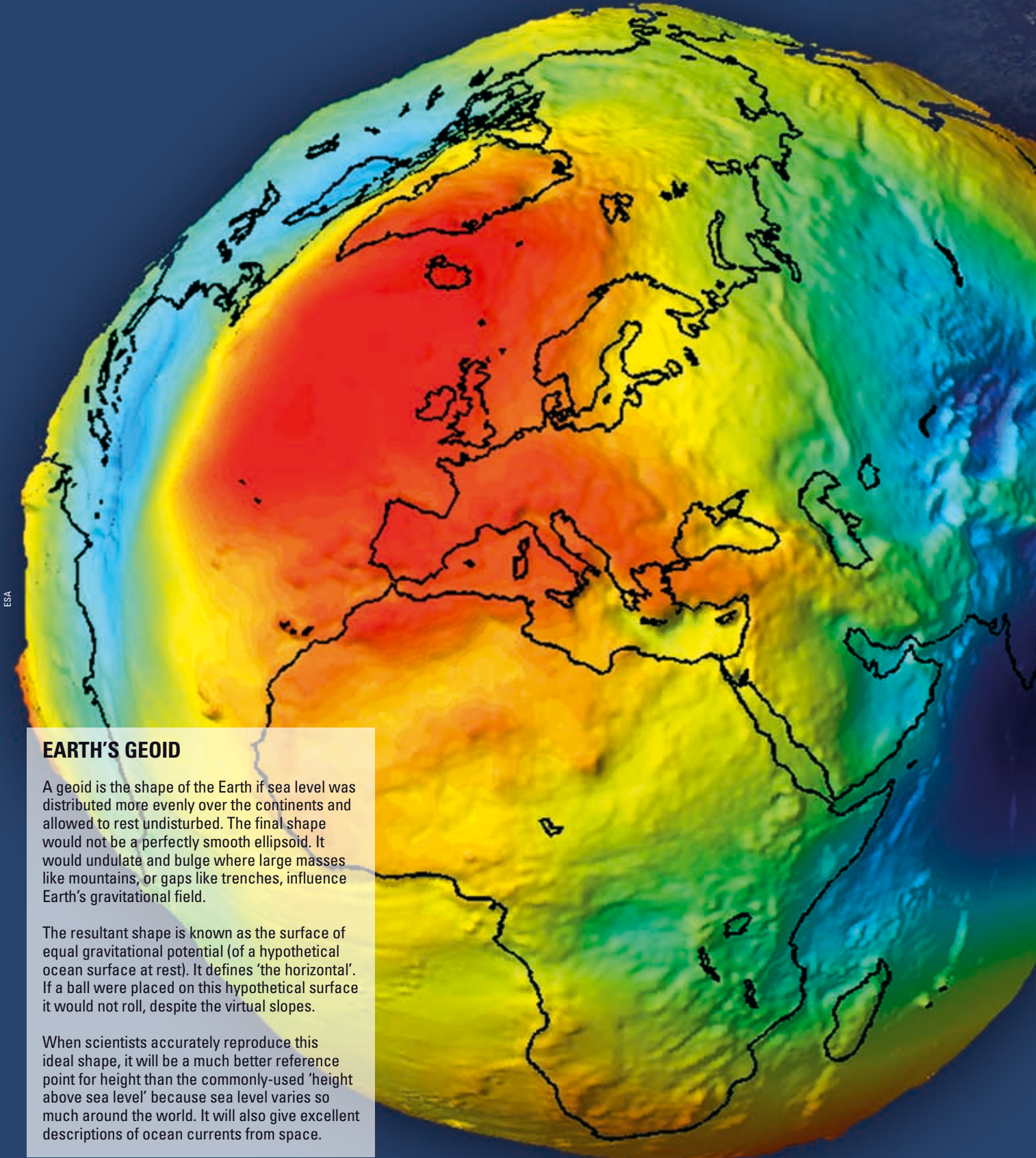


# Physical attractions

Chris Hughes gets up close and personal with planet Earth's gravity field.




ESA

## EARTH'S GEOID

A geoid is the shape of the Earth if sea level was distributed more evenly over the continents and allowed to rest undisturbed. The final shape would not be a perfectly smooth ellipsoid. It would undulate and bulge where large masses like mountains, or gaps like trenches, influence Earth's gravitational field.

The resultant shape is known as the surface of equal gravitational potential (of a hypothetical ocean surface at rest). It defines 'the horizontal'. If a ball were placed on this hypothetical surface it would not roll, despite the virtual slopes.

When scientists accurately reproduce this ideal shape, it will be a much better reference point for height than the commonly-used 'height above sea level' because sea level varies so much around the world. It will also give excellent descriptions of ocean currents from space.



The European Space Agency's first Earth Explorer satellite is due to launch from Plesetsk in northern Russia on 5 October. It will fly in the lowest technically feasible orbit – 270km above Earth's surface.

“ Everyone knows that water flows downhill, but that's not what happens in the ocean.

By the time you read this, if all goes well, a new satellite will be in orbit. GOCE – the Gravity and steady-state Ocean Circulation Explorer – is the first in a new series of European Space Agency\* (ESA) satellites to focus on this planet. Its mission is to map our planet's gravity field in greater detail than ever before.

Why would we want to do that? Gravity is such an ever-present and constant part of daily life that we tend to forget about it. Did I say constant? Well, not quite. And that's the point.

Every mass on the planet attracts every other. The net effect of all of these pulls is a gravitational attraction towards the centre of the Earth. But exactly which way gravity pulls depends on where you are.

If you are close to a mountain, there will be a small pull towards the mountain, deflecting the direction of the vertical slightly (gravity will not be pulling straight down). And the mass of ice on Greenland pulls the ocean towards Greenland and away from the UK. In fact, if we look at the shape of the sea surface, we find that it is bumped and rippled by the gravitational effects of underwater mountains, ridges and canyons so that the sea surface looks almost like a map of the sea floor. Whole ranges of underwater mountains have been discovered by looking at maps of the sea surface.

This is why the details are important. Is that glacier flowing downhill? To answer that question you need to know which way is down (see box). How high is this mountain? What you really mean

is 'how much work would I have to do to climb it?', and that is measured by the gravity field. In fact, heights are usually given as heights above sea level, but what does that mean?

In Britain, 'sea level' is defined as an average of tide gauge measurements at Newlyn in Cornwall some time in the 1920s. But to measure height above that level, we need to first draw an imaginary level surface through that point, to a point beneath the mountain in question.

Other countries have their own definitions of sea level, leading to discontinuities in definitions of height across borders. In these days of accurate GPS positioning, and with autonomous aircraft high in the sky, it is becoming ever more important for people to agree on how high things are.

An accurately mapped gravity field makes it possible to construct a global level surface, known as the geoid, and to define whether two things are at the same height however far apart they may be. This is great for unifying mapping systems, but the real pay-off is over the ocean. It is usually assumed that the ocean is, on average, a level surface, and that's almost true. But the difference is very important, and can tell us a lot.

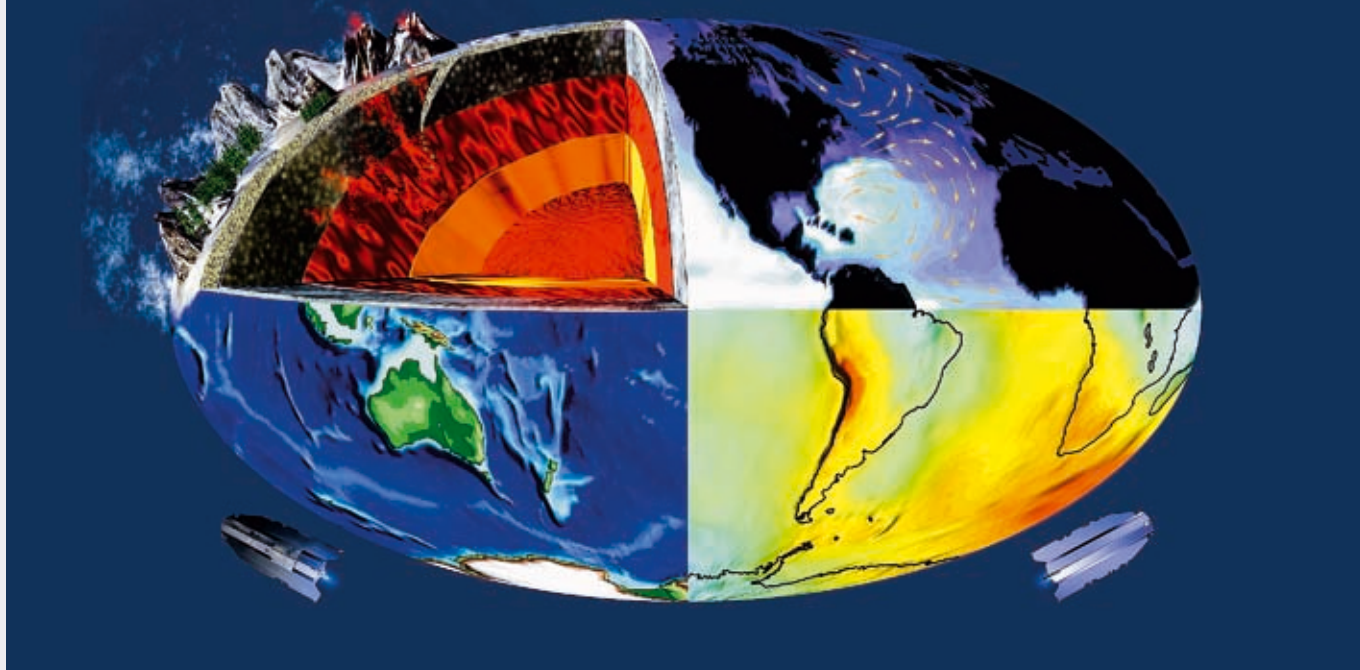
### The physics of tea cups

There's a rather quirky bit of physics involved here. Everyone knows that water flows downhill, but that's not what happens in the ocean. Think of a whirlpool, or a recently-stirred cup of tea: the water is not flowing down into the dip (well, it is, but only slowly). The flow is mostly in circles around the dip. The Earth's rotation makes the ocean act rather like a stirred cup of tea.

If you look along the direction of flow of an ocean current you will find that the sea surface is higher to the right and lower to the left. The opposite is true in the southern hemisphere. The speed of the flow is proportional to the steepness of the slope. If only we could measure these slopes accurately enough, we could map the

\*The Natural Environment Research Council manages the UK's £40 million annual contribution to the European Space Agency's Earth observation programme. Many scientists employed or funded by NERC use satellite technology to monitor the planet.

The GOCE satellite (Gravity and steady-state Ocean Circulation Explorer) will provide valuable data on ocean circulations, sea level, ice motion and processes going on deep in Earth's interior. The five-metre-long satellite is the first of a series of six Earth observation satellites to be launched by the European Space Agency (ESA).



world's ocean currents from space. In the northern hemisphere, a dip in the sea surface means that there is an anticlockwise flow around the dip.

We can already measure changes in ocean currents from space. Since 1992, satellite altimeters have been using radar pulses to monitor the shape of the sea surface with an accuracy of a few centimetres. With these measurements we can see how the slopes, and therefore the currents, are changing. This allows us to see the propagation of long, slow wave motions and eddies across the oceans and to detect changes to the great ocean gyre circulations which fill the ocean basins and encircle the world. But, to calculate the steady part of the flow, we need to know whether the average sea surface is level, and for that we need to know the location of the geoid.

The US/German gravity mission GRACE, launched in 2002, has measured this sufficiently well to provide a broad brush picture of the ocean circulation, but GOCE will bring this picture into sharp focus for the first time.

If we want to appreciate the scale of the problem, it is worth giving a few numbers. Very basically, the geoid is a flattened sphere (an ellipsoid), bulging at the equator because of the Earth's rotation. It is about 21 kilometres further from the Earth's centre here than at the poles. (At school we were taught gravity was about  $9.8\text{m/s}^2$ . But it varies from  $9.78\text{m/s}^2$  at the equator to  $9.83\text{m/s}^2$  at the poles.)

The geoid is further distorted by huge mantle plumes and other features deep in the Earth's interior. These drive the motions of the continents and push the geoid up to 100 metres away from the ellipsoid. On top of this, the geoid has smaller bumps related to more local mountains and geological features.

In comparison, ocean currents produce changes in sea level of at most about a metre. If we want to resolve more than just the gross characteristics of the ocean circulation, we have to aim for an accuracy approaching one centimetre. Typically, the geoid will be 20m away from the ellipsoid, and the sea surface will be 20.1m away. The slope we are looking for is the slope in the difference

between the two. A tall order.

To make things more difficult, measuring gravity from a satellite means measuring at a distance. But gravity decays with distance, with the shorter length scales (mountains and ocean currents) decaying fastest. GOCE aims to measure the geoid with an accuracy of about 1-2cm, down to length scales as short as 100km. To do this, it has to fly in an extremely low orbit (about 270km). It is barely out of Earth's atmosphere, so it needs innovative drag-compensating ion thruster engines, provided by Qinetiq, to stop it falling out of orbit. The harsh conditions also mean it has a very limited shelf-life. The mission is designed to last just 18 months.

### The satellite is the instrument

GOCE has to be extremely precise. It contains six accelerometers capable of measuring accelerations as small as  $10^{-13}$  (a ten-trillionth) of the strength of gravity at the Earth's surface. This requires enormous care in the satellite design, which can have no moving parts and must be extremely rigid. It is under careful thermal control to stop small expansions and contractions of the satellite from producing accelerations. Satellites are usually thought of as a vehicle carrying a scientific instrument. In the case of GOCE it is no exaggeration to say that the satellite is the instrument.

As soon as data starts to flow, UK scientists and others around the world will begin the delicate operation of combining the gravity and sea level measurements. From the tiny differences in the accelerations of test masses in a satellite grazing the uppermost atmosphere, we will be able to deduce the patterns of flow in the world's great ocean currents to a level of detail never seen before. GOCE is about to add a third dimension – height – to maps of the world. ❖

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