GEOFORSCHUNGSZENTRUM POTSDAM
STIFTUNG DES ÖFFENTLICHEN RECHTS

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CHAMP
Phase B
Executive Summary

Scientific Technical Report STR96/13

Impressum

GeoForschungsZentrum Potsdam
Telegrafenberg A17
D-14473 Potsdam

Gedruckt in Potsdam
November 1996

Satellitenmethode
gravimetrisches Feld
Magnetfeld
Atmosphäre
Systembeschreibung

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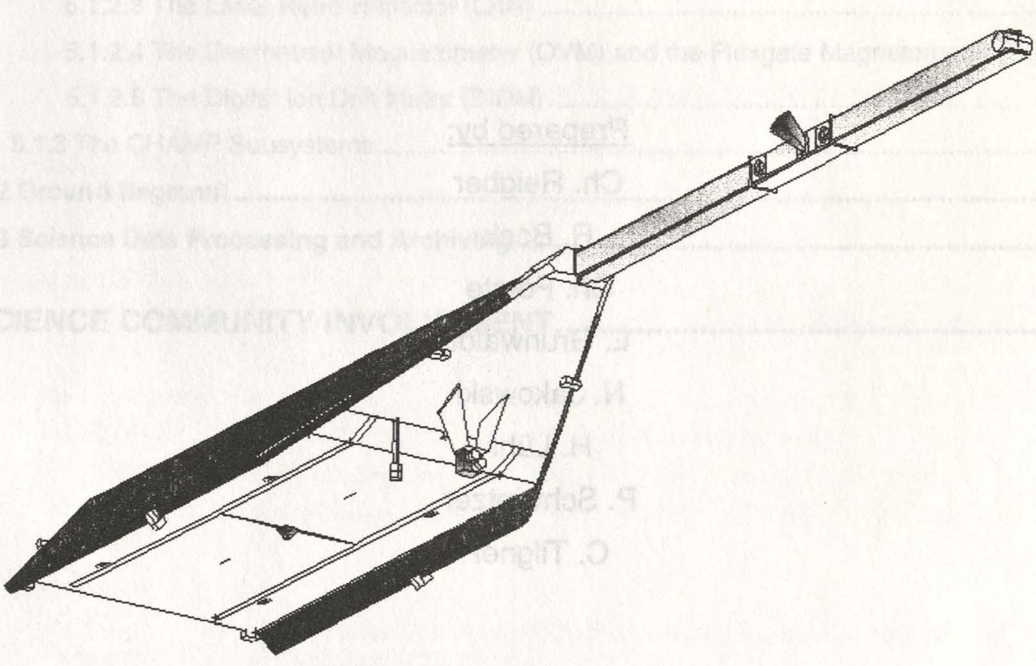

CHAMP

Phase B
Executive Summary

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1. BACKGROUND

The small satellite mission CHAMP was initiated and is primarily funded by the German Space Agency (DARA) as a lead project for the East German space industry. It is defined in its main mission goals by researchers of the GeoForschungsZentrum Potsdam (GFZ), and is conducted under lead of GFZ in cooperation with the German Aerospace Establishment (DLR) and the industry. After completion of an initial feasibility study (Phase A) and of the project's definition/specification phase (Phase B), followed by a two months redesign phase (Phase ΔB), CHAMP is supposed to enter into Phase C/D in late 1996.

CHAMP as a geoscientific mission with a multi-purpose and complementary payload shall substantially contribute to one of the basic research objectives of studies of planet Earth, that is, to the determination of the composition, structure, and dynamics of the solid planet, its oceans and atmosphere, and its surrounding envelope of charged particles and fields.

CHAMP being one element in a timely sequence of Earth observations and platforms, satellites, and mini-satellites could be a contributor to the acquisition of global, synoptic and long-term measurements of global processes through space and ground instrumentation.

CHAMP shall fulfil the criteria of a small satellite mission, i.e., only a few years of development time through the usage of existing sensors and commercial spacecraft subsystem components, and reduced costs through protoflight approach, reduced quality standards and test efforts.

The most challenging parts of the CHAMP mission are the variety of payload components especially the accelerometer and the magnetometers, each one with demanding environmental requirements. It is designed to observe both the gravitational as well as the magnetic potential from one platform in order to get a complementary scientific payback. The GPS-receiver on-board CHAMP being employed for gravity field recovery, simultaneously will perform atmosphere and ionosphere profiling by Earth limb sounding. It is also for the first time a three-axes accelerometer will be flown to measure with a required accuracy of 10^{-8} m/s² the non-gravitational forces, e.g. air drag, perturbing the satellite's motion.

2. THE COURSE OF CHAMP'S PHASE B

Phase B of the CHAMP project was kicked off on 6 November 1995 and started with an intensive Mission Design Update Phase. The outcome of the Update Phase were the baseline mission concept and the baseline satellite configuration which were frozen as the essential working assumptions on 21 November 1995.

The progress of the work on the detailed specifications was reviewed during two meetings in January and March 1996 and the final result, comprised in the central document „Mission and System Requirements Specification", was presented to DARA in April 1996. The „Ground Segment Requirements" and „Science Data Processing and Archiving Requirements" define the satellite and mission operation and science data management part of the CHAMP project. These basic documents are accompanied by „Detailed Payload Specification" documents for each payload component and a „System Description" provided by the industry for the satellite configuration. Following these requirement specifications, requests for quotation were sent out in May 1996 for the launcher and the instruments. The received answers were evaluated as well as the C/D proposal for the satellite prepared by an industrial team under lead of DJO which was received on 22 July 1996. Resulting from the evaluation process, it turned out that the baseline concept had to be changed in some essential parts: COSMOS instead of START-1 launcher and ONERA accelerometer instead of MACEK accelerometer due to CNES' decision to participate in the CHAMP mission by contributing the accelerometer. These changes caused impacts on the orbit and satellite configuration requiring a mission and system redesign including the necessity to reduce the costs for the satellite. The intensive redesign phase (Phase ΔB) started on 2 September 1996 and was completed at the end of October 1996 with the new submission of the industrial C/D proposal and the revision of the documents mentioned above.

In the following, the Phase B+ΔB participating institutes and companies and their responsibilities / contributions are listed:

Project lead, mission engineering, science/application data management:

GFZ - GeoForschungsZentrum Potsdam

supported by:

Mission engineering:

DSS - DASA, Dornier Satellitensysteme GmbH, Friedrichshafen

Payload engineering:

EST - EUROSPACE Technische Entwicklungen GmbH, Flöha

Payload (GPS receiver):

NASA/JPL - NASA, JET Propulsion Laboratory, Pasadena, California, USA

Payload (Magnetometer):

MAGSON - Magnetische Sondierungsgeräte GmbH, Niemegk
TUBS - Technische Universität Braunschweig, Institut für Geophysik
MPE - Max-Planck-Institut für Extraterrestrische Physik, Berlin-Adlershof

Payload (Accelerometer):

TUM - Technische Universität München, Institut für Astronomische und Physikalische Geodäsie

Launch Services:

ART - Ingenieurbüro für Automatisierung und Raumfahrttechnik, Schwerin (START-1 launcher)

OHB - Unternehmensgruppe Fuchs, Bremen (COSMOS launcher)

Satellite Mission Operations, science/application data management:

DLR - Deutsche Forschungsanstalt für Luft- und Raumfahrt, Oberpfaffenhofen, Neustrelitz

Satellite system engineering:

DJO - DASA, Jena-Optronik GmbH, Jena
DSS - DASA, Dornier Satellitensysteme GmbH, Friedrichshafen (Phase ΔB)
EST - EUROSPACE Technische Entwicklungen GmbH, Flöha
FPM - Space Sensor GmbH, Freiberg
RST - DASA, Raumfahrt und Umwelttechnik GmbH, Rostock

3. SCIENTIFIC RATIONALE AND OBJECTIVES

3.1 SCIENTIFIC RATIONALE AND RELATED MISSIONS

CHAMP shall be employed to perform the following three tasks:

- global long- to medium-wavelength Earth gravity field mapping with applications in geophysics, geodesy and oceanography ,
- global Earth magnetic field mapping with applications in geophysics and solar-terrestrial physics, and
- atmosphere/ionosphere sounding with applications in global climate studies, operational weather forecasting, disaster research and navigation.

Global gravity field recovery from observed gravitational satellite orbit perturbations requires global coverage by a near-polar orbit, a low satellite altitude for increased sensitivity and a multi-year mission duration for the resolution of temporal variations due to mass redistributions in atmosphere, hydrosphere, cryosphere and the Earth's interior. Precise continuous tracking and a tool to separate gravitational and non-gravitational (mainly air-drag) orbit perturbations are prerequisites to achieve a major step forward towards precise geoid representation.

Numerical simulations have proven that with CHAMP a long-wavelength ($\lambda/2$ = 550 km) geoid model could be realised with an accuracy of one decimetre which is an improvement of one order of magnitude compared to present-day geoid representations. By this, and supported by CHAMP's magnetic field component, detailed mantle convection and core-mantle boundary studies will be largely enhanced, and the geoid can be employed in oceanography as a reference surface for the reduction of altimeter data to study geostrophic ocean currents and sea level changes.

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

The principal goal to be achieved with CHAMP's magnetic field mission component is the recovery of the Earth's main field and its secular variation to understand the functioning of the geodynamo. Observing induced electric currents in the Earth mantle and remnant crustal magnetisation will allow to study the Earth interior and geotectonics. By this, the gravitational and magnetic field components of CHAMP are to a large extent complementary. On the other hand, probing the electric and magnetic field of the Earth magnetosphere strongly supports the atmosphere/ ionosphere applications of the CHAMP mission.

For atmosphere/ionosphere investigations the quite new method of radio occultation measurements by limb-sounding between the low-flying CHAMP satellite and the high-flying GPS spacecraft (Figure 3-2) shall be applied to get a huge amount of vertical temperature, pressure and water vapour profiles along the neutral atmosphere. With global warming due to a CO_2 increase, the atmosphere would expand leading to pressure changes, to a predicted temperature increase in the troposphere and decrease in the stratosphere. As these effects could well be monitored applying the GPS occultation technique, global and regional climate changes could be detected. The huge amount of readily available atmospheric temperature and pressure profile data in addition is a valuable data set to augment the initial conditions of numerical global and regional weather prediction computations. Additional atmospheric state parameters shall be gained by employing in an experiment two-colour laser ranging.

Travel time differences between the two-frequency ranging signals allow to resolve the electron density of the ionosphere resulting, if combined with ground-based measurements, in a tomographic reconstruction of the ionosphere actual state. By this, Travelling Ionospheric Disturbances (TIDs) or gravity waves due to seismo-volcanic and atmospheric events are going to be resolved. For ionospheric sounding by radio occultation a higher orbit outside the ionosphere would be the optimum.

Dedicated satellite gravity field missions are discussed and studied since many years in the European, French and American space agencies and scientific institutions. The only one having a chance for a

Phase A study presently is the GOCE mission within ESA's Earth Explorer Mission Program where GOCE is one of eight candidates for Phase A selection. The anticipated launch dates are around the 2002 to 2005 time frame. With CHAMP having a different orbit and by this a different orbit perturbation spectrum, both missions would strongly benefit from each other as the long wavelength gravity field constituents to be recovered could be better decorrelated and systematic perturbation effects inherent with each mission would show a different behaviour. CHAMP also would provide a reliable, most accurate long wavelength gravity field model as a basis for the GOCE gradiometer measurements addressing the medium to high frequency gravity field constituents.

The Danish ØRSTED magnetometer satellite mission planned for launch in autumn 1997 with an active lifetime of at least 14 months will strongly enhance the scientific value of the magnetometer part of the CHAMP mission due to the enlargement of the time basis for recovering the secular change and for separating periodic and irregular temporal variations in the Earth magnetic field.

Valuable experiences and experimental data are going to be gained with NASA's GPS-MET mission for preparing and exploiting the atmosphere/ionosphere part of the CHAMP mission. GPS-MET, launched in April 1995, employs for the first time GPS satellite-to-satellite tracking for neutral atmosphere sounding by radio occultation measurements down to the limb of the Earth, the same scenario foreseen with CHAMP. As the satellite's altitude is close to 800 km, GPS-MET is not designed for global gravity field model improvement. Within the above mentioned ESA's Earth Explorer Mission Program there is an atmospheric limb sounding mission being one candidate for selection with an on-board GPS/GLONASS receiver presently being under development for ESA using in addition to GPS the signals from the Russian GLONASS navigation system.

3.2 SCIENTIFIC OBJECTIVES

3.2.1 Gravity

Global models of the gravity field at the surface of the Earth are derived from observed gravitational satellite orbit perturbations. Due to insufficient data coverage and non-optimised orbit configurations, tracking data from three dozens of satellites have to be merged together to get a state-of-the-art global gravity field model from satellite tracking only. Satellite only models represent, due to the attenuation of the signal at orbit altitude, the broad structure of the global field. Adding terrestrial gravity measurements and altimetry data over the oceans allows to resolve within this given frame the smaller signatures of the Earth's gravity field (combined gravity models). Thanks to its dedicated orbit design, an unpreceded low altitude in a (near-) polar orbit, and its continuous GPS satellite-to-satellite tracking capability together with a direct on-board measurement of the non-gravitational orbit perturbations, improvement of one order of magnitude in accuracy shall be achieved with CHAMP in the recovery of the coarse structures of the Earth gravity field. This tremendous breakthrough will open new insights and application areas in geodesy, solid Earth physics and oceanography.

In geodesy, the geoid, the special surface of equal gravitational potential close to sea level, up to a spatial resolution of about 650 km half-wavelength would become available with nearly perfect accuracy which then will serve as an ideal reference for higher resolution global or regional gravity field modelling. Perfect accuracy also means that temporal changes in the gravitational field due to global mass redistributions, which are in general small, slow and large scaled, can be recovered with high reliability and an increased spectral resolution. By this, a discrimination between various signal sources becomes possible, provided that the mission duration of CHAMP will last several years. The most interesting temporal gravity variations causing a global signature result from atmospheric mass redistributions, sea level changes due to ice melting and the elastic response of the Earth's lithosphere. Gravity field variations always reflect the mass effect of water volume changes opposite to tide gauge or altimetry which measure a combined mass and density (due to temperature changes) effect. A combination of the various monitoring techniques will allow the separation of the global temperature effect in water volume change (Figure 3-1).

In geophysics the observed irregularities in the gravity field constrain Earth models obtained from observed seismic velocities. Seismic tomography models of the Earth interior now approach resolutions corresponding to wavelengths of about 2000 km. To verify and to discriminate among seismic models, gravity at long-wavelength should be known to a homogeneous accuracy of 1 % of its signal which is one order of magnitude more than what presently can be achieved. Such an improvement will strongly enhance studies concerning the structure and static/dynamic mass compensation at the core-mantle boundary and the upper mantle discontinuities, and the conversion of seismic velocities into density values to model lateral density variations in the Earth's interior. This is to address the still unsolved question whether mantle convection takes place in a single, double layered or a mixed system. This will have a large impact on recent models of the driving forces of plate tectonics and on the recycling of oceanic lithosphere to the interior. Besides seismic velocities and gravity, the magnetic field outside the Earth is a direct observable originating from the Earth interior. The evaluation of all three kinds of signals will allow a complete and integrated modelling of the structure and dynamics of the Earth core and mantle generating the gravitational and magnetic long wavelength signals to be observed by CHAMP (Figure 3-1).

The most stringent requirement concerning accuracy and resolution of global Earth gravity field models comes from oceanography. Whereas altimetry monitors the ocean surface with cm-accuracy, the geoid is only known to an accuracy of 1 m. The geometric difference between ocean surface and geoid, the sea surface topography, is however the essential information, to derive directly the absolute mean ocean circulation pattern and the hydrostatic pressure field, respectively. The absolute ocean circulation reflects the currents down to large depths. The knowledge of the absolute ocean circulation with its heat and CO_2 transportation is a prerequisite for global climate models and the interpretation of long-term sea level changes. With CHAMP the resolution of a 10 cm-geoid will be increased from presently 4000 km to about 1000 km full wavelength.

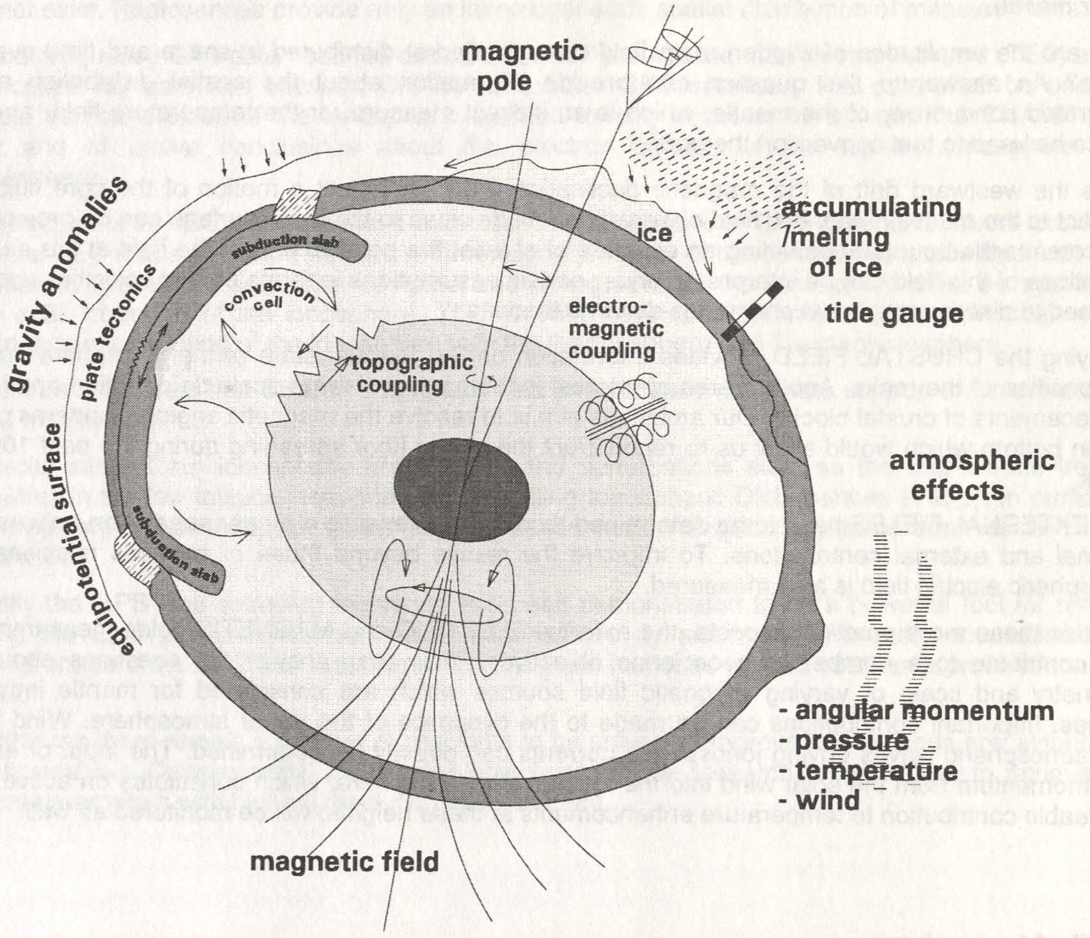


Figure 3-1 Dynamics of the Earth generating the Gravity and Magnetic Field

3.2.2 Magnetic Field

Global measurements of the magnetic field provide much more than just a mapping of the field distribution. By separating the observations into their source terms, it is possible to obtain information about the structure and dynamics of the source. In that respect magnetic field surveys can be regarded as remote sensing missions.

The magnetic fields measured in a low Earth orbit comprise contributions from three sources:

- from the geodynamo in the Earth core (MAIN FIELD),
- form the magnetic rocks and sediments in the crust (CRUSTAL FIELDS), and
- from electric currents flowing in the ionosphere and magnetosphere (EXTERNAL FIELDS).

The validity of the results deduced from magnetic field data depends to a good fraction on the quality of the source separation.

A number of questions concerning the dynamics and structure of the Earth interior can be addressed when studying the MAIN FIELD (Figure 3-1).

Are there magnetic signatures in the secular variations that can be related to the polar motion (e.g. Chandler Wobble) or length-of-day (LOD) variations? A positive result would suggest a differential motion between the inner core and the mantle. Phase relations give hints about the conductivity of the lower mantle.

How are the amplitudes of sudden main field changes (jerks) distributed in space and time over the globe? An answer to this question can provide information about the spatial distribution of the integrated conductivity of the mantle, which is an indirect measure for the temperature field and can hence be used to test convection theories.

Does the westward drift of the magnetic declination (~0.1°/a) reflect a motion of the core fluid with respect to the mantle? Magnetic field observations made close to the Earth surface can be projected to the core/mantle boundary providing an estimate of at least the poloidal part of the field at this surface. Variations of this field can be interpreted under certain assumptions in terms of fluid velocities and may be used to discriminate between various dynamo theories.

Studying the CRUSTAL FIELD provides information on the thermal state of the lithosphere and the composition of the rocks. Another area of interest is the tracing of large-scale deformation and lateral displacements of crustal blocks. Our ambitious aim is to resolve the magnetic anomaly patterns on the ocean bottom which would allow us to reconstruct the ocean floor spreading during the past 100 Mil. years.

The EXTERNAL FIELDS have to be determined thoroughly to ensure a proper separation between the internal and external contributions. To improve the results beyond those of previous missions, the ionospheric electric field is also measured.

Besides these more practical aspects, the external ELECTRIC and MAGNETIC fields measurements can contribute to a number of geoscience objectives. They may answer the questions about the geometry and scale of varying magnetic field sources which are considered for mantle induction studies. Important contributions can be made to the dynamics of the upper atmosphere. Wind fields and atmospheric waves driving ionospheric currents can directly be determined. The input of energy and momentum from the solar wind into the ionosphere/atmosphere, which constitutes on active days a sizeable contribution to temperature enhancements at these heights, will be monitored as well.

3.2.3 Atmosphere

The Atmospheric/Ionospheric Profiling (AIP) experiment onboard CHAMP provides data which can be used in several fields of scientific applications. Principal objectives are related to ionospheric and to atmospheric research with essential contributions to weather analysis and global change research. Principally the AIP data contribute to our understanding of the thermal structure of the atmosphere from the Earth surface up to the mesosphere and of how troposphere, stratosphere and mesosphere interact (Figure 3-3).

Compared with other remote sensing techniques based on microwave and IR sounding the radio occultation measurements of GPS L-band signals are not affected by atmospheric absorption lines and particle scattering. Furthermore, radio occultation provides a self-calibrating measuring system usable as an absolute standard and / or calibration system for other temperature monitoring systems ranging from Earth surface up to about 60 km altitude.

Considering the vertical resolution (≤ 1km), the accuracy of retrieved temperatures (≤ 1 K in the troposphere and stratosphere), and the global coverage of measurements, the radio occultation technique is well suited for global temperature monitoring in climatology studies to monitor long-term trends. Since there is much uncertainty about the magnitude and related processes of global change, the CHAMP limb sounding observations can help to understand climate and global change issues. To detect global warming trends due to an increase of greenhouse gases from anthropogenic sources, the global mean temperature has to be separated from natural variability effects.

Especially at high latitudes stratospheric temperatures play a critical role to ozone depletion. The CHAMP limb sounding data can improve our understanding of the formation and dissipation of polar stratospheric clouds which are closely related to the chemistry of ozone loss in the stratosphere.

Climate change is expected to be associated not only with temperature change but also with an increase of water vapour which is a greenhouse gas too.

Since the measured refractivity is a function of both temperature and moisture, the refractivity could be a useful measure of long-term changes and trends in the global atmosphere. Although water vapour plays a fundamental role in weather and climate, an adequate climatology of atmospheric water vapour does not exist. Radiosondes provide only an inhomogeneous spatial distribution of measurements.

The dual frequency GPS data obtained onboard CHAMP provide the total electron content (TEC) along the occulted ray path and between CHAMP and other GPS satellites. The data shall be used to compute vertical profiles of the ionospheric electron density between 60 km and the CHAMP orbit height and to derive conclusions about the electron content of the topside ionosphere and plasmasphere.

In conjunction with TEC measurements obtained from a network of GPS ground receivers providing horizontal TEC maps, a comprehensive 4-dimensional analysis of the ionosphere is possible with high resolution in space and time. The computerised tomography of the ionosphere shall be applied to derive a 3D-structure of the ionosphere. This recently developed technique offers new chances to explore dynamic coupling of the ionosphere with the thermosphere and the magnetosphere.

It should be mentioned that CHAMP's magnetic field and accelerometer data support the interpretation of TEC measurements.

Of special interest are ionospheric irregularities and perturbations such as the mid-latitude trough, instabilities in the low latitude ionosphere or Travelling Ionospheric Disturbances (TID's). In particular such irregularities can seriously affect satellite based radio navigation systems such as GPS and GLONASS.

Recently the GPS limb sounding technique has been demonstrated to be a powerful tool for remote sensing the Earth's neutral atmosphere and ionosphere by analysing GPS radio occultation data obtained onboard the GPS/MET satellite which has been launched in April 1995 as a proof-of-concept satellite.

Nevertheless there remain a number of problems to be solved to improve the methods and algorithms for data analysis. Consequently, the mission objectives include research activities how to retrieve the different parameters with highest resolution and accuracy.

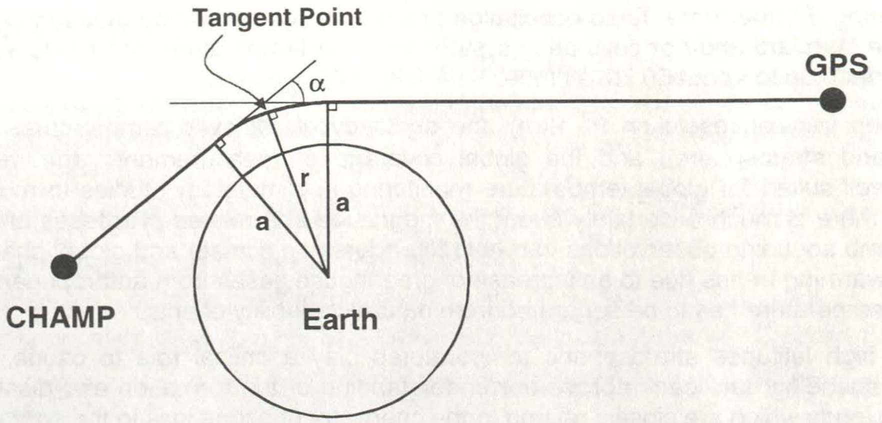


Figure 3-2 Occultation Geometry

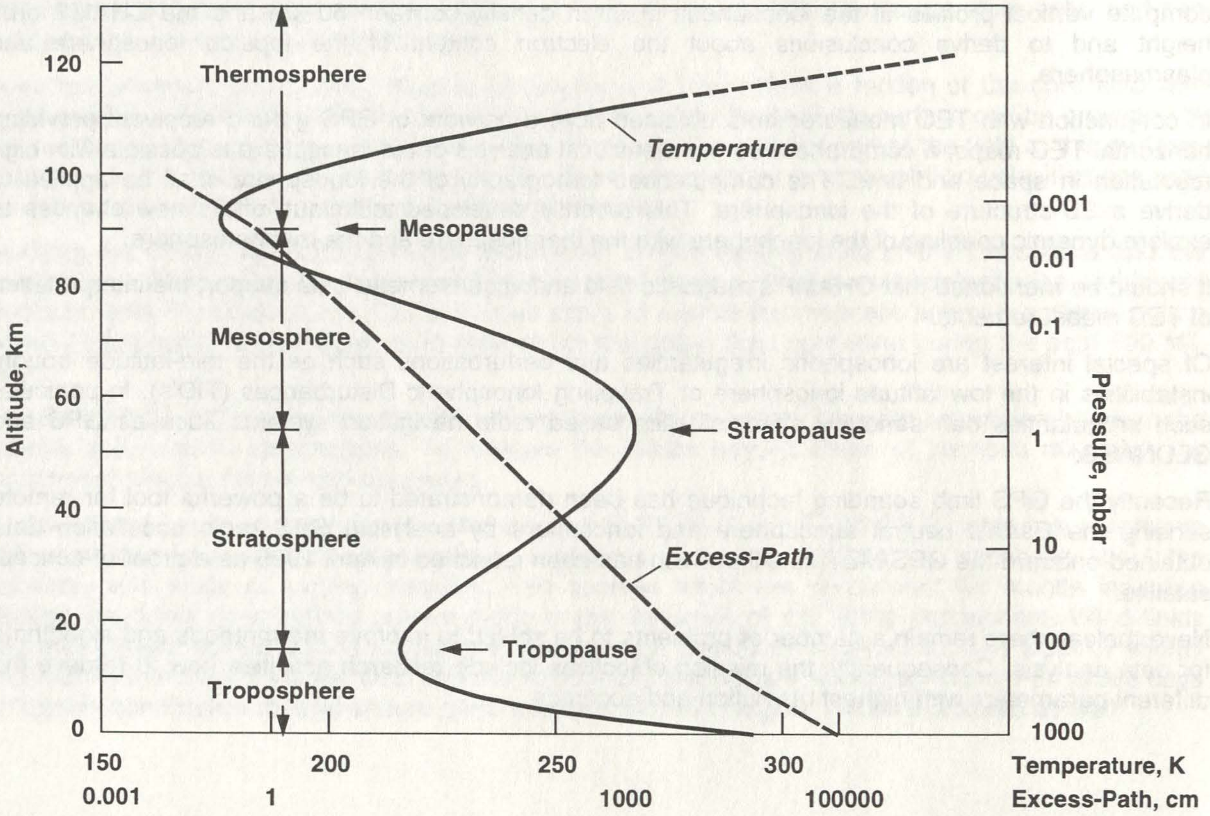


Figure 3-3 Temperature and Excess-Path in the Standard Atmosphere

3.3 POTENTIAL APPLICATIONS

Gravity Field

The geoid constitutes the surface which is most commonly known as 'sea level' in land surveying. Topographic heights are related to the geoid: heights above 'sea level'. Modern satellite positioning systems, like the American GPS, measure point heights which are related to a geometric surface, the ellipsoid. In order to transform ellipsoidal heights to topographic heights, the geoid undulations have to be subtracted. To compete with the high GPS measurement accuracy, which is at cm-level, the geoid has to be known with the same accuracy. Then, effective GPS-levelling could replace the man-power intensive geometric levelling in surveying.

With CHAMP, only the broad signatures of the geoid will be recoverable with an unpreceded accuracy, i.e. the CHAMP derived global geoid will serve as an ideal basis for a further refinement in regional and local areas evaluating existing or dedicated high resolution gravity information for a detailed geoid computation. The long-wavelength geoid will also give a reference for a unified global height system, being important when employing modern satellite surveying methods and constructing digital terrain models covering large areas.

Any progress in the accuracy and completeness of long-wavelength gravity field models will also directly improve the reliability and accuracy of precise satellite orbit restitution as required in satellite altimetry and SAR-interferometry.

Magnetic Field

The prime product of the magnetic survey will be an improved global magnetic field model (e.g. IGRF). Magnetic field models are nowadays among the most widely used geophysical models. Because of their quality they are implemented in navigation systems of aircraft, ship and satellites at least for redundancy purposes.

Of paramount importance are these models for exploration techniques. For example drilling heads for boreholes are given nowadays directions significantly differing from vertical. The comparison between measured magnetic fields close to the head and the model determines the steering action needed to achieve the desired direction. Similarly, for sea seismic surveys the orientation of the vector geophones is determined with respect to the magnetic reference frame.

In space applications, magnetic field models are needed in satellites using magneto torquers for manoeuvring. Also the prediction of radiation belts and the assessment of cosmic ray particle orbits, hence the safety of spacecraft and crews, rely on the quality of the models. Due to the continuous and unpredictable change of the magnetic field, global mappings have to be repeated every decade to assure the necessary quality of the models.

Crustal magnetic field studies will provide, along with the results of gravity anomalies, important inputs for mineral resource assessments.

A continuous monitoring of the external electric and magnetic fields is an important contribution to the presently starting Space Weather Prediction initiative. Suitable activity indices will be generated and made available with short delays.

Atmosphere / Ionosphere

Providing temperature and / or water vapour profiles, the GPS limb sounding measurements onboard CHAMP have the potential to enhance the analysis and prediction of weather. The measurements carried out with high vertical resolution and accuracy contribute to a better observational coverage of temperature and moisture data over both oceans and land areas. So the data could improve operational weather forecasting by providing better weather forecast models and by providing an extended atmospheric data base.

Due to the global coverage of the measurements valuable data for global ionospheric models may be derived for high solar activity conditions. Such models are of interest in ionospheric research but are also used for applications in different fields such as satellite tracking, navigation, geodesy, radio astronomy.

4. MISSION DESCRIPTION

The launch of the CHAMP satellite is planned for mid 1999 with a Russian COSMOS launch vehicle. The satellite will have an overall mass of about 400 kg including about 25 kg of payload mass.

Its power consumption amounts to about 140 W (45 W payload). The satellite will be Earth-pointing and three-axes stabilised by a cold gas propulsion system supported by three magnetic torquers. Two star sensor pairs provide the attitude knowledge required by the accelerometer (±0.045°) and the vector magnetometers (±0.003°). The spacecraft configuration consists of a trapezoid shaped body of rough dimensions LxHxW 4.0 x 1.0 x 1.6 (base) 0.3 (top) m^3, a deployable boom of 4m length in flight direction, a body mounted $6m^2$ solar generator surface and an inclined surface at the rear side for limb sounding antenna accommodation (c.f. Figure 5-1).

The characteristic orbit parameters are near-polar (i = 83°), initial altitude of 470 km, and circular. The active lifetime is designed to last 5 years.

The rationale to choose an almost circular and near-polar orbit is because of the advantage to get a homogeneous and complete global coverage of the Earth's sphere with orbit and magnetometer measurements, being important to resolve the gravitational and magnetic geopotentials. An advantage of the 83° orbit vs. a dawn-dusk sun-synchronous orbit is the local time variation of the satellite's ground track which is essential for all three scientific applications in order to enable the separation of constituents of periodic phenomena like tides and day-night variations.

The mission should last 5 years in order to provide a sufficiently long observation time to resolve long-term temporal variations primarily in the magnetic field (secular variation of the main field), in the gravity field (e.g. rate in dynamic flattening of the Earth due to post-glacial uplift and sea level changes) and within the atmosphere (e.g. temperature).

An initial altitude of 470 km is chosen (a) in order to guarantee a multi-year mission duration even under severe solar activity conditions, (b) to account for the requirement by the atmosphere/ionosphere application to look from the outside through the different atmospheric layers, i.e. an even higher altitude would be the optimum, and (c) because 470 km is the adequate altitude to observe the Earth's magnetic main field. From the gravity field's point of view an even lower initial altitude could be desirable.

Due to atmospheric drag the altitude will decrease over the 5 years mission duration. As CHAMP will pass through the solar activity maximum in 2001, the predicted natural decay depends on the magnitude of the actual solar activity cycle and may amount to more than 200 km or only 50 km. Therefore Δv-manoeuvres by thruster firing with remaining cold gas are foreseen, correcting for orbit injection errors and rising or lowering the orbit to provide some months of observation time below 300 km altitude towards the end of the mission (c.f. Figure 4-1).

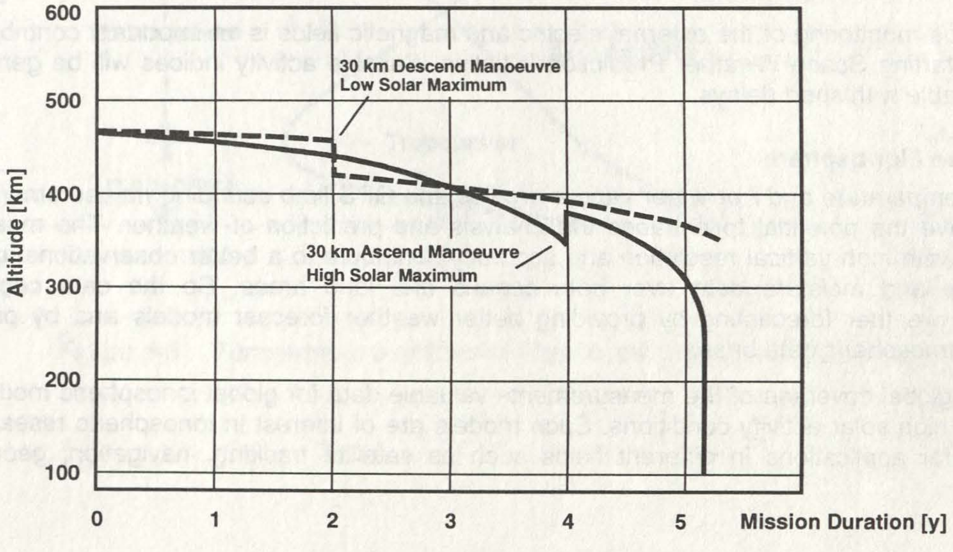


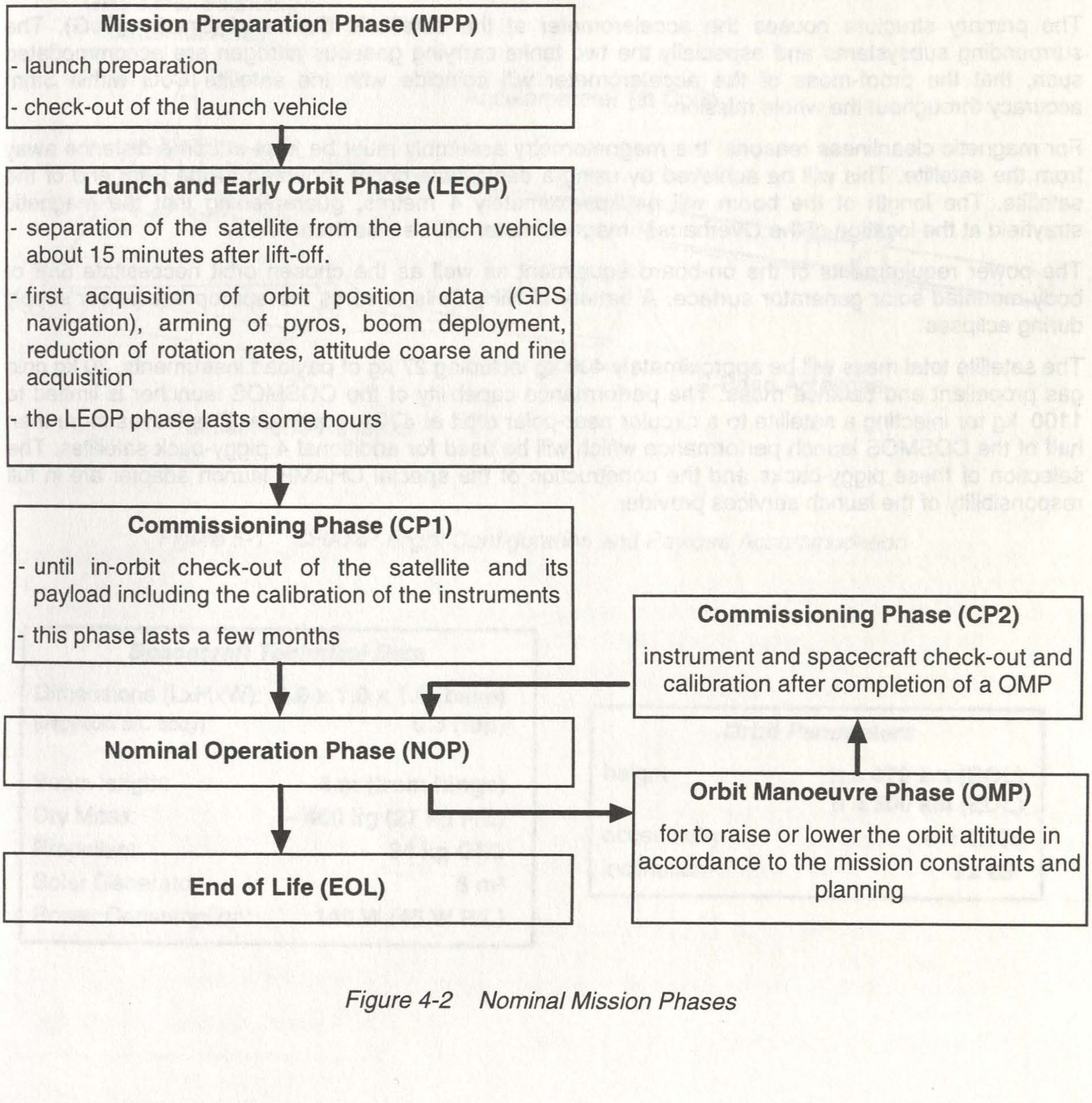
Figure 4-1 Orbit Change Manoeuvres depending on solar activity

To achieve the above given scientific goals and target applications the following payload components are foreseen:

- 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,
- a three-axes accelerometer at the spacecraft's centre of gravity to measure directly the non-gravitational orbit perturbations, rigidly connected to two star sensors for precise inertial orientation information
- a laser retro-reflector array for additional laser tracking from ground,
- a magnetometer instrument package consisting of an Overhauser scalar magnetometer and two Fluxgate vector magnetometers, rigidly connected on an optical bench together with two star sensors to provide highly accurate inertial orientation information, all accommodated on a 4m long boom pointing in CHAMP's flight direction
- a digital ion drift meter to measure the electrical field along the orbit

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

Figure 4-2 defines the mission phases from an operational point of view.



Mission Preparation Phase (MPP)

- launch preparation
- check-out of the launch vehicle

Launch and Early Orbit Phase (LEOP)

- separation of the satellite from the launch vehicle about 15 minutes after lift-off.
- first acquisition of orbit position data (GPS navigation), arming of pyros, boom deployment, reduction of rotation rates, attitude coarse and fine acquisition
- the LEOP phase lasts some hours

Commissioning Phase (CP1)

- until in-orbit check-out of the satellite and its payload including the calibration of the instruments
- this phase lasts a few months

Commissioning Phase (CP2)

instrument and spacecraft check-out and calibration after completion of a OMP

Nominal Operation Phase (NOP)

Orbit Manoeuvre Phase (OMP)

for to raise or lower the orbit altitude in accordance to the mission constraints and planning

End of Life (EOL)

Figure 4-2 Nominal Mission Phases

5. DESCRIPTION OF THE SYSTEM

The CHAMP system consists of the space segment, i.e. the satellite with its payload and subsystems, the dedicated ground segment as well as the launcher vehicle which injects CHAMP into its planned orbit.

This chapter describes the CHAMP system according to the Phase B baseline concept fixed in November 1995 and the specifications worked out until October 1996. Due to the new launcher selection in July 1996, the satellite had to be redesigned during a Phase ΔB.

5.1 SPACE SEGMENT

Main aspects that essentially determine the satellite design are the mission requirements, the instruments performance, the in-orbit environment, the launcher interface and the overall costs.

5.1.1 The CHAMP Satellite

The satellite primary structure is of a trapezoid shaped body with rough dimensions LxHxW 4.0 x 1.0 x 1.6 (base) 0.3 (top) m^3. A boom, that accommodates the magnetometry assembly will be deployed during the early orbit phase. Figure 5-1 depicts CHAMP in its deployed flight configuration.

The primary structure houses the accelerometer at the satellite's Centre of Gravity (CoG). The surrounding subsystems and especially the two tanks carrying gaseous nitrogen are accommodated such, that the proof-mass of the accelerometer will coincide with the satellite CoG within 5mm accuracy throughout the whole mission.

For magnetic cleanliness reasons, the magnetometry assembly must be kept at some distance away from the satellite. This will be achieved by using a deployable boom mounted at the front end of the satellite. The length of the boom will be approximately 4 metres, guaranteeing that the magnetic strayfield at the location of the Overhauser magnetometer will be less than 1 nT.

The power requirements of the on-board equipment as well as the chosen orbit necessitate $6m^2$ of body mounted solar generator surface. A battery of NiH_2-Cells ensures the appropriate power supply during eclipses.

The satellite total mass will be approximately 400 kg including 27 kg of payload instruments, 30 kg cold gas propellant and balance mass. The performance capability of the COSMOS launcher is limited to 1100 kg for injecting a satellite to a circular near-polar orbit at 470 km altitude. This leaves more than half of the COSMOS launch performance which will be used for additional 4 piggy-back satellites. The selection of these piggy-backs and the construction of the special CHAMP launch adapter are in full responsibility of the launch services provider.

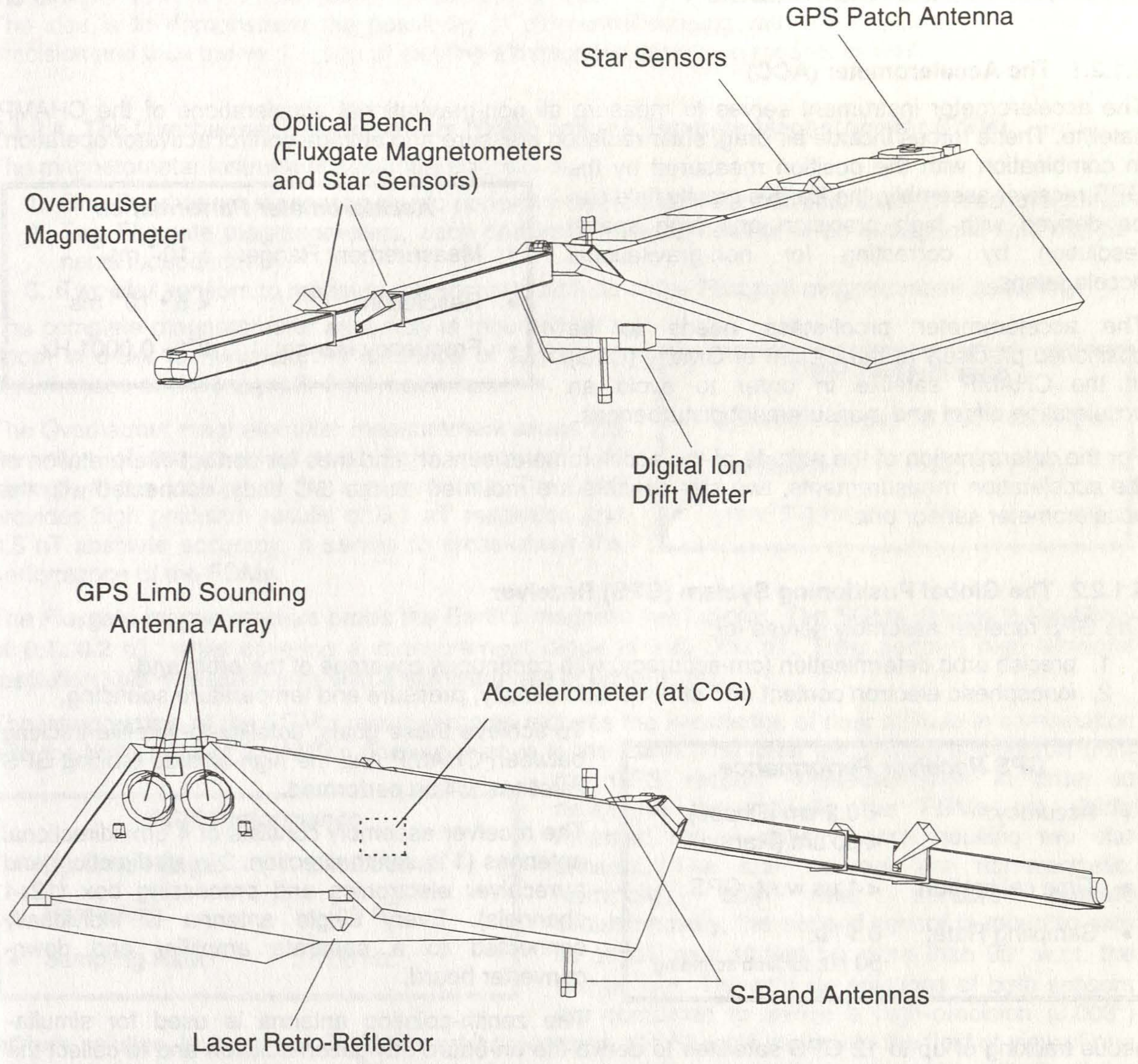


Figure 5-1 CHAMP Flight Configuration and Payload Accommodation

Spacecraft Technical Data	
Dimensions (LxHxW): (trapezoid S/C body)	**4.0 x 1.0 x 1.6 (base)** **0.3 (top)**
Boom length:	**4 m (from hinge)**
Dry Mass:	**~ 400 kg (27 kg P/L)**
Propellant:	**34 kg GN2**
Solar Generator:	**6 m²**
Power Consumption:	**140 W (45 W P/L)**

Orbit Parameters	
height	**h = 470 km (BOL)** **h = 300 km (EOL)**
eccentricity	**e < 0.005**
inclination	**i = 83°**

5.1.2 The CHAMP Instruments

5.1.2.1 The Accelerometer (ACC)

The accelerometer instrument serves to measure all non-gravitational accelerations of the CHAMP satellite. These forces include air drag, solar radiation pressure and attitude control activator operation. In combination with the position measured by the GPS receiver assembly, the Earth's gravity field can be derived with high precision and high spatial resolution by correcting for non-gravitational accelerations.

The accelerometer proof-mass needs to be positioned precisely at the Centre of Gravity (CoG) of the CHAMP satellite in order to avoid an acceleration offset and measurement disturbances.

Accelerometer Performance

- Measurement Range: $\pm 10^{-4}$ ms^{-2}
- Resolution: $< 5 \bullet 10^{-9}$ ms^{-2}
- Frequency Range: 0.1 - 0.0001 Hz

For the determination of the attitude of the accelerometer sensor, and thus for correct interpretation of the acceleration measurements, two star sensors are mounted on the S/C body, connected with the accelerometer sensor unit.

5.1.2.2 The Global Positioning System (GPS) Receiver

The GPS receiver assembly serves for:

1. precise orbit determination (cm-accuracy) with continuous coverage of the orbit; and
2. ionospheric electron content and atmospheric density, pressure and temperature sounding.

GPS Receiver Performance

- Accuracy: < 0.2 cm (Phase)
  < 30 cm (Range)
- Time calibration: < 1 μs w.r.t. GPS
- Sampling Rate: 0.1 Hz
  50 Hz for limb sounding

To achieve these goals, satellite-to-satellite tracking between CHAMP and the high-altitude orbiting GPS satellites will be performed.

The receiver assembly consists of 4 omnidirectional antennas (1 in zenith direction, 3 in aft direction) and a receiver electronics and processing box (12+4 channels). Every single antenna is individually connected to a separate amplifier and down-converter board.

The zenith-pointing antenna is used for simultaneous tracking of up to 12 GPS satellites to derive the on-board navigation solution and to collect the tracking data for on-ground precise orbit restitution. The complete navigation solution includes position, velocity and time mark, in addition to the carrier phases and pseudoranges from the GPS satellites tracked.

The aft antennas are Earth-limb pointing. Usually one GPS satellite will be tracked in setting phase during occultation by the Earth's atmosphere, while a non-occulted GPS satellite will be tracked in parallel. This allows to derive ionospheric and atmospheric parameters by measuring propagation delays of the two different carrier phases transmitted by each GPS satellite.

The GPS receiver assembly is fully autonomous: initialisation, GPS satellites acquisition and signal processing are performed automatically once the instrument is switched on.

5.1.2.3 The Laser Retro Reflector (LRR)

The laser retro reflector is a simple passive payload instrument consisting of 4 prisms to reflect short laser pulses back to the transmitting ground station. This enables to measure the direct two-way range between ground station and satellite with an accuracy of 1...2 cm without any ambiguities. These data will be used for:

1. precise orbit determination in connection with GPS for gravity field recovery,
2. calibration of the on-board microwave orbit determination system (GPS),
3. technological experiments (two-colour ranging).

LRR Performance

- Passive Instrument
- Ranging Accuracy: < 10 mm

Besides its usual purpose for precise orbit determination and calibration of the on-board GPS receiver, the CHAMP LRR is an ideal target for two-colour laser ranging stations presently under construction. The idea is to demonstrate the possibility of differential ranging with a few millimetres single-shot precision and thus the verification of existing atmospheric correction models as well.

5.1.2.4 The Overhauser Magnetometer (OVM) and the Fluxgate Magnetometer (FGM)

The magnetometer instrument assembly consists of:

1. One Overhauser magnetometer to perform total (scalar) magnetic field strength measurements.
2. Two Fluxgate magnetometers, each performing measurements of all 3 magnetic field components independently.
3. Two star sensors to measure the accurate attitude of the Fluxgate magnetometer assembly.

The complete magnetometer assembly is mounted on a boom in order to minimise the influence of spacecraft disturbances on the magnetic field measurements.

The Overhauser magnetometer measurement allows the derivation of the absolute total Earth magnetic field strength at the location of the measurement. The OVM provides high precision results of 0.1 nT resolution and 0.5 nT absolute accuracy. It serves to cross-check the performance of the FGMs.

OVM Performance

- Dynamic Range: 18.000 - 65.000 nT
- Resolution: < 0.5 nT (abs.)
- Sampling Rate: 1 Hz

The Fluxgate magnetometers probe the Earth's magnetic field vector. The FGMs provide a sensitivity of 0.1...0.2 nT, while covering a measurement range of ±65 000 nT. They perform high temporal resolution field measurements with a sampling rate of up to 50 Hz.

The interpretation of the FGM's measurements requires the knowledge of their attitude in combination with the knowledge of CHAMP's position relative to the Earth. The latter information is available from the GPS receiver measurements. In order to determine the attitude, the FGMs are rigidly mounted on an optical bench housing two star sensors. The star sensors are non-magnetic. Nominally, both star sensors operate simultaneously, the second sensor is mounted with its optical axis shifted by more than 90° w.r.t. the first sensor. The attitude solutions of both sensors are combined to derive a high-precision (0.003°) attitude solution. In course of CHAMP's orbit precession, the Sun will move into the field of view of one of the star sensors; in this case the second star sensor will proceed to measure the attitude of the satellite.

FGM Performance

- Dynamic Range: ± 65.000 nT
- Resolution: < 0.5 nT
- Sampling Rate: ≤ 50 Hz

5.1.2.5 The Digital Ion Drift Meter (DIDM)

The DIDM primarily measures the drift velocity of the ambient ions. This velocity is the sum of the spacecraft velocity and the ion drift. Electric fields can be estimated using the v x B-relation. Both quantities, the spacecraft velocity and the ambient magnetic field are known with high precision. The DIDM will furthermore repeatedly determine the ion density and temperature.

DIDM Performance

- Ion velocity: 0 -8 km/s
- Electric Field: 0 - 300 mV/m
- Resolution: < 5 mV/m
- Ion density: 10^{8} - 10^{12} ions/m^3

5.1.3 The CHAMP Subsystems

The Attitude and Orbit Control Subsystem (AOCS) employs a cold gas propulsion system for attitude and orbit change manoeuvres. A set of three magnetic torquers for pre-compensation of environmental disturbances will support the cold gas propulsion system comprising 16 thrusters. Task is to control the orientation and angular rates within a deadband of ±2° and ±0.1°/s. Star Sensors, Sun Sensors, GPS and Fluxgate magnetometer will be used for the exact measurement of the attitude and the calculation of the angular rates.

The Thermal Control Subsystem (TCS) guarantees a secure temperature for all instruments and subsystems during all possible space environment conditions. To achieve this, primarily paint with small α/ε-values (absorptivity/emissivity), solar cells, Second Surface Mirrors (SSMs) and Multilayer Insulation (MLI) will serve for passive thermal control. For critical spots with high demands on temperature stability, active thermal control will be pursued by means of heaters.

Power generation, conditioning, distribution and storage will be the tasks of the power subsystem. Therefore approximately 6 m^2 of solar cell surface, a combined Power Control and Distribution Unit (PCDU) as well as a NiCd-battery consisting of 21 cells are planned.

The On-Board Data Handling (OBDH) Subsystem will manage all scientific and Housekeeping (H/K) data. In addition, it has limited autonomous capability of Failure Detection, Isolation and Recovery (FDIR) occurring during data handling. Since most instruments provide scientific as well as H/K-data, the AOCS data handling and software will be integrated into the OBDH. The OBDH will accept a 1 Hz time reference pulse derived from the GPS signal and distribute it to all instruments and attitude sensors. Additionally a clock, synchronised to the GPS 0.1 Hz refresh pulse, will maintain the pulse in case of a missing GPS synchronisation. A Mass Memory Unit (MMU) of 1 Gbit capacity will store all data arising in between ground contacts, dumping them when CHAMP is visible from its dedicated ground stations.

Telecommunication will be accomplished by means of the Telemetry, Tracking and Command (TT&C) Subsystem in S-band. This subsystem consists of a receiver, a transmitter, an encoding/decoding device and two antennas with complementary semi-spherical radiation patterns (one primarily for LEOP and another for nominal operation). All components will be purchased from experienced manufacturers to avoid long development times. CHAMP will be operated via the DLR-GSOC ground station at Weilheim (Germany), while data reception will be done at the DLR ground station located in Neustrelitz (Germany).

5.2 GROUND SEGMENT

The tasks of the ground segment are

- operation of the satellite including its payload,
- Acquisition of the telemetry data and processing of the level 0 products,
- Management of the whole CHAMP system (ground and space segment), and
- Provision of the level 0 products to the processing and archiving facilities of the experimenters (Prime Investigators).

Except for Mission Management & Control one organisation shall be responsible for all ground segment functions: the Mission Operation System. The routine tasks of the telemetry data processing, including raw data archiving and science data provision are within the responsibility of the subsystem the so-called Raw Data Centre.

The Functions of CHAMP's ground segment, which does not include science data processing and archiving for levels higher than level 0, are shown in Figure 5-2.

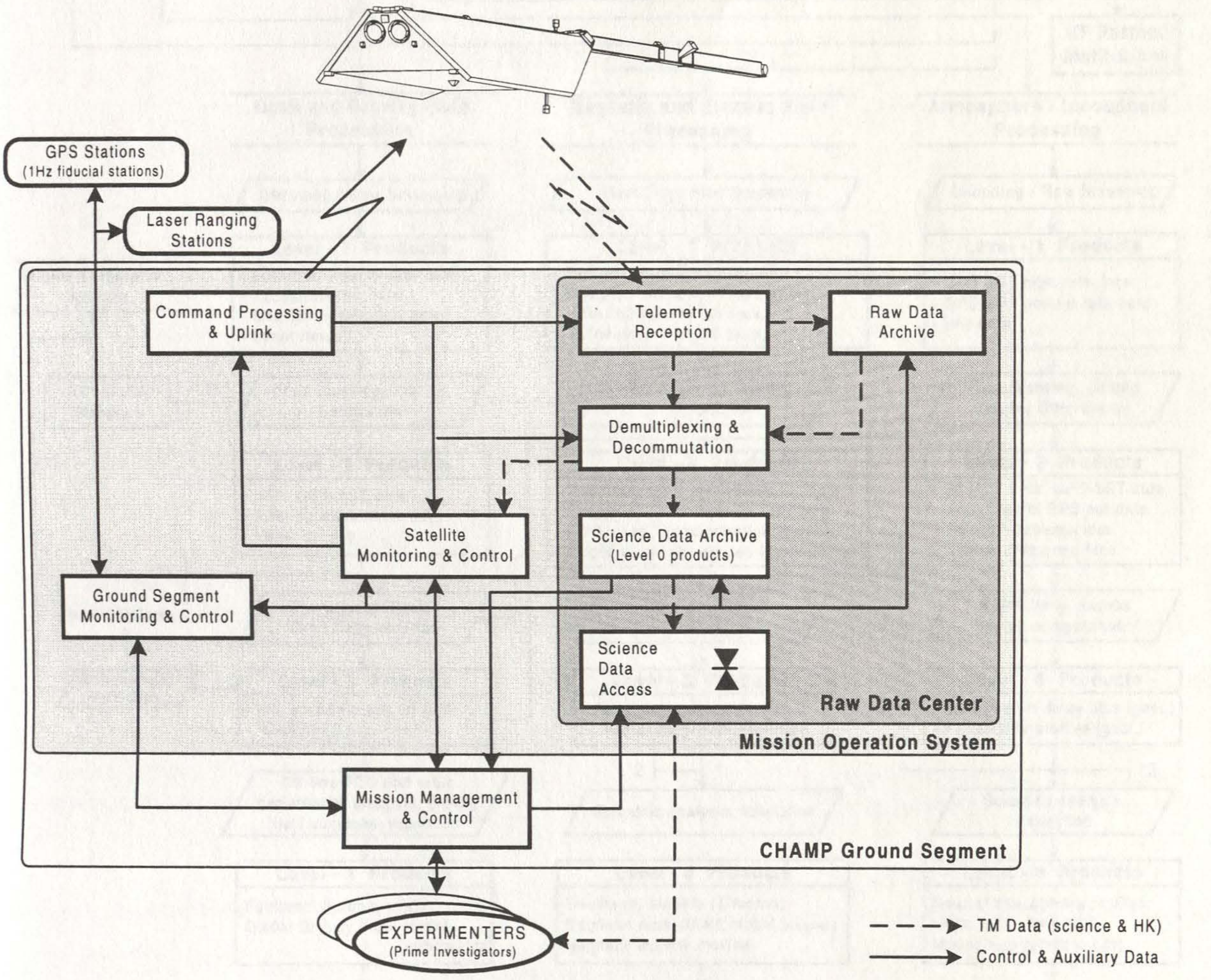


Figure 5-2 Functions of the CHAMP Ground Segment

5.3 SCIENCE DATA PROCESSING AND ARCHIVING

Figure 5-3 summarises the flow of scientific data originating from the CHAMP instruments and the GPS and SLR ground tracking stations. It depicts the processing steps and data products to be generated within the three processing subsystems associated with CHAMP's three science/application areas. The raw and level-0 data are archived in a back-up and rolling archive respectively, located at the CHAMP Raw Data Centre at the receiving station in Neustrelitz. All products of higher levels are transferred to the Product Archiving and Retrieval Systems, where also the interfaces to the users will be established. Each of the processing subsystems maintains their own product data base, i.e. these will be located in Potsdam with GFZ for orbit and gravity field as well as magnetic and electric field processing and in Neustrelitz with DLR for atmosphere and ionosphere processing.

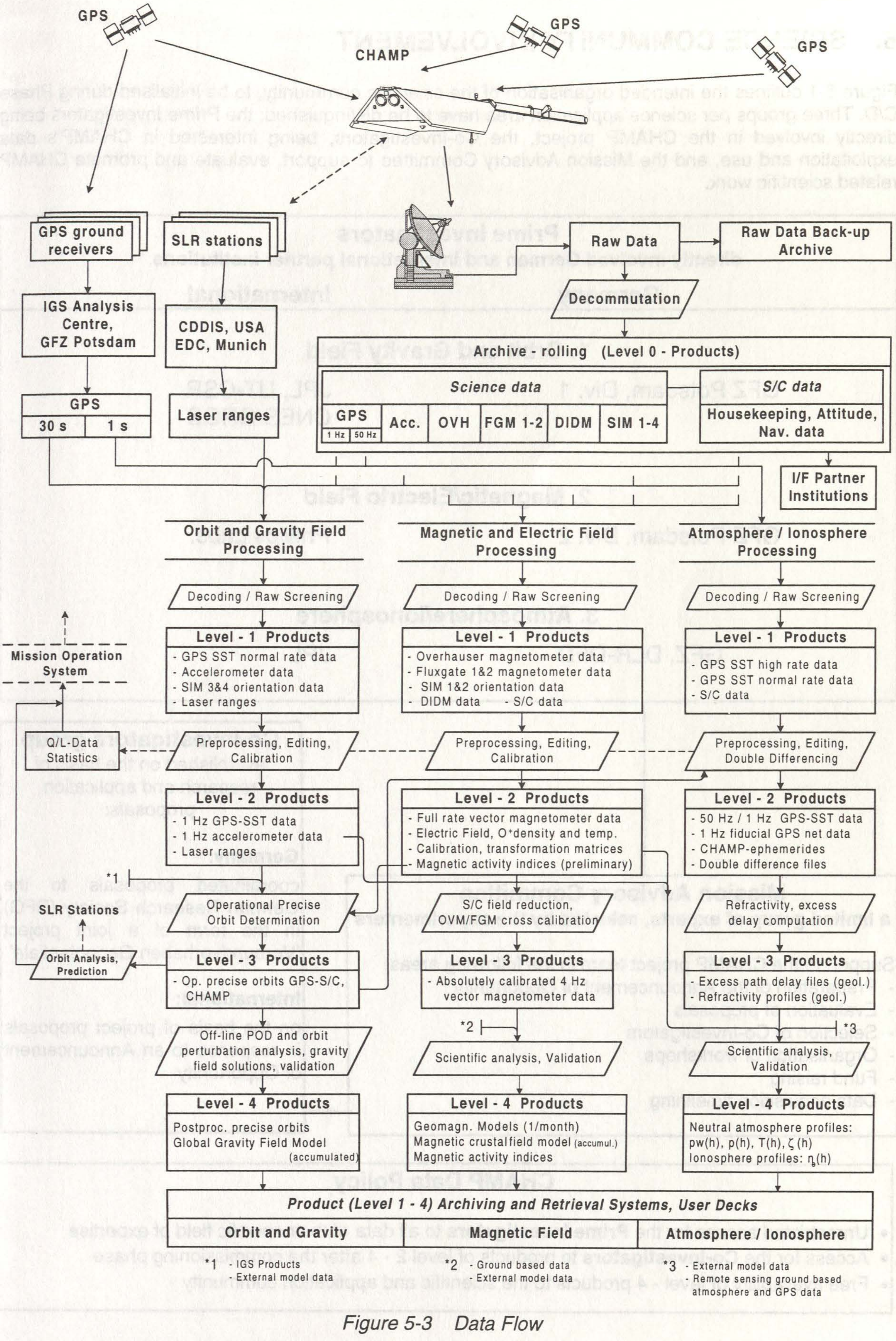
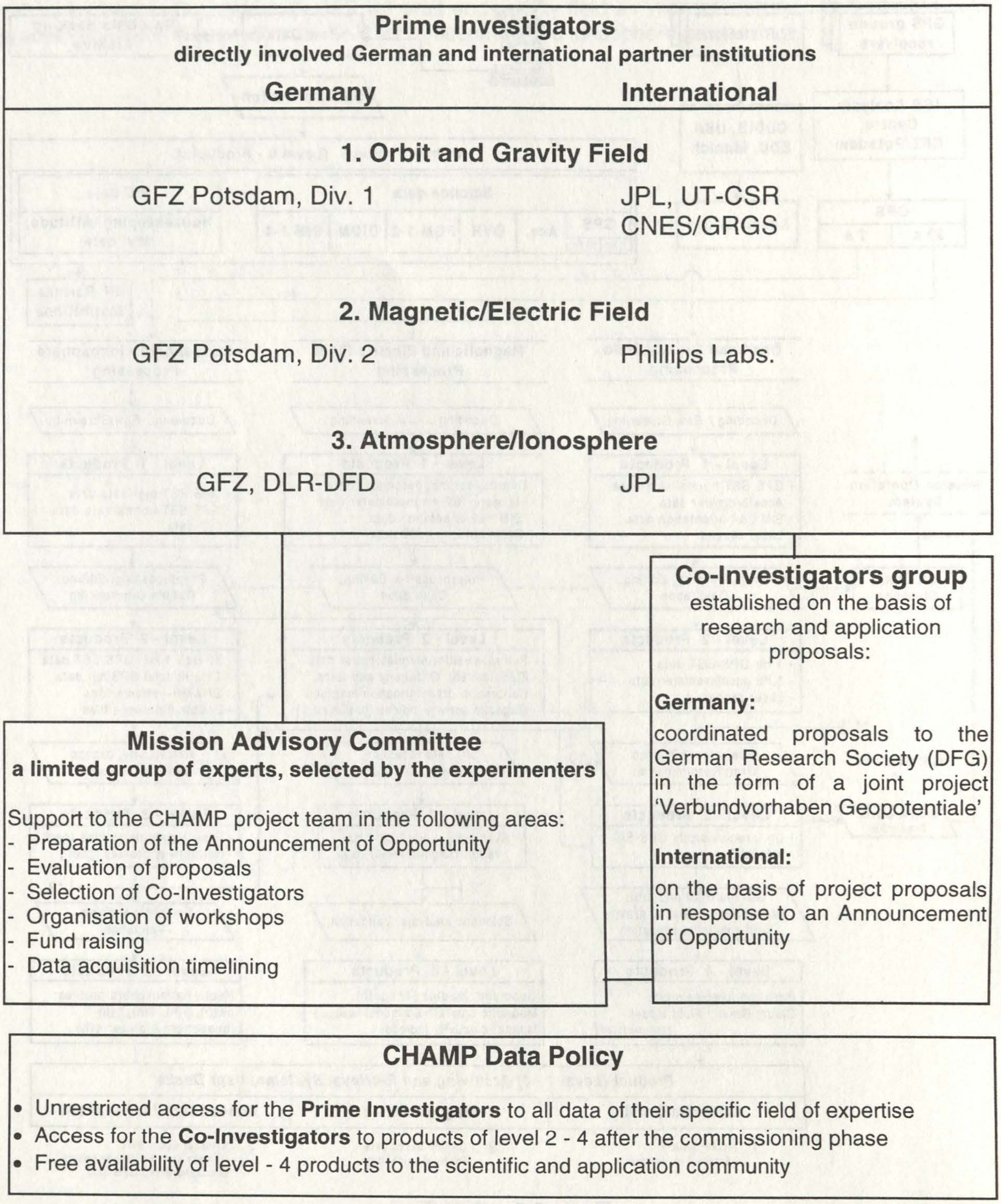


Figure 5-3 Data Flow

6. SCIENCE COMMUNITY INVOLVEMENT

Figure 6-1 outlines the intended organisation of the scientific community, to be initialised during Phase C/D. Three groups per science/application area have to be distinguished: the Prime Investigators being directly involved in the CHAMP project, the Co-Investigators, being interested in CHAMP's data exploitation and use, and the Mission Advisory Committee to support, evaluate and promote CHAMP related scientific work.



Prime Investigators

directly involved German and international partner institutions

Germany	**International**
1. Orbit and Gravity Field	
GFZ Potsdam, Div. 1	JPL, UT-CSR CNES/GRGS
2. Magnetic/Electric Field	
GFZ Potsdam, Div. 2	Phillips Labs.
3. Atmosphere/Ionosphere	
GFZ, DLR-DFD	JPL

Co-Investigators group

established on the basis of research and application proposals:

Germany:

coordinated proposals to the German Research Society (DFG) in the form of a joint project 'Verbundvorhaben Geopotentiale'

International:

on the basis of project proposals in response to an Announcement of Opportunity

Mission Advisory Committee

a limited group of experts, selected by the experimenters

Support to the CHAMP project team in the following areas:
- Preparation of the Announcement of Opportunity
- Evaluation of proposals
- Selection of Co-Investigators
- Organisation of workshops
- Fund raising
- Data acquisition timelining

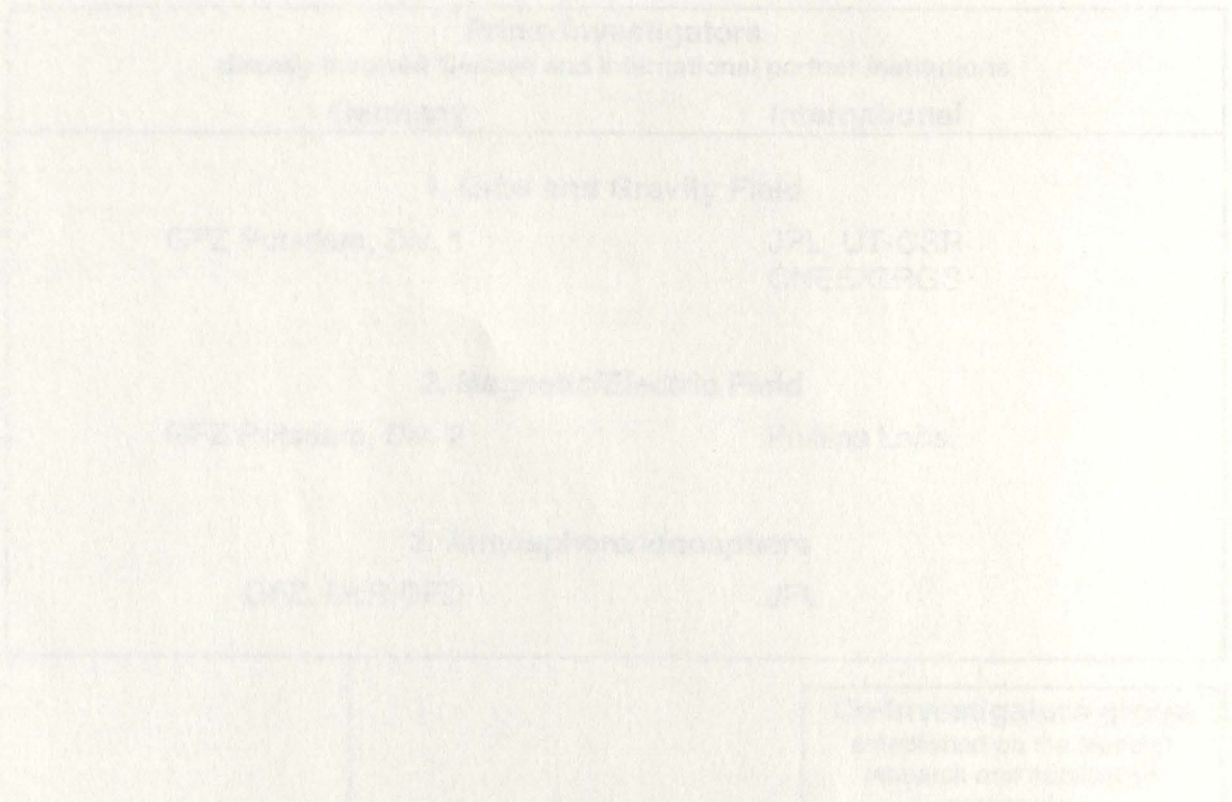
CHAMP Data Policy

- Unrestricted access for the **Prime Investigators** to all data of their specific field of expertise
- Access for the **Co-Investigators** to products of level 2 - 4 after the commissioning phase
- Free availability of level - 4 products to the scientific and application community

Figure 6-1 CHAMP's Science Community Organisation and Data Policy

[illegible] INVOLVEMENT

Figure 3-1 depicts the way [illegible] the scientific community [illegible] CHAMP [illegible] Co-Investigators [illegible] Advisory Committee to support, evaluate and promote CHAMP related scientific work.



Prime Investigators

(mostly financed German and international partner institutions)

Germany	International
1. Orbit and Gravity Field	
GFZ Potsdam, Div. 1	JPL, UT-CSR CNES/GRGS
2. Magnetic/Electric Field	
GFZ Potsdam, Div. 2	Phillips Labs.
3. Atmosphere/Ionosphere	
GFZ, DLR-DFD	JPL

Co-Investigators (project oriented on the basis of research and technical proposals)

Germany:
[illegible] proposals to the German Research Society (DFG) in the form of a joint [illegible]

International:
on the basis of project proposals in response to an Announcement of Opportunity

[illegible] Committee

[illegible]

- [illegible]
- Evaluation of [illegible]
- [illegible]
- [illegible]
- Final [illegible]
- Data [illegible]

CHAMP Data Policy

- [illegible]
- [illegible]
- [illegible]

Figure 3-1 CHAMP [illegible]