



ELSEVIER

Available online at www.sciencedirect.com

SCIENCE @ DIRECT®

Physics of the Earth and Planetary Interiors 151 (2005) 320–322

PHYSICS
OF THE EARTH
AND PLANETARY
INTERIORS

www.elsevier.com/locate/pepi

Short communication

The 10th generation international geomagnetic reference field

S. Maus^{*}, S. Macmillan, T. Chernova, S. Choi, D. Dater, V. Golovkov, V. Lesur,
F. Lowes, H. Lühr, W. Mai, S. McLean, N. Olsen, M. Rother,
T. Sabaka, A. Thomson, T. Zvereva

International Association of Geomagnetism and Aeronomy (IAGA),
Division V, Working Group VMOD

NOAA/NGDC, 325 Broadway, Boulder, CO 80305, USA

Received 2 March 2005; accepted 5 March 2005

Abstract

The International Association of Geomagnetism and Aeronomy (IAGA) on 12 December 2004 released the 10th generation International Geomagnetic Reference Field (IGRF)—the latest version of a standard mathematical description of the Earth's main magnetic field and used widely in studies of the Earth's deep interior, its crust, ionosphere and magnetosphere. The coefficients were finalised by a task force of IAGA. The IGRF is the product of a large collaborative effort between magnetic field modellers and the institutes involved in collecting and disseminating magnetic field data from satellites and observatories around the world. © 2005 Elsevier B.V. All rights reserved.

Keywords: Geomagnetic field model; Geomagnetic reference field; IGRF; Secular variation

The IGRF is a series of mathematical models of the Earth's main field and its annual rate of change (secular variation). In source-free regions at the Earth's surface and above, the main field, with sources internal to the Earth, can be represented as the negative gradient of a scalar potential V , expanded into spherical harmonics as

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

where r , θ , λ are geocentric coordinates (r is the distance from the centre of the Earth, θ the colatitude, i.e. 90° —latitude and λ is the longitude), R the magnetic reference radius (6371.2 km); $g_n^m(t)$ and $h_n^m(t)$ are the coefficients at time t and $P_n^m(\theta)$ are the Schmidt semi-normalised associated Legendre functions of degree n

^{*} Corresponding author. Tel.: +1 3034976522; fax: +1 3034976513.

E-mail address: stefan.maus@noaa.gov (S. Maus).

and order m . The main field coefficients are functions of time. For the IGRF the change is assumed to be linear over 5-year intervals. For the upcoming 5-year epoch, the rate of change is given by predictive secular variation coefficients \dot{g}_n^m and \dot{h}_n^m . For more details on main-field modelling the reader is referred to [Chapman and Bartels \(1940\)](#) and [Langel \(1987\)](#).

The coefficients of the 10th generation IGRF are available from the IAGA web site www.iugg.org/IAGA and the World Data Centers listed at the end of this paper, along with software to compute magnetic field values from them. The new coefficients are the preliminary main-field coefficients for 2005.0 and the predictive secular-variation coefficients for 2005.0–2010.0. The previous (ninth) generation IGRF with the definitive coefficients for 1995.0 and 2000.0 was finalized at the XXIII General Assembly of the International Union of Geophysics and Geodesy, held at Sapporo in Japan in July 2003 ([Macmillan et al., 2003](#)).

The satellite magnetic missions of the International Decade of Geopotential Research (Ørsted launched 1999, CHAMP launched 2000) are providing an unprecedented wealth of highly accurate magnetic field measurements. In order to ensure that the accuracy of the IGRF reflects the high quality of available data, IAGA decided in 2001 that the main-field coefficients of the IGRF from the year 2000 onwards should extend to degree $n_{\max} = 13$ and be quoted to 0.1 nT precision (to reflect improved spatial resolution and instrument precision). Pre-2000 coefficients extend to degree 10 and are quoted to 1 nT precision. The predictive secular variation coefficients \dot{g}_n^m and \dot{h}_n^m for the upcoming

5-year epoch are given to degree 8 with a precision of 0.1 nT/year.

With the previous ninth generation IGRF, there was an update in the nomenclature. [Table 1](#) gives the new nomenclature that should be used henceforth, and provides a summary of the history of the IGRF. It is recommended not to use the term IGRF without reference to the generation, as then it is difficult to establish which coefficients were actually used. For example, one cannot recover the original full-field data from an aeromagnetic anomaly dataset in order to tie it with adjacent surveys if one does not know which generation of the IGRF was used. Finally, it is now recommended to use the World Geodetic System 1984 (WGS84, $a = 6378.137$ km, $b = 6356.752$ km) when specifying the IGRF in geodetic coordinates.

Details of the geomagnetic modelling methods will be published later this year in a special issue of *Earth, Planets and Space*. The 10th generation IGRF coefficients were computed from candidate sets of coefficients produced by the participating members of IAGA Working Group VMOD, listed at the head of this announcement. Their institutes and the many organisations involved in operating magnetic survey satellites, observatories and World Data Centers are thanked for their continuing support of the IGRF project.

World Data Centers

WDC for Solid Earth Geophysics, National Geophysical Data Center, 325 Broadway, Boulder, CO 80303-3328, USA. Email: susan.mclean@noaa.gov, Internet: www.ngdc.noaa.gov.

Table 1
Summary of nomenclature and IGRF history

Full name	Short name	Valid for	Definitive for
IGRF 10th generation (revised 2004)	IGRF-10	1900.0–2010.0	1945.0–2000.0
IGRF ninth generation (revised 2003)	IGRF-9	1900.0–2005.0	1945.0–2000.0
IGRF eighth generation (revised 1999)	IGRF-8	1900.0–2005.0	1945.0–1990.0
IGRF seventh generation (revised 1995)	IGRF-7	1900.0–2000.0	1945.0–1990.0
IGRF sixth generation (revised 1991)	IGRF-6	1945.0–1995.0	1945.0–1985.0
IGRF fifth generation (revised 1987)	IGRF-5	1945.0–1990.0	1945.0–1980.0
IGRF fourth generation (revised 1985)	IGRF-4	1945.0–1990.0	1965.0–1980.0
IGRF third generation (revised 1981)	IGRF-3	1965.0–1985.0	1965.0–1975.0
IGRF second generation (revised 1975)	IGRF-2	1955.0–1980.0	–
IGRF first generation (revised 1969)	IGRF-1	1955.0–1975.0	–

WDC for Geomagnetism, Data Analysis Center for Geomagnetism and Space Magnetism, Graduate School of Science, Kyoto University, Kyoto 606-8502, Japan. Email: iyemori@kugi.kyoto-u.ac.jp, Internet: swdcwww.kugi.kyoto-u.ac.jp.

WDC for Geomagnetism, British Geological Survey, Murchison House, West Mains Road, Edinburgh EH9 3LA, UK. Email: smac@bgs.ac.uk, Internet: www.geomag.bgs.ac.uk.

References

- Chapman, S., Bartels, J., 1940. Geomagnetism, vol. 2. Oxford University Press, London.
- Langel, R.A., 1987. In: Jacobs, J.A. (Ed.), Main Field in Geomagnetism, vol. 1. Academic Press, London, pp. 249–512.
- Macmillan, S., Maus, S., Bondar, T., Chambodut, A., Golovkov, V., Holme, R., Langlais, B., Lesur, V., Lowes, F., Lühr, H., Mai, W., Manda, M., Olsen, N., Rother, M., Sabaka, T., Thomson, A., Wardinski, I., 2003. The ninth-generation international geomagnetic reference field. *Phys. Earth Planet. Inter.* 140, 253–254.