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A hot rod for the solar system

ABL aims at final tests

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The Gravity Field and Steady State Ocean Circulation Explorer, an ESA satellite launched earlier this year, will take measurements of unprecedented precision, providing information not just for esoteric scientific purposes but also for down-to-earth applications.

GOCE adds gravity to ESA's agenda

by J.R. Wilson
Contributing writer

This year has seen several milestones in international space programs, from claimed first satellite launches by Iran and North Korea to the launch of the first satellite that will seek Earth-like planets elsewhere in the galaxy to delivery of the final U.S. component of the ISS. On March 17, ESA made a major contribution to the list with its launch of the Gravity Field and Steady State Ocean Circulation Explorer (GOCE) from the Plesetsk cosmodrome in northern Russia.

The first of a new generation of European satellites dedicated to studying the Earth, GOCE was developed to bring about a whole new level of understanding of one of the planet's most fundamental natural forces: gravity.

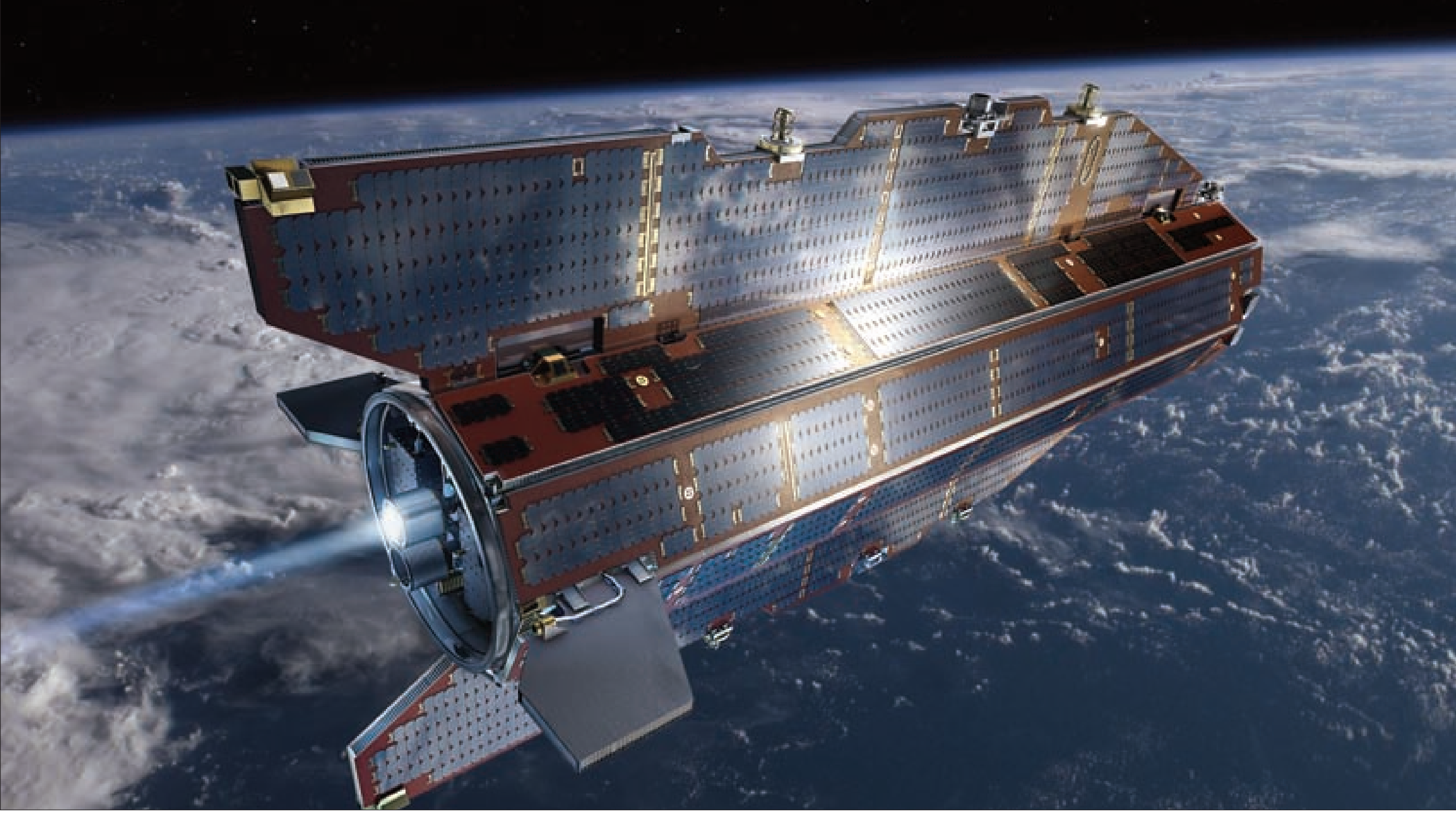
Lifted into near-Sun-synchronous LEO by a Rockot launcher, GOCE will measure minute differences in the Earth's gravity field at points all over the globe. It is also the first in a series of ESA satellites designed to expand scientific understanding of a host of planetary system processes involving Earth's atmosphere, biosphere, hydrosphere, cryosphere, and interior, and how they interact with each other and with human activities—including a possible impact on global climate change.

"GOCE is ESA's first science satellite dedicated to Earth observation since Envisat in 2002. The size has changed, but the rationale remains the same: To provide the best science our technology can deliver for the maximum benefit of the science community and ultimately the citizens of Europe and the world," said ESA Director General Jean-Jacques Dordain after the successful launch.

Timing the mission cycle

Selected in 1999 as the first Earth Explorer Core Mission under ESA's Living Planet Program, GOCE originally was intended for launch in 2006, but was delayed by a series of setbacks. The most recent, which negated the last 2008 launch window in October, resulted from a launch vehicle problem discovered last fall during ground tests.

"When the mission was designed, we determined there were periods of the year that are optimal for launch," ESA GOCE project manager Danilo Muzi tells *Aerospace America*. "The period in which we can perform measurements also



depends on solar activity, which influences the Earth's atmosphere; during periods of high solar activity, we would have higher air drag. Right now we are in a minimum solar activity period, which allows us to fly low.

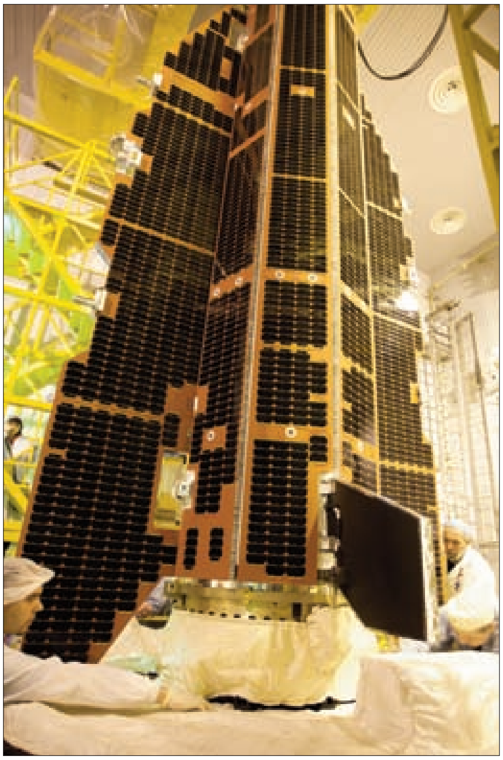
"If we'd waited too long and solar activities had gone up, we would have had to raise the altitude of the orbit, which would have impacted the quality of the measurements. The orbit also dictates the utility of the ion track. For all those reasons, and because of all the delays we had incurred, we were determined to launch as soon as possible [rather than shoot for the optimal window]."

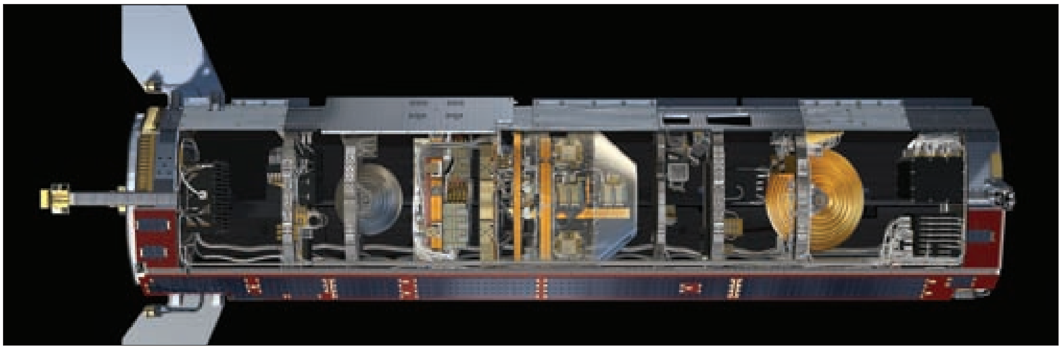
The nominal mission duration is about 20 months, including two measurement phases of six months each, with the possibility of extending the lifetime for about 10 months, based on expendables aboard the satellite. The time between measurement phases represents periods of long eclipses, each lasting about four months, during which the satellite will hibernate. The 20-month mission begins with about three months of calibration and commissioning, followed by six months of measurement, four months of hibernation, and a final six-month measurement cycle.

If onboard fuel stores are sufficient at the end of that period, ESA may elect to put GOCE into one more hibernation and conclude an extended mission with a third measurement phase.

"We are hoping, then, for two more years of relatively low solar activity, based on current predictions on the evolution of solar activity. But that is open to change and could be quite different a year from now when we are in our second period of measurement," Muzi says. "By using the ion tracker, we can raise the orbit. That will

GOCE is equipped with four body-mounted and two wing-mounted solar panels. In orbit, the same side always faces the Sun. Images courtesy ESA-AOES Medialab.





GOCE is 5 m long and about 1 m in diameter. It consists of a central octagonal tube with seven internal 'floors' that support the equipment and electronic units. It is built largely of carbon-fiber-reinforced plastic sandwich panels to guarantee stable conditions and minimize mass. The gradiometer is mounted close to the satellite's center of mass.

take time, but we will increase the altitude by about 15 km when we move from a measurement period to a hibernation period—going from, say, 263 km to 280 km, then descending back to 263 if we can, or staying higher if there is increased solar activity."

The satellite can fly at a minimum altitude of 250 km, based on thermal influences, air drag, and so on; the maximum for quality measurements is roughly 290-300 km, with an optimal altitude of about 260 km to meet all of the mission requirements. After completing its first orbit, the 1,052-kg spacecraft was successfully released into a circular polar orbit at 280-km altitude with a 96.7° inclination to the equator. After six weeks of initial checkouts, it will be moved into a 263-km operational orbit for payload calibration before beginning mission operations this summer.

Modeling the geoid

"The data to be collected from this satellite will be used to devise a really precise gravity field [map] of our planet and create a model of the geoid," Muzi says of the 3D gravity data GOCE will collect from across the globe. "These two models are of high interest to a quite wide scientific user community, from geophysicists to geodetics to geographers."

The geoid is the irregular gravity field that shapes a virtual surface at mean sea level. According to Muzi, this is the surface of equal gravitational potential of a hypothetical ocean surface at rest and is often employed as a reference for traditional height systems used for leveling and construction. However, the surface of the geoid can deviate by as much as 100 m from an ellipsoidal model representing the Earth.

"By having this precise geoid and Earth gravity model, we will be able to increase our understanding of ocean currents; this plays a significant role in improving climate models, because the oceans are an important mechanism of heat transfer from the equatorial regions to the poles," he notes. "Once you have the precise geoid, you also are able to determine sea levels in a uniform and global way, rather than just using local reference systems.

"With a unified measurement of sea levels, you can determine gravity field anomalies and how the field differs from the theoretical distribution of densities. So this will refine the characteristics of the gravity field and provide more information on the interior of the Earth, especially magma under volcanoes and tectonic movement.

"This information will not be able to forecast an earthquake, but it will certainly help geophysicists better understand the areas subject to earthquakes by giving them indirect information on the characteristics of the interior of the Earth. Until now, scientists have had to make some assumptions on key elements; with GOCE, those now can be refined, making these models more accurate and precise, providing better analysis and extrapolations."

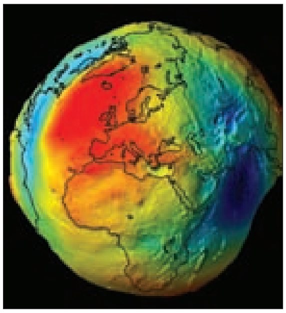
Outdoing ancient Rome

Other uses for the geoid include the measurement of height for engineering applications, such as building long bridges or canals or a tunnel through a mountain ridge. That is especially important for projects that cross national borders, where countries may have different methods of measurement.

The ancient Romans, in building aqueducts that carried water hundreds of miles over terrain of varying heights, managed to accomplish that through extensive local measurements and adjustments, a difficult, time-consuming process given the limited instruments available to them. Despite advances in surveying equipment and the use of computers, that process has remained essentially the same—and with limited application—for more than 2,000 years.

"With GOCE, we have a reference system that is planet-wide. In theory, you could say you could do these measurements on the

GOCE will measure high-accuracy gravity gradients and provide a global model of Earth's gravity field and of the geoid, which 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.



ground, but it would take a lot of time and money, making certain everyone was using the same instruments and measurement systems," Muzi says. "Planet-wide, that would be very difficult, if not impossible; using the satellite, you know you are using the same instruments and measurements and so have uniform data."

Polar ice, ocean currents

GOCE's advanced instruments and orbital perspective also will provide monitoring of sea levels and distributions across the Earth's surface that can be used to help measure the size, location, and changes in polar ice sheets. The satellite's data also will be combined with other measurements, including those from radar satellites that measure the actual height of the sea at specific times and locations to determine sea levels.

"When we say GOCE will actuate sea level measurements, we mean using the GOCE geoid information in combination with other satellite data on the height of the sea at a specific location," Muzi points out. "Because the geoid actuates to a level of 1-2 cm and provides a global reference system, a better understanding of this huge flow of water will be a highlight of this mission. In respect to those things that are not known, and now will be better known, the main area will be the ocean currents."

To accomplish its goals, GOCE is equipped with a state-of-the-art electrostatic gravity gradiometer that is being flown on a satellite for the first time.

"Basically, it is able to measure differences in gravity in two forms. It comprises six accelerometers, aligned in pairs, and will enable us to recover data for the gravity field model and geoid," Muzi says. "We also have a satellite-to-satellite tracking instrument, a special GPS receiver that will be used to determine very accurately the orbit of the satellite and deviations with respect to the radial line. These differences are considered to be characteristics of anomalies in the gravity field. Variations across big expanses will be determined by looking at these perturbations in the satellite's orbit."

Achieving extremes

Combined, the information from these two sources will be processed to determine differences in the model with far greater accuracy than scientists and engineers have been able to achieve before. To accomplish that, the team had to develop ultrasensitive accelerometers—which can measure acceleration 100 times better than anything previously available—and also needed to provide extreme stability for the instrument package.

"To be able to do this very accurate measurement, we are compensating for air drag. We are flying quite low, where there is still some remnant of the atmosphere. These remaining molecules tend to slow down the satellite. That will be seen in the accelerometers as a deceleration that would dilute our measurements. But we compensate for that by tracking along the velocity vector. We use an ion propulsion tracker to precisely compensate for the deceleration the satellite otherwise would have due to air drag. This drag-


The star trackers on GOCE were tested in a dimmed clean room.

"This launch success marks the dawn of a new generation of Earth sciences satellites in Europe."

Volker Liebig, *director, ESA Earth Observation Programs* free control system is unique in satellites and required the development of new control algorithms," Muzi notes.

Each of the two low-power xenon ion engines—one primary and one backup—deliver 1-20 mN of thrust, roughly equivalent to the force of a human exhaling. That such a minute amount of thrust can be so critical to a low-altitude platform such as GOCE demonstrates the extremes required for successful space missions.

"Overall, the satellite is quite advanced because of the technology being used and represents quite a piece of engineering work, because it has no moving parts—no electric motors or anything that would create disturbances that would perturb the measurements of the accelerometers. We spent quite some effort to ensure, for example, the thermal gradient does not create disturbances. And the satellite will be extremely quiet as well."

A group effort

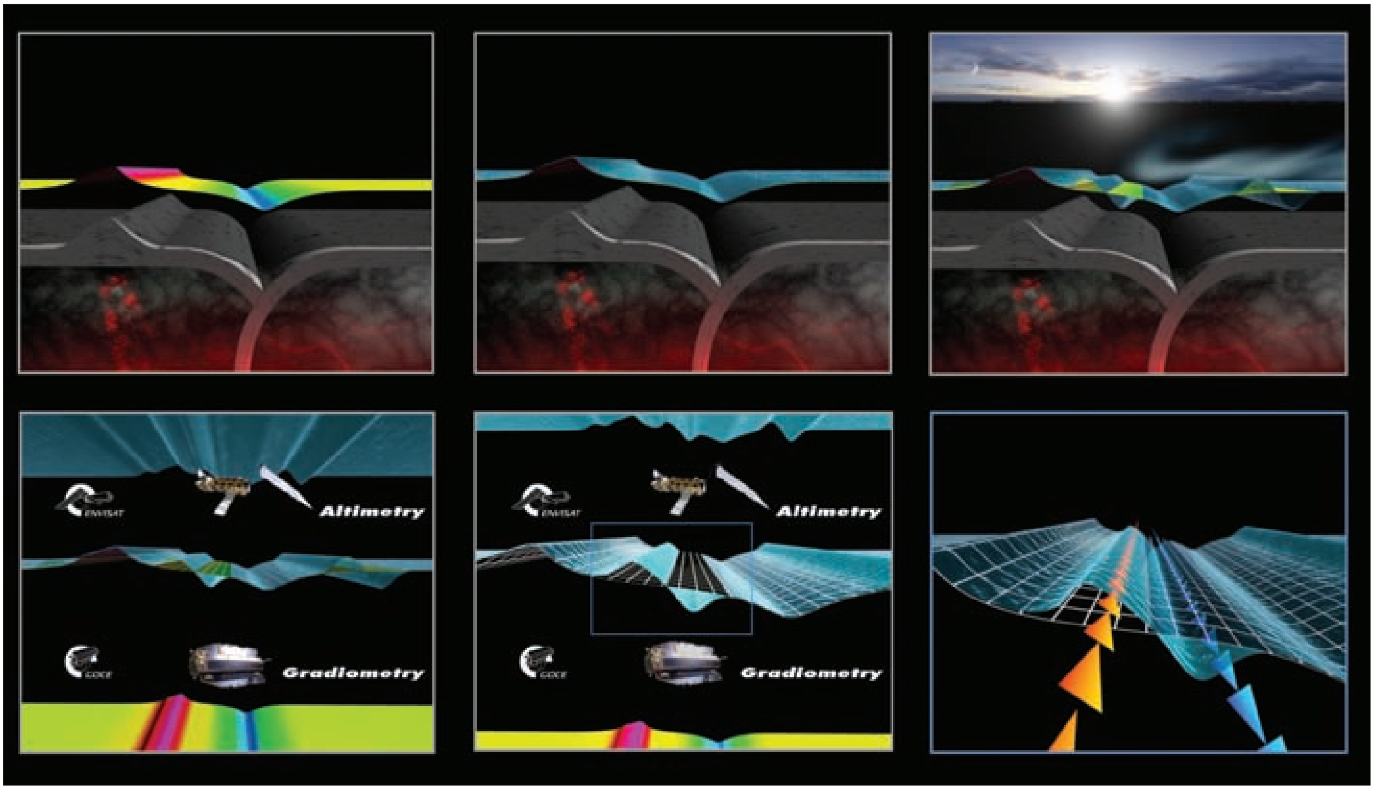
Thales Alenia Space in Italy was prime contractor for GOCE, but the satellite and its components were the result of input from a consortium of about 45 companies from throughout Europe. EADS Astrium Space in Friedrichshafen, Germany, provided the platform, for example, while Thales Alenia Space in Cannes, France, developed and integrated the main instrument using ultraprecise sensors developed by Onera of France.

"For the ground segment, we divide data processing into two stages," Muzi adds. "A consortium of 10 leading scientific institutes and universities across Europe have developed the infrastructure for the processing facilities. This consortium is led by the Technical Institute of Munich."

Some of the technologies developed for GOCE are expected to make significant contributions to other space systems in the future.

"Whenever you need a dimensionally stable structure or large carbon-carbon construction—for a space telescope, for example—we will be able to do that better," Muzi explains. "And if you need to very accurately measure acceleration, what we have developed is the best so far.

"Another advance is the ion tracker, which is capable of continuously modulating its track level in a very precise way. In the past, ion propulsion engines were used more for on-off activations with a constant thrust, especially on communications satellites for station-keeping. We are using these thrusters to compensate for air drag, so we had to expand the capability of this type of engine to move the satellite track in a very precise way.



Density variations in the Earth's crust are an important factor in shaping the geoid. External forces such as the wind cause the sea surface to deviate from the geoid. The combination of sea-surface height mapped by altimeters and the knowledge of the precise ocean geoid will improve our understanding of surface currents. Credit: ESA-AOES Medialab.

Anyone who needs that kind of actuator on a future mission will now have it available."

Gravity varies

While most people assume gravity is a constant on the Earth's surface, it actually varies, by minute degrees, depending on a variety of factors. "If you jump from a window, you accelerate at 1 *g*. At [an altitude of] 160 km, the acceleration is attenuated and compensated by centrifugal acceleration in orbit; you remain in orbit because your centrifugal acceleration matches gravitational acceleration," Muzi says. "If centrifugal acceleration is less than gravitational acceleration, you will begin to drop; if it is greater, you will move away from the Earth.

"For a satellite, the rotational speed creates a perfect match between centrifugal and gravitational acceleration. The six GOCE accelerometers, by being in a diamond configuration as close as possible to the center of gravity, but not exactly at the center, experience and measure acceleration. The distance between the accelerometers in each pair is just 50 cm, so they can measure the mismatch between centrifugal and gravitational acceleration over very small distances, with a sensitivity much greater than the human mind can appreciate."

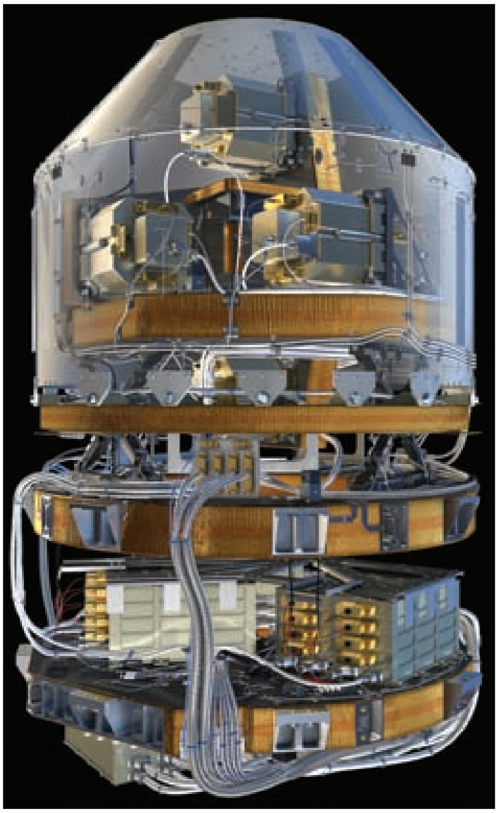
The satellite instruments will not measure gravitational waves, so Muzi says it is unlikely the sensors involved will lead to any major discoveries in physics.

"What we may find are features in the gravity field that were not known, at least at that level of spatial resolution," he adds. "We may find there are some areas on the Earth where the local gravity field looks pretty strange and unexpected, which may give rise to future investigation. This interests geophysicists because it gives information about characteristics of the composition of the Earth's mantle. If you have areas of dense material, you would have a strong local gravity field; where the material is less dense, you have a lower local gravity field.

"For example, 1 *g* is 9.8 m/sec^2. The Earth is shaped like a potato, with a bigger radius at the equator than at the poles, so at the equator you might have a *g* that is 9.78 and 9.83 at the poles. And that has implications. Smaller changes than that influence ocean circulation, for example."

Data for future efforts

As with any experiment that collects new data in new ways from a new place, exactly what will be learned from GOCE, near- and long-term, is not predictable. How the satellite operates at the very edge of the atmosphere may be of great interest to those who plan to launch suborbital and low-orbit spacecraft carrying tourists into space, for example, while fractional variations in gravity could affect the location of future launch sites or even the viability of the space elevator concept.



The GOCE gradiometer consists of three pairs of identical ultrasensitive accelerometers, mounted on three mutually orthogonal arms. One arm is aligned with the satellite's trajectory; one points toward the center of the Earth; the third is perpendicular to the other two. This allows the simultaneous measurement of six independent but complementary components of the gravity field.

"[GOCE] is the first of a new generation of small, dedicated science satellites, and it paves the way for more Earth Explorer missions," says Volker Liebig, director of ESA's Earth observation programs. "The scientists are urgently awaiting the data sets from these missions. We have four more launches due over the next two years."

Those include the ADM-Aeolus satellite, to be launched in 2011 to study atmospheric dynamics, and EarthCARE, a 2013 mission to investigate Earth's radiative balance. Also under development are three smaller Earth Explorer Opportunity Missions, including two for launch later this year—Cryosat 2, to measure ice-sheet thickness, and SMOS to study soil moisture and ocean salinity. The third, in 2011, is Swarm, a constellation of satellites to study the evolution of Earth's magnetic field. As Liebig points out, "This means that we are in for a very busy time."