Analysis of errors in simple geomagnetic field model predictions

British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

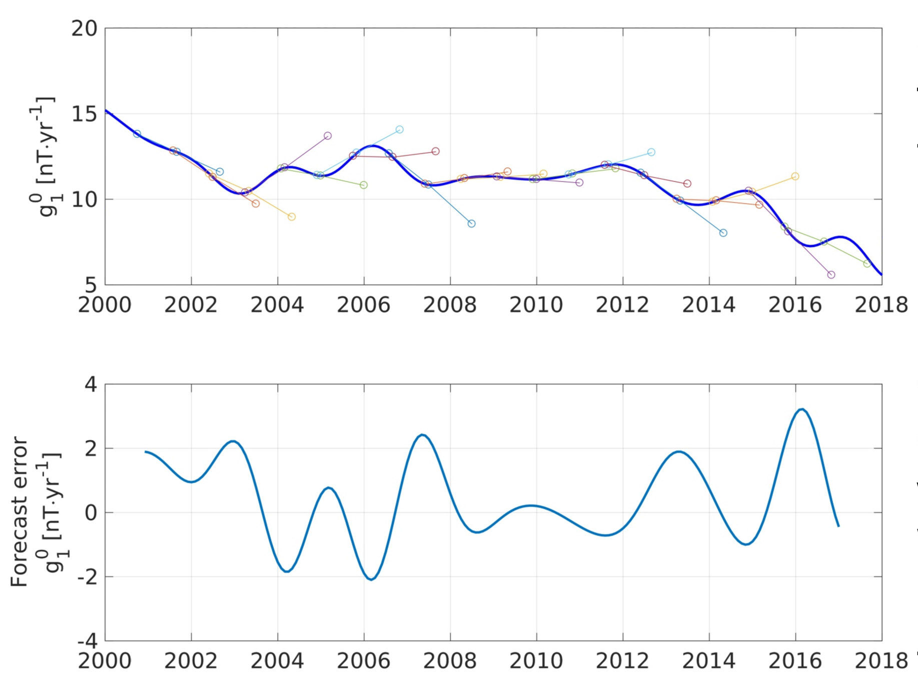
William Brown [wb@bgs.ac.uk], Ciarán Beggan, Susan Macmillan

British Geological Survey, The Lyell Centre, Edinburgh, United Kingdom.

1. Overview

- **Geomagnetic core field models are often used predictively, particularly for navigation and coordinate system determination**
- **Unpredictable secular acceleration hinders forecasting of the core magnetic field**
- **Simple linear extrapolations of a field model is often used to forecast on sub-decadal timescales**
- **We quantify the typical forecasting errors from simple extrapolated forecasts of the BGS MEME field model**
- **We assess spatial and temporal patterns in forecast errors**
- **We separate the forecast errors into data+modelling, and secular variation effects**

2. Method for field forecasts and errors



Simple geomagnetic model forecasts are made by assuming the **secular variation (SV)** of each modelled Gauss coefficient is linear in time.

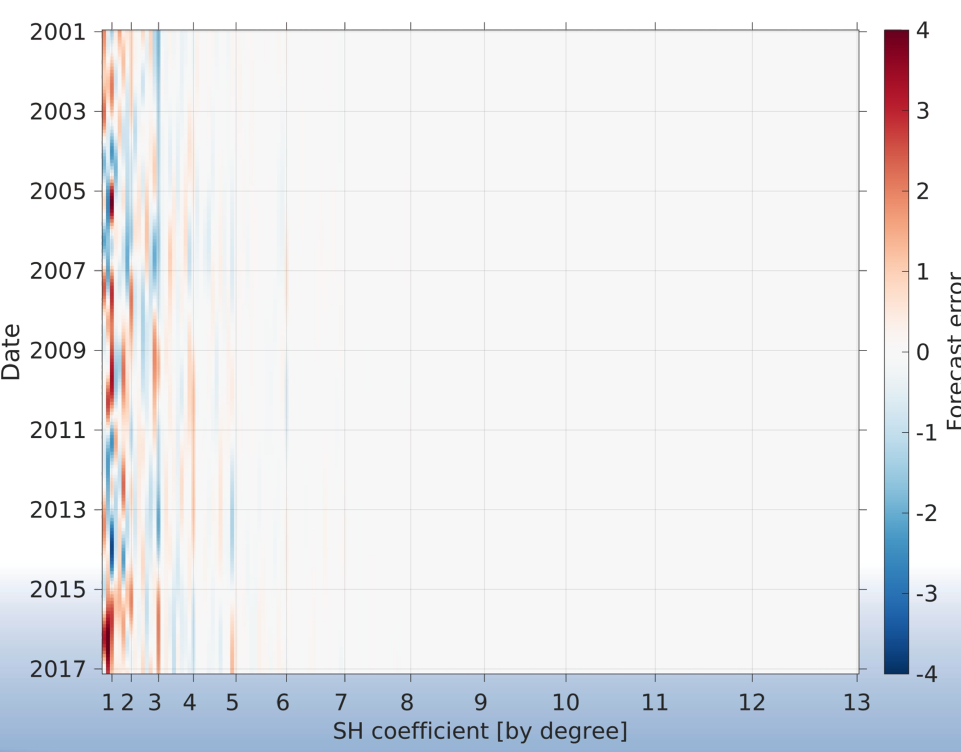
MEME model coefficients to degree and order 13 have a 6th-order B-spline time dependence, with annual knots.

We take a 1 year window of each modelled SV Gauss coefficient time series, make a linear fit, then extrapolate forward 1 year.

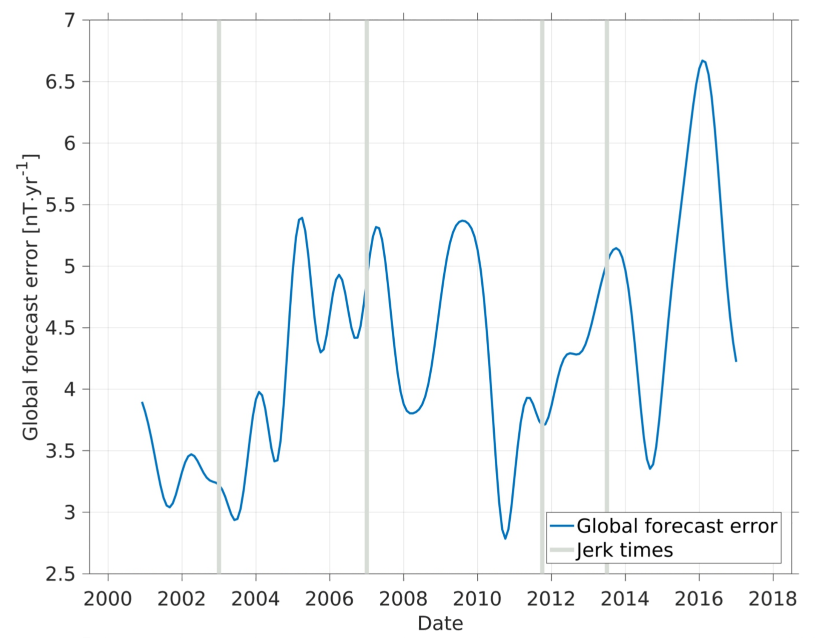
The short lines in the top panel show examples of these linear fits, the **forecast error** in the coefficient, shown in the bottom panel, is given by the difference between the extrapolated coefficient value, and the smooth modelled curve.

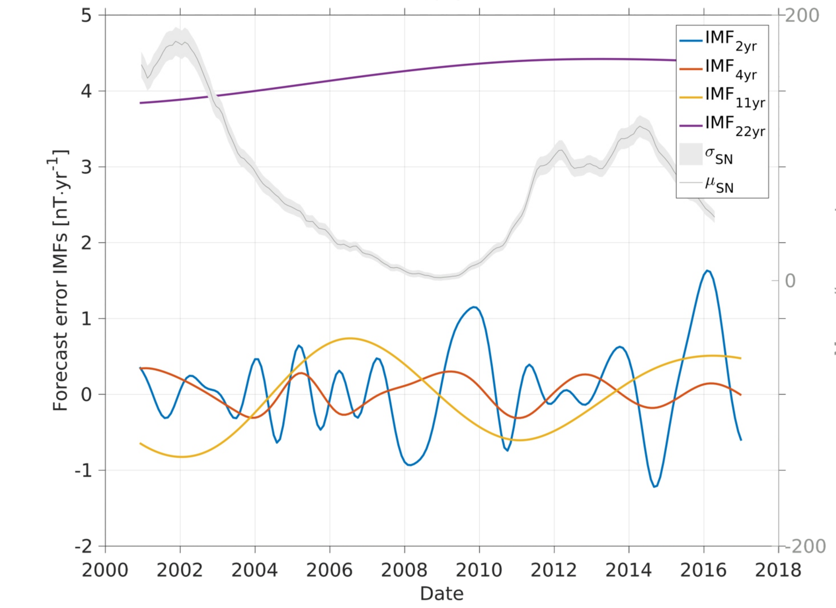
The **largest magnitude forecast errors are seen in the low degree coefficients** (right), since these coefficients are of the largest magnitude.

The magnitude of the forecast error depends on the forecast period - a longer period gives larger errors - but as the forecasts are linear, the same temporal and spatial trends are seen for forecast periods from 1 to 10 years.



3. Forecast errors in time

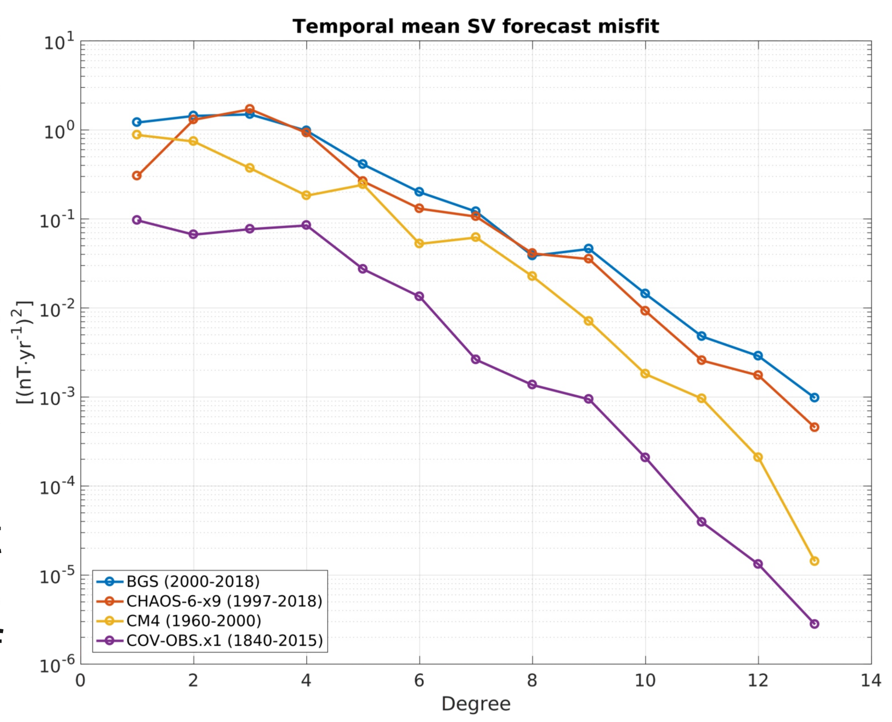




The **root-sum-square error** over all Gauss coefficients gives a **global measure of misfit for each forecast through time** (top left).

The forecast errors show **no obvious correlation with known geomagnetic jerks or secular acceleration pulses**. Larger global misfit coincides with some jerks and pulses, but is also seen at other times. **Periodic trends in the errors are present** however, as highlighted by **empirical mode decomposition (EMD)** (bottom left). These include a sub-decadal mode which agrees with the periodicity seen in **secular acceleration (SA)** pulses [1], and an 11 year period mode that suggests a link to the solar-cycle. It may be that despite careful selection and modelling to separate external fields, core field coefficients are still contaminated by solar effects.

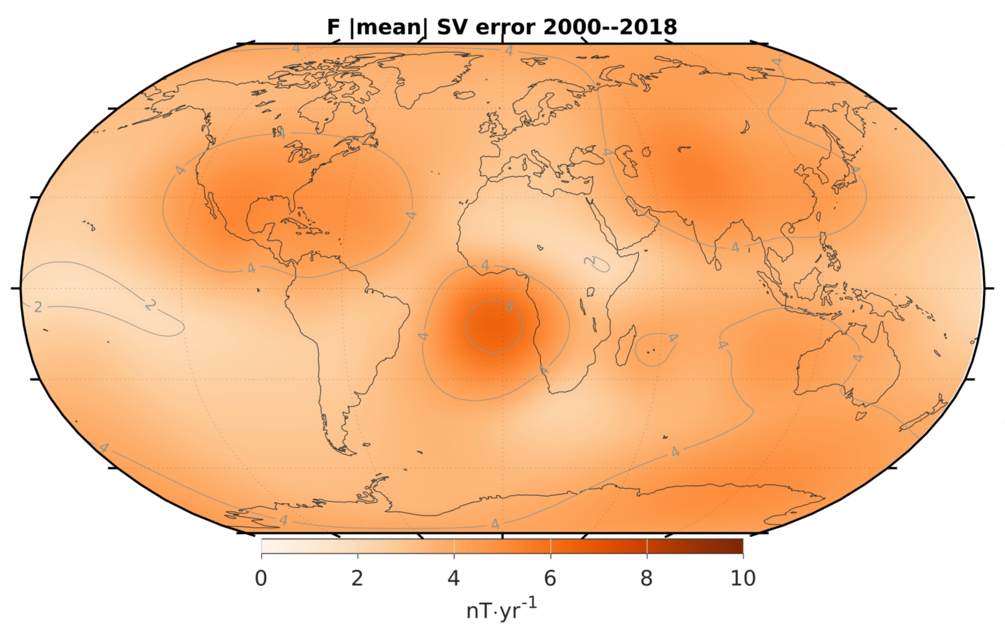
The **forecast error time series is broadly consistent between the MEME, CHAOS-6-x9 [2], CM4 [3] and COV-OBS.x1 [4] field models.** While similar periodic content is seen in each model's error, the time lags between the sub-decadal error mode and SA pulses, and between the 11 year error mode and the mean sun spot number, are not consistent between models. Further analysis is needed to understand the origin of these periodic modes.



While the temporal mean of SV forecast errors has similar spectral content for each model, we find **models with higher spatiotemporal resolution of SV and SA show greater magnitude forecast errors** (top right). Smoothly varying, large-scale SV leads to more accurate forecasts in this assessment, as the lower degree coefficients govern the bulk of the SV. This suggests that, with current forecasting methods, there is no strong case for models such as the IGRF [5] or WMM [6] to involve high resolution SV or SA to improve forecast accuracy generally.

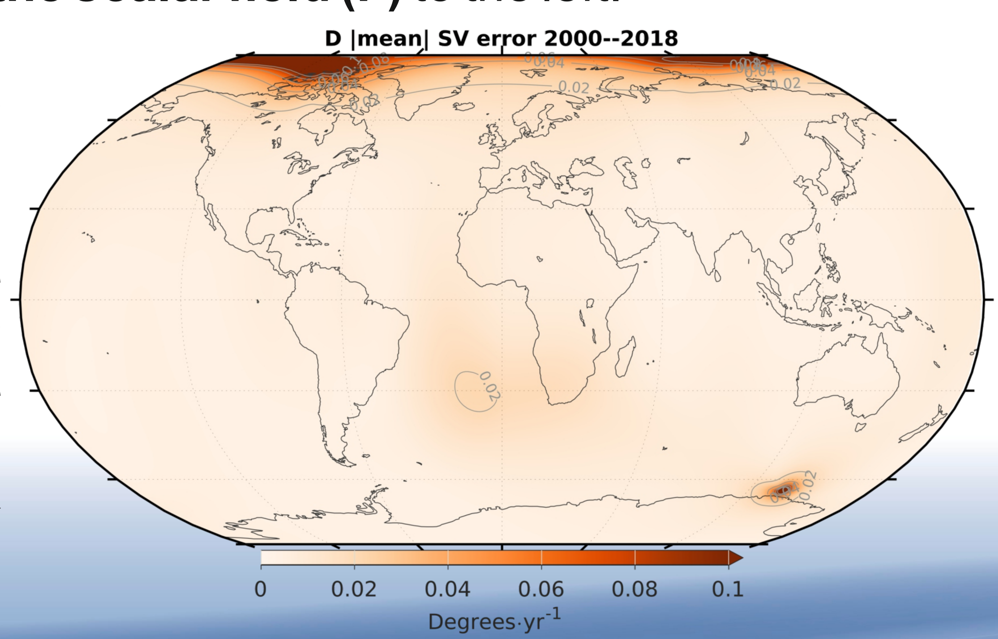
MEME is updated annually, so comparing the forecasts from 18 model versions to the forecasts made throughout the latest continuous model version allows us to **separate forecast errors arising from SV and SA, from errors arising from data availability and model end effects.** As annual scalable 1σ equivalents, **SV and SA effects account for 3nT in scalar field and 0.01° in declination, compared to data availability and model end effects of 8nT in scalar field and 0.01° in declination.**

4. Forecast errors in space



Forecast errors in both the main field and the SV show similar spatial patterns on average through time, although larger localised, short-lived errors occur due to rapid SV. **Consistently larger errors over the last 20 years match the persistent high SV of the non-dipole field, particularly in the South Atlantic Anomaly (SAA),** as shown in the **map of the SV of the scalar field (F)** to the left.

In terms of the forecast errors **potential impact on magnetic navigation, declination is most negatively affected over the SAA** (map right). The largest errors are consistently seen near the dip poles due to weak horizontal field, particularly in the northern hemisphere.



5. Summary and further work

- **Errors from simple model forecasts show common spatiotemporal trends through recent decades**
- **Regions of persistent high SV and SA, and particularly the South Atlantic Anomaly, show largest errors**
- **Data availability and end-of-model effects are a greater contribution to SV forecast error than the assumption of linear SV**
- **Principle component analysis of forecast Gauss coefficient errors through time would likely be a more robust way to identify the origins of periodic error modes**

Acknowledgements and References

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[2] Finlay et al., (2016), Recent geomagnetic secular variation from Swarm and ground observatories as estimated in the CHAOS-6 geomagnetic field model, *EPS*, 68:112.
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Contact Information

William Brown wb@bgs.ac.uk www.bgs.ac.uk

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