-REFERENCE        TRANSFORMED-REFERENCE
       SITE    EAST(M)  NORTH(M)  UP(M)       EAST(M)  NORTH(M)  UP(M)

       WANW     0.0008  -0.0004   0.0004      0.0002   0.0005  -0.0007
       WARK    -0.0007  -0.0011  -0.0006     -0.0003  -0.0002   0.0002
       WASE     0.0011   0.0023  -0.0009      0.0009  -0.0007   0.0003
       WASW     0.0027  -0.0003  -0.0003     -0.0008   0.0005   0.0002


TRANSFORMATION PARAMETERS: ARBITRARY TO GLOBAL (OR REFERENCE SET)

CARTESIAN SYSTEM        : CENTROID ORIGIN

VARIANCE FACTOR         :         2.71253e-07
SIGMA                   :         5.20820e-04


         TX        TY        TZ        RX        RY        RZ
          M         M         M        AS        AS        AS

     -0.0000   -0.0011    0.0005      9.77     -3.72      2.93

FRAME                   : TRANSFORMED
SOLUTION STATIONS       : CARTESIAN COORDINATES - EARTH CENTRE ORIGIN (METRES)

       WANW  -5115318.9241    477857.4633  -3767185.5075
       WARK  -5115333.3149    477886.8944  -3767147.3447
       WASE  -5115311.8393    477826.1503  -3767200.7569
       WASW  -5115309.7165    477854.2932  -3767199.4823
 IVP-013-031  -5115324.4218    477843.2955  -3767192.8254
 IVP-013-041  -5115324.4218    477843.2955  -3767192.8254

APRIORI TRACE           :         2.83785e-07
APOSTERIORI TRACE       :         9.28676e-08


UPDATED SOLUTION CENTROID :  -5115320.4397    477851.8987  -3767186.4570

RESIDUAL SCALE BIAS            6.8 PPM
```

Figure 7.2: Warkworth 2012 local to ITRF2008 alignment results

7.5. SINEX FILE GENERATION

A SINEX file was generated using the Axis software run by Geoscience Australia. It is named WARK2012LT.snx.

7.6. DISCUSSION OF RESULTS

7.6.1. Results

The final derived cartesian coordinates for the radio telescope IVP and continuous GNSS station (WARK) are shown in the table below (all units are in metres). GRS801 ellipsoid, aligned to ITRF2008 at December 2012 (date of survey).

SITE	X	Y	Z
WARK A 50243M001	-5115333.3149	477886.8944	-3767147.3447
IVP	-5115324.4218	477843.2955	-3767192.8254

Table 7.3: Cartestian Co-ordinates for WARK and IVP of WARK12M

7.6.2. Comparison with Previous Surveys

There are no previous results to compare.

8. Planning Aspects

The Warkworth radio telescope local tie survey required approximately four days of field work. This encompassed one day to observe the telescope through changes in azimuth, half a day to observe the telescope through changes in elevation, one day to observe the terrestrial ground network and GNSS antenna and one day to perform a precise levelling survey between the ground marks.

It is proposed that during the next survey at the Warkworth observatory the 30M radio telescope also located on site (WARK30M) should be included in the local tie survey. An additional reference mark will have to be installed orthogonal to either WRK1 or WRK 3 and the telescope. Also, an additional two days should be allowed to measure the 30m radio telescope

If in the future the GNSS antenna on WARK is removed for replacement or repair, it is suggested that an offset be measured between a point on the monument and WARK. This will allow for an easier and more accurate height determination of the height for the mark. The current method requires a prism to sit on the top of the antenna which presents some difficult in slightly windy conditions.

9. References

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