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International geomagnetic reference field — 2000

International Association of Geomagnetism and Aeronomy (IAGA), Division V, Working Group 8

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A group of geomagnetic field modelers associated with the International Association of Geomagnetism and Aeronomy (IAGA), Division V, Working Group 8 periodically examines various geomagnetic field representations from which the Earth's main field and its secular variation can be computed. They produce a set of coefficients to represent the main field at a particular epoch, usually every 5 years, and name it as the International Geomagnetic Reference Field (IGRF). Also, if a previous IGRF is re-derived using new data not available at the time of its production and agreed upon when it is clear that no additional data are likely to emerge, it is called a Definitive Geomagnetic Reference Field (DGRF). For similar reasons, no DGRF model for 1995 has yet been adopted by the IAGA, Division V, Working Group 8. Note that when referring to these models, the designation ''IGRF'' refers to all available models viewed collectively. If a particular model is intended, the reference must be specific, i.e. IGRF2000 or DGRF1990, rather than simply IGRF or DGRF.

The IGRF is a series of mathematical models describing the Earth's main field and its secular variation. The main field $\vec{B}$ is the negative gradient of a scalar potential:

$$\vec{B} = -\nabla V$$

Each model comprises a set of spherical harmonic coefficients (called Gauss coefficients in recognition of Gauss' development of this technique for geomagnetism), g_n^m and h_n^m, in a truncated series expansion of a geomagnetic potential function of internal origin:

$$V = a \sum_{n=1}^{N} \sum_{m=0}^{n} \left(\frac{a}{r}\right)^{n+1} \times \left(g_n^m \cos m\phi + h_n^m \sin m\phi \right) P_n^m(\cos\theta)$$

where a is the mean radius of the Earth (6371.2 km) and r, ϕ, θ are the geocentric spherical coordinates

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Table 1
Spherical harmonic (Gauss) coefficients of the IGRF2000 (in nT) and SV2000–2005 (in nT/year)

g/h	*n*	m	IGRF-2000	SV 2000–2005
g	1	0	−29615	14.6
g	1	1	−1728	10.7
h	1	1	5186	−22.5
g	2	0	−2267	−12.4
g	2	1	3072	1.1
h	2	1	−2478	−20.6
g	2	2	1672	−1.1
h	2	2	−458	−9.6
g	3	0	1341	0.7
g	3	1	−2290	−5.4
h	3	1	−227	6.0
g	3	2	1253	0.9
h	3	2	296	−0.1
g	3	3	715	−7.7
h	3	3	−492	−14.2
g	4	0	935	−1.3
g	4	1	787	1.6
h	4	1	272	2.1
g	4	2	251	−7.3
h	4	2	−232	1.3
g	4	3	−405	2.9
h	4	3	119	5.0
g	4	4	110	−3.2
h	4	4	−304	0.3
g	5	0	−217	0.0
g	5	1	351	−0.7
h	5	1	44	−0.1
g	5	2	222	−2.1
h	5	2	172	0.6
g	5	3	−131	−2.8
h	5	3	−134	1.7
g	5	4	−169	−0.8
h	5	4	−40	1.9
g	5	5	−12	2.5
h	5	5	107	0.1
g	6	0	72	1.0
g	6	1	68	−0.4
h	6	1	−17	−0.2
g	6	2	74	0.9
h	6	2	64	−1.4
g	6	3	−161	2.0
h	6	3	65	0.0
g	6	4	−5	−0.6
h	6	4	−61	−0.8
g	6	5	17	−0.3
h	6	5	1	0.0
g	6	6	−91	1.2
h	6	6	44	0.9
g	7	0	79	−0.4
g	7	1	−74	−0.4
h	7	1	−65	1.1

Table 1 (*continued*)

g/h	*n*	m	IGRF-2000	SV 2000–2005
g	7	2	0	−0.3
h	7	2	−24	0.0
g	7	3	33	1.1
h	7	3	6	0.3
g	7	4	9	1.1
h	7	4	24	−0.1
g	7	5	7	−0.2
h	7	5	15	−0.6
g	7	6	8	0.6
h	7	6	−25	−0.7
g	7	7	−2	−0.9
h	7	7	−6	0.2
g	8	0	25	−0.3
g	8	1	6	0.2
h	8	1	12	0.1
g	8	2	−9	−0.3
h	8	2	−22	0.0
g	8	3	−8	0.4
h	8	3	8	0.0
g	8	4	−17	−1.0
h	8	4	−21	0.3
g	8	5	9	0.3
h	8	5	15	0.6
g	8	6	7	−0.5
h	8	6	9	−0.4
g	8	7	−8	−0.7
h	8	7	−16	0.3
g	8	8	−7	−0.4
h	8	8	−3	0.7
g	9	0	5	0.0
g	9	1	9	0.0
h	9	1	−20	0.0
g	9	2	3	0.0
h	9	2	13	0.0
g	9	3	−8	0.0
h	9	3	12	0.0
g	9	4	6	0.0
h	9	4	−6	0.0
g	9	5	−9	0.0
h	9	5	−8	0.0
g	9	6	−2	0.0
h	9	6	9	0.0
g	9	7	9	0.0
h	9	7	4	0.0
g	9	8	−4	0.0
h	9	8	−8	0.0
g	9	9	−8	0.0
h	9	9	5	0.0
g	10	0	−2	0.0
g	10	1	−6	0.0
h	10	1	1	0.0
g	10	2	2	0.0
h	10	2	0	0.0

Table 1 (*continued*)

g/h	*n*	m	IGRF-2000	SV 2000–2005
g	10	3	−3	0.0
h	10	3	4	0.0
g	10	4	0	0.0
h	10	4	5	0.0
g	10	5	4	0.0
h	10	5	−6	0.0
g	10	6	1	0.0
h	10	6	−1	0.0
g	10	7	2	0.0
h	10	7	−3	0.0
g	10	8	4	0.0
h	10	8	0	0.0
g	10	9	0	0.0
h	10	9	−2	0.0
g	10	10	−1	0.0
h	10	10	−8	0.0

(r denotes the distance from the centre of the Earth, ϕ denotes the longitude eastward from Greenwich and θ denotes the colatitude C90° minus the latitude). When converting from geodetic to geocentric system, the use of the IAU ellipsoid (International Astronomical Union, 1966) is recommended (equatorial radius of 6378.16 km and flattening 1/298.25). The P_n^m (cos θ) are Schmidt quasi-normalised associated Legendre functions of degree n and order m ($n \geq 1$ and $m \geq n$). The maximum spherical harmonic degree of the expansion is N. For more details on main-field modeling, the reader is referred to Chapman and Bartels (1940), Langel (1987), Merrill et al. (1996), Campbell (1997).

The IGRF models for the main field are truncated at $N = 10$ (120 coefficients), which represents a compromise adopted to produce well-determined main-field models while avoiding most of the contamination resulting from crustal sources. Coefficients for dates between the 5-year epochs are obtained by linear interpolation of the corresponding coefficients for the neighbouring epochs. The coefficients of the main field are rounded to the nearest nanotesla (nT) to reflect the limit of the resolution of the available data. The IGRF models for the secular variation are truncated at $N = 8$ (80 coefficients). In this case, the coefficients are rounded at the nearest 0.1 nT/year to reduce the effect of accumulated rounding error.

The new IGRF coefficients and the computer programs for synthesizing the field components are available from the World Data Centers listed below, from the IAGA web page (http://www.ngdc.noaa.gov/IAGA/wg8/wg8.html) and from national geomagnetic observatory agencies and geological surveys throughout the world. They are listed in Table 1. Details of the derivation of the IGRF2000, including the secular variation model for forward-continuation of the field from epoch 2000.0 up to 2005.0, will appear in a special issue of the journal *Earth, Planets and Space* journal in 2000.

The IGRF is produced by the IAGA Working Group V-8, *Analysis of the Global and Regional Geomagnetic Field and its Secular Variation*. During the XXII General Assembly of the International Union of Geodesy and Geophysics held in Birmingham (UK) in July 1999, a task force [1] was created and was assigned the role of preparing a better IGRF model using data from the Ørsted satellite due to the poor quality of the candidate models proposed for the main field (they did not include any Ørsted satellite data). The new main field model adopted for the 2000.0 epoch is the model provided by Nils Olsen and Terry Sabaka.[2] The new secular variation model for the 2000.0–2005.0 time-span is based on candidate models provided by British Geological Survey Edinburgh (Susan Macmillan) and United States Geological Survey (John Quinn), Institut de Physique du Globe de Paris (Benoit Langlais and Mioara Mandea), and Institute of Terrestrial Magnetism, Ionospheric and Radio Wave Propagation, Moscow (Vadim Golovkov). We would like to thank the Ørsted team, the staff of magnetic observatories and survey organisations worldwide for providing data on which the IGRF depends and the World Data Centers for data services. For further information about the IGRF models, contact IAGA Working Group V-8 (Chair: Mioara Mandea, Institut de Physique du Globe de Paris, 4 Place Jussieu, 75252 Paris, France. Fax: 33 238 339 504, e-mail: mioara@ipgp.jussieu.fr).

[1] Frank Lowes (chair), Vadim Golovkov , Susan Macmillan, Mioara Mandea, Nils Olsen and Terry Sabaka.

[2] Information about the model is available on http://www.dsri.dk/Oersted/Field_models

World Data Centers

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World Data Center — A: Rockets and Satellites, NASA/Goddard Space Flight Center, Code 633, Greenbelt, Maryland 20771, USA	Tel.: +1-301-286-6695; fax: fax: +1-301-286-1771; e-mail: request@nssdca.gsfc.nasa.gov; web:http://nssdc.gsfc.nssdc.gov
World Data Center — B2: Solid Earth Geophysics, Russian Geophysical Committee , 3 Molodezhnaya, Moscow 117 296, Russia	Tel.: +7-095-9300-0546; fax: +7-095-930 5509; e-mail: webmaster@wdcb.rssi.ru; web:http://www.wdcb.rssi.ru
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