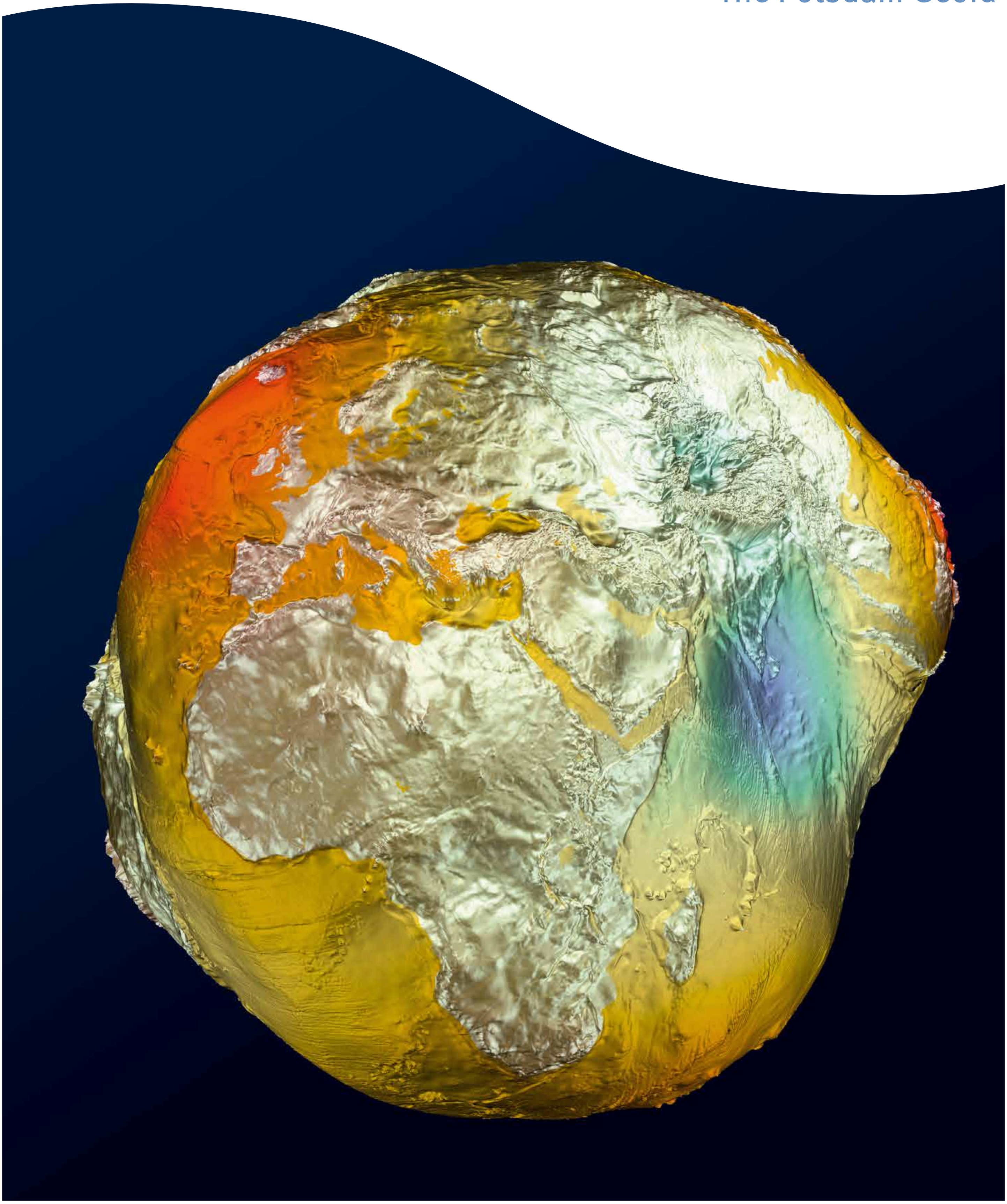
GFZ
Helmholtz Centre
Potsdam

The Earth as a Potato

The Potsdam Geoid



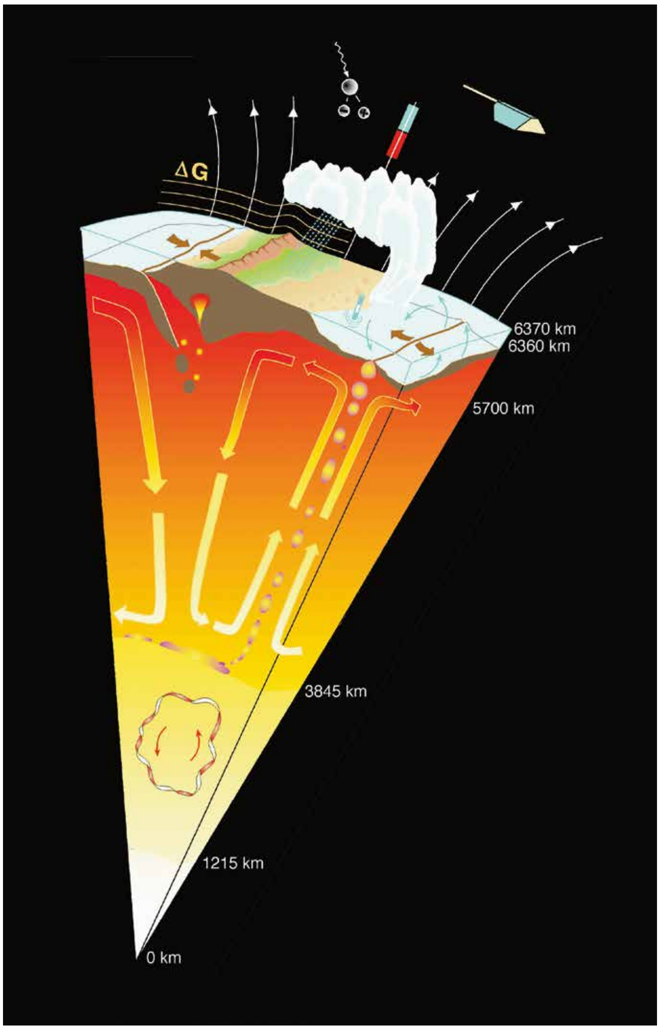
Seen from space, our Earth looks like a sphere at first glance. However, from geodetic measurements, which were carried out even before the age of satellites, we know that the Earth is flattened. This flattening results from the rotation of the Earth, which behaves like a viscous body. The outcome is a shortening of the Earth's radius by 21 km at the poles and an „equator bulge", which are, however, hardly visible to the human eye from space. Thus, the Earth has, in first approximation, the figure of a rotation ellipsoid.

The flattening of the Earth is, however, not perfect. As the distribution of the Earth's masses – and thus the shape-giving gravitational field – is spatially non-uniform, further deviations take place. The illustration of the gravity-induced deviations of the Earth's shape from the regular ellipsoidal surface has become known as the "Potsdam Potato." The basis of this illustration is a gravity model calculated at the GeoForschungs-Zentrum Potsdam. Scientifically, the depicted surface is called a "geoid". Thereby the deviations of maximum ± 100 m compared to the rotational ellipsoid are strongly exaggerated in order to be visible compared to the mean Earth radius of 6371 km. The geoid would be the equilibrium figure of the Earth if its surface was completely covered with water at rest, i.e. water which is only exposed to the centrifugal force of the Earth's rotation and gravity and which is not affected by tides, ocean currents and winds. As an equilibrium figure, the geoid thus forms the physically based reference surface for all topographic heights ("normal zero").

The bumps and dents that give the geoid its potato-like appearance are caused by anomalies in gravity, which in turn are caused by density variations in the structure of the Earth's body. Such variations result firstly from convective processes in the Earth's interior, which over geological time lead to temperature- and material-related density variations and thus ultimately to the irregularities in the gravity field. Second, in the Earth's crust, the uneven distribution of topographic masses on the continents and ocean floor provides further variations in the gravity field that are imprinted on the shape of the geoid. And third, persistent geophysical and climatic processes cause seasonal and long-term changes in gravity due to mass shifts in the atmosphere (air), hydrosphere (water), and cryosphere (ice).

Satellites as gravity field sensors

All satellites orbiting the Earth experience perturbations under the influence of the irregular structure of the Earth's gravity field. These disturbances can be measured and used to calculate a global Earth gravity field model. Using this principle, the gravity field has been continuously mapped since the beginning of the satellite era and continuously improved over the last decades by the analysis of more and more accurate measurements. Initially, the measurement of the gravity field using artificial Earth satellites remained limited to the resolution of very large structures with an extent of a few thousand kilometers. It is only possible with the help of a series of special gravity satellites that significant progress in the spatial resolution and accuracy of the gravity field model has been achieved in recent years. These satellite missions were or are the GFZ-1 (1995-1999), CHAMP (2000-2010), and GRACE (2002-2017) and GRACE Follow-On (since 2018), which were designed and realized under the leadership or with significant participation of the GFZ. In addition, the European gravity field mission GOCE, with GFZ participation in data analysis, was carried out from 2009 to 2013.



In the variations of gravity at the Earth's surface the irregular mass or density distributions in the Earth's interior manifest themselves.

The CHAMP geoscience satellite was the starting point for a generation of satellites and measurement methods (CHAllenging Mini-Satellite Payload for Geosciences and Application). Fig.: AIRBUS

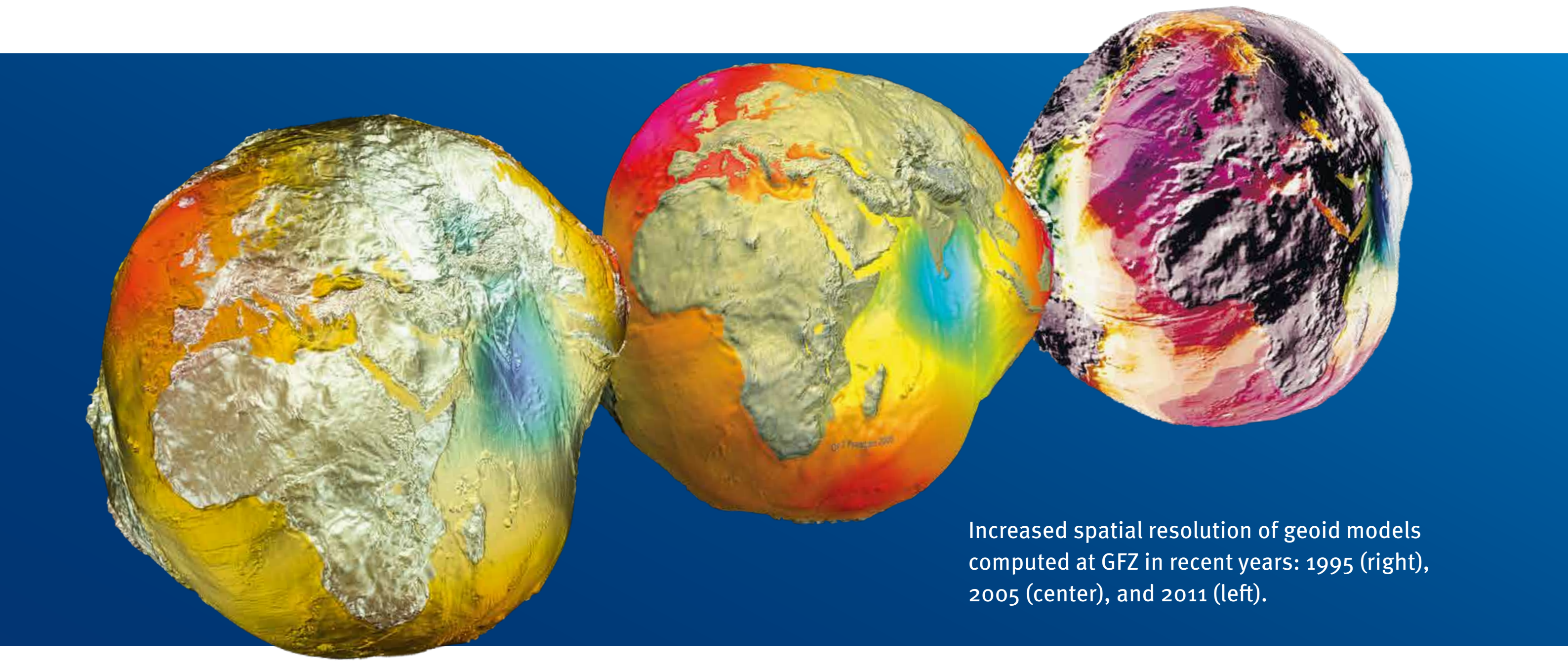
The GRACE (Gravity Recovery And Climate Experiment) satellite pair. Fig.: AIRBUS

Today, with the help of the American-German missions GRACE and GRACE-FO in combination with the data of the European mission GOCE, a spatial resolution of structures of the gravity field with an extension of about 80 kilometers is achieved. In addition, the GRACE and GRACE-FO missions, in particular, allow for the first time the detection of temporal (monthly) variations of the gravity field with a spatial resolution of several hundred kilometers.

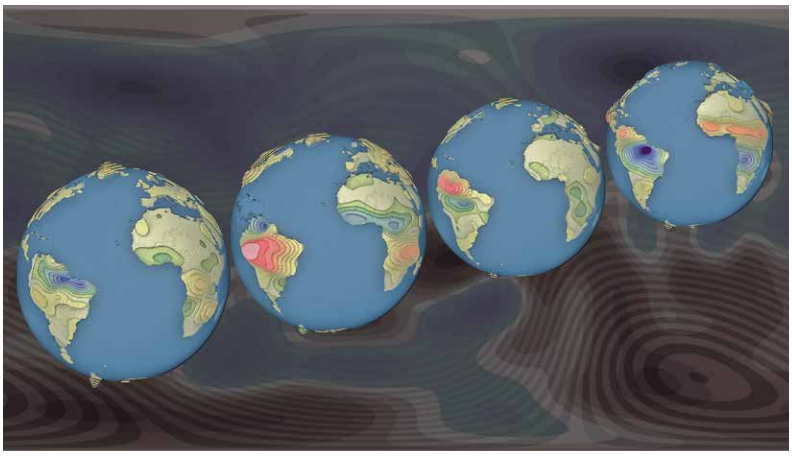
Benefits for land and ocean surveying

The global models of the Earth's gravity field from satellite data provide a uniformly accurate, global, and above all, physically based reference surface for all topographic heights, i.e. the geoid. With today's possibilities of geometric height transfer between points on Earth using satellite navigation systems such as the American Global Positioning System (GPS) or the European Galileo system, the availability of an accurate geoid is of central importance for tasks of land surveying, but also for the navigation of water, land, air and space vehicles.

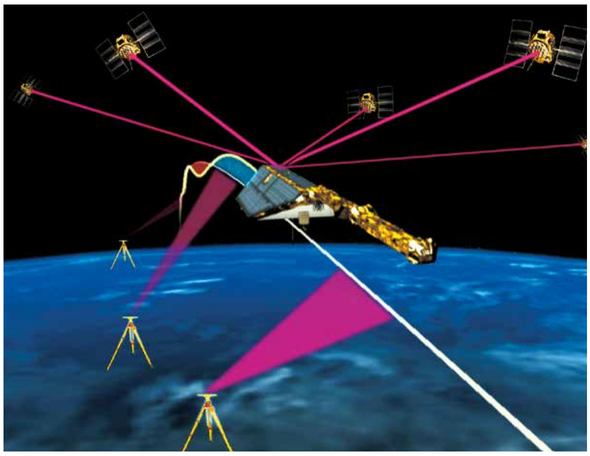
The measured spatial variations in gravity at the sea surface are due, in particular, to a non-uniform density distribution in the Earth's interior. In particular, large density contrasts, such as between oceanic crust (about 2.9 g/cm^3) and seawater (1 g/cm^3), have a strong influence on gravity, so that the observed geoid variations can be directly inferred from the depth distribution in the world ocean. Especially in regions with little shipping traffic and a consequent lack of data from multibeam sounders or other in-situ observations, geodetic satellite missions provide very important data on bathymetry.



Increased spatial resolution of geoid models computed at GFZ in recent years: 1995 (right), 2005 (center), and 2011 (left).



Seasonal variation of continental water storage as a variable signal of the Earth's gravity field derived from GRACE data.
(in January, April, July and October 2008, f. l. t. r.)



Orbital perturbations of near-Earth satellites using the example of CHAMP.

Geophysical applications

Using data on the gravity field, obtained through measurements from outer space, the non-uniform density distribution within the Earth's body can be determined. Whereas the contrast in density between seawater and basaltic crust is small, disparity in thicknesses of the different layers within the crust and upper mantle is much greater. Gravity field data thus provide unique information on the layered structure of the Earth, which together with other observational data (seismic, geoelectric, magnetotelluric) lead to improved model ideas on composition and temperature distribution in the Earth's interior. Not least, in regions with limited accessibility such as Antarctica, satellite data provide valuable new insights into the structure of the crust and thus indirectly also into the orogeny of the various rock formations.

The Potsdam potato represents an average state of the Earth's gravity field, compiled from a wide variety of observations over several decades. However, diverse dynamic processes in the Earth's interior and the near-surface geophysical fluids (atmosphere and hydrosphere) also cause temporal changes in the gravity field on time scales ranging from seconds (earthquakes) to centuries (slow melting of inland ice masses). These very small changes can nowadays be measured with high precision using the GRACE and GRACE-FO gravity field missions developed with the participation of the GFZ. Examples of such processes already studied are the large-scale ocean circulation systems, sea level changes due to increased meltwater input, and the still ongoing postglacial land uplift after the melting of the ice masses of the last ice age.

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