

# The 9th-Generation International Geomagnetic Reference Field

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

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## SUMMARY

The International Association of Geomagnetism and Aeronomy has recently released the 9th-Generation International Geomagnetic Reference Field—the latest version of a standard mathematical description of the Earth’s main magnetic field used widely in studies of the Earth’s deep interior, its crust and its ionosphere and magnetosphere. The coefficients were recently finalized at the XXIII General Assembly of the International Union of Geophysics and Geodesy, held at Sapporo in Japan in 2003 July. The IGRF is the product of a huge collaborative effort between magnetic field modellers and the institutes involved in collecting and disseminating magnetic field data from satellites and from observatories and surveys around the world.

**Key words:** 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, is the negative gradient of a scalar potential  $V$ , which can be represented by a truncated series expansion

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

where  $r$ ,  $\theta$  and  $\lambda$  are geocentric coordinates ( $r$  is the distance from the centre of the Earth,  $\theta$  is the colatitude, i.e.  $90^\circ$ -latitude, and  $\lambda$  is the longitude),  $R$  is a 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-normalized associated Legendre functions of degree  $n$  and order  $m$ . The coefficients are functions of time and for the IGRF they are assumed to vary at constant rates for 5-year intervals. For more details on main-field modelling the reader is referred to Chapman & Bartels (1940) and Langel (1987).

The coefficients of the 9th-generation IGRF are listed in Table 1 and are available in digital form from the IAGA web site [www.iugg.org/IAGA](http://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 main-field coefficients for 1995.0 and 2000.0 (these are now definitive) and the secular-variation coefficients for 2000.0–2005.0. The previous (8th) generation IGRF was determined by a Task Force at the end of 1999 rather than at IUGG in 1999 July so that as many Ørsted satellite

data could be incorporated as possible (IAGA Division V, Working Group 8, 2000). Since then, much progress has been made on producing models of the Earth’s magnetic field with the unprecedented amount of good quality satellite data available during the first half of the International Decade of Geopotential Research. In order to ensure that the accuracy of the IGRF reflects the high quality of available data, IAGA decided in 2001 that the 9th-generation IGRF should be determined at the IUGG meeting in 2003, and that for 2000.0 the main-field coefficients should extend to degree 13 and be quoted to 0.1 nT precision (to reflect improved instrument resolution).

As it is unusual to have a revision of the IGRF in a year not close to the epoch of a constituent main-field model and as this is the first generation of the model where a definitive set of main-field coefficients is followed by a set of secular-variation coefficients, there is a need to update the nomenclature used. Table 2 gives the new nomenclature that should be used henceforth, and gives 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 data set in order to tie it with adjacent surveys if one does not know which generation of the IGRF was used. It is also recommended that the full name be used, so that it is more apparent whether the output values are ‘predictive’ and are therefore less accurate.

The International Astronomical Union 1966 spheroid has been recommended for coordinate transformations when using the IGRF until now. The parameters of IAU66 are  $a = 6378.160$ ,  $b = 6356.775$  km. However, the World Geodetic System 1984 datum and spheroid are more widely recognized as a standard ( $a = 6378.137$ ,

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Table 1. (Continued)

g/h	n	m	1900.0	1905.0	1910.0	1915.0	1920.0	1925.0	1930.0	1935.0	1940.0	1945.0	1950.0	1955.0	1960.0	1965.0	1970.0	1975.0	1980.0	1985.0	1990.0	1995.0	2000.0	SV	
g	7	6	-12	-12	-13	-15	-16	-17	-18	-19	-20	-17	-18	-20	-18	-23	-23	-23	-23	-23	-23	-24	-25.4	-0.1	
g	7	7	6	6	6	6	6	6	6	6	5	29	19	18	8	1	-2	-5	-2	0	0	-2	-1.2	0.5	
h	7	7	-22	-22	-22	-22	-22	-21	-20	-19	-19	-19	-16	-18	-17	-12	-11	-12	-10	-7	-4	-6	-5.8	0.2	
g	8	0	11	11	11	11	11	11	11	11	11	13	22	11	15	13	14	14	18	21	23	25	24.4	0.1	
g	8	1	8	8	8	8	8	7	7	7	7	7	15	9	6	5	6	6	6	6	5	6	6.6	0.2	
h	8	1	8	8	8	8	8	8	8	8	8	12	5	10	11	7	7	6	7	8	10	11	11.9	-0.2	
g	8	2	-4	-4	-4	-4	-3	-3	-3	-3	-3	-8	-4	-6	-4	-4	-2	-1	-1	0	-1	-6	-9.2	-0.5	
h	8	2	-14	-15	-15	-15	-15	-15	-15	-15	-14	-21	-22	-15	-14	-12	-15	-16	-18	-19	-19	-21	-21.5	0.1	
g	8	3	-9	-9	-9	-9	-9	-9	-9	-9	-10	-5	-1	-14	-11	-14	-13	-12	-11	-11	-10	-9	-7.9	0.2	
g	8	3	7	7	6	6	6	6	5	5	5	-12	0	7	7	9	6	4	4	5	6	8	8.5	0.3	
h	8	4	1	1	1	2	2	2	2	1	1	9	11	6	2	0	-3	-8	-7	-9	-12	-14	-16.6	-0.4	
h	8	4	-13	-13	-13	-13	-14	-14	-14	-15	-15	-7	-21	-23	-18	-16	-17	-19	-22	-23	-22	-23	-21.5	0.4	
g	8	5	2	2	2	3	4	4	4	5	6	7	15	10	10	8	5	4	4	4	3	9	9.1	0.2	
h	8	5	5	5	5	5	5	5	5	5	5	2	-8	3	4	4	6	6	9	11	12	15	15.5	0.1	
g	8	6	-9	-8	-8	-8	-7	-7	-6	-6	-5	-10	-13	-7	-5	-1	0	0	3	4	4	6	7	0.5	
h	8	6	16	16	16	16	17	17	18	18	19	18	17	23	23	24	21	18	16	14	12	11	8.9	-0.3	
g	8	7	5	5	5	6	6	7	8	8	9	7	5	6	10	11	11	10	6	4	2	-5	-7.9	-0.7	
h	8	7	-5	-5	-5	-5	-5	-5	-5	-5	-4	1	-3	-4	1	-3	-6	-10	-13	-15	-16	-16	-14.9	0.4	
g	8	8	8	8	8	8	8	8	8	7	7	2	-1	9	8	4	3	1	-1	-4	-6	-7	-7	0.4	
h	8	8	-18	-18	-18	-18	-19	-19	-19	-19	-19	-11	-17	-13	-20	-17	-16	-17	-15	-11	-10	-4	-2.1	0.4	
g	9	0	8	8	8	8	8	8	8	8	8	5	3	4	4	8	8	7	5	5	4	4	5		
g	9	1	10	10	10	10	10	10	10	10	10	-21	-7	9	6	10	10	10	10	10	9	9	9.4		
h	9	1	-20	-20	-20	-20	-20	-20	-20	-20	-21	-27	-24	-11	-18	-22	-21	-21	-21	-21	-20	-20	-19.7		
g	9	2	14	14	14	14	14	14	14	15	15	17	19	12	12	15	16	16	16	15	15	15	13.4		
h	9	2	-11	-11	-11	-11	-11	-11	-12	-12	-12	-11	-25	-5	-9	-13	-12	-12	-12	-12	-12	-10	-8.4		
g	9	3	5	5	5	5	5	5	5	5	5	29	12	7	7	2	6	7	9	9	9	12	12.5		
h	9	3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-9	2	6	0	-4	-4	-4	-5	-6	-7	-6	-6.2		
g	9	4	12	12	12	12	12	12	12	11	11	3	10	2	1	10	10	10	9	9	9	8	6.3		
h	9	4	-3	-3	-3	-3	-3	-3	-3	-3	-3	-2	6	6	0	-4	-4	-4	-5	-6	-7	-6	-6.2		
g	9	5	1	1	1	1	1	1	1	1	1	16	5	4	4	-1	-1	-3	-3	-4	-4	-8	-8.9		
h	9	5	-2	-2	-2	-2	-2	-2	-2	-3	-3	0	-2	-2	-3	-5	-5	-6	-6	-6	-7	-8	-8.4		
g	9	6	-2	-2	-2	-2	-2	-2	-2	-2	-2	-3	-5	1	-1	-1	0	-1	-1	-1	-2	-1	-1.5		
h	9	6	8	8	8	8	8	8	8	8	8	9	8	10	9	10	10	10	9	9	9	8	8.4		
g	9	7	2	2	2	2	2	2	2	3	3	-4	-2	2	-2	5	3	4	7	7	7	10	9.3		
h	9	7	10	10	10	10	10	10	10	10	11	6	8	7	8	10	11	11	10	9	8	5	3.8		
g	9	8	-1	0	0	0	0	0	0	0	1	-3	3	2	3	1	1	1	2	1	1	-2	-4.3		
h	9	8	-2	-2	-2	-2	-2	-2	-2	-2	-2	1	-11	-6	0	-4	-2	-3	-6	-7	-7	-8	-8.2		
g	9	9	-1	-1	-1	-1	-1	-1	-1	-2	-2	-4	8	5	-1	-2	-1	-2	-5	-5	-6	-8	-8.2		
h	9	9	2	2	2	2	2	2	2	2	2	8	-7	5	1	1	1	1	2	2	2	3	2.6		
g	10	0	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-8	-3	1	-2	-3	-3	-4	-4	-3	-3	-2.6		
h	10	1	-4	-4	-4	-4	-4	-4	-4	-4	-4	11	4	-5	-3	-3	-3	-3	-4	-4	-4	-6	-6		
g	10	1	2	2	2	2	2	2	2	2	2	5	13	-4	-4	2	1	1	1	1	2	1	1.7		
h	10	1	2	2	2	2	2	2	2	2	2	1	-1	4	4	2	2	2	2	3	2	2	1.7		
g	10	2	1	1	1	1	1	1	1	1	1	1	-2	0	1	1	1	1	0	0	1	0	0		
h	10	2	-5	-5	-5	-5	-5	-5	-5	-5	-5	-20	13	-2	0	-5	-5	-5	-5	-5	-5	-4	-3.1		
g	10	3	-2	-2	-2	-2	-2	-2	-2	-2	-2	-5	-4	-3	-1	-2	-1	-2	-2	-2	-2	-1	-0.5		
h	10	3	-2	-2	-2	-2	-2	-2	-2	-2	-2	-4	-3	-1	-2	-2	-2	-2	-2	-2	-2	-1	-0.5		
g	10	4	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	5	4.9		
h	10	4	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	5	4.9		
g	10	5	-4	-4	-4	-4	-4	-4	-4	-4	-4	-6	-3	-4	-5	-4	-4	-4	-4	-4	-4	-5	-5.9		
h	10	5	4	4	4	4	4	4	4	4	4	8	12	4	6	4	4	4	3	3	3	2	1	-1.2	
g	10	6	0	0	0	0	0	0	0	0	0	6	6	1	1	1	1	0	0	0	0	-1	-1.2		
h	10	6	0	0	0	0	0	0	0	0	0	6	6	1	1	1	1	1	1	1	1	2	2	2	
g	10	7	0	0	0	0	0	0	0	0	0	-1	3	-2	1	0	1	1	1	1	1	2	2	2	
h	10	7	-2	-2	-2	-2	-2	-2	-2	-1	-1	-4	-3	-2	6	-1	-1	-1	-1	-1	-1	-2	-2.9		
g	10	8	2	2	2	2	2	2	2	2	2	-3	2	6	-1	2	0	0	2	2	3	5	4.2		
h	10	8	4	4	4	4	4	4	4	4	4	-2	6	7	6	3	3	3	4	4	4	1	0.2		
g	10	9	2	2	2	2	2	2	2	2	2	5	10	-2	2	2	3	3	3	3	3	1	0.3		
h	10	9	0	0	0	0	0	0	0	0	0	0	11	-1	0	1	1	1	1	1	0	-1	-2		
g	10	10	0	0	0	0	0	0	0	0	0	-2	3	0	0	0	-1	-1	0	0	0	0	-1.1		
h	10	10	-6	-6	-6	-6	-6	-6	-6	-6	-6	-2	8	-3	-7	-6	-4	-5	-6	-6	-6	-7	-7.4		

Table 1. (Continued.)

g/h	n	m	1900.0	1905.0	1910.0	1915.0	1920.0	1925.0	1930.0	1935.0	1940.0	1945.0	1950.0	1955.0	1960.0	1965.0	1970.0	1975.0	1980.0	1985.0	1990.0	1995.0	2000.0	SV	
g	11	0																						2.7	
g	11	1																							-1.7
h	11	1																							0.1
g	11	2																							-1.9
h	11	2																							1.3
g	11	3																							1.5
g	11	3																							-0.9
g	11	4																							-0.1
h	11	4																							-2.6
g	11	5																							0.1
h	11	5																							0.9
g	11	6																							-0.7
h	11	6																							-0.7
g	11	7																							0.7
h	11	7																							-2.8
g	11	8																							1.7
h	11	8																							-0.9
g	11	9																							0.1
h	11	9																							-1.2
g	11	10																							1.2
h	11	10																							-1.9
g	11	11																							4
h	11	11																							-0.9
g	12	0																							-2.2
h	12	1																							-0.3
g	12	1																							-0.4
h	12	2																							0.2
g	12	2																							0.3
h	12	2																							0.9
g	12	3																							2.5
h	12	3																							-0.2
g	12	4																							-2.6
h	12	4																							0.9
g	12	5																							0.7
h	12	5																							-0.5
g	12	6																							0.3
h	12	6																							-0.5
g	12	7																							0.3
h	12	7																							0
g	12	8																							-0.3
h	12	8																							0
g	12	9																							-0.4
h	12	9																							0.3
g	12	10																							-0.1
h	12	10																							-0.9
g	12	11																							-0.2
h	12	11																							-0.4
g	12	12																							-0.4
h	12	12																							0.8
g	13	0																							-0.2
h	13	1																							-0.9
g	13	1																							0.3
h	13	2																							0.2
g	13	2																							0.1
h	13	3																							1.8
g	13	3																							-0.4
h	13	4																							-0.4
g	13	4																							-0.4

Table 1. (Continued.)

g/h	n	m	1900.0	1910.0	1915.0	1920.0	1925.0	1930.0	1935.0	1940.0	1945.0	1950.0	1955.0	1960.0	1965.0	1970.0	1975.0	1980.0	1985.0	1990.0	1995.0	2000.0	SV
g	13	5																					1.3
h	13	5																					-1
g	13	6																					-0.4
h	13	6																					-0.1
g	13	7																					0.7
h	13	7																					0.7
g	13	8																					-0.4
h	13	8																					0.3
g	13	9																					0.3
h	13	9																					0.6
g	13	10																					-0.1
h	13	10																					0.3
g	13	11																					0.4
h	13	11																					0.4
g	13	12																					-0.2
h	13	12																					0
g	13	13																					-0.5
h	13	13																					0.1
																							-0.9

Table 2. Summary of nomenclature and IGRF history.

Full name	Short name	Valid for	Definitive for
IGRF 9th generation (revised 2003)	IGRF-9	1900.0–2005.0	1945.0–2000.0
IGRF 8th generation (revised 1999)	IGRF-8	1900.0–2005.0	1945.0–1990.0
IGRF 7th generation (revised 1995)	IGRF-7	1900.0–2000.0	1945.0–1990.0
IGRF 6th generation (revised 1991)	IGRF-6	1945.0–1995.0	1945.0–1985.0
IGRF 5th generation (revised 1987)	IGRF-5	1945.0–1990.0	1945.0–1980.0
IGRF 4th generation (revised 1985)	IGRF-4	1945.0–1990.0	1965.0–1980.0
IGRF 3rd generation (revised 1981)	IGRF-3	1965.0–1985.0	1965.0–1975.0
IGRF 2nd generation (revised 1975)	IGRF-2	1955.0–1980.0	–
IGRF 1st generation (revised 1969)	IGRF-1	1955.0–1975.0	–

$b = 6356.752$  km). Present-day satellite magnetic data are mostly positioned using WGS84 but for other data we are often unaware which datum is used. Differences in output IGRF magnetic field values at the Earth's surface are less than 1 nT when the change of spheroid is made. It is recognized that some software already in circulation uses WGS84. It is therefore recommended that the WGS84 spheroid is used for coordinate transformations for the IGRF.

The 9th-generation IGRF coefficients were computed from candidate sets of coefficients produced by the participating members of IAGA Working Group V-8 listed in this paper. Their institutes and the many organizations involved in operating magnetic survey satellites, observatories, magnetic survey programmes and World Data Centers are to be thanked for their continuing support of the IGRF project.

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