The past and future of Earth's magnetic field

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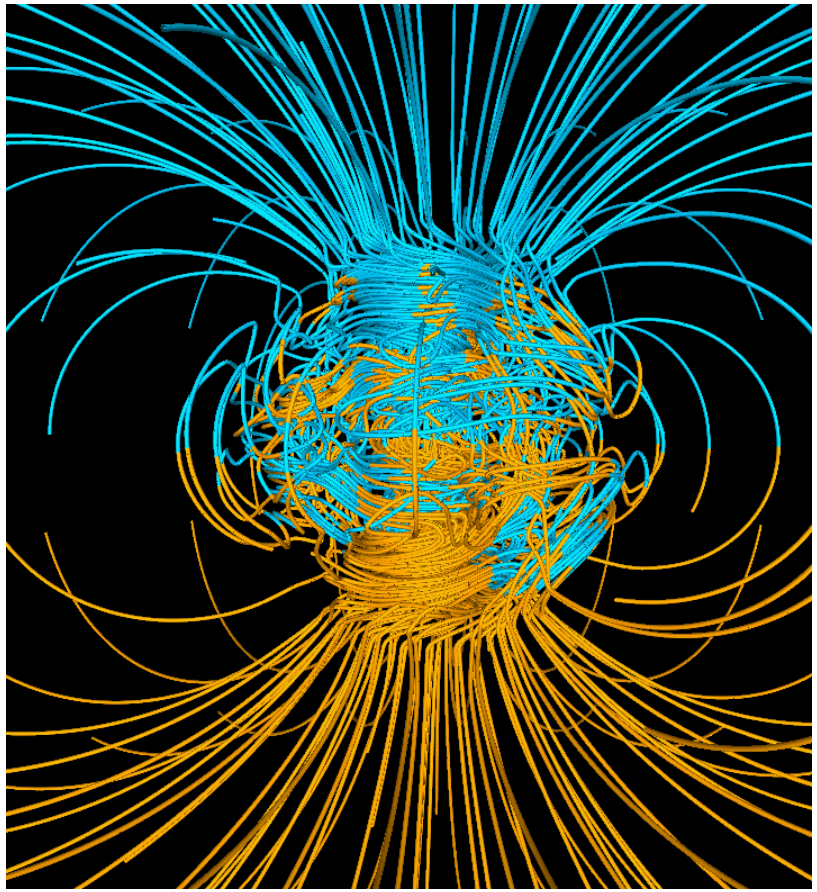
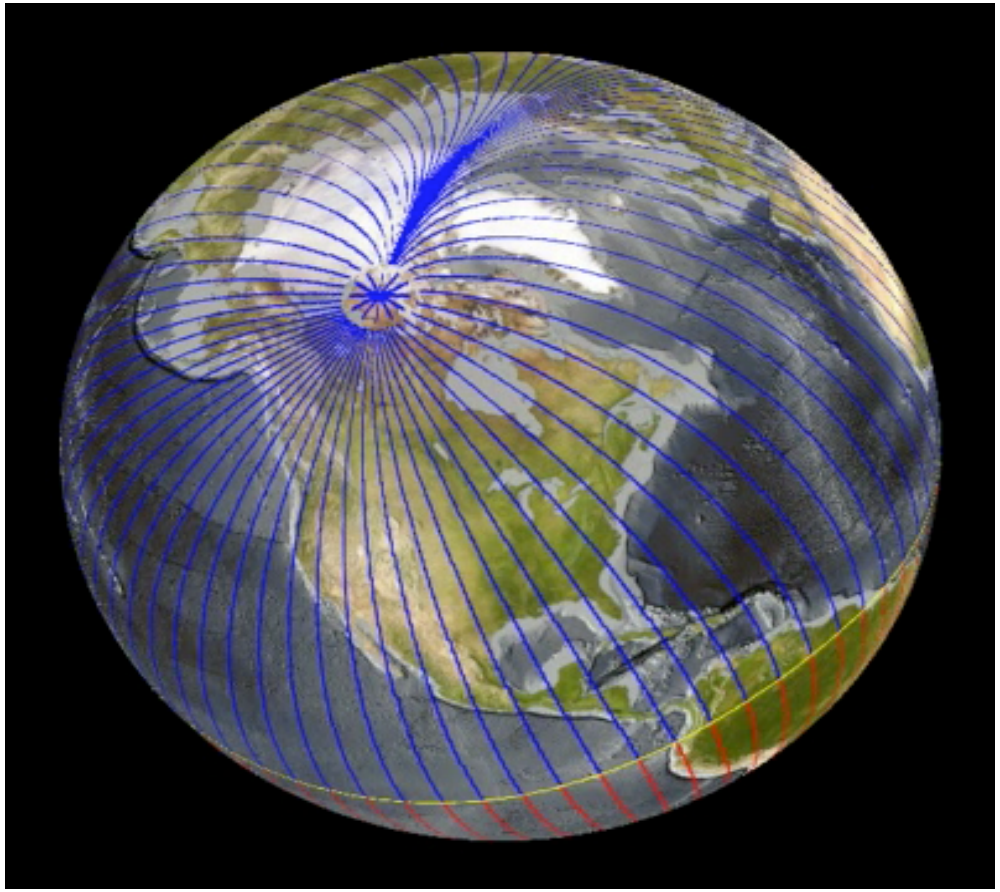
The Earth's magnetic field



- The result of convection of fluid in the liquid outer core.
- Evolution of the field takes place on scales from tens of years to millions of years
- Reversals of the magnetic poles occurs every several hundred thousand years.
- How far into the future can we forecast these changes?

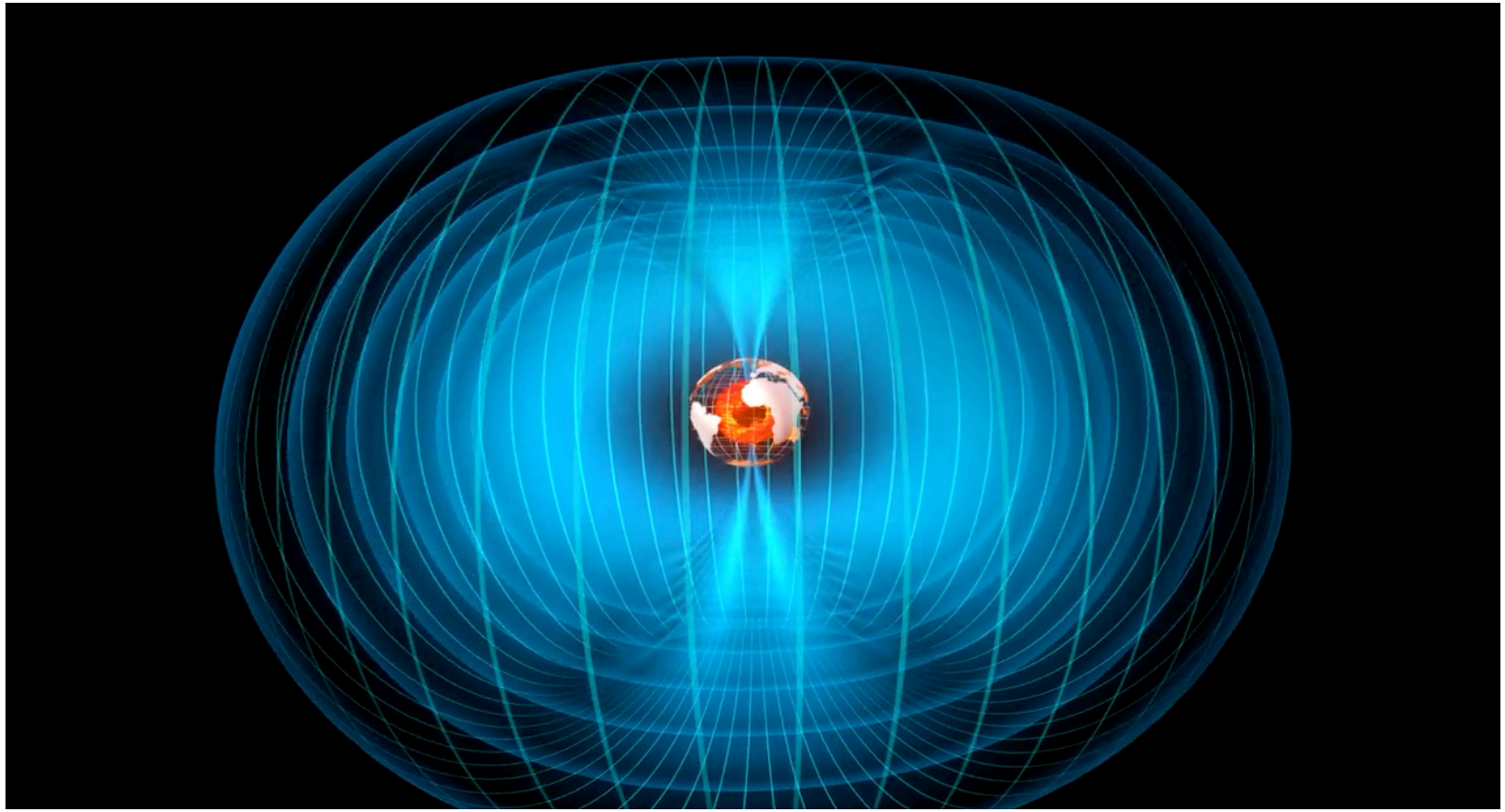
Recent history of the geomagnetic field



- The magnetic north pole is defined as the point where the magnetic field lines are vertical into the earth.
- Magnetic north pole has been moving between northern Canada and the geographic north pole.
- This variation is due to changes in the convective motion within the core.
- Over much longer times the magnetic poles can reverse.

Why do we care about the geomagnetic field

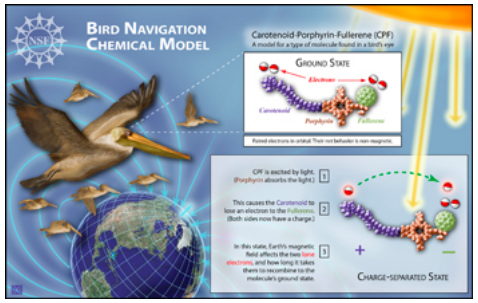
1. Protects the atmosphere from the solar wind.



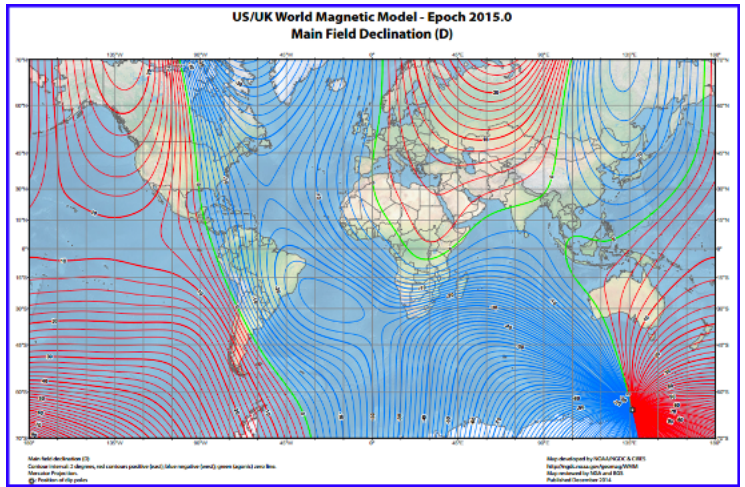
Why do we care about the geomagnetic field

2. Navigation

- Animals, particularly fish and birds use the magnetic field for migration.



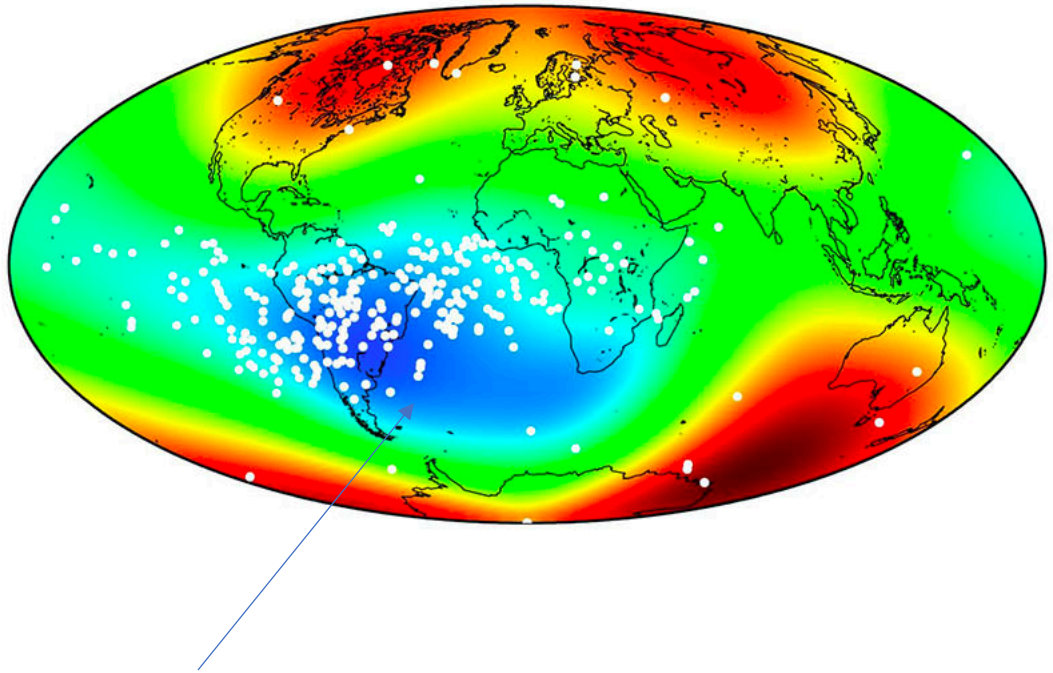
- Humans have been using it for hundreds of years, and it remains important in spite of the advent of GPS.



Submarines cannot receive GPS signals and therefore need a high resolution geomagnetic model for navigation

Why do we care about the geomagnetic field

3. Satellites and Communications



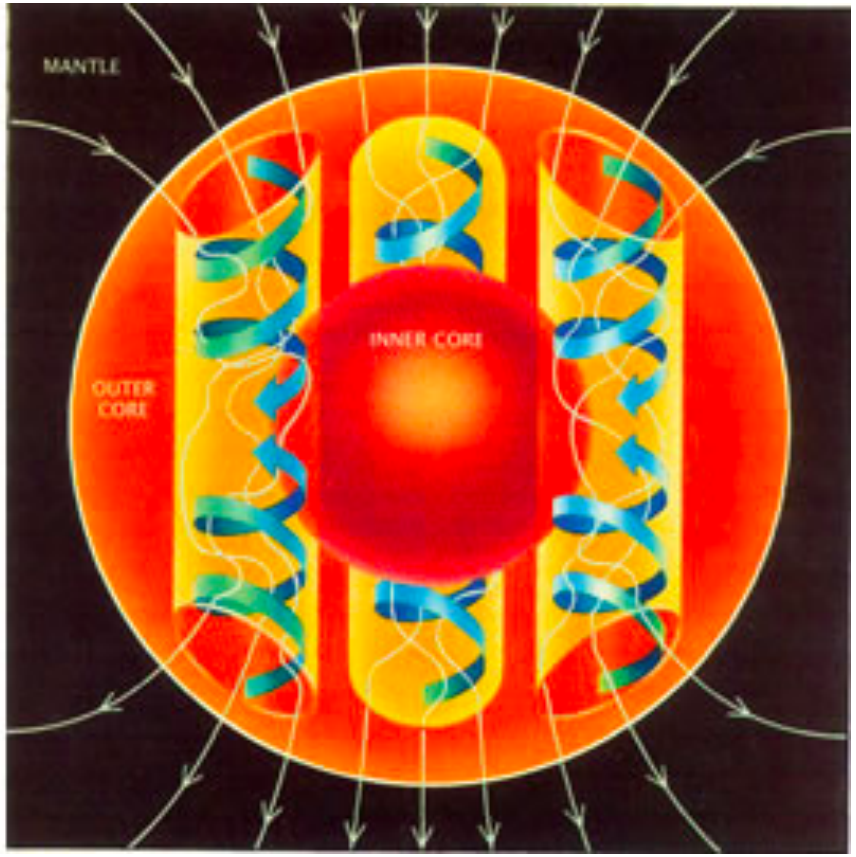
South Atlantic anomaly

Weaker magnetic field allows charged particles closer to the Earth's surface.

TOPEX/Poseidon satellite was affected by radiation at each of these locations

Why do we care about the geomagnetic field ?

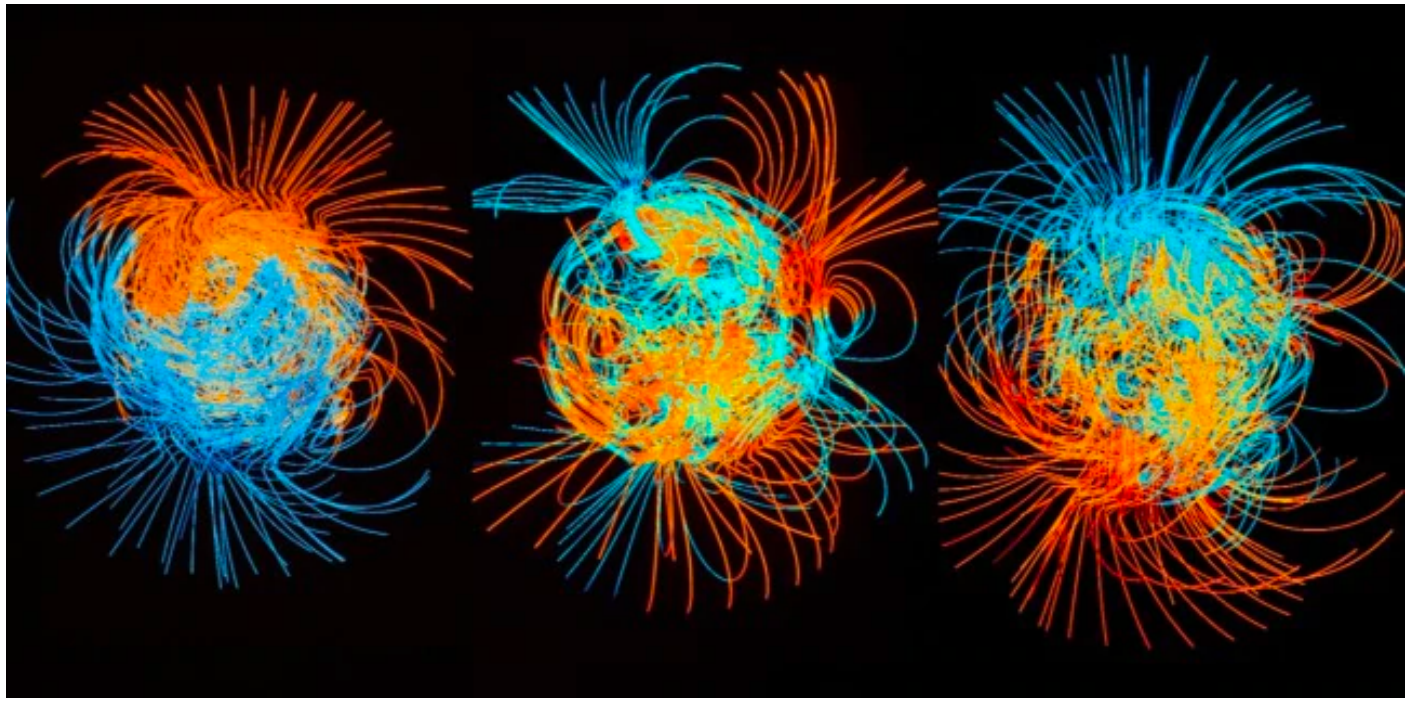
4. Improved Knowledge of fluid motion within the Earth's core.

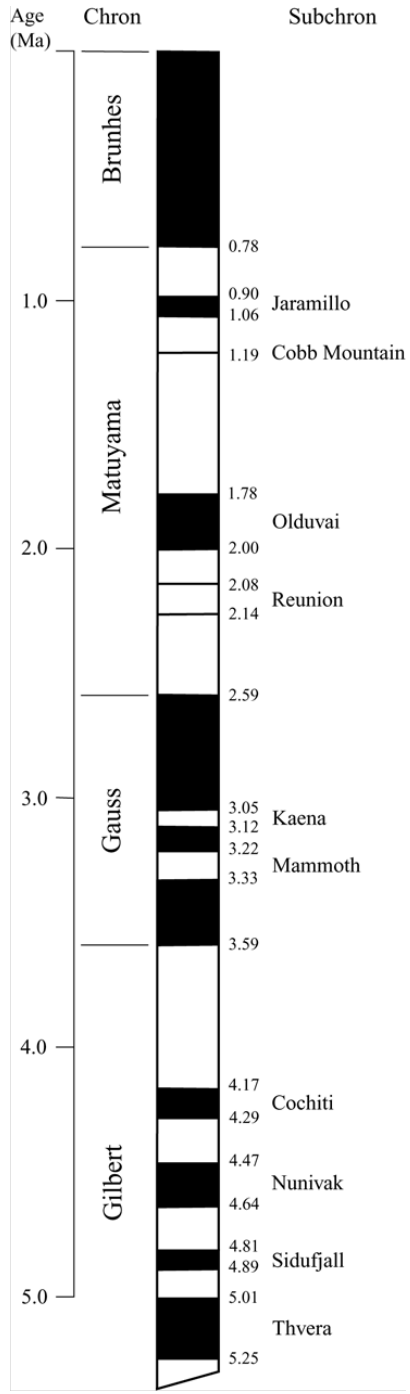


- We can learn about the structure of the fluid motion by simulating the geodynamo and comparing with the geomagnetic record.
- The fluid motion is likely in the form of Taylor columns due to the rotation of the Earth.
- We can get estimates of this fluid motion through inverse methods like data assimilation.

Geomagnetic Reversals

- Reversals are changes in the magnetic polarity where the north and south magnetic poles are reversed.
- These happen spontaneously due to changes in convective patterns within the core.
- There have been 183 reversals during the past 83 million years.
- The last reversal occurred around 780,000 years ago.
- The strength of the magnetic field decreases greatly during a reversal, which may take on the order of hundreds of years.





Historical Record of the geomagnetic field

How do we now how the geomagnetic field changed in the past?

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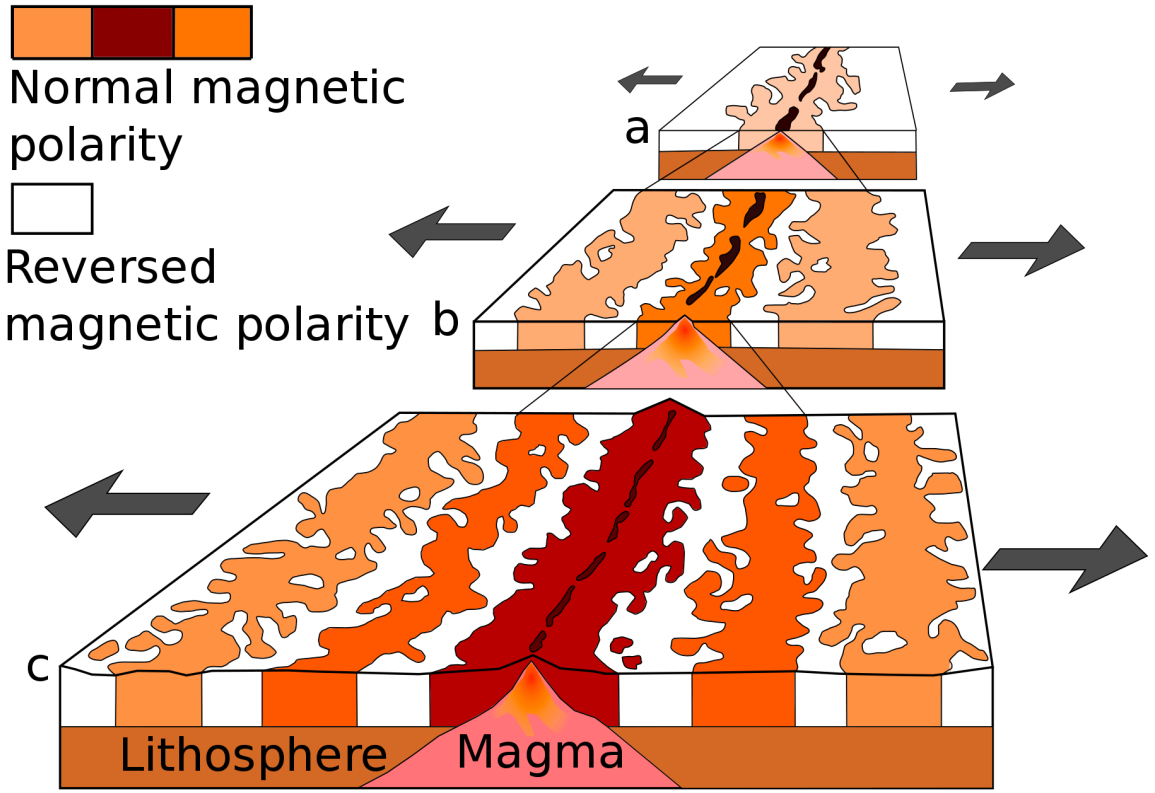
- The historical record of the earth's magnetic field is recorded in rocks, sediments and archeological materials.

1. Paleomagnetism – hundreds of millions of years

When molten rock cools below 570 C (Curie point), the orientation of magnetic materials are frozen into the orientation of the magnetic field at that time.



- Seafloor spreading results in rising magma
- New oceanic crust is magnetized as it forms and then it moves away from the ridge in both directions.
- This produces a record of magnetic field orientation with time.
- These measurements have large temporal uncertainty, but can be used to create a history of polar reversals.
- More recent measurements have greater accuracy.

Historical Record - continued

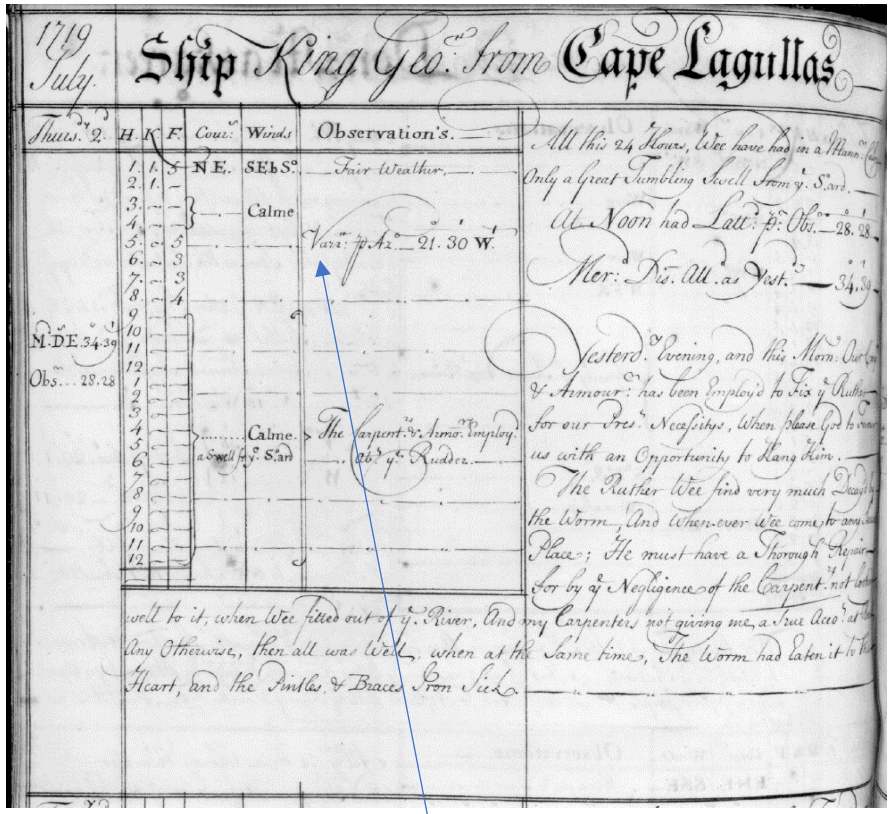
Archaeomagnetic measurements – 10,000 years

- Archaeomagnetism is the study of burnt material found on archaeological sites.
- Any clay or mud material material that has been subjected to heat at some point so that it's temperature exceeds the Curie point will contain information on geomagnetic declination, inclination and intensity.

The magnetic orientation recorded is during the last time the material is heated, which could be a fire that causes the collapse of the structure.

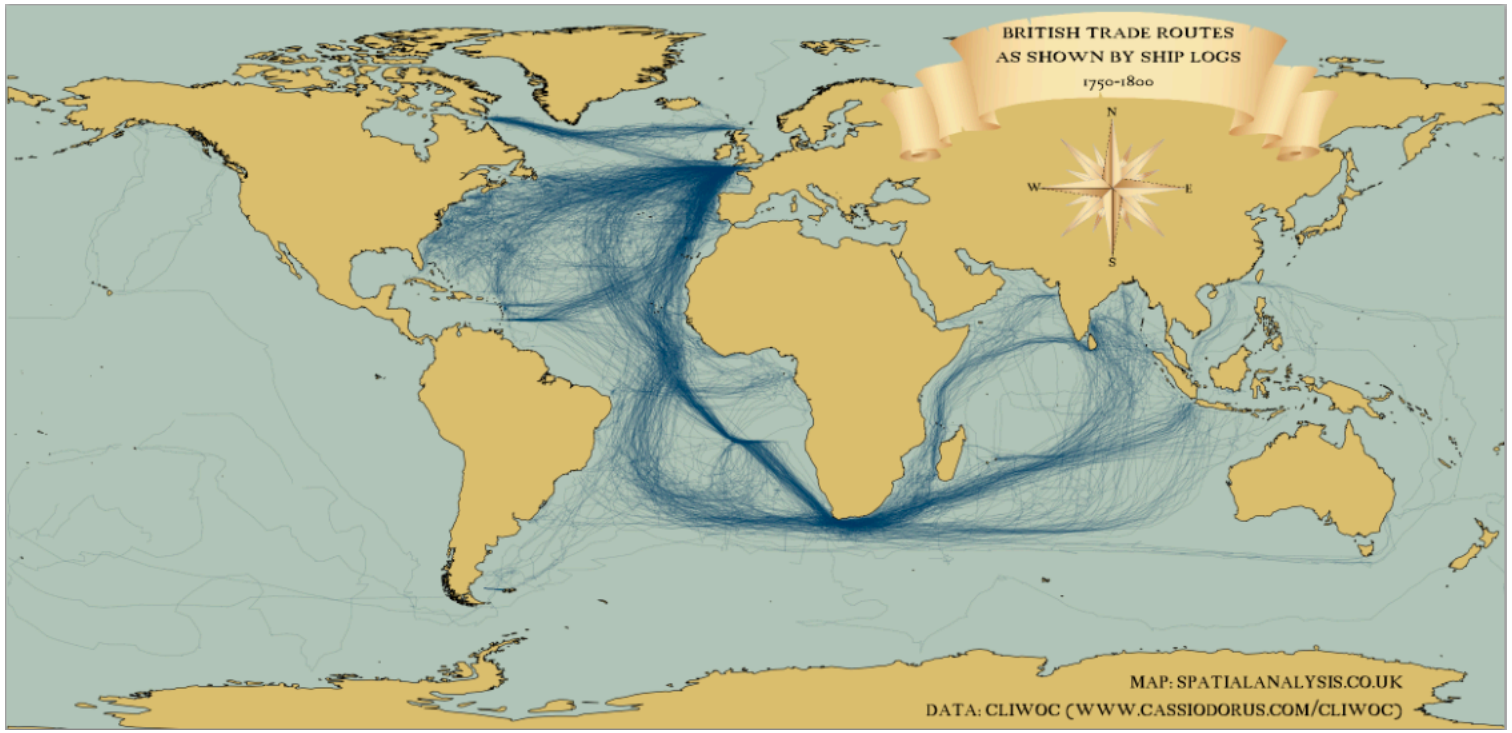
Historical Record – continued

ship logs - 1590 to 1930



Compass reading

British trade routes – 1750-1800



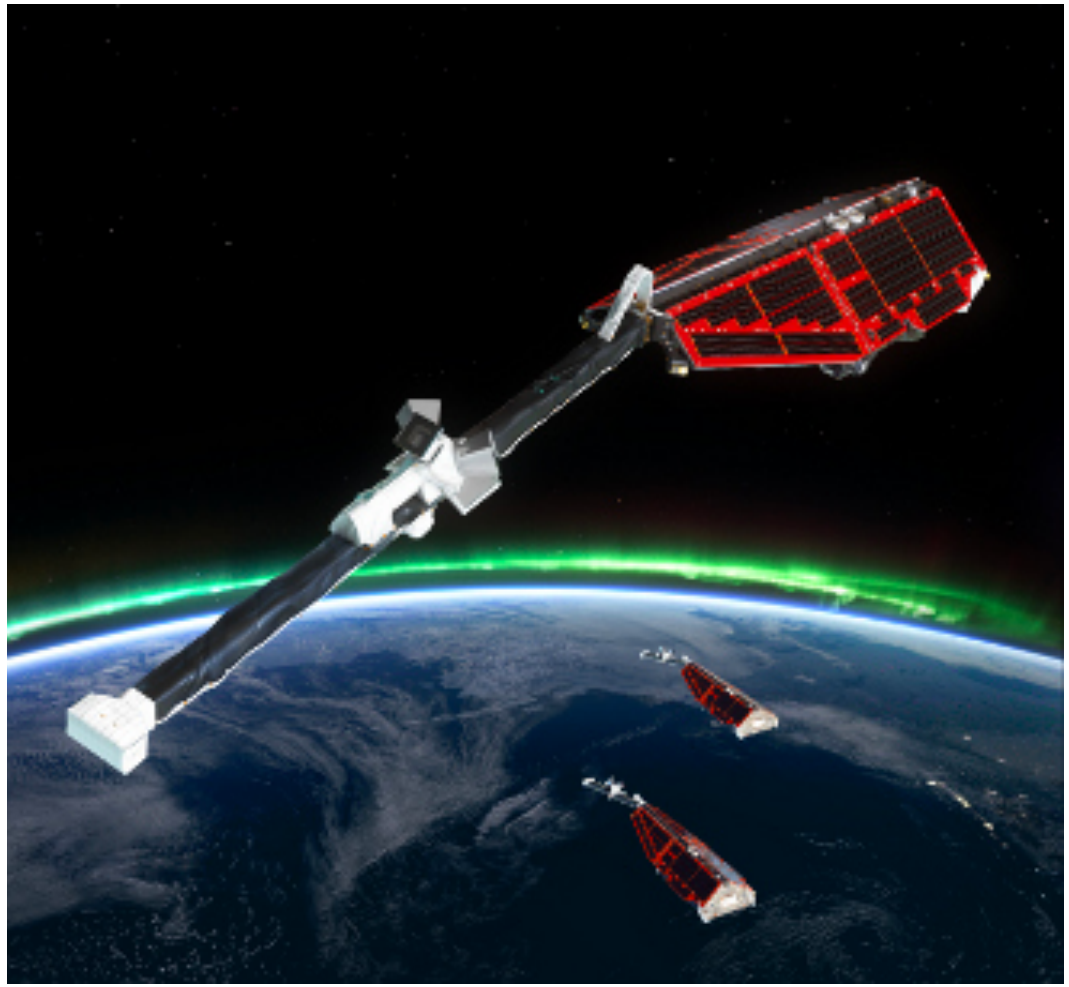
Global geomagnetic observatory network

- Magnetometer invented by Gauss in 1833; Can measure intensity of magnetic field.
- Magnetic observatories were set up gradually around the world.
- These are not uniformly distributed around the globe.

Satellite Measurements

Global Coverage:

Magsat 1979 - 1980
Ørsted 1999 -
CHAMP 2000 - 2010
Swarm 2013 -

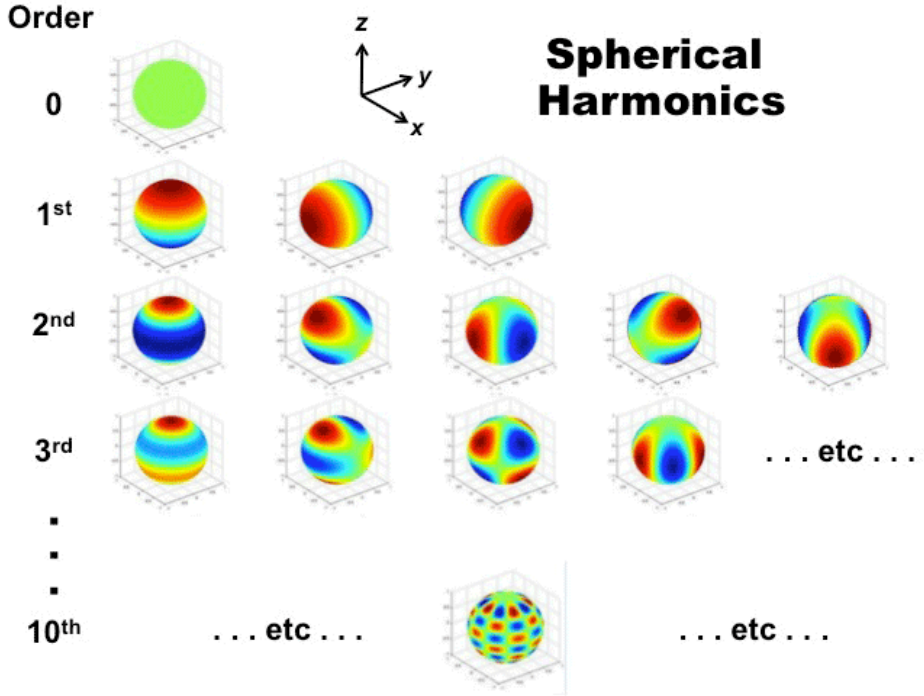


Swarm constellation of 3 satellites

Combining diverse observations into a global field model

Spherical Harmonics

Data inversions used to compute spherical harmonic coefficients



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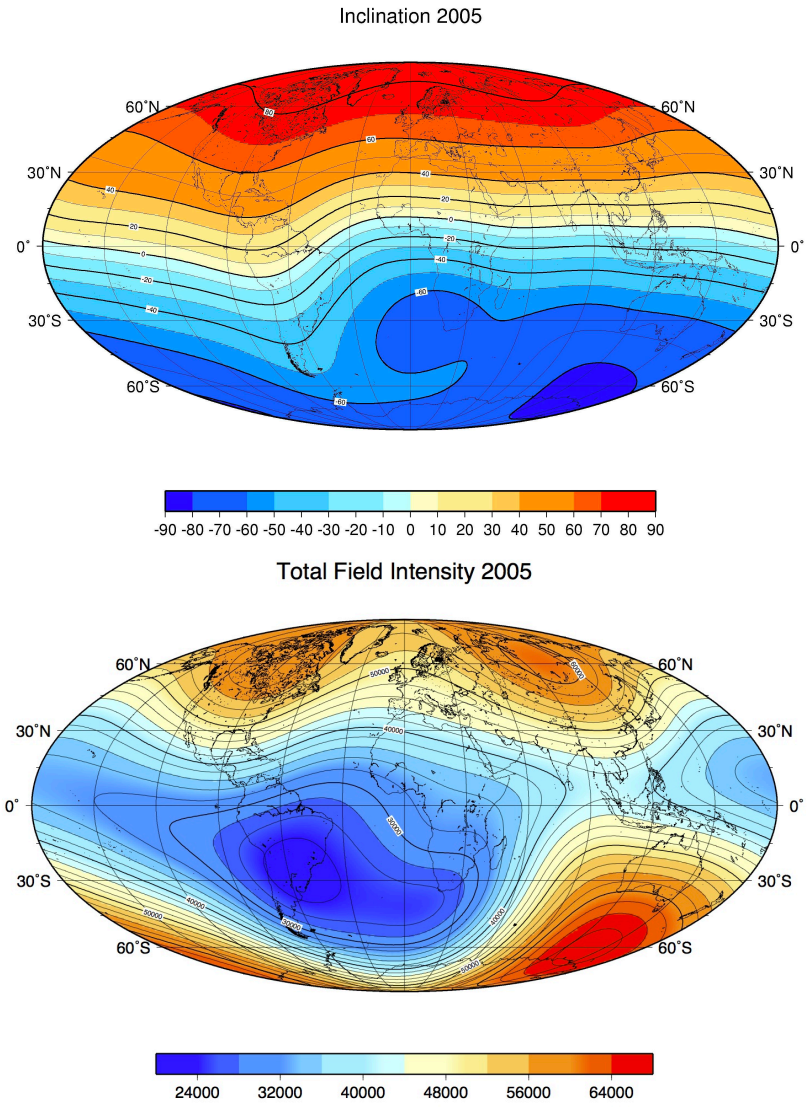


Predicting Future Changes

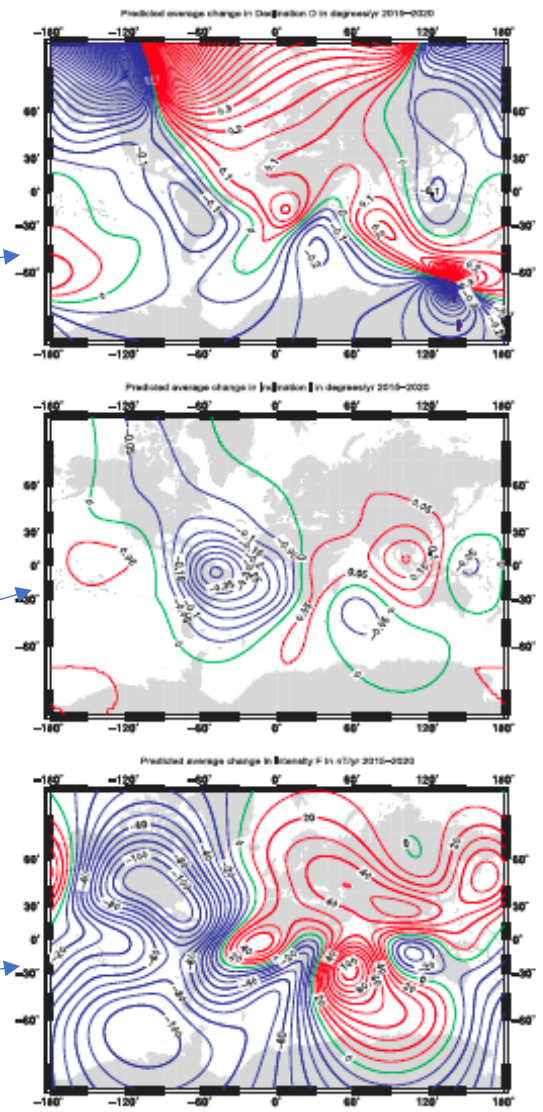
- International Geomagnetic Reference Frame: Forecasts next 5 years of changes to the spherical harmonic coefficients.
- Uses an ensemble of predictions from independent research groups.
- Many of these use linear extrapolation of current rates of change.
- The last forecast was made in 2015.

Forecast Rates of change 2015-2020

declination

inclination

intensity



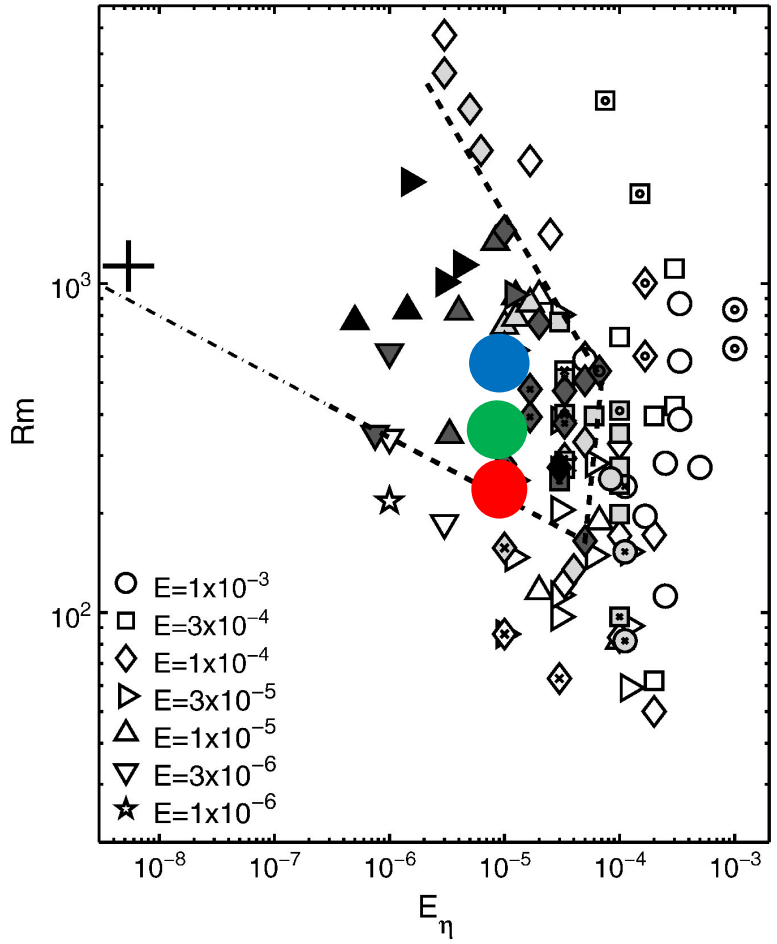
Can we use some of the techniques employed in weather forecasting?

- At NASA Goddard and UMBC we have be been using a numerical model of the Earth's core to simulate the changing geomagnetic field.
- We assimilate the measurements from hundreds and thousands of years into the model in the same way as numerical prediction.
- This approach is difficult because data is limited to a single component of the geomagnetic field, with no direct information of the fluid motion within the core.
- But the ensemble Kalman filter (EnKF) provides the means to estimate the state within the core.
- We are also limited by computational constraints that keep the models from operating in the correct parameter regime.

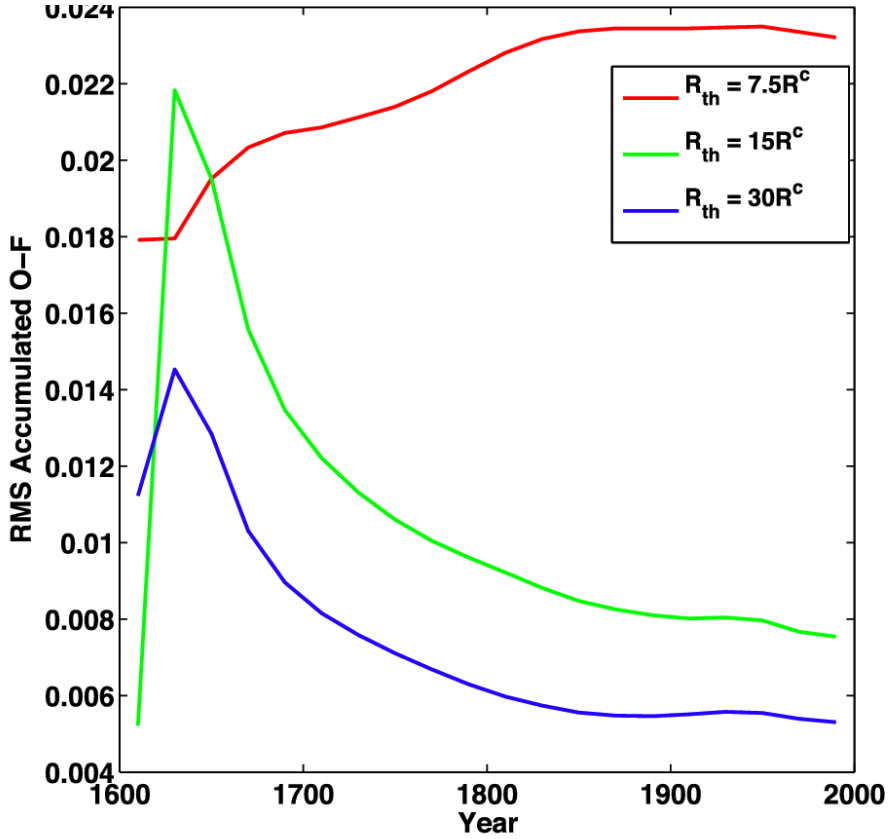
What assimilation tells us about model parameters:

Experiments with varying Rayleigh numbers.

Earthlike parameter regimes



Accuracy of 20 year forecasts



Where is the magnetic field headed?

- Forecasts are now possible on 5-10 year timescales.
- Due to the turbulent nature of the core flows, we can likely never predict more than 50 years into the future.
- So we probably can’t predict the next magnetic reversal, until it’s already happening.
- Improvements will come with increases in computational resources, to allow for higher resolution models, more realistic model parameters and larger ensemble sizes.