The IGS Proposal for the New International Geomagnetic Reference Field

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In accordance with the rules adopted at the IAGA meeting in Canberra in 1979, we proposed for adoption as the new International Geomagnetic Reference Field a series of main-field models to degree and order ten for 1965, 1970, 1975, and 1980, and a secular variation model for the interval 1980 to 1985. These models are briefly described.

1. Introduction

At its Assembly in Canberra in 1979, the International Association of Geomagnetism and Aeronomy (IAGA) recommended that the International Geomagnetic Reference Field (IGRF) be revised, and specified the form the revised version should take. The problem of continuity with previous versions of the IGRF, which had featured strongly in the deliberations that resulted in the last revision in 1975, was disregarded and it was decided to make a fresh start. The format of the new IGRF was specified to be (i) a set of definitive main-field models for 1965, 1970, and 1975; (ii) a main-field model for 1980, and (iii) a secular variation model for the interval 1980 to 1985. The three earlier main-field models (i) were to be definitive in the sense that further revisions of them were not envisaged. The maximum degree and order of the models was to be in the range eight to ten. Proposed models were to be submitted by April 1981 so that they could be evaluated before the IAGA Assembly in August 1981.

The models proposed by the Institute of Geological Sciences for the new IGRF are described below. The values of the coefficients are given in Table 1. The units are nT for main-field coefficients and nT yr^{-1} for those of secular variation.

2. Main-Field Model for 1965

The model proposed is that of BARRACLOUGH *et al.* (1978). It is an interpolative model, of maximum degree and order eight and was based on all available data in the interval 1955 to 1975. A detailed description of the model and its derivation are given by BARRACLOUGH *et al.* (1978), but the main points may be summarized as follows. A total of nearly 700,000 observations contributed to the model and they consisted of data from land, sea, and aeromagnetic surveys (including observatory annual mean values), total intensity observations from oceanographic surveys and, with much lower weight, declination observations made in the remoter oceanic regions by merchant vessels during routine compass checks. Total intensity data from the POGO series of satellites were included via a spherical

Table 1. IGS proposal for the IGRF.

	m	n	1965	1970	1975	1980	SV 1982.5
g	0	1	-30337.	-30227.	-30104.	-30001.	22.8
g	1	1	-2119.	-2071.	-2016.	-1950.	11.4
h	1	1	5777.	5742.	5683.	5634.	-16.7
g	0	2	-1661.	-1778.	-1907.	-2038.	-18.1
g	1	2	2999.	3002.	3010.	3035.	3.2
h	1	2	-2016.	-2051.	-2065.	-2134.	-12.8
g	2	2	1596.	1614.	1633.	1652.	8.4
h	2	2	116.	27.	-58.	-179.	-24.6
g	0	3	1299.	1290.	1278.	1293.	-0.1
g	1	3	-2037.	-2089.	-2142.	-2156.	-6.2
h	1	3	-406.	-372.	-330.	-382.	-0.4
g	2	3	1291.	1277.	1255.	1244.	-0.3.
h	2	3	242.	253.	266.	261.	2.7
g	3	3	854.	835.	831.	851.	1.5
h	3	3	-164.	-197.	-227.	-235.	-8.0
g	0	4	958.	952.	947.	919.	-1.5
g	1	4	803.	801.	792.	777.	-1.7
h	1	4	147.	166.	193.	189.	4.4
g	2	4	479.	460.	444.	411.	-8.9
h	2	4	-268.	-265.	-266.	-265.	1.3
g	3	4	-390.	-395.	-404.	-428.	-1.9
h	3	4	15.	32.	53.	69.	2.2
g	4	4	254.	234.	212.	224.	-6.0
h	4	4	-268.	-277.	-285.	-289.	0.8
g	0	5	-219.	-216.	-221.	-216.	2.1
g	1	5	357.	357.	351.	354.	0.9
h	1	5	18.	25.	25.	74.	2.1
g	2	5	253.	262.	262.	261.	-0.2
h	2	5	126.	136.	148.	147.	-0.4
g	3	5	-30.	-41.	-64.	-66.	-3.1
h	3	5	-128.	-142.	-161.	-149.	0.4
g	4	5	-156.	-159.	-157.	-173.	0.4
h	4	5	-96.	-90.	-83.	-71.	1.7
g	5	5	-59.	-52.	-40.	-52.	1.4
h	5	5	83.	84.	92.	101.	2.0
g	0	6	45.	44.	44.	51.	0.4
g	1	6	62.	65.	70.	57.	-0.1
h	1	6	-10.	-12.	-11.	-15.	-0.6
g	2	6	9.	16.	28.	47.	3.6
h	2	6	100.	100.	100.	98.	-1.4
g	3	6	-228.	-212.	-194.	-194.	0.6
h	3	6	68.	73.	78.	75.	0.0
g	4	6	5.	2.	-1.	6.	1.3
h	4	6	-31.	-37.	-40.	-44.	-2.0
g	5	6	3.	3.	4.	17.	0.1
h	5	6	-9.	-8.	-8.	2.	1.0
g	6	6	-110.	-111.	-109.	-104.	-0.5
h	6	6	-5.	6.	16.	27.	-0.5
g	0	7	78.	74.	71.	65.	-1.4

(continued)

Table 1. (continued)

	m	n	1965	1970	1975	1980	SV 1982.5
g	1	7	-58.	-57.	-53.	-55.	-1.2
h	1	7	-59.	-68.	-77.	-71.	-0.5
g	2	7	6.	3.	2.	7.	0.2
h	2	7	-27.	-26.	-25.	-24.	0.7
g	3	7	13.	13.	13.	17.	0.5
h	3	7	1.	-2.	-5.	9.	0.3
g	4	7	-23.	-17.	-6.	-17.	1.5
h	4	7	4.	6.	7.	8.	1.5
g	5	7	-6.	-2.	3.	-1.	-0.3
h	5	7	27.	24.	25.	12.	-0.3
g	6	7	14.	16.	17.	16.	-0.2
h	6	7	-22.	-22.	-22.	-17.	-0.2
g	7	7	3.	-1.	-6.	9.	-0.3
h	7	7	-9.	-8.	-13.	-14.	1.3
g	0	8	13.	13.	11.	13.	1.1
g	1	8	4.	5.	5.	8.	0.0
h	1	8	5.	5.	5.	12.	-0.1
g	2	8	-5.	-3.	-3.	-4.	-0.1
h	2	8	-11.	-14.	-14.	-21.	-1.2
g	3	8	-16.	-14.	-13.	-5.	0.4
h	3	8	12.	9.	5.	11.	0.0
g	4	8	0.	-6.	-14.	-12.	-0.8
h	4	8	-17.	-18.	-18.	-20.	-0.8
g	5	8	5.	3.	0.	0.	0.1
h	5	8	5	7	6.	10.	-0.3
g	6	8	1.	1.	-2.	-1.	0.9
h	6	8	23.	19.	15.	7.	0.6
g	7	8	11.	11.	12.	10.	-0.4
h	7	8	-3.	-7.	-11.	-13.	-1.0
g	8	8	5.	5.	5.	3.	1.4
h	8	8	-16.	-16.	-17.	-13.	0.9
g	0	9	0.	9.	9.	5.	0.0
g	1	9	0.	10.	10.	3.	0.0
h	1	9	0.	-20.	-20.	-13.	0.0
g	2	9	0.	2.	2.	-4.	0.0
h	2	9	0.	16.	16.	20.	0.0
g	3	9	0.	-11.	-11.	-13.	0.0
h	3	9	0.	5.	5.	7.	0.0
g	4	9	0.	11.	11.	4.	0.0
h	4	9	0.	-3.	-3.	1.	0.0
g	5	9	0.	1.	1.	3.	0.0
h	5	9	0.	-4.	-4.	-5.	0.0
g	6	9	0.	0.	0.	-3.	0.0
h	6	9	0.	10.	10.	11.	0.0
g	7	9	0.	1.	1.	3.	0.0
h	7	9	0.	12.	12.	13.	0.0
g	8	9	0.	1.	1.	2.	0.0
h	8	9	0.	0.	0.	-1.	0.0

(continued)

Table 1. (continued)

	m	n	1965	1970	1975	1980	SV 1982.5
g	9	9	0.	1.	1.	-2.	0.0
h	9	9	0.	0.	0.	-1.	0.0
g	0	10	0.	-5.	-5.	-7.	0.0
g	1	10	0.	-3.	-3.	1.	0.0
h	1	10	0.	1.	1.	3.	0.0
g	2	10	0.	2.	2.	-1.	0.0
h	2	10	0.	2.	2.	-1.	0.0
g	3	10	0.	-6.	-6.	0.	0.0
h	3	10	0.	3.	3.	2.	0.0
g	4	10	0.	-1.	-1.	-3.	0.0
h	4	10	0.	3.	3.	2.	0.0
g	5	10	0.	7.	7.	9.	0.0
h	5	10	0.	-4.	-4.	-9.	0.0
g	6	10	0.	5.	5.	8.	0.0
h	6	10	0.	0.	0.	3.	0.0
g	7	10	0.	1.	1.	-1.	0.0
h	7	10	0.	0.	0.	-3.	0.0
g	8	10	0.	-2.	-2.	1.	0.0
h	8	10	0.	3.	3.	5.	0.0
g	9	10	0.	3.	3.	4.	0.0
h	9	10	0.	3.	3.	3.	0.0
g	10	10	0.	-1.	-1.	0.	0.0
h	10	10	0.	-3.	-3.	-6.	0.0

harmonic model based on quiet-time POGO observations. The data were reduced to 1965.0 (near the mean epoch of the observations) using a series of secular variation models based on observatory annual mean values. For the purposes of the IGRF submission the coefficients of degree nine and degree ten are to be regarded as having value zero.

3. Main-Field Model for 1970

The proposed model is a composite of two models: (a) the 1965 model of BARRACLOUGH *et al.* (1978), mentioned in Section 2, corrected to 1970 using its own secular variation coefficients and (b) the 1975 model of BARRACLOUGH *et al.* (1975) (see Section 4), corrected to 1970 using a secular variation model for 1970 based on observatory annual mean values. The first 80 coefficients (up to and including $m = n = 8$) are the means of the coefficients of models (a) and (b); the remaining 40 are from model (b). Since the 1970 secular variation coefficients are those used to up-date a main-field model for 1965 (near the mean epoch of the data base) to produce the 1975 main-field model, their removal enhances the 1970 model rather than degrading it.

4. Main-Field Model for 1975

For this model we proposed that given and fully described by BARRACLOUGH *et al.* (1975) (a twelfth degree and order model) truncated at $m = n = 10$. The model was based

on a very similar data set to that used for the 1965 main-field model of Section 2, the main difference being that the earlier data (in the interval 1955 to 1965) were given half the weight of the later data. The equivalent of approximately 555,000 observations thus contributed to the model. The data were reduced to 1970 using the same set of secular variation models as were used for the 1965 main-field model and, as noted in Section 3, this 1970 model was up-dated to 1975 using a further secular variation model based on observatory data.

5. Main-Field Model for 1980

Our proposed model is that of BARKER *et al.* (1981) (again a twelfth degree and order model) truncated at $m = n = 10$. This model was based on all available pairs of observations of declination and inclination made since 1950, reduced to 1968 using the 1965 model of BARRACLOUGH *et al.* (1978). Nearly 110,000 data pairs were used. Total intensity data from the POGO series of satellites were included via a spherical harmonic model. The main-field model for 1968 was up-dated to 1980 using a secular variation model for 1975 based mainly on observatory annual mean values but including also information from repeat stations, surveys and the POGO satellites.

6. Secular Variation Model for the Interval 1980 to 1985

The method of producing the proposed model is essentially that described by BARRACLOUGH *et al.* (1975) and incorporates data from (a) observatories, (b) satellites, (c) surveys (land, sea and aeromagnetic) and (d) repeat stations.

(a) Observatory data

New estimates were made of the secular variation at observatories at 1982.5 from plots of first differences of annual mean values, incorporating the most recent available data. There resulted 166 values of $\dot{D}$ (the secular variation of declination), 164 of $\dot{H}$ (the secular variation of horizontal intensity), two of $\dot{X}$ (the secular variation of north component), two of $\dot{Y}$ (the secular variation of east component), and 166 of $\dot{Z}$ (the secular variation of vertical component), together with estimates of their uncertainties. From these data, weighted according to the inverse square of the uncertainties, we derived all the 56 coefficients, up to and including $m = n = 8$, that exceeded their internal standard deviations.

(b) Satellite data

A mean secular variation model for the interval 1970 to 1980 was derived from the difference between the first 80 coefficients of the POGO (8/73) model (Cain *et al.* 1974) and the recently derived model from Magsat data, MGST (12/80) (R. A. Langel, private communication). This secular variation model was up-dated to 1982.5 using the difference between the model described in (a) above and a similar model for 1975 based on observatory data.

(c) Survey data

A model of the secular variation at 1980, based on survey data and described by BARKER *et al.* (1981), was up-dated to 1982.5 using the difference between the model described in (a) above and a similar model for 1980 based on observatory data.

(d) Repeat station data

A secular variation model for 1980, based on repeat station data and described by BARKER *et al.* (1981), was similarly up-dated to 1982.5. This model was truncated at $m = n = 6$.

(e) Combination of results

The observatory estimates of secular variation for 1982.5, on which model (a) was based, formed an independent data set against which models (b), (c), and (d), which were not based on observatory data, could be tested. The weighted sums of squares of the residuals of these three latter models from the observatory estimates suggested a relative weighting of 36:10:1 for models (b), (c), and (d), respectively. There was no indication, however, of the weight of model (a) relative to the other three and the test was biased against model (d) whose data were chosen to complement the distribution of the observatory data. A second method of assessing the relative weighting was the following. The weight of each model was based on the sum of the squares of the residuals of its coefficients from those of the weighted mean of the other three models. Starting with unit weight for each model, an iterative procedure rapidly converged to relative weights of 40:48:9:3 for models (a), (b), (c), and (d), respectively. These weights were used in producing the first 48 coefficients of the mean model. The remaining 32 coefficients were derived from models (a), (b), and (c) combined in the ratio 40:48:9.

We do not believe that present knowledge of the distribution of secular variation warrants the inclusion of coefficients beyond degree and order eight.

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