Warkworth Radio Astronomical Observatory, New Zealand

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Abstract We describe geodetic research activities related to the Warkworth 12-m VLBI Station: WARK12M. We present a summary of baseline lengths (obtained with the participation of WARK12M) based on IVS results for the 2.5 year period, from the beginning of 2011 to August 2013, and compare them with baselines for the corresponding (co-located) GNSS stations.

1 Introduction

New Zealand′s location on the boundary of the Pacific and Australian Plates makes it one of the most active geological areas in the world [1]. Figure 1 shows the plate boundary, epicenters of earthquakes in the last 3.5 years and location of major volcanoes in New Zealand. Two continuous GNSS networks are used in New Zealand to monitor these geological processes: PositioNZ and GeoNet [2]. The PositioNZ network of 31 GNSS stations has been used to support the New Zealand Geodetic Datum 2000 (NZGD2000) [3]. Prior to 2008, New Zealand had no VLBI capability; the NZGD2000 was therefore based solely on GNSS data and ITRF96. GeoNet is a network designed for monitoring earthquakes, volcanic activity, and crustal deformation. The New Zealand Velocity Model has been estimated by using GeoNet network data [4]. This model is referenced to the Australian Plate, so points near Auckland move little, points near Christchurch move southwest at about 40 mm/yr. About 5 mm/yr uplift is reported in the Southern Alps of the South Island from GNSS observations [5].

The Global Geodetic Observing System (GGOS) aims to achieve a challenging 1 mm positioning and 0.1 mm/yr velocity accuracy by using and integrating advanced geodetic techniques [6], [7]. To achieve these goals, geodetic (GGOS) stations should be equipped with two or more co-located geodetic observation techniques (e.g., GNSS and VLBI).

New Zealand first obtained the space geodetic technique of VLBI in 2008 when Auckland University of Technology (AUT) established a 12-m geodetic radio telescope near Warkworth, 60 km north of Auckland (Figure 1). In 2010, WARK12M became an IVS network station. Within the scope of global geodetic VLBI observations, WARK12M plays an important role in improving the geographic distribution of VLBI stations in the Southern Hemisphere and contributing to the definition of both the International Celestial Reference Frame (ICRF) and the International Terrestrial Reference Frame (ITRF) [8]. Locally, within the New Zealand context, WARK12M provides important geodetic information which can be used (in conjunction with GNSS data) to support the NZGD2000 and contribute to establishment of the next generation, GGOS inspired, New Zealand Geodetic Datum.

In addition to participating in regular IVS sessions, WARK12M is engaged in joint geodetic research with the National Institute of Information and Communications Technology (NICT), Japan and with the AuScope project [9]. The latter operates three 12-m radio telescopes located in Hobart (HOBART12), Yarragadee (YARRA12M), and Katherine (KATH12M). Located on the Australian tectonic plate, both WARK12M and AuScope radio telescopes are ideally placed

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for measurements of intra-plate deformation. The WARK12M–AuScope baselines are long enough to contribute to Earth Orientation Parameter (EOP) observations, particularly when coupled together with New Zealand–Japan (NICT) baselines (Figure 2).

2 Warkworth Developments

Specifications of Warkworth 12-m and 30-m antenna are provided in Table 1 and Table 2.

During 2013, work continued on the 30-m (Cassegrain beam-waveguide NEC antenna) dish as first reported in [10]. In February 2013, the dish became fully steerable with the commissioning of a new control system and motors supplied by Control Technologies and Antenna Measurement and Consultancy Services. In October and November 2013, with the assistance of Ed Himwich, we commenced work to develop a first pointing model using the existing Satellite Communication C-Band RF system and a new Field System. An uncooled C-band receiver is currently under development; significant improvement in performance is anticipated once it is fitted to the antenna.

In 2014, the existing 1 Gbps network connection to Warkworth will be upgraded to 10 Gbps, greatly enhancing our eTransfer throughput for IVS. Currently eTransfers to the Curtin correlator (for example) are limited to a maximum sustained rate of just over 800 Mbps with the existing 1 Gbps link via KAREN and AARNET. The 15-day continuous AUST experiment of December 2013 conducted with AuScope and HartRAO required some two weeks to eTransfer the approximately 100TBytes of data collected with the existing service.

Table 1 Specifications of the Warkworth 12-m antenna.

Antenna type	Dual-shaped Cassegrain
Manufacturer	Cobham/Patriot, USA
Main dish Diam.	12.1 m
Secondary refl. Diam.	1.8 m
Focal length	4.538 m
Surface accuracy	0.35 mm
Pointing accuracy	$18''$
Mount	alt-azimuth
Azimuth axis range	$90^\circ \pm 270^\circ$
Elevation axis range	4.5° to 88°
Azimuth axis max speed	5°/s
Elevation axis max speed	1°/s

Table 2 Specifications of the Warkworth 30-m antenna.

Antenna type	Cassegrain, beam waveguide
Manufacturer	NEC, Japan
Main dish Diam.	30 m
Frequency range	3.5 — 7 GHz
Mount	alt-azimuth, wheel and track
Azimuth axis range	-179.0° to 354.0°
Elevation axis range	6.0° to 90.1°
Azimuth axis max speed	15.0°/min
Elevation axis max speed	21.6°/min

3 Analysis of VLBI and GNSS Baselines for Warkworth

Since 2012, AUT has been engaged in collaborative research with NICT, which operates three IVS network stations (KASHIM34, KASHIM11, KOGANEI). Teams at both institutions have worked towards establishing a "geodetic environment" — correlation processing, bandwidth synthesis, VLBI data analysis, and Time and Frequency Transfer by using VLBI. The baseline WARK12M–KASHIM11 is a long North-South baseline of over 8000 km (Figure 2). The first observation of the WARK12M–KASHIM11 baseline carried out in 2012 resulted in the baseline length of 8,075,003,545$\pm$150 mm. More observations for monitoring this baseline are in preparation, as well as an experiment aimed to derive Earth Orientation Parameters in an Ultra-rapid mode by using existing UT1 products and high-speed data transfer networks.

Since 2011, AUT has also been engaged in collaborative research with the AuScope project. Here we analyse Warkworth–AuScope baseline lengths and their rates of change using IVS Analysis Center results. The number of sessions and session types (R1, R4, AUSTRAL) are listed separately in Table 3.

We analyzed databases of the three types (R1, R4, AUSTRAL) using Calc/Solve software. Different types of IVS sessions are optimised for different purposes. For example, R1 and R4 sessions are optimised for providing twice-weekly EOP results; the purpose of AUSTRAL sessions is to determine the station coordinates and their evolution in the WARK12M–AuScope network. It is important, therefore, to apply a uniform strategy across all session types when analyzing the VLBI databases. When analyzing AUSTRAL sessions, we used only WARK12M and AuScope station data. For R1 and R4 sessions, we excluded TIGOCONC and Japanese stations (TSUKUM32, KASHIM34 and KASHIM11) in order to avoid the effects of potential earthquake after-slip.

Figure 3 shows the baseline length residuals vs. time for three baselines that include Warkworth. The linear trends of baselines estimated for different types of sessions are provided in each graph in brackets along with the standard errors. The rates of change determined from VLBI data and the corresponding standard errors are of the same order of magnitude, so based on this data we cannot as yet conclude that the above rates of change are statistically significant.

WARK12M and AuScope VLBI stations are co-located with the corresponding GNSS stations WARK, HOB2, KAT1, and YAR2 (Figure 2). We analyzed GNSS data of the co-located IGS (and PositioNZ) stations using GAMIT/GLOBK software. We combined the results with the SOPAC global network file.

Figure 4 shows the baseline length residuals and the linear trends of three baselines between Warkworth and AuScope co-located GNSS stations. Rates of change indicated in Figure 4 were estimated by formally fitting linear functions to all sets of GNSS baseline data. All GNSS rates of change are very small (about 1-2 mm/yr), which seems realistic given that all four stations are located on the same tectonic plate. Due to the small number of observations, the errors of VLBI rates are greater than the order of magnitude of the rates themselves. There is a clear annual/seasonal periodic pattern in GNSS baseline data (Figure 4) with an amplitude of about 5-10 mm. We do not have enough data to identify an annual pattern in VLBI data that include WARK12M.

4 Conclusion

Auckland University of Technology operates a 12-m geodetic radio telescope in New Zealand and participates in collaborative research programs in space geodesy with IVS, NICT, and AuScope. We have analyzed the first 2.5 years of IVS observations in which WARK12M participated and compared the Warkworth–AuScope baseline lengths and their changes with the corresponding GNSS results. We do not find long term (>1 year) changes in GNSS baselines, but do find an annual periodic pattern with an amplitude of 5-10 mm. The small number of VLBI baseline measurements and large errors do not allow robust conclusions about VLBI baseline changes with certainty at this time.

To monitor tectonic dynamics with high precision, a large number of observations is necessary. It is important to carry out observations continuously with minimal gaps. This was not the case in the first 2.5 years of WARK12M geodetic VLBI observations. We hope regular and more frequent observations will improve the accuracy of WARK12M VLBI measurements in the future.

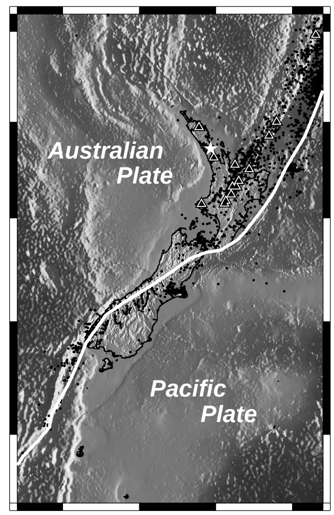

Fig. 1 New Zealand's geological situation. Tectonic plate boundary is shown with the white curve. Dots indicate the earthquake epicenter locations ($M \geq 1$, from January 2010 to July 2013) according to the USGS/NEIC earthquake catalog. Triangles indicate locations of major volcanoes. The location of WARK12M is marked with a star.

Table 3 The number of sessions used for calculations over the total number of sessions of a given type.

	WARK12M HOBART12	WARK12M KATH12M	WARK12M YARRA12M
ALL	15/23	10/12	7/8
R1	4/6	5/6	2/2
R4	6/7	2/2	3/3
AUSTRAL	4/4	3/3	2/3
Others	1/6	0/1	0/0

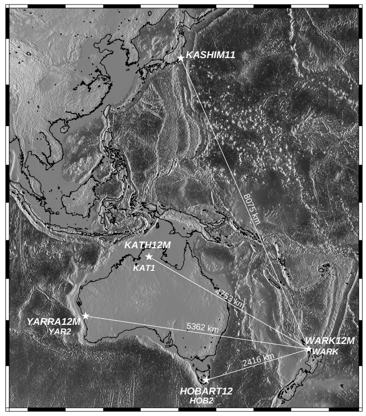

Fig. 2 The geographical distribution of VLBI stations (WARK12M, AuScope, KASHIM11) with baseline lengths.

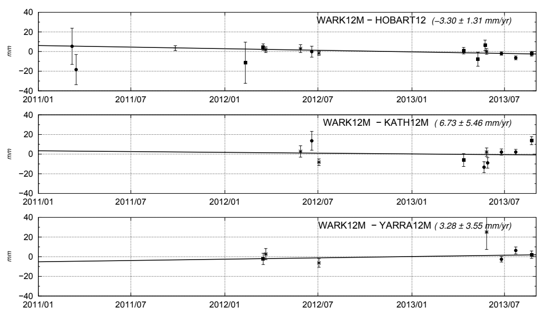

Fig. 3 Time series of the baseline length residuals of WARK12M and AuScope baselines. Points and squares indicate R1 and R4 session respectively. Asterisks indicate AUSTRAL session. Rates of change (linear trends) and standard errors are shown in brackets.

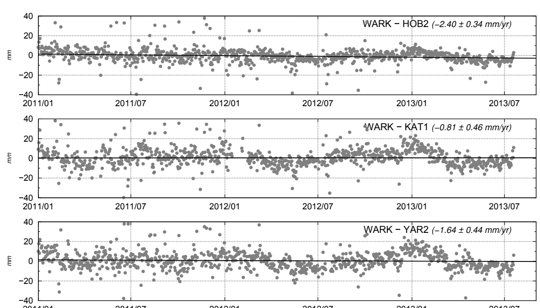

Fig. 4 Time series of the baseline length residuals calculated from GNSS data (WARK, HOB2, KAT1, YAR2). Rates of change (linear trends) and standard errors are shown in brackets.

Acknowledgements

The authors would like to acknowledge organisations and institutions such as IVS, IGS, LINZ, GNS Science, NICT, Geoscience Australia, University of Tasmania and CSIRO. We are grateful to the makers of Calc/Solve, GAMIT/GLOBK, and Generic Mapping Tools developers for providing the software.

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