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)

Weijia Kuang, NASA Goddard Space Flight Center

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!**

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NEWS

Jersey

Jersey airport runway re-named as magnetic pole shifts

15 October 2014 | Jersey

The changes should last for 56 years, the airport said

Jersey's runways will be re-numbered on Wednesday night as island aviation authorities catch up with the planet's shifting magnetic field.

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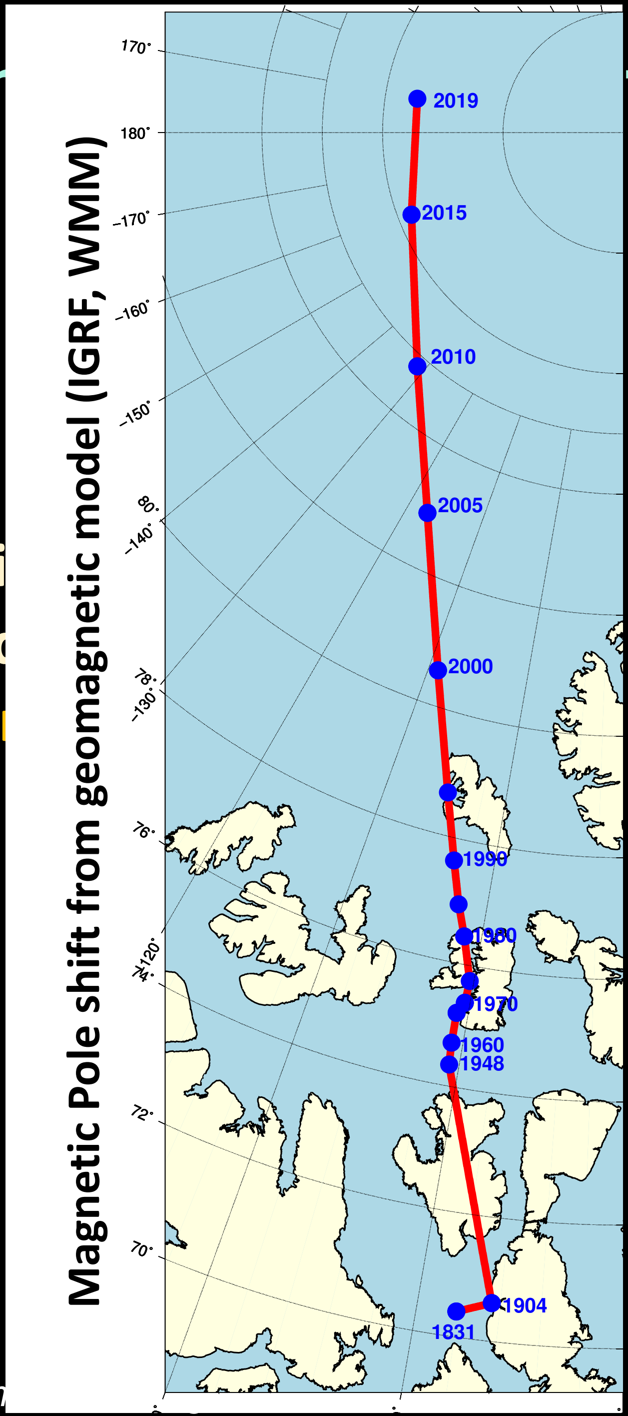

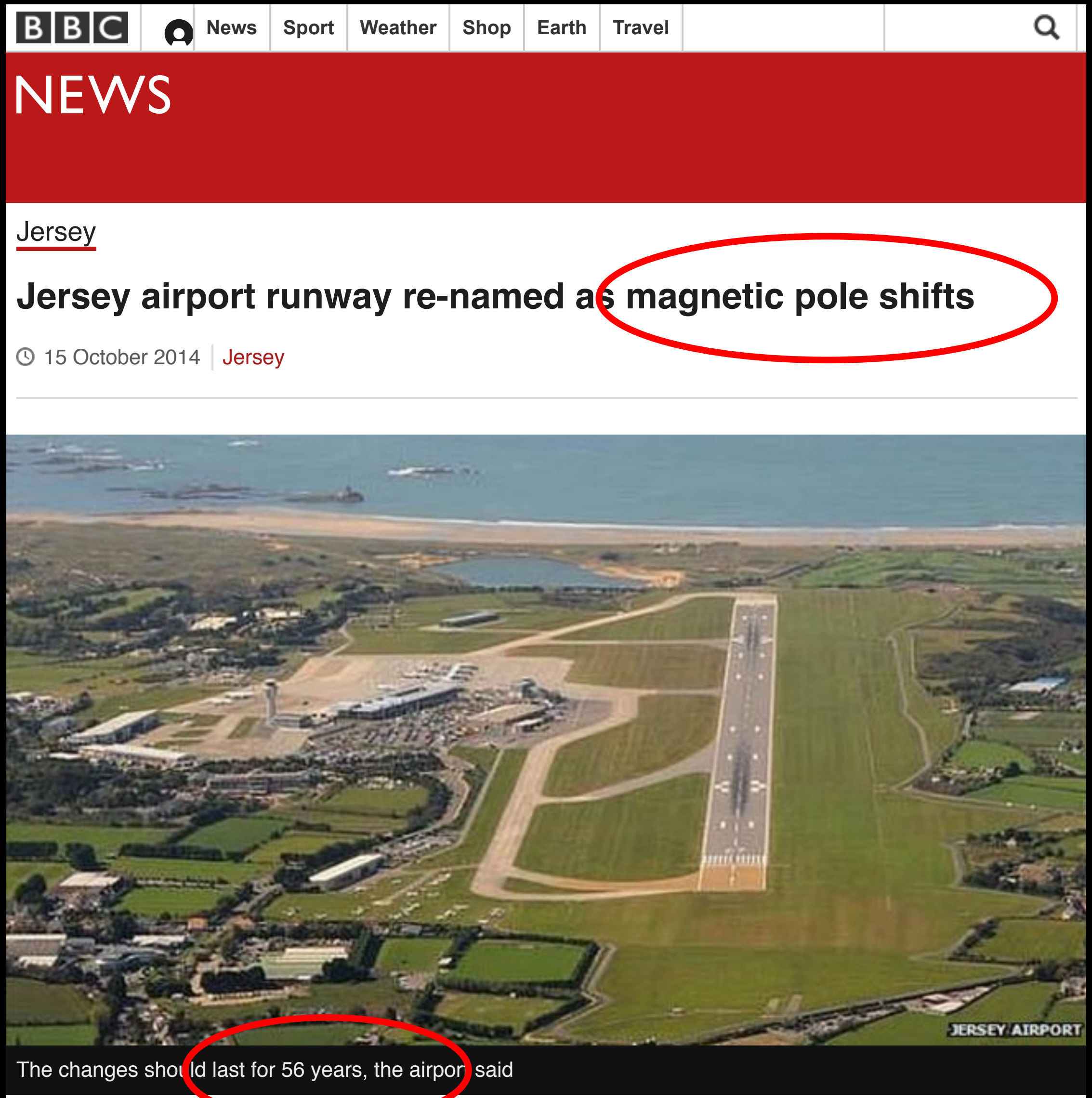

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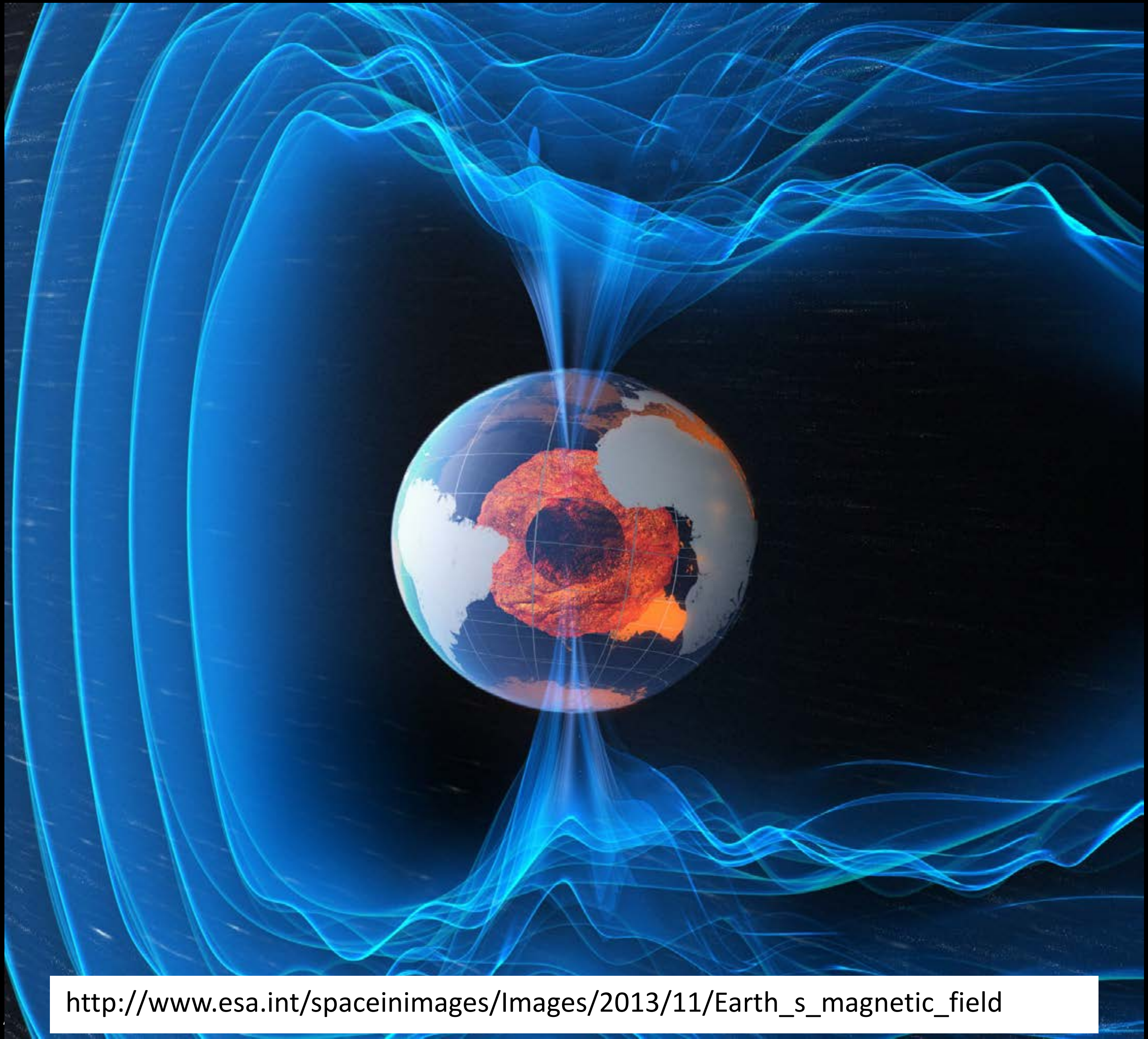
Geomagnetic SV holds the key information of Earth's interior

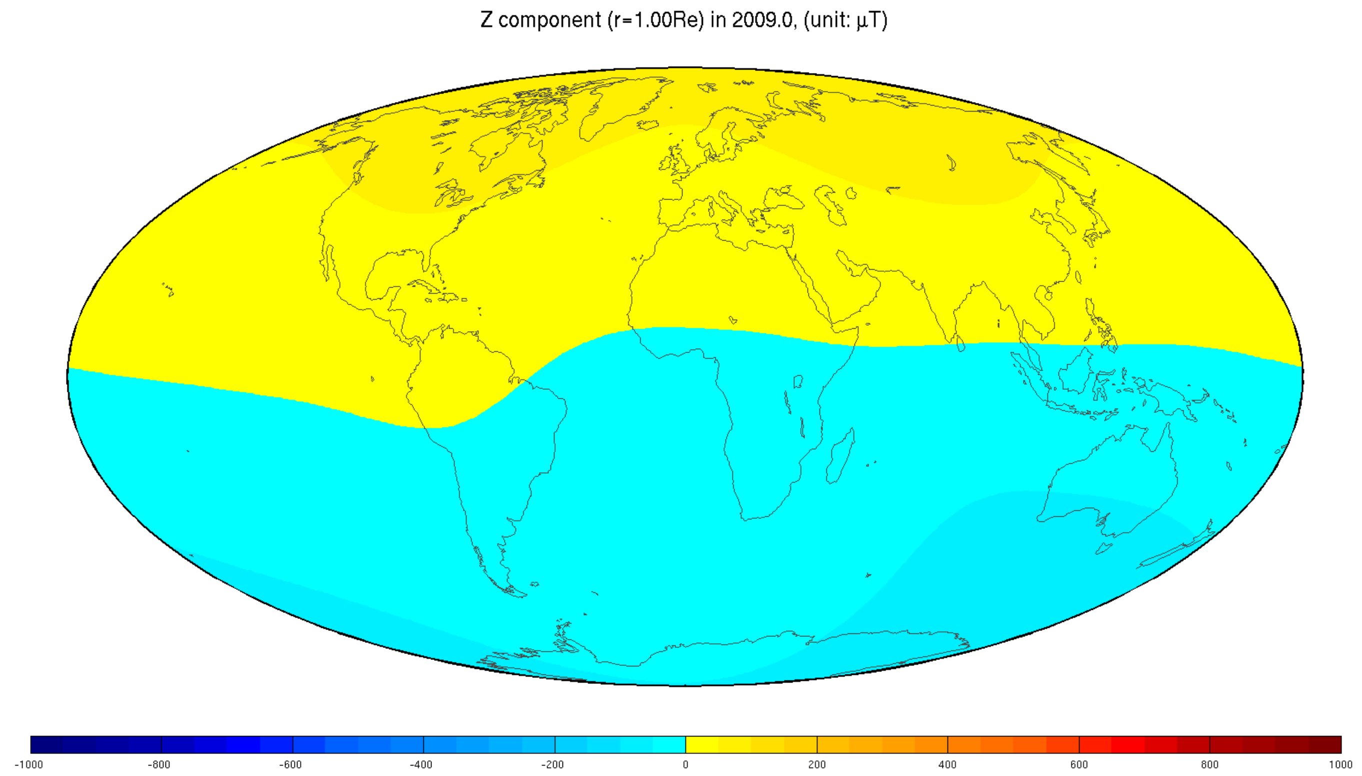
- It is a dominantly dipole field at surface
- It originates from the Earth's liquid core



http://www.esa.int/spaceinimages/Images/2013/11/Earth_s_magnetic_field

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
- It displays complex spatial and temporal variations



Plots are based on the CM4 model (Sabaka et al 2004)

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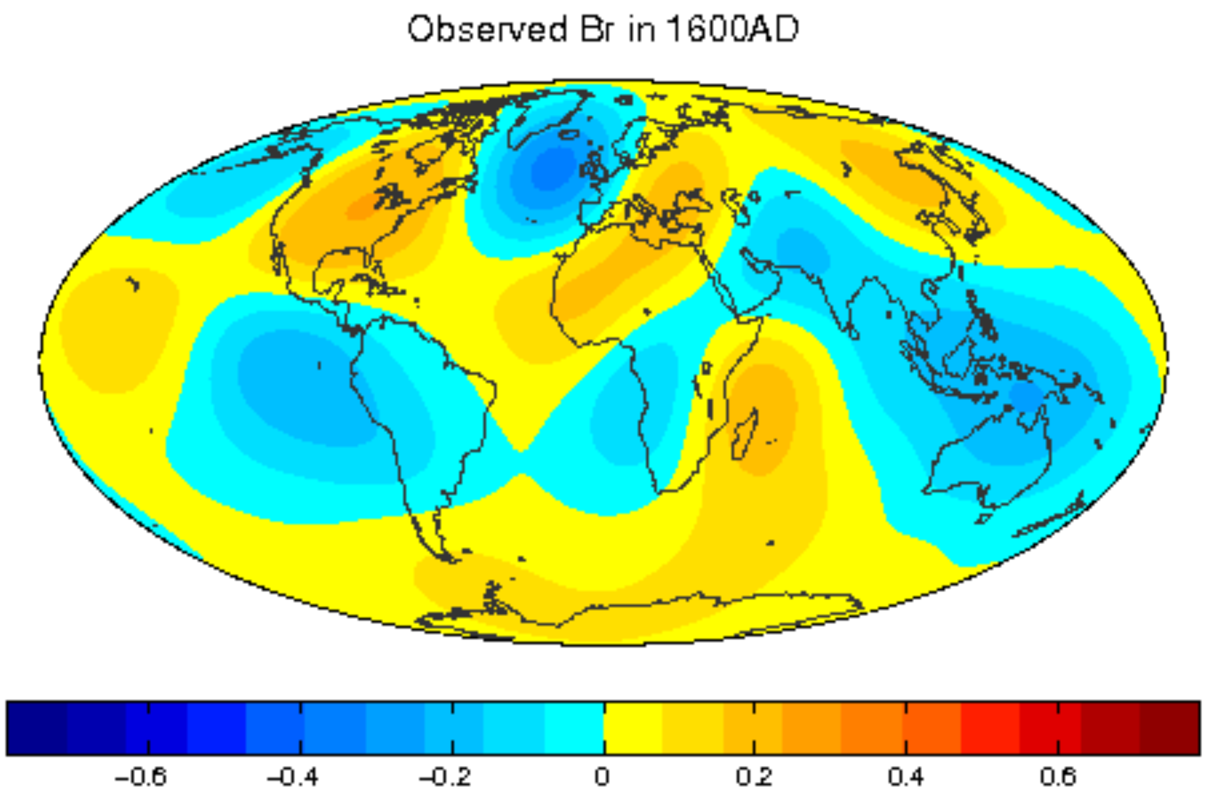
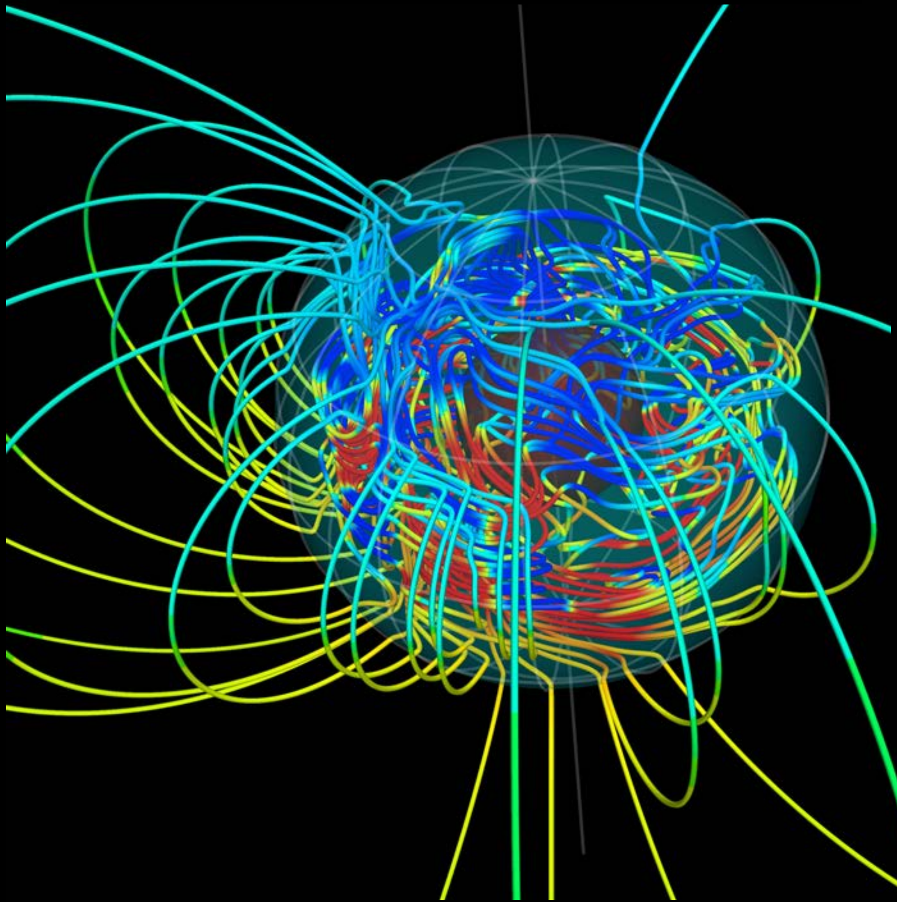


Non-dipolar magnetic field at CMB over the past 400 years from gufm1 (Jackson et al 2000) and CM4 (Sabaka et al 2004)

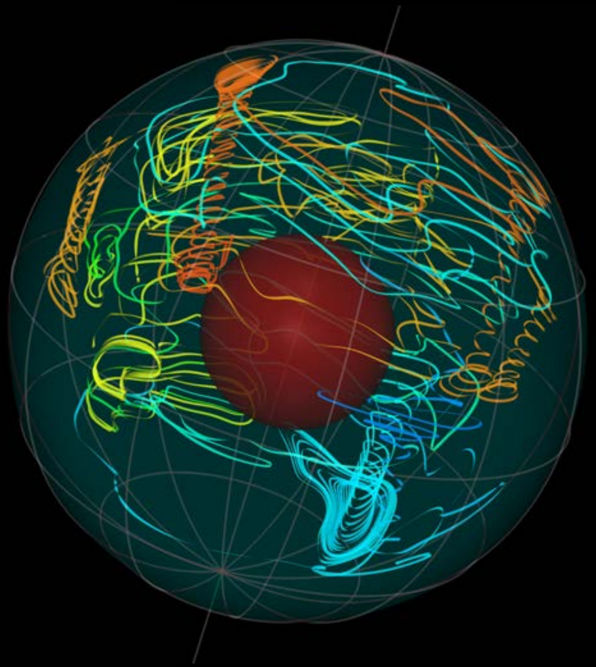
Geomagnetic SV holds the key information of Earth's interior

- It is a dominantly dipole field at surface
- It originates from the Earth's liquid core
- It displays complex spatial and temporal variations
- It is generated and maintained by the convection in the Earth's fluid core (geodynamo)

Magnetic field line generated by core convection



Streamline of convective flow in the outer core



Geodynamo process (visualization of simulation results)

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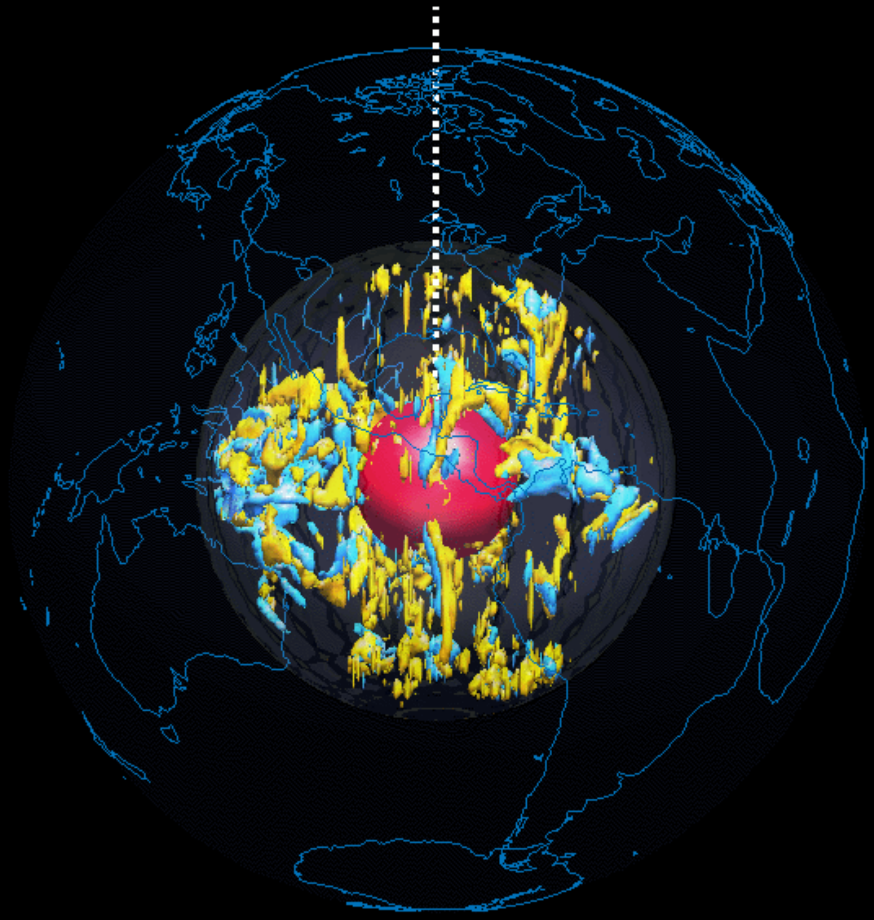
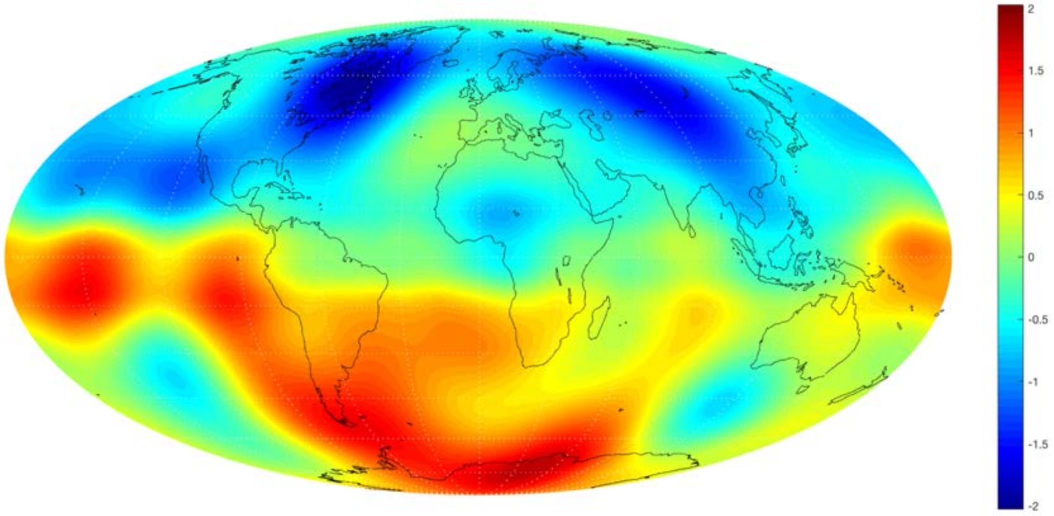


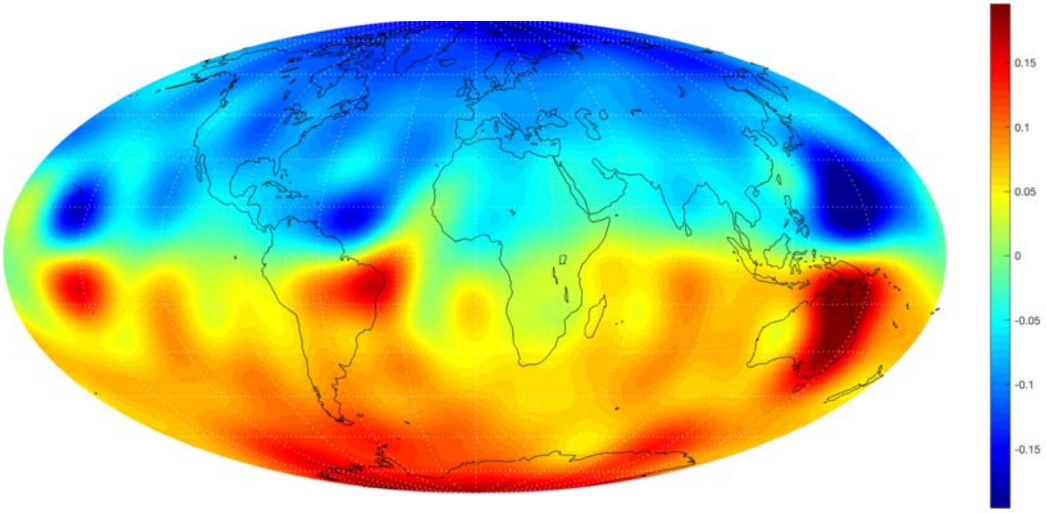
Net magnetic energy change from kinematic -> magnetic energy transfer and Ohmic dissipation (simulation results)

Geomagnetic data assimilation (GDAS) is unique for fundamental research and societal application

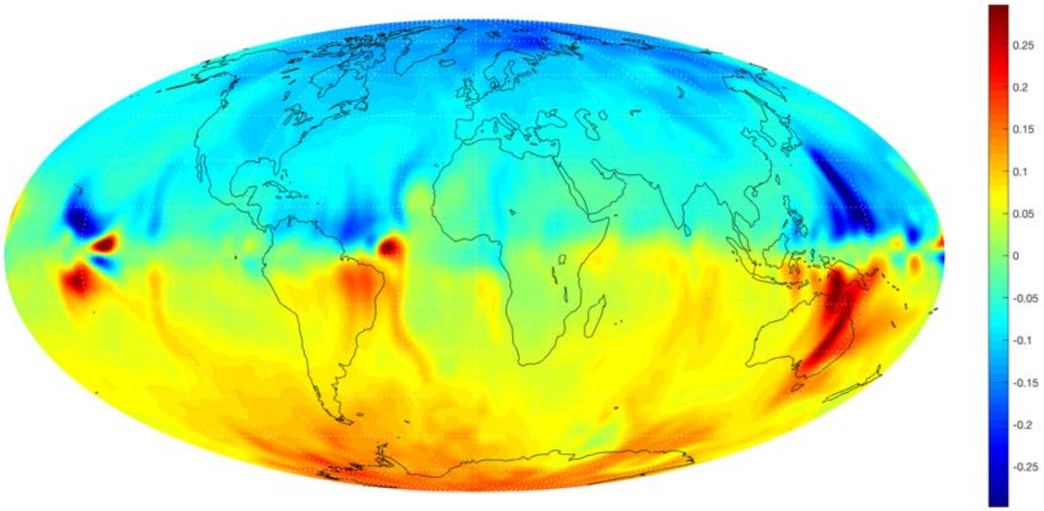
Observed Br at CMB in 1990



Truncated simulated Br at CMB



Simulated Br at CMB



Numerical geodynamo models simply cannot reproduce observations!

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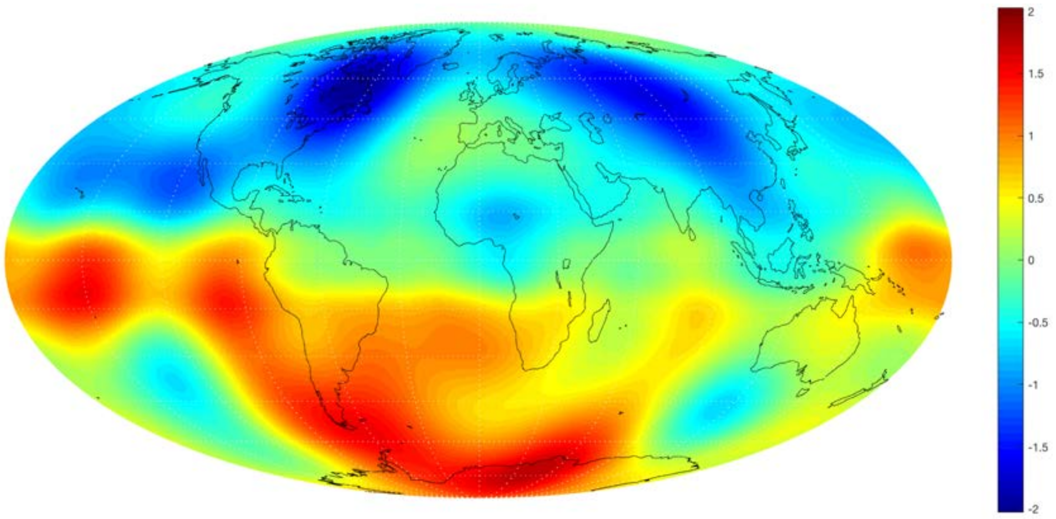

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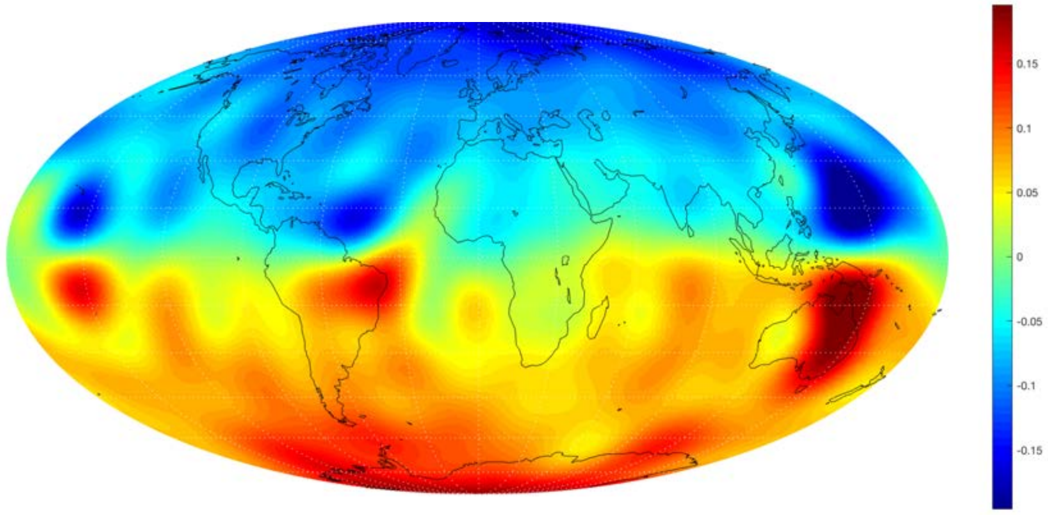
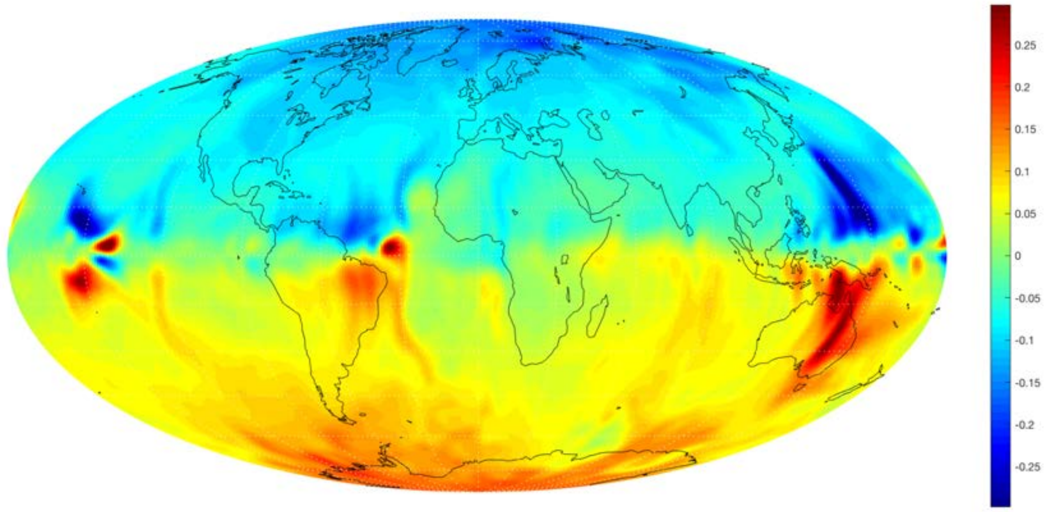


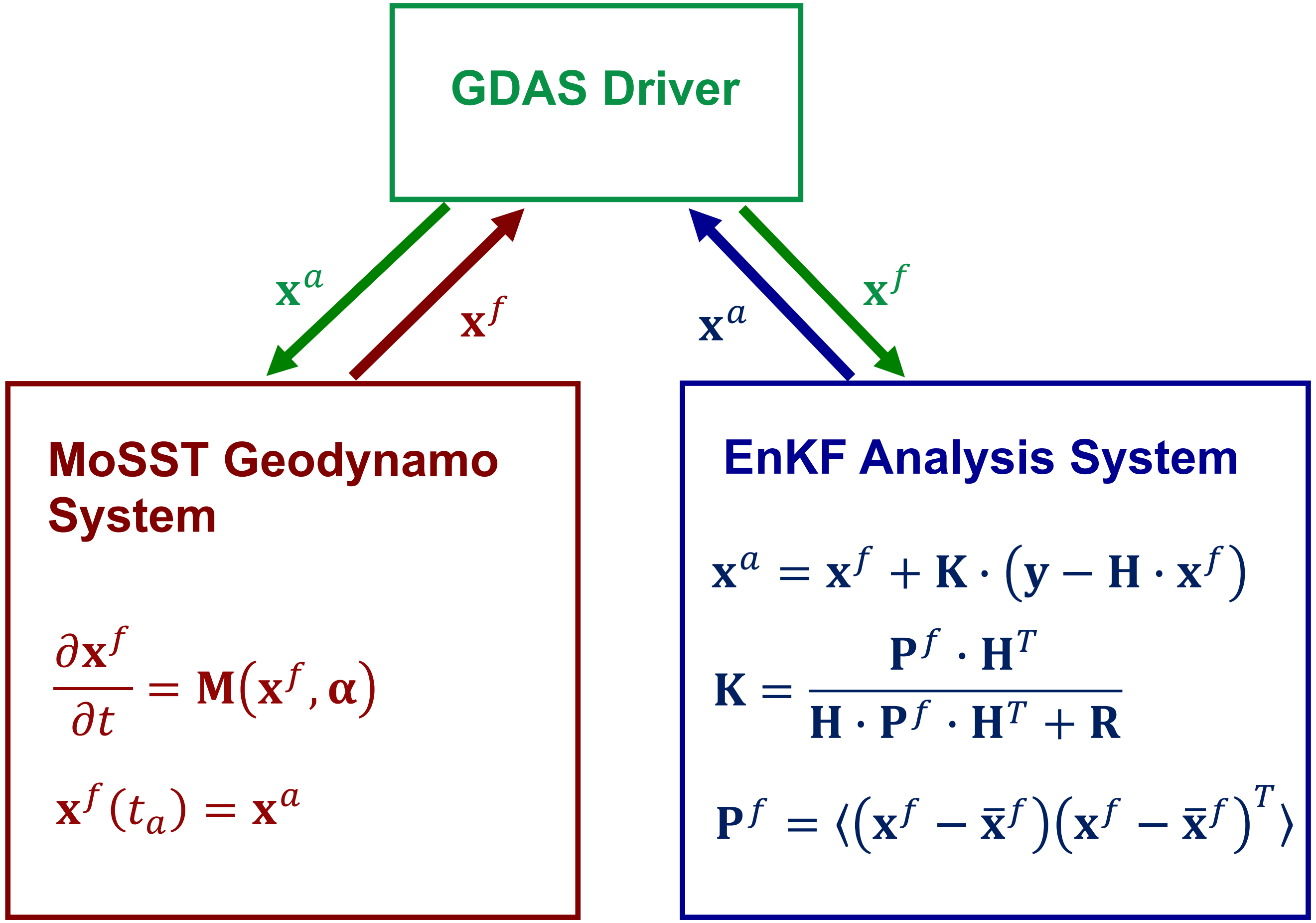
Simulated Br at CMB



Numerical geodynamo models simply cannot reproduce observations!

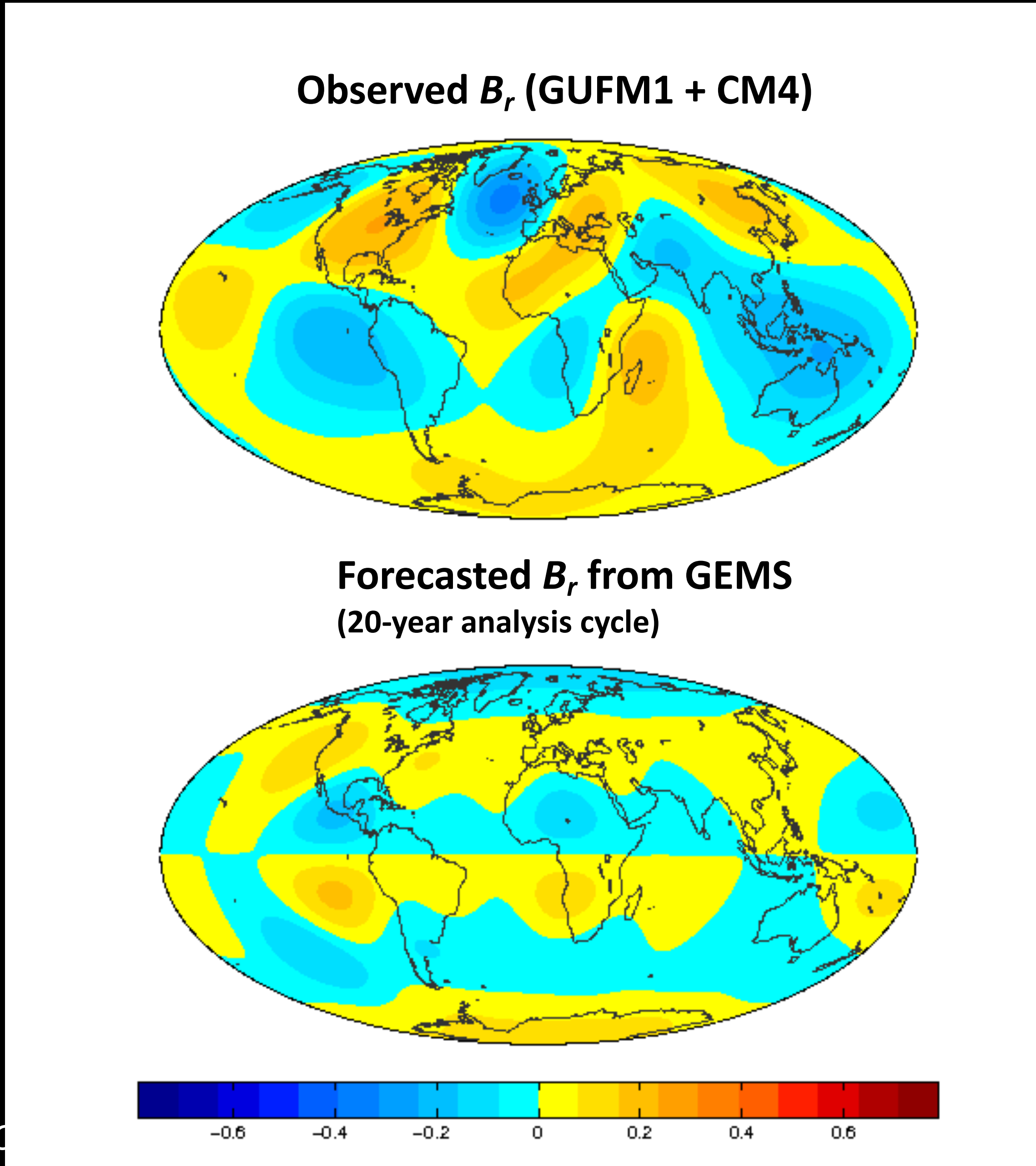
GDAS can help improve the models!

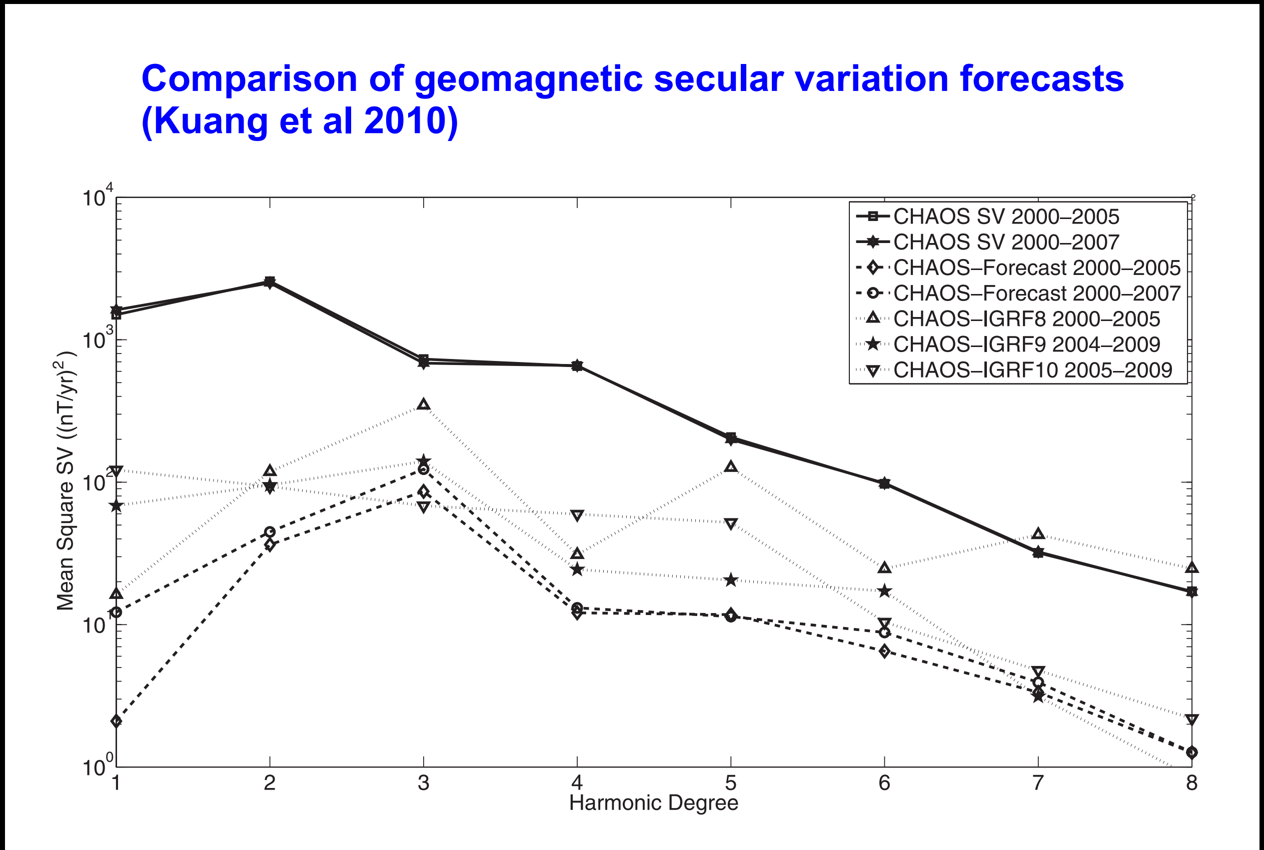
NASA GEMS: the framework for geodynamo simulation and geomagnetic forecast



$\mathbf{x}^f$: forecast
$\boldsymbol{\alpha}$: 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)…





NC

But GDAS is computationally very expensive

Algorithm

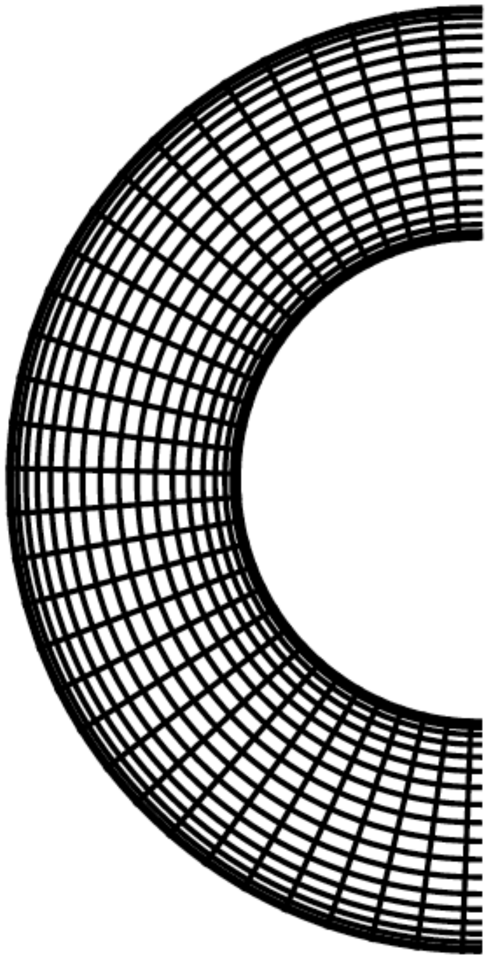
A hybrid pseudo-spectral scheme (on spherical surface) and a finite difference scheme (in radius)

Estimated resolution

$$\Delta h \sim E^{1/4}$$
$$\Delta t \sim \Delta h\, R_o^{1/2} \sim (E R_o^2)^{1/4}$$

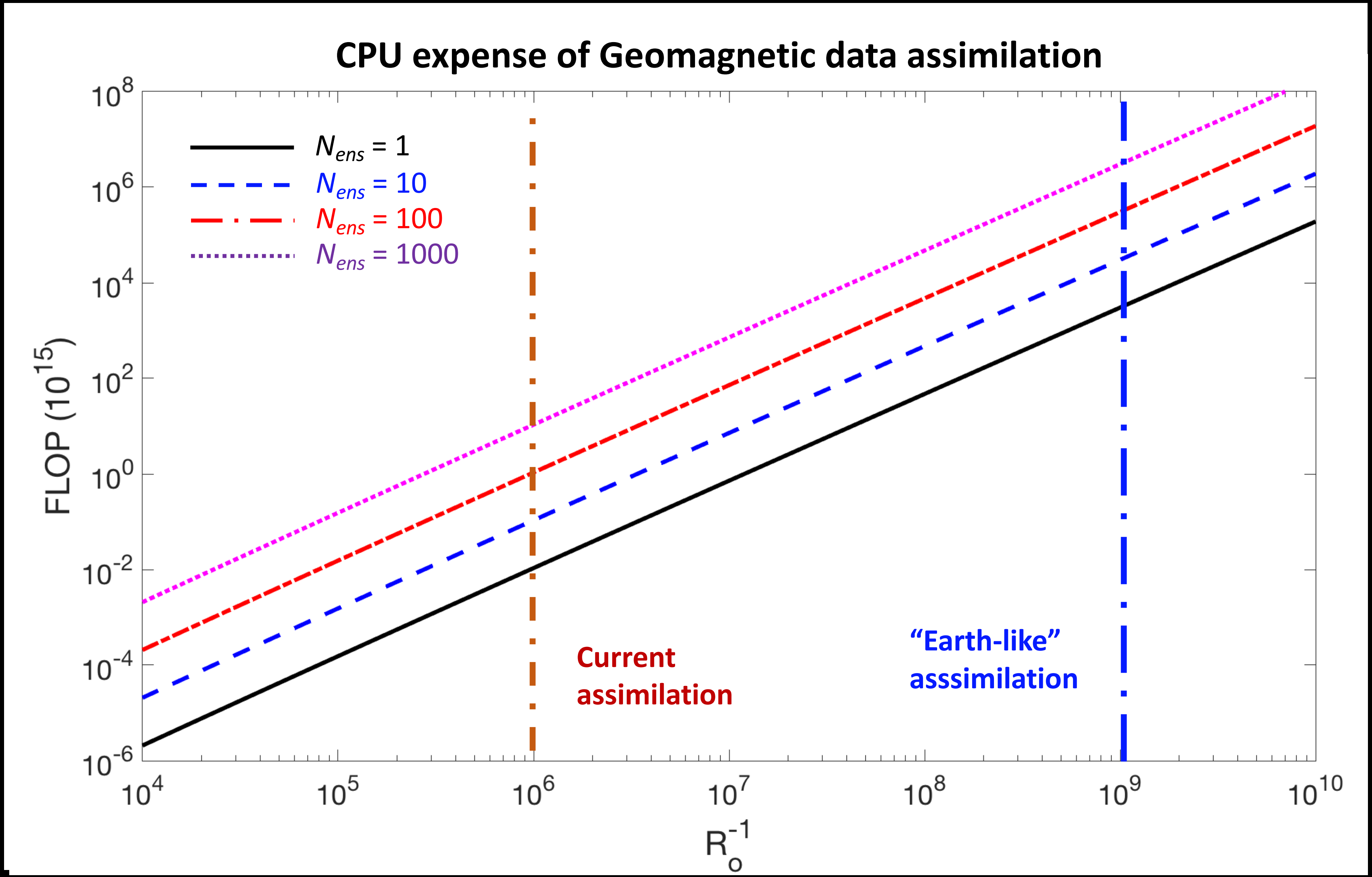
$R_o = E = 10^{-6}$ (current values)

$R_o \sim 10^{-9}$, $E \sim 10^{-15}$ (For Earth's core)



Numerical grid in meridional surface

But GDAS is computationally very expensive

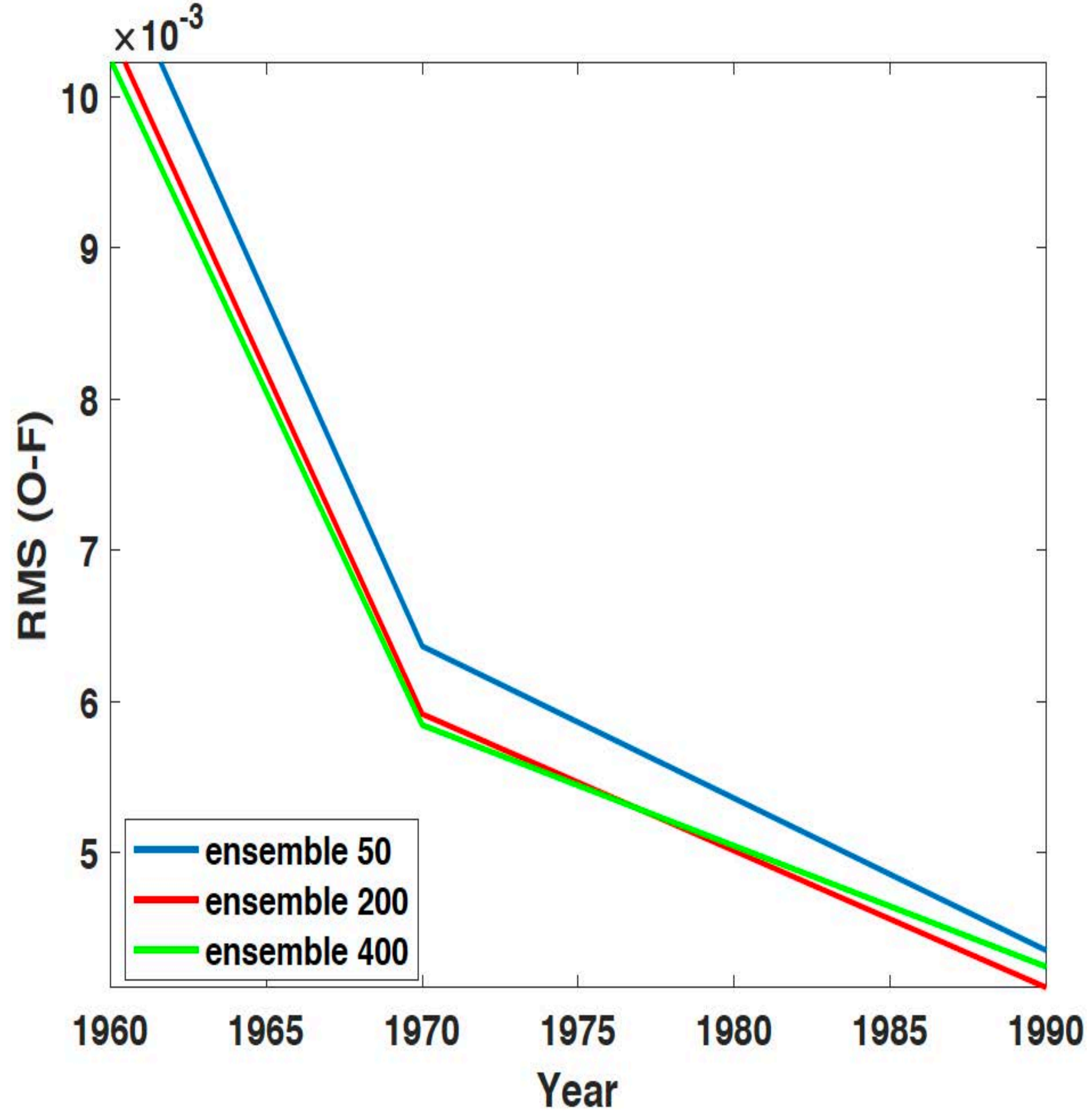


What is our BW project?

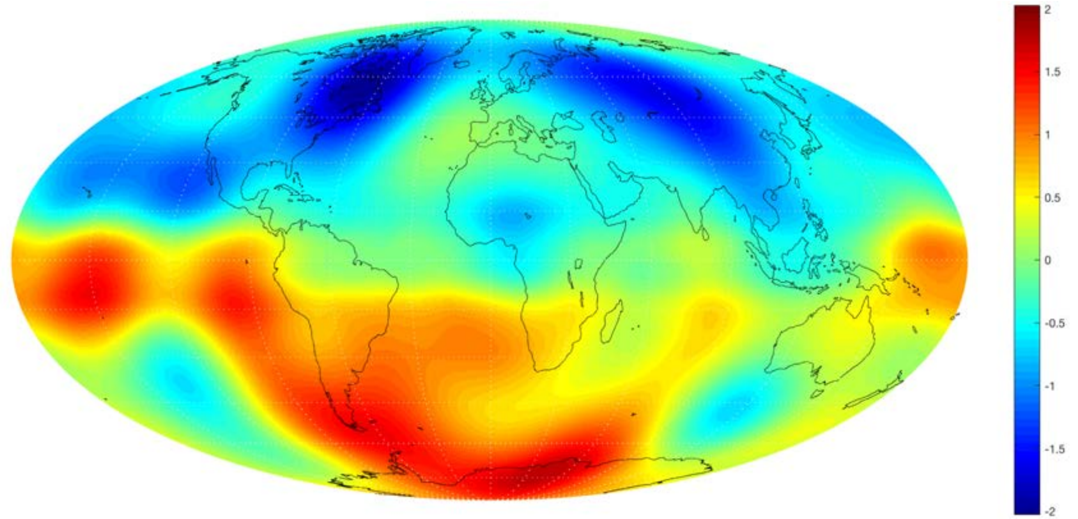
Find the computationally cost-effective geomagnetic data assimilation (GDAS) approach

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

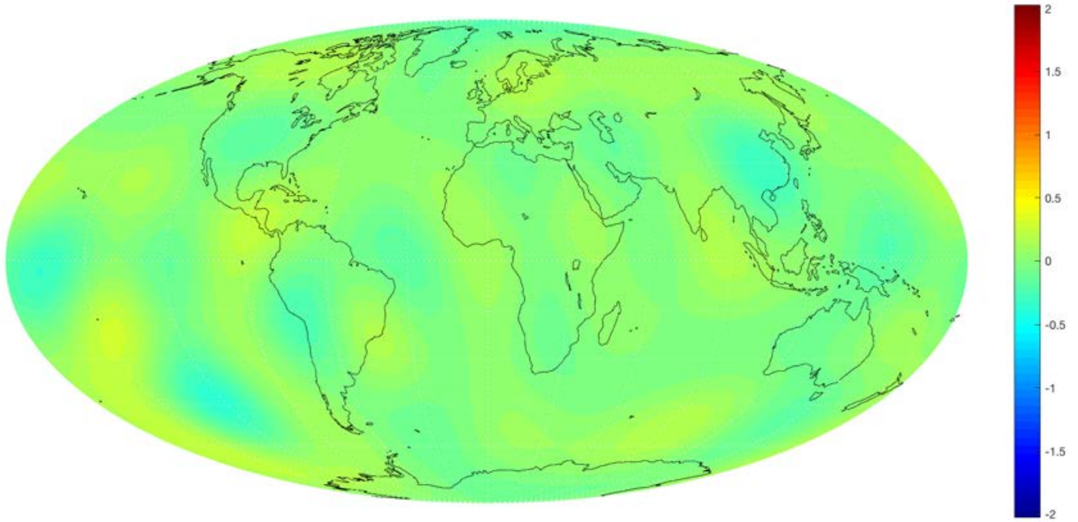
Optimal ensemble sizes are possible!



Mean forecasted B_r at CMB in 1990



10×(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