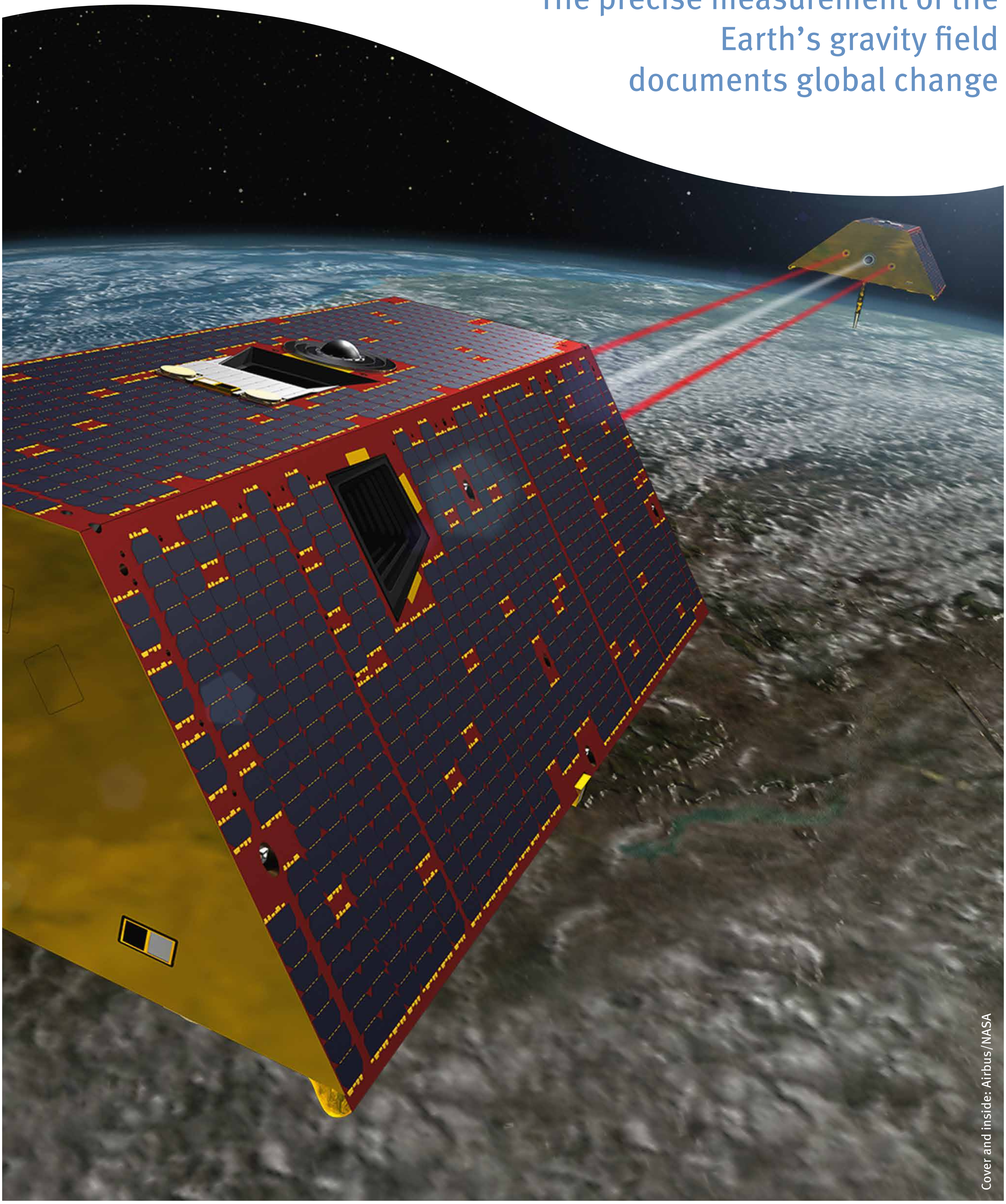
GFZ
Helmholtz-Zentrum
Potsdam

GRACE Follow-On

The precise measurement of the Earth's gravity field documents global change



Cover and inside: Airbus/NASA

From 2002 to 2017 the twin satellites GRACE (Gravity Recovery and Climate Experiment) measured the Earth's gravity field with extreme precision. Spatial and temporal changes were recorded, documenting, among other things, the loss of ice masses or the over-exploitation of groundwater resources. The successor mission, GRACE Follow-On, has been continuing this series of measurements since May 2018 making it possible to depict the dynamic processes in the Earth system over longer periods of time and, in doing so, to also better understand them.

Earth gravity and measurement

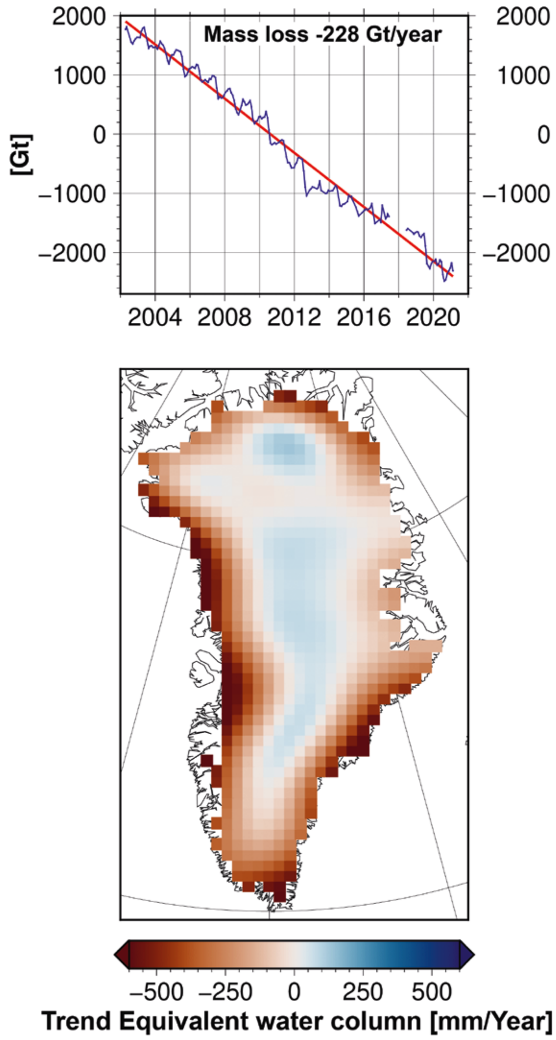
The mass distribution within the Earth's body and on the surface of our planet is not the same at all locations. In the interior of the Earth, molten rock masses move, water masses flow in the oceans and on the continents, and the air masses are also in constant motion. Since the gravitational pull of a body depends on its mass, the uneven mass distribution of our planet results in a non-uniform field of gravity.

The tandem satellites of the GRACE Follow-On mission fly at a distance of about 220 km one behind the other along their orbital track. Depending on the mass below them, the satellites undergo a sometimes stronger or weaker pull. This leads to a small change in the distance between both satellites. Thanks to a precise microwave instrument it is possible to determine this change in distance to within a few thousandths of a millimeter. This corresponds to about one tenth of the diameter of a human hair. As a result, even small mass variations in the Earth system can be detected.

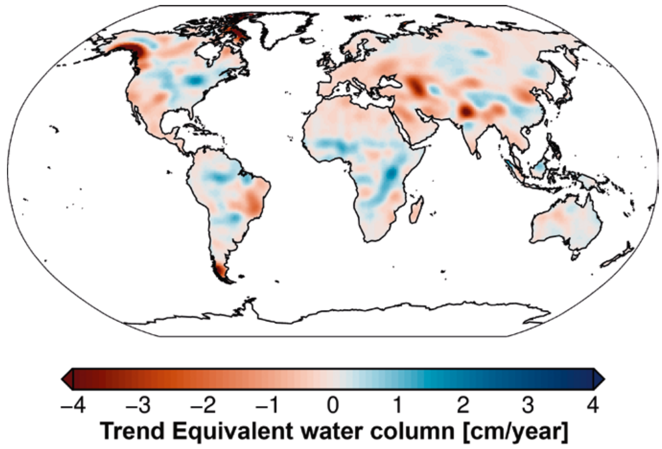
Instruments

Each of the two satellites is equipped with a GPS receiver for position determination. In addition, an accelerometer is integrated at the center of gravity of the satellites. This instrument is used to correct deceleration caused by residual atmosphere and solar radiation. Using three star sensors it is possible to determine the exact orientation of the satellite in space.

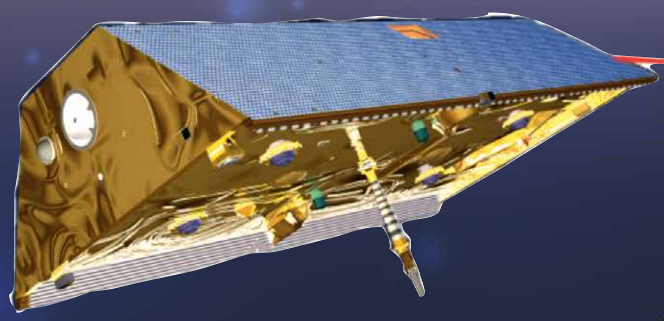
Ice mass loss Greenland



This figure shows the trend of ice mass loss in Greenland based on GRACE and GRACE-FO data between 2002 and 2021. The mass loss was about 230 giga tons (= billion tons) per year.



GRACE and GRACE-FO measurements document how water resources on the continents change over time (loss in red, increase in blue).

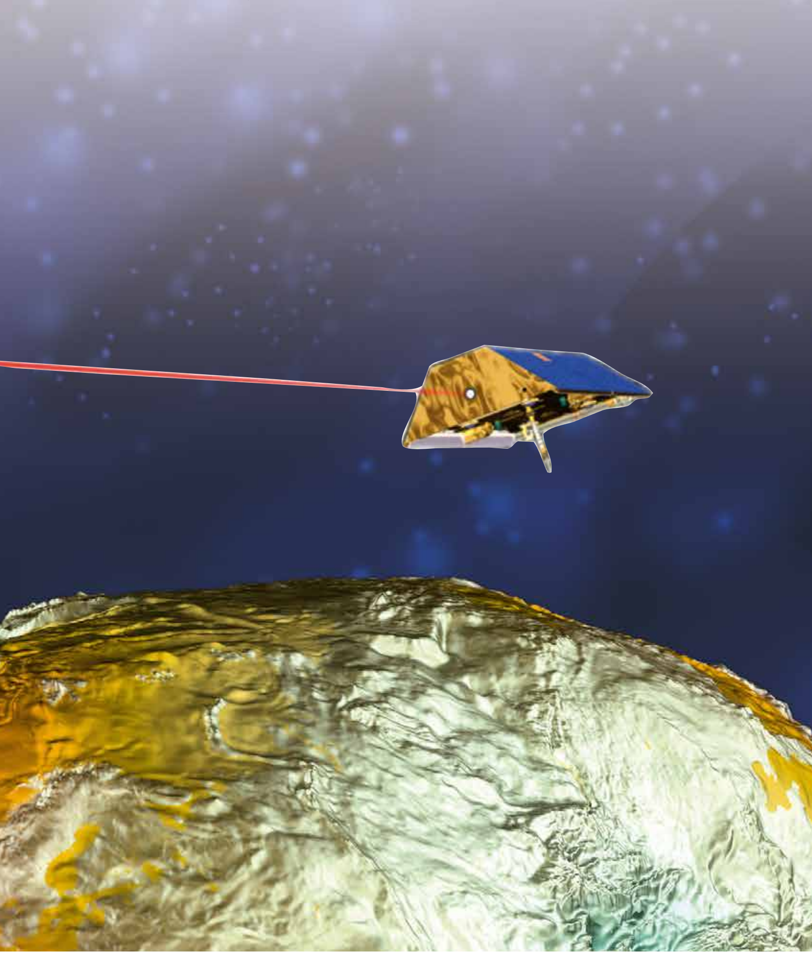


With the help of various measurements, this highly exaggerated representation of the global gravitational field and associated deviations from the ideal rotational ellipsoid was created. It is also called the "Potsdam potato".

Laser reflectors developed at the GFZ are mounted on the satellites. They reflect laser light emitted by selected observation stations (including stations at the GFZ). From these measurements, the distance to Earth and thus the orbit can be determined very precisely.

The heart of the instrumentation is the HAIRS (High Accuracy Inter-satellite Ranging System) distance measuring system, which is based on microwave technology. In addition, a novel laser-based measurement method (Laser Ranging Interferometer) is operated as a technology demonstrator. It measures the length between the satellites over a distance roughly equal to that from Potsdam to Hannover, even down to 20 nanometers (millionths of a millimeter). This corresponds approximately to the size of a corona surface protein („spike“).

To complete the instruments, the GFZ has manufactured a laser retro-reflector for both satellites. This allows to determine the distance to the two satellites from the Earth to within a few millimeters and the satellite orbits calculated on the basis of GPS data to be independently verified.



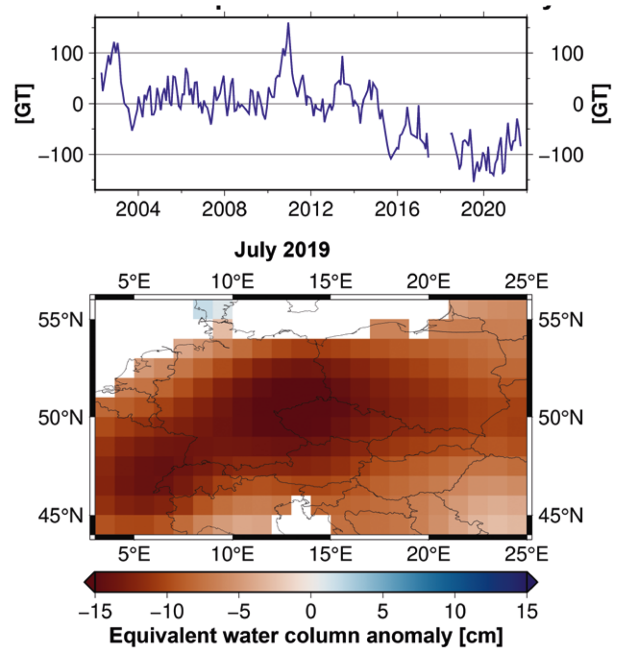
Water – the big player in the climate

Due to the extreme accuracy of the distance measurement, it is possible to specify even very small changes in the Earth’s gravitational field, and together with the data from the predecessor GRACE mission, these changes have been determined month by month over a period of more than two decades. From this information, new insights can be gained into the continental water cycle, changes in ice over Greenland and Antarctica, ocean currents or sea level rise.

With GRACE Follow-On, the amounts of water, ice, and other matter that are redistributed over time are observed in great detail. This provides a completely new picture of the dynamic processes in and on Earth, with the help of which water exchange processes between land, ocean and atmosphere can be described quantitatively. These data are ultimately also incorporated into climate models and thus improve our understanding of the current changes in the Earth system.

The additional vertical temperature and water vapor profiles obtained daily using a method called GPS radio occultation at about 200 globally distributed measurement points also contribute to this understanding. The method is based on the fact that the radio signals received on GRACE Follow-On from GPS satellites, disappearing behind the Earth, are refracted as a result of temperature- and humidity-related changes in the density of the atmosphere. These changes can be reconstructed from GPS signals recorded aboard the satellites. Atmospheric measurements from GRACE Follow-On are delivered with a delay of about two hours to various international weather centers to improve their daily forecasts.

Anomaly of the water reservoir of Central Europe



Central European drought 2018-2020 observed with GRACE-FO compared to the entire GRACE and GRACE-FO time series.
The water storage anomaly shows the mass deviation from the long-term mean annual cycle (about 160 Gt difference between February and September). The extent of drought across Central Europe is well visible for the driest month (July 2019).

The GRACE Follow-On Mission
at a glance

- Satellites: two identical spacecraft, manufactured by Airbus in Friedrichshafen
- Launch: on May 22, 2018 aboard a Falcon 9 rocket from SpaceX from Vandenberg Air Force Base / California
- Orbit: practically over the two poles, at an altitude of about 490 km
- Distance between the satellites: approx. 220 km
- Duration of one revolution: approx. 93 minutes
- Mission operation: German Space Operations Center of the German Aerospace Center (DLR / GSOC) Oberpfaffenhofen under subcontract of GFZ
- Mission duration: nominal mission lifetime of 5 years, it is planned to extend the mission another 5 years until 2028
- The GRACE Follow-On mission is a cooperation with the US space agency NASA. The German contributions to the mission are led by the GFZ and jointly funded by the Federal Ministry of Education and Research, the Federal Ministry of Economics and Climate Protection, the Helmholtz Association, the German Aerospace Center and the GFZ.

Photo: NASA

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Data processing and distribution

The GRACE Follow-On mission continuously collects data from all regions of the Earth. They are primarily received and forwarded via the GFZ's own receiving station Ny-Ålesund on Spitsbergen. On the European side, the GFZ — namely the Co-PI of the mission, Prof. Frank Flechtner, and his team — is responsible for the analysis and distribution of the scientific data. The instrument and gravity field products can be downloaded from the Information System and Data Center (ISDC): *http://isdc.gfz-potsdam.de*
Visualizations of various application-ready gravity field products can be found under our Gravity Information Service: *http://gravis.gfz-potsdam.de*

GFZ's own receiving station on Spitsbergen is located near the North Pole allowing for contact with the satellites almost every orbit for timely provision of the data to the users.

Photo: Airbus

The two satellites were built in Germany and extensively tested for their space suitability before being shipped to the launch site in California.

Federal Ministry of Education and Research

Federal Ministry for Economic Affairs and Climate Action

MAX PLANCK INSTITUTE FOR GRAVITATIONAL PHYSICS (Albert Einstein Institute)

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