Sub-task Number: DA-09-02c
Sub-task Title: Global Geodetic Reference Frames

Overarching Task*:* Data Integration and Analysis
Area: DATA MANAGEMENT
Relevant Committee*:* ADC
Related Targets: Availability of a sufficiently accurate and stable global reference frames is a mandatory prerequisite for most Earth observations.

Sub-task Definition *(as given in the 2009-2011 Work Plan):*

Ensure the availability of accurate, homogeneous, long-term, stable, global geodetic reference frames as a mandatory framework and the metrological basis for Earth observation. Identify steps towards such consistent high-accuracy global geodetic reference frames for Earth observation and the observing systems contributing to GEOSS.

Leads *(GEO Member or PO, Entity carrying out the work, Contact: e-mail)*:

IAG (GGOS), *Point of Contact:* Hans-Peter Plag, hpplag@unr.edu

Motivation/Background:

The ability to assign time-dependent coordinates to points and objects is fundamental for any Earth observation, and these coordinates need to be comparable over long time periods. Most areas of science, Earth observation, and society at large depend today on the ability to determine positions down to the millimeter level. All current global reference frames relay on the availability of the *International Terrestrial Reference Frame* (ITRF), which is the most accurate realization of the *International Terrestrial Reference System* (ITRS). ITRF is maintained by IAG on the basis of globally coordinated, science-oriented infrastructure committed voluntarily by a large number of national agencies and research institutes. The organizational and institutional background for this infrastructure, which is fundamental to GEOSS, urgently needs to be reviewed. Programs for a more sustainable approach, which will ensure continuous availability of a global reference frame meeting the requirements of GEOSS and its users, have to be developed and discussed in the intergovernmental frame of GEO.

Outputs *(e.g. products and services which result from the activities of the Task/sub-task; outlined in the form of deliverables with timelines)*

Planned:

(1) The GGOS 2020 Book "The Global Geodetic Observing System: Meeting the Requirements of a Global Society on a Changing Planet in 2020"; to be published in 2009.

(2) Report "Towards an ISO Standard for ITRS"; to be made available in 2009.

(3) Report "A sustainable framework for the maintenance of ITRF"; to be made available in 2010.

Produced:

(1) The GGOS 2020 will be published by Springer in July 2009. On about 350 pages, the book documents the requirements for observations of Earth's shape, gravity field and rotation as well as the requirements for geodetic products (including the terrestrial reference frame) as they result from many applications in science and society, including the SBAs of Earth observations. Based on these requirements, the book provides functional specifications for a global geodetic observing system meeting these requirements, and lays out principal considerations for the design of the system. Full reference: Plag, H.-P. & Pearlman, M., eds., 2009. *The Global Geodetic Observing System: Meeting the Requirements of a Global Society on a Changing Planet in 2020*, Springer Berlin.

(2) A Working Group has been set up with the charter to write the Report "Towards an ISO Standard for ITRS", see http://www.iag-ggos.org/wgs/itrsstandard.

Activities *(operations or work processes through which resources are mobilized to produce specific outputs; outlined in the form of milestones including timelines)*

Planned:

The user-related activities, which were a main focus of the previous Task AR-07-03, are reported below.

Here we focus on the activities directly related to ensuring the availability of appropriate global geodetic reference frames for GEOSS. Individual steps include:

(1) Identify steps towards ensuring consistent, high-accuracy, homogeneous, and long-term stable global geodetic reference frames for Earth observation and the observing systems contributing to GEOSS (output (3) in 2010).

(2) Advocate the continuous support of the global geodetic infrastructure required for the maintenance and development of the global geodetic reference frames at an appropriate level (on-going).

(3) Critically assess the sustainability of the global geodetic infrastructure and the Services, which are currently based on: the voluntary commitments of a large number of national agencies, research institutions, and individuals, and consider alternative organizational models, including an intergovernmental framework for the maintenance of the geodetic reference frames, which would support the transition to fully operational reference frames (to be completed in 2010).

(4) Consider the potential of regional organizations to address reference frame related challenges in their regions and to stimulate cross-disciplinary solutions (on-going; requires capacity building).

(5) Promote the establishment of sufficient geodetic infrastructure in regions currently lacking such infrastructure, particularly in Africa and parts of Asia and Latin America (on-going; requires capacity building).

(6) Improve the accessibility and applicability of the geodetic reference frames for all GEOSS components (on-going, output (2) in 2009).

(7) Advocate the development and implementation of a global height reference system needed among others for global and regional digital elevation models (to be completed in 2010).

(8) Ensure a terminology for global and regional geodetic reference frames and the availability of tools, including transformations, that improve interoperability.

Progress (current status): …

The GGOS 2020 Book provides an excellent basis for completion of activities (1), (3), and (4).

In the frame of activities (2) and (5), several stakeholder events have taken place and are planned for 2009 and 2010, in which GEO Communities of Practice, GEO Task Teams and other groups are brought together with relevant experts and informed about the potential, benefits, and availability of global reference frames.

A key progress related to activity (6) has been made with the establishment of a working group that will look into the possibility to establish an ISO standard for ITRS as a basis for significantly improved interoperability of reference frames and any Earth observation system depending on geo-referencing.

Resources *(indication of resources – e.g. financial, human – contributed by GEO Members or Participating Organizations to produce outputs)*

Contributions to the task are on several levels:

(1) Member countries (see the list below) provide resources through their national agencies for several activities in the frame of this task, including activities (6), (7), (8);

(2) Representatives of Participating Organizations commit voluntarily their resources to activities in the frame of this task, in particular activities (1) to (5); most of the representatives listed below are in leading roles in their PO and bring in the resources available to the Commissions, Working Groups or Committees they chair;

(3) Invited individuals commit voluntarily their resources to contribute to writing teams for the reports listed under outputs, working groups serving the task, and other activities directly contributing to several of the activities listed above.

Architecture and Data Component

1) Please briefly describe any task-related Earth observation resources (data set, system, website/portal) and any related Web Service interfaces that are contributed to GEOSS. State whether these items are or will be registered with the GEOSS Component and Service Registry for access via the GEO Web Portals, and whether any associated standards or other interoperability arrangements will be registered in the Standards and Interoperability Registry.

The global geodetic reference systems and frames come with a number of standards, conventions, and – in the case of the frames - data sets, which will be registered in the respective GEOSS registries. The IAG Services, in particular, the International Earth Rotation and Reference Systems Service (IERS) and the International GNSS Service (IGS) provide a number of data sets and Web Services relevant for access to the ITRF and ICRF, and these data sets and Services will be registered as well.

2) Please also describe what data and information your activity/system needs that you would request to be accessible through the GEOSS Common Infrastructure.

The maintenance of the global geodetic reference frames and the improvements necessary to meet the continuously growing accuracy requirements requires a Earth system approach in order to account for many interactions of atmosphere, ocean, land water storage, cryosphere, and the solid Earth that all impact the reference frame. Therefore, access to data sets related to mass redistribution and dynamics in these Earth system components (pressure, temperature, wind fields, circulation, land water storage, etc), is crucial for improvements of the reference frame. Currently, no central portal for all these data sets is available. It would be very helpful if these data sets would become accessible through the GEOSS Common Infrastructure.

Capacity Building Component

(capacity building is defined to include the development of capacity related to: (i) Infrastructure and technology transfer (Hardware, Software and other technology required to develop, access and use EO); (ii) Individuals (education and training of individuals to be aware of, access, use and develop EO) and (iii) Institutions – building policies, programs & organizational structures to enhance the value of EO data and products).

1) In accordance with the above definition does this Task have a capacity-building component? If so, please provide a short description of this component including a description of end users.

Although the maintenance and utilization of the global geodetic reference frame involves considerable capacity building efforts, for example through technology transfer to and infrastructure support for developing countries, and through training, the task itself does not have specific capacity building activities. However, the documents to be produced as output of this task, in particular, document 3, will address capacity building issues. Since the maintenance of a global reference frame requires globally distributed infrastructure and since the availability of a global reference frame generates regional and national benefits, there is a mutual dependence between capacity in developing countries and the quality and availability of a global reference frame. These aspects are addressed in activities (4) and (5).

2) Have any additional CB needs for this Task been identified? Please provide a short description.

This aspect of the task needs further development and will be addressed in the near future.

User Engagement Component

(please briefly describe to what extent end users are engaged in this Task and influence the nature of the outputs produced)

In the frame of the previous Task AR-07-03, the following user-related activities were carried out or were anticipated:

User requirement coordination: Establish a comprehensive GEOSS database of user requirements concerning georeferencing and geodetic reference frames by identifying, describing and establishing links to relevant user communities in the nine societal benefit areas and conducting appropriate surveys. Individual steps include:

(1) Identify relevant user groups in the societal benefit areas, including groups of users relevant for several benefit areas, and create a matrix of users, groups of users and benefit areas.

(2) Identify and quantify the requirements of the nine benefit areas with respect to georeferencing and access to a long-term stable reference frame.

(3) Facilitate an assessment of the current status and future requirements for the geodetic reference frames and geodetic observations with particular focus on the needs of the nine benefit areas.

(4) Identify user-oriented capacity building needs within the different user groups with respect to reference frames.

(5) Establish links between representatives of the different user groups within the nine benefit areas and an appropriate expert team to coordinate georeferencing and reference frame issues across these areas.

Most of the results of these activities are documented in the GGOS 2020 Book. The writing team of this book included representatives of numerous user communities in at least seven of the nine SBAs. The database of user requirements will be part of the overall user needs database of GEOSS.

Science and Technology (S&T) Component

1) Please briefly describe the elements of scientific research or technological development contained in this Task.

The global geodetic reference frame is challenged with constantly increasing requirements in terms of stability, accuracy, consistency, and availability. In particular, many observations serving global change research depend on reference frame stable at the 0.1 mm/yr level. At the same time, geodetic observations of changes in Earth's surface (including ocean and ice surfaces), rotation, and gravity field increasingly are utilized for global change research as well as assimilation in forecasting models for weather, climate, draughts, etc. In order to serve all these requirements, constant research and development is required, Science challenges include the integration of different technologies, development of improved or new sensors, and development of more advance Earth system models. Provision of a global geodetic reference frame meeting the current and future requirements crucially depends on addressing the scientific and technological challenges in the field.

2) In relation to the S&T component(s) of this task, please describe gaps, priorities, continuity needs, barriers, scientific expertise and additional resource needs (this information will be used for developing a gaps and needs assessment in Task ST-09-01)

With respect to the global geodetic reference frame, priorities are on improving long-term stability, in particular with respect to the connection of the reference frame to the Center of Mass of the Earth system. The uncertainty in this connection is currently a key contribution to the error budget of, for example, for observations of global sea level changes. Other priorities are on improved accessibility and accuracy particularly for low latency down to real time. Key gaps are not so much in technology but rather in the available infrastructure. The global geodetic tracking networks are maintained based on best effort of many, often associated with science-driven funding, and recent instabilities in these networks due to changing national priorities have caused considerable problems. It therefore must be a priority to maintain these networks consistently over time. Large spatial gaps in the networks limit the accuracy of and the accessibility to the reference frame, and a priority is on reducing these gaps over the coming years, which will require not only funding for new infrastructure but also capacity building in relevant scientific and technological fields.

With respect to the geodetic observations of Earth's surface, rotation and gravity field, which are highly relevant as part of the Earth ocean, cryosphere, atmosphere, and solid Earth observing systems, priority is on maintaining an appropriate combination of ground-based and spaceborne components. Severe gaps hampering science and applications based on these observations, could arise if some of the current mainly science-driven satellite missions would not be continued by follow-on missions. Most critical examples are

satellite altimetry over ocean, land water surfaces, and ice; and satellite gravity field missions crucial for monitoring changes in the global water cycle (including land water storage, ocean, and ice). The large ice sheets have been identified as a key unknown in term of their response to global warming, with potential large impacts on sea level and humanity, and a lack of sufficient monitoring of these ice sheets with satellites would hamper the development of improved dynamical models. The lifetime of the GRACE satellite is projected to be limited to 2012, and not having a follow-on mission would seriously hamper science based on these very valuable observations related to mass redistribution in the global water and energy cycle. Emerging applications using these observations, such as regional water management depend on both continued and improved gravity satellite missions, a stable and accurate reference frame, further integration of the space-geodetic observations, and improved models. Critical gaps are in the infrastructure as well as the available integrated models.

Members and POs' Contributions to Outputs and Activities above:

Germany
Bundesamt für Kartographie und Geodäsie (BKG): Introduction of a global reference system, provision of IERS Products, eg ITRF2005.

Portugal
University of Beira Interior /Instituto D. Luíz (UBI/IDL): Focus on the link with regional (continental) reference frames.

USA
NOAA's National Geodetic Survey is the lead federal agency with respect to U.S. geodetic reference frames.

GGOS
With the global geodetic reference frames, the *International Terrestrial Reference Frame* (ITRF) and the *International Celestial Reference Frame* (ICRF), GGOS provides the metrological basis for all Earth observations independent of the targeted benefit areas. These reference frames depend on considerable global infrastructure comprising not only the global *in situ* networks of several space-geodetic techniques (GNSS, VLBI, SLR, DORIS) with up to 400 stations in more than 80 countries, and gravimetric techniques, but also the GNSS satellites and, increasingly, dedicated satellite missions, like, for example, GRACE . In total, an estimated 500 person years/year are provided on a best effort and voluntary commitment basis by national operational and research institutes to maintain the networks, data centers, analysis centers and user interfaces, that are required to determine and maintain the reference frames as well as to make them accessible for a wide range of applications.

Maintaining a terrestrial reference frame at the level that allows, for example, the determination of global sea level changes at the sub-millimeter per year level, pre- co- and postseismic displacement fields associated with large earthquakes at the sub-centimeter level, timely early warnings for earthquakes, tsunamis, landslides, and volcanic eruptions, as well as the monitoring of mass transport in the Earth system at the few Gigatons level requires an Earth system approach, encompassing all Earth sciences. Among others, this has recently been acknowledged by IGOS-P, for which a proposal for an Earth System Dynamics Theme is in preparation. In particular, this activity will contribute to the items 1.1 and 1.2 of the task description.

Currently, GGOS is facing an increasing demand from science, the Earth observation community, and society at large for improved services, observations and products. Most of these requirements are in terms of improved accuracy, in particular, instantaneous accuracy, better reliability (including liability), and improved access to the reference frame. The IAG and GGOS are aware of the enormous challenge implied in the demand to improve the accuracy from an average level of close to 10^{-9} to an instantaneous level (with daily or higher temporal resolution) of 10^{-10}, which is required in order to meet emerging user requirements. Therefore, GGOS is currently carrying out a strategy process (denoted as GGOS 2020) which aims to provide the scientific basis for an implementation of the geodetic observing system that will meet the requirements of the society at large and GEO and IGOS-P in particular. This activity will lead to the first delivery of the task. Taking into account that the geodetic observations and products are relevant at least for

the GEO benefit areas of water, disasters, energy, weather, climate, health, and agriculture, and that the GGOS is a major component in the architecture of GEOSS, GGOS 2020 facilitates the assessment of the GEO requirements for the reference frames (items 1.1 to 1.4) as well as the status of the GGOS as a basis for the development of the geodetic frames and services such that they meet these requirements (items 2.3 and 2.4). The resulting strategy document and accompanying reference document will provide a basis for the dialogs that will take place under items 2.1, 2.2, and 2.5.

As a consequence of the growing demands for georeferencing in a wide range of applications, on the one side, issues are raised concerning reliability and continuity of the geodetic products, as well as liability of the providers. On the other side, funding for the global geodetic infrastructure depends on the national decisions and priorities in many countries and this implies considerable fluctuations, sometimes threatening the proper maintenance of the reference frames and the IAG Services. GGOS therefore has started a dialog at international level, for example with UNESCO, and at national level with various agencies in order to assess the need for an intergovernmental framework for the reference-related activities. This dialog is a part of the task and through the task linked to other GEO activities. This activity contributes to items 2. 1 and 2.2.

IAG

A number of activities in the IAG Commissions are relevant for the task. Specifically, the work of IAG Commission 1 (Reference Frames) is directly supporting the Task. One of the main objectives of IAG Commission 1 is the definition, establishment, maintenance and improvement of the geodetic reference frames. Commission 1 role is in particular to facilitate research and development activities that impact the reference frame determination and its accuracy as well as the best and optimal usage of reference frame in Earth Science applications. A dedicated web site of Commission 1 is available at http://iag.ensg.ign.fr.

Within each regional sub commission, Commission 1 encourages and assists countries to re-define and modernize their national geodetic systems, to be compatible with the ITRF. These activities are conducted within each regional sub commission by Working Groups in charge of the transformations between their respective regional/national reference frames and the global ITRF. More details are available at the web page mentioned above.

For the Task and GEO, a registry of geodetic reference frames is highly desirable. For three years the IOS TC211 Geographic Information/Geomatics has striven to establish an ISO Registry for Geodetic Codes and Parameters, based on ISO19135 "Registries for geographic information". The IAG is liaison member in TC211, and one of the Task team members is a IAG representatives to the TC211. A number of the ISO Standards of the 19100 family are important for the Task. In particular, ISO 19111 is relevant for describing coordinate reference systems and ISO 19115 for the provision of meta data attached to geodetic products. IAG has become active in the framework of the TC211 from the mid-nineties especially with the development of the standard 19111 "Geodetic referencing by Coordinates". Later, there was the project 19127 "Geodetic Codes and Parameters" and the results were published as Technical Specification.
In 2008, an agreement was reached on the essential main features of an ISO Registry for Geodetic Codes and Parameters. The respective Control Body is being built up under the leadership of the IAG.

Concerning a world height system, which is relevant for a number of GEO Tasks, an IAG InterCommission Project has been established in 2007 with an anticipated duration of four years: ICP 1.2 Vertical Reference Frames. The main issues for the realization of a world height system are:

- Discussion of the results of ICP1.2 (GGOS action);
- Initiation of a pilot project for an International Vertical Reference System (IVRS) realization on the basis of the TIGA Pilot Project of the International GNSS Service, the Global Geodynamics Project, and the International Gravity Field Service (IGFS, call for participation as an IGFS action);
- Further development of the Conventional Vertical Reference System (CVRS);
- Decision about numerical standards as task of GGOS in cooperation with the International Astronomical Union (IAU) and international hydrological associations.

The project shall be realized in cooperation with other organizations, especially the International Association of Hydrological Sciences (IAHS), the International Association for the Physical Sciences of the Oceans (IAPSO), the International Hydrographic Organisation (IHO), and the International Federation of Surveyors (FIG).

United Nations Economic Commission for Africa (ECA)

AFREF Project

ECA - AFREF

ECA effort to develop AFREF is carrying out through a long-term commitment. In collaboration with the Ghana Institution of Surveyors, the International Federation of Surveyors (FIG) and other partners, a workshop was organized on AFREF during the 5th FIG Regional Workshop in Accra, Ghana, in March 2006. In July 2006 a technical workshop, co-sponsored by 6 organizations incl. IAG, UNAVCO, UNOOSA, was convened in Cape Town, South Africa. More than 40 delegates and 15 presenters attended. In August 2007 an other technical Workshop was organized in collaboration with RCMRD with the support of the University of Lisbon, the University of Beira-Interior (Portugal) and Hart RAO. Attended by representatives from 8 countries mainly from East Africa, the workshop dealt with GNSS reference stations and processing of GNSS data. Leica and Trimble, two leading corporations in the market of GNSS receiving stations have donated respectively three and five GPS permanent stations to the International Steering Committee of AFREF. The three Leica GPS stations were installed within RCMRD, RECTAS and in Ghana. The installation of the five remaining stations is on-going in each of the five ECA's Sub-regional Offices in Africa. A new proposal has been drafted, in conjunction with AU, to bring the AFREF project under the structures of the African Ministerial Council of Science and Technology.

Work to be performed:

1. Geodetic reference: Implement the African Reference Frame (AFREF) through the establishment of a network of permanent GNSS reference stations to be used for computing the parameters of an African Geocentric Datum, and to be used as base stations for satellite positioning in Africa.
2. 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.
3. Realize a unified vertical datum and support efforts to establish a precise African geoid, in concert with the African Geoid project activities;
4. Establish continuous, permanent GNSS stations such that each nation or each user has free access to, and is, at most, 1000km from such stations;
5. Determine the relationship between the existing national reference frame or frames and the ITRF to preserve the legacy geospatial data and information based on the existing reference frame:
6. Provide a sustainable development environment for technology transfer, so that these activities will enhance the national networks, and numerous applications, with readily available technology; and
7. Assist in establishing in-country expertise for the implementation, operation, processing and analysis of modern geodetic techniques, primarily GNSS.

AFREF Project deliverables:

- A network of permanent GPS reference stations that will define the African Reference Frame for practitioners to use for position determination, and forming part of the global geodetic infrastgructure. The stations will conform to IGS standards, continuously collecting data and transmitting same to relevant data processing centres.
- A network of regional data processing centres to receive data from stations in their respective regions, process them and transmit the processed data to a designated main data processing and archiving facility.
- A data archiving and dissemination facility to compute parameters for the African reference frame and disseminate it continuously to users.
- A network of African and European Geodesists sharing lessons and working together to realize the objectives of the AFREF project, extend and densify the network, and continuously compute and disseminate improvements and corrections to the parameters of the African reference frame.

Participation:

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