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The CHAMP geopotential mission

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Abstract. CHAMP is a German small satellite mission aiming at the simultaneous precise observation of both the gravity and magnetic field from a low altitude orbit. Thanks to the dedicated orbit design, an unprecedented low altitude in a near polar orbit, its continuous undisturbed observation of the magnetic field vector through scalar and vector magnetometers and its continuous GPS satellite-to-satellite tracking capability together with a direct on-board measurement of the non-gravitational orbit perturbations, a dramatic improvement in the global modeling of the magnetic field and also an order of magnitude improvement for the broad to mesoscale structures of the gravity field can be expected. In addition, due to the designed 5 years mission duration, temporal changes in both fields will be detectable with a higher signal/noise ratio and at increased spatial resolution as it is possible now. CHAMP was successfully launched on 15 July 2000.

1. Background

The idea of a small satellite mission was initiated in 1994 by the German Space Agency (formerly DARA, now German Aerospace Centre, DLR) as a lead project for the East German space industry. The mission's goals and the instrumentation for a geoscientific mission, called CHAMP (CHAllenging Mini-satellite Payload), were defined by scientists of the GeoForschungsZentrum Potsdam (GFZ). The mission was studied for its feasibility, designed and specified under the leadership of the GFZ together with an industrial consortium and the German Aerospace Centre (DLR). When the project's definition/specification phase (Phase B) was over, CHAMP entered its manufacturing/integration phase (Phase C/D) at the end of 1996. The launch is scheduled for spring 2000.

CHAMP will be employed to map both, the gravitational and the magnetic geopotential of the Earth, and in addition to perform atmospheric and ionospheric profiling by GPS radio occultation measurements. The instrumentation is composed of a GPS receiver for continuous

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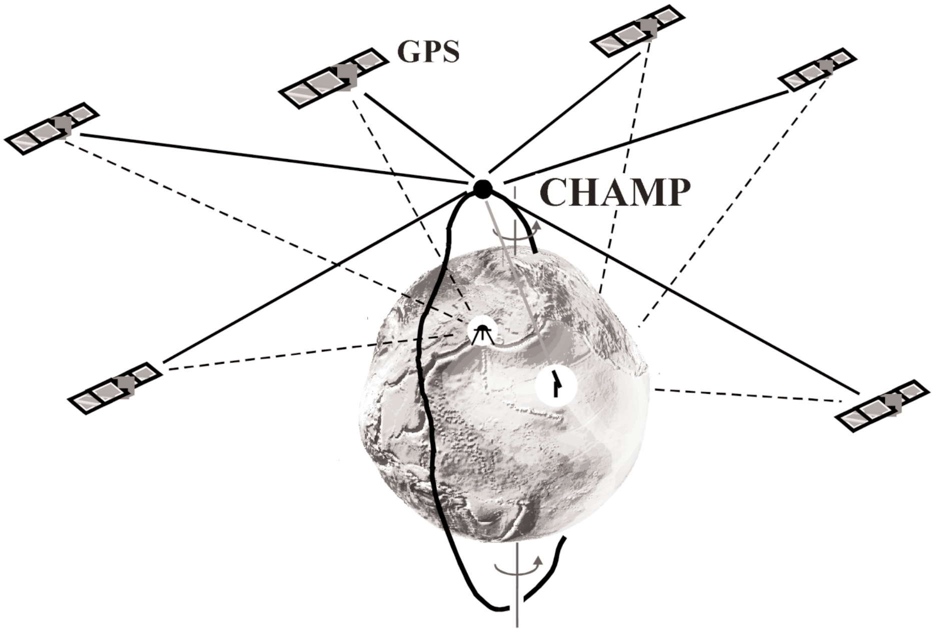

Fig. 1 - CHAMPS GPS satellite-to-satellite tracking and ground-based satellite laser ranging.

high-low satellite-to-satellite tracking, for experimental GPS altimetry and atmospheric limb sounding, a laser retro-reflector for ground-based laser ranging, an accelerometer to measure non-gravitational satellite accelerations, scalar and vector magnetometers, and an ion drift meter to measure the electric field.

With its multi-purpose and complementary payload, CHAMP will contribute to a number of themes relevant to the Earth's system sciences, in particular to studies of the Earth's interior, the oceans and the atmosphere.

2. Recovery of the gravitational geopotential

The analysis of observed gravitational orbit perturbations of near-Earth orbiting satellites is the only means of homogeneously resolving, on a global scale, the long- to mesoscale structures of the Earth's gravity field. Due to satellite orbit configurations and tracking systems employed to date, tracking data of about three dozen satellites have to be evaluated to get a state-of-the-art satellite-only model of the Earth's gravity field with a spatial resolution of about λ=1200 km at the Earth's surface, and an accuracy of about 1m in terms of geoid heights (Schwintzer et al., 1997). Long-wave satellite-only models are combined with surface data from altimetry, shipborne-, airborne and terrestrial gravimetry to increase the resolution of detailed structures, without, however, reducing the overall error in the long-wave features of the gravity field model.

Global Earth gravity field models together with seismic observations are taken in geophysics for studies on the Earth's deep interior, in particular on the lateral density distribution, isostatic compensation mechanisms and dynamic processes within the Earth's mantle to address for example, the open question about mantle convection and its relation to plate tectonics (Kaban et al., 1999).

In oceanography, the geoid constitutes the reference surface needed to derive the quasi-stationary sea surface topography from altimetry which immediately translates into the geostrophic ocean circulations, which is an input for global climate studies. For this application a geoid accuracy of 1cm is required over all wavelengths down to 30 km (Wunsch 1993).

Of increasing importance is the monitoring of climate change induced processes at the Earth's surface, like sea-level variations due to changes in the polar ice and oceanic water mass balance, and post-glacial relaxation processes which reflect the physical properties of the Earth's subcrustal material. These phenomena, complemented by variations in hydrology and atmospheric pressure, are connected with large-scale secular and cyclic mass redistributions which can be observed via satellite orbit perturbations as temporal changes in the low degree and order spectral constituents of the gravitational geopotential. As the amplitudes of these effects are small, over short time periods, extremely high accuracies are required to resolve and separate these time-varying gravity signals (NRC 1997).

In geodesy and land surveying, a most accurate and homogeneous geoid model is employed as a reference surface for large-scale digital terrain models and for topographic hight determination with modern satellite methods (GPS-levelling).

For all these applications, present-day long-wave geoid models are by far too inaccurate and, therefore, many efforts are undertaken, within the international geodetic community, to support and promote dedicated satellite gravity missions: CHAMP, followed in 2001 by GRACE (Tapley, 1998) and lateron GOCE (Schuyer, 1997). CHAMP, as the first one of these missions, will be a tool to achieve a major step forward in precise geoid and gravity field representation. Numerical simulations have proven that with CHAMP a geoid model could be realized with an accuracy of one centimeter at a spatial resolution of λ=1000 km, which is an improvement of two orders of magnitude in accuracy compared to actual satellite-only gravity field models. The unique advantages of the CHAMP mission, with respect to any earlier missions, are a near-polar and extremely low orbit, continuous multi-directional tracking by GPS (Fig. 1) and a direct measurement of non-gravitational orbit perturbations by three-axes accelerometry together with a multi-year mission duration.

3. Recovery of the magnetic geopotential

To recover the Earth’s internal and external magnetic field, in-orbit scalar and vector magnetic, as well as, electric field observations of global coverage will be collected. Resolution of the Earth's main magnetic field favours a low to medium altitude orbit with the regional magnetic anomalies fairly attenuated, while resolution of the static crustal field requires an as low as possible orbit. A mission of multi-year duration is needed to resolve the rich spectrum of temporal variations and to be able to separate the different sources: the Earth’s core, the Earth’s crust, the Earth’s magnetosphere and solar wind.

CHAMP’s principal goal is the recovery of the Earth's main magnetic field, generated by the

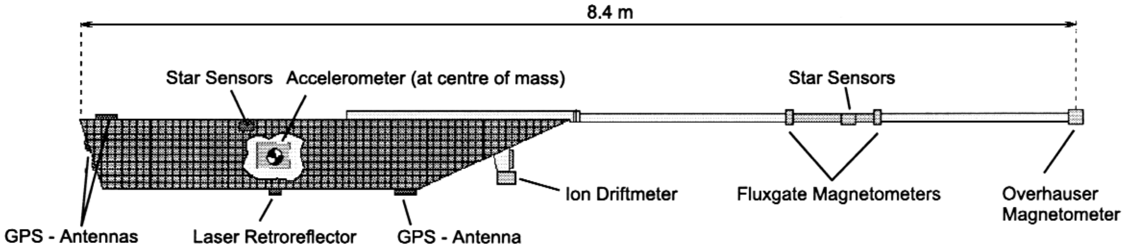

Fig. 2 - Side view of CHAMPS and its payload components.

core, and its secular variations to understand the functioning of the geodynamo. By observing induced electric currents in the Earth's mantle and broad structures of remnant crustal magnetization the thermal state of the Earth's mantle and lithosphere can be studied. In this, the gravitational and magnetic field components of CHAMP are, to a large extent, complementary.

4. CHAMP mission scenario and instrumentation

The launch of the CHAMP satellite with a Russian Cosmos rocket is planned for spring 2000 from Plesetzk. The satellite will have an overall mass of about 500 kg including about 32 kg of payload mass. Its power consumption amounts to about 150W (45 W payload). The satellite will be Earth-pointing and stabilized by three-axes with a cold gas propulsion system supported by three magnetic torquers. Two star sensor pairs accommodated on the body and the boom, respectively, provide the attitude knowledge required by the accelerometer (±0.01°) and the vector magnetometers (±0.003°). The spacecraft's configuration consists of a 4m long trapezoidal body with a cross-sectional area of about 0.9 m^2, and a deployable 4m long boom in-flight direction to accomodate the magnetometers (Fig. 2).

CHAMP will fly in a circular and polar, but non-sunsynchronous, orbit with an initial altitude of 460 km. The active lifetime is designed to last 5 years.

Due to atmospheric drag, the altitude will decrease over the 5-years active lifetime. As CHAMP will pass through the solar activity maximum around the year 2001, the predicted natural decay depends on the magnitude of the actual solar activity cycle. Therefore, a Δv-manoeuvre is foreseen, to raise or to lower the orbit in order to provide observation time at about a 300 km altitude towards the end of the mission.

The payload and sub-system data collected on board CHAMP amount to about 90 MByte per day, which will be downloaded to DLR's ground receiving station in Neustrelitz from 3 to 4 overflights per day. The mission and satellite control and command system will use the facilities of the DLR's German Space Operation Centre (GSOC) located in Oberpfaffenhofen with its ground station in Weilheim.

To achieve the above given scientific goals and target applications CHAMP is equipped with

the following payload components (Fig. 2):
- a space-borne 16 channel, dual-frequency GPS receiver connected to a multi-antenna system for precise satellite-to-satellite tracking between CHAMP and the high-flying GPS satellites (top-antenna: orbit determination, rear-antenna: limb sounding, nadir-antenna: altimetry from surface reflected signals);
- a three-axes accelerometer at the spacecraft’s center of mass to measure the non-gravitational orbit perturbations directly (air drag, solar and Earth radiation pressure), rigidly connected to two star sensors for precise inertial orientation information;
- a laser retro-reflector for additional tracking from the ground;
- a magnetometer instrument package consisting of an Overhauser scalar magnetometer and two Fluxgate vector magnetometers, rigidly mounted on an optical bench along the boom together with two star sensors;
- a digital ion drift meter to measure the electrical field vector along the orbit.

5. Outlook

From new dedicated gravity satellite missions like the coming CHAMP one, a breakthrough in global gravity field modelling can be expected. CHAMP will be the forerunner of a new kind of gravity mission. In Italy, SAGE is a similar plan to CHAMP. Other even more advanced mission concepts are the American/German twin-satellite project GRACE, aiming in particular at a most precise resolution of temporal gravity variations, and ESA’s gradiometer mission, GOCE, for an ultimate, high resolution of the static gravity field from space. CHAMP, as a geopotential mission, combines both, gravity and magnetic field observations for a synergetic use in geophysics. The CHAMP orbit and long-mission status are ideal for resolving temporal gravitational and magnetic field variations. In magnetometry, the observation time will be extended by the Danish Ørsted mission, which preceeds the CHAMP one.

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