Building the New VGOS Radio Telescope at Hartebeesthoek as Part of Our New Geodetic Infrastructure

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Abstract The Geodesy Programme at Hartebeesthoek has been expanding since its first geodetic VLBI session with the 26-m radio telescope during 1986. Various equipment types were added on site as well as at several remote locations. The latest additions and expansions include a Site Tie, a data management system, and a VGOS dish. The VGOS dish project plan for implementation is a long-term undertaking which started during 2014. Mechanical commissioning has concluded during June 2018; the next stage will be sourcing and equipping it with the necessary receiver and backend instruments.

Keywords VGOS, Geodesy, Hartebeesthoek

1 Introduction

The Hartebeesthoek site, previously known as the Hartebeesthoek Radio Astronomy Observatory, now forms part of the larger South African Radio Astronomy Observatory (SARAO). Geodesy is one of the main activities on this site, which are aligned to support the Global Geodetic Observing System (GGOS) goals. Monitoring the global sea level change is one of the most demanding applications which drives the continued improvement and expansion of instruments and instrumentation networks [1]. The Hartebeesthoek site plays an important role in the international networks and is expanding to meet the new requirements of fiducial sites.

South African Radio Astronomy Observatory: Hartebeesthoek site

2 Geodesy Program and Equipment

The geodetic activities at the Hartebeesthoek site took off during 1986 with the first IVS-linked geodetic VLBI and later with the installation of the GNSS reference station *HRAO* during 1996. Since then the site has been expanding its geodetic activities and instrumentation by participation in geodetic VLBI using the 26-m radio dish, installation of a DORIS beacon, addition of GNSS reference stations, conversion of a 15-m radio dish for geodetic use, installation of a seismometer and accelerometer, and the establishment of two Satellite Laser Rangers. The Hartebeesthoek site is considered a fiducial site due to the co-location of all these techniques. Recently we have secured funding for and obtained, a total station for use in an automated site tie and a 13.2-m VGOS-type radio dish. These new additions to the site helps to ensure our continued participation in, and support of, global geodetic networks and experiments. We also have a distributed geodetic sensor network in and around Southern Africa with stations from Antarctica to Ghana, each consisting of at least a GNSS reference system. All these instruments and techniques produce large volumes of data and products; therefore, a new Geodetic Research Data Management System (GRDMS) is also being implemented piecewise.

2.1 Automated Site Tie

The Site Tie system at the Hartebeesthoek site will be used to determine mm-level inter-instrumentation offsets on a regular basis. This data will be used in-house and available to the community for accurate site deformation studies in the drive to support the GGOS goal of mm-level positional accuracy [1]. The instrumentation hardware (Figure 1) and software was installed and initial tests, measurements, and calibrations are in process. Once an experimental method delivering consistent and accurate results is developed, this process will be automated.

Fig. 1 The Leica MS50 Total Station of the Site Tie.

2.2 Distributed Sensor Network

The distributed sensor network is currently being expanded by 10+ stations combining at least GNSS, meteorological, and seismic equipment. Of particular interest is the derived products that can be obtained from the co-location. These stations are placed throughout Southern Africa and even at locations such as the Ghana Radio Astronomy Observatory at Kutunse, Marion and the Gough Islands.

2.3 Geodetic Research Data Management System

Through the years the data management systems were developed on an *ad hoc* and per-technique basis, resulting in fragmented systems. These also do not cater for the large data volumes resulting from modern techniques and the increased number of instruments. This necessitated the design of a new and unified GRDMS [2, 3] which is currently being implemented.

3 Overview of the VGOS-SA Project

During 2014 we received funding to build a new Very Long Baseline Interferometry (VLBI) Global Observing System (VGOS) antenna. Such antennas are required for achieving GGOS goals by having faster slew rates, observing at higher frequencies and higher data rates. Our VGOS project was divided into four phases: planning, civil works, antenna construction, and commissioning.

3.1 Planning – June 2014 to March 2016

Activities during this stage included visiting other observatories with VGOS antennas and attending conferences to become knowledgeable about improvements and the implementation of VGOS related technologies.

- Detailing the specifications of the VGOS antenna towards tender documentation.
- Performing an Environmental Impact Assessment to ensure compliance with environmental regulations and best practices.
- Analyzing the Radio Frequency Interference experienced on our site.
- Using Direct Current Resistivity measurements to ascertain the ground conditions with subsequent verification of the depth to bedrock through core drilling.

3.2 Civil works – April 2016 to February 2017

During November 2015, the tender for the VGOS antenna was awarded and the design and infrastructure requirements was finalized. The antenna design incorporates a concrete base upon which the moving parts are mounted. This base structure contains steel reinforcement throughout with the concrete being poured in five stages: first the foundations measuring 9 m by 9 m with a depth of around 2 m; thereafter the ground floor, walls, top floor, and finally the tapered walls. Figure 2 is a photo of the finished base prior to assembly of the radio dish.

Fig. 2 The finished concrete base.

3.3 Assembling the Dish – April 2017 to June 2017

Assembly started with installing the control, power, and drive cabinets inside the base. It was easier to pre-assemble the azimuth and elevation cabins on ground level, before installing it on top of the concrete base. Most of the work was therefore completed before the backup structure, quadrupod, and subreflector were assembled (Figure 3). Assembly of the azimuth cabin

Fig. 3 Assembly of the main reflector.

with the counterweights and the main reflector was completed by mounting these parts, in sequence, onto the concrete base. To finish off the process, the exposed bolts were painted, cables were routed and connected, and the panel alignment was verified through photogrammetry.

3.4 Commissioning – September 2017 to June 2018

Commissioning of the VGOS dish involved the checking and verification of all electrical connections, calibration of sensors, and following all of the Site Acceptance Tests (SAT). Typically this process takes around three months, but due to unforeseen circumstances our process had to be interrupted and was finalized during 2018. The VGOS antenna eventually passed all SATs during June 2018 (Figure 4). Our 13.2-m VGOS dish can sustain slew rates of 12°/s in azimuth, 6°/s in elevation, and has a surface accuracy of 189.4 μm *RMS*. Although it is mechanically fully functional a lot remains to be done before it can participate in international VLBI experiments.

Fig. 4 The VGOS radio dish, far left, at Hartebeesthoek.

4 Next Steps in our VGOS Project

Work is in progress to monitor and control the VGOS dish remotely from a Linux-based system. The ideal would be to have the same software interface to all our radio telescopes albeit with different limitations as imposed by the equipment. During the next few months the plan is to install an ambient temperature 12-GHz receiver (Figure 5), with a radiometer as backend, to start defining a pointing map. Many decisions have to

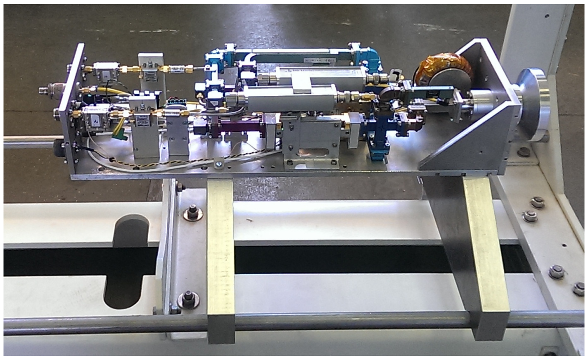

Fig. 5 A 12-GHz ambient temperature receiver that was built in-house.

be made before we can participate in VGOS observations:

- **Recorder**: Taking into consideration the vast amounts of data that will be acquired during VGOS observations and the significant investment in network infrastructure required at the correlators, a Mark 6 recorder was procured. This allows more flexibility with regards to e-shipping data or physically storing and shipping disk packs.
- **Backend**: During 2012, tests were performed to investigate and compare the available digital backends with a focus on the growing VGOS network [4]. Currently the DBBC-3, R2DBE, ADS-3000+, and CDAS implementations are still undergoing development and engineering changes to address challenges identified from VGOS test observations.
- **Receiver**: Two broadband feed types are of interest: the Quadridge Feed Horn and the Eleven Feed. A clear case comparing the advantages and disadvantages of these feeds has yet to be concluded since there is no consensus about which feed to use within the global community.

Ideally the VGOS network should have identical equipment at all observatories—this is impossible to achieve in such a diverse society. It is, however, possible to have antennas with comparable specifications delivering data formats that are compatible—therefore the networks' datasets can still be correlated. There are advantages in having a larger user base of a specific technology and while research and development continues, our VGOS dish will be used for other experiments to test its operational capabilities until such time that an informed decision can be made about our signal chain specifics.

5 Conclusions

The addition of a Site Tie instrument as well as a VGOS dish are important steps in achieving the alignment with GGOS goals, while the implementation of a unified and modern data management system forms part of the supporting infrastructure. Work on all these and supporting systems are ongoing but contribution to the international networks should start during 2019.

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