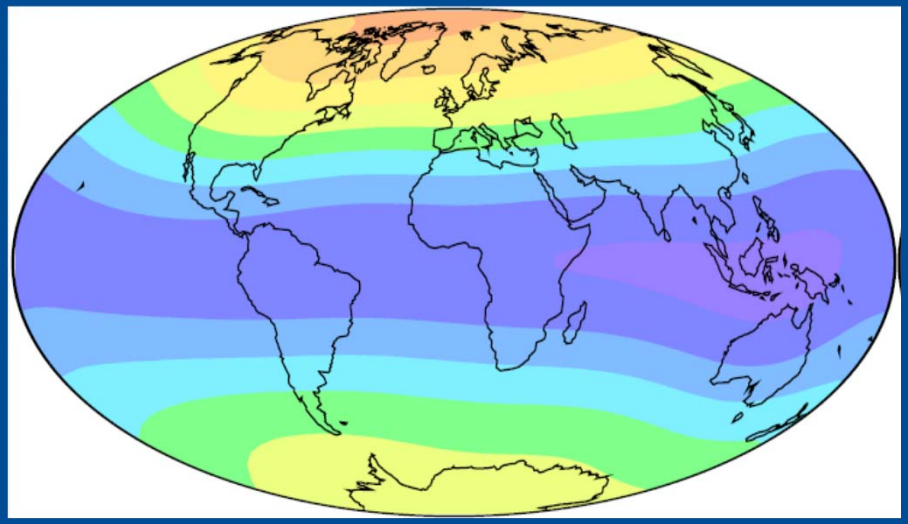
Reconstructing the global geomagnetic field from archeo- and paleomagnetic data

Monika Korte
GFZ German Research Centre for Geosciences



With thanks to
Cathy Constable,
Fabio Donadini,
Richard Holme,
Agnes Genevey,
Ute Frank

& everyone producing Holocene archeo- and paleomagnetic results

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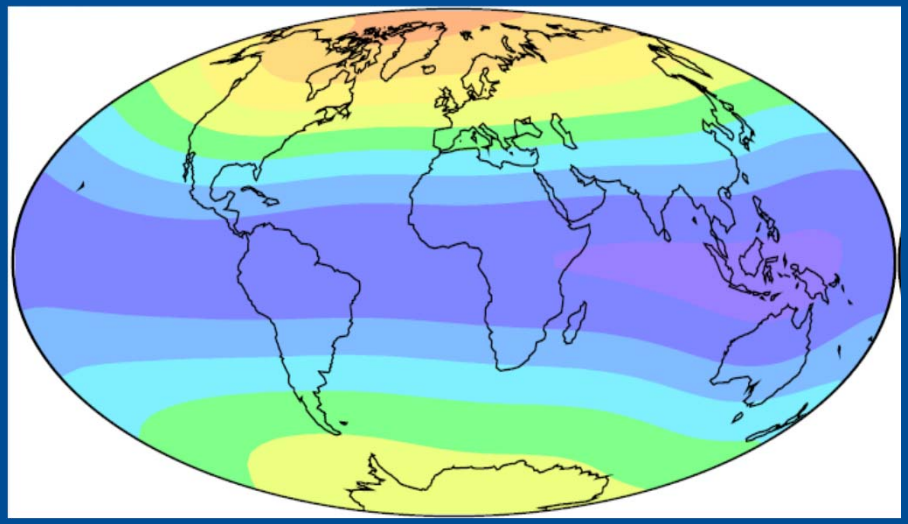

Outline

- Introduction: global magnetic field models
- Applications of millennial scale models
- Holocene data sources and databases
- Data uncertainties and metadata
- Summary: the importance of databases

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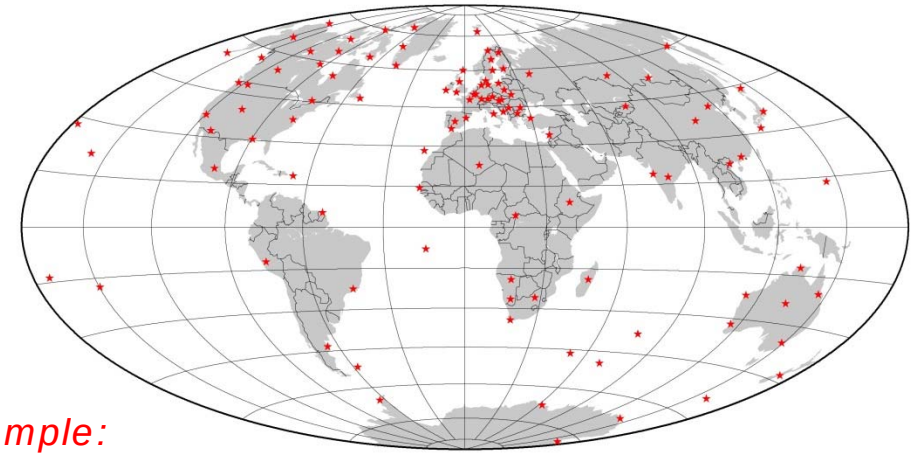
Spherical harmonic magnetic field models

- **Data** from individual locations, e.g. magnetic observatories, satellite measurements, historical observations, paleomagnetic results



Example:
distribution of INTERMAGNET observatories

- Inversion based on a spherical harmonic expansion:

$$\mathbf{B} = -\text{grad}\,\Phi$$

$$\Phi(r,\theta,\lambda) = R_E \sum_{l=1}^{l_{\max}} \sum_{m=0}^{l} \left(\frac{R_E}{r}\right)^{l+1} \left(g_l^m \cos(m\lambda) + h_l^m \sin(m\lambda)\right) P_l^m(\cos\theta)$$

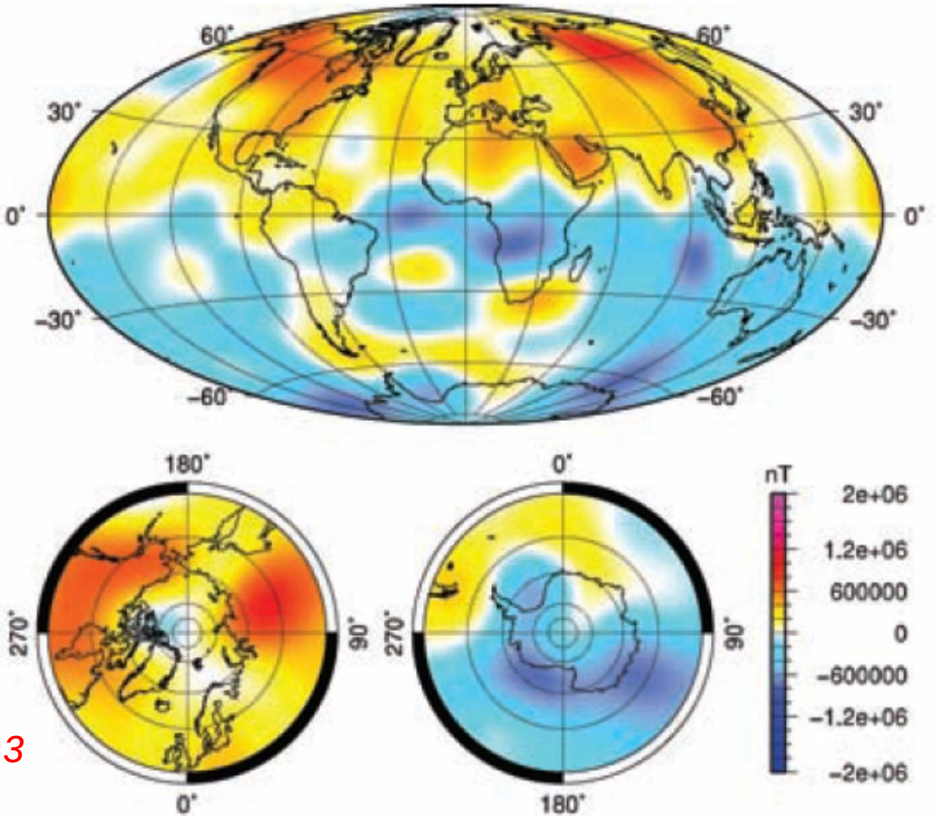
Potential — Earth's radius — Gauss-coefficients — Spherical harmonics, degree l, order m

Spherical harmonic magnetic field models

- **Model:** set of Gauss coefficients g,h which provide a description of the field intensity and directions everywhere on Earth

- Continuous models by time-dependent coefficients, e.g. based on Taylor series or splines

- Simple upward- and downward continuation within source-free region,
  e.g. to core-mantle boundary
  (assuming insulating mantle)



Example:
vertical field component at the CMB 2003
(model GRIMM2x, Lesur et al., 2010)

The CALSxk Holocene field models

- Series of continuous millennial scale models developed since 2002 (ALS3K 100 yr snapshot models [Constable et al., 2000])
- **C**ontinuous models based on **A**rcheomagnetic and **L**ake **S**ediment data spanning the past **x k**yrs
- Parameterization
  - SH models up to degree and order 10
  - Cubic B spline basis in time
- **Regularization**, i.e. smoothing by constraining a property of the field, e.g. minimizing $<\mathbf{B}^2>$, to find the "simplest" model explaining the data within the desired accuracy
- Regularization parameters chosen by power spectra considerations

The CALSxk models

- ***CALS3k.1*** (2003): only directional data, smoothed curves instead of individual data, axial dipole constrained
  500 directional data
  outdated!

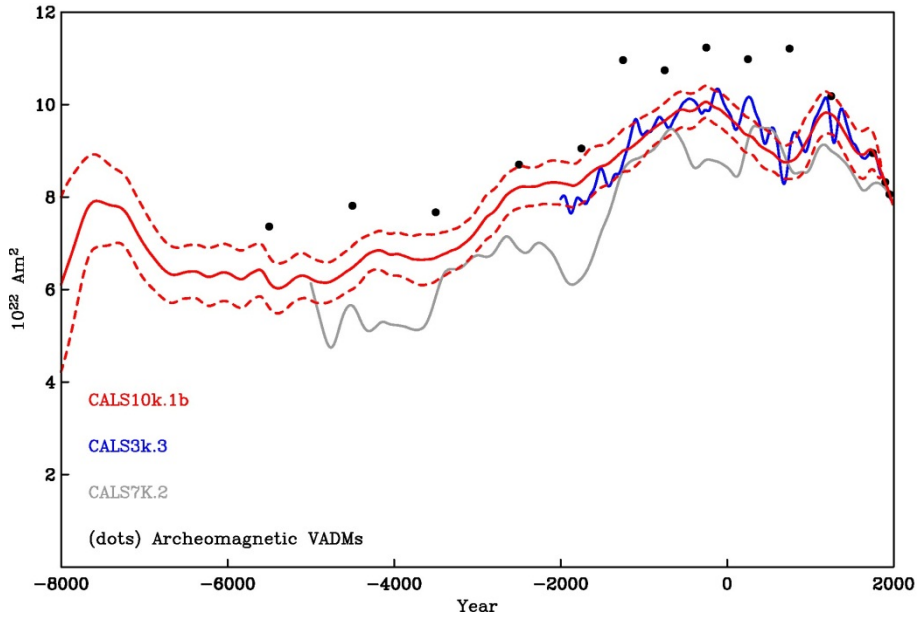
- ***CALS7k.2*** (2005): directional and absolute intensity data
  19,376 data in 0-3ka, 32,353 total
  longest published model to date, some known shortcomings

- ***CALS3k.3*** (2009): calibrated relative intensity data included, investigation of influence of different data types on model (ARCH3.1 and SED3k.1)
  29,589 data
- ***CALS3k.4*** (2011): update of CALS3k.3 with slightly more data and improved agreement with historical model gufm1 [Jackson et al. 2000]
  34,361 data
  currently best model for past 3 kyrs

- ***CALS10k.1b*** (2011?): dominated by sediment data, robust low resolution estimate by uncertainty bootstrap average
  86,996 data
  first 10 kyr model, strongly smoothed, best model for > 3 kyrs

All published models available at www.earthref.org

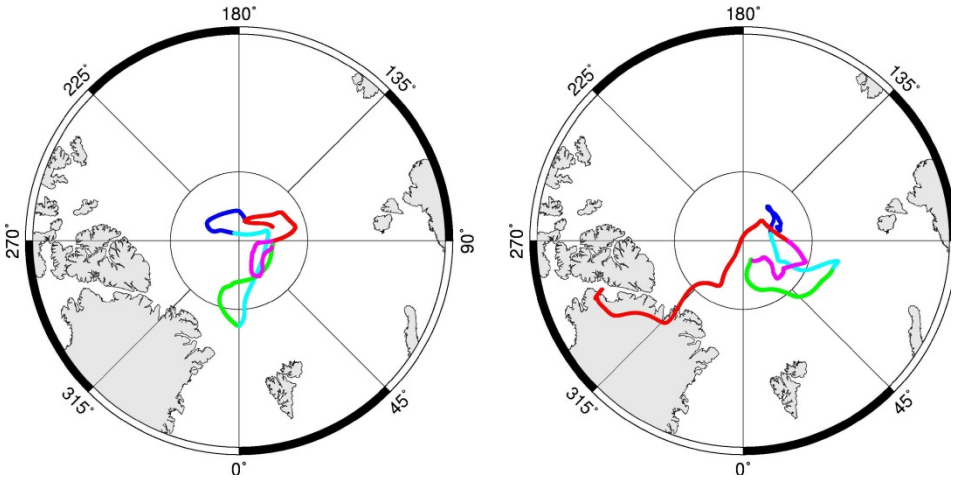
Dipole moment and tilt evolution



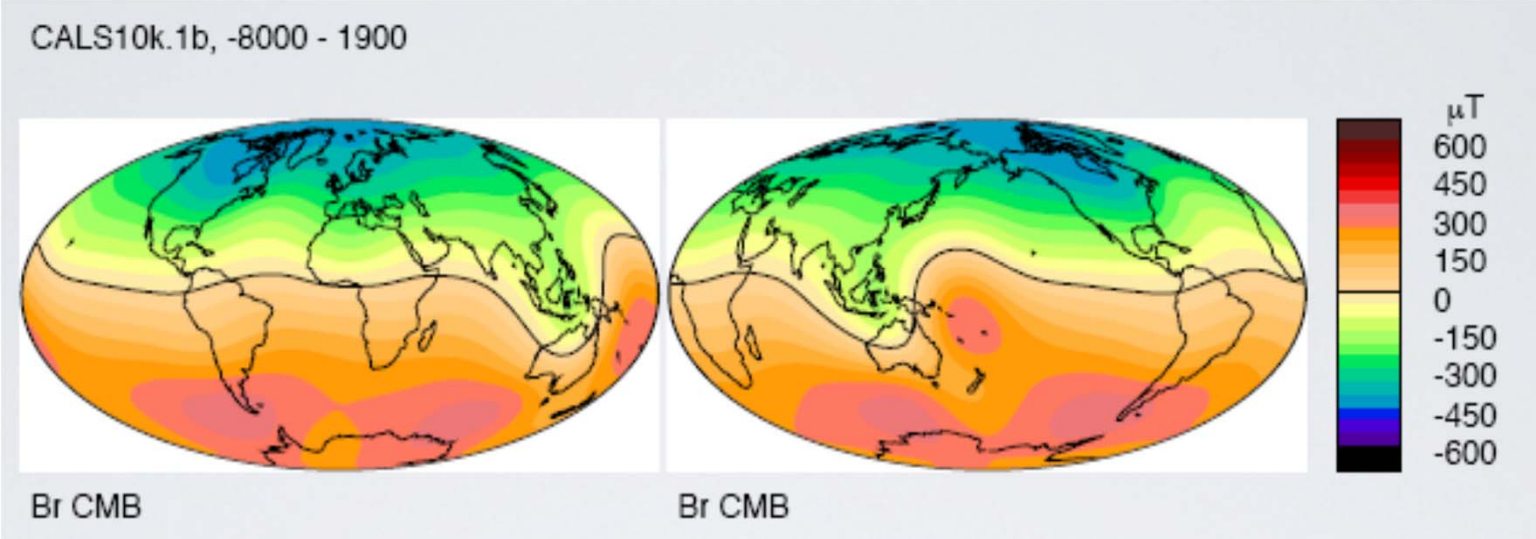
8000 BC – 7001 BC
7000 BC – 6001 BC
6000 BC – 5001 BC
5000 BC – 4001 BC
4000 BC – 3001 BC

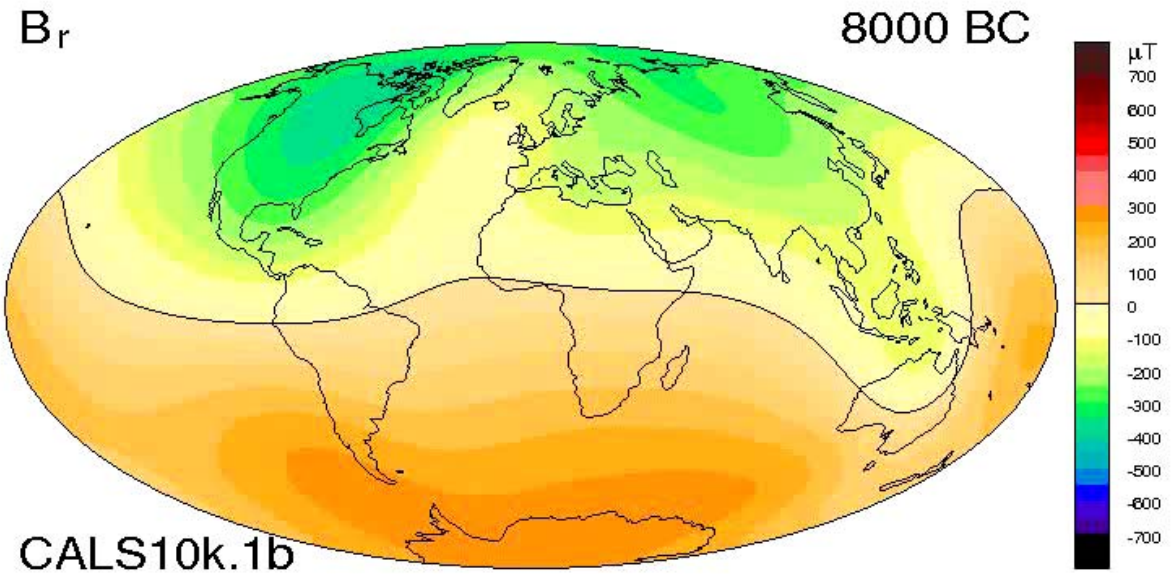
3000 BC – 2001 BC
2000 BC – 1001 BC
1000 BC – 1 BC
0 – 999 AD
1000 AD – 1990 AD

=> Shielding against galactic cosmic rays;
studies involving cosmognic nuclide production rates



Radial field at the CMB





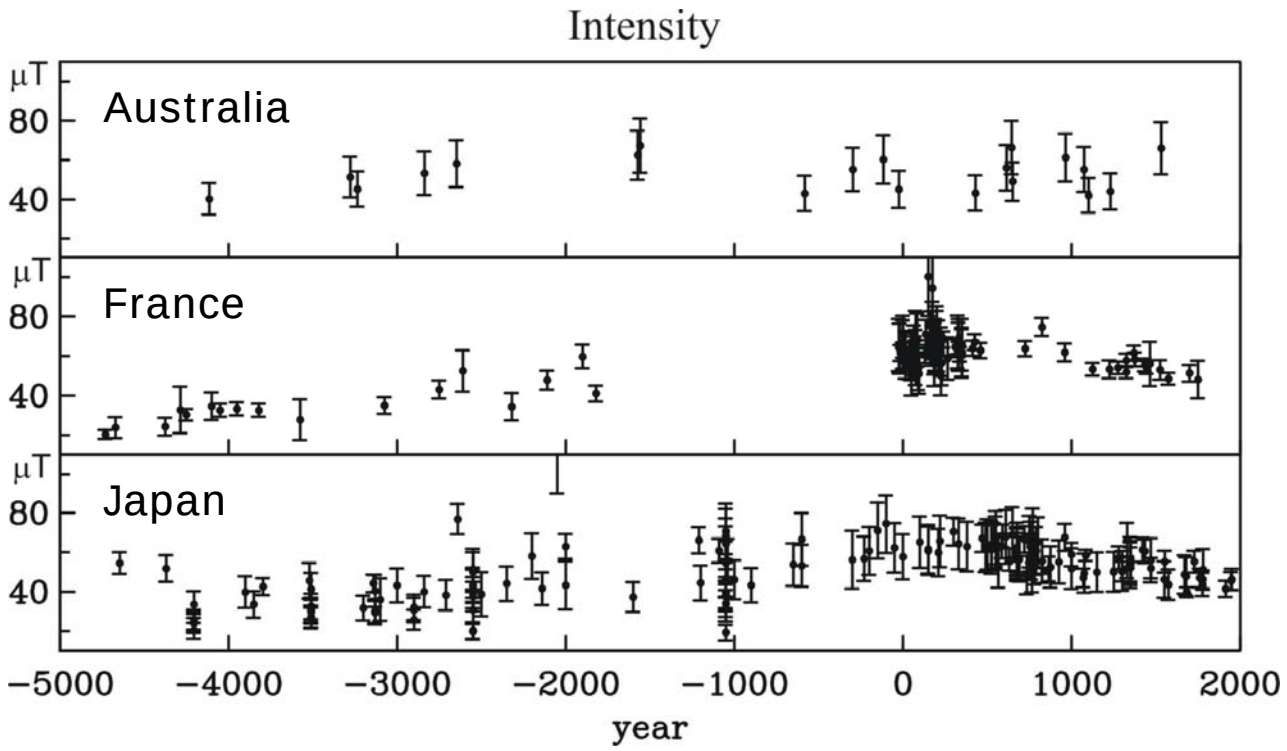
=> Studies of geodynamo process

Archeo- and paleomagentic data

- **Thermoremanent magnetisation:**
  - Permanent magnetisation obtained by cooling below Curie temperature
  - e.g. lavas, burnt archeomagnetic artefacts
  - in situ material can provide directional field information
  - paleointensity can be determined experimentally

- **Depositional remanence:**
  - Magnetisation obtained by magnetic grains embedded during sedimentation
  - measured on drill cores from lakes and oceans
  - directional field information
  - information about relative intensity variations might be determined

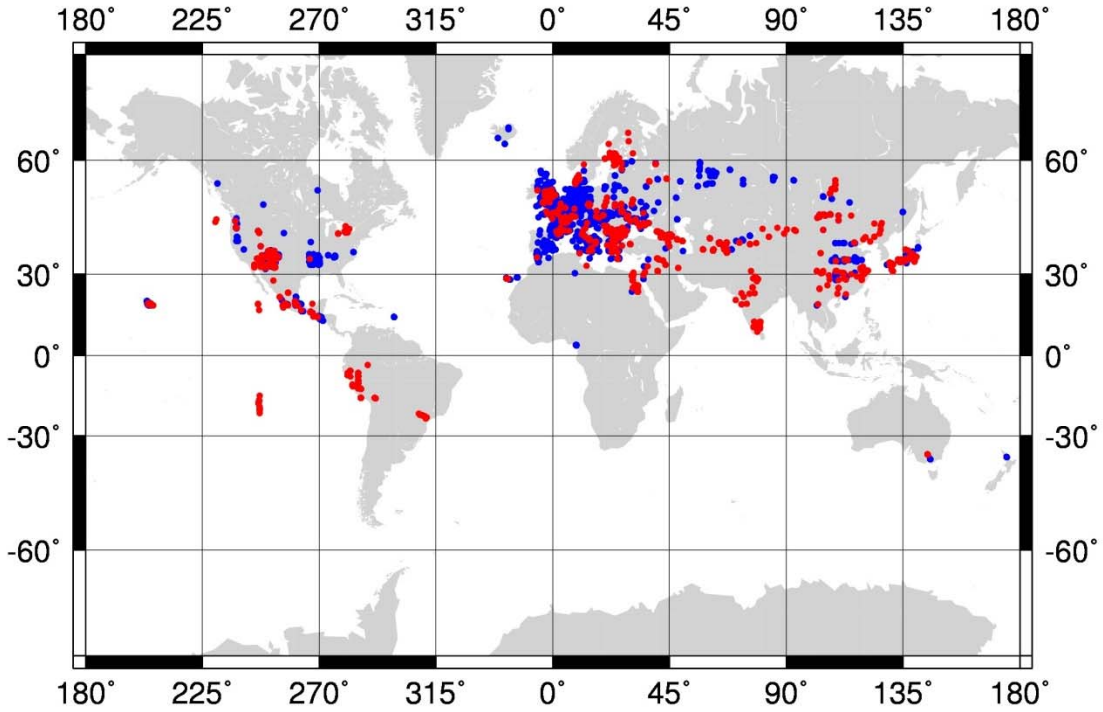
Archeomagnetic data (and lavas)



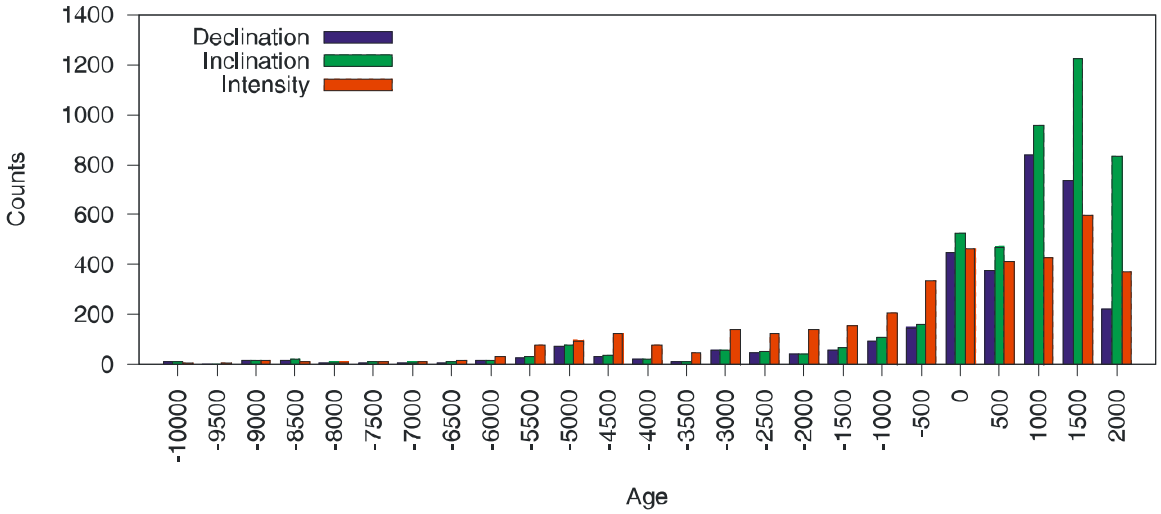
+ Directions and intensity
+ fast acquisistion of magnetisation (good temporal resolution)

- Scattered, no time series
- fewer data for earlier times
- insufficient global distribution

Holocene archeomagnetic and lava data available 2009



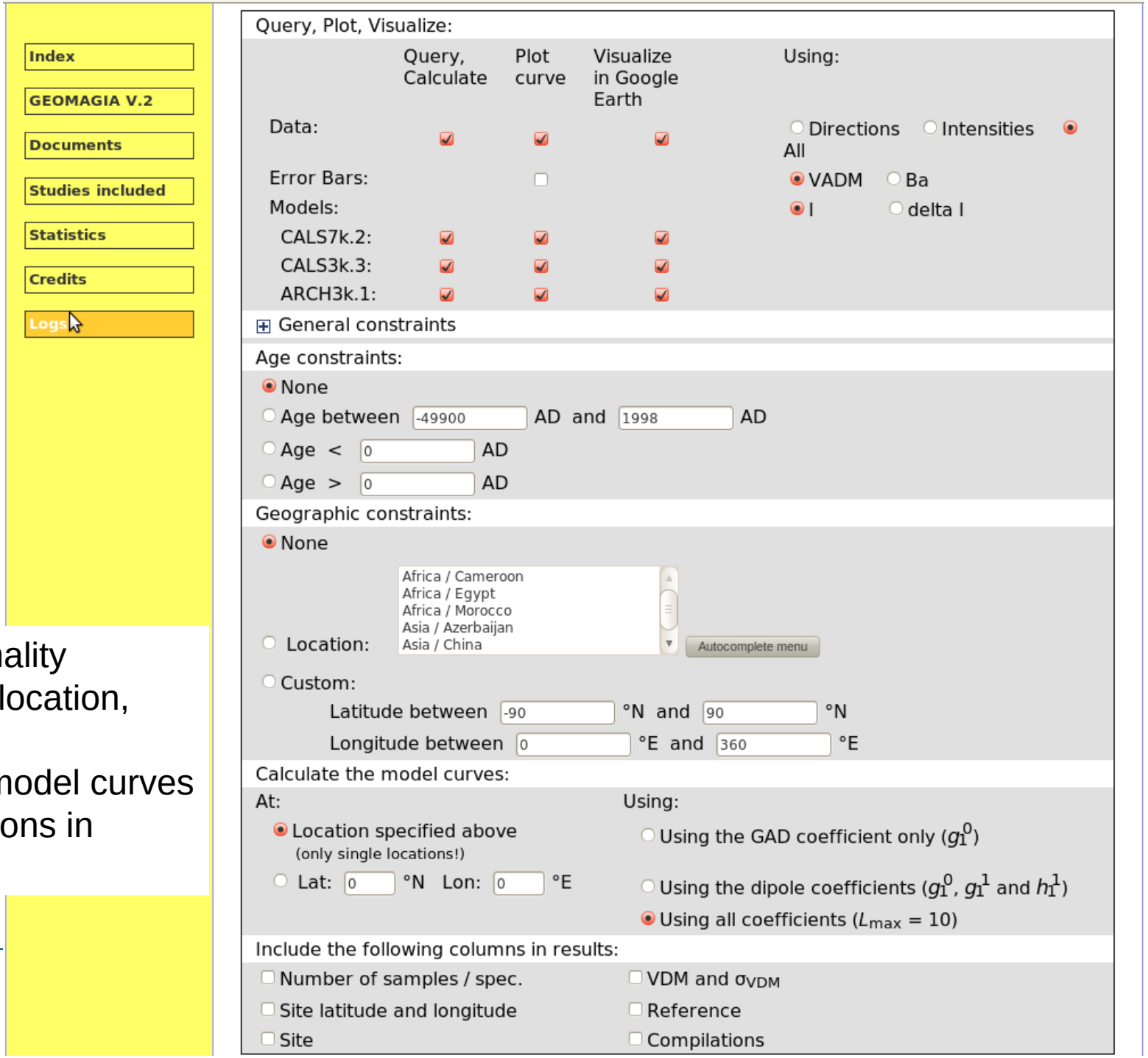
Blue: directions
Red: intensities



Archeomagnetic (Holocene) databases

- ARCHEO00 (D. Tarling, 1999; directional archeomagnetic data)
- SECVR00 (McElhinny & Lock, 1996; sediments + directional comp. by Daly & LeGoff, 1996)
- PINT00 (Perrin, Schnepp & Shcherbakov, 1998; Precambrian to present intensities)
- ArcheoInt (Genevey et al., 2008; Holocene archeointensities)
- GEOMAGIA50 (Donadini et al., 2008; archeointensities & lavas past 50 kyrs)
- GEOMAGIA50 V.2 (Donadini et al., 2009; Holocene archeomagnetic & lava directional data included) => included in MagIC paleomagnetic database

GEOMAGIA



General functionality
- Query by age, location, region etc.
- Plot data and model curves
- Visualize locations in Google Earth

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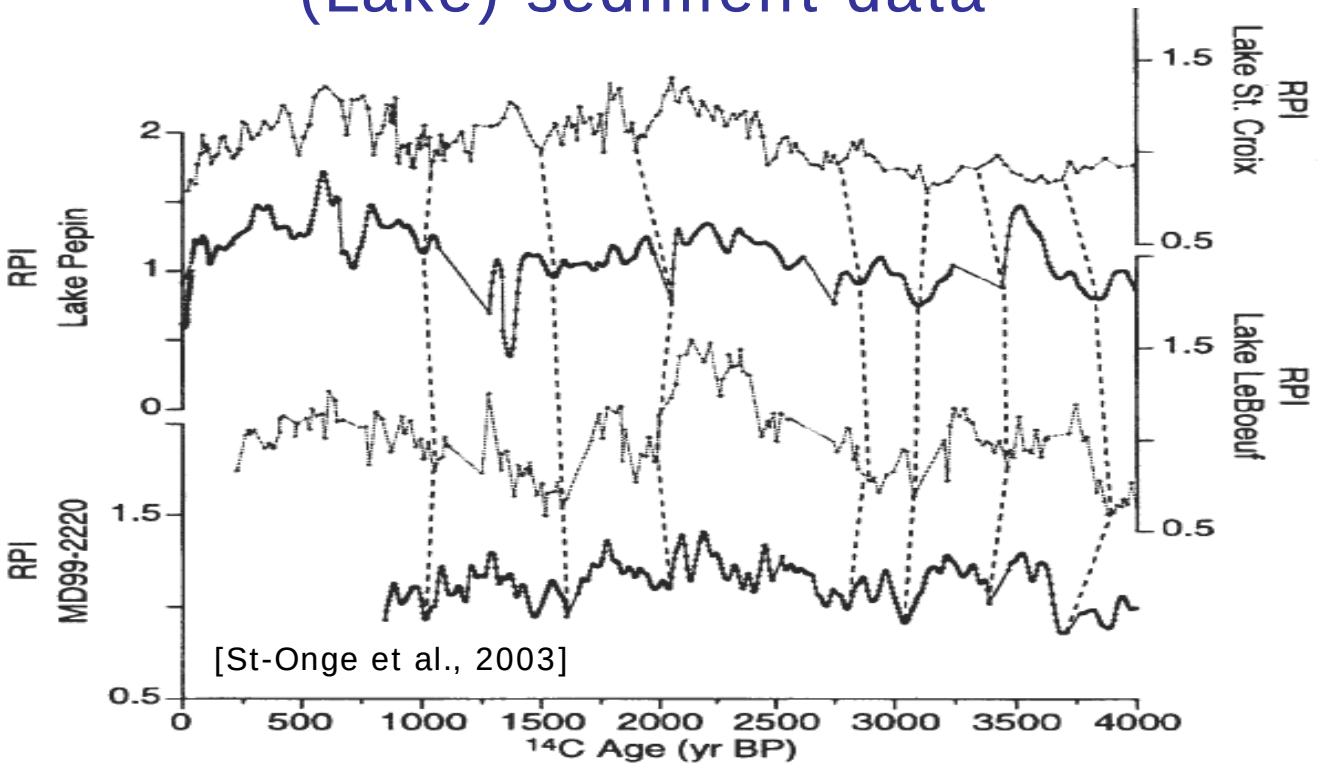
(Lake) sediment data

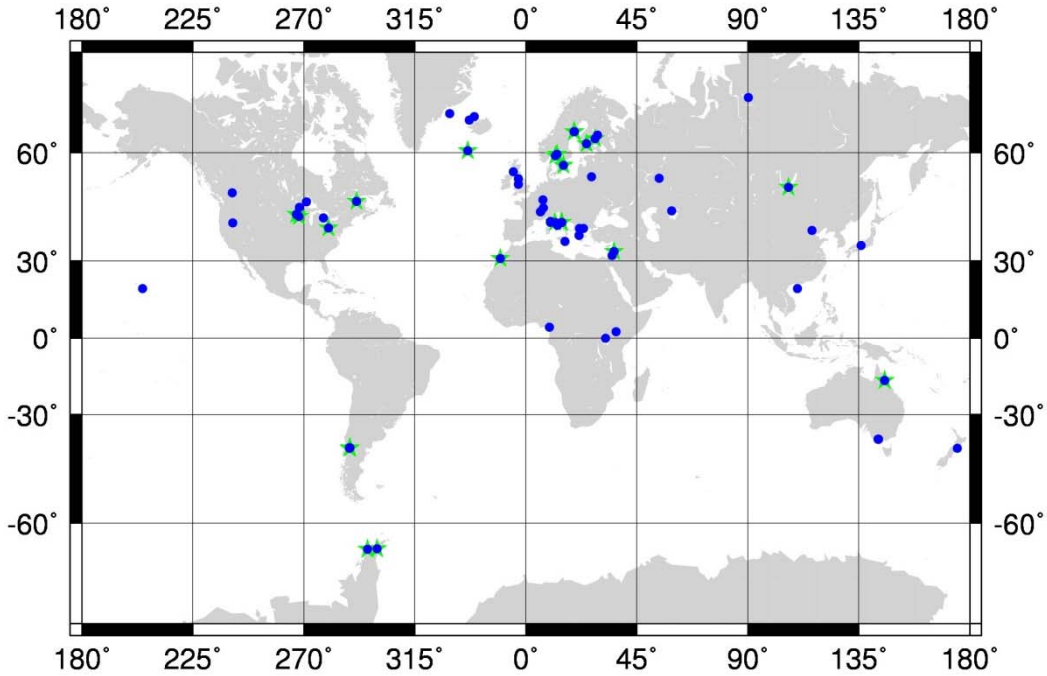


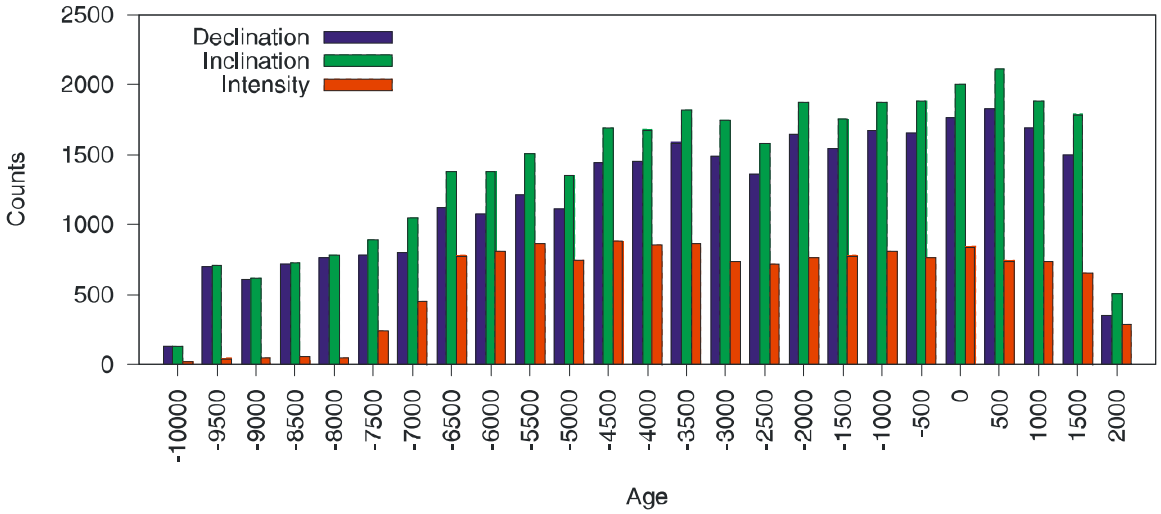
+ ~uniform distribution in time
+ mostly long time series
+ better global distribution

- no absolute intensities
- slow acquisisition of magnetisation (temporal smoothing)

Holocene sediment data compiled for CALS10k.1b

Blue dots: directions
Green stars: relative intensities





Sediment data base ?

- SECVR00 (McElhinny & Lock, 1996; sediments + directional comp. by Daly & LeGoff, 1996)
- No updated global database so far
- Work in progress: see poster by Maxwell Brown

Data – Uncertainties

- **Measurement uncertainties**

  * Exact orientation (directional data)

  * Alterations of initial magnetization

  * High in particular in field intensity determinations

- **Dating uncertainties limit the temporal resolution**

  * Archeological dating, varve counting:
    can be 1 to a few years

  * Archeological dating, radiocarbon dating:
    generally decades to 1-2 centuries

  * Sediments:
    mostly only samples from a few tie-points dated;
    assumptions about sedimentation rates;
    magnetization might be younger than sediment age (lock-in depth);

The importance of meta-data

Data from a wide variety of

- Materials
- Experimental techniques
- Dating methods

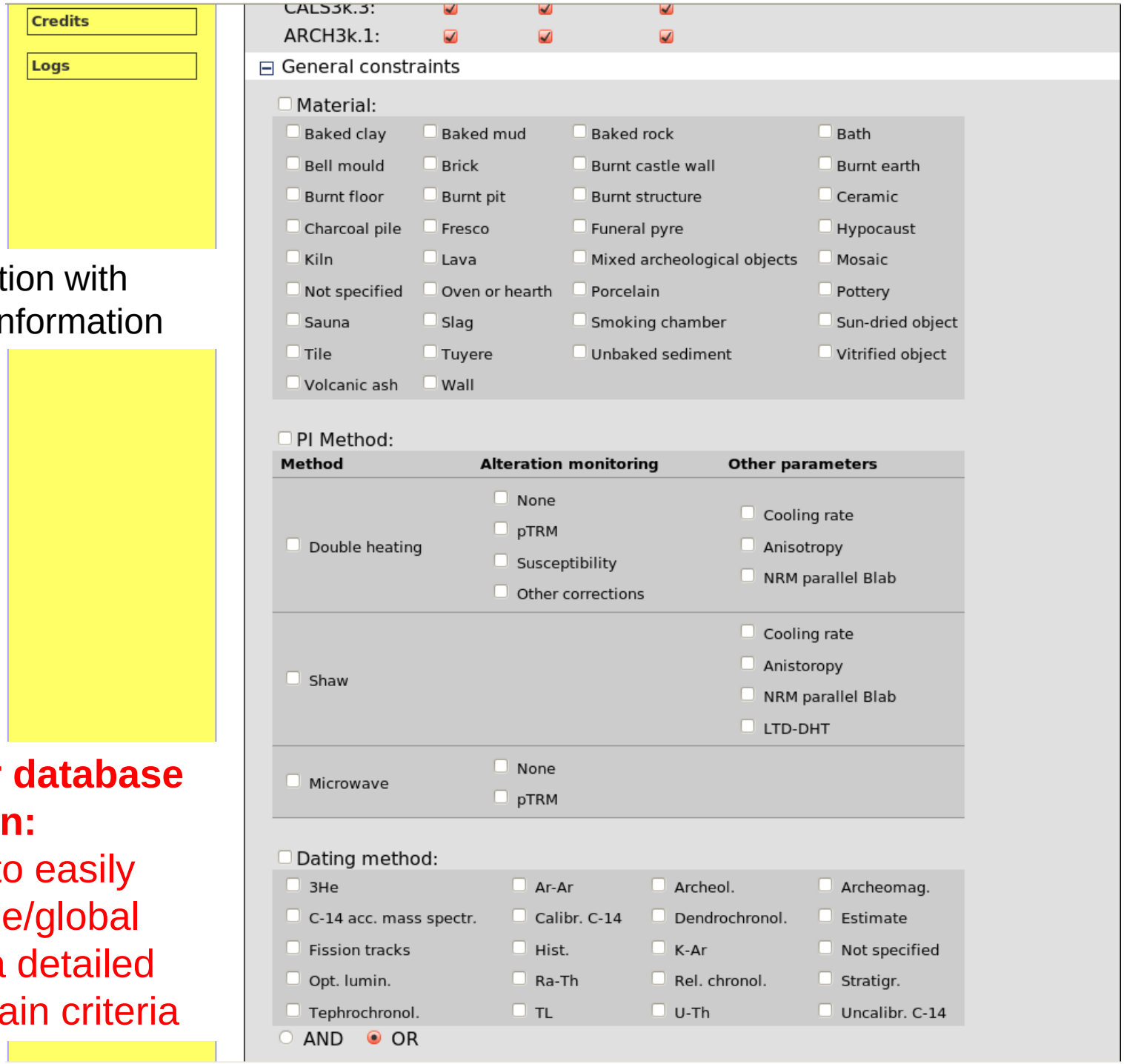
Information on these characteristics can provide important information on reliability and accuracy of the data,e.g. for adequate weighting in global modeling

G E O M A G I A

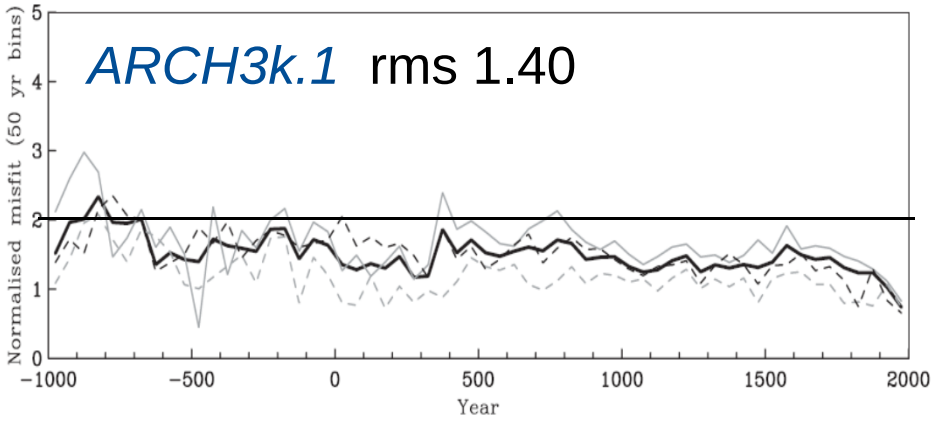
Data selection with metadata information

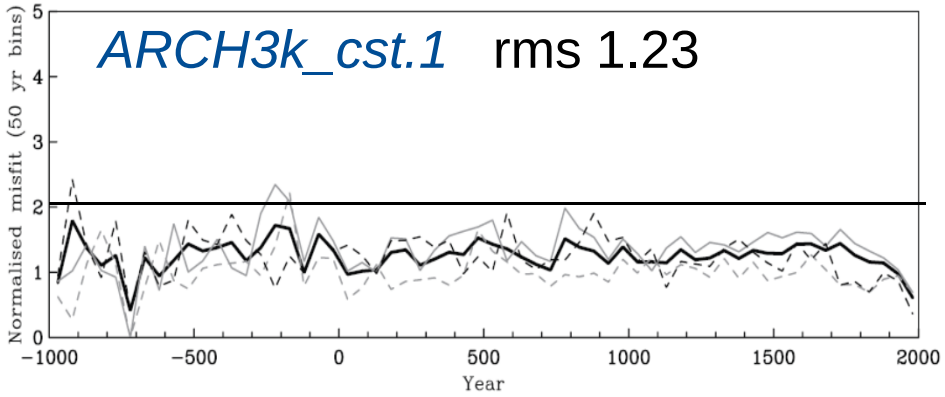
Challenge for database design:

Both allow to easily retrieve large/global datasets or a detailed choice by certain criteria



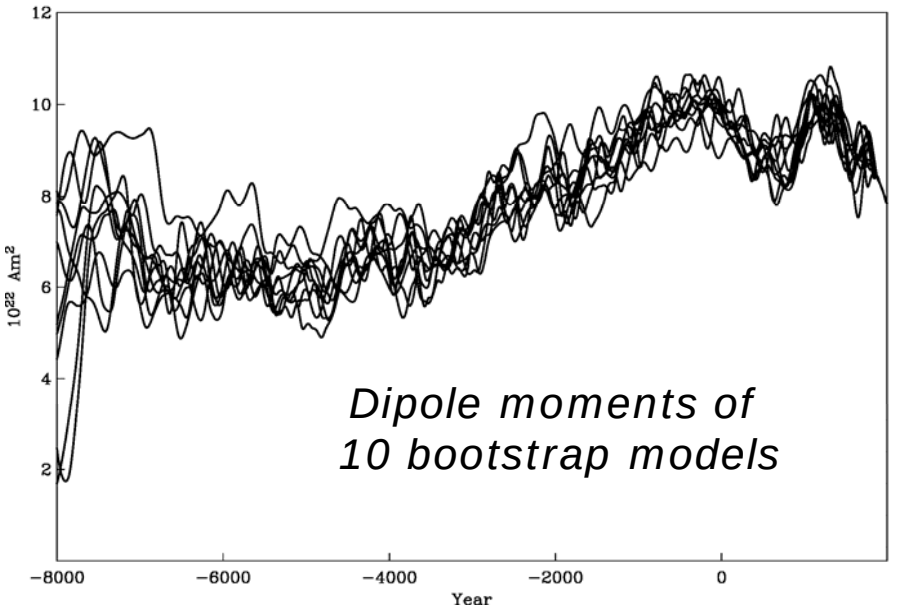
Metadata for global field modeling





Model from archeomagnetic data without and with data selection for quality criteria

Bootstrap resampling of all data for the *CALS10k.1b* model.
Future plan: consider metadata information for weighting and bootstrap type resampling



Summary

- Long-term global magnetic field reconstructions are a useful tool to describe and study the evolution of the geomagnetic field
- Databases of global data compilations facilitate the development of global models and other global/large-scale studies.
- Meta-data, e.g. on experimental methods or dating techniques, are crucial to assess the quality of individual data and thus e.g. to improve the accuracy and resolution of global models.
- The increasing amount of paleomagnetic data and new efforts to better assess the relative quality of the compiled sediment records will further improve global long-term field reconstructions in the future, particularly if the data can be made easily available in a global database.