Swarm Fast Track spherical harmonic model of the external magnetic field to degree and order 3

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Introduction

Magnetospheric currents

The interaction between the solar and terrestrial magnetic fields is a complex and rapidly varying. Magnetic reconnection within the Earth's magnetosphere has been recognised as the cause of geomagnetic storms. These are events where the magnetic energy is converted into thermal energy warming up the plasma and accelerating the particles in the terrestrial system and, as a consequence, the electromagnetic field measured at the Earth's surface is disturbed.

Measurements

There have been various models of the magnetospheric and ionospheric current systems, and some are complex and computationally intensive. However, measurements are limited to in-situ spacecraft data. There are various single-point missions studying different regions of the magnetosphere, and there have been also past multi-point imaging missions, i.e. THEMIS (5 spacecrafts distributed over the magneto tail on the equatorial plane) and Cluster (4 spacecrafts flying in a close, tetrahedral formation), see Rajan et al, (2022).

Spherical harmonic global extrapolation

In this work, we have used the ESA SWARM satellite constellation to probe the near earth ring current using global spherical harmonic analysis to obtain 3D global measurements in real time. We have validated our inversion and created a database of this potential field dating back to the beginning of the mission in 2013 to date.

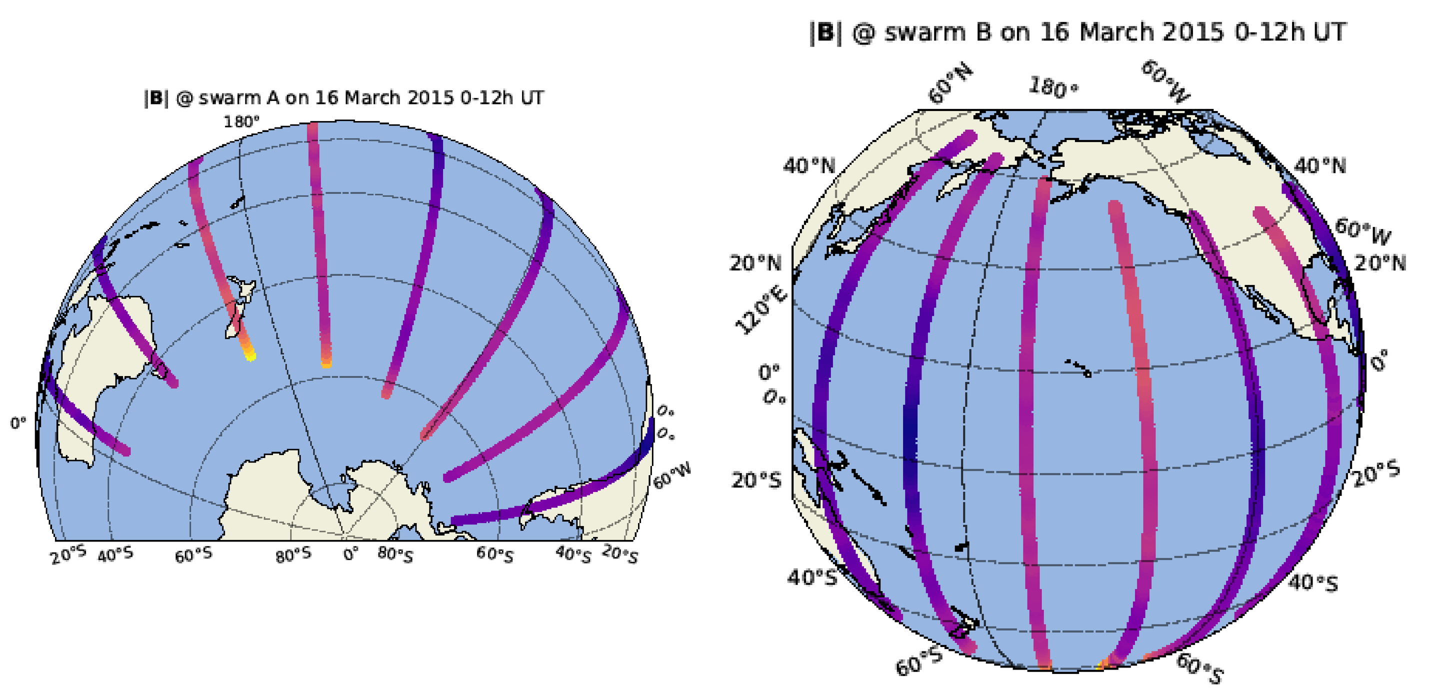

Figure 1
Magnetic field residual magnitude measured at the satellite altitude SWARM A (left) and SWARM B (right). This data set here belong to the selected data tracks on the night side measured on March 16th from 0h to 12h UT. The angular separation between the orbits in 2015 is about 25 degrees

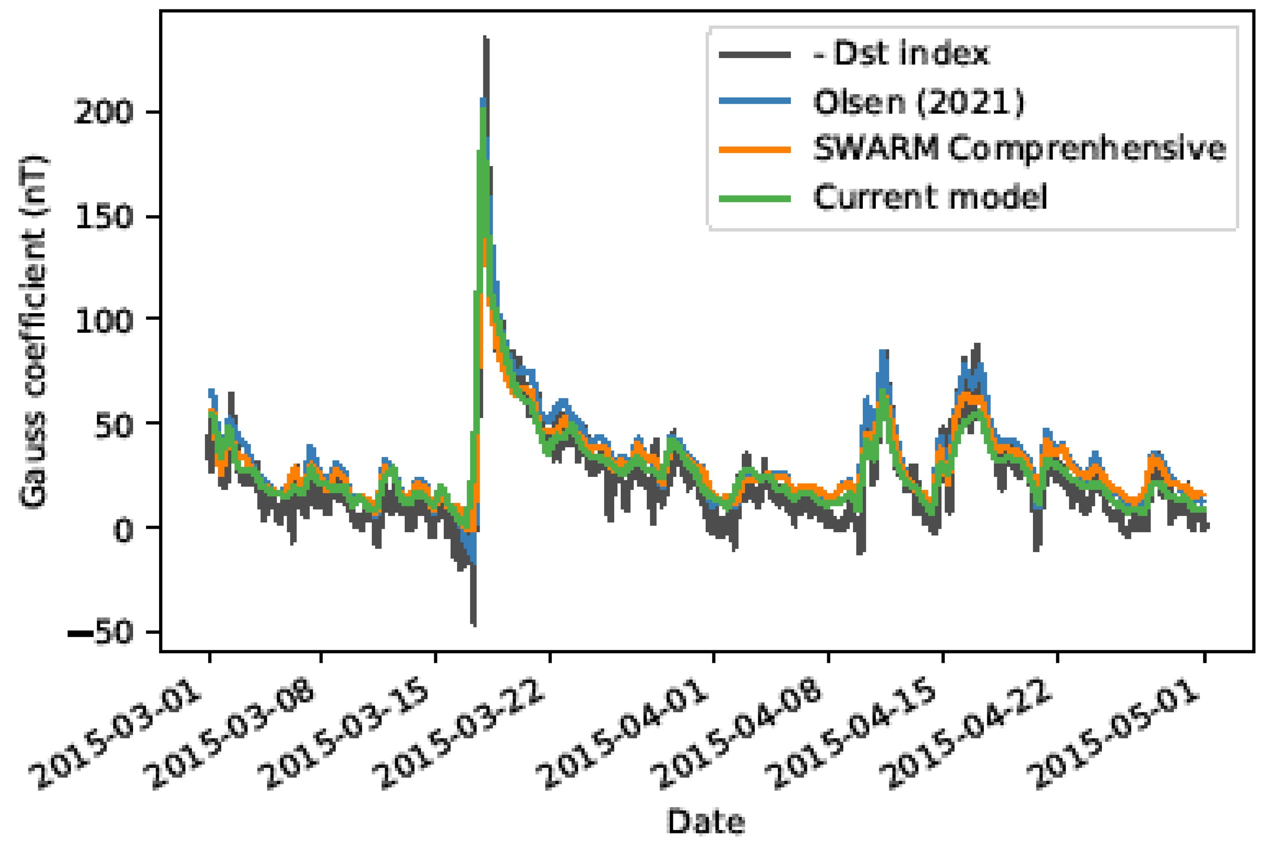

Figure 2
Time series of the external axisymmetric dipole gauss coefficient, and the negative of the definitive Dst-index for two months including the St Patrick's day geomagnetic storm in 2015. We compare our results with an independent model, SWARM comprehensive solution, as well as an equivalent model, Olsen 2021 (this paper employs the same method but uses 5 different spacecraft instead of 2).

Methodology

Using the residual (i.e., data minus the geomagnetic field from IGRF) data from Swarm A and Swarm B we select tracks on the night side with dipolar latitude between +/-56 degrees, as shown in Figure 1. We use the method described by Grayver et al. (2021) using the Q-response matrix to separate internal and external contributions. In the case of the Swarm satellites the external field on the night side is dominated by the signal from the ring current . In order to do the inversion we need sufficient data coverage in latitude and longitude, so if the field sources do not vary significantly during a time interval Δt, then we could assume that earlier and later measurements refer to the same source but they are taken in a different location. In Figure 2 we have used a Δt=12h and we used this data set (each of the three components instead of the magnitude shown in Figure 1) to determine one single snapshot on the plot in Figure 2.

We have produced two models from data since the start of the mission in 2013 to date. The first model is done with a 8h cadence, and maximum degree 2, the second with a 12h cadence and a maximum degree 3.

The ring current and the magnetosphere balances change rapidly during geomagnetic storms (with periods smaller than 8h). We do not have enough samples to capture those fast changes in the magnetosphere and we can only describe the field averaged every 12h, as shown in Figure 2. We have down sampled other models (blue and orange curves) in order to compare with the current model.

Results

Validation

Using data form Swarm A and Swarm B, we are able to calculate the spherical harmonic terms of the external field at satellite altitude. In Figure 1 we show a times series of the q_1^0, the external (imposed) axisymmetric dipole, and we show the same coefficients from the Swarm Comprehensive model (in orange), the model reconstructed in Olsen (2021) (in blue) and the negative value of the Dst-index. We have also compared the higher multipoles (equatorial dipole and degree 2 components) in Solar Magnetic coordinates and they match reasonable well from all three models. We have also compare with results from Grayver et al (2021).

Symmetry

The ring current is known to be asymmetric with respect to local time, being more intense on the night side. The Dst-index correlates with the q_1^0 (Figure 2), which is an axisymmetric part of the external inducing field, however the non-zonal components are dominant in the ring current and are needed to characterise the behaviour and energy transfer during geomagnetic storms.

With our algorithm we can use this decomposition up to degree and order 3.

Conclusions

We have been able to separate the external and internal fields for Swarm spacecraft measurements. This can be done in near-real time and the cadence depends on the data spatial (latitudinal and longitudinal) coverage. The coverage depends on the orbital plane separation between the two spacecrafts and the orbital period. The larger the orbital plane separation the better the coverage (up to 90 degrees), however this changes with time.

We can reproduce features in higher spherical harmonics time series from the St. Patrick storm in 2015 when compared with a better local time coverage model (Olsen, 2021). We are confident that we are able to reproduce the higher harmonics despite the rapidly changing magnetospheric currents. We constrain our measurements to the night time so our data has a hemispherical bias that introduces aliasing in our results.

With this new Fast-Track processing pipeline, we will be able to process the smaller scale features of the ring current in near real time.

Bibliography

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