2015 - Warkworth Observatory Local Tie Survey

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Contents

Executive Summary

The Warkworth Observatory is located approximately 60km north of Auckland, New Zealand. A local tie survey was completed between 13-19 March 2015. Supplementary levelling work was completed on 21 September 2015.

The purpose of the survey was to determine the relationship between the permanent GNSS CORS site (WARK 50243M001), the invariant reference points (IVP) of the 12 metre (7377 50243S001) and 30 metre (7391 50243S002), radio telescopes 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) 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 accompanies the SINEX file computed as part of the local tie survey. Below are the high level steps in our approach for the observation and computation:

- 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 survey marks at the observatory
- The observation of a three dimensional geodetic network by conventional terrestrial geodetic observations, including angles and distances to survey marks at the observatory
- The observation of a Global Navigation Satellite System (GNSS) network on suitable survey marks at 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
- Analysis of GNSS observations to derive GNSS only coordinate estimates and associated geocentric covariance (VCV) matrix
- Least squares (minimally constrained) adjustment of all observations, including the terrestrial observations and the coordinates/covariance matrix calculated from the GNSS observations. The adjustment treats the VLBI antennae as rigid bodies with two axes of rotation and calculates the Invariant Point (IVP), the orientation and separation of the axes, and the locations of the targets on the antennae
- The generation of a SINEX file of the stations of interest (ie: those with DOMES)

This report assumes that the reader has an understanding of the basic concepts of geodetic surveying and does not detail or justify the approach taken.

2. Site Description

The Warkworth Observatory is located 60km north of Auckland, New Zealand. The observatory contains two radio telescopes, a 30m Radio Telescope (7391), converted from a telecommunications antenna in 2014 and a Warkworth 12m Patriot Radio Telescope (7377). Both radio telescopes are owned and operated by AUT.

A permanent GNSS CORS station was established on site in 2009. The station WARK was included into the International GNSS Service (IGS) network in 2013.

LOCAL DETERMINATION	GLOBAL/IERS DESIGNATION
WARK12M AXIS IVP	7377 50243S001
WARKWORTH GNSS CORS	WARK 50243M001
WARK30M AXIS IVP	7391 50243S002

Table 2.1 List of survey marks with DOMES at Warkworth Observatory

3. Instrumentation

The following section provides the specification and calibration procedures of the equipment used in the December 2015 survey.

3.1. TOTAL STATION

3.1.1. Total Station

Leica TDRA6000 (S/N 362969)

Specification

- EDM (infrared) distance standard deviation of a single measurement: 0.6 mm + 1 ppm;
- Angular standard deviation of a mean direction measured in both faces: 0.15mgon (0.5”).

3.1.2. Auxiliary Equipment

A Paroscientific MET4 meteorological sensor located at Warkworth Observatory recorded the temperature, pressure and humidity during the survey.

Specification

- Temperature: Accuracy ± 0.5 °C
- Pressure: Accuracy ± 0.1 mbar
- Relative Humidity: Accuracy ± 2%

3.2. SETUP AND CENTERING EQUIPMENT

A Leica FG-L30 (S/N: 609048) zenith and nadir 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
4 x Leica GPH1P Precision Prisms
4 x Leica Tribrach
4 x Leica GZR3 Prism Carriers with Optical Plummets

- Precision Mini Prisms have an offset of approximately +0.0185m
- Leica GPH1P prisms have an offset of approximately 0.0000m
- The precise offsets for each target 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 for work undertaken in March 2015.

Leica DNA03 Precise Level (S/N 332837) with a three piece aluminium staff.

3.3.2. Levelling Rods

- A fixed height stainless steel rod with Leica style bayonet mount was used with a bi-pole for stability.

3.4. TRIPODS

A single standard Leica 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 50243M001	5034K69668	TRIMBLE NetR9
WAN3	5133K77662	TRIMBLE NetR9
WANW	5130K77201	TRIMBLE NetR9
WASE	5130K77167	TRIMBLE NetR9

Table 3.1: List of GNSS receiver information

3.5.2. GNSS Antennae

SITE	SERIAL NO.	TYPE
WARK 50243M001	30477149	TRM55971.00 NONE
WAN3	1441138156	TRM57971.00 NONE
WANW	1441137986	TRM57971.00 NONE
WASE	1441137889	TRM57971.00 NONE

Table 3.2 List of GNSS antennae information

4. Network Measurement

4.1. GROUND NETWORK

4.1.1. Listing

SITE	DESCRIPTION
7377 50243S001 (IVP) WARK12M	The intersection of the azimuth axis with the common perpendicular of the azimuth and elevation axes of the 12m Radio Telescope
7391 50243S002 (IVP) WARK30M	The intersection of the azimuth axis with the common perpendicular of the azimuth and elevation axes of the 30m Radio Telescope
WARK 50243M001 Warkworth	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
WAS3	Stainless steel pin set in concrete block reinforced with 4 x 12mm dia SS bars extending 1.5m into subbase.
WAN3	Stainless steel pin set in concrete block reinforced with 4 x 12mm dia SS bars extending 1.5m into subbase.

Table 4.1 Description of network

4.1.1. Map of Survey Network

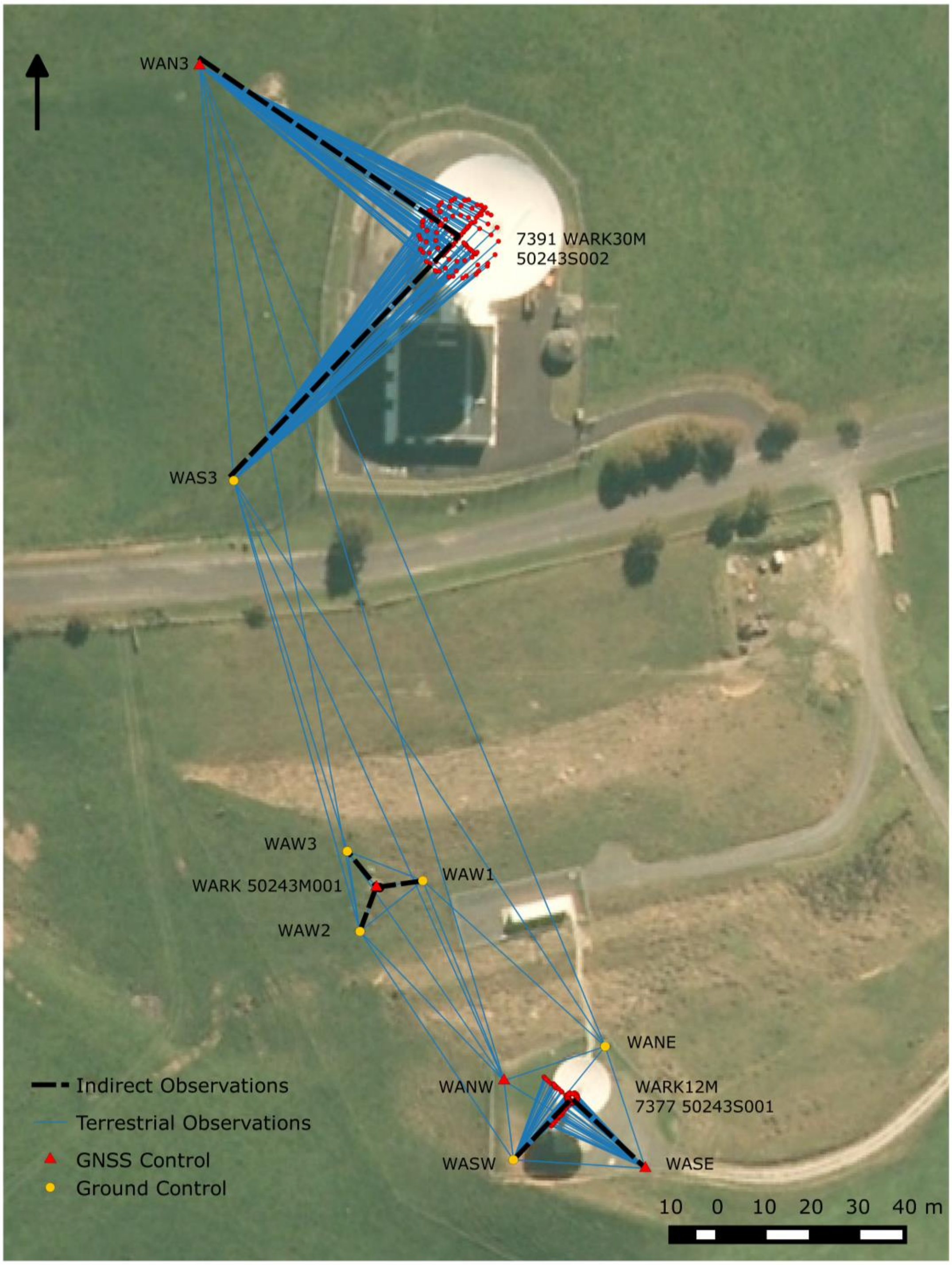


Figure 4.2: The terrestrial network showing the ground control

5. Description of Observing Systems

5.1. VERY LONG BASELINE INTERFEROMETRY (VLBI)

There are two radio telescopes used for geodetic observations at the Warkworth Observatory. The 12m patriot dish was commissioned by Auckland University of Technology (AUT) in 2008 while the 30m dish is an ex-telecommunication telescope upgraded for geodetic observations. It completed its first geodetic observations in early 2015.

The geodetic reference point of each antenna is its invariant point, or IVP, which is the intersection of its primary (azimuth) axis with the common perpendicular between that axis and its secondary (elevation) axis.

This point is located by surveying a number of targets on the tower (affected by the rotation around the primary axis) and on the antenna (affected by rotations around each axis). The targets on the tower are observed for a number of orientations of the primary axis at approximately 10 degree intervals and the points on the antenna are observed for a fixed orientation of the primary axis and number of orientations of the secondary axis at approximately 10 degree intervals.

The observations made are horizontal angle, zenith distance and slope distance from two fixed standpoints. The same antenna targets are observed at each standpoint, but using different primary and secondary axis orientations.

A least squares method is used for the computation of the axes of rotation and the IVP as part of the combined network adjustment. This assumes that each observation of a target on the tower can be expressed in terms of the following parameters:

- the location of the antenna invariant reference point (3 parameters)
- the orientation of the primary axis of rotation (2 parameters)
- the rotation of the tower about the primary axis (1 parameter per orientation)
- the position of the target (3 parameters per target, expressed as distance along the primary rotation axis from the IVP, distance from the primary axis (ie: radius of arc), and direction of the perpendicular from the primary axis to the target). Note that the direction of the perpendicular is arbitrarily set to zero for one of the targets. For the other targets the direction is relative to that target.

Similarly each observation of a target on the antenna is defined by:

- the location of the antenna invariant reference point (3 parameters)
- the orientation of the primary axis of rotation (2 parameters)
- the rotation of the tower about the primary axis (1 parameter)
- the perpendicular offset of the secondary axis from the primary axis (1 parameter)
- the orientation of the secondary axis relative to an axis orthogonal to the primary axis and the common perpendicular to the two axes (1 parameter per orientation)
- the position of the target (3 parameters per mark, expressed as distance along the secondary rotation axis from the intersection with the perpendicular to the primary axis), distance from the secondary axis (ie: radius of arc), and direction of the perpendicular from the secondary axis to the target). As for the targets on the tower the direction of the perpendicular is arbitrarily set to zero for one of the targets.

This formulation assumes that the telescope is completely rigid other than the rotations about the two axes. It does not take account of any deformation within the telescope such as flexing or thermal expansion.

The analysis was computed using the LINZ pyaxis software. It operates in three phases:

- calculation of each observed position of each target. This is a standard surveying least squares adjustment and takes no account of the telescope's geometrical constraints
- based on these calculated positions form initial estimates the telescope and target parameters
- calculation of the entire network expressing the telescope target locations in terms of the parameters listed above

The first and third phases use iterative least squares in which each iteration uses a first order linear approximation to the relationship between the observations and the parameters (station coordinates, telescope and target parameters) to improve the estimates of the parameters. This is iterated until there are no significant changes to the parameters.

The versions used to calculate this solution are below and are available at http://github.com/linz

python-linz-geodetic	1.7.0-1
python-linz-adjustment	2.4.1-1
python-linz-pyaxis	1.2.1-1
python-numpy	1:1.8.2-0ubuntu0.1
python-scipy	0.13.3-1build1

5.2. GLOBAL NAVIGATION SATELLITE SYSTEM (GNSS)

An indirect survey of the GNSS antenna was conducted from each of the reference marks evenly spaced around WARK 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. The horizontal position of the ARP was estimated using triangulation.

The antenna for WARK 50243M001 was not removed during the March 2015 survey to avoid introducing an offset in the time series, due to the shape of the antenna and the equipment available at the time the vertical position of WARK was not able to be determined. To avoid difficulties in future surveys a vertical offset mark (WARH) was established on one of the monuments legs in September 2015, the antenna was removed during this visit to determine the vertical relationship between WARK and WARH.

Figure 5.1 WARH – WARK vertical offset mark

This method makes the following assumptions:

- The spacer between the ARP and VRP is manufactured to the factory specifications of 0.002m
- 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 (refer 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 logged at the met station onsite and corrections were applied during post processing corresponding to the time of setup and timestamp.

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 TDRA6000 Total Station to a prism mounted on a fixed height stainless steel prism pole (approximately 1.5m 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 zenith and horizontal distances were reduced to determine change of height with between marks.

Additional measurements were taken between WARK and WARH and other reference marks using a Leica DNA03 precise level with a three piece aluminium staff.

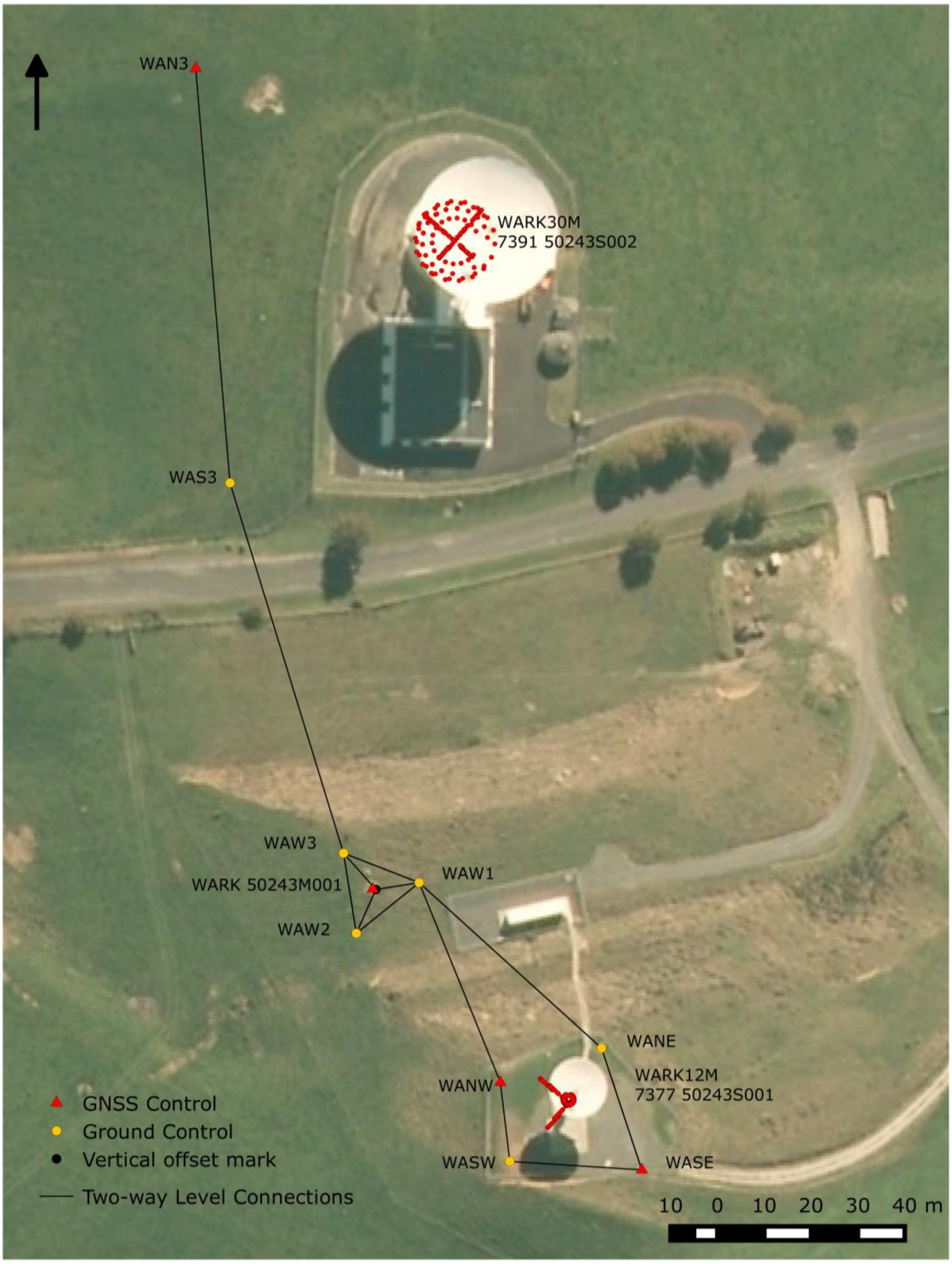


Figure 6.1: Precise levelling network, observed two way height differences

6.3. GNSS

At least 12 hours of GNSS observations were collected at the WARK continuous GNSS station, WAN3, WASW and WASE.

6.3.1. GNSS Receivers

SITE	DATA START (YY:DDD:SSSSS)	DATA END (YY:DDD:SSSSS)	DESCRIPTION
WARK 50243M001	15:075:16740	15:075:73050	TRIMBLE NETR9
WAN3	15:075:16740	15:075:73050	TRIMBLE NETR9
WANW	15:075:16740	15:075:73050	TRIMBLE NETR9
WASW	15:075:16740	15:075:73050	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 50243M001	15:075:16740	15:075:73050	TRM57971.00 NONE
WAN3	15:075:16740	15:075:73050	TRM57971.00 NONE
WANW	15:075:16740	15:075:73050	TRM57971.00 NONE
WASW	15:075:16740	15:075:73050	TRM57971.00 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 WASE 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.

Azimuth Observations (5 targets)

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 from each standpoint 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 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. 30m Radio Telescope

The 30m Radio Telescope was observed indirectly from two standpoints WAN3 and WAS3 for both elevation and azimuth. Leica Precision Mini Prisms were mounted onto the substructure for the azimuth axis and elevation axis observations using magnetic mounts.

Azimuth Observations (4 targets)

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 from each standpoint to all visible targets on the radio telescope for each 20 degree rotation.

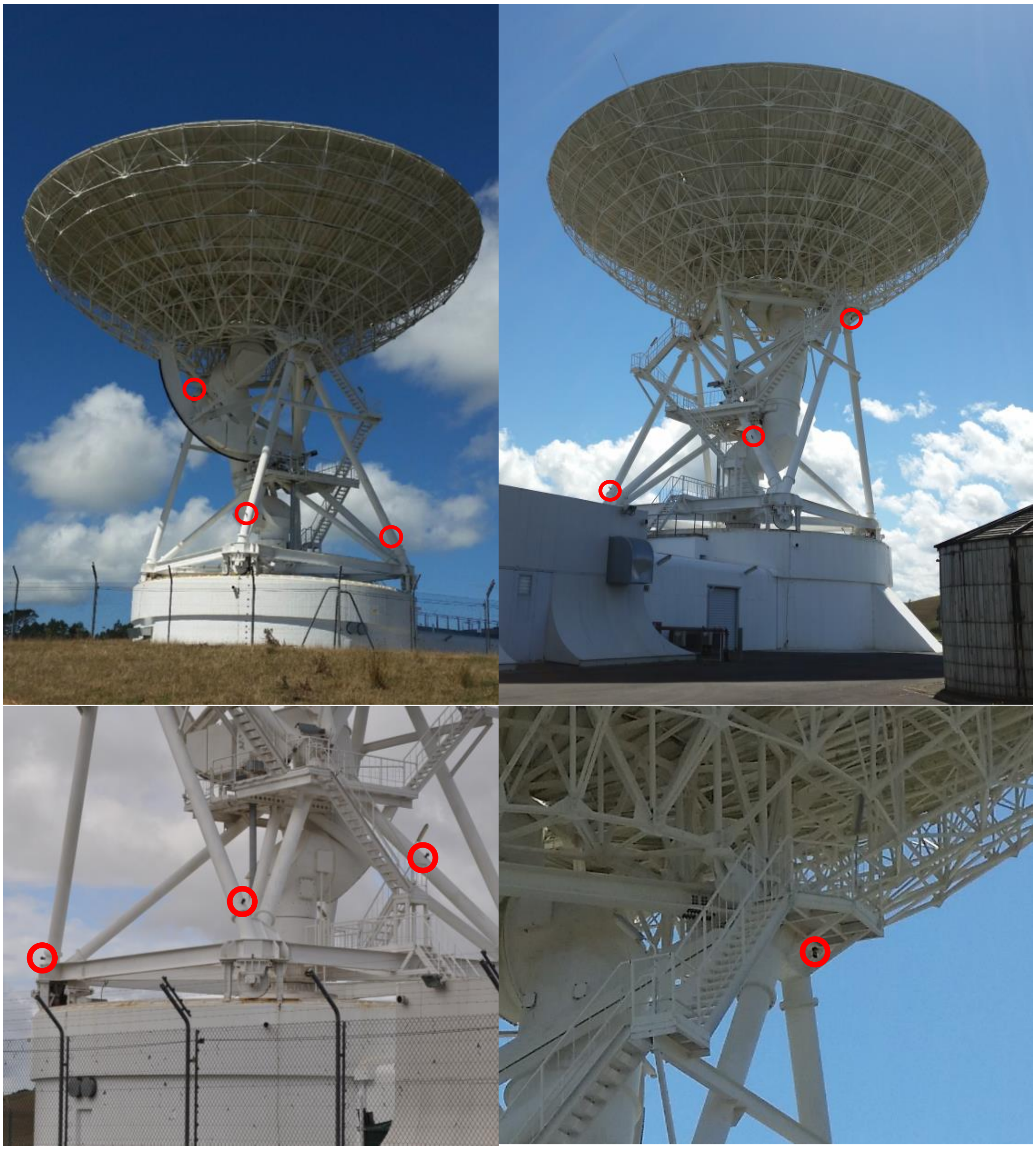


Figure 6.4: Target placement on the main structure of telescope in stall position. View from WAN3 (top left), looking from entrance to compound (top right) and close up of targets looking from WAS3 (bottom left) and close up of highest target (bottom right)

Elevation Observation (5 targets)

The azimuth axis was fixed in a horizontal orientation of 40 degrees and 310 degrees, to be orthogonal to the total station line of sight. The elevation axis was set to 90 and lowered in 10 degree increments down to 6 degrees (its lowest elevation). A complete set of observations were taken from each the two standpoints.

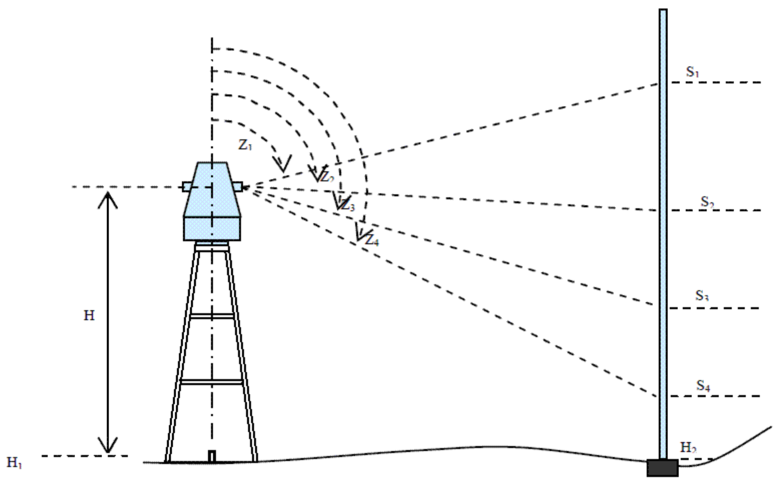
Figure 6.5: Placement of targets on 30 metre dish for the elevation observations. The second target in is obstructed by the telescope frame.

6.5. 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**).

The instruments heights with associated uncertainties are derived within the combined adjustment using the pyaxis software (Section **7.3**)



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

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. Terrestrial data reductions

The horizontal angle, slope distance, and zenith angle observations were reduced using software prepared by LINZ to average observation sets and apply corrections for atmospherics and target offsets. This software outputs the reduced observations into a format compatible the pyaxis adjustment software (Section **7.3**).

7.1.1. Levelling

The raw observations were reduced using the same process described in 7.1.1. The levelling observations were reduced further using levelling reduction script to derive the change in heights between survey marks with a prior uncertainties derived from ZD and SD uncertainties. The software outputs the reduced observations into a format compatible the pyaxis adjustment software (Section **7.3**)

7.2. GNSS

7.2.1. Analysis Software

The GNSS data analysis was undertaken using the Bernese GPS Processing Software Version 5.2 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.

7.3. COMBINED LEAST SQUARES ADJUSTMENT

All reduced data including observations to WARK12M, WARK30M, WARK, the control and levelling networks and the GNS only SINEX solution are combined into a single adjustment using pyaxis. This programme also calculates the instrument (using the Reuger method for telescope setups) see section **6.5**) and target heights.

18 XYZ coordinate observations

739 horizontal angle observations in 172 rounds

1 horizontal distance observations

46 height difference observations

699 slope distance observations

767 zenith distance observations

7.3.1. Absolute positions and additional parameters of telescope

WARK12M

Antenna invariant reference point
X coordinate: -5115324.4740 +/- 0.0029
Y coordinate: 477843.2908 +/- 0.0016
Z coordinate: -3767192.7500 +/- 0.0023

Antenna azimuth axis deflection from geodetic vertical
East deflection: -6.98 +/- 5.00 seconds of arc
North deflection: 20.61 +/- 2.51 seconds of arc
(Local geodetic deflection of vertical -5.10 -7.70)

Elevation axis configuration
Offset from azimuth: 0.0010 +/- 0.0001 metres
Non-orthogonality: 1.05 +/- 0.10 seconds of arc

Maximum coordinate residual 0.00164m

WARK30M
Antenna invariant reference point
X coordinate: -5115425.7883 +/- 0.0030
Y coordinate: 477880.2559 +/- 0.0017
Z coordinate: -3767042.1614 +/- 0.0023

Antenna azimuth axis deflection from geodetic vertical
East deflection: -5.13 +/- 1.24 seconds of arc
North deflection: -17.94 +/- 2.04 seconds of arc
(Local geodetic deflection of vertical -5.10 -7.70)

Elevation axis configuration
Offset from azimuth: 2.5043 +/- 0.0003 metres
Non-orthogonality: 0.07 +/- 0.06 seconds of arc

Maximum coordinate residual 0.00268m at 06B1

7.3.2. 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.

7.4. REFERENCE TEMPERATURE

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

7.5. TRANSFORMATION

No transformation was required as all computations were completed in terms of ITRF2008.

7.6. SINEX FILE GENERATION

A SINEX file was generated using the pyaxis software run by LINZ.

The SINEX file name is WARK2015LT.snx.

7.7. DISCUSSION OF RESULTS

7.7.1. 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). GRS80 ellipsoid, aligned to ITRF2008 at 16 March 2015, day of year 075 (date of survey).

SITE	X (M)	∂(MM)	Y (M)	∂(MM)	Z (M)	∂(MM)
WARK 50243M001	-5115333.3684	+/- 2.9	477886.8898	+/- 1.5	-3767147.2809	+/- 2.3
7377 50243S001 WARK12M IVP	-5115324.4740	+/- 2.9	477843.2908	+/- 1.6	-3767192.7500	+/- 2.3
7931 50243S002 WARK30M IVP	-5115425.7883	+/- 3.0	477880.2559	+/- 1.7	-3767042.1614	+/- 2.3

Table 7.1: Cartesian co-ordinates for WARK and IVP of WARK12M and WARK30M

7.7.2. Comparison with Previous Surveys

The vectors between WARK and WARK12M are in good agreement. The largest difference is in up component of 0.0018m. A comparison of the coordinates for WARK show good agreement (refer to Table **7.2**) suggesting the different could have be caused by a change in the radio telescopes position.

The differences between the 2012 and 2015 show that the site is relatively stable, except for WAW3 which will need to be monitored as it appears the mark has subsided. All comparisons are made from the 2012 data reprocessed using the pyaxis software.

YEAR	WARK TO …	Δ EAST (M)	∂(MM)	Δ NORTH (M)	∂(MM)	Δ UP (M)	∂(MM)
2012	WARK12M (7377 50243S001)	42.58316	0.87	-44.25775	0.84	16.62461	0.51
2015	WARK12M (7377 50243S001)	42.58274	0.24	-44.25749	0.22	16.62280	0.95
Difference	WARK12M (7377 50243S001)	-0.00042		0.00027		-0.00181	
2012	WARK30M (7391 50243S002)	-	-	-	-	-	-
2015	WARK30M (7391 50243S002)	15.20170	0.66	138.84840	0.16	11.11313	0.95
Differences	-	-		-		-	

Table 7.2 Vector between WARK and the two radio telescopes WARK12M and WARK30M with associated standard errors

SITE	ΔEAST (M)	ΔEAST (M)	ΔHEIGHT (M)
WANE 2012-2015	0.0006	0.0000	0.0001
WANW 2012-2015	-0.0004	0.0000	0.0003
WARK 2012-2015	0.0001	-0.0005	0.0004
WASE 2012-2015	0.0001	-0.0005	0.0002
WASW 2012-2015	-0.0003	0.0000	0.0006
WAW1 2012-2015	0.0004	-0.0001	0.0009
WAW2 2012-2015	0.0000	0.0004	-0.0007
WAW3 2012-2015	-0.0005	0.0007	-0.0018

Table 7.3 Comparison of topocentric coordinates between 2012-2015 surveys after subtracting the mean difference in coordinates

8. Planning Aspects

The Warkworth radio telescope local tie survey required approximately seven days of field work. This encompassed one day each to observe the telescopes through changes in their azimuths, half a day to observe each of the telescopes through changes in their 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.

The GPH1P prisms are recommended targets for the next survey of WARK30M. The distances from standpoints WAS3 and WAN3 to the targets were pushing the capability of the mini prisms.

The reference marks surrounding the continuous station are subject to water inundation. WAW3 had moved by 0.0018m between March 2016 and September 2016. Care should be taken when analysing the data to insure these movements do not affect the over local tie survey results.

9. References

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