

Global Geodetic Observing System (GGOS)

Science Rationale

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Introduction. “*Living On a Restless Planet*”, this is the theme of the published report of the NASA Solid Earth Science Working Group (2002). Indeed, the Earth with its atmosphere, oceans, ice covers, land surfaces and its interior is restless. It is subject to a multitude of dynamic processes that cover a broad variety of spatial and temporal scales and are driven by large interior and exterior forces. In modern times these processes are influenced, as well, by man-made effects; to what extent is still largely unknown. Earthquakes, volcano eruptions, tectonic deformations, land slides, de-glaciation, sea level rise, floods, desertification, storms, global warming and many more are typical and well known phenomena of this highly dynamic engine. All of them affect our life and the life of future generations. Major decisions facing human societies will depend on a much deeper understanding of this complex system and large international efforts on governmental and scientific levels are currently underway towards this goal.

The international geodetic community, organized under the umbrella of the International Association of Geodesy (IAG), is preparing to contribute a new and very important segment to the study of system Earth. It will provide on a global scale the spatial and temporal changes of the shape of our planet, of the oceans, ice covers and land surfaces. In other words, it will be a global picture of surface dynamics of our planet. It will provide, in addition, an assessment of mass anomalies, of mass transport and of mass exchange processes in the Earth’s system. These two elements together are the key to global mass balance determination and an important contribution to the understanding of the global energy budget. IAG will achieve this by establishing a Global Geodetic Observing System (GGOS). GGOS will fully exploit (and try to extend) the unique constellation of satellite missions relevant to this goal, that is in orbit now and during the next decade by integrating them into one measurement system, Table 1. The backbone of this integration is the existing global ground network, based on the geodetic space techniques VLBI, SLR, GPS and DORIS. GGOS will complement the space segment and global ground network by airborne and terrestrial campaigns that serve the purpose of calibration and validation and, equally important, regional densification and refinement. Assimilation of these observations into models of weather, climate, ocean, hydrological, ice and solid Earth will fundamentally enhance the understanding of the role of surface changes and mass transport for the dynamics of our planet.

Table 1. Selection of Satellite Missions Relevant to GGOS

Mission	Type	Mission Duration
CHAMP	Gravity/ magnetic field/ atmosphere	2000 – 2007
GRACE	Gravity (static+ temporal), atmosphere	2002 – 2010
GOCE	Gravity (stationary, high-resolution)	2006 – 2008
TOPEX-POSEIDON	Ocean altimetry	1992 – 2004
Jason-1	Ocean altimetry	2001 – 2006
ICESAT	Ice altimetry	2003 – 2008
CRYOSAT	Ice altimetry	2004 – 2007
ERS-2	Altimetry/ climate/ environment	1995 – 2005
ENVISAT	Altimetry/ climate/ environment	2002 – 2007
TerraSAR-X	SAR/ INSAR/ atmosphere	2005 – 2010
LAGEOS-1 & 2	Reference system, gravity	1975 - open
GPS	Navigation/ positioning, orbits, time transfer/ earth rotation,...	1978 - open
GALILEO	Navigation/ positioning,...	2008 - open

Global Geodetic Observing System (GGOS). The International Association for Geodesy (IAG) will establish a Global Geodetic Observing System (GGOS). This document describes on the one hand the science and application rationale for GGOS and on the other hand the research challenges associated with its implementation.

“After three decades and three orders of magnitude of advances, space geodesy is poised for prime time in observing the integrated mass transports that take place in the Earth system, from high atmosphere to the deep interior of the core. As such space geodesy has become a new remote sensing tool, in monitoring climatic and geophysical changes with ever increasing sensitivity and resolution.

The transport of mass and energy are key processes that determine the dynamics of our earth system. The earth system can be conveniently viewed through its components, so-called geophysical fluids – the atmosphere, hydrosphere, cryosphere, biosphere, lithosphere, and the deep interior of mantle and cores. All geophysical fluids undergo a host of mass transports for various reasons, external as well as internal. Studying these processes is undoubtedly a most interdisciplinary field in all of Earth sciences. However, mass transport has not received due attentions.” [Benjamin F. Chao in EOS, vol.84, no.16, page 145, 2003]

Geodesy traditionally measures by space as well as terrestrial techniques

- all changes of the surface geometry of the Earth i.e., the variations in time and space of ocean surfaces and ice covers and the shape and deformations of land surfaces

(geometry part),

- the variations of the orientation of our planet relative to the stars divided into precession, nutation, polar motion and changes in spin rate (Earth rotation part), and
- all variations in space and time of the Earth's gravitational field usually expressed as anomalies of gravity and of the geoid (gravity and geoid part).

Furthermore, through the analysis of the dense web of microwave rays connecting satellites among themselves and with the Earth's surface a powerful method emerges for probing the atmosphere's density composition.

GGOS adds to these fundamental pillars of geodesy a new quality and dimension in the context of Earth system research by combining them to one observing system with utmost precision and in a well-defined and reproducible global terrestrial frame.

The observing system, in order to meet its objectives, has to combine greatest measurement precision (a relative precision of one part per billion ($1 \text{ ppb} = 10^9$)) with spatial and temporal consistency and stability over decades.

Science and application argument – Central GGOS Science Theme

The integration of the three basic components geometry, earth rotation, and gravity/geoid will permit – as part of global change research - the assessment of surface deformation processes and the quantification of mass anomalies and mass transport inside individual components and mass exchange between the components of the Earth's system.

These quantities serve as input to the study of the physics of solid earth, ice sheets and glaciers, hydrosphere and atmosphere. They are of particular value for the study of complex phenomena such as glacial isostatic adjustment, the evolution of tectonic stress patterns, sea level rise and fall, the hydrological cycle, transport processes in the oceans, the dynamics of the atmosphere (troposphere and ionosphere).

Research challenges.

The quantities to be delivered are very small and therefore difficult to measure. Furthermore, in order to be useful for global change studies they have to be derived free of biases and consistently in space and time. In general they cannot be measured directly but are derived from the combination of complementary sensor and observation systems. For example, dynamic ocean topography is to be derived from the accurate measurement of the ocean surface by radar altimetry in combination with a geoid surface provided by gravity satellite missions. It shows that a variety of sensor systems, mission characteristics, and tracking systems have to be combined with utmost precision. The resulting research challenges are as follows:

1. The various space segments with their respective instrumentation as well as geodetic space techniques have to operate as one global entity and in one global reference frame.

This implies that geometric space techniques (SLR, GPS, DORIS, INSAR, ocean

altimetry, ice altimetry), gravimetric space techniques (orbit analysis, high-low satellite-to-satellite tracking, low-low satellite-to-satellite tracking, satellite gradiometry), geodetic space techniques delivering earth rotation (VLBI, LLR, SLR, GPS as well as the relevant astrometric techniques and missions) and atmospheric sounding techniques (GNSS-to-LEO and GNSS to Earth) have to be integrated at the 1 ppb level. They have to function as one global measurement device.

This requires, in turn, the available global terrestrial network (VLBI, SLR, GPS, DORIS) as well as the global height systems to be combined and unified at the same precision level and with the same long term stability.

An overview is given in Table 2.

2. The space segment has to be complemented by terrestrial and airborne/shipborne techniques and campaigns.

The techniques have a twofold purpose. They serve the calibration and validation of the space segment and they lead to a regional densification in terms of spatial and temporal resolution and accuracy. Ideally the land, ice and ocean surfaces are to be monitored with high spatial resolution. The required resolution depends on the surface type (land, ice, or ocean) and on the region (tectonically active zones, major ocean currents etc.). The latter implies the necessity of integration or organisation of regional projects (science and government projects) in areas of particular geophysical relevance. These projects have to comply with the overall standards of GGOS. The development of new terrestrial and airborne/shipborne techniques has to be encouraged.

3. The link has to be established between the global time series of newly derived parameters and all relevant geophysical models.

This is a highly interdisciplinary task and asks for a close cooperation with geophysicists/geologists, glaciologists, oceanographers, hydrographers and atmospheric physicists. It requires geodesists to get deeper involved into Earth modelling. The ultimate goal should be the development of comprehensive numerical Earth models that are able to assimilate global surface processes and mass transport and exchange. They should lead to a deeper understanding of solid Earth processes such as glacial isostatic adjustment (GIA), tectonic motion, volcanic activity or earthquakes, of ice mass dynamics and balance and the dynamics of sea ice, to ocean circulation and mass and heat transport in the oceans, to the various components of sea level change and to their quantification, to the global water cycle and to atmospheric dynamics.

The measured temporal variations of Earth rotation and gravity/geoid represent the total, integral effect of all mass changes in Earth system. Thus, conclusive strategies have to be developed for their separation into the individual contributions. This is a difficult but important task and requires the development of a sophisticated strategy. The complementarities of satellite techniques, sampling strategies, formation flights of several satellites, terrestrial calibration sites and campaigns and geophysical models will prove important for this. Of similar character is the problem of the limited resolution in time and space of any space configuration. This leads to aliasing problems that need careful analysis.

The research concept is summarized in Table 3.

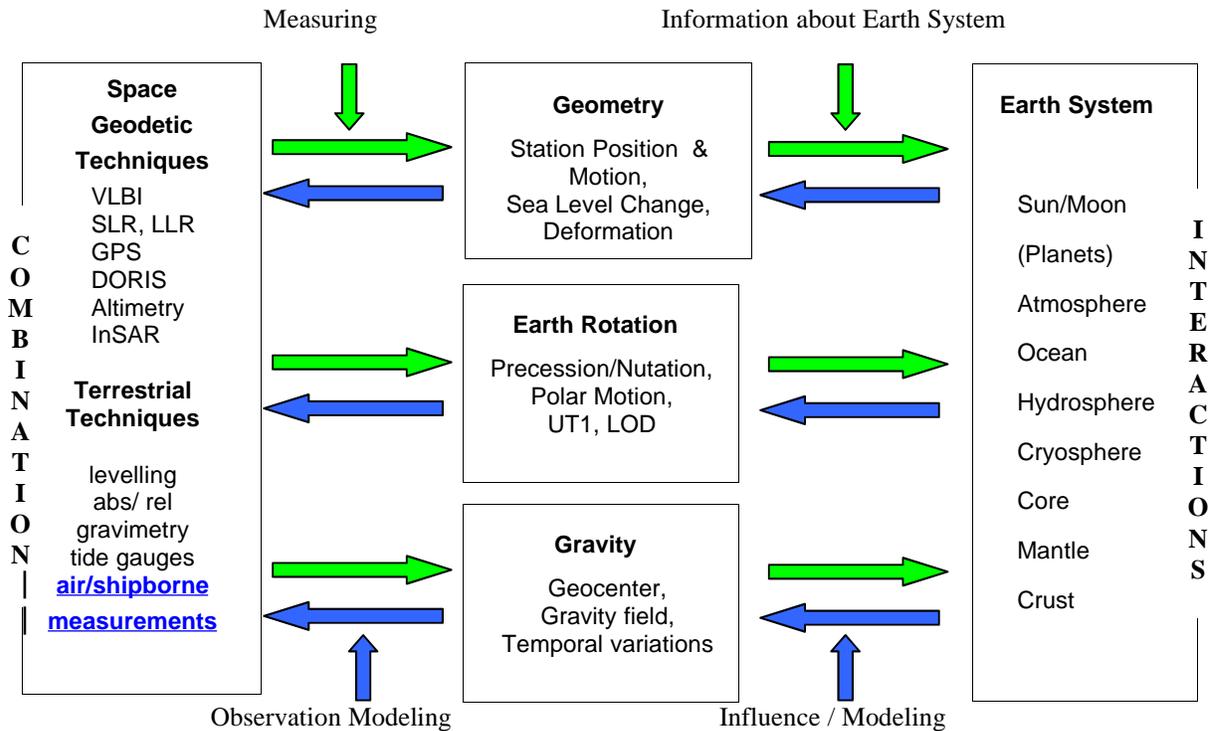
The research objectives and required research and development have to be formulated in a sound and comprehensive *GGOS Science Plan*. The science plan shall provide a logical framework for the work of GGOS. The science objectives, the research and development strategy, the contributions expected from the various IAG bodies and the interface to Earth sciences have to be made clear. It should also include an assessment of strengths and deficiencies and of priorities.

The GGOS Science Plan should be a central issue of a first *GGOS Retreat* in 2004.

Table 2. Global Geodetic Observing System (GGOS)

COMPONENT	OBJECTIVE	TECHNIQUES	RESPONSIBLE
I. TERRESTRIAL FRAME	Global cluster of fiducial points, determined at mm to cm level	VLBI, GPS, SLR, LLR, DORIS, time keeping/transfer absolute gravimetry, gravity recording	International geodetic community (IERS with support of IVS, ILRS, IGS and IDS)
II. GEOMETRY DEFORMATION	Shape and temporal variations of land/ice/ocean surfaces(plates, intra-plates, volcanos, earthquakes, glaciers, ocean variability, sea level)	Altimetry, INSAR, GPS-clusters, imaging techniques, leveling, tide gauges	International and national projects; space missions
III. EARTH ROTATION (nutation, polar motion, variations in l.o.d.)	Integrated effect of changes in angular momentum (mass changes in atmosphere, cryosphere, oceans, solid earth, core/-mantle; momentum exchange between earth system components)	Classical astronomy, VLBI, LLR, SLR, GPS, DORIS, under development: terrestrial gyroscopes	International geodetic and astronomical community (IERS, IGS, IVS, ILRS, IDS)
IV. GRAVITY FIELD Geoid and gravity anomalies, temporal variations	Adds mass transport to the observing system; (isostasy models, ice flux), ocean circulation mass transport, unification of height systems: for geodesy, sea level monitoring, hydrological cycle	Terrestrial gravimetry, Gravity ship & airborne gravimetry and gradiometry, dedicated satellite missions: hi-lo SST, lo-lo SST, gradiometry	IAG/IGFS, national space pro-grams, e.g. NASA,ESA

Table 3: Measuring and Modeling the Earth System



IAG inside argument.

From the above it follows that GGOS provides a central theme to research and development inside IAG. In order to meet the objectives of GGOS a master plan will have to be formulated concerning technology development, required terrestrial, airborne and satellite observation programmes, data connection, flow, archiving and processing, theory and methodology, collaboration with other earth sciences, education and outreach.

Outside argument.

GGOS is geodesy's contribution to earth system monitoring and science. Geodesy is able to provide unique, very central and important information to the study of global change. IAG intends to integrate the work of GGOS into the Integrated Global Observing Strategy (IGOS) which is a joint initiative of UNESCO and ICSU. To this end, joint initiatives with government organisations and international bodies will have to be strengthened. At the same time this initiative will enhance the visibility of geodetic activities in the context of earth sciences.

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