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 2019+2020, including progress with the VGOS antenna and continued operations under COVID-19 restrictions.

1 Geodetic VLBI at HartRAO

The Hartebeesthoek Radio Astronomy Observatory (HartRAO) forms part of the larger South African Radio Astronomy Observatory (SARAO). 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 some protection from terrestrial radio frequency interference. HartRAO currently operates 13.2-m, 15-m, and 26-m radio telescopes. The 13.2-m VGOS radio telescope is not fully operational yet, but funding has been made available to equip it with a broadband VGOS receiver and DBBC3 backend. It should achieve operational status in the first half of 2022. 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», two IGS GNSS stations (HRAO and HRAG00ZAF), a seismic vault, and an IDS DORIS station (HBMB) at the adjoining South African National Space Agency Earth Observation (SANSA EO) site. SARAO is also a full member of the EVN.

Fig. 1 The HartRAO trio (from left to right): the VGOS, 26-m, and 15-m antennas. The newly installed VGOS backup generator is visible next to the shadow of the VGOS antenna.

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2 Technical Parameters of the 15-m, 26-m, and VGOS 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 5B and a Mark 5C recorder are used for e-transfer of data and conditioning and testing of disk packs. Internal power-wiring upgrades to the DBBC2s and commissioning of a new Flexbuff recording system for geodetic use, have been delayed due to COVID-19 restrictions. A 258-TB Flexbuff recording system is already 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 not reliable but still usable. A heater controller replacement on EFOS-28 is also pending, again due to COVID-19 restrictions. The older EFOS-6 hydrogen maser is completely down at the moment and attempts to restart it following recent repairs have so far failed.

Table 1 Antenna parameters.

Parameter	Hart15	Hart26	HartVGOS
Owner and operating agency	NRF	NRF	NRF
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: $2^\circ\,s^{-1}$ El: $1^\circ\,s^{-1}$	HA: $0.5^\circ\,s^{-1}$ Dec: $0.5^\circ\,s^{-1}$	Az: $12^\circ\,s^{-1}$ El: $6^\circ\,s^{-1}$

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 2019 and 2020, the 15-m antenna participated in 111 and 117 geodetic/astrometric IVS sessions, respectively (see Figure 2). The 26-m antenna participated in 37 and 30 sessions during 2019 and 2020, respectively (see Figure 3). In 2019, the antennas observed together in two T2 sessions and in 2020 in only one T2 session. Whilst the 15-m antenna's maser was offset in frequency to prevent PCAL cross-correlation during the first dual T2 of 2019, the antennas were run off the same maser for the other two dual T2 sessions. During June, July, and August 2020 the 26-m antenna partcipated in three mixed-mode RD sessions aimed at tying the S/X and VGOS frames together in support of ITRF2020. The 26-m antenna served as one of three southern stations used to orient the S/X and VGOS frames. Astrometric single-baseline VLBI sessions in collaboration with Hobart (UTAS) to further improve the K-band reference frame in the South, as included in the ICRF-3, continued to be observed on the 26-m antenna. All sessions from 19 March 2020 onwards were run under remote control due to COVID-19 restrictions. VLBI data for all sessions was e-transferred to the correlators.

The 15-m antenna's cable wrap mechanism caused damage to various cables during 2019 which led to an upgrade of the azimuth wrap cabling later that year. During 2019 and 2020, problems with the 15-m an-

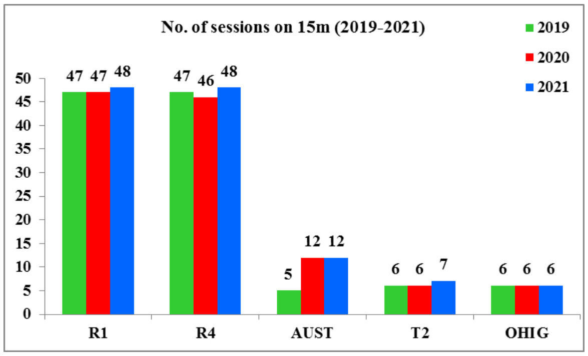

Fig. 2 HartRAO 15-m IVS sessions observed during 2019 and 2020, as well as planned for 2021.

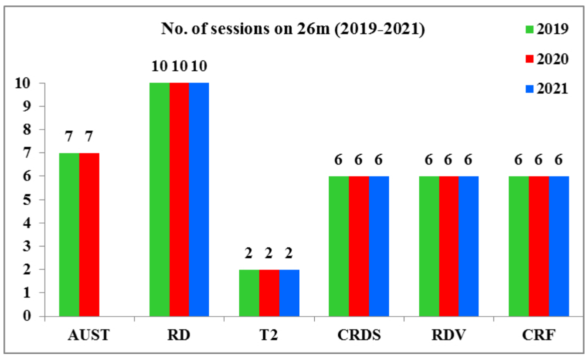

Fig. 3 HartRAO 26-m IVS sessions observed during 2019 and 2020, as well as planned for 2021.

tenna's cryogenic dewar caused several sessions to be observed with a warm or partially cooled receiver. The receiver has been operating since inception and is due for a full service once a gap becomes available in the observing schedule.

The 26-m antenna's encoders continued to be unreliable during 2019–2020, failing and misreading intermittently. In 2019, it was also discovered that the 26-m antenna's west declination shaft bearing had failed. This failure has delayed the installation of new higher resolution Heidenhain absolute encoders (see Figure 4). Fault finding on the current, aged encoders revealed that the power supply to the encoders was marginal. Increasing the value of the supply voltage and some software improvements seems to have solved the reliability issues. An unexpected consequence of the encoder misreadings is that the antenna engaged the brakes every time the encoders misread and, as a result, when it was finally thought to be fixed, the antenna failed to drive because of a catastrophic failure in the brake pads on the declination motors. With these problems addressed, the reliability of the encoders are again at a level that allows for the continuous use of the 26-m antenna, while planning for the declination bearing replacement.

Fig. 4 One of the new HEIDENHAIN 26-bit absolute encoders awaiting installation after bearing replacement.

4 Personnel

Table 4 lists the HartRAO station staff involved in geodetic VLBI. Jonathan Quick (VLBI friend) handles all local telescope scheduling issues, provides technical support for the Field System as well as support for hardware problems. During the COVID-19 lockdown, from the 19th of March onwards, Jon has been running all geodetic VLBI sessions under remote control.

Table 4 Staff supporting geodetic VLBI at HartRAO.

Name	Function	Program
Aletha de Witt	Operations Scheduling	Fundamental Astronomy
Jonathan Quick	Hardware/ Software	Astronomy
Sayan Basu	Operator	Student
Siphelele Blose	Operator	Technical
Jacques Grobler	Operator	Technical
Philip Mey	Operator	Technical
Ronnie Myataza	Operator	Technical
Marisa Nickola	Logistics/ Operations	Fundamental Astronomy
Pieter Stronkhorst	Operator	Technical

Operations astronomer, Aletha de Witt, provides support for astrometric VLBI. Alet is the principal investigator for some of the IVS Southern Hemisphere astrometric and geodetic VLBI sessions as well as for the K-band celestial reference frame project. In 2019, Alet was elected as secretary of the IAU astrometry commission A1. She is also the chair of the newly established IVS CRF Committee. Alet was re-elected to the IVS Directing Board in December 2020.

Since the retirement of Keith Jones at the end of August 2019, the VGOS project manager, Philip Mey, has been given the added responsibility of heading up the Engineering department at HartRAO. In May 2019, Philip and electronics technician, Siphelele Blose, attended the 10th IVS TOW held at MIT Haystack Observatory in Westford, Massachusetts, USA. Siphelele joined the HartRAO geodetic VLBI operator team in 2019.

Antenna systems technician and geodetic VLBI operator, Jacques Grobler (see Figure 5), has left a huge gap with his departure from HartRAO at the end of February 2020 for the shores of the Black Sea.

Fig. 5 Jacques Grobler greasing the 15-m antena's gears.

5 New Developments

Although 2020 COVID-19 lockdown restrictions disrupted the supply chain, causing several projects to be delayed or to be put on hold, remote operations allowed HartRAO to continue supporting geodetic VLBI sessions on the 15-m and 26-m antennas in full. The Space Geodesy programme was recognized as an essential service and staff obtained permits to perform essential duties on-site. This allowed for site visits during which inspection, repairs, and maintenance could be performed. It also allowed for installation/removal of the necessary dichroic reflector system on the 26-m antenna.

A backup generator for the VGOS antenna was installed in 2019 (see Figures 1 and 6) and a four-bank Mark 6 recorder was acquired in 2020. A fully VGOS-capable DBBC3 terminal was ordered from Hat-Lab during the early part of 2020 with expected delivery in the first half of 2021. Yebes Observatory was recently appointed to build a complete wide-band VGOS receiver system to match, with delivery of the latter expected in early 2022.

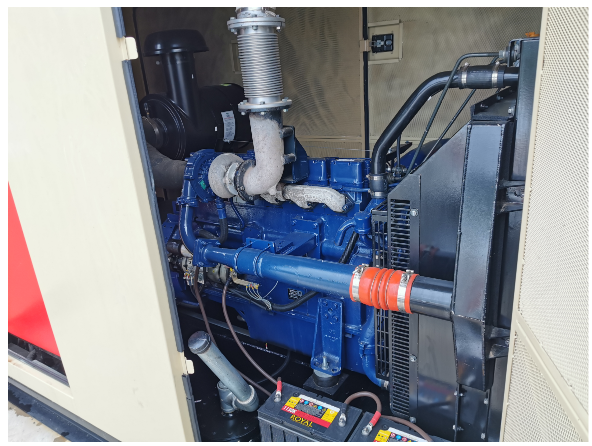

Fig. 6 Inside the housing of the VGOS antenna's backup generator.

We are also currently soliciting bids for possible replacement of the 26-m declination shaft bearings, which would probably involve some significant period of down-time at some yet to be determined date.

During 2019 and 2020, plans were put in place and preparation started to improve the performance and enhance the reliability of the 15-m and 26-m antenna systems. This includes an upgrade to electronic equipment to better find and quickly address problems as they arise; migrating communications to use fiber optics; removing obsolete equipment and connections; and upgrading noise diode controllers to name a few. Work towards this end is continuously in progress and refined as required.

Since the start of 2020, the 15-m antenna has been particpating in Southern Intensive (SI) test sessions in order to compare southern dUT1 results with that from the north. During 2020, these hour-long test sessions were observed monthly on Ht-Hb-Yg baselines during the AUA sessions at the same time as the regular IVS Intensives. From June 2020, SI test sessions were also added to run prior to the weekly R1 sessions, with a total of 35 SI sessions having been observed during 2020.

A further 24-hour VLBI–GNSS session, comprising VLBI observations of GNSS satellites, was run on 23 June 2019 in collaboration with Onsala, Badary, Svetloe, and Zelenchukskaya.

From December 2019 until December 2020, local interferometer sessions between the HartRAO 26-m legacy antenna and the co-located 15-m antenna have been conducted on a regular basis. During these monthly short baseline experiments of four-hour duration (22:00 UT to 02:00 UT the next day), the two antennas simultaneously observe ICRF2/ICRF3 defining sources covering the full range of azimuth, elevation, and cable wrap. Not only do these sessions allow for determining the local tie between the antennas, but it also affords the opportunity to test HartRAO's ability to meet the GGOS requirement of 1-mm accuracy in station coordinates and global baselines.

In August 2020, a request by the IVS Network Coordinator for updated information regarding station meteorological data prompted the condition of HartRAO meteorological sensors to come under scrutiny. Sensors have not been upgraded or calibrated for at least ten years. We are currently utilizing a new MET4 unit as a calibrator for comparative analysis of historical and current meteorological data from HartRAO sensors towards potential reprocessing of historical data sets.

6 Future Plans

Of the 149 geodetic VLBI sessions scheduled for 2021, 119 sessions are allocated to the 15-m antenna, 28 sessions to the 26-m antenna, and two T2P sessions will be run on both antennas.

Progress with the local automated site tie system for continuous monitoring of vector ties was slow due to several factors, but the preparation of various hardware items is near completion with initial measurements and tests to commence in 2021 (see Figure 7).

Fig. 7 Site tie: multi-prism pillar being installed co-axially on the 26-m telescope's shaft.

Work is still under way on an in-house cryogenic receiver that will be used to test the VGOS antenna and resolve possible interface/control issues before arrival of the broadband VGOS receiver. Preliminary participation in VGOS obervations is only expected to begin in the second half of 2022.

Funds were allocated for a complete renewal of onsite meteorological sensors supporting VLBI activities. The MET4 unit is to be installed at the reference height of the 15-m antenna, while two highly accurate pressure sensors will be mounted at the reference heights of the 26-m and VGOS antennas, respectively. Additionally, we plan to obtain a Laboratory Pressure Standard to enable in-house calibration of our pressure sensors.

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 programme, combining VLBI, SLR, and GNSS, and it is active in several collaborative projects with DLR, ESA, GFZ (Potsdam), GSFC, ILRS, JPL, «Roscosmos» as well as numerous local institutes. General information as well as news and progress on geodesy and related activities can be found at `http://geodesy.hartrao.ac.za/`.