The extended Dedicated Lithospheric field model (xDLFI) and its interpretation in terms of global magnetic crustal thickness

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xDLFI and the datasets

What is the eXtended Dedicated Lithospheric Field Inversion chain ?

- This is an iterative modelling joint inversion of near-surface and satellite data within (1000) independent but overlapping caps using the regional R-SCHA inversion technique (Thébault et al., 2021).
- The series of regional models is then transformed into a SH model to degree 1600 and a prototype to SH degree 2030
- Regional data misfit are based on Huber weights and iterative scheme, regional regularization of the Backus effect between +-20° geomagnetic latitudes can be applied, parallelization and reworking in some specific regions is feasible.

This version of xDLFI will be called: SW_OPER_MLI_SHA_2E_00000000T000000_99999999T999999_0901

SWARM Measurements

- Level 1b vector and scalar measurements of Swarm A and C between **1st January 2016 to 1st January 2022 (low solar activity).**
- Swarm North-South 15s time spacing between measurements along the satellite orbits, following Finlay et al., (2020) and across track gradients.

CHAMP measurements

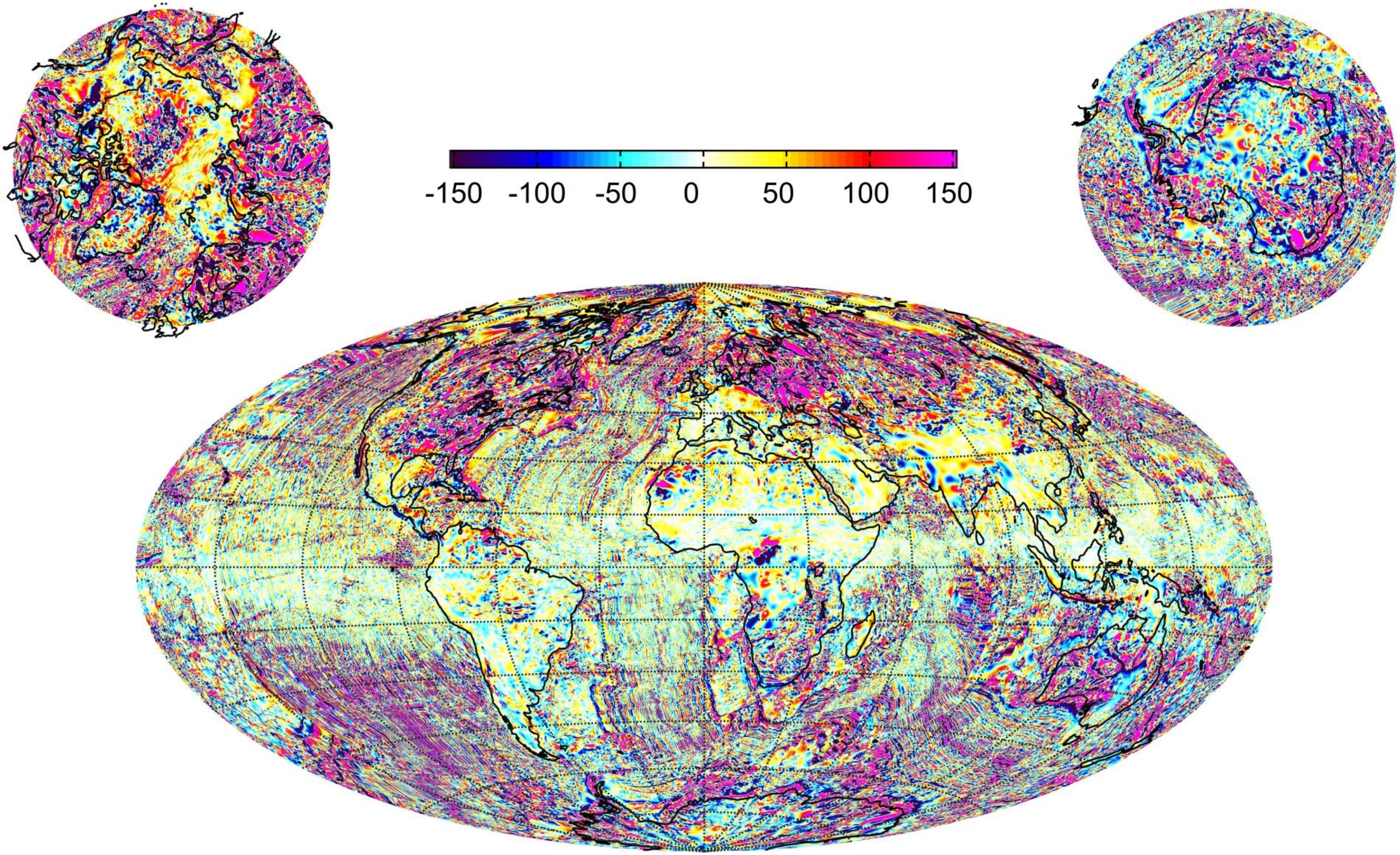
- CHAMP vector and scalar measurements from **January 2006 to September 2010** , and 15s along-track gradients (**low solar activity**).

All satellite measurements are selected during magnetic quiet days and corrected for the core and the magnetospheric fields with additional filtering by Singular Spectral Analysis independently in polar and mid latitude regions.

Near-surface data

- Use of the **WDMAM-2.1 grid** (Dyment et al., 2021) available at 5km or 0km altitude and transformation on a quasi equal area grid of 13 million points on the sphere: transformation between geodetic to geocentric is applied (latitude and altitudes).

The extended model to SH 1600

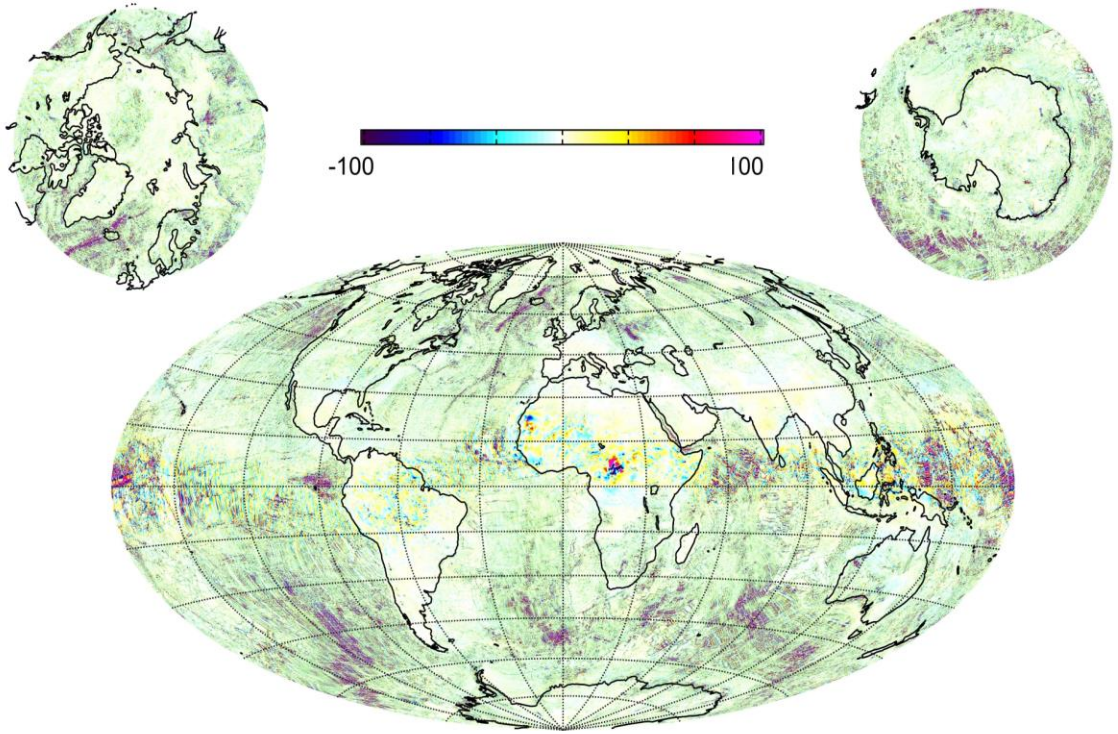


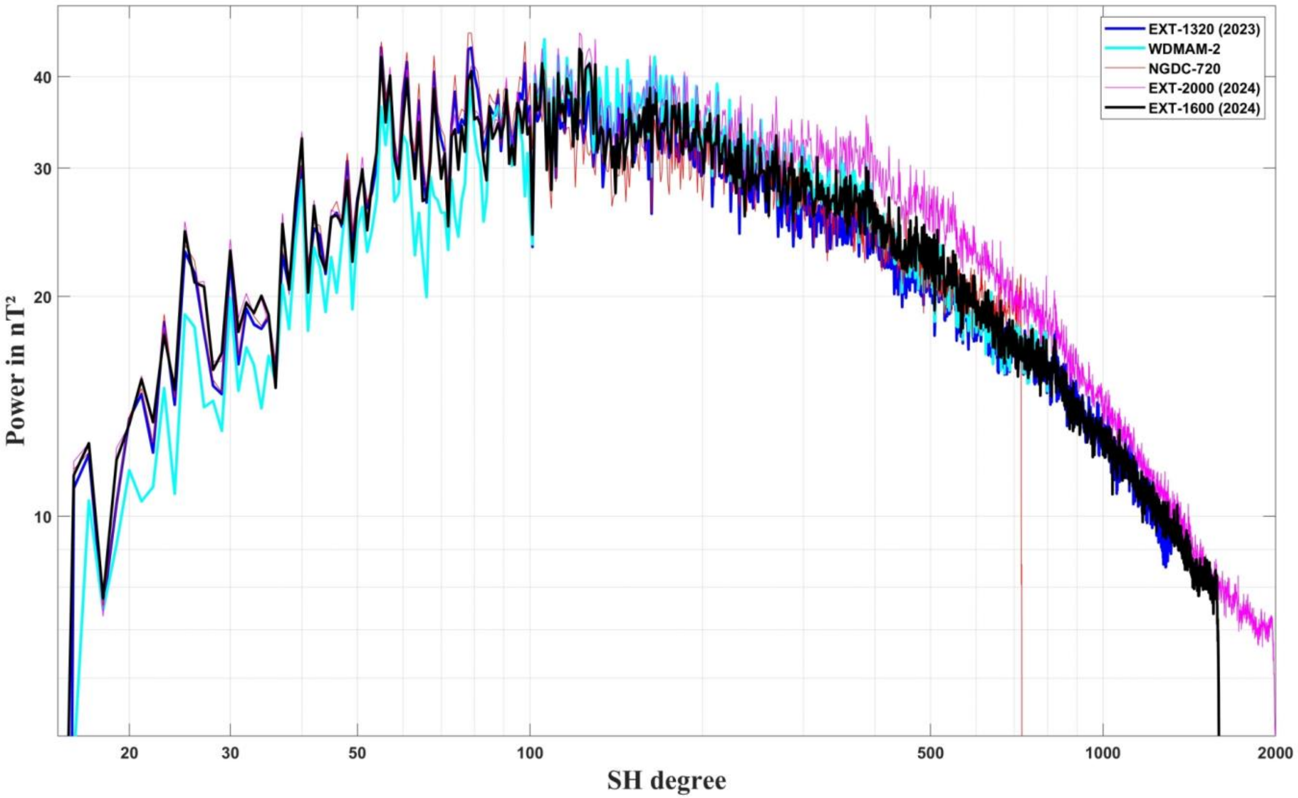
Radial component of xDLFI-1600 at the Earth's mean radius:

- Backus effect was accounted for (slightly too strong?)
- Difference between WGS84 et geocentric altitudes are considered.

After years of continuous developments we finally reach the stage where deriving a SH model to the same resolution as the full available datasets is achievable.

The extended model to SH 1600





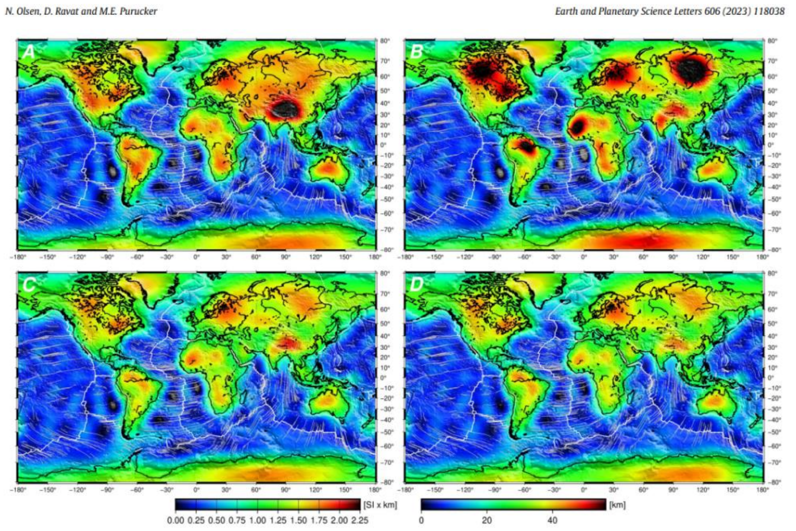
Anomaly misfit with the original WDMAM-2.1 grid:
Most remaining energy is due to spatial scales smaller than 25 km, but also to the ocean floor model.
The equatorial residuals are stronger suggesting that the regularization for the Backus effect should be lighter.

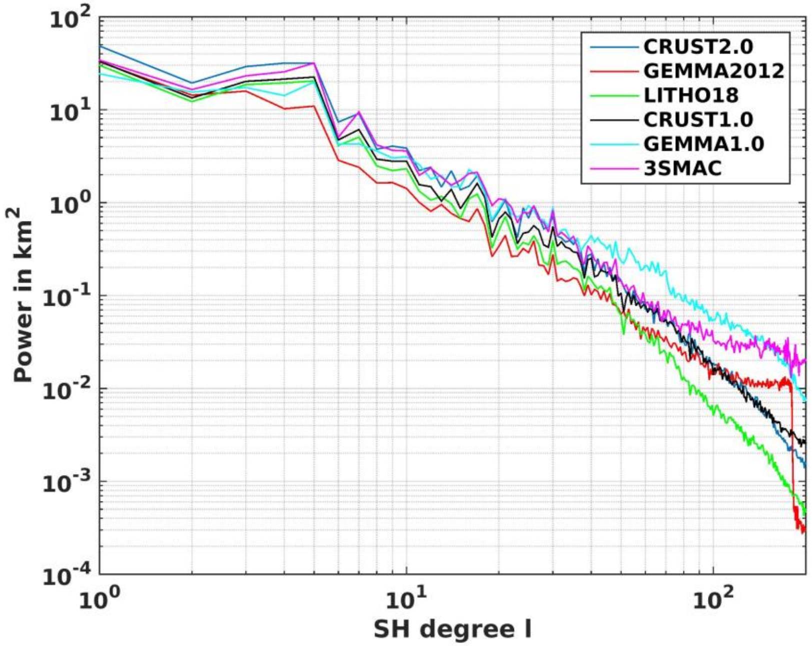
Power spectra comparisons:
The prototype model to SH degree 2000 is too energetic: visual inspection indicate clear Backus effect on the vector components.

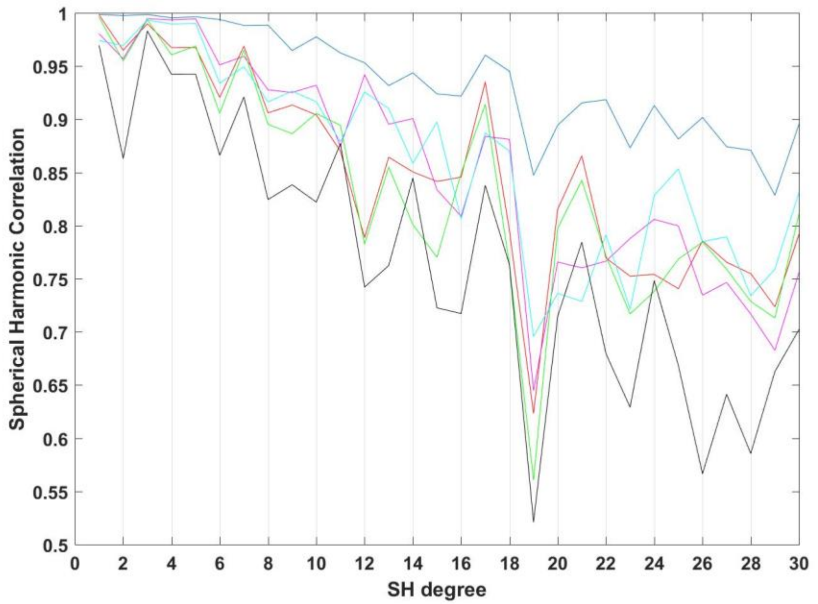
Transformation in terms of global magnetic thickness

The lithospheric magnetic field is due to magnetization sources placed at depth: we definie the magnetic thickness as the bottom depth of the magnetized sources.

For the large scales we do not consider other source of geophysical information because they are not robust enough







After
Olsen et al. (2023). On the determination and interpretation of the lithospheric induced magnetisation.

- The available Moho depth models differ significantly, in shape, strength, and mean depth.
- The Moho as a magnetic boundary is a subject of ongoing (debate) research.

Transformation in terms of global magnetic thickness: The large scales by statistical inference

Hypothesis 1: Continental magnetization on global scales is mostly induced (Maus and Haak, 2003).

Hypothèse 2: For the global Earth and from space the continental crustal thickness is nearly constant (Arkani-Hamed et al., 1996) → fonction of ε.

Hypothèse 3: Magnetic susceptibility is not randomly distributed on Earth (Pilkington and Todoeschuck, 1993) → power law structural index γ.

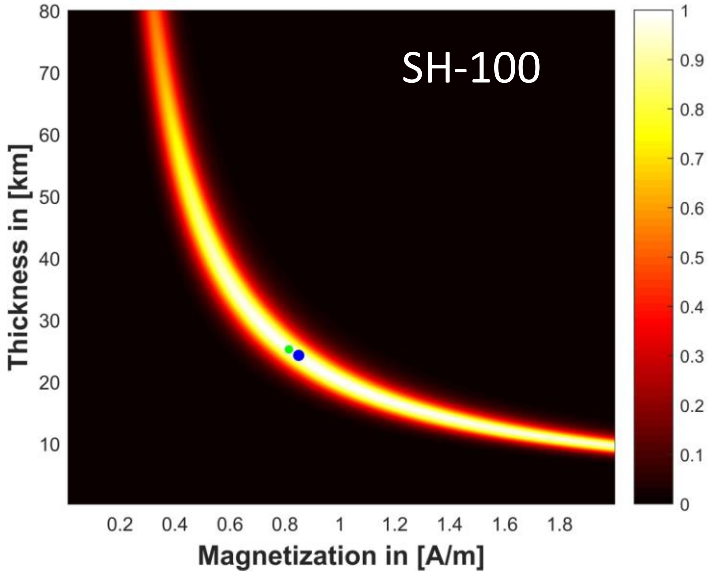
$$E^a\{R_l\} = (l+1)(\mu_0|\overline{\mathbf{M}}|F_l^a(\varepsilon))^2 l^{-\gamma} C_l,$$

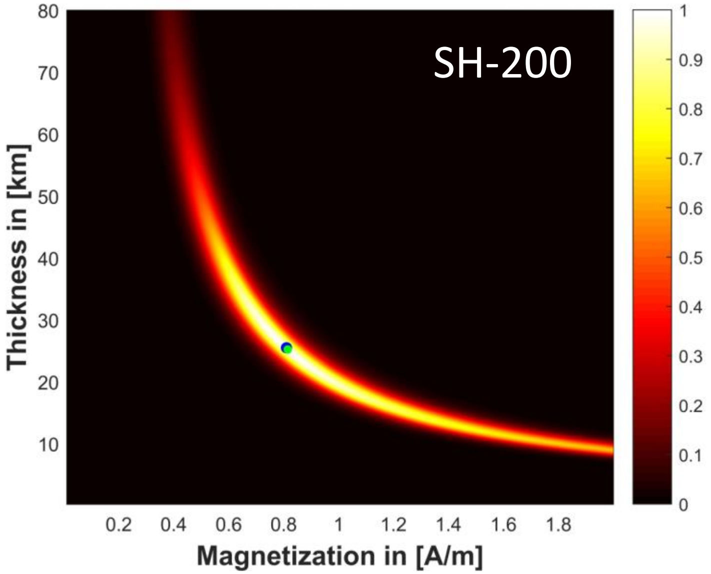
Thébault, E., & Vervelidou, F. (2015). A statistical spatial power spectrum of the Earth's lithospheric magnetic field.

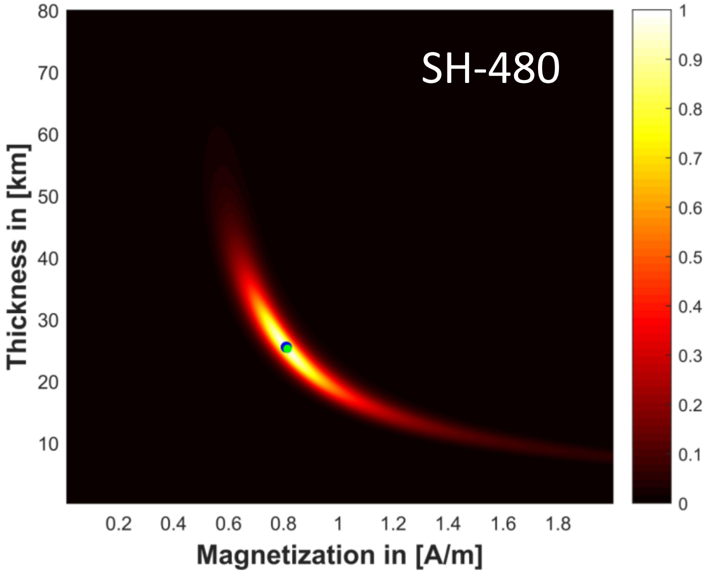
The same hypothesis are applied on regional scales by computing Spherical Cap Harmonic Power spectra (Vervelidou and Thébault, 2015) in order to estimate the regional depths and magnetizations.

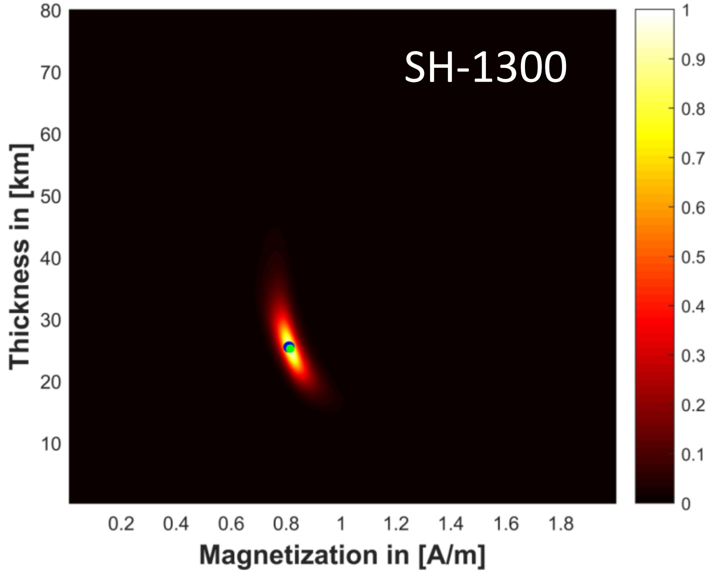
Vervelidou, F., & Thébault, E. (2015). Global maps of the magnetic thickness and magnetization of the Earth's lithosphere.

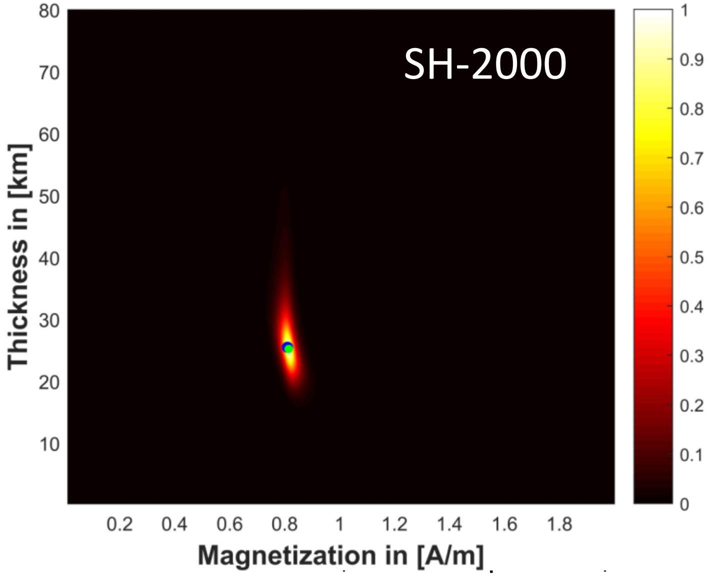
Transformation in terms of global magnetic thickness:
The large scales by statistical inference







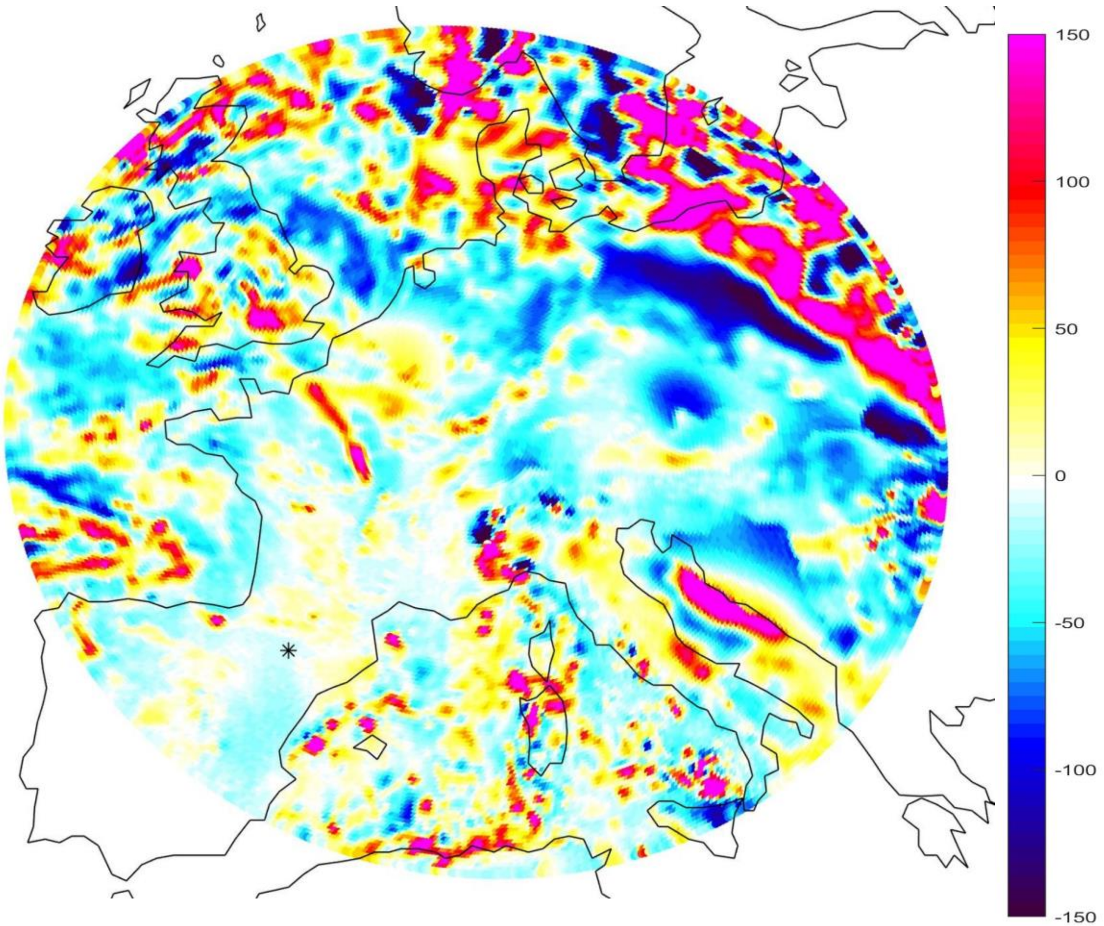


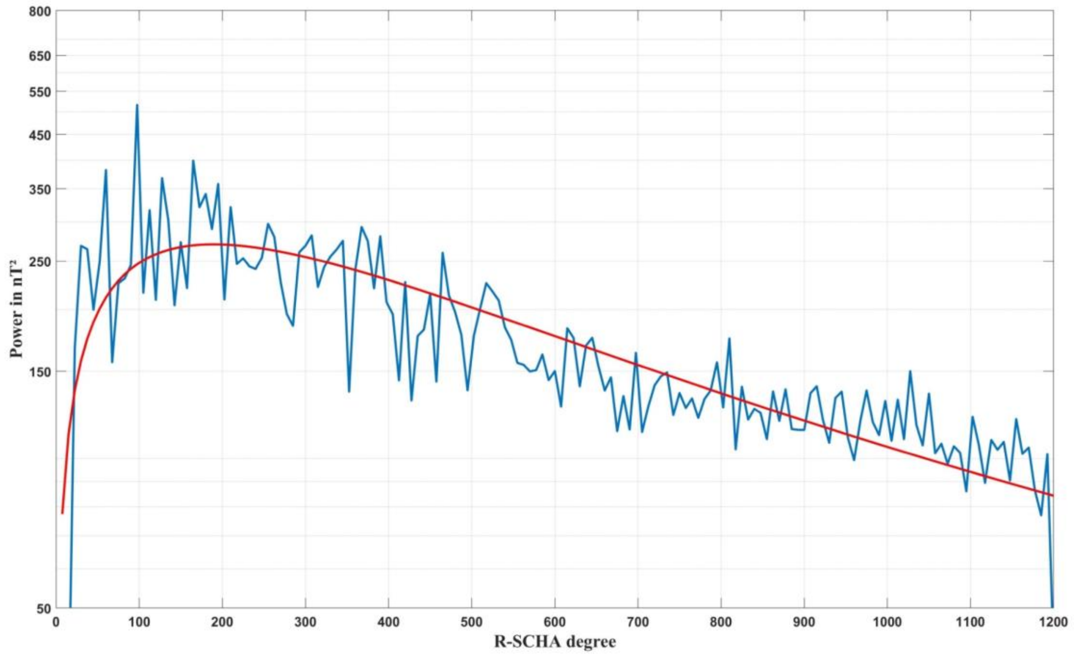


Spectral analyses requires high resolution models to allow the bets separation between magnetization and depth.

Spectral gap is an issue !

Transformation in terms of global magnetic thickness: The large scales by statistical inference





Best fit :

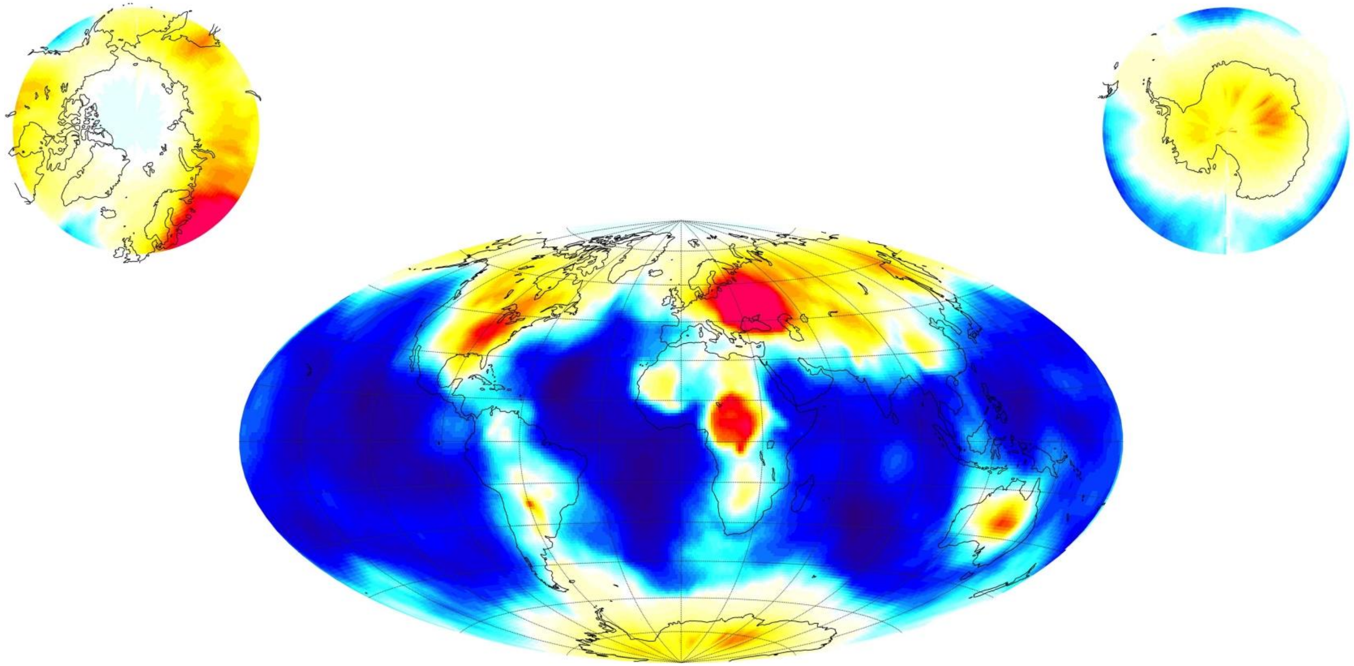
Power law = - 1.39 (+/-) 0.05

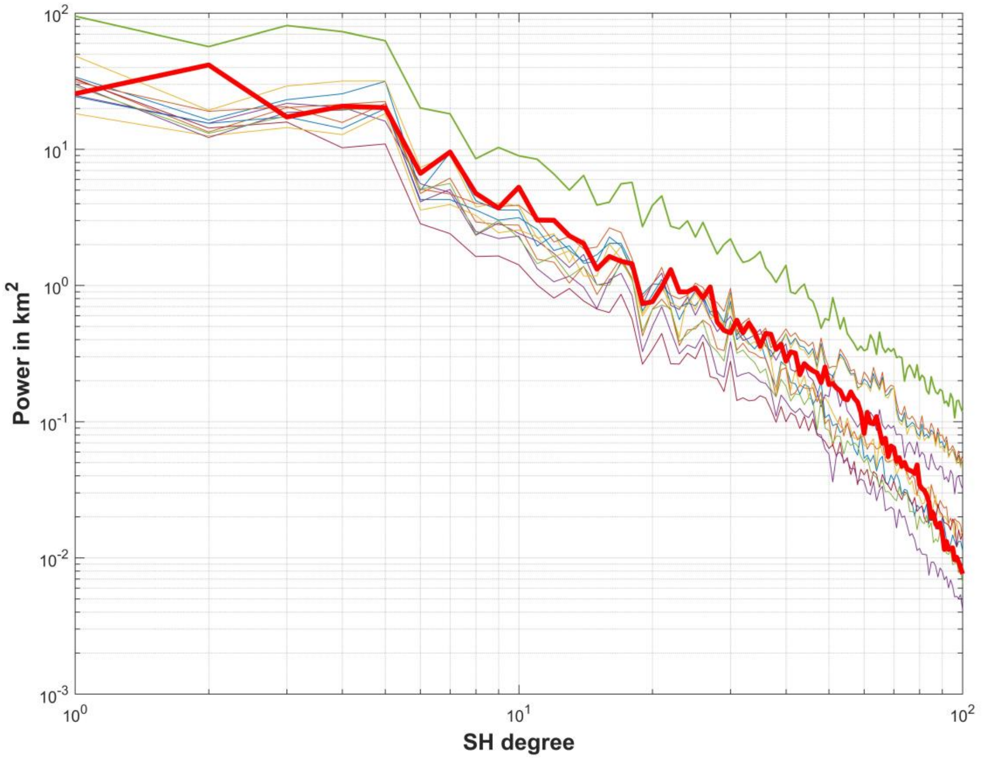
Thickness = 24.3 (+/-)2.9 km

M = 0.41 (+/-)0.26 A/m

One current limit: the statistical properties for each cap are assumed stationary. This is not correct between oceans/continents, or when the data resolution is varying sharply in space, for example.

Transformation in terms of global magnetic thickness: The large scales by statistical inference





<u>The magnetic depth is correlated with the resolution of the available airborne and marine data:</u>

Bangui is not reliable because the spectrum is skewed;

Kursk is not reliable because it creates ringing: it has to be worked out.

<u>Note :</u> this map represents the estimated values estimated at the centers of 2000 caps: it should be filtered out.

Transformation in terms of global magnetic thickness: The small scales by Equivalent Source Dipoles

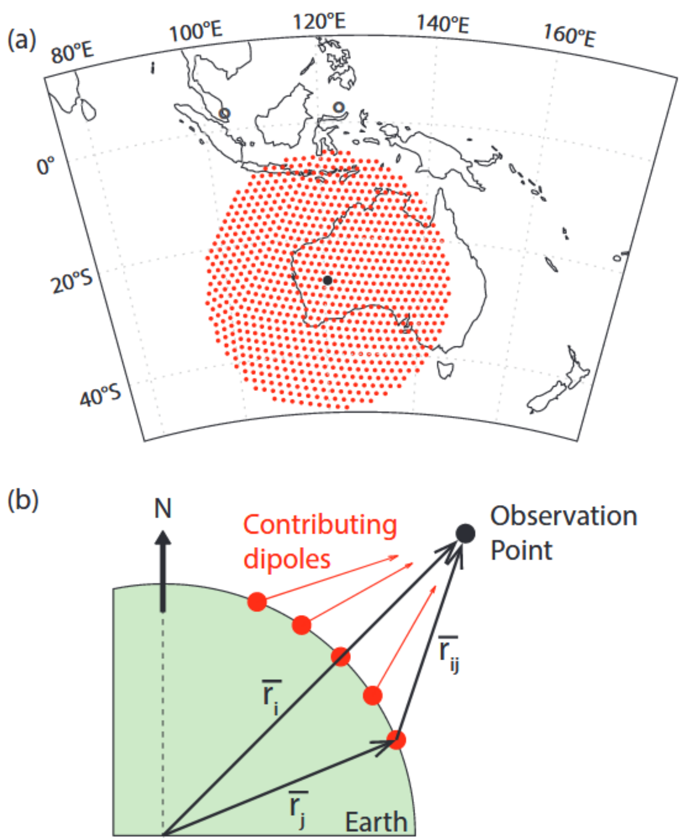
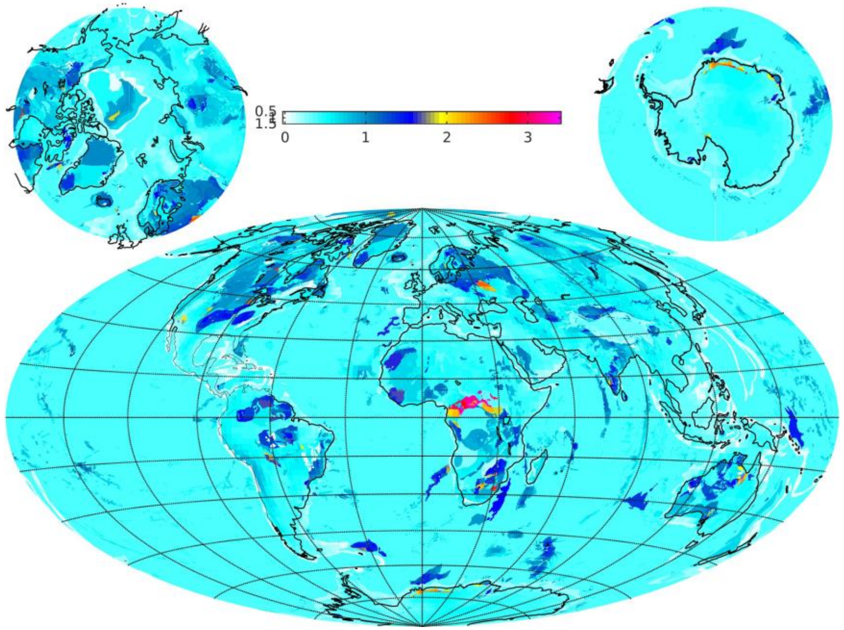


Figure from: Gard, M., & Hasterok, D. (2021), A global Curie depth model utilising the equivalent source magnetic dipole method.



After Hemant and Maus, 2005, Geological modeling of the new CHAMP magnetic anomaly maps using a geographical information system technique.

We build the matrix for the three components and without cutoff distance.

30,000 ESD are estimated by misfit with the xDLFI-1600 model at 100 km altitude.

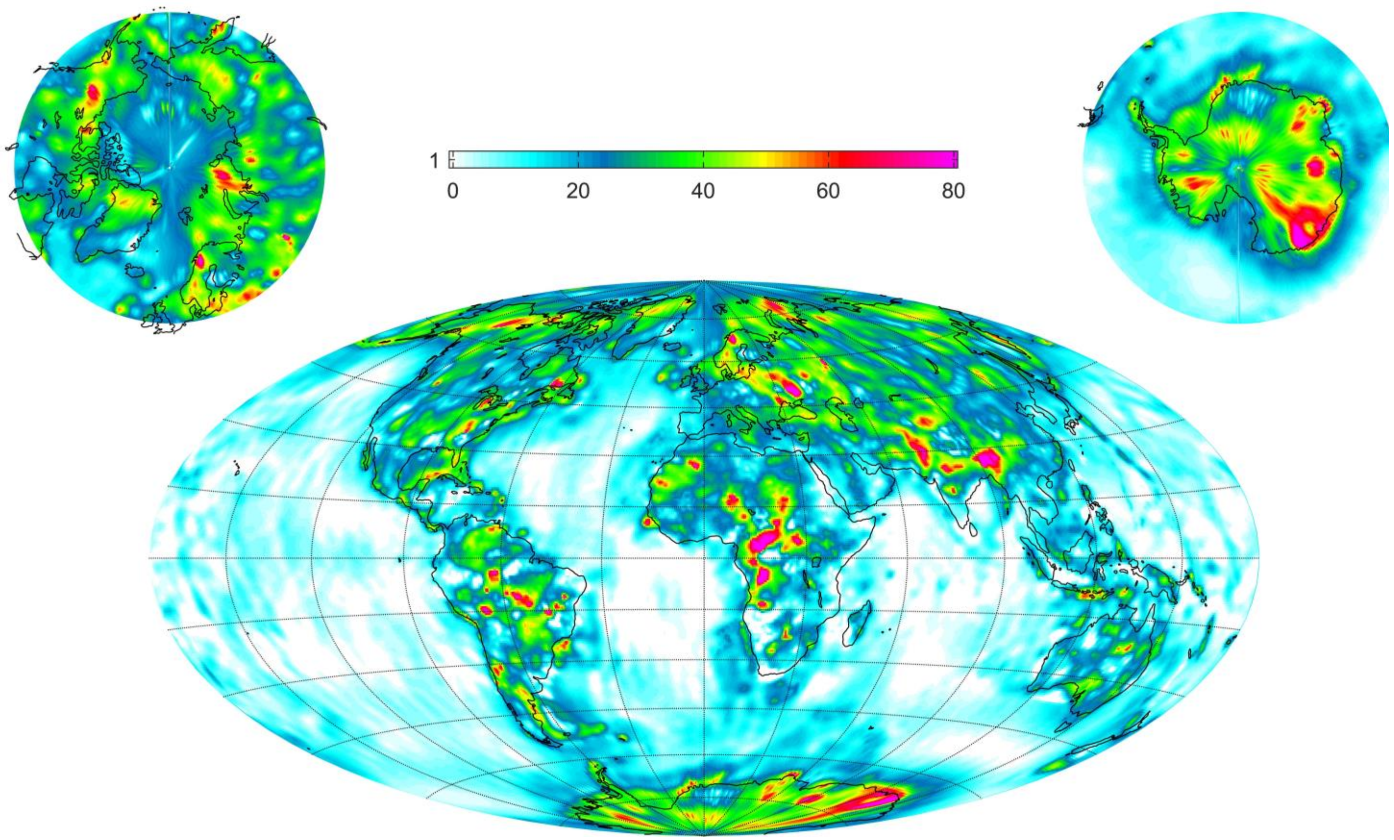
Severe limits of ESD:

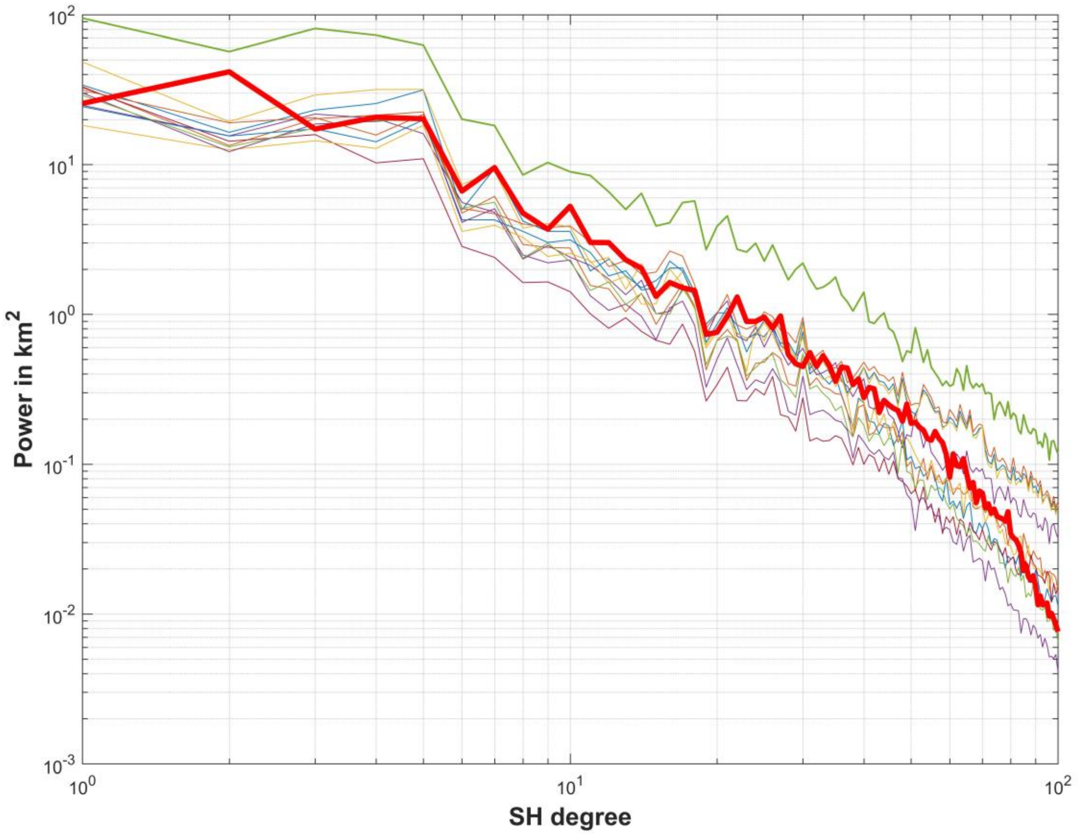
The ESD with one single layer cannot help separating magnetization and depth at the same time without a priori information.

The corresponding lithospheric field power spectrum at the Earth's mean radius cannot converge.

The thin layer hypothesis is acceptable to maximum degree 80-100.

Transformation in terms of global magnetic thickness: The estimated ESD-Statistical hybrid model

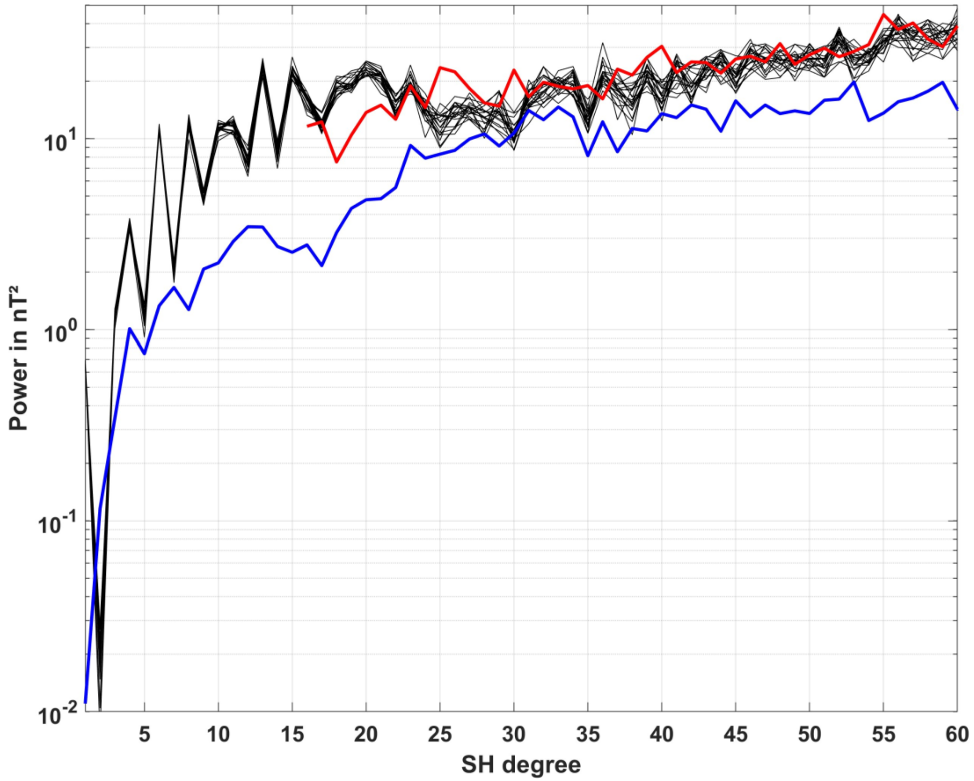


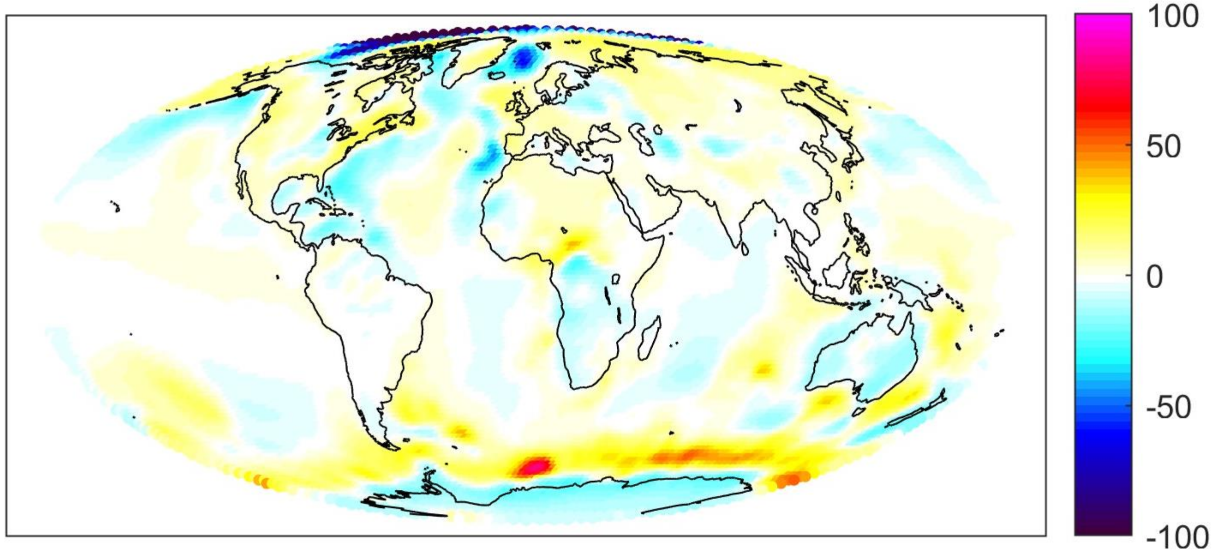


Estimated crustal thickness using spectral and spatial modelling for the scales covers SH degrees 0 to 80-100.

Comparisons between the obtain crustal spectrum with all moho depth models available as open science grids. All grids are transformed into SH by fast spherical transform and compared.

The lithospheric field missing wavelengths





The forward lithospheric field prediction provides the stenght and shape of the missing lithospheric field wavelenght (SH degree 1-15 mask by the core field). We can propagate the errors from the measurements (grid) to the estimation. Kursk and Bangui regions are spoiling the model…we need more high resolution and complete data !!

Overall, we get the correct strength and the correct shape from SH degree 1 to 80 (60 shown).

Summary

- We have again improved the Extended Dedicated Lithospheric Field chain (xDLFI): We estimated two magnetic lithospheric field models to SH degree 1600 and 2000: in both cases dealing with the Backus effect around the equator is a difficult issue;

- Fortunately, the piecewise modelling in terms of spherical caps allows us to test locally different regularization scenarios in a minimum of time;

- The lithospheric field model is then processed in order to estimate regionally the magnetic field power spectra and to compare them with a statistical model expressed in terms of magnetization, thickness and a power law;

- This misfit analysis allows us to estimate the large wavelengths of the magnetic crustal thickness independently from seismic models;

- The smaller spatial scales are estimated using an in-house Equivalent Source Dipole algorithm and a generalized inverse algorithm.

- A major conclusion is that it is possible to estimate the crustal thickness in SH the range 0-130 from magnetics only and that the the power spectrum of the estimated thickness falls within the range of all published Moho depth models.*

- We could estimate the missing lithospheric field wavelengths…