Forecast Geomagnetic Secular Variation via NASA Geomagnetic Ensemble Modeling System (GEMS)

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BW Project: bavk
Forecast Geomagnetic Secular Variation via NASA Geomagnetic Ensemble Modeling System (GEMS)

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1. Geomagnetic secular variation (SV) is of fundamental importance
2. Decadal SV forecast is feasible, but is computationally challenging
3. BW project aims to find cost-effective geomagnetic data assimilation (GDAS)
Geomagnetic SV affects very much our life

In addition to water and air, our life depends also on geomagnetic field!
Geomagnetic SV affects very much our life. In addition to water and air, our life depends also on the geomagnetic field!
Geomagnetic SV holds the key information of Earth’s interior

- It is a dominantly dipole field at surface
- It originates from the Earth’s liquid core

http://www.esa.int/spaceinimages/Images/2013/11/Earth_s_magnetic_field
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- It displays complex spatial and temporal variations

Plots are based on the CM4 model (Sabaka et al 2004)
Geomagnetic SV holds the key information of Earth’s interior

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Non-dipolar magnetic field at CMB over the past 400 years from gufm1 (Jackson et al 2000) and CM4 (Sabaka et al 2004)
It is a dominantly dipole field at surface

It originates from the Earth’s liquid core

It displays complex spatial and temporal variations

It is generated and maintained by the convection in the Earth’s fluid core (geodynamo)
• It is a dominantly dipole field at surface
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• It is generated and maintained by the convection in the Earth’s fluid core (geodynamo)

Net magnetic energy change from kinematic -> magnetic energy transfer and Ohmic dissipation (simulation results)
Geomagnetic data assimilation (GDAS) is unique for fundamental research and societal application.

Numerical geodynamo models simply cannot reproduce observations!
Geomagnetic data assimilation (GDAS) is unique for fundamental research and societal application.

- Observed Br at CMB in 1990
- Truncated simulated Br at CMB
- Simulated Br at CMB

Numerical geodynamo models simply cannot reproduce observations!

GDAS can help improve the models!
NASA GEMS: the framework for geodynamo simulation and geomagnetic forecast

**MoSST Geodynamo System**

\[
\frac{\partial \mathbf{x}^f}{\partial t} = \mathbf{M}(\mathbf{x}^f, \alpha) \\
\mathbf{x}^f(t_a) = \mathbf{x}^a
\]

**EnKF Analysis System**

\[
\mathbf{x}^a = \mathbf{x}^f + \mathbf{K} \cdot (\mathbf{y} - \mathbf{H} \cdot \mathbf{x}^f) \\
\mathbf{K} = \frac{\mathbf{P}^f \cdot \mathbf{H}^T}{\mathbf{H} \cdot \mathbf{P}^f \cdot \mathbf{H}^T + \mathbf{R}} \\
\mathbf{P}^f = \langle (\mathbf{x}^f - \bar{x}^f)(\mathbf{x}^f - \bar{x}^f)^T \rangle
\]

- \( \mathbf{x}^f \): forecast
- \( \alpha \): dynamo parameters
- \( \mathbf{y} \): observation
- \( \mathbf{x}^a \): analysis
- \( \mathbf{H} \): observation operator
- \( \mathbf{R} \): observation error covariance
Geomagnetic SV forecast is feasible (old results)...

**Comparison of geomagnetic secular variation forecasts** (Kuang et al 2010)

- **Observed $B_r$ (GUFM1 + CM4)**
- **Forecasted $B_r$ from GEMS** (20-year analysis cycle)

![Observed $B_r$ map](image1)

![Forecasted $B_r$ map](image2)

![Rms spectra of SV and the prediction differences](image3)
But GDAS is computationally very expensive

Algorithm
A hybrid pseudo-spectral scheme (on spherical surface) and a finite difference scheme (in radius)

Estimated resolution
\[ \Delta h \sim E^{1/4} \]
\[ \Delta t \sim \Delta h R_o^{1/2} \sim (ER_o^2)^{1/4} \]

\[ R_o = E = 10^{-6} \] (current values)

\[ R_o \sim 10^{-9} , E \sim 10^{-15} \] (For Earth’s core)
But GDAS is computationally very expensive

CPU expense of Geomagnetic data assimilation

- $N_{ens} = 1$
- $N_{ens} = 10$
- $N_{ens} = 100$
- $N_{ens} = 1000$

Current assimilation vs. “Earth-like” assimilation

NCSA BW Symposium, Sun River, Oregon, June 2-6, 2019
What is our BW project?

Find the computationally cost-effective geomagnetic data assimilation (GDAS) approach

1. The optimal ensemble size with full covariance analysis?
2. A working hybrid covariance using small ensemble sizes?
Optimal ensemble sizes are possible!

Mean forecasted $B_r$ at CMB in 1990

$10 \times (O-F)$ at the CMB
Summary

1. Geomagnetic secular variation (SV) is of fundamental importance

2. Decadal SV forecast is feasible, but is computationally challenging

3. BW project aims to find cost-effective geomagnetic data assimilation (GDAS) showed possible optimal ensemble sizes

4. Next step: search for a working hybrid covariance for GDAS