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Use of Swarm gradient field data to improve lithospheric field models

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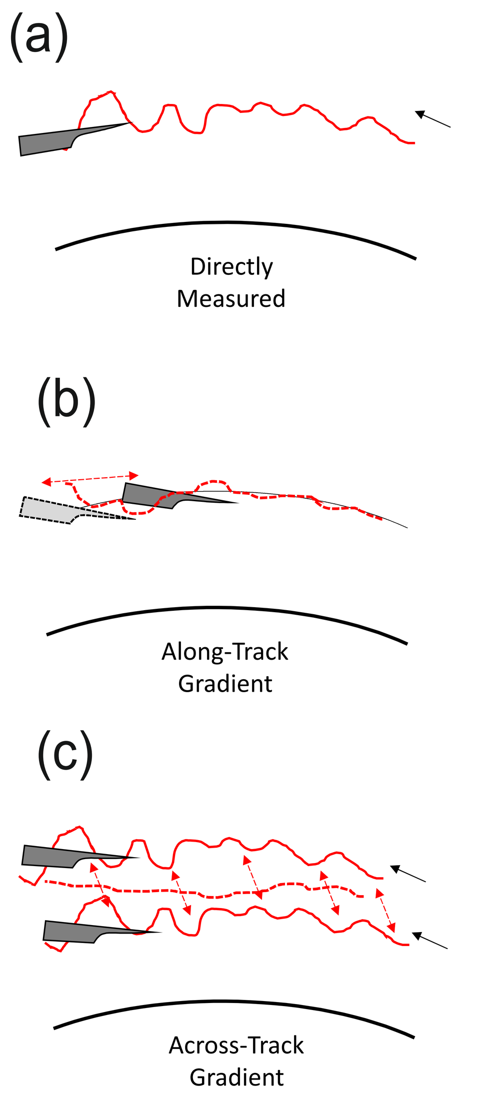
The Swarm mission, launched in November 2013, consists of three identical satellites designed to measure the magnetic field to the highest resolution ever. One of the Swarm mission's unique aspects is the ability to measure the magnetic field at approximately the same location using two satellites (Swarm A and Swarm C) which travel close to one another at the same altitude.

Using measurements of the gradient of the field between the satellites (i.e. across-track) removes much of the external magnetic field's influence in the data, leaving the contribution from the steady internal field, each time the satellites pass over the same location [Ref. 1].

In combination with measurements of the satellites' along-track differences this adds a new capability that can be exploited to produce models of the crustal magnetic field with higher accuracy than ever before. As the mission accumulates more data at lower altitudes, our understanding of the Earth's magnetic field will continue to improve.

We apply a Slepian decomposition technique to the new BGS lithospheric field model to analyse the relative contributions to the magnetic field from the ocean and continents, which may be useful for geological applications.

What is Field Modelling?



To produce a model of the magnetic field, we collect data from Swarm (and other satellites) and remove the known contributions of the main field and the external magnetospheric field to leave just the lithospheric field.

The data points are inverted to form a model of the magnetic field described using Spherical Harmonic coefficients. This method is useful for compactly describing the magnetic field across the globe in a small number of parameters.

However, there are still several issues in terms of noise within the *directly measured* data:

- Ionospheric currents in the auroral regions
- Field-aligned currents in the polar regions
- Large-scale magnetospheric currents
- The polar gap from the satellite orbit

Some of these noise issues can be overcome by using the *along-track gradient* (the difference between measurements at two points in time) and the *across-track gradient* (east-west difference between two satellites). Swarm uniquely allows across-track gradients to be measured and used in lithospheric field models.

What are the Input Data?

The latest BGS lithospheric field model is defined for spherical harmonic degrees 16-133 (~300 km resolution). It is derived from CHAMP and Swarm vector and scalar magnetic field data which have had a core field and magnetospheric field model removed prior to inversion (CHAOS5-v4 [Ref. 2]). We use an iterative residual re-weighting scheme from Tarantola [Ref. 3] to down-weight the influence of noisy data. Figure 1 shows the input data.

The model employs (a) 391,348 CHAMP data from altitudes below 300 km, along with (b) 380,978 along-track gradient measurements of (r, θ, φ) derived from the same CHAMP dataset. The Swarm data consist of (c) 38,720 across-track values from Swarm A and Swarm C, taken at altitudes of between 442 and 530 km and (d) 171,398 along-track measurements. For comparison, the model values from CHAOS-5 are shown in (e) and (f), which closely match. All data were selected during geomagnetically quiet-times from the night-side portions of the respective satellite orbits. Data cadence is 15 seconds.

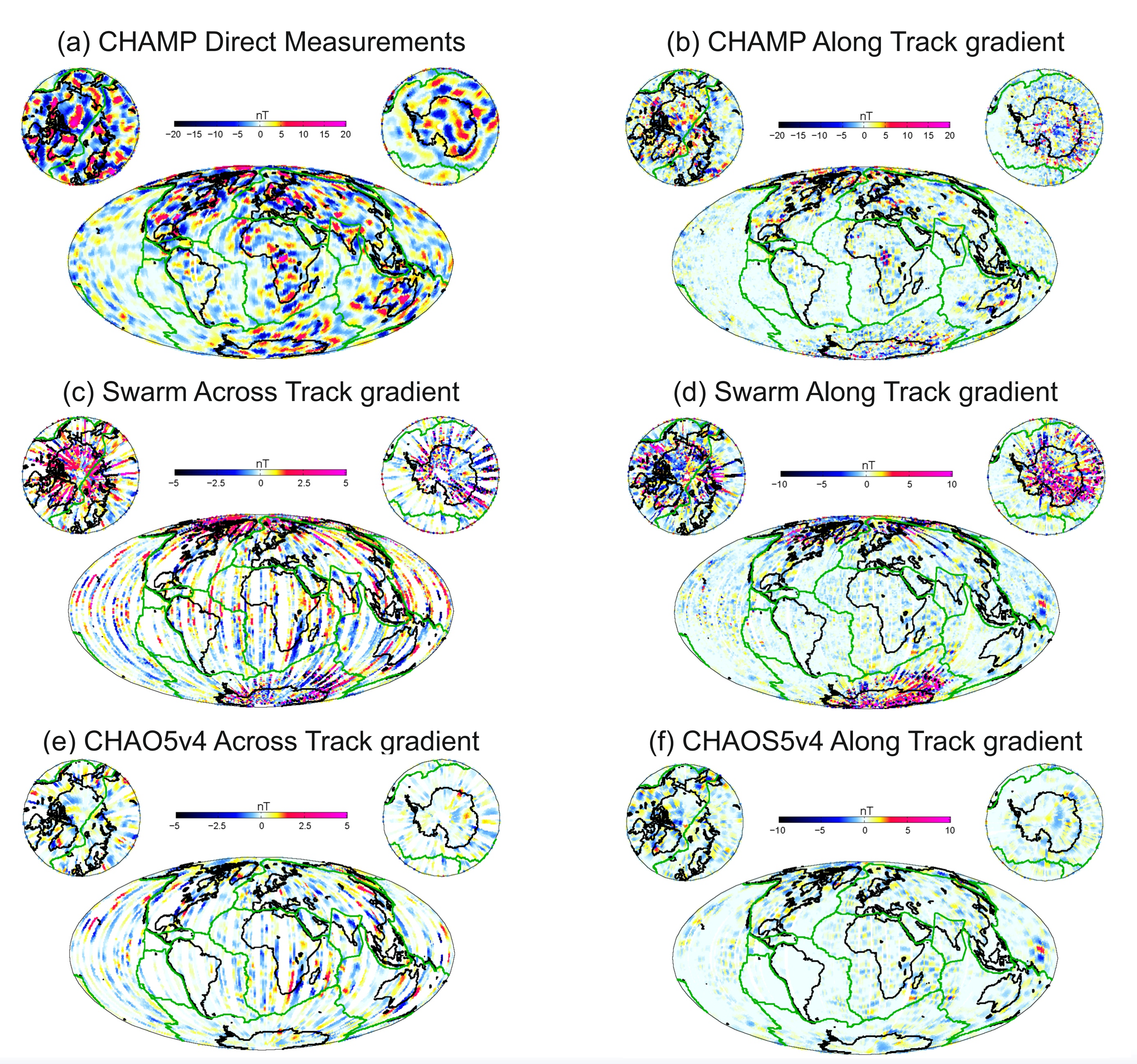


Figure 1: (a) CHAMP observed radial lithospheric field (with CHAOS-5 core and magnetosphere removed); (b) CHAMP along-track radial gradient data; (c) Swarm A and C across-track radial gradient; (d) Swarm A and C along- track radial gradient; (e) CHAOS5v4 model across-track radial gradients and (f) CHAOS5v4 model along-track radial gradients are shown for comparison.

The BGS Lithospheric Field Model

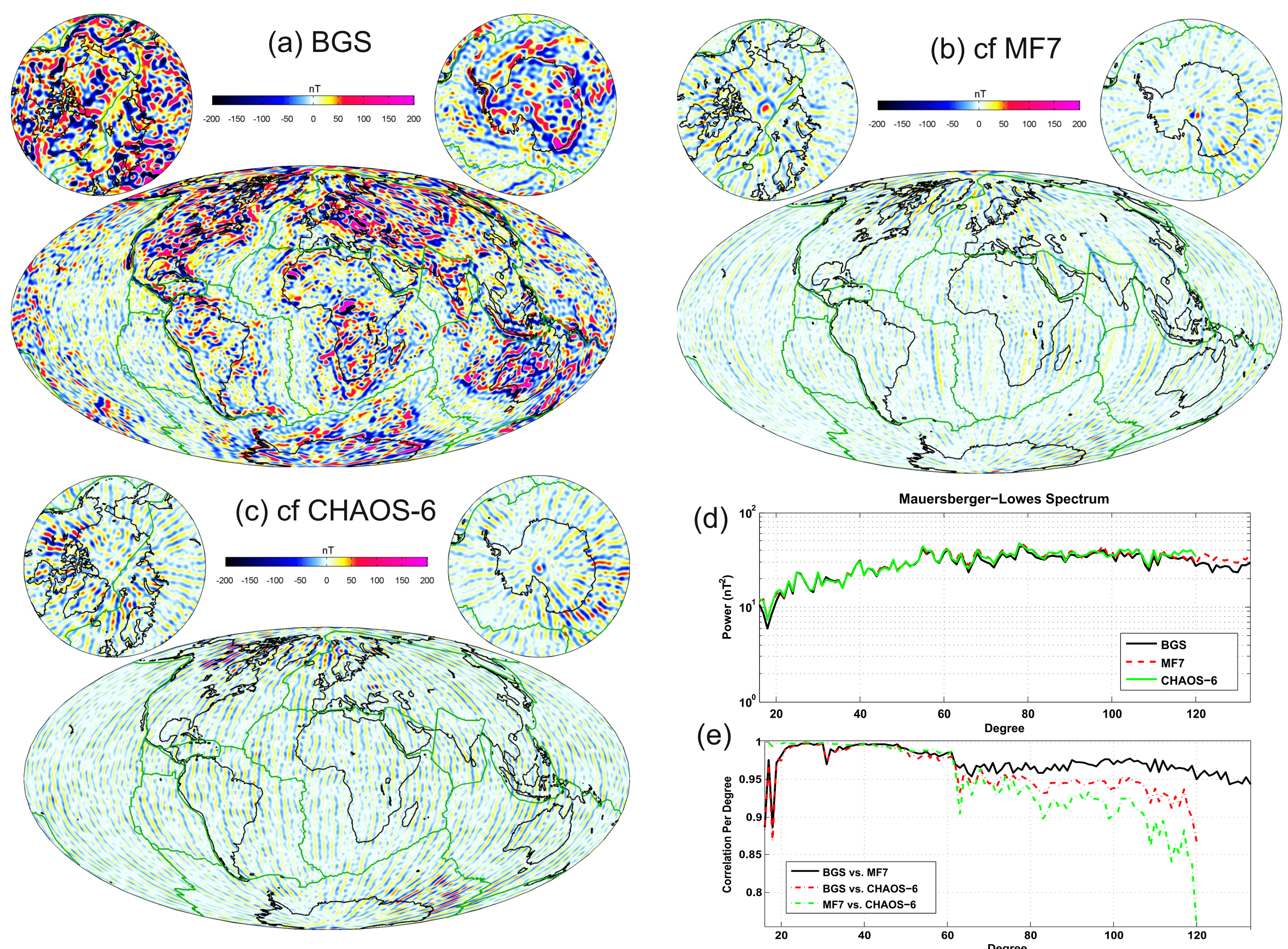


Figure 2: (a) Map of the radial component of the BGS lithospheric field model and (b) differences to MF7 (for degree 16-133); (c) differences to CHAOS-6 (for degrees 16-120). (d) Power spectra and (e) degree correlation between the three models.

Figure 2 shows the comparison of the BGS lithospheric model to the MF7 [Ref. 4] and CHAOS-6 models. Panel (a) shows the radial (outward pointing) component of the magnetic field. The differences between the BGS and other two models are shown panels (b) and (c). The Lowes-Mauersberger power spectrum of the models and the degree correlation between the models are shown in panels (d) and (e), respectively.

The spatial differences betwen the models are small, consisting of north-south striping with some indications of the auroral zones around the polar regions. The spectra are closely matched, though the BGS model has less power than MF7. The BGS and MF7 model correlate well out to degree 120, while the CHAOS-6 model is less well correlated with the BGS model above degree 105.

Analysis using Slepian functions

Slepian functions are a type of mathematical basis function which can be used to optimally divide a spectro-spatial dataset into one or more parts [Ref. 5]. In this study, the crust has been divided into two regions, oceanic and continental, similar to the analysis of [Ref. 6], though this is the first time such a high degree model (N=16-133) has been analysed in this manner.

The oceanic crust has much lower energy than the continental crust at all nearly degrees (spatial wavelengths). A comparison of the spectra of the BGS lithospheric model to that of MF7 shows differences mainly at the higher degrees in the continental region. The differences may be attributable to the use of the gradient method in the BGS model, particularly at higher degrees (> 120), though there will also be effects arising from the different methodologies used to make the models.

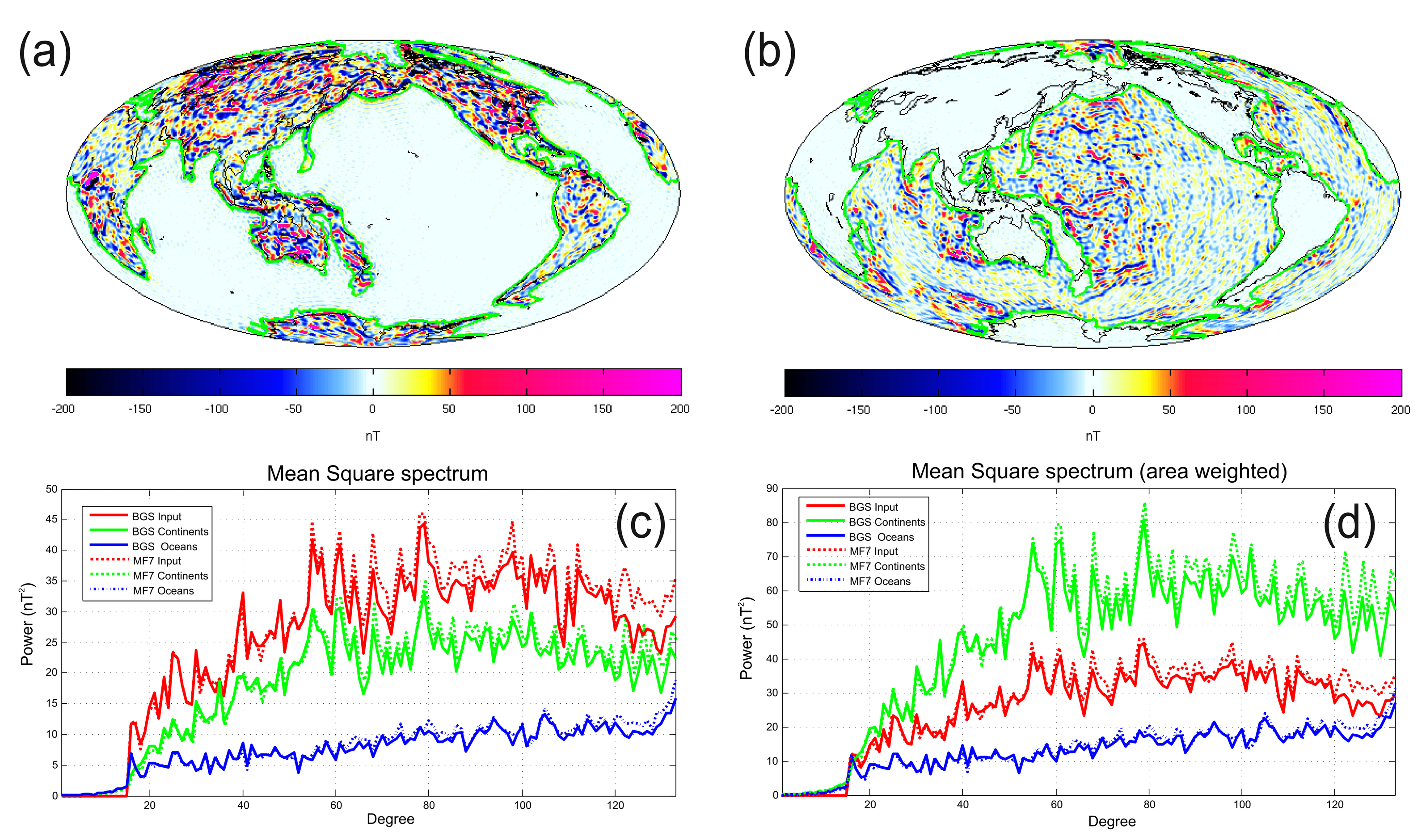


Figure 5: (a) Continental separation and (b) oceanic seperation using spherical Slepian functions. (c) Spectra of the separation from the BGS model and the MF7 models up to degree and order 133. (d) Area-weighted spectra of the BGS model, showing the true power in each region.

Future Improvements

The ESA Swarm mission is providing an unprecedented volume of quality magnetic field data to the community. This is allowing researchers to produce better and better models as more data are collected, particularly during quiescent periods when conditions are suitable for lithospheric field measurements.

The iterative nature of the modelling process means that as the characterisation of the other sources (core, external fields etc) improves, the lithosphere will also improve. As the lower part of the Swarm constellation descends over the mission, the resolution of crustal field models should improve to degree 150 and beyond.

Acknowledgements and references

The Swarm mission and data centre are operated by the European Space Agency. GFZ Helmholtz Zentrum Potsdam runs the CHAMP data centre.

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