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International Geomagnetic Reference Field—the tenth generation

Susan Macmillan[1] and Stefan Maus[2]

[1]*British Geological Survey, Murchison House, West Mains Road, Edinburgh, EH9 3LA, U.K.*
[2]*National Geophysical Data Center, E/GC 325 Broadway, Boulder, Colorado, 80305-3328, U.S.A.*

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The International Geomagnetic Reference Field (IGRF) 10th Generation was adopted in 2004 by the International Association of Geomagnetism and Aeronomy (IAGA) Working Group V-MOD. It is the latest version of a standard mathematical description of the Earth's main magnetic field and is used widely in studies of the Earth's deep interior, its crust and its ionosphere and magnetosphere. This generation differs from the previous generation with the replacement of the secular-variation model for 2000.0–2005.0 with a main-field model at 2005.0 and a secular-variation model for 2005.0–2010.0. 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. This paper lists the new coefficients and includes contour maps and pole positions.

Key words: Main field modelling, IGRF.

1. Introduction

The IGRF is an internationally agreed series of global spherical harmonic models of the Earth's magnetic field whose sources are mainly in the Earth's core. In source-free regions at the Earth's surface and above, the main field, with sources inside 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, θ, λ are geocentric coordinates (r is the distance from the centre of the Earth, θ is the colatitude, i.e. 90°-latitude, and λ 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-normalised 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 five-year intervals. For more details on main-field modelling the reader is referred to Chapman and Bartels (1940) and Langel (1987).

The first generation of the IGRF was available in 1969, and this current revision is the 10th generation of the IGRF. For a history of the IGRF see Barton (1997). The new constituent models are a main-field model for 2005.0 and a secular-variation model for 2005.0–2010.0.

2. Development of New Constituent Models for IGRF-10

The call for candidate main-field models at epoch 2005.0 to maximum degree 13 and for annual secular-variation models to maximum degree 8 for 2005.0–2010.0 went out in March 2004 from the chairman, Stefan Maus, of the IAGA Working Group V-MOD Task Force and in response, models were received in October 2004 from four teams. The teams are: Danish Space Research Institute (Denmark), Goddard Space Flight Center (USA) and Newcastle University (UK)—team A; National Geophysical Data Center (USA), GeoForschungZentrum (Germany)—team B; British Geological Survey (UK)—team C; and Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation (Russia)—team D.

Whilst all teams have had access to similar datasets the most distinctive features of each of their contributions may be summarised as follows. Team A applied ionospheric corrections, team B applied diamagnetic plasma correction to CHAMP data and oceanic tidal corrections to all input data, team C used observatory hourly mean data and incorporated outputs from linear prediction filters to long-term annual mean data into their secular-variation model, and team D used natural orthogonal component analysis. Sections 1 and 2 of Maus *et al.* (2005a) give some more information about the candidate models submitted, but for detailed information the reader is referred to Olsen *et al.* (2005), Maus *et al.* (2005b), Lesur *et al.* (2005) and Golovkov *et al.* (2005) in this special issue of the journal Earth, Planets and Space.

A web page was set up and the models with associated descriptions were posted during October 2004 (www.ngdc.noaa.gov/IAGA/vmod/IGRF-10). In November 2004 various evaluations of the candidate models were posted, and these are summarised in Maus *et al.* (2005a), and the final decision on the selection and weighting of

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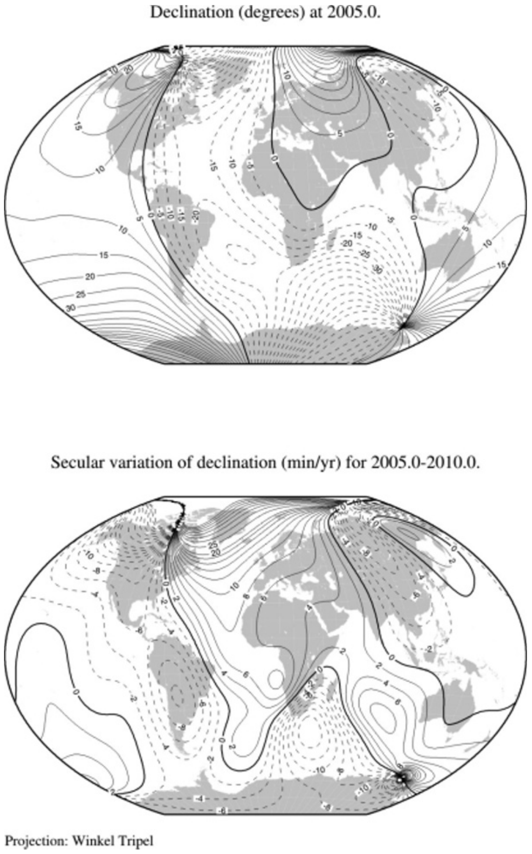
Table 1. Spherical harmonic (Gauss) coefficients for the IGRF main-field model at 2005.0 and secular-variation model for 2005.0–2010.0 in the 10th Generation IGRF.

g/h	n	m	MF 2005 (nT)	SV 2005–2010 (nT/year)
g	1	0	−29556.8	8.8
g	1	1	−1671.8	10.8
h	1	1	5080.0	−21.3
g	2	0	−2340.5	−15.0
g	2	1	3047.0	−6.9
h	2	1	−2594.9	−23.3
g	2	2	1656.9	−1.0
h	2	2	−516.7	−14.0
g	3	0	1335.7	−0.3
g	3	1	−2305.3	−3.1
h	3	1	−200.4	5.4
g	3	2	1246.8	−0.9
h	3	2	269.3	−6.5
g	3	3	674.4	−6.8
h	3	3	−524.5	−2.0
g	4	0	919.8	−2.5
g	4	1	798.2	2.8
h	4	1	281.4	2.0
g	4	2	211.5	−7.1
h	4	2	−225.8	1.8
g	4	3	−379.5	5.9
h	4	3	145.7	5.6
g	4	4	100.2	−3.2
h	4	4	−304.7	0.0
g	5	0	−227.6	−2.6
g	5	1	354.4	0.4
h	5	1	42.7	0.1
g	5	2	208.8	−3.0
h	5	2	179.8	1.8
g	5	3	−136.6	−1.2
h	5	3	−123.0	2.0
g	5	4	−168.3	0.2
h	5	4	−19.5	4.5
g	5	5	−14.1	−0.6
h	5	5	103.6	−1.0
g	6	0	72.9	−0.8
g	6	1	69.6	0.2
h	6	1	−20.2	−0.4
g	6	2	76.6	−0.2
h	6	2	54.7	−1.9
g	6	3	−151.1	2.1
h	6	3	63.7	−0.4
g	6	4	−15.0	−2.1
h	6	4	−63.4	−0.4
g	6	5	14.7	−0.4
h	6	5	0.0	−0.2
g	6	6	−86.4	1.3
h	6	6	50.3	0.9
g	7	0	79.8	−0.4
g	7	1	−74.4	0.0
h	7	1	−61.4	0.8
g	7	2	−1.4	−0.2
h	7	2	−22.5	0.4
g	7	3	38.6	1.1
h	7	3	6.9	0.1
g	7	4	12.3	0.6
h	7	4	25.4	0.2
g	7	5	9.4	0.4
h	7	5	10.9	−0.9
g	7	6	5.5	−0.5
h	7	6	−26.4	−0.3
g	7	7	2.0	0.9
h	7	7	−4.8	0.3
g	8	0	24.8	−0.2
g	8	1	7.7	0.2
h	8	1	11.2	−0.2
g	8	2	−11.4	−0.2
h	8	2	−21.0	0.2
g	8	3	−6.8	0.2
h	8	3	9.7	0.2
g	8	4	−18.0	−0.2
h	8	4	−19.8	0.4
g	8	5	10.0	0.2
h	8	5	16.1	0.2
g	8	6	9.4	0.5
h	8	6	7.7	−0.3
g	8	7	−11.4	−0.7
h	8	7	−12.8	0.5
g	8	8	−5.0	0.5
h	8	8	−0.1	0.4
g	9	0	5.6	
g	9	1	9.8	
h	9	1	−20.1	
g	9	2	3.6	
h	9	2	12.9	
g	9	3	−7.0	
h	9	3	12.7	
g	9	4	5.0	
h	9	4	−6.7	
g	9	5	−10.8	
h	9	5	−8.1	
g	9	6	−1.3	
h	9	6	8.1	
g	9	7	8.7	
h	9	7	2.9	
g	9	8	−6.7	
h	9	8	−7.9	
g	9	9	−9.2	
h	9	9	5.9	
g	10	0	−2.2	
g	10	1	−6.3	
h	10	1	2.4	
g	10	2	1.6	
h	10	2	0.2	
g	10	3	−2.5	
h	10	3	4.4	
g	10	4	−0.1	
h	10	4	4.7	
g	10	5	3.0	
h	10	5	−6.5	
g	10	6	0.3	
h	10	6	−1.0	
g	10	7	2.1	
h	10	7	−3.4	
g	10	8	3.9	
h	10	8	−0.9	
g	10	9	−0.1	
h	11	1	0.3	
h	10	9	−2.3	
g	10	10	−2.2	
h	10	10	−8.0	
g	11	0	2.9	
g	11	1	−1.6	
g	11	2	−1.7	
h	11	2	1.4	
g	11	3	1.5	
h	11	3	−0.7	
g	11	4	−0.2	
h	11	4	−2.4	
g	11	5	0.2	
h	11	5	0.9	
g	11	6	−0.7	

Table 1. (continued).

g/h	n	m	MF 2005 (nT)	SV 2005–2010 (nT/year)
h	11	6	−0.6	
g	11	7	0.5	
h	11	7	−2.7	
g	11	8	1.8	
h	11	8	−1.0	
g	11	9	0.1	
h	11	9	−1.5	
g	11	10	1.0	
h	11	10	−2.0	
g	11	11	4.1	
h	11	11	−1.4	
g	12	0	−2.2	
g	12	1	−0.3	
h	12	1	−0.5	
g	12	2	0.3	
h	12	2	0.3	
g	12	3	0.9	
h	12	3	2.3	
g	12	4	−0.4	
h	12	4	−2.7	
g	12	5	1.0	
h	12	5	0.6	
g	12	6	−0.4	
h	12	6	0.4	
g	12	7	0.5	
h	12	7	0.0	
g	12	8	−0.3	
h	12	8	0.0	
g	12	9	−0.4	
h	12	9	0.3	
g	12	10	0.0	
h	12	10	−0.8	
g	12	11	−0.4	
h	12	11	−0.4	
g	12	12	0.0	
h	12	12	1.0	
g	13	0	−0.2	
g	13	1	−0.9	
h	13	1	−0.7	
g	13	2	0.3	
h	13	2	0.3	
g	13	3	0.3	
h	13	3	1.7	
g	13	4	−0.4	
h	13	4	−0.5	
g	13	5	1.2	
h	13	5	−1.0	
g	13	6	−0.4	
h	13	6	0.0	
g	13	7	0.7	
h	13	7	0.7	
g	13	8	−0.3	
h	13	8	0.2	
g	13	9	0.4	
h	13	9	0.6	
g	13	10	−0.1	
h	13	10	0.4	
g	13	11	0.4	
h	13	11	−0.2	
g	13	12	−0.1	
h	13	12	−0.5	
g	13	13	−0.3	
h	13	13	−1.0	

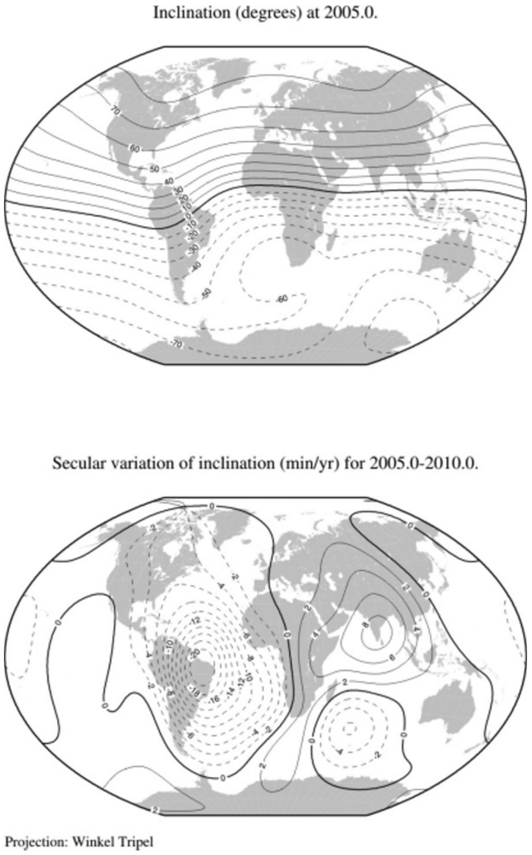


Declination (degrees) at 2005.0.

Secular variation of declination (min/yr) for 2005.0-2010.0.

Projection: Winkel Tripel

Fig. 1. Contour maps for the D component from IGRF-10.



Inclination (degrees) at 2005.0.

Secular variation of inclination (min/yr) for 2005.0-2010.0.

Projection: Winkel Tripel

Fig. 2. Contour maps for the I component from IGRF-10.

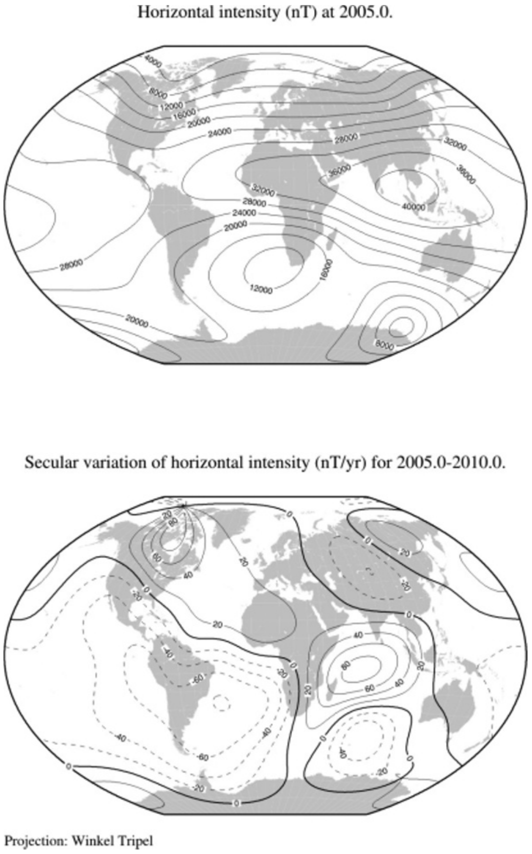


Fig. 3. Contour maps of the H component from IGRF-10.

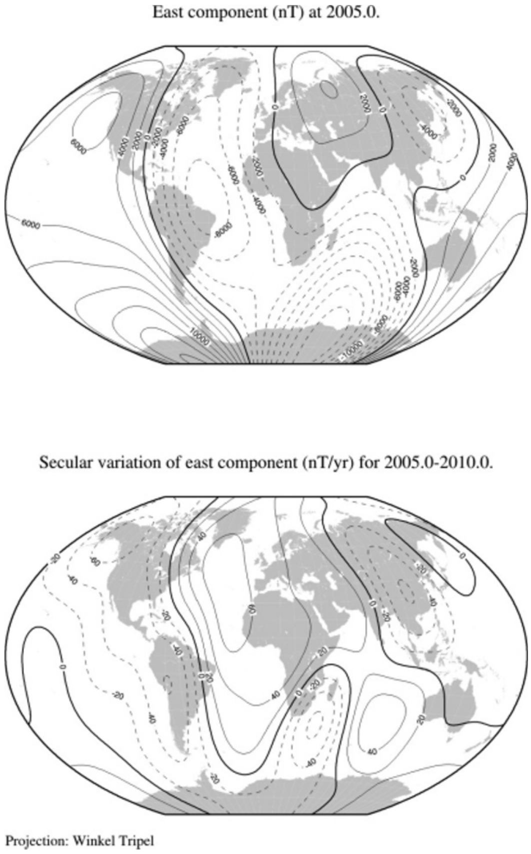


Fig. 5. Contour maps for the Y component from IGRF-10.

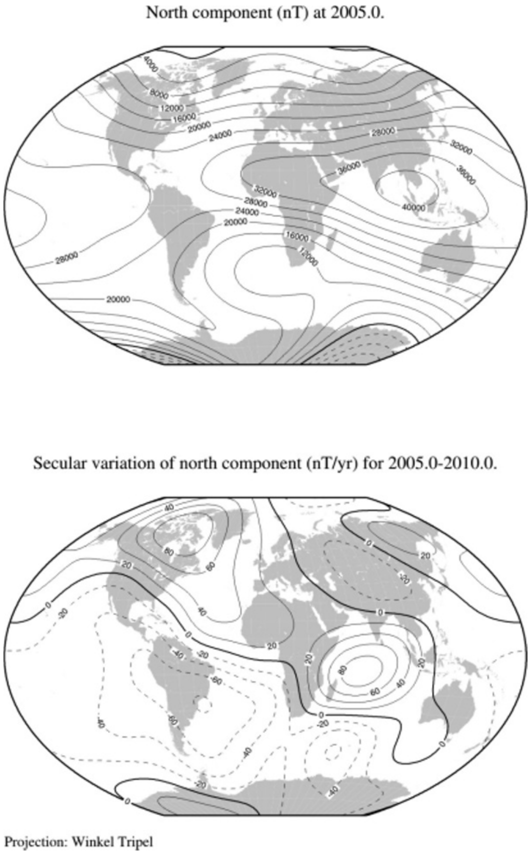


Fig. 4. Contour maps for the X component from IGRF-10.

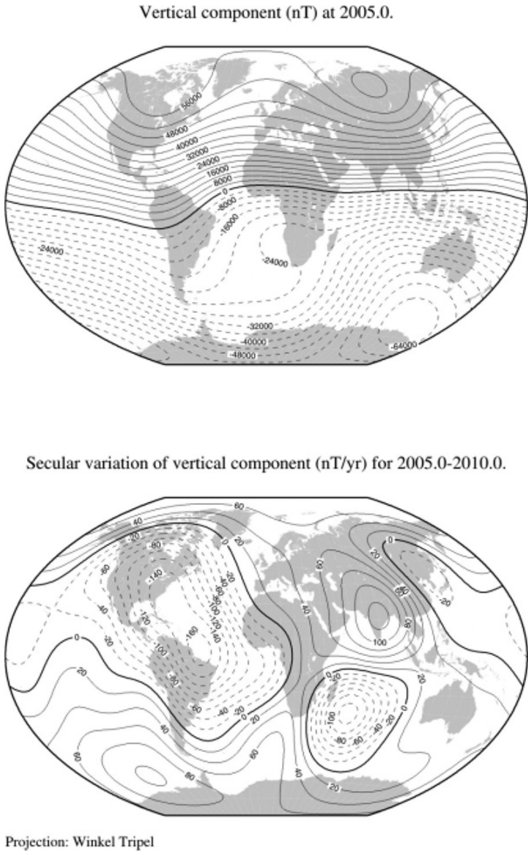
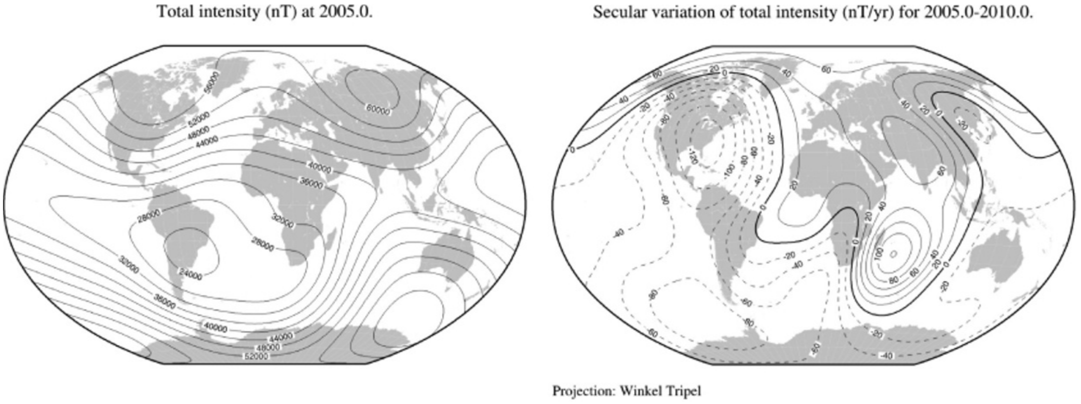


Fig. 6. Contour maps for the Z component from IGRF-10.


Total intensity (nT) at 2005.0.

Secular variation of total intensity (nT/yr) for 2005.0-2010.0.

Projection: Winkel Tripel

Fig. 7. Contour maps of the F component from IGRF-10.

Table 2. 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 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	—

candidate models was taken at the start of December 2004. Thus the new coefficients extending the previous generation of the IGRF to beyond its expiry date at end of 2004 were available on the internet in time.

3. Coefficients and Maps

The coefficients of the main-field model at 2005.0 and secular-variation model for 2005.0–2010.0 are listed in Table 1 and are available in digital form from the IAGA web site www.iugg.org/IAGA and the World Data Centres listed at the end of this paper, along with software to compute magnetic field values from them.

Figures 1–7 show global maps of the various magnetic elements and their annual rates of change for the period 2005.0–2010.0.

Table 2 gives the nomenclature that should be used with the IGRF, and gives a brief summary of its history (Barton, 1997).

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. 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 World Geodetic System 1984 datum and spheroid is recommended for use in coordinate transformations as they are widely recognised as standards (major axis = 6378.137 km, minor axis = 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 this spheroid is used in place of the former preferred spheroid, the International Astronomical Union 1966 spheroid.

Table 3. Positions of geomagnetic and magnetic poles 1900.0–2010.0 estimated from IGRF-10.

	North dipole pole		North dip pole		South dip pole	
Epoch	Latitude	Longitude	Latitude	Longitude	Latitude	Longitude
1900.0	78.68	−68.79	70.46	−96.19	−71.72	148.32
1905.0	78.68	−68.75	70.66	−96.48	−71.46	148.55
1910.0	78.66	−68.72	70.79	−96.72	−71.15	148.64
1915.0	78.64	−68.57	71.03	−97.03	−70.80	148.54
1920.0	78.63	−68.38	71.34	−97.39	−70.41	148.20
1925.0	78.62	−68.27	71.79	−98.00	−69.99	147.63
1930.0	78.60	−68.26	72.27	−98.69	−69.52	146.79
1935.0	78.57	−68.36	72.80	−99.34	−69.06	145.77
1940.0	78.55	−68.51	73.30	−99.87	−68.57	144.60
1945.0	78.55	−68.53	73.93	−100.24	−68.15	144.44
1950.0	78.55	−68.85	74.64	−100.86	−67.89	143.55
1955.0	78.54	−69.16	75.18	−101.41	−67.19	141.50
1960.0	78.58	−69.47	75.30	−101.03	−66.70	140.23
1965.0	78.60	−69.85	75.63	−101.34	−66.33	139.53
1970.0	78.66	−70.18	75.88	−100.98	−66.02	139.40
1975.0	78.76	−70.47	76.15	−100.64	−65.74	139.52
1980.0	78.88	−70.76	76.91	−101.68	−65.42	139.34
1985.0	79.04	−70.90	77.40	−102.61	−65.13	139.18
1990.0	79.21	−71.13	78.09	−103.68	−64.91	138.90
1995.0	79.39	−71.42	79.09	−105.42	−64.79	138.76
2000.0	79.61	−71.57	80.97	−109.64	−64.66	138.30
2005.0	79.81	−71.78	83.23	−118.31	−64.54	137.86
2010.0	80.02	−71.98	85.19	−133.16	−64.44	137.44

4. Pole Positions Computed from IGRF-10

One use of the IGRF is for computing locations of poles through time. Table 3 lists the locations of the geomagnetic (or dipole) north pole (the south pole is exactly antipodal to this) and the magnetic (or dip) poles. These have been computed at 5-year intervals using the 10th generation IGRF.

World Data Centres

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

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

Table 4. List of agencies supporting observatories whose data were used in deriving the new constituent models in IGRF-10.

Supporting Agency	Country	Observatory IAGA code
Centre de Recherche en Astronomie Astrophysique et Geophysique	ALGERIA	TAM
Servicio Meteorologico Nacional	ARGENTINA	PIL
Universidad Nacional de la Plata	ARGENTINA	LAS, TRW
Geoscience Australia	AUSTRALIA	ASP, CNB, CSY, CTA, DVS, GNA, KDU, LRM, MAW, MCQ
Zentralanstalt für Meteorologie und Geodynamik	AUSTRIA	WIK
Institut Royal Météorologique	BELGIUM	DOU, MAB
CNPq-Observatório Nacional	BRAZIL	TTB, VSS
Academy of Sciences	BULGARIA	PAG
Geological Survey of Canada	CANADA	ALE, BLC, CBB, FCC, GLN, IQA, MBC, MEA, OTT, PBQ, RES, STJ, VIC,YKC
Academy of Sciences	CHINA	BMT
State Seismological Bureau	CHINA	BJI, CDP, CHD, CNH, DLN, GLM, GZH, KSH, LSA, LZH, MZL, QGZ, QIX, QZH, SSH, THJ, WHN, WMQ
Instituto Geográfico Agustín Codazzi	COLOMBIA	FUQ
Instituto Costarricense de Electricidad	COSTA RICA	CRP
Academy of Sciences	CZECH REPUBLIC	BDV
Danish Meteorological Institute	DENMARK	BFE, GDH, NAQ, THL
National Research Institute of Astronomy and Geophysics	EGYPT	MLT
Addis Ababa University	ETHIOPIA	AAE
Finnish Meteorological Institute	FINLAND	NUR
Geophysical Observatory	FINLAND	OUL, SOD
Institut de Physique du Globe de Paris	FRANCE	CLF, KOU, PPT
Ecole et Observatoire des Sciences de la Terre	FRANCE	AMS, CZT, DRV, PAF
Institut Français de Recherche Scientifique pour le Développement	FRANCE	BNG, MBO
Academy of Sciences	GEORGIA	TFS
Universitat München	GERMANY	FUR
Alfred-Wegener-Institute for Polar & Marine Research	GERMANY	VNA
GeoForschungsZentrum Potsdam	GERMANY	NGK, WNG
Institute of Geology and Mineral Exploration	GREECE	PEG
Academy of Sciences	HUNGARY	NCK
Eötvös Loránd Geophysical Institute	HUNGARY	THY
University of Iceland	ICELAND	LRV
Indian Institute of Geomagnetism	INDIA	ABG, NGP, PND, SHL, SIL, TIR, TRD, UJJ, VSK
National Geophysical Research Institute	INDIA	ETT, HYB
Survey of India	INDIA	SAB
Badan Meteorologi dan Geofisika	INDONESIA	TND, TUN
Meteorological and Geophysical Agency	INDONESIA	TNG
Meteorological Service	IRELAND	VAL
Survey of Israel	ISRAEL	AMT, BGY, ELT
Instituto Nazionale di Geofisica	ITALY	AQU, CTS, TNB
Japan Coast Guard	JAPAN	HTY
Japan Meteorological Agency	JAPAN	CBI, KAK, KNY, MMB
Geographical Survey Institute	JAPAN	ESA, KNZ, MIZ
National Institute of Polar Research	JAPAN	SYO
Ministry of Education and Science	KAZAKHSTAN	AAA
National Centre for Geophysical Research	LEBANON	QSB
Université d'Antananarivo	MADAGASCAR	TAN
Ciudad Universitaria	MEXICO	TEO
Institute of Geological and Nuclear Sciences	NEW ZEALAND	API, EYR, SBA
University of Bergen	NORWAY	DOB
University of Tromsø	NORWAY	BJN, DOB, NAL, TRO
Space & Upper Atmosphere Research Commission	PAKISTAN	KRC
Meteorological Department	PAKISTAN	QUE
Instituto Geofisico del Peru	PERU	ANC, HUA
Academy of Sciences	POLAND	BEL, HLP, HRN
Universidade de Coimbra	PORTUGAL	COI
Directorate General of Telecommunications	REPUBLIC OF CHINA	LNP
Instituto Nacional de Geologia	REPÚBLICA DE MOÇAMBIQUE	LMM
Geological Survey of Romania	ROMANIA	SUA
Arctic and Antarctic Research Institute	RUSSIA	CCS, DIK, HIS, MIR, MOL, TIK, VOS
Academy of Sciences	RUSSIA	ARS, ASH, BOX, KIV, KZN, LNN, LVV, MGD, MNK, MOS, NKK, NVS, ODE, PET, POD, TKT, VLA, YAK
Institute of Solar-Terrestrial Physics	RUSSIA	IRT
Slovenska Akademia Vied	SLOVAKIA	HRB
National Research Foundation	SOUTH AFRICA	HBK, HER, TSU
Observatori de l'Ebre	SPAIN	EBR, LIV
Real Instituto y Observatorio de la Armada	SPAIN	SFS
Instituto Geográfico Nacional	SPAIN	GUI, SPT
Sveriges Geologiska Undersökning	SWEDEN	ABK, LOV, UPS
Swedish Institute of Space Physics	SWEDEN	KIR
Boğaziçi University	TURKEY	ISK
Academy of Sciences	UKRAINE	AIA
British Geological Survey	UNITED KINGDOM	ASC, ESK, HAD, LER, PST
US Geological Survey	UNITED STATES	BRW, BOU, BSL, CMO, DLR, FRD, FRN, GUA, HON, MID, NEW, SIT, SJG, TUC
National Centre for Science and Technology	VIETNAM	CPA, PHU
Geomagnetic Institute	YUGOSLAVIA	GCK

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S. Macmillan (e-mail: smac@bgs.ac.uk) and S. Maus