Using Swarm Satellite Data to Improve Global Geomagnetic Reference Modelling

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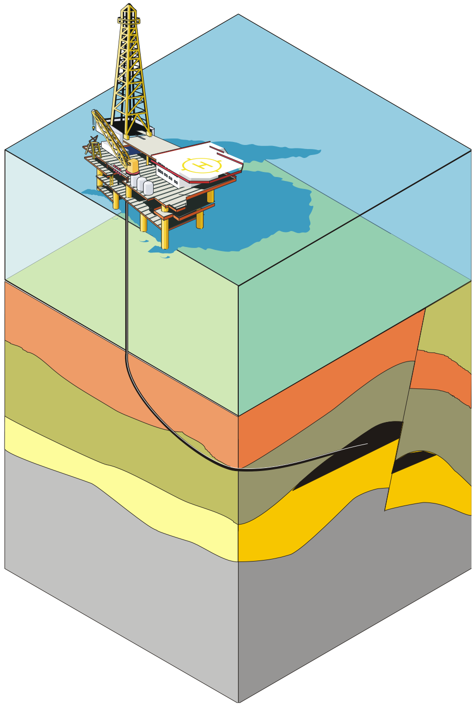
Wellbore Positioning Technical Section

ISCWSA
The Industry Steering Committee on Wellbore Survey Accuracy (ISCWSA)

Speaker Information

- Dr. Ciaran Beggan
- Using Swarm Satellite Data to Improve Global Geomagnetic Reference Modelling
- 22-Sep-2016
- 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

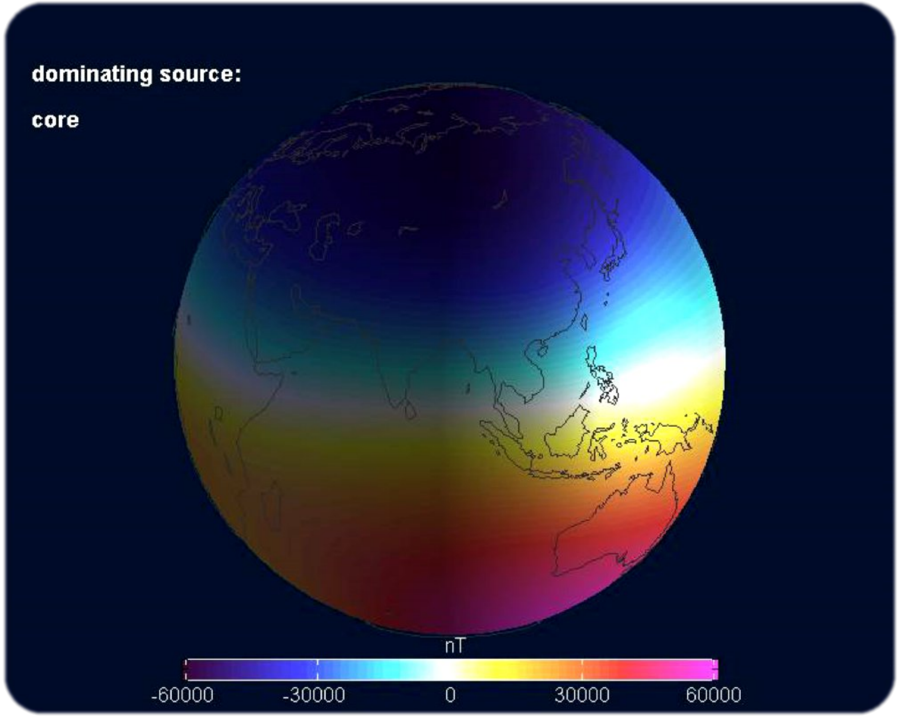
Reducing uncertainties

Overview

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

Earth's Magnetic Field

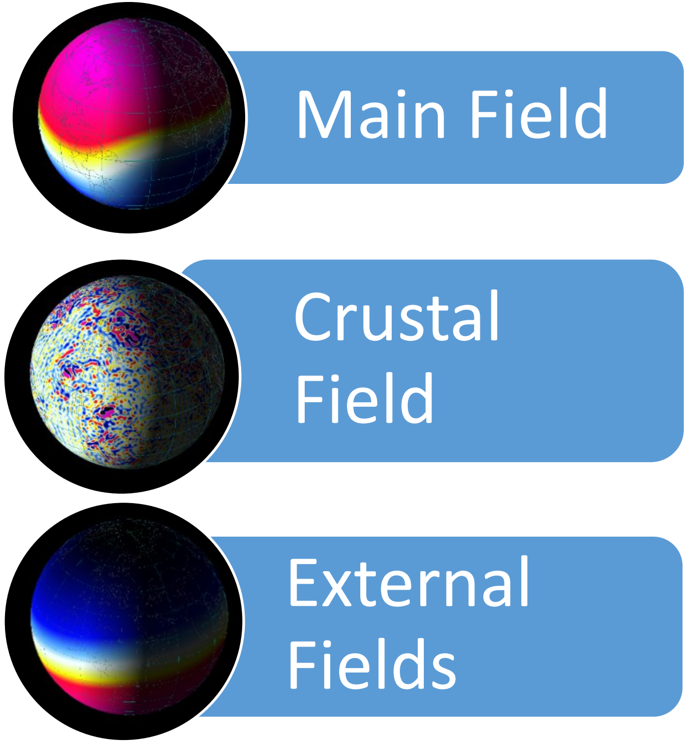
- Dominant core field varies over months to years (±60,000 nT)
- Fields due to complex current systems in the ionosphere and magnetosphere vary from seconds to years (±60 nT)
- Localised crustal field stable through time (±10 nT)
- Now resolving ocean tides induced fields (±2 nT)



Credit: GFZ,DTU

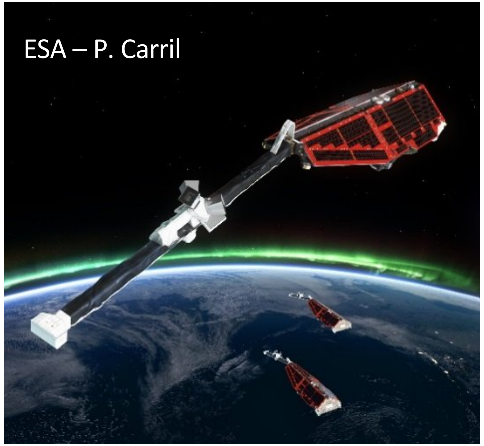
Global Magnetic Field Modelling

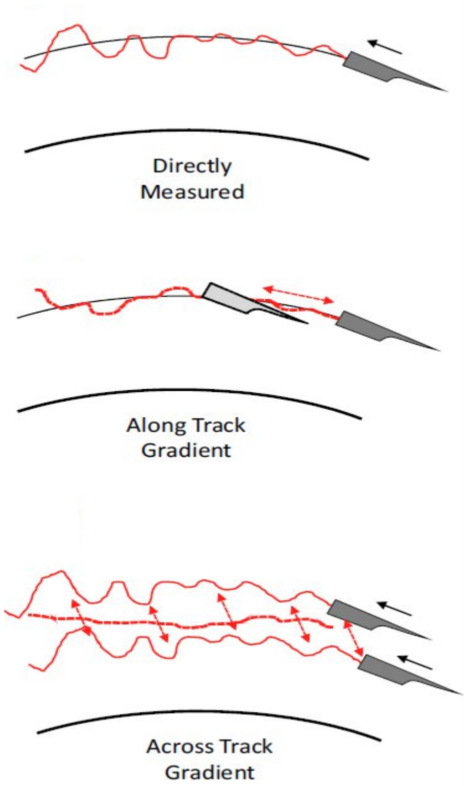
- Spherical harmonic 'degree' of model represents spatial resolution
- Produced annually since 1990s
- A high temporal and spatial resolution
- Most models describe time-varying main field and include crustal and some external fields
- Accurately quantified errors (compared against ground measurements)



ESA Swarm Mission

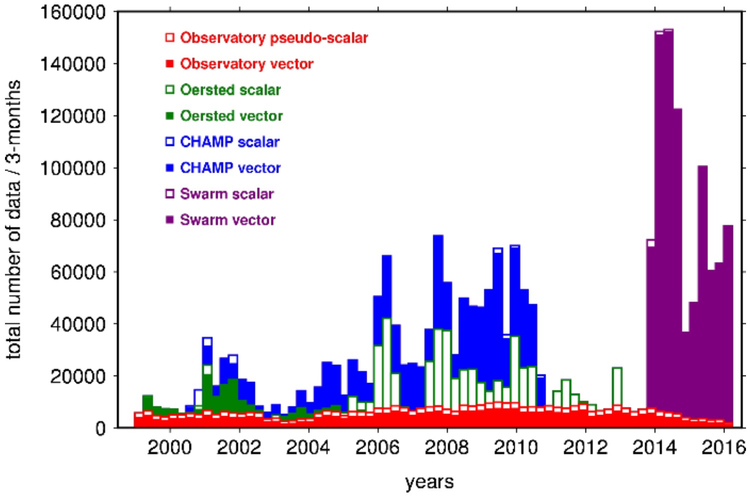
- CHAMP, Ørsted satellites have driven previous decade of modelling development
- Novel 3-satellite constellation
- Launched November 2013
- Two lower satellites (A and C)
- Swarm B flies in different local time orbit
- Unique multi-satellite magnetic gradients (A and C)
- Currently flying at ~450/510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

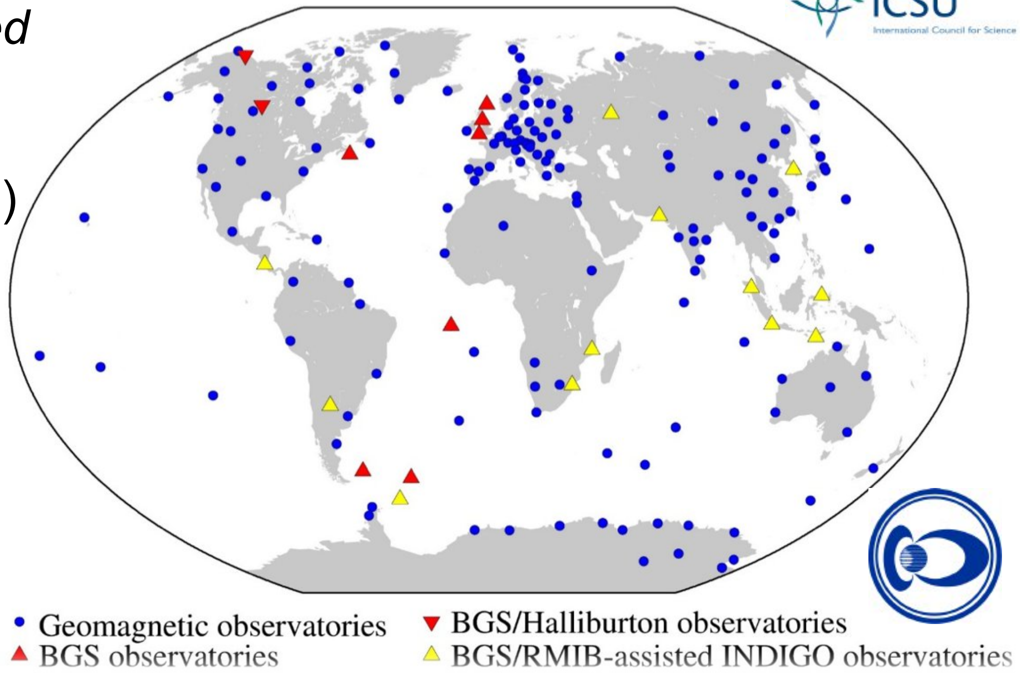




Other Data – Ground Observatories

- 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)

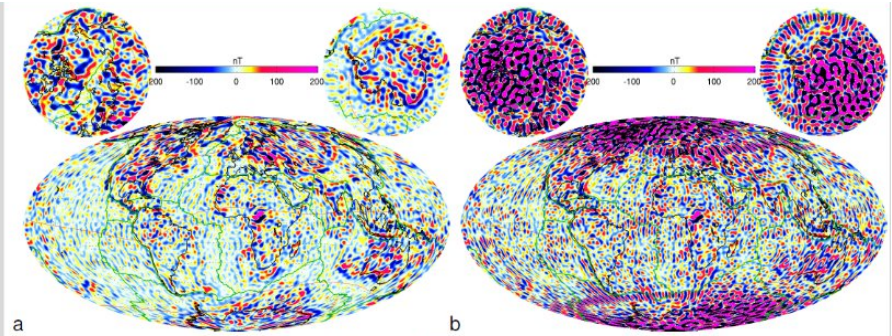


Figure: Maps of radial lithospheric field calculated at the Earth's surface from coefficients of degrees $16 \leq n \leq 90$ taken from a: $SM_{\Gamma(1)}$ and b: $SM_{\Gamma(2)}$. Green lines indicate the boundaries of the major tectonic plates whereas red lines locate the dip equator (0°) and ±55° iso-QD latitudes.

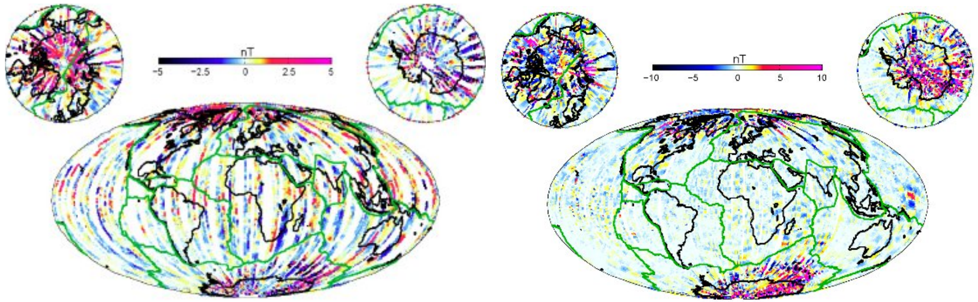
Model using radial and EW/NS gradients (better)

Model using differences of NS/EW gradients (poorer)

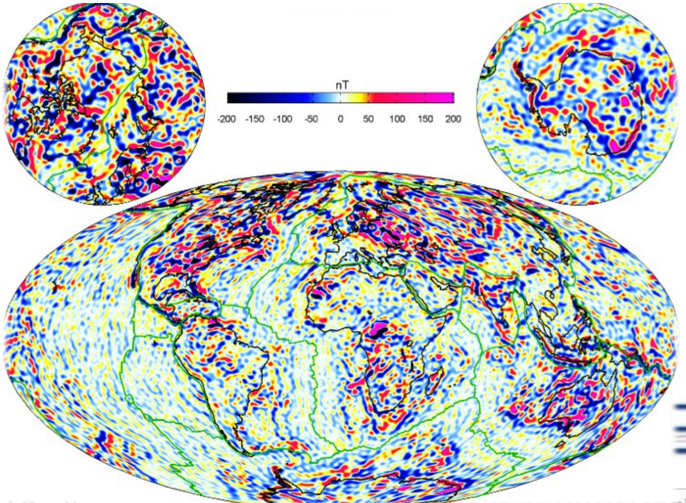
Gradients in use

- ‘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

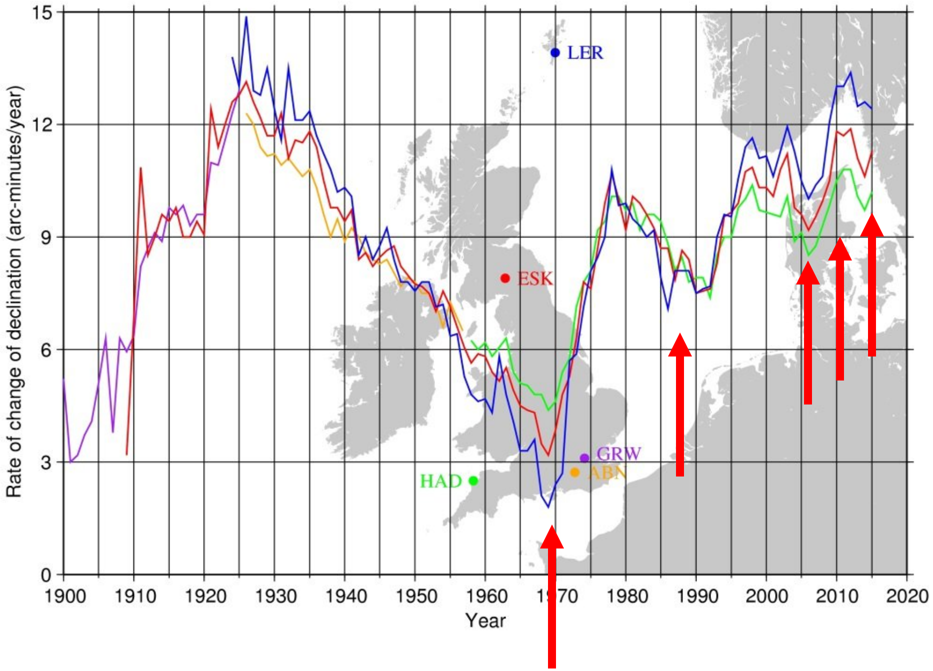


Final model: B_r at surface, L =16-133



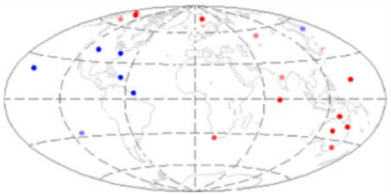
Secular variation of the main field

- Flow of liquid iron core generates secular variation at the surface
- Non-linear and constantly changing ('jerks')
- Current research looking to improve understanding

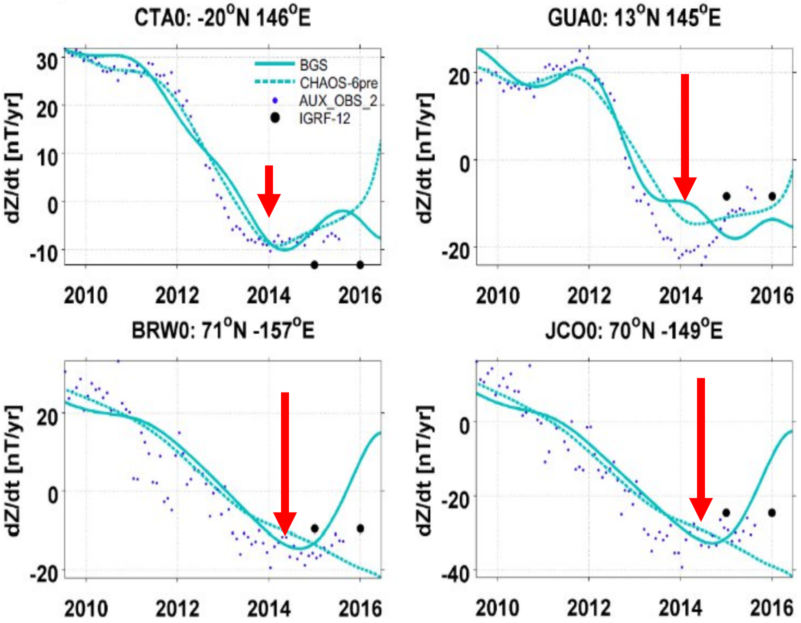


Imaging the 2014 Jerk

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



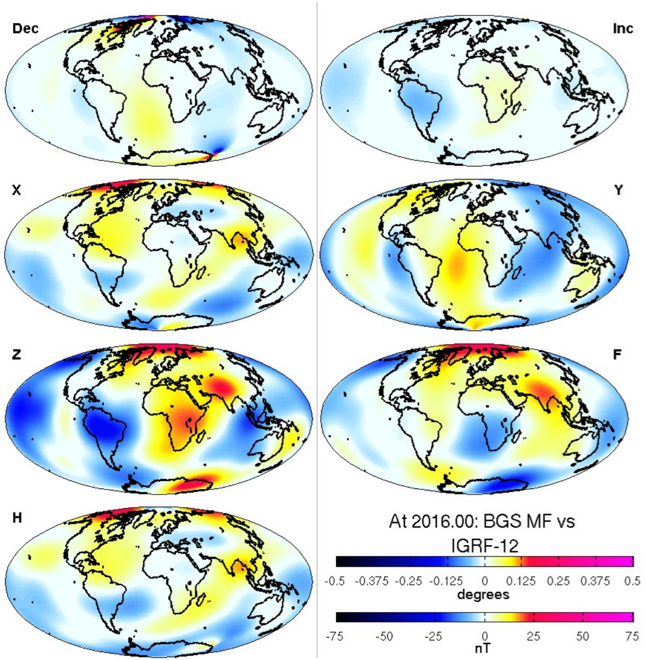
Measured jerks from obs. data



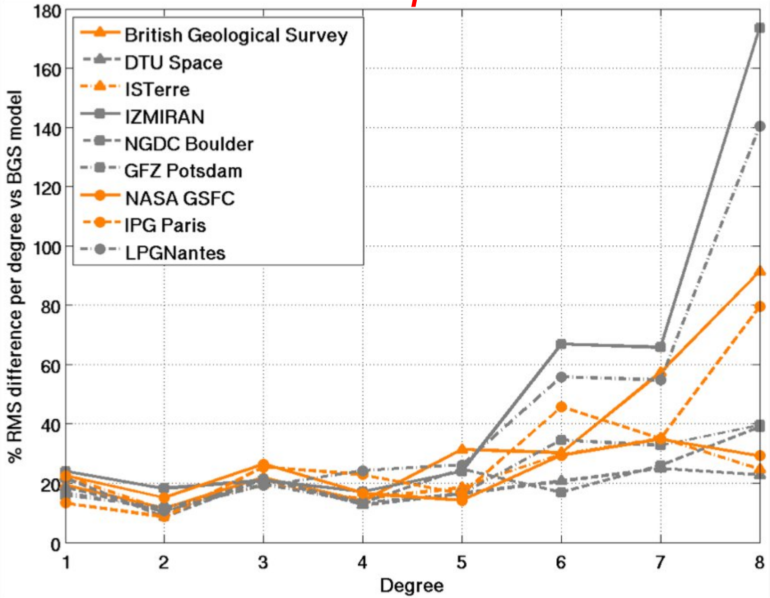
- Rapid Swarm and observatory data provision is key – the (BGS) model uses ~9 months of additional data to CHAOS-6 and IGRF-12

Jerks, 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

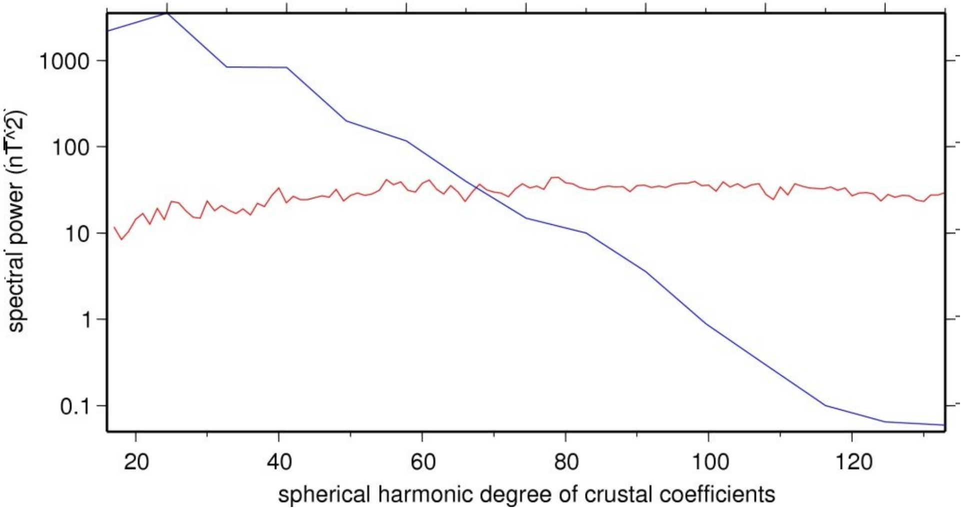


IGRF-12 predictions



- 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



(following convention of logarithmic Y axis which emphasises small values)

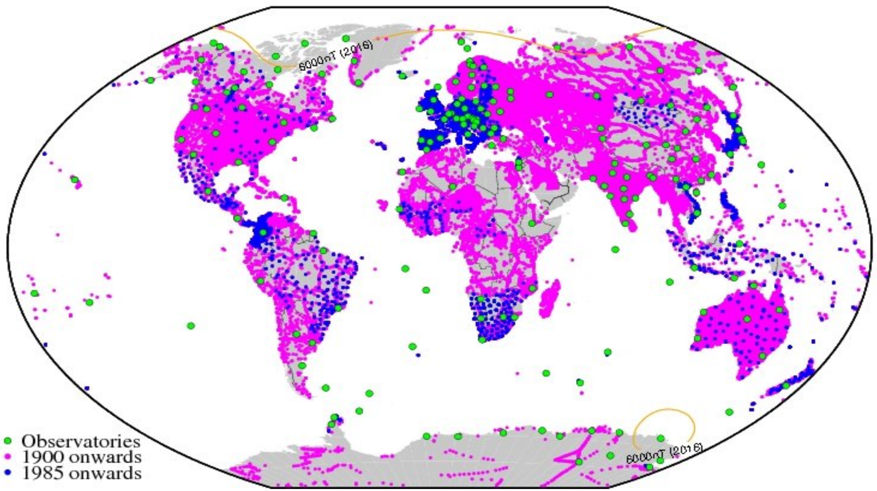
- Total power in core field (up to degree 15) ≈ *1,912,660,000 nT²*
- Total power in core field change ≈ *7,750 (nT/yr)²* ***every year***
- Total power in crustal field (degree 16-133) ≈ *3,410 nT²*
- Degree 133 is about the current max with satellite data = a *globally homogeneous* dataset
- Note: <u>locally</u> the crust can vary significantly

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

Update on model uncertainties

Original analysis 2008 (SPE119851)	Comparisons were made using 6-8k **vector** data and a degree 45 model
New analysis 2016	Comparisons were made in September 2016 using 8-10k **vector** data avoiding poles (H < 6μT) and a degree 133 model

Locations of observatory and magnetic survey stations with usable data



New model uncertainties

Confidence Level	Original Declination Limit (degrees)
68.3% (1σ if Gaussian)	0.148
90%	0.419
95%	0.823
95.4% (2σ if Gaussian)	0.874
99%	1.641
99.7% (3σ if Gaussian)	2.613

(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

- SPE119851: Macmillan & Grindrod, 2010. Confidence Limits Associated With Values of the Earth's Magnetic Field used for Directional Drilling. *SPE Drilling & Completion*, 25(2), 230-238. doi: 10.2118/119851-PA
- Kotsiaros, S. (2016) Toward more complete magnetic gradiometry with the Swarm mission, *Earth Planet Space,* 68, 130. doi:10.1186/s40623-016-0498-x