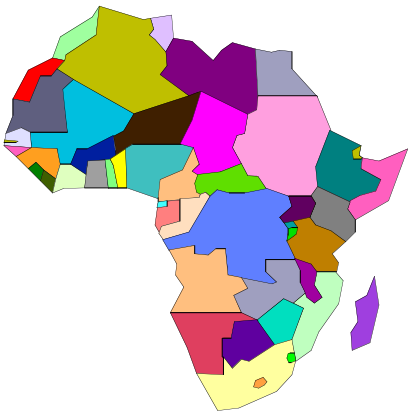
Establishing A Continental Reference System in Africa

AFREF

Proposal to International Council for Science

International Union of Geodesy and Geophysics/International Association of Geodesy
International GPS Service/International Earth Rotation Service
International Society of Photogrammetry and Remote Sensing



March 1, 2002

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International Society of Photogrammetrry and Remote Sensing
National Research Foundation, South Africa ICSU Secretariat
Department of Land Affairs, Chief Directorate of Surveys and Mapping
Economic Commission of Africa, Development Information Services Division

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Proposal Abstract

A number of discussions and activities over the past two years strongly suggest that it is now time to formally establish a broadbased project and project structure with the primary objective of realizing a continental modern geodetic reference system for Africa. This African Reference System, 'AFREF', is fundamental to numerous activities, and essential, given today's demanding science, technology and multi-disciplinary applications. Such a continental system is now viable due to the satellite positioning techniques of the Global Positioning System (GPS). GPS technology is at once accessible, precise, economical, highly sustainable and can be embraced by the interested organizations in the 50+ nations of Africa. It is important to highlight the need for a reference system that is fully integrated with the International Terrestrial Reference System (ITRS), and its realization, the International Terrestrial Reference Frame (ITRF) for national, regional and continental applications. Global consistency is demonstrated for many parameters and these techniques extend this level of precision and consistency to all users. This proposal seeks support of the International Council for Science (ICSU) for this project. ICSU sponsorship will provide the catalyst to unify African-managed geodetic activities by stimulating national motivation, combined with support and assistance of the international constituents of the International Association of Geodesy (IAG) and its related services: International GPS Service (IGS), International Earth Rotation Service (IERS), International Gravimetric Bureau (BGI) and International Geoid Service (IGeS) [1,2,3]; and the support of the International Society of Photogrammetry and Remote Sensing (ISPRS) [4]. The IGS, IERS, BGI are recognized services of an ICSU Interdisciplinary Body, the Federation of Astronomical and Geophysical Data Analysis Services (FAGS).

AFREF Rationale and Justification

Specific Reasons For Proposal To ICSU

A uniform coordinate reference system is fundamental to any project, application, service or product that requires some form of georeferencing. Most countries in the world have established such reference systems that are used for national surveying, mapping, photogrammetry, remote sensing, Geographical Information Systems (GIS), development programs, and hazard mitigation (earthquake studies, fault motion, volcano monitoring, severe storms). Many of these national coordinate systems are based on reference figures of the Earth which are somewhat outdated and, when based on a local origin or datum point, are restricted to a particular country , makingcross-border or regional mapping, development, and planning projects very difficult indeed. In some instances, more than one datum has been used within a country. When using modern positioning technology such as GPS, technical understanding and careful mathematical manipulation is required to relate GPS derived coordinates to the national coordinate system upon which national surveying and mapping products and services are based. Many countries are therefore updating these national reference systems to be compatible with the global reference system and the GPS reference system in particular. Extension and densification of the ITRF is largely made possible through GPS. The ITRS is the global terrestrial reference system officially adopted by the IAG;

the WGS84 (World Geodetic System 1984) reference system of the GPS, which is widely used by several communities, is now identical to ITRS at the centimeter level.

The explosive growth of GPS applications and the economics of GPS make it the technique of choice for sustainable geodetic operations, a particularly positive aspect within the developing nations of Africa and elsewhere. The existing global infrastructure operated and maintained by the IGS provides high quality GPS data, products and information resources that can advance the realization of an African continental reference system. It is this framework that is also prerequisite for many multi-disciplinary applications. The IGS supports a number of projects and applications dependent on the robust reference system which are thriving at both global and regional levels[1]. The classic IGS products, based on the global network (Fig. 1), provide information to generate the global plate motion maps (Fig. 2), enable strain and fault motion monitoring for Earthquake hazard research and, and support dense regional GPS arrays (for example, in California and Japan). With a fundamental reference system, GPS can further increase our understanding of complex Earth Science systems as depicted in an appended graphic.

Over recent years there are models of other continents and countries realizing such a system and its benefits; two excellent examples are EUREF (the European Reference System for Europe) [5] and SIRGAS (Sistema de Referencia Geocentrico para America del Sur, a continental reference system throughout South America) [6,7]. Currently a new initiative to join reference networks within North America is being pursued by the national mapping agencies and organizations within the U.S., Canada, Mexico, and the Caribbean nations.

Realization of this reference frame has vast potential in geodesy, mapping, surveying, geoinformation, geomanagement, natural hazards mitigation, Earth sciences, etc. Additionally, the AFREF project will provide a major springboard for the transfer and enhancement of skills in surveying and geodesy and especially GPS technology and applications. Participation of surveyors, engineers, scientists, and geodesists from the involved African countries in all phases of the project is essential.

Furthermore, leadership for such a project must come from within the African professional community. Meetings within Africa to discuss project interest and approach are ongoing and IAG experts and advisors strongly advocate the formation of this project. The IGS and IAG are willing to coordinate international resources and assistance to facilitate such a leveraged activity. It is important for the longer term to ensure that this project will produce established, dedicated African analysis and data information centers, with links between African agencies and other international organizations.

A primary difficulty encountered in efforts to date has been a lack of resources to bring the appropriate people together for detailed project planning and development of the international cooperation, as well as a general lack of resources for the capital equipment costs and training. Venues for the organizational meetings have been generally planned in an ad-hoc manner in conjunction with related meetings, resulting in insufficient time to develop in-depth dialogue. Discussions will continue to take place mostly in this manner as opportunities arise at scheduled conferences and meetings. However, in securing ICSU funding this activity will be formalized and enable serious and dedicated project formulation and implementation to begin.

[1] The variety of multi-disciplinary applications enabled through GPS technology are demonstrated through IGS projects and working groups which include: IGS Reference Frame Densification, Precise Timing And Time Transfer, Atmospheric Precipitable Water Vapor (PWV), Ionospheric mapping and research, Low Earth Orbiter Precise Orbit Determination (TOPEX, CHAMP, SAC-C, JASON, GRACE), Tide gauge benchmark monitoring (long term sea level change and altimeter calibration), International GLONASS Service Pilot Project, Real-time GPS network applications. All of these are well documented in IGS publications.

AFREF Project Endorsement and Progress

There are over 50 countries in Africa, each with different geodetic reference figures of the Earth, datums and coordinate systems, which makes the mapping and planning of regional and continental geospatially related projects an exceptionally challenging task. A number of National Surveying and Mapping organizations as well as programs within the Organization African Unity (OAU), the United Nations Food and Agriculture Organization (UN FAO) and the United Nations Economic Commission for Africa (UN ECA) have recognized the strong need for a uniform African coordinate system. An example of this recognition is the statement set out in Resolution 1 the Subcommittee for Geo-information of the Ministers Council of the ECA Committee on Development Infrastructure (CODI) [8] in July 1999, which states that:

> "National governments are requested to transform their respective national datums to the worldwide WGS84 and International Terrestrial Reference Systems (ITRS) including the determination of the geoid."

In July 2001, the OAU approved a document titled "A New African Initiative: Merger of the Millennium Partnership for the African Recovery Programme (MAP) and Omega Plan" which also identifies the promotion of cross-border co-operation and connectivity as a precondition for the success of the creation of regional and continental infrastructures [9].

Because of the logistic and organizational complexities involved in coordinating the activities of more than 50 countries in such a project, it is has been proposed that the project be organized on a more regional basis, such as North, West, East, Central and South contributing projects. However, these regional projects, as AFREF contributing projects, must share the vision of the whole to ultimately achieve a unified continental system. Two excellent models for this approach are the Northern Africa Reference Frame [10, 11], and the recently initiated Southern Africa Reference Frame (SAREF) [12]. For example, In southern Africa, a recent design for the distribution of the permanent or semi-permanent base stations has been proposed. (Fig. 3). Good communications, electricity supply and a secure and physically stable environment are among the requirements of these permanent base stations.

A key element of this activity within Africa is the Hartebeesthoek Radio Astronomy Observatory (HartRAO), a national facility of the National Research Foundation (NRF) of South Africa. HartRAO is the only multi-techinique space geodetic facility on the continent. It operates a number of GPS stations that contribute to the IGS, along withVery Long Baseline Interferometry (VLBI) instrumentation which provides a critical link for the global VLBI network. VLBI is the only observational source of UT1 and is the key relation between the celestial and terrestrial reference systems, a necessary component of the AFREF geodetic initiative. HartRAO also operates a Satellite Laser Ranging (SLR) station, GLONASS (the Russian based satellite positioning system complementary to GPS) receiver, and a DORIS station of the French system. A combined map of space geodetic locations in Africa is appended.

The IGS, through these and additional cooperating agencies currently has about ten sites throughout Africa that operate continuously and transmit data for analysis on a daily, hourly, and even one-second basis. These provide the skeletal network on which to build the permanent geodetic network for AFREF.

Summary - AFREF Project Objectives:

1. Define the continental reference system of Africa. Establish and maintain a unified geodetic reference network as the fundamental basis for the national 3-d reference networks fully consistent and homogeneous with the global reference frame of the ITRF.
2. Realize a unified vertical datum and support efforts to establish a precise African geoid, in concert with the African Geoid project activities.

3. Establish continuous, permanent GPS stations such that each nation or each user has free access to, and is at most 1000km from, such stations.
4. Provide a sustainable development environment for technology transfer, so that these activities will enhance the national networks, and numerous applications, with readily available technology.
5. Understand the necessary geodetic requirements of participating national and international agencies.
6. Assist in establishing in-country expertise for implementation, operations, processing and analyses of modern geodetic techniques, primarily GPS.

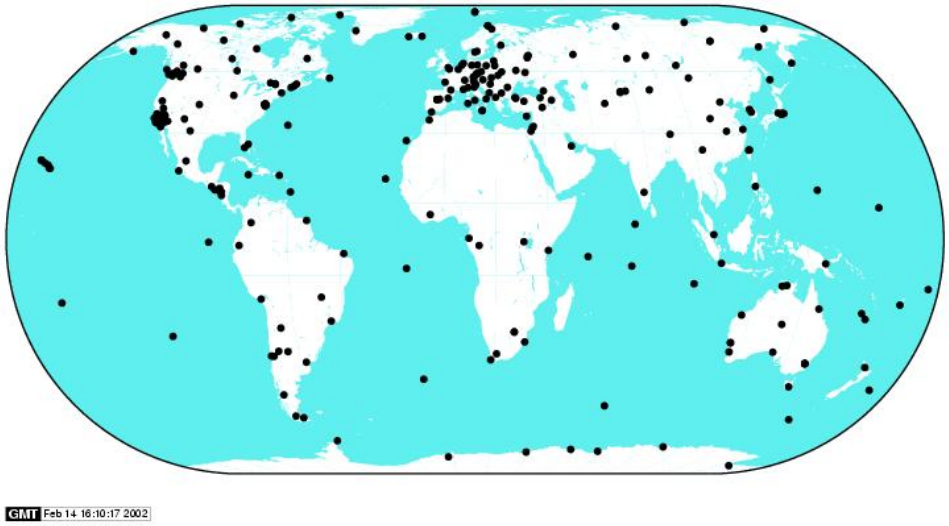


Fig. 1 Map of GPS Tracking Network of the International GPS Service.

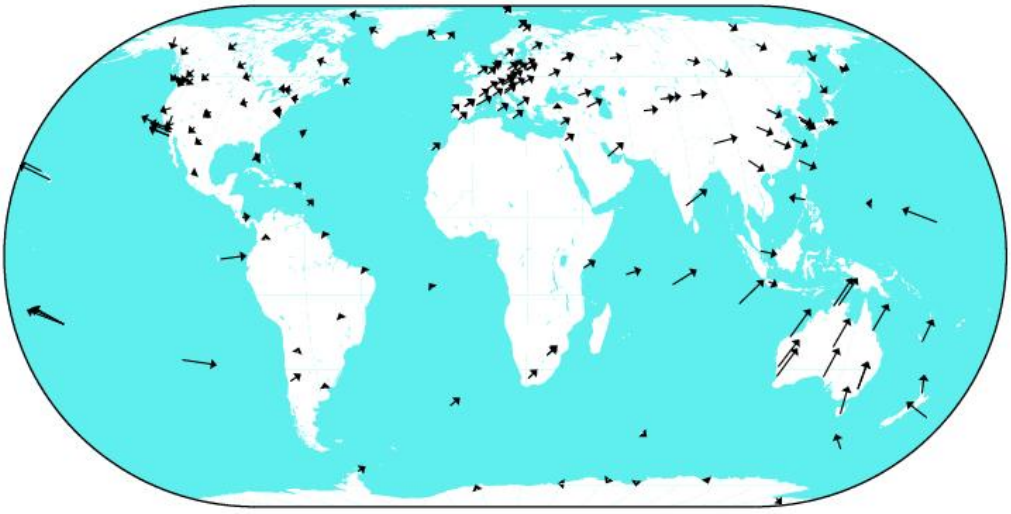
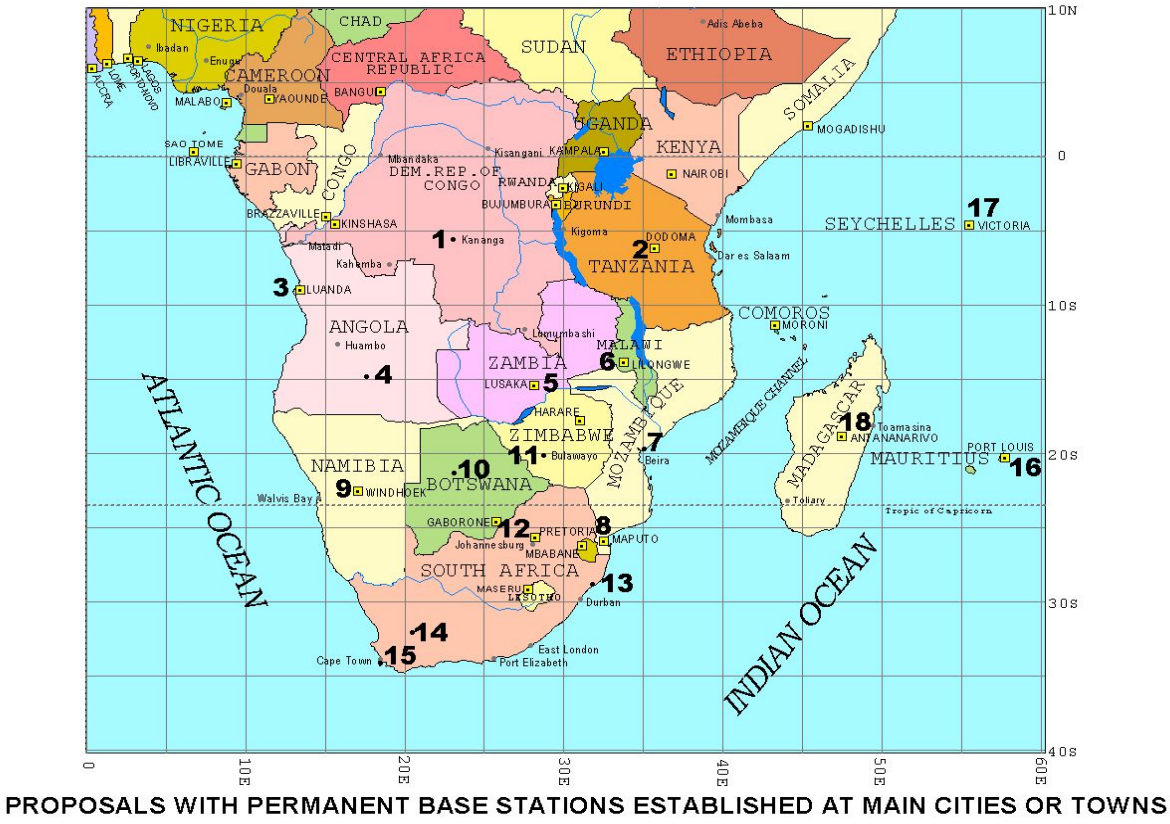


Fig. 2 Tectonic plate motion map depicts the locations and velocities of GPS station locations measured continuously since 1994. Note the absence of long-term observations within Africa.



PROPOSALS WITH PERMANENT BASE STATIONS ESTABLISHED AT MAIN CITIES OR TOWNS

Fig. 3 Map of proposed GPS Stations for southern Africa 'SAFREF' demonstrates a regional approach to AFREF.

ICSU Priority Themes and AFREF

Science and Technology for Sustainable Development

Through support of this AFREF project, ICSU will demonstrate a proactive role in furthering the science and technology critically dependent upon a modern geodetic system within the developing African nations. A key goal of this project is to ensure appropriate technology transfer so that this reference system can be maintained by the African nations. The previous IAG sponsored African Doppler Survey (ADOS) campaign (1981-1986) laid much of the rationale and ground work for a unified geodetic network within Africa; however, the TRANSIT satellite system utilized was not economically viable nor sustainable on a large scale. The next generation satellite navigation system, GPS, and the new era of Global Navigation Satellite Systems (GNSS, such as GLONASS and Galileo) herald an accessible, economical technology that can be fundamentally incorporated into the day-to-day geosystems. To achieve the stated objectives, this effort relies on external assistance for partnerships, training, education, and equipment.

Besides the establishment of a uniform modern reference system for Africa, a key outcome of the 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. In addition to scientific project applications, this will include projects for the development of agricultural schemes, road, rail, power line construction, projects for the supply of water and the control or eradication of disease, hazard mitigation and more.

Capacity Building and Science Education

One of the key requirements for AFREF success is developing a sense of continental (and moreover, global) responsibility in building the framework for current and future science and engineering applications. GPS/GNSS has incredible potential beyond the compelling geodetic justifications: long term climate monitoring, ground-based weather forecasting, long term sea-level trends at the millimeter level, Low Earth Orbiting satellites with on-board GPS receivers which will contribute to much greater understanding of the Earth's gravity field and atmospheric refraction, ionospheric mapping and research, precise timing and time transfer, and so forth.

In order to transfer the technical, scientific and managerial skills required for a project such as AFREF, it is imperative that organizations of Africa, principally the national surveying and mapping agencies, and professionals, professors and researchers in organizations of related science and multi-disciplinary applications be directly involved at all stages and levels of the project. Through the funds provided to this project by ICSU, targeted in-depth educational sessions will be organized and offered so that end-to-end system processes, benefits and applications will be understood, embraced, and managed within Africa.

Science / Policy Interface

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, such as earthquakes, volcanoes, tectonic motion and subsidence along coastal regions; larger arrays are contributing to better understanding of weather systems, and over a longer periods, climate change research. These applications benefit hazard mitigation and response, and these capabilities will enable science and engineering communities to provide relevant advice to policy makers, industry, news media, the general public, and educators.

Dissemination of Information on Science and Technology

This project will improve the dissemination of Earth science information to advance research and education especially within Africa. One of the difficulties to overcome is the general lack of reliable and affordable telecommunications infrastructure within Africa. Through improved outreach and project organization, innovative solutions will be explored and partnerships created to help sustain a productive two-way flow of information. The project will depend largely on existing web sites that contain valuable resources and information; modest augmentations are envisioned over the coming years. For example, the IGS established an AFREF mailing system in late 2000 which archives information for the activity and provides email distribution to the currently ~100 subscribed people [12], while providing direct world wide web access to the information. The extensive IGS Information System is mirrored at the Hartebeesthoek Radio Astronomy Observatory (HartRAO) and can be duplicated at other locations as needed. Sadly, a number of interested people within Africa still do not have regular nor reliable access to the internet. This project will address ways to resolve and improve the accessibility of the information, data, and data products.

Emerging Science and Technology – Creation of new Knowledge

The rich dual-frequency data set gathered by geodetic GPS stations has already proven conducive to novel usage in emerging fields. For instance, atmospheric water vapor causes a signal delay which was initially perceived as a nuisance error term in geodesy, but now climatologists and meteorologists actively pursue precise solutions of the tropospheric terms. African agencies participating in the improvement of the continental reference frame will likewise find the technology beneficial to other pursuits in their countries.

Schedule and Program of Work

2000

March 31	IGS Tutorials on GPS Resources, Cape Town, and Johannesburg (April 3)
April	Meeting in Nice, France, IAG Commission X, AFREF
May 18-20	1st Workshop on Northern African Reference Frame (NAREF), Tunisia
November	AFREF Mail Distribution Service established

2001

March	Meeting in Cape Town, AFREF: Southern Africa
May 26-27	2nd, Workshop on Northern African Reference Frame, Algeria
June 5	Economic Commission for Africa endorses AFREF participation, proposes AFREF workshop in conjunction with Committee on Development Information (CODI)
July 10	Cooperative agreement signed, IAG and OACT
September 7	NAREF Meeting, IAG General Assembly, Budapest
October	UN Office of Outer Space Affairs 'Workshop on GNSS Applications' approve AFREF session, July 2002, Lusaka, Zambia

2002

February	IUGG submits AFREF Proposal to ICSU
April	European Geophysical Society Meeting, AFREF splinter planning session to enlist international support
May	3rd Workshop North African Geodesy, Morocco
July	UN/GNSS Workshop on GNSS, Lusaka, Zambia, AFREF session and follow-on planning session for 2003 activities

2003 ICSU Funding Requested for:

1st quarter	Prepare instructions for planning workshops, preparatory material
	Conduct detailed pilot project planning meetings, 4-5 days (Addis Ababa/Cape Town)
	Development of joint project schedules
	Finalize Call for Participation in the project, obtain commitment of organizations including international support and resources
	Finalize network system design
2nd quarter	Implementation of stations, data center development, communication paths
[June 30-July 11]	[IUGG General Assembly, Sapporo Japan]
3rd quarter	Conduct AFREF pilot project campaign
	Convene in-depth tutorial and data analysis training (1 week) including vertical systems and geoid session (Possibly before or after International Cartographic Assoc. General Assembly to be held in Durban, August 2003)
4th quarter	Assess solution results
	Prepare status report

2004

1st quarter	Prepare and publish first years report
	Pilot Project summary workshop, network, analysis (location(s) tbd)
2nd quarter	Tutorial and seminar, analysis for densification, applications oriented, vertical system and geoid session

2005-2006

Continued project activities to ensure long term viability of AFREF.

Project Plan Description

A flexible approach can be implemented to accomplish the continental reference system for Africa, due to the permanent global infrastructure of the IGS. First, permanent GPS stations within Africa are or can be linked to the highly consistent daily processing of the IGS. A sparse number of these currently exist on the continent and provide a backbone of precise control – it would be clearly beneficial to increase the number of permanent IGS stations within the African area (see Fig. 1, IGS map). Secondly, additional stations are required for the regional densification, such as establishing national GPS networks through either permanent or semi-permanent stations, or through campaign style or single point measurements with mobile GPS receivers.

In contrast to previous GPS network observations where it was important to have an entire network observe simultaneously, it is no longer necessary to do so, though it may be desirable for relating epoch measurements. Through the continuity and permanency of the global GPS infrastructure, observations taken at one time can be linked to observations taken at a subsequent locations and times with little degradation of accuracy. In fact, given the vast extent of Africa and logistical difficulties of coordinating between more than 50 nations, a more regional approach tied to a robust fiducial continental network seems more feasible and prudent. Realizing a *permanent* fiducial network throughout the continent is a top priority.

All subsequent analysis and results can be based on the precise products and orbits produced by the IGS to position stations in the ITRF, as well as providing the basis for transformations between ITRF and any national geodetic datum. By following IGS/IERS recommendations and conventions, centimeter level 3-dimensional positioning can be obtained within this framework.

It is envisaged that regionalization of AFREF will follow an approach that consists of two initial major phases:

a) The establishment of a framework of permanent or semi-permanent GPS base stations throughout the regions which will become part of the world wide IGS network of stations; and

b) 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 ITRS, and to refine the transformation parameters necessary to relate the national systems to a common ITRF.

The conversion of current national and regional mapping products and services to the new ITRF based national geodetic networks will follow from AFREF . At that same time, efforts must address the development of a more refined geoid model for Africa and the definition of a common vertical datum for the continent.

Project Steps

1. Prepare instructions for planning workshops, preparatory material, technical questionnaire and requirements for consideration of joint planning. Identify preparation research that individual organizations must conduct prior to detailed joint sessions.

2. Conduct detailed pilot project planning meetings, 4-5 days (e.g., Addis Ababa/Cape Town); ensuring that principal African contacts participate. Establish AFREF project structure recognizing and depending on regional efforts with African leadership. Develop joint project schedules and contingencies.

3. Based on results of the project planning meetings, prepare and distribute a 'Call for Participation in AFREF' to gain official commitment of participating organizations including contributing international support. Guarantee the requisite committed responsibilities within Africa, and allocation of capital resources from the international community (GPS receivers, communication equipment, monumentation hardware, possibly both non-recurring and recurring costs). Finalize network system design and resource allocation.

4. Implementation of stations, data center development, communication paths through the African organizations and international partners.

5. Conduct pilot project observing campaign, focus on three-month period, with view to sustain permanent operations of select stations.

6. Convene in-depth tutorial and data analysis training/school (1+ week) including vertical system and geoid sessions.

7. Assess solution results, generate a combined solution for all observing stations. Draw on expertise of the IGS Reference Frame Coordinator and the IGS /IERS Analysis Center Coordinators. Prepare project status report, executive summary with recommendations for 'next steps'.

8. Prepare and publish first years technical report with contributions from all participating organizations.

9. Pilot Project summary workshop, network, analysis (location(s) tbd)

10. *Seek out future funding for:* Tutorial and seminar: innovative analysis techniques for densification, precise point positioning, applications oriented, vertical system and geoid session

Budget

Notes: The primary need for ICSU funding of AFREF Project is to bring the principal people together and create a unified project organization. Quoting the communication from Mr. Orlando Nino-Fluck of the ECA concerning the recent CODI meeting:

> "… delegates and observers, particularly from Africa, may not be in a position to fund their sojourn for those days. It is well known that African participants find it difficult to attend meetings where their governments/institutions must bear the cost of participation."

This is particularly true for travel outside of the national boundaries. For AFREF to be successful, the appropriate level of technical personnel must be able to participate in the project organization and training sessions so that the technology transfer is achieved.

Budget detail

All costs are estimated in US dollars. The IAG Secretary General will administer project funds.

Planning Meetings, Workshop, and Education Costs (4 days, + 1 for Summary Session)

Detailed project planning meeting, **Addis Ababa**, expect ~30 participants/observers	$US	$US
Travel/ transportation/lodging/meals, 20 –25 people@ $600 full or partial travel costs dependent on need	15,000	
Facilities costs, UN Conference Center estimate, $125/day @ 5 days	625	
Meeting expenses (document copying, supplies, equipment fees, etc.)	450	
Sub total		$16,075
Project planning meeting **Cape Town**/Johannesburg, expect ~25 participants		
Travel/ transportation/lodging/meals, 15-20 people@ $600 full or partial travel costs dependent on need	12,000	
Facilities costs, $50/day (Univ. of Cape Town or CSDM facilities) @ 5 days	250	
Meeting expenses (document copying, supplies, equipment fees, etc.)	300	
Sub-total		$12,550

AFREF School and Analysis Seminar (6 days)

Seminar, AFREF International School on GPS & Geodesy, location to be negotiated (Addis Ababa, Cape Town, HartRAO) expect max 40-50 participants/10 lecturers	$US	
Travel/ transportation/lodging/meals, 25 people@ $700 full or partial travel costs dependent on need	17500	
Facilities costs, UN Conference Center estimate, $125/day @ 6 days	750	
Meeting expenses (document copying, supplies, equipment fees, etc.), computer/internet connectivity required	1100	
Sub-total		$19,350
Total Project Planning		$47,975

Equipment, Communication and Power Costs

Station distribution goal, at least 1 per country (50+) and IGS stations (~25 with even distribution) that are at most 1000km from any user location.	$US	$US
Ancillary communication equipment fund, establishing and maintaining communications from stations to data centers for the three month observing campaign and to ensure data archive/access integrity (e.g., modems/ wireless modems: $300 - $1,500 ea.; data storage media, hardisk, CDs, firewire drive, etc.). 4 pairs of modems, 8 @ a $1,500 ea Data storage devices and media Communications costs: $450 /station for three months, assume 15 stations need support for data transfer to the data center(s)	 12,000 10,500 6,750	
Ancillary station equipment fund, monumentation hardware, antenna protection, UPS/ battery pwer back-ups for critical locations, estimate 8-10 stations @ $500/station	4,200	
Sub-total *Project experience in these areas will provide budget benchmark justifications for sustaining operations at permanent locations*		$33,450

Publication Costs

Project Executive Summary and AFREF Technical Report Editors are project organizers, assume graphics and publications costs of $7.00 per document for 2500 copies (may be substantially cheaper if printed in Africa)	17,750	
Sub-total		$17,750

AFREF Project Total Funding Requested

Total		**$99,175**

Leveraged Costs

GPS Equipment: It is not intended to purchase any receivers with ICSU funds, but to use the project status to approach international organizations to donate equipment on long-term loan or permanent donation. The project will approach manufacturers to request very competitive and reduced equipment pricing so that the African agencies will have the opportunity to purchase and own outright. The project will also look at other funding sources for equipment costs to support the project.

Salaries of all project members are covered by their home institution, including consulting, seminar and training by international partners. This is a substantial contribution and is difficult to quantify the total cost sharing benefit to ICSU.

Travel of most international participants will be funded by their own organizations, potentially as a pledged budget item once AFREF is recognized as an official international project. (For reference, to date investments over the past two years borne only by the IGS Central Bureau total nearly $24,000 for non-salary costs - travel, tutorial preparation and conduct, meeting expenses in Africa and Europe and US).

Initial website support and training will be through the IGS and participating organizations.

Expected Results

- Unified reference system for Africa, sustainable geodetic network, unified vertical datum.
- Structure for maintaining system and densification for regional and national priorities.
- Publications documenting the project, plans and results.
- Visibility of the project by policy makers and funding organizations for continued financial backing.
- Partnerships with international groups to ensure long term observing system as part of a global system.

Assessment Of Potential Follow-On Actions

AFREF will continue beyond the 2003 timeframe and the project structure will remain active to ensure success. The follow-on actions will be the development and utilization of the related applications referred to in this proposal, as a means for continuing technological advancements within Africa, e.g., climate, weather forecasting, timing and time transfer, longer term sea-level trends, and so forth.

The project will have the organizational strength and stature in follow-on years to successfully seek the resources for the on-going operations and evolution of the African reference system and corresponding precise geoid.

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This proposal is prepared for the IUGG/IAG on behalf of the many interested people who advocate the concept and realization of the African Reference System. This proposal is coordinated by the IGS Central Bureau Director, Ms. Ruth Neilan, and the South African National Representative to the IAG, Chief Directorate of Surveys and Mapping, Director of Survey Services, Mr. Richard Wonnacott.

Appendices

Figures
African space geodetic station locations

Chart of GPS benefits for atmospheric, ionospheric, solid Earth and ocean sciences.

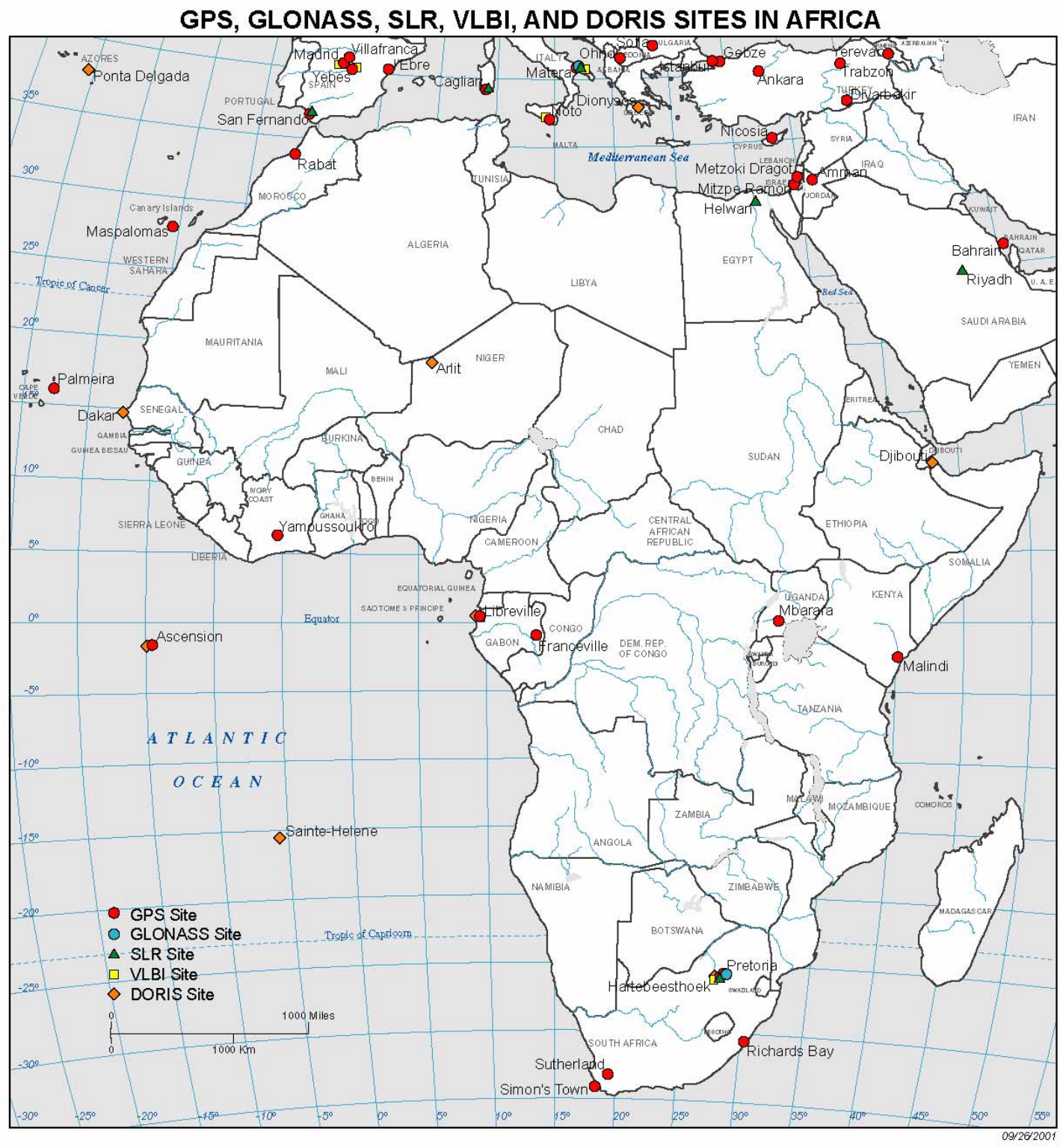
Attached Letters of Support:

International Society of Photogrammetrry and Remote Sensing
Prof. J. Trinder communication to ICSU Secretariat, dated Feb. 21, 2002

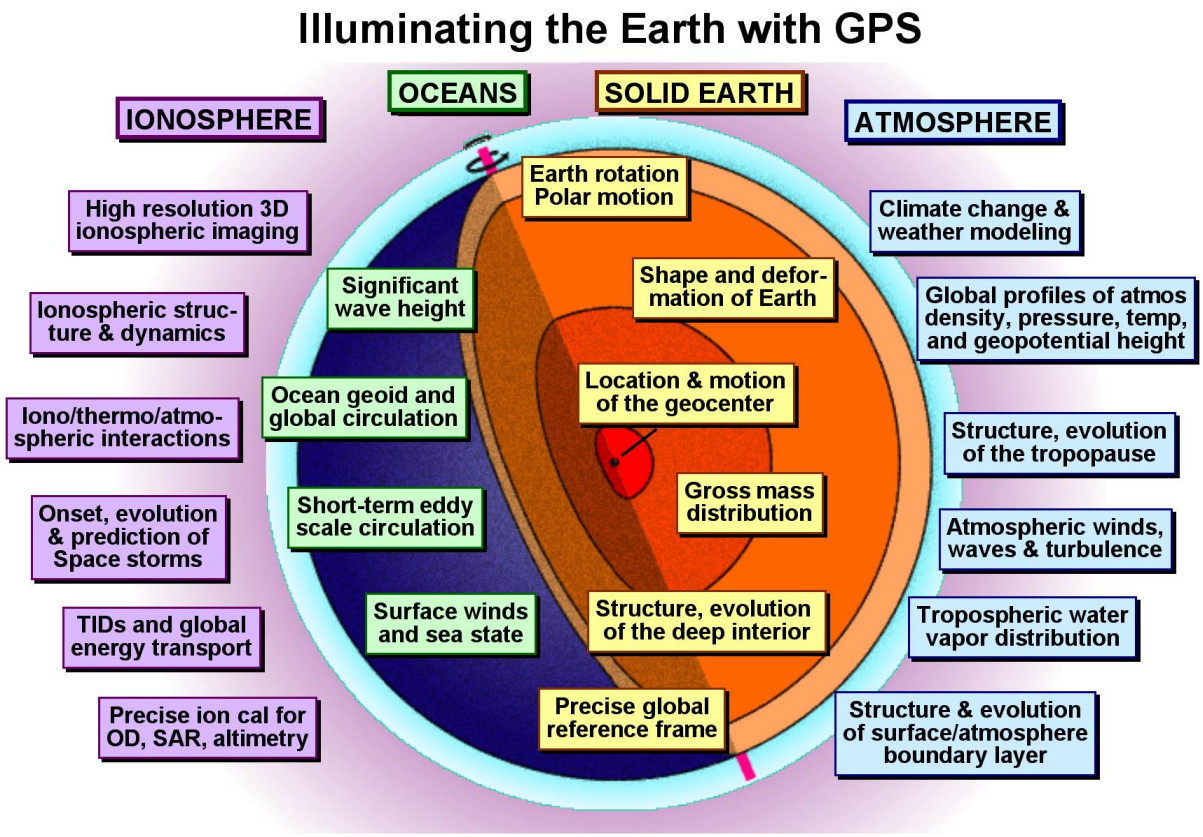
National Research Foundation, South Africa ICSU Secretariat
Mr. R. Kriger communication to ICSU Grants Programme, Prof. T. Rosswell, dated Feb. 21, 2002

Department of Land Affairs, Chief Directorate of Surveys and Mapping
Mr. R. Wonnacott communication to President of IAG, Prof. Sanso, dated Feb 12. 2002

Economic Commission of Africa, Development Information Services Division
Senior Cartographic Officer, Mr. Orlando Nino-Fluck communication to C. Boucher and R. Neilan dated June 5, 2001.



Space geodetic station locations in Africa. The scarcity of stations in Africa are in contrast to those in southern Europe and globally, given the ~7,000km length and width of this continent. Note that all techniques are collocated at the Hartebeesthoek Radio Astronomy Observatory supported by the National Research Foundation of South Africa. *(Figure courtesy of C. Noll, CDDIS, see: http://cddisa.gsfc.nasa.gov/mappage.html)*



With a permanent, modern geodetic reference system in place, many additional applications and multi-disciplinary research investigations can be supported. *(Figure courtesy of T. Yunck, GPS Observatories Office, Jet Propulsion Laboratory, Caltech.)*