The Global Geodetic Observing System – Part 1, the Organisation

by Hans-Peter Plag, Markus Rothacher, and Ruth Neilan

The advent of space-geodetic techniques has revolutionised the methods of geodesy and created new potential for it to contribute to the monitoring of the Earth system in the service of science, earth observation, and society. The Global Geodetic Observing System (GGOS) is the infrastructure that will make this happen.

Over the last thirty to forty years, the accuracy of positioning in a global geodetic reference frame has increased by roughly an order of magnitude every decade, reaching today to sub-centimetre accuracy in relative positions on global scales and sub-millimetre accuracy in annual changes in these positions. While previously point coordinates were given with respect to local or regional reference frames, with space geodetic techniques, positions can now be observed with respect to a global reference frame with continuously increasing accuracy. With the space-techniques available today, changes in the shape of the solid Earth, the ocean, land, water, and ice sheet surfaces, can be measured with unprecedented accuracy as well as spatial and temporal resolution.

Helping understand the atmosphere-ocean-Earth system

These observations provide critical information on the geodynamic processes that produce geohazards such as earthquakes, volcanic eruptions, landslides, subsidence, changes in the global water cycle such as sea level rise, melting of ice sheets, and changes in land water storage. The accuracy of observations of variations in Earth rotation has increased by several orders of magnitude over the last few decades, and these observations are inherently related to the global dynamics of the coupled atmosphere-ocean-solid Earth system. These observations are not only critical for our understanding of the processes in the core and mantle of the solid Earth but also provide important constraints on climate models for the last ~50 years.

Dedicated gravity satellite missions measuring the static and temporal parts of the Earth's gravity field provide for the first time accurate estimates of the changes in water storage on subcontinental scales with temporal resolutions down to 10 days. In the near future, these observations will result in valuable products for regional water management. In combination, the observations in the three core fields of geodesy have allowed the determination of a global terrestrial reference frame with centimetre accuracy, an internal precision at the sub-centimetre level, and a long term stability of the order of 1 mm/yr.

Most of these developments have been facilitated by the scientific expertise of the global geodetic community gathered in the International Association of Geodesy (IAG). In order to stimulate the development of globally coordinated infrastructure, the IAG has established a number of technique-specific services. The first of these was the International GNSS Service (IGS) which was established in 1994. Based on the observations and analysis results provided by the IAG Services, the International Earth Rotation and Reference Systems Service (IERS) determines and provides access to the International Terrestrial Reference Frame (ITRF), which is a realisation of the International Terrestrial Reference System (ITRS). ITRS is founded on a well-defined and maintained scientific standard. ITRF is today the most accurate realisation of a global geodetic reference system, and it is the basis for most other reference frames, including WGS84 and the reference frame GTRF for the GALILEO system. ITRS and the ITRF are indispensable for many practical applications ranging from navigation, mapping, surveying, national and regional reference frames, to engineering, and Earth observations.

Recognising the growing user community, which depends on geodetic observations and the global geodetic reference frame, and the need to have a common voice for the

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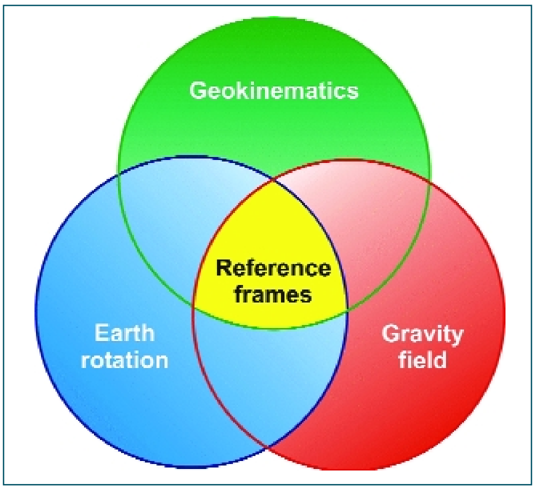

The so-called three pillars of geodesy: Today, the space-geodetic techniques and dedicated satellite missions are crucial in the determination and monitoring of changes in Earth shape (geokinematics), Earth's rotation and the gravity field. These "three pillars" of geodesy are intrinsically linked to each other as they relate to the same unique Earth system processes. Together, the observations provide the basis for the determination of the geodetic reference frames with high accuracy, spatial resolution and temporal stability.

increasing number of technique-specific services as well as a link between IAG and relevant international programs, IAG in 2003 initiated the Global Geodetic Observing System (GGOS) project.

GGOS: organisation and observation system

There are two distinct aspects of GGOS which should not be confused:

- *the "organisation" consisting of components such as committees, panels, working groups, etc., and*
- *the "observation system" comprising the infrastructure of many different instrument types, satellite missions, and data and analysis centres.*

The components of the organisation are an integral part of the IAG structure. The same is not true for all the components contributing to the observing system. Many parts of the infrastructure are provided by other organisations not, or only loosely, affiliated with IAG. For example, the GPS system, which is crucial for the IGS, is operated and maintained by the U.S. Department of Defense. Many of the relevant satellite missions including satellite altimetry, satellite gravimetry, and InSAR are under the control of space agencies, while GGOS only utilises the observations. Consequently, the observing system GGOS depends on infrastructure provided by others, and the organisation GGOS faces the challenge of ensuring through dialog with the relevant volunteer providers that this infrastructure is available on a continuous basis. Considering that ITRF provides the backbone for techniques that enable many modern societal applications, GGOS thus faces the challenge of promoting to those who can provide the resources to sustain it, a core, but often invisible, element of the infrastructure of a modern society.

In the present article we focus on GGOS as an organisation. In a second article, we will consider GGOS as an observing system and describe the infrastructure of this system, the observations and products provided by this system, and the applications benefiting from the system.

Providing the envelope and interface for the IAG Services

GGOS as an organisation provides a unifying envelope and umbrella for the IAG Services and an interface between the Services and the "outside world". Internally, the GGOS Committees, Science Panel, and Working Groups focus on cross-cutting issues relevant for all Services. The research needed to achieve the goals of GGOS influences the agenda of the IAG Commissions and the GGOS Working Groups. Externally, it provides the links between the IAG Services and the main programs in Earth observation and Earth science. GGOS constitutes a unique interface for many users to the geodetic Services. In particular, it participates on behalf of IAG in large international programs focusing on Earth observation.

The implicit vision for GGOS is to support and enhance Earth science to extend our knowledge and understanding of the Earth system processes, to monitor ongoing changes, and to increase our capability to predict the future behavior of the Earth system. Likewise, the embedded mission is to facilitate networking among the IAG Services and Commissions and other stakeholders in the Earth science and Earth observation communities, to provide scientific advice and coordination that will enable the IAG Services to develop products with higher accuracy and consistency meeting the requirements particularly of global change research, and to improve the accessibility of geodetic observations and products for a wide range of users.

Understanding future needs: GGOS in 2020

Currently, geodesy 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 addressing the issue of liability), and improved access to the reference frame.

In order to get a clear picture of current and future observational requirements that GGOS needs to meet in order to serve emerging scientific and societal needs, it has carried out an extensive study of the anticipated requirement of a global society on a changing planet in 2020. This study revealed that the most demanding users of the terrestrial reference frame in terms of accuracy and long-term stability are most likely to be scientific studies of sea level change caused by climate change. In order to have a frame at least an order of magnitude more accurate than the signal to be monitored, the terrestrial reference frame should be accurate at a level of 1 mm and be stable at a level of 0.1 mm/yr.

The most demanding applications of the static geoid are likely to be the determination of mean sea surface topography for oceanic general circulation models, and the GNSS determination of the height of objects at the millimetre level. These applications require the static geoid to be accurate at a level of 1 mm and to be stable at a level of 0.1 mm/yr, consistent with the accuracy and stability of the terrestrial reference frame. For the time-variable geoid, the monitoring of the water cycle at regional to global scales appears to be the most demanding application requiring the geoid variations to be monitored accurate to 1 mm, stable to 0.1 mm/yr, with a spatial

Above: the authors

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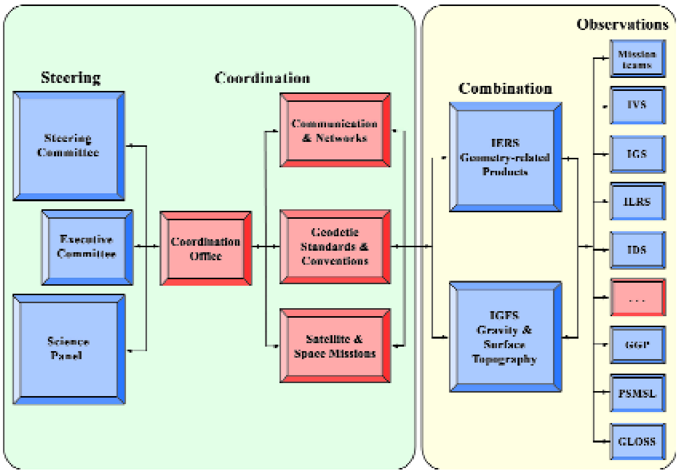

The organisational structure of GGOS. GGOS is built on the IAG Services, which provide the infrastructure, observations and products. Existing entities are indicated in blue, new entities to be established in red. Lines and arrows indicate information flow and do not imply any hierarchical relation.

resolution of 50 km and a time resolution of 10 days.

The most demanding application in terms of accuracy and latency of Earth orientation parameters and their consistency with the terrestrial and celestial reference frames is likely to be the tracking and navigation of interplanetary spacecraft. This application is capability-driven and requires the most accurate parameters that can be determined, realising that those determined in near real-time are somewhat less accurate than those determined with a delay of a couple of weeks. Quantitatively, an accuracy at a level of 1 mm should be achieved.

"The challenge is to appropriately integrate GGOS as an organisation into the context of Earth observation and society…"

The challenges for GGOS

The IAG and GGOS are aware of the enormous challenges implied by the demand to improve the accuracy from an average level of close to10^{-9} (i.e., parts per billion of the Earth radius) to an instantaneous level (with daily or higher temporal resolution) of 10^{-10}, which is required in order to meet the emerging user requirements described above. In fact, GGOS faces two main scientific and technological challenges.

One technological challenge is associated with developing GGOS and the geodetic technologies in order to meet the demanding requirements in terms of reference frame accuracy and availability, as well as in terms of spatial and temporal resolution and accuracy of the observations. In many cases, it is not so much the measurement of a single technique that limits accuracy but rather the ability to attribute signals to specific sources and to model these. Therefore, meeting this challenge requires integration of techniques and models. This challenge provides a central theme for research and development inside IAG for many years to come.

The other challenge is related to geodesy's contribution to Earth system monitoring and science. The signals induced by global change in the Earth's shape, gravity field and rotation are small (in the order of parts-per-billion of the quantities) and often embedded in larger variations not caused by global change. Besides measuring the geodetic quantities with an accuracy considerably better than the signals, identifying and extracting the global change signals also requires the modeling of all known processes in an Earth system model taking into account the interactions between the various Earth system components. This challenge requires geodesy to interact with all Earth sciences and to accommodate the terrestrial processes in data processing and modeling.

Linking to the outside

The biggest challenge for geodesy and for GGOS as an organisation, however, may arise from recent developments in global Earth observation. Stimulated by the international quest for sustainable development and the resulting demand for information on the current state and future evolution of the Earth system, the need for comprehensive Earth observations is acknowledged in extensive programs of the United Nations, the European Union, and the international community. This culminated in the establishment of the intergovernmental Group on Earth Observation (GEO) at the Earth Observation Summit III (EOS-III) on 16 February 2005 in Brussels, Belgium. GEO, which today has about 75 member countries and more than 45 participating organisations, has the task of implementing the Global Earth Observation System of Systems (GEOSS) according to the Ten-Year Implementation Plan endorsed by EOS-III.

The challenge is to appropriately integrate GGOS as an organisation into the context of Earth observation and society, and to develop it as an observing system in accordance with the strategies and methodologies of the global observing systems for the mutual benefit of all. Earth observation and society at large will benefit from the availability of geodetic observations and products, and GGOS will benefit from an improved visibility and acknowledgment of the valuable service it provides.

In order to facilitate the integration of GGOS into GEOSS, IAG is a participating organisation in GEO and is represented there by GGOS. GGOS is also a contributing system to GEOSS. Moreover, steps are being taken to strengthen joint initiatives with government organisations and international bodies. These initiatives have already and will continue to enhance the visibility of geodetic activities in the context of Earth science, Earth observation and practical applications.

Much of the work of GEO and GEOSS is carried out in Task Teams and the so-called Communities of Practice. IAG leads the GEO Task on "Global Geodetic Reference Frames" through GGOS, and GGOS contributes to a number of Communities of Practice including "Geohazards", "Coastal Zone", and "Water".

Acknowledgments

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