Chapter 10

The International Geomagnetic Reference Field

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Abstract The International Geomagnetic Reference Field (IGRF) is an internationally agreed and widely used mathematical model of the Earth's magnetic field of internal origin. It is produced and agreed under the auspices of IAGA. We describe its inception in the 1960s and how it has developed since. We also describe the current generation of the IGRF and potential future developments. Maps of the geomagnetic field derived from the IGRF and valid for 2010–2015 are also included.

10.1 Introduction

The International Geomagnetic Reference Field (IGRF) is an internationally agreed and widely used mathematical model of the Earth's magnetic field of internal origin. We describe its inception in the 1960s and how it has developed since. We also describe the current generation of the IGRF (the 11th) and potential future developments.

10.2 Scope of the IGRF

The IGRF is designed to provide an easily accessible approximation, near and above the Earth's surface, to the large-scale part of the Earth's magnetic field which has its origin inside the surface. This field is predominantly that due to electric currents in the Earth's liquid metal core.

Rapid field fluctuations due to variations of electric current systems in the magnetosphere and ionosphere, as well as the weak, smaller scale field due to magnetized crustal rocks are not included in the IGRF.

10.3 Inception and Development

The concept of an IGRF grew out of discussions concerning the presentation of the results of the World Magnetic Survey (WMS) (Barraclough, 1993). The WMS was a deferred element in the programme of the 1957–1958 International Geophysical Year which, during the next 12 years, encouraged magnetic surveys on land, at sea, in the air and from satellites and organised the collection and analysis of the results. At a meeting in 1960, the Committee on World Magnetic Survey and Magnetic Charts of IAGA recommended that, as part of the WMS programme, a global spherical harmonic model of the field be derived using the results of the WMS. This proposal was accepted but another 8 years of argument and discussion followed (see Zmuda (1971) for a summary of this, together with a detailed description of the WMS programme) before the first IGRF was ratified by IAGA in 1969.

The IGRF has now been revised and updated ten times since 1969 and a summary of the revision history is given in Table 10.1 (see also Barraclough (1993) and Barton (1997) and references therein). More details concerning the latest revision—IGRF 11th generation (Finlay et al. 2010)—are given below.

Each generation of the IGRF comprises several constituent models at five-year intervals, each one of

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Table 10.1 Summary of IGRF history

Full name	Short name	Valid for	Definitive for	References
IGRF 11th generation (revised 2009)	IGRF-11	1900.0–2015.0	1945.0–2005.0	Finlay et al. (2010)
IGRF 10th generation (revised 2004)	IGRF-10	1900.0–2010.0	1945.0–2000.0	Macmillan and Maus (2005)
IGRF 9th generation (revised 2003)	IGRF-9	1900.0–2005.0	1945.0–2000.0	Macmillan et al. (2003)
IGRF 8th generation (revised 1999)	IGRF-8	1900.0–2005.0	1945.0–1990.0	Mandea and Macmillan (2000)
IGRF 7th generation (revised 1995)	IGRF-7	1900.0–2000.0	1945.0–1990.0	Barton (1997)
IGRF 6th generation (revised 1991)	IGRF-6	1945.0–1995.0	1945.0–1985.0	Langel (1992)
IGRF 5th generation (revised 1987)	IGRF-5	1945.0–1990.0	1945.0–1980.0	Langel et al. (1988)
IGRF 4th generation (revised 1985)	IGRF-4	1945.0–1990.0	1965.0–1980.0	Barraclough (1987)
IGRF 3rd generation (revised 1981)	IGRF-3	1965.0–1985.0	1965.0–1975.0	Peddie (1982)
IGRF 2nd generation (revised 1975)	IGRF-2	1955.0–1980.0	–	IAGA (1975)
IGRF 1st generation (1969)	IGRF-1	1955.0–1975.0	–	Zmuda (1971)

which is designated definitive or non-definitive. Once a constituent model is designated definitive it is called a Definitive Geomagnetic Reference Field (DGRF) and it is not revised in subsequent generations of the IGRF. The non-definitive constituent models are referred to, rather confusingly, as IGRFs.

10.4 Applications and Availability

The original idea of an IGRF had come from global modellers, including those who produced such models in association with the production of navigational charts. However, the IGRF as it was first formulated was not considered to be accurate or detailed enough for navigational purposes.

The majority of users of the IGRF at the time of its inception consisted of geophysicists interested in the geological interpretation of regional magnetic surveys. An initial stage in such work is the removal of a background field, that approximates the field whose sources are in the Earth's core, from the observations. With different background fields being used for different surveys, difficulties arose when adjacent surveys had to be combined. An internationally agreed global model, accurately representing the field from the core, eased this problem considerably.

Another group of researchers who were becoming increasingly interested in descriptions of the geomagnetic field at this time were those studying the ionosphere and magnetosphere and behaviour of cosmic rays in the vicinity of the Earth. This remains an important user community today, with the IGRF being the internal field model of many ionospheric and magnetospheric models (for example, Tsygenenko, 2002).

Geomagnetic coordinate systems are almost exclusively based on the IGRF (Russell, 1971; Hapgood, 1992, 1997). A commonly used axis in these coordinate systems is that of the centred dipole and for 2010.0 from IGRF-11, this is tilted at an angle of 9.99° to the Earth's axis of rotation and has longitude 72.22°W in the northern hemisphere.

Today, there are many on-line calculators available for the IGRF, screenshots of two examples are shown in Figs. 10.1 and 10.2. Most on-line calculators demand position input relative to the surface of the WGS84 reference ellipsoid model of the Earth, and convert the position from a geodetic to a geocentric coordinate system for use in the spherical harmonic expansion. A few (e.g., Fig. 10.1) also permit the input position to be in the geocentric coordinate system.

10.5 Geomagnetic Field Components

The geomagnetic field vector **B** is fully described by an appropriate set of three elements selected from the seven possible elements (Fig. 10.3). The orthogonal set is the northerly intensity X, the easterly intensity Y and the vertical intensity Z (positive downwards). The other elements are the horizontal intensity H, the total intensity F, the inclination angle I, (also called the dip angle and measured from the horizontal plane to the field vector, positive downwards), and the declination angle D (also called the magnetic variation and

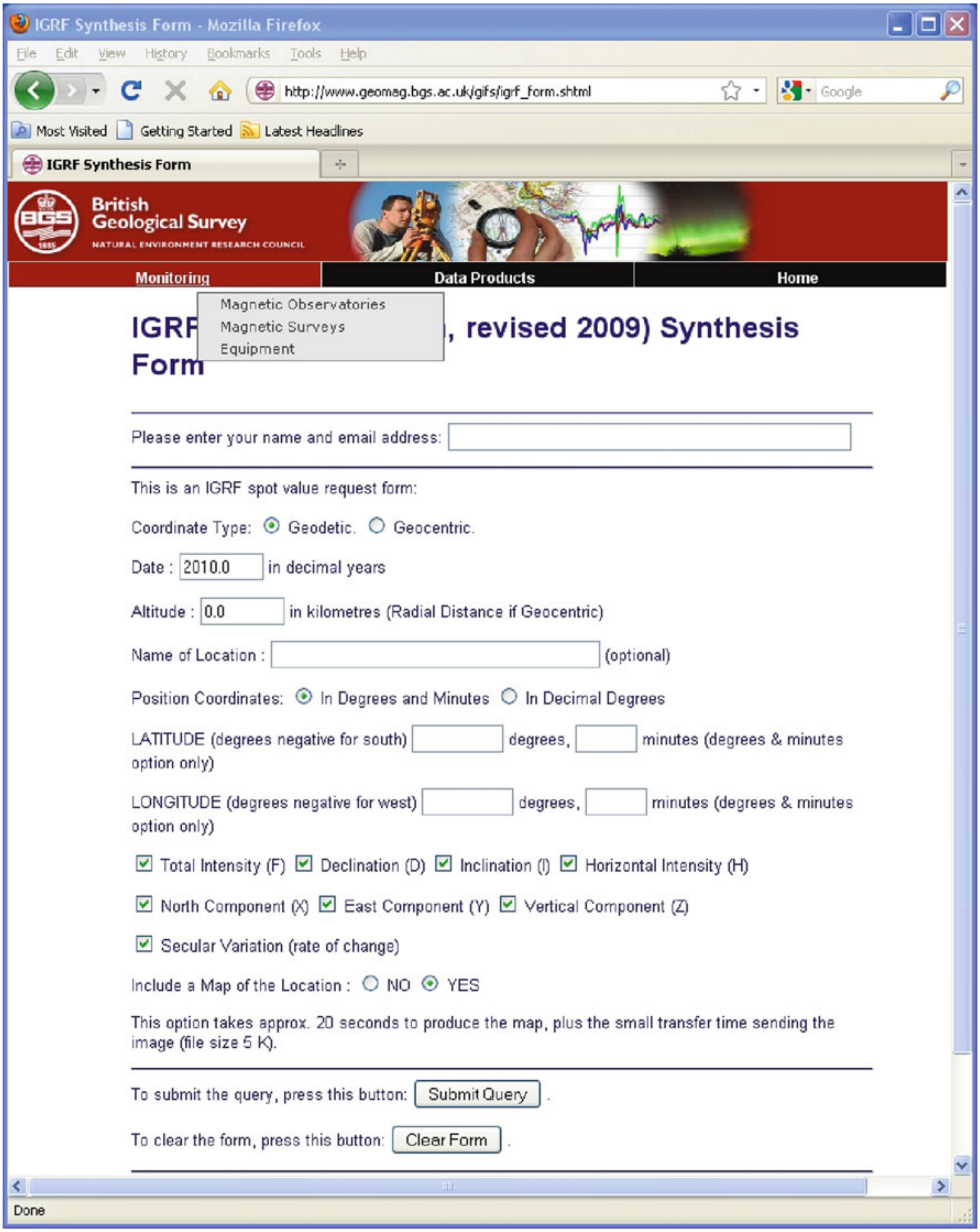

Fig. 10.1 On-line IGRF calculator maintained by the British Geological Survey

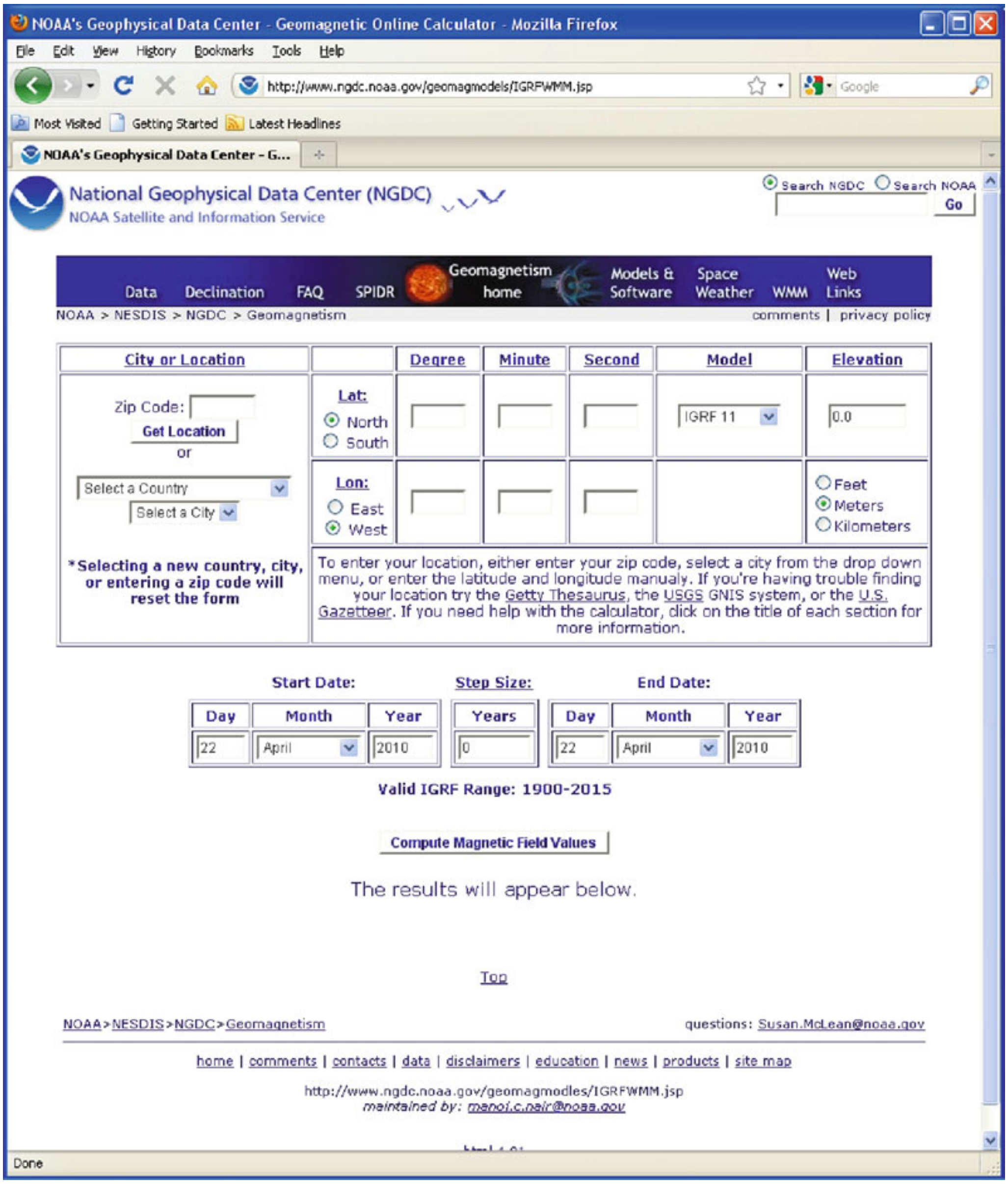

Fig. 10.2 On-line calculator maintained by the US National Oceanographic and Atmospheric Administration

measured clockwise from true north to the horizontal component of the field vector). In this description of X, Y, Z, H, F, I and D, the vertical direction is assumed perpendicular to the WGS84 reference ellipsoid model of the Earth's surface and the clockwise rotational direction is determined by a view from above the Earth. Conventionally the intensities are given in units of nanoTeslas (nT).

10.6 Mathematical Representation

In a source-free region the Earth's magnetic field **B** is the negative gradient of a magnetic potential V that satisfies Laplace's equation:

$$\mathrm{B} = -\nabla V \quad \text{where} \quad \nabla^2 V = 0$$

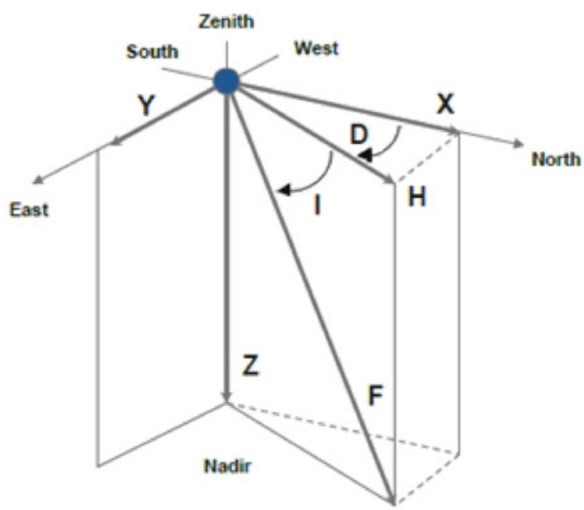

Fig. 10.3 The 7 elements of the magnetic field

Each constituent model of the IGRF is a set of spherical harmonics of degree n and order m, representing a solution to Laplace's equation for the magnetic potential arising from sources inside the Earth at a given epoch; the harmonics are associated with the Gauss coefficients g_n^m and h_n^m:

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

In this equation r, θ, λ are geocentric coordinates (r is the distance from the centre of the Earth, θ is the geocentric colatitude, i.e., 90°—latitude, and λ is the longitude), a is a reference radius for the Earth (6371.2 km), $P_n^m(\theta)$ are the Schmidt semi-normalised associated Legendre polynomials and $n_{\max}$ is the maximum degree of the spherical harmonic expansion. Conventionally the units of the Gauss coefficients are nT.

In addition to the DGRFs and IGRFs which represent the main field at 5-year intervals there is always a predictive secular-variation model to allow computation of the magnetic field for some time after the epoch of the last main-field model, generally for 5 years after but sometimes longer. Recent generations of the IGRF have been produced in a timely manner, i.e., before the previous generation was no longer strictly valid, but this was not always the case for the early generations of the IGRF. The predictive secular-variation model comprises Gauss coefficients in units of nT/year. Between the DGRF and IGRF main-field models the magnetic potential, and therefore the magnetic field, is assumed to vary linearly with time.

New constituent models of the IGRF are carefully produced and well documented. The IAGA Working Group charged with the production of the IGRF invites submissions of candidate models several months in advance of decision dates. Detailed evaluations are then made of all submitted models and the final decision is made by the IAGA Working Group. The evaluations are also widely documented. For most generations of the IGRF there is a special issue of a journal containing papers describing the candidate models and the evaluations. For IGRF-10 see volume 57, number 12 of the journal *Earth, Planets and Space*, a similar special issue of *Earth, Planets and Space* is in preparation for IGRF-11 at time of writing.

The coefficients of the new constituent models are derived by taking means (sometimes weighted) of the coefficients of selected candidate models. This method of combining several candidate models has been used in almost all generations as, not only are different selections of available data made by the teams submitting models, there are many different methods for dealing with the fields which are not modelled by the IGRF, for example the ionospheric, magnetospheric and crustal fields.

The constituent main-field models of the most recent generation of the IGRF (Finlay et al. 2010) extend to spherical harmonic degree 10 up to and including epoch 1995.0; thereafter they extend to degree 13 to take advantage of the excellent coverage and quality of satellite data provided by Ørsted and CHAMP. The predictive secular-variation model has extended to degree 8 for all generations of the IGRF to date.

10.7 IGRF 11th Generation (Revised 2009)

For IGRF-11 a Working Group was set up at the 2007 IAGA meeting in Toulouse. During 2009 eight modelling teams around the world worked on production of candidate sets of coefficients for IGRF-11. These were a DGRF set of coefficients for 2005.0, an IGRF set of coefficients for 2010.0 and a predictive secular-variation set of coefficients for 2010.0–2015.0 (Finlay et al. 2010). At the 2009 Sopron meeting of IAGA a report on progress towards IGRF-11 was given, i.e., the teams participating and summaries of their data selections and modelling techniques. The final sets of coefficients were determined later in the year by vote.

The most common approach taken by each modelling team to produce their candidate models was to select data from the satellite and ground-based datasets available, to decide on an appropriate parameterisation of parent models, invert the selected datasets for the parent models, iterate this process several times, and extract or extrapolate the final sets of candidate coefficients. The parent models generally included time-varying signals of external origin, i.e., from outside the Earth in the ionosphere and magnetosphere, and signals from the Earth's crust represented by spherical harmonic degrees greater than 13. This is because any observation of the magnetic field includes signals from the core, the crust and the coupled ionosphere-magnetosphere system. When trying to model the field of internal origin, the biggest challenge at present is probably dealing with the simultaneous presence of time-varying fields produced by the ionosphere and magnetosphere. Most teams select periods of undisturbed data (using a variety of indices and solar wind data) on the night-side of the Earth in order to reduce the ionospheric and magnetospheric contamination but there is no general agreement as to how best to choose these periods. (There is a trade-off between good spatial and temporal coverage and not using contaminated data.) Then modellers generally attempt an estimation of any remaining signal in the data of external origin, often relying on other data (indices) to do so. The results are variable.

One predictive secular variation candidate model, however, was derived from the assimilation of a parent model into a numerical geodynamo model, showing how this area of ongoing research is now starting to find application.

The evaluation process involved several independent assessments followed by a vote. The final IGRF-11 coefficients are available from the IAGA web page at http://www.ngdc.noaa.gov/IAGA/vmod/.

The coefficients which are revised for IGRF-11 are listed in Table 10.2.

Table 10.2 The new coefficients (in nT and nT/year) in IGRF-11

g/h	n	m	2005.0	2010.0	SV
g	1	0	−29554.63	−29496.5	11.4
g	1	1	−1669.05	−1585.9	16.7
h	1	1	5077.99	4945.1	−28.8
g	2	0	−2337.24	−2396.6	−11.3
g	2	1	3047.69	3026.0	−3.9
h	2	1	−2594.50	−2707.7	−23.0
g	2	2	1657.76	1668.6	2.7
h	2	2	−515.43	−575.4	−12.9
g	3	0	1336.30	1339.7	1.3
g	3	1	−2305.83	−2326.3	−3.9
h	3	1	−198.86	−160.5	8.6
g	3	2	1246.39	1231.7	−2.9
h	3	2	269.72	251.7	−2.9
g	3	3	672.51	634.2	−8.1
h	3	3	−524.72	−536.8	−2.1
g	4	0	920.55	912.6	−1.4
g	4	1	797.96	809.0	2.0
h	4	1	282.07	286.4	0.4
g	4	2	210.65	166.6	−8.9
h	4	2	−225.23	−211.2	3.2
g	4	3	−379.86	−357.1	4.4
h	4	3	145.15	164.4	3.6
g	4	4	100.00	89.7	−2.3
h	4	4	−305.36	−309.2	−0.8
g	5	0	−227.00	−231.1	−0.5
g	5	1	354.41	357.2	0.5
h	5	1	42.72	44.7	0.5
g	5	2	208.95	200.3	−1.5
h	5	2	180.25	188.9	1.5
g	5	3	−136.54	−141.2	−0.7
h	5	3	−123.45	−118.1	0.9
g	5	4	−168.05	−163.1	1.3
h	5	4	−19.57	0.1	3.7
g	5	5	−13.55	−7.7	1.4
h	5	5	103.85	100.9	−0.6
g	6	0	73.60	72.8	−0.3
g	6	1	69.56	68.6	−0.3
h	6	1	−20.33	−20.8	−0.1
g	6	2	76.74	76.0	−0.3
h	6	2	54.75	44.2	−2.1
g	6	3	−151.34	−141.4	1.9
h	6	3	63.63	61.5	−0.4
g	6	4	−14.58	−22.9	−1.6
h	6	4	−63.53	−66.3	−0.5
g	6	5	14.58	13.1	−0.2
h	6	5	0.24	3.1	0.8
g	6	6	−86.36	−77.9	1.8
h	6	6	50.94	54.9	0.5
g	7	0	79.88	80.4	0.2
g	7	1	−74.46	−75.0	−0.1
h	7	1	−61.14	−57.8	0.6
g	7	2	−1.65	−4.7	−0.6

Table 10.2 (continued)

g/h	*n*	m	2005.0	2010.0	SV
h	7	2	−22.57	−21.2	0.3
g	7	3	38.73	45.3	1.4
h	7	3	6.82	6.6	−0.2
g	7	4	12.30	14.0	0.3
h	7	4	25.35	24.9	−0.1
g	7	5	9.37	10.4	0.1
h	7	5	10.93	7.0	−0.8
g	7	6	5.42	1.6	−0.8
h	7	6	−26.32	−27.7	−0.3
g	7	7	1.94	4.9	0.4
h	7	7	−4.64	−3.4	0.2
g	8	0	24.80	24.3	−0.1
g	8	1	7.62	8.2	0.1
h	8	1	11.20	10.9	0.0
g	8	2	−11.73	−14.5	−0.5
h	8	2	−20.88	−20.0	0.2
g	8	3	−6.88	−5.7	0.3
h	8	3	9.83	11.9	0.5
g	8	4	−18.11	−19.3	−0.3
h	8	4	−19.71	−17.4	0.4
g	8	5	10.17	11.6	0.3
h	8	5	16.22	16.7	0.1
g	8	6	9.36	10.9	0.2
h	8	6	7.61	7.1	−0.1
g	8	7	−11.25	−14.1	−0.5
h	8	7	−12.76	−10.8	0.4
g	8	8	−4.87	−3.7	0.2
h	8	8	−0.06	1.7	0.4
g	9	0	5.58	5.4	0.0
g	9	1	9.76	9.4	0.0
h	9	1	−20.11	−20.5	0.0
g	9	2	3.58	3.4	0.0
h	9	2	12.69	11.6	0.0
g	9	3	−6.94	−5.3	0.0
h	9	3	12.67	12.8	0.0
g	9	4	5.01	3.1	0.0
h	9	4	−6.72	−7.2	0.0
g	9	5	−10.76	−12.4	0.0
h	9	5	−8.16	−7.4	0.0
g	9	6	−1.25	−0.8	0.0
h	9	6	8.10	8.0	0.0
g	9	7	8.76	8.4	0.0
h	9	7	2.92	2.2	0.0
g	9	8	−6.66	−8.4	0.0
h	9	8	−7.73	−6.1	0.0
g	9	9	−9.22	−10.1	0.0
h	9	9	6.01	7.0	0.0
g	10	0	−2.17	−2.0	0.0
g	10	1	−6.12	−6.3	0.0
h	10	1	2.19	2.8	0.0
g	10	2	1.42	0.9	0.0
h	10	2	0.10	−0.1	0.0
g	10	3	−2.35	−1.1	0.0

Table 10.2 (continued)

g/h	n	*m*	2005.0	2010.0	SV
h	10	3	4.46	4.7	0.0
g	10	4	−0.15	−0.2	0.0
h	10	4	4.76	4.4	0.0
g	10	5	3.06	2.5	0.0
h	10	5	−6.58	−7.2	0.0
g	10	6	0.29	−0.3	0.0
h	10	6	−1.01	−1.0	0.0
g	10	7	2.06	2.2	0.0
h	10	7	−3.47	−4.0	0.0
g	10	8	3.77	3.1	0.0
h	10	8	−0.86	−2.0	0.0
g	10	9	−0.21	−1.0	0.0
h	10	9	−2.31	−2.0	0.0
g	10	10	−2.09	−2.8	0.0
h	10	10	−7.93	−8.3	0.0
g	11	0	2.95	3.0	0.0
g	11	1	−1.60	−1.5	0.0
h	11	1	0.26	0.1	0.0
g	11	2	−1.88	−2.1	0.0
h	11	2	1.44	1.7	0.0
g	11	3	1.44	1.6	0.0
h	11	3	−0.77	−0.6	0.0
g	11	4	−0.31	−0.5	0.0
h	11	4	−2.27	−1.8	0.0
g	11	5	0.29	0.5	0.0
h	11	5	0.90	0.9	0.0
g	11	6	−0.79	−0.8	0.0
h	11	6	−0.58	−0.4	0.0
g	11	7	0.53	0.4	0.0
h	11	7	−2.69	−2.5	0.0
g	11	8	1.80	1.8	0.0
h	11	8	−1.08	−1.3	0.0
g	11	9	0.16	0.2	0.0
h	11	9	−1.58	−2.1	0.0
g	11	10	0.96	0.8	0.0
h	11	10	−1.90	−1.9	0.0
g	11	11	3.99	3.8	0.0
h	11	11	−1.39	−1.8	0.0
g	12	0	−2.15	−2.1	0.0
g	12	1	−0.29	−0.2	0.0
h	12	1	−0.55	−0.8	0.0
g	12	2	0.21	0.3	0.0
h	12	2	0.23	0.3	0.0
g	12	3	0.89	1.0	0.0
h	12	3	2.38	2.2	0.0
g	12	4	−0.38	−0.7	0.0
h	12	4	−2.63	−2.5	0.0
g	12	5	0.96	0.9	0.0
h	12	5	0.61	0.5	0.0
g	12	6	−0.30	−0.1	0.0
h	12	6	0.40	0.6	0.0
g	12	7	0.46	0.5	0.0
h	12	7	0.01	0.0	0.0

Table 10.2 (continued)

g/h	n	*m*	2005.0	2010.0	SV
g	12	8	−0.35	−0.4	0.0
h	12	8	0.02	0.1	0.0
g	12	9	−0.36	−0.4	0.0
h	12	9	0.28	0.3	0.0
g	12	10	0.08	0.2	0.0
h	12	10	−0.87	−0.9	0.0
g	12	11	−0.49	−0.8	0.0
h	12	11	−0.34	−0.2	0.0
g	12	12	−0.08	0.0	0.0
h	12	12	0.88	0.8	0.0
g	13	0	−0.16	−0.2	0.0
g	13	1	−0.88	−0.9	0.0
h	13	1	−0.76	−0.8	0.0
g	13	2	0.30	0.3	0.0
h	13	2	0.33	0.3	0.0
g	13	3	0.28	0.4	0.0
h	13	3	1.72	1.7	0.0
g	13	4	−0.43	−0.4	0.0
h	13	4	−0.54	−0.6	0.0
g	13	5	1.18	1.1	0.0
h	13	5	−1.07	−1.2	0.0
g	13	6	−0.37	−0.3	0.0
h	13	6	−0.04	−0.1	0.0
g	13	7	0.75	0.8	0.0
h	13	7	0.63	0.5	0.0
g	13	8	−0.26	−0.2	0.0
h	13	8	0.21	0.1	0.0
g	13	9	0.35	0.4	0.0
h	13	9	0.53	0.5	0.0
g	13	10	−0.05	0.0	0.0
h	13	10	0.38	0.4	0.0
g	13	11	0.41	0.4	0.0
h	13	11	−0.22	−0.2	0.0
g	13	12	−0.10	−0.3	0.0
h	13	12	−0.57	−0.5	0.0
g	13	13	−0.18	−0.3	0.0
h	13	13	−0.82	−0.8	0.0

10.8 Global Magnetic Field Patterns

Global maps of the magnetic elements, based on IGRF-11 and valid for the period 2010.0 to 2015.0, are shown in Figs. 10.4, 10.5, 10.6, 10.7, 10.8, 10.9, and 10.10.

Using IGRF-11 to compute the root mean square magnetic field vector at the Earth's surface through time arising from all spherical harmonic terms ($n \leq 10$), the centred dipole terms ($n = 1$) and the non-dipole terms ($1 < n \leq 10$), gives Fig. 10.11. It can be seen that since 1900 the Earth's magnetic field is weakening overall, by reduction of the dipole field. However the non-dipolar part is strengthening, though to a lesser extent. This may have consequences for the trajectories of energetic charged particles that enter the Earth's magnetosphere. One manifestation of this increase in the non-dipole field is the deepening, and westwards movement, of the South Atlantic Anomaly (Macmillan et al. 2009), a region where the Earth's magnetic field is weaker than elsewhere (see Fig. 10.8). In this region energetic charged particles are able to penetrate closer to the Earth, and cause a radiation hazard for satellites passing through the region.

10.9 Limitations

The limitations of the IGRF are discussed in a "health warning" available from the IAGA web page at http://www.ngdc.noaa.gov/IAGA/vmod/. The accuracy of the IGRF is considered to be limited by a combination of two types of error, namely error of commission where there is a difference between the IGRF and the part of the field that it is attempting to model, and error of omission where the error is the part of the field that the IGRF is not attempting to model. The difficulty is that it is not easy to directly separate those parts of the observed magnetic field due to the different sources since they each produce signals spanning a range of wavelengths and frequencies. In fact the separation can only properly be done through co-estimation of all sources.

The errors of commission are estimated mainly by comparing different generations of the IGRF at dates common to both. They vary considerably with time. Recent constituent models of the IGRF for epochs when satellite data were available are thought to be within 5-10 nT root mean square (rms) of the true value, the true value in this case being the internal field up to spherical harmonic degree n_{max} at the Earth's surface. Other constituent models are thought to be within 50–300 nT of the true value.

The error of omission is dominated by the crustal field and the rms value is estimated to be 200–300 nT. At high latitudes and on the day-side of the Earth the ionospheric and magnetospheric fields will become more significant.

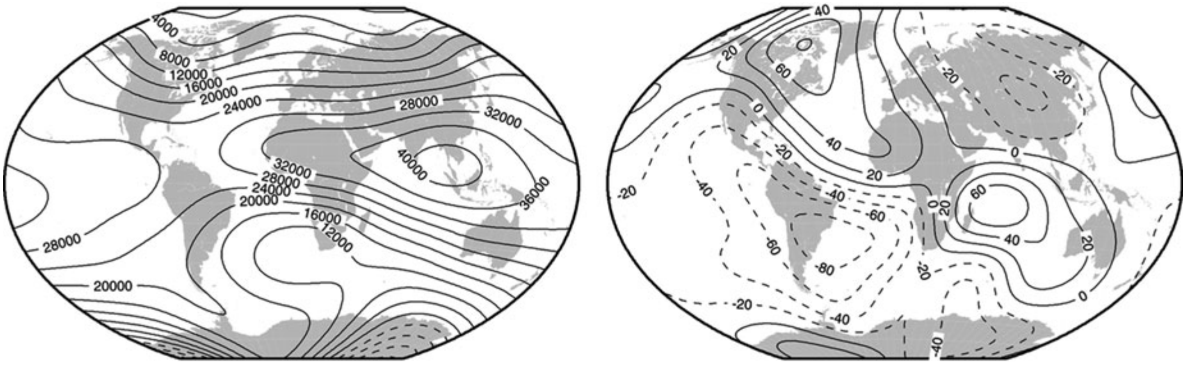

Fig. 10.4 Northerly intensity *X* (nT) at 2010.0 and its rate of change (nT/year) for 2010.0–2015.0 computed from IGRF-11. Map projection is Winkel Tripel

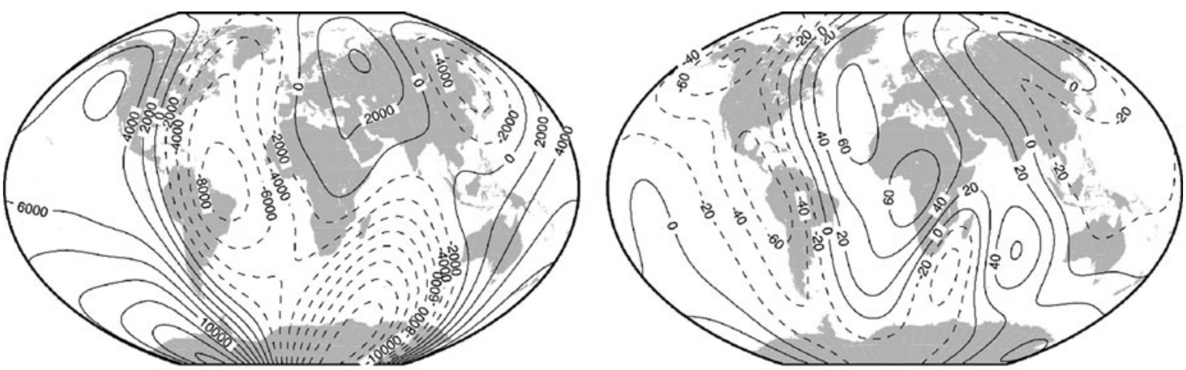

Fig. 10.5 Easterly intensity *Y* (nT) at 2010.0 and its rate of change (nT/year) for 2010.0–2015.0 computed from IGRF-11

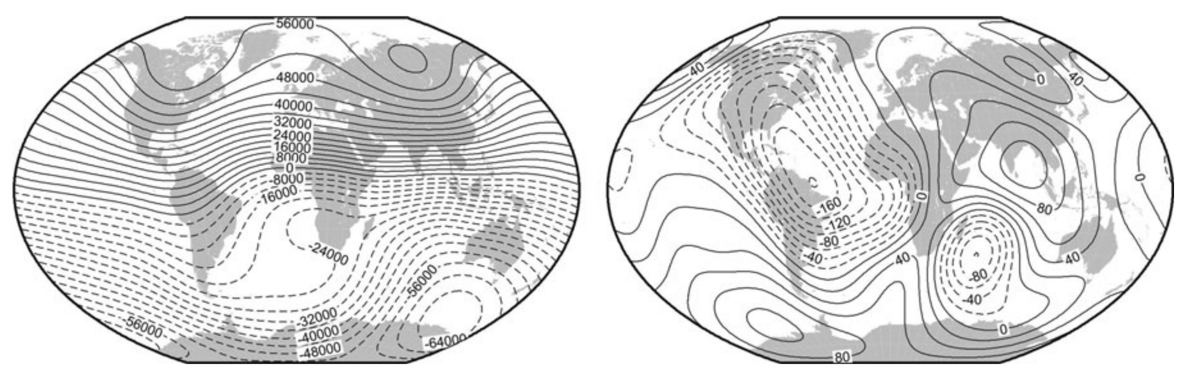

Fig. 10.6 Vertical intensity *Z* (nT) at 2010.0 and its rate of change (nT/year) for 2010.0–2015.0 computed from IGRF-11

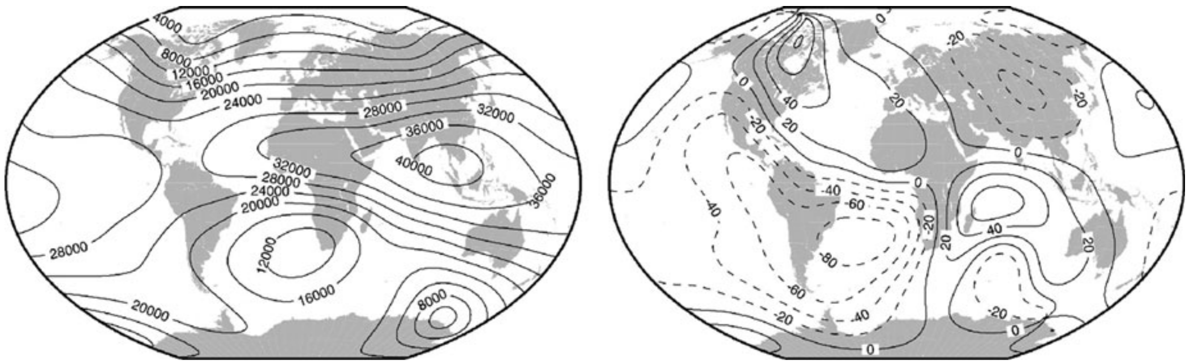

Fig. 10.7 Horizontal intensity H (nT) at 2010.0 and its rate of change (nT/year) for 2010.0–2015.0 computed from IGRF-11

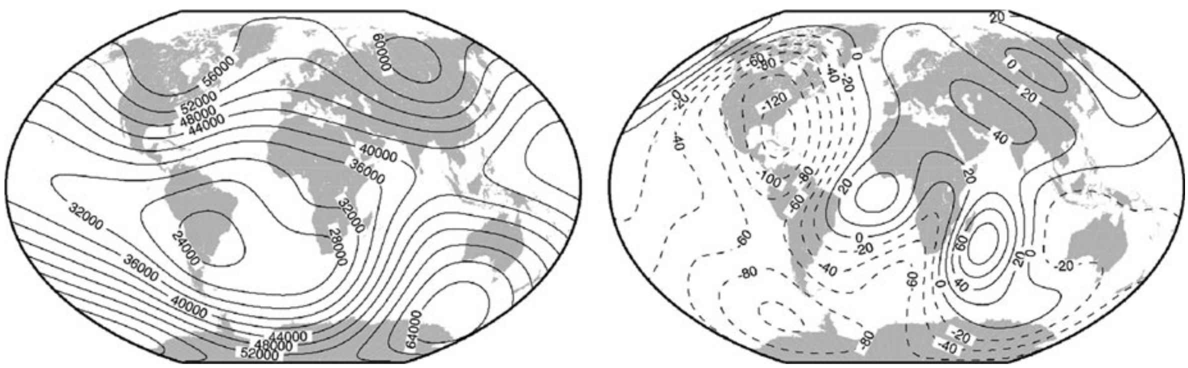

Fig. 10.8 Total intensity F (nT) at 2010.0 and its rate of change (nT/year) for 2010.0–2015.0 computed from IGRF-11

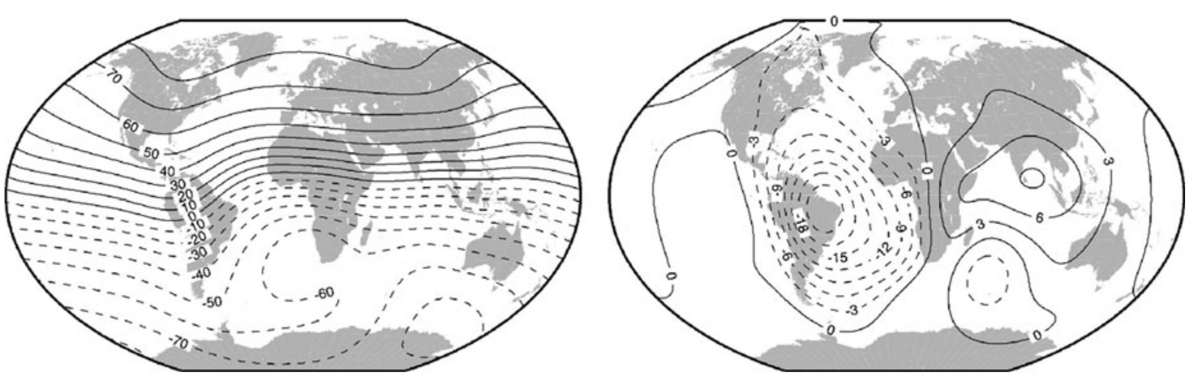

Fig. 10.9 Inclination I (degrees) at 2010.0 and its rate of change (arc-minutes/year) for 2010.0–2015.0 computed from IGRF-11

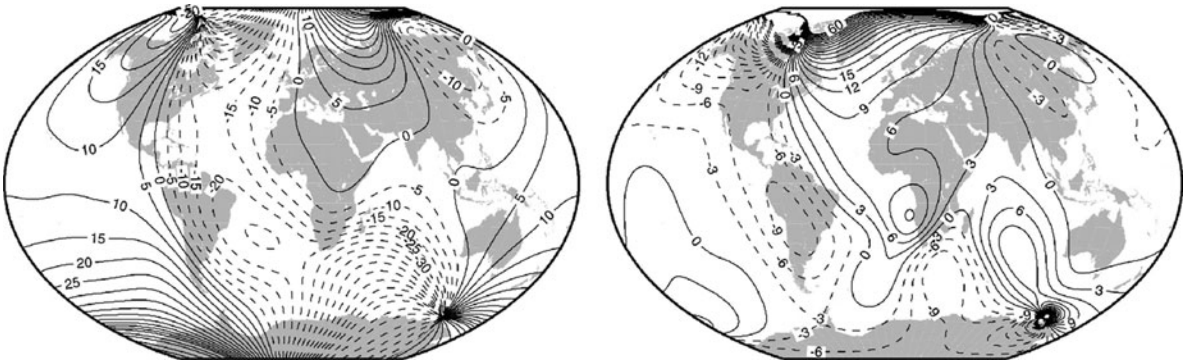

Fig. 10.10 Declination *D* (degrees) at 2010.0 and its rate of change (arc-minutes/year) for 2010.0–2015.0 computed from IGRF-11. (Declination is not defined at the geographic poles or magnetic dip poles)

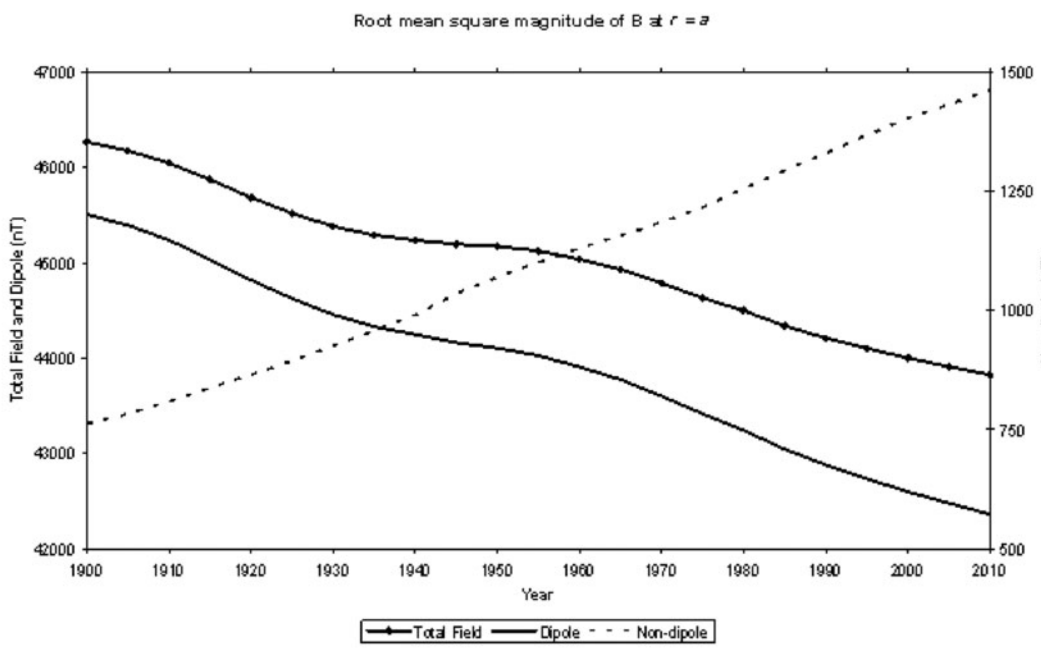

Fig. 10.11 The decline of the whole, and dipolar part of the magnetic field at the Earth's surface and the growth of the non-dipolar part since 1900, computed from IGRF-11

10.10 Future

Firstly, no model of the geomagnetic field can be better than the data on which it is based. An assured supply of high-quality data distributed evenly over the Earth's surface is therefore a fundamental prerequisite for a continuing and acceptably accurate IGRF. Data from magnetic observatories continue to be the most important source of information about time-varying fields. However their spatial distribution is poor and although data from other sources such as repeat stations, the high-level vector aeromagnetic survey Project MAGNET programme lasting from 1953 to 1994, and marine magnetic surveys have all helped to fill in the gaps, the best spatial coverage is provided by near-polar satellites. Measurements made by the

POGO satellites (1965–1971), Magsat (1979–1980), POGS (1990–1993), Ørsted (1999–), SAC-C (2001–2004) and CHAMP (2000-) have all been utilised in the production of the IGRF. They have ultimately been responsible for the improved quality of recent IGRF revisions.

Secondly, the future of the IGRF depends on the continuing ability of the groups who have contributed candidate models to the IGRF revision process to produce global magnetic field models. This ability is dependent on the willingness of the relevant funding authorities to continue to support this type of work.

Thirdly, the continued interest of IAGA is a necessary requirement for the future of the IGRF. This is assured as long as there is, as at present, a large and diverse group of IGRF-users around the world. One reason why the IGRF has gained the reputation it has is because it is endorsed and recommended by IAGA, the recognised international organisation for geomagnetism.

Finally the extension of the predictive secular-variation model to spherical harmonic degree 13 (same as the main field) will be considered for the IGRF-12. The decision will be based on whether the European Space Agency Swarm mission is delivering good-quality data by the time of the model revision and the success of some trial predictive secular-variation models that were submitted at the time of production of the IGRF-11.

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