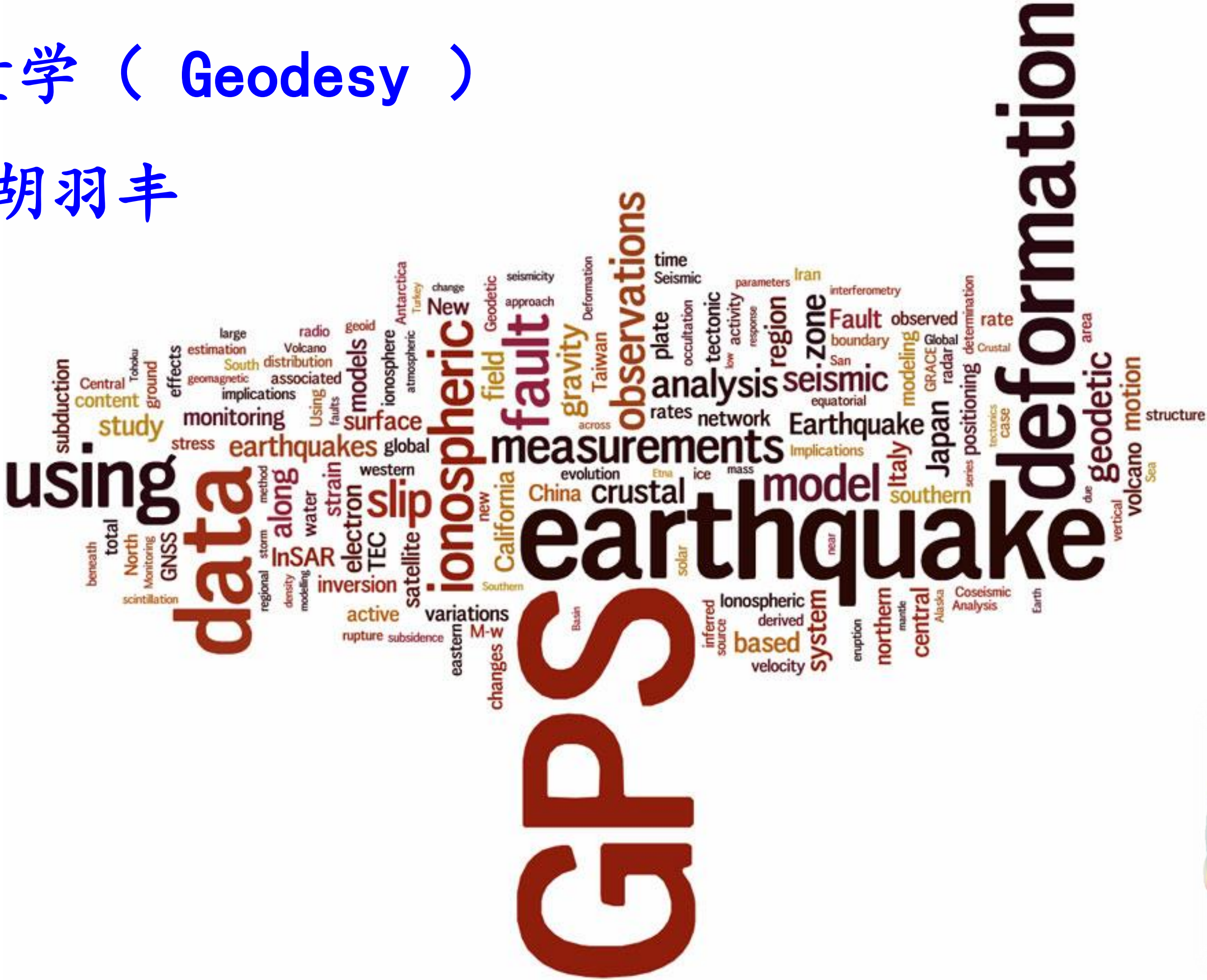
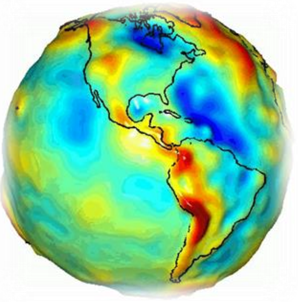
大地测量学（ Geodesy ）

张双成 胡羽丰





思考？？？

- 什么是测绘？
- 测绘工程能做什么？
- 你掌握了多少测绘知识？
- 长安大学的测绘如何？
- 国内外测绘发展如何？
- 测绘发展前景如何？
- 通过什么渠道了解测绘？
- ……

大地测量学背景


古铜日晒中心
中国民生银行
北大街
HBT文化会所
华夏银行
伊尔萨洗衣
B座
养生小岛
B座
博泰国际商业广场
博泰国际
五时舞刻
宏泰西街
湖光北街
14号线东段
213号楼
广顺北大街
望和益民商城-北门
望和益民商城广龙建材
望京望和
望京站广场综合楼
延吉明太鱼馆
217号楼
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S50
S50北五环
费家村
S12
北湖渠路
望京北路
北皋
辛店路
G45
S50
广泽路
望京西路
广顺北大街
S11
草场地村
小营北路
小营路
中国电影博物馆
育慧东路
姜庄路
望京
望京街
阜荣街
G45
花家地街
文学馆路
S50
北四环东路
S11
太阳宫北街
北土城东路
S12
芳园西路

传统大地测量

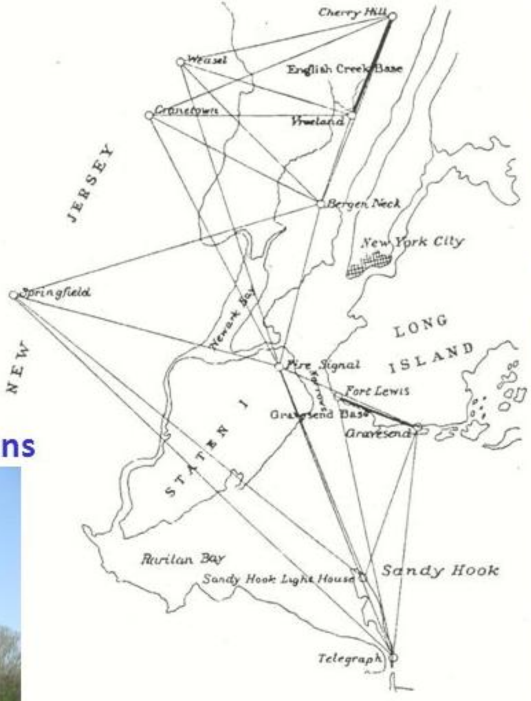

U.S. GEOLOGICAL SURVEY
FOR INFORMATION WRITE THE DIRECTOR WASHINGTON, D.C.
MAMMOTH CAVE NATIONAL PARK, KY
ROTUNDA ELEVATION
ABOVE SEA
599 FEET
TT 2 W
1936
BENCH MARK
NEBRASKA
SHELTON BASE NET
TO PAGE BASE
1.255
65
155.630
65
1.100
0.465
80
154.995
85
2.095
0.130
80
153.030
85
0.245
5.765
77
158.550
73
0.345
BM 35
154.375
154.530
152.900
152.785
BM 36
158.205

传统大地测量

Classical Survey Components

Control Mark

Theodolites & Total Stations

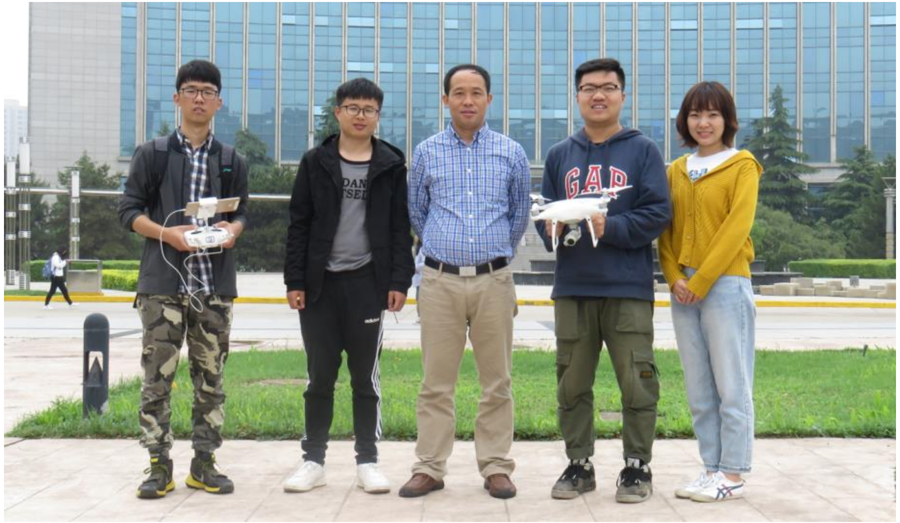


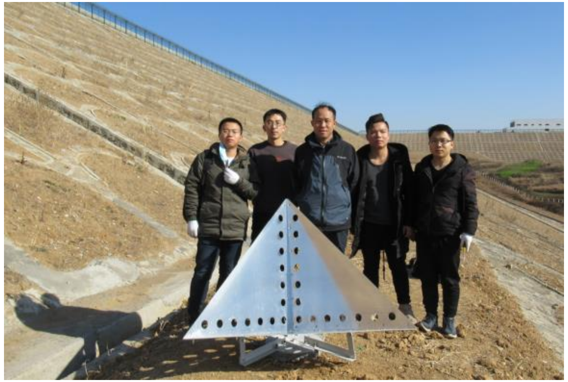
Hassler's First Field Work, 1816–1817

Survey Network (inter-visible stations)

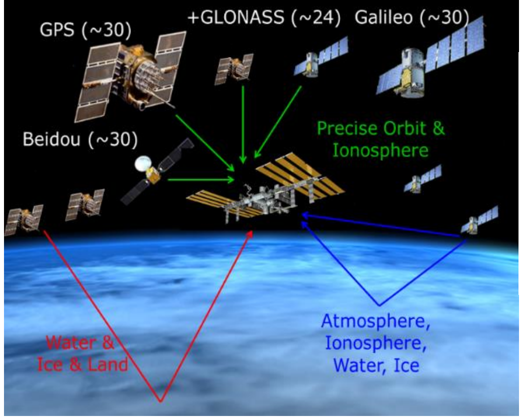
Control Mark

Angle, Distance & Height Measurements



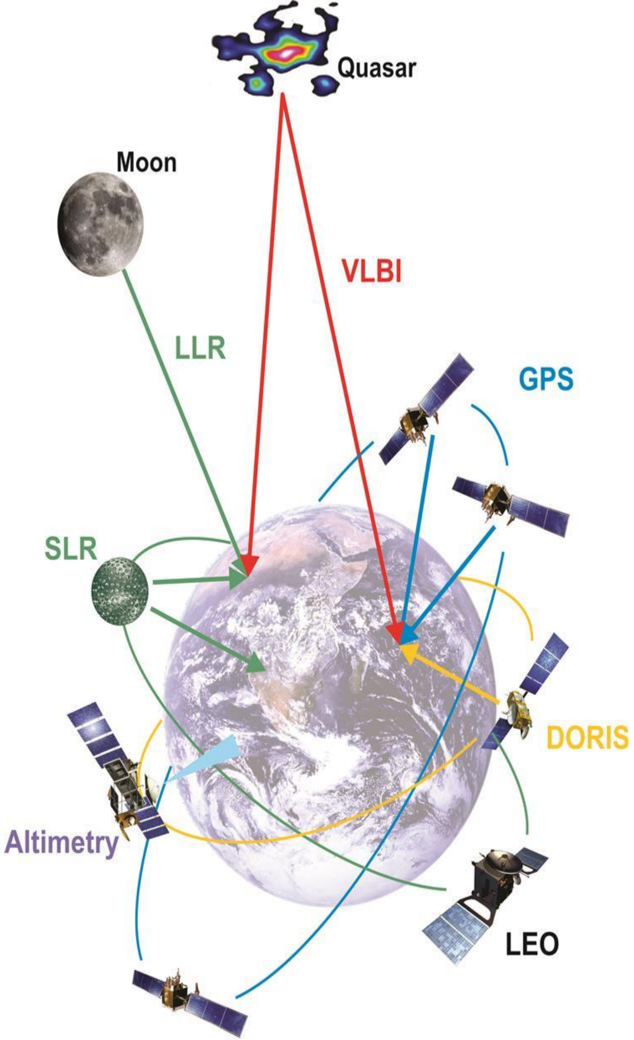


现代大地测量

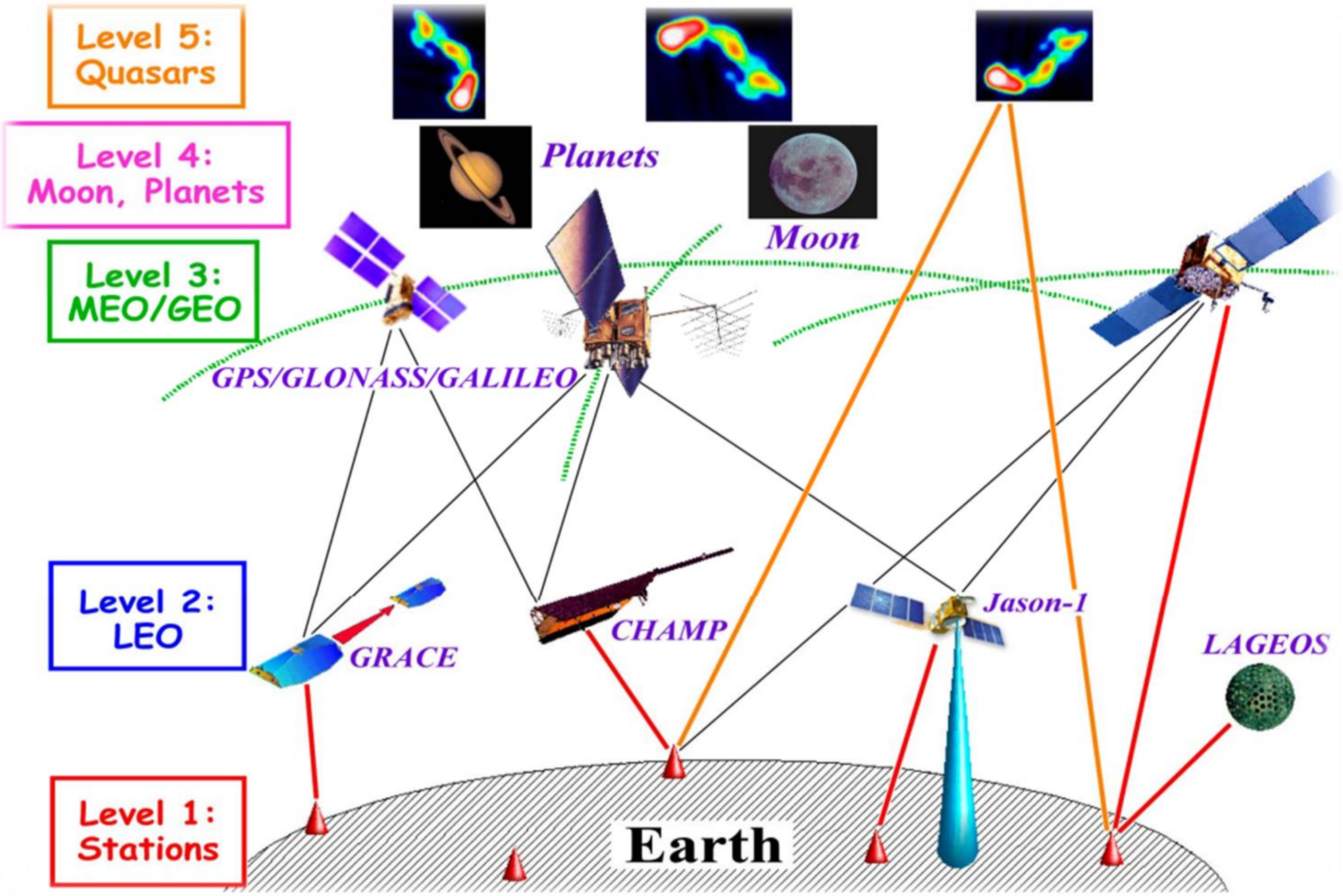


NASA

NAVSTAR GPS



现代卫星大地测量



Level 5:
Quasars
Level 4:
Moon, Planets
Planets
Moon
Level 3:
MEO/GEO
GPS/GLONASS/GALILEO
Level 2:
LEO
GRACE
CHAMP
Jason-1
LAGEOS
Level 1:
Stations
Earth

现代（卫星）大地测量


DSCOVR
(NOAA)
SMAP
OSTM/Jason 2
(NOAA)
Terra
CYGNSS
(EVM-1)
Landsat 7
(USGS)
Suomi NPP
(NOAA)
Aqua
SORCE
LIS on ISS
SAGE III on ISS
TSIS-1 on ISS
ECOSTRESS on ISS (EVI-2)
International
Space Station
Landsat 8
(USGS)
Aura
GRACE-FO
CALIPSO
GPM
Core Observatory
OCO-2
CloudSat

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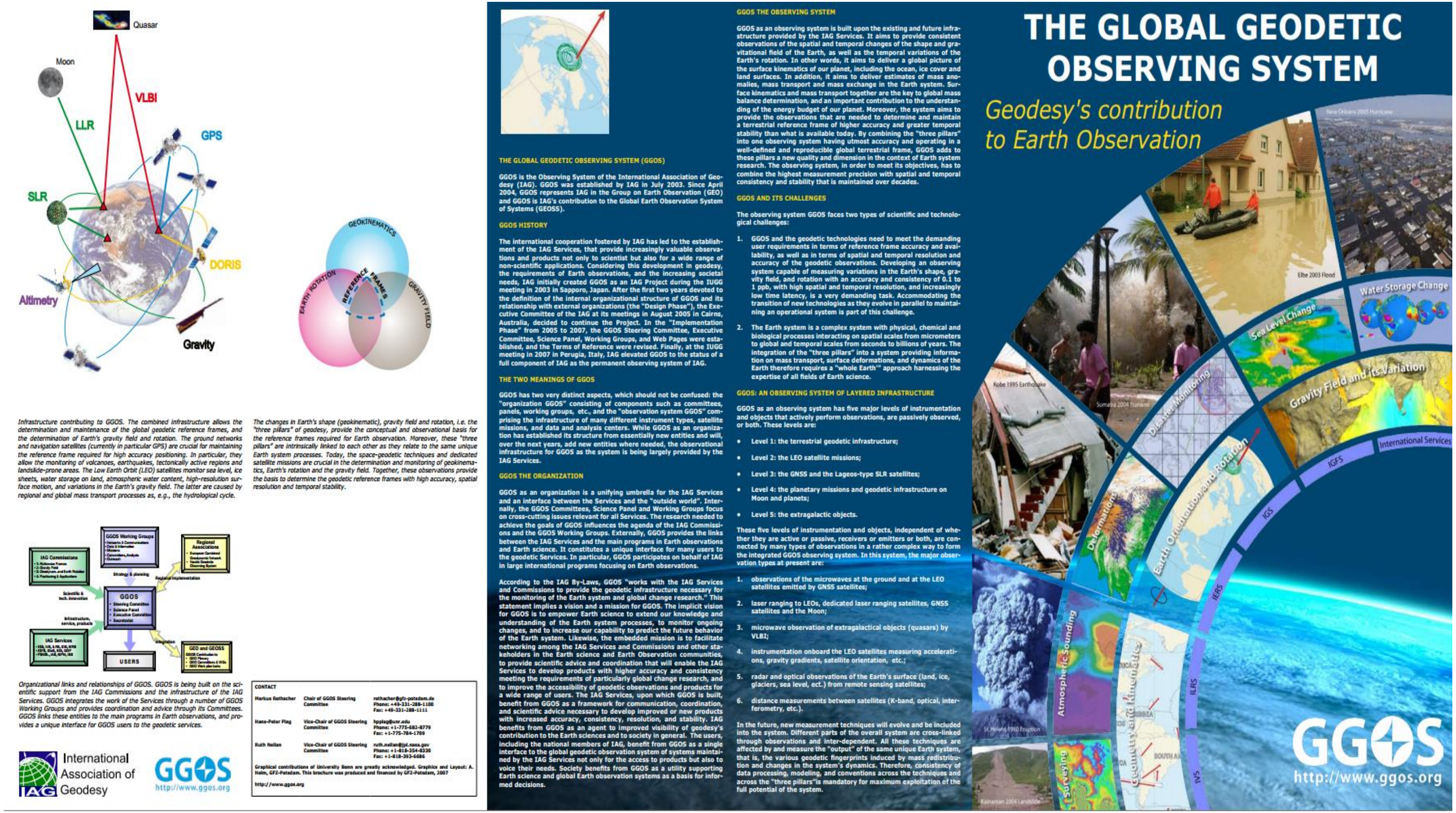

Infrastructure contributing to GGOS. The combined infrastructure allows the determination and maintenance of the global geodetic reference frames, and the determination of Earth's gravity field and rotation. The ground networks and navigation satellites (currently in particular GPS) are crucial for maintaining 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.

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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.

THE GLOBAL GEODETIC OBSERVING SYSTEM

Geodesy's contribution to Earth Observation

GGOS
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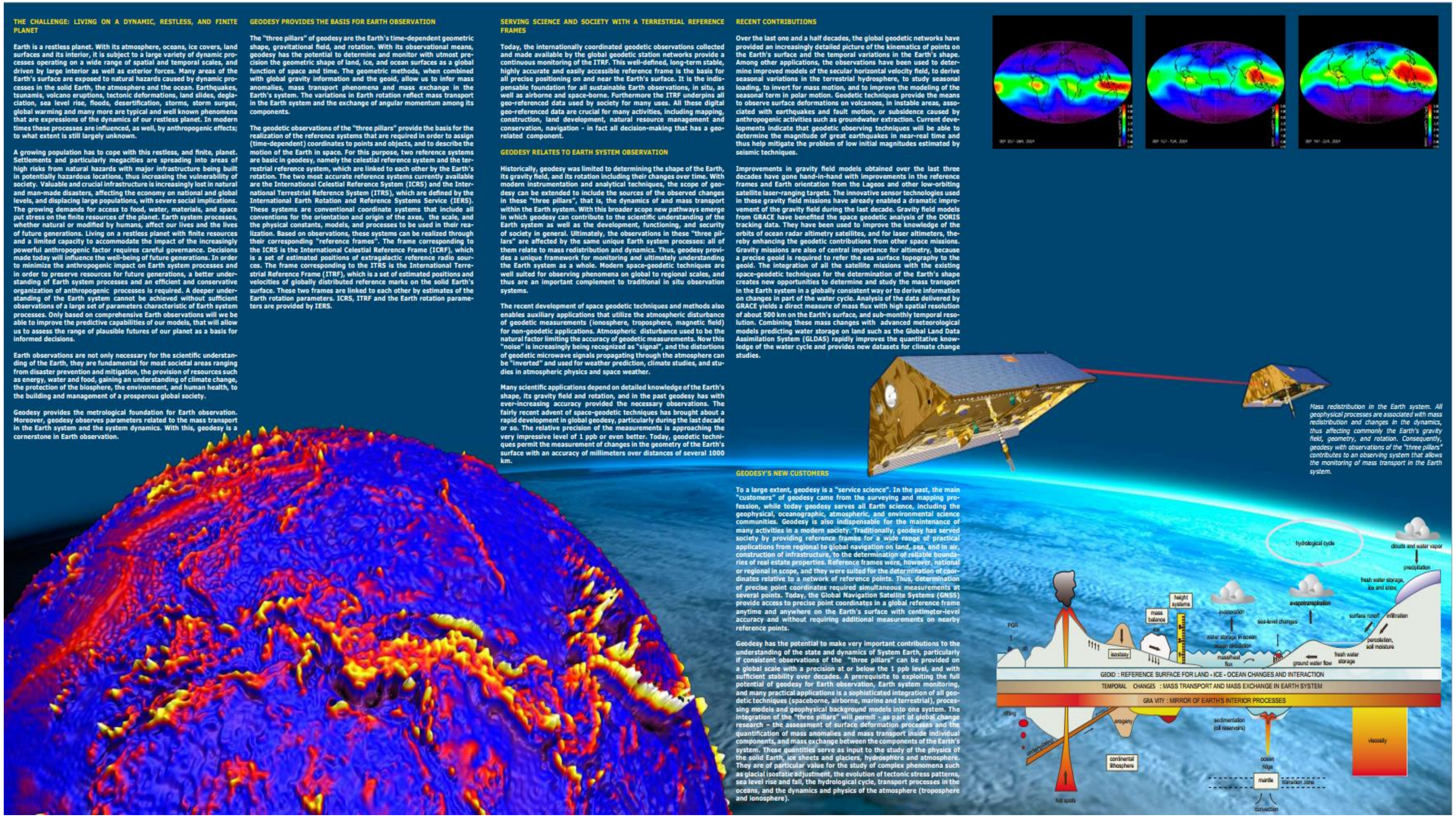

THE CHALLENGE: LIVING ON A DYNAMIC, RESTLESS, AND FINITE PLANET

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.

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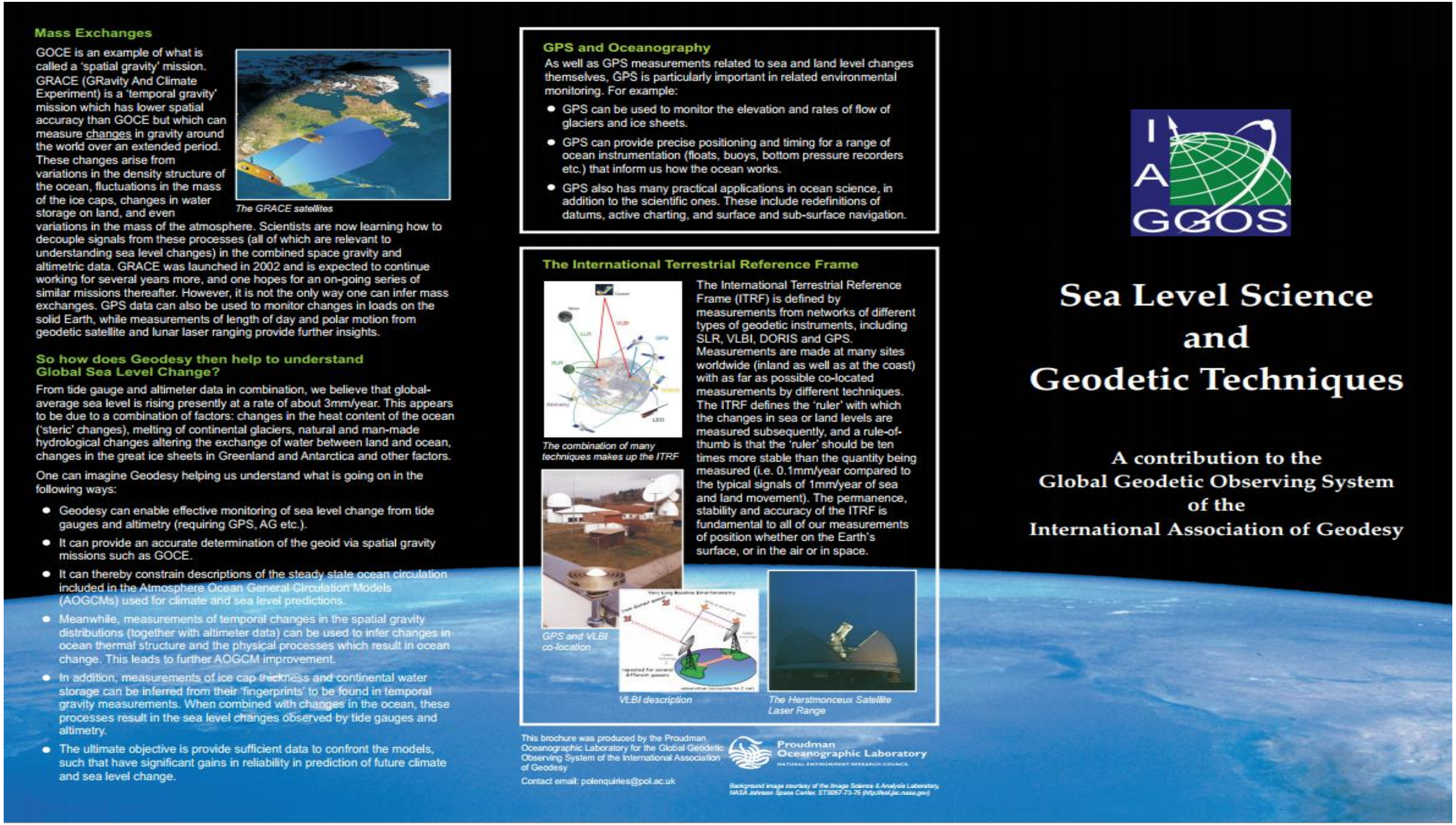


Mass Exchanges

GOCE is an example of what is called a 'spatial gravity' mission. GRACE (GRavity And Climate Experiment) is a 'temporal gravity' mission which has lower spatial accuracy than GOCE but which can measure changes in gravity around the world over an extended period. These changes arise from variations in the density structure of the ocean, fluctuations in the mass of the ice caps, changes in water storage on land, and even variations in the mass of the atmosphere. Scientists are now learning how to decouple signals from these processes (all of which are relevant to understanding sea level changes) in the combined space gravity and altimetric data. GRACE was launched in 2002 and is expected to continue working for several years more, and one hopes for an on-going series of similar missions thereafter. However, it is not the only way one can infer mass exchanges. GPS data can also be used to monitor changes in loads on the solid Earth, while measurements of length of day and polar motion from geodetic satellite and lunar laser ranging provide further insights.

The GRACE satellites

So how does Geodesy then help to understand Global Sea Level Change?

From tide gauge and altimeter data in combination, we believe that global-average sea level is rising presently at a rate of about 3mm/year. This appears to be due to a combination of factors: changes in the heat content of the ocean ('steric' changes), melting of continental glaciers, natural and man-made hydrological changes altering the exchange of water between land and ocean, changes in the great ice sheets in Greenland and Antarctica and other factors.

One can imagine Geodesy helping us understand what is going on in the following ways:

- Geodesy can enable effective monitoring of sea level change from tide gauges and altimetry (requiring GPS, AG etc.).
- It can provide an accurate determination of the geoid via spatial gravity missions such as GOCE.
- It can thereby constrain descriptions of the steady state ocean circulation included in the Atmosphere Ocean General Circulation Models (AOGCMs) used for climate and sea level predictions.
- Meanwhile, measurements of temporal changes in the spatial gravity distributions (together with altimeter data) can be used to infer changes in ocean thermal structure and the physical processes which result in ocean change. This leads to further AOGCM improvement.
- In addition, measurements of ice cap thickness and continental water storage can be inferred from their 'fingerprints' to be found in temporal gravity measurements. When combined with changes in the ocean, these processes result in the sea level changes observed by tide gauges and altimetry.
- The ultimate objective is provide sufficient data to confront the models, such that have significant gains in reliability in prediction of future climate and sea level change.

GPS and Oceanography

As well as GPS measurements related to sea and land level changes themselves, GPS is particularly important in related environmental monitoring. For example:

- GPS can be used to monitor the elevation and rates of flow of glaciers and ice sheets.
- GPS can provide precise positioning and timing for a range of ocean instrumentation (floats, buoys, bottom pressure recorders etc.) that inform us how the ocean works.
- GPS also has many practical applications in ocean science, in addition to the scientific ones. These include redefinitions of datums, active charting, and surface and sub-surface navigation.

The International Terrestrial Reference Frame

The International Terrestrial Reference Frame (ITRF) is defined by measurements from networks of different types of geodetic instruments, including SLR, VLBI, DORIS and GPS. Measurements are made at many sites worldwide (inland as well as at the coast) with as far as possible co-located measurements by different techniques. The ITRF defines the 'ruler' with which the changes in sea or land levels are measured subsequently, and a rule-of-thumb is that the 'ruler' should be ten times more stable than the quantity being measured (i.e. 0.1mm/year compared to the typical signals of 1mm/year of sea and land movement). The permanence, stability and accuracy of the ITRF is fundamental to all of our measurements of position whether on the Earth's surface, or in the air or in space.

The combination of many techniques makes up the ITRF

GPS and VLBI co-location

VLBI description

The Herstmonceux Satellite Laser Range

This brochure was produced by the Proudman Oceanographic Laboratory for the Global Geodetic Observing System of the International Association of Geodesy

Contact email: polenquiries@pol.ac.uk

Proudman Oceanographic Laboratory
NATURAL ENVIRONMENT RESEARCH COUNCIL

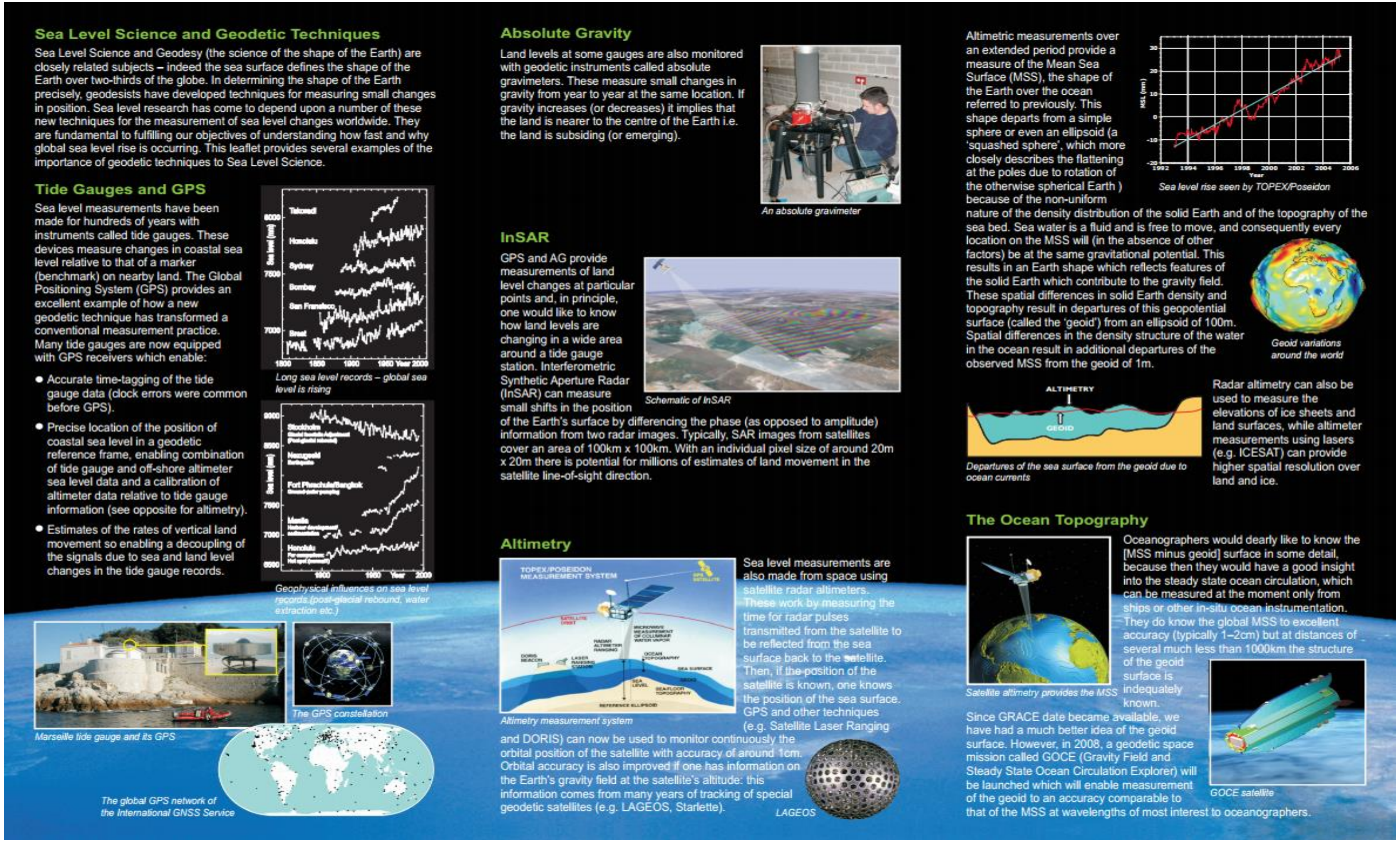
Background image courtesy of the Image Science & Analysis Laboratory, NASA Johnson Space Center. STS057-73-75 (http://eol.jsc.nasa.gov)

IAG GGOS

Sea Level Science and Geodetic Techniques

A contribution to the
Global Geodetic Observing System
of the
International Association of Geodesy

现代（卫星）大地测量



Sea Level Science and Geodetic Techniques

Sea Level Science and Geodesy (the science of the shape of the Earth) are closely related subjects – indeed the sea surface defines the shape of the Earth over two-thirds of the globe. In determining the shape of the Earth precisely, geodesists have developed techniques for measuring small changes in position. Sea level research has come to depend upon a number of these new techniques for the measurement of sea level changes worldwide. They are fundamental to fulfilling our objectives of understanding how fast and why global sea level rise is occurring. This leaflet provides several examples of the importance of geodetic techniques to Sea Level Science.

Tide Gauges and GPS

Sea level measurements have been made for hundreds of years with instruments called tide gauges. These devices measure changes in coastal sea level relative to that of a marker (benchmark) on nearby land. The Global Positioning System (GPS) provides an excellent example of how a new geodetic technique has transformed a conventional measurement practice. Many tide gauges are now equipped with GPS receivers which enable:

- Accurate time-tagging of the tide gauge data (clock errors were common before GPS).
- Precise location of the position of coastal sea level in a geodetic reference frame, enabling combination of tide gauge and off-shore altimeter sea level data and a calibration of altimeter data relative to tide gauge information (see opposite for altimetry).
- Estimates of the rates of vertical land movement so enabling a decoupling of the signals due to sea and land level changes in the tide gauge records.

Long sea level records – global sea level is rising

Geophysical influences on sea level records (post-glacial rebound, water extraction etc.)

Marseille tide gauge and its GPS

The GPS constellation

The global GPS network of the International GNSS Service

Absolute Gravity

Land levels at some gauges are also monitored with geodetic instruments called absolute gravimeters. These measure small changes in gravity from year to year at the same location. If gravity increases (or decreases) it implies that the land is nearer to the centre of the Earth i.e. the land is subsiding (or emerging).

An absolute gravimeter

InSAR

GPS and AG provide measurements of land level changes at particular points and, in principle, one would like to know how land levels are changing in a wide area around a tide gauge station. Interferometric Synthetic Aperture Radar (InSAR) can measure small shifts in the position of the Earth's surface by differencing the phase (as opposed to amplitude) information from two radar images. Typically, SAR images from satellites cover an area of 100km x 100km. With an individual pixel size of around 20m x 20m there is potential for millions of estimates of land movement in the satellite line-of-sight direction.

Schematic of InSAR

Altimetry

Sea level measurements are also made from space using satellite radar altimeters. These work by measuring the time for radar pulses transmitted from the satellite to be reflected from the sea surface back to the satellite. Then, if the position of the satellite is known, one knows the position of the sea surface. GPS and other techniques (e.g. Satellite Laser Ranging and DORIS) can now be used to monitor continuously the orbital position of the satellite with accuracy of around 1cm. Orbital accuracy is also improved if one has information on the Earth's gravity field at the satellite's altitude: this information comes from many years of tracking of special geodetic satellites (e.g. LAGEOS, Starlette).

Altimetry measurement system

LAGEOS

Altimetric measurements over an extended period provide a measure of the Mean Sea Surface (MSS), the shape of the Earth over the ocean referred to previously. This shape departs from a simple sphere or even an ellipsoid (a 'squashed sphere', which more closely describes the flattening at the poles due to rotation of the otherwise spherical Earth) because of the non-uniform nature of the density distribution of the solid Earth and of the topography of the sea bed. Sea water is a fluid and is free to move, and consequently every location on the MSS will (in the absence of other factors) be at the same gravitational potential. This results in an Earth shape which reflects features of the solid Earth which contribute to the gravity field. These spatial differences in solid Earth density and topography result in departures of this geopotential surface (called the 'geoid') from an ellipsoid of 100m. Spatial differences in the density structure of the water in the ocean result in additional departures of the observed MSS from the geoid of 1m.

Sea level rise seen by TOPEX/Poseidon

Geoid variations around the world

Departures of the sea surface from the geoid due to ocean currents

Radar altimetry can also be used to measure the elevations of ice sheets and land surfaces, while altimeter measurements using lasers (e.g. ICESAT) can provide higher spatial resolution over land and ice.

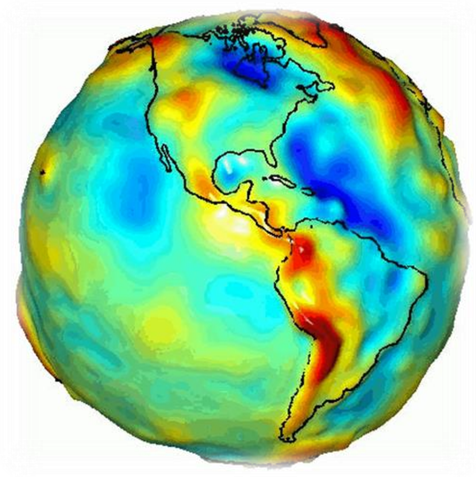
The Ocean Topography

Oceanographers would dearly like to know the [MSS minus geoid] surface in some detail, because then they would have a good insight into the steady state ocean circulation, which can be measured at the moment only from ships or other in-situ ocean instrumentation. They do know the global MSS to excellent accuracy (typically 1–2cm) but at distances of several much less than 1000km the structure of the geoid surface is indequately known.

Satellite altimetry provides the MSS

Since GRACE date became available, we have had a much better idea of the geoid surface. However, in 2008, a geodetic space mission called GOCE (Gravity Field and Steady State Ocean Circulation Explorer) will be launched which will enable measurement of the geoid to an accuracy comparable to that of the MSS at wavelengths of most interest to oceanographers.

GOCE satellite



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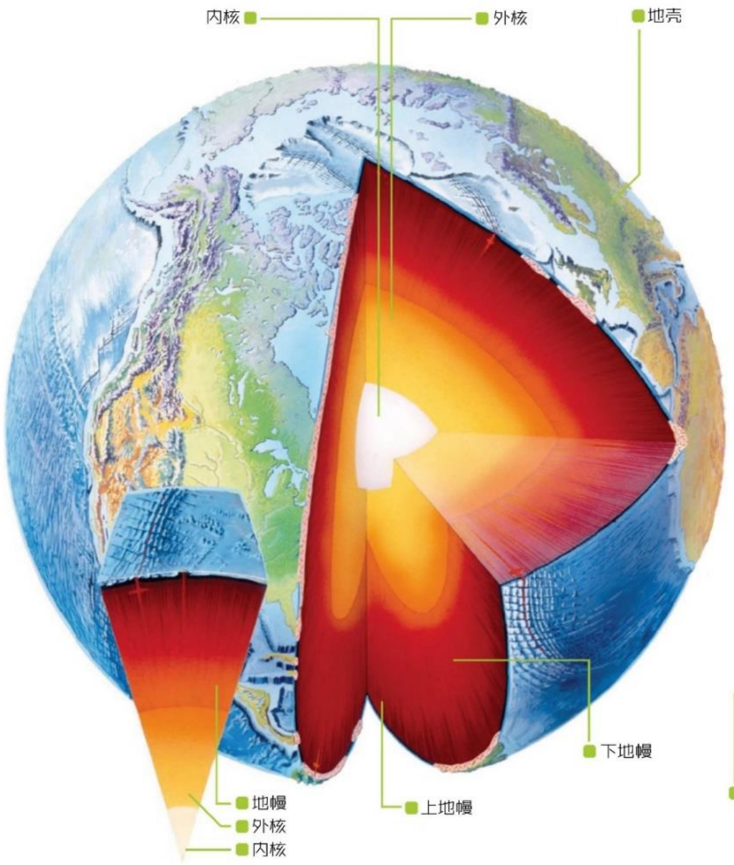
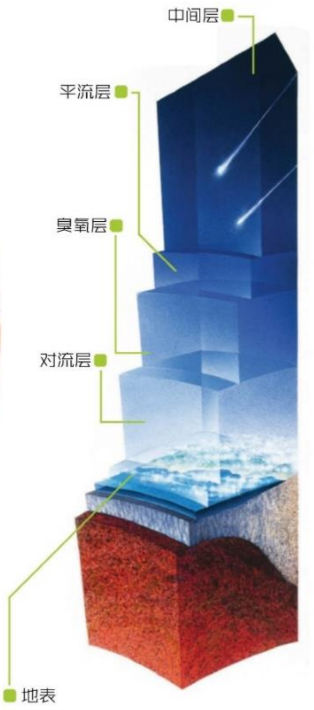
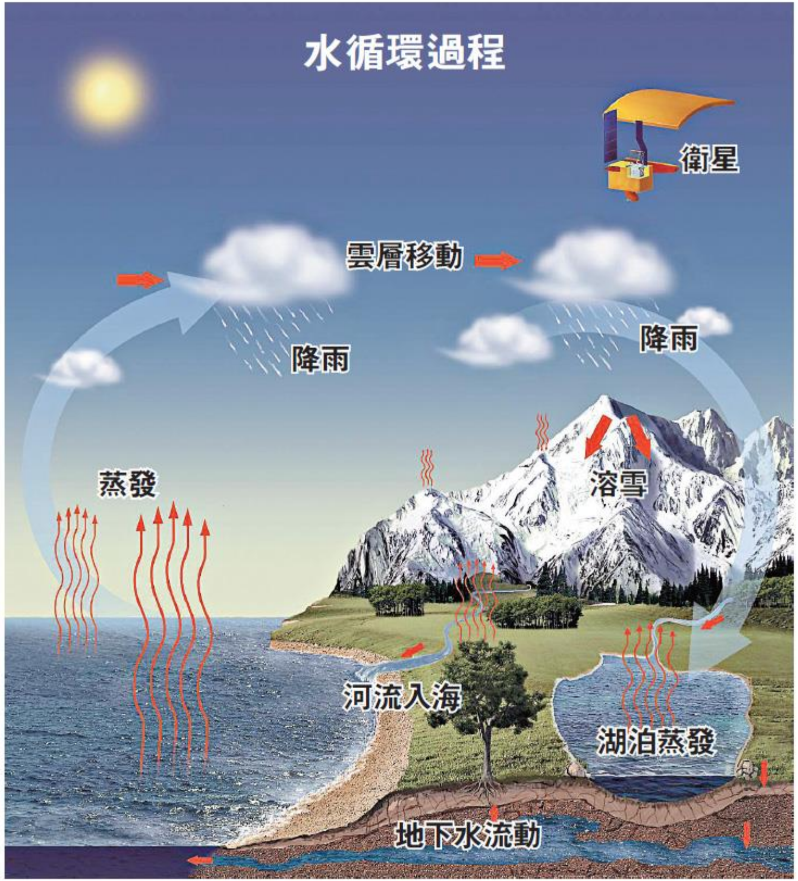
地球的结构

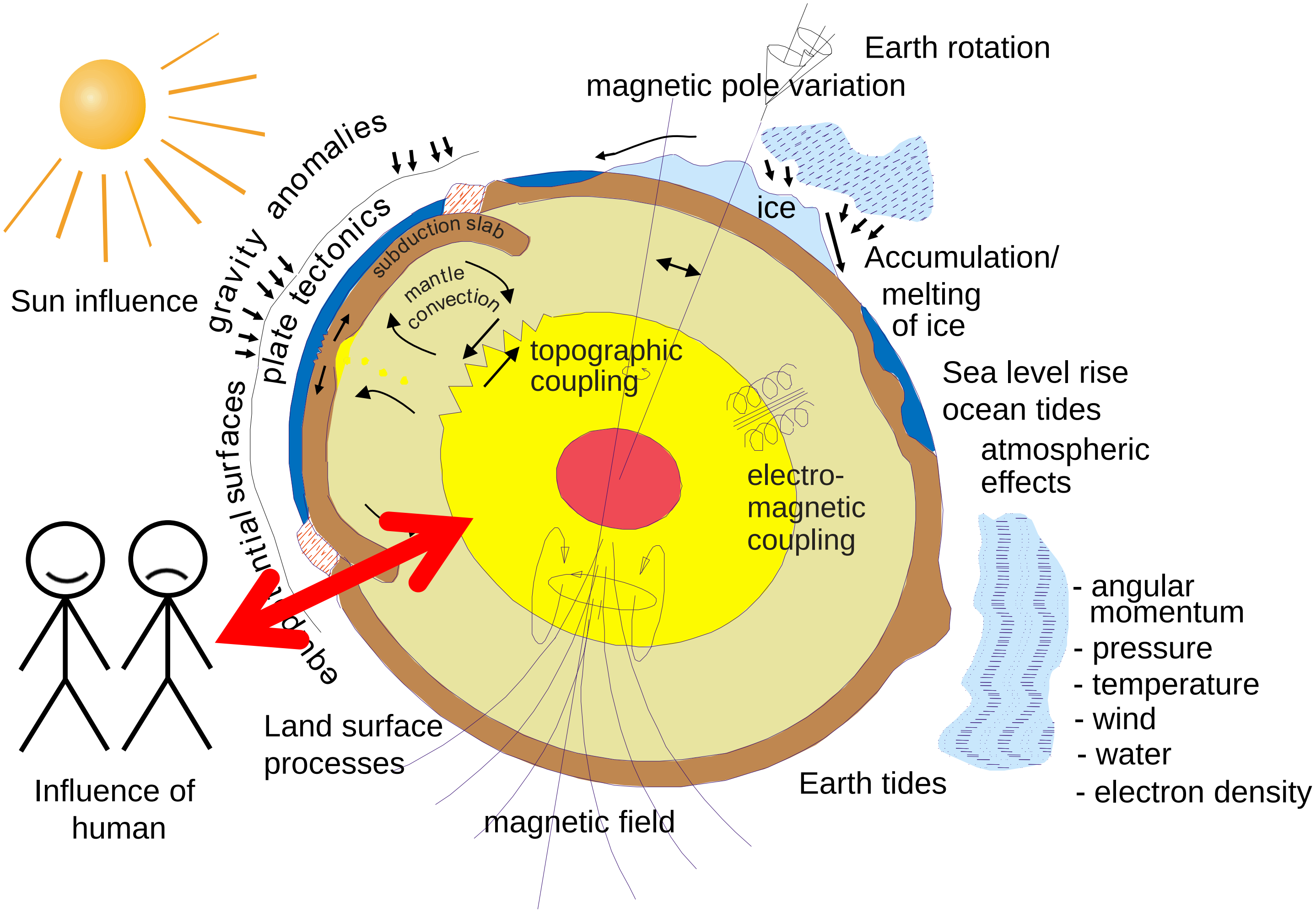




地球的水循环

- 大气圈
- 水　圈
- 生物圈
- 岩石圈





Earth rotation

magnetic pole variation

Sun influence

gravity anomalies

plate tectonics

subduction slab

mantle convection

topographic coupling

ice

Accumulation/
melting
of ice

Sea level rise
ocean tides

atmospheric
effects

electro-
magnetic
coupling

- angular momentum
- pressure
- temperature
- wind
- water
- electron density

ntial surfaces

Influence of
human

Land surface
processes

magnetic field

Earth tides

Geodesy Groups and Missions ……

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IAG
ERS
IGS
International Laser Ranging Service
IVS
IDS
GGOS
SPACE GEODESY PROJECT
ICSU WORLD DATA SYSTEM

Missions

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CNES NASA OSTM JASON2 NOAA EUMETSAT
METEOP-3M / SAGE III
CRYOSAT
TOPEX/POSEIDON
QZSS みちびき
GALILEO
GALILEO GIOVE
NAVSTAR GPS
GLONASS
CHAMP GFZ
TERRA SAR X
GOCE
GRACE
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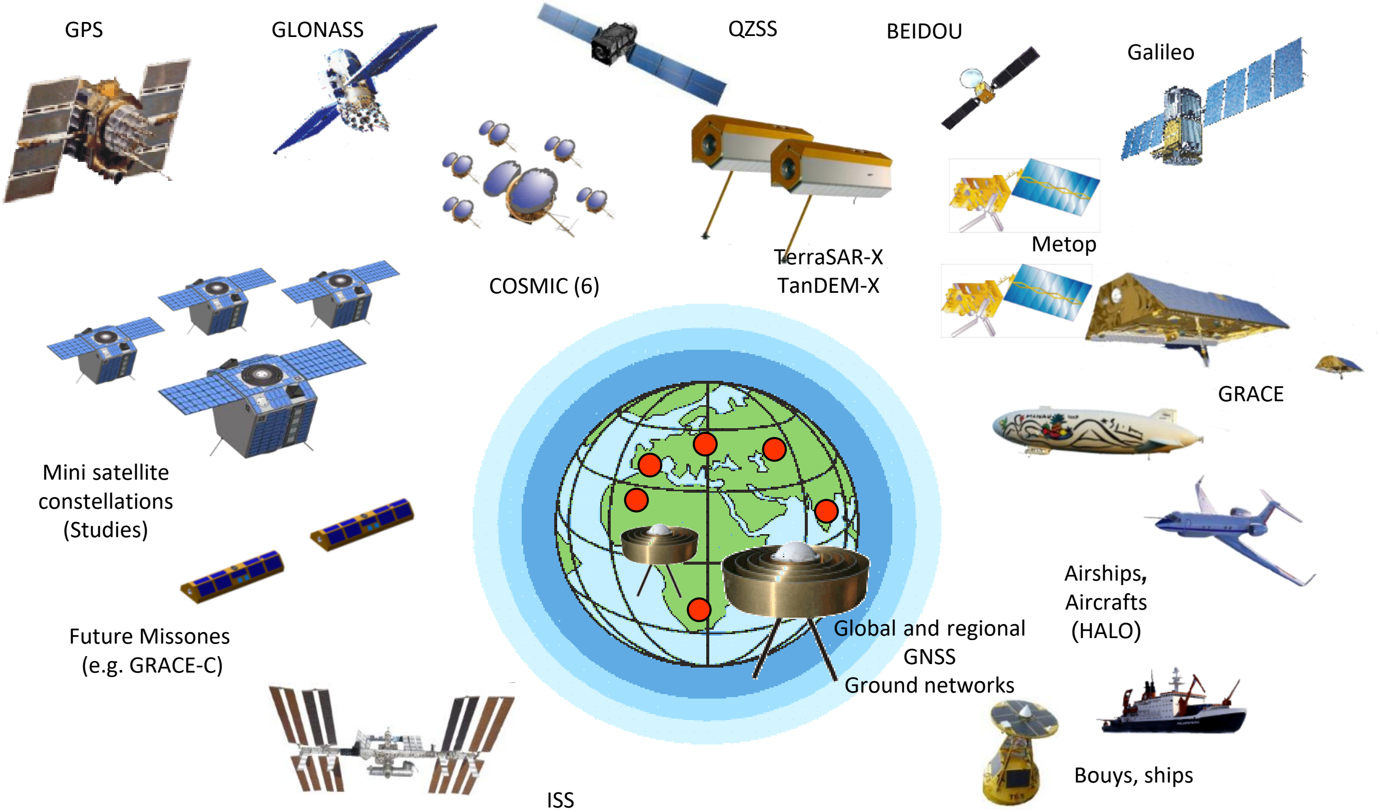
测绘大数据时代已经到来



大地测量学课程介绍

课程的发展进程

“大地测量学基础”是为了满足测绘工程及相关专业从“**模拟**”到“**数字化**”、由“**地面**”到“**太空**”、并进一步走向“**信息化**”的专业建设和人才培养需求，经过综合分析**应用大地测量学**、椭球大地测量学、卫星大地测量学、地球重力场、地球动力学、卫星导航定位系统GNSS原理等多门课程的公共基础内容，建立形成的以几何、物理以及现代空间大地测量学为基本框架的**专业基础课**。

课程定位

以坐标系统、大地网、大地测量观测技术和数据处理为主线进行讲授，充分理解“从整体到局部”的测量原则，是在前期课程“误差理论与测量平差基础”、“数字测图原理与方法”等课程之后的理论加深课，同时又为后续的“工程测量”、“GPS原理及应用”、“物理大地测量”等课程奠定学习基础。

课程考核方式

（1）期末试卷：占总成绩的<u>70%</u>；

（2）课堂作业：占总成绩的<u>30%</u>。

课堂作业包括出勤、期中测试、读书报告（PPT）等。

本课程学习要求

- 基本掌握大地测量的发展趋势
- 主动完成课后作业
- 精读大地测量相关的学术论文
- 结合课堂相关内容准备PPT汇报
- 了解常用大地测量软件并进行程序设计

主讲教材及参考教材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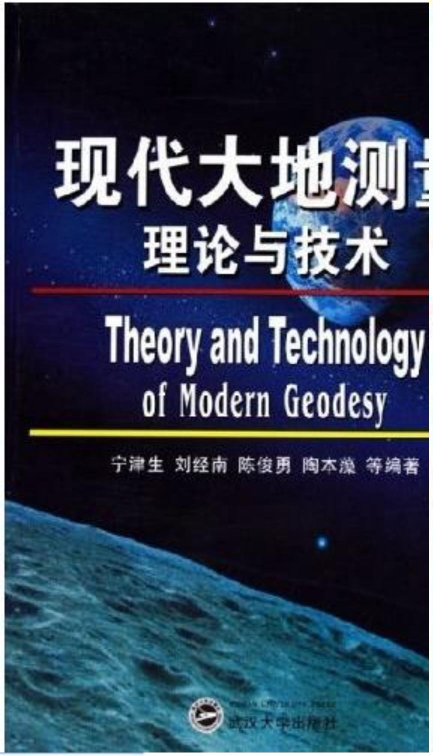
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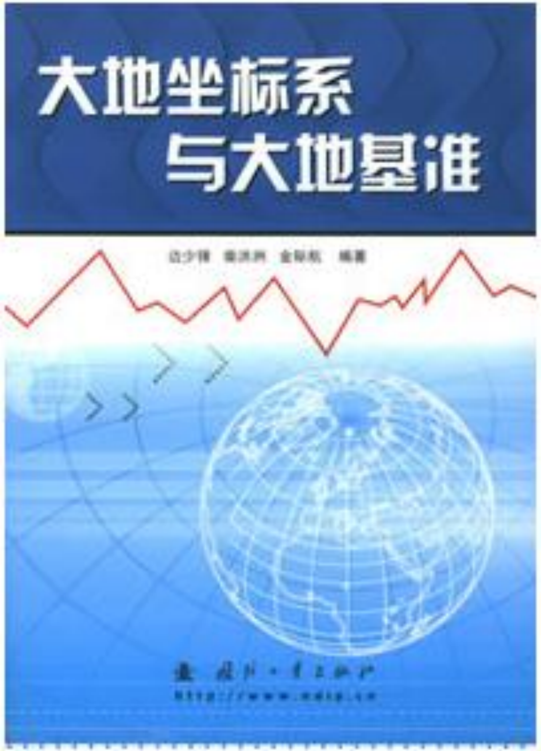
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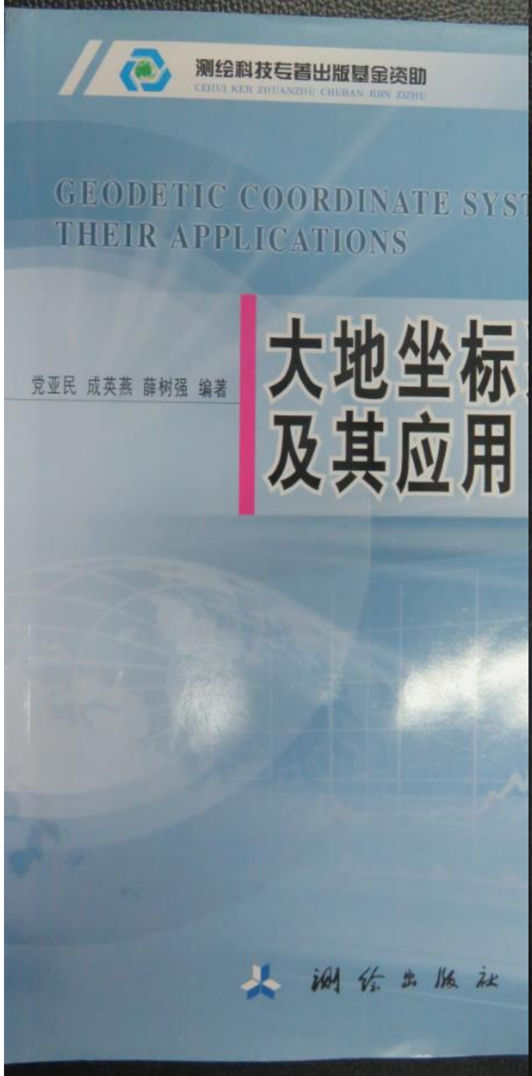

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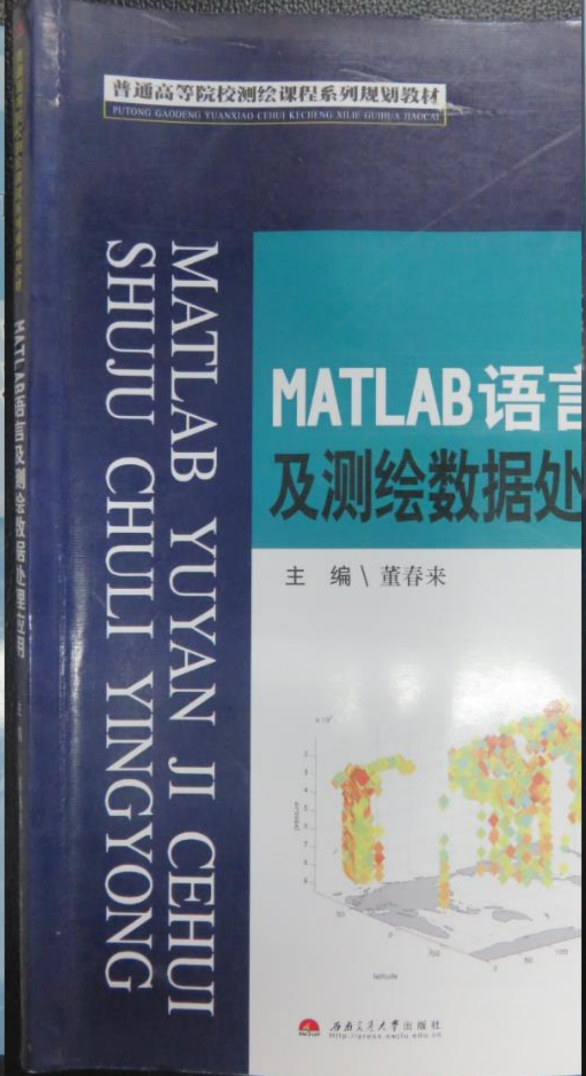

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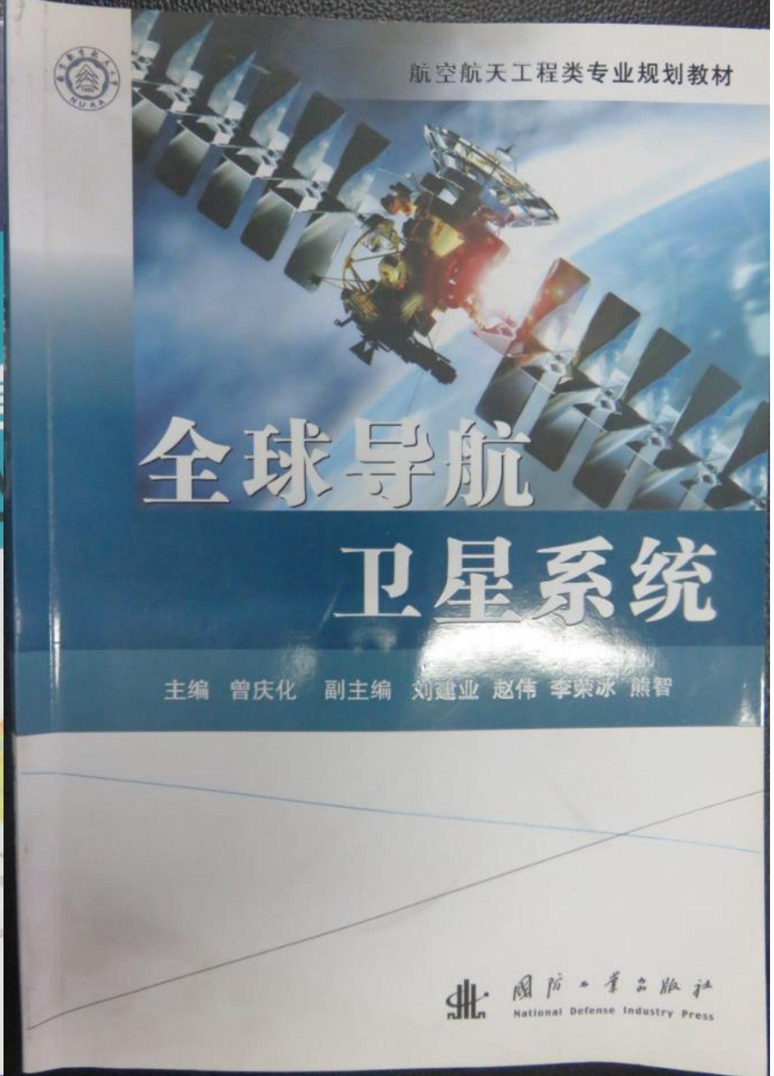

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合与插值中龙格现象的处理方法

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of Runge s phenomenon in fitting & interpolating GPS precise ephemeris

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-dong①②; XU Ai-gong①; FENG Lei①(①School of Geomatics; Liaoning Technical University; Liaoning Fuxin 123000; China; ②Key Laboratory of Geomatics and Digital Technology of Shandor

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广播星历和精密星历计算卫星位置是GPS定位基础,为确保精度可靠,广播星历由地面控制部分约每2小时更新一次,在对广播星历拟合与插值时有龙格现象发生,本文用Chebyshev和Legendre多项式拟合
值数学机理认真分析研究的基础上,通过实验得出龙格现象的有效处理方法,对GPS精密星历高采样率拟合与插值具有参考意义。

adcast ephemeris and precise ephemeris are the foundation of using GPS for positioning;the ground control part updates broadcast ephemeris about every 2 hours to ensure the accuracy.While
.This article handled the precise ephemeris with the Chebyshev and Legendre polynomial fitting and Lagrange,Neville and Newton interpolation methods.On that basis of studying mathematical

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中国北斗卫星导航系统对全球 PNT 用户的贡献

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摘要　北斗卫星导航系统作为全球四大卫星导航系统之一, 不仅增加中国及周边地区定位、导航和授时(PNT=Positioning, Navigation and Timing)用户的卫星可见性和可用性, 而且也将提高全球用户的 PNT 精度. 在全球导航卫星系统(GNSS)兼容与互操作条件下, 分析全球导航定位定时用户的卫星可见性和精度衰减因子改善情况; 利用仿真数据分析北斗卫星导航系统对全球用户的贡献, 侧重分析北斗卫星导航系统与 GPS, GLONASS 和 Galileo 多卫星导航系统组合模式下用户获得的收益.

关键词
北斗卫星导航系统
定位
导航
授时
精度衰减因子
卫星可见性

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