Quantifying Uncertainties in High-resolution Magnetic Field Models

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Speaker Bio

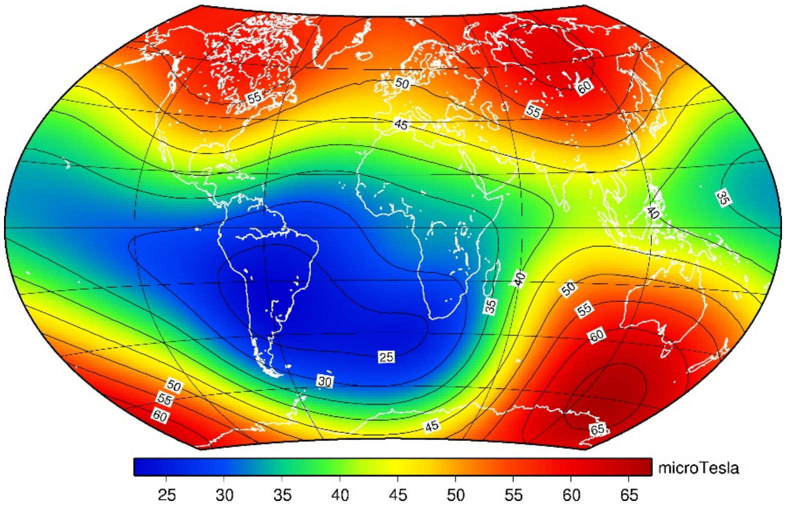
- Introduction
  - British Geological Survey
  - 10+ years in geomagnetism
  - PhD, Univ. Edinburgh (2009)
  - Based in Edinburgh, UK
  - Specialize in main field modelling and forecasting, space weather, crustal field modelling

Magnetic field models

Industry requests higher degree, smaller scale magnetic models:

- Are these justified by the data available?
- What are the associated reduction (or otherwise) in uncertainties?
- What are the main sources of uncertainty and how to quantify them?

- We examine and quantify the main sources of error: (i) high degree *crustal field* and
  (ii) *spatial limitations* of crustal field input data
  (iii) *forecasting* uncertainty;
  (iv) *external field*;



Total field (F): 2019.0

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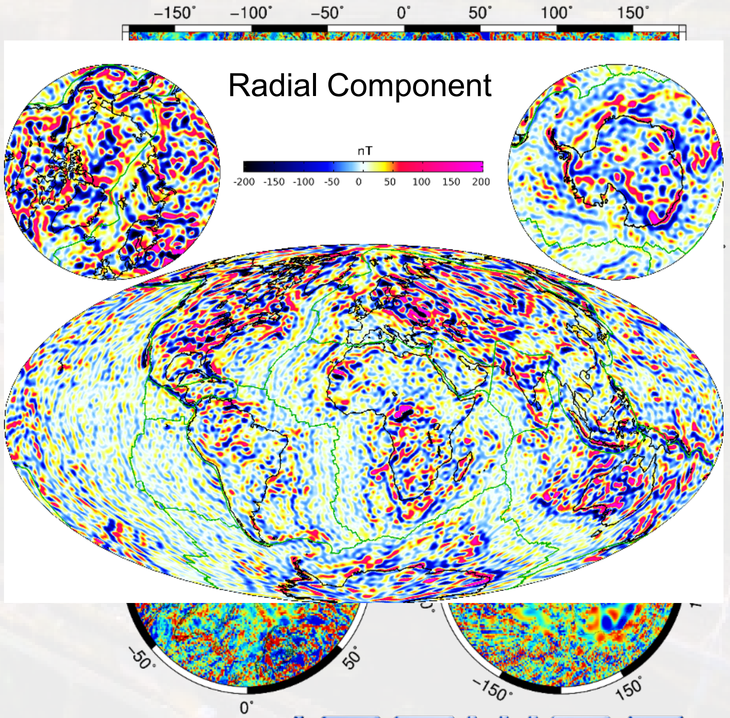
High degree models (degree > 133)

- Satellite data can be used to *consistently* model the field to degree 133 [wavelengths ~300 km]

- Adding in ground aeromagnetic and marine surveys; Global grid compilations at 0.05°
- Theoretical degree = 7200 [~4km]
- Realistically, available memory/computation time are limiting factors e.g. 800--1440 [~28-50 km]
- Look at errors in X, Y and Z (linear) and convert to Dec, Inc and Total Field (F) at the end
- Use **95.4% CI divided by 2** = 1 sigma equivalent

Degree 1440 model: Z crustal comp



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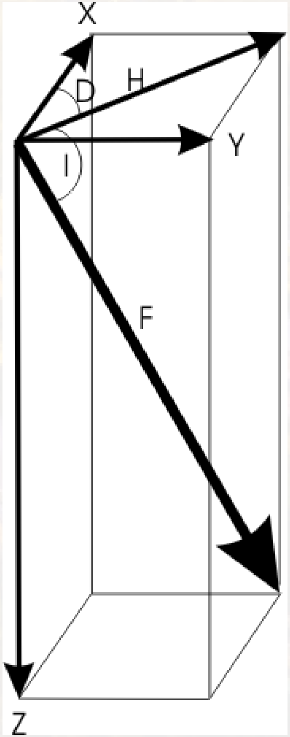
Analysis in XYZ

- Working with magnetic field values in X, Y and Z is **linear**
- Computing errors and differences in DIF is **non-linear** (e.g. angles with cosine/sine, square roots)
- Errors computed in XYZ and converted to DIF (using main field, H and F values) at the end



$$\delta D = \frac{\sqrt{(\delta X)^2 \sin^2 D + (\delta Y)^2 \cos^2 D}}{H}$$

$$\delta I = \frac{\sqrt{(\delta H)^2 \sin^2 I + (\delta Z)^2 \cos^2 I}}{F}$$

$$\delta F = \sqrt{(\delta H)^2 \cos^2 I + (\delta Z)^2 \sin^2 I}$$

$$\delta H = \sqrt{[(\delta X)^2 (\cos D)^2 + (\delta Y)^2 (\sin D)^2]}$$

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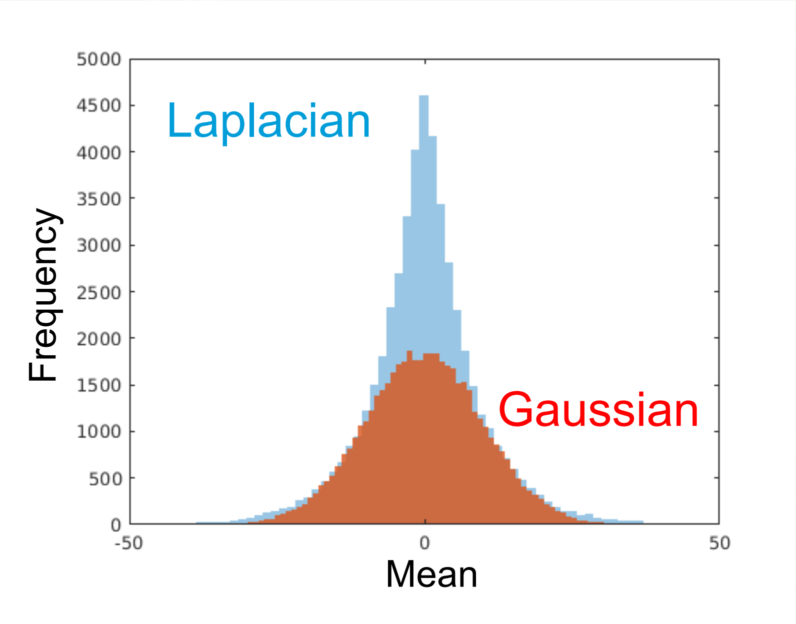
Errors in magnetic data

- Errors in magnetic data are **not Gaussian**
  - 1σ = 68.3%
  - 2 x 1σ = 95.4%
  - 3 x 1σ = 99.7%, etc
- Usually, better described by Laplacian
  - 2 x 1σ ≠ 95.4%!
- To compute confidence intervals: sort the residuals, then *find* the 68.3%, 95.4% values
- Typically, CI 68.3% < 1σ; CI 95.4% > 2σ
- To be conservative: use CI 95.4% divided by 2; call this a **scalable 1 sigma equivalent**



Value of adding more SH degrees

Adding more resolution is better, *right*?

- Comparison with *independent* ground vector data reveals real signal being missed
- Adding more degrees is a diminishing *return on investment*

Mean absolute differences of 85000 global ground vector data 1900-2018

Max degree/resolution	D (°)	I (°)	F (nT)
133/300 km	0.35	0.17	189
800/50 km	0.30	0.15	168
1440/28 km	0.29	0.15	165

- Start with crustal field differences for the satellite era (1979 MAGSAT)
- Estimate the total uncertainty from various sources

1 sigma equiv (9300 global ground vector data 1979-2018)

1 sigma CI equiv	X (nT)	Y (nT)	Z (nT)
133/300 km	107	100	195
1440/28 km	90	91	185

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Crustal field uncertainties

1 sigma CI equiv.	X (nT)	Y (nT)	Z (nT)
1440/28 km	90	91	185

North Sea fields and ground shots

- These are global averages (include volcanoes etc.)
- Better to use a crustal field error estimates applicable for *hydrocarbon geology,* where appropriate.
- Compare IFR setups and ground shots in hydrocarbon areas (including e.g. Alberta) to HD model
- Derive a reducing scaling factor for hydrocarbon areas:

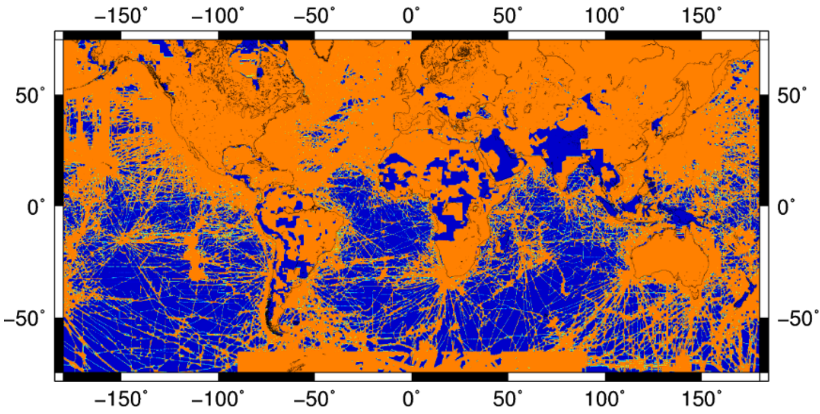
	X	Y	Z
Scaling factor (hydrocarbon)	0.66	0.75	0.85

Data coverage

- High-degree magnetic field models based on airborne/shipborne surveys
- Other areas use satellite-only or other inferences
- Use this as a basis for introducing hydrocarbon scaling factor i.e.

Orange = use lower uncertainties
Blue = use higher uncertainties

WDMAM2



Orange = survey data
Blue = satellite only/model *pseudo-data*

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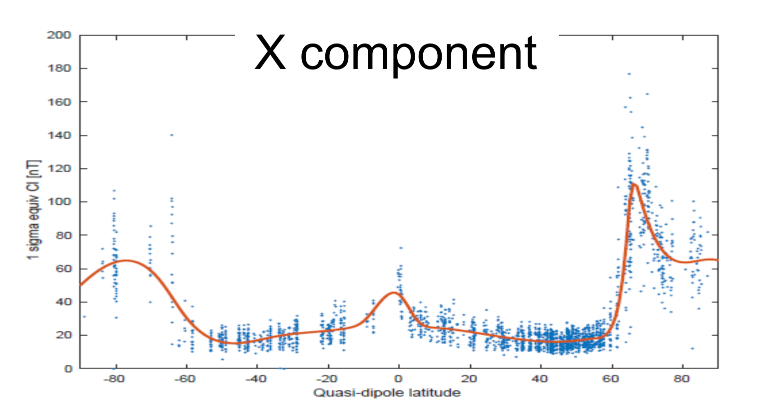
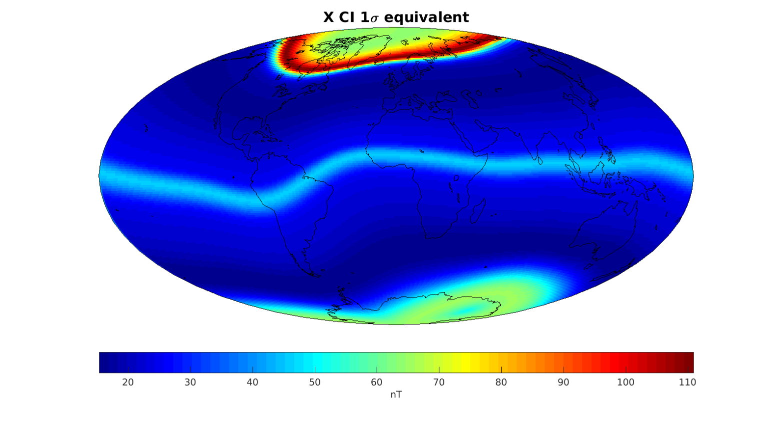
External field uncertainty

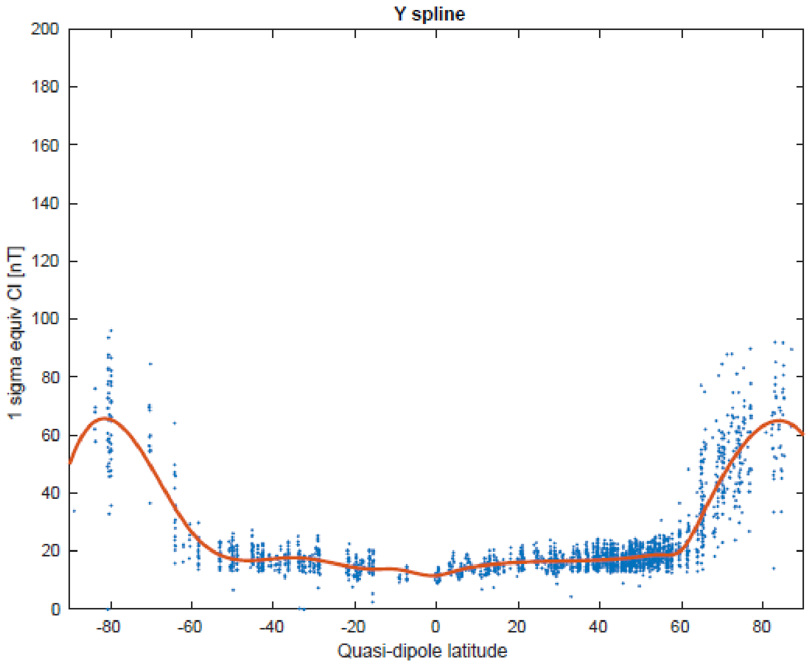
External fields:

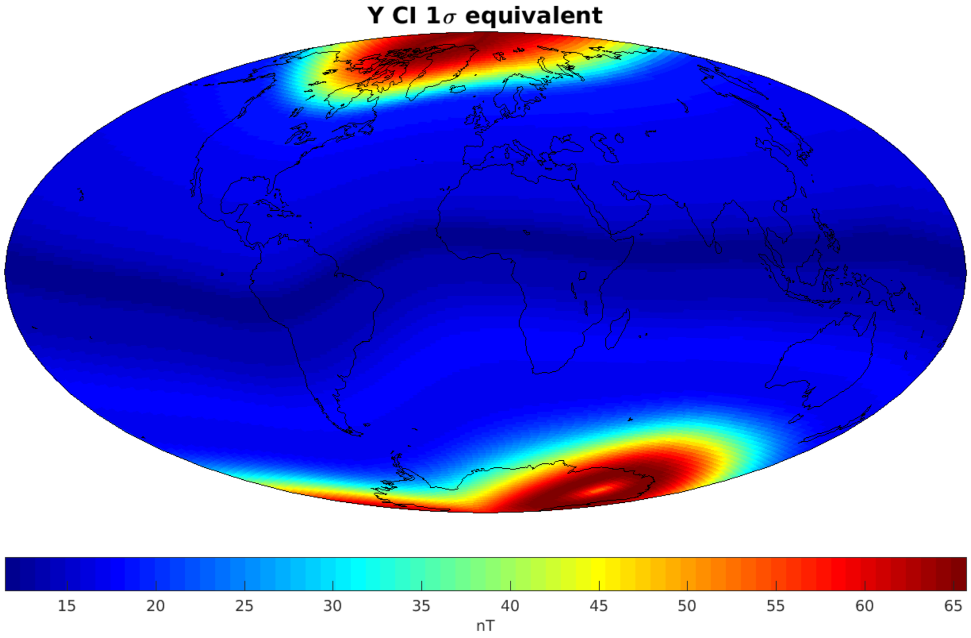
- Auroral electrojets; Equatorial electrojet; Geomagnetic storms
- Look at global observatories (1997-2018)
- Each year: collect XYZ minute mean data; remove core field and crustal offset; detrend; sort external field into 1/2/3 CI equivalents
- Organised in quasi-dipole (QD) coordinate system
- Fit spline in QD coords
- Convert to geographic coordinates



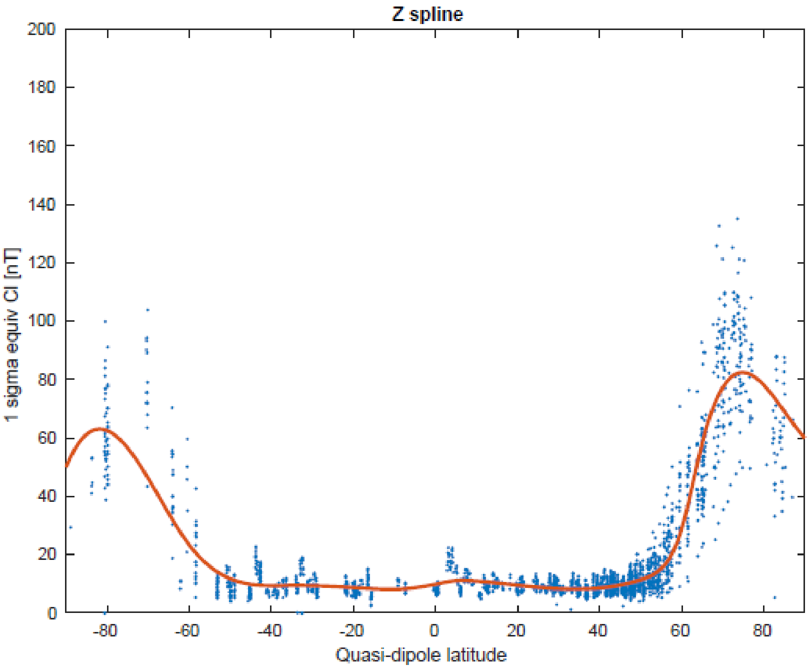


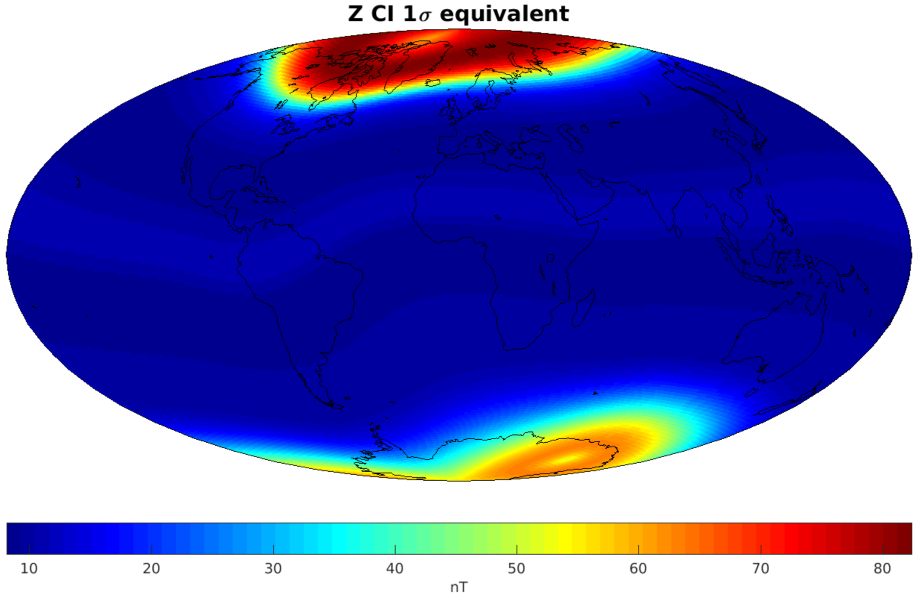
External field contribution - Y





External field contribution - Z

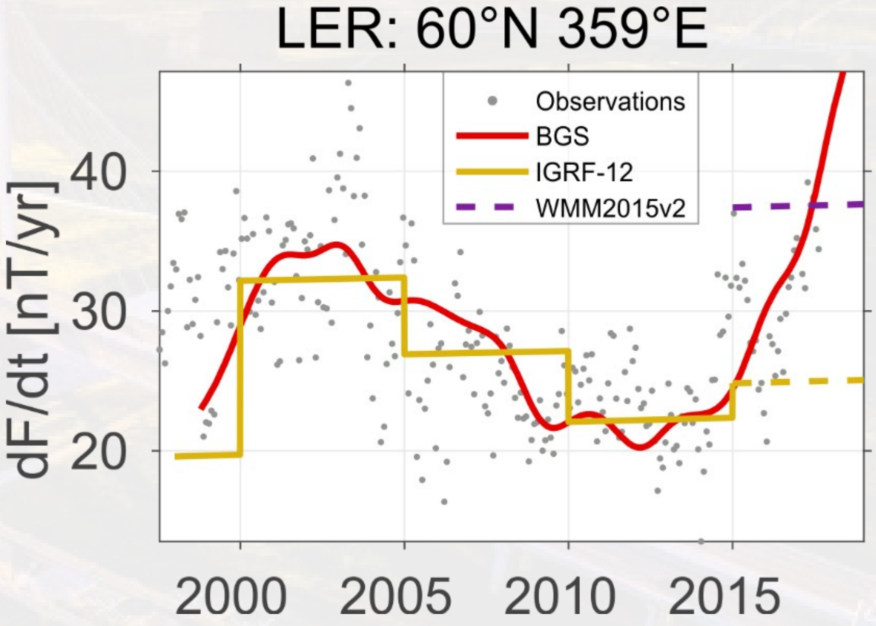




Core field prediction uncertainty

- Errors in SV prediction assessed by comparing 1-year forecast of a core field, to the subsequent model release
- Difference is e.g. BGGM2015 at 2016.0 and BGGM2016
- Derive a scaling factor for annual 'look-ahead' uncertainty in satellite era
- Global RMS changes (small scale)

CI 1sigma equiv RMS (nT)	X	Y	Z
Uncertainty from forecasting	3	3	6



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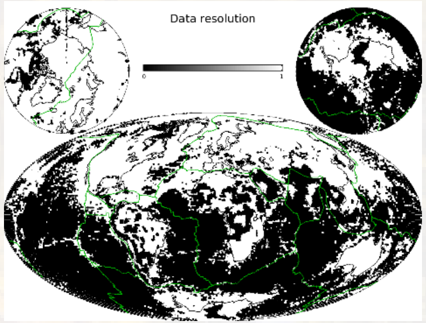
Combining the uncertainties

- Aiming for lat-long grid of useful **scalable 1-sigma error estimates**
- Robust spatial variations can only be obtained for the crustal field (with hydrocarbon area scaling) and external field
- Combine via Root Sum Square (as uncertainties are assumed independent)
- Scale by temporal variations for core field prediction uncertainties

Use main field model to obtain values for DIF from XYZ



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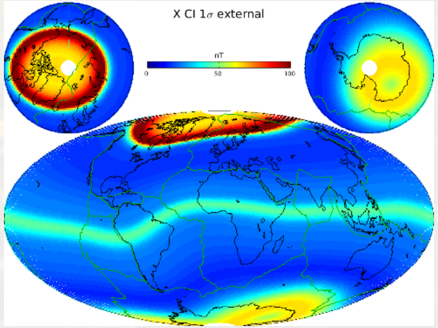
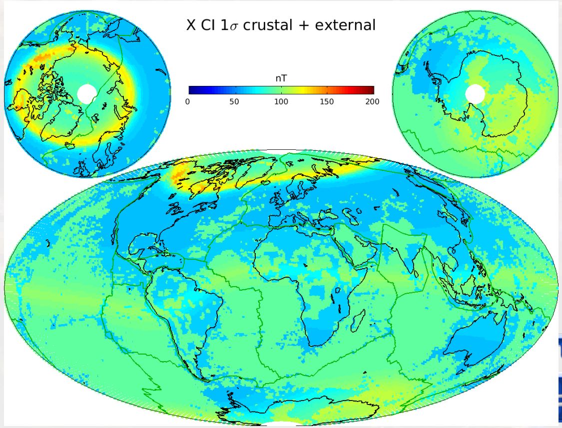


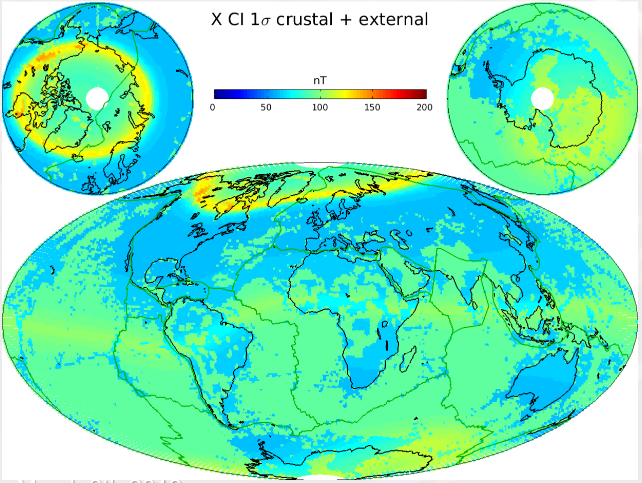
* *"Hydrocarbon scaling"*

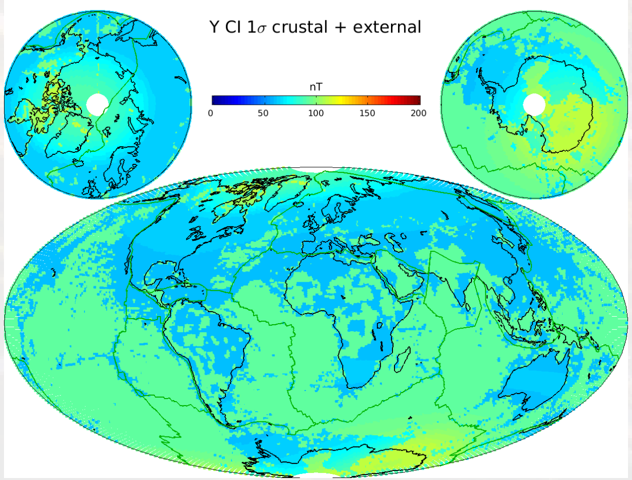


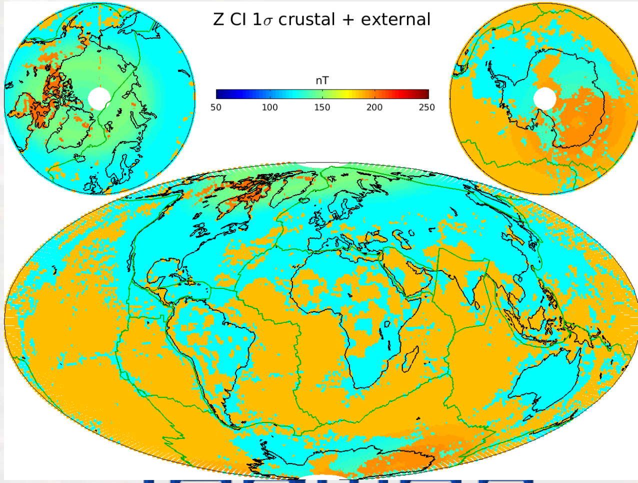
Final CI 1 sigma equivalent values

1 sigma CI equiv.	X	Y	Z
L = 1440/28 km Global RMS* (nT)	86	82	160
Forecast scaling per year (%)	3.5	3.6	3.7

*not latitude weighted







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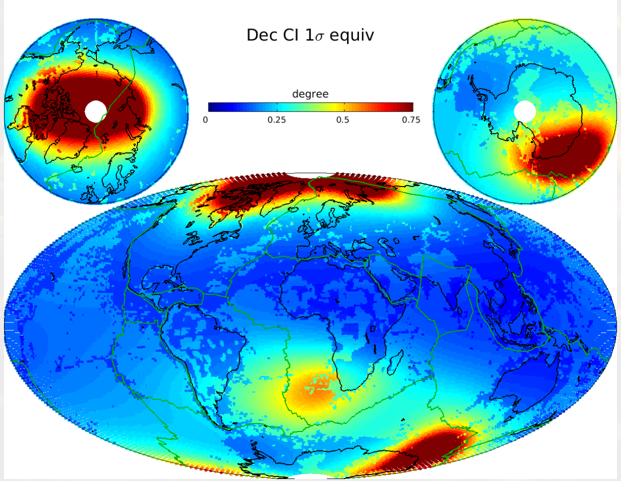
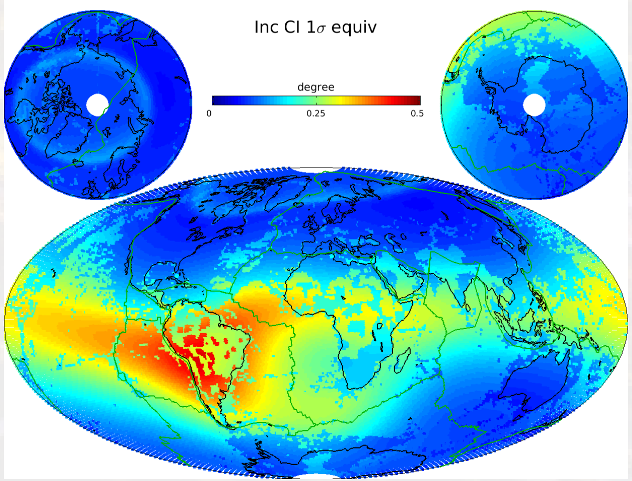
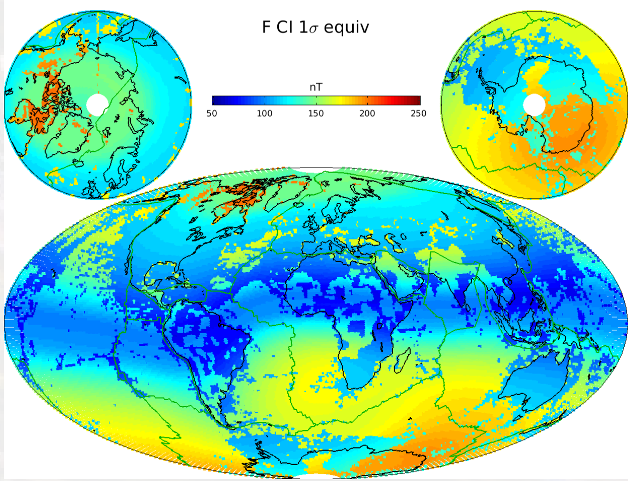
Conversion to DIF

1 sigma CI equiv. RMS	Dec (°)	Inc (°)	F (nT)
L = 1440/28 km*	0.22	0.15	91

* latitude weighted







Fit of Dec to DECG/DBHG

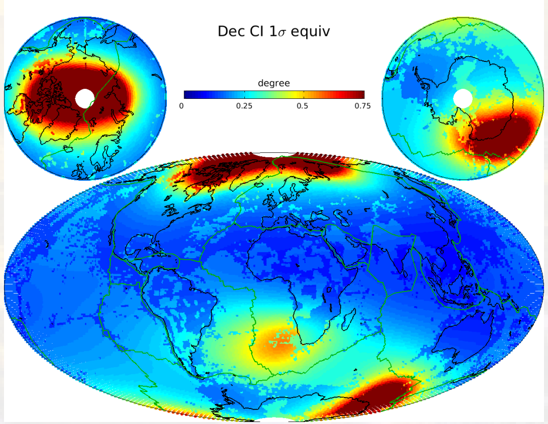
Can fit Dec CI to the ISCWSA 2 parameter model (Williamson, 2000)

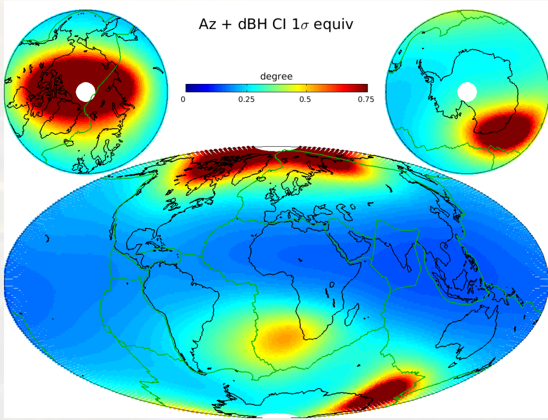
Solve (least-squares) for:

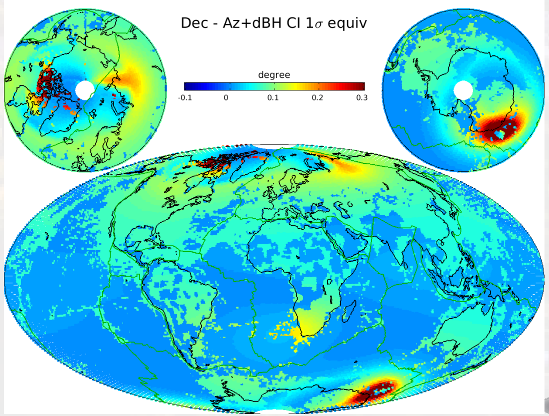
$$Dec = \sqrt{DECG^2 + \frac{DBHG^2}{H^2}}$$

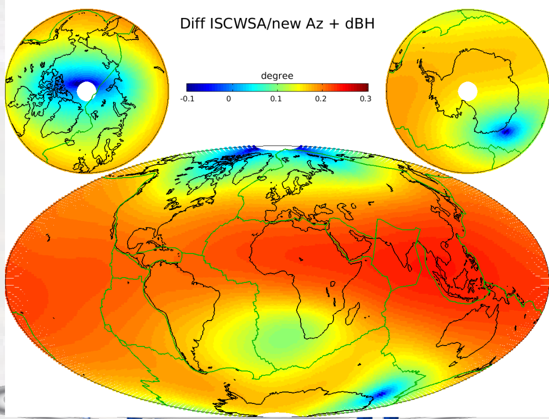
Best fit: **0.07°; 5055 ° nT**

- DECG = 0.36° (const)
- DBHG = 5000 ° nT (H dependent)





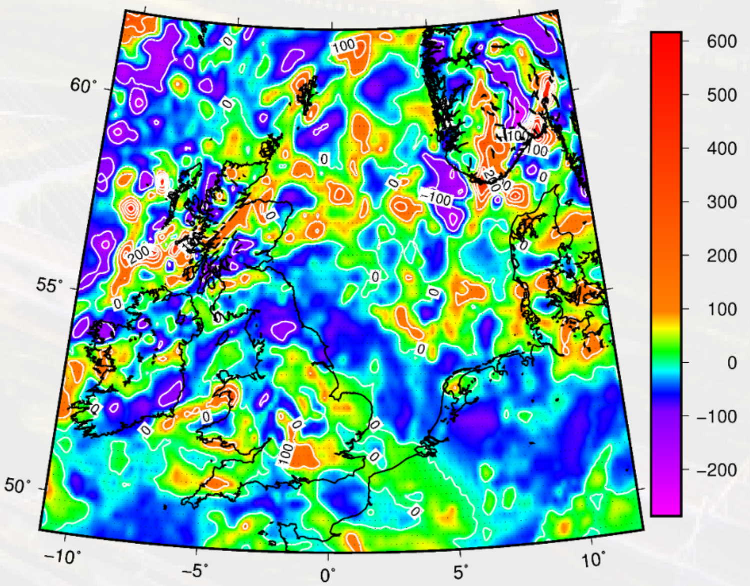




Conclusions

- Investigated uncertainties in high degree models
- Captures external fields, core field prediction, hydrocarbon crustal fields and more general data availability
- Available as XYZ or DIF uncertainties in a 1° x 1° degree maps (with temporal scaling)
- Numbers are given as scalable 1-sigma equivalent uncertainties
- Some areas (Offshore SA) have larger uncertainties than expected

L = 1440; Crustal field Z comp



1 sigma CI equiv. RMS	X (nT)	Y (nT)	Z (nT)
L = 1440/28 km	86	82	160

Questions?

Thank you for listening