Reporter review:

New results from geomagnetic secular variation studies

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Session A011 (Div. I & V, Saturday 2 July 2011):

Main field and secular variation: observations, modeling and mechanisms

Other sessions dealing with SV (not covered by this talk):

- A013: Numerical simulations and observations: looking back and predicting the future (Div. I)
- A132: Results from the decade of geopotential research an beyond (Div. V; see C. Beggan's report)
- U03: Recent progress in the studies of the Earth's deep interior

Outline

1. **Main field and secular variation modeling**
    - IGRF-11 and parent models
    - S. Maus, F. Lowes, E. Thébault's presentations

1. **Geomagnetic jerks**
    - The 2007 jerk
    - C. Demetrescu's presentation

1. **Dipole decay**
    - The role of flux expulsions
    - R. Holme's presentation

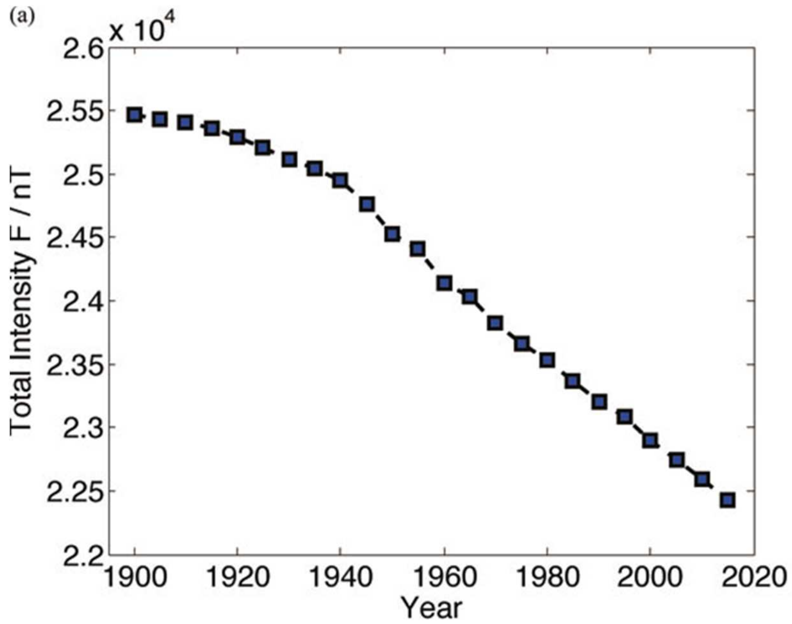
2. **Interpretation in terms of core processes**
    - A list of some recent papers (2010-2011)

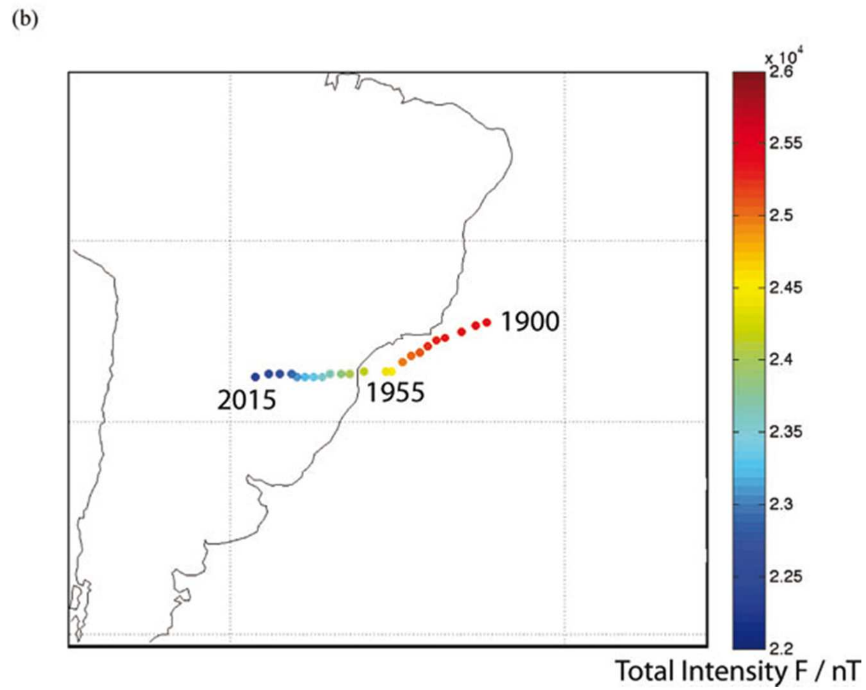
Many thanks to the speakers for kindly providing me with their slides!

This is <u>not</u> a review of the field, only a personal account of the session and a few selected recent papers.

Main field and secular variation modeling

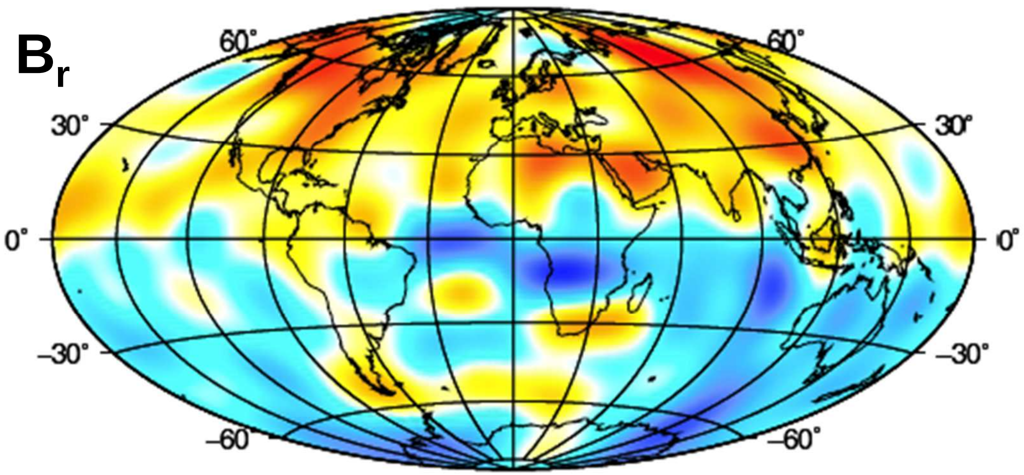
December 2009: release of the IGRF-11 model
(Finlay et al., GJI, 2010; EPS special issue, Dec. 2010)



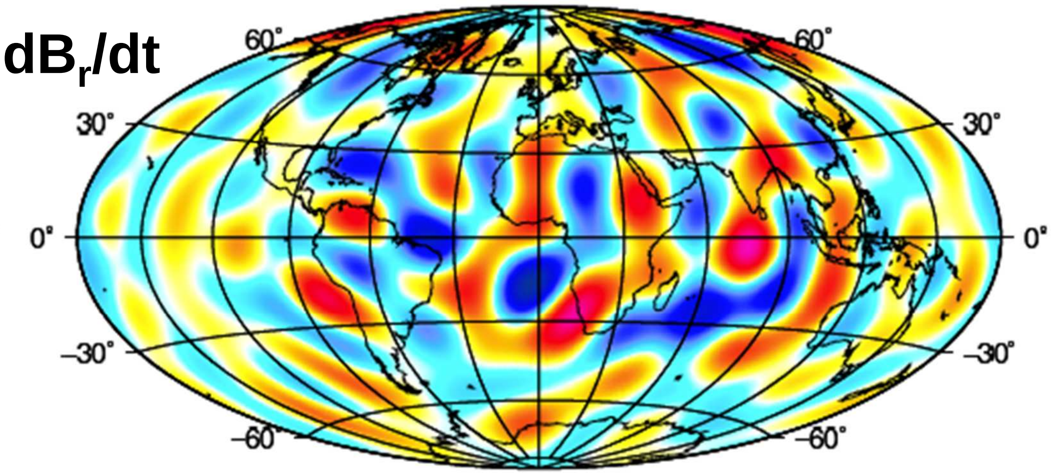


Parent models: CHAOS-3 (Olsen et al. 2010), GRIMM-2 (Lesur et al. 2010)

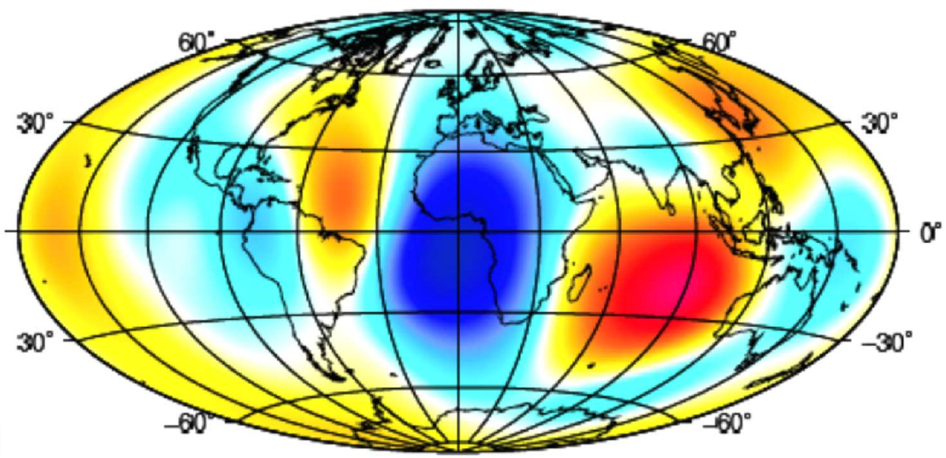
B_r



dB_r/dt



d^2Br/dt^2



2006

Now CHAOS-4 (AGU 2010) and GRIMM-3 (cf. C. Beggan's report) from the full CHAMP dataset

Stefan Maus' presentation: What is the accuracy of geomagnetic field models?

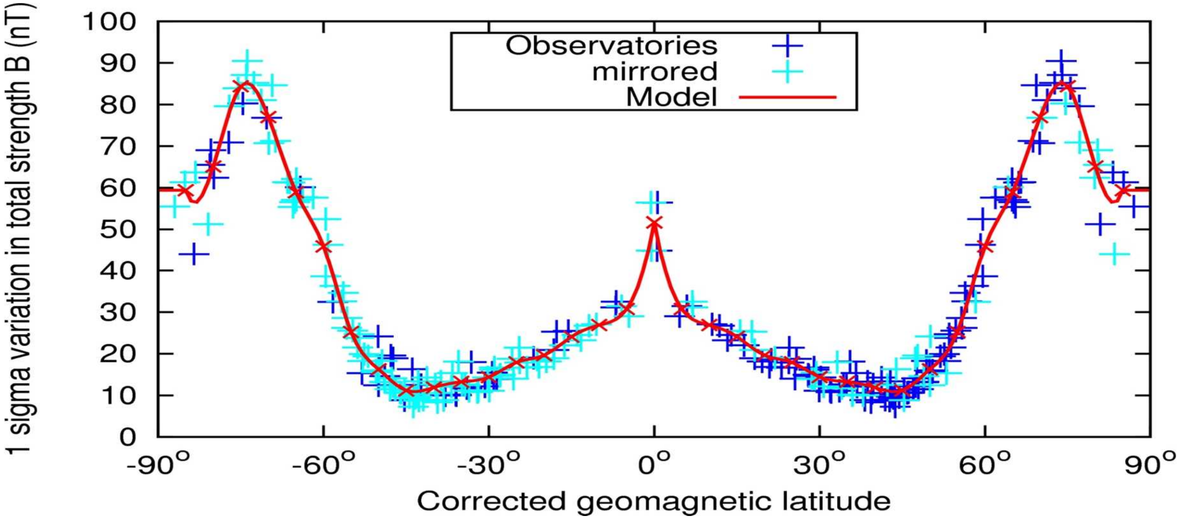
Valid IGRF Range: 1900-2015

Compute Magnetic Field Values

Results:

NGDC online calculator snapshot

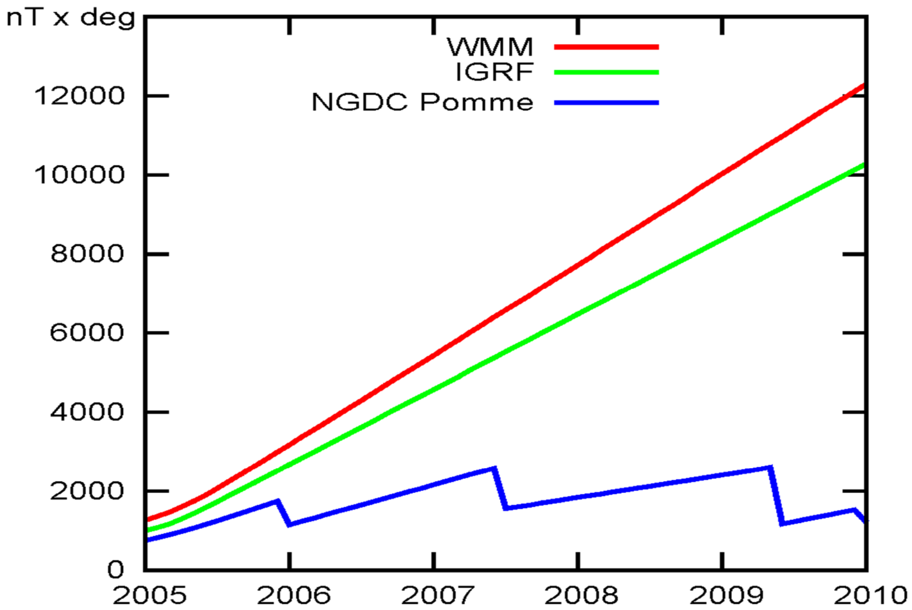
Lat: - 37° 51' Lon: 145° 4' 12'' Elev: 0.00 m	**Declination** + East - West	**Inclination** + Down - Up	**Horizontal Intensity**	**North Component** + North - South	**East Component** + East - West	**Vertical Component** + Down - Up	**Total Field**
6/23/2011	11° 38' ± ?	- 68° 45' ± ?	21,757.2 nT ± ?	21,310.0 nT ± ?	4388.7 nT ± ?	-55,958.8 nT ± ?	60,039.7 nT ± ?
Change per year	- 0' per year	1' per year	6.7 nT/year	6.9 nT/year	-0.5 nT/year	23.8 nT/year	-19.8 nT/year



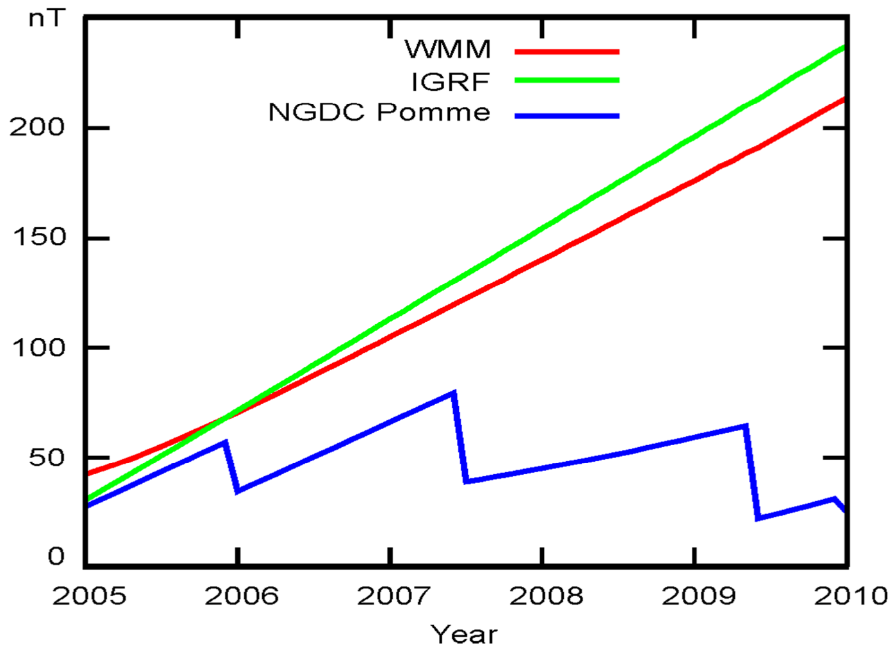
- MF commission error
- crustal field omission error
- disturbance field omission error

Main field: 3σ error against IGRF-11

Error in D x H



Error in total field



Models are accurate on their release date and deteriorate subsequently

Typical* 99.7 percentile error at Earth surface

	Total field	Dip	Declination
Main field, IGRF	172 nT	0.26º	7 160 ºnT/H
Crustal field	590 nT	0.86º	26 200 ºnT/H
Disturbance field	270 nT	0.98º	11 300 ºnT/H
Total ($\sqrt{\Sigma e^2}$)**	670 nT	1.33º	29 400 ºnT/H

*Actual values depend on magnetic latitude

** Only approximately valid for non-Gaussian errors

Frank Lowes' presentation: "Orthogonality of Harmonic Potentials and Fields in Spheroidal Coordinates"

Spherical harmonics are orthogonal, but the Earth is not exactly spherical.
$\Rightarrow$This matters for short wavelength crustal fields.

In spheroidal coordinates, the potential V may be expressed as

$V'^m_n = U^m_n(u)\, S^m_n(\vartheta,\lambda)$

where $U^m_n(u)$ is a complicated function of u,
and $S^m_n(\vartheta,\lambda)$ has the same algebraic form as for spherical surface harmonics.

BUT these $S^m_n(\vartheta,\lambda)$ are NOT orthogonal over the spheroid!

Orthogonality can be regained if we weight the integration over the spheroidal surface by a simple function, $W'(\vartheta)$, of reduced colatitude:

$$W'(\vartheta) = [(u^2+E^2)/(u^2+E^2\cos^2\vartheta)]^{1/2}.$$

This weighting function gives unit weight at the poles, and more weight at the equator, in such a way that

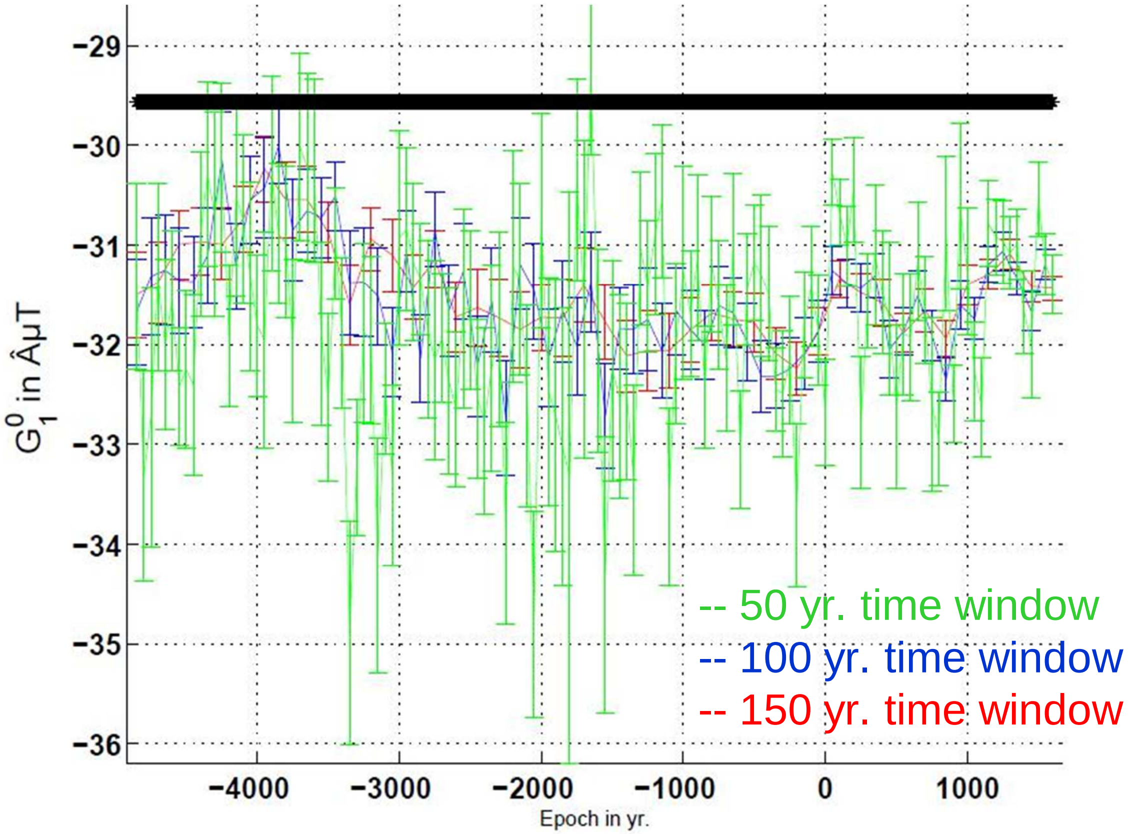
$$\iint_{spheroid} W'(\vartheta)\, S_n^m(\vartheta,\lambda) S_N^M(\vartheta,\lambda)\, dA_{spheroid} = 0$$

unless $n=N$ *and* $m=M$

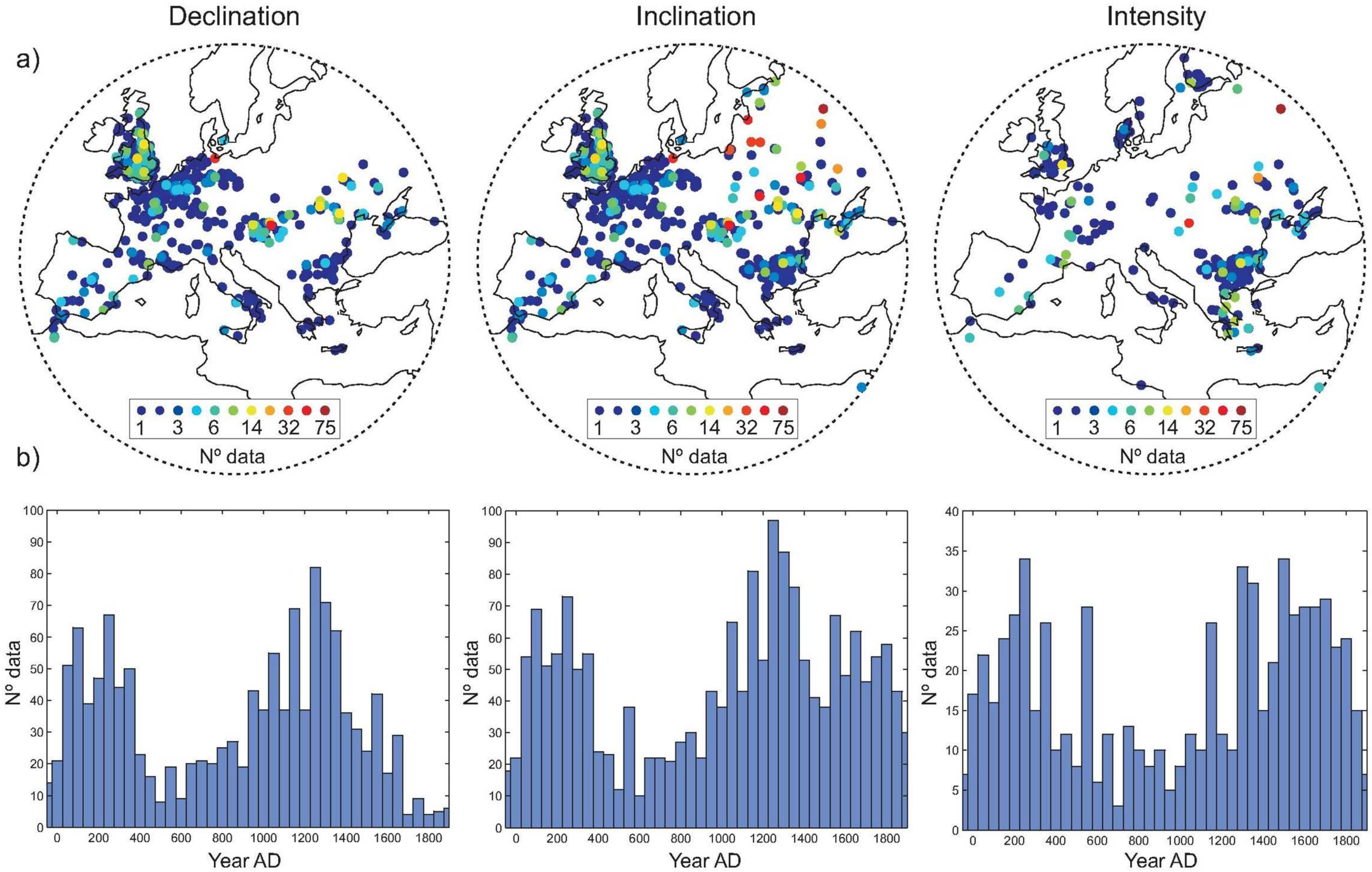
Erwan Thébault's presentation: "A parade of archeomagnetic field models – from global to local scales"

Global modeling

"1) We consider the actual archeomagnetic data base between 5000 BC and 2000 AD. – 2) We compute the IGRF magnetic field on these data locations. – 3) We solve for the dipole field only (n=1, m=0,1) within sliding time windows of 50, 100 and 150 years."

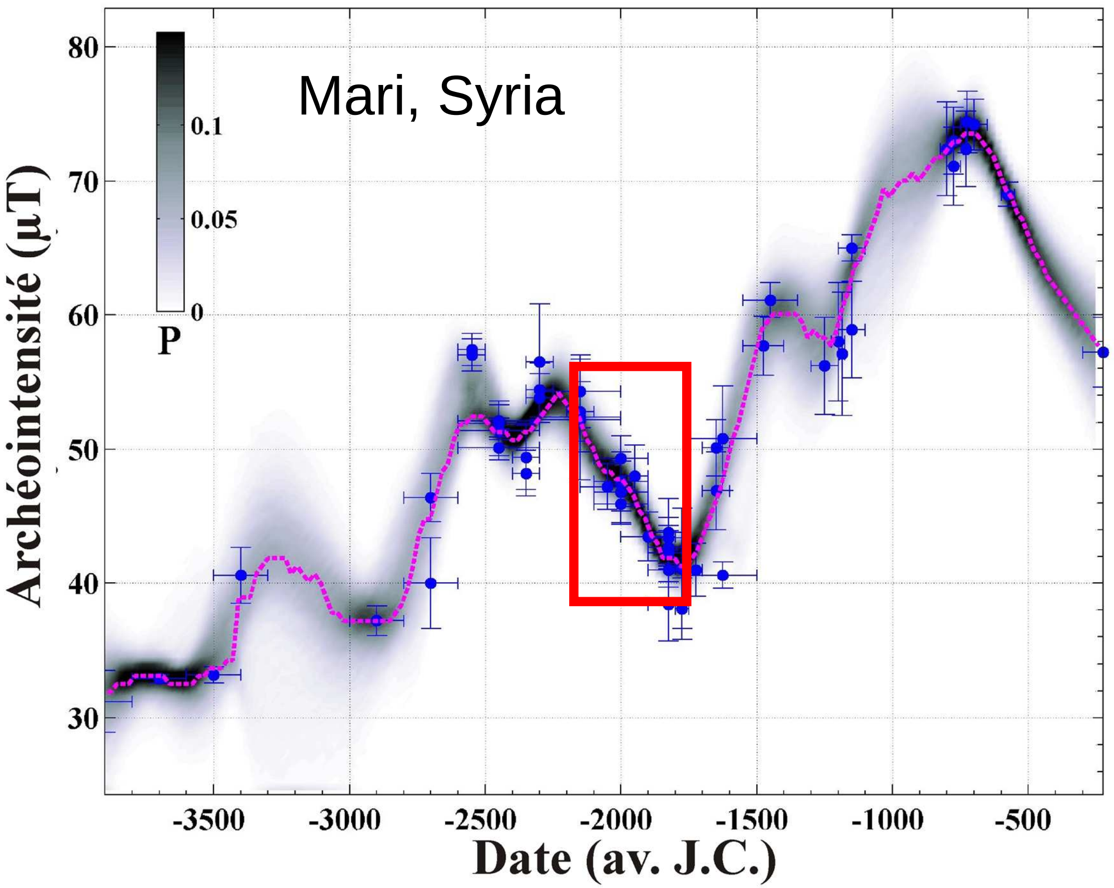


Regional modeling



Despite a sophisticated inversion scheme, regional models are not able to correctly represent the intensity variations.

Proposed solution: calculating intensity master curves.



An algorithm for deriving intensity master curves (cubic B-splines, bootstrap + IRWLS, L1-norm)

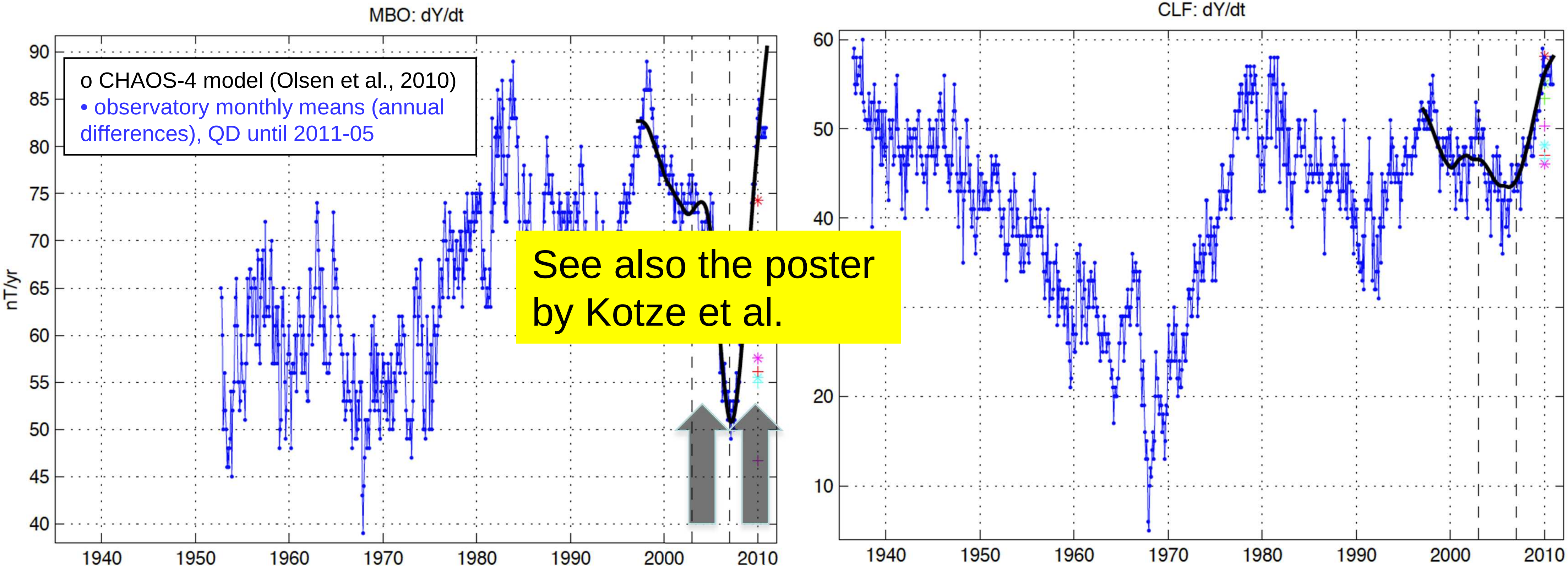
[Thébault & Gallet, GRL, 2010]

⇒ "Virtual archeomagnetic observatories"?

⇒ Relative datation becomes conceivable.

Geomagnetic jerks

A new jerk around 2007, marking the end of an acceleration pulse at the core-mantle boundary (Chulliat et al., 2010); a new jerk in 2010?



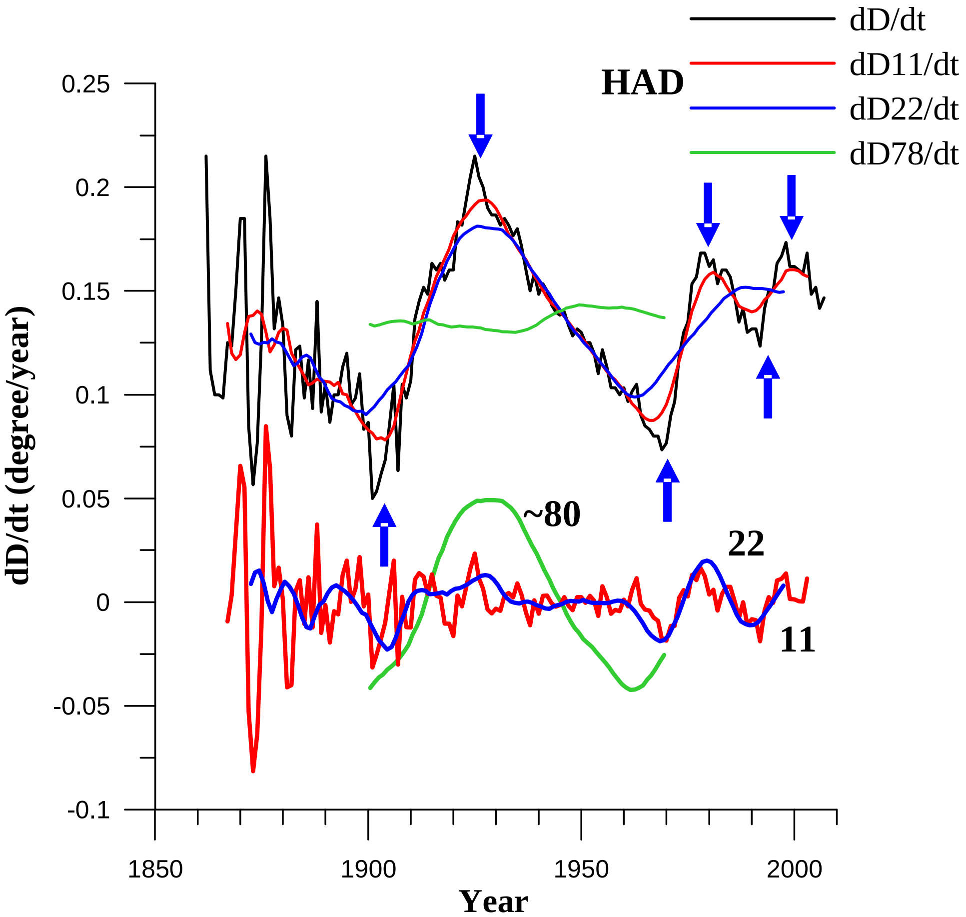
See also the poster by Kotze et al.

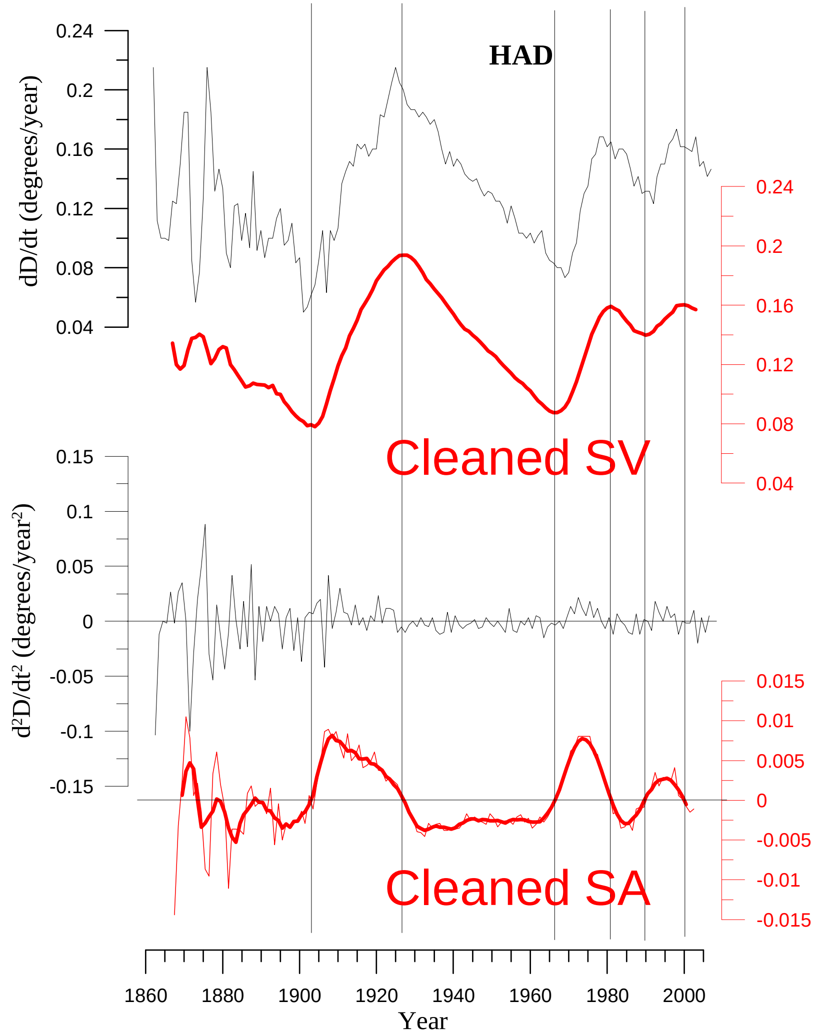
Crisan Demetrescu's presentation: "Toward changing a paradigm? New insights on geomagnetic jerks from long time-series of geomagnetic data and models**"**

What are the (quasi)-periodicities in the SV signal at magnetic observatories?

Normal modes	Jackson and Mound [2010]	Zatman and Bloxham [1997]	Dickey and de Viron [2009]	Buffett et al. [2009]
1	81 years	76.2 years	85 years	86.3 years
2	62	52.7	50	42.9
3	30.5		35	30.6
4			27.5	23.6

+ sunspot-cycle variations in annual means





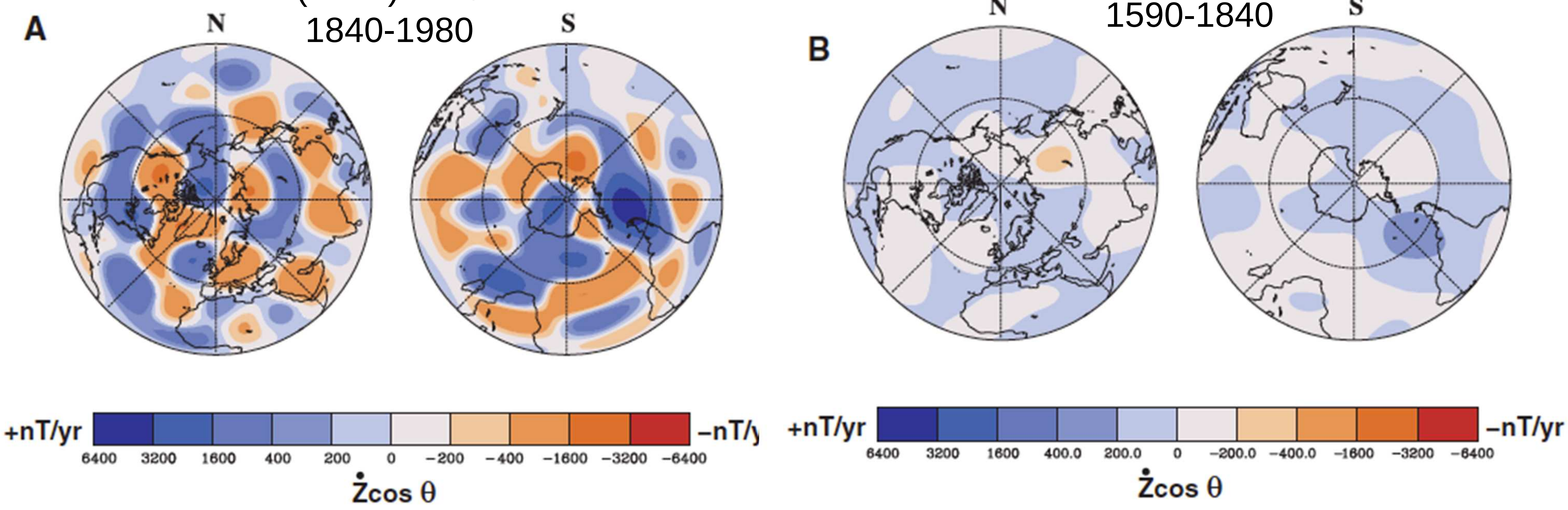
+ 23 other observatories with series > 100 yrs

Dipole decay

The dipole decay over 1840-1980 is almost entirely due to the growth of the South Atlantic reversed flux patches. No patch before 1840 => no dipole decay? (Gubbins et al., 2006)

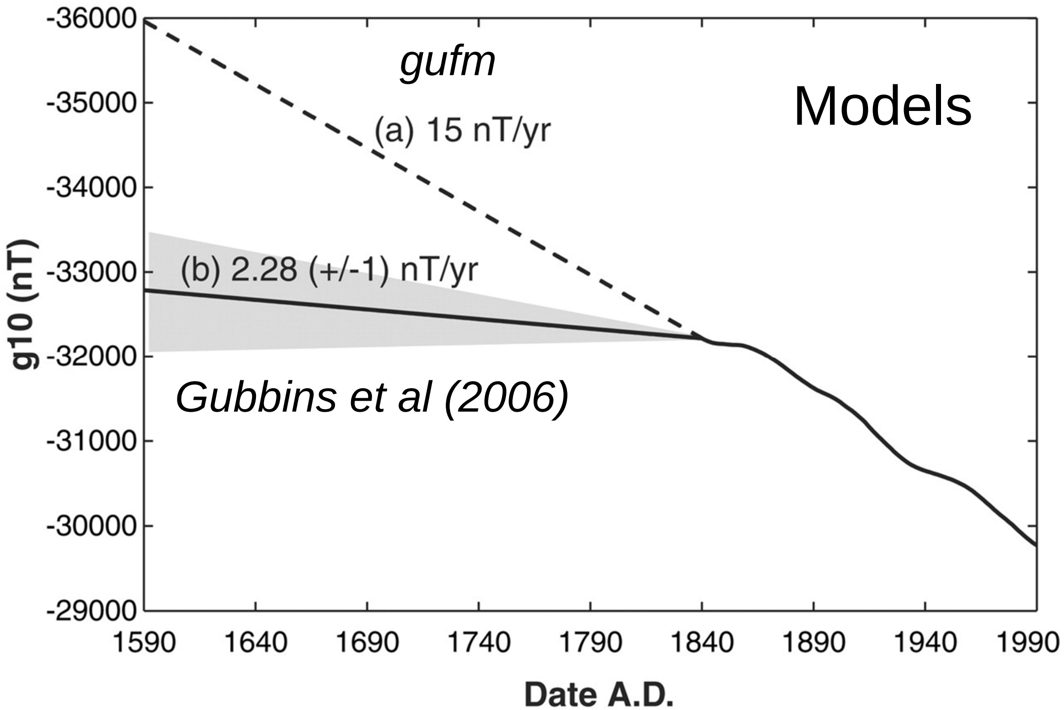
(dZ/dt) cosθ 1840-1980

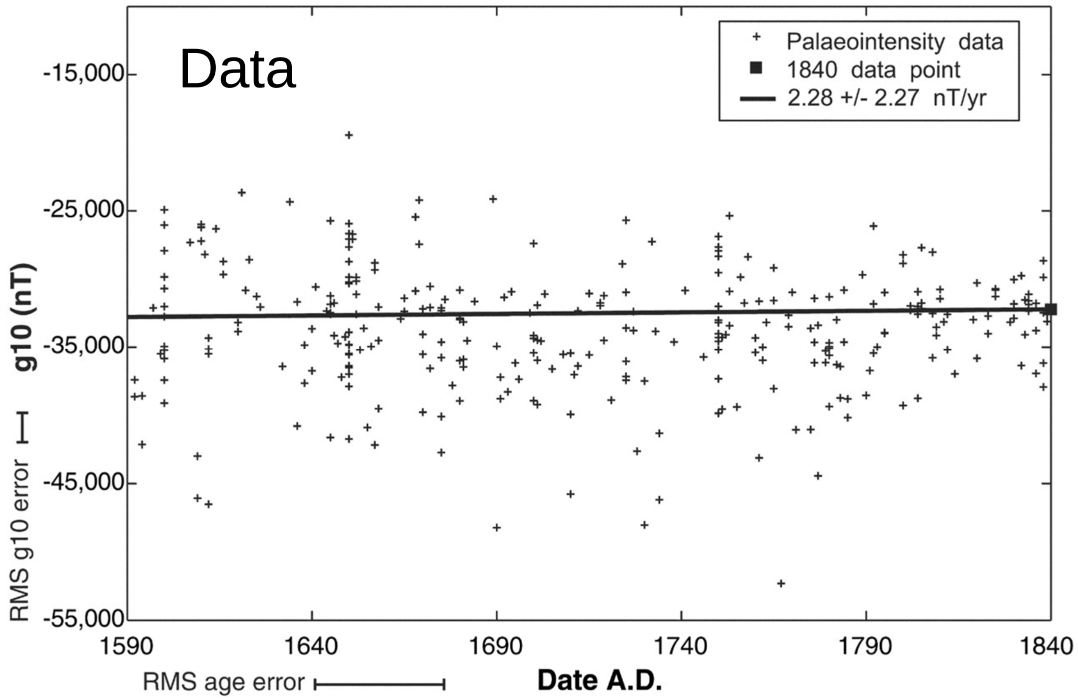
(dZ/dt) cosθ 1590-1840



Richard Holme's presentation: "The strength of the geomagnetic field, 1590-1840"

The dipole decay before 1833 (first scalar measurement by Gauss) is poorly known.



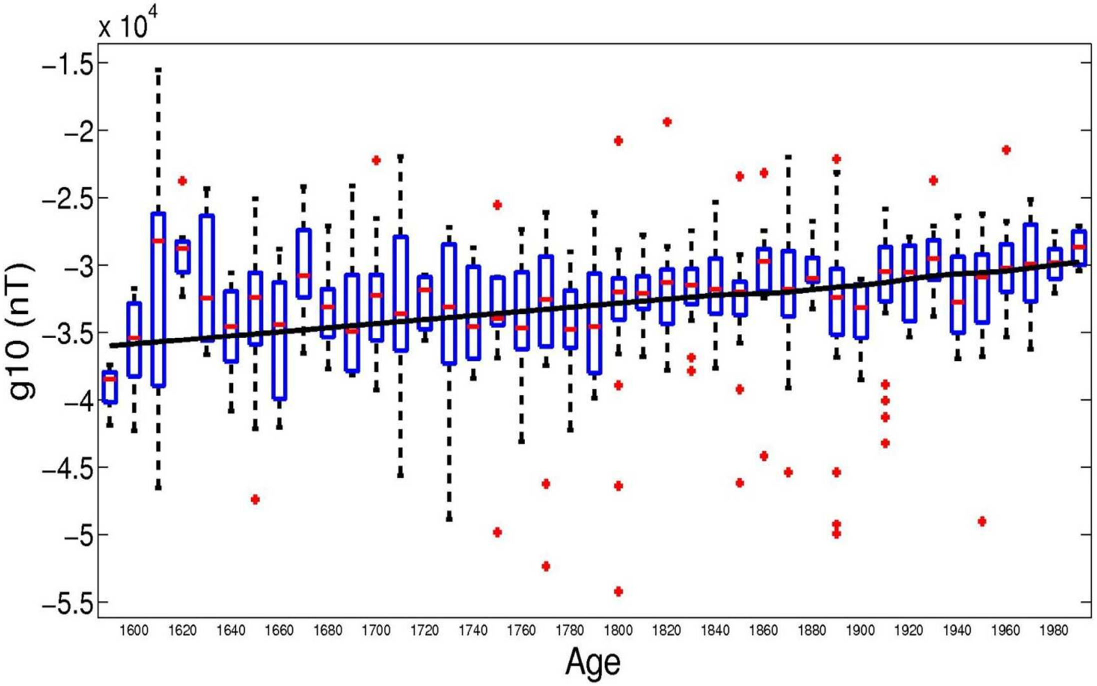


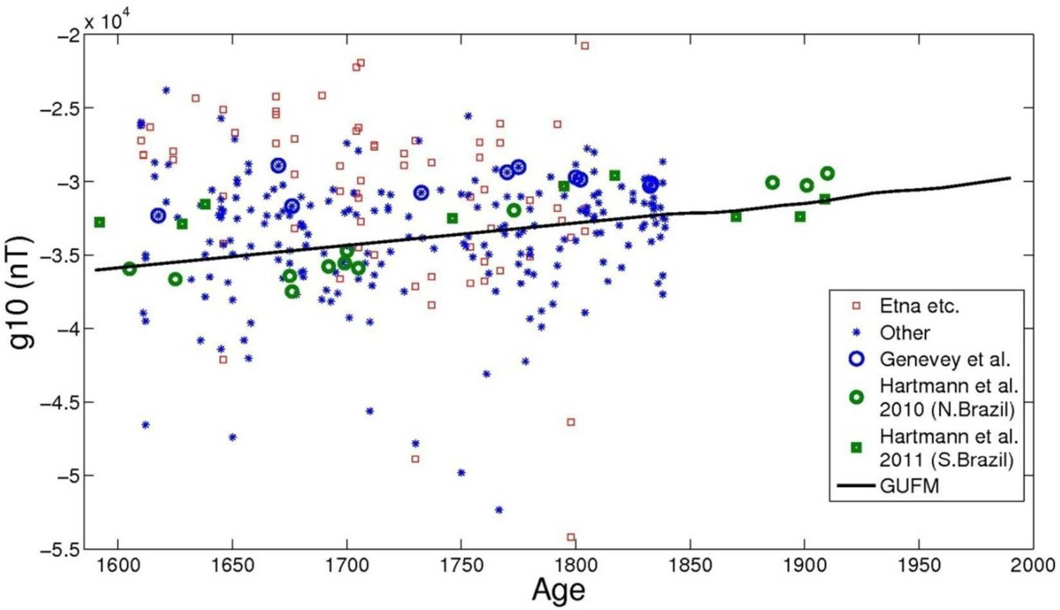
Robust statistics

⇒ The fit to gufm is as good before and after 1840…

⇒ Improvement when using only “good” data

⇒ Disagreement with some of the “best” data => should not limit to the best data





Direct measurements

- Between 1820 and 1840, several workers measured *relative* intensity directly – aimed to establish variation with location
- Hansteen (based in Christiania, Oslo) made particularly careful measurements, and reports that his instrument did not demagnetise (supported by Sabine)
- In Annalen der Physik, **82**, 309-330, 1826, he reports a drop in intensity at Christiania of 0.005% from 1820 to 1825. gufm1 predicts a fall of 0.003%.
- Less well-constrained decay rates for London and Paris similarly also slightly greater than gufm1.
- Consistent with continued field decay, at least back 20 years!

Interpretation in terms of core processes

Other modeling and jerk studies: Ballani et al. (2010), Wardinski & Holme (2011), Holme et al. (2011)

Core flows: Beggan & Whaler (2010), Schaeffer & Pais (2011), Finlay & Amit (2011), Fournier et al. (2011)

SV time scales: Lhuillier et al. (2011)

Magnetic diffusion: Chulliat & Olsen (2010), Chulliat et al. (2010), Asari et al. (2010)

Torsional oscillations: Gillet et al. (2010)

Conclusion

- The decade of geopotential research was highly successful with respect to MF and SV modeling; a radically new dynamical picture of the core surface has emerged from recent models (and still remains to be understood).
- Research on the fast SV and its interpretations (short timescale TO, acceleration pulses, rapid core flows) should greatly benefit from the Swarm data and models.
- The global archeomagnetic dataset is still growing, and more robust modeling methods are being developed. A better understanding of the present field could lead to the use of physical constraints in archeomagnetic models.
- Despite much progress in modeling, predicting the future SV is still largely impossible beyond a few years; a grand challenge for the next decade?