'Gravity is climate' - 10 years of climate research satellites GRACE

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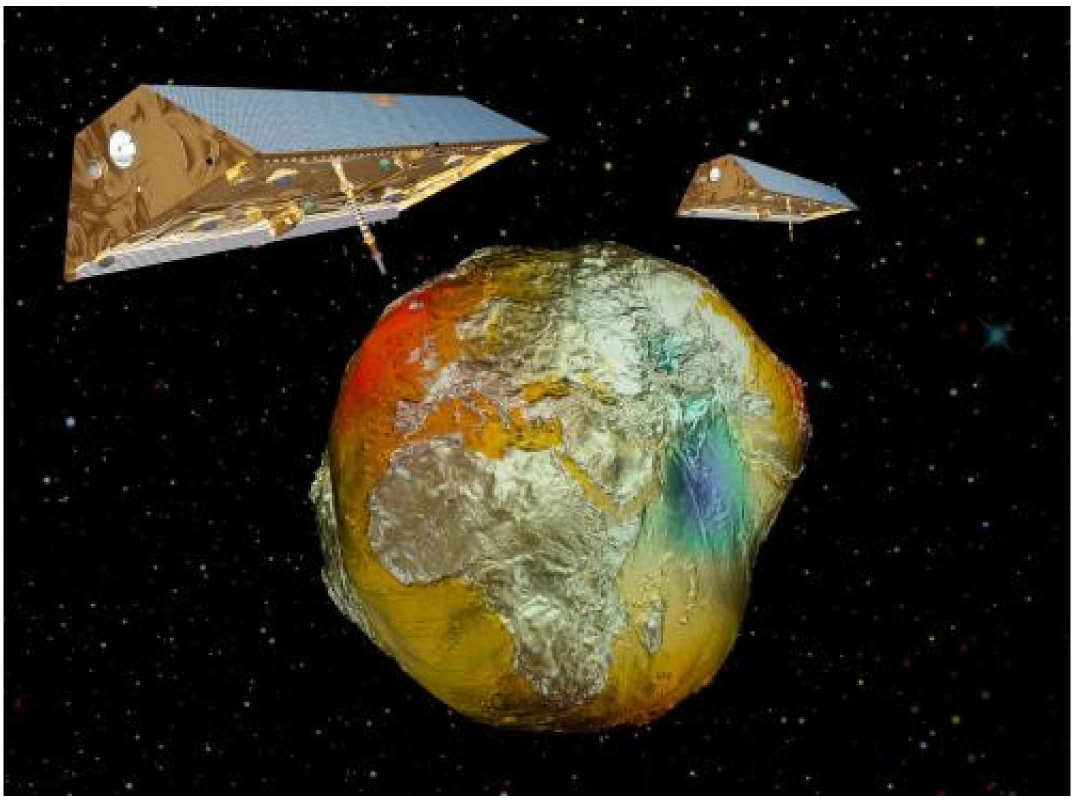

Twin-satellites GRACE with the earth's gravity field (vertically enhanceded) calculated from CHAMP data. © GFZ / Astrium

For the first time, the melting of glaciers in Greenland could now be measured with high accuracy from space. Just in time for the tenth anniversary of the twin satellites GRACE (Gravity Recovery and Climate Experiment) a sharp image has surface, which also renders the spatial distribution of the glacial melt more precisely. The Greenland ice shield had to cope with up to 240 gigatons of mass loss between 2002 and 2011. This corresponds to a sea level rise of about 0.7 mm per year. These statements were made possible by the high-precision measurements of the GRACE mission, whose data records result in a hitherto unequaled accurate picture of the earth's gravity. One of Newton's laws states that the gravity of an object depends directly on its mass. "When the mass of the Greenland ice sheet changes, so does the gravity there," explains Dr. Frank Flechtner from the GFZ German Research Centre for Geosciences. "The GRACE gravity field measurements therefore give us information on mass changes, including climate-related ones."

But there's more. The uneven distribution of mass on and within the planet causes, due the resulting variability of gravity, the earth to have an irregular shape, which deviates significantly from sphericity. Known as the "Potsdam Gravity Potato, the geoid has achieved global notoriety. But this potato shape is equally subject to temporal changes. During the last Ice Age, a mile-thick ice sheet covered North America and Scandinavia. Since the ice melted, the crust, now liberated from its load, continues to rise to this day. This causes material flow in the earth's interior, in the mantle, to replenish. With GRACE, this glacial-isostatic adjustment can for the first time be accurately detected globally as a change in the geoid height: the ice ages continue to have an effect, which is especially evident in North America and Scandinavia.

Anniversary in space

On 17 March 2012, the two GRACE twin satellites will have been in orbit for exactly 10 years. The scientists named them "Tom and Jerry", because they chase each other on exactly the same orbit around the earth. Since their launch from the Russian cosmodrome in Plesetsk, the two satellites have circled the Earth more than 55 000 times on a near polar orbit at about 450 to 500 km altitude and a distance of 220 km, and continuously collected data.

GRACE is a joint project of the U.S. space agency NASA and the German Aerospace Center (DLR). The mission was planned in 1996 by the GFZ German Research Centre for Geosciences, the University of Texas Center for Space Research (UTCSR) and the Jet Propulsion Laboratory in Pasadena, and in 1997 was selected to be the second mission in NASA's program Earth System Science Pathfinder (ESSP). The scientific analysis of the data is carried out jointly by GFZ, UTCSR and JPL. Principal Investigator of the mission is Prof. Byron Tapley (UTSCR), Co-Principal Investigator is Dr. Frank Flechtner (GFZ). Especially noteworthy: with GRACE, NASA for the first time commissioned a non-American company to build satellites. Astrium in Friedrichshafen, who built the GFZ's founding father satellite CHAMP (Challenging Mini-satellite Payload), produced the satellite duo GRACE for NASA.

A hair's breadth: gravity field measurements with satellite

The primary scientific goal of the GRACE satellite mission is to measure the gravitational field of the earth and its changes over time on a global scale with unprecedented accuracy. If the earth were a homogeneous sphere, the two satellites would orbit at exact elliptical orbits around the Earth. But the uneven distribution of mass causes perturbations in the trajectory. "Their analysis allows us to derive the irregular structure of the Earth's gravity," explains Dr. Frank Flechtner. "This, however, requires the satellites' orbits to be measured with high precision. Each of the two GRACE satellites is therefore equipped with a GPS receiver for positioning, an accelerometer to correct for disturbing forces due to the residual atmosphere and solar radiation, and two star trackers to determine the satellites' position in space." But the core is the ultra-precise distance measurement system developed by NASA / JPL, which allows the separartion of the two satellites to be continuously measured with a precision of one tenth of a hair's breadth.

From the varying distance between the two satellites, GFZ scientists can determine the gravitational field of the earth. Approximately every 30 days, the satellite pair has collected enough data for a complete global map. This monthly survey of gravity is at least 100 times more accurate than any previous model, and thus invaluable for the research at the GFZ and the international user community. "Many processes in the climate of our planet are accompanied by large-scale water mass redistributions, which are made visible in the gravitational field," adds Flechtner. This enabled, as the name of the mission suggests, the first observation and analysis of homogeneous and globally numerous climate-related processes from the monthly gravity field models over the last 10 years. Particularly worth mentioning are

- The mass balance study of the continental water content, which is ultimately a sum of precipitation, evaporation, runoff and storage. GRACE monitors the season-dependent changes in the major river basins, but also the huge groundwater extraction due to irrigation in northern India and California.
- Quantification of the increase or decrease of the ice and snow masses in the polar or large glacier areas. GFZ scientists were able to demonstrate a strong correlation between the climatic phenomenon ENSO / La Nina, the rainfall patterns in West Antarctica and the reduction of ice mass there.
- The observation of surface and deep currents, which - in combination with the sea surface topography derived from satellite altimetry – brought about a much better understanding of the global ocean circulation and thus the heat transport from the

equator toward the poles.
- The first-time possibility of separation of mass (ice melt) or temperature (global warming) induced sea level changes.
- The changes in the solid earth after large earthquakes, such as Sumatra-Andaman (2004), Chile (2010) and Fukushima (2011).

New potatoes and improved weather forecast

The 'Potsdam Gravity Potato', originally developed in 1995, is now much more precise thanks to GRACE. This is not a gimmick, but is required, for example, to improve the trajectories of geodetic satellites and derive accurate global reference systems from them - a prerequisite for the combination and evaluation of various global sensor systems such as the Global Positioning System (GPS), Satellite Laser Ranging (SLR), the satellite altimetry or local gauge measurements such as for the observation of sea level rise. Another scientific objective of the GRACE mission is to derive about 150 globally distributed vertical temperature and water vapor profiles from GPS data on a daily basis. These data reach the GFZ via its own receiving station in Ny Ålesund (Spitsbergen) and are delivered to the global weather centers within 2 hours to improve global forecasts. In addition, these data are used for studies of climate induced changes in the earth's atmosphere.

A scientific birthday gift

Right from the beginning, GRACE was planned to be an international program. "For the 10th Birthday, the researchers have devised a special gift for the more than 3,000 users", says Professor Reinhard Huettl, Chair of the Board of the GFZ. "The entire mission was recalculated with improved correction models, instrument data and processing standards." Initial analyzes show that the accuracy of gravity field models could be further improved by a factor of 2. These new models will be released to the global users on 17 March via the Information

System and Data Centre (ISDC) of the GFZ.

Like its predecessor mission CHAMP (Challenging Mini-Satellite Payload), GRACE will on 17 March be running for twice as long as originally planned. An end of the mission is, however, still in sight. Therefore, the GFZ have initiated a follow-up mission together with the U.S. colleagues. Professor Hüttl is confident: "We hope that at Christmas 2016 two GRACE-FO (follow-on) satellites will orbit around the Earth, because only long time series can provide reliable information on global trends in climate."

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