Using Swarm Satellite Data to Improve Global Geomagnetic Reference Modelling

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• Dr. Ciaran Beggan
• Using Swarm Satellite Data to Improve Global Geomagnetic Reference Modelling
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• British Geological Survey
BGS Geomagnetic Referencing

- **BGGM** – global field model
  - includes quiet night time external field and long wavelength crustal field (> 300 km)

- **IFR** – combines internal field with estimates of local crustal field
  - higher spatial resolution of crustal field at drilling site (~1km)

- **IIFR** – combines IFR with estimates of field from external sources
  - higher time resolution (1 min)
  - supplied in real-time

Reducing uncertainties
Overview

• The Earth’s Magnetic Environment
• ESA Swarm Mission
• Secular variation: Jerks, IGRF and Model Updates
• Modelling Uncertainties
• Summary
Earth’s Magnetic Field

- Dominant core field varies over months to years (±60,000 nT)
- Fields due to complex current systems in the ionosphere and magnetosphere vary from seconds to years (±60 nT)
- Localised crustal field stable through time (±10 nT)
- Now resolving ocean tides induced fields (±2 nT)

Credit: GFZ,DTU
Global Magnetic Field Modelling

- Spherical harmonic ‘degree’ of model represents spatial resolution
- Produced annually since 1990s
- A high temporal and spatial resolution
- Most models describe time-varying main field and include crustal and some external fields
- Accurately quantified errors (compared against ground measurements)
**ESA Swarm Mission**

- CHAMP, Ørsted satellites have driven previous decade of modelling development
- Novel 3-satellite constellation
- Launched November 2013
- Two lower satellites (A and C)
- Swarm B flies in different local time orbit
- Unique multi-satellite magnetic gradients (A and C)
- Currently flying at ~450/510 km altitude, discussion next week in Edinburgh as to orbital evolution for 2017-2025
Other Data – Ground Observatories

- Ground observatories offer *stable fixed* measurement sites
- Removes the *time-space ambiguity*
- Offer long-term datasets (> 150 years)

Over 100 are INTERMAGNET standard
Swarm offers great improvements

- Swarm offers new ways to use magnetic field data
- Gradients (various combinations)
- Boot-strapping crustal field
- Better external field descriptions
- Inclusion of smaller field components (e.g. tidal)
- Informs other research such as space weather effects on magnetic field and GPS etc

From Kotsiaros et al. (2016)

Model using radial and EW/NS gradients (better)
Model using differences of NS/EW gradients (poorer)
Gradients in use

- ‘Gradient’ data is calculated as the difference between two nearby measurements
- 15–50 second separation along track
- Nearest geomag latitude and time across track between A and C
- Sensitive to localised, small scale features
- Requires Swarm and CHAMP vector and scalar measurements (i.e. most of the data used)

Swarm across-track and along-track radial gradients

Final model: $B_r$ at surface, $L = 16-133$
Secular variation of the main field

• Flow of liquid iron core generates secular variation at the surface

• Non-linear and constantly changing (‘jerks’)

• Current research looking to improve understanding

![Graph showing secular variation over time](image-url)
Imaging the 2014 Jerk

- Observatory distribution is sufficient to capture large scale SV of jerks but satellite data needed for fine detail.

- Rapid Swarm and observatory data provision is key – the (BGS) model uses ~9 months of additional data to CHAOS-6 and IGRF-12.

Measured jerks from obs. data
Jarls, IGRF and the importance of model updates

- Due to 2014 jerk, IGRF-12 prediction is different by **15.7 nT RMS** from recent core field model at 2016.0

- Note, all 9 IGRF-12 candidate SV models **show 20% difference** from updated (BGS) model after one year into 5 year lifetime
Global mean power spectra

- Total power in core field (up to degree 15) \( \approx 1,912,660,000 \text{ nT}^2 \)
- Total power in core field change \( \approx 7,750 \text{ (nT/yr)}^2 \text{ every year} \)
- Total power in crustal field (degree 16-133) \( \approx 3,410 \text{ nT}^2 \)
- Degree 133 is about the current max with satellite data = a \textit{globally homogeneous} dataset
- Note: locally the crust can vary significantly

→ Accurately modelling the core field on a global scale arguably more important than crust

(following convention of logarithmic Y axis which emphasises small values)
## Update on model uncertainties

<table>
<thead>
<tr>
<th>Original analysis 2008 (SPE119851)</th>
<th>Comparisons were made using 6-8k <strong>vector</strong> data and a degree 45 model</th>
</tr>
</thead>
<tbody>
<tr>
<td>New analysis 2016</td>
<td>Comparisons were made in September 2016 using 8-10k <strong>vector</strong> data avoiding poles ($H &lt; 6\mu T$) and a degree 133 model</td>
</tr>
</tbody>
</table>

Locations of observatory and magnetic survey stations with usable data
New model uncertainties

<table>
<thead>
<tr>
<th>Confidence Level</th>
<th>Original Declination Limit (degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>68.3% (1σ if Gaussian)</td>
<td>0.148</td>
</tr>
<tr>
<td>90%</td>
<td>0.419</td>
</tr>
<tr>
<td>95%</td>
<td>0.823</td>
</tr>
<tr>
<td>95.4% (2σ if Gaussian)</td>
<td>0.874</td>
</tr>
<tr>
<td>99%</td>
<td>1.641</td>
</tr>
<tr>
<td>99.7% (3σ if Gaussian)</td>
<td>2.613</td>
</tr>
</tbody>
</table>

(Using vector survey data 1985 and onwards only in both cases)

- These errors (attributable to the local crustal field) to be combined with
  - estimates from hydrocarbon geology locations
  - external field
  - predictive core field errors
- Objective is one new error look-up table (scalable 1-sigma values) for annually revised high-degree global models, ideally with all-party agreement

Locations of oil fields with local magnetic data
Summary

• Annually updated models necessary to counter large and unpredictable rapid changes from Earth’s core

• Uncertainties are lowering but care needed not to misunderstand what global models can do

• Swarm is promptly delivering a large quantity of highly accurate measurements

• Swarm gradient data offers unique global resolution of small scale field, especially as orbit lowers
Acknowledgements & References

- Swarm: European Space Agency and Swarm Data, Innovation and Science Cluster
- Ground-based data: institutes worldwide with geomagnetism programmes, World Data Centre for Geomagnetism, survey companies Halliburton, Baker Hughes, Schlumberger, Weatherford