GGOS and it User Requirements, Linkage and Outreach

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Abstract

The *Global Geodetic Observing System* (GGOS) is going to be the interface between the IAG services and a wide range of external users ranging from the *Global Earth Observation System of Systems* (GEOSS) over the European *Global Monitoring for Environment and Security* (GMES) Programme and the Themes of the *Integrated Global Observing Strategy Partnership* (IGOS-P) to practical application in monitoring of infrastructure and the control of processes. Taking the user requirements (UR) compiled by the different IGOS-P Themes and GEOSS as a starting point, a detailed set of URs for the GGOS products is derived. The URs are specified in terms of spatial and temporal resolution, accuracy, and latency. The analysis of the URs reveals that GGOS is facing a rather demanding set of URs ranging from high accuracy observations of the Earth's surface displacements in near-real time to long-term observations of Earth system parameters such as gravity, Earth's rotation and sea level over several decades.

In order to integrate GGOS into on-going programs such as GEOSS and IGOS-P and to enable users to fully exploit the products and services offered by GGOS, outreach activities are a central issue for GGOS, including educational measures. A suggested IGOS-P Theme centered around mass transports in the Earth system and the associated dynamics has considerable potential to achieve the integration of GGOS into the main global Earth observation programs and to enable the full implementation of GGOS.

Keywords:*Global Geodetic Observing System, User requirements, Global Earth Observation System of Systems, Integrated Global Observing Strategy*

1 Introduction

Geodesy is in a transition of methods brought about by the advent of space-geodetic techniques and the combination of these with rapidly improving communication technologies and capacities. The development in computer technology, data communication, satellite based positioning and navigation creates many new opportunities and increases the demand for geographical information technologies. Cooperation between countries, globalisation, and increasing international transport demand uniform geodetic reference frames as a basis. In fact, such a reference frame, sufficiently accurate, homogeneous in space and time, and easy to access and use, is a prerequisite for an effective support of many of the existing and emerging applications. Despite a general unawareness of the public of geodesy and its services, the current economic benefit of the geodetic infrastructure and the future potential is astonishingly large: a recent study of the requirements for the national geodetic infrastructure in Canada (Williams et al., 2005) concluded that the Canadian Spatial Reference System (CSRS) contributes directly 60 to 90 billion dollars annually (7 to 10%) to Canada's Gross Domestic Product and several economic fields depend heavily on the CSRS. The study also diagnosed that geodesy is in a revolution based on the ability to determine highly accurate and reliable point coordinates in a global reference frame 'ad hoc', emphasizing the importance of the *International Terrestrial Reference Frame* (ITRF).

Geodesy also is fundamental in the frame of Earth observation as the provider of both the global reference frame and observations of the fundamental geodetic quantities, that is the Earth's geometry, its gravity field and its rotation (see Plag et al., 2006, for a more details). Recently, this has been widely acknowledged in the process of setting up the *Global Earth Observation System of Systems* (GEOSS, see GEO, 2005b). The geodetic quantities and their temporal variations are observed with space-geodetic techniques using a combination of space-borne and air-borne sensors and *in-situ* networks. After three decades and an increase in accuracy of more than three orders of magnitude (Chao, 2003), the space-geodetic techniques are apt to observe the integrated mass transport in the Earth system and particularly the global water cycle, as well as the dynamics of the system and the kinematics of the surface with unprecedented accuracy. The geodetic observations thus provide a truly global monitoring of mass movements as well as the associated Earth system dynamics.

The last few years have seen a rapid programmatic development in Earth observations on global scale. Following up the recommendations of the Johannesburg conference, the first *Earth Observation Summit* (EOS-I) was held in Washington, DC, in July 2003 and initiated an unprecedented global effort towards coordination of global Earth observation. Through its declaration (see Annex 1 in GEO, 2005b), EOS-I established the *ad hoc Group of Earth Observation* (GEO) with the task to draft a 10-year Implementation Plan for the GEOSS. Subsequently, this *ad hoc* GEO met six times, and, supported by several Subgroups, the requested plan was drafted (GEO, 2005a) together with a reference document containing many details of the vision for GEOSS (GEO, 2005b). This Implementation Plan was adopted by EOS-III in February 2005 in Brussels. The work of GEO was guided by the Framework document adopted by the EOS-II, held in Tokyo in April 2004 (see Annex 2 in GEO, 2005b). This Framework document identifies nine major societal benefit areas of Earth observations (Box 1).

The *International Association of Geodesy* (IAG) over the last decade has set up a number of successful technique-specific services that provide valuable observations and products to scientific and increasingly non-scientific users (for a brief overview, see Plag et al., 2006). The internationally coordinated geodetic observations carried out by the IAG Services 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, and highly accurate 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. Recognizing the need for a consistent treatment of the geodetic observations across technique-specific boundaries in a Earth system approach and also the need for a unique interface for users to the geodetic products, the IAG in 2003 established the *Global Geodetic Observing System* (GGOS, see next section).

The presence is dominated by the first steps towards an implementation of GEOSS. IAG is involved in this process in order to ensure that GGOS is developed consistently with the needs and progress of GEOSS for a maximum mutual benefit.

The development of the scientific basis and the implementation of GGOS needs to be guided by a well defined and consistent set of user requirements (UR). The level to which these URs are met by the available observing system, including the generation of higher level products, is an important indicator for the assessment of global, regional and national geodetic infrastructure. In several countries, assessment studies have been carried out (e.g. Williams et al., 2005; Plag, 2006). However, a thorough specification of the global geodetic infrastructure that would meet a wide range of user requirements is still missing. A first step towards such a specification is to set up specific URs in terms of accuracy, resolution, latency, and availability for the geodetic observations and products.

In the next Section, the role of GGOS as an interface to global geodesy will be discussed briefly. In Section 3, the URs particularly from Earth Observation and scientific applications will be considered. The linkage of GGOS to its main user groups is sketched in Section 4, and in Section 5 recommendations related to the implementation of GGOS are given.

2 GGOS: the external interface to users

GGOS is envisaged as the unique interface for a wide range of external users. A main task for GGOS will be to ensure that this interface is fully interoperable with other systems contributing to GEOSS. Considering that IGOS-P will be a major driver in the development of the scientific basis for Earth observation systems, GGOS is intended to contribute to the IGOS-P Themes (see Plag et al., 2006).

Internally, GGOS will facilitate a fully consistent data processing, quality control and modeling. GGOS also has the task to advocate standardization of products for a better service for the users. GGOS is envisaged to be an umbrella for the existing services. Like GEOSS, GGOS has the important task to identify gaps and deficiencies and to facilitate the necessary steps to close the gaps and remove the deficiencies. GGOS also has the task to identify the external users and their requirements, as well as to promote new products and the transition from data to information, as required by the users. The structure of GGOS will have to reflect this set of tasks very clearly.

3 The users and their requirements

For Earth observations in general, the awareness of the benefit of the observations and knowledge of the requirements decreases with distance to the observation system (G. Foley, 2004, personal communication). Scientists involved in studies of the Earth system are mostly fully aware of their needs with respect to Earth observation. However, the end users involved in decision making normally show little awareness of the requirements for Earth observations.

For GGOS and the geodetic contribution to Earth observation, this lack of explicit knowledge of the requirements is even more pronounced. In fact, geodesy faces specific challenges with respect to the UR. On the one hand, users are often not aware of their needs with respect to geodetic observations and products. They are often not aware of the fact that they are using tools that would not be possible or less practical without geodesy providing crucial input. On the other hand, IAG services and GGOS evolve in a mainly scientific environment (affiliation to IUGG and ICSU) without clear links to an increasing group of non-scientific users. The ITRF is the basis not only for scientific applications but also for Earth observation and, increasingly, other applications, though often not recognized by the users. With respect to reference frames, the user groups and URs are fairly well known internally in IAG and Earth science, but far less externally in the wider range of societal applications. For Earth system observations, user groups are less known, and URs in the frame of GEOSS are unclear, particularly for long-term observations.

The Subgroup *User Requirements and Outreach* of the *ad hoc* GEO discussed the URs for Earth observations, and a number of UR studies were stimulated, mainly on national level. Generally, the goal of these studies was to identify the extent to which Earth observations are required for societal applications. For example, an extensive inquiry carried out in Canada revealed a clear need for Earth observations across a broad range of societal areas, but the results were complex and hard to interpret in terms of quantitative requirements (Béchard, 2005, personal communication).

Access to highly accurate geodetic positions is fundamental for many scientific and non-scientific applications. This is equivalent to requiring access to an unique, technique-independent reference frame decontaminated for short-term fluctuations due to global Earth system processes. Providing instantaneous and *ad hoc* access to highly accurate positions in such a unique, global, long-term stable reference frame would considerably ease present applications and support many new applications, particularly if combined with the rapidly developing communication tools and geo databases. *Global Navigation Satellite Systems* (GNSS) techniques are, in principle, able to provide such positions relative to a unique, global reference frame *ad hoc*, that is without simultaneous measurements at local reference points. However, only the integration of the space-geodetic techniques into a consistent system monitoring the Earth surface kinematics, rotational perturbations and gravity field changes will eventually enable the realization of the reference frame as well as the determination of the surface velocity field with sufficient accuracy and long-term stability required for the utilization of the full potential of *ad hoc* positioning.

GEO advocates an strongly user-driven approach to the implementation of GEOSS (see GEO, 2005b), which may serve as a guideline for GGOS. GEO recommends to establish and maintain a distinct and common UR database. The database will be oriented on the CEOS/WMO database of URs and observation system capabilities, and it will be ensured that the database provides a mechanism for the analysis of gap. GEO will use the WMO approach of *Rolling Review of Requirements* (RRR) as a basis.

The study of the URs for geodetic observations and products has to address three key areas, namely

- **Earth observation for sustainable development**, which includes a global component that allows the derivation of information on all spatial scales from global to local and from short time scales of warnings for extreme events and disasters to long-term predictions;
- **scientific applications** that study the Earth system on all spatial and temporal scales; and
- **non-scientific applications** including surveying on land and in the ocean, mapping of the Earth's surface, steering of processes, monitoring of infrastructure and environmental parameters, and navigation.

Here we will focus mainly on the requirements resulting from Earth observation and scientific applications. The former can be derived on the basis of the requirements of the nine benefit areas identified by GEO (see Box 1) as well as the requirements discussed in the frame of the IGOS-P Themes (see Plag et al., 2006). The latter are linked to key scientific problems currently studied in the wide range of Earth sciences. A discussion of the URs from non-scientific applications can be found in e.g. Plag (2006).

Currently, there is a broad political and scientific consensus that comprehensive monitoring of the Earth system is a crucial prerequisite for sustainable development. The monitoring techniques need to be developed within the research community and transformed into operational activities. The necessary properties of a sustainable monitoring include long-term stability, operational mode, homogeneity in time, multi-parameter sites, global coverage and participation, and integrated observation and data sets.

The GEO Reference Document (GEO, 2005b) provides for each of the nine benefit areas an overview of the requirements in terms of observable and status of the observational capacity. Many of these requirements include or depend on quantities provided by GGOS (see Table 1 in Plag et al., 2006). The next step is to convert the information provided in the

– Disaster: reducing loss of life and property from natural and human-made disasters
– Health: understanding environmental factors affecting human health and well being
– Energy resources: improving management of energy resources
– Climate: understanding, assessing, predicting, mitigating, and adopting to climate variability and change
– Water: improving water resource management through better understanding of the water cycle
– Weather: improving weather information, forecasting, and warning
– Ecosystems: improving the management and protection of terrestrial, coastal, and marine ecosystems
– Agriculture: supporting sustainable agriculture and combating desertification
– Biodiversity: understanding, monitoring and conserving biodiversity

Box 1: The nine societal benefit areas identified by EOS-II (see Appendix 2 in GEO, 2005b).

GEOSS Reference document into URs in terms of accuracy, latency and resolution. A number of the requirements are being discussed in the frame of the IGOS-P Themes. Currently, IGOS-P has several approved themes and others are in the planning or proposal stage (see Plag et al., 2006). These themes address different components of the Earth system, different processes, or different societal issues. In general, all these themes will address space-borne or air-borne observations that require highly accurate positioning of the sensors. Thus, the themes are linked to the global geodetic networks through their requirements for access to an accurate and stable reference frame. The relevant themes potentially benefiting to a considerable extent from observations of the fundamental geodetic quantities are those addressing dynamics and mass transport in the Earth system or being affected by these processes (see Plag et al., 2006).

Here we emphasize only two of the themes, namely the Geohazards and the Global Water Cycle Themes. Geohazards such as earthquakes, volcanic eruptions, landslides, subsidence, and precarious rocks are intimately connected to displacements and deformations of the Earth's surface (Marsh & the Geohazards Theme Team, 2004). Thus, key observing techniques for an anticipated integrated solid Earth observing system complementing the existing systems such as GOOS, GCOS and GTOS would have to be the geodetic techniques capable of observing surface displacements on local to global scales at the highest possible accuracy. The existing global and regional geodetic networks, in fact, could provide the basis for such a *Solid Earth Observing System* (SEOS). For the purpose of the Geohazards Theme, SEOS would have to rely on a strong global component providing the stable reference frame as well as the technologies and products required to get easy and reliable access to this frame. This is one of the prime objectives of GGOS. The required frame and associated products are today partly available through the IERS and the other IAG services, particularly the IGS. However, the part of SEOS dedicated to geohazards would also have to be flexible in spatial and temporal resolution, as well as readiness on demand. In many parts of the world, dedicated ground-based networks are needed, some of them on temporary basis (e.g. at certain volcanoes, in areas with unstable slopes and large rocks), which could be established under the guidance of GGOS in coordination with the Geohazards Theme.

Of particular importance for monitoring surface deformations with high spatial resolution is *Interferometric Synthetic Aperture Radar* (InSAR). The establishment of an international InSAR service has been suggested as an important step towards coordination, capacity building, and the transition to operational applications. A link between InSAR and the global terrestrial reference frame through integration of GNSS and InSAR is a step that would greatly improve the applicability of InSAR for monitoring of surface displacements.

A major process moving mass throughout the Earth system is the global water cycle. Changes in the distribution of water stored on land, in the ocean and in the atmosphere affect geodetic observations related to the time-variable gravity field, shape and rotation of the Earth. At time scales of months to a decade, loading of the solid Earth by fluids dominates non-secular variations in the geodetic observables. Space geodetic observations on surface mass variability are inherently strong at the regional to global scale and thus provide a unique tool to complement traditional in-situ measurements of terrestrial water storage.

The *Global Geophysical Fluid Center* (GGFC) of the IERS was established in acknowledgment of the interactions between the solid Earth and its fluid envelop and the necessity to understand these interactions in order to improve the interpretation of the geodetic observations. Thus, the satellite gravity field mission, already provide new insight into the motion and storage of water in the different components of the Earth system. InSAR is increasingly applied to monitor surface displacements induced by changes in groundwater levels. The GNSS are increasingly used to extract information on atmospheric water contents from regional networks.

The Water Cycle Theme report (Lawford & the Water Theme Team, 2004) acknowledges that a strategy for a water cycle observing system will have to rely to a large extent on contributions from geodetic techniques, and in particular, from GGOS. Moreover, geodetic techniques such as in-situ gravity measurements and InSAR will also have to be integrated, particularly for the management of water resources.

The report *Living on a Restless Planet* (Solomon & The Solid Earth Science Working Group, 2002) gives an excellent overview of the many scientific problems that need to be solved in order to better understand the Earth system processes that affect human well-being. The understanding of these processes and their interactions is a prerequisite for sustainable development. With respect to the Earth system processes, a number of scientific questions and problems can be identified, that are associated with mass transport and thus with changes in the gravity field and displacements of the solid Earth's surface. The certainly incomplete list given in Box 2 is indicative of the scientific problems that benefit directly from geodetic observations.

Based on the current state of the art in the different areas, it is possible to derive specific requirements in terms of accuracy, spatial and temporal resolution, and long-term reproducibility for the geodetic quantities that would allow for an improvement in our scientific understanding of the problems. Table 1 compiles some of these requirements given at a high level. The list of relevant quantities includes but is not limited to 3-d displacements and velocities of the Earth's surface, strain rates, the static geoid, temporal variations of the Earth's gravity field, motion of the geocenter with respect to the origin of the reference frame, and perturbations of the Earth's rotation.

For most scientific applications requiring knowledge of the Earth surface kinematics, we have identified the accuracy requirement to be of the order of 1 mm/yr or better. Similarly, using *ad hoc* positioning for the determination of coordinates in a national reference frame also requires knowledge of the velocity field with an accuracy of 1 mm/yr in all three components. Monitoring of infrastructure and hazardous areas have the same requirement on the accuracy of the velocity field. Moreover, the positioning of sensors (e.g. in airborne gravimetry, hydrographic survey, satellite altimetry) has similar accuracy requirements.

The static geoid is relevant for studies of ocean circulation (mean dynamic sea surface topography, MDT), as well as the mass distribution in the interior of the Earth (see e.g. Ilk et al., 2005). In both cases, the accuracy requirement are better than 1 cm, and ocean circulation studies require spatial resolution down to small scales of a few kilometers. Similarly, for the full utilization of satellite altimetry a geoid accurcay of 1 cm for wavelength down to a few tens of km is required (Drinkwater et al., 2003), translating into an accuracy of 10^{-9} or better. In order to monitor the mass movements in the Earth system and particular the global water cycle, accuracy requirements are on the order of 10 mm of equivalent water column for spatial wave length of 500 km, which translates into 0.2 mm in geoid height and 0.3 μGal for gravity. Temporal resolution is of the order of 1 month.

Temporal variation in the Earth's gravity field appears to be the most important parameter for monitoring the mass transport in the Earth system on global to regional scales, which is particularly relevant for the global water cycle, including variations in ocean circulation, water storage on land, sea level changes, ice load changes, etc. (see e.g. Ilk et al., 2005). The currently accepted accuracy requirements are better than 10^{-9} with a tendency to 10^{-10} (e.g. for ice load changes and ocean circulation changes), and spatial resolution of a few hundred kilometers. Mass transport in the global water cycle shows strong variations at sub-seasonal scales, and temporal resolution of several weeks are considered as a reasonable requirement.

Two prominent application of sea level observations are the study of climate change, where the volume and mass changes of the ocean are of importance for studies of the global water cycle, and impact studies, where scenarios for future local sea levels are required. Both applications have demanding requirements with respect to the relation between reference frame origin and the *Center of Mass* (CM) of the Earth system. For global sea level studies, an accuracy of 0.1 mm/yr is required for the tie of the frame orgin to the CM, while local studies of sea level often require an accuracy of 0.5 mm/yr for vertical land motion.

A rather crucial limitation for sea level studies and, more general, applications in both Earth observations and scientific studies originates from a significant uncertainty in the relation between ITRF and the CM. The ITRS is defined to have its origin in the CM. However, due to the particular sensitivity of the different techniques with respect to geocenter variations, there is a time-dependent difference between the origin of ITRF and the CM. The effect of this unknown differential movement, which is estimated to be of the order of 2 mm/yr (see Fig. 1), on observations of surface displacements, sea level, and comparative studies between local gravity changes and vertical displacements is severe, as it demonstrated in Fig. 1. For the example shown there, the effect on global mean sea level

Convection: Are the anomalies in seismic velocities detected by seismic tomography in the Earth's mantle due to chemical anomalies or temperature anomalies? This is equivalent to the question whether convection is throughout the whole mantle or layered.
Plate tectonics: the location of and the processes at plate boundaries still pose several questions. Likewise, the extent of deformation zones is uncertain in many regions of the Earth surface.
Ice sheets/glaciers and sea level: there are large uncertainties with respect to the ice load history, in particular, for Antarctica. The present-day changes in ice sheets are still not known, even to the sign. Consequently, their contribution to sea level changes are highly uncertain. The global global ocean volume and mass changes are not well constrained.
Post-glacial rebound: the appropriate rheology of the Earth mantle and its dependency on time scales is not well understood.
Ocean circulation: improved monitoring is required in order to separate steric and non-steric components, and to determine absolute circulation.
Hydrological cycle: better quantification of the fluxes between the different reservoirs is required. How large are groundwater movements? What are the variations in continental water storage?
Seasonal variations: What is the contribution from the terrestrial hydrosphere? For the cryosphere: what is the seasonal mass balance? For sea level: what part of the seasonal variations is steric and what non-steric?
Atmospheric circulation: reconstruction of past wind fields on the basis of Earth rotation? Past and present air pressure field?
Tides: validation of ocean tide models.
Seismic waves and free oscillations: structure and mechanical parameter of the solid Earth?

Box 2: Selected scientific problems requiring geodetic observations.

Table 1: URs for selected scientific applications. S.R. stands for spatial resolution, T.R. for Temporal resolution, Fr. stands for Frame, where we distinguish L: local frames, N: national frames, G: global frame. R. stands for Reproducibility and gives the time window over which the parameters are expected to be reproducible with the stated accuracy. More detailed requirements for the geoid and gravity field can be found in e.g. Drinkwater et al. (2003). Note that an accuracy of 10^{-9} for the geoid translates into an accuracy of 1 cm.

Application	Parameter	Accuracy	S.R.	T.R.	Fr.	R.
Mantle convection and plate tectonics	3-d velocities	< 1 mm/yr	n/a	n/a	G	several decades
	static geoid	$< 10^{-9}$	n/a	n/a	G	and longer
	secular strain rate	10^{-15} s^{-1}	10^3 km	n/a	G	
Postglacial rebound	3-d velocities	< 1 mm/yr	10^2 km	n/a	G	several decades
	geoid	$< 10^{-9}$	n/a	n/a	G	and longer
	strain rates	10^{-15} s^{-1}	10^2 km	n/a	G	
	Earth rotation	0.1 mas/yr	n/a	n/a	G	
	local sea level	< 1 mm/yr	2 to $10 \cdot 10^2$ km	n/a	G	
Climate change, including present changes in ice sheets and sea level	3-d displacements	1 mm	10^2 km	months	G	decades
	3-d velocities	< 1 mm/yr	$< 10^2$ km	n/a	G	decades
	local gravity	< 0.3 μGal	$< 10^2$ km	n/a	L	decades
	geoid	< 10 mm	200 km	n/a	G	decades
	geocenter	0.1 mm/yr			G	decades
	Earth rotation	0.1 mas/yr				
	local sea level	< 1 mm/yr	10^2 km	months	n/a	decades
Ocean circulation	gravity field	$< 10^{-9}$	10^2 km	months	G	decades
Hydrological cycle	gravity field	$< 10^{-9}$	10^2 km	months	G	decades
	3-d displacements	< 1 mm	10^2 km	months	G	decades
Seasonal variations	gravity field	$< 10^{-9}$	10^2 km	months	G	decades
	local gravity	< 1 μGal	n/a	months	L	decades
	3-d displacements	< 1 mm	10^2 km	months	G	decades
	Earth rotation	1 mas				
Atmospheric circulation	Earth rotation	1 mas		days		decades
Earth tides	gravity	0.01 μGal	10^3 km	hours	G	years
	3-d displacements	1 mm	10^3 km	hours	G	years
	strain	10^{-15} s^{-1}				
Surface loading	3-d displacements	< 1 mm	10^2	< 1 day	G	years
	local gravity	0.1 μGal				
Seismotectonics	3-d displacements	1 mm	$< 10^2$ km	days	G	hours to years
	strain					
Volcanoes	3-d displacements	1 mm	1 to 10^2 km			years
	gravity	1 μgal				
Earthquakes, tsunamis	3-d displacements	1 mm to 1 cm	$< 10^2$ km	sec to days		
	local gravity	0.3 μGal				

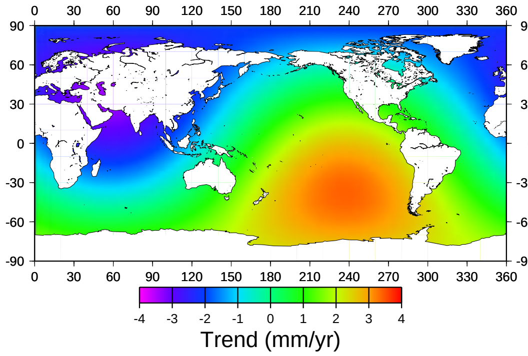

Fig. 1: Effect of differential motion between the origins of ITRF and IGP-00 on local vertical motion. The vertical motion is given for a differential velocity between the origin of ITRF2000 and IGS-P00, that is a reference frame determined by GPS alone, which is estimated by Kierulf & Plag (2006) as $\delta\vec{v} = (-1.5, -2.2, -2.1)$ mm/yr. The mean vertical motion over the complete surface of the ocean is 0.4 mm/yr.

estimates would be as large as 0.4 mm/yr, which is far above the uncertainties discussed in the IPCC assessments.

Requirements on Earth rotation result mainly from scientific applications. For these applications, an increasing accuracy of the observations normally leads to new applications.

4 Linkage and Outreach activities

Besides maintaining the links to the scientific organizations in IUGG, the implementation of GGOS in agreement with the URs requires firm links to the Earth observation environment, and in particular GEO, the IGOS-P, the relevant UN agencies and other international programs. The links to GEO are well established, (a) through IAG being a participating organization in GEO, with the representative coming from GGOS. Moreover, IAG has representatives in all relevant GEO Working Groups, and these representatives are recruited from appropriate GGOS Working Groups.

The relationship between GGOS and IGOS-P is currently being progressed towards a full membership of GGOS in IGOS-P (see Plag et al., 2006, for more details). It is expected that this process eventually will lead to the establishment of a ’Earth System Dynamics Theme’, which will have a major contribution from GGOS. Moreover, the links to the existing IGOS-P Themes deserve considerable attention, too.

However, GGOS will have to maintain on a high level outreach activities in order to increase the awareness in the societies of the importance of the geodetic contribution to science, Earth observation and many non-scientific applications. In particular, links to and formal acknowledgments through relevant UN agencies have to be established. It can be expected that both the increased awareness of the importance of the geodetic contribution, which has already been achieved in the process of GEO, as well as the formal acknowledgment through GEO, IGOS-P, and eventually UN agencies, will help to secure the funding for the operational activities in GGOS.

The process of establishing a comprehensive UR database and converting these in quantitative system specifications is an important tool for the identification of gaps and deficiencies in the current system. An example is the uncertainty in the relation between reference frame origin and geocenter, which is mainly caused by the low number of SLR stations, their insufficient geographical distribution, and a lack of low-orbit SLR targets. The channels through GEO can be used to raise the awareness for this crucial gap in the geodetic observing system, and eventually also the funds to close this gap.

In its outreach activities, GGOS also needs to educate the users both with respect to their requirements and the benefits from the geodetic observations and products. Knowledge of the geodetic standards and conventions is important for using the products and therefore, it is crucial to support the dissemination.

The implementation of GGOS most likely will have to be based on regional implementation, similar to the structures of GOOS, GCOS and GLOSS. Such components are already developing, e.g. the *European Combined Geodetic Network* (ECGN) and the *Nordic Geodetic Observing System* (NGOS), and the links to the regional implementations need to be well maintained and formalized.

GGOS also will have to be open for new developments in observational techniques. An example is InSAR, which receives considerable attention from GEO, while GGOS has not fully recognized the potential of InSAR, particularly in combination with GNSS.

The increasing need for early warning systems for natural and man-made hazards in order to prevent or mitigate disasters requires also the integration of geodetic observations and products in these systems. Here, too, GGOS outreach activities are needed in order to avoid unnecessary duplication of efforts.

5 Conclusions and Recommendations

There is an emerging consensus that geodetic techniques are indispensable for Earth observation systems. GGOS coordinates an impressive number of operational global networks for monitoring displacements, gravity variations and Earth's rotation variations. With the ITRF, geodesy provides the metrological basis for all Earth observations. Moreover, GGOS provides observations related to the dynamics of the Earth, relevant in particular (but not only) for geohazards and the understanding of the global water cycle. Nevertheless, many users are (still) not fully aware of the potential of geodetic observations.

The URs originating from the nine benefit areas of GEO and from open scientific questions are demanding and not all can be met with the currently available geodetic observing system. GGOS therefore should use the URs to systematically identify the gaps in the observing systems and the deficiencies in products with the goal to improve the system so that the URs are eventually met.

In order to promote the awareness of the geodetic contribution outside of the traditional scientific environment, it is recommended that GGOS establishes strong links to IGOS-P and the IGOS-P Themes. One element in these links could be a IAG Commission or GGOS WG on geodesy and geohazards, which would not only provide a formal interface to the IGOS-P Geohazards Theme but also to international programs such as the *International Strategy for Disaster Reduction* (ISDR) of the UN.

Acknowledging the importance of InSAR as a technique for observations of surface deformations with high spatial resolution, it is recommended that GGOS initiates or facilitates the establishment of an InSAR service as one component in GGOS. GGOS also should promote work towards combined analysis techniques for GNSS and InSAR observations.

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