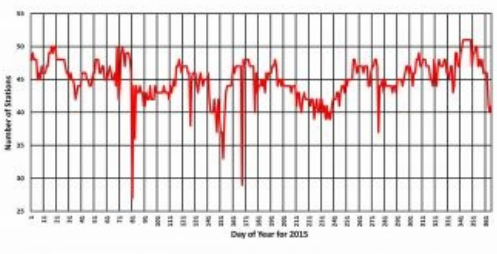
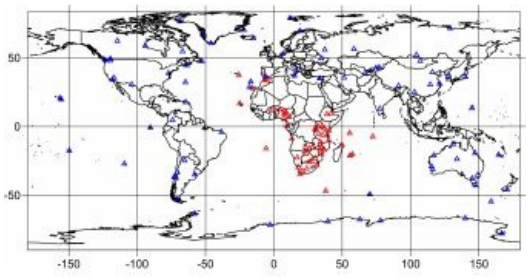
The African Geodetic Reference Frame



The African Geodetic Reference Frame (AFREF) was conceived to unify the patchwork of geodetic reference frames and vertical datums in the 54 countries in Africa. A common reference frame is intended to make it easier to co-ordinate planning and development activities within countries and across national boundaries. This article looks at the progress made from the year 2000 up to the end of 2015.



(By Richard Wonnacott, Umvoto Africa (Pty) Ltd, and Andre Nonguierma, United Nations Economic Commission for Africa)

All georeferencing requires a uniform coordinate reference frame, yet each of the 54 countries in Africa has its own geodetic reference frame. In addition, some countries have more than one reference frame based on different datums. This patchwork of reference systems and frames in Africa makes it difficult to co-ordinate planning and development activities within countries and across national boundaries. The African Geodetic Reference Frame (AFREF) was conceived in 2000 to unify Africa's geodetic reference frames and vertical datums.

Objectives of AFREF

Once fully implemented, the reference frame will consist of a network of continuously operating GNSS reference stations distributed throughout Africa at a spacing of at most 1,000km. The objectives of AFREF can be separated into geodetic objectives and knowledge building objectives.

The geodetic objectives are:

- Define the continental reference system of Africa. Establish and maintain a unified geodetic reference network as the fundamental basis for the national 3D reference networks fully consistent and homogeneous with the global reference frame of the International Terrestrial Reference Frame (ITRF)
- Realise a unified vertical datum and support efforts to establish a precise African geoid, in concert with the African Geoid project activities
- Establish continuous, permanent GPS stations such that each nation or each user has free access to, and is at most 1,000km from, such stations
- Determine the relationship between the existing national reference frames and the ITRF to preserve legacy information based on existing frames.

The knowledge building objectives are:

- Provide a sustainable development environment for technology transfer, so that these activities will enhance the national networks and numerous applications with readily available technology
- Understand the necessary geodetic requirements of participating national and international agencies
- Assist in establishing in-country expertise for implementation, operations, processing and analysis of modern geodetic techniques, primarily GPS.

Previous attempts

In 1981 a project was proposed to use the United States Navy Navigation Satellite System (NNSS) to unify the geodetic datums of Africa. This project was known as the Africa Doppler Survey (ADOS), after the Doppler principle of measurement used in the NNSS. ADOS was initiated by the International Association of Geodesy (IAG) in conjunction with the African Association of Cartography (AAC), the United Nations Economic Commission for Africa (UNECA) and the Regional Centre for Mapping of Resources for Development (RCMRD). Observations were carried out by African national mapping organisations (NMOs) and international geodetic organisations under bilateral agreements. Although nearly 300 zero-order points had been established within the project by the end of 1986, the goal to unify the geodetic datums in Africa was not met. The main reasons for this were:

- the logistics of carrying out the observations simultaneously proved exceptionally difficult indeed and limited the amount of suitable data
- the rationale was not fully understood by participating African countries, resulting in a lack of motivation and enthusiasm for the project
- the project was planned almost entirely by the IAG and the international community with little input from African countries
- there were no set observing standards and procedures, resulting in observations of unacceptable standard
- the bilateral agreements between countries and sister organisations did not always materialise.

Organisation of AFREF

Although ADOS did not entirely meet its objectives, it did serve to provide a number of valuable lessons which have been carried into AFREF. With the introduction of global navigation satellite systems (GNSS) and the establishment of the International GNSS Service (IGS) it became possible to execute a project such as AFREF without the major logistics headache of having to observe all points simultaneously in a network as with ADOS.

The concept of using GNSS to unify the reference frames in Africa was first proposed at the Global Spatial Data Infrastructure (GSDI) meeting held in Cape Town, South Africa, in 2000. Since then, many meetings and workshops have been held to address AFREF. In 2002, AFREF was formalised as a project within UNECA with the signing of a declaration of intent to promote and support the objectives of AFREF by the heads of several African NMOs in Windhoek, Namibia.

Unlike ADOS, which was driven by the international community, the primary principle of AFREF is that it is being designed, managed and executed by and for African countries with assistance from the international community. At the same time, data from AFREF contributes to the global pool of GNSS data through the IGS and provides a better understanding of global geodesy and geophysics.

AFREF stations

Initial progress was very slow with very few stations being established. In 2005 there were just 15 IGS-approved stations in Africa (see Figure 1). Since about 2006, however, there has been steady progress with the installation of permanent GNSS base stations. The increase in contributing stations can largely be attributed to scientific groupings such as Africa Array, SCINDA, AMMA-GPS, etc., who have co-located permanent GNSS receivers with seismometers, meteorological sensors and suchlike. In addition, a number of countries have installed their own permanent networks and have made data from these networks available to AFREF.

Although the stations are generally well spread out across the African continent, there is a lack of stations in the area from Angola through Central Africa into Sudan and across North Africa. A number of stations are known to be in some of these areas but data from them is not openly available.

Operational Data Centre

In 2009 the AFREF Operational Data Centre (ODC) was established to process the data from the permanent GNSS base stations. By the end of 2015 there were approximately 65 stations in total contributing data to the ODC. On any given day, there are approximately 45 stations streaming open data (free of charge and openly available) to the ODC (see Figure 2).

The results of two weeks of measurements at 50 stations in December 2012 were processed into an initial reference frame for ITRF 2008 Epoch 2012 Day 340 23h 59s (GPS Week 1717). Four processing centres, either in Africa or with African affiliations, processed the collected data and computed a set of static AFREF coordinates. The centres involved were:

- HartRAO in South Africa
- SEGAL (UBI/IDL) in Portugal
- Directorate of Surveys & Mapping in Tanzania
- Ardhi Univ in Tanzania.

The Institut Géographique National (IGN) in France combined the results of these four independent computations. The results were statistically analysed, which produced a weighted root mean square (RMS) of approximately 3.0mm in Longitude and Latitude and 7.5mm in Up for all the coordinates. The resulting coordinates are available on the AFREF ODC (ftp.afrefdata.org) (see Figure 3).

Knowledge building

One of the objectives of AFREF is to ‘provide a sustainable development environment for technology transfer’ and AFREF has certainly achieved that when one considers how many African researchers are now making use of AFREF data in a wide range of geo-related disciplines. Numerous workshops have been held at the Regional Centre for Mapping of Resources for Development (RCMRD) in Nairobi, Kenya, and at the Regional Centre for Training in Aerospace Surveys (RECTAS) in Ile-Ife, Nigeria, as well in various other centres in Africa. Training has been given by experts in the field of GNSS station hardware and installation, the management of continuously operation reference station (CORS) networks and the processing of data derived from the network. RCMRD has published an AFREF newsletter on a regular basis since 2006 with contributions coming from many African authors. Numerous AFREF-related peer-reviewed

papers have been published in respected international journals or presented at international conferences. And in the spirit of AFREF being an African project to be designed, managed and carried out by Africans with assistance from the international community, it can be safely said that the project has achieved this objective.

Challenges

AFREF has been slow to move forward since its inception in 2000. In spite of this, progress has been made with the establishment of the ODC and the computation of a set of static co-ordinates for over 50 stations based on the ITRF, thus creating a uniform reference frame for Africa. Apart from the coverage of CORS across Africa the co-ordination of activities, such as the installation of references stations in close proximity to one another, remains problematic and needs attention. As with any project of this magnitude, obtaining funding and political buy-in from national leaders is a challenge.

Acknowledgements

AFREF would not exist without the support of many organisations and individuals including IGS, IAG and UNECA, without whose continuing support from the start this project would never have reached the stage at which it is now.

Further Reading

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- Wonnacott, R., Ezibalike, C. 2009. AFREF – A Unified Geodetic Reference Frame for Africa. *Civil Engineering Surveyor* GIS/GPS supplement, Inst of Civil Engineering Surveyors.

Biography of the Authors

Richard Wonnacott retired from the Chief Directorate: National Geospatial Information, South Africa in 2013 where he was responsible for the national control survey network including the network of permanent GNSS base stations, TrigNet. He was a member of the Governing Board of the IGS from 2006 until 2013 and the Executive Committee of the IAG from 2007 until 2015 and a member of the AFREF Steering Committee from 2006.

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Andre Nonguierma has focused for more than 20 years on leveraging the use of geospatial data, information and analytics for strategic decision-making. He is the officer-in-charge of the Geoinformation Systems Section at UNECA where he has worked for eight years on spatial data infrastructures in Africa.

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Figure Captions

Figure 1, *The South African TrigNet station DEAR which is also an IGS and AFREF station. DEAR has been co-located with a weather station.*

Figure 2*, Daily record of AFREF stations in the Operational Data Centre database for 2015.*

Figure 3, *AFREF stations (red triangles) and global stations (blue triangles) used to compute static coordinates for AFREF based on ITRF 2008 (epoch 2012.934).*

Figure 4, *Participants in the 2015 AFREF and GNSS Data Processing Training held in Kenya (source: RCMRD).*

Figure 5, *Participants in the 2006 AFREF Workshop held in Cape Town, South Africa. Participants included representatives from IAG, IGS, NGS, NGA, IGN and many African countries.*