Evidence-based uncertainty estimates for the International Geomagnetic Reference Field (IGRF-13)

Ciarán D. Beggan

1 British Geological Survey, Edinburgh, UK

What is the IGRF?
(**I**nternational **G**eomagnetic **R**eference field)

- A community-based main field magnetic model:
  - Based on a blend of between 8-14 candidates
  - Models the time-variation of the large scale field
  - Computes the seven magnetic components: Declination (D), Inclination (I), Horizontal (H), North (X), East (Y), Vertical (Z) and Total Field (F)
  - Updated every 5 years (2015, 2020 etc)
  - Valid from 1900 to 2025 (13th generation)

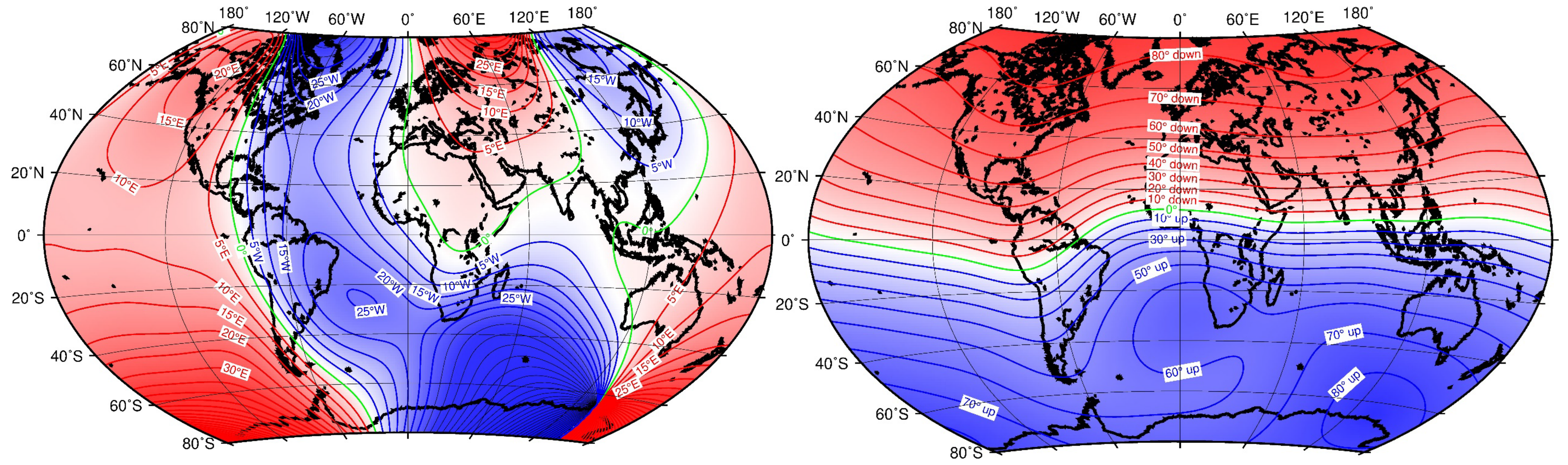

Fig 1: IGRF-13 (Left) Declination angle at 2020. (Right) Inclination angle at 2020.

- **The IGRF captures:**
  - Quiet, night-time average of the core field and large scale crustal field
  - The slow secular variation of the main field
- **The IGRF does not capture:**
  - Small-scale crustal field
  - Space weather effects (ring current, auroral electojet), tides, ionosphere, Sq currents, externally induced field

Given the known limitations of the model, if a user computes a model value, how accurate is it on average to a measured value?

Q: What are the global expected magnetic uncertainties for the average user?

Comparison to Repeat Stations and Observatories

- Using independent quiet-time data from repeat stations and (semi-independent) ground observatories from 1980-2020. Repeat station values are reduced to quiet night time. Observatory data are monthly or annual means. [Fig 2, left]
- We compute residual values) for each component (DIHXYZF) [Fig 2, right]

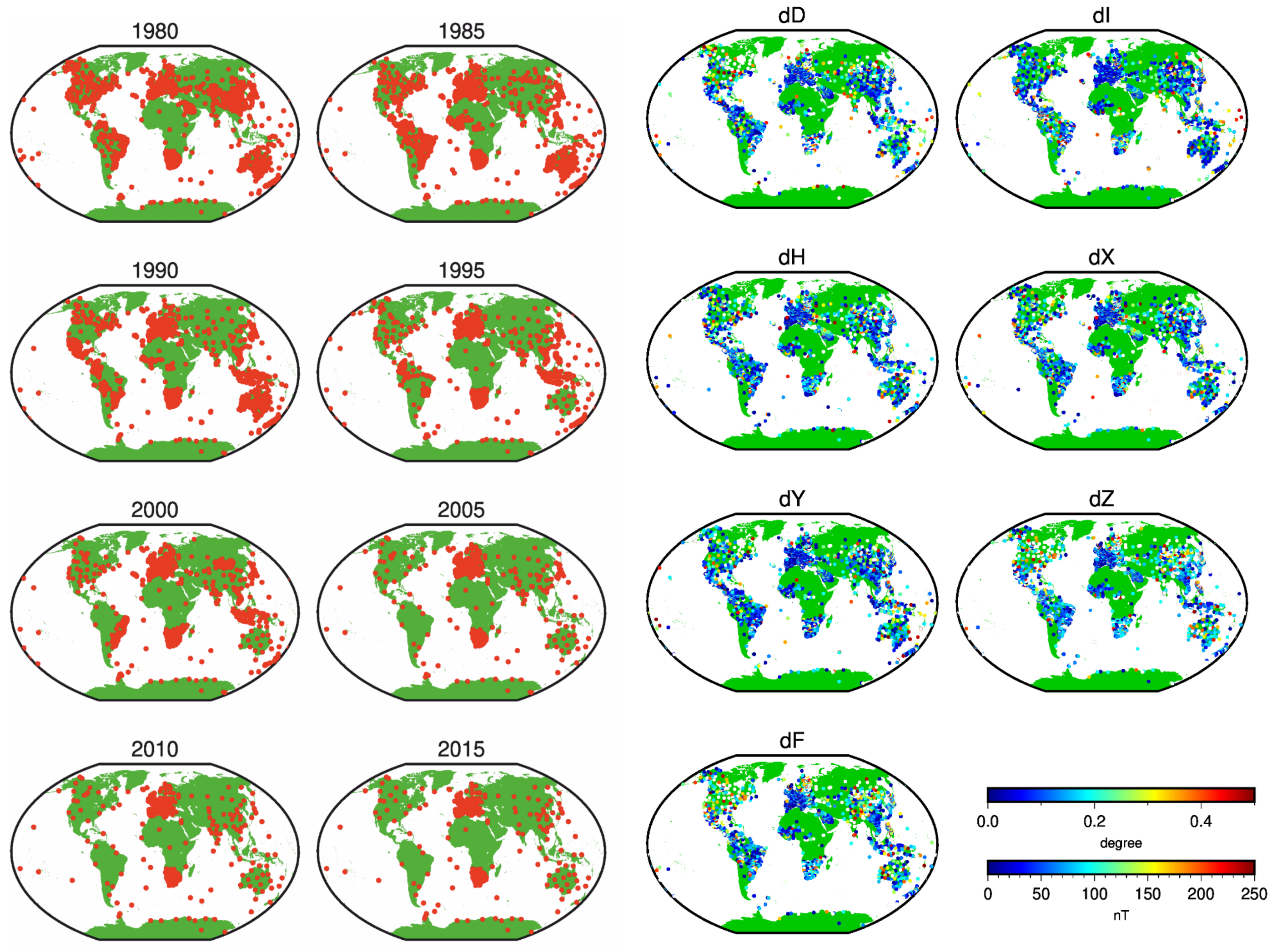

Fig 2 (Left) Location of the repeat station and observatories in each five year period from 1980 to 2020. (Right) Residuals between IGRF-13 and the ground measurements for all data.

"If you measure the magnetic field at a point on the Earth's surface, do not expect to get the value predicted by the IGRF!", Frank Lowes (2010)

Statistical variation

- Residuals are Laplacian (strongly peak around mean, long tailed)
- Therefore the Standard Deviation is not scalable and pessimistic
- Instead compute Confidence Intervals of 68.3%, 95.4%, 99.7% (1/2/3σ equivalents) by taking the absolute values and ranking in ascending order.

Table 1. Mean, standard deviation and the 68.3%, 95.4% and 99.7% confidence intervals (CI) of the residuals for each magnetic component. Number of data used are also shown.

	#data	Mean	Std dev	68.3% CI	95.4% CI	99.7% CI
D (°)	17460	-0.02	0.39	0.18	0.95	2.06
I (°)	18288	0.01	0.29	0.12	0.52	2.29
H (nT)	19310	-22	135	82	341	610
X(nT)	16332	-20	144	87	344	526
Y (nT)	16360	-2	136	73	322	575
Z (nT)	18183	-17	293	114	481	2236
F (nT)	18367	-16	178	103	432	839

Table 1: Statistical summary of the ground data residuals to IGRF. Note the standard deviation values are greater than the 68.3% (1σ equivalent).

Spatial Distribution

- Order by quasi-dipole latitude (to account for SV) [Fig 3]
- No obvious latitude dependence
- Variation mainly attributable to unmodelled crustal field contributions
- Repeat stations have external field removed
- Land-based, mostly NH, most data from pre-2000

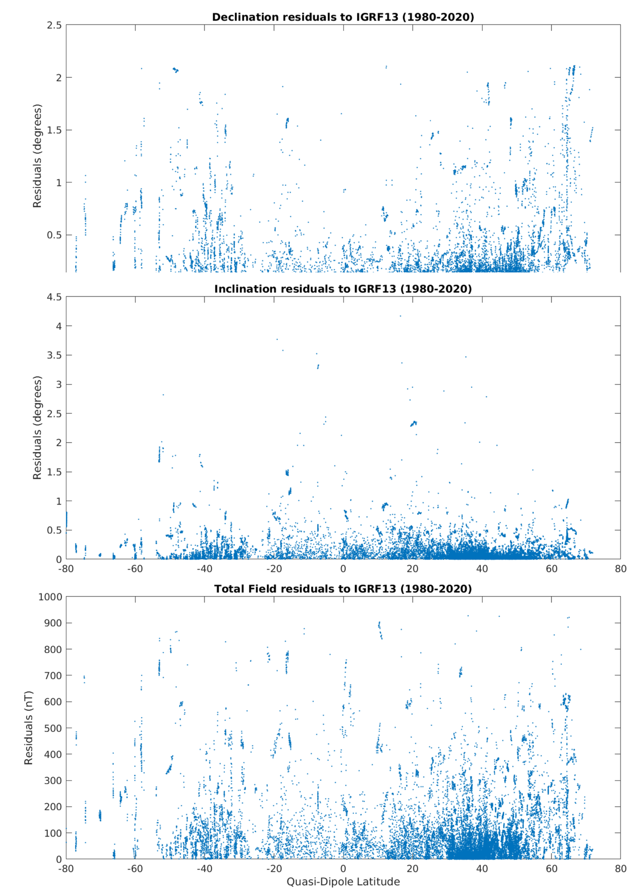

Fig 3 Spatial distribution of the D, I and F residuals between 1980 to 2020.

Conclusion

The 68.3% Confidence Intervals (1σ equivalent) are relatively small:
Declination: 0.18°; Inclination : 0.12°; Total Field : 103 nT (or ~1 part in 500)

Variation mainly attributable to unmodelled crustal field contributions

CIARAN BEGGAN ciar@bgs.ac.uk

Beggan, C. (2022). Evidence-based uncertainty estimates for the International Geomagnetic Reference Field, Earth Planets and Space, 17, 74, doi:10.1186/s40623-022-01572-y

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