AFREF, Establishment of a Common and Modern African Geodectic Reference Frame

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Key words: AFREF, common reference frame, ITRF, WGS84, NEPAD objectives, Geo referenced products & services, Cross border applications, GNSS

SUMMARY

There are almost as many coordinate systems and thus reference systems in Africa as there are countries. Cross border, regional and continental geo-referenced applications, services and products require a uniform coordinate reference system. Africa requires such common a coordinate system. The World Geodetic 84(WGS84) and International Terrestrial Reference Frame (ITRF) are global reference and coordinate systems. To solve this problem, the African Reference Frame (AFREF) has therefore been proposed. It is aimed at establishing the reference system using GNSS technology based on WGS84 and ITRF systems standards. It is proposed that the project be implemented by all countries in the continent through their National Mapping Organisations(NMOs) with the support of the international community through various Scientific and Research organization in geosciences, donor agents, GNSS product manufacturers and users among others. This paper is aimed at sensitizing and seeking wider support for the AFREF project both within the continent and the globe. The objectives, proposed implementation strategy, current status and expected benefits are addressed.

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1. WHAT IS AFREF?

According to United Nation Economic Commission for Africa (UN ECA) Committee on Development Information (CODI), the African Geodetic Reference Frame (AFREF) was conceived as a unified geodetic reference frame for Africa to be the fundamental basis for the national and regional 3D reference networks fully consistent and homogeneous with the International Terrestrial Reference Frame (ITRF) Standards. ITRF is the global reference frame system for the earth as adopted by the International Association of Geodesy (IAG).

When fully implemented, it will consist of a network of permanent GPS stations, continuous or otherwise, such that a user anywhere in Africa would have free access to GPS data and products, and would be at most 500 km from such stations. Its full implementation will include a unified vertical datum and shall support efforts to establish a precise African Geoid.

The concept of a unified geodetic datum for Africa is not entirely new. An effort was made in the 1980s to establish a unified datum using satellite techniques via the African Doppler Survey (ADOS) project. The ADOS project was started in 1982 and was completed in 1986.

2. OBJECTIVES

The following are some of the identified objectives of AFREF

- Define a continental geodetic reference frame for Africa
- Establish precise and uniform African geoid
- Establish permanent GNSS base stations such that each nation and users have free access to GNSS data and product from such stations
- Promote African development through GNSS and ICT products and technology transfer within the continent and at international level
- Understand the necessary geodetic requirements of participating nationals and international agencies
- Establish an in-country expertise for implementation, operation, management, analysis and presentation GNSS data and products.
- Determine transformation parameters between GNSS/GPS to local refererence systems
- Promote the use and application of GNSS technology for african development

3. JUSTIFICATION

Any application, service or product requiring geo-referencing requires a coordinate reference system. Cross border national, regional, continental and global geo-referenced applications,

services and products require a uniform coordinate reference system. Most regions and nations have different coordinate reference systems making cross border geo-referenced applications, services, and products difficult. Similarly some countries including Kenya, use different coordinate reference system, some based on local origin. This also makes geo-referenced applications, services, and products difficult. This therefore calls for the establishment of a common and uniform continental reference coordinates system.

All African countries have started embracing the use and applications of Global Navigation Satellite System (GNSS) technologies particularly Global Positioning system (GPS) in the various geo-information applications, services and products. GPS is a satellite based positioning system developed by USA initially for military use, though it is now is open to civilian users all over the world. GPS uses World Geodetic System 1984 (WGS84) coordinates system. WGS 84 system is a modern, global and uniform coordinate system best fitting the earth. The International Terrestrial Reference System (ITRS) is the global terrestrial reference system officially adopted by the International Association of Geodesy (IAG). The WGS84 reference system of GPS, which is widely used in the world and Africa as stated earlier, is now identical to ITRS at centimetre level. GPS technology may therefore be used in the implementation of AFREF.

GPS technology is very accessible, precise, economical and sustainable. Most GPS products do not require the user to have in depth knowledge of its technology as their production is application based with user in mind. With the increased use and application of GNSS (read GPS) and the requirements to relate the GPS solutions with the already existing mapping products based on local and national coordinates reference systems, there is an urgent need to establish and determine the transformation data to and from such systems to GNSS reference systems. This will be achieved on full realization of the AFREF project.

The priority areas of NEPAD for sustainable growth of Africa require maps and other geographic information products for effective planning and efficient implementation of relevant and appropriate projects. Geographic information products provide the link between all activities and the places or locations where they happen. Everything that happens actually happens somewhere. Activities are therefore not complete without the information about the location where they will be implemented. Traditionally, this information has been presented i as maps, but with the recent advancement in technologies, they are now presentable in digital formats using digital mapping techniques. Geo-information(geomatic) scientists including surveyors and other mapping and planning professionals will not be able to produce maps and other geographic information products on which all planning is based without the use of an established reference frame.

Countries have traditionally maintained their own reference frames resulting in maps which are not edge-matched properly at the borders. Apart from increasing the potential for misunderstanding and conflicts, this situation makes it difficult for countries to share information and to work on joint plans and projects. Information on one country's maps could not be easily referenced to that on another country's maps. As we move towards regional integration, and adopt regional approaches to peace and security, environmental

management, trade and industry, we need maps that are continuous across national boundaries. This shall be possible via a common reference frame, such as AFREF.

The realization of AFREF has vast potentials for geodesy, mapping, surveying, geo-information, natural hazards mitigation, earth sciences, etc. Its implementation will provide a major springboard for the transfer and enhancement of skills and knowledge in surveying, geodesy and especially Global Navigation Technologies (GNSS) with its applications.

The international framework, of which AFREF will be a part, is a prerequisite for many multi-disciplinary applications. The International GPS Service (IGS), a service of the IAG, supports a number of projects and applications dependent on the robust reference systems that are thriving at both global and regional levels. The classic IGS products, based on the global network provide information to generate global plate motion maps, enable strain and fault motion monitoring for earthquake hazard research and support dense regional GPS networks. This fundamental reference system can further increase the understanding of complex earth science systems and assist and facilitate in solving regional and global problems.

A key outcome of the AFREF project will be the transformation parameters from AFREF to local frame on which currently most geo referenced products including maps are based. Conversion of all national surveying and mapping products may be converted to the same common reference system (AFREF). A practical outcome of this will be the ease with which cross-border and regional geo-referenced projects can be carried out. In addition to scientific project applications, this will include projects for the development of agricultural schemes, road, rail, power line construction or eradication of disease, hazard mitigation, etc.

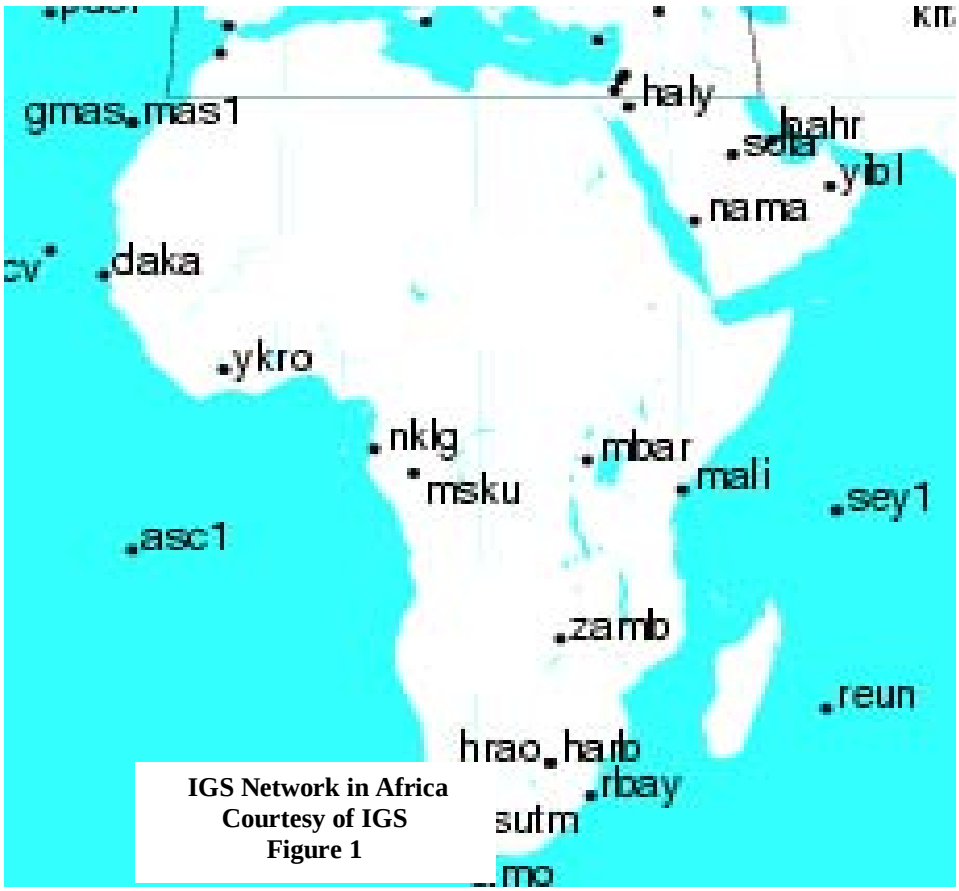
Satellite positioning techniques have the potential for long-term climate monitoring, ground-based weather forecasting, long-term sea level trends at the millimetre level, and low-earth orbiting satellites with on-board GPS receivers which will contribute to much greater understanding of the earth's gravity field and atmosphere, ionosphere mapping and research, precise timing and time transfer. With a uniform geodetic system throughout the continent, the applications of GPS promise increasing benefit to society through greater understanding of earth science systems. GPS is used in many locations to monitor crustal deformation phenomenal, such as earthquakes, volcanoes, tectonic motions and subsidence along coastal regions.

4. PROPOSED IMPLEMENTATION STRATEGY

The successful implementation of AFREF depends on the application of Global Navigation Satellite system (GNSS), and in particular the Global Positioning System (GPS). The UN Office for Outer Space Affairs (UN OOSA) is the coordinating body for the peaceful use of space, including GNSS. AFREF has been presented and discussed at USA/UN OOSA sponsored workshops, including one held at Lusaka, Zambia in July 2002, and Vienna, Austria in December 2003 and 2004; and its importance for the development of Africa accepted. A number of other meetings have been held including Governing Councils (GOC)

meetings for the Regional Centre for Mapping of Resources for Development (RCMRD), UN ECA CODI meeting, IAGG/IAG and IGS international meetings among others where AFREF issues have been discussed.

International Association of Geodesy (IAG) promotes the concept of a unified regional geodetic reference frames all over the world. IAG and its service organizations, in particular the International GPS Services (IGS) has established a network of continuous GPS observation stations across the globe. To date more than 200 such stations have been established all over the world since 1992. GPS data from IGS tracking networks is freely is available from the IGS data holding and analysis centres. Fig. 1, shows the distribution of IGS stations in africa which currently stands at 18.



IGS Network in Africa
Courtesy of IGS
Figure 1

Most of the stations are distributed in the Eastern and Southern Africa and part of Western African coastal region. Central and Northern part of Africa is not covered. Densification of IGS networks with its products in Africa is the first step toward the realization of AFREF.

For practical effectiveness, the following implementation and coordination structures has been developed and proposed through various workshops and accepted by the Economic

Commission for Africa (UN ECA). The proposal is based on continental and regional coordination "*with national implementation***"**. The following are the proposed implementation regions on based on United Nations economic blocks

- NAFREF, North Africa Reference Frame for North Africa comprising of Algeria, Egypt, Libya, Mauritania, Morocco and Tunisia.
- SAFREF, South Africa reference frame for SADAC countries including Botswana Lesotho, Malawi ,South Africa, Swaziland, Namibia, Zambia, Zimbabwe
- EAFREF, East African Reference Frame for IGAD countries including Burundi, Djibouti, Ethiopia, Eritrea, Kenya, Somalia, Rwanda, Tanzania and Uganda
- CAFREF, Central Africa Reference frame (for Central Africa)
- WAFREF, West Africa Reference Frame (for West Africa)

Following the discussions at various forums including UN ECA CODI meetings, the implementation of AFREF will follow an approach consisting of following three major phases,

- The establishment of a frame work of continuous permanent GPS base stations throughout the region that will become part of the worldwide IGS network of stations. These stations must comply with the internationally accepted standards as set out by IGS. During the Governing Council meeting of the Regional Centre for Mapping of Resources for Development (RCMRD) held in December 2000 at Windhoek Namibia, it was declared that densification of IGS network be carried out to at least 1000km by the National Mapping Organizations(NMO) with assistance and collaboration of IGS. A number of sites were identified for establishment of such points.
- The densification of the network of permanent base stations, largely on a country-by-country basis, to determine the relationship between the national geodetic system and the ITRF, and to refine the transformation parameters necessary to relate the national systems to ITRF. The densification may be carried by individual nationals by way of establishing GPS networks through either continuous or semi continuous permanent GPS stations.
- The third and equally important phase of the project will be to address the development of a more refined geoid model for Africa and the definition of a common vertical datum for the continent. The unification of national land levelling networks will follow from this. This phase of the project can run parallel to the two phases described above.

Countries will be expected to actively participate in the planning, management and execution of field campaigns, and in the processing, computation and interpretation of the observations in all phases of the project, through National Mapping Organisations(NMOs). They will also be expected to maintain electrical and communication facilities at the continuous permanent stations, and arrange for the delivery of requisite data sets to the AFREF data centres.

The steering committee, regional centres, working groups and National Mapping Organizations(NMOs) are be expected to sensitize and seek various support including political and financial support of national governments, financial support from development partners like JICA, UN OOSA, etc, technical support from collaborative Partners like IGS,

IAG, HartRao amongst others, and also cost subsidies on hardware and software is expected from GNSS manufacturers.

5. ORGANISATIONAL STRUCTURE

Fig 2 shows the organisational structure for AFREF. The executive steering commmitte is responsible for the continental coordination on the implementation of AFREF as described in its Terms of Reference(TORs). It draws its membership from the Regional Centres in Surveys and Mapping technologies, IAG through the commission on reference frames and Africa and AFREF implementating regions as listed herewith;

- Regional Centre for Mapping of Resources for Development(RCMRD), the Director General, Dr. Wilbur K Ottichilo, Chair
- African Organisation of Cartography and Remote Sensing(AOCRS), the General Secretary , Dr. Muftah Unis, Co chair
- Regional Centre For Training In Aerospace Surveys(RECTAS), the Director General, Dr. Jide Kufoniyi
- International Association of Geodesy(IAG) sub commission on Referencec Frames , Africa(SC 1.3d), Chaired by Mr. Richard Wonnacott
- NAFREF represented by head of National Surveys & Mapping Organisation, Tunisia
- EAFREF represented by Director of Surveys & Mapping, Mr. Lazarus Mollel, Tanzania
- WAFREF represented by head of NMO, Nigeria
- SAFREF represented by Director of Surveys & Mapping, Dr. Karim. Owolabi, Namibia
- CAFREF represented by head of NMO, Congo Braziville

The regional bodies dealing with surveys and mapping desciplines, including geo-information are expected through their TORs, to coordinate the implementation at regional level. They are also expected to provide the linkages between the executive steering committe, regional and national working groups and make periodic reports to the executive steering committe on the status of AFREF.

The terms of reference(TORs) for the executuive steering committe and the UN Regional centres have been developed(AFREF workshop held at RCMRD on 17th octomber 2004) and are as listed below;

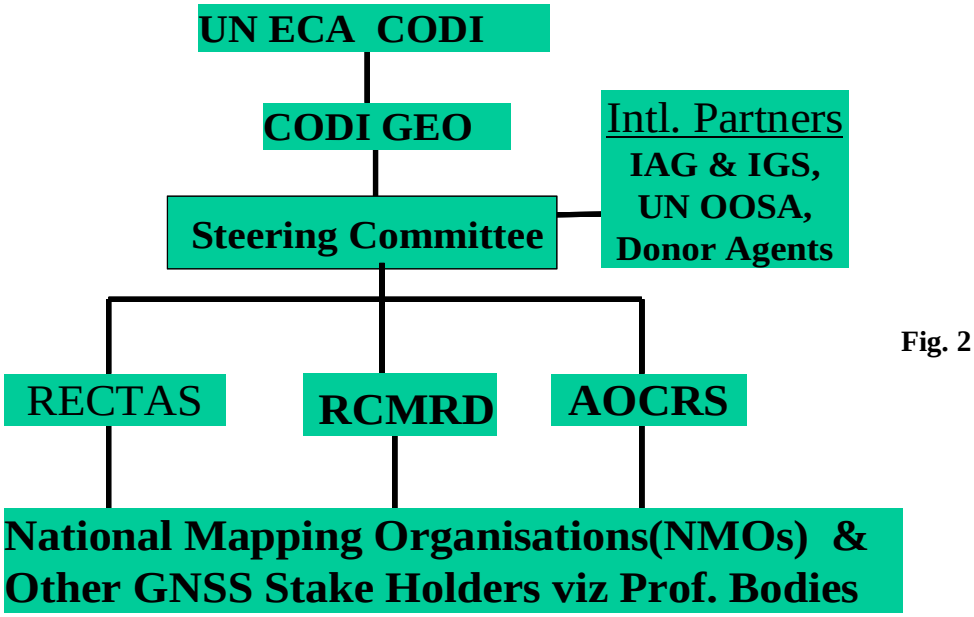


Fig. 2

5.1 ToRs for Executive Steering Committee

- Co-ordinate the implementation of the AFREF project at the continental level;
- Set guidelines and standards to be used for the AFREF project;
- Provide justification, communication and publicity for the project to political groupings, stake holder international organisations and other users. Political groupings will include NEPAD while ICAO is an example of a stake holder international organisation;
- Secure funding and other resources such as equipment to ensure the success of the project;
- Liaison with international organisations to provide guidance, expertise and training
- Co-ordinate training, workshops and seminars
- Report to CODI and funding agencies with respect to progress and future actions.

5.2 ToRs for Regional Centres

- Provide justification, communication and publicity for the project to political groupings, stake holder organisations and other users at regional level;
- Coordinates the implementation at regional level;
- Assist member states to secure funds;
- Carry out trainings specific to AFREF requirements;
- Liaise with international bodies;
- Assist member states in selection and installation of CORS;
- Coordinate data processing, storage and dissemination;
- Act as regional data holding centres and;
- Make progress reports to steering committee for every six months

The national surveys and mapping organisations(NMOs) are expected to lead the implementation at national level supported by national working groups on AFREF. The

national working groups are expected to be coodinated by NMOs and should comprise of all possible GNSS stakeholders including professional bodies in surveying, geodesy, engineering, meteorology including GNSS users in transportation, aviation and military among others. NMOs are therefore expected to spearhead the formation of national working groups for speedy coordination and implementation of AFREF in their countries.

Heads of National Mapping Organisations are members of UN ECA CODI GEO, Steering Committe, regional working groups and finally national coordination and implementation working groups. This ensures national representation at levels and thus national project ownership. The structure also ensures smooth desemination of GPS data.

6. REQUIRED RESOURCES

Because of the "plan and coordinate continental & regional, *implement national*" approach, it is important to consider what resources are likely to be required;

Personnel and institutional resources are required at both national and regional levels. This requires persons well versed in the field of geodesy and particularly in establishing, manning, and processing of Global Navigation satellite systems (GNSS) data and products.

AFREF participants will be expected to use up-to-date positioning equipment, mainly GPS of appropriate precision for the global network. These will include receivers and other ancillary components.

The permanent computing stations will need dedicated computers and storage peripherals to hold the data. Software packages and hardware are required for the processing of GPS data.
In the second phase of AFREF, software and expertise will be required for the re-computation and adjustment of national coordinate products to the new reference system for surveying, mapping and scientific communities.

Communications and network connectivity are essential components for the successful implementation of the reference network. AFREF being part of the global network, there will be constant need to upload and download data to and from designated data centres and IGS centres.

7. CURRENT STATUS

International Association of Geodesy (IAG) supports AFREF under the commission for developing countries and reference frames and sub commission on regional reference frames. A dedicated sub commission (SC1.3d) for AFREF was established and is currently chaired by Mr. Richard Wonnacott of directorate of South Africa.

International GPS services(IGS) with its Affiliates supports AFREF as evidenced by the CORS currently established in Africa. As stated earlier, a total of 18(eighteen) such stations have been already been established with new ones being continuously installed. The

densification of IGS network with the support of the National Mapping Organizations (NMOs) is expected to take place at faster rate under AFREF.

United Nation Office for Outer Space Affairs(UN OOSA) has facilitated discussions at various fora including the July 2002, "Use and applications of GNSS workshops" at Lusaka, Zambia, and others follow up meetings in December 2003 and 2004 at Venna, Austria.

Towards the implementation of AFREF, some African coutries and the regional implementation blocks have already met to chart out ways and means of implementing AFREF at national and regional levels.

SAFREF under the stewardship of South Africa have already met in Cape Town on March 2001 to gauge the level of interest among NMO's in the region. The following eight (8) countries including Botswana, Malawi, Mozambique, Namibia, South Africa Swaziland, Zambia and Zimbabwe attended the meeting and all supported the project. The sub region has 10(Ten) IGS stations, 6(six) in South Africa, 1(one) in Namibia, 1(one) in Zambia, 1(one) in Seychelles, and 1(one) in Re union Islands. South Africa has also established its national network of GPS CORS.

Two workshops on the implementation AFREF in the NAFREF sub region were held in May 2000 in Tunis and May 2001in Algiers, respectively. Five of the NAFREF countries including, Algeria, Libya, Mauritania Morocco and Tunisia participated. The Algiers workshop established the following three working groups coordinated by AOCRS, and charged with:

- Definition and implementation of a Terrestrial Reference Frame
- Determination of the unified Geoid
- Establishment of general institutional framework for implementing NAFREF project

Another meeting was held in Rome, Italy, July 2001, for the participating NAFREF countries at the invitation of the Italian Space Agency (ISA) 2001. During the meeting ISA offered to place at the disposal of NAFREF project two fully operational permanent GPS stations at both Algeria and Mauritania. The African Organization of Cartography and Remote Sensing (AOCRS), was nominated to coordinate the implementation of NAFREF. One IGS station is available in Rabat, Morocco.

EAFREF as a sub region have not met. However RCMRD had organised stakeholders meeting for Kenya at its offices on 19th May 2004 which attracted participation from Survey of Kenya, Nairobi and Jomo Kenyatta Universities, Kenya Institute of Surveying & Mapping (KISM) and a few private firms in survey, mapping and geo-information. A Local Organising Committee(LOC) was formed and tasked with coming up with the proposals and work plans for implementation of AFREF in Kenya in line the continental and regional proposals with the coordination of Survey of Kenya(SOK). LOC was also mandated to seek support from other stakeholders and donors. Within the sub regions, there are two IGS stations at Malindi and Mbarara in Kenya and Uganda respectively. The Kenya Institute of Surveying &

Mapping (KISM) in collaboration with Hokkaido University, Japan has also established five CORS for East African Rift Valley Monitoring project. These are however not connected to IGS and need to be verified on whether they meet IGS standards.

At the time of writing this, the paper author had no information on the status of WAFREF and CAFREF sub regions. However three IGS stations are available in WAFREF at Cote D'ivoire, Cape Verde and Grand Canaria Islands, and two in CAFREF at Gabon. It was reported during AARSE pre-conference meeeting on AFREF that some countries in WAFREF have already formed national working groups.

8. APPLICATIONS AND BENEFITS

The international framework, of which AFREF will be part, is a prerequisite for many multi-disciplinary applications. Besides the establishment of a uniform modern reference system for Africa, a key outcome of the AFREF project will be the conversion of all national surveying and mapping products to the same common reference system. A practical outcome of this will be the ease with which cross-border and regional geo-referenced projects can be carried out.

The realization of AFREF has vast potentials in the scientific world for geodesy, mapping, surveying, geo-information, natural hazards mitigation, earth sciences, etc. The traditional geodetic techniques have limitations in terms scientific applications due to their inability to provide sufficient knowledge of the earth's centre and its gravity field. With a uniform geodetic system throughout the continent, the applications of GPS promise increased benefit to society through greater understanding of earth science systems. GPS is used in many locations to monitor crustal deformation, such as earthquakes, volcanoes and tectonic motions. KISM, in corroboration with some Japanese universities, is doing research in monitoring the East African Rift Valley.

Aviation industry is one of the other many areas where a global coordinate system is required. Aircrafts need to have the origin and destination airports in the same coordinate system, the World Geodetic System of 1984 (WGS84), for navigation purposes as required by the International Civil Aviation Organisation (ICAO).

Similarly, positioning techniques have the potential for long-term climate monitoring, ground-based weather forecasting, long-term sea level trends at the millimetre level, and low-earth orbiting satellites with on-board GPS receivers which will contribute to much greater understanding of the earth's gravity field and atmosphere, ionosphere mapping and research and precise timing.

Similar products to IGS will be available under the AFREF project. These include GPS data from each station, precise orbits for precise computations, and navigation data for atmospheric modelling.

At the local level within the national context, practicing Surveyors/Engineers and other GPS users with one receiver at their disposal may benefit with the establishment of continuous GPS stations, since such GPS data shall be available for post processing. This means that surveyors with single receivers will be able to post process baselines using data from such CORS.

9. SIMILAR REGIONAL REFERENCE FRAMES

EUREF is the common geodetic reference frame for Europe. Permanent tracking stations form the backbone of the EUREF network, which are densified at the national level using local campaigns of finite duration. The main components of the network are permanent GPS stations, Operational Centres, Local Data Centres, a Regional Data Centre, Local Analysis Centres, a Regional Analysis Centre and a Network Coordinator. The creation of EUREF took advantage of the existence of various components, adding the network coordinator function to coordinate activities that were already on-going in member countries. EUREF is the European regional component of the Global Network of IGS. As such it delivers free-network solutions from EUREF local analysis centres to IGS for the maintenance of the International Earth Rotation Service (IERS).

SIRGAS (Sistema de Referencia Geocentrico para Americas del Sur) is the equivalent organ for the South American countries. It was initially established in 1993 during the International Conference on the Definition of a South American Geocentric Datum, sponsored by the IAG, Pan-American

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Presentations on status of WAFREF, NAFREF, EAFREF and minutes of disussions during AARSE pre conference workshop on AFREF held at RCMRD in october 2004

http://igscb.jpl.nasa.gov

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BIOGRAPHICAL NOTES

BSC. Degree in Engineering, Surveying & Photogrammetry, University of Nairobi, Kenya, 1986/89. Post Graduate Diploma in Integrated Map & Geo Information Production(IGP), International Institute for Aerospace and Earth Sciences (ITC), Netherlands, 1995. Global Positioning System training at Geographic Survey Institute (GSI), Japan, 2000/2001.

Survey of Kenya Training School and Kenya Institute of Surveying and Mapping (KISM), 1989-2003. At KISM, I was involved in coordinating and trainining surveying and related coursee including JICA/GOK GPS sponsored third country GPS training courses for eastern and southern african states. Also has been carryoing out consultancy and production services in survey and mapping projects. At Regional Centre for Mapping of Resource Mapping for Development (RCMRD) Jan 2004 to date, carrying out similar task as at KISM and Survey of Kenya (SOK).
Been involve in Monitoring of Kenyan Rift Valley project at KISM in conjunction with Hokkaido University, Japan, using GPS since 1998.
Attended various Workshops and Seminars on geoinformation including, GPS99, an IAG International Seminar on Global Positioning System held at Tsukuba, Japan on October 2001, United Nations / United States of America workshop on the use of the Global Navigation Satellite Systems (GNSS) in Lusaka, Zambia, July 2002 and in Vienna, Austria December 2004, International Conference on Spatial Information for Sustainable Development, A FIG meeting held in Nairobi, Kenya on 2nd to 5th October 2001.
Registered Member(MISK) and Assistant Secretary, Institution of Surveyors of Kenya(ISK), Land Surveyors. Also Faculty of Engineering Board representative for ISK at University of Nairobi(UON) and Jomo Kenyatta University(JKUAT).

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