Earth-like criteria from archeomagnetic field models

Terra-Nova & Wardinski

SETS OF OBSERVATIONS

+ observations of the geomagnetic field
  - direct observations made by ground-based or satellite-based geomagnetic measurements

    $\rightarrow$ geomagnetic field models (spherical harmonics degree 1-20)

  - indirect observations from sampling the magnetic recordings of rocks, sediments and kilns

    $\rightarrow$ archeo and paleo-geomagnetic field models (spherical harmonics degree 1-10)

+ numerical experiments based on ab-inito calculations of magnetic field generation and heat transfer between Earth's core and mantle

  $\rightarrow$ see talks of F. Deschamps

  $\rightarrow$ see talks of F. Terra-Nova

SETS OF OBSERVATIONS

+ paleo-geomagnetic field models are based on data that un-evenly sample Earth's magnetic field in time and space
+ severely, temporal uncertainties range from a few decades to 10^6 years, depending on the age of the sample
+ spatial data distribution allows, at maximum, to resolve spherical harmonic degree $\sim$6 (Brown et al., 2018)

SET OF MAGNETIC FIELD MODELS

The list of archeomagnetic field models evaluated:

+ CALS3k.4a Korte & Constable, 2011 - past 3 kyr.
+ CALS10k.2 Constable et al., 2016 - past 10 kyr.
+ HFM.OL.A1 Constable et al., 2016- past 9 kyr.
+ pfm9k.1 Nilsson et al., 2014 - past 9 kyr.
+ pfm9k.2 Nilsson & Suttie, 2021 - past 9 kyr.
+ SHA.DIFF.14k Pavon-Carrasco et al., 2014 - past 2014 kyr
+ LSMOD.2 Brown et al., 2018 - 30–50 kyr.
+ GGFSS70k Panovska et al., 2021 - 15-75kyr.
+ GGF100k Panovska et al., 2018 - past 100 kyr.
+ SHAWQ2K Campuzano et al., 2019 - past 3 kyr.
+ COV-ARCH and COV-LAKE Hellio & Gillet, 2018 - past 3 kyr.
+ A_FM, ASD_FM and ASDI_FM Licht2013 et al., 2013 - past 3 kyr.
+ BIGMUDI4k Arneitz et al., 2019 - past 4 kyr.
+ ArchKalmag14k.r Schanner et al., 2022

SET OF MAGNETIC FIELD MODELS

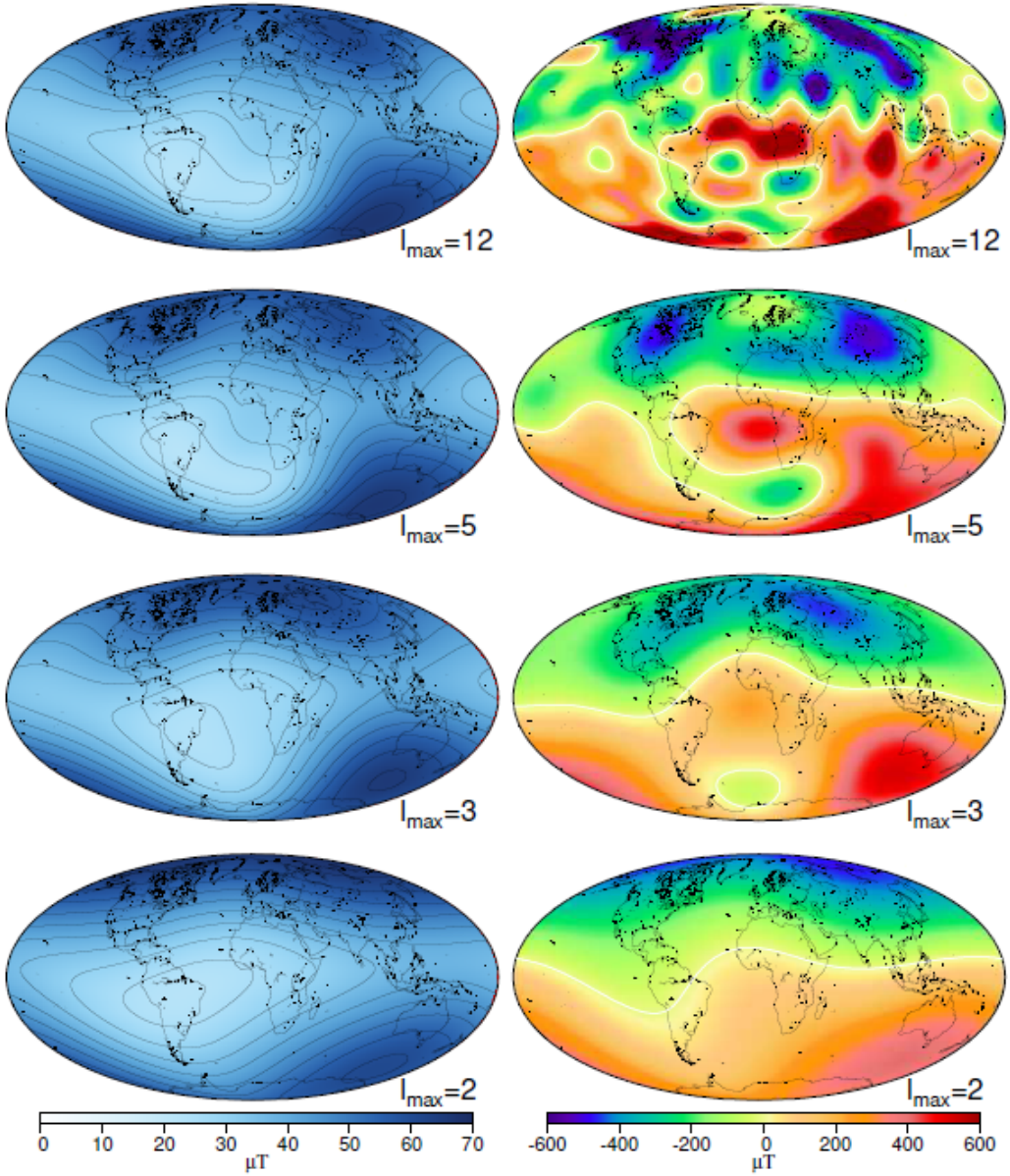
Models based on stochastic inversion

CALS3k.4a	past 3 kyrs	10	cubic B-splines	A & L
CALS10k.2	past 10 kyrs	10	cubic B-splines	A & L & S
HFM.OL.A1	past 10 kyrs	10	cubic B-splines	A & L & S
pfm9k.1	past 9 kyrs	10	cubic B-splines	A & L & S
SHA.DIFF.14k	past 10 kyrs	10	cubic B-splines	A & L
SHAWQ2k	past 2.3 kyrs	10	cubic B-splines	A & L & S
GGF100k	past 100 kyrs	10	cubic B-splines	A & L & S
GGFSS70k	15-75kyrs BC	6	cubic B-splines	A & L & S

Models based on ensemble and Bayesian approaches

pfm9k.2	past 9 kyrs	5	A & L & S
COV-ARCH & COV-LAKE A_FM, ASD_FM, ASDI_FM	past 3 kyrs	5	A & L & S
BIGMUDI4k	past 4 kyrs	8	H & A & L
ArchKalmag14k.r	past 14 kyrs	8	H & A & L

SET OF MAGNETIC FIELD MODELS



radial magnetic field at the CMB (Brown et al. 2018)

MEASURES OF FIELD COMPLEXITY

+ Mauersberger-Lowes spectra are one way to characterize magnetic field complexity
+ another way: compute spatial quantities like

$$\text{Norm 1}: \oint B^2 dS|_{r=c} = (l+1)\left(\frac{a}{c}\right)^{(2l+4)}$$

$$\text{Norm 2}: \oint B_r^2 dS|_{r=c} = \frac{(l+1)^2}{2l+1}\left(\frac{a}{c}\right)^{(2l+4)}$$

$$\text{Norm 3}: \oint (\nabla_h B_r)^2 dS|_{r=c} = \frac{l(l+1)^3}{2l+1}\left(\frac{a}{c}\right)^{(2l+6)}$$

these norms are used to construct most of the field models

EARTH'S LIKENESS OF DYNAMO SIMULATIONS

+ Christensen et al. 2010
  - → relative axial dipole power

$$AD/NAD = P_{10}/\left(P_{11} + \sum_{n=2}^{8}(a/c)^{2n-2}\sum_{m=0}^{n}P_{nm}\right)$$

with

$$P_{nm} = (n+1)(g_{nm}^2 + h_{nm}^2)$$

  - → equatorial symmetry

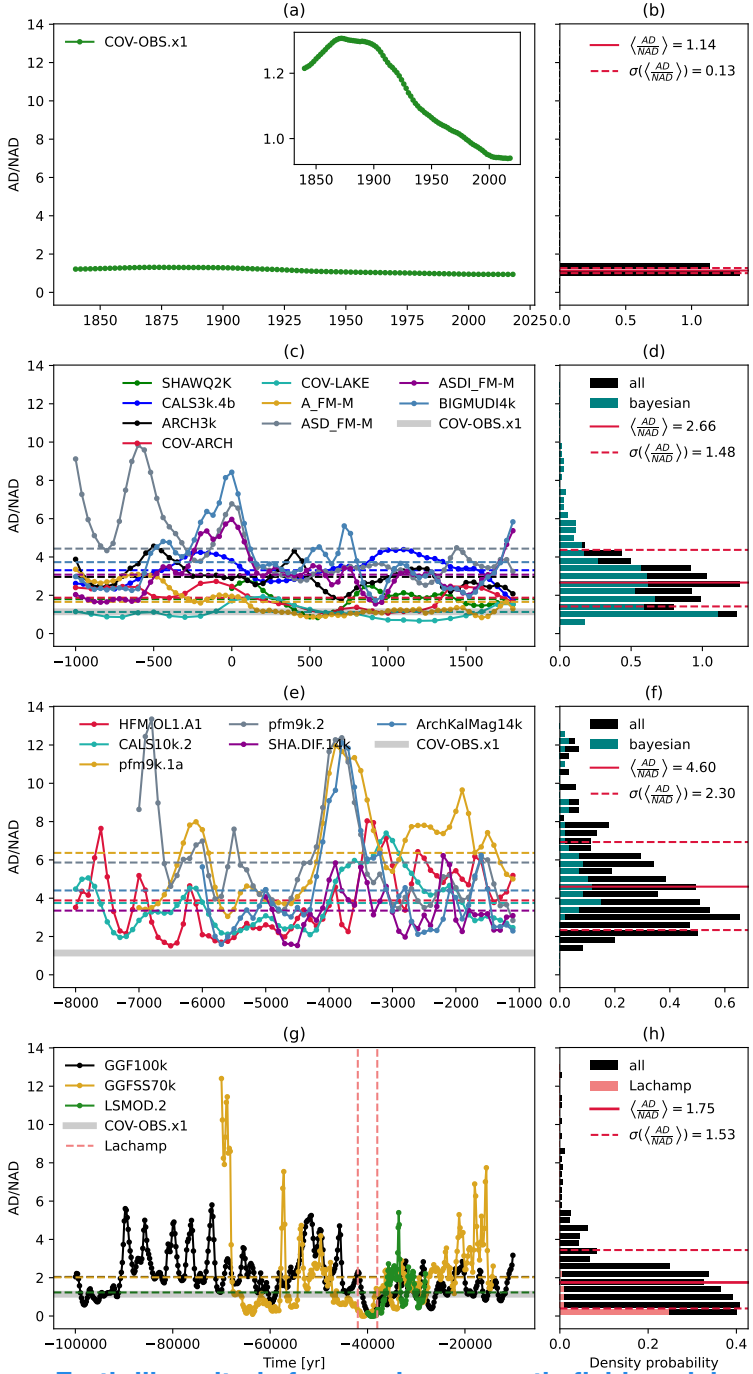
$$\text{odd} = n + m \rightarrow \text{equatorial anti-symmetric}$$
$$\text{even} = n + m \rightarrow \text{equatorial symmetric}$$

  - → zonality
    relative power of axisymmetric components in the non-dipole field (Z/NZ)
  - → flux concentration

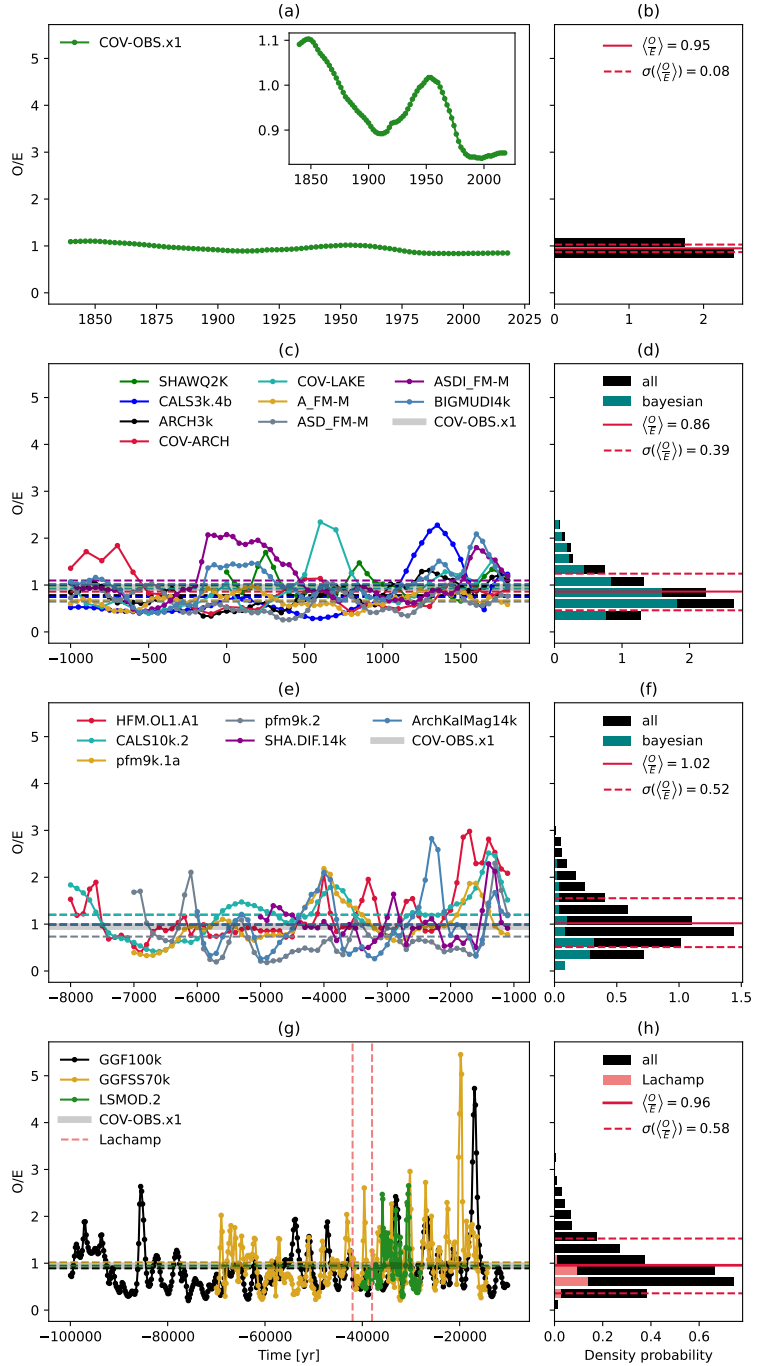
$$\text{FCF} = (\langle B_r^4\rangle - \langle B_r^2\rangle^2)/\langle B_r^2\rangle^2$$

+ this study:
  - → derive same criteria from archeo- and paleomagnetic field models
  - → temporal complexity, new criteria

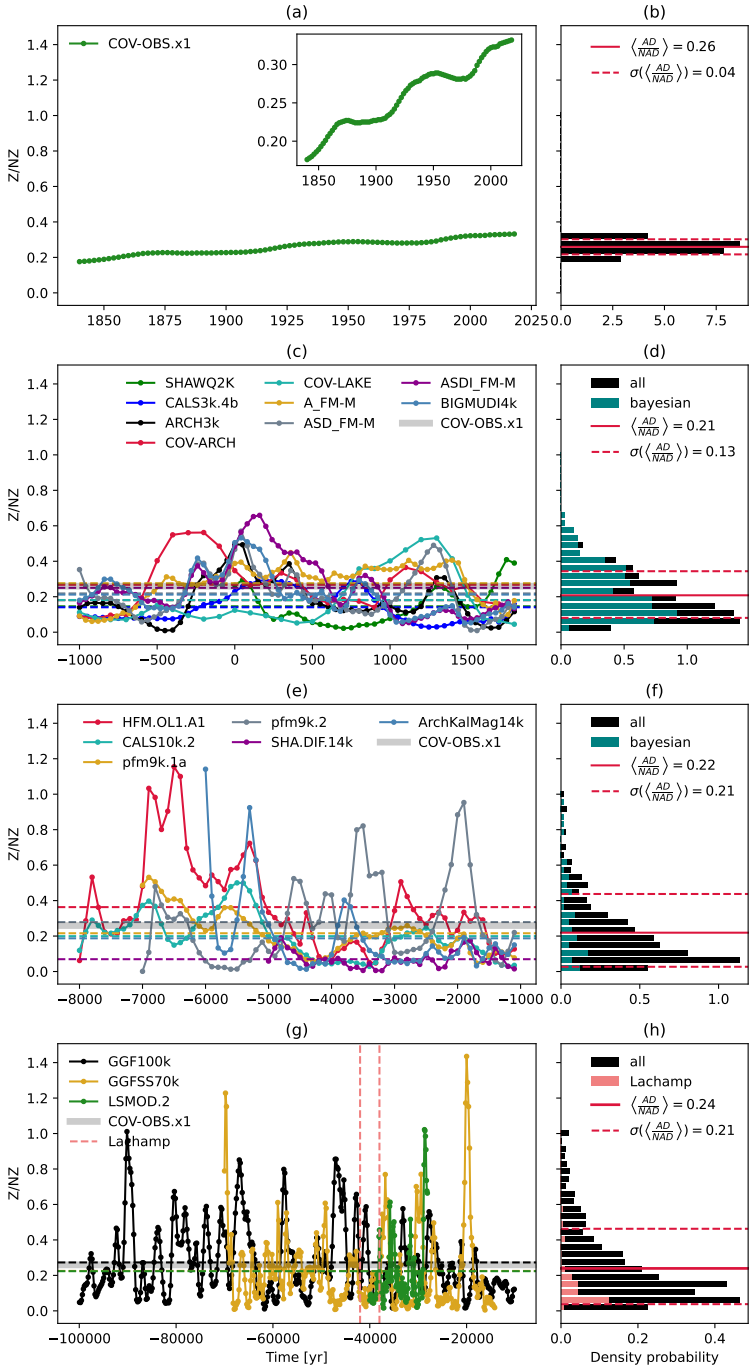
RELATIVE AXIAL DIPOL POWER



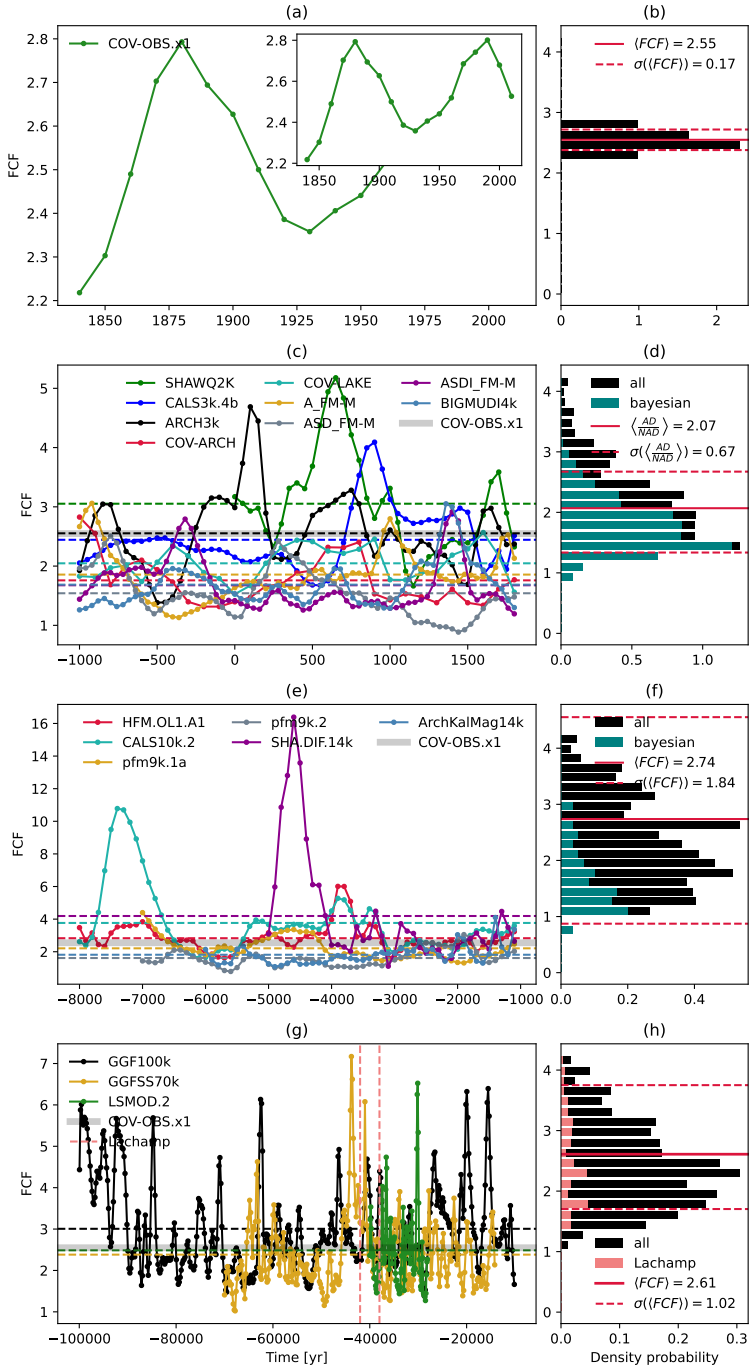
EQUATORIAL SYMMETRY



ZONALITY


(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
Z/NZ
COV-OBS.x1
$\langle \frac{AD}{NAD} \rangle = 0.26$
$\sigma(\langle \frac{AD}{NAD} \rangle) = 0.04$
SHAWQ2K
CALS3k.4b
ARCH3k
COV-ARCH
COV-LAKE
A_FM-M
ASD_FM-M
ASDI_FM-M
BIGMUDI4k
COV-OBS.x1
all
bayesian
$\langle \frac{AD}{NAD} \rangle = 0.21$
$\sigma(\langle \frac{AD}{NAD} \rangle) = 0.13$
HFM.OL1.A1
CALS10k.2
pfm9k.1a
pfm9k.2
SHA.DIF.14k
ArchKalMag14k
COV-OBS.x1
$\langle \frac{AD}{NAD} \rangle = 0.22$
$\sigma(\langle \frac{AD}{NAD} \rangle) = 0.21$
GGF100k
GGFSS70k
LSMOD.2
COV-OBS.x1
Lachamp
Lachamp
$\langle \frac{AD}{NAD} \rangle = 0.24$
$\sigma(\langle \frac{AD}{NAD} \rangle) = 0.21$
Time [yr]
Density probability

FLUX CONCENTRATION



OUTLOOK

+ derive mean characteristics of the archeo- and paleomagnetic field that are robustly resolved independently of the model priors
+ the mean characteristics (spatially and maybe temporally) should be compared to dynamo simulations