IGRF-11
GFZ Candidate Models
German Research Centre For Geosciences
Section 2.3,
Earth's Magnetic Field

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1 Summary

The candidates are derived from the existing GRIMM-2x core field model, which is parameterised in time by using order 6 B-splines and co-estimated together with part of the lithospheric field, the large scale external field and its induced counterpart. The GRIMM-2x model is derived by fitting, using a $\mathcal{L}_1$ measure of the misfit, a data set made of CHAMP satellite and hourly mean observatory vector data selected for magnetically quiet times. The DGRF candidate for 2005.0 is derived by averaging the GRIMM-2x model around this epoch. The IGRF candidate for 2010.0 is derived by extrapolating the GRIMM-2x parent model evaluated for year 2009.0, using the estimated secular variation for the same epoch. In order to compute the SV candidate for 2012.5, the temporal evolution of each SV coefficient has been linearly fitted between 2001.0 and 2009.5; the linear fit is extrapolated to the epoch 2012.5. The uncertainty interval given for each coefficient is derived from the misfit of the individual coefficients to the linear trend between 2001.0 and 2009.5.

2 Deriving the DGRF candidate for 2005.0

A candidate for the Definitive Geomagnetic Reference Field (DGRF) model for epoch 2005.0 is derived by averaging the GRIMM-2x model between 2004.5 and 2005.5. This is done in order to improve the robustness of the Gauss coefficient estimates. The resulting model is truncated to spherical harmonic degree 13. Information on the time varying GRIMM-2x model is given below.

Compared with a model directly derived from GRIMM-2x at epoch 2005.0, our DGRF candidate does not differ by more than 0.25 nT for any Gauss coefficients. This maximum difference is reached for g_1^1.

Standard deviation estimates for our candidate Gauss coefficients are not provided.

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3 Deriving the IGRF candidate for 2010.0

A candidate model for the International Geomagnetic Reference Field (IGRF) for epoch 2010.0 is derived following three different approaches. In the first approach, the IGRF candidate model is the parent model GRIMM-2x for epoch 2010.0. The Second approach extrapolates the GRIMM-2x parent model estimated for 2009.0 using secular variation estimates calculated for the same epoch. In the third approach, the Gauss coefficients are derived from GRIMM-2x for each year in between 2001.0 and 2009.0. A linear regression process give then estimates of the Gauss coefficient values for 2010.0.

We point out that the GRIMM-2x model present a relatively strong secular acceleration for the coefficient h_1^1 around epoch 2009.0, compared to the 2001-2007 period. Furthermore, the secular acceleration estimates are not robust after 2009.0. By carefully analysing the Gauss coefficients we find out that the second method is the most apropriate, and our IGRF 2010.0 candidate is based on this method.

Compared with a model directly derived from GRIMM-2x at epoch 2010.0, our IGRF candidate differs by around 1.5nT for the h_1^1 Gauss coefficient. The differences stay below 1nT for any other Gauss coefficient.

Standard deviation estimates for our candidate Gauss coefficients are not provided.

4 Deriving the SV candidate for 2010 to 2015

We provide a model of the averaged secular variation for the period 2010 to 2015. Below we give a detailed description of its computation.

- The temporal evolution of the individual GRIMM-2x SV coefficients are linearly interpolated between 2001.0 and 2009.5 in a least square sense.

- Then, these linear interpolations were used to extrapolate the SV coefficients to the epoch 20012.5. The set of extrapolated SV coefficients represent our candidate model of the averaged SV for 2010 to 2015. In Fig. 1, fits to some coefficients and their forecasts are shown. We note that a linear SV is equivalent to a constant secular acceleration.

- In addition to the SV coefficients for 2012.5, uncertainties are given. These estimates are the rms of the differences between the SV coefficients given by GRIMM-2x and the linear interpolation for the time interval [2001:2009.5].

- Apart from the linear fitting of the SV coefficients there were no other procedures of hindcasting tested.

5 Information on parent model GRIMM-2x

5.1 Satellite, Observatory and Repeat Station Data sets

Regarding the data used in the derivation or GRIMM-2x, we point out that:

- No repeat station data are used.

- Hourly mean observatory vector data from 2001 to 2009.0 are used.

- The most recent version 51 Level-2 CHAMP data with improved time dependent FGM-ASC orientation corrections are used from 2001.0 to 2009.58

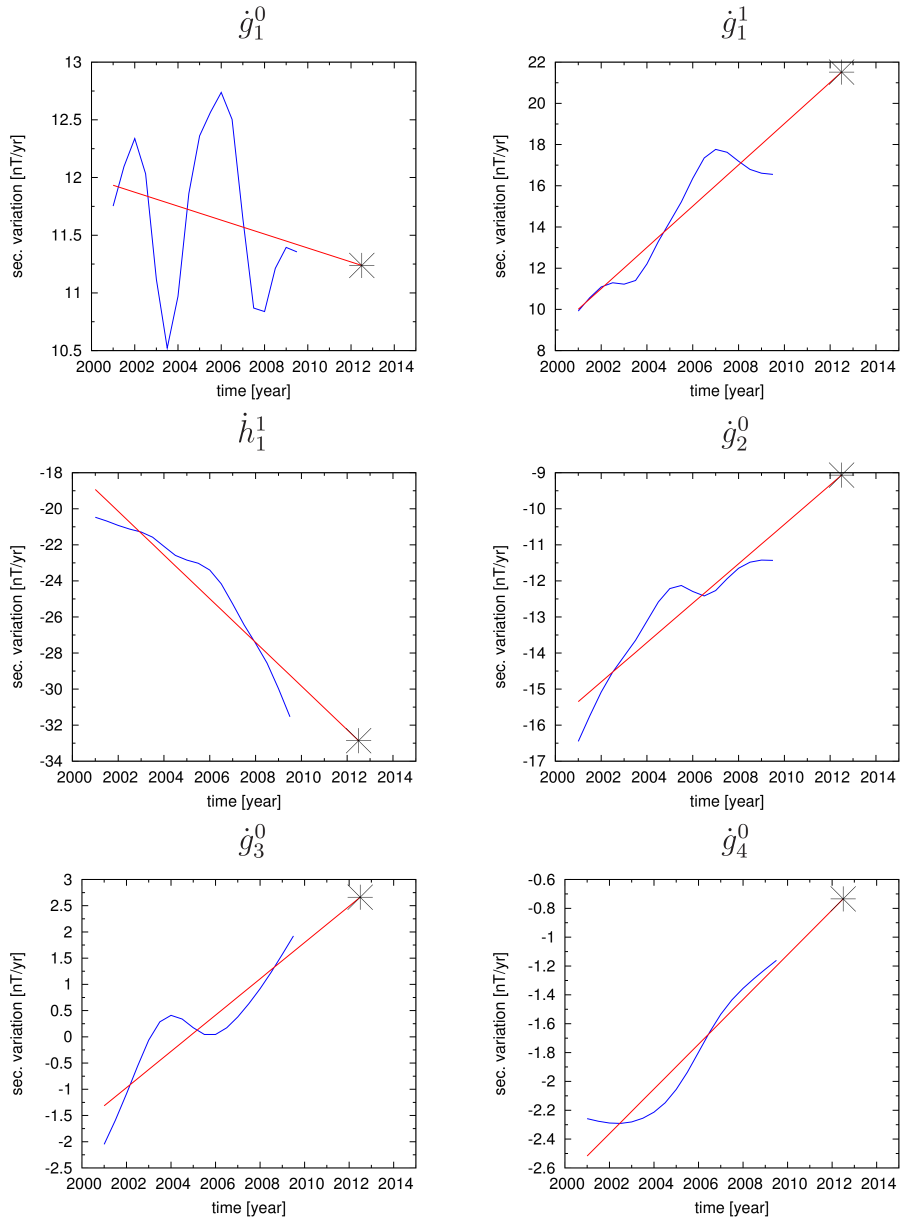

Figure 1: Temporal evolution of the SV coefficients $\dot{g}_1^0, \dot{g}_1^1, \dot{h}_1^1, \dot{g}_2^0, \dot{g}_3^0, \dot{g}_4^0$ (blue line), the linear fit (red line) and the prediction of the SV coefficient at 2012.5 (black symbol). Note that the y-scales differ for each plot.

5.2 Data selection

5.2.1 CHAMP Data

Mid- and Low-Latitudes : (i.e. inside $\pm 55^o$ magnetic latitudes) Only the X and Y components in SM coordinates are used. Data are selected following the criteria set below:

- Positive IMF Bz only.
- 20s minimum separate two data points.
- Local Time is between 23:00 and 05:00
- Sun is below the horizon at 100 km above the Earth's reference radius.
- The Vector Magnetic Disturbance time-series (VMD), an estimate of the disturbances due to the large scale external field, is used and data are selected if the VMD norm is not larger than 20nT and the norm of its derivative is less than 100 nT/d.
- Quality = 0 for the general FGM quality flag.
- Quality = 3 (dual head only) for the Star Camera mode flag.
- Flag digit describing attitude processing technique larger than 1.

High Latitudes : (i.e. outside $\pm 55^o$ magnetic latitudes) All three components in NEC coordinates are used. Data are selected following the criteria set below:

- Positive IMF Bz only.
- 20s minimum separate two data points.
- No Local Time selection.
- No Sun position selection.
- The Vector Magnetic Disturbance time-series (VMD), an estimate of the disturbances due to the large scale external field, is used and data are selected if the VMD norm is not larger than $20nT$ and the norm of its derivative is less than 100nT/d.
- Quality = 0 for the general FGM quality flag.
- Quality = 3, 2 or 1 for the Star Camera mode flag (by order of preference).
- Flag digit describing attitude processing technique larger than 1.

5.2.2 Observatory Data

At all latitudes, observatory hourly mean values are selected following the same criteria as for satellite data between low- and mid-latitudes. Three component vector data in the NEC are used at high latitudes while, between $\pm 55°$ magnetic latitudes only X and Y (SM) data are used.

5.3 Data weights

The initial data weights are functions of magnetic latitude, vector component and the star camera mode (single head or dual head) as given in the table below. Furthermore, the data are weighted depending on their density.

Source	Heads	Component	Limits	Weight (nT)
Sat	dual	X	$\lvert$MagLat$\rvert < 55^o$	-3.7
		Y		-3.9
		X	$\lvert$MagLat$\rvert > 55^o$	-48.1
		Y		-53.8
		Z		-20.2
	single	X	$\lvert$MagLat$\rvert > 55^o$	-62.8
		Y		-73.3
		Z		-26.7
Obs	–	X	$\lvert$MagLat$\rvert < 55^o$	-3.3
	–	Y		-3.5
	–	X	$\lvert$MagLat$\rvert > 55^o$	-19.7
	–	Y		-11.3
	–	Z		-17.3

5.4 Inversion process

Fitting the vector data by adjusting the Gauss coefficients is a linear inverse problem. The Gauss coefficients are estimated by an iterative reweighted least squares procedure using an $\mathcal{L}_1$ norm.

The starting model of this iterative process is derived using a least-squares process, and an $\mathcal{L}_2$ measure of the misfit. This was followed by five iterations of the reweighted least squares procedure leading to a stable model solution.

5.5 Regularisation

The $\mathcal{S}_3$ measure of the field time complexity was minimized together with $\mathcal{S}_2(t)$ for t_1 =2000.0 and t_2 =2011.0. These quantities are defined by:

$$\mathcal{S}_3 = \int_{t_1}^{t_2} \int_{CMB} |\partial_t^3 B_r(c, \theta, \phi, t)|^2 ds\, dt,$$

$$\mathcal{S}_2(t) = \int_{CMB} |\partial_t^2 B_r(c, \theta, \phi, t)|^2 ds.$$

We point out that the spatial complexity of the field was not minimized.

5.6 Fit to the data

The fit to the data is given in the table below.

Source	Component	Limits	Mean of residuals in nT	STD in nT
Sat	X (SM)	$\lvert$MagLat$\rvert < 55^o$	0.04	2.69
	Y (SM)		-0.43	3.15
	X	$\lvert$MagLat$\rvert > 55^o$	-0.32	48.41
	Y		0.26	54.90
	Z		-1.05	19.73
Obs	X (SM)	$\lvert$MagLat$\rvert < 55^o$	0.06	3.32
	Y (SM)		0.02	3.45
	X	$\lvert$MagLat$\rvert > 55^o$	-1.25	19.11
	Y		0.04	11.13
	Z		0.19	16.96