Special issue ”International Geomagnetic Reference Field: the thirteenth generation”

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PREFACE **Open Access**

Special issue "International Geomagnetic Reference Field: the thirteenth generation"

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The large-scale time-varying portion of Earth's internal magnetic field originates from a dynamo process inside the outer core. This geodynamo drives changes in Earth's magnetic field on timescales ranging from less than 1 year to hundreds of millions of years. Monitoring the large-scale internal geomagnetic field and its temporal variations is fundamental to improving our understanding of our planet's interior dynamics, as well as maintaining and developing technology designed to utilize magnetic field observations for the benefit of society.

The International Geomagnetic Reference Field (IGRF) is a mathematical representation of the large-scale, time-varying, internal part of Earth's magnetic field. The IGRF consists of a set of model coefficients which can be input into a mathematical equation to produce the three vector components of the geomagnetic field from the surface of the core mantle boundary (about 2900 km below the Earth's surface), to low-Earth orbiting satellite altitudes. The 13th generation IGRF (IGRF-13), which is the subject of this special issue, provides model coefficients from 1900 to 2025, allowing a description of the geomagnetic field over the past one and one quarter centuries. The IGRF is a truly international collaboration, by which multiple teams of magnetic field experts submit candidate model coefficients to improve past model predictions, as well as make forecasts for the next 5 year period.

The 13th generation IGRF received a record number of candidate model submissions from a total of 15 international teams. Eleven candidate models were received to update the geomagnetic field description at the epoch 2015.0. Twelve candidate models were received for the epoch 2020.0. And finally fourteen candidate models were received to forecast the field evolution over the period 2020 to 2025. A task force was assembled to evaluate each candidate model and combine all candidates into a final set of model coefficients for IGRF-13. The findings of this task force are documented in Alken et al. (2021b). A summary of the final IGRF-13 model is presented in Alken et al. (2021c). Each team who participated in IGRF-13 prepared manuscripts detailing their work, which are collected into this special issue. Below, we provide a brief description of the methods used for building their candidate models.

Brown et al. (2021) describes three candidate models submitted by the British Geological Survey based on data from the European Swarm satellite mission and ground observatories. They discuss their main field candidates for 2015.0 and 2020.0 as well as a secular variation forecast (2020 to 2025) based on advection of the main field using steady core surface flow modeling. They additionally provide a retrospective analysis of the IGRF-12 secular variation forecasts.

Yang et al. (2021) present the only IGRF-13 candidate model which did not utilize data from the Swarm mission. Instead, they used measurements from the China Seismo-Electromagnetic Satellite (CSES) to build a main field candidate for epoch 2020.0 and performed a validation analysis comparing their model with the other candidate models for epoch 2020.0. The lead institute for this candidate is the China Earthquake Administration.

Pavón-Carrasco et al. (2020) present main field candidate models for epochs 2015.0 and 2020.0, as well as a secular variation forecast for 2020 to 2025 submitted by the Universidad Complutense de Madrid. They developed a bootstrapping method to build models from

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Swarm and ground observatory data which allowed them to provide uncertainties on their candidate model coefficients.

Alken et al. (2021a) detail the candidate models submitted by NOAA/NCEI and the University of Colorado. They present main field candidates for epochs 2015.0 and 2020.0, as well as a secular variation forecast for 2020 to 2025. Swarm satellite measurements were their primary data source, supplemented by ground observatory measurements for validation. They additionally provide a retrospective assessment of their previous IGRF-12 candidate model.

Finlay et al. (2020) presents the CHAOS-7 geomagnetic field model, which served as the parent model for the Danish Technical University candidates to IGRF-13. They built a model spanning more than two decades using data from Ørsted, CHAMP, SAC-C, Cryosat-2, Swarm, and the ground observatory network. In addition to discussing their IGRF-13 candidates, they analyze the recent behavior of the South Atlantic Anomaly.

Rother et al. (2021) presents the Mag.num geomagnetic core field model developed at GeoForschungsZentrum (GFZ) Potsdam, which served as the parent model for that institute's IGRF-13 candidates. This model used Swarm and ground observatory data to construct candidates for the main field at 2015.0 and 2020.0 as well as a secular variation forecast for 2020 to 2025. They additionally analyze recent trends of the South Atlantic Anomaly.

The Institut de Physique du Globe de Paris (IPGP) provided three candidate models to IGRF-13 which are detailed in three separate papers in this special issue. Vigneron et al. (2021) presents a main field candidate for epoch 2015.0 using the experimental vector mode on Swarm's absolute scalar magnetometer (ASM-V). Ropp et al. (2020) presents a novel approach to core field estimation by combining a sequential modeling approach, a Kalman filter, and a correlation-based modeling step. Their method was used for the IPGP main field candidate for epoch 2020.0. Fournier et al. (2021a) presents the IPGP secular variation candidate model to IGRF-13 based on integrating an ensemble of 100 geodynamo models between epochs 2019.0 and 2025.0, with each ensemble member differing only in initial conditions.

Huder et al. (2020) detail the candidate models to IGRF-13 submitted by the Institut des Sciences de la Terre (ISTerre). They construct a model named COV-OBS.x2 covering the time period 1840 to 2020, integrating ground observatory data, satellite data, and older surveys. This team submitted main field candidates for epochs 2015.0 and 2020.0, as well as a secular variation forecast for 2020 to 2025.

Petrov and Bondar (2021) present the IGRF-13 candidates submitted by the Pushkov Institute of Terrestrial Magnetism (IZMIRAN), which included main field candidates for epoch 2015.0 and 2020.0, as well as a secular variation forecast for 2020 to 2025. Their approach was to bin Swarm measurements into discrete cells covering Earth's surface and applying spherical harmonic analysis to the resulting grid.

Minami et al. (2020) present an IGRF-13 candidate secular variation forecast for 2020 to 2025 developed by several research groups in Japan. Their methodology applied a data assimilation scheme to a magnetohydrodynamic (MHD) dynamo simulation code. Their data assimilation method incorporated measurements from CHAMP, Swarm, and the ground observatory network.

Metman et al. (2020) detail a secular variation forecast candidate to IGRF-13 developed at the University of Leeds. They use secular variation estimates provided by the CHAOS-6 model to fit a steady core flow model, followed by fitting the residual to a magnetic diffusion model in order to provide a forecast over the 2020 to 2025 time period.

Sanchez et al. (2020) present the Max Planck Institute for Solar System Research secular variation candidate for IGRF-13. They use a sequential ensemble data assimilation method, with the ensembles consisting of parallel 3D dynamo simulations. The input data to the assimilation comes from the COV-OBS.x1 and Kalmag models.

The NASA candidates to IGRF-13 are detailed in two publications in this special issue. Sabaka et al. (2020) present the latest development in the Comprehensive Model (CM) series, culminating in a model called CM6 which includes Ørsted, SAC-C, CHAMP and Swarm satellites, and ground observations. CM6 models not only the core field, but also contributions from the lithosphere, ionosphere, magnetosphere, and oceanic tides. CM6 was used to generate main field candidates for epochs 2015.0 and 2020.0. Tangborn et al. (2021) present a secular variation forecast for 2020 to 2025 combining a geodynamo model with an ensemble Kalman filter. Various geomagnetic field models are used as inputs to the data assimilation scheme.

Baerenzung et al. (2020) detail the University of Potsdam candidate models for IGRF-13. They present a model named Kalmag, which assimilates CHAMP and Swarm data using a Kalman filter scheme, and has a validity period spanning two decades. This team submitted main field candidates for epochs 2015.0 and 2020.0, as well as a secular variation forecast for 2020 to 2025.

Wardinski et al. (2020) present the Université de Strasbourg's candidate model submissions to IGRF-13. They combine satellite and ground measurements to build a continuous model of the main field and its secular variation from 1957 to 2020. This approach was used to derive main field candidates for 2015.0 and 2020.0, as well as a secular variation forecast for 2020 to 2025 based on a multi-variate singular spectrum analysis of the secular variation recorded over the past six decades.

Finally, Fournier et al. (2021b) contributed a Frontier letter to this special issue, on the topic of secular variation forecasting. Recent satellite observations have revealed significant short time-scale variations in the geomagnetic field which are difficult to predict by routinely used methods to extrapolate current measurements several years into the future. These authors analyze 35 years of past IGRF secular variation forecasts and find that the quality of 5-year forecasts deteriorates significantly during times of rapid geomagnetic field changes. They review the current state-of-the-art methods in physics-based forecasting of secular variation, discuss lessons learned over the past several decades, and comment on possible future directions.

The task force thanks all the participants for providing their time, resources and expertise to create the main field models and forecasts for this generation of the IGRF. We also thank the many data providers for the freely-available scientific magnetic data, without which it would not be possible to produce such high quality models.

Authors' contributions

PA is chair of the IAGA DIV V-MOD (2019–2023) and initiated, coordinated and organised the call and delivery of the 13th generation of the IGRF. ET is former chair (2015–2019). CB is present co-chair (2019–2023). All authors have read and approved the manuscript.

Availability of data and materials

Not applicable.

Declarations

Competing interests

The authors declare that they have no competing interests.

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