The Ørsted Satellite Project

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Project Scientist for the Ørsted satellite

Introduction. 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, at 11:29:55 on 23 February, 1999, on the 11'th count down, 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. The aging has reduced the power delivered from its solar panels and has diminished the efficiency of the batteries needed for satellite operation in the Earth's shadow. One of the instruments, the so-called Star Imager, needed for precise information on the satellite attitude has been worn-out by the hard radiation environment. However, great care is exercised to nurse the satellite and the remaining instruments. 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. An updated publications list is included below.

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 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.

Table 1. Ørsted satellite specifications

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

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 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.

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 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 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.


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

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. 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.

![Figure 7. Ørsted detection of high-energy radiation (colour code) and occurrences of computer memory bit flips (dots).](image)
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 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 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.
Ørsted's many unique results

1. Frontpage illustrations in international science journals
2. Ørsted-based geomagnetic models

International Geomagnetic Reference Model IGRF2000
Degree/order of main field 13
Deg/order of secular variations 8
Deg/order of external field 0
References: Olsen, Sabaka and Tøffner-Clausen, Earth, Planets and Space, 52, 1175-1182, 2000

Orsted Initial Field Model (OFIM)
Degree/order of main field 19
Deg/order of secular variations 8
Deg/order of external field 0

Orsted Main and Secular Variation Model (OSVM)
Degree/order of main field 29
Deg/order of secular variations 13
Deg/order of external field 0

CHAMP-Oersted (CO2) Model
Degree/order of main field 29
Deg/order of secular variations 13
Deg/order of external field 2

Comprehensive Model CM3e_J-2
Degree/order of main field 65
Deg/order of secular variations 13
Deg/order of external field special handling

International Decade Earth Magnetic Model (IDEMM)
Degree/order of main field 49
Deg/order of secular variations 16
Deg/order of external field 2

CHAMP, Oersted, SAC-C model (CHAUOS)
Degree/order of main field 50
Deg/order of secular variations 16
Secular acceleration 16
Deg/order of external field special handling

International Geomagnetisk Reference Model IGRF2005
Degree/order of main field 32
Deg/order of secular variations 16
Secular acceleration 8
Deg/order of external field 2

3. Ørsted Publications (1999-2007)

Outreach and education publications (2003-07)


P. Stauning, Ørsted, the Danish Miracle in Space, Nordic Space; 15, (2), 2007.


P. Stauning: “Ørstedsatellitten – 6 års succes i rummet”. Dansk Rumfart, nr. 63, 2005


Ørsted Scientific (reviewed) Publications

Publications 2007


Publications 2006


Publications 2005


Fox Maule, C., Purucker, M., Olsen, N., and K. Mosegaard,


Han, D.-S., Longitudinal structure of low-latitude Pi2 pulsations obtained from the ground and Oersted observations, Ph.D. thesis of Kyoto University, March 2005.


Jung, H., Estimation Problems for Satellite Orbit and Attitude Determination and for GPS-Based Remote Ionospheric Sensing, Ph.D. Thesis, Field of Aerospace Engineering, Cornell University, 2005


Olsen,N., H. Lühr, Terence J. Sabaka, M. Manda, M. Rother, L. Teffner-Clausen, S. Choi, CHAOS – A Model of Earth’s Magnetic Field derived from CHAMP, Ørsted, and SAC-C magnetic satellite data, accepted for publ. in Geophys. J. Int.


Stauning, P., F. Christiansen, J. Watermann, and O. Rasmussen: Detection of intense fine-scale field-aligned current structures in the cusp region from the Ørsted satellite, in: Earth Observation with CHAMP, Results from Three Years in Orbit, C. Reiger et al., Eds., p. 381 Springer-Verlag, 2005.

Stauning, P., F. Christiansen, J. Watermann, and O. Rasmussen: On the modelling of field-aligned currents from magnetic observations by polar orbiting satellites, in: Earth Observation with CHAMP, Results from Three Years in Orbit, C. Reiger et al., Eds., p. 371, Springer-Verlag, 2005.


Stauning, P., F. Christiansen, and J. Watermann, On the modelling of field-aligned currents from magnetic...

Voorhies, C. V., A Geomagnetic Estimate of Mean Paleointensity, EOS, Trans. AGU, 85, (47), Fall Meeting Suppl. GP1C-0843, F635-6, 2004


Voorhies, C.V., Correction to Ibid, JGR, 109, B03106, 10.1029/2003JB002833, 2004

Published 2003.


Published 2002.


Publications 2001


Publications 2000


Publications 1999 and earlier.


4. Ørsted Conference Proceedings and Reports

Proceedings and Reports 2006:


Proceedings and Reports 2005:


Proceedings and Reports 2004:

Proceedings and Reports 2003:


Proceedings articles herein:

Cain, J.C., D. Mozzoni, and B. Ferguson, Where do we stand on geomagnetic modeling.


Iyemori, T., and V. Papitashvili, Storm time field-aligned currents detected by Oersted and CHAMP.


Kotzé, P.B., Secular variation characteristics over Southern Africa as revealed by observatory and satellite data.

Loves, F.J., and N. Olsen, A realistic estimate of the variances of the Ørsted OSVM (Ørsted 10b/01) spherical harmonic field model.

Macmillan, S., V. Lesur, Use of observatory data in geomagnetic field models and derivation of a crustal total intensity map.

Neubert, T., F. Sedgemore, F. Christiansen, and J. Watermann, Current filamentation observed with Ørsted.

Papitashvili, V.O., and F. Christiansen, Quiet, moderate, and storm-time high-latitude field-aligned currents from Ørsted and CHAMP magnetic field observations.

Parucker, M., T. Sabaka, N. Olsen, and S. Maus, How have Ørsted, CHAMP, and SAC-C improved our knowledge of the oceanic regions.

Parucker, M., and N. Olsen, Modeling of the Earth's magnetic field and its variations with Ørsted, CHAMP, and Oersted-2/SAC-C.

Risbo, T., J.L. Jørgensen, and F. Primdahl, Ørsted calibration mission: Status and overview.

Sabaka, T., and N. Olsen, Comprehensive modelling of the Earth's magnetic field: Current status and future prospects.

Stauning, P., Detection of currents in space by Ørsted, SAC-C and CHAMP geomagnetic missions.

Stauning, P., F. Primdahl, F. Christiansen, and J. Watermann, Detection of fine-scale field-aligned current structures from Ørsted.

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their comparison with other ground and satellite based observations and with models.


**Thomson, A.**, Satellite data selection and weighting for core field modelling in the presence of estimated external fields.

**von Frese, R.R.B.**, Advances in crustal and subcrustal studies from new generation satellite geopotential field missions.


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**Cain, J.C.,** O. Ajayi, D. Mozzoni, and C. Musat, Comparing an Ørsted-Observatory magnetic field model with the IGRF's.

**Cerisier, J.-C.,** C. Senior, and A. Marchaudon, Plasma convection and currents parallel to the earth magnetic field at the Ørsted orbit.

**Christensen, T.,** P. Stauning, F. Christiansen, and J. Thayer, Event study of high-energy electron precipitation by comparison of Ørsted data and ground-based observations.

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**Gjerlov, J.W.,** R. Fuji, M. Sugino, and Y. Ogawa, The Ørsted-EISCAT Conjunction Study

**Grammatica, N.,** M. Menvielle, and P. Tarits, Study of the diurnal variation at a global scale.

**Holme, R.,** Modelling of attitude error in Ørsted vector data.

**Hulot, G.,** A., A. Chulliat, A. Pais, B. Langlais, and M. Mande, Core surface flows derived from Ørsted data, tests and first estimates.


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**Moretto, T.,** F. Christiansen, and N. Olsen, Detection of ionospheric and field-aligned current patterns - A comparison of different methods.

**Newitt, L.R.,** The use of Ørsted data in regional magnetic field modeling.

**Neubert, T.** Ørsted Commissioning, Status and Future.

**Olsen, N.,** ØRSTED-2/SAC-C

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Yamashita, S., T. Iyemori, S. Nakano, M. Takeda, T. Kamei, A. Saito, T. Araki and M. Sugiyama, Middle latitude field-aligned current effects observed by Ørsted and a comparison with the Magsat and DE-2 observations.

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Conferences 2007


Conferences 2006


Conferences 2005

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Gaya-Pique, L.R., D. Ravat, A. De Santis, and J. Torta, 2005, New Model Alternatives for Improving the Representation of the Core Magnetic Field of Antarctica

Hemant, K., E. Thebault, M. Mande, D. Ravat, S. Maus, 2005, Merging airborne, marine and ground-based magnetic anomaly maps with satellite derived lithospheric field models.


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EGU General Assembly, Vienna, April 2005

Lagergaard, A.M.S., S Vennerstrom and E. Friis-Christensen, Observed and simulated field-aligned currents during northward IMF.


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**Lesur, V., S. Macmillan, and A. Thomson, Alternative parameterisation of the external magnetic field and its induced counterpart for 2001 and 2002 using Ørsted, CHAMP and observatory data.**

**Maulde, C. F., M. Purucker, N. Olsen, and K. Mosengaard, Magnetic crustal thicknesses in Greenland from CHAMP and ØRSTED data.**

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**Stauning, P., F. Christiansen, J. Watermann, and O. Rasmussen, Detection of intense fine-scale field-aligned current structures in the cusp region from the Ørsted satellite and from ground.**

**Wardinski, I., and R. Holme, New insights into the secular variation between MAGSAT and CHAMP/ØRSTED.**

**Watermann, J., P. Stauning, F. Christiansen, O. Rasmussen, H. Lühr, K. Schlegel, J.P. Thayer, and P.T. Newell, The low-altitude cusp seen from various perspectives: Multi-instrument observations during the February 2002 SIRCUS campaign.**

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**Golovkov, V.P., T.N. Bondar, S.V. Yakovleva, Space-Time Model for Obtaining Candidate Models for DGRF’95, and IGRF SV 00.**

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