

2019 - Warkworth Observatory Local Tie Survey



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2019 - Warkworth Observatory Local Tie Survey

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Executive Summary

The Warkworth Observatory is located approximately 60km north of Auckland, New Zealand. A local tie survey was completed between 7 – 13 February 2019.

The purpose of the survey was to determine the relationship between the permanent GNSS CORS site (WARK 50243M001) and 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. Previous surveys were undertaken for WARK30M, WARK12M and WARK in March 2015 and February 2017. Only WARK12M and WARK were surveyed in December 2012.

Differences have been calculated between the surveys. It is still to be determined whether they are caused by movement in the reference points or are the result of random errors in the survey and the methods used to calculate the local tie.

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 understands 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 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 specifications and calibration procedures of the equipment used in the February 2019 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 on both faces: 0.15mgon (0.5").

3.1.2. Auxiliary Equipment

Kestrel 5500 Weather Meter (S/N 2111309) recorded the temperature, pressure and humidity during the survey.

Specification

- Temperature: Accuracy ± 0.5 °C
- Pressure: Accuracy ± 1.5 mbar
- Relative Humidity: Accuracy $\pm 2\%$

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 Plummetts

- 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

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3.3. LEVELLING

3.3.1. Levelling Instruments

Refer to section 3.1.1 for description of Total Station for work undertaken in Feb 2019

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	5522R50052	TRIMBLE NetR9
WASE	5133K77679	Trimble NetR9
WAS4	5144K79408	TRIMBLE NetR9
WAN4	5133K77662	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
WASE	1312118477	TRM57971.00	NONE
WAS4	1312118502	TRM57971.00	NONE
WAN4	1312118456	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 5/8 th 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.
WAS4	Stainless steel pin set in concrete block reinforced waratah rod extending 1.5m into subbase.
WAN4	Stainless steel pin set in concrete block reinforced waratah rod extending 1.5m into subbase.

Table 4.1 Description of network

4.1.1. Map of Survey Network

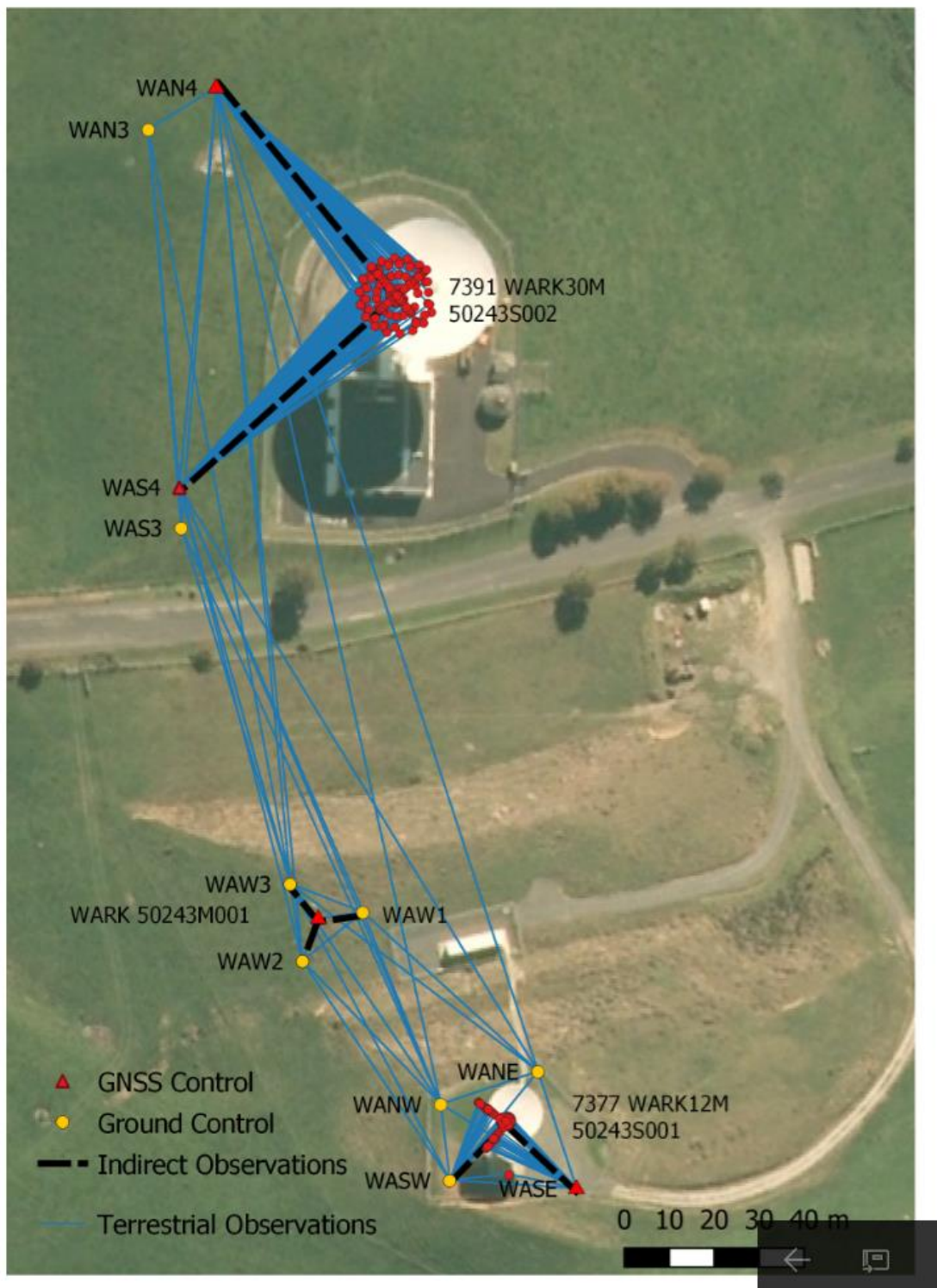


Figure 4.2: The terrestrial network showing the ground control

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.

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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 monument legs in September 2015 and the antenna was removed during this visit to determine the vertical

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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. Atmospheric conditions 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.

Measurements taken in 2015 using a Leica DNA03 Precise Level (S/N 332837) with a three-piece aluminium staff have been reused within the adjustment for the connection between WARK and its vertical reference mark WARH.

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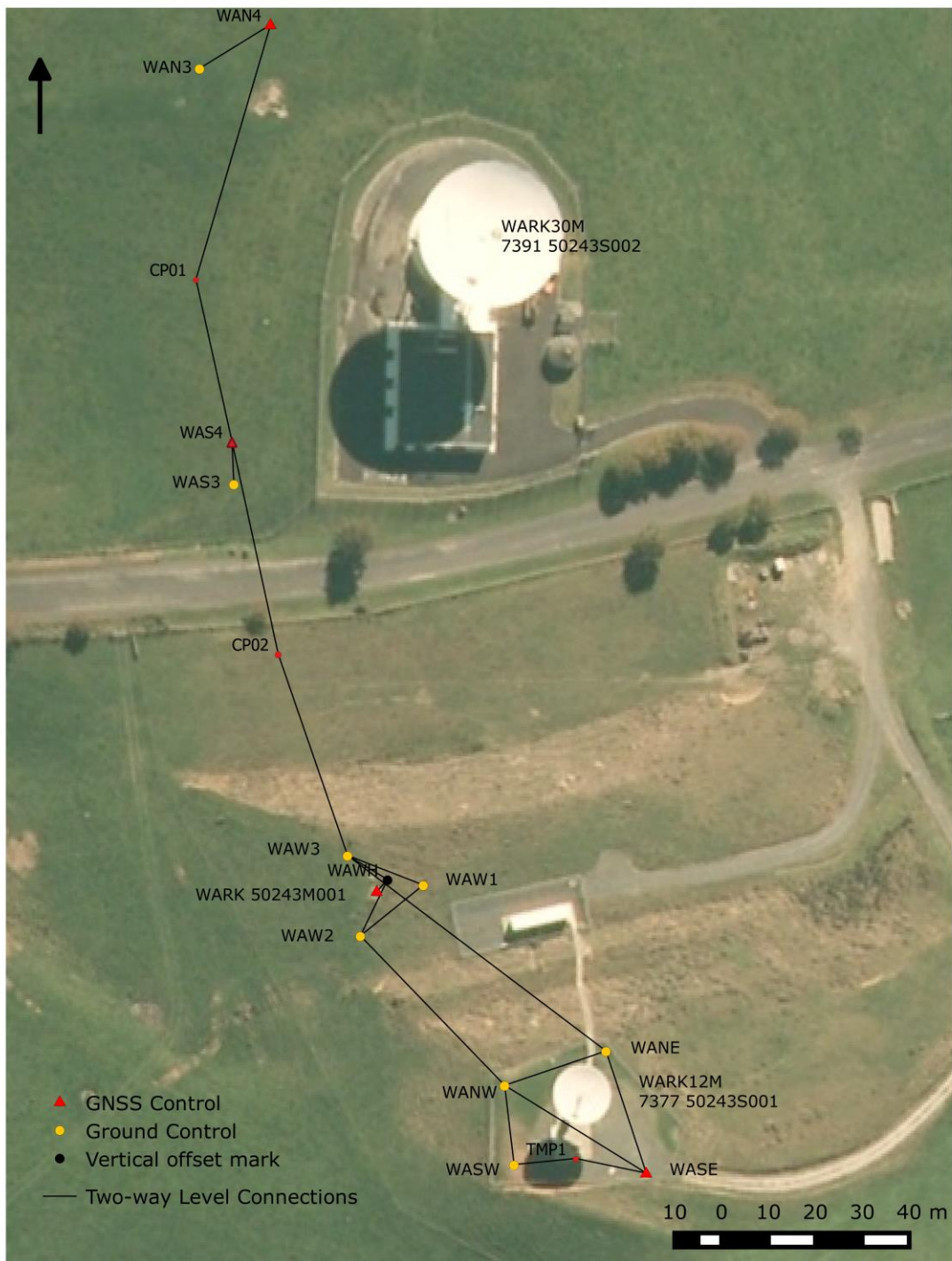


Figure 6.1: Precise levelling network, observed two way height differences

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6.3. GNSS

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

6.3.1. GNSS Receivers

SITE	DATA START (YY:DDD:SSSS)	DATA END (YY:DDD:SSSS)	DESCRIPTION
WARK 50243M001	19:043:22140	19:043:69990	TRIMBLE NETR9
WASE	19:043:24900	19:043:69960	TRIMBLE NETR9
WAS4	19:043:22140	19:043:67980	TRIMBLE NETR9
WAN4	19:043:23160	19:043:68910	TRIMBLE NETR9

Table 6.1: List of GNSS receivers and observation times

6.3.2. GNSS Antennae

SITE	DATA START (YY:DDD:SSSS)	DATA END (YY:DDD:SSSS)	DESCRIPTION
WARK 50243M001	19:043:22140	19:043:69990	TRM55971.00 NONE
WASE	19:043:24900	19:043:69960	TRM57971.00 NONE
WAS4	19:043:22140	19:043:67980	TRM57971.00 NONE
WAN4	19:043:23160	19:043:68910	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.

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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)

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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 (Rueger 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 (H_1 and H_2) 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)

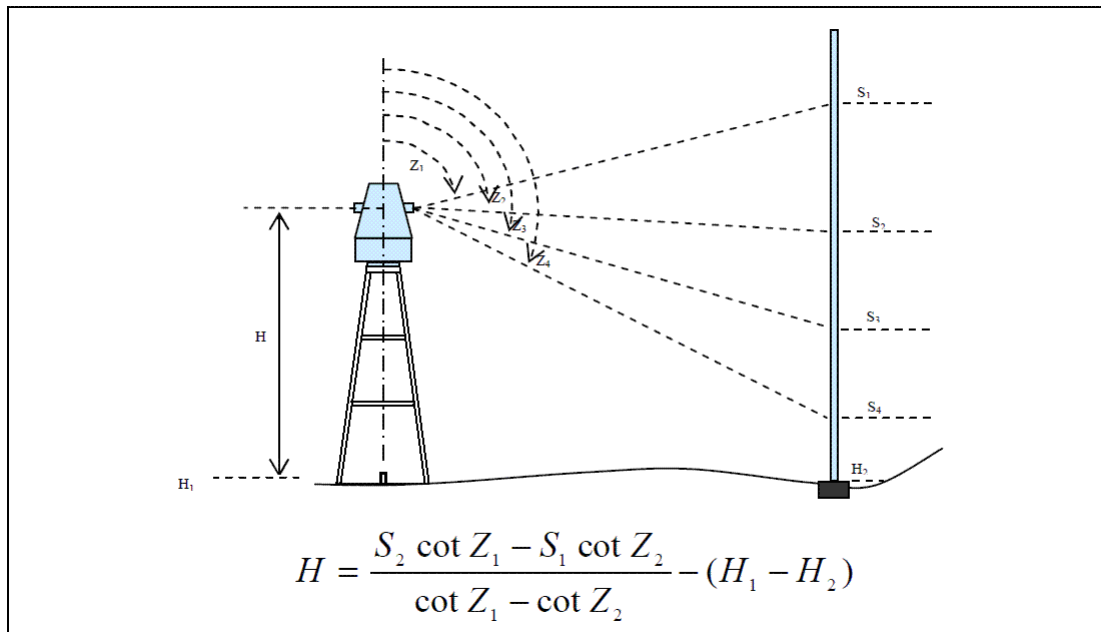


Figure 6.4: Total station instrument heighting technique where S_n are the staff readings, Z_n are the zenith angles (Rueger and Brunner, 1981).

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 atmospheric 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 priori 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 2014 (ITRF 2014) 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 Rueger method for telescope setups; see section 6.5) and target heights.

7.3.1. Absolute positions and additional parameters of telescope

WARK12M

Antenna invariant reference point

X coordinate: -5115324.5517 +/- 0.0146

Y coordinate: 477843.2763 +/- 0.0073

Z coordinate: -3767192.6192 +/- 0.0113

Antenna azimuth axis deflection from geodetic vertical

East deflection: -22.00 +/- 4.94 seconds of arc

North deflection: 32.57 +/- 3.95 seconds of arc

(Local geodetic deflection of vertical -5.10 -7.70)

Elevation axis configuration

Offset from azimuth: 0.0009 +/- 0.0001 metres

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Non-orthogonality: -0.81 +/- 0.13 seconds of arc

Maximum coordinate residual 0.00107m at 34B2

WARK30M

Antenna invariant reference point

X coordinate: -5115425.8648 +/- 0.0146

Y coordinate: 477880.2422 +/- 0.0073

Z coordinate: -3767042.0220 +/- 0.0112

Antenna azimuth axis deflection from geodetic vertical

East deflection: 3.65 +/- 1.72 seconds of arc

North deflection: -8.48 +/- 2.27 seconds of arc

(Local geodetic deflection of vertical -5.10 -7.70)

Elevation axis configuration

Offset from azimuth: 2.5035 +/- 0.0003 metres

Non-orthogonality: 0.14 +/- 0.08 seconds of arc

Maximum coordinate residual 0.00220m at 26H2

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 **6.7**) 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 ITRF2014.

7.6. SINEX FILE GENERATION

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

The SINEX file name is 50243_LNZ_2019-040.snx.

7.7. DISCUSSION OF RESULTS

7.7.1. Results

The final derived cartesian coordinates for the radio telescope IVPs and continuous GNSS station (WARK) are shown in the table below (all units are in metres). GRS80 ellipsoid, aligned to ITRF2014 at 9 February 2019, day of year 40 (date of GNSS survey).

SITE	X (M)	σ (MM)	Y (M)	σ (MM)	Z (M)	σ (MM)
WARK 50243M001	-5115333.4447	14.6	477886.8770	7.3	-3767147.1377	11.2
7377 50243S001 WARK12M IVP	-5115324.5517	14.6	477843.2763	7.3	3767192.6192	11.3
7931 50243S002	-5115425.8648	14.6	477880.2422	7.3	3767042.0220	11.2

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WARK30M IVP						
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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 the up component of 0.0018m. A comparison of the coordinates for WARK shows good agreement (refer to Table 7.2) suggesting the difference could have been caused by a change in the radio telescope's position.

The differences between the 2012 and 2015 surveys 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.

In order to determine the differences due to the origin and alignment to the reference frame all surveys were re-processed using the same reference epoch and GNSS data collected during the 2015 survey. Due to this the calculated vector below may be different from any vectors calculated directly from the supplied SINEX.

YEAR	WARK TO ...	Δ EAST (M)	σ (MM)	Δ NORTH (M)	σ (MM)	Δ UP (M)	σ (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	16.62236	0.95
2017	WARK12M (7377 50243S001)	42.58350	0.64	-44.25696	0.61	16.62347	0.28
2019	WARK12M (7377 50243S001)	42.58427	1.1	-44.25897	1.1	16.62519	0.20
Difference 2019-2017	WARK12M (7377 50243S001)	0.00077		-0.00201		0.00172	
Difference 2017-2015	WARK12M (7377 50243S001)	0.00076		0.00052		0.00112	
Difference 2015-2012	WARK12M (7377 50243S001)	-0.00042		0.00027		-0.00181	
2012	WARK30M (7391 50243S002)	-	-	-	-	-	-
2015	WARK30M (7391 50243S002)	15.20170	3.5	138.84840	0.40	11.11313	0.50
2017	WARK30M (7391 50243S002)	15.20208	3.47	138.84968	0.40	11.10702	0.49
2019	WARK30M (7391 50243S002)	15.20357	5.39	138.85337	0.61	11.10959	0.39
Difference 2019-2017	WARK30M (7391 50243S002)	0.00149		0.00370		0.00259	

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Difference 2017-2015	WARK30M (7391 50243S002)	0.00038		0.00127		-0.00611	
Difference 2015-2012	-						

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

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 (vertically) between March 2015 and September 2015. Care should be taken when analysing the data to ensure these movements do not affect the overall local tie survey results.

The 2017 and 2019 surveys were undertaken in hot temperatures. The large residuals observed in the adjustment may be accounted for by thermal expansion of the steel towers used during the survey. There appears to be a relationship between high temperatures and lower accuracies especially if there were bursts of heat throughout the day.

Temperature during each survey

Year	Average °C	Max °C	Min °C
2019	25.1	31.5	12.3
2017	24.7	30.8	16.0
2015	20.5	24.0	16.3
2012	20.4	27.0	12.0

This survey is also prone to centring errors as the removable towers are not force centred.

The two sites WAN3 and WAS3 were replaced by WAN4 and WAS4 in the 2019 survey.

9. References

Hodge B , Continuous GPS Station – New Site Report WARK – Warkworth (2009)

Ruddick, R. Woods A. The 2009 Mount Pleasant (Hobart) Observatory Local Tie

Johnston, G., Twilley, B. and Yates, S., 2002. Total Station Levelling, Geoscience Australia,

National Mapping Division internal document, presented at *26th National Surveying Conference*, Darwin NT, July 2002.

Rueger J. M., and Brunner F.K., 1981. Practical results of EDM-Height Traversing, *The Australian Surveyor*, June, 1981, Vol. 30, No. 6.

Sarti, P., Sillard, P. and Vittuari, L. (2004). Surveying co-located space-geodetic instruments for

ITRF computation. *Journal of Geodesy* (2004) 78: 210-222.

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