Magnetic Field Modelling at the BGS and Readiness for Utilising Swarm Data

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Introduction

Using data from Ørsted, CHAMP and geomagnetic observatories, the British Geological Survey is deriving models of the Earth's magnetic field at least every year to gain a better understanding of the different magnetic field sources and to support various navigational applications. Research highlights over the past few years are summarised and recent modelling efforts for the World Magnetic Model and International Geomagnetic Reference Field are described here.

1. Data for modelling

As the models characterise the undisturbed magnetic field at or near the Earth's surface, data from satellites and observatories are selected which were collected during magnetically quiet periods on the night-side of the Earth.

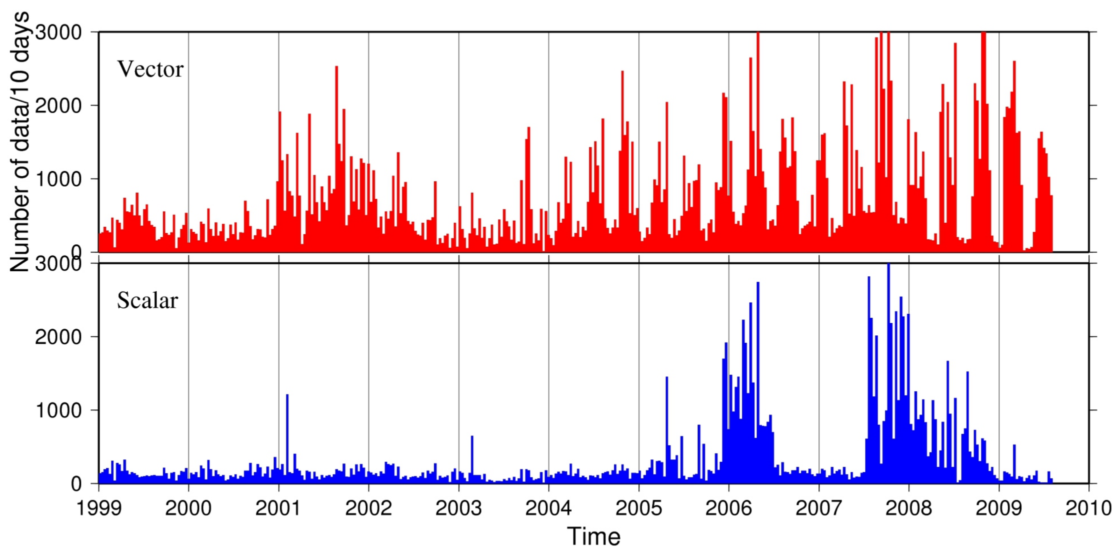
Every 60th satellite data from Ørsted and CHAMP (approx 1/minute) during 1999.2-2009.6 were sampled. A scalar data point was only considered if no vector sample was available.

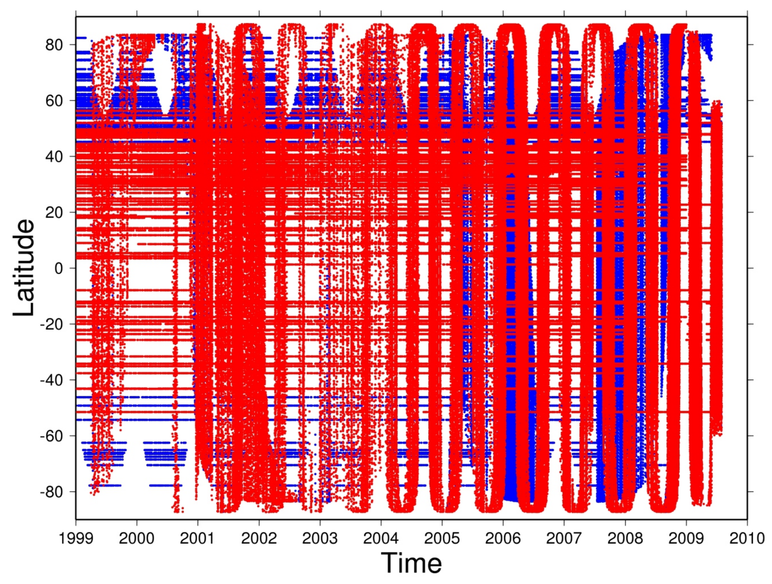
Magnetic indices	Kp for contemporary and previous 3 hours ≤ 2-, |dDst/dt| ≤ 5 nT/hour, IE (from IMAGE magnetometer chain) ≤ 30 nT, PC ≤ 0.2 mV/m
Solar wind data	0 ≤ IMF Bz ≤ 6 nT, -3 ≤ IMF By ≤ 3 nT, -10 ≤ IMF Bx ≤ 10 nT, solar wind speed ≤ 450 km/s
Other	22:30 ≤ local time ≤ 05:00, |observed value - value from *a priori* model| ≤ 100 nT, |scalar F from OVH – vector F from CSC| ≤ 2 nT

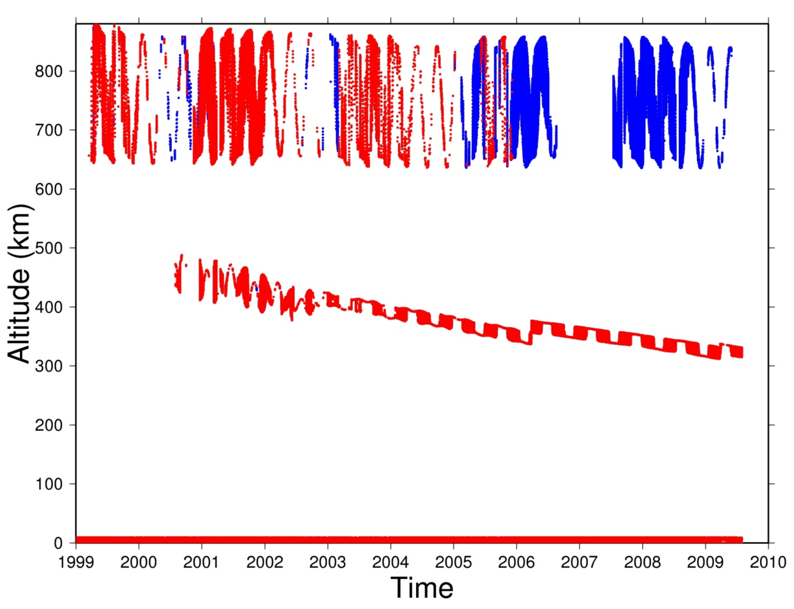
Hourly means from 152 observatories 1999.0-2009.5 (data during 2009 are preliminary INTERMAGNET data from selected observatories).

Magnetic indices	Kp ≤ 2+, |dDst/dt| ≤ 5 nT/hour
Solar wind data	IMF Bz ≥ 0 nT
Other	night-time (01:00 to 02:00 LT + darkness test at 110 km above observatory)

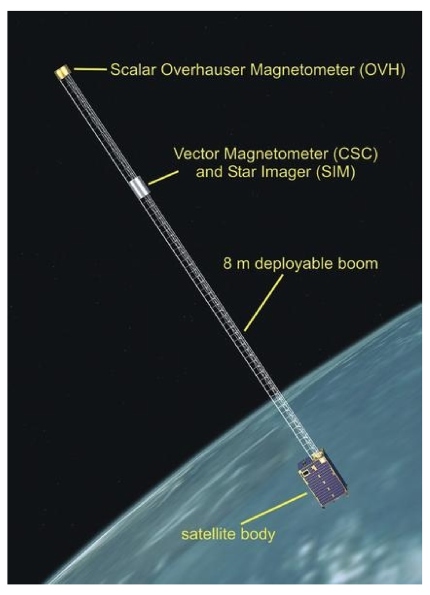
The distributions in space/time of all vector (red) and scalar (blue) data are shown below.





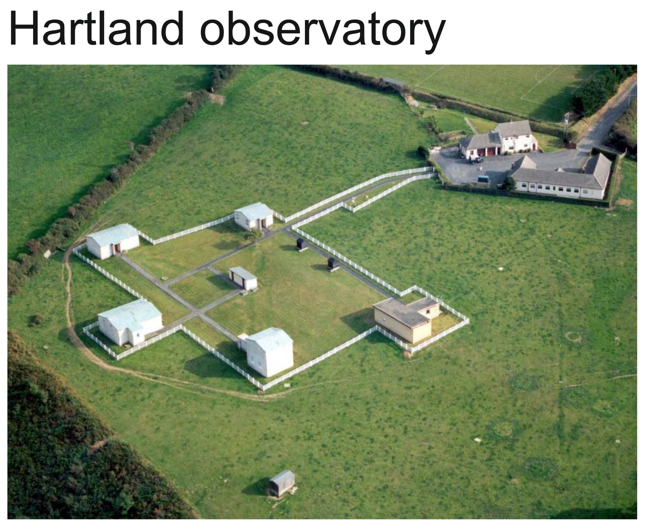


Ørsted



CHAMP

Hartland observatory



2. Data covariance matrix

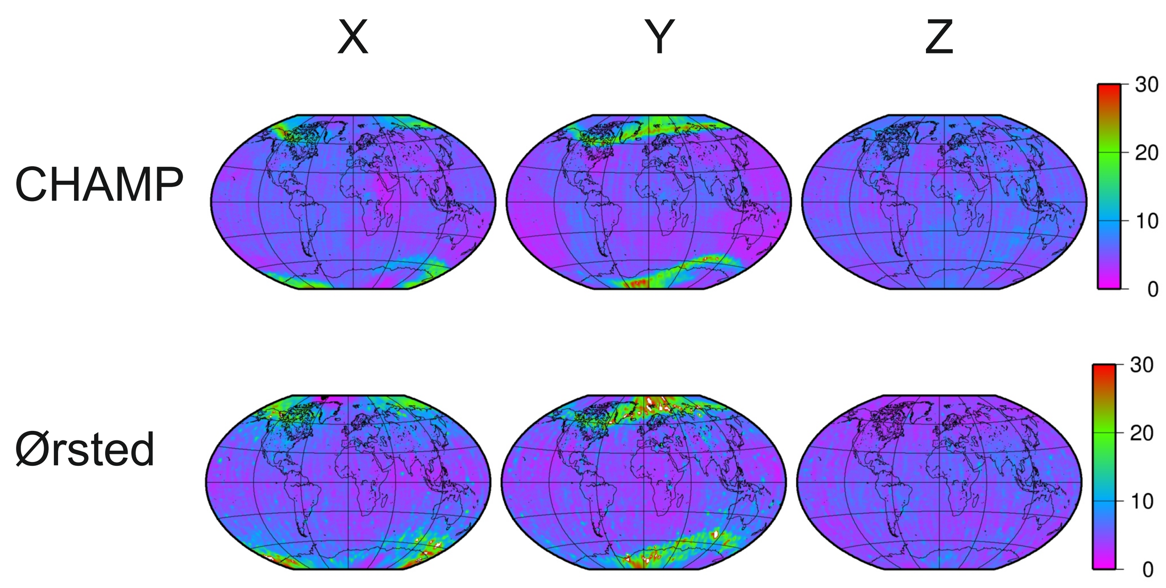
Variance for satellite data i in equal-area tessera j (off-diagonal terms are included for Ørsted data due to anisotropic error of star camera) is calculated by

$$\sigma^2_{i,j} = K.f\,(SD_i, LAVA_i, n_j)$$

K	4 nT^2 for vector data, 36 nT^2 for scalar data
SD_i	along-track (20 samples ~ 150 km) standard deviation
$LAVA_i$	index derived from data at 3 (max) nearest observatories to detect *unusual* magnetic activity for data location *i*
n_j	number of data in equal-area tessera *j* (compensates for high density near poles)

Observatory variances = K and are scaled according to mean satellite variances with and without SD_i and $LAVA_i$.

Shown here are the square roots of the variances without the data density (n_j) factors, averaged over the duration of satellite data. Satellite data over the auroral zones are assigned higher variance. This helps extend the use of vector data to all latitudes.



3. Deriving the Models

The models include terms for the internal field, large-scale external field and crustal field at the observatories. They are spherical harmonic models and are derived by iterative reweighted least squares, first assuming a Gaussian distribution of errors (L2 norm) then a more realistic Laplacian distribution of errors (L1 norm). A 300-core Clustervision High Performance Computing facility at BGS is used for the inversion. The magnetic potential is the sum of an internal potential (V^{int}), an external potential (V^{ext}), a potential dependent on the 20-minute Vector Magnetic Disturbance index (V^{vmd}) and a potential dependent on annual and semi-annual variations (V^{ann}):

$$V^{int}(\theta,\phi,r,t) = a\sum_{l=1}^{l=20}\sum_{m=-l}^{+l} g_l^m(t)\left(\frac{a}{r}\right)^{l+1} Y_l^m(\theta,\phi) + a\sum_{l=21}^{l=60}\sum_{m=-l}^{+l} g_l^m\left(\frac{a}{r}\right)^{l+1} Y_l^m(\theta,\phi)$$

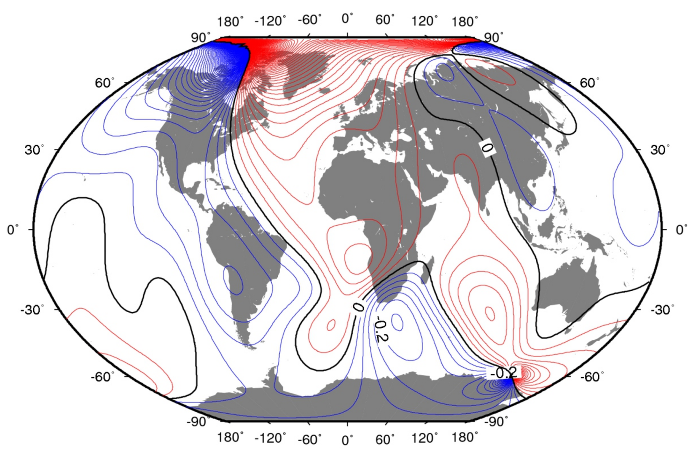
$$V^{ext}(\theta,\phi,r,t) = a\sum_{m=-1}^{+1} q_l^m(t)\left(\frac{r}{a}\right) Y_1^m(\theta,\phi)$$

$$V^{vmd}(\theta,\phi,r,t,vmd) = a\sum_{m=-1}^{+1}\left\{\left[a_{1,m}+ta_{2,m}+a_{3,m}VMD_m^{int}(t)\right]\left(\frac{a}{r}\right)^2 + \left[b_{1,m}+tb_{2,m}+b_{3,m}VMD_m^{ext}(t)\right]\left(\frac{r}{a}\right)\right\} Y_1^m(\theta,\phi)$$

$$V^{ann}(\theta,\phi,r,t) = a\sum_{m=-1}^{+1}\left[i_m(t)\left(\frac{a}{r}\right)^2 + e_m(t)\left(\frac{r}{a}\right)\right] Y_l^m(\theta,\phi) + a\sum_{m=-1}^{+1}\epsilon_m(t)\left(\frac{r}{a}\right) Y_l^m\left(\theta,\tilde{\phi}\right)$$

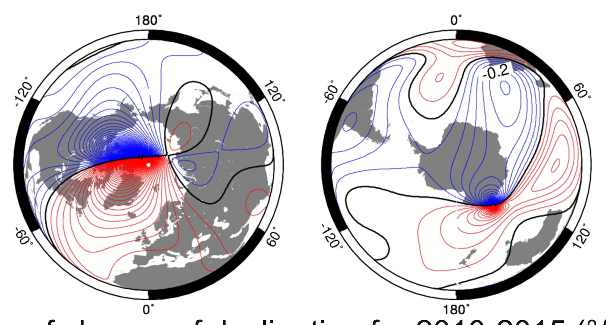
4. World Magnetic Model

The World Magnetic Model is derived through a collaboration of BGS and the US National Oceanographic and Atmospheric Administration. It is revised every 5 years and we are presently working on the next revision which will be valid for 2010-2015. It is widely used in military and civilian navigation systems.



5. IGRF

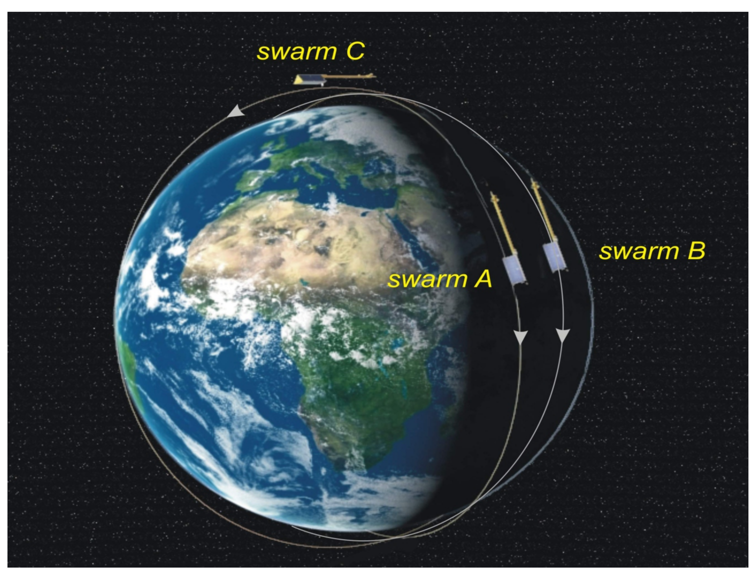
The 11th generation of the International Geomagnetic Reference Field is currently being determined by a Task Force of the International Association of Geomagnetism and Aeronomy. We have submitted candidate sets of coefficients.



Rate of change of declination for 2010-2015 (°/yr)

6. How Swarm will help

Swarm will provide essential data for magnetic field models. The main advantage of Swarm over one satellite will be the improved determination of external fields. One thing we hope to do with the data is to derive an hourly estimate of the large-scale magnetospheric field. We also hope to develop existing algorithms appropriate for selecting and weighting of satellite data from a constellation. Improved understanding of ionospheric fields, particularly in the polar regions, should also help us in crustal field mapping and determining core flows within the tangent cylinder.



Acknowledgments

The CHAMP mission and data center is operated by GeoForschungsZentrum Helmholtz Zentrum, Potsdam, Germany, supported by the German Aerospace Center (DLR) and by the Federal Ministry of Education and Research (BMBF). The Danish Space Center and the Ministries of Trade, Research and Transport operates the Ørsted satellite mission and data center. Many institutes and agencies are involved in the operation of geomagnetic observatories around the world. The INTERMAGNET program and the World Data Centre for Geomagnetism at Edinburgh assist in the quality control and dissemination of observatory data. Magnetic activity indices are computed and provided by GeoForschungsZentrum Helmholtz Zentrum (Kp) and World Data Center for Geomagnetism in Kyoto (Dst). Solar wind data are measured by the ACE satellite and made available by NASA. This model could not have been produced without the efforts of all of these institutes.

References

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RAS Swarm meeting
London, 9 October 2009