

Ørsted Satellite

The Danish Miracle in Space

Insight in the vortex-like flows in the Earth's core of fluid metal, information on the electrical properties of the viscous mineral mass in the Earth's mantle, estimates of the crustal thickness and its remnant magnetism, calculation of the heat flow from Earth's interior to the bottom of ice caps, measurements of large-scale ocean currents, sounding of the temperature and humidity profiles in the atmosphere, mapping of the electron content in the upper atmosphere, scaling of the electric currents in outer space, detection of the high-energy particles in the radiation belts, estimates of the electric fields in the solar wind.

No, this is not the table of contents for an encyclopedia on Space Research. These are among the brilliant results of the Danish Ørsted satellite mission. On 23 February 2007 the satellite reached a remarkable milestone: 8 years in space and still operational.

The long and winding road to success

The Ørsted satellite had no easy way to its success. The satellite was first targeted for a launch in 1995 paid for by NASA on a Delta-II rocket scheduled to launch a large American ARGOS satellite. Unfortunately, the 2700 kg heavy ARGOS satellite had grave technical difficulties. Hence the 60 kg small Ørsted satellite had to be put on the shelf to await launch. The green light came on in late 1998 and Ørsted was shipped to the Vandenberg Air Force base in California. The first launch count-down took place on 15 January 1999 but was aborted due to high winds. Then followed a lengthy series of launch attempts until finally on the 11'th count

down, at 11:29:55 on 23 February, 1999, we finally succeeded. The large Delta rocket, majestically, lifted-off from its ramp and standing on a column of fire and smoke it reached for the sky and disappeared from sight with its precious payload of the ARGOS, the Ørsted, and the South-African Sunsat satellites. At 14:20, after almost 3 hours of nerve-racking waiting, as the satellite had to be separated from the launcher and pass over Denmark, we received at the ground station at DMI the first radio signals from the small satellite. Ørsted was in its planned orbit and alive. Denmark was now represented in Space with its first national satellite.

The Ørsted satellite is still in operation, now in its 9'th year. In spite of its high age most of the satellite instrumentation and systems are still functional. Hence the Ørsted satellite still supplies valuable data from its measurements in space. Now the Ørsted satellite is also theme for a DVD video and accompanying book written by Charlotte Autzen (in Danish) for educational uses.

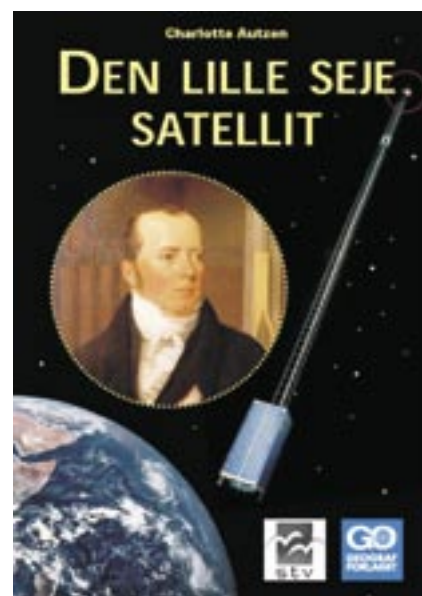


Figure 1. Cover of book on the Ørsted satellite. Portrait of H.C.Ørsted.

Ørsted satellite and instruments

The main instrumentation onboard Ørsted is a set of two magnetometers. One is a "Compact Spherical Coil" (CSC) vector magnetometer combined with a "Star Imager" (SIM) stellar compass. Both are constructed at the Danish Technical University (DTU) and are satellite instruments of "world-class" with unsurpassed precision and stability. The absolute magnitude of the geomagnetic field is measured by an Overhauser (OVH) scalar magnetometer supplied by CNES, France.

The high-energy radiation in space, particularly in the Earth's radiation belts, is detected by a "Charged Particle Detector" (CPD) instrument constructed at DMI. In addition to a standard GPS (TANS) receiver for positioning and timing information, the satellite carries a



Figure 2. Ørsted satellite at test. (Photo: P.L. Thomsen)

Table 1. Ørsted satellite specifications

Satellite mass	60.7 kg
Body dimensions	72x45x34 cm
Foldable mast	6+2 m
Average power	37 W
Data storage cap.	12 hrs
Telemetry	S-band 2.2 GHz
Apogee height	865 km
Perigee height	649 km
Inclination	96.48 deg.
Orbital period	100 min

TurboRogue GPS high precision receiver supplied from NASA to be used for profiling of atmospheric temperature and humidity and for mapping of the electron contents in the upper atmosphere.

A particularly ingenious construction is the 8 m foldable mast made of three glass-fibre longerons with interleaved wires and spacers. During assembly, tests and launch the mast including canisters for the two magnetometer systems are folded into the satellite body. The long mast keeps the sensitive magnetic instruments at a safe distance from possible disturbing stray fields from materials and current loops in the satellite body. For supply of electrical power the satellite has solar panels on all sides except the bottom side, which carry the telemetry antennas always facing the Earth. A rechargeable NiCd battery provides power during eclipse. The basic parameters are listed in Table 1.

Main field modelling.

The primary task for the Ørsted satellite is the delivery of high-precision data for modelling the Earth's magnetic field, which at the Ørsted orbit varies between around 20.000 nT and 60.000 nT (1 nanoTesla=10⁻⁹ Vs/m²). First occasion for this application was the new "International Geomagnetic Reference Field" (IGRF) model for epoch 2000. The IGRF models are updated every 5 years.

They are used for numerous technical and practical tasks all over the world. Ørsted succeeded to deliver the data in spite of the strongly delayed launch, and the IGRF2000 model issued on time was mainly based on Ørsted's measurements. In later modelling the Ørsted magnetic data are supplemented by data from the German

CHAMP satellite launched in July 2000. This satellite also carries Danish magnetic instruments similar to those on Ørsted.

The models for the Earth's magnetic field are continuously refined with the most recent data. For scientific uses an "Ørsted Initial Field Model" (OIFM) was developed to provide modelling with an

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Research areas:

- Solar Wind - Magnetosphere - Ionosphere interactions, - Auroral substorm processes, - Radiation in Space, - Wave propagation in the Ionosphere

Current Research projects:

- Project scientist for the Ørsted satellite, - PI for the CPD instrument at Ørsted
- PI for the "External Field" research at DMI, - PI for polar imaging riometer observations

Publications (since 1980):

- 100 scientific publications in refereed journals, books and proceedings
- 150 conference talks and poster presentations
- numerous popular, educational and news articles

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accuracy (RMS deviation between model and data) of around 5 nT. More recent an “Ørsted Secular Variation Model” (OSVM), which includes coefficients for the temporal development (secular variation) of the main field, has been published. The accuracy of this model is around 3 nT. Using specialized processing of Ørsted (and CHAMP) data has enabled an estimate of localized magnetic anomalies with an accuracy of around 1-2 nT.

Comparing these accurate models with models based on the data obtained 20 years earlier from Magsat (1979-80) - the only satellite prior to Ørsted providing high-precision magnetic data - makes it possible to calculate the global change in the Earth’s magnetic field. The results are illustrated in figure 3. The two upper diagrams present in colour code on a scale ranging from 20.000 to 60.000 nT the global distribution of the magnetic field strength in years 2000 (Ørsted) and

1980 (Magsat), respectively. The strong fields in the Polar Regions and the weak field particularly in the South-Atlantic region are noticeable. The bottom diagram presents on a more sensitive scale ranging from -2000 to +2000 nT the increases and decreases in field strength developed during the 20 years interval between the observations. On the average the Earth’s magnetic field has decreased by around 2% between the two missions. In some regions, among others in the so-called Bermuda Triangle, the field has decreased by over 6% during just 20 years.

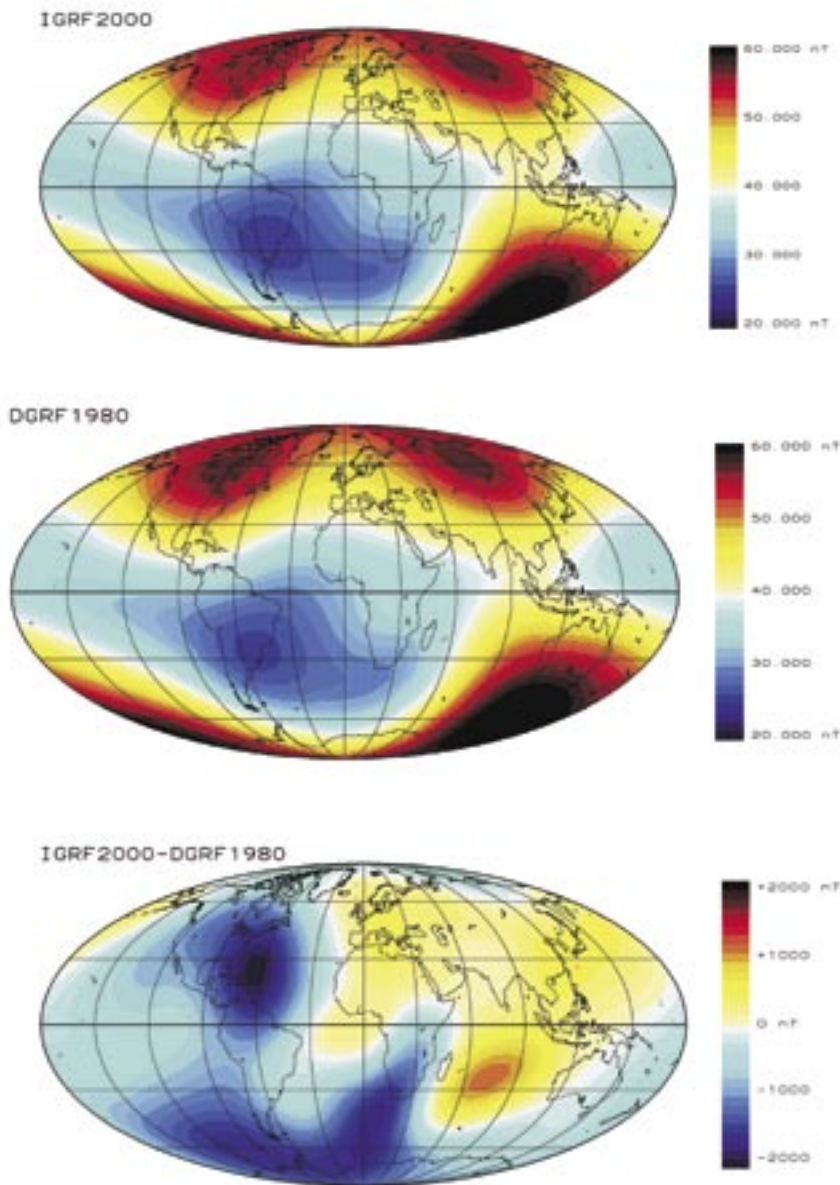


Figure 3. Top: Ørsted-based IGRF2000 field model. Middle: Magsat-based DGRF1980 model. Bottom: Magnetic field change 1980-2000.

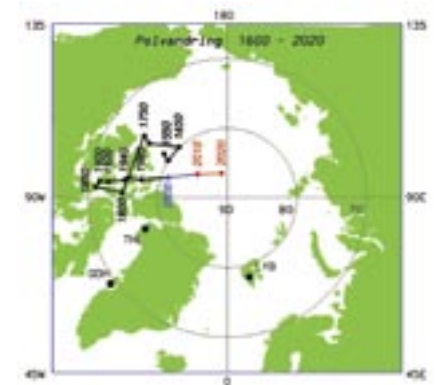
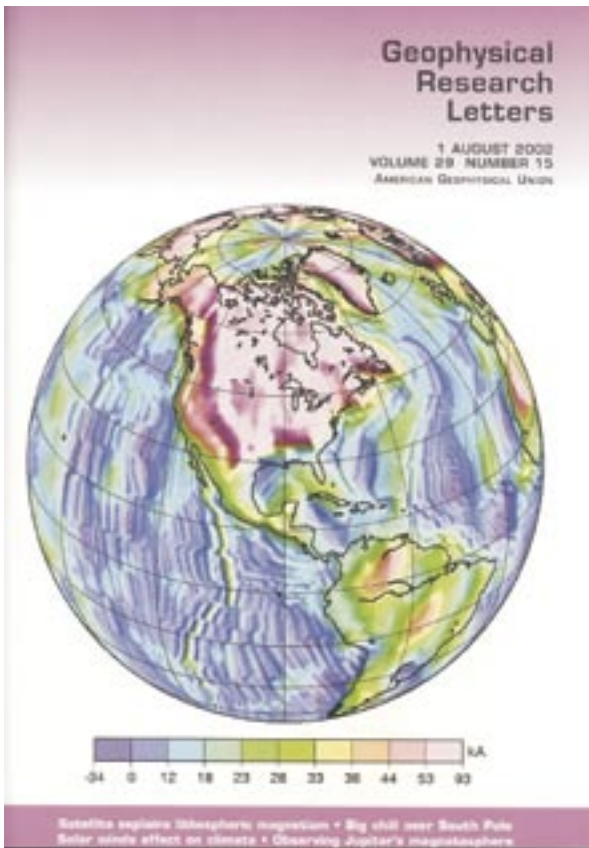


Figure 4. Varying position of the northern magnetic pole since 1550 .

The main field models provide terms to calculate the variations in field strength with distance from the centre of the Earth. The material in the “Mantle” 3000 km downward from the surface is hot viscous mineral, magma. This medium is poorly conductive for electrical currents and has such a high temperature (above the Curie temperature) that the material is non-magnetic. In this case the field model can be extrapolated all the way down to the core of fluid metal (Iron and Nickel) to provide the distribution of field strengths at the “Core-Mantle Boundary” (CMB). Comparing Ørsted and Magsat models for the CMB fields provides an estimate of the changes during the 20 years interval. The changes can be converted into material motions, which may reach magnitudes of typically 20 km/year in vortex-like patterns. These vortex patterns can be interpreted to represent the projection to the CMB of rotating cylinders in the fluid core material. Such data-based models combined with the most recent theories for self-magnetizing dynamos have given completely new insight in



changes affect the compass North direction everywhere. In Thule, for instance, the present temporal change in magnetic declination is around 1 degree/year.

Crustal magnetism

The highly accurate satellite-based models of the main field has enabled the precise determination of the magnetism in the Crust, the outermost solid layer of the Earth, which has a thickness of around 30-50 km. Figure 5 displays in colour code the results of the global mapping of the crustal magnetism. The dark red colour indicates mountainous regions where the crust is thick. In the oceans the crust is generally much thinner. The striped

structure is the combined result of the drift of the continental plates and magnetic field reversals. As the plates drift apart they leave an open rift from which fresh magma emerge. As the magma cools off to temperatures below the Curie point it then becomes magnetized in a direction depending on the actual magnetic field polarity, which may reverse from time to time.

Another use of the precise modelling of the crustal magnetism is the estimate of the heat flux from the Earth's interior to the surface. The level of crustal magnetism is used to calculate the depth to the layer where the temperature exceeds the Curie temperature, which for most magnetic minerals is in the range from 500 to 600 degrees, above which the material is non-magnetic. With an estimate of this depth it is now possible to calculate the heat flux from the interior to the surface, which could be the bottom side of the ice caps in Antarctica and Greenland. Figure 6 presents an analysis of the crustal thickness and the derived heat flux beneath the ice cap in Greenland. The analysis is the result of geomagnetic modelling based on measurements from the Ørsted satellite.

Figure 5. Model of remnant and induced magnetism in the Crust. (Cover page, Geophys. Res. Lett., 29 (15), 2002. M. Purucker)

the processes acting in the interior of the Earth that create its variable magnetic field. Using realistic models it has now been possible to reconstruct the changes involved in magnetic field reversals where the northern and southern magnetic poles exchange their positions. On the average such reversals have occurred every 250.000 years. The most recent field reversal occurred 780.000 years ago as the magnetic field first weakened and then almost completely disappeared to finally recover in the opposite direction.

On a smaller scale such changes of the dynamo processes are responsible for the secular variations in the global distribution of the strength of magnetic fields and for the changes in the position of the geomagnetic poles. Figure 4 displays the variable position of the northern magnetic pole through almost 500 years. The most recent positions have been determined from Magsat data (1980) and Ørsted data (2000) and from extrapolation using the new field models (2010-2020). Such

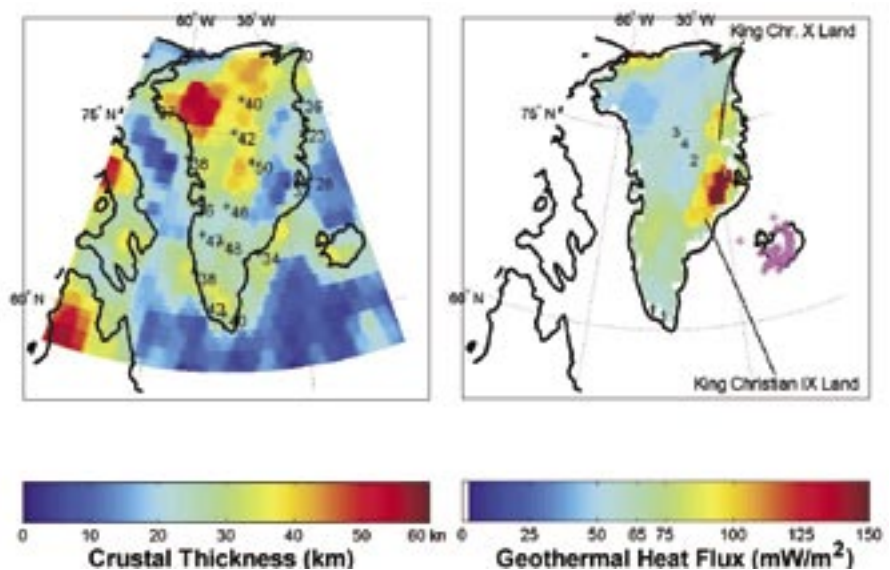


Figure 6. Crustal thickness and geothermal heat flux in Greenland calculated from modelling based on Ørsted geomagnetic observations. C. Fox Maule.

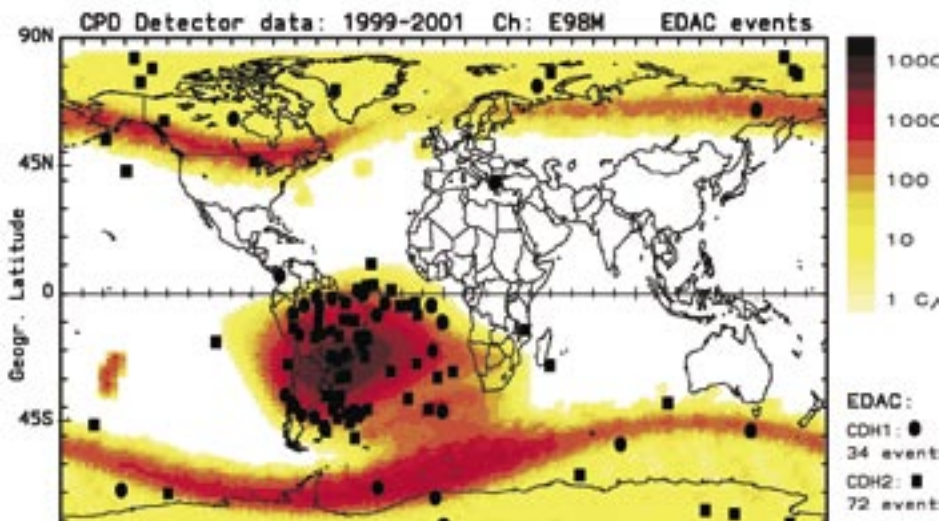


Figure 7. Ørsted detection of high-energy radiation (colour code) and occurrences of computer memory bit flips (dots).

Modelling of the heat flux to the bottom of ice caps is extremely important for the interpretation of ice cores drilled at various places in Greenland and in Antarctica. The analysis of ice cores provides us detailed information on the climatic conditions and atmospheric composition in the past. Such information is vital for predictions of the future climatic developments. In some locations the heat flux is strong enough to melt the bottom ice. Then the overlying ice cap is no longer firmly attached to the bed rock and may thus become extremely unstable to break off and slide away.

Radiation belts

The geomagnetic observations and the detection of high-energy particle radiation have helped us to understand the properties of the Earth's radiation belts. In these regions, the so-called Van Allen belts, high-energy electrons and ions may move around but they are still kept in place by the geomagnetic field. In regions where the magnetic field is weak these high-energy particles may approach the Earth and thus be detected by the Ørsted satellite in its rather low orbit (c.f., Table 1). This hard radiation may penetrate into the electronic units and cause damage on sensitive

satellite systems like memory circuits.

Figure 7 presents in colour code the global distribution of high-energy radiation at the satellite orbit and also the occurrences of memory bit errors detected by the satellite computer (EDAC events). These events are particularly frequent within the above-mentioned South-Atlantic anomaly, where the geomagnetic field is weak. Such EDAC events also occur in places like the polar regions, where the geomagnetic field is open toward the outer space and thus gives access to high energy particles from external sources like, for instance, the active Sun.

Summary.

The results from the Ørsted satellite mission can be summarized in the following points:

- The precise magnetic measurements conducted from the Ørsted satellite have provided basis for International Geomagnetic Reference Field models, which are used for many technical and scientific tasks, among other, to develop models for the internal geo-dynamo and its secular variations, to provide mapping of magnetic anomalies in the crust, and to estimate geothermal heat flux to the bottom of ice caps.

- The accurate magnetic measurements made at high time resolution have provided detailed mapping of electric currents in Space and have been used to study the coupling of the solar wind to the Earth's magnetosphere.

- The detection of high-energy particles from Ørsted has helped us to understand the properties of the radiation belts and the effects of high-energy radiation on satellite-borne computer circuits.

- The precise detection of the phases and amplitudes of GPS signals have helped the development of satellite-based methods to measure the atmospheric temperature and humidity profiles, which are essential parameters in meteorology.

- Ørsted has provided basis for more than 200 scientific publications in international journals and basis for more than 400 talks or posters presented at international scientific conferences.

The construction of the satellite and the analysis of data have been accomplished through a close national collaboration between three universities (Danish Technical University, University of Copenhagen, Ålborg University), eight private companies (Terma A/S, CRI, Copenhagen Optical Company, DDC International, Innovision, Per Udsen Co., Rescom, and Ticra), two institutes (DNSC and DMI). The international collaboration has included the large Space Agencies, NASA, ESA, CNES and DLR, and more than 40 universities and research institutes all over the world. This successful collaboration is perhaps the most brilliant accomplishment in the Ørsted satellite project.