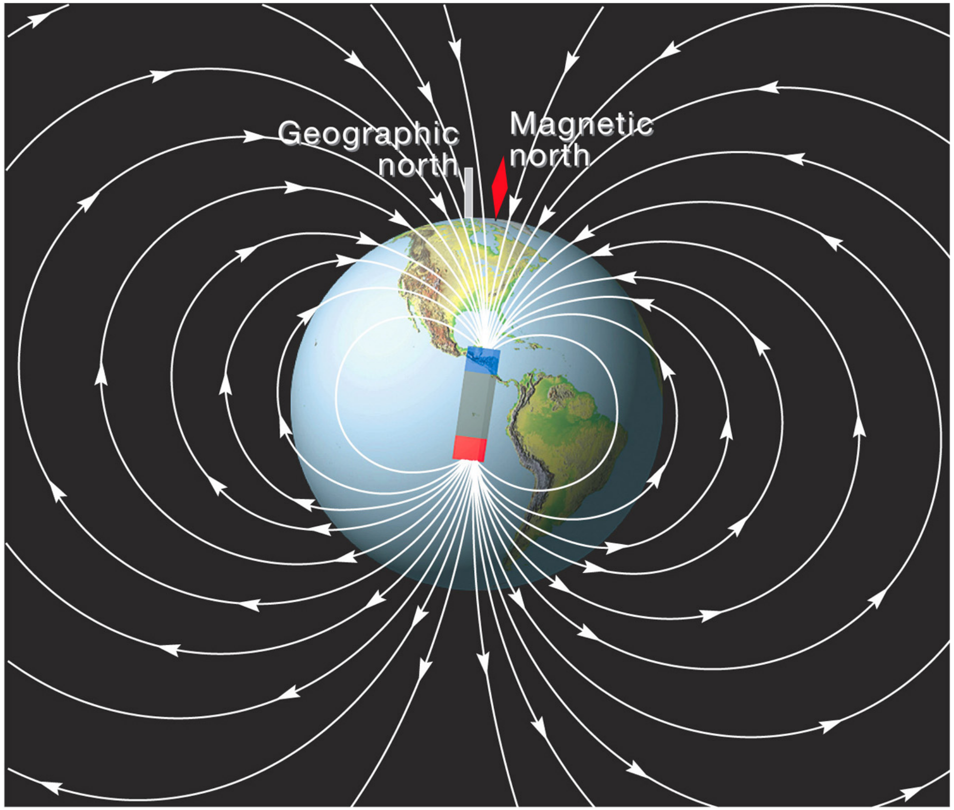
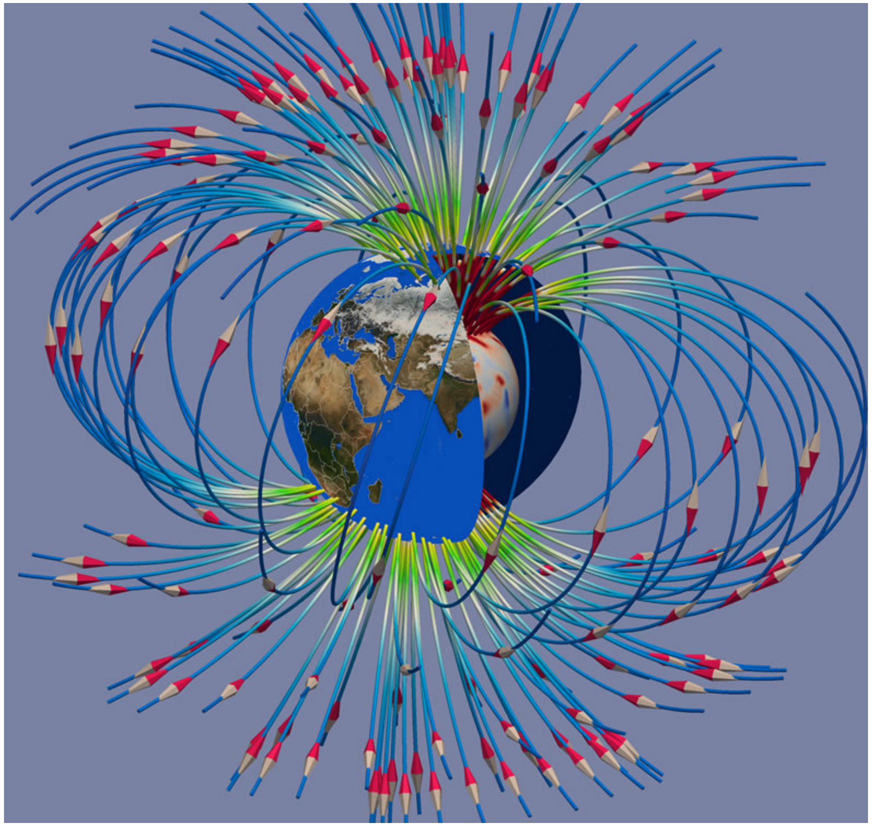
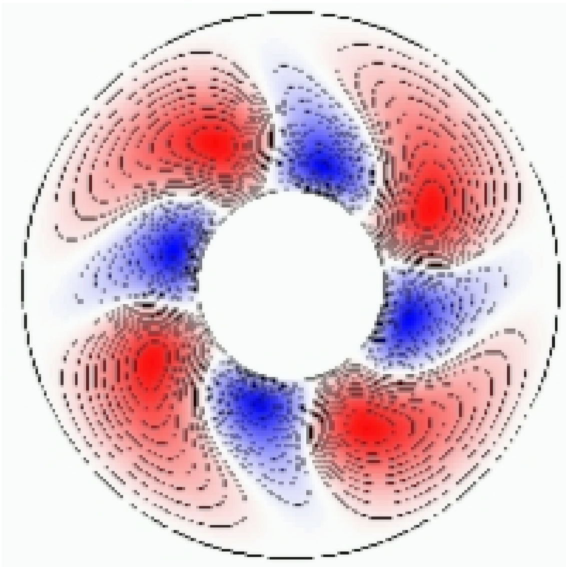
Earth's Main Field (Core Field)





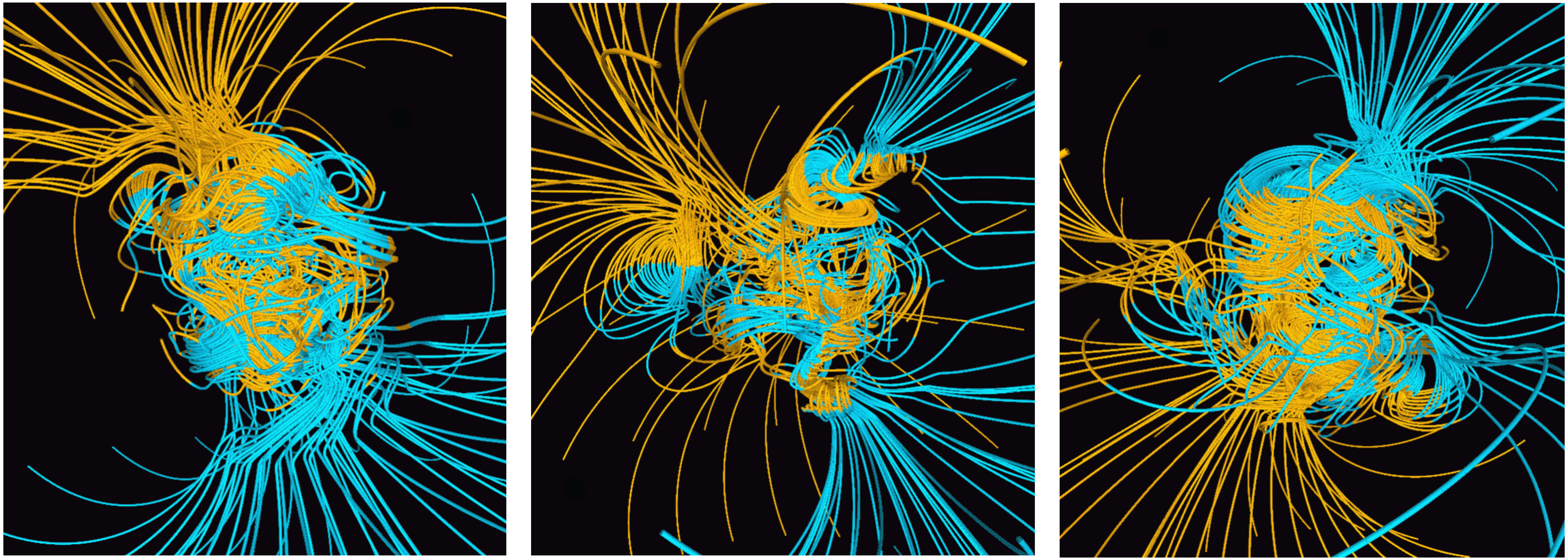
Earth's Main Field (Core Field)

Earth's main field is generated by convection of Earth's



fluid Ni-Fe outer core. As the solid inner core cools & grows, released heat drives thermo-chemical convection. Motion of the electrically-conductive molten iron produces electric currents which in turn generate a magnetic field.

Rotation of the Earth → ***Coriolis forces*** which cause a ***Magnetohydrodynamic Dynamo Effect***, in which magnetic fields organize in a way that amplifies the current flow. Positive feedbacks are self-stabilizing & produce a very large, ***predominantly dipolar*** magnetic field (with smaller higher-order terms).



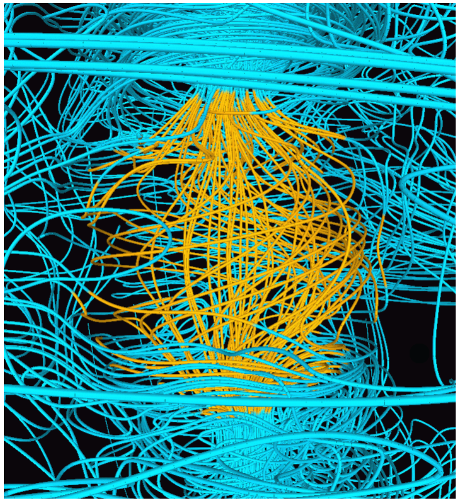
500 yrs before reversal

mid-reversal

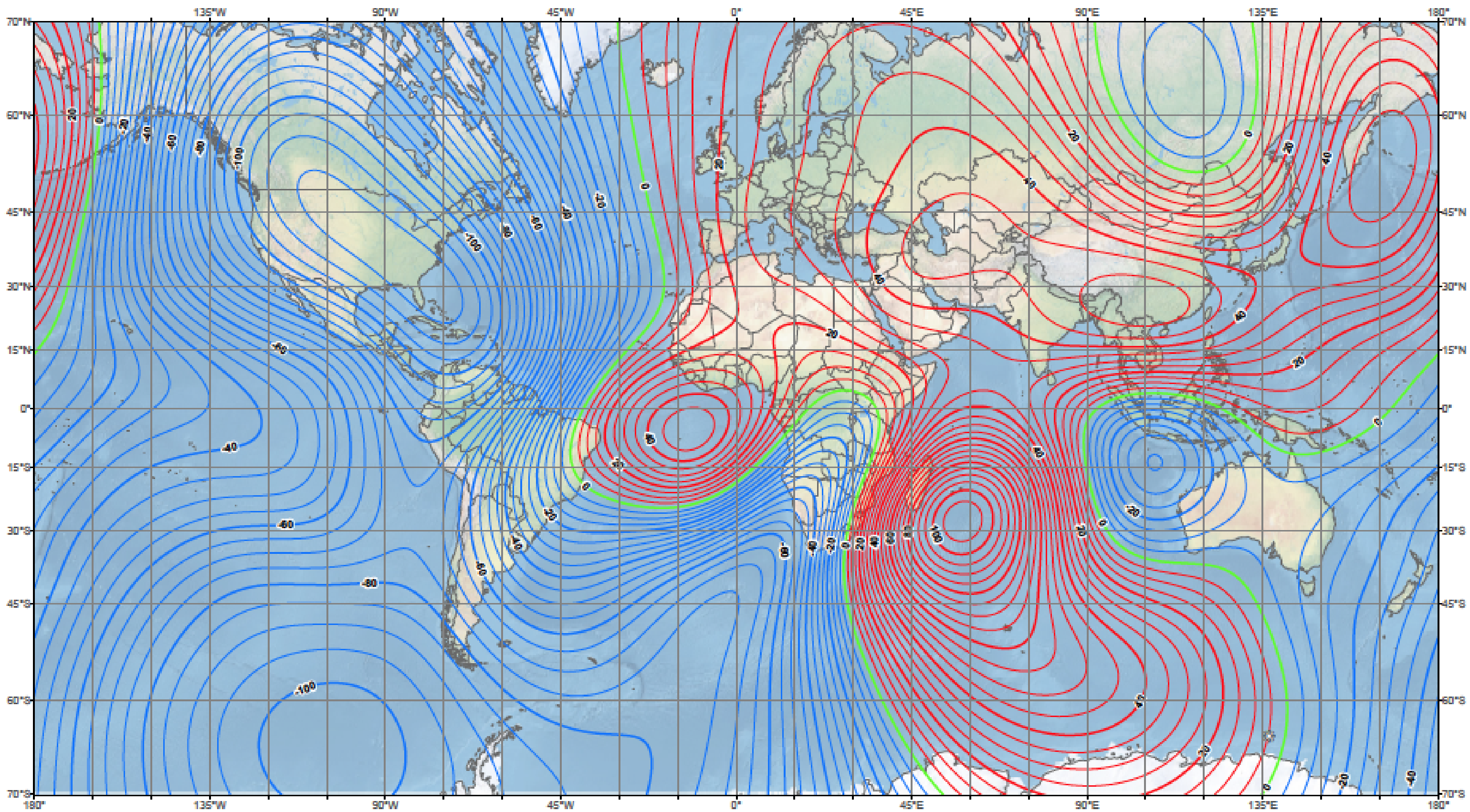
500 yrs after reversal

Glatzmeier & Roberts (1995) model:

- Solid inner core magnetized opposite main field; forced to rotate by applied torque ⇒ ***precession*** (~0.2°/yr for real Earth)
- Inner core stabilizes field dipole; long time required to diffuse outer core field to inner core controls reversal timescale



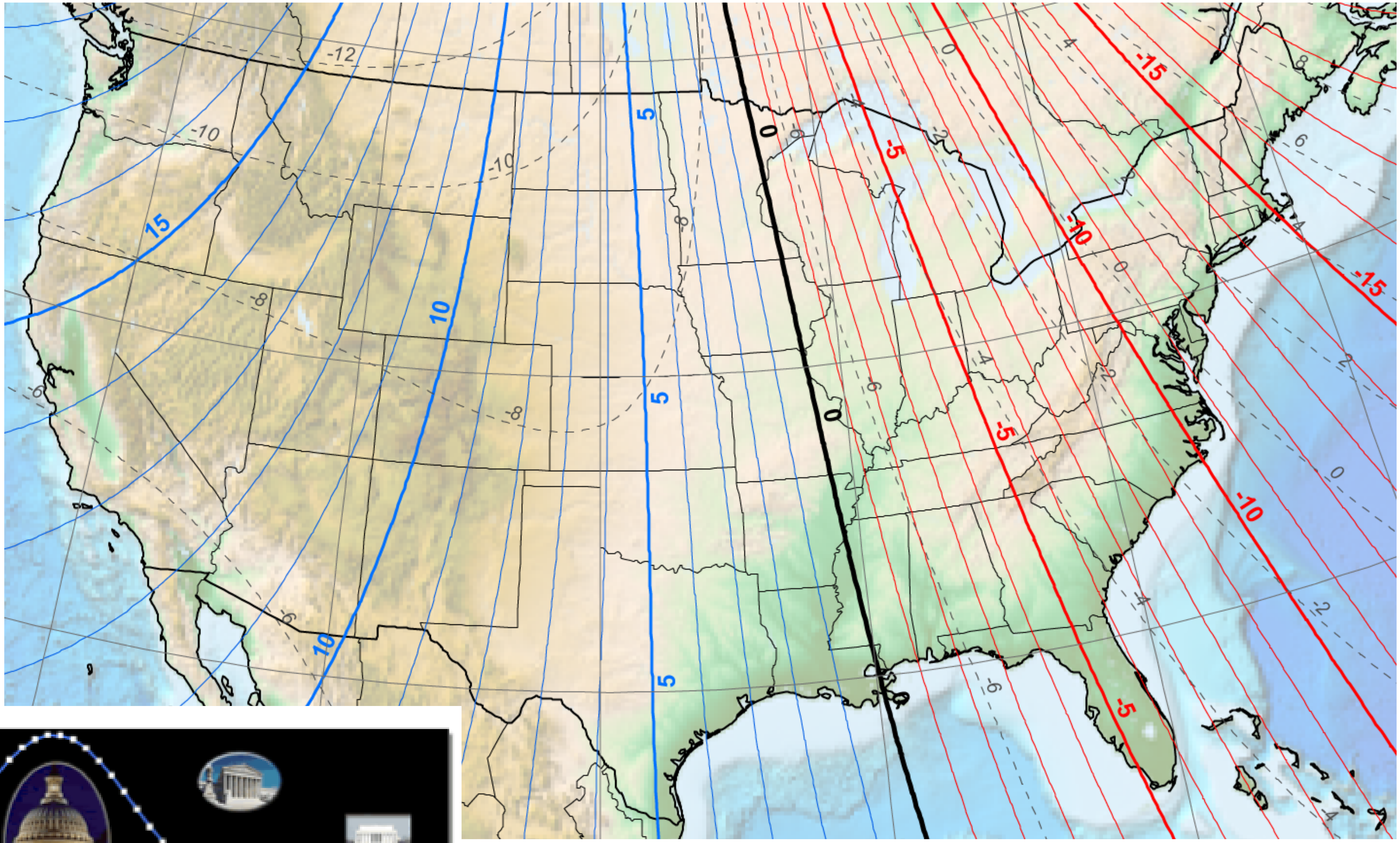
US/UK World Magnetic Model - Epoch 2015.0
Annual Change Total Intensity (F)

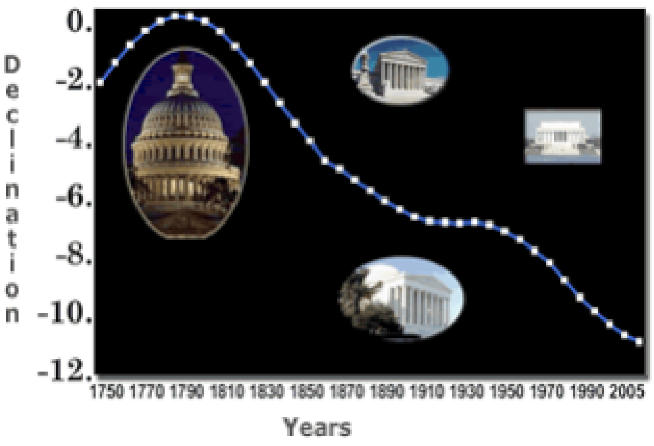


Because the field is constantly changing, important to know the time of measurement for reduction to anomaly…

World Magnetic Model calculator: http://www.ngdc.noaa.gov/geomag-web/#igrfwmm

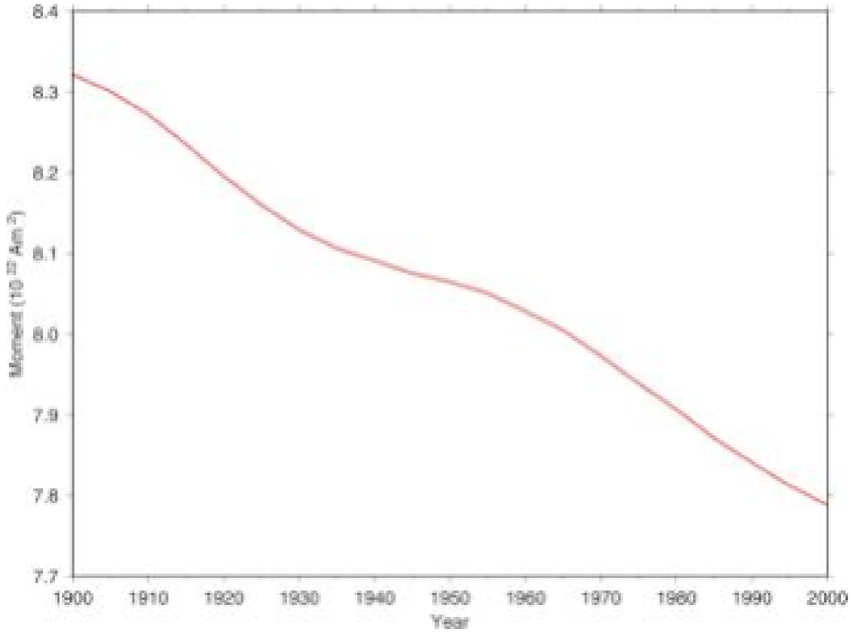
Magnetic Declination: Contiguous U.S.

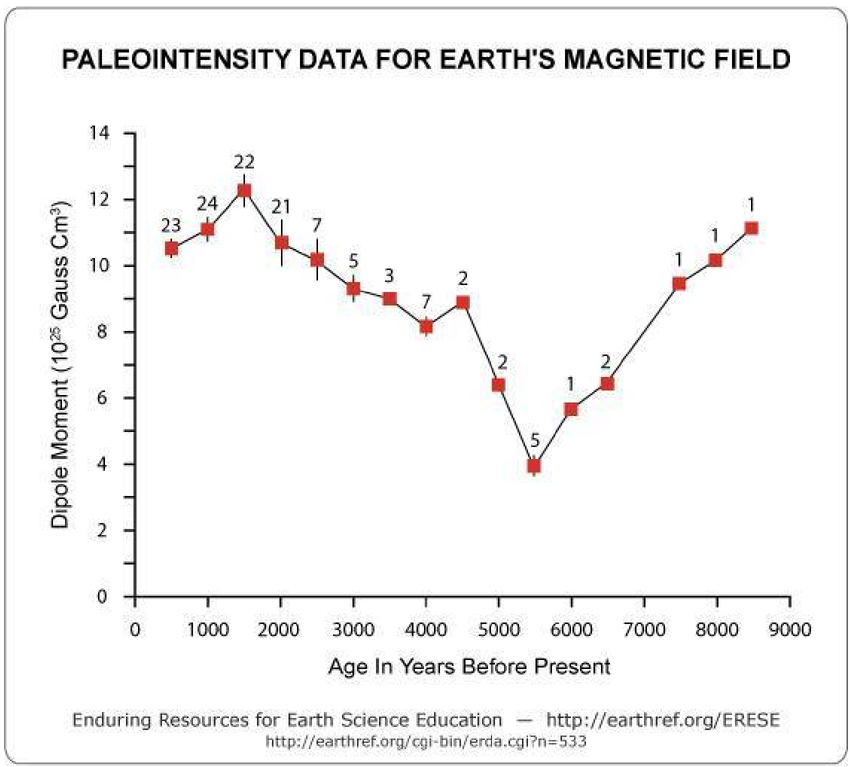




Westward drift of "non-dipole" field (& precession of magnetic field about rotation pole)

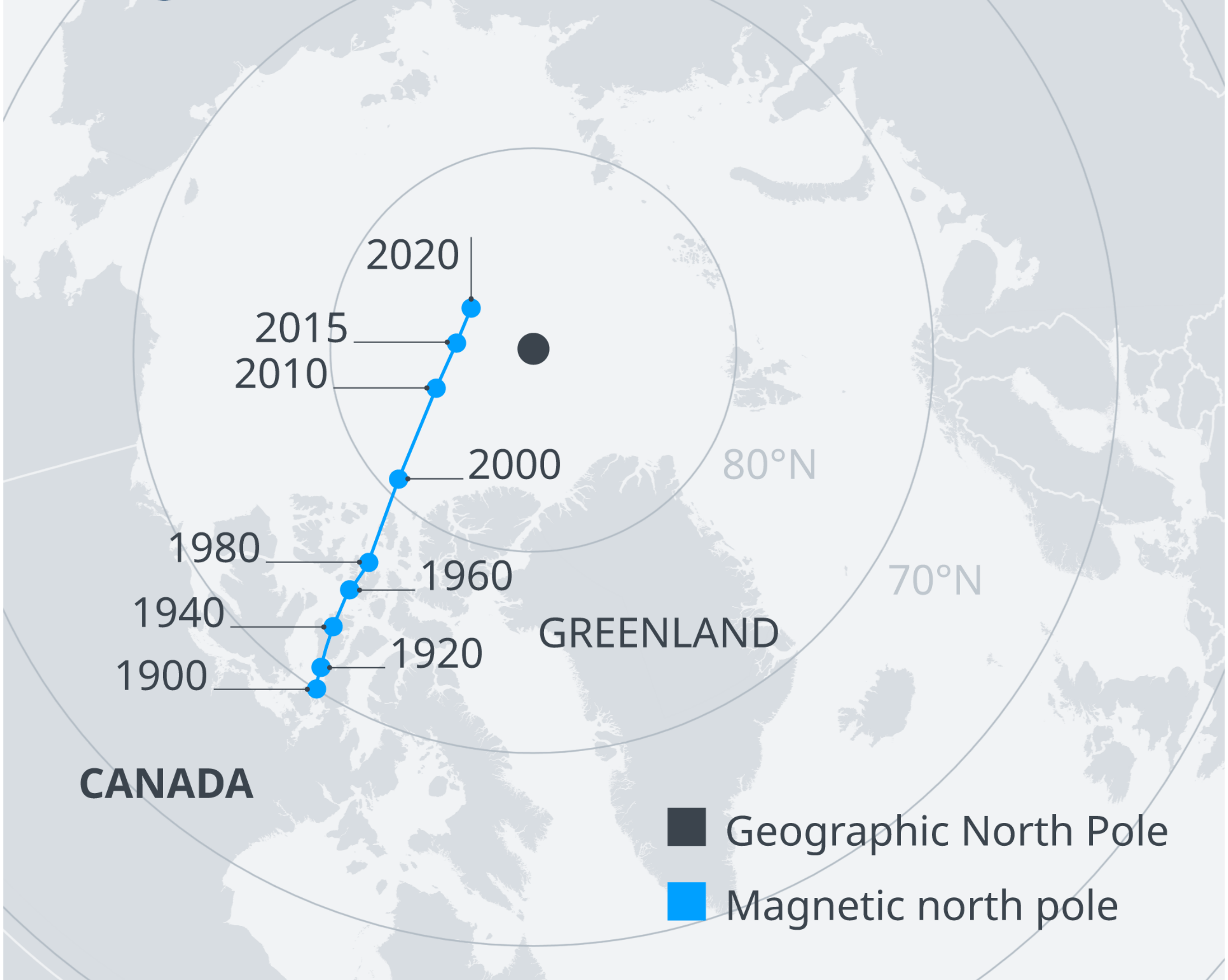
$\Rightarrow$ declination changes relatively rapidly





Intensity of Earth’s total dipole field also changes through time… Paleointensity measurements are very noisy but they and models of the core dynamo suggest field is strong immediately after a reversal & weakens (~ exponential decay) for some period to near zero, then jumps to high value… Reversal may or not accompany the jump. This “sawtooth” pattern is basis for suggestion by some that Earth will experience a reversal in next ~2000 years.

Magnetic north in motion



Source: Nature; World Data Center for Geomagnetism ©DW

Can express vector $\vec{H}_E = \hat{x}X_E + \hat{y}Y_E + \hat{z}Z_E$, where $\hat{x}, \hat{y}, \hat{z}$ are the ***geographical*** East, North, Up directions. Then

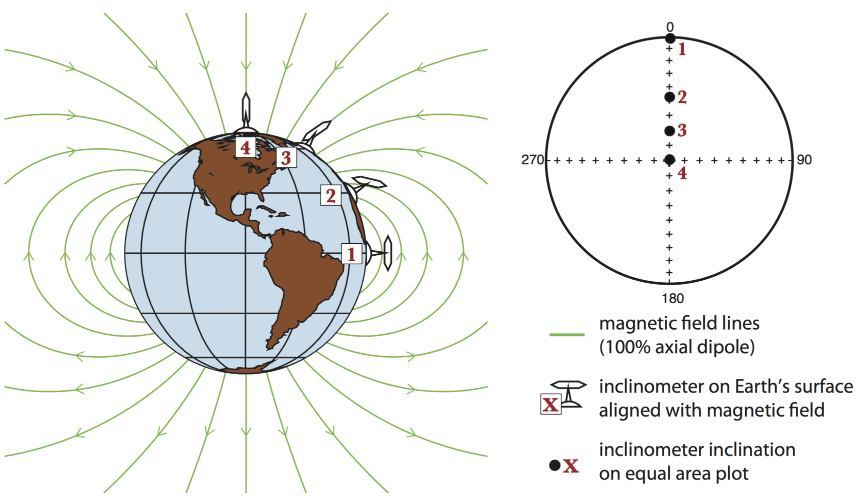
intensity $$H_E = \left\| \vec{H}_E \right\| = \sqrt{X_E^2 + Y_E^2 + Z_E^2}$$

inclination i is the angle of field direction from horizontal (positive downward):

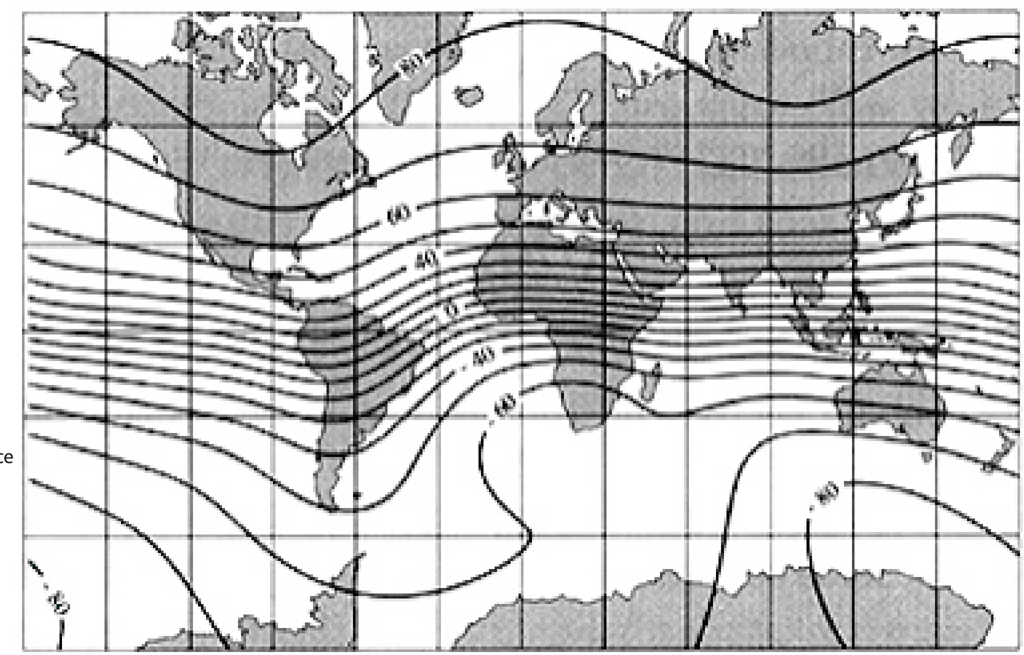
$$i = \tan^{-1}\left(\frac{Z_E}{\sqrt{X_E^2 + Y_E^2}} \right)$$

declination d is the angle from true north to magnetic north (positive clockwise):

$$d = \tan^{-1}\left(\frac{Y_E}{X_E} \right)$$



IGRF Inclination 1995



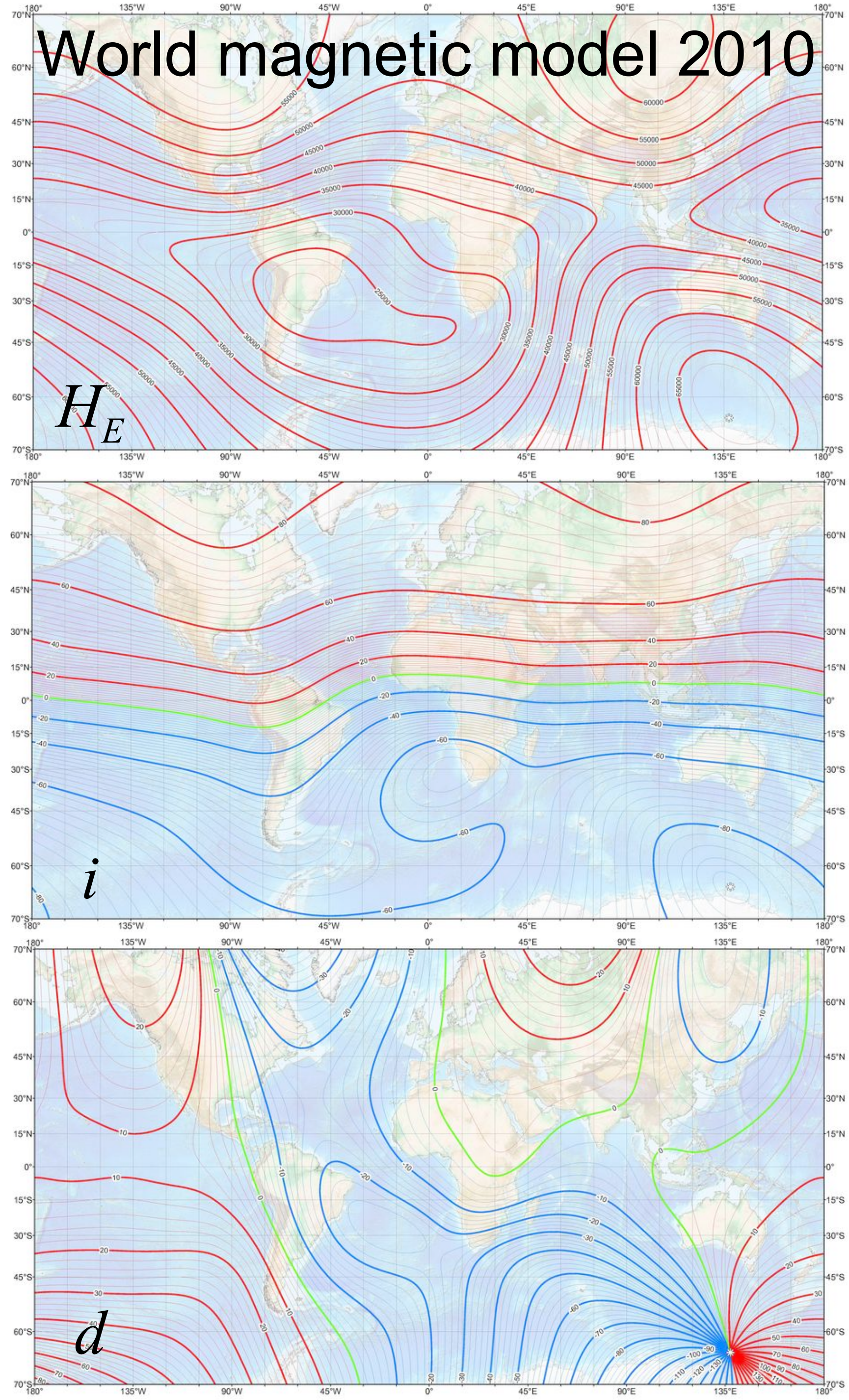
Core-generated magnetic field is a ***vector quantity*** so has magnitude and direction. Most often described by:

- ***intensity*** H_E (i.e., magnitude)
- ***inclination*** i (∠ from horiz)
- ***declination*** d (∠ from true N)

These vary depending on location on Earth's surface, and also change ***nonlinearly*** with time!

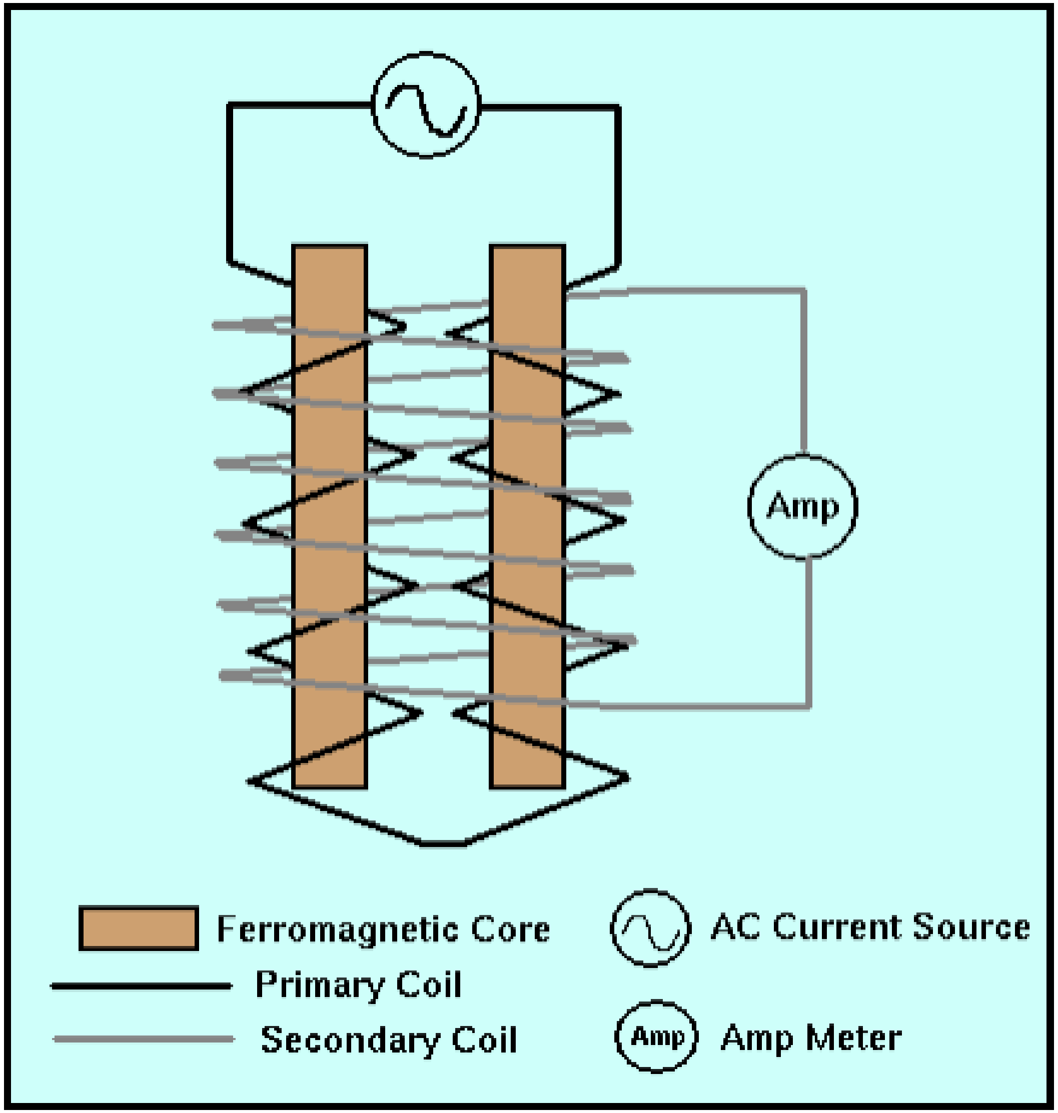
Intensity H_E varies from **~30k nT** at equator to **~70k nT** at poles

Here blue is negative
(i is positive down)



Measurement:

Fluxgate magnetometer



Wire coils wound in opposite directions; these cancel & produce zero current in secondary coil in absence of External magnetic field, but if aligned with a field, one core Reinforces, other counteracts external field resulting in a current.

Records intensity ***in the*** **direction of** ***orientation of the coils***.

Measurement:

Proton precession magnetometer

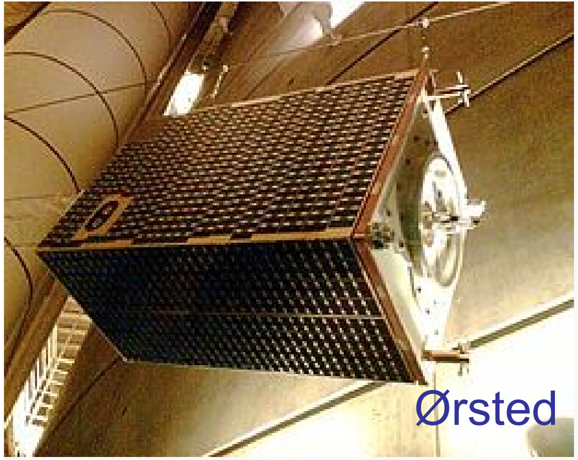
Bottle containing a hydrogen-rich fluid (distilled water or hydrocarbon) is surrounded by a wire coil. Current through the coil produces a strong magnetic field; protons (H^+) align with the field… Current is shut off & as protons realign with the ambient magnetic field, they precess at a frequency determined by magnetic field strength (0.042576 Hz/nT). So, measure frequency of the induced AC current and convert to a total field strength.

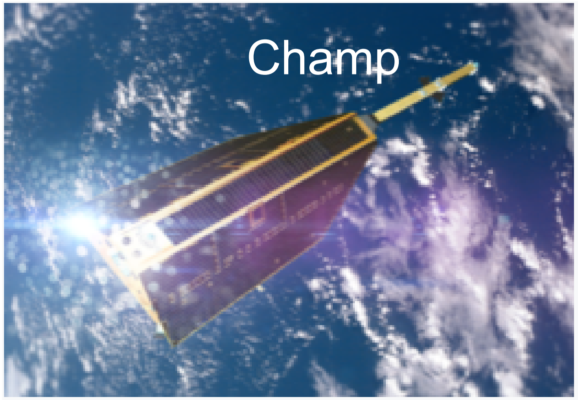
(Number of other types but these two are most commonly used for terrestrial geophysics!)

Measurement:

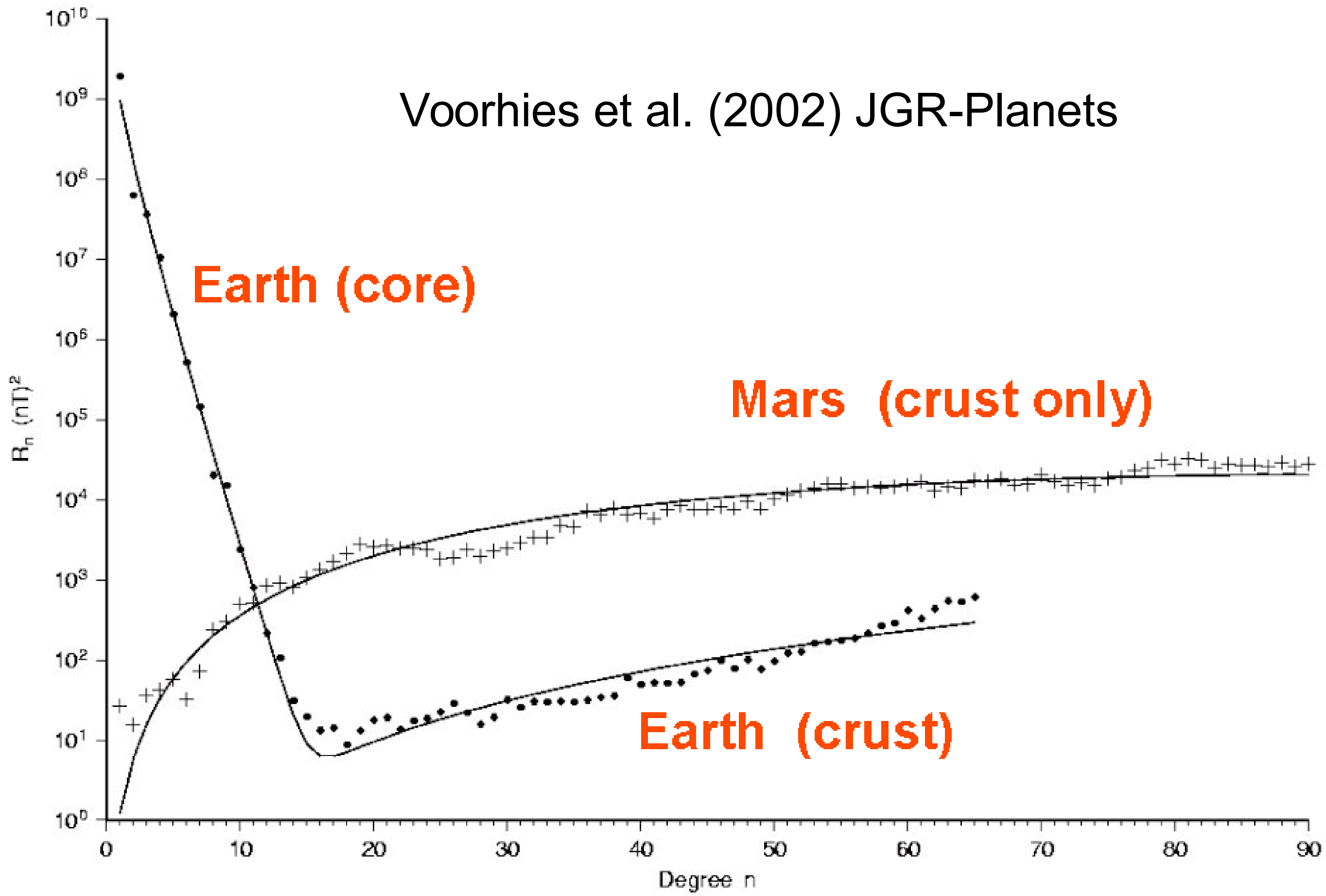
Satellite missions including Ørsted, Champ and most recently Swarm included three-component oriented fluxgate magnetometers to measure all three components of the magnetic field, to characterize the time-varying core-derived main field, crustal magnetization and magnetospheric (space weather) phenomena…

Typically combined with other instruments for measuring space-weather interactions, charge, lower atmospheric phenomena, and in Swarm’s case 3D mantle electrical conductivity!

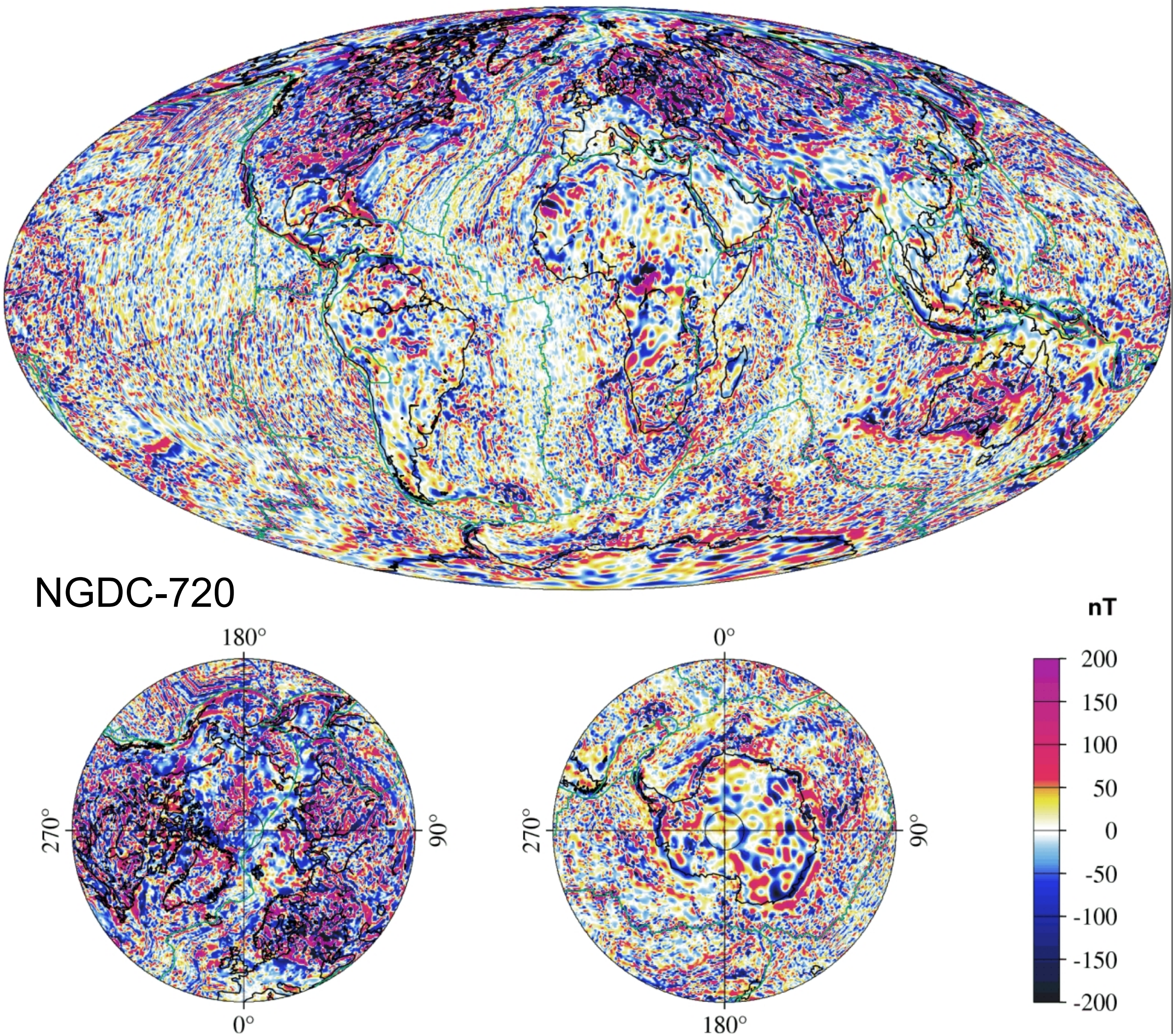




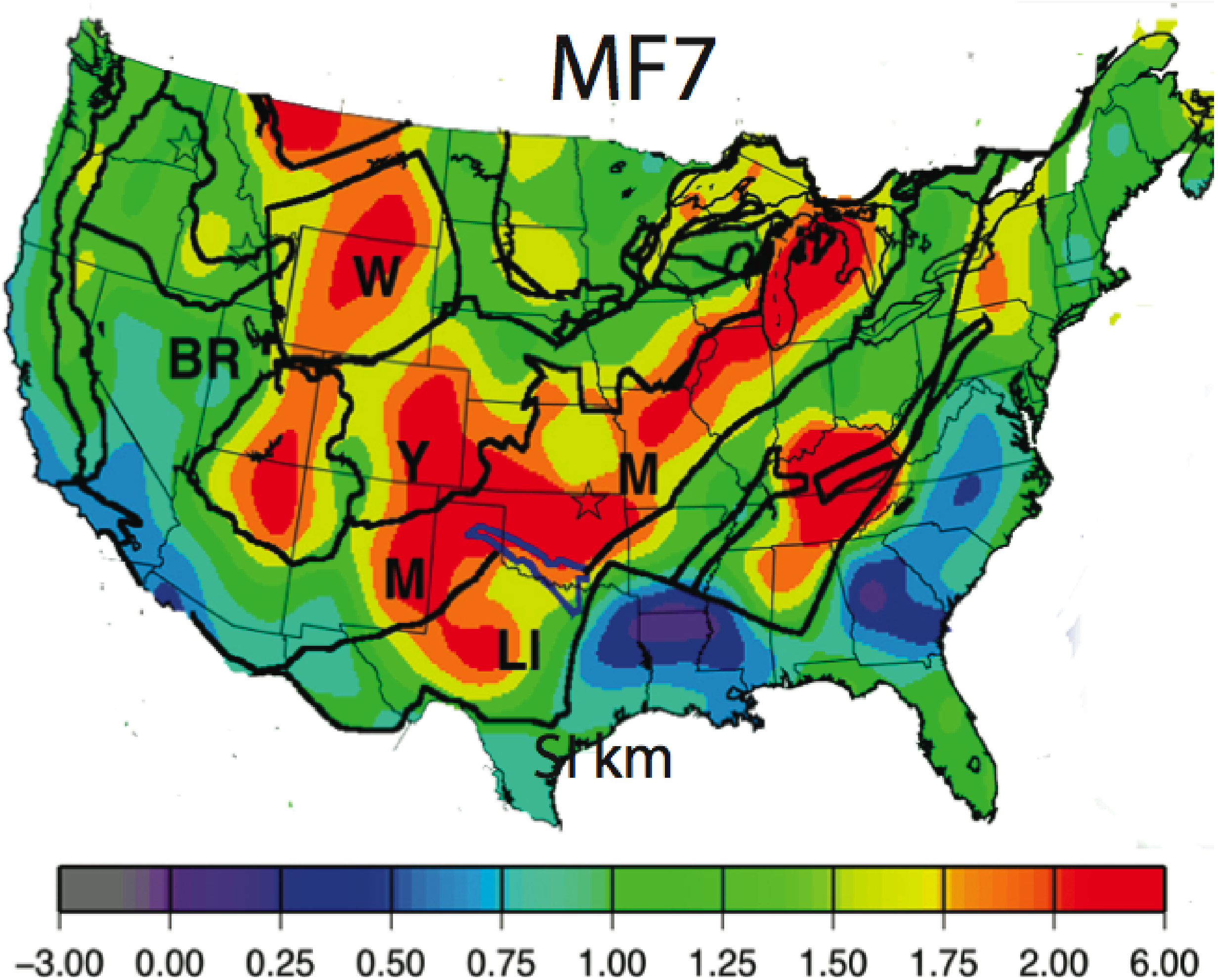
Problem: If both Earth's main field and crustal field are determined from measurements, how do we separate them?



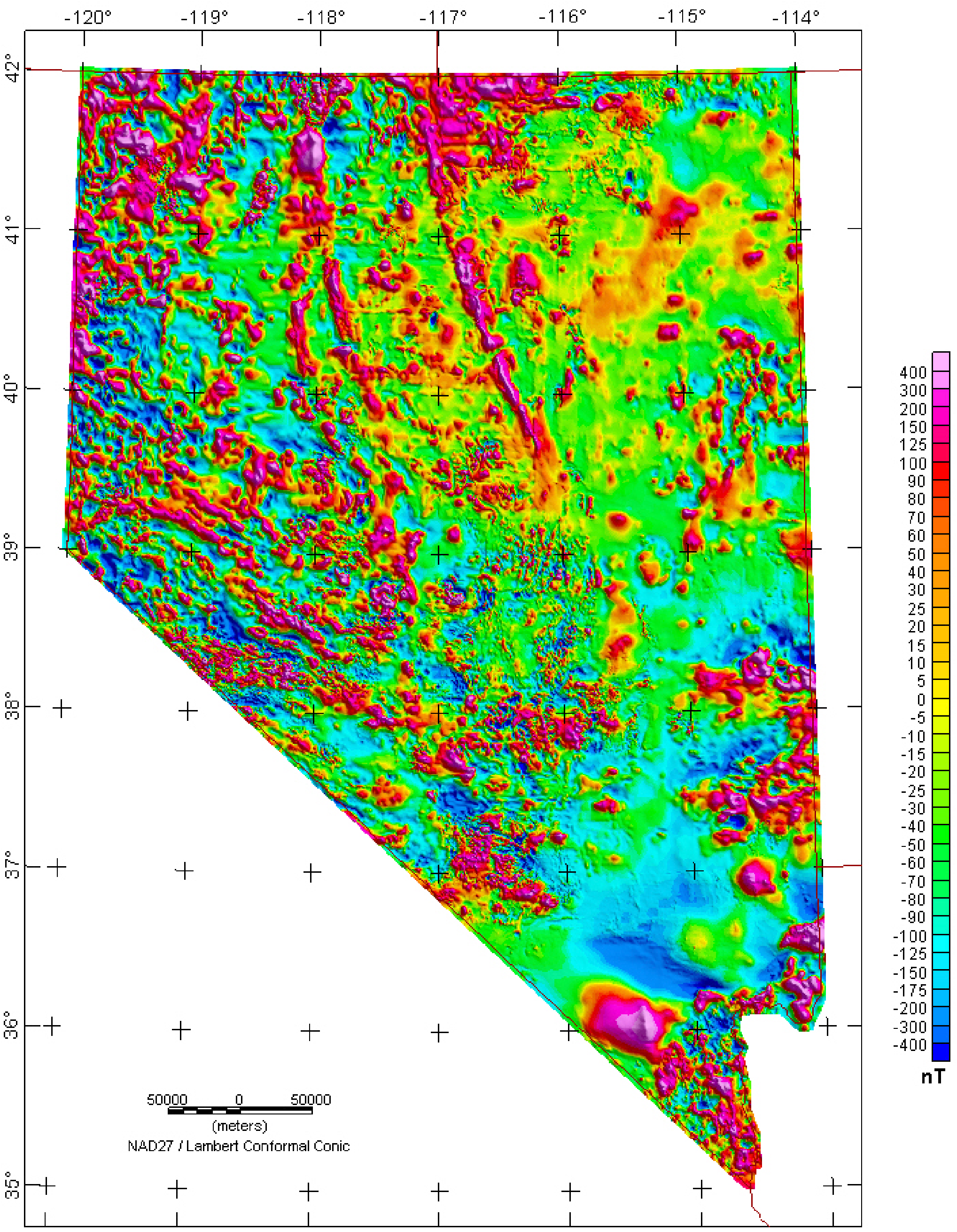
Core field dominates long wavelengths (small n of spherical harmonics). We describe core field only out to n = 14–15 where it dominates the total field.



Satellite measurements of induced + remanent magnetization of the Earth's crust (scalar total field anomaly relative to Earth's main, i.e. core, field)

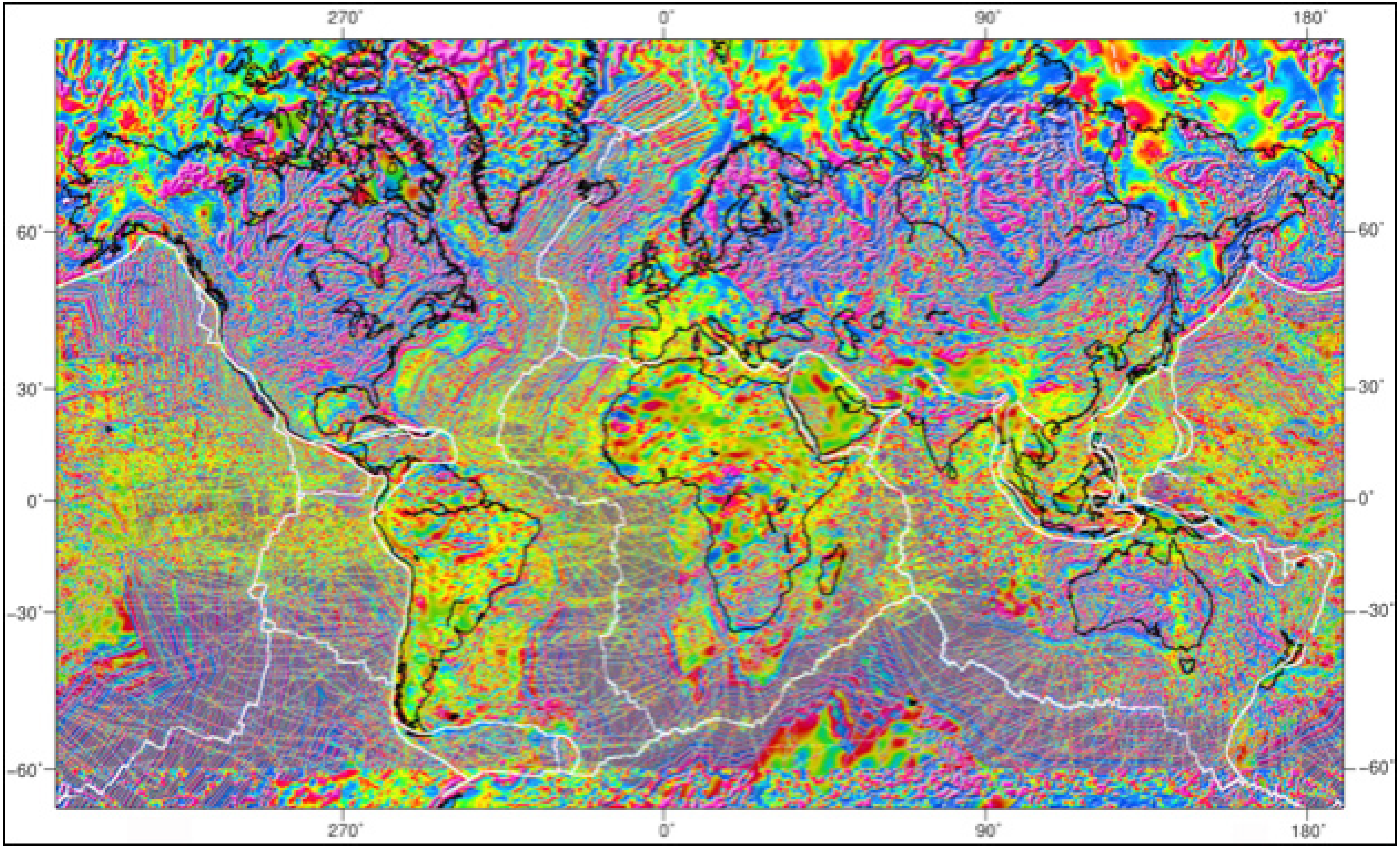


Satellite data are more self-consistent and useful for regional-scale tectonics studies– Here depth-integrated magnetic susceptibility shows strong relationships to Proterozoic accretion history of the mid-continent.



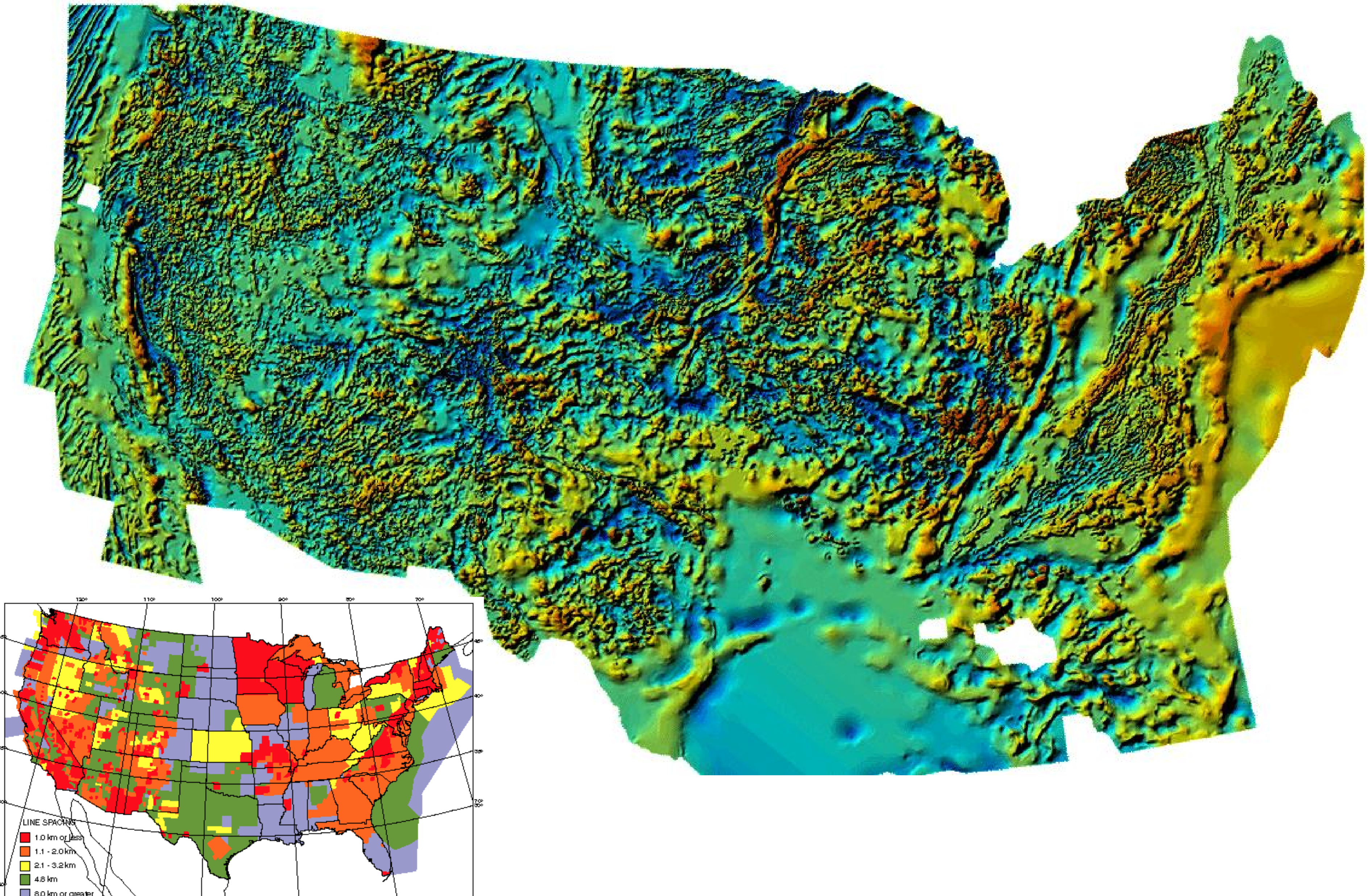
Many regions also have aeromag measurements (e.g., magnetic anomalies over Nevada… USGS has flown the entire conterminous United States).

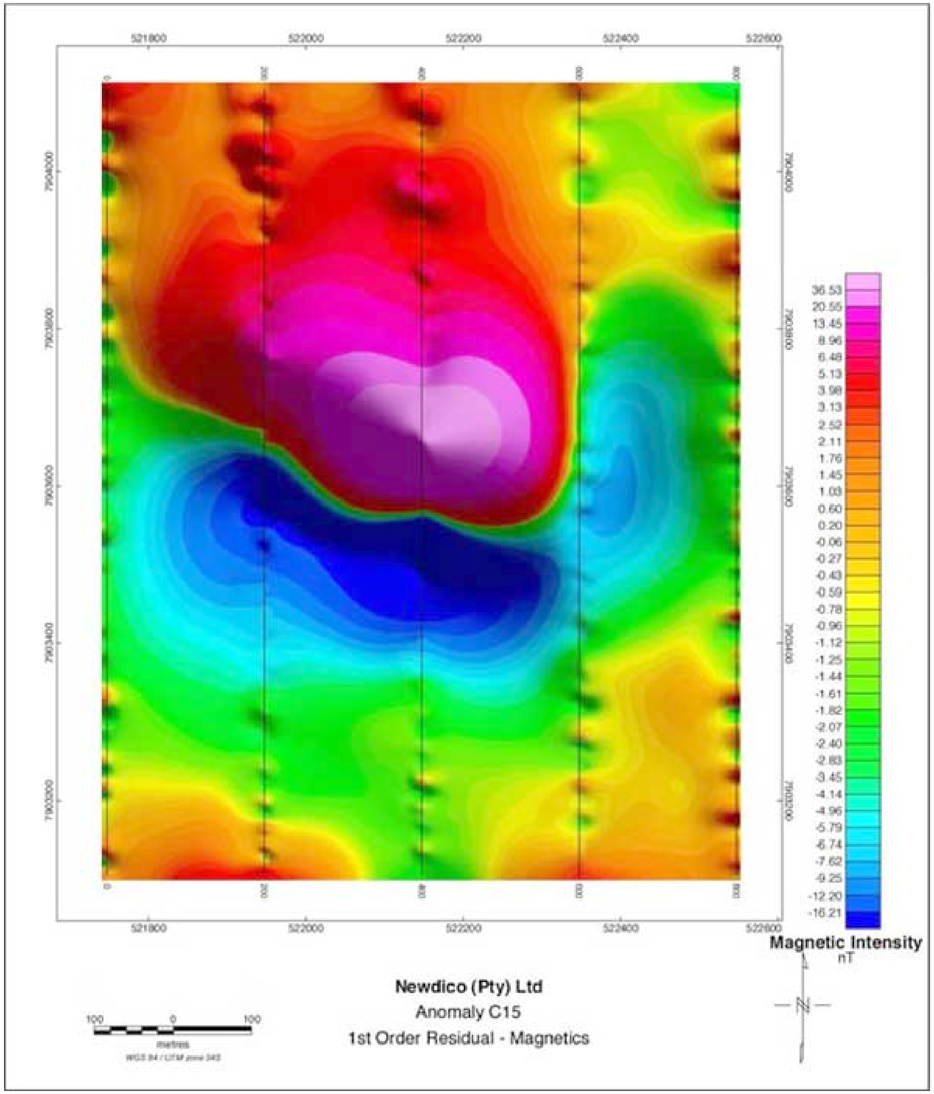
Most magnetic anomaly maps on scales < 500 km use magnetometer data collected by flying an airplane in a grid pattern over the target region

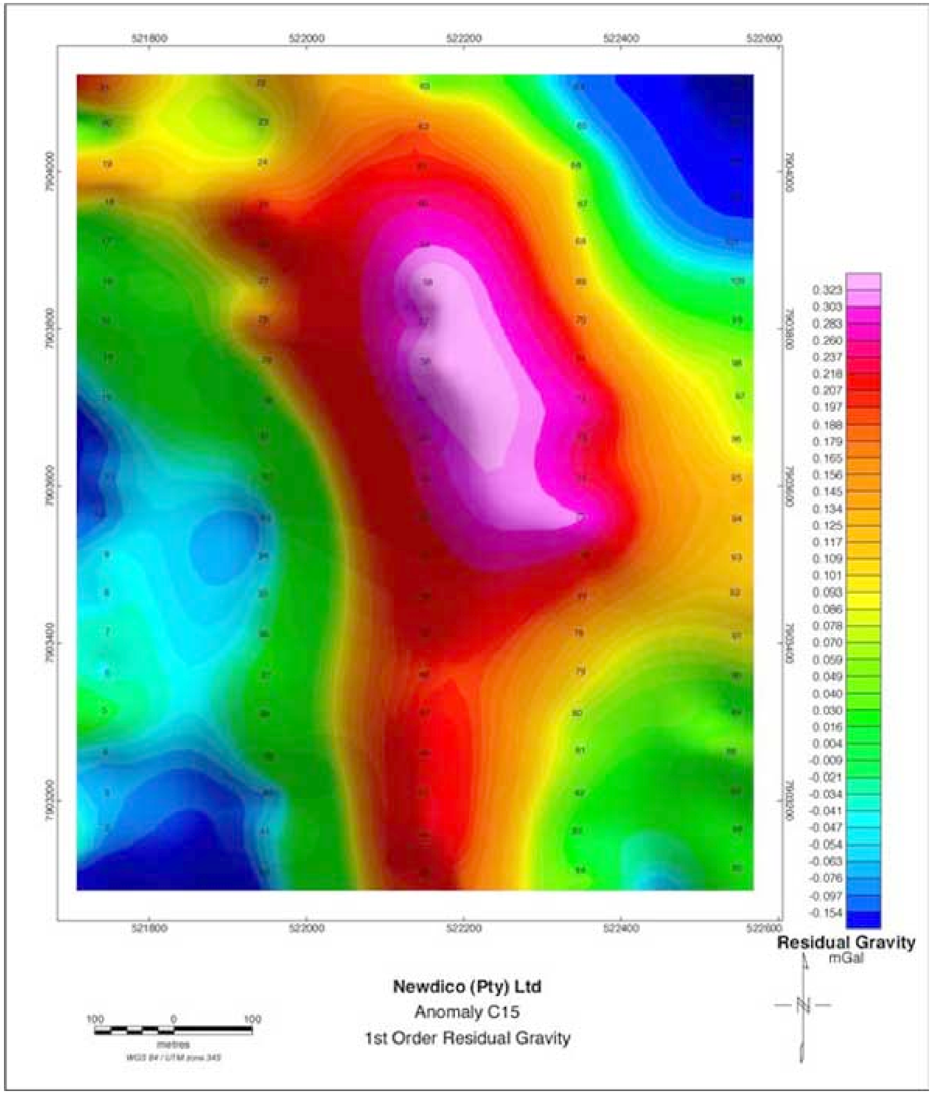


Combination of global aeromag and CHAMP satellite crustal magnetic anomalies… Note merging problems!

Conterminous US aeromag merge is better… But data line sampling varies!







Commonly use in combination with gravity, e.g. this kimberlite prospect in Botswana