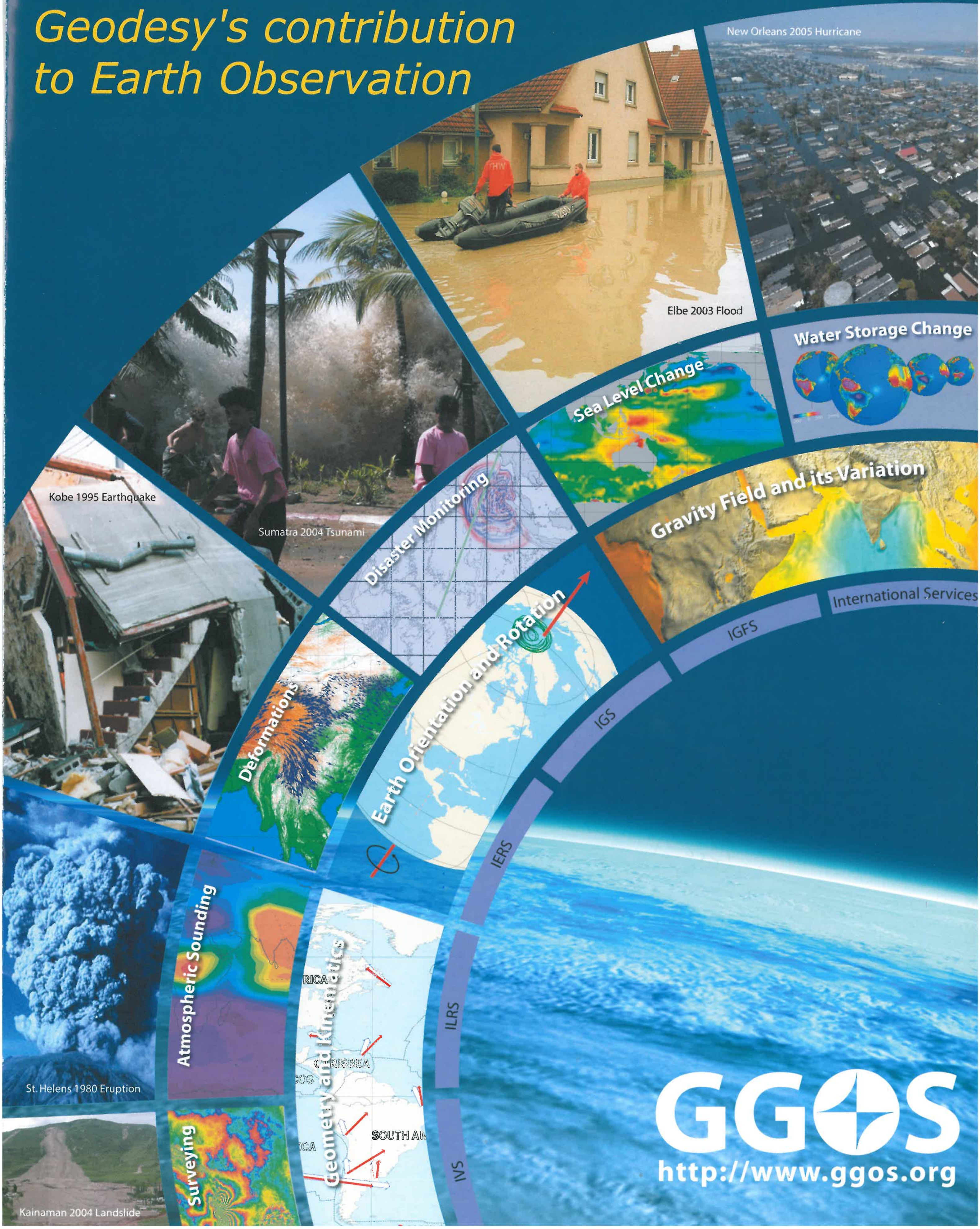
THE GLOBAL GEODETIC OBSERVING SYSTEM

Geodesy's contribution to Earth Observation



THE CHALLENGE: LIVING ON A DYNAMIC, RESTLESS, AND FINITE PLANET

Earth is a restless planet. With its atmosphere, oceans, ice covers, land surfaces and its interior, it is subject to a large variety of dynamic processes operating on a wide range of spatial and temporal scales, and driven by large interior as well as exterior forces. Many areas of the Earth's surface are exposed to natural hazards caused by dynamic processes in the solid Earth, the atmosphere and the ocean. Earthquakes, tsunamis, volcano eruptions, tectonic deformations, land slides, deglaciation, sea level rise, floods, desertification, storms, storm surges, global warming and many more are typical and well known phenomena that are expressions of the dynamics of our restless planet. In modern times these processes are influenced, as well, by anthropogenic effects; to what extent is still largely unknown.

A growing population has to cope with this restless, and finite, planet. Settlements and particularly megacities are spreading into areas of high risks from natural hazards with major infrastructure being built in potentially hazardous locations, thus increasing the vulnerability of society. Valuable and crucial infrastructure is increasingly lost in natural and man-made disasters, affecting the economy on national and global levels, and displacing large populations, with severe social implications. The growing demands for access to food, water, materials, and space put stress on the finite resources of the planet. Earth system processes, whether natural or modified by humans, affect our lives and the lives of future generations. Living on a restless planet with finite resources and a limited capacity to accommodate the impact of the increasingly powerful anthropogenic factor requires careful governance. Decisions made today will influence the well-being of future generations. In order to minimize the anthropogenic impact on Earth system processes and in order to preserve resources for future generations, a better understanding of Earth system processes and an efficient and conservative organization of anthropogenic processes is required. A deeper understanding of the Earth system cannot be achieved without sufficient observations of a large set of parameters characteristic of Earth system processes. Only based on comprehensive Earth observations will we be able to improve the predictive capabilities of our models, that will allow us to assess the range of plausible futures of our planet as a basis for informed decisions.

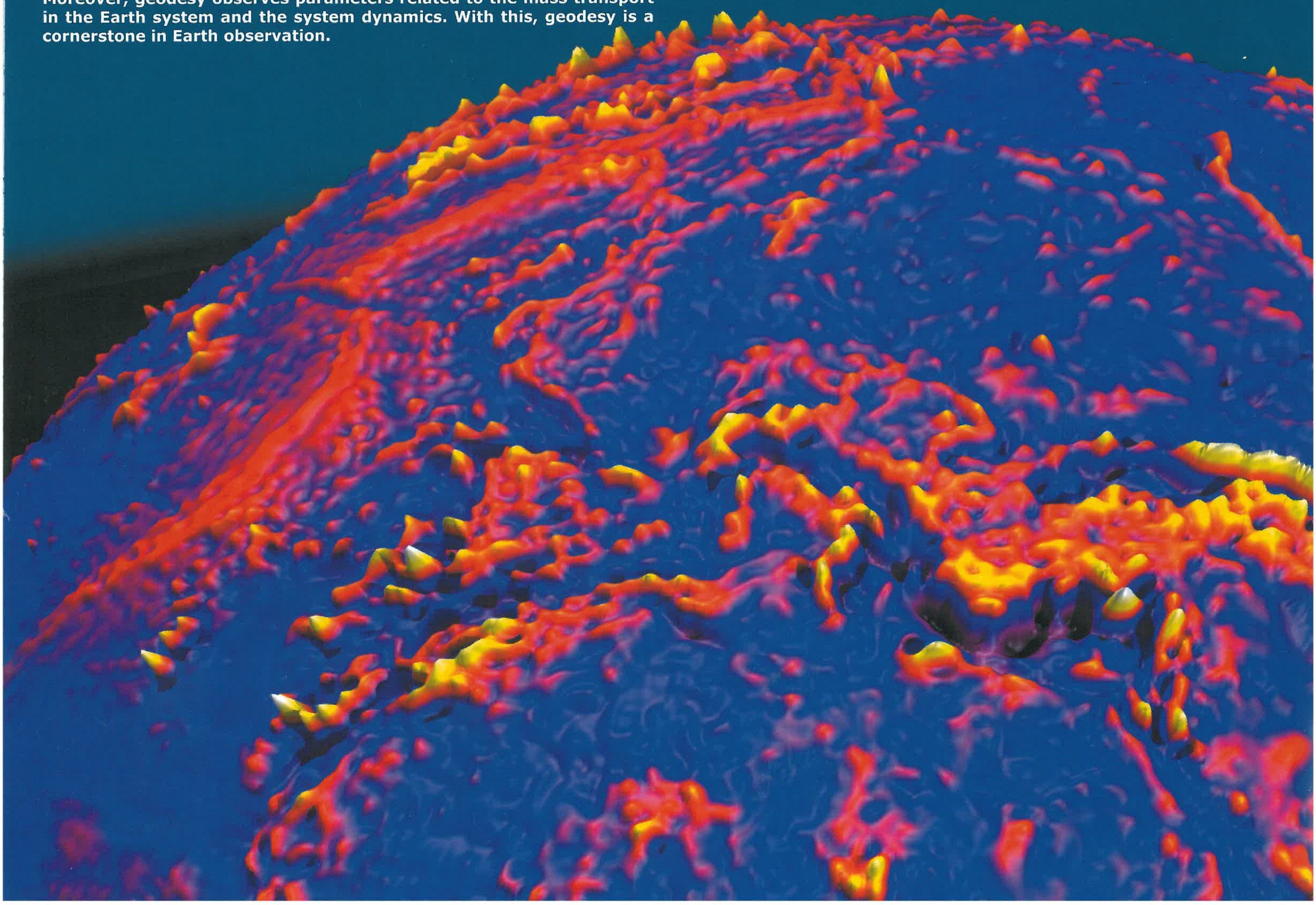
Earth observations are not only necessary for the scientific understanding of the Earth, they are fundamental for most societal areas ranging from disaster prevention and mitigation, the provision of resources such as energy, water and food, gaining an understanding of climate change, the protection of the biosphere, the environment, and human health, to the building and management of a prosperous global society.

Geodesy provides the metrological foundation for Earth observation. Moreover, geodesy observes parameters related to the mass transport in the Earth system and the system dynamics. With this, geodesy is a cornerstone in Earth observation.

GEODESY PROVIDES THE BASIS FOR EARTH OBSERVATION

The "three pillars" of geodesy are the Earth's time-dependent geometric shape, gravitational field, and rotation. With its observational means, geodesy has the potential to determine and monitor with utmost precision the geometric shape of land, ice, and ocean surfaces as a global function of space and time. The geometric methods, when combined with global gravity information and the geoid, allow us to infer mass anomalies, mass transport phenomena and mass exchange in the Earth's system. The variations in Earth rotation reflect mass transport in the Earth system and the exchange of angular momentum among its components.

The geodetic observations of the "three pillars" provide the basis for the realization of the reference systems that are required in order to assign (time-dependent) coordinates to points and objects, and to describe the motion of the Earth in space. For this purpose, two reference systems are basic in geodesy, namely the celestial reference system and the terrestrial reference system, which are linked to each other by the Earth's rotation. The two most accurate reference systems currently available are the International Celestial Reference System (ICRS) and the International Terrestrial Reference System (ITRS), which are defined by the International Earth Rotation and Reference Systems Service (IERS). These systems are conventional coordinate systems that include all conventions for the orientation and origin of the axes, the scale, and the physical constants, models, and processes to be used in their realization. Based on observations, these systems can be realized through their corresponding "reference frames". The frame corresponding to the ICRS is the International Celestial Reference Frame (ICRF), which is a set of estimated positions of extragalactic reference radio sources. The frame corresponding to the ITRS is the International Terrestrial Reference Frame (ITRF), which is a set of estimated positions and velocities of globally distributed reference marks on the solid Earth's surface. These two frames are linked to each other by estimates of the Earth rotation parameters. ICRS, ITRF and the Earth rotation parameters are provided by IERS.



SERVING SCIENCE AND SOCIETY WITH A TERRESTRIAL REFERENCE FRAMES

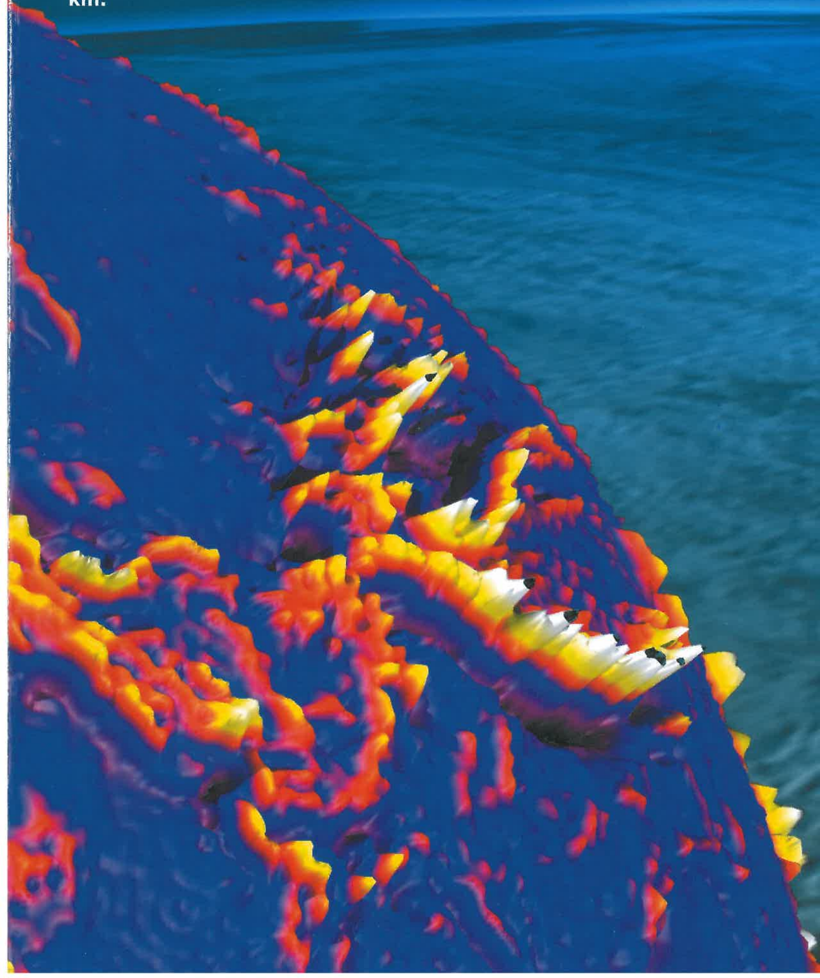
Today, the internationally coordinated geodetic observations collected and made available by the global geodetic station networks provide a continuous monitoring of the ITRF. This well-defined, long-term stable, highly accurate and easily accessible reference frame is the basis for all precise positioning on and near the Earth's surface. It is the indispensable foundation for all sustainable Earth observations, in situ, as well as airborne and space-borne. Furthermore the ITRF underpins all geo-referenced data used by society for many uses. All these digital geo-referenced data are crucial for many activities, including mapping, construction, land development, natural resource management and conservation, navigation - in fact all decision-making that has a geo-related component.

GEODESY RELATES TO EARTH SYSTEM OBSERVATION

Historically, geodesy was limited to determining the shape of the Earth, its gravity field, and its rotation including their changes over time. With modern instrumentation and analytical techniques, the scope of geodesy can be extended to include the sources of the observed changes in these "three pillars", that is, the dynamics of and mass transport within the Earth system. With this broader scope new pathways emerge in which geodesy can contribute to the scientific understanding of the Earth system as well as the development, functioning, and security of society in general. Ultimately, the observations in these "three pillars" are affected by the same unique Earth system processes: all of them relate to mass redistribution and dynamics. Thus, geodesy provides a unique framework for monitoring and ultimately understanding the Earth system as a whole. Modern space-geodetic techniques are well suited for observing phenomena on global to regional scales, and thus are an important complement to traditional in situ observation systems.

The recent development of space geodetic techniques and methods also enables auxiliary applications that utilize the atmospheric disturbance of geodetic measurements (ionosphere, troposphere, magnetic field) for non-geodetic applications. Atmospheric disturbance used to be the natural factor limiting the accuracy of geodetic measurements. Now this "noise" is increasingly being recognized as "signal", and the distortions of geodetic microwave signals propagating through the atmosphere can be "inverted" and used for weather prediction, climate studies, and studies in atmospheric physics and space weather.

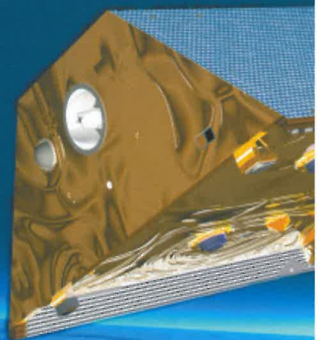
Many scientific applications depend on detailed knowledge of the Earth's shape, its gravity field and rotation, and in the past geodesy has with ever-increasing accuracy provided the necessary observations. The fairly recent advent of space-geodetic techniques has brought about a rapid development in global geodesy, particularly during the last decade or so. The relative precision of the measurements is approaching the very impressive level of 1 ppb or even better. Today, geodetic techniques permit the measurement of changes in the geometry of the Earth's surface with an accuracy of millimeters over distances of several 1000 km.



RECENT CONTRIBUTIONS

Over the last one and a half decades, the global geodetic networks have provided an increasingly detailed picture of the kinematics of points on the Earth's surface and the temporal variations in the Earth's shape. Among other applications, the observations have been used to determine improved models of the secular horizontal velocity field, to derive seasonal variations in the terrestrial hydrosphere, to study seasonal loading, to invert for mass motion, and to improve the modeling of the seasonal term in polar motion. Geodetic techniques provide the means to observe surface deformations on volcanoes, in instable areas, associated with earthquakes and fault motion, or subsidence caused by anthropogenic activities such as groundwater extraction. Current developments indicate that geodetic observing techniques will be able to determine the magnitude of great earthquakes in near-real time and thus help mitigate the problem of low initial magnitudes estimated by seismic techniques.

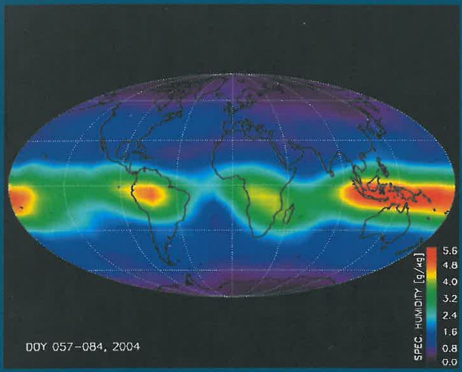
Improvements in gravity field models obtained over the last three decades have gone hand-in-hand with improvements in the reference frames and Earth orientation from the Lageos and other low-orbiting satellite laser-ranging targets. The innovative sensor technologies used in these gravity field missions have already enabled a dramatic improvement of the gravity field during the last decade. Gravity field models from GRACE have benefited the space geodetic analysis of the DORIS tracking data. They have been used to improve the knowledge of the orbits of ocean radar altimetry satellites, and for laser altimeters, thereby enhancing the geodetic contributions from other space missions. Gravity missions are also of central importance for altimetry, because a precise geoid is required to refer the sea surface topography to the geoid. The integration of all the satellite missions with the existing space-geodetic techniques for the determination of the Earth's shape creates new opportunities to determine and study the mass transport in the Earth system in a globally consistent way or to derive information on changes in part of the water cycle. Analysis of the data delivered by GRACE yields a direct measure of mass flux with high spatial resolution of about 500 km on the Earth's surface, and sub-monthly temporal resolution. Combining these mass changes with advanced meteorological models predicting water storage on land such as the Global Land Data Assimilation System (GLDAS) rapidly improves the quantitative knowledge of the water cycle and provides new datasets for climate change studies.

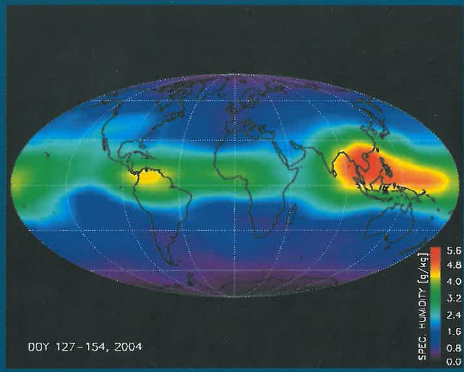


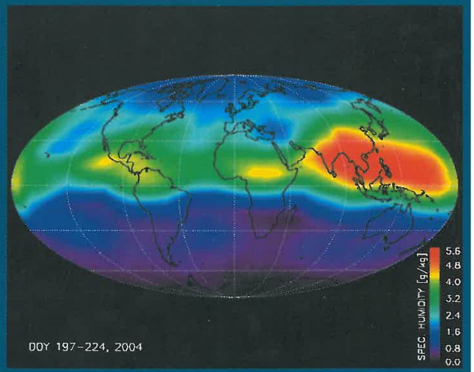
GEODESY'S NEW CUSTOMERS

To a large extent, geodesy is a "service science". In the past, the main "customers" of geodesy came from the surveying and mapping profession, while today geodesy serves all Earth science, including the geophysical, oceanographic, atmospheric, and environmental science communities. Geodesy is also indispensable for the maintenance of many activities in a modern society. Traditionally, geodesy has served society by providing reference frames for a wide range of practical applications from regional to global navigation on land, sea, and in air, construction of infrastructure, to the determination of reliable boundaries of real estate properties. Reference frames were, however, national or regional in scope, and they were suited for the determination of coordinates relative to a network of reference points. Thus, determination of precise point coordinates required simultaneous measurements at several points. Today, the Global Navigation Satellite Systems (GNSS) provide access to precise point coordinates in a global reference frame anytime and anywhere on the Earth's surface with centimeter-level accuracy and without requiring additional measurements on nearby reference points.

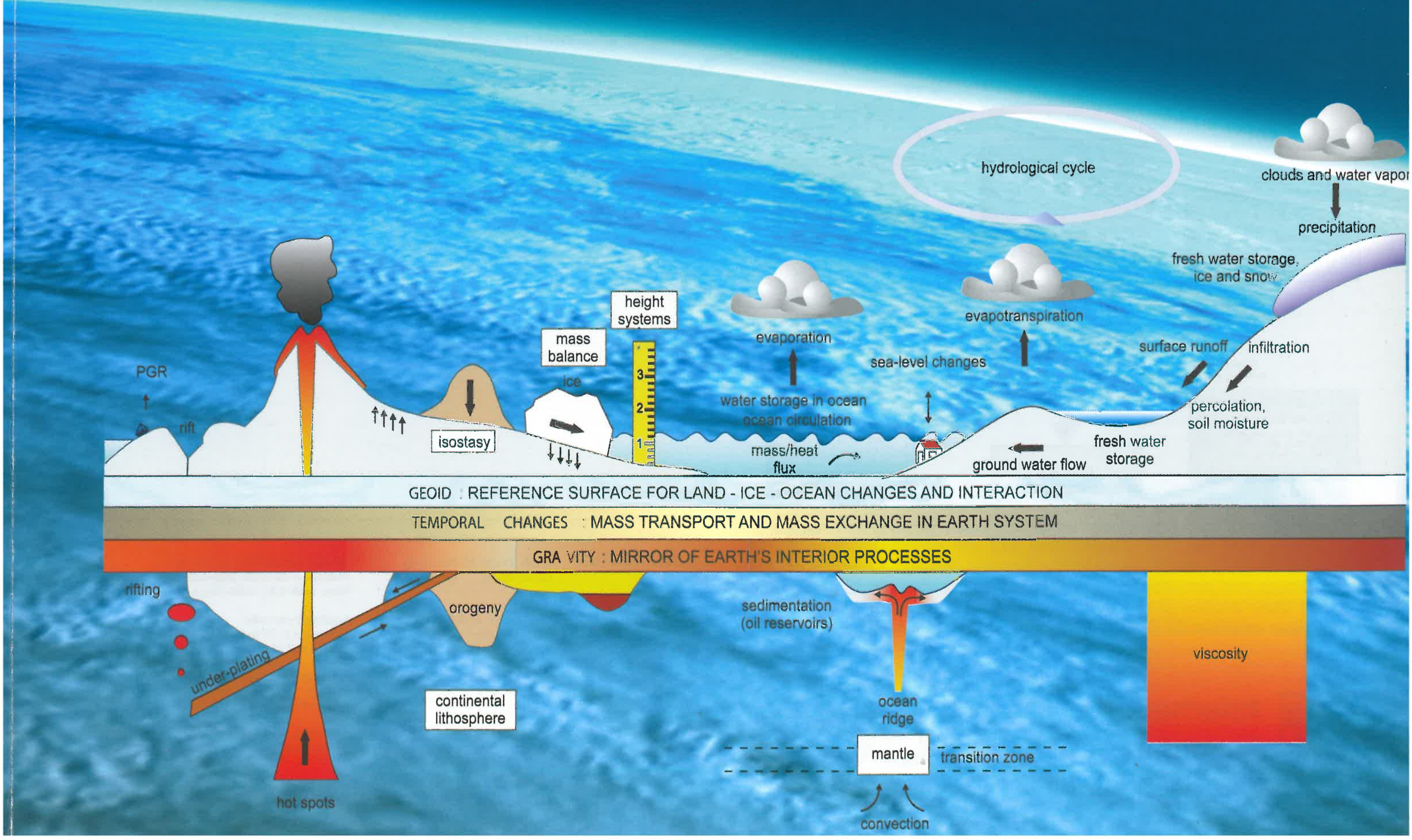
Geodesy has the potential to make very important contributions to the understanding of the state and dynamics of System Earth, particularly if consistent observations of the "three pillars" can be provided on a global scale with a precision at or below the 1 ppb level, and with sufficient stability over decades. A prerequisite to exploiting the full potential of geodesy for Earth observation, Earth system monitoring, and many practical applications is a sophisticated integration of all geodetic techniques (spaceborne, airborne, marine and terrestrial), processing models and geophysical background models into one system. The integration of the "three pillars" 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 the 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, and the dynamics and physics of the atmosphere (troposphere and ionosphere).

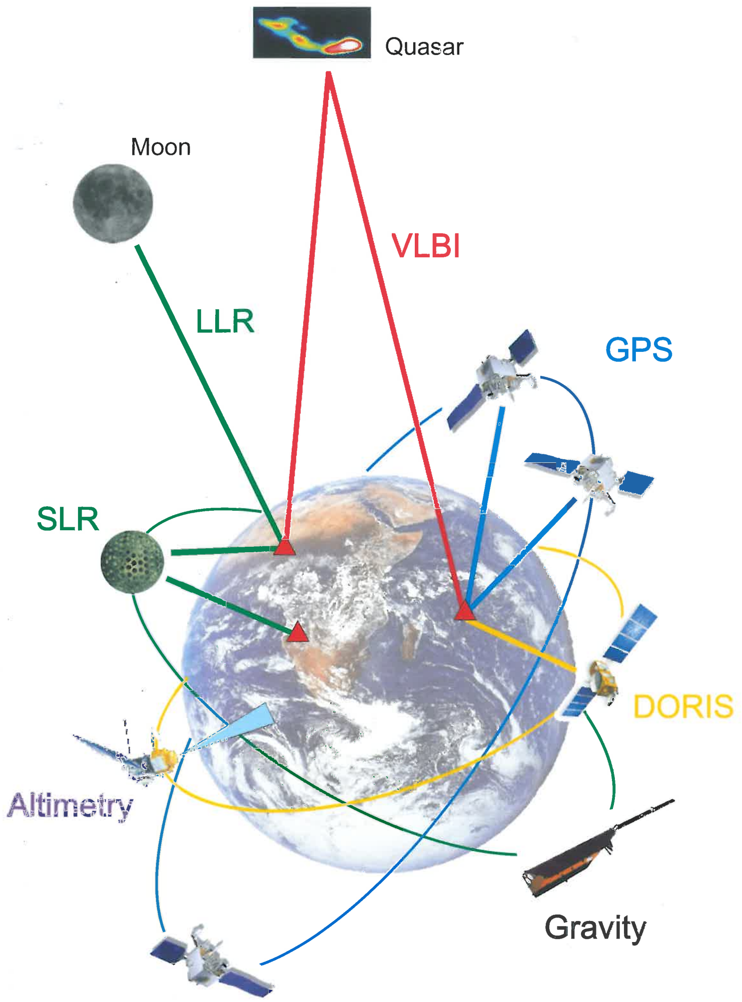


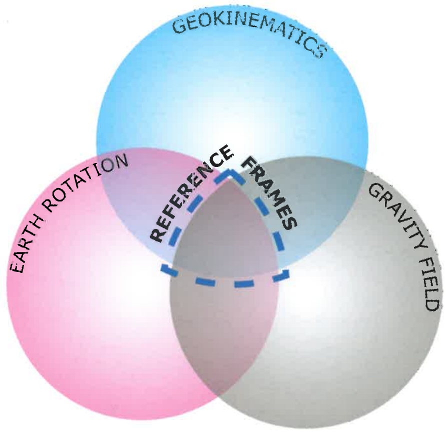




Mass redistribution in the Earth system. All geophysical processes are associated with mass redistribution and changes in the dynamics, thus affecting commonly the Earth's gravity field, geometry, and rotation. Consequently, geodesy with observations of the "three pillars" contributes to an observing system that allows the monitoring of mass transport in the Earth system.

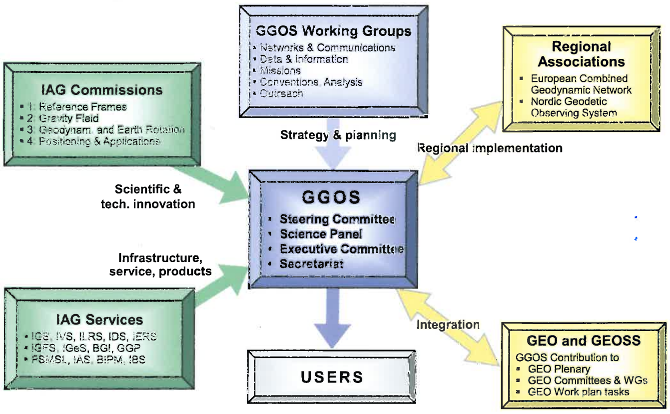






Infrastructure contributing to GGOS. The combined infrastructure allows the determination and maintenance of the global geodetic reference frames, and the determination of Earth's gravity field and rotation. The ground networks and navigation satellites (currently in particular GPS) are crucial for maintaining the reference frame required for high accuracy positioning. In particular, they allow the monitoring of volcanoes, earthquakes, tectonically active regions and landslide-prone areas. The Low Earth Orbit (LEO) satellites monitor sea level, ice sheets, water storage on land, atmospheric water content, high-resolution surface motion, and variations in the Earth's gravity field. The latter are caused by regional and global mass transport processes as, e.g., the hydrological cycle.

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



Organizational links and relationships of GGOS. GGOS is being built on the scientific support from the IAG Commissions and the infrastructure of the IAG Services. GGOS integrates the work of the Services through a number of GGOS Working Groups and provides coordination and advice through its Committees. GGOS links these entities to the main programs in Earth observations, and provides a unique interface for GGOS users to the geodetic services.

International Association of Geodesy

GGOS
http://www.ggos.org

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http://www.ggos.org

THE GLOBAL GEODETIC OBSERVING SYSTEM (GGOS)

GGOS is the Observing System of the International Association of Geodesy (IAG). GGOS was established by IAG in July 2003. Since April 2004, GGOS represents IAG in the Group on Earth Observation (GEO) and GGOS is IAG's contribution to the Global Earth Observation System of Systems (GEOSS).

GGOS HISTORY

The international cooperation fostered by IAG has led to the establishment of the IAG Services, that provide increasingly valuable observations and products not only to scientist but also for a wide range of non-scientific applications. Considering this development in geodesy, the requirements of Earth observations, and the increasing societal needs, IAG initially created GGOS as an IAG Project during the IUGG meeting in 2003 in Sapporo, Japan. After the first two years devoted to the definition of the internal organizational structure of GGOS and its relationship with external organizations (the "Design Phase"), the Executive Committee of the IAG at its meetings in August 2005 in Cairns, Australia, decided to continue the Project. In the "Implementation Phase" from 2005 to 2007, the GGOS Steering Committee, Executive Committee, Science Panel, Working Groups, and Web Pages were established, and the Terms of Reference were revised. Finally, at the IUGG meeting in 2007 in Perugia, Italy, IAG elevated GGOS to the status of a full component of IAG as the permanent observing system of IAG.

THE TWO MEANINGS OF GGOS

GGOS has two very distinct aspects, which should not be confused: the "organization GGOS" consisting of components such as committees, panels, working groups, etc., and the "observation system GGOS" comprising the infrastructure of many different instrument types, satellite missions, and data and analysis centers. While GGOS as an organization has established its structure from essentially new entities and will, over the next years, add new entities where needed, the observational infrastructure for GGOS as the system is being largely provided by the IAG Services.

GGOS THE ORGANIZATION

GGOS as an organization is a unifying 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, GGOS provides the links between the IAG Services and the main programs in Earth observations and Earth science. It constitutes a unique interface for many users to the geodetic Services. In particular, GGOS participates on behalf of IAG in large international programs focusing on Earth observations.

According to the IAG By-Laws, GGOS "works with the IAG Services and Commissions to provide the geodetic infrastructure necessary for the monitoring of the Earth system and global change research." This statement implies a vision and a mission for GGOS. The implicit vision for GGOS is to empower 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 of particularly global change research, and to improve the accessibility of geodetic observations and products for a wide range of users. The IAG Services, upon which GGOS is built, benefit from GGOS as a framework for communication, coordination, and scientific advice necessary to develop improved or new products with increased accuracy, consistency, resolution, and stability. IAG benefits from GGOS as an agent to improved visibility of geodesy's contribution to the Earth sciences and to society in general. The users, including the national members of IAG, benefit from GGOS as a single interface to the global geodetic observation system of systems maintained by the IAG Services not only for the access to products but also to voice their needs. Society benefits from GGOS as a utility supporting Earth science and global Earth observation systems as a basis for informed decisions.

GGOS THE OBSERVING SYSTEM

GGOS as an observing system is built upon the existing and future infrastructure provided by the IAG Services. It aims to provide consistent observations of the spatial and temporal changes of the shape and gravitational field of the Earth, as well as the temporal variations of the Earth's rotation. In other words, it aims to deliver a global picture of the surface kinematics of our planet, including the ocean, ice cover and land surfaces. In addition, it aims to deliver estimates of mass anomalies, mass transport and mass exchange in the Earth system. Surface kinematics and mass transport together are the key to global mass balance determination, and an important contribution to the understanding of the energy budget of our planet. Moreover, the system aims to provide the observations that are needed to determine and maintain a terrestrial reference frame of higher accuracy and greater temporal stability than what is available today. By combining the "three pillars" into one observing system having utmost accuracy and operating in a well-defined and reproducible global terrestrial frame, GGOS adds to these pillars a new quality and dimension in the context of Earth system research. The observing system, in order to meet its objectives, has to combine the highest measurement precision with spatial and temporal consistency and stability that is maintained over decades.

GGOS AND ITS CHALLENGES

The observing system GGOS faces two types of scientific and technological challenges:

1. GGOS and the geodetic technologies need to meet the demanding user requirements in terms of reference frame accuracy and availability, as well as in terms of spatial and temporal resolution and accuracy of the geodetic observations. Developing an observing system capable of measuring variations in the Earth's shape, gravity field, and rotation with an accuracy and consistency of 0.1 to 1 ppb, with high spatial and temporal resolution, and increasingly low time latency, is a very demanding task. Accommodating the transition of new technologies as they evolve in parallel to maintaining an operational system is part of this challenge.

2. The Earth system is a complex system with physical, chemical and biological processes interacting on spatial scales from micrometers to global and temporal scales from seconds to billions of years. The integration of the "three pillars" into a system providing information on mass transport, surface deformations, and dynamics of the Earth therefore requires a "whole Earth'" approach harnessing the expertise of all fields of Earth science.

GGOS: AN OBSERVING SYSTEM OF LAYERED INFRASTRUCTURE

GGOS as an observing system has five major levels of instrumentation and objects that actively perform observations, are passively observed, or both. These levels are:

- Level 1: the terrestrial geodetic infrastructure;
- Level 2: the LEO satellite missions;
- Level 3: the GNSS and the Lageos-type SLR satellites;
- Level 4: the planetary missions and geodetic infrastructure on Moon and planets;
- Level 5: the extragalactic objects.

These five levels of instrumentation and objects, independent of whether they are active or passive, receivers or emitters or both, are connected by many types of observations in a rather complex way to form the integrated GGOS observing system. In this system, the major observation types at present are:

1. observations of the microwaves at the ground and at the LEO satellites emitted by GNSS satellites;
2. laser ranging to LEOs, dedicated laser ranging satellites, GNSS satellites and the Moon;
3. microwave observation of extragalactical objects (quasars) by VLBI;
4. instrumentation onboard the LEO satellites measuring accelerations, gravity gradients, satellite orientation, etc.;
5. radar and optical observations of the Earth's surface (land, ice, glaciers, sea level, ect.) from remote sensing satellites;
6. distance measurements between satellites (K-band, optical, interferometry, etc.).

In the future, new measurement techniques will evolve and be included into the system. Different parts of the overall system are cross-linked through observations and inter-dependent. All these techniques are affected by and measure the "output" of the same unique Earth system, that is, the various geodetic fingerprints induced by mass redistribution and changes in the system's dynamics. Therefore, consistency of data processing, modeling, and conventions across the techniques and across the "three pillars"is mandatory for maximum exploitation of the full potential of the system.