The Swarm DISC (Data, Innovation, and Science Cluster) is a consortium of more than 30 research institutions funded by ESA with the goal of deriving scientific Level-2 products by combination of data from the three Swarm spacecraft together with observations from other sources such as ground based observatories and complementary space missions. Here, we present the results of the Swarm DISC team at DTU Space and NASA Goddard who conducts the Comprehensive Inversion (CI) magnetic field modeling project chain which takes full advantage of the Swarm constellation by doing a comprehensive co-estimation of the magnetic fields from Earth’s core, lithosphere, ionosphere, and magnetosphere together with induced fields from Earth’s mantle and ocean tides using direct field measurements as well as single and dual satellite gradient information. This is complemented by data from 180 geomagnetic ground observatories around the world as well as modelled platform magnetometer data from the CryoSat-2 mission. We present the results from using 10 years of Swarm data denoting our model CIY10. Level-2 products containing the corresponding model parameter estimations are distributed via ESA at ftp://swarm-diss.eoa.esa.int/Level2Inversion/ (see also https://earth.esa.int/swarm).

### Model Parametrization, Data, and Data Selection

#### Table: Comprehensive Model Parametrization

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Number of Coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core</td>
<td>Spherical harmonic expansion up to degree 5, order 5 appropriate with year long smoothing, regularisation of the 27th and 3rd derivative of B.</td>
<td>5,700</td>
</tr>
<tr>
<td>Lithosphere</td>
<td>Spherical harmonic expansion up to degree 19, order 19. Regularisation of high degree terms.</td>
<td>14,260</td>
</tr>
<tr>
<td>Atmocore</td>
<td>Spherical harmonic expansion in quasi-global form (with underlying order 7).</td>
<td>50,590</td>
</tr>
<tr>
<td>Magnetospheric field</td>
<td>Geomagnetic field estimated in two steps: First, data from magnetically quiet conditions (see “Data Selection” to the left) are used to estimate the “Quiet time” model. Second, all data are used to estimate the “Full time” model.</td>
<td>106,170</td>
</tr>
</tbody>
</table>

Swarm satellite data for this work consist of magnetic field measurements version 0620/03 for the period 25 November 2013 through November 2023 with gross outliers removed and decimated to 45 second sampling rate. Along-track differences (“gradients”) are formed by taking single satellite differences separated by 15, and then further formed from the three Swarm spacecraft Alpha, Beta, and Charlie; satellite magnetometer measurements at equal geographic latitude temporally separated by typically 4 to 15 seconds. The optimum satellite constellation for the cross-track differences was obtained and maintained since mid-April 2014 except for May-June 2022 and May-April 2023 where the altitudes of Alpha and Charlie were raised causing larger separation between the two spacecraft. To avoid the essential doubling of the number of data along the tracks of Alpha and Charlie, the 45 second samples are taken intermittent between Alpha and Charlie. Magnetic data denoting our model CIY10. Level-2 products containing the corresponding model parameter estimations are distributed via ESA at ftp://swarm-diss.eoa.esa.int/Level2Inversion/ (see also https://earth.esa.int/swarm).

### Magnetic Field

The part of the lithospheric field of degree n ≤ 19 is determined from nighttime scalar and vector data as well as from along-track (North-South) and cross-track (East-West) differences from all local times. Vector differences are used at low latitudes (GD latitude below 45°) whereas scalar differences are used at all latitudes. We obtain excellent agreement between our model and the L5S- (extension of Olsen, 2016) up to degree at least 105. and very good agreement with the Swarm DISC model of the University of Nantes (MLISHA_2, Thebault) up to degree 100 above which the Thebault-Nantes model shows a sudden jump in comparison possibly due to a transition of their model from a global to a regional, non-satellite based surveys, basis.

### Residual Statistics and Weights

The data residual statistics of the quiet time data vs. the comprehensive model (with “Quiet time” magnetospheric model included in the database). Grey circles indicate data from 1-hour (1-h) bin, white circles show data from 6-hour (6-h) binning, and squares show data from 24-hour (1-day) binning. The green curves show theoretical values based on the joint conductivity models of ETH (Grayver 2018), which demonstrates quite good agreement through out the mission period. The red line shows the data residuals and the blue line shows the model predictions.

To the right, plots of the power specras of the secular variation (SV) respectively secular acceleration (SA) of CIY10, CHAOS-7, Thebault, and LCS-2. Similar plots are shown for CIY10 from Swarm satellite data. The power spectra show the magnetic field variability in the frequency domain and are a useful tool for understanding the noise and signal characteristics of the magnetic field observations. The power spectra are calculated using Welch’s method with a Hamming window and a 25% overlap.

To the right plots show the power spectra of the secular variation (SV) and secular acceleration (SA) of CIY10, CHAOS-7, Thebault, and LCS-2. The grey circles indicate data from 1-hour (1-h) bin, white circles show data from 6-hour (6-h) binning, and squares show data from 24-hour (1-day) binning. The green curves show theoretical values based on the joint conductivity models of ETH (Grayver 2018), which demonstrates quite good agreement through out the mission period. The red line shows the data residuals and the blue line shows the model predictions.

### Acknowledgements

The author thanks Terence J. Sabaka for developing the concept of the Comprehensive Inversion.

### References

Fink, C. G., et al., The CHAOS/7 geomagnetic field model and observed changes in the South Atlantic Anomaly, Earth, Planets and Space, 72 (DOI: 10.1186/s40627-020-01259-9), 2020


Livermore, P. W., et al., An accelerating high-latitude jet in Earth’s core, Nature Geoscience, 13, 63–68. (DOI: 10.1038/ngeo3265), 2020

Olsen, N., et al., LCS-1: A high-resolution global model of the lithospheric magnetic field derived from CHAMP and Swarm satellite observations. Geophysical Research Letter, (ISSN: 0094-8276); (DOI: 10.1029/2015GL065128), 2016


![Image of Earth's magnetic field](Image)