IGRF2025 / DGRF2020 Candidates from GR RAS Team

• Team members

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• Introduction

This technical note will describe general approaches that were used to create candidate magnetic field models for IGRF 2025 and DGRF 2020. We will review the data selection and mathematical methods and algorithms used to build the magnetic field model.

• Data Selection

The selection involves magnetic measurement data from each SWARM satellite: scalar data provided by the Absolute Scalar Magnetometer (ASM) and designated as F, and vector data obtained by the Vector Field Magnetometer (VFM), i.e., the north X, east Y, and vertical Z components that correspond to the B_λ, B_φ, and B_r elements in the North-East-Center (NEC) coordinate system, respectively. All satellite data is selected in such a way to avoid measurements during high external geomagnetic activity. To determine the periods with low geomagnetic activity, the following were used: satellite transit time at night and quiet periods by the geomagnetic activity indices Kp, Dst, and dDst/dt (time derivative of Dst)

The satellite data is cleaned of erroneous values and rescaled to minute values. The data selection is based on the following criteria:

1. data from the shadow regions of the Earth, i.e., the Sun is at least 10° below the horizon,
2. the absolute difference between the magnetic field vector values measured by the scalar magnetometer and vector magnetometer is less than 3 nT,
3. the value of the Kp index for the measurement periods is less than 2,
4. the absolute value of the Dst index is less than 30 nT,
5. the absolute value of the time derivative of the Dst index is less than 5 nT/hr.

- DGRF 2020

The data from 01/01/2019 to 31/12/2020 for all the Swarm satellites is taken.

- IGRF 2025

The data from 01/01/2023 to 25/09/2024 for all the Swarm satellites is taken.

• Field modelling

We take the main magnetic field B as the gradient of the magnetic potential V:

$$\mathrm{B}(\lambda, \varphi, r, t) = -\nabla \mathrm{V}(\lambda, \varphi, r, t)$$

Where V can be separated into internal and external sources and decomposition of V internal into spherical harmonics is written as:

$$\mathrm{V}(\lambda, \varphi, r, t) = \sum_{n=1}^{L} \sum_{m=0}^{n} \left(\frac{a}{r}\right)^{n+1} (g_n^m(t) \cos m\varphi + h_n^m(t) \sin m\varphi) P_n^m(\cos\theta)$$

Where $g_n^m(t)$ and $h_n^m(t)$ are Gauss coefficients and linearly decomposed into

$$g_n^m(t) = g_n^m(t_0) + (t - t_0)\frac{dg_n^m(t_0)}{dt},$$

$$h_n^m(t) = h_n^m(t_0) + (t - t_0)\frac{dh_n^m(t_0)}{dt},$$

where $a = 6371{,}2\ km$ - radius of the Earth, r - radius of the observation, (λ, φ, r) - coodinates of the observation in spherical coordinates, t_0 – starting point in time for the observations, t - the time of the current observation, for which the equation is built, P_n^m - associated Legendre Polynomials, L - maximum truncation degree for the polynomial, n and m are correspondingly degree and order for the polynomial.

This parametrization gives the linear problem to calculate the Gauss coefficients representing the components of the magnetic field model X, Y, Z. The least squares method is used. Then the values of the absolute measurements of the magnetic field F where

$$F(\lambda, \varphi, r, t) = \sqrt{\left(X^2(\lambda, \varphi, r, t) + Y^2(\lambda, \varphi, r, t) + Z^2(\lambda, \varphi, r, t)\right)},$$

are introduced, what makes the problem non-linear. We build the model by solving the linear inverse problem with Least-Squares method, to obtain the first set of Gauss coefficient, and then the absolute measurements are used to solve the non-linear inverse problem with Levenberg–Marquardt algorithm.

• Resulting maps

The resulting models for DGRF2020 and IGRF2025 are visualized on the following maps of the vertical component of the magnetic field: Figures 1 and 2.

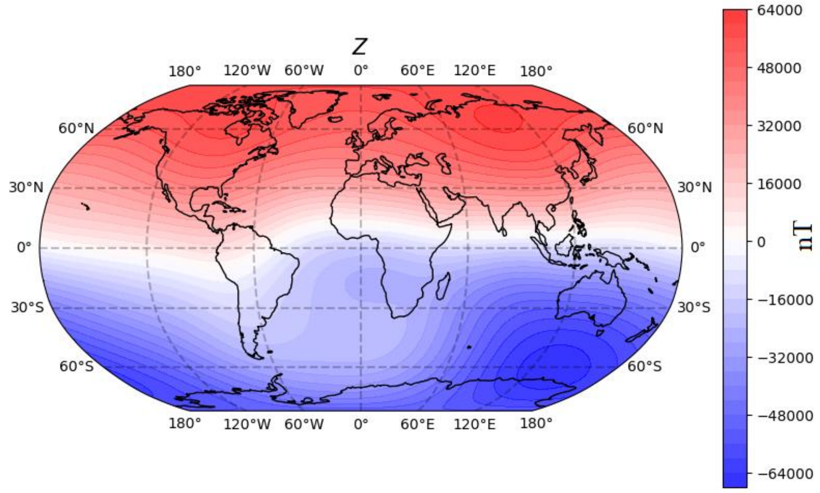

Fig. 1. – Vertical component of the magnetic field Z of the candidate model for the DGRF2020

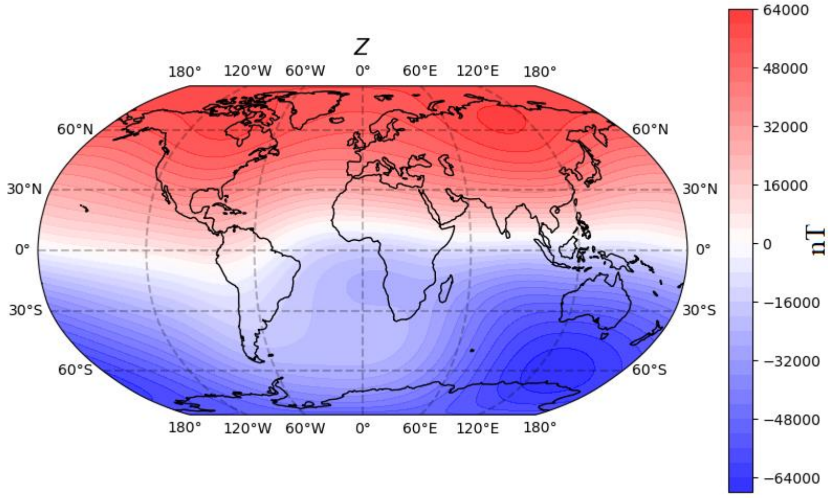

Fig. 2. – Vertical component of the magnetic field Z of the candidate model for the IGRF2025