The 13m Geodetic VLBI Antenna in Toro, Centre for Geodesy and Geodynamics, National Space Research and Development Agency (NASRDA)

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Abstract

Geodesy and space science have become increasingly central to global efforts in understanding Earth's dynamics, monitoring tectonic activity and supporting satellite navigation. The Centre for Geodesy and Geodynamics (CGG) Toro of National Space Research and Development Agency (NASRDA) was established to advance Nigeria's capability in earthquake monitoring and global geodynamics. Toro was strategically selected for its stable granitic bedrock, providing an immobile foundation for sensitive geodetic instruments. Since its conception in 1985, CGG has pursued numerous researches including the use of GPS and form part of the Global GNSS Network, Monitor the Nigerian Seismic activity, Volcanic activity and Environmental Disaster Monitoring, Landslides and Flooding, using available tools to investigate African plate tectonics and earthquake mechanisms. Building on early cooperation including that of NASA, Nigeria formalized another international collaboration in 2022 through an MOU (Memorandum of Understanding) with the Shanghai Astronomical Observatory (SHAO), Chinese Academy of Sciences, to construct and operate a new VLBI antenna.

Site validation was completed in 2023, and a Radio Frequency Interference (RFI) survey in 2024 confirming minimal interference levels. The VLBI tower and a 13-metre antenna have since been installed. Upon commissioning, the Nigerian VLBI project will hopefully be integrated into global geodetic systems, contributing to tectonic studies, earthquake monitoring, and refinement of the global reference frame. This paper examines the historical development, technical foundations, and anticipated scientific contributions of the Nigerian VLBI initiative, situating it within the broader trajectory of African participation in global geodetic networks.

Keywords: Global Positioning System, Very Long Baseline Interferometry, Earthquake, Tectonics

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Introduction

Geodesy and space science have become increasingly central to global efforts in understanding Earth's dynamics, monitoring tectonic activity, and supporting satellite navigation. Very Long Baseline Interferometry (VLBI), alongside complementary techniques such as Global Positioning System (GPS) and Satellite Laser Ranging (SLR), provides the precision required to establish and maintain global reference frames. These systems are critical for studying plate tectonics, earthquake mechanisms, and Earth rotation, while also enabling accurate spacecraft tracking.

Nigeria's commitment to advancing geodetic science led to the establishment of the Centre for Geodesy and Geodynamics (CGG) in Toro, National Space Research and Development Agency (NASRDA). Conceived in 1985 following the inauguration of the National Technical Committee on Earthquake Phenomena, CGG was envisioned as a hub for geodynamic research in Africa. Toro was strategically selected for its stable granite bedrock, offering an immobile foundation for the deployment of sensitive instruments. Early collaborations with (National Aeronautic Space Administration (NASA) have contributed immensely which lays the groundwork for international cooperation's. Several collaborations were conceived with Government institutions, Universities and Research corporations within Nigeria (Nasrda, 2024). To further strengthen international collaborations, a Memorandum of Understanding was signed with Shanghai Astronomical Observatory (SHAO), Chinese Academy of Sciences in 2022 (Maidabino et al., 2025)..

This partnership has facilitated knowledge transfer, training, and the construction of Nigeria's first VLBI antenna (Figure 10). Site validation was completed in 2023 (Figure 7) and a Radio Frequency Interference (RFI) survey in December, 2023 (Figure 8) confirming minimal interference levels, ensuring the suitability of Toro for VLBI and future Satellite Laser Ranging (SLR) operations (Maidabino et al., 2025). With the completion of the VLBI tower and installation of a 13-metre diameter antenna (Figure 2;3&4). Nigeria is poised to join CVN and contribute to Africas Space ambitions by filling the gap already felt by scientific community.

The commissioning of the Toro VLBI project (Figure 1) represents a milestone for Nigeria and Africa, promising to enhance tectonic and earthquake monitoring, strengthen the continental geodetic reference frame, and integrate African science more fully into global geodynamics and space research (Nasrda, 2024). This paper examines the historical development, technical foundations, and anticipated scientific contributions of the Nigerian VLBI initiative, situating it within the broader trajectory of African participation in global geodetic networks.

Figur 1: Groundbreaking Ceremony by the DG (NASRDA) Dr. Mathew Adepoju at CGG Toro

Figur 2: VLBI tower under construction at CGG Toro

Figure 3: A 13m diameter Antenna under contruction at CGG Toro

Figure 4: Hoisting of the Antenna in process at CGG Toro

The Chinese VLBI Network

The Chinese VLBI network consist of several radio telescope separated by large distances (Hundreds of Kilometres) for high precision measurements, Space tracking and geodesy. The CVN consist of 25m radio telescopes at Sheshan of Shanghai, 25m diameter Nanshan of Urumqi, a 50m diameter radio telescope at Miyun near Beijing, 40m diameter at Fenghuangshan of Kunming (J, et al., 2008). Two additional radio telescopes were later constructed with Shanghai Tianma 65 m diameter and Changbai Mountain (Jilin) 40 m. Since August 2025, Beijing has left CVN station and will focus on deep space mission data reception (Weimin et al, 2024) with a servo system upgrade at Kunming and sheshan stations. Currently, CVN extends geographically over east-west and south-north, with baselines ranging from 1,115km to 3,800km. If the new 13m diameter antenna in CGG were to be integrated into CVN, the baseline is assumed to increases by approximately **11,000–12,000 km**, thus, dramatically increasing east–west coverage and resolution for global VLBI observations. This will be more than triple CVN's longest baseline, providing **sub-milli arcsecond angular resolution** in east–west directions, crucial for imaging compact radio sources and improving geodetic precision.

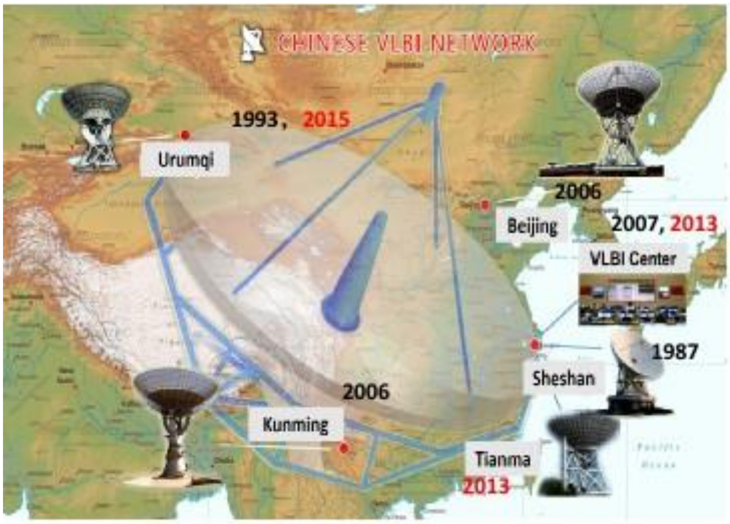

Figure 5: Photograph of distributed Chinese VLBI Network (Weimin et al, 2024)

Efforts to Form African VLBI Network

The African Very Long Baseline Interferometry Network (AVN) is an ambitious project that will establish a network of radio telescopes across the African continent to support the existing international Very Long Baselines Interferometry (VLBI) network (Copley1 et al., 2016). The development of Very Long Baseline Interferometry

(VLBI) infrastructure in Africa has been limited but steadily expanding over the past decades. Historically, South Africa's Radio Astronomy Observatory (Hart RAO) has been the continent's primary contributor to global VLBI networks (Mayer et al., 2014). Established in 1961, Hart RAO transitioned from satellite tracking to radio astronomy and geodesy, providing data to the International VLBI Service (IVS) and supporting studies of Earth rotation, tectonic plate motion, and global reference frames (Mayer et al., 2014). Despite its contributions, Africa's participation in VLBI remained constrained by the absence of additional stations across the continent.

In 2017, Ghana converted a redundant 32 metre telecommunications antenna at Kuntunse into a radio astronomy and geodesy facility. Operated by the Ghana Space Science and Technology Institute (GSSTI), the station became the first outside South Africa to join VLBI experiments, bridging a geographic gap between Europe and Africa (Proven et al., 2026). This milestone marked the beginning of the African VLBI Network (AVN), a collaborative initiative among nine African partner countries of the Square Kilometre Array (SKA) project. The AVN aims to establish a continental geodetic reference frame, expand radio astronomy training, and integrate Africa into global VLBI collaborations (Asabere et al., 2015). Stations located across Africa would greatly improve the image fidelity of VLBI observations, since the geographic location of these stations improves sensitivity to angular scales on the sky that are not well sampled using the currently available global configuration. This is illustrated in the U-V coverage plot in Figure 6 (Copley et al., 2016).

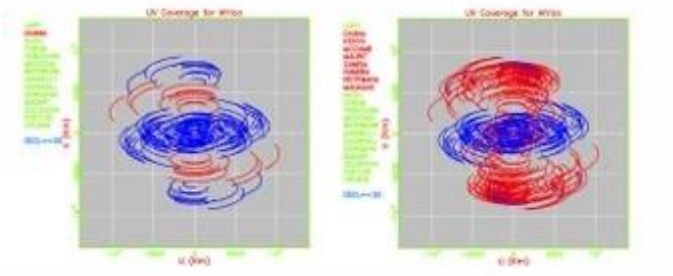

Figure 6: *The blue lines are associated with European Baselines, blue arc shows improvement of sensitivity when (HartRAO) is included,This is further improved (see the red arcs) by the addition of the Ghana station (left) and other African stations (right). (Copley et al., 2016).*

Nigeria's Toro VLBI project, conceived by the Centre for Geodesy and Geodynamics in 1985, was chosen for its stable granite bedrock ideal for geodetic instruments. Located in northern Nigeria, Toro sits between Ghana's Kuntunse station and East African partners, filling a geographic gap in West Africa. Its inclusion would extend African VLBI baselines up to ~4,500 km north–south and east–west, strengthening astronomy and geodesy while complementing South Africa and Ghana's contributions.

Figure 7: Photograph of site inspection by Chinese Geodesist at CGG Toro

Figure 8: Photograph of the set-up for the First RF-Interference Measurement at CGG Toro

Comparatively, South Africa and Ghana have established operational VLBI facilities, while Nigeria's Toro station is in the commissioning phase. Together, these efforts reflect Africa's growing capacity in geodesy and radio astronomy (Table 1). These paper highlights the recurring challenges, including the need for sustained funding, technical expertise, and spectrum management. Nonetheless, Nigeria's entry into the AVN is expected to strengthen West Africa's role in global geodetic science, enhance tectonic and earthquake monitoring, and contribute to refining the global reference frame.

Table 1: Role of every VGOS in Africa

Country	Facility	Status	VLBI Role	Strategic Importance
South Africa	HartRAO (26m)	Operational	Global VLBI contributor	Only African station in IVS historically
Ghana	Kuntunse (32m, converted)	Operational	Astronomy + geodesy VLBI	Bridges Europe–Africa VLBI gap
Nigeria	Toro (13m, new build)	Yet to Commisson	Geodesy + spacecraft tracking	Strengthens West African presence in AVN

Table 2: Comparison between VLBI and S/X systems (Maidabino et al.,2025).

	Legacy S/X System	VGOS	Benefit
Antenna Size Frequency Range	5-100m Dish Two Band: S-Bands: 2210.94 – 2390.94 GHz X-Band: 8106.25 – 8982.81 GHz	12 – 13m Dish Four Band Band A: 3000.40 – 3480.40 GHz Band B: 5240.40 – 5720.40 GHz Band C: 6360.40 – 6840.40 GHz Band D: 10200.40 – 10680.40 GHz	Reduced cost Increases sensitivity and data precision
Signal Processing	Analogue/Digital	Digital	Stable instrumentation

Mandate CGG Toro

The eventual goal of the Centre's programme which constitutes its mandate, is to achieve Nigeria's capability, manpower and hardware development that can sufficiently address national issues concerning Space Geodesy, Crustal deformation, Coastal deformation and subsidence, and global mean sea level.

Mission Statement of CGG Toro

The mission of the Centre is to carry out earth observation research as well as monitor and predict geo-hazards using Space Geodetic and Geophysical Techniques for sustainable National Development. This involves areas such as: Crustal and Coastal Deformation monitoring; Subsidence; Landslide; Flood and Global Mean Sea Level Monitoring; the provision of products and services with the geodetic accuracy necessary to address important geophysical questions and societal needs, and to provide the robustness and continuity of service which will be required in order to meet future needs and make intelligent decisions.

Methodology

The methodological framework for the Nigerian VLBI project at the Centre for Geodesy and Geodynamics (CGG), Toro, is structured around three core phases: site validation, infrastructure development, and system integration. Each phase was designed to ensure scientific reliability, technical feasibility, and alignment with international geodetic standards.

Figure 9: Photograph of CGG Engineers and Chinese Engineers at CGG Toro

Figure 10: Photograph of the First Nigerian VLBI at CGG Toro

Site Validation

The selection of Toro was based on geological and geophysical criteria. The granite bedrock provides a stable, immobile foundation for sensitive geodetic instruments. In July 2023, site validation was conducted by geodesists from the Shanghai Astronomical Observatory (SHAO) confirming Toro's suitability for VLBI operations (Figure 7). Subsequently, in December 2024, physicists from NASRDA and CGG performed the first Radio Frequency Interference (RFI) survey across the 2–14 GHz band (Figur 8). Measurements were taken at multiple times of day and from four cardinal directions within a 13–14 km radius. Results indicated interference levels were minimal validating the site's spectral environment for VLBI applications (Maidabino et al.,2025).

Infrastructure Development

Construction of the VLBI tower was completed in late 2025. The facility includes operational spaces, backup power systems, and data monitoring units. A 13-metre diameter antenna (Figure 3&4) was hoisted onto the tower, designed to operate with high precision in geodetic and astronomical observations. Complementary systems such as Global Navigation Satellite Systems (GNSS) and Metrological equipment's were incorporated to enable multi- technique geodesy and ensure good data acquisition.

System Integration and Commissioning

The VLBI in Toro will combine signals from widely separated telescopes to achieve exceptional precision, making it crucial for both Earth science and astronomical research. The VLBI system is equipped with an atomic clock for global time synchronization, ensuring compatibility with the International VLBI Service (IVS). Data pipelines are being established to facilitate real-time transmission. Once Commissioned, Toro will begin contributing to international geodetic experiments, including Earth rotation monitoring, tectonic plate motion analysis, and spacecraft tracking.

Results and Discussion

Radio Frequency Interference (RFI) Findings

The RFI survey conducted in December 2023 demonstrated that the Toro site possesses a favourable spectral environment for VLBI operations. Interference levels across the 2–14 GHz band confirms the suitability of Toro for geodetic and radio astronomical applications, aligning with international standards for VLBI observatories. The findings are particularly significant given the rapid expansion of telecommunications infrastructure in Nigeria, underscoring the importance of continuous monitoring and regulatory coordination to preserve spectral quality.

Infrastructure Readiness

The completion of the VLBI tower and installation of a 13-metre antenna (Figure 3&4) represent major milestones in Nigeria's geodetic capacity. The integration of complementary systems GNSS, metrological station and the inclusion of an atomic clock for time synchronization further positions Toro to contribute high precision measurements thereby contributing to International Celestial and Terrestrial Reference Frame. These infrastructural achievements demonstrate Nigeria's readiness to transit from construction to operational phases when commissioned.

Anticipated Scientific Contributions

Once commissioned, the Toro VLBI station will combine signals from widely separated telescopes to provide exceptional precision data critical for tectonic plate motion analysis, earthquake monitoring, and Earth rotation studies. Its integration into other VLBI Networks such as CVN, will strengthen continental geodetic reference frames, which remain underdeveloped compared to other regions. Nigeria's participation will also expand Africa's geographic coverage in global VLBI experiments, improving baseline diversity and enhancing the accuracy of geodetic solutions. Beyond geodesy, the station will support spacecraft tracking, contributing to Nigeria's broader space science agenda.

Comparative Context

Compared to South Africa's Hart RAO 26 m antenna and Ghana's Kuntunse station, Nigeria's Toro facility represents a new build rather than a conversion of existing infrastructure. This distinction highlights Nigeria's commitment to establishing purpose, built geodetic capacity. While South Africa has historically been Africa's sole contributor to IVS, and Ghana has recently joined through conversion efforts, Nigeria's entry into the AVN marks a significant expansion of West Africa's role in global geodesy. Together, these facilities form the foundation of a continental network capable of addressing Africa's scientific and developmental needs.

Challenges and Future Directions

Despite these achievements, several challenges such as sustained funding and technical expertise are essential to ensuring long term operations of the equipment beyond initial foreign intervention. Spectrum management will require ongoing collaboration with national regulators to mitigate future RFI risks. Furthermore, integration into global VLBI networks such as CVN will depend on Nigeria's ability to maintain data quality and adhere to international protocols. Addressing these challenges will be critical to realizing the full scientific and strategic potential of the Toro VLBI project.

Conclusion

The establishment of the Very Long Baseline Interferometry (VLBI) station at the Centre for Geodesy and Geodynamics (CGG) in Toro represents a landmark achievement for Nigeria and the African continent. It will foster scientific collaborations across Nigerian Universities and beyond there by leading the way for future generations to compete globally in terms of scientific research and innovation.

Recommendations

Long term success of the project will depend on sustained investment, capacity building, and effective spectrum management to mitigate future RFI risks. Addressing these challenges will be critical to ensuring that Nigeria's VLBI initiative not only contributes to global geodynamics but also fosters scientific innovation and resilience across Africa. The Toro VLBI project thus stands as both a national milestone and a continental opportunity, advancing Africa's integration into the global scientific community.

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