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The Contribution of GPS Flight Receivers to Global Gravity Field Recovery

Peter Schwintzer, Christoph Reigber

GeoForschungsZentrum Potsdam, Germany

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Biography

Christoph Reigber, Prof. Dr.-Ing. Dr.-Ing. E.h, Director of Division 1 'Kinematics and Dynamics of the Earth' of GeoForschungsZentrum Potsdam, is in particular engaged in all aspects of satellite geodesy and its relation to geotectonics, Earth rotation, Earth gravity field, oceanography and atmosphere/ionosphere.

He is Director of the CHAMP mission, Co-Principal Investigator of the GRACE mission and Chair of the Coverning Board of the international GPS Service.

Peter Schwintzer, Dr.-Ing., Head of Section 1.3, 'Gravity Field and Figure of the Earth' within Division 1 of GeoForschungsZentrum Potsdam, is engaged in global gravity field modelling from space and its geophysical application.

He is the Science Data System manager of the CHAMP mission.

On July 15, 2000, the German geoscientific satellite CHAMP (CHAllenging Mini-satellite Payload) was launched into an almost circular, near-polar orbit with an initial altitude of 454 km, slowly decreasing to 300 km during the expected lifetime of five years. The CHAMP mission is conducted since the beginning under full responsibility of GeoForschungsZentrum Potsdam with participation of the German Centre for Aerospace (DLR).The mission is funded by the German Ministry of Education and Research (cf. GFZ website http://op.gfz-potsdam.de/CHAMP).

For the first time a satellite in such a low altitude is equipped with a GPS receiver. The 2nd generation Turbo Rogue Space Receiver (TRSR-2) is provided by NASA and manufactured at NASA's Jet Propulsion Laboratories (JPL) [Kuang et al., 2001]. The purpose of this instrument is to allow a recovery of CHAMP's trajectory with an uncertainty of only a few centimetres. The receiver acquires up to 12 GPS satellites simultaneously and measures dual-frequency carrier phases and pseudo-ranges at a rate of 10 s. Monitoring CHAMP's orbit by GPS allows the observation of gravity induced orbit perturbations which then are analysed to map the global structure of the Earth's gravitational field [Reigber et al., 1999] (Figure 1).

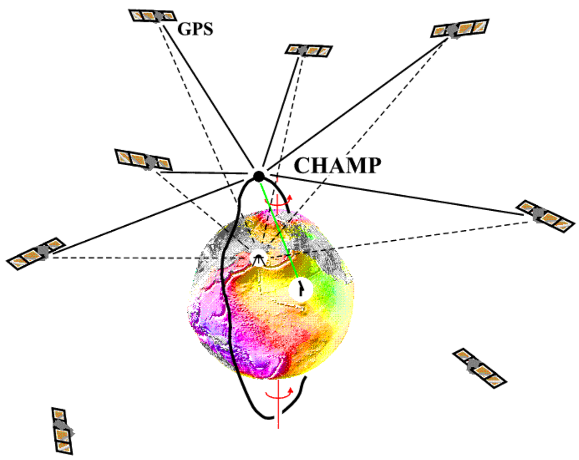

Fig. 1 High-low GPS-CHAMP satellite-to-satellite tracking for gravity field recovery

Earth gravity field recovery from observed satellite orbit perturbations has been applied since the beginning of the space age in the late 1950s and evolved to long-wavelength gravity field models which today resolve spatial features in the gravity field with half wavelengths larger than 500 km at the Earth's surface. The models which were generated prior to the launch of CHAMP exploited mainly ground-based camera, microwave and laser tracking data from some tens of satellites at different altitudes and orbit inclinations [Biancale et al., 2000]. With CHAMP it becomes for the first time possible to derive a global gravity field model from orbit perturbations gathered over a short time interval of a few months from one satellite only (Figure 2). Moreover, the resulting model is up to four times more accurate than what has been achieved with the earlier multi-satellite solutions and multi-year tracking records. Geodesy, Oceanography and Geophysics benefit from the advanced knowledge of the Earth's gravity field.

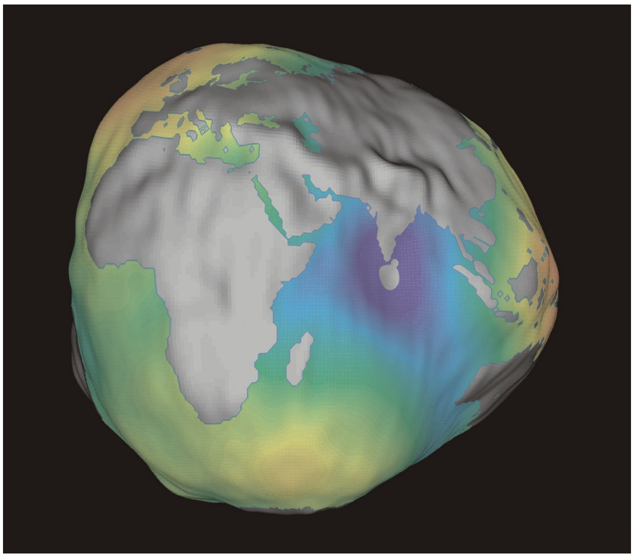

Fig. 2 Global gravity field model from three months of CHAMP data only

The advantages of the CHAMP mission with respect to all former geodetic gravity missions are the following: (1) Orbit configuration - The effect of the attenuation of the gravitational signal with altitude is minimized due to the low orbit altitude, and there is no restriction in ground track coverage thanks to the almost polar orbit. (2) GPS receiver – The on-board GPS receiver allows continuous tracking by up to 12 GPS satellites simultaneously compared to one-dimensional ground-based tracking of only short orbit pieces during satellites passes. (3) Accelerometer – CHAMP experiences at its low altitude enhanced accelerations due to air drag. These non-gravitational orbit perturbations have to be accounted for when using the GPS observed overall orbit perturbations for gravity field recovery. The on-board three axes accelerometer, provided by the French space agency CNES and manufactured by the French company ONERA directly measures the vector of non-gravitational accelerations, i.e. air drag plus direct and indirect solar radiation pressure [Touboul et al., 1999]. These measurements replace air density models which are of insufficient accuracy and temporal resolution. The orientation of the accelerometer's axes is known from two star camera.

The sum of these mission characteristics already led to a break-through in the determination of the long-wavelength gravitational field [Reigber et al., 2002]. The ability to achieve, thanks to uninterrupted GPS space-based tracking, accurate gravity field solutions from only a short observation time interval also opens the possibility to study non-tidal temporal gravitational field variations. These are mainly due to seasonal, interannual and long-term mass redistributions in and among the Earth's atmosphere, hydrosphere and cryosphere. The observation of these phenomena which are relevant for climate studies is in particular the objective of the GRACE (Gravity Recovery And Climate Experiment) mission. The two satellites of the GRACE constellation were launched on March 17, 2002, for a 5 years' mission. The GRACE satellites are part of NASA's Earth's System Science Pathfinder project. The German Center for Aerospace (DLR) participates in the mission. The science processing system is chaired by the Center for Space Research (CSR) of Texas University in Austin with a distribution of work between CSR, JPL and GFZ [Tapley and Reigber, 2001].

The two GRACE satellites, flying one after the other at a distance of about 220 km in an initial altitude of 500 km and in a near-polar orbit, are similar to CHAMP. Both carry a GPS receiver and an accelerometer, but with an increased resolution. The new element of the GRACE mission is the K-Band Ranging System (KBR) which measures the dual one-way range between both satellites with a precision of about 5 µm. By measuring gravity-induced relative distance variations between the two satellites, the resolution in global gravity field recovery from space can be very likely extended from about 500 km to 150 km (half-wavelength) with a gain in accuracy by one to two orders in magnitude compared to the present knowledge (CSR website http://www.csr.utexas.edu/grace, and GFZ website http://op.gfz-potsdam.de/grace). GRACE also relies on the exploitation of GPS high-low satellite-to-satellite tracking data for the restitution of the long-wavelength part of the gravitational spectrum.

The third satellite in the sequence of recent dedicated gravity satellite missions will be GOCE (Gravity field and steady-state Ocean Circulation Explorer). GOCE is planned to be launched in 2006 and was selected as the first Core Mission within the Earth Explorer Programme of the European Space Agency [ESA 1999]. The payload of GOCE will consist of a GPS/GLONASS receiver, again for resolving the long-wavelength gravity field, and an assembly (gradiometer) of six three-axes accelerometers to measure in-orbit gravity gradients. For the first time gravity field recovery from space will not be based purely on the analysis of orbit perturbations. GOCE will fly in an extremely low orbit (250 km altitude) which is permanently maintained by ion-thrusters compensating for air-drag (drag-free concept).

The relatively short mission with twelve months observation time, aims at an ultimately high and accurate resolution of the gravity field down to half wavelengths below 100 km. By this, the requirement of the oceanographers for a high-resolution precise geoid shall be fulfilled. This is needed as a physical reference surface for the determination of the global ocean circulation pattern with satellite altimetry.

The combination of GPS high-low satellite-to-satellite tracking with accelerometry, a low-low intersatellite link and/or a gradiometer on low Earth orbiting platforms provides an excellent tool for mapping the Earth's gravity field homogeneously from space with ever increased accuracy and resolution over the globe and in time.

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