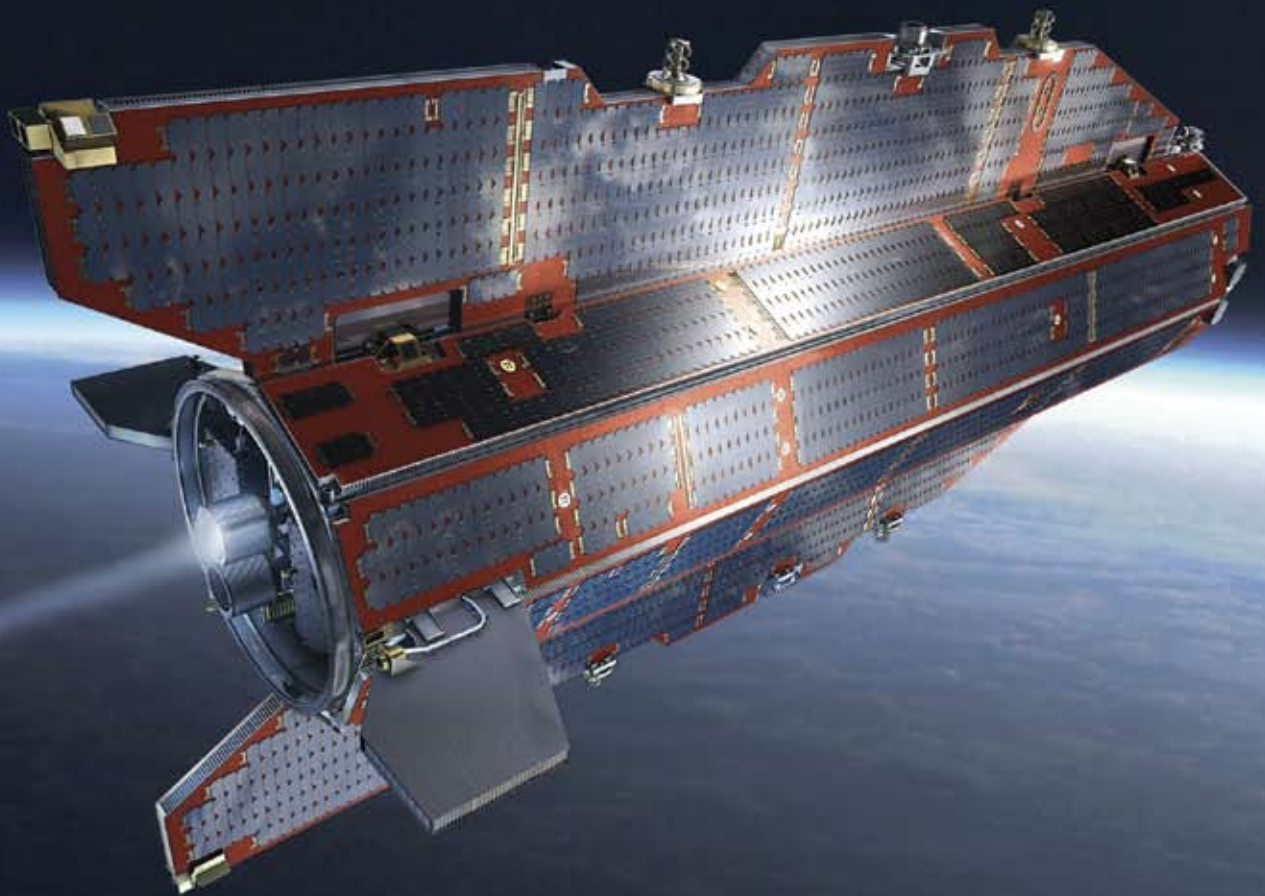


goce

→ ESA'S GRAVITY MISSION

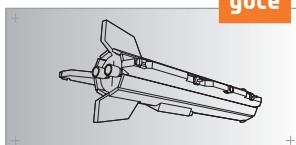


ESA'S EARTH EXPLORER MISSIONS

The Earth Explorer series of Earth observation missions focuses on the science and research elements of ESA's Living Planet Programme. Developed in direct response to issues identified by the scientific community, they aim to improve our understanding of how the Earth system works and the impact human activity is having on natural Earth processes. Earth Explorers are also designed to demonstrate breakthrough technology and remote sensing techniques and, together with the scientific questions addressed, form the basis for the development of new applications for Earth observation data.

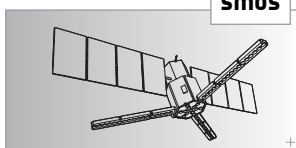
As a result of the continuing, user-driven approach for realising Earth Explorers, six missions have been selected so far for implementation:

goce



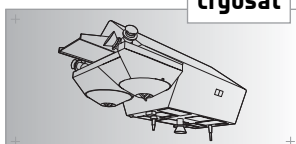
GOCE (Gravity field and steady-state Ocean Circulation Explorer) Launched in March 2009, GOCE is dedicated to measuring Earth's gravity field with unprecedented accuracy and spatial resolution. The resulting model of the geoid – the surface of equal gravitational potential defined by the gravity field – will advance our knowledge of ocean circulation, sea-level change and Earth-interior processes. GOCE will also make significant advances in geodesy and surveying.

smos



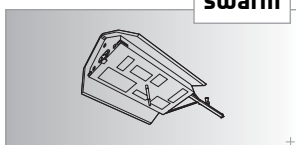
SMOS (Soil Moisture and Ocean Salinity) Launched in November 2009, SMOS is making global observations of soil moisture over landmasses and salinity over the oceans. The data will result in a better understanding of the water cycle and, in particular, the exchange processes between Earth's surfaces and the atmosphere. Data from SMOS will help to improve weather and climate models, and also have practical applications in areas such as agriculture and water resource management.

cryosat



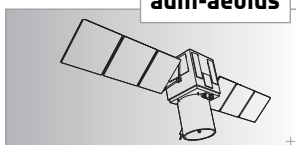
CRYOSAT The first mission to be selected, CryoSat will determine variations in the thickness of floating sea-ice so that seasonal and interannual variations can be detected. The satellite will also survey the surface of continental ice sheets to detect small elevation changes. Information on precise variations in ice thickness will further our understanding of the relationship between ice and climate change. The CryoSat-2 satellite replaces the original CryoSat, which was lost due to a launch failure in October 2005.

swarm



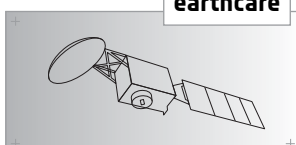
SWARM Swarm is a constellation of three satellites to provide high-precision and high-resolution measurements of the strength and direction of Earth's magnetic field. The models of the geomagnetic field resulting from the mission will provide new insights into Earth's interior, further our understanding of atmospheric processes related to climate and weather, and will have practical applications in areas such as space weather and radiation hazards.

adm-aeolus



ADM-AEOLUS (Atmospheric Dynamics Mission) Aeolus will be the first space mission to measure wind profiles on a global scale. The mission will improve the accuracy of numerical weather forecasting and advance our understanding of atmospheric dynamics and processes relevant to climate variability.

earthcare



EARTHCARE (Earth, Clouds, Aerosols and Radiation Explorer) EarthCARE is being implemented in cooperation with the Japan Aerospace Exploration Agency. The mission addresses the need for a better understanding of the interactions between clouds and the radiative and aerosol processes that play a role in climate regulation.

Further information about ESA's Earth Explorer missions can be obtained via:
www.esa.int/livingplanet

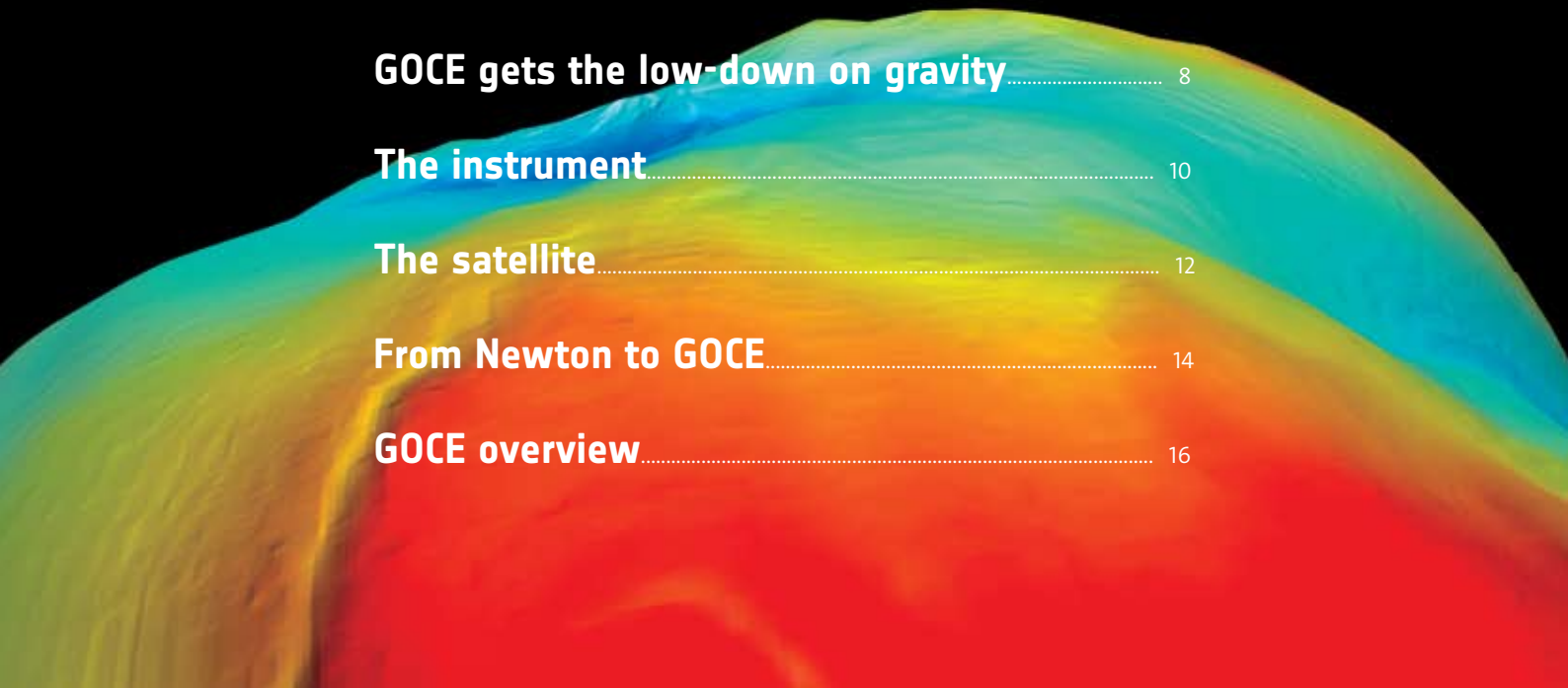




GOCE: ESA'S GRAVITY MISSION

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→ GOCE

Gravity Field and Steady-State Ocean Circulation Explorer



Rijkswaterstaat, NL

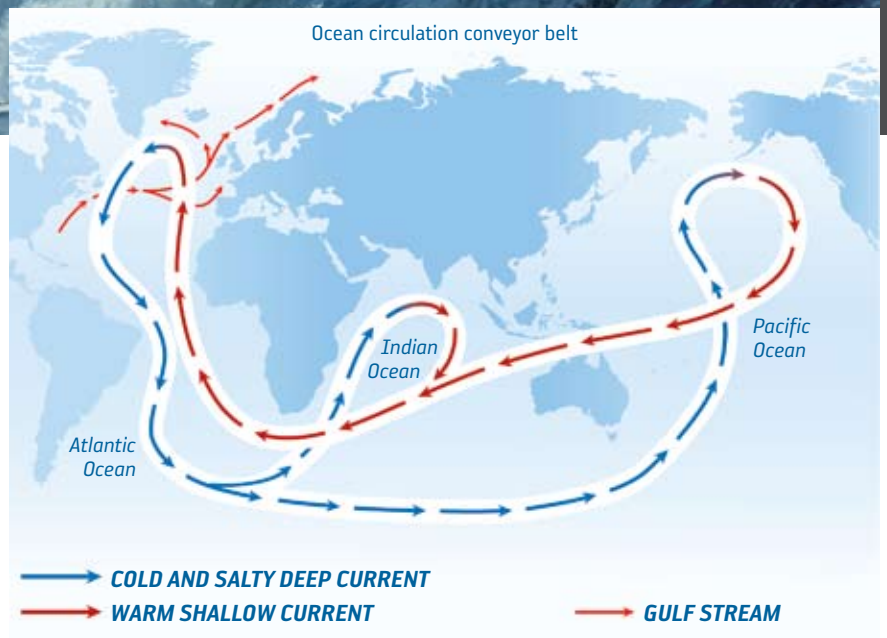
Papendrecht, The Netherlands 1953 flood

Gravity is a fundamental force of nature that influences many dynamic processes within Earth's interior, and on and above its surface. It is sometimes assumed that the force of gravity on the surface of Earth has a constant value, but this is actually not the case and would only be true if Earth were a perfect sphere, and if each layer of material within the interior were evenly distributed. In reality, the shape of Earth is slightly flattened because, as our planet rotates, centrifugal force tends to pull material outwards around the Equator where the velocity of rotation is at its highest. This results in Earth's radius being 21 km greater at the Equator compared to the poles, which is the main reason why the force of gravity is weaker at the Equator than it is at the poles. Rather than being smooth, the surface of Earth is relatively 'lumpy' if topographical features such as mountain ranges are taken into consideration. In fact, there is about a 20 km difference in height between the highest mountain and the deepest part of the ocean floor. Also, the different materials that make up

the layers of Earth's crust and mantle are far from homogeneously distributed, and even the depths of the layers vary from place to place. For instance, the crust beneath the oceans is a lot thinner and denser than the continental crust. It is factors such as these that cause the gravitational force on the surface of the planet to vary significantly from place to place.

Although terrestrial data on the subject of gravity have been collected for many years now, the advent of the space age has provided the opportunity to acquire a detailed map of the global gravity field within a short period of time. GOCE (Gravity Field and Steady-State Ocean Circulation Explorer) is an ESA mission dedicated to measuring Earth's gravity field and modelling the geoid, with extremely high accuracy and resolution. An improved knowledge of gravity anomalies will contribute to a better understanding of Earth's interior, such as the physics and dynamics associated with volcanism and earthquakes.

The geoid, which is defined by Earth's gravity field, is a surface of equal gravitational potential. It follows a hypothetical ocean surface at rest, in the absence of tides and currents. A precise model of Earth's geoid is crucial in deriving accurate measurements of ocean circulation, sea-level change and terrestrial ice dynamics, all of which are affected by climate change. The geoid is also used as a reference surface from which to map all topographical features on the planet,



whether they belong to land, ice or the ocean – a reference that can be used, for example, to compare accurately height measurements of features such as mountain ranges on different continents.

GOCE is the second Earth Explorer satellite to be developed as part of ESA's Living Planet Programme and was launched from Russia in 2009. The gravitational signal is stronger closer to Earth, so GOCE has been designed to fly in a very low orbit. However, the 'atmosphere' at low altitudes creates a very demanding environment for the satellite in terms of resources such as propellant and electrical power, and therefore data will be collected for just 20 months. This is sufficient time to gather the essential data to advance our knowledge of Earth's gravity field and geoid, which will be vital for the next generation of geophysical research and will contribute significantly to furthering our understanding of Earth's climate.

GOCE will contribute significantly to a better understanding of general ocean circulation patterns.



→ EARTH'S GRAVITY FIELD



When thinking of gravity, most of us conjure up an image of Sir Isaac Newton observing an apple falling from a tree more than 300 years ago. The mass of Earth is greater than that of the apple; therefore the apple falls towards Earth and not vice versa. It was Newton who established the basic principles of gravitation, and the concept more commonly known as the 'g' force. This force is the result of the gravitational attraction between any two objects as a consequence of their mass and their separation.

The geoid (EGM96 model):
The geoid represents deviations from Earth's ellipsoid. Although it has 'highs' and 'lows', it is a surface of equal gravitational potential. Therefore, if an object were placed on this surface it would not move. The surface of the geoid defines the horizontal.



Every body attracts every other body with a force directly proportional to the product of their masses and inversely proportional to the square of the distance between them.

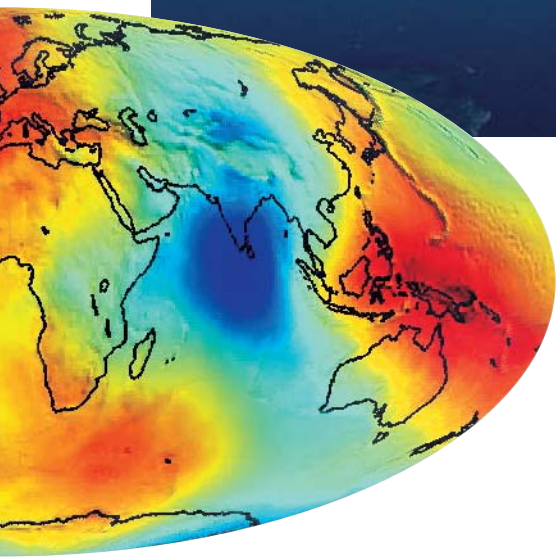
Sir Isaac Newton (1642–1727)



At school we generally learn that $g = 9.8 \text{ m/s}^2$. Indeed, this value for gravitational acceleration was for a long time assumed to be constant for the entire planet. However, as more sophisticated and sensitive tools have been developed to measure g , it has become apparent that the force of gravity actually varies from place to place on the surface of the planet. The standard value of 9.8 m/s^2 refers to Earth as a homogeneous sphere, but in reality there are many reasons for this value to range from a minimum of 9.78 m/s^2 at the Equator to a maximum of 9.83 m/s^2 at the poles.

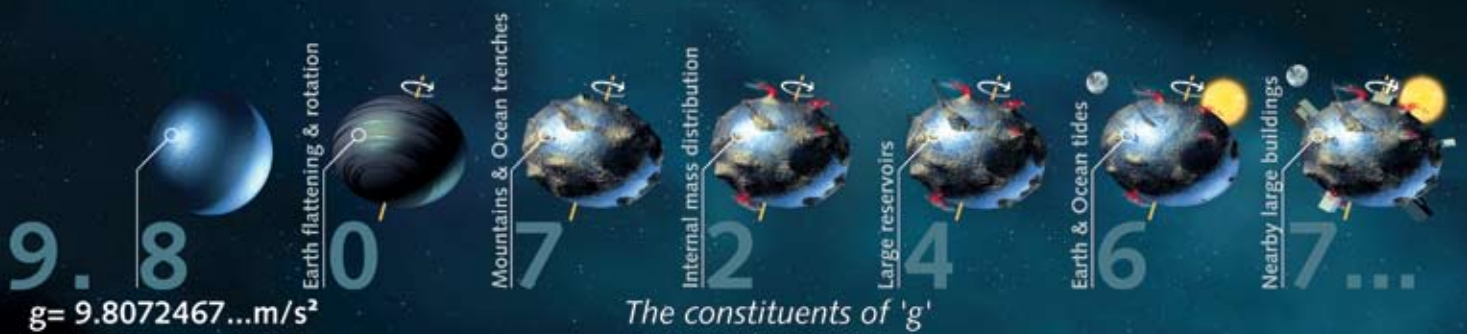
We can now measure how g varies to more than eight decimal places, but what causes these small but significant changes?

The most significant deviation from the standard value of g is a result of Earth's rotation. As Earth spins, its shape is slightly flattened into an ellipsoid, so that there is a greater distance between the centre of Earth and the surface at the Equator, than the centre of Earth and the surface at the poles. This greater distance results in the force of gravity being weaker at the Equator than at the poles. Secondly, the surface of Earth is very uneven; high mountains and deep ocean trenches cause the value of gravity to vary. Thirdly, the materials within Earth's interior are not uniformly distributed. Not only are the layers within the crust and mantle irregular, but also the mass distribution within the layers is inhomogeneous. Petroleum and mineral deposits or groundwater reservoirs can also subtly affect the gravity field, as can a rise in sea level or changes in topography such as ice-sheet movements or volcanic eruptions. Even large buildings can have a minor effect. Of course, depending on location, many of these factors are superimposed upon each other, and can also change with time.

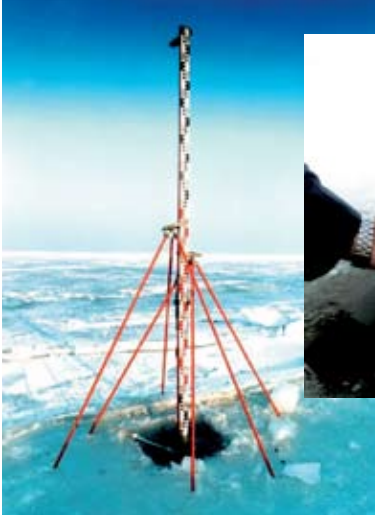


DID YOU KNOW?

- The word 'gravity' is derived from the Latin word 'gravitas', meaning 'weight'.
- 'Mass' is a measure of how much matter an object has, and 'weight' is a measure of how strongly gravity pulls on that matter.
- You weigh less at the Equator than you do at the North Pole.
- Dutchman Christiaan Huygens invented the pendulum clock in 1656, which was the first practical means of measuring 'the rate of falling of a heavy body', or gravity. French astronomers noted afterwards that pendulum clocks lost time near the Equator when compared with observations made in Paris, implying that the intensity of gravity was less at low latitudes – this observation initiated a long debate on the shape of Earth.
- In a vacuum, all objects have the same acceleration due to gravity because there is no air drag. Therefore, if a rock and a feather were dropped off the top of a building at exactly the same time, they would hit the ground simultaneously.
- Although invisible to the naked eye, the sea surface has undulations that echo the topography of the ocean floor – on a reduced scale. For example, the extra mass of a 2 km-high seamount attracts water over it, causing a 'bulge' in the sea surface about 2 m high and about 40 km across. Similarly, the reduced gravity over trenches in the sea floor means that less water is held by gravitational attraction over these regions, so that locally the sea surface is depressed.
- The word 'tide' is a generic term used to define the alternating rise and fall in sea level with respect to the land, as a result of the gravitational attraction of the Moon and the Sun. To a much lesser extent, tides also occur in large lakes, the atmosphere, and within the solid crust of Earth. For example, in some places Earth's crust can rise and fall up to a total of 30 cm every day.
- Birds would choke and die in a zero-gravity environment because they need gravity to help them swallow!



Rijkswaterstaat, NL



As a result of the ice, the water level 'at rest' can be used to transfer heights by levelling over large distances.

The irregular gravity field shapes a virtual surface at mean sea level called the 'geoid'. This is the surface of equal gravitational potential of a hypothetical ocean surface at rest and is often employed as a reference for our traditional height systems, used for levelling and construction. The surface of the geoid can deviate by as much as 100 m from an ellipsoidal model representing Earth.

→ WHY WE NEED TO MAP EARTH'S GRAVITY FIELD

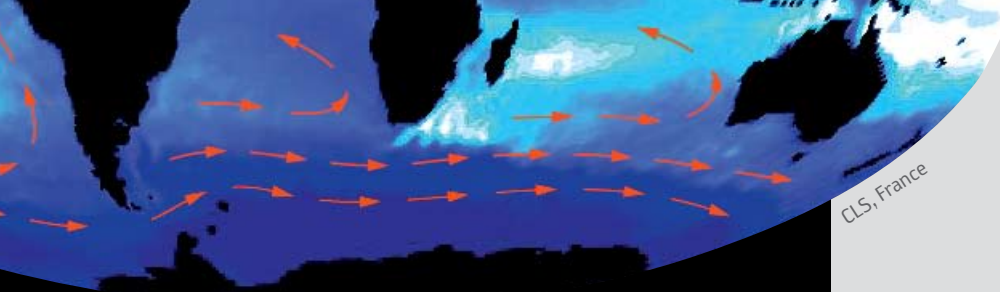
Most of us take Earth's continuous pull of gravity for granted. Although invisible, it provides us with the sense of the horizontal and the vertical. However, if gravity is studied in detail we appreciate how complex this force actually is. We are currently aiming to achieve a better understanding of Earth's gravity field and its associated geoid. This will significantly advance our knowledge of how Earth works and also have a number of important practical applications. For instance, because gravity is directly linked to the distribution of mass within Earth, an improved gravity-field map will provide an insight into the physics and dynamics of Earth's interior. An accurate global geoid model will contribute to an improved understanding of ocean circulation, which plays an important role in energy exchanges around the globe. It will also lead to a greater insight into sea-level change, and to a global unification of height systems, so that for example, mountain ranges in America can be measured against those in Europe or Africa.

Ocean Circulation

Ocean circulation plays a crucial role in climate regulation by transporting heat from low to high latitudes in surface waters, while currents cooled at high latitudes flow in deeper waters back towards the Equator. The Gulf Stream, which carries warm surface waters northwards from the Gulf of Mexico, is a good example of how important ocean currents are in redistributing heat. Thanks to this current, the coastal waters of Europe are actually 4°C warmer than waters at equivalent latitudes in the North Pacific. However, knowledge of the role that the oceans have in moderating the climate is currently insufficient for the accurate prediction of climate change. In order to study ocean circulation more effectively, it is necessary to have an accurate map of Earth's geoid. The GOCE derived model of the geoid will serve as a reference from which to study circulation patterns of not only surface waters but also deeper currents. Radar altimetry provides us with the actual shape of the ocean surface and then by subtracting the shape of the geoid this provides the ocean topography. Surface ocean circulation can then be derived directly from these '1–2 metre mountains'.

Solid Earth

How are mountain roots formed? Where are oil fields and ore deposits hidden? Why do plates in Earth's crust move and cause earthquakes? Where does lava rise through the crust to



Mean dynamic ocean topography model

the surface of Earth? Detailed mapping of density variations in the lithosphere and upper mantle, down to a depth of 200 km, derived from a combination of the gravity field map and seismic data will provide an improved understanding of processes such as these. GOCE will also further our knowledge of land uplift due to post-glacial rebound. This process describes how Earth's crust is rising in places as it has been relieved of the weight of thick ice sheets since the last Ice Age, when the heavy load caused the crust to depress. Scandinavia is rising at up to 1 cm per year, and Canada is rising at up to 2 cm a year.

Geodesy

Geodesy is concerned with mapping the shape of Earth, to the benefit of all branches of Earth sciences as well as having numerous practical applications. For example, an improved geoid will be used for levelling and construction, ensuring for instance that water flows in the direction intended. It will replace expensive and time-consuming procedures that are currently undertaken. It will also be used for a high-accuracy global height reference system for studying the topography of Earth. This will also facilitate one global system for tide gauge records, so that sea levels can be compared all over the world.

Sea-level Change

Data derived from the GOCE mission will contribute to observing and understanding sea-level change as a result of melting continental ice-sheets associated with a changing climate and postglacial rebound.



Rijkswaterstaat, NL



Rijkswaterstaat, NL



Rijkswaterstaat, NL



- 1 Dams typically built as protection from the sea, the operation of which depends upon the prevailing sea level.
- 2 Expensive and time-consuming levelling, which GOCE can replace by the combination of GPS and an advanced map of the geoid.
- 3 The ancient use of an aqueduct relied upon gravity to transport water.

→ GOCE GETS THE LOW-DOWN ON GRAVITY

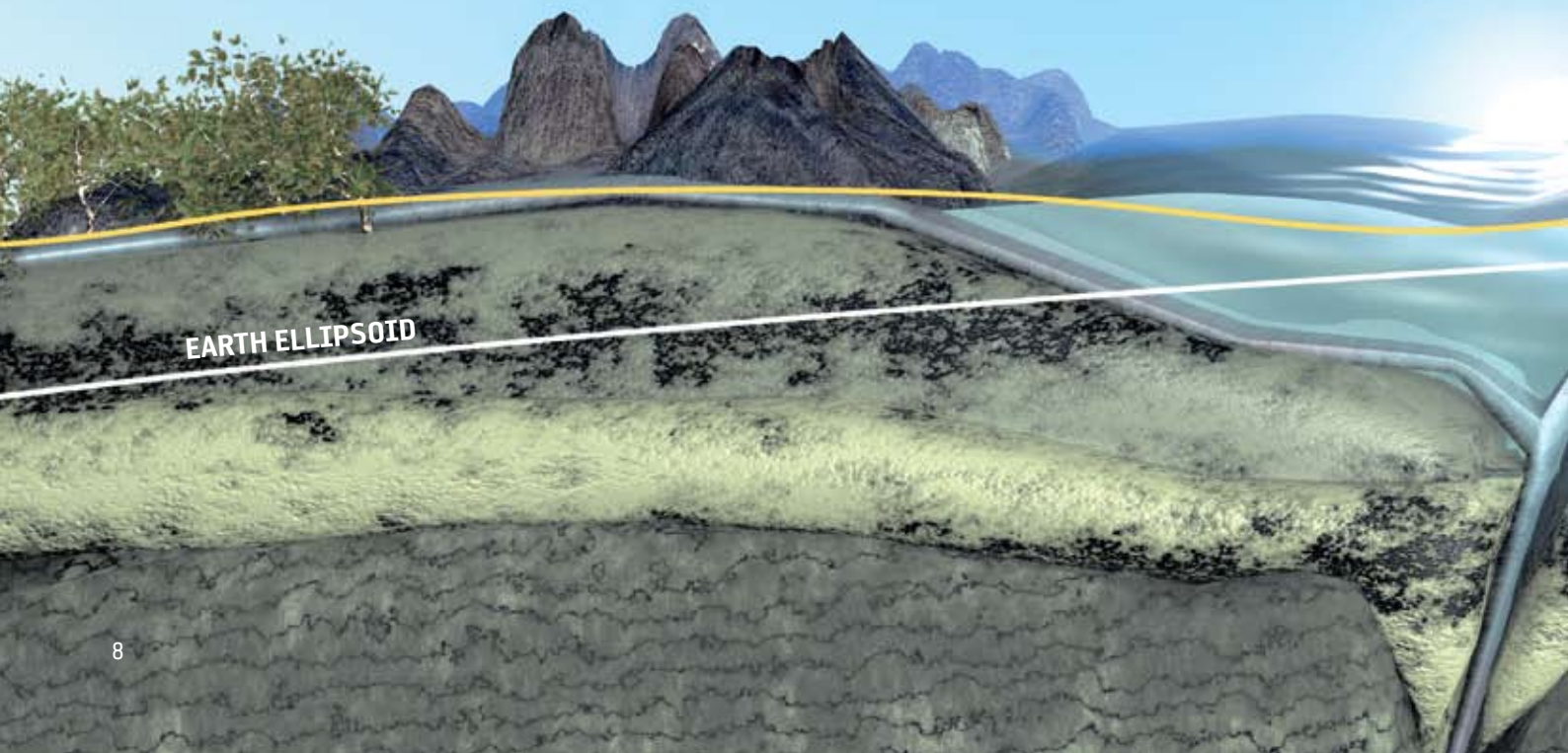
The traditional method of measuring Earth's gravity field is based on comparing the differences in how a 'test mass', such as a pendulum or gravimeter, responds to the gravitational attraction at different locations on the surface of Earth. Although data on gravity have been collected from many parts of the world by traditional means, they vary considerably in quality and are also incomplete. The process of acquiring data on land and at sea is very time-consuming and expensive – global coverage with data of a consistent quality would take decades. With the need for a global map of Earth's gravity field, coupled with recent advances in the accuracy of the necessary instrumentation, the obvious solution is to make the appropriate observations from space.

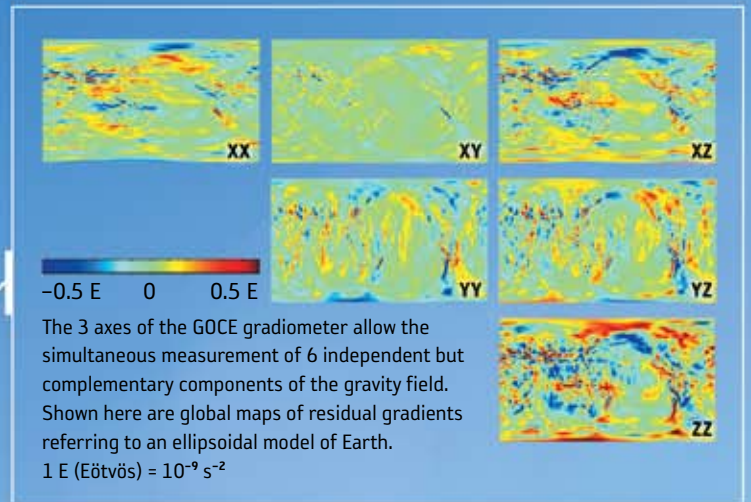
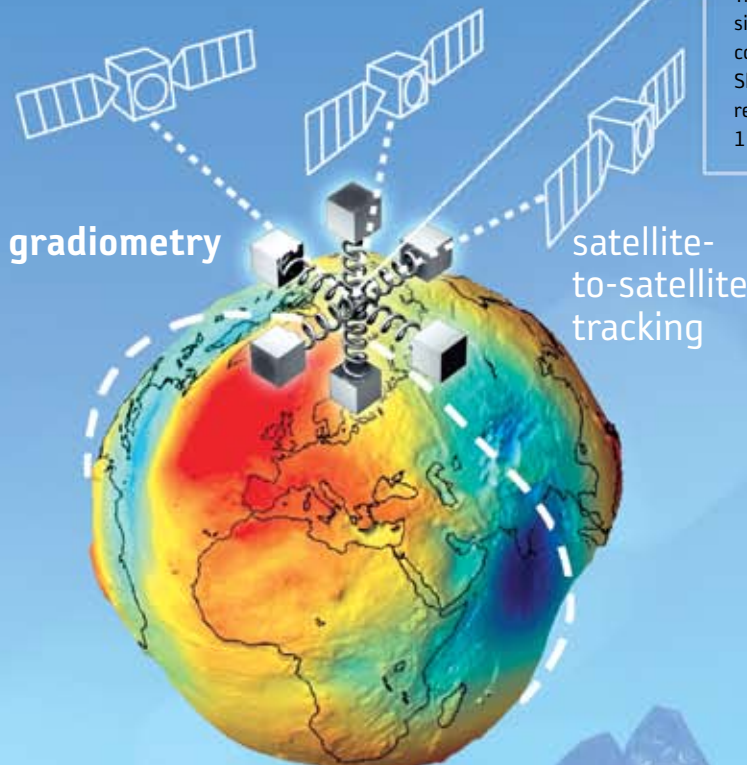
One of the main problems with observing gravity from space is the fact that the strength of Earth's gravitational attraction diminishes with altitude. The orbit of the satellite must therefore be as low as possible to observe the strongest gravity field signal. However, the lower the orbit the more air-drag the satellite experiences. This causes disturbances in the motion of the satellite that therefore cannot be attributed to gravity alone. The effects of non-gravitational accelerations caused by air-drag have to be kept to a minimum and accounted for in order to derive the best possible gravity-field model. As a compromise between gravity attenuation and the influence of the atmosphere, the optimum orbital altitude for GOCE is about 250 km, which is considerably lower than that of other remote-sensing satellites. However, the details of the

large fluctuations in the gravity signal such as in the Indonesian Archipelago would not easily be read in the diminished signal retrieved at this altitude. In order to counteract the attenuation effect and to amplify the gravity signal, GOCE is equipped with a gradiometer instrument. The gradiometer contains six proof masses capable of observing detailed local changes in gravitational acceleration in three spatial dimensions with extremely high precision. By capturing changes in local variations of the gravity field at satellite height, the 'blurring and flattening' of the signal is largely counteracted. In effect, the gradiometer 'zooms-in' on details of the gravity field from satellite height.

Although the gradiometer is highly accurate, it is not possible to map the complete gravity field at all spatial scales with the same quality. To overcome this limitation the position of the GOCE satellite is tracked by GPS relative to GPS satellites at an altitude of 20 000 km – this procedure is known as satellite-to-satellite tracking. The gradiometer is used to measure high-resolution features of the gravity field while GPS is used to obtain low-resolution data.

The combination of these two principles provides the opportunity to derive a global geoid model with a 100 km spatial resolution and 1–2 cm accuracy. A model for gravity can be determined with a precision of 0.000001 g (the standard value of $g = 9.8 \text{ m/s}^2$) at a spatial resolution of 100 km or better.





The gradiometer contains three pairs of proof masses positioned at the outer ends of three, around 50 cm-long orthogonal axes. All experience the gravitational acceleration of Earth slightly differently because of their different positions in the gravitational field. The common acceleration of each pair of accelerometers is proportional to nongravitational forces such as air-drag acting on the satellite. The difference in acceleration for each pair, scaled with the length of the connecting arm, called the gravity gradient, is used for gravity field analysis. An angular acceleration correction is needed, however, because the instrument rotates around one axis during each orbital revolution around Earth.

The influence of gravity on the instrument is the compound effect of all constituents of \mathbf{g} . For example, the Himalayas have a small influence on the value of \mathbf{g} sensed in Europe. It takes the art of mathematical gravity inversion to disentangle the compound effect and identify each individual contribution.



→ THE INSTRUMENT

An advanced gravity mission such as GOCE requires that the satellite and the system of sensor and control elements form one 'gravity-measuring device'; this is because the satellite itself also acts as a prime sensor. In other words, in contrast to most remote-sensing missions, there is virtually no division between the satellite and the instruments.

The GOCE concept is unique in meeting four fundamental criteria for a high-resolution and high-accuracy gravity-field mission:

- Uninterrupted tracking in three spatial dimensions
- Continuous compensation for the effect of non-gravitational forces such as air-drag and radiation pressure
- Selection of a low orbital attitude for a strong gravity signal, and
- Counteraction of the gravity-field attenuation at altitude by employing satellite gravity gradiometry.

From a scientific standpoint, these are the building blocks of the GOCE mission. In general, the lower the orbit and the higher the gravity signal, the more demanding are the requirements on all subsystems, as well as on the structure of the satellite and on the choice of materials. In turn, these building blocks dictate the choice of a related set of technical solutions for the instruments, sensors and actuators:

- An onboard GPS receiver used as a Satellite-to-Satellite Tracking Instrument (SSTI)
- A compensation system for all non-gravitational forces acting on the spacecraft, including a very sophisticated propulsion system, and
- An Electrostatic Gravity Gradiometer (EGG) as the main instrument.

The Satellite-to-Satellite Tracking Instrument (SSTI)

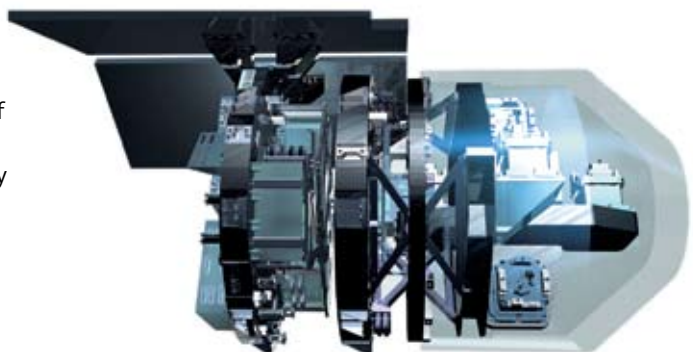
The Satellite-to-Satellite Tracking Instrument (SSTI) consists of an advanced dual-frequency, 12-channel GPS receiver and an L-band antenna. The SSTI receiver is capable of simultaneously acquiring signals broadcast from up to 12 satellites in the GPS constellation. The SSTI instrument delivers, at 1Hz, pseudo-range and carrier-phase measurements on both GPS frequencies, as well as a realtime orbit navigation solution.

The drag-free and attitude-control system

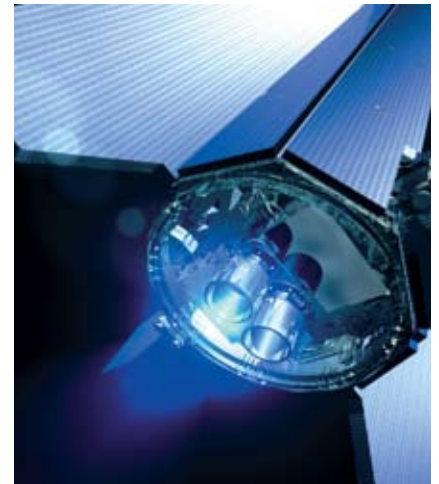
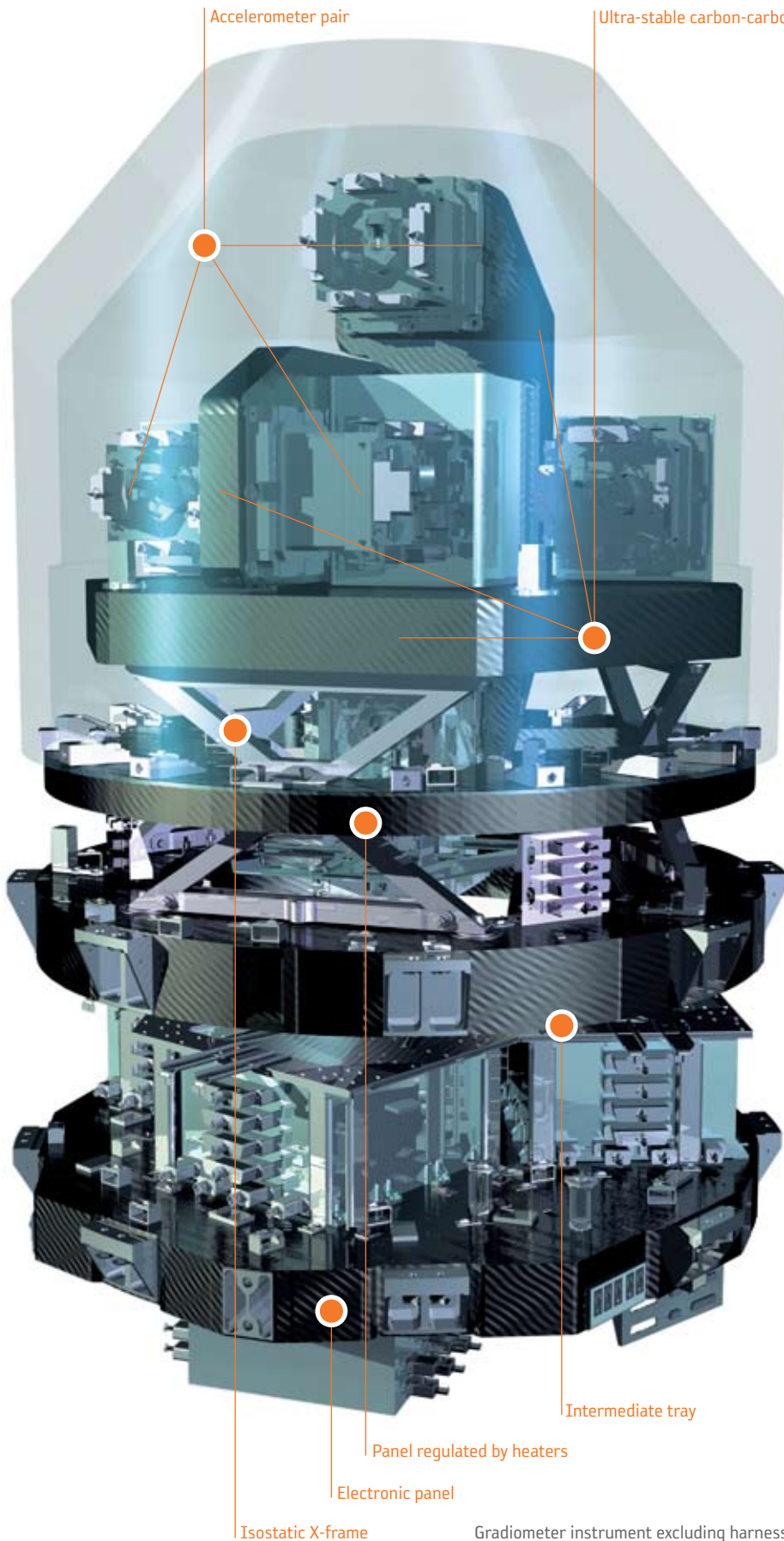
The advanced drag compensation and attitude-control system is a key feature required to keep the sensor heads in near 'free fall motion' and to maintain the average orbital altitude at about 250 km. The system is based on ion-propulsion technology. A particular feature of the GOCE system design is that the drag-free and attitude-control system uses the scientific payload as a sensor. In addition to the fusion between 'satellite' and 'measuring device' in terms of scientific data quality, there is therefore also some fusion between the satellite system and the measuring device in terms of how the GOCE satellite will actually operate.

The Electrostatic Gravity Gradiometer (EGG)

The principle of operation of the gradiometer relies on measuring the forces that maintain a 'proof mass' at the centre of a specially engineered 'cage'. Servo-controlled electrostatic suspension provides control of the proof mass in terms of linear and rotational motion. Three pairs of identical accelerometers, which form three 'gradiometer arms', are mounted on the ultra-stable structure. The difference between accelerations measured by each of two accelerometers (which are about 50 cm apart), in the direction joining them, is the basic gradiometric datum. The average of the two accelerations is proportional to the externally induced drag acceleration (common mode measurement). The three arms are mounted orthogonal to one another: one aligned with the satellite's trajectory, one perpendicular to the trajectory, and one pointing approximately towards the centre of Earth. By combining the differential accelerations, it is possible to derive the gravity-gradient components as well as the perturbing angular accelerations.



Gradiometer instrument including a radiator for thermal control



GOCE Facts

- The accelerations measured by each accelerometer can be as small as 1 part in 10 000 000 000 000 of the gravity experienced on Earth.
- The GOCE accelerometers are about a factor of 100 more sensitive than previously flown accelerometers.
- In order to guide the satellite in a smooth trajectory around Earth, free from all effects except the gravity field itself, it has to be equipped with a drag compensation and angular-control system. All nongravitational forces need to be rejected to 1 part in 100 000. The angular control requires the orientation of the satellite to be known relative to the stars (startrackers). The drag control requires the position of the satellite to be known by SSTI/GPS.
- The satellite is aligned to the velocity vector, which is determined in real time by the SSTI.
- The satellite is very rigid and has no moving parts in order to avoid any internal microscopic disturbances that would otherwise cause 'false gravity' readings by the highly sensitive accelerometers.

→ THE SATELLITE

Configuration

Unlike other missions, where various independent instruments are carried on a satellite, GOCE is unique in that the instrumentation actually forms part of the structure of the satellite. The satellite has no mechanical moving parts because it has to be completely stable and rigid to ensure the acquisition of true gravity readings. In order to receive the optimum gravity signal, GOCE has been designed to fly in a particularly low orbit – just 250 km above Earth. The satellite is configured to keep aerodynamic drag and torque to an absolute minimum and allow for the flexibility of either a dusk/dawn or dawn/dusk orbit, depending upon the actual launch date. The mass and volume of the satellite have been limited by the capacity of the launch vehicle.

The result is a slim, octagonal, 1100 kg satellite about 5 metres in length with a cross-sectional area of 1 m². The satellite is symmetrical about its flight direction and two winglets provide additional aerodynamic stability. The side of the satellite that faces the Sun is equipped with four body-mounted and two wing-mounted solar panels, using the maximum available volume under the fairing. The gradiometer is mounted close to the centre of mass.

Structure

The satellite consists of a central tube with seven internal floors that support all the equipment and electronic units. Two of the floors support the gradiometer. To ensure that the satellite is as light as possible and that the structure is stable under varying temperatures, it is built largely of carbon-fibre-reinforced plastic sandwich panels.

Thermal Control

The thermal design has to cope during nominal measurement modes with eclipses lasting up to 10 minutes, and during survival modes with eclipses lasting up to 30 minutes. It also has to be compatible with either a dawn/dusk or a dusk/dawn orbit. Thermal control is achieved mainly by passive means such as coatings and blankets and active control by heaters where necessary. The internal equipment is protected against the high temperatures of the solar panels by multi-layer insulation blankets, which are positioned between the solar panels and the main body of the satellite. The cold side that faces away from the Sun is used extensively as a radiator area to dissipate heat into space. All the external coatings, in particular those situated in the direction of flight, are protected against high atomic oxygen flux, which would otherwise erode unprotected materials very quickly in this

low orbit. Due to its stringent temperature stability requirements (for the gradiometer core, in the range of milli-degrees kelvin within the measurement bandwidth) the gradiometer is thermally decoupled from the satellite and has its own dedicated thermal control system. An outer active thermal domain is kept at a very stable temperature by heaters and is separated by blankets from an inner passive domain, thus providing an extremely homogeneous environment for the accelerometers.

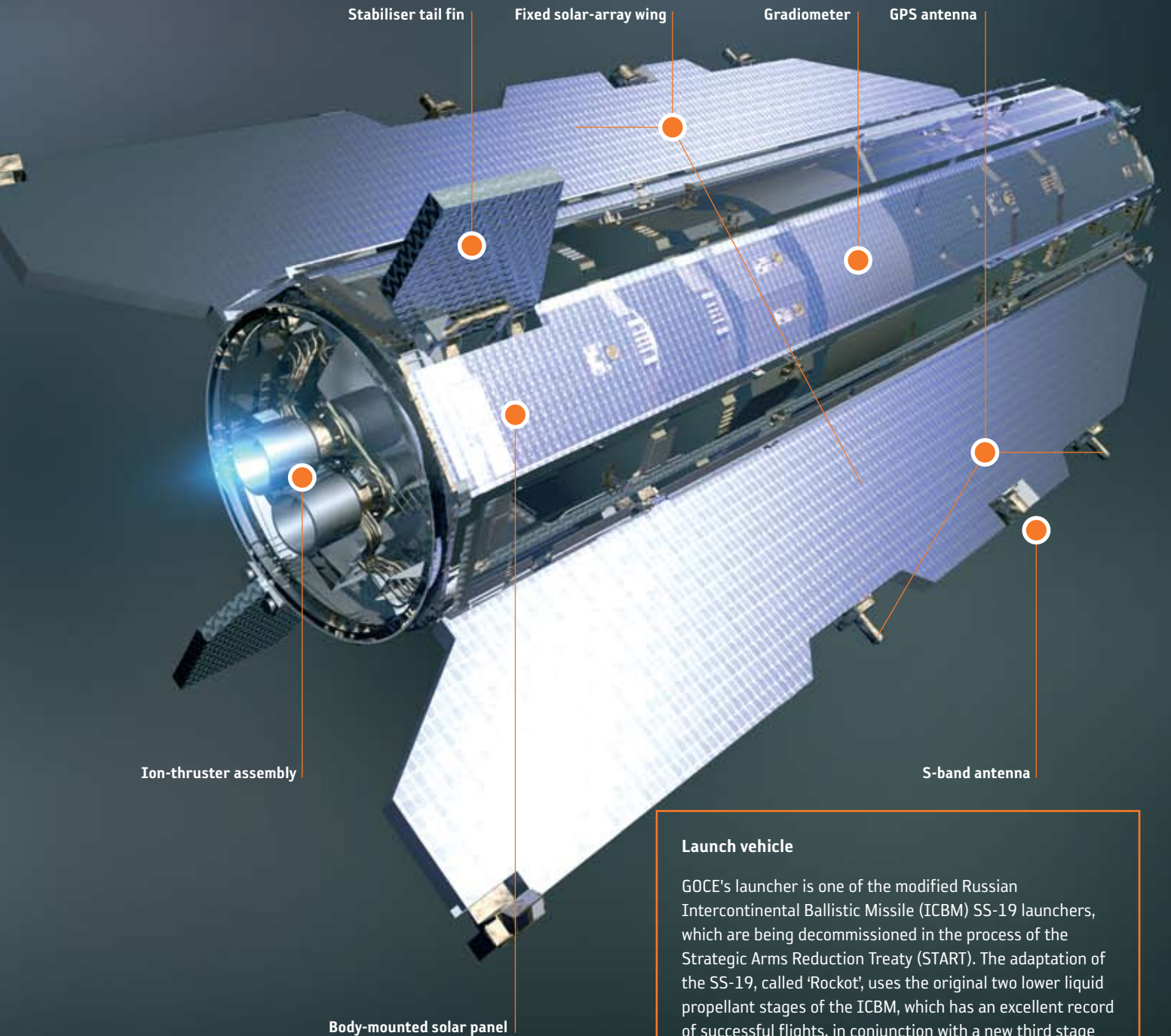
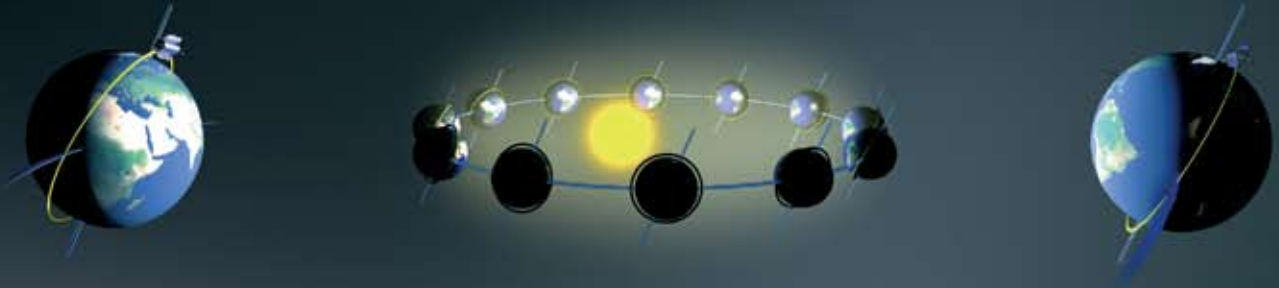
Power Subsystem

The solar-array panels, which use highly efficient gallium arsenide solar cells, provide the necessary power for the satellite. At times when the solar array is not illuminated by the Sun, i.e. during the launch and early orbit phase and during the eclipse periods, a lithium-ion battery delivers the power required. A power control and distribution unit maximises the power output from the solar array and controls the charge and discharge processes of the battery.

Due to the satellite configuration and orbit, the solar panels experience extreme temperature variations. It has therefore been necessary to use materials that will tolerate temperatures as high as 160°C and as low as -170°C.

ESA's quiet mission

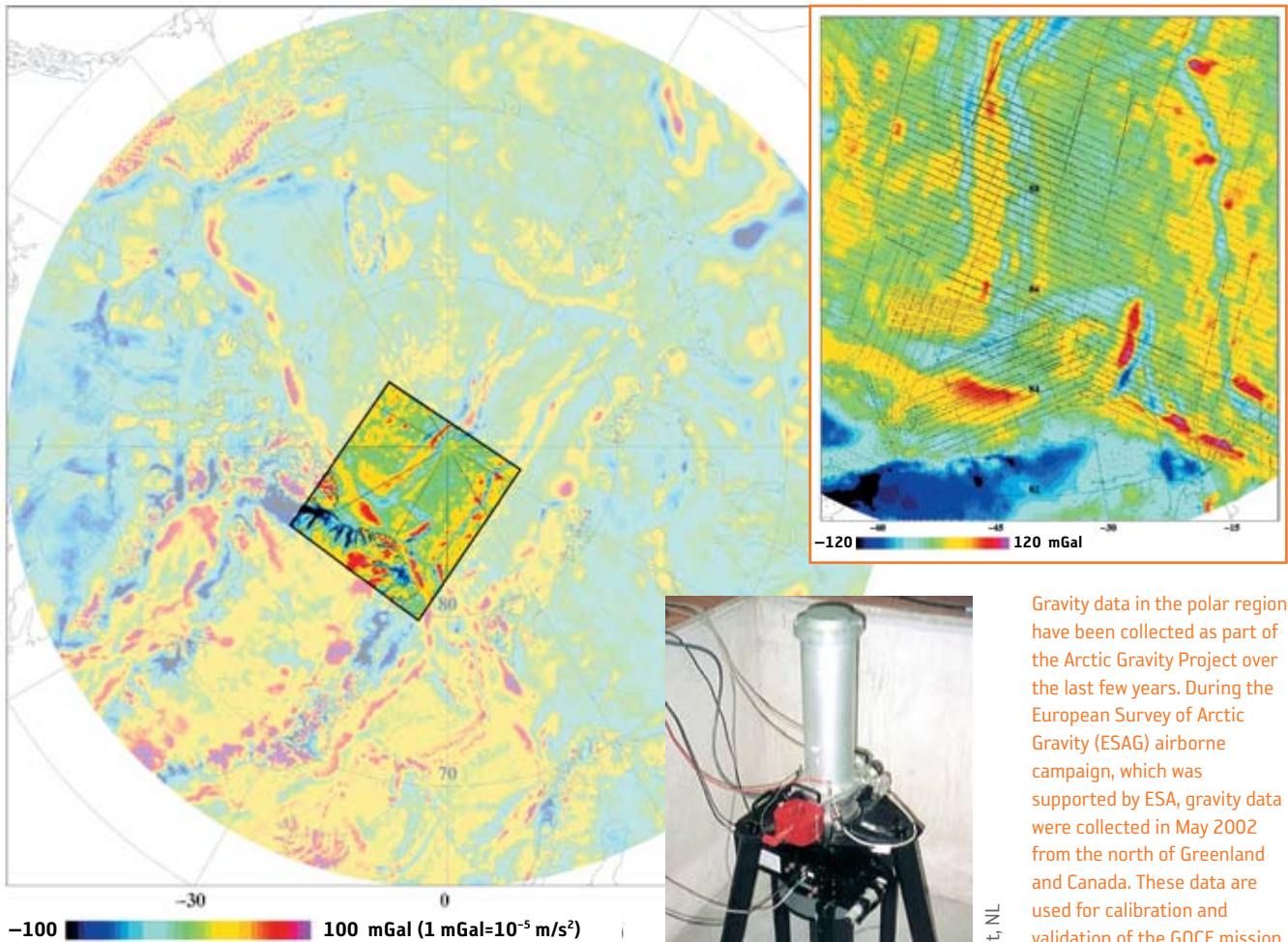
It is vital to this mission that the measurements taken are of true gravity and not influenced by any relative movement of the satellite. Therefore, strict requirements apply to the dimensional stability of the structure. In addition, any micro disturbances caused by moving parts, sudden stress releases due to differential thermal expansions, inductive electromagnetic forces, gas and liquid flows, etc. are eliminated or minimised to the greatest extent possible. A comprehensive test programme, covering structural items, electronic units and the multi-layer insulation blankets, verified potential noise sources that could affect the gradiometric measurements.



Launch vehicle

GOCE's launcher is one of the modified Russian Intercontinental Ballistic Missile (ICBM) SS-19 launchers, which are being decommissioned in the process of the Strategic Arms Reduction Treaty (START). The adaptation of the SS-19, called 'Rockot', uses the original two lower liquid propellant stages of the ICBM, which has an excellent record of successful flights, in conjunction with a new third stage for commercial payloads. Rockot is marketed and operated by Eurokot, a German-Russian joint venture. Launch is from the Plesetsk Cosmodrome in northern Russia.

→ FROM NEWTON TO GOCE



KMS, Denmark

Rijkswaterstaat, NL

Gravity data in the polar region have been collected as part of the Arctic Gravity Project over the last few years. During the European Survey of Arctic Gravity (ESAG) airborne campaign, which was supported by ESA, gravity data were collected in May 2002 from the north of Greenland and Canada. These data are used for calibration and validation of the GOCE mission.

Approx. 1.5 metre high free-fall absolute gravimeter (FG5).

Our present-day understanding of gravity is based upon Isaac Newton's *Philosophiæ Naturalis Principia Mathematica* (1687). Over the last 300 years many instruments have been developed and many experiments conducted to observe local, regional and global characteristics of Earth's gravity field. Until a few decades ago, terrestrial gravity variations were mainly observed with 'relative' gravimeters, but more recently high-precision 'absolute' gravimeters have been developed. An absolute gravimeter uses the principle of accurately measuring the time it takes for a prism to free-fall inside a tube. Nowadays a precision of 0.00000005 g ($g = 9.8 \text{ m/s}^2$) can be obtained. The combination of relative and absolute measurements allows the possibility of accurately connecting gravity surveys in different locations. The areas of the world that have been extensively surveyed may contribute to the validation of the results derived from the GOCE satellite.

From Newton's theory we know that any satellite in Earth's orbit is actually free falling in Earth's gravity field. The traditional technique of gravity-field determination from satellite trajectories led to the development of global gravity field models, albeit only representing large-scale features. In the early 1960s the concept of satellite-to-satellite tracking was developed. This technique is based upon tracking the orbit differences between satellites that experience different

gravitational accelerations at different locations. The concept of gradiometry followed soon after and is based upon analysing the difference in gravitational acceleration of proof masses within one satellite. In fact, the GOCE gradiometer is based upon principles similar to those used by Loránd Eötvös (1848–1918), who developed the ‘torsion balance’ that could observe local horizontal gravity-gradients.

CHAMP, a German satellite launched in 2000, exploits the satellite-to-satellite tracking concept between a low orbiting satellite at an altitude of approximately 400 km and high GPS satellites at an altitude of around 20,000 km. This has led to an impressive improvement in global gravity models for features of up to a few thousand kilometres. For example, there has been a significant improvement in the data from polar regions, which are traditionally difficult to access.

GRACE, a US-German satellite, launched in 2002, makes use of satellite-to-satellite tracking between two low-flying satellites about 200 km apart, at an altitude of 400 km. In addition, both satellites track signals transmitted by the GPS constellation. As with CHAMP, non-gravitational forces are measured by micro accelerometers. The GRACE mission aims to map monthly changes in the gravity field for features down to 600–1000 km, with high accuracy.

GOCE exploits a combination of the principle of gradiometry and satellite-to-satellite tracking relative to GPS satellites. The data derived from GOCE will provide an unprecedented model of Earth’s gravity field. The GOCE mission is complementary to the aforementioned missions in that it is a high-resolution gravity-field mission and will address a completely new range of spatial scales, in the order of 100 km.



→ GOCE OVERVIEW

GOCE Mission

The Gravity Field and Steady-State Ocean Circulation Explorer (GOCE) mission will measure high-accuracy gravity gradients and provide global models of Earth's gravity field and of the geoid. The geoid (the surface of equal gravitational potential of a hypothetical ocean at rest) serves as the classical reference for all topographical features. The accuracy of its determination is important for surveying and geodesy, and in studies of Earth interior processes, ocean circulation, ice motion and sea-level change.

GOCE was selected in 1999 as an Earth Explorer Core mission as part of ESA's Living Planet Programme.

Mission Objectives

- To determine the gravity-field anomalies with an accuracy of 1 mGal (where 1 mGal = 10^{-5} m/s²).
- To determine the geoid with an accuracy of 1–2 cm.
- To achieve the above at a spatial resolution better than 100 km.

Mission Details

Launch: 2009

Duration: Nominally 20 months, including a nominal 3-month commissioning and calibration phase and two science measurement phases (each lasting 6 months), separated by a long-eclipse hibernation period.

Mission Orbit

Sun-synchronous, near circular, dawn/dusk or dusk/dawn low Earth orbit, depending on the launch date.

Inclination: 96.5°

Measurement altitude: about 250 km

Hibernation altitude: 270 km

Configuration

Rigid structure with fixed solar wings and no moving parts. Octagonal spacecraft body approximately 1 m diameter by 5 m long. Cross-section minimised in direction of flight to reduce drag. Tail fins act as passive stabilisers.

The GOCE mission uses a single ground station in Kiruna, Sweden, to exchange commands and data with the ground. The satellite is monitored and controlled by the Flight Operations Segment (FOS). The FOS generates and uplinks the commands to programme GOCE operations via Kiruna. It also processes the housekeeping data received from the satellite to monitor the status of the platform and the instruments. The generation of the scientific Level-1b products of the GOCE mission is done by the Payload Data Segment (PDS), which also receives the GOCE science data via Kiruna. Level-2 products, including gravity field models and precise GOCE orbits, are generated by the High-Level Processing Facility (HPF), a European consortium of ten scientific institutes specifically aimed at the complex processing of GOCE Level-1b data. The final products are distributed to the GOCE user community to be used for different applications.

Payload

- Gradiometer; 3 pairs of 3-axis, servo-controlled, capacitive accelerometers (each pair separated by a distance of about 0.5 m).
- 12-channel GPS receiver with geodetic quality.
- Laser retroreflector enabling tracking by ground-based lasers.

Satellite Attitude Control

- 3-axis stabilised
- Drag-Free and Attitude-Control System (DFACS) comprising:
 - Actuators – an ion thruster assembly (xenon propellant) and magnetotorquers.
 - Sensors – startrackers, a 3-axis magnetometer, a digital Sun sensor and a coarse Earth and Sun sensor.
- Cold-gas calibration thrusters.

Budgets

Mass: <1100 kg (including 40 kg xenon fuel).

Power: 1300 W (solar-array output power) including a 78 Ah Li-ion battery for energy storage.

Telemetry and Telecommand: S band (4 kbit/s up-link; 850 kbit/s down-link).

Launch Vehicle

Rocket (converted SS-19), from Plesetsk, Russia.

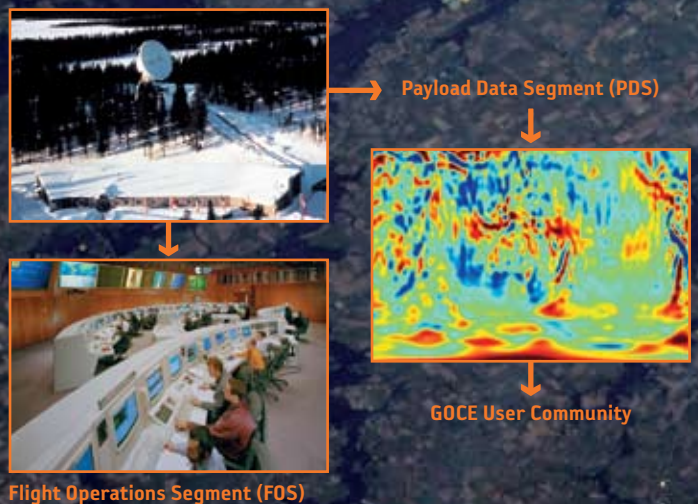
Flight Operations

Mission control from European Space Operations Centre (ESOC) via Kiruna ground station.

Satellite Contractors

Industrial Core Team:

- Alenia Spazio (Satellite Prime Contractor)
- EADS Astrium GmbH (Platform Contractor)
- Alcatel Space Industries (Gradiometer)
- ONERA (Accelerometers & System Support)





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