Hartebeesthoek Radio Astronomy Observatory (HartRAO)

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Abstract HartRAO is the only fiducial geodetic site on the African continent and participates in global networks for VLBI, GNSS, SLR, and DORIS. This report provides an overview of geodetic VLBI activities at HartRAO during 2017+2018, including progress with the VGOS project and the automated site tie system at HartRAO.

1 Geodetic VLBI at HartRAO

The Hartebeesthoek Radio Astronomy Observatory (HartRAO) now forms part of the larger South African Radio Astronomy Observatory (SARAO). Our director, Prof Ludwig Combrinck, took early retirement at the end of 2017. His position has not been filled. The Hartebeesthoek site is located 65 km northwest of Johannesburg, just inside the provincial boundary of Gauteng, South Africa. HartRAO is located 32 km away from the nearest town, Krugersdorp. The telescopes are situated in an isolated valley which affords protection from terrestrial radio frequency interference. HartRAO currently operates both a 15-m and a 26-m radio telescope. Construction of the new 13.2-m VGOS radio telescope has been completed, but further funding is required before it can become fully operational and start participating in VGOS observations (see Figure 2). The 26 m is an equatorially mounted Cassegrain radio telescope built by Blaw Knox in 1961. The telescope was part of the NASA deep space tracking network until 1974, when the facility was converted to an astronomical observatory. The 15 m is an az-el radio telescope built as a Square Kilometre Array (SKA) prototype during 2007 and converted to an operational geodetic VLBI antenna during 2012. The telescopes are co-located with an ILRS SLR station (MOBLAS-6), a Russian satellite laser and radio ranging system «Sazhen-TM+OWS», an IGS GNSS station (HRAO), a seismic vault, and an IDS DORIS station (HBMB) at the adjoining South African National Space Agency Earth Observation (SANSA EO) site. HartRAO is also a full member of the EVN.

Fig. 1 Farewell to Ludwig, the father of Geodesy at HartRAO. The legend lives on.

SARAO

HartRAO Network Station

IVS 2017+2018 Biennial Report

2 Technical Parameters of the 15-m and 26-m Telescopes at HartRAO

Table 1 contains the technical parameters of the HartRAO 15-m, 26-m, and VGOS radio telescopes, while Table 2 and Table 3 contain technical parameters of the HartRAO 15-m and 26-m receivers, respectively. The current data acquisition systems consist of a DBBC terminal and a Mark 5B+ recorder for both the 15-m and the 26-m antennas. A Mark 5C recorder is used for e-transfer of data and conditioning and testing of disk packs. A 258-TB Flexbuff reading system is also available for astronomical VLBI use. Currently, the hydrogen maser, iMaser 72, is being used for VLBI on both the 15-m and 26-m antennas. The EFOS-28 hydrogen maser, previously employed for VLBI on the 15-m antenna, developed an internal heater fault and has been taken out of service. It is unreliable but still usable. It is still used for running T2 sessions on the 15-m antenna when these sessions are observed with both antennas simultaneously. EFOS-28 will undergo repairs in July 2019. The older EFOS-6 hydrogen maser is completely down at the moment and is also awaiting repairs.

Table 1 Antenna parameters.

Parameter	Hart15M	HartRAO	VGOS
Owner and operating agency	HartRAO	HartRAO	HartRAO
Year of construction	2007	1961	2017
Mount type	Offset az-el	Offset equatorial	Az-El
Receiving feed	Prime focus	Cassegrain	Ring-focus
Diameter of main reflector d	15 m	25.914 m	13.2 m
Focal length f	7.5 m	10.886 m	3.7 m
Focal ratio f/d	0.5	0.42	0.4
Surface error of reflector (RMS)	1.6 mm	0.5 mm	0.1894 mm
Short wavelength limit	3 cm	1.3 cm	3 mm
Pointing resolution	0.001°	0.001°	0.0001°
Pointing repeatability	0.004°	0.004°	(unknown)
Slew rate on each axis	Az: 2° s^{-1} El: 1° s^{-1}	HA: 0.5° s^{-1} Dec: 0.5° s^{-1}	Az: 12° s^{-1} El: 6° s^{-1}

Table 2 Parameters of the 15-m co-axial receiver.

Parameter	X-band	S-band
Feeds	stepped horn	wide-angle corrugated horn
Amplifier type	cryo HEMT	cryo HEMT
T_{sys} (K)	40	42
S_{SEFD} (Jy)	1400	1050
PSS (Jy/K)	35	25
3 dB beamwidth (°)	0.16	0.57

Table 3 Parameters of the 26-m receiver (degraded performance due to dichroic reflector being used for simultaneous S/X VLBI).

Parameter	X-band	S-band
Feeds	dual CP conical	dual CP conical
Amplifier type	cryo HEMT	cryo HEMT
T_{sys} (K)	52	40
S_{SEFD} (Jy)	849	1190
PSS (Jy/K)	16.3	29.8
3 dB beamwidth (°)	0.096	0.418

3 Current Status

During 2017 and 2018, the 15-m antenna participated in 132 and 122 geodetic/astrometric IVS sessions, respectively (Table 4). The 26-m antenna participated in 38 and 30 sessions during 2017 and 2018, respectively (Table 4). In 2017, the antennas observed together in nine dual sessions (three R1s, two T2s, and four astrometric AUSTRALs) and in 2018 in four dual sessions (two T2s, one astrometric AUSTRAL, and one CRDS). During the dual geodetic VLBI sessions, the 15-m antenna's maser was offset in frequency to prevent PCAL cross-correlation. PCAL was usually turned off on the 15-m antenna for the astrometric AUSTRAL sessions. The 15-m antenna successfully participated in the CONT17 campaign from 28 November to 12 December 2017 with minimal loss of data and then only due to wind-stows. Astrometric single-baseline VLBI sessions in collaboration with Hobart (UTAS) to help improve the S/X- and K-band reference frames in the South and contribute to the ICRF-3 continued to be observed on the 26-m antenna. VLBI data for all sessions were e-transferred to the correlators.

The 15-m antenna suffered several antenna drive failures during this period. Various cable faults necessitated the replacement of cables. Damage to cables may be ascribed to continued problems being experienced with the cable wrap mechanism. We are in the process of investigating a suitable solution for the cable wrap on the 15-m antenna. The 26-m antenna's focus drive controller was refurbished and is now more stable. A linear encoder installed on the focus drive has improved repeatability.

Table 4 Geodetic VLBI sessions in which HartRAO participated during 2017+2018.

Session	No. of sessions on 15-m		No. of sessions on 26-m	
	2017	2018	2017	2018
R1	45	48	3	0
R4	46	47	0	0
AUST	17	11	6	2
RD	0	0	10	10
T2	4	6	4	3
CRDS	0	1	6	6
CONT17	15	0	0	0
RDV	0	0	6	6
OHIG	5	6	0	0
CRF	0	3	3	3
Total	132	122	38	30

4 Personnel

Table 5 lists the HartRAO station staff involved in geodetic VLBI. Jonathan Quick (VLBI friend) provides technical support for the Field System as well as support for hardware problems. Operations astronomer, Aletha de Witt, provides support for astrometric VLBI. Aletha is a member of the ICRF-3 Working Group and was elected to the IAU commission on astrometry in June 2018. The ICRF-3 was adopted by the IAU in September 2018. Aletha was elected to the IVS Directing Board, effective 1 March 2019. Aletha has also been coordinating the annual month-long AVN training program hosted by HartRAO since 2015. During this School, students from African VLBI Network (AVN) partner countries receive CHPC computer training and Observational and Technical Radio Astronomy training, the last week of the training program being dedicated to the topics of VLBI and geodesy (see Figures 4 and 7).

Table 5 Staff supporting geodetic VLBI at HartRAO.

Name	Function	Program
A. de Witt	Operations/ Scheduler	Fundamental Astronomy
J. Quick	Hardware/ Software	Astronomy
S. Basu	Operator	Student
J. Grobler	Operator	Technical
P. Mey	Operator	Technical
R. Myataza	Operator	Technical
M. Nickola	Logistics/ Operations	Fundamental Astronomy
P. Stronkhorst	Operator	Technical

5 New Developments

Our VGOS antenna arrived at the end of March 2017. Assembly was carried out by a team from MT Mechatronics and CETC 54. Assembly of the antenna and installation onto the concrete foundations took only 20 days (see Figure 3). Commissioning activities commenced thereafter with Site Acceptance Tests successfully completed during June 2018. Current efforts are geared towards interfacing and controlling the antenna through the Field System. While waiting for the required funding and a decision to be made with regards to a full broadband VGOS receiver and the associated signal chain, an in-house receiver is being developed for test purposes. A Mark 6 recorder was acquired in January 2018.

The HartRAO Operations Astronomer, Aletha de Witt, has become involved in planning for and scheduling of astrometric AUSTRAL and CRDS sessions (since AUA025 on 22 August 2017 and CRDS93 on 24 January 2018). This included improving schedules and setup for existing astrometric VLBI observations, e.g., an increase in data rate to 1 Gbps and revising the stations involved in the southern astrometric VLBI networks. A proposal for HartRAO to become an official Operation Center of the IVS was submitted to the IVS Directing Board in November 2018.

During the first half of 2017, short test experiments comprising VLBI observations of GNSS satellites were run in collaboration with Onsala and later Zelenchukskaya also, culminating in full 24-hour VLBI–GNSS test sessions on the 24th of July 2018, with HartRAO, Onsala, and Zelenchukskaya observing, and on the 8th of May 2018 with HartRAO, Onsala, Svetloe, and Zelenchukskaya participating.

Regarding determination of HartRAO local ties, a first short baseline test experiment was conducted on the 11th of May 2018 between the HartRAO 26-m legacy antenna and the co-located 15-m antenna with a view to testing the GGOS requirement of 1-mm accuracy in station coordinates and global baselines and to improve our understanding of the HartRAO complex. The site tie system has concluded initial tests and automation software implementation (see Figures 5 and 6).

The Russian Satellite Laser Ranger, Sazhen-TM, reached full operational status during 2018 and was accepted in the ILRS network on 3 May 2018 (see Figure 8). Two ESA GNSS reference stations, one at Hartebeesthoek and one at Matjiesfontein, were installed during the period of this report (see Figure 9). A new GNSS station was installed at the AVN partner site—the Ghana Radio Astronomy Observatory, at Kutunse, Ghana—during May 2018.

6 Future Plans

Of the 146 geodetic VLBI sessions scheduled for 2019, 108 sessions are allocated to the 15-m antenna, 36 sessions to the 26-m antenna, and two sessions will be run on both antennas.

Participation in VGOS obervations is dependent upon obtaining the necessary funding for the receiver and backend instruments. Until such time, in-house receivers will be employed to test operational capabilities.

The site tie measurement and product delivery is planned for 2019/20. GeoStations (GNSS, Seismometer, and weather station) installations are planned for the following locations during 2019 and 2020: Thomas River (near East London), Aliwal-North, Gamsberg (Namibia), Vaalputs (nuclear waste dump site), and Grabouw.

Acknowledgements

HartRAO forms part of SARAO, which is a National facility operating under the auspices of the National Research Foundation (NRF), South Africa.

The Space Geodesy Programme is an integrated program, combining VLBI, SLR, and GNSS, and it is active in several collaborative projects with GSFC, JPL, GFZ (Potsdam), and «Roscosmos» as well as numerous local institutes. Collaboration also includes OCA/NASA and the ILRS community in a Lunar Laser Ranger (LLR) project with local support from the University of Pretoria, amongst others. General information as well as news and progress on geodesy and related activities can be found at `http://geodesy.hartrao.ac.za/`.

Fig. 2 The HartRAO VGOS radio telescope—mechanically functional but awaiting funding for receiver and backend.

Fig. 3 The Big Lift—the VGOS telescope's azimuth cabin and main reflector being lifted and bolted onto the concrete structure.

Fig. 4 Chris Jacobs in action during the last week of the 2018 February/March AVN Training School hosted by HartRAO.

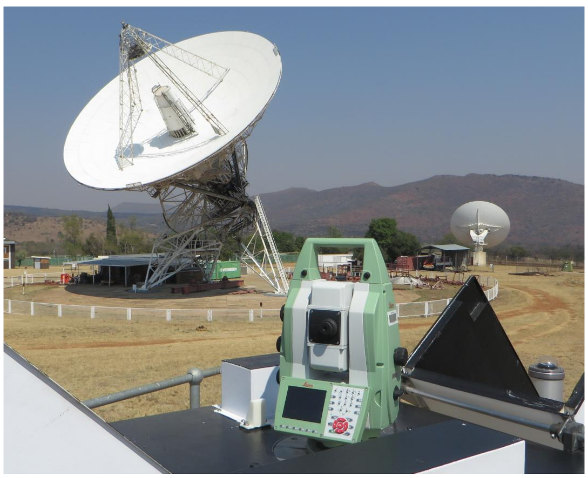

Fig. 5 Leica MS50 Total Station—the local automated site tie system under test with measurements and calibrations being carried out.

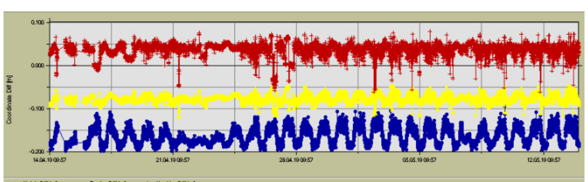

Fig. 6 Automated site tie system—data collection of 30 days from one of the measurement network targets showing coordinate offsets. A daily oscillation is clearly visible.

Fig. 7 2018 February/March AVN Training School students from Botswana, Namibia, and Zambia together with VLBI and Geodesy lecturers.

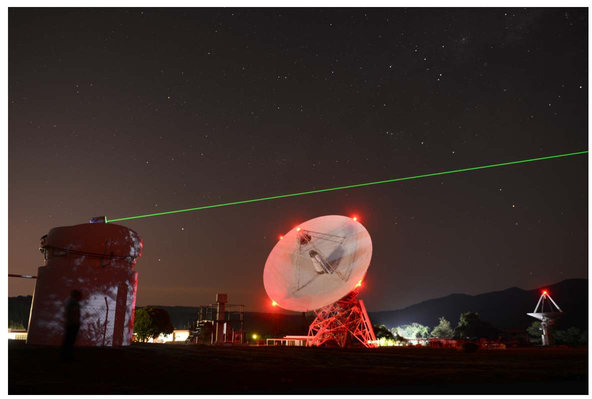

Fig. 8 The Sazhen-TM laser ranger.

Fig. 9 The ESA GNSS reference station antenna at Matjiesfontein.