GEO, GEOSS and IGOS-P: The framework of global Earth observations

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Abstract

The last four decades have seen an initially slow but recently increasingly rapid programmatic development in Earth observations on global scale, with the acceleration mainly being due to a growing awareness of the political and societal leaders of the need for comprehensive Earth observations in support of their quest for sustainable development. As a starting point for this development, the first World Summit in Stockholm in 1972 can be identified, where the importance of Earth observations was emphasized. In 1992, the World Summit in Rio de Janeiro, Brazil, confirmed the need for comprehensive Earth observations both in its Agenda 21 and the United Nations' Framework Convention on Climate Change. Important steps following this Summit were in the early 1990ies the initiation of the Global Climate, Ocean, and Terrestrial Observing Systems (GCOS, GOOS, and GTOS, respectively), and the development towards an Integrated Global Observing Strategy (IGOS), with the latter emphasizing stable, homogeneous, long-term observations and the necessity of a transition from research to operational monitoring. In 1998 the establishment of the IGOS Partnership (IGOS-P) brought together most major global providers, users, and funding agencies in Earth observation.

The last five years have seen a very rapid progress: Following up the recommendations of the recent World Summit on Sustainable Development in Johannesburg, South Africa, in 2002, the first Earth Observation Summit (EOS-I) was held in Washington, DC, in July 2003. EOS-I initiated an unprecedented effort towards coordination of global Earth observation. Through its declaration, EOS-I established the *ad hoc* Group of Earth Observation (*ad hoc* GEO) with the task to draft within 18 months a 10-year Implementation Plan for the Global Earth Observation System of Systems (GEOSS). Guided by the Framework document adopted by EOS-II, held in Tokyo in April 2004, the *ad hoc* GEO drafted the requested plan together with a reference document containing many details of the envisaged GEOSS. including climate. This Implementation Plan was adopted by EOS-III in February 2005 in Brussels, which also established GEO permanently. The presence is dominated by the first steps towards an implementation of GEOSS, which is to a large extent built around the nine societal benefit areas identified by the EOS-II Framework document. The benefit areas include climate, water, and disasters, which heavily depend on geodetic observations. In parallel to this global development, IAG has developed the concept of a Global Geodetic Observing System (GGOS). As a Participating Organization in GEO, IAG was involved in designing GEOSS and contributes to the implementation of GEOSS with the goal to develop GGOS consistently with the needs of GEOSS for a maximum mutual benefit. Moreover, GGOS has been established as a partner in IGOS-P. The goal is to integrate GGOS as the umbrella for the IAG services appropriately into a rapidly developing Earth observation framework for the benefit of the global society. IGS, on the one side, provides crucial contributions to GGOS, and, on the other side, can greatly benetfit from improved framework conditions expected from GGOS links to IGOS-P and GEO.

1 Introduction

A deep understanding of the complex Earth system is a basis for the development of strategies for a sustainable management of the planet and the protection and preservation of its environment and climate for future generations. Sufficient monitoring of the Earth system is one of the cornerstones required to ensure sustainable development. The last two decades have seen the emergence of many global or regional programs and activities directed towards monitoring of the environment. However, until very recently, monitoring the Earth system was strongly subdivided and organized according to disciplines and subsystems. A major disadvantage of this lack of integration was the nearly complete absence of the integrated data sets required for the study of Earth system processes. Consequently, science programs or projects aiming at a better understanding of system processes were and currently often still are forced to build up such integrated databases first.

Currently, the monitoring system is still characterized by a number of sub-networks with spatial and temporal heterogeneities and with a lack of coordination and cooperation across disciplinary boundaries. The ground-based component consists of meteorological, hydrological, oceanographic, geophysical, geodetic and chemical networks, with the number of operational stations varying in time. Additionally, a significant amount of data is collected in campaign-type measurements at varying time intervals and locations. All these sub-networks produce data sets which are inhomogeneous due to spatial and temporal heterogeneities in the station distribution, and due to variations in the observation procedures including the sensors and recording equipment. Problems due to these inhomogeneities are exemplified in Ellsaesser et al. (1986) using the station temperature observations at land and sea sites. For a sustainable monitoring, the problem of long-term homogeneity is a crucial one.

Over the last two decades, a strong space-borne component has been introduced into the monitoring. The nearly complete spatial coverage of most of the remote sensing satellites has greatly improved monitoring. However, in terms of sustainable monitoring, the limited lifetime of the satellites and sensors, and the high costs of most of the missions, are severe limitations likely to introduce temporal heterogeneities into the data sets. Space-borne sensors require a long planning phase. The high risk during launch easily can introduce significant gaps if a launch turns out to be unsuccessful, like the recent launch of CryoSat. In many cases, only single sensors exist, and the danger of processing errors and miss-interpretation is high.

Major early milestones towards more integration of the observing systems were the definition of the *Integrated Global Observing Strategy* (IGOS), and the establishment of three *Global Observing Systems* (G3OS) in the context of the *United Nations Framework Convention on Climate Change* (UNFCCC). Most recently, the work of the *ad hoc Group on Earth Observations* (*ad hoc* GEO) led to the first steps of the implementation of the *Global Earth Observation System of Systems* (GEOSS), which has the aim to be a unifying and integrating umbrella for the existing systems.

Here, we will first briefly review the development that led to the establishment of the *ad hoc* GEO (Section 2) and report on the work of this *ad hoc* group (Section 3), before we introduce the *Group on Earth Observation* (GEO) and the *Integrated Global Observing Strategy Partnership* (IGOS-P) in Sections 4 and 5, respectively, and then summarize the input that global Earth observations requires from geodesy (Section 6). Subsequently, in Section 7 we address the relevance of this context of global Earth observation for the *Global Geodetic Observing System* (GGOS), which acts as IAG's interface to global Earth observations. Finally, we will consider the role of IGS for the contributions of GGOS to global Earth observation, and the links between GGOS and IGS in Section 8, before we end with recommendations concerning that relation in Section 9.

2 The Pre-Geo Era

As a starting point of the current rapid development in Earth observation, the first World Summit in 1972 in Stockholm could be seen. As a consequence, UN programs for a more comprehensive monitoring of the Earth as a whole were started, namely the Earth Watch programme of UNESCO. In the same year, the landmark report 'Limits of Growth' was published by the Club of Rome (Meadows et al., 1972), and the ensuing discussion of mankind's future was dominated by fear of a growing population running out of resources for further economic developments. Twenty years later, when the second World Summit took place in Rio de Janeiro, Brazil, in 1992, two other landmarks had refocused this discussion towards a recognition of the Earth's limits to absorb the waste and impacts of an increasingly more active anthroposphere, in particular, the limit of the climate system to absorb the output of an economy based on fossil fuels without major changes in climate. In 1987, the so-called Brundlandt Report 'Our common future' (World Commission on Environment and Development, 1987) revitalized the concept of Sustainable Development, which recognizes the finite nature of the Earth system, establishes the need to preserve the quality of the system from generation to generation, and postulates the right of equal access to resources, both through space and time. It is appropriate to state that this report marks the starting point of mankind's quest for sustainable development. A year later, UN Agencies together with the *World Meteorological Organization* (WMO) established the *Intergovernmental Panel on Climate Change* (IPCC), thus formally recognizing that climate change inflicted by anthropogenic changes in the Earth system could be one of the major threats for a sustainable development. It also marks a change in the political arena, in that political decision makers established a large international scientific body with the goal to get information about the state of the Earth system as a basic input to their decision making.

Among the major outputs of the 1992 Earth Summit in Brazil are the UNFCCC, and the Agenda 21. The latter directed the international economic and societal discussion at political level since then. Among many other important aspects, the Agenda 21 identified the gap between data on the one side and information needed by the decision makers on the other side, and demanded a bridging of this gap. Following the Summit, the three *Global Observing Systems* (G3OS) were initiated with the *Global Climate Observing System* (GCOS) and the *Global Ocean Observing System* (GOOS) sponsored by UNEP, ICSU, IOC, and WMO, and the *Global Terrestrial Observing System* (GTOS) sponsored by FAO, UNEP, UNESCO, ICSU, and WMO.

As a strategic foundation for these observing system the IGOS developed (see e.g. Williams & Townshend, 1998). A major focus of the strategy was the transition from research-oriented to operational sustainable monitoring (Dahl, 1998), which would ensure long-term datasets which were homogeneous in time. Around this IGOS, a partnership of users (mainly UN agencies), providers (space agencies and science organizations), and funding groups evolved (Smith, 1998), which in June 1998 was formalized through the exchange of Letters of Understanding as the IGOS-P.

Within IUGG, in 1995 an attempt was made by IAG to make progress towards a more integrated geodetic and geophysical observing system but unfortunately rejected by IUGG. Subsequently, the IAG Symposium 'Towards a Integrated Global Geodetic Observing System' held in October 1998 in Munich is a major landmark. This meeting greatly facilitated the ensuing discussion of the concepts of a global, integrated geodetic and geodynamic observing system (Rummel, 2000), which over the next years clarified the main ideas and concepts. IUGG in 2003 followed IAG and promoted the establishment of the *Integrated Global Geodetic Observing System* (IGGOS), which was later renamed into GGOS.

In 2002, the World Summit on Sustainable Development in Johannesburg, South Africa emphasized the urgent need for coordinated Earth observations relating to the state of the Earth as a mandatory input for the global political discussion of the road towards sustainable development. This Summit marks the start of what can be called the *ad hoc* GEO era.

3 The Beginning: The *ad hoc* GEO Era

Following up the outcomes of the 2002 World Summit, the G8 Meeting in Evian in June 2003 affirmed the importance of Earth Observations and called for immediate actions. Already in July 2003, the *First Earth Observation Summit* (EOS-I) took place in Washington, DC, with a participation of 33 countries plus the European Commission and 21 international organizations. This summit initiated an unprecedented global effort towards coordination of global Earth observation. At this meeting, the *ad hoc* GEO was established and tasked with the development of an initial 10 year implementation plan for an appropriate Earth observation system within only 18 months by February 2005.

Up to April 2004, supported by a small secretariat, the main work of the *ad hoc* GEO took place in five technical subgroups, and during three GEO meetings. A major step was made in April 2004, when the *Second Earth Observation Summit* (EOS-II) in Tokyo bringing together 43 countries plus the European Commission and 25 international organizations adopted the so-called 'Framework Document' (see Annex 2 in GEO, 2005b, for the full text), which defines nine societal benefit areas for Earth observations. From then on the work of GEO was focused around these benefit areas. By February 2005, a small writing team supported by the GEO subgroups and several GEO plenary meetings had drafted the "10 Year Implementation Plan" for what was named the *Global Earth Observation System of Systems* (GEOSS). This Implementation Plan (GEO, 2005a) was adopted together with the Reference Document (GEO, 2005b) at the *Third Earth Observation Summit* (EOS-III) held in Brussels in February 2005. At this meeting, the permanent *Group on Earth Observation* (GEO) was established and tasked with the implementation of GEOSS. This event marks the beginning of what is called here the GEO Era.

The Implementation Plan and the Reference Document are built around the nine benefit areas defined by EOS-II. The Vision for GEOSS *is to realize a future wherein decisions and actions for the benefit of humankind are informed by coordinated, comprehensive, and sustained Earth observations and information.* It is this vision that can be sensed throughout the two documents. It is also visualized in Figure 1, which illustrates the interaction of GEOSS with science and societal users.

IAG had joint the *ad hoc* GEO at EOS-II in April 2004, with the President of IAG and the Chair of GGOS being the principal representatives. IAG also named a number of representatives to work in the GEO subgroups. This small team of IAG representatives contributed to the development of the Implementation Plan and ensured, among other aspects, that the importance of the geodetic reference frame for GEOSS is appropriately reflected in the Implementation Plan.

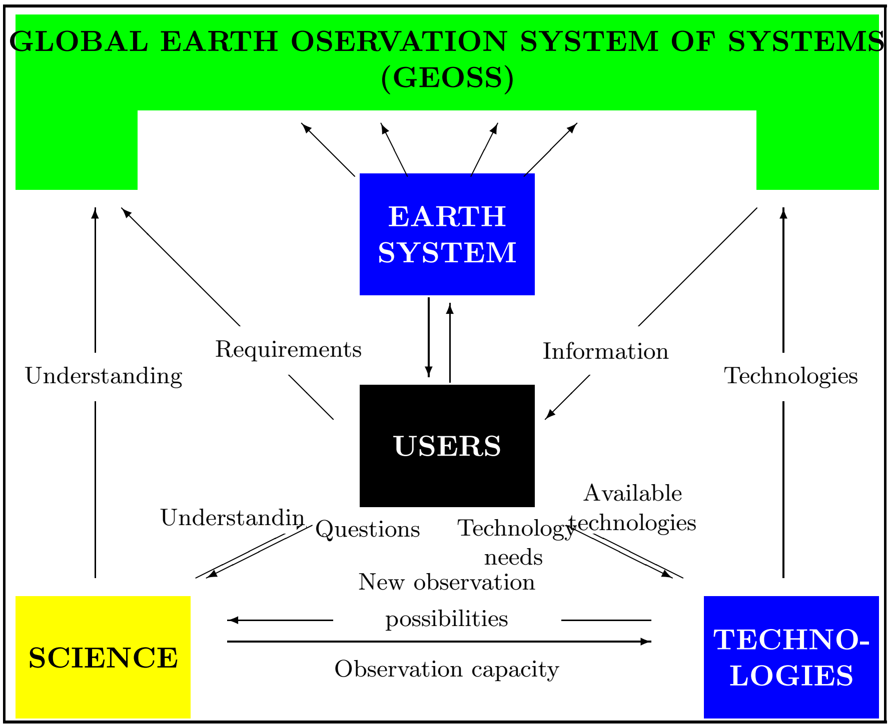

Figure 1: The vision of GEO and the role of GEOSS in Earth observation.

4 The GEO Era

Since EOS-III, much of the activities related to global Earth observation have been centered around the definition of what GEO is, how it should work, and what GEOSS actually will be based on and deliver. The first major event after EOS-III was GEO-I, which took place in Geneva in May 2005, with the discussions focusing on the internal structure of GEO, the missions and rules for its working groups, as well as the main priorities for the first year.

In December 2005, GEO-II took place, again in Geneva, with now 60 Member States and 43 Participating Organizations. Major achievements at that meeting were the finalization of the structure and mission of the Committees and Working Groups, including the acceptance of Terms of Reference for these functional elements. Moreover, the work plan for 2006 was accepted as a 'living document' to be developed further by the Committees in the first part of 2006.

The current structure of GEO is sketched in Figure 2. More information about GEO and its structure can be found at the GEO Web Page at http://www.earthobservations.org.

Prior to GEO-II, GEO had received more than 150 new applications from organizations that wanted to participate in GEO. Overwhelmed by this huge interest, GEO decided not to accept new Participating Organizations until clear rules had been established for the acceptance of new organizations. In the light of this decision, it appears to have been a positive step of IAG to join the *ad hoc* GEO at an early stage in its development, together with organizations such as UNESCO, UNEP, WMO, CEOS, IGOS-P, IEEE, WCRP, IGBP, ICSU, and IUGG.

Since GEO-II, the Work Plan for 2006 has undergone a very rapid process in which the details of 96 single tasks were refined and the participating members and organization

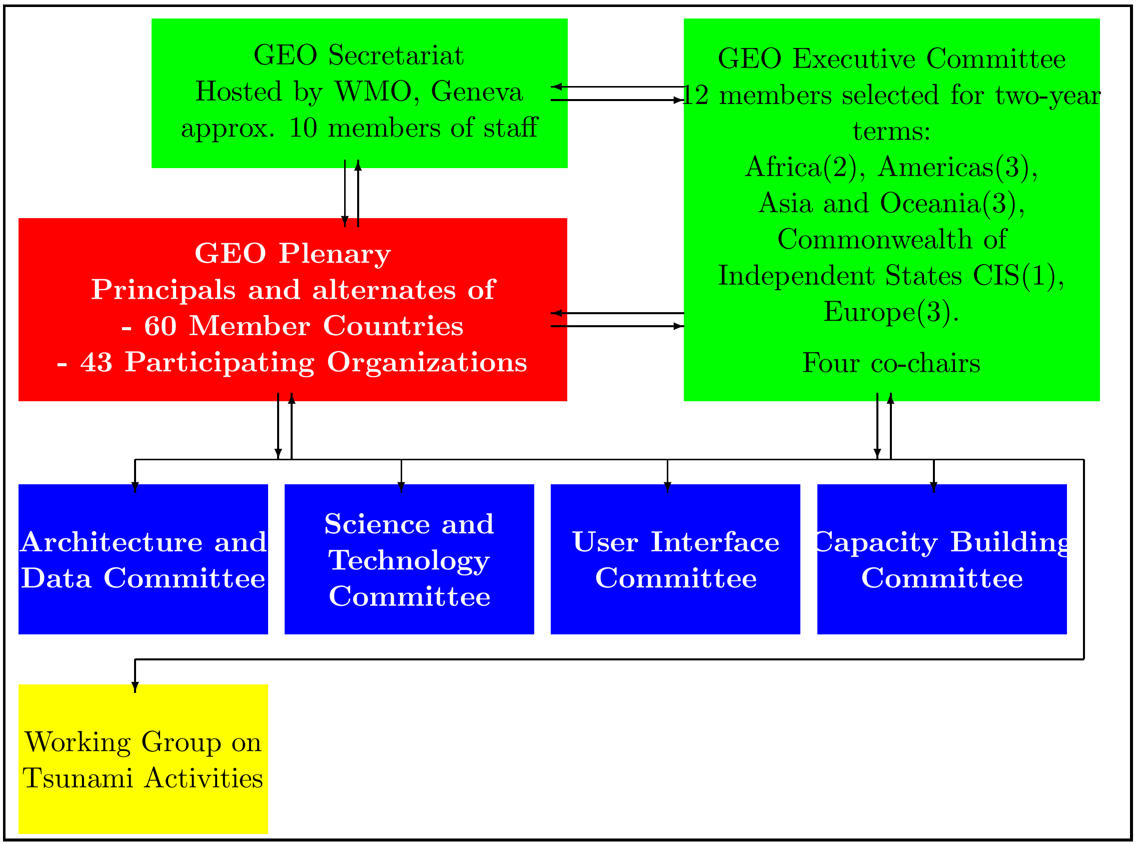

Figure 2: Organizational components of GEO.

identified. IAG is involved in a number of tasks, and some of these are directly related to IGS activities.

It should be mentioned here that the role of GEO is still under discussion. In particular, there is not yet a common understanding of what GEO actually should do. Should it be an organization that mainly facilitates activities carried out be others? Should it take a lead in coordinating Earth observation activities and programs? Or should GEO actually implement and operate services? There is a tendency among its members to focus more on the first and maybe the second role, i.e. to foster, by creating appropriate framework conditions in the member countries, Earth observation, and to coordinate international activities, where this appears to be appropriate. An example for the latter is the GEO Working on Tsunami Activities, which was established shortly after the December 2004 Sumatra earthquake and tsunami with the task to coordinate the international activities to establish and improve the tsunami warning systems.

5 IGOS and IGOS-P

In the pre-GEO Era, the development of IGOS as a strategy for the G3OS and the establishment of the IGOS-P may be considered the most important development in international Earth observation activities. IGOS-P is a non-governmental organization, and as such complementary to the intergovernmental GEO. IAG and IUGG have realized the importance of IGOS-P and already in the resolution that established GGOS expressed the goal to achieve membership status for GGOS in IGOS-P.

The IGOS, which was developed from 1995 onward as the strategy for the G3OS, aims at sustainable, comprehensive monitoring of the Earth system. This monitoring is characterized by long-term stability, an operational mode, homogeneity in time, multi-parameter sites, global coverage and participation, integrated observation and data sets, accessible databases, and the transition from research to operational.

IGOS-P defines itself as a partnership of organizations that are concerned with global environmental change issues (see http://www.igospartners.org). The Partnership seeks to provide a comprehensive framework to harmonize the common interests of the major space-based and in situ systems for global observations of the Earth. Its aim is to provide an overarching strategy for conducting observations relating to climate and atmosphere, oceans and coasts, the land surface and the Earth's interior. The Partners intend to build upon the strategies of existing international global observing programs and current achievements, in seeking to improve observing capacity and deliver observations in a cost-effective and timely fashion. IGOS-P efforts are generally directed to those areas where satisfactory international arrangements and structures do not currently exist.

IGOS-P focuses on a theme approach to define the Integrated Global Observing Strategy. The goal of IGOS-P is a (small) number of themes with strong linkages to critical societal issues. Currently a number of themes exist or are in the planning, namely the themes concentrating on the observation systems for carbon cycle, atmospheric chemistry, ocean, the global water cycle, geohazards, coast (including Coral reefs), cryosphere, and land. Of these, several themes have direct requirements for geodetic observations:

- The Geohazards Theme (Marsh & the Geohazards Theme Team, 2004): Plate tectonics, pre-, co- and post-seismic strain, processes associated with volcanoes, early warning for tsunamis, subsidence, precarious rocks, landslides, and local and regional predictions of sea level rise are examples of topics that link this Theme to geodetic observations.
- The Ocean Theme (IGOS-P Ocean Theme Team, 2001): Ocean circulation, sea level rise, isostasy, dynamic sea surface topography, are linked to the three geodetic quantities, both for the monitoring and studies of the ocean's variability as well as model validation.
- Water Cycle Theme (Lawford & the Water Theme Team, 2004): The geodetic observations provide a unique tool to monitor the global to local scale movements of water through the Earth system and the Theme is strongly linked to geodesy.
- The Coast Observation Theme : Sea level and ocean circulation are relevant parameters influencing the dynamic processes in the coastal zone and linking the Theme to geodesy.
- The Cryosphere Theme (Barrie & the IGACO Writing Team, 2004): Ice mass balance, glacial isostasy, and induced sea level variations all are important parameters, that are directly observed by the geodetic observation techniques.
- The Land Theme (Townshend & the IGOL Writing Team, 2004): Changes in the elevation are directly observed by geodetic techniques.

In 2004, GGOS made a first step towards membership in IGOS-P. IGOS-P requested more clarifying information, and during 2005, with support from UNESCO and the IGOS-P Geohazards Theme, IGOS-P was informed about the potential contribution of GGOS to the IGOS-P Themes (Plag et al., 2005, 2006). During its meeting in November 2005 in London, IGOS-P accepted GGOS as a new member, pending two minor actions. GGOS

Table 1: Requirements for geodetic observables for the nine benefit areas.
The status is indicated with the follow classes: 0: ok; 1: marginally acceptable accuracy and resolution; 2: could be ok within two years; 3: could be available in six years; 4: still in research.

Observable quantity	Status
Deformation monitoring, 3-D, over broad areas	3
Subsidence maps	3
Strain and creep monitoring, specific features or structures	2
Gravity, magnetic, electric fields - all scales	3
Gravity and magnetic field anomaly data	2/3
Groundwater level and pore pressure	4-1
Tides, coastal water levels	1
Sea level	2-1
Glacier and ice caps	2
Snow cover	2
Moisture content of atmosphere/water vapor	2
Extreme weather and climate event forecasts	3
Precipitation and soil moisture	3-1

was awarded membership status during the IGOS-P meeting in May 2006 in Geneva. This step carries a significant international recognition of GGOS as an important component in the system of global observing systems.

With respect to IGOS-P, GGOS is currently discussing two issues:

- How can GGOS link and contribute to the existing themes, in particular those that have clear links to geodesy?
- Should there be a new 'Earth System Dynamics' Theme focused around mass transport in the Earth system and associated dynamics?

The latter would be a theme developing the strategy for mainly the integration of the geodetic observation techniques across the three pillars of geodesy into a system for the observation of mass transport in and dynamics of the Earth system.

Within IGOS-P, the process of themes selection is regulated by the IGOS-P Process Paper (available at http://www,igospartners.org). The process of establishing a new theme is long, normally between 18 and 24 months. As a main output, themes provide the implementation plan for a theme-related observing system, and initiate steps towards the implementation.

6 What does GEO, GEOSS and IGOS-P need from geodesy?

The Framework document resulting from EOS-II, which formed the basis for the 10-year Implementation Plan for the GEOSS (GEO, 2005a) and the associated Reference Document (GEO, 2005b), identifies nine societal benefit areas for Earth Observations (see Appendix 2 in GEO, 2005b). For each of these areas the Reference Document list the requirements in terms of observables and an assessment of the status of the observational capacity. Extracting the quantities potentially provided by geodesy, results in the list compiled in Table 1. This list shows that geodesy will be a major contributor to GEOSS. Moreover, a geodetic reference frame, which is not explicitly mentioned in any of these requirements, is indispensable for GEOSS to reach its goals.

Modern geodetic observations of the three fundamental geodetic quantities, that is the Earth's figure (geometry), its gravity field and its rotation, allow the detection of mass movements in the Earth's subsystems with unprecedented accuracy and with high temporal resolution. Thus, these observations link the subsystems together and provide a truly global monitoring of mass movements and the associated Earth system dynamics. Observations of the displacements of the Earth's surface furnish records of the movements and deformations associated with atmosphere and ocean dynamics as well as earthquakes, volcanos, tsunamies, natural and man-made subsidence, landslides, and other potential hazards.

The internationally coordinated geodetic observations result in a global terrestrial reference frame, which is determined and monitored on the basis of observations provided continuously by the geodetic station networks. This well-defined, long-term stable, highly accurate and easily accessible reference frame is the basis for all precise positioning on and near the Earth's surface. It is the indispensable foundation for all sustainable Earth observations, *in situ*, as well as air-borne and space-borne.

In summary, geodesy provides a unique frame for the monitoring, understanding and prognosis of the Earth system as a whole. Modern space-geodetic techniques are inherently strong on global to regional scales and thus constitute an important complement to traditional *in situ* observation systems.

7 GGOS: IAG Interface to global Earth observation

Over the last decade, IAG has established a system of services (see Plag et al., 2005, for an overview), which provide a number of products to a wide range of scientific and non-scientific users. These services have established considerable observing infrastructure, comprising global ground-based networks of observing sites, dedicated satellite missions, data and analysis centers and web sites giving access to the products. Organizationally, most of these geodetic services are based on the 'best effort' principle and depend on the contributions of globally distributed institutes.

In order to establish a coherent geodetic observing systems and thus to meet the user requirements in a consistent and efficient way, the IAG is currently integrating all existing global geodetic observation infrastructure into GGOS. The GGOS as proposed by Rummel (2000), Rummel et al. (2002), and further developed by Beutler et al. (2003) "*aims at maintaining the stability of and providing the ready access to the existing time series of geometric and gravimetric reference frames by ensuring the generation of uninterrupted time series of state-of-the-art global observations related to the three pillars of geodesy*". This system will provide on a global scale the spatial and temporal changes of the three pillars (geometry and kinematics, Earth orientation and rotation, and gravity field and its variability). The system will allow the determination and maintainance of a terrestrial reference frame with higher accuracy, much improved temporal stability, and consistency across the three pillars. On the basis of the observations provided by GGOS, it will be possible to determine mass movements in the atmosphere, the ocean, and the terrestrial hydrosphere as well as in the Earth's interior. The way to achieve this goal is long and will require considerable developments, both in observational capabilities and physical modeling, including theoretical developments. In particular, the transition from a mainly research-based and science-driven system to an operational, user-driven system will deserve special attention.

GGOS provides the metrological basis for Earth sciences. Moreover, GGOS is an unique contribution to the monitoring system in its capability to provide sufficient information on the dynamics of the solid Earth and its fluid envelop on all relevant spatial and temporal scales. The accuracy level targeted by GGOS for the three fundamental geodetic quantities (and their mutual consistency level) is 10^{-9} or better. At this level of accuracy, a wide variety of mechanical interactions between the different Earth system components are relevant and need to be treated consistently. In this respect, modern geodesy requires a holistic system approach to the dynamics of the Earth and involves expertise from all Earth sciences in the analysis and interpretation of the geodetic observations. GGOS is IAG's tool to facilitate this approach across the three pillars of geodesy.

From an organizational point of view, GGOS is particularly needed as the unique interface between GEOSS and other users on the one side and the IAG Services on the other side (Figure 3). Participation of IAG in GEO will foster the implementation of GGOS. For the GEO Workplan 2007-2009, IAG has proposed a task focusing on the improvement of the framework conditions for the determination and maintenance of the geodetic reference frames. The membership of GGOS in IGOS-P supports the development of GGOS in line with the IGOS and facilitates a proper linkage between GGOS and other existing and developing Earth observation systems, such as GEOSS. In order to further detail the science basis for GGOS, GGOS has taken a first step to propose a specific IGOS-P Theme addressing the dynamics of the Earth system from a focus on mass movements. It is the objective of the suggested 'Earth System Dynamics' Theme to provide the science basis for the implementation of GGOS and to ensure that GGOS can be fully integrated in the frame of IGOS. Most importantly, the theme will ensure that GGOS meets the user requirements both from the other IGOS-P Themes and the nine societal benefit areas identified by the EOS-II.

8 Why is GEO, GEOSS and IGOS-P relevant for IGS?

With more than 60 Member Countries, GEO represents a major fraction of all users in the field of Earth observations. It addresses most of the societal needs requiring Earth observations. It can be expected to influences the framework conditions for Earth observations. GGOS as a Participating Organization in GEO will foster improved conditions for the IAG Services, including IGS. Through GGOS, IGS will be linked to GEOSS and thus to many other systems as users.

IGOS-P comprises expertise from all field of Earth sciences in the various themes. GGOS, through its membership in IGOS-P gains access to this expertise, which will help to develop the GGOS implementation plan in a way benefitial for the IAG Services. IGOS-P themes constitute interfaces to relevant societal user groups and facilitate an observing system design focused on their needs. It can be expected that the Earth system dynamics theme to be proposed by GGOS will possitively impact the implementation of GGOS.

IGS is central to GGOS for various reasons: it provides a crucial contribution to the determination of the global terrestrial reference. With its GNSS tracking network, it monitors the changes in Earth's geometry with high spatial resolution. With its products, it provides access to the ITRF with increasingly lower latency. IGS will also be central in meeting the challenge in providing an instantaneous accuracy of 10^{-9} or better for the reference frame and the access to it.

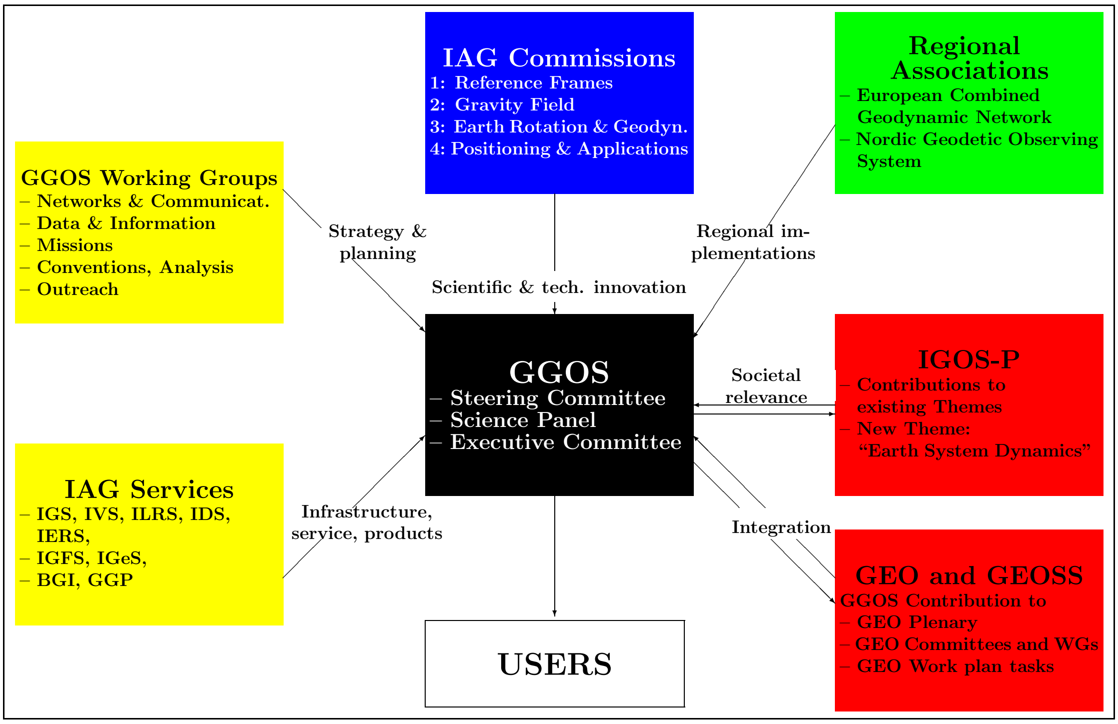

Figure 3: GGOS: The IAG Interface to Earth observation.

Among others, GGOS is the IAG interface to the global Earth observation community, of which a major part is represented by GEO and IGOS-P. GGOS is build upon the IAG Services. The GGOS Working Groups provide the strategy and planning for GGOS, while the IAG Commissions contribute scientific input and techological innovations. Emerging regional associations will facilitate the regional implementation of GGOS.

The integration of IGS into GGOS is a win-win situation: on the one side, IGS contributes to the determination and monitoring of ITRF, provides access to ITRF, and contributes to the monitoring of Earth's geometry. On the other side, GGOS provides links to major user groups, helps to consolidate the user requirements, and ensures consistency of IGS with other geodetic services across the three pillars. Not least, GGOS contributes to improved visibility of the geodetic services in the society and eventually to improvements of general conditions for geodetic infrastructure.

9 Conclusions and recommendations

Current global Earth observation activities are dominated by the first steps towards an implementation of GEOSS. GEOSS is unique in that it is a system that is "ordered" by a global cooperation of its users, that is currently more than 60 Member Countries. GEO is the intergovernmental body building GEOSS. It is interesting to note that this body is open for non-governmental Participating Organizations. It is likely that GEO will be the major global coordinating body for Earth observation systems.

IGOS-P brings together major users and providers of Earth observation, including the relevant United Nations agencies, space agencies, global observing systems, as well as the funding agencies. Based on the Theme approach, IGOS-P develops the plans for observing systems responding to specific societal needs. Moreover, IGOS-P facilitates the steps towards the implementation of these systems. Being non-governmental in its nature, IGOS-P is complementary to GEO and works closely together with GEO.

IAG is participating in these major activities in Earth observations. One goal for IAG is to ensure that the geodetic observing system is developed consistently with the needs and progress of GEOSS for a maximum benefit. IAG has delegated the representation in GEO and IGOS-P as well as the contribution to GEOSS and the IGOS-P Themes to GGOS. Thus, GGOS is IAG's interface to Earth observations, and particularly to GEO and IGOS-P. In these functions, GGOS links the IAG Services to major user groups. GGOS integrates the three pillars of geodesy.

IGS is a crucial component of GGOS, and success of GGOS depends on the ability of IGS and GGOS to exploit the mutual benefits, which the current development offers for both. IGS is expected to be central in meeting major challenges faced by GGOS, including the improvement of the current mean accuracy of ITRF (mean coordinates and velocities) on the order of 10^{-9} to an instantaneous accuracy of better than 10^{-9}, both in determination and access. Important steps towards this ambitious goal are an improved link between future ITRF versions and the IGS frames and higher accuracy of real-time access to ITRF. Moreover, in the frame of GEOSS, quality information and assurance for IGS products will increasingly be of importance. It is recommended that IGS addresses these issues in close coordination with GGOS.

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