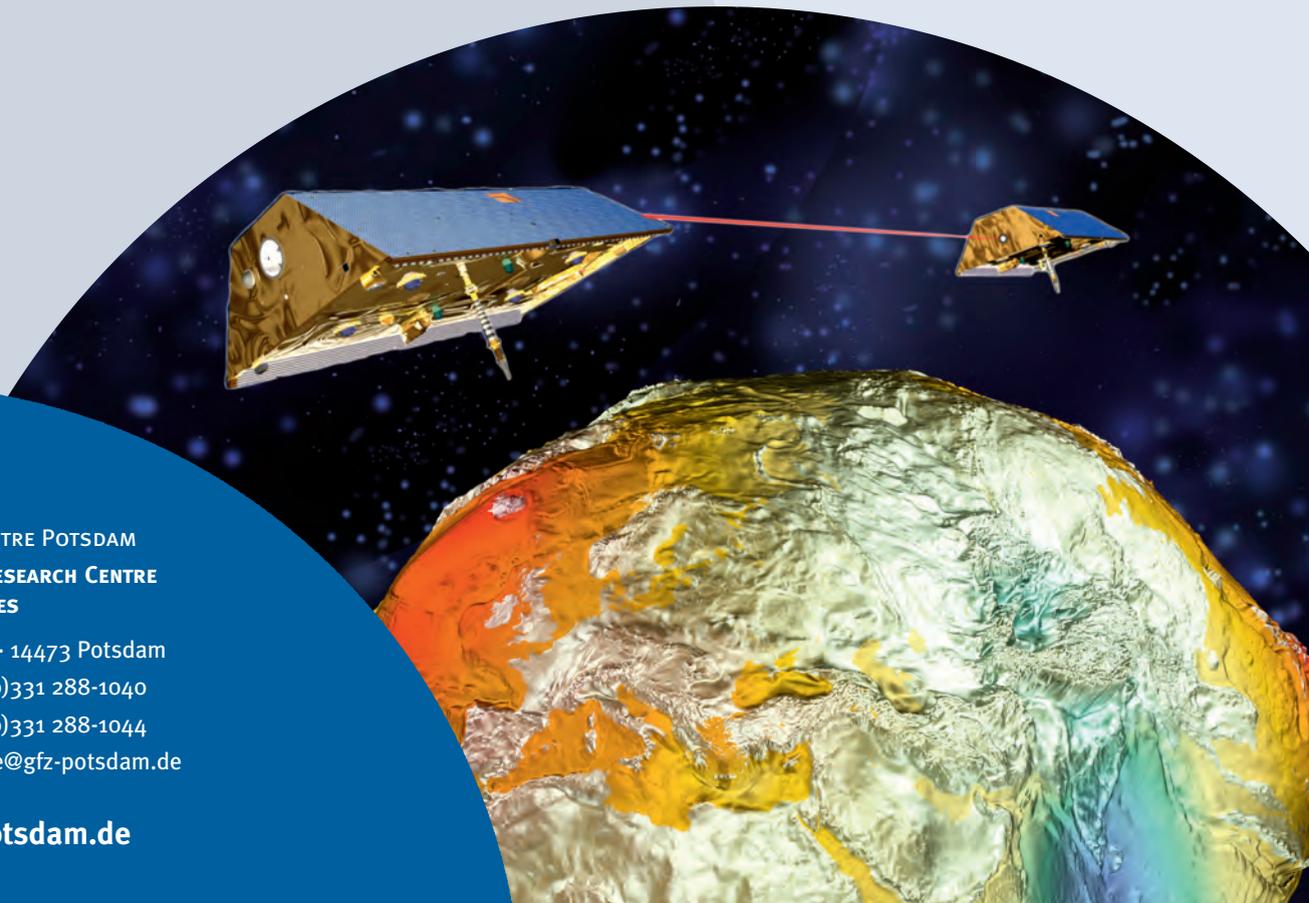


## The GRACE Satellite Tandem High-Precision Earth Monitoring for a Better Understanding of Climate

*The satellite pair GRACE (Gravity Recovery and Climate Experiment) began its geoscientific space mission on March 17, 2002 from the Russian launch site Plesetsk. The mission maps Earth's gravity field and its temporal variations with hitherto unprecedented accuracy. Furthermore GRACE provides information on vertical temperature and water vapour distribution of the Earth's atmosphere.*

The GRACE experiment consists of two identical spacecrafts flying on the same orbit about 220 kilometres apart. Thus the engineers involved called the satellite tandem unofficially "Tom and Jerry". GRACE is the first mission launched under the NASA Earth System Science Pathfinder (ESSP) Program. With GRACE, the GFZ German Research Centre for Geosciences went into its third satellite mission.

Both satellites weigh 485 kg each, fly at an initial altitude of 500 km and orbit the Earth in about 95 minutes.



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### Gravity and Gravity Mapping

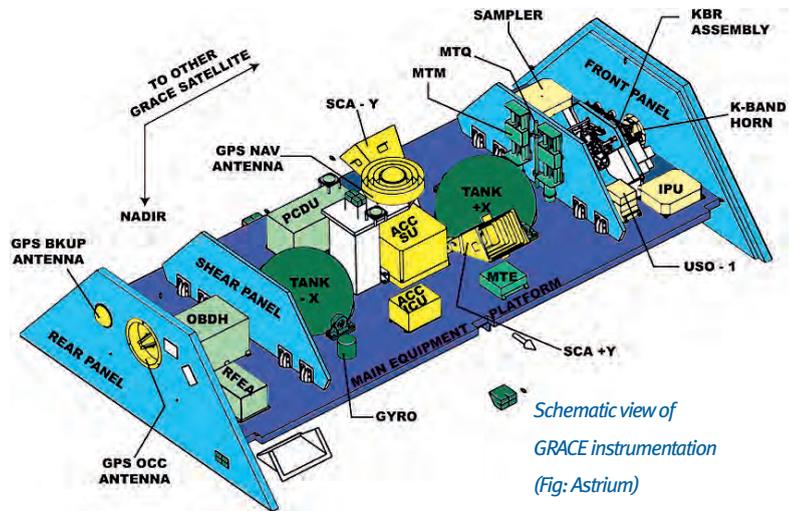
The mass within the Earth and on its surface is not evenly distributed. Molten rock flows in the Earth core, water masses move in the oceans and on the continents and atmospheric masses are also in continuous movement. Since the gravity force of a body depends on its mass, the irregular mass distribution on our planet causes an inhomogeneous gravity field. Therefore regions of slightly stronger gravity will affect the leading GRACE satellite first, pulling it slightly away from the trailing satellite. This is reflected by a small change in the distance between the satellites.

Consequently, by high-precision tracking of the constantly changing distance, tiny mass variations can be measured. For this end, GRACE uses a uniquely precise microwave ranging system measuring the distance between both satellites with an accuracy of some microns – about one-tenth the width of a human hair – over a distance of 220 km!

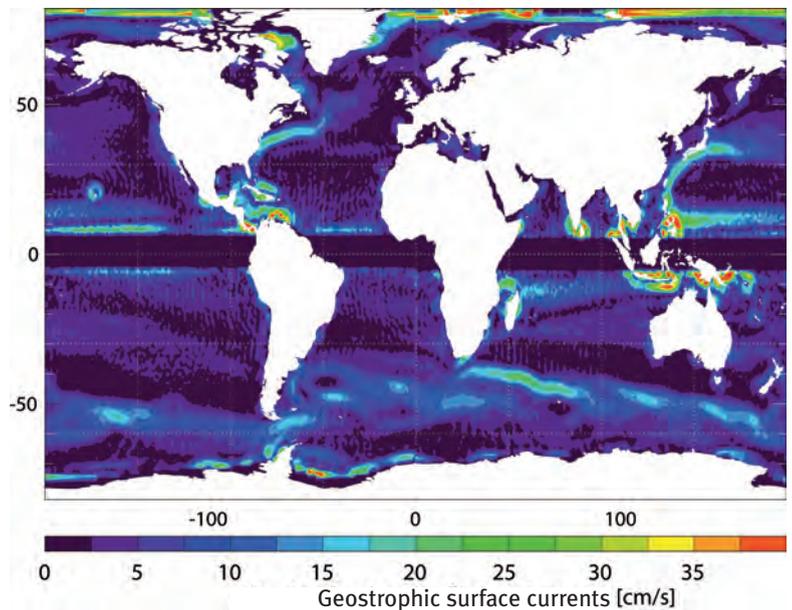
### GRACE instrumentation

As its predecessor CHAMP (Challenging Mini-Satellite Payload), each of the GRACE satellites is equipped with a GPS receiver for positioning, an accelerometer approximately 10 times more precise than the CHAMP accelerometer to measure non-gravitational accelerations acting on the GRACE satellites due to air drag or solar radiation pressure, and two star sensors to determine the satellite orientation. The highly-accurate inter-satellite ranging system HAIRS, uniquely designed by the NASA Jet Propulsion Laboratory (JPL), constitutes the core of the instrumentation.

Complementing the payload, the GFZ German Research Centre for Geosciences had provided two laser retro-reflectors (LRR) identical to the CHAMP LRR. They serve both for the direct distance measurement between laser ground stations and the GRACE satellites with a few millimetres accuracy and an independent checking of the satellite orbits as computed on the basis of GPS tracking data.



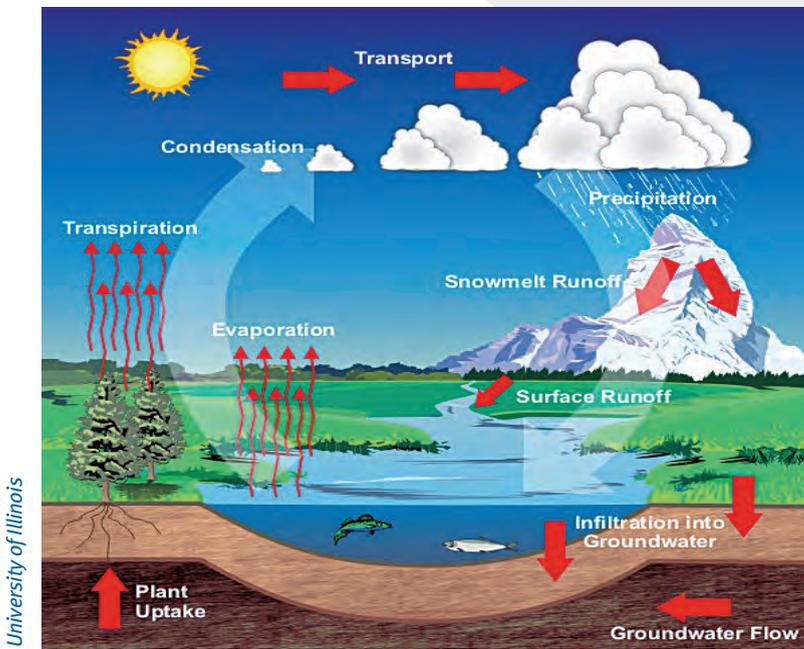
Schematic view of GRACE instrumentation (Fig: Astrium)



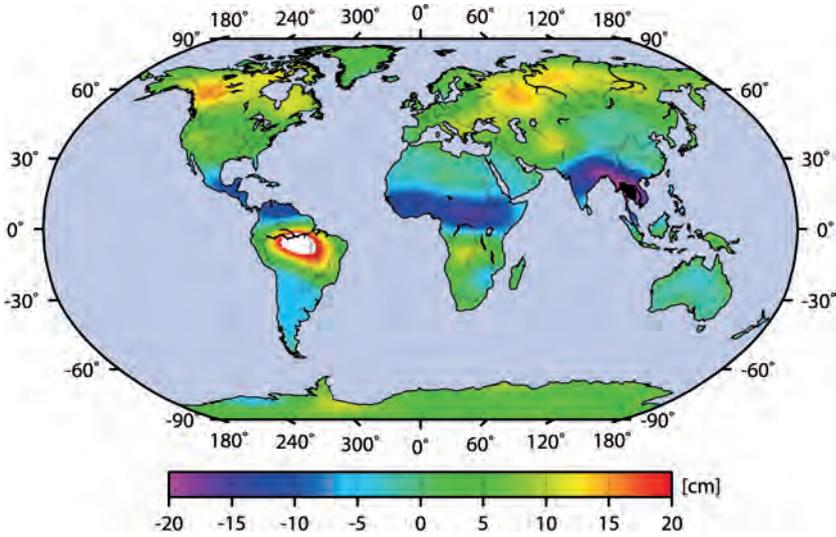
Geostrophic surface currents as derived from GRACE gravity field models. The entire set of major ocean currents can be identified.

### Water – a Key Factor of Climate Change

The immense accuracy of the distance measurements allows to map the Earth gravity field approximately once a month over a period of several years. From the temporal variations geo-scientists have already derived new insight into dynamic processes in the Earth interior, into water mass transfer processes over land and in the oceans and into the changes of ice sheets and glaciers on Greenland and Antarctica. With the GRACE mission, for the first time a systematic and thorough monitoring of the amounts of

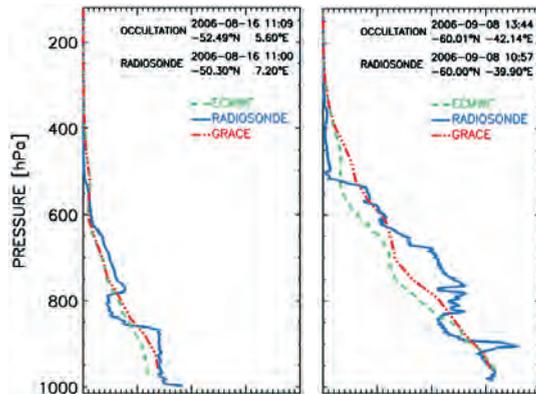


University of Illinois

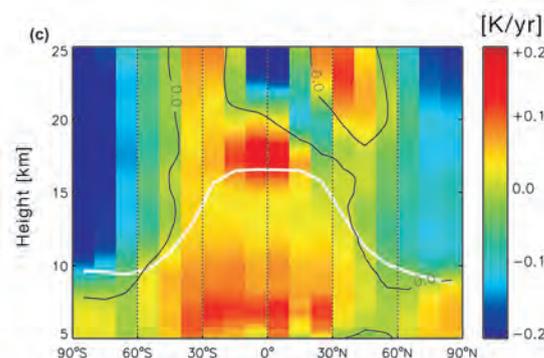


Above: GRACE derived temporal hydrological annual mass variations (in cm equivalent water column) due to mass redistribution in the global hydrological cycle (top)

Right: Two examples of vertical water vapour profiles, derived from GRACE occultation measurements (red), compared with ECMWF model data (green) and radiosonde measurements (blue) from the German research vessel POLAR-STERN. Altitude is given as pressure.



Below: Zonal mean temperature variability (short-term trend) at various altitudes in Kelvin/year derived from CHAMP and GRACE radio occultation measurements between 2001 and 2010. Red colour indicates warming and blue indicates cooling.



water, ice and matter moving around is performed and thus a completely new picture emerges of the dynamic processes within Earth and on its surface.

On the other hand, these parameters serve for the mapping of water transfer processes between land, ocean and atmosphere and are key input for climate modelling.

In addition, the GPS signals travelling through the atmosphere and received by GRACE can be used to obtain about 150 very precise globally distributed vertical temperature and humidity profiles of the atmosphere per day. This is called the GPS radio occultation technique.

The occultation method is based on the atmospheric refraction of the GPS radio signals, which depends on temperature and water vapour content.

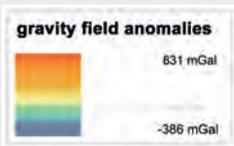
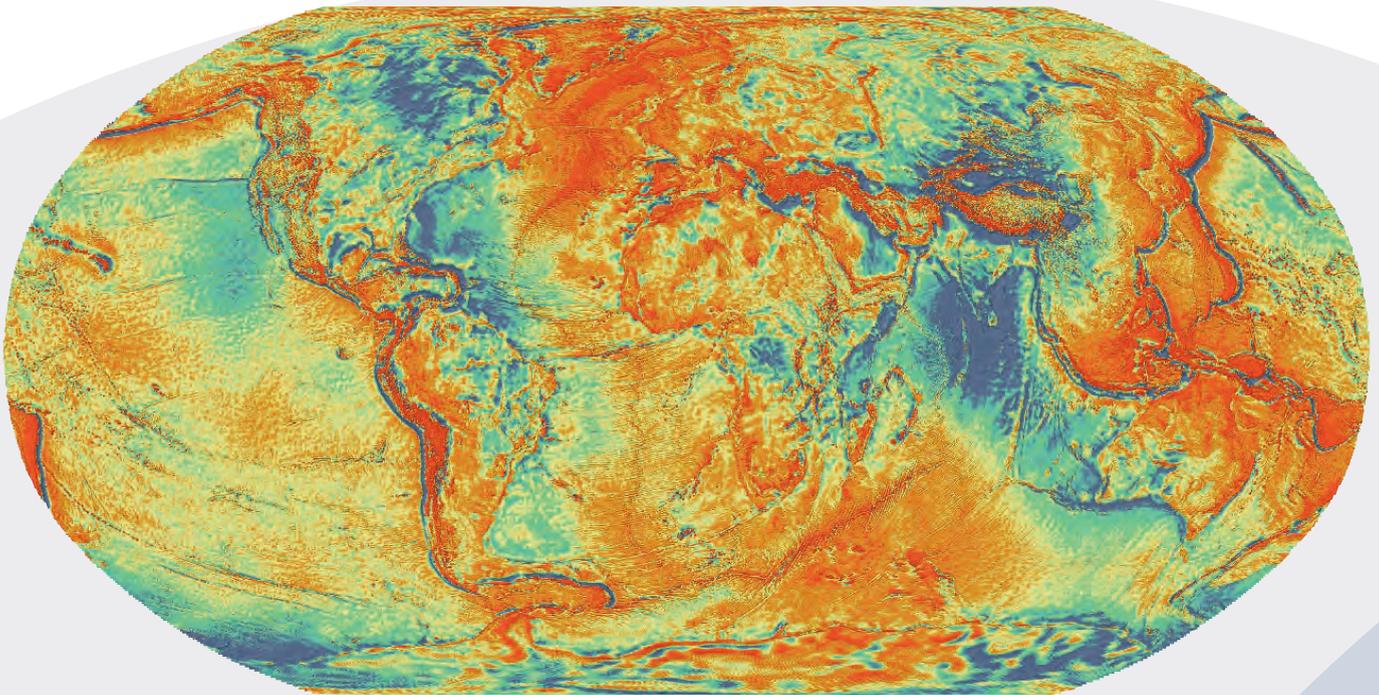
The figures slightly left down show two examples of vertical water vapour profiles, derived from GRACE occultation measurements. The data are compared with corresponding meteorological model data from the European Centre for Medium-Range Weather Forecasts (ECMWF) and measurements from radiosondes (weather balloons) aboard the German research vessel POLARSTERN. The measurements from GRACE are continuously provided within 2 hours after the measurement to various international meteorological centres to improve their daily global weather forecasts.

The figure bottom left shows zonal mean temperature variabilities (short-term trends) for different altitudes, derived from CHAMP and GRACE occultation measurements. Tropospheric warming is observed (red colour) and stratospheric cooling (blue). The high accuracy of the GPS radio occultation technique allows for the detection of climate change related atmospheric temperature variations.

### GRACE: International Cooperation for Solving Global Environmental Issues

GRACE is a direct successor of the second GFZ satellite, CHAMP, and represents a prime example of international cooperation in geosciences. The satellite

## SATELLITE TANDEM GRACE



*Gravity anomalies derived from the EIGEN-5C high-resolution gravity field model based on GRACE, LAGEOS and terrestrial gravity data. This model was chosen for JASON reprocessing and GOCE data analysis.*

tandem GRACE is a joint project of the American space agency NASA, and the German Aerospace Center (DLR). The German Space Operations Center of DLR is responsible for satellite operation and data reception. Mission Management is performed by the Center for Space Research (CSR), Austin (PI Prof. Byron Tapley) and NASA/JPL. The two satellites were manufactured by the company Astrium GmbH in Friedrichshafen. Launching of the spacecrafts was performed by the German-Russian enterprise Eurockot. JPL, CSR and GFZ are responsible for the scientific data analysis. Dr. Frank Flechtner, the GRACE Co-PI and head of the German GRACE Science Data System, is in charge of the scientific management at GFZ.

GRACE Level-1 instrument and Level-2 gravity field products can be downloaded from the Information System and Data Centre (ISDC) at:

<http://isdc.gfz-potsdam.de/grace>



*Left: The GRACE satellites were developed and manufactured for NASA/JPL by Astrium GmbH in Friedrichshafen and tested at IABG in Ottobrunn. (Fig: Astrium)*



*Right: Launch on March 17, 2002 from the cosmodrome Plesetsk in northern Russia (Fig: Eurockot)*

