Geomagnetism and Paleomagnetism

GP22A CC: 202 Tuesday 1330h

Earth and Planetary Magnetic Survey Satellites I *(joint with P)*

Presiding: **Y Cohen,** Institut de Physique du Globe de Paris**; N Grammatica,** Danish Space Research Institute

GP22A-01 1330h INVITED

A Status Report on the Magnetic Exploraton of the Planets

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Magnetometer-carrying spacecraft have flown close enough to all the planets, save Pluto, to be able to detect the presence or absence of an intrinsic magnetic field. Of these only Venus and Mars have no presently detectable global magnetic field. Mars does have a strong remanent field composed of localized magnetic anomalies suggesting an ancient global field. The Earth's moon and Jupiter's Galilean moons have also been probed closely enough to detect any global intrinsic field and one, Ganymede, has a dipolar field and one, the Earth's moon, has localized remanence. We interpret all global intrinsic fields as indicative of a presently active dynamo and remanent fields as evidence for ancient dynamos, although we are aware that such views are not universally held. No missions have yet been flown to the large main belt asteroids such as Ceres and Vesta. Ceres is a low-density asteroid that may have accreted wet and did not differentiate to form a metallic core in contrast. Vesta shows evidence of differentiation, and has a density slightly larger than that of Mars. Meteorite evidence suggests Vesta has an iron core. Thus we would expect to see remanent magnetic fields at Vesta.

To fully characterize a planetary magnetic field requires an orbiter, preferably a low-altitude polar orbiter. Of the planets with intrinsic magnetic fields only Earth and Jupiter have been orbited to date. Thus, while we know some details of the multipole structure of the other planetary magnetic fields, much uncertainty remains. Most importantly we have an accurate determination of the secular variation only of the terrestrial field. Nevertheless, there is some evidence for a Jovian secular variation.

GP22A-02 1400h INVITED

The First Martian Magnetic Survey Satellite: Mars Global Surveyor

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The Mars Global Surveyor Mission was designed to replace the ill fated Mars Observer Mission which failed to achieve orbit around Mars in 1993. Due to resource limitations the mission was designed to use aerobraking as a primary strategy to circularize its orbit by dragging the spacecraft solar panels against the planet's atmosphere. This orbit geometry was highly favorable to the magnetic mapping objectives of MGS since it brought the spacecraft to less than 100km above the surface of Mars during peripasis. The highly elliptical orbits associated with aerobraking resulted in non-ideal coverage of the planet but were instrumental in the discovery of intensely magnetized regions of the Martian crust and the determination that the Martian dynamo had ceased to exist very early in the history of the planet. Crustal magnetism at Mars exceeds by an order of magnitude that observed at Earth and has significant implications for our knowledge of the planet's thermal evolution, its interaction with the solar wind, and the possible role of the magnetic field in the loss of volatiles from the atmosphere.This talk will present details of the MGS mission, its orbits, the unique accommodation of the magnetic field instruments and highlights of the scientific results achieved to date.

GP22A-03 1420h INVITED

Present and Future Magnetic Exploration of Mars

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The Mars Global Surveyor (MGS) magnetometer experiment has provided an intriguing data set with which to probe the planets evolution. The discovery of intense crustal magnetism, dominantly present in the ancient southern highlands, confirms the existence of a global magnetic field in Mars past, whereas no global internal field exists there today. These crustal magnetic field data are being used to probe the timing of the Martian dynamo, and to characterize the processes that created and modified the crust. We have analyzed the magnetic field data in conjunction with gravity data from the radio science investigation on MGS, as well as high-resolution topography from the MGS Mars Orbital Laser Altimeter (MOLA). The potential field data provide a perspective limited in spatial resolution to 200 km for the magnetic field and 400 km for the gravity field. Distinct variations in crustal properties within the Terra Cimmeria region of the southern highlands, where the most intense magnetic anomalies are found, are revealed by examining the ratio of Bouguer gravity to topography as a function of wavelength (admittance). These density and crustal thickness variations correlate with the magnetic anomalies. The thinnest, highest density crust is associated with the very intense positive anomaly centered at 50S, 178E. Modeling of the magnetic anomaly pattern in Terra Cimmeria, guided by the density/thickness constraints from the admittance study, indicates that the positive anomalies drive the observed pattern, favoring a contrast between positively magnetized regions and nonmagnetic (or uniformly magnetized) crust within the regions of observed negative anomalies. Two possible scenarios to explain this result are demagnetization of previously-magnetized crust within the region of negative anomalies, or acquisition of magnetization in the regions of positive anomalies subsequent to the major phase of crustal formation which would have occurred prior to the dynamo initiation. The absence of magnetic anomalies in vast regions of the southern highlands argues for the latter scenario, indicating that the initiation of Mars dynamo may have been delayed relative to the initial cooling phase, similar to the Moons evolution. The presence of anomalies in the northern lowlands and on the Tharsis Rise argues for a prolonged period of dynamo activity, extending perhaps to 2 Ga. The resolution limit of the magnetic field prevents an understanding of the true magnetism of the Martian crust and hinders interpretation of the magnetic anomaly record. Therefore, future exploration of the magnetic field of Mars must obtain high-resolution data to test hypotheses posed using the MGS data, and to search for high frequency anomalies that may correlate with surface geology that is dated by crater-counts, in order to refine the magnetic field history. We advocate a balloon aerial platform as an efficient and technically feasible approach to provide these data at the same resolution as a ship on the Earths ocean.

GP22A-04 1440h

Terrestrial and Martian magnetizations of lithospheric origin: Comparative Planetology

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Magnetic field observations from the Mars Global Surveyor mapping orbit (400 km altitude) are compared with terrestrial magnetic field observations (Magsat and Orsted, 400-740 km). The radial magnetic field at 400 km ranges from +-21 nT over the Earth vs +-250 nT over Mars. Our understanding of the sources of the terrestrial magnetic field of lithospheric origin (Degrees 15-40+) is such that we have produced physically-motivated global earth models of induced and remanent magnetization that explain most of the long-wavelength field seen at satellite altitude. A comparison of the terrestrial model and observations illustrates the complexity of the sources hidden by the long-wavelength observations, and the difficulties of inferring the source magnetizations from the observations. Several of the Martian sources sampled during the aerobraking (down to 90 km altitude) phase of the mission can be associated with distinct tectonic or geologic provinces and we discuss our interpretations of those provinces.

GP22A-05 1515h

Interpretation of the Martian Southern Highland Magnetic Anomalies using the Euler and Analytic Signal Methods

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We use the Analytic Signal and Euler methods to derive source locations and interpret a number of Z-component magnetic anomalies from the southern highlands of Mars. The amplitude of the Analytic Signal (AAS), a function of three orthogonal derivatives, exhibits maxima over the edges of regionally large polygonal magnetic sources and can be used to determine the edges of these sources. However, model studies of circular crater-like sources show that the maxima of the analytic signal occur near the center of the sources and not on their edges. The Euler method uses anomaly gradients and attenuation rates, which are related to the source shape, in order to estimate source locations. Ideally, it can recover both horizontal and vertical source locations. From model studies, "half-width" depth estimates derived from the AAS of the anomalous Z-component field, computed at the altitude of 150 km, were found to be 15 km from the upper surface of the crater-like source having a radius of $\sim$60 km and a depth from 0 to 5 km. A model of a crater-like source with a radius of $\sim$300 km (depth from 0 to 10 km) shows that the AAS again has a high over the source; depth estimates for this method were 5 km from the upper surface of the source. Although, the Euler method outlines the models of circular crater-like sources nearly perfectly from this altitude, the best quality depth estimates have too great a range to be useful. Models of long linear anomalies, such as the ones observed by the Mars Global Surveyor spacecraft magnetometer, show the maxima of the AAS occur directly over the edges of the sources. Depth estimates for these sources are 20 km from the top of the source. The Euler method outlines these sources well, but again the depth estimates show a large scatter and therefore are not usable. We use these methods on the Z-component magnetic anomalies computed at 150 km altitude from the equivalent source model of Purucker et al. (2000, GRL, v.27, pp. 2449-2452). Both these methods point to a number of buried crater-like structures not recognizable from the 0.25 degree topographic grid of Mars. The two most prominent of these features occur at (33 degrees S, 136 degrees E) and (42 degrees S, 136 degrees E). These craters could have formed and acquired magnetization during the time period when the Martian internal dynamo was active, but presently they appear buried under the products of subsequent meteoritic bombardment. The Analytic Signal results also indicate that the sources of two of the longest linear magnetic anomalies (60 degrees S, 152-220 degrees E) and (75 degrees S, 160-230 degrees E) are about 700-1000 km long - much shorter than the length of the Z-component anomalies which show superposition effects leading to their observed 1200-2100 km extent. In general, for some anomalies the Analytic Signal method gives more interpretable results while for others the Euler method works better. When the results of both the methods are in agreement, the interpretation has a higher confidence level.

GP22A-06 1530h

Satellite Magnetic Anomalies from MGS over the South Tharsis Region of Mars.

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Very high amplitude crustal field anomalies were revealed over a significant for portion of Mars by the Mars Global Surveyor (MGS) mission. Several terrestrial crustal anomalies could be interpreted as resulting from remanent magnetization; however, since there is no ambient magnetizing field all of these Martian anomalies must be produced by remanence. In this investigation, we applied some methods and techniques developed to study the Magsat crustal magnetic field at satellite altitude to these recently acquired Martian anomaly data. Our goal is to derive the direction of magnetization and compute a virtual geomagnetic pole for selected anomalies as well as information on their likely source.

The study region extends from 50°S-10°N 135°W-75°W and includes the Southern Tharsis region. Some 252 descending (night-side) orbital passes from the mapping phase of the MGS mission were examined to determine extent of contamination by external fields. A second-order polynomial was used to de-trend each orbit followed by low-pass filtering, with a 250 km wavelength cut off. Total field and component crustal anomaly maps were made at the altitude of the MGS mapping phase, 400 km. After selecting and analyzing an isolated anomaly in the southwest corner of the Tharsis area, an average direction of magnetization was computed as -10° inclination and 212° declination. Assuming a dipolar main field this yielded a virtual geomagnetic pole at 45°N,58°W. This pole lies in the eastern sector of Tempe Terra some 400 km southeast of the Tempe Fossae.

GP22A-07 1545h

Probing Mars' Crustal Magnetic Field with the MGS Electron Reflectometer

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The ~400-km-altitude mapping orbit of Mars Global Surveyor (MGS) is close to the median altitude of the ionopause, a plasma boundary separating Mars' ionosphere from the solar wind. Consequently, the spacecraft makes numerous ionopause crossings as the boundary moves up and down in response to variations in the solar EUV flux and the solar wind dynamic pressure. The MGS Electron Reflectomerer (ER) observes these crossings as abrupt changes in the electron energy spectrum.

Crustal magnetic fields can greatly enhance the probability that the ionosphere above them will extend to altitudes of 400 km or higher. Intense crustal magnetic fields in the southern hemisphere trap ionospheric plasma and shield it from the solar wind, forming localized "magnetospheres" that extend well above the 400-km mapping orbit. Enhancements in the probability can also be discerned over much weaker magnetic anomalies, providing a new technique to detect their presence. The large volume of uniformly sampled data (> 2.5 million spectra) allows a complete map of the crustal fields at ~2-degree resolution.

Away from the crustal fields, the ionosphere shows many similarities to the ionosphere of Venus. In weak-field regions of the northern hemisphere, there is a pronounced flaring of the ionosphere from the sub-solar point to the terminator. In addition, the ionosphere is observed to expand and contract in response to variations in both the solar EUV flux and the solar wind dynamic pressure.

GP22A-08 1600h

Martian Magnetic Topology: Evaluation of Crustal Magnetization and Solar Wind Interaction Models Using MGS MAG Data

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Results from the MAG/ER experiment aboard Mars Global Surveyor indicate that the magnetic topology near Mars is governed both by the interaction of the solar wind with the Martian obstacle and by regions of magnetized crust. Consequently, the arrangement of magnetic field lines near Mars depends upon solar wind conditions, solar wind magnetic field orientation, and planetary local time. At present there are no models for the magnetic environment of Mars that account for both internal (crustal) and external (solar wind) contributions to magnetic field measurements. However there are a variety of models that account for either crustal magnetization or the solar wind interaction. At the same time a wealth of data has been returned by MGS MAG that could be used to topologically evaluate these models.

We compare MGS MAG data to different available models for Martian magnetic topology. We use premapping and mapping data below 1000 km altitudes to evaluate a global crustal magnetization model by Purucker et al. and a local magnetization model by Connerney et al. Similarly, we compare MAG data to the Spreiter and Stahara gas dynamic model for the Martian solar wind interaction. We look specifically for where and under what conditions the models provide reliable estimates of the magnetic field measured by MAG.

Our efforts are directed toward the construction of a superposition of magnetic field models that is topologically supported by MAG data. We show the results of a preliminary attempt at such a superposition that combines the model of Purucker et al. with different external fields. We apply this combined model at different planetary local times and create animations of Martian magnetic field topology as Mars rotates. We find that magnetic field lines associated with crustal sources reconnect to the solar wind under different conditions, providing conduits for particle deposition into the Martian atmosphere.

GP22A-09 1615h

Why is EROS, "non-magnetic"?

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In anticipation of the encounter with 443 EROS we have been evaluating the concept of S-type Asteroid magnetization which led to a reconsideration of the magnetization records of Ordinary Chondrite meteorites. The recent discovery of low magnetization for the 433 EROS asteroid allows us a step up in explaining why the magnetization might be so low. We evaluated most of the available chondritic meteorite data and found that most exceeds Eros magnetization (< 7.5 e-7 A m^2kg^{-1}) by at least two orders of magnitude (1e-4 A m^2kg^{-1}). We explore the possibility of contaminating the magnetic record by exposure to the terrestrial environment. This includes history of meteorite from the time when it enters the geomagnetic field, warms up from interplanetary space temperatures to the temperature of the Earth surface, and transport to the magnetic facility where the magnetization data is measured.

Magnetic record of the Bjurbole chondrite, and by analogy perhaps all meteorites, is complicated be the fact that it contains magnetic material capable of acquiring a wide range of magnetic remanence records by warming from space temperature and magnetic conditions to 300K inside the terrestrial environment. However, there is also a significant fraction of chondrule record that contains stable remanent directions that is unlikely to be contaminated by exposure to the geomagnetic field and terrestrial temperatures. Consequently the next step is to assess the bulk effect of the space to earth transit.

We also analyzed a few samples of large meteorites (ALH76009 23.7 kg, Allende 17.2 kg, Canyon Diablo 454 kg) using similar technique and methodology as the ones used on EROS. The advantage of using large meteorites is that we are able to better assess the contamination which is often experienced by small size meteorite samples. Large sample studies reveal the orientation of the bulk magnetization with respect to sample geometry and internal structure. Large samples are measured at the GSFC facility where the intensity and gradient of the magnetic field can be fully controlled. Magnetic remanence was measured in pristine state and also after demagnetization by 5 mT alternating magnetic field in near zero magnetic field. Results show that large samples have lower magnetization than small samples which points either to a larger potential for contamination of small samples or to the vector subtraction associated with randomly oriented magnetized regions within the large meteorites.

GP22A-10 1630h

The Magnetization of 433 Eros as Measured from its Surface

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The Near Earth Asteroid Rendezvous (NEAR) spacecraft performed several close range (<5 km) magnetic field measurements of 433 Eros from December 2000 until its landing on the asteroid on February 12th, 2001. After the surprising spacecraft survival of the landing, operation of the Magnetic Field Experiment on the surface of Eros was resumed on Feb 14th and data were acquired during two DSN contacts providing a total of 5 hours of data. Consistent with the collection of Eros orbital data which yields data over the entire asteroid at Eros-centric distances of 35 km, the new measurements yielded no detectable signature of an intrinsic magnetic field to a confidence of 1 nT. Current best estimates places an upper limit on the volume magnetization of Eros at 0.001 A-m2. The magnetic field measurements acquired during the late phase of the mission will be presented and discussed, including inferences derived from previous and synergistic measurements as well as finite element modeling results. The null result implies that the magnetization state of Eros is substantially lower than that of meteorites, including LL-chondrites which are the closest compositional analog to Eros.

GP22A-11 1645h

Demagnetization Signatures of Lunar Impact Craters

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Observations of lunar crustal magnetic fields by the Apollo subsatellites and the Lunar Prospector (LP) spacecraft have shown many indications that the distribution of crustal fields may be largely controlled by impact processes. The largest concentrations of strong

magnetic fields (>100 nT) are correlated with the antipodes of large impact basins, and some smaller concentrations are associated with impact ejecta. Large impact basins themselves, however, tend to be areas of low magnetic fields (<2 nT), suggesting that impacts can demagnetize the crust.

High resolution LP measurements have allowed us to investigate the magnetic properties of impact basins and craters down to ~50 km in diameter. We have found that even the smallest craters in this observable size range often show demagnetization signatures similar to those associated with large basins. Many such signatures are symmetric and clearly associated with individual craters, leaving little doubt that we are actually observing the results of demagnetization by crater impacts.

The demagnetization signatures tend to extend more than one radius from the center of the crater or basin, showing that the shock and/or thermal effects responsible for demagnetization affect regions past one radius. Some craters show the edge effects that one would expect if an area smaller than the local magnetic scale size was demagnetized. Most larger craters and basins, on the other hand, do not show such an effect. This suggests that the crustal magnetism is jumbled on a scale smaller than ~100 km.

There are clear differences in the demagnetization of craters and basins of different ages, and there are also hints of differences in the demagnetization of craters and basins of different sizes. This suggests that careful studies of crater demagnetization can help to determine both the age and depth of lunar crustal magnetism.

GP31A CC: Hall C Wednesday 0830h

Paleomagnetic Studies of the Atlantic-bordering Continents: Rodinia to Pangea to Present I - Posters *(joint with T)*

Presiding: **L Brown,** Univ. of Massachusetts**; C MacNiocaill,** Oxford Univ.

GP31A-01 0830h POSTER

The Position of Fennoscandia in the Late Proterozoic: Paleomagnetic Data from the Egersund-Ogna Anorthosite, Rogaland, Norway

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Apparent polar wander paths for Rodinia are ambiguous for Laurentia and Baltica with both clockwise or counter-clockwise loops proposed. A detailed magnetic study has been undertaken on the Egersund-Ogna anorthosite body of the Rogaland Igneous Complex, southeastern Norway to provide pole data for southern Fennoscandia. The anorthosite, with published U-Pb ages of 930 Ma, is part of a larger complex of massif-type anorthosites and layered intrusions. Thirteen paleomagnetic sites were collected distributed throughout the body. Average susceptibilities range from 0.03 to 2.24 x 10-3 SI and NRM intensities range from 0.004 to 1.54 A/m. Corresponding Q values range from 3 to 148 with a mean value of 36, indicating remanent-controlled magnetic anomalies. NRM directions from all samples are characterized by steep negative inclinations with southwest to northeast variable declinations. Thermal demagnetization reveals square shouldered demagnetization curves, with little or no loss of intensity until 550 or 575C. Alternating field demagnetization produces a wide range of demagnetization behaviors with mean destructive fields varying from less than 5 mT to greater than 80 mT. There is little evidence of overprinting or secondary components, and all information points to a remanence gained during initial cooling of the anorthosite. Mean directional data for the 13 sites are I = -81.7 and D = 326.8, a95 = 6.0. Assuming this mean direction represents normal polarity, paleolatitude for southern Fennoscandia at this time is 70S. The magnetic pole calculated for Egersund-Ogna is at -45 S latitude and 200 E longitude, in good agreement with earlier published poles determined from other southern Scandinavian rocks of similar age. This work supports reconstructions that place Baltica in high (southern) latitude at approximately 900 Ma.

GP31B CC: Hall C Wednesday 0830h

Precise Correlation of Strata: Magnetic and Other Methods I - Posters *(joint with V)*

Presiding: **W D MacDonald,** SUNY - Binghamton**; J K Ferris,** British Antarctic Survey

GP31B-01 0830h POSTER

A more accurate age for the Cockburn Island lavas (Antarctic Peninsula), from magnetic data.

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Cockburn Island basaltic lavas are currently dated at between 2.8 and 3.0 million years old from fossil pectinids and microfossils in interleaved sediments, and 40Ar/39Ar dating. Aeromagnetic data over the Island show that the lavas cooled during a period of reversed magnetization, (a near perfect magnetic low with flanking highs exists over the Island.) Between 2.58 and 3.22 Ma, magnetic polarity is normal except for one short period of reversed polarity; this lies between 3.04 and 3.11 Ma. The Cockburn Island Formation must therefore date from within that reversed polarity interval. Interpretation of the assemblage of fossils interleaved with the lavas indicates warmer water, possibly interglacial conditions, which in turn implies a relatively warm climate consistent with partial collapse of the Antarctic Ice sheet. If this is true, then the evidence presented here indicates a precise age for the warm interval of between 3.04 and 3.11 Ma.

GP31B-02 0830h POSTER

CORRELATION OF EARLY TERTIARY TERRESTRIAL DEPOSITS OF THE AMAGA BASIN, CAUCA DEPRESSION, COLOMBIAN ANDES

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The Amaga Formation of the Amaga Basin preserves early Tertiary terrestrial deposits of many facies: channel, crevasse splay, paludal, flood plain, point bar, etc. These deposits lie between two major strike-slip fault zones, the Cauca and the Romeral in the Cauca Valley of the northern Andes of Colombia. Coal deposits characterize the lower part of the stratigraphic section; fine to medium clastic sediments otherwise dominate the sections. Within the basin, correlation between sections is difficult because various discontinuities interrupt the continuity of the strata. These include Tertiary intrusives, folding and faulting. Rapid lateral facies changes further complicate the correlations. Detailed studies on five stratigraphic sections are underway. Multiple methods of correlating sections are being used, including fluvial sequence stratigraphy in outcrops, architectural facies analysis, heavy mineral separates, grain-size and grain-ratio variations, paleocurrent directions, and magnetic property variations. Distinctive regional variations in magnetic anisotropic susceptibility indicate areas in which tectonic effects overprint sedimentary fabrics. The presence of secondary hematite and siderite is related to that overprinting. A major compositional break (identified by grain-ratio variations) has been found in the middle of the section. The integrated correlation results are summarized.

GP31C CC: 202 Wednesday 0830h

Earth and Planetary Magnetic Survey Satellites II *(joint with P)*

Presiding: **Y Cohen,** Institut de Physique du Globe de Paris**; N Grammatica,** Danish Space Research Institute

GP31C-01 0835h INVITED

The magnetic survey mission CHAMP: Early results

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On July 15, 2000 the geoscientific satellite CHAMP was launched from the Russian launch site Plesetsk into a near-polar (87.3°) orbit. The mission is devoted to global investigations of the gravity, magnetic and electric fields and to atmospheric profiling. Cruising at a low, circular orbit - 460 km at the beginning, decaying to 300 km after a 5 years mission period - CHAMP promises to return a unique data set. The orbital plane moves with respect to local time at rate of about 1h per 11days, thus covering all LTs within 4.5 months.

In this talk I will focus on the magnetic field investigation. The satellite is equipped with a scalar Overhauser magnetometer at the tip of a 4m boom. Half way down the boom there are two (redundant) fluxgate magnetometers mounted together with a dual-head star camera on an optical bench. This magnetometry package provides the capability of maintaining absolutely calibrated vector field measurements throughout the mission. During an extended commissioning and calibration phase of 8 months the various instruments on board have been tuned to the environmental conditions and intrinsic factors and biases are determined.

The evaluation of preliminary data sets confirms that all instruments meet their specification. Initial results will be presented which allow to show the performance of the measurements. When comparing repeat tracks it is encouraging to see how well features like crustal anomalies match each other. The precision of vector field data is particularly high on the night side. Here we can make use of the simultaneous readings of the two star trackers. By combining the individual measurements we obtain a precise attitude. The quality of the vector data will be demonstrated in comparison with main field models.

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Oersted and Oersted-2/SAC-C: Mission Status and Data Availability

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After the launch of Oersted, the first high-precision mission since Magsat, geomagnetic field research is in a period of unprecedented opportunity. In addition to Oersted (launched in February 1999) the CHAMP satellite and the SAC-C satellite with the Oersted-2 experiment was launched in July and November 2000, respectively. All three missions carry essentially the same instrumentation and provide for the first time near-Earth high-precision multi-point magnetic observations for mapping of the Earth's magnetic field and its time variation. We will present the status of Oersted and Oersted-2 and discuss the accuracy and availability of scalar and vector data from the two missions.

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Fine Tuning Geomagnetic Models

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