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British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Concerning BGS activities for the Swarm Data, Innovation, and Science Cluster

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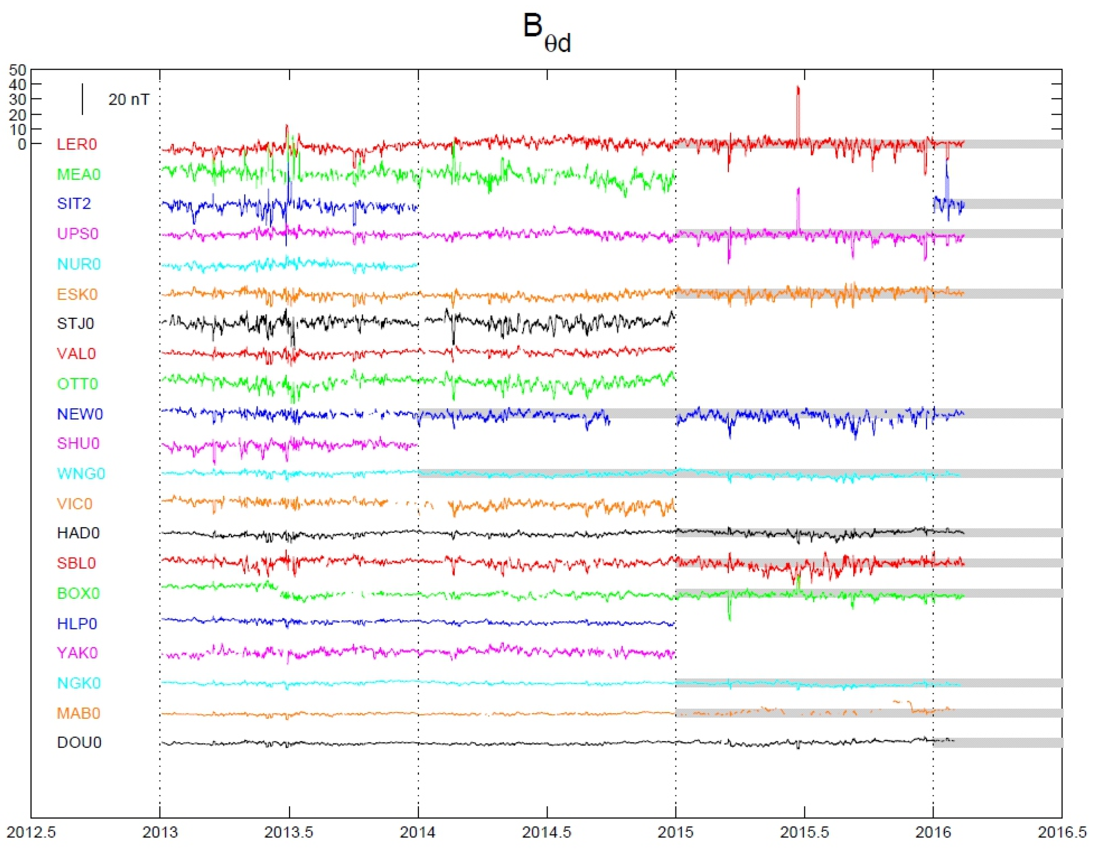
The British Geological Survey (BGS) is responsible for the Swarm Level-2 fast-track magnetospheric field model product (MMA_SHA_2F), Quick-Look (MAG_QL and EFI_QL) and geomagnetic observatory data (AUX_OBS_2_) products and VALidation of many of the Level-2 CAT-1 products, as part of the consortium of institutes making up the Swarm Data, Innovation, and Science Cluster (DISC). We summarise these activities and provide updates on recent progress.

Geomagnetic Observatory Data

Ground-based magnetic data are used in a variety of ways when analysing satellite data. Selecting satellite data often involves the use of magnetic disturbance indices derived from ground-based stations. And inverting satellite magnetic data for models of fields from various sources often requires ground-based data. Ground-based data can also be valuable independent data for validation purposes.

Prior to use in magnetic field models, close-to-definitive observatory data are regularly collated from INTERMAGNET and other sources and combined with definitive data from WDC Edinburgh. As the observatory data are of variable quality it is necessary to make a manual selection and to eliminate poor quality data. Detecting such data in individual observatory time series is sometimes hard but looking at data from multiple observatories at the same time is more revealing. Cleaned-up hourly mean data are then made available from the ESA data centre and on the BGS geomagnetism FTP server once every three months as AUX_OBS_2_ files[1].



(a) Examples of observatory hourly mean Quality Control plots for the dipole northward (theta_d) component of some observatories in northern hemisphere. All signals in the data that can be characterised or modelled, except at high latitudes, are removed from the data. The residuals (left) can be indicative of measurement artefacts. Poor quality data can then be excluded. Grey background denotes quasi-definitive data.

Plots are produced every 3 months and made available at ftp://ftp.nerc-murchison.ac.uk/geomag/smac/IMAG_QD/

(b) Suspended Tri-axial Fluxgate magnetometer; typical of a variometer instrument found in magnetic observatories around the world.

(c) Locations of currently operating observatories in 2016 (according to IAGA).

(d) Number of INTERMAGNET observatories producing 1-minute means and 1-second values as either variometer (v) provisional (p) or even quasi-definitive (q) data, up to four days after collection.

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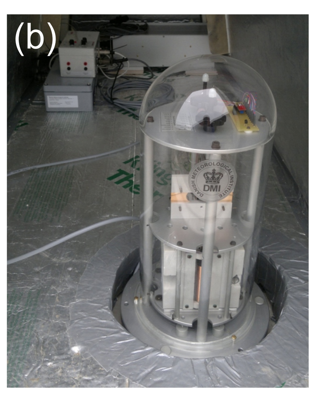

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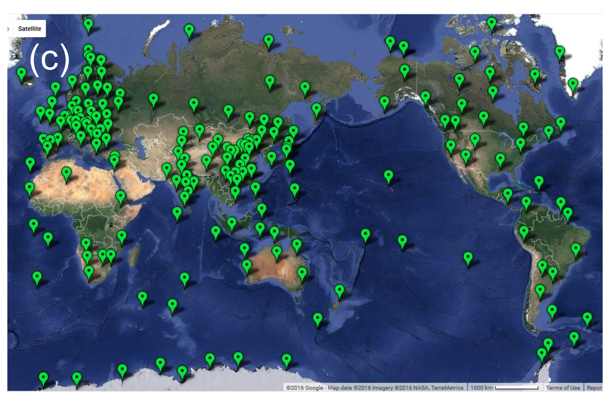

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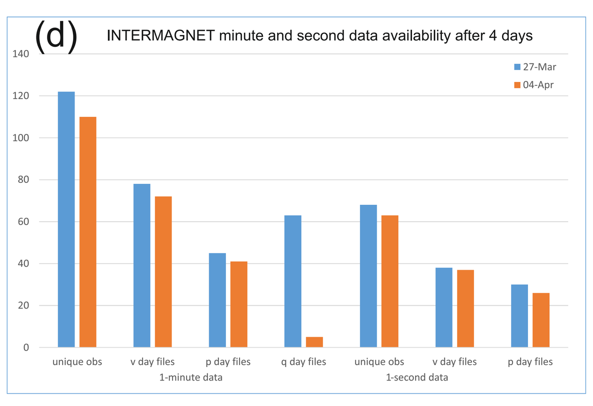

Because of the excellence of the Swarm magnetic and plasma data there is now a growing user group concerned with rapid variations whose sources are outside the Earth. These users are less concerned about the data being definitive or close-to-definitive but require higher resolution and more rapid delivery, possibly daily 1-second files with 4-day delay to match that of Swarm.

The standard observatory product is 1-minute means, however with instrument and data-processing upgrades an increasing number of observatories are producing 1-second data. With the same latency as Swarm data, about 120 INTERMAGNET observatories are generating 1-minute means as either variometer (v) provisional (p) or even quasi-definitive (q) data. About 60% of these are producing 1-second data. BGS are now working to compile minute- and second-mean data for the Swarm mission at a similar cadence to the Level 1b MAG products.

Validation

The BGS Validation work package examines the DISC-produced Swarm-derived magnetic field models to other independent models and data where possible, and also makes inter-comparisons of models from the dedicated and comprehensive processing chains. A validation report is written to describe each of the models and their differences before release to the public. An example of plots from recent validation reports are shown below. Nearly 30 reports have been written since Swarm lauched in 2013.

Swarm Core Field Models: Cross-Comparison

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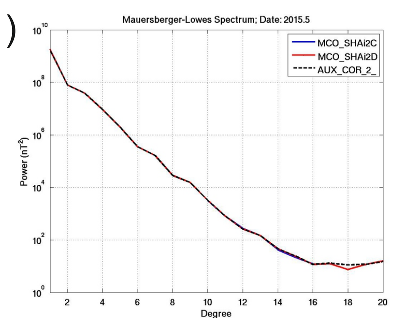

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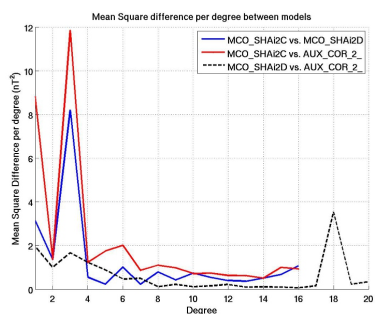

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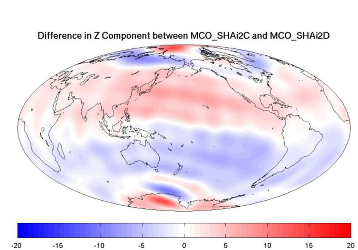

Swarm Lithospheric Field Model: Comprehensive

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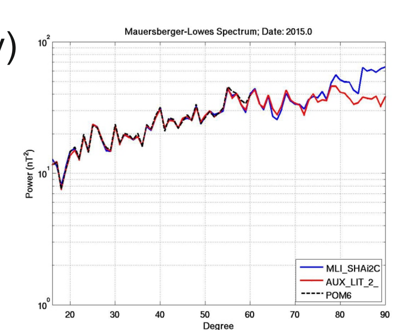

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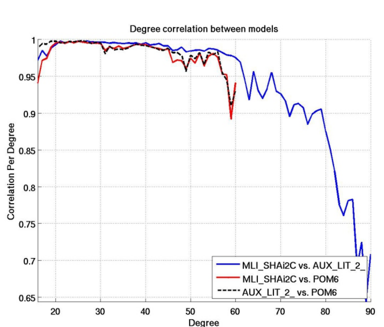

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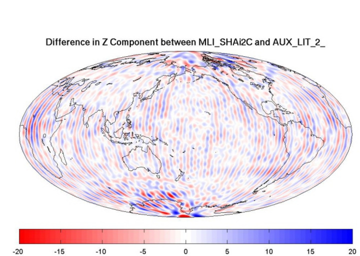

Swarm Magnetospheric Field Model: Comprehensive

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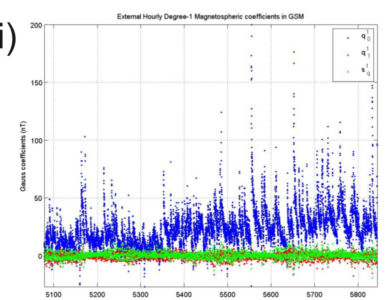

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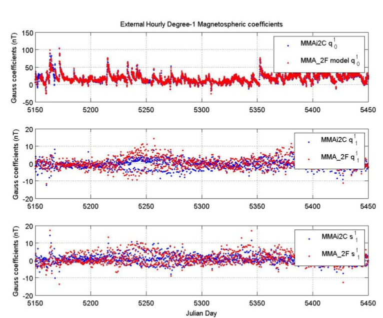

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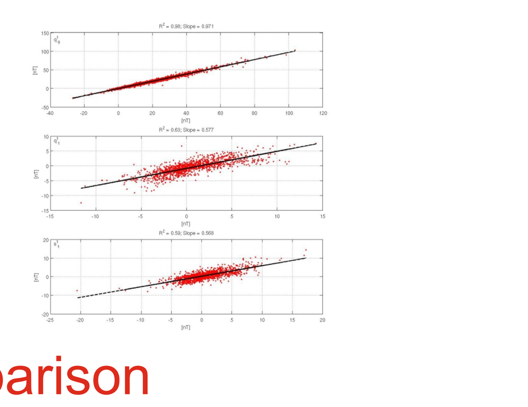
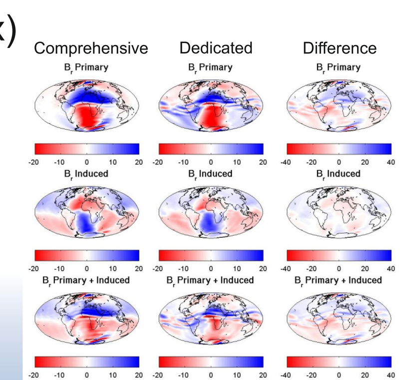


Swarm Ionospheric Field Model: Cross-Comparison

(x)


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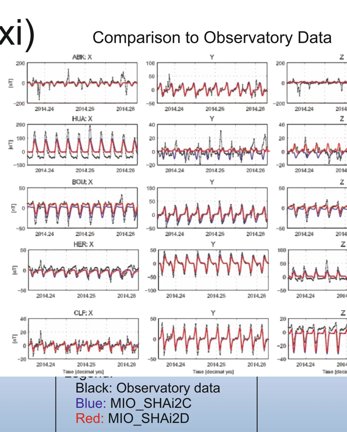
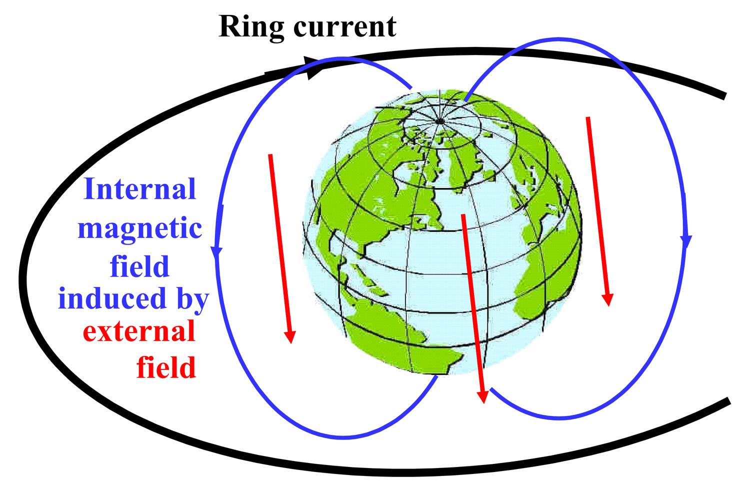
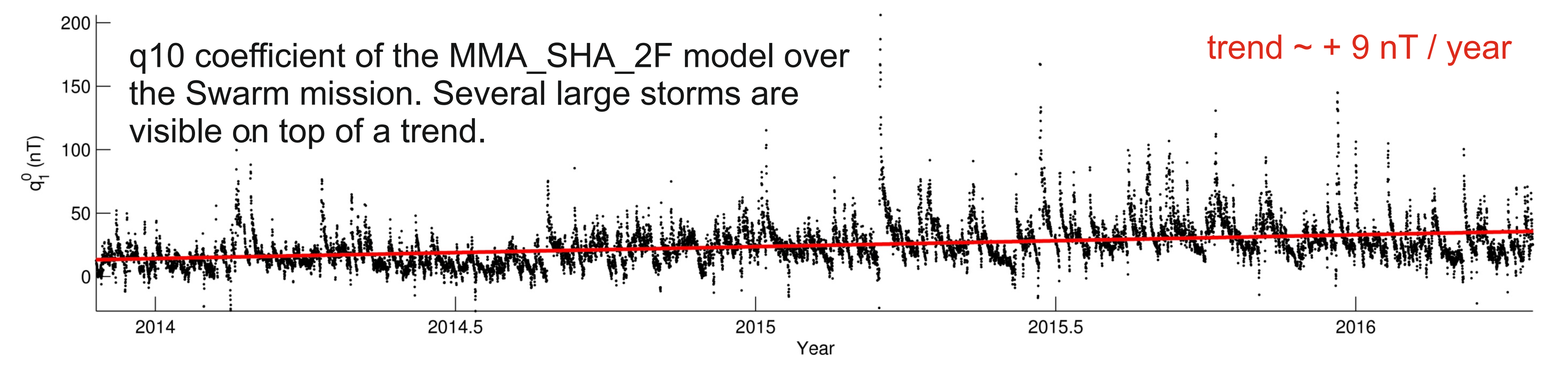


MCO_SHAi2C vs MCO_SHAi2D:
(i) Power spectra (ii) Mean square difference per coefficient; (iii) Difference in the Z component of two models.
MLI_SHAi2C:
(iv) Power spectra (v) Degree correlations between coefficients of two other independent (AUXiliary) models; (vi) Difference in the Z component of the Swarm and independent models.
MMA_SHAi2C:
(vii) Time series of the Degree-1 coefficients of the external magnetospheric field; (viii) comparison to the MMA_SHA_2F product; (ix) correlation between models
MIO_SHAi2C vs MIO_SHAi2D:
(x) Comparison of the radial components and difference at 12:00UT; (xi) Comparison to selected ground observatories after core, lithosphere and magnetospheric models have been removed.

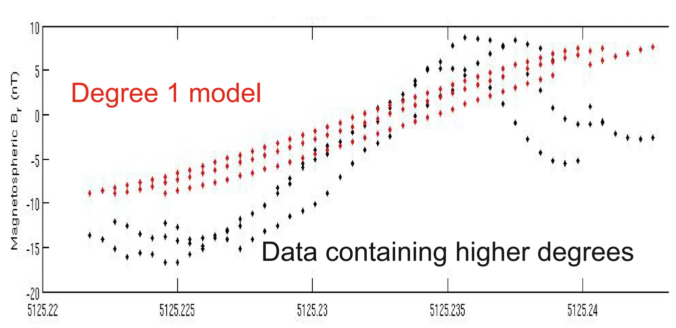
Fast-Track Magnetospheric Model

The fast-track magnetospheric field model (MMA_SHA_2F) product is a spherical harmonic degree 1 model generated automatically on a daily basis at BGS after receipt of the Swarm L1b files, and delivered to ESA for onward public dissemination. As the time series of magnetospheric field estimates lengthens, long-term trends and patterns can be extracted. As the mission continues, the satellites continually cycle through different local times / orbit orientations relative to the Sun-direction. Furthermore, the Swarm B satellite drifts in local time relative the other two satelites. These changing configurations and their effects on the models are investigated further.



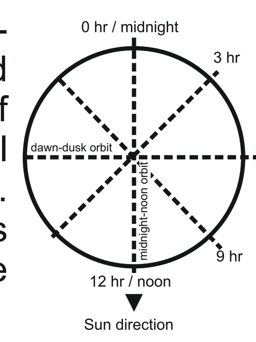


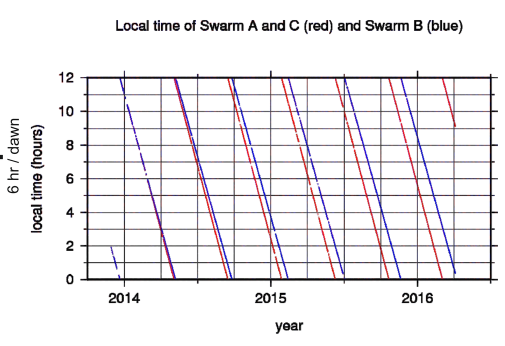
External q10 coeff shows trend increase since Swarm launch, possibly tracking solar cycle. Such trends are not visible in indices like Dst/Est/Ist[2,3,4,5] and VMD[8], which intentionally remove longer-period variations. A comparison with the comprehensive model is shown in the **Validation** section of this poster.

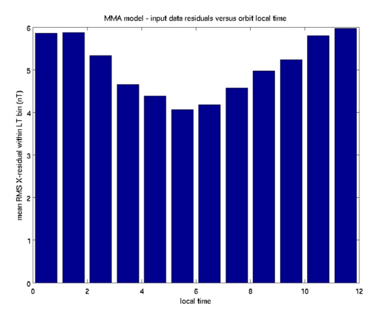


Real magnetospheric fields have higher degree (>1) signals[6] caused by current systems other than the symmetric ring-current. Figure left shows input data (black) and modelled (degree 1) field (red) over a single night-side half-orbit. Some higher degree fields will be *local-time dependent*. These local-time dependencies may be visible in residuals between data and model and also in any contamination of the model from higher degrees.

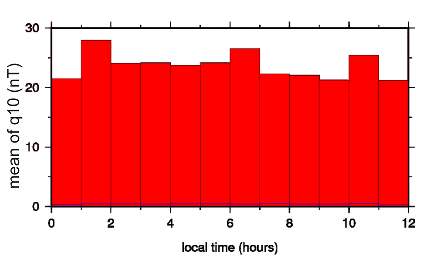
Swarm satellites continually drift in local time. In near-right figure, we take local time of orbit to be defined between 0 and 12 hours. Far-right shows evolution of Swarms A & C versus B over mission to date. All local times have been sampled at least 6 times to date. Swarm B leads Swarms A & C in local time and this has grown to almost 3 hours in 2016. We can examine the models and residuals ordered by local time.





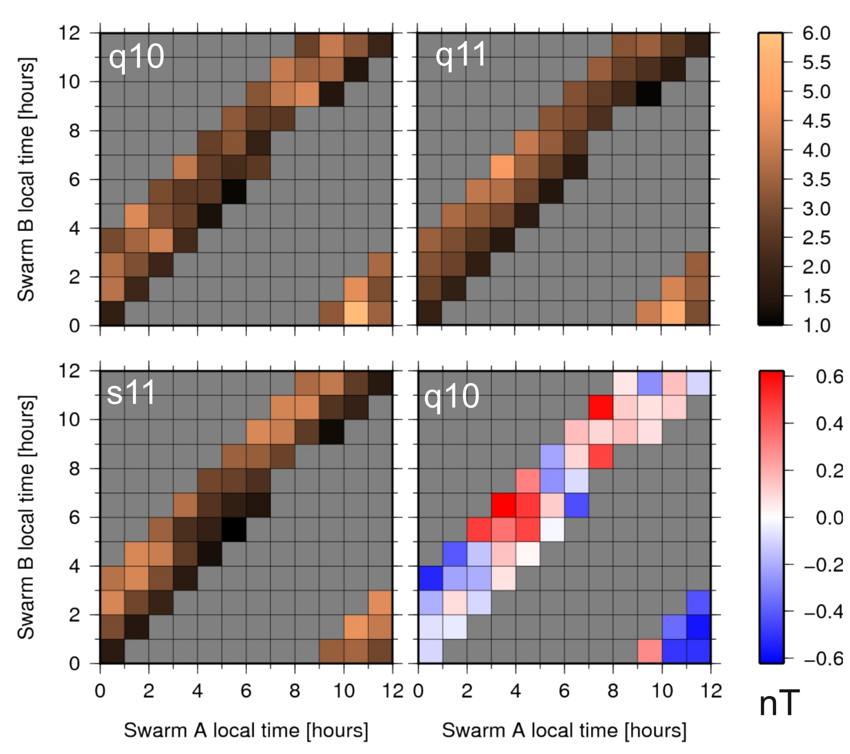


The data used to derive the magnetospheric models have already been pre-processed to subtract a priori core-, lithospheric-, and ionospheric[7]-models. Figure left shows mean RMS-residuals between these processed data and the magnetospheric models binned by orbit local-time configuration. The residuals are clearly larger around noon-midnight orbits (0/12hr) compared with dawn-dusk (6hr). This may be due to imperfect ionospheric signal subtraction on the day side.



The figure left shows the quiet-time mean q10 coefficient of the model (a uniform field aligned with geomagnetic dipole) that shows some local-time dependence, being slightly stronger for orbits orientated after midnight and before dawn. This may result from the enhanced influence of asymmetric (e.g. partial) ring currents in the magnetosphere. But the effect of imperfect ionospheric model subtraction, which is also local-time dependent, may also contribute.

RMS- and mean-differences between model coefficients from Swarm A vs B



Mean-differences are in the sense: Swarm A's coefficient minus Swarm B's

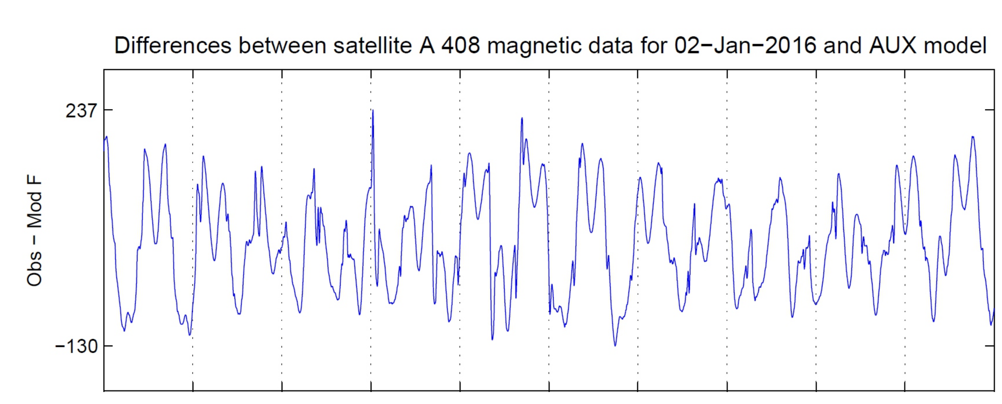
The Swarm constellation allows simultaneous measurements at different local times. Models produced from Swarms A & B *separately* can be examined for local time effects. This is concisely shown in figure left. Grids show RMS- and mean-differences between the external coefficients binned by each combination of Swarm A and B local times. At the start of the mission, Swarms A & B were at the same local time, represented by the diagonal line form (0,0) to (12,12) (note that two outliers have been removed). These show smaller RMS differences compared with the models from diverging satellites, plotted off this centre line. Furthermore, the differences do not vary so much with local time when the two satellites are in similar orbits but more structure is visible as they diverge. There appears to be a slight increase RMS differences away from the dawn-dusk orbits for q10 and s11. The mean differences in the q10 coefficient (bottom-right panel) also tend to increase in magnitude as the satellites separate and are typically more positive (Swarm A's greater than B's) near dawn-dusk orbits compared with noon-midnight.

At the moment it is difficult to distinguish what is causing the differences in model output for different local times. Both imperfect a priori model subtraction and asymmetric magnetospheric currents would have a local-time effect. As the Swarm mission continues, more data will be collected and more of the sample space shown in the above grids will be filled, hopefully making it easier to identify the processes involved.

Quick Look

The quick-look products are generated automatically on a daily basis at BGS after receipt of the L1b files, and are intended for internal use and inspection of the Swarm data.

An example of one of many outputs is a daily comparison of data to a priori models to highlight any problems that may not be visible by inspection of only the data themselves.



Acknowledgements

Data from the Swarm satellite mission for the observatory QC plots were provided by the European Space Agency (ESA), supported by ESA member states. Many institutes and agencies are involved in the operation of geomagnetic observatories around the world. . The INTERMAGNET program and the ICSU World Data System (primarily World Data Centre for Geomagnetism, Edinburgh) assist in the quality control and dissemination of observatory data.

References

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[6] Luhr, H. and S. Maus, Solar cycle dependence of quiet-time magnetospheric currents and a model of their near-Earth magnetic fields, Earth Planets Space, 62, 843–848, 2010.
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