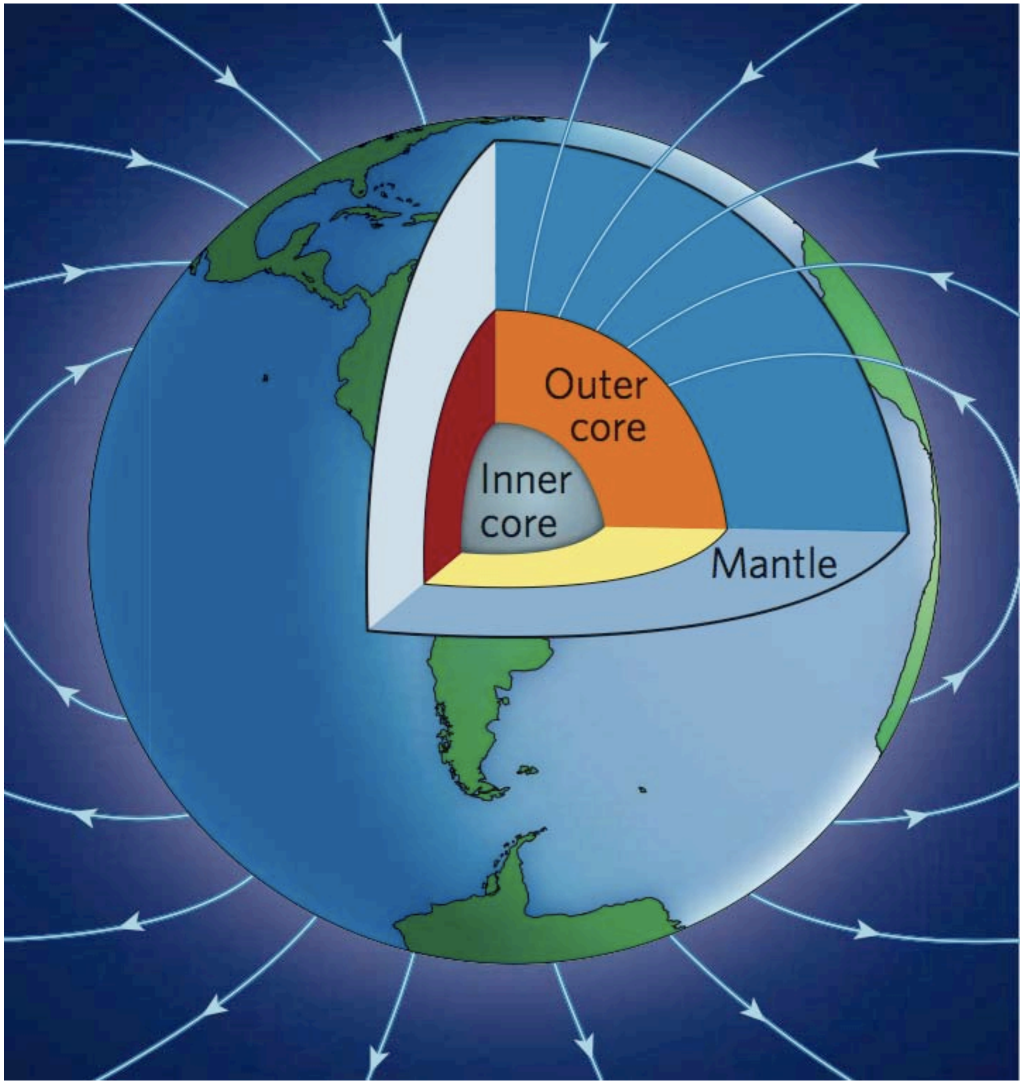
Internal Geomagnetic Fields on the Millenium Time Scale

Are we Going Into Another Excursion?



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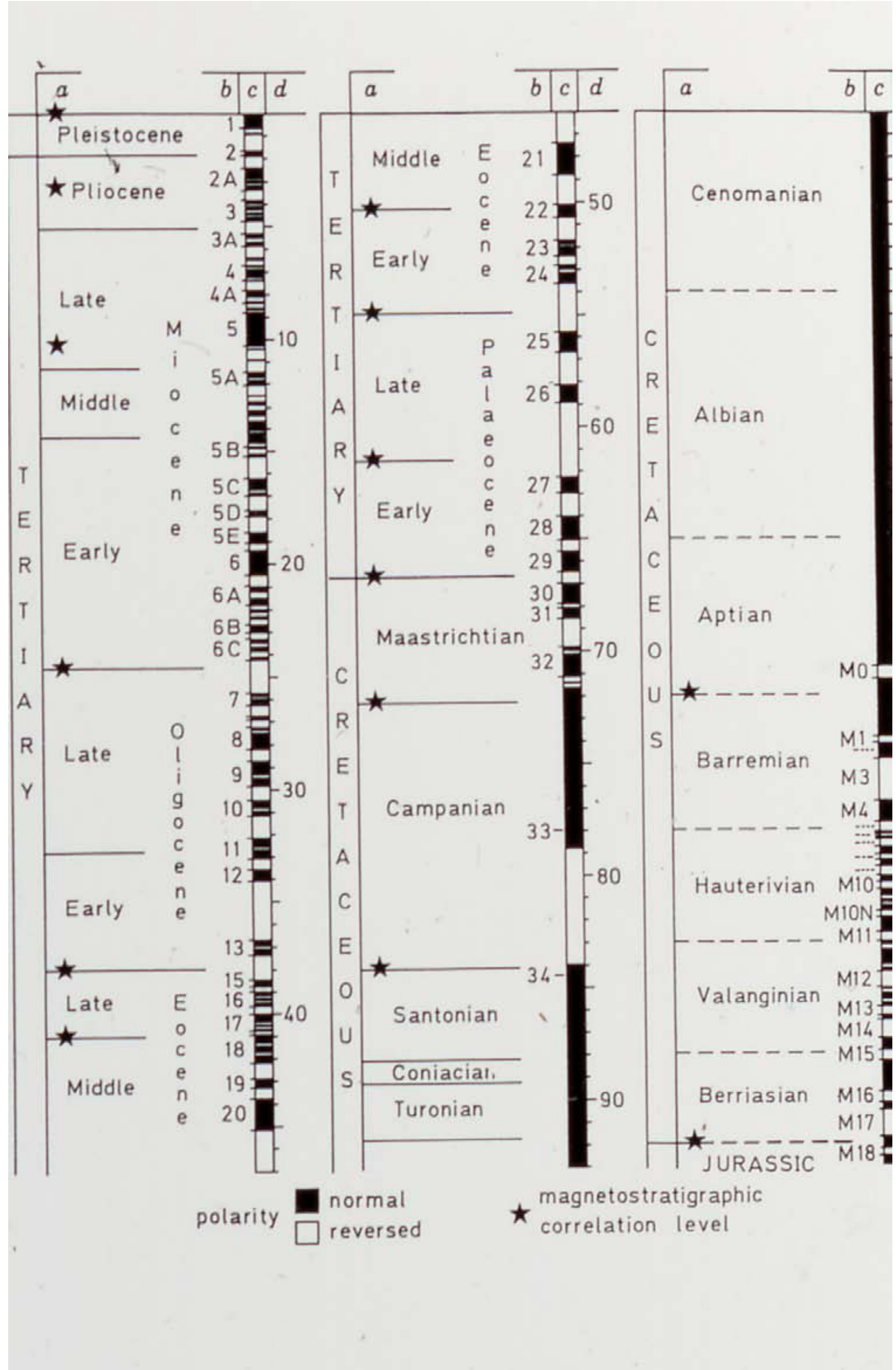
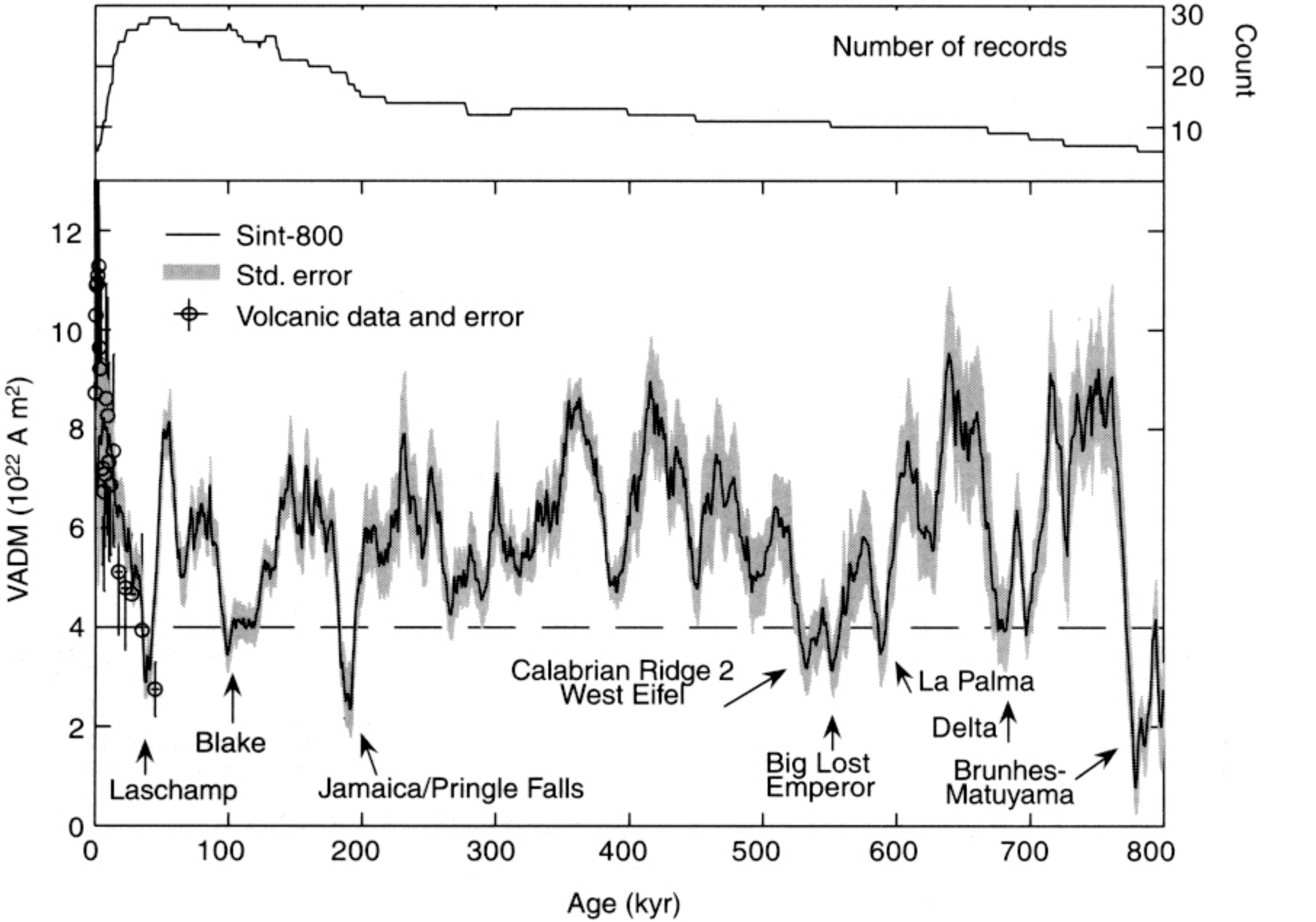
AGCI Global Change and the Solar-Terrestrial Environment, 12-17 June 2010.

REVERSALS

- There are long periods called superchrons when no reversals occurred
- This is thought to arise from changes in the solid mantle, which affect the heat flow out of the core
- The Earth's field has reversed polarity many times in the past

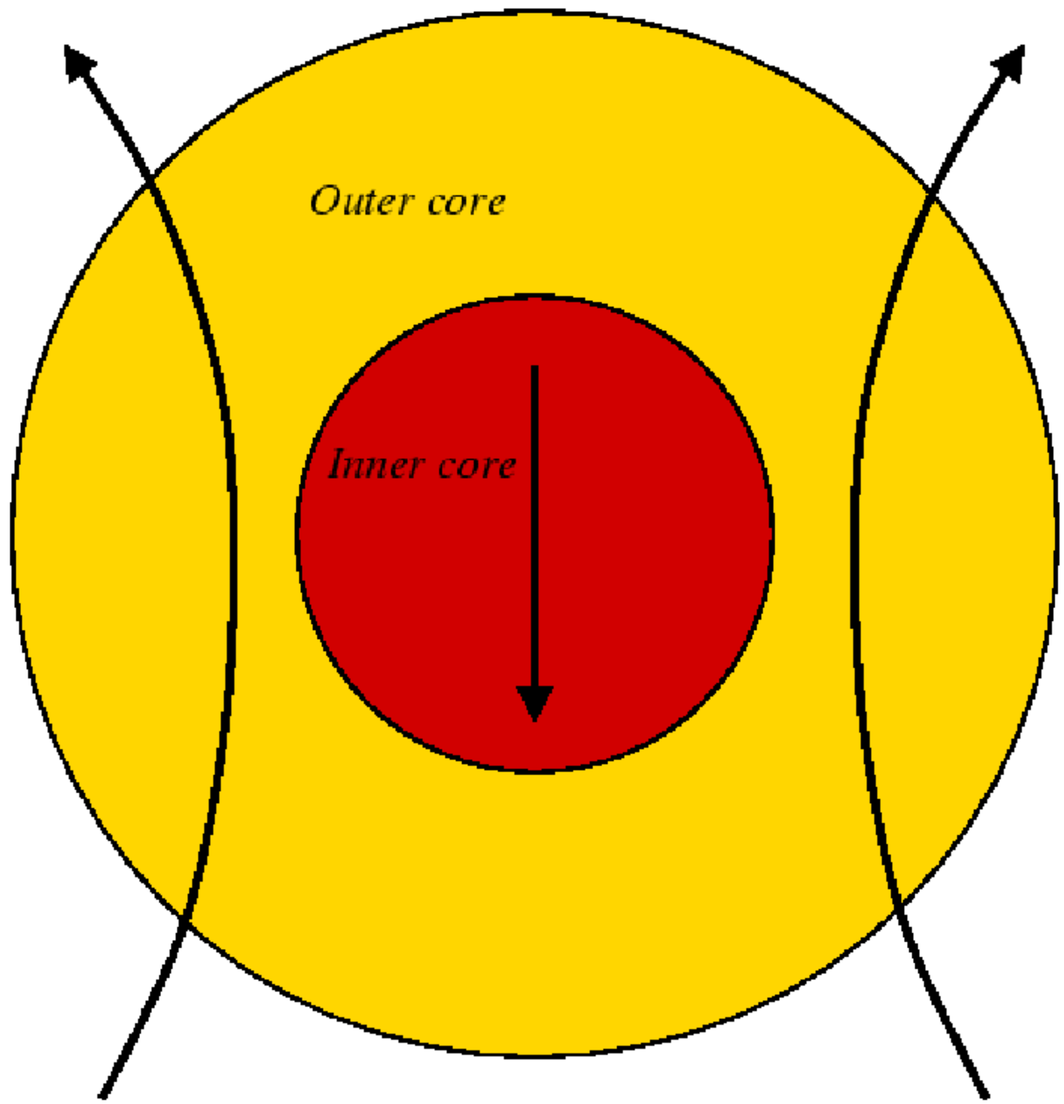



Number of records
Count
30
20
10
12
10
8
6
4
2
0
VADM (10^{22} A m^2)
Sint-800
Std. error
Volcanic data and error
Laschamp
Blake
Jamaica/Pringle Falls
Calabrian Ridge 2
West Eifel
Big Lost
Emperor
La Palma
Delta
Brunhes-
Matuyama
0
100
200
300
400
500
600
700
800
Age (kyr)

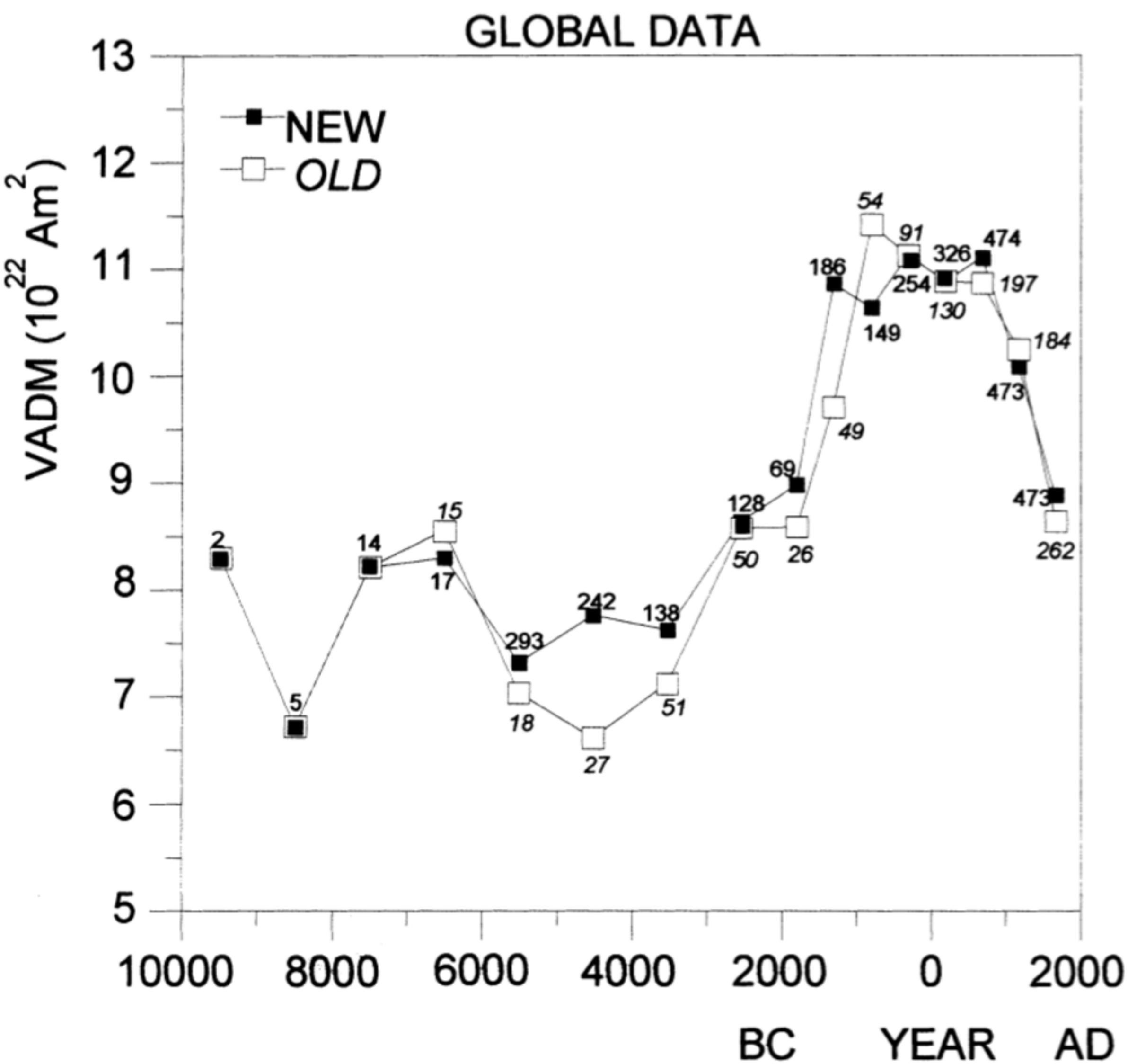
EXCURSION OR FULL REVERSAL?

Time scale to change B in outer core: 500 yr

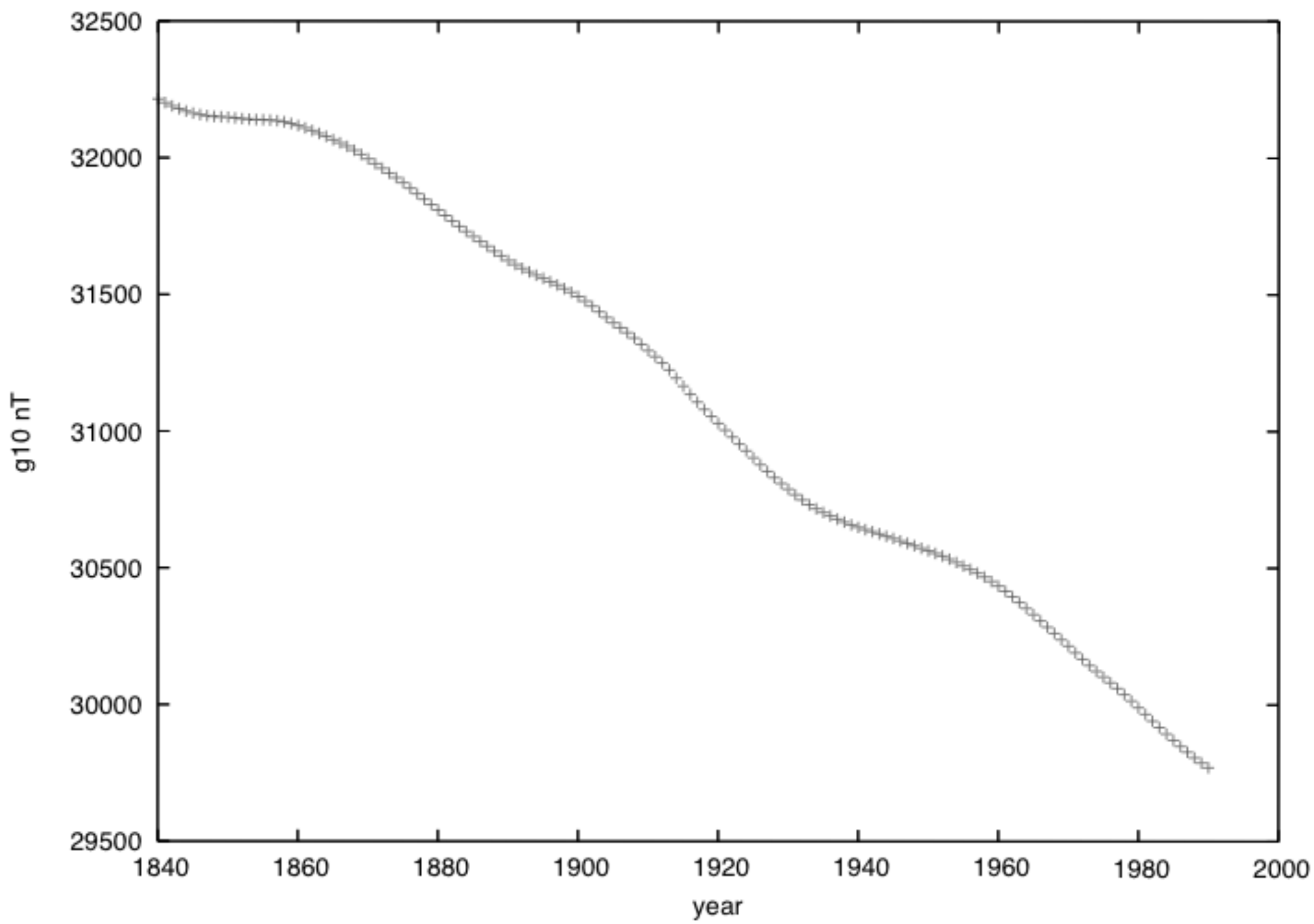
Time scale in inner core (diffusion) 5 kyr



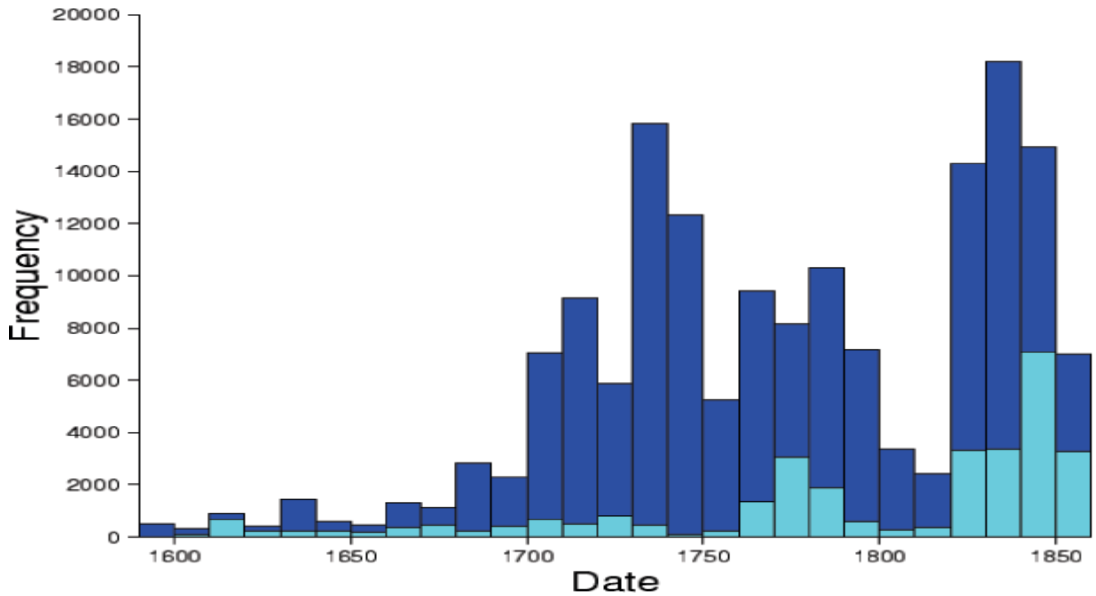
Change in dipole moment last 10,000 years



Fall of the dipole moment since AD1840



Distribution of historical data (after Jackson, Walker & Jonkers 2000)



- 1595-1715: *I* in Europe only, *D* good in oceans
- 1715-1840: *I*,*D* good in oceans
- 1840-1900: improving on land, worse in oceans (Suez Canal)
- 1900-1926: good (Carnegie)
- 1926-1955: poor
- 1955->: excellent (Proton magnetometer, satellites)

FIRST MEASUREMENT OF GEOMAGNETIC INTENSITY

Alexander von Humboldt

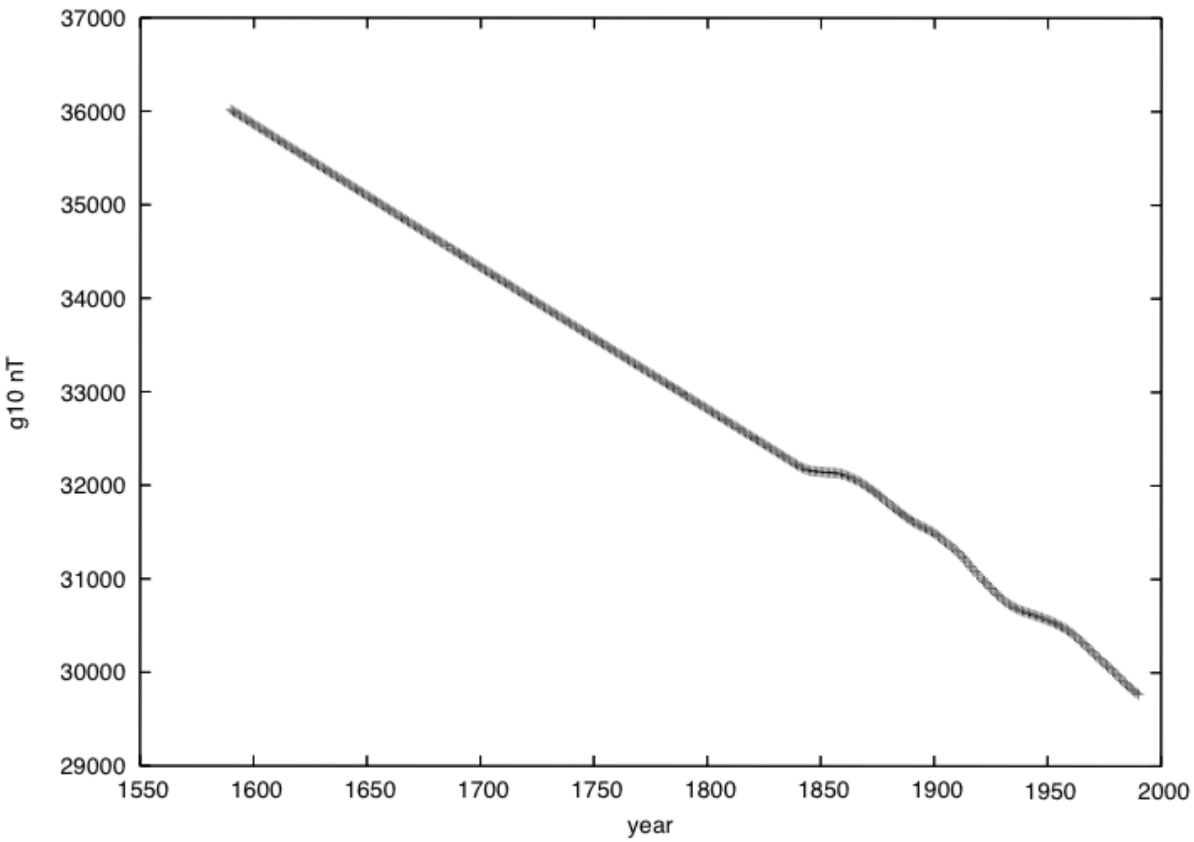
Carl Friedrich Gauss devised the first method to measure magnetic intensity in 1837, replacing Humboldt's measurements of relative intensity, made by timing the oscillation period of a suspended magnet. In the context of a global field model, relative intensity contains no more information than direction.

Carl Friedrich Gauss

The *Göttinger Magnetische Verein* was set up to make global measurements in 1836. This was continued and driven for the next 40 years by Edward Sabine and Humphrey Lloyd in what is now called the *Magnetic Crusade.* This has left us with good global coverage of intensity from 1840 onwards, with no direct measurements earlier than 1837.

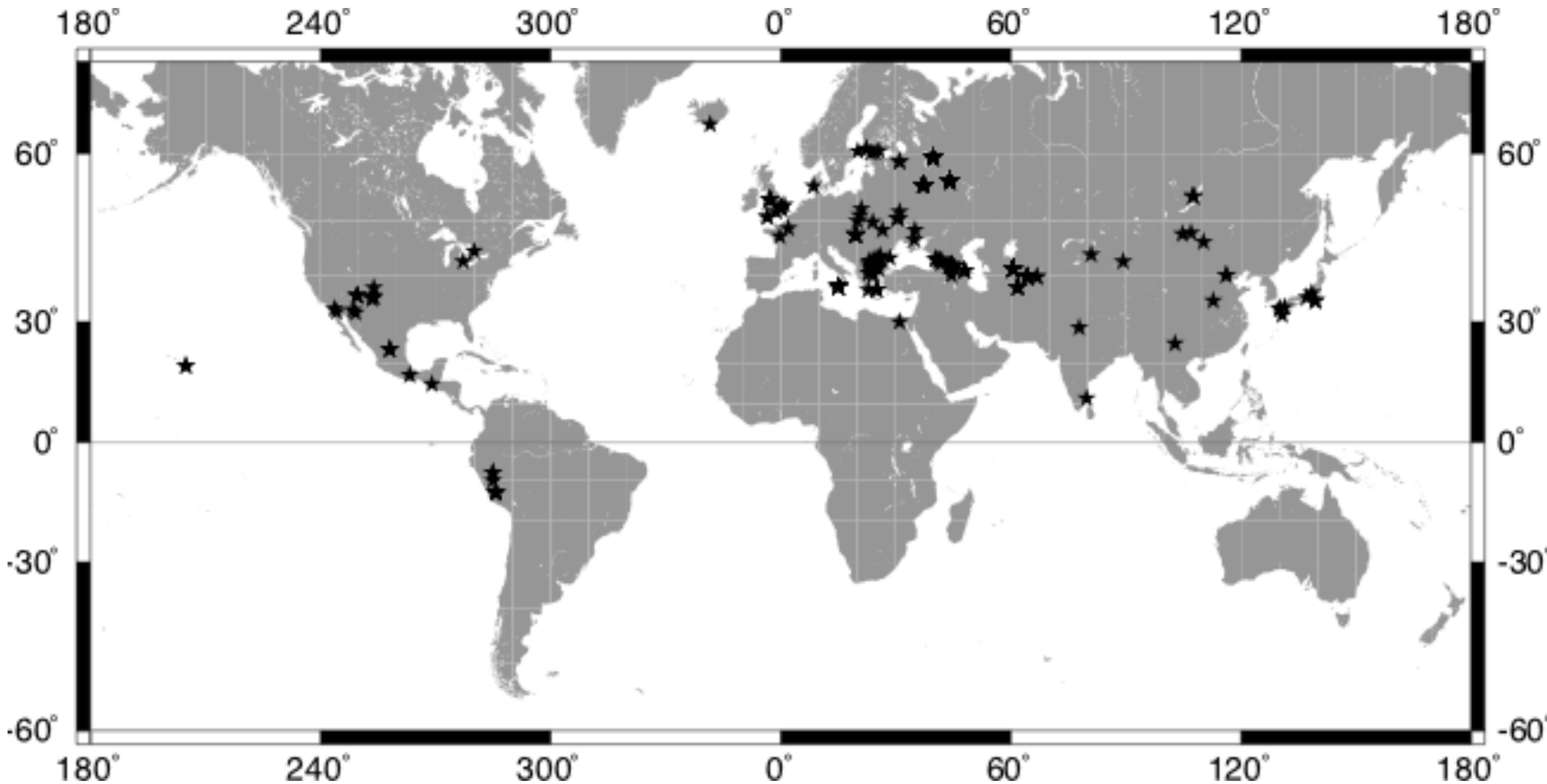
Fall of the dipole moment since AD1595

15 nT/year assumed before 1840



Paleo- and archeo-intensity data 1595-1840

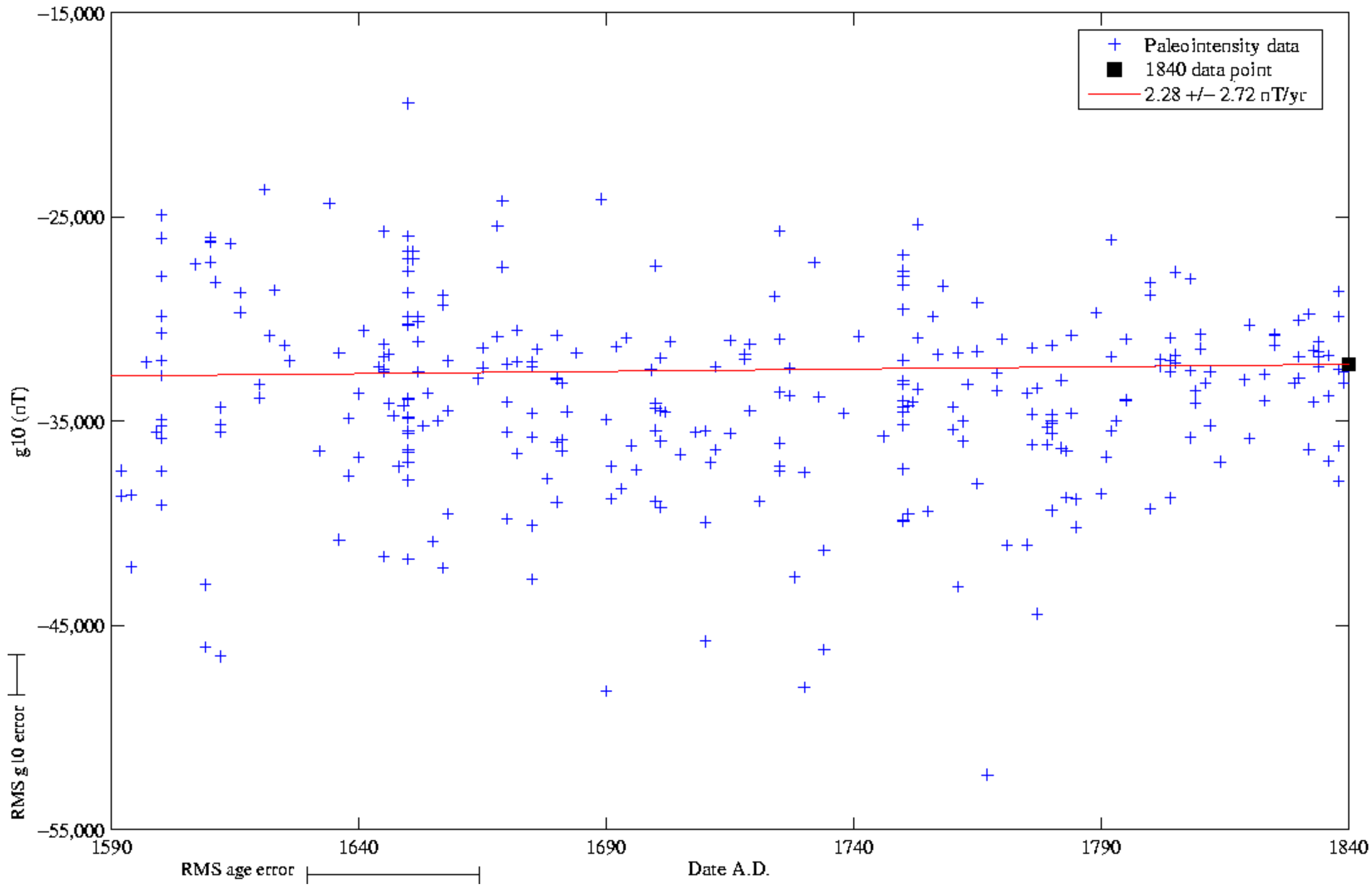
- There are 315 measurements of intensity in the database
- Typical errors 10% or 3000 nT, equivalent to 200 years @ 15 nT/yr
- Single measurements therefore do not constrain historical SV at all



METHOD

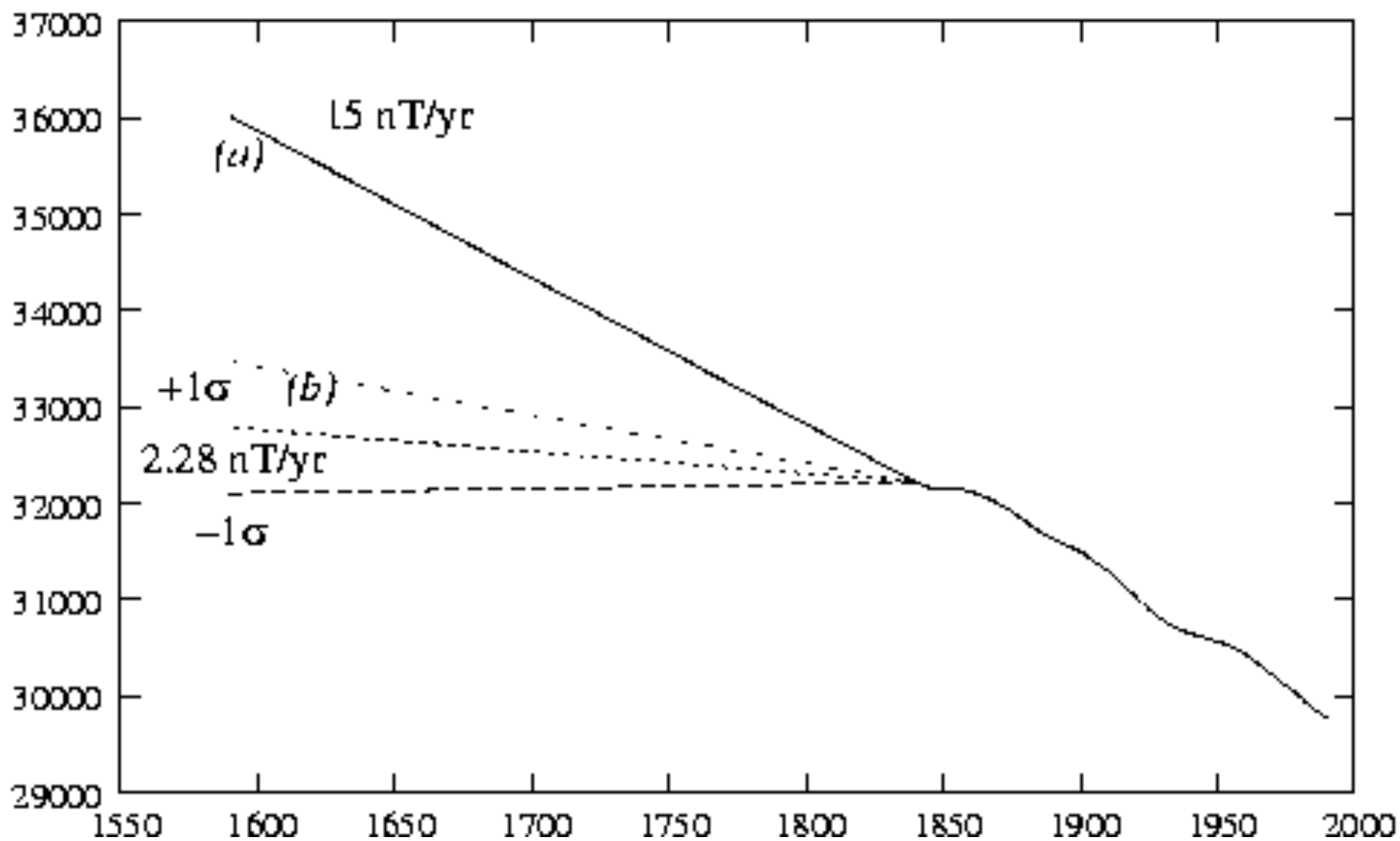
- Given a good directional model, only one intensity measurement is needed to normalise the intensity everywhere provided there are only 2 dip-poles *[Hulot et al. 1997].*
- We therefore map each intensity determination into an estimate of g_1^0 and map its error into an error on g_1^0.
- We assume a constant fall in g_1^0 from AD 1595 to 1840 and fix its 1840 value to be that of the global model *gufm*.
- This leaves one parameter, the slope of the line, to be determined from 315 paleointensity measurements.
- We determine the slope of the best-fitting straight line taking into account errors in **both** *F* and time.
- χ^2 gives the goodness-of-fit, how well the data can be fitted to a straight line
- σ^2 gives the standard error on the determined slope, and a Student t-test gives the confidence the slope is different from some other value - notably the assumed 15 nT/yr of the later epoch 1840-1990.

BEST-FITTING STRAIGHT LINE



RESULTS

- The rate of fall in *g10* before 1840 was 2.28±2.72 nT/yr
- χ2=258 with 314 degrees of freedom - a straight line is a good fit
- The derived slope differs of 2.28 differs from the later 16.1 nT/yr with more than 99.9% confidence



SO WHAT HAPPENED IN 1840?

The fall in dipole moment is actually caused by redistribution of magnetic flux on the core surface:

$$\frac{dg_1^0}{dt} = \frac{3c^2}{8\pi a^2} \oiint \frac{\partial B_r}{\partial t} \cos\theta dS$$

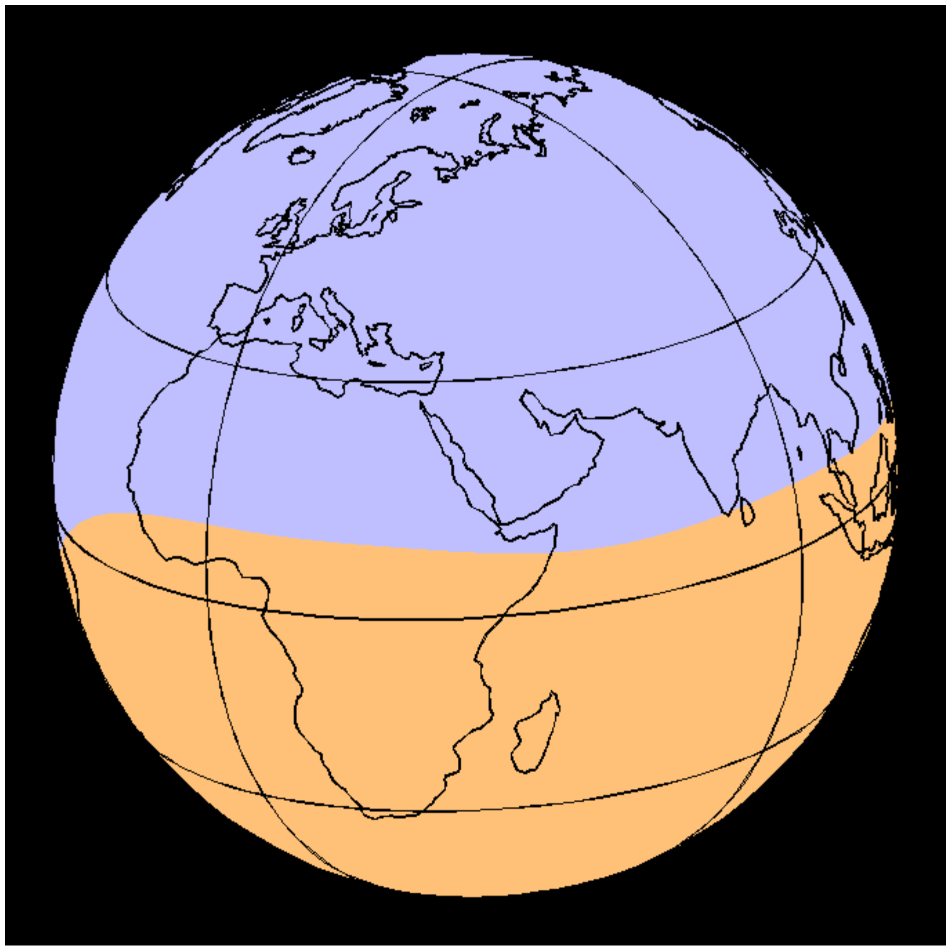
either by flux weakening or reversing or by flux drifting in latitude.

Since about 1840 this effect has been most prominent in the Southern Hemisphere, with particularly strong expulsion of flux in the early 20th century creating a reversed flux patch at the core surface off SE Africa.

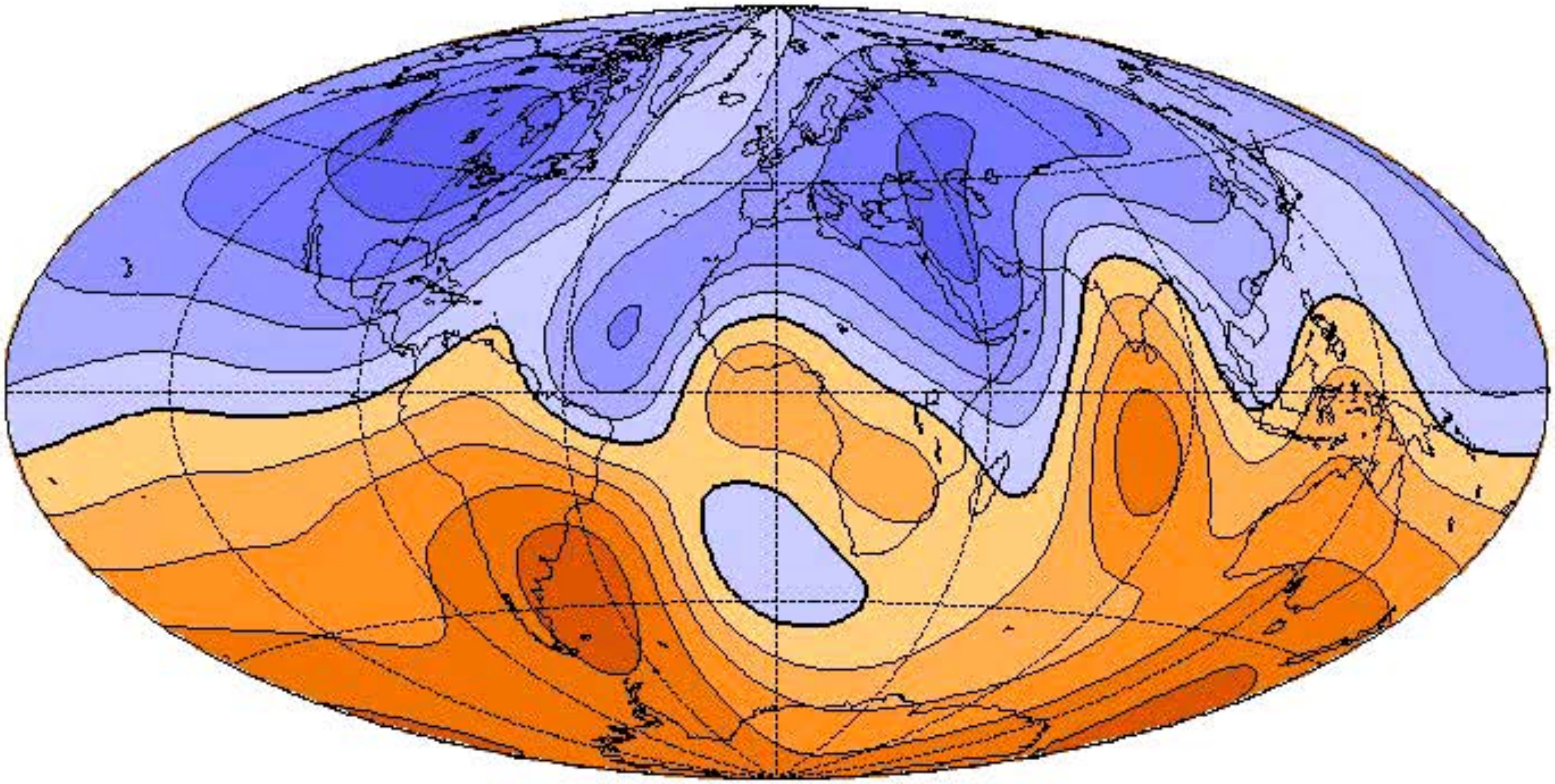
Prior to 1840 these reverse flux patches were absent or much less active.

Intensities are not needed to follow the location or relative sizes of the reverse flux patches

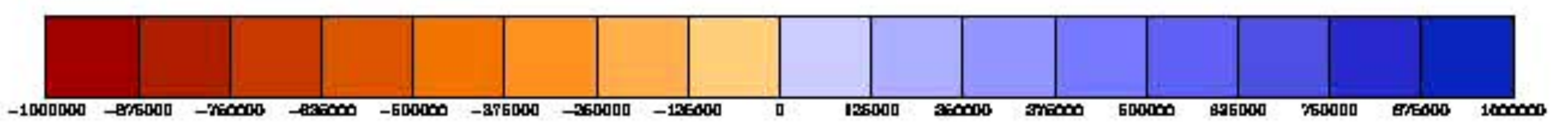
Downward Continuation to the Core Surface



1590

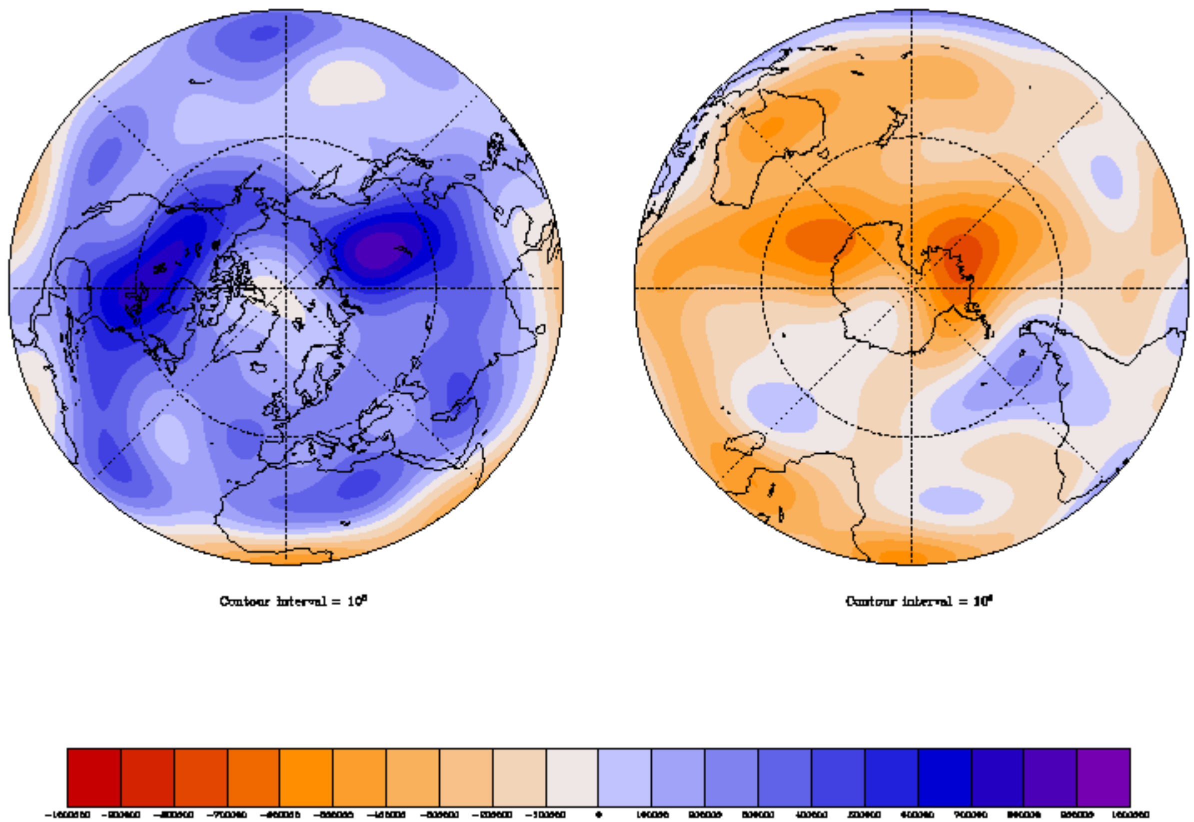


Contour interval = 125000

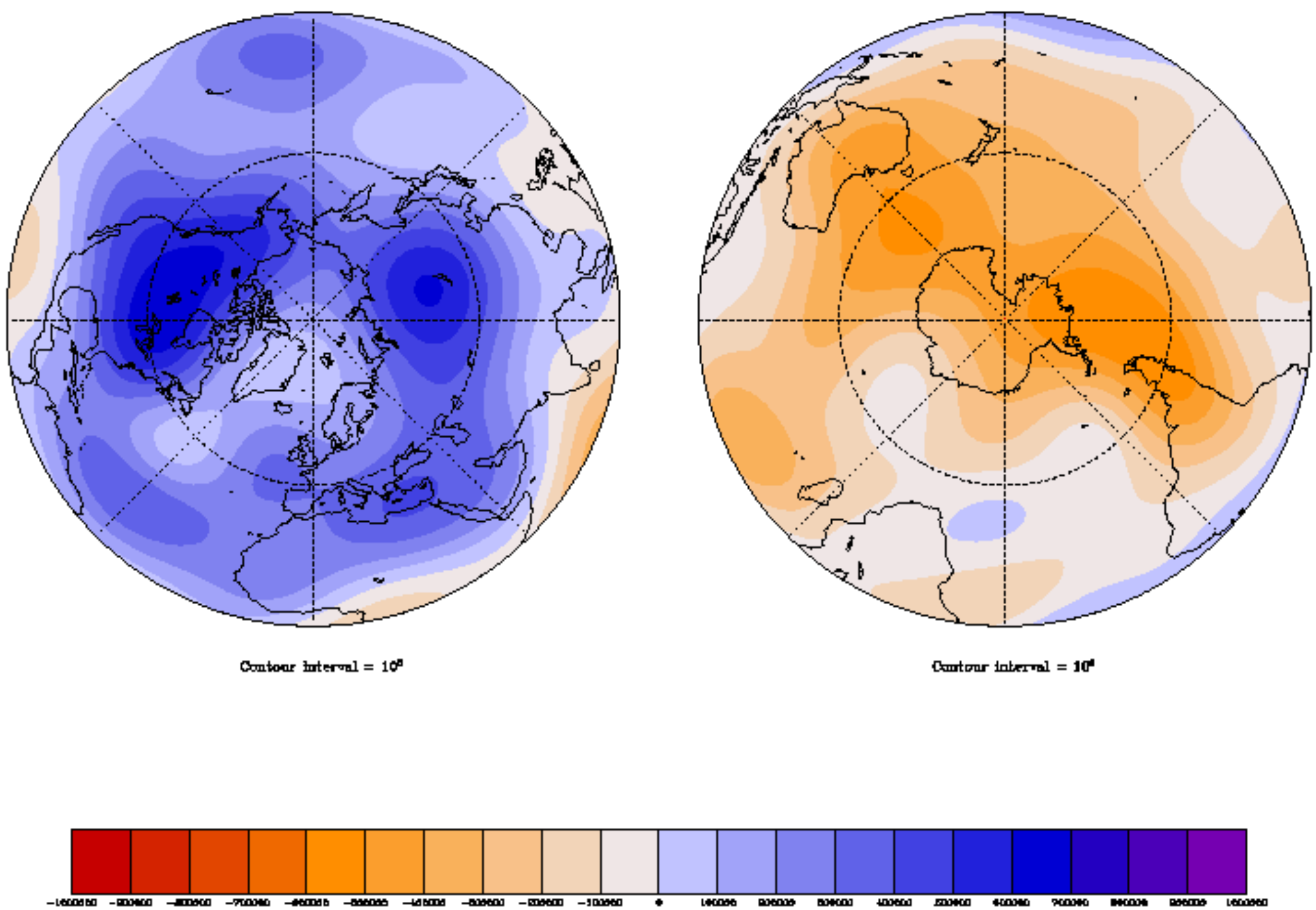


Vertical component of field on CMB in 1980

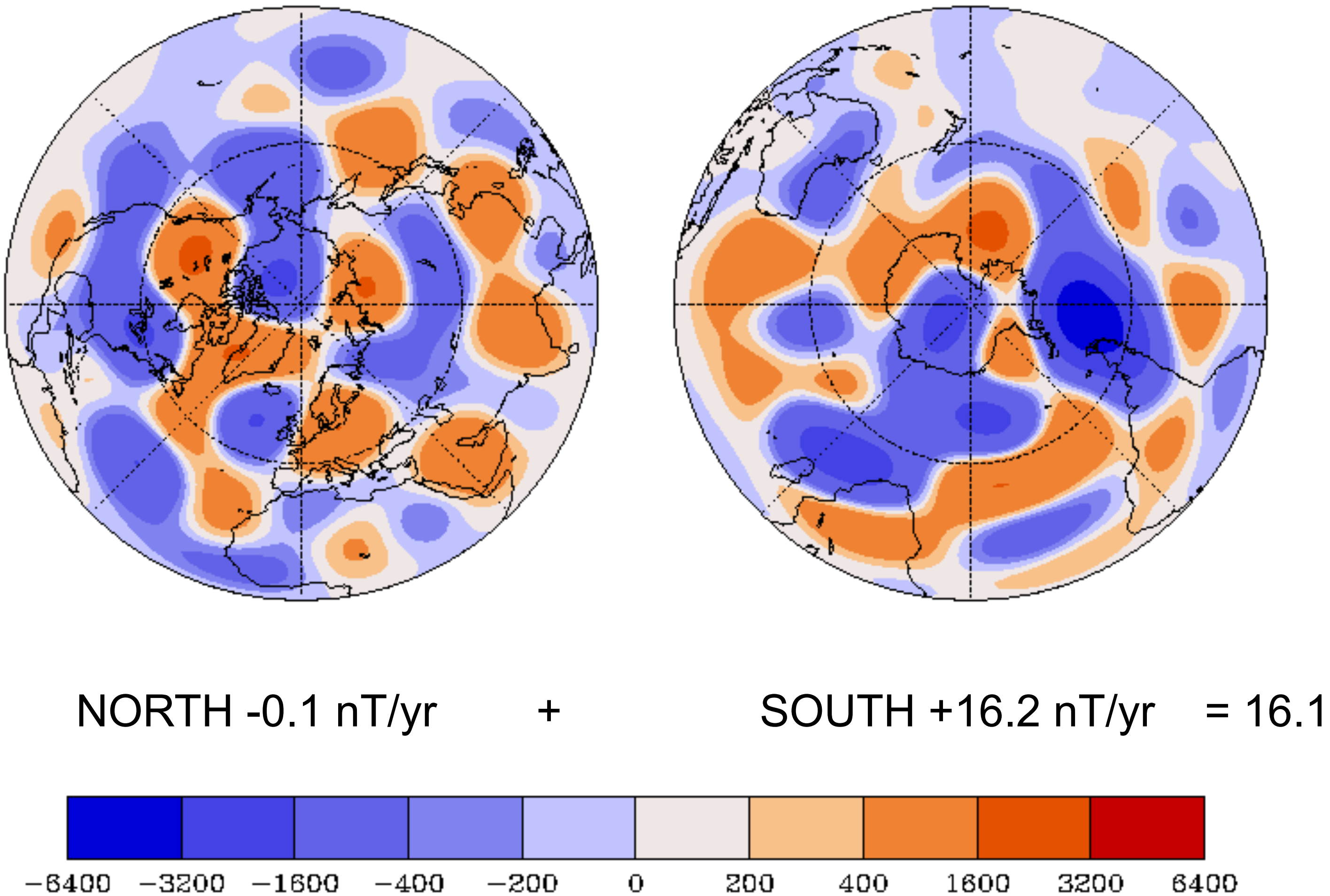
Lambert equal area projection



Vertical component of magnetic field 1780

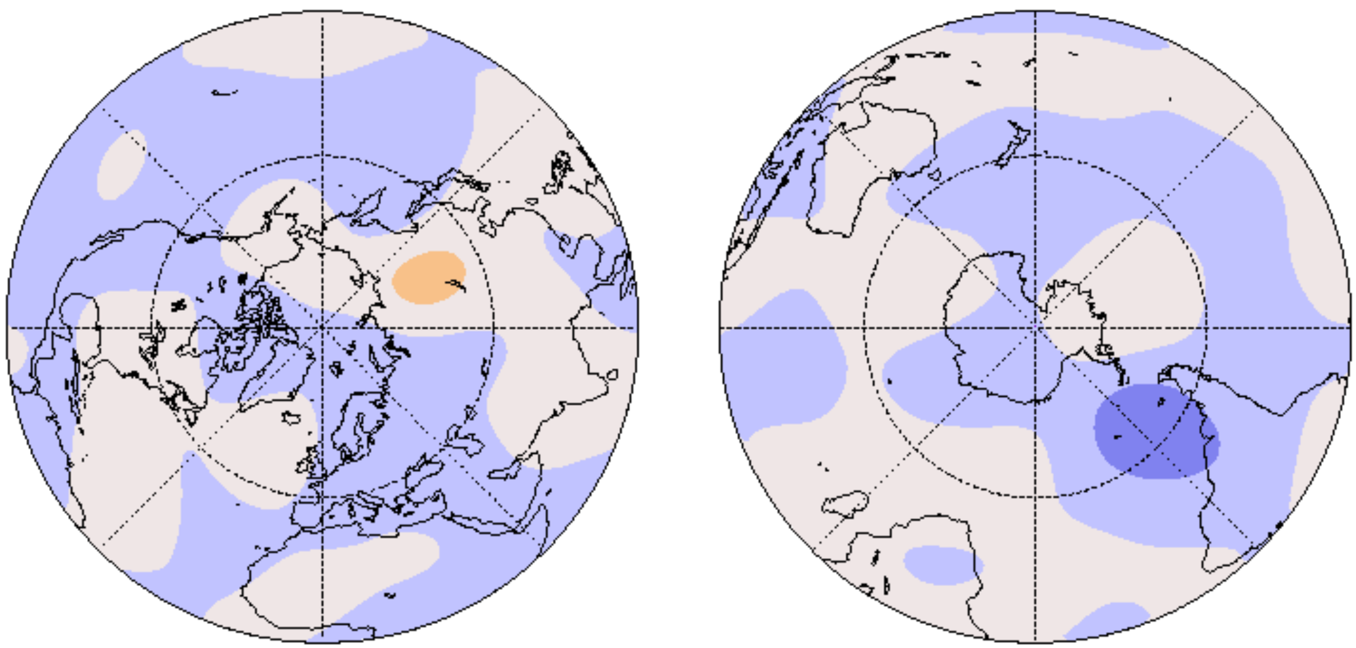


Mean rate of change of *g10* since 1840

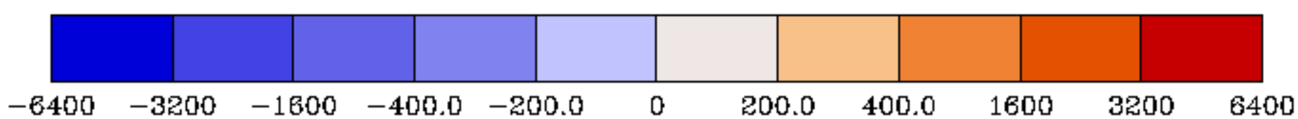


Mean rate of change of *g10* before 1840

(2.28 nT/yr)



NORTH -0.8 nT/yr + SOUTH +3.1 nT/yr = 2.3

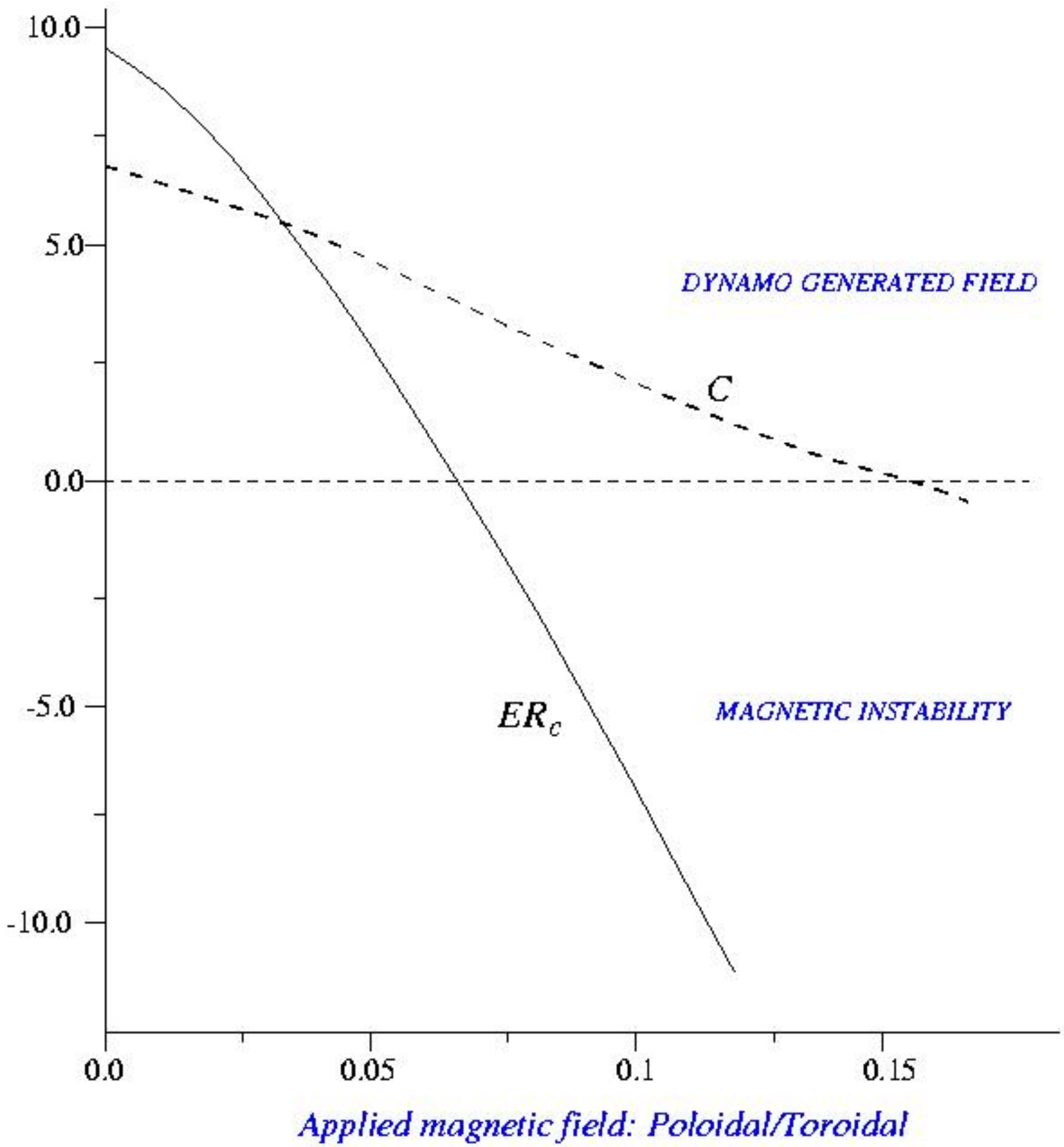


CONCLUSIONS

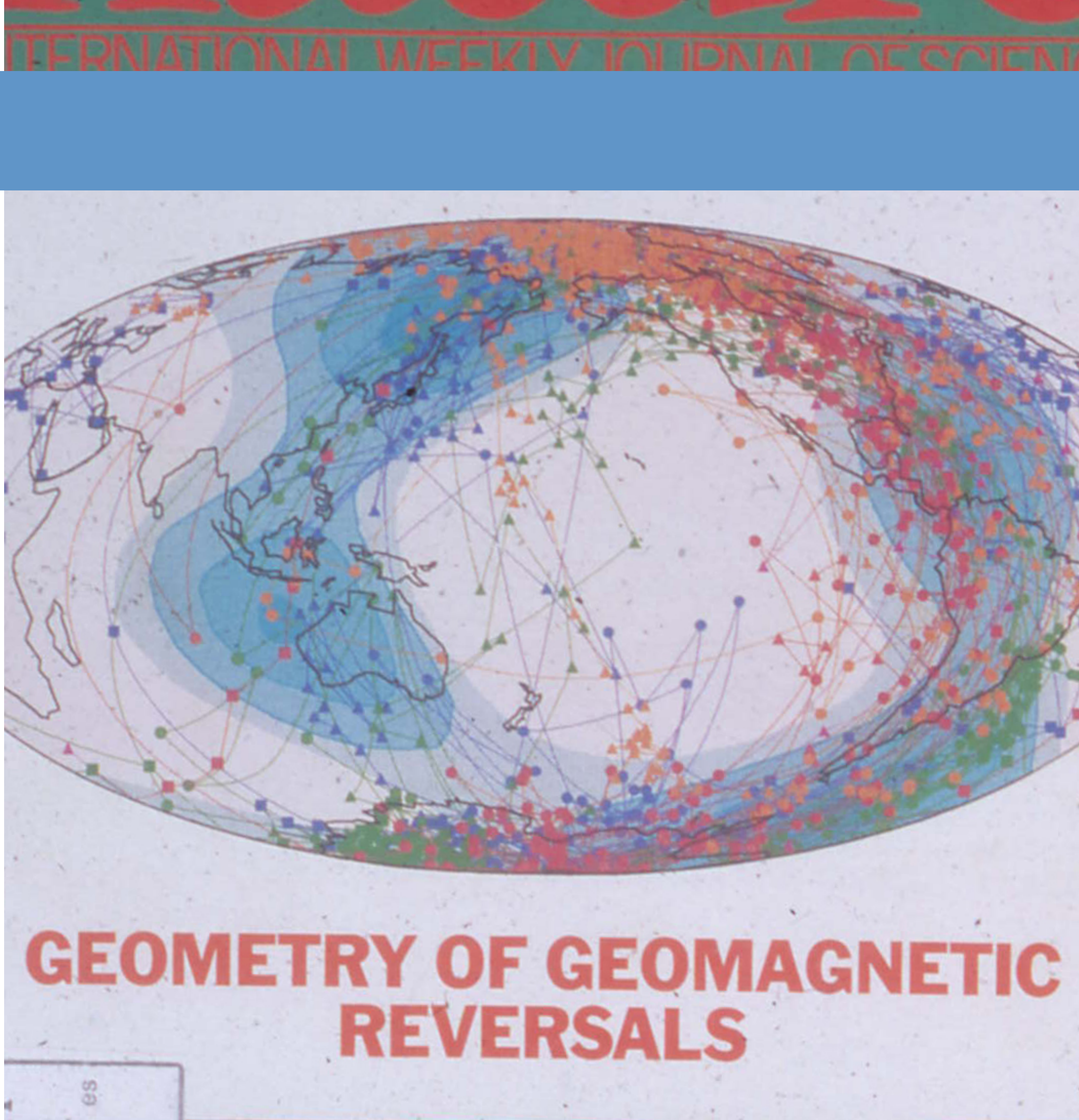
- The present rapid fall in dipole moment started about 1860
- Paleointensities show that a slower average fall has been underway at least since Roman times, about 20000 nT in 2000 years or 10 nT/yr
- Both are consistent with intervals of rapid fall separated by intervals of quiescence
- A plausible cause is periods of expulsion of toroidal flux through the core surface followed by periods of regeneration of toroidal flux inside the core
- Falls to about half the present value have been associated with geomagnetic excursions many times since the last reversal
- We could therefore be heading for an excursion in < 1,000 years
- … or perhaps a full reversal

CAN WE PREDICT MORE THAN JUST THE DIPOLE?

- IGRF a conservative extrapolation primarily for mapping purposes
- DGRF is made once all the data for that epoch are in
- Simple linear extrapolation is used
- *Geomagnetic Jerks* (discontinuities in second time derivative) make accurate prediction impossible without further theory…
- …they may be manifestations of *torsional oscillations*, but there is little theory at present
- *Geodynamo models* account well for the long time scale (including reversals) but do not account well for short time scale phenomena because
  - *Viscosity and thermal conductivity is too large*
  - *The day is too long*
- *Data assimilation* has been used with geodynamo models as a prediction tool but it is too early to report any success



10.0
5.0
0.0
-5.0
-10.0
DYNAMO GENERATED FIELD
C
ER_c
MAGNETIC INSTABILITY
0.0
0.05
0.1
0.15
Applied magnetic field: Poloidal/Toroidal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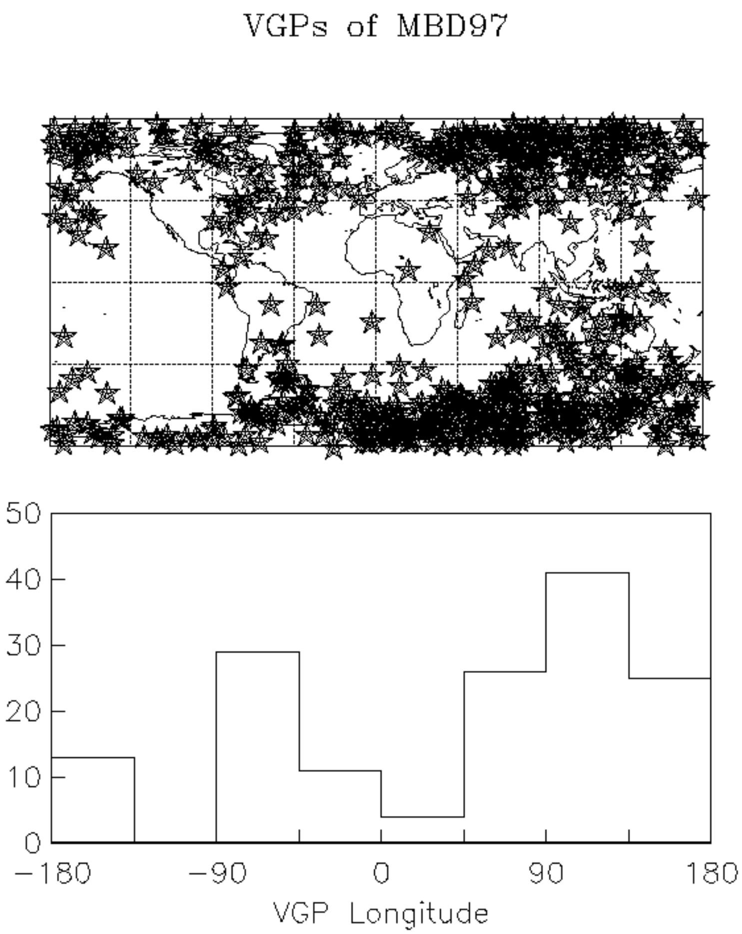
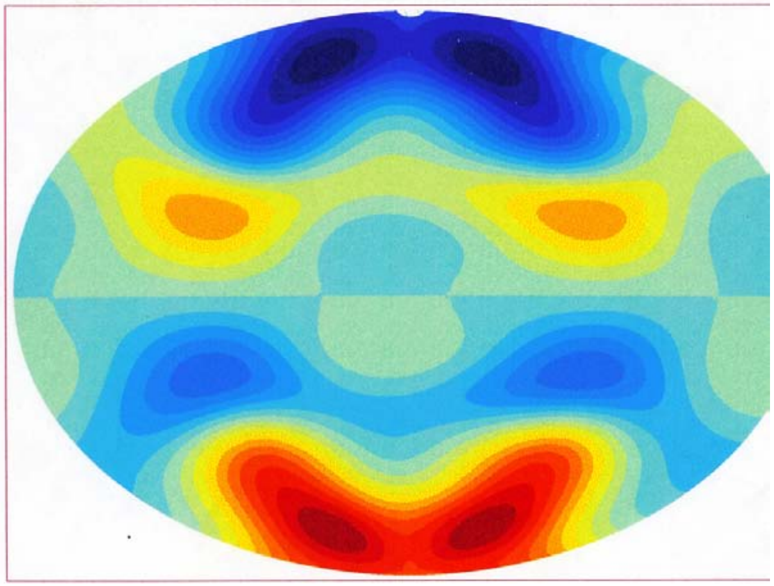
REVERSALS

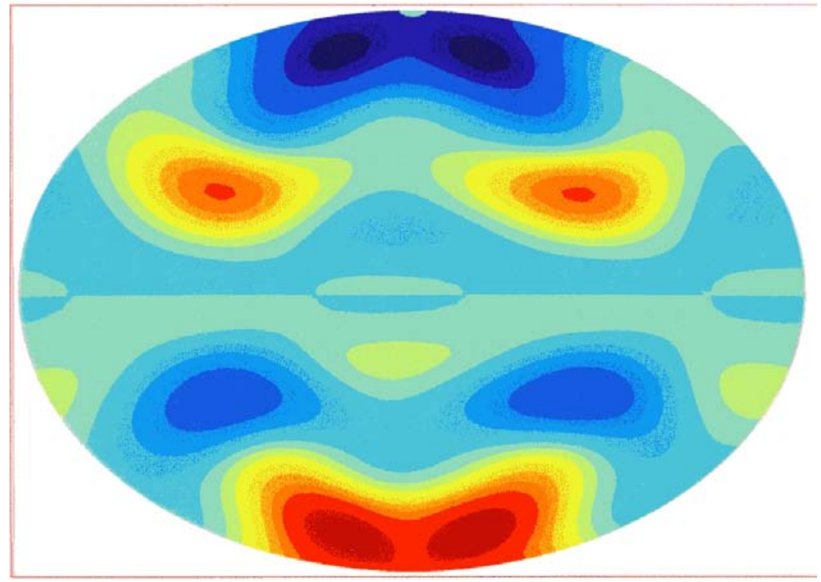


Matuyama-Brunhes, after Love & Mazau (1997)

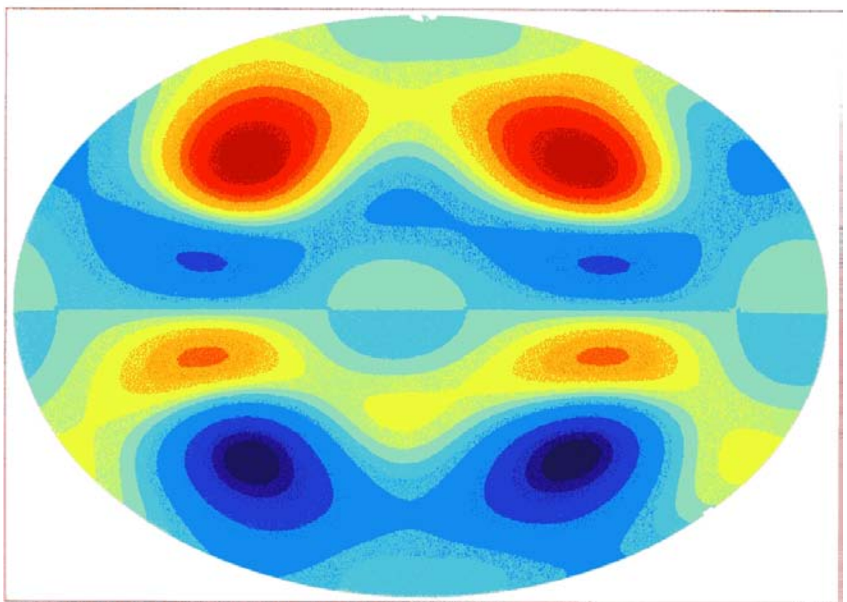
Gubbins & Sarson (1994). Radial field, time =0.



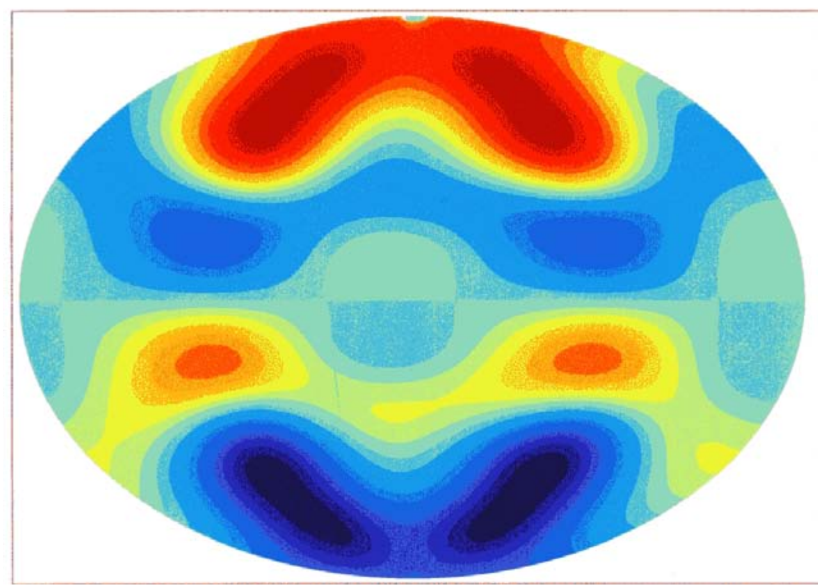
Gubbins & Sarson (1994). Radial field, time = 1/4 cycle.



Gubbins & Sarson (1994). Radial field, time = 1/2 cycle.



Gubbins & Sarson (1994). Radial field, time = 3/4 cycle.



VGP PATHS