Study of the geomagnetic field over southern Africa applying harmonic splines technique on CHAMP satellite data

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Abstract. The monitoring of the Earth's magnetic field time variation requires a continuous recording of geomagnetic data with a good spatial coverage of the area of study. In the southern Africa, ground recording stations are limited and the use of satellite data is needed for the studies where high spatial and temporal resolution data is required. The study of the fast time variation of geomagnetic field in the southern Africa region was conducted applying the harmonic splines technique on CHAMP satellite data that has been recorded between 2001 and 2005. The derived core field model, the Southern Africa Core Field Model (SACFM-1), was evaluated using the ground-based data and the International Geomagnetic Reference Field model (IGRF-11). The results of this study suggest that the southern Africa regional model can be improved combining the satellite data and ground data.

1. Introduction

The geomagnetic field changes on different space and time scales. The core field represents the dominant part of the Earth's magnetic field and its variation over time scales of decades to centuries is referred to as secular variation. This study focuses on southern Africa that is situated in the region where the most rapid decrease of field intensity is observed at the Earth's surface stretching across southern Africa and south Atlantic Ocean [1]. This coincides with a region known as the South Atlantic Anomaly where the field is already very weak compared to other locations at the same latitude.

In this region, the ground recording stations are limited and the use of satellite data is needed for the studies where high spatial and temporal resolution data is required. The attempt to study the time variation of geomagnetic field in this region using the harmonic splines technique was done previously using only the ground-based data [2]. In this paper, the results of the use of harmonic splines technique on CHAMP satellite data recorded between 2001 and 2005 were evaluated using the ground based data and the global IGRF-11 model [3].

2. Method

The use of the harmonic splines technique was first introduced by [4] for global magnetic field modelling, but it is as well suitable for regional modelling. The core field model is derived over southern Africa using harmonic splines. The harmonic spline functions satisfy Laplace's equations, therefore allowing a potential field approach combining the individual components in a physical meaningful way [5].

According to [2] and [6], the Earth's magnetic field can be written as:

$$B(\vartheta,\varphi,r) = -\bigtriangledown\left\{\sum_j \alpha_j^r F_j^{Lr}(\vartheta,\varphi,r) + \sum_j \alpha_j^\vartheta F_j^{L\vartheta}(\vartheta,\varphi,r) + \sum_j \alpha_j^\varphi F_j^{L\varphi}(\vartheta,\varphi,r)\right\}, \qquad (1)$$

where the functions $F_j^{Lr}(\vartheta,\varphi,r)$, $F_j^{L\vartheta}(\vartheta,\varphi,r)$ and $F_j^{L\varphi}(\vartheta,\varphi,r)$ are defined as follows:

$$F_j^{Lr} = a\sum_{l,m}^{L} f_l(l+1)\left[\left(\frac{a}{r_j}\right)^{l+2} Y_l^m(\vartheta_j,\varphi_j)\right]\left(\frac{a}{r}\right)^{l+1} Y_l^m(\vartheta,\varphi), \qquad (2)$$

$$F_j^{L\vartheta} = a\sum_{l,m}^{L} f_l\left[\left(\frac{a}{r_j}\right)^{l+2} \partial_\vartheta Y_l^m(\vartheta_j,\varphi_j)\right]\left(\frac{a}{r}\right)^{l+1} Y_l^m(\vartheta,\varphi), \qquad (3)$$

$$F_j^{L\varphi} = a\sum_{l,m}^{L} f_l\left[\left(\frac{a}{r_j}\right)^{l+2} \frac{\partial\varphi}{sin\vartheta_j} Y_l^m(\vartheta_j,\varphi_j)\right]\left(\frac{a}{r}\right)^{l+1} Y_l^m(\vartheta,\varphi), \qquad (4)$$

where $\sum_{l,m}^{L}$ denotes the double sum $\sum_{l=1}^{L}\sum_{m=-l}^{l}$, ϑ, φ and r are the geocentric colatitude, longitude and radius, a is the Earth's reference radius (6371.2 km), $Y_l^m(\vartheta,\varphi)$ are the usual Schmidt semi-normalised spherical harmonic functions of degree l and order m, L is the maximum degree of expansion of internal sources and $f_l = \frac{2l+1}{4\Pi(l+1)^4 l^2}$. The parameter f_l imposes smooth characteristics on the derived field model.

Equation (1) is time independent, it defines a linear system of equations where α_j^r, α_j^ϑ and α_j^φ are unknowns. This linear system is square and can be solved directly. For time representation, we expand each of the coefficients α_j^r, α_j^ϑ and α_j^φ on a basis of B-splines. The maximum degree of expansion of internal sources was set to 20. This degree is small enough to reveal mostly the field contributions from the core. For the time representation, order four B-splines with spline knots spaced at 1 year intervals between 2001.0 and 2006.0 are used.

3. Data selection and processing

The CHAMP satellite data was recorded between 300 km and 450 km of altitude. The quiet night data recorded between 2001 and 2005 were selected over the southern Africa region covering the area between 10°S and 38°S in latitude and 10°E and 38°E in longitude. Only quiet time data corresponding to a Dst index between -20 nT and +20 nT measured during the local times between 18:00 - 07:00 were considered.

The model input data were obtained by creating 225 data bins of 0.2°×0.2° on a grid of 2° of latitude and 2° of longitude. The middle point of the bin was considered to be the data center and consequently 225 data centers were created (fig. 1). The data values recorded in the same bin at the same epoch (within 37 days, e.g. 2003.2) were averaged to get a single data value at the data center (6687 different data values of X, Y and Z over 5 years between 2001 and 2005 were obtained). In this process, it was possible to get a number of data values recorded at different epochs and altitudes at the same data center for the period of 2001 - 2005.

The comparative evaluation of SACFM-1 with the global model IGRF-11 was performed using data recorded at geomagnetic repeat stations (CRA, GAR, MES, OKA, UND, MAU and SEV) and geomagnetic observatories (HER, HBK and TSU) over the same time period between 2001 and 2005 (Table 1). These 10 reference points were selected

Table 1. Geodetic coordinates of 10 points used in the comparative evaluation of the developed models.

Station	Latitude (°)	Longitude (°)	Altitude (m)
Cradock (CRA)	-32.2	25.6	847
Garies (GAR)	-30.6	18.0	229
Messina (MES)	-22.4	30.1	484
Okaukuejo (OKA)	-19.2	15.9	1039
Underberg (UND)	-29.8	29.5	1530
Maun (MAU)	-20.0	23.4	907
Severn (SEV)	-26.6	22.9	890
Hermanus (HER)	-34.4	19.2	26
Hartebeesthoek (HBK)	-25.9	27.7	1555
Tsumeb (TSU)	-19.2	17.6	1273

based on the availability of data at geomagnetic repeat stations (also available at http://www.geomag.bgs.ac.uk/data_service/data/home.html) and geomagnetic observatories (also available at http://www.intermagnet.org) in the southern Africa region. The secular variation at the repeat station was determined by means of the procedure given by Newitt et al. [7].

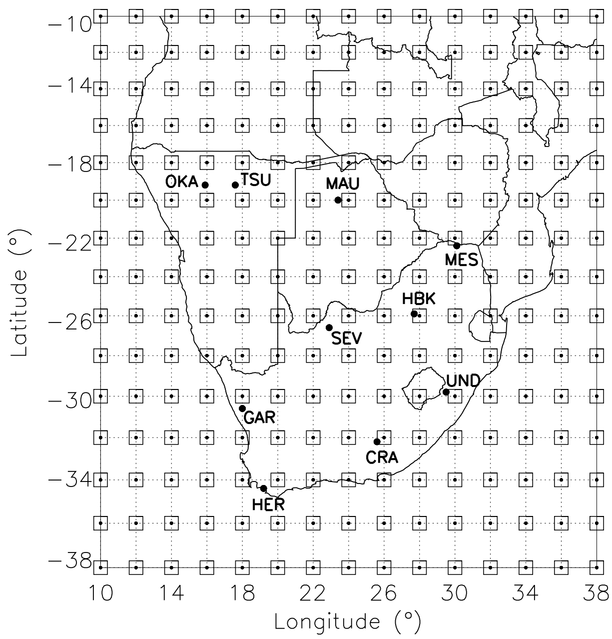

Figure 1. The data bins (0.2°×0.2°) used for generating input data (represented by square shapes), the middle of each data bin represents a data center (not all data centers have data points for every year). The black big dots represent the reference ground points used to evaluate the developed model.

4. Data modelling results

4.1. Main field models

Using 225 centers and 6687 different data values of X, Y and Z over 5 years between 2001 and 2005, the root mean square (RMS) values of the difference between observed and model values were 13.7 nT, 8.6 nT and 6.9 nT for X, Y and Z components respectively.

The presented results of the main field models were obtained by predicting the geomagnetic field at 225 points at 1 km altitude. To validate the SACFM-1, the only 2003.5 epoch main field values and 2003.0 epoch secular variation values for H, D and Z field components and total field intensity F are compared with the ground based data and the global IGRF-11 model. The comparison of two models is presented in fig. 2 and Table 2. The latter presents the comparison of 2 models using the ground data. The SACFM-1 and IGRF-11 performances in D and F are very close. But, there is a poor performance of the SACFM-1 model in H and Z components. The RMS values of the differences between SACFM-1 and ground data are 148.4 nT and 102.9 nT for H and Z components, respectively.

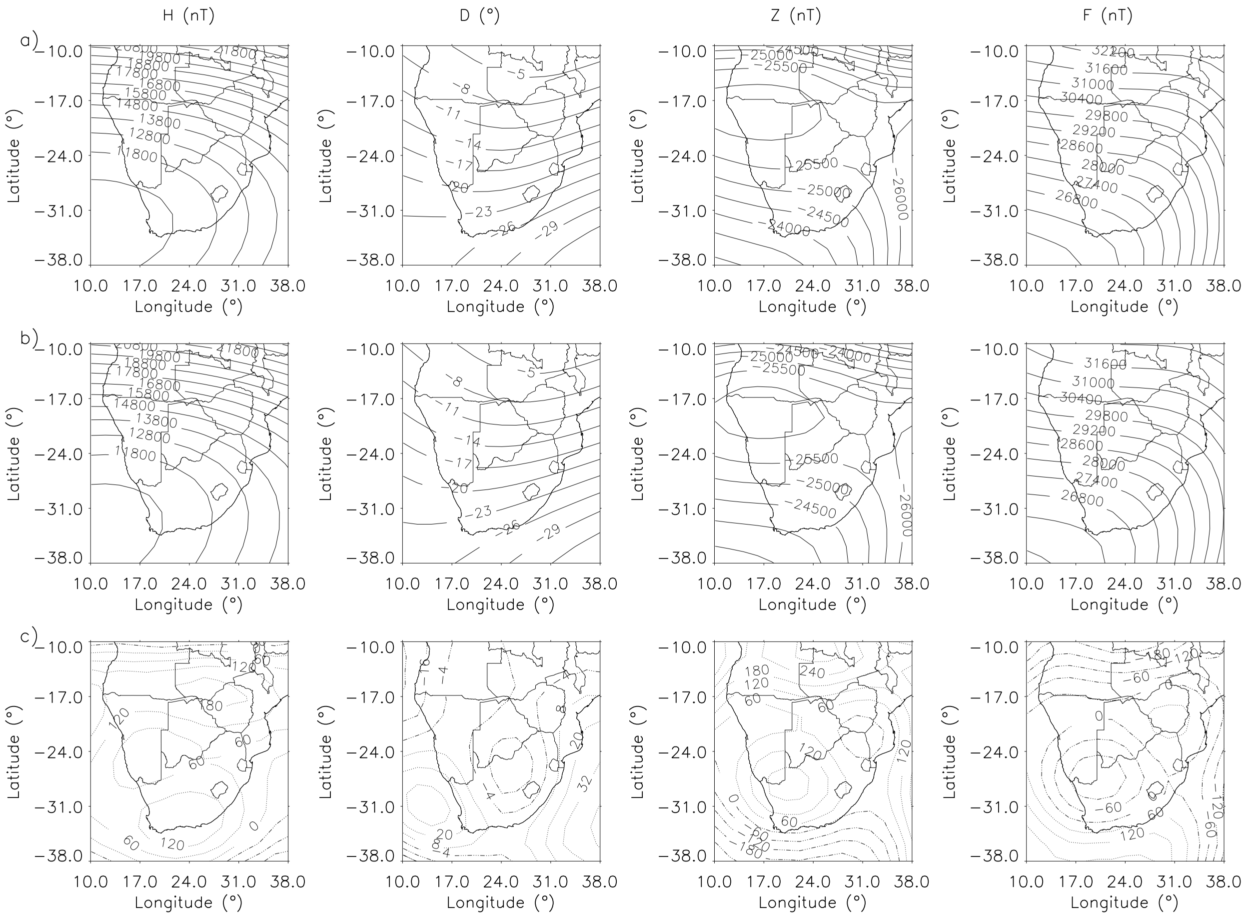

Figure 2. The comparison between (a) SACFM-1 (first row) and (b) IGRF-11 (second raw) models for H, D, Z and F (from left to right) at 1 km of altitude for epoch 2003.5. The third raw (c) represents the difference between the main field models of SACFM-1 and IGRF-11 for H, D (min), Z and F (from left to right).

Table 2. The RMS values of the differences between the SACFM-1 and IGRF-11 main field models and ground data at 10 reference points for epoch 2003.5.

Field component	SACFM-1 - Ground data	IGRF-11 - Ground data
D (min of arc)	29.6	29.3
H (nT)	148.4	77.7
Z (nT)	102.9	66.9
F (nT)	74.3	68.6

4.2. Secular variation models

The results of the secular variation models for H, D, Z and F are presented in fig. 3 and the comparison of these 2 models using the ground data is illustrated in Table 3. The SACFM-1 performs better than the global IGRF-11 model in H and Z components and there is a close performance of two models in the D component and the total intensity F.

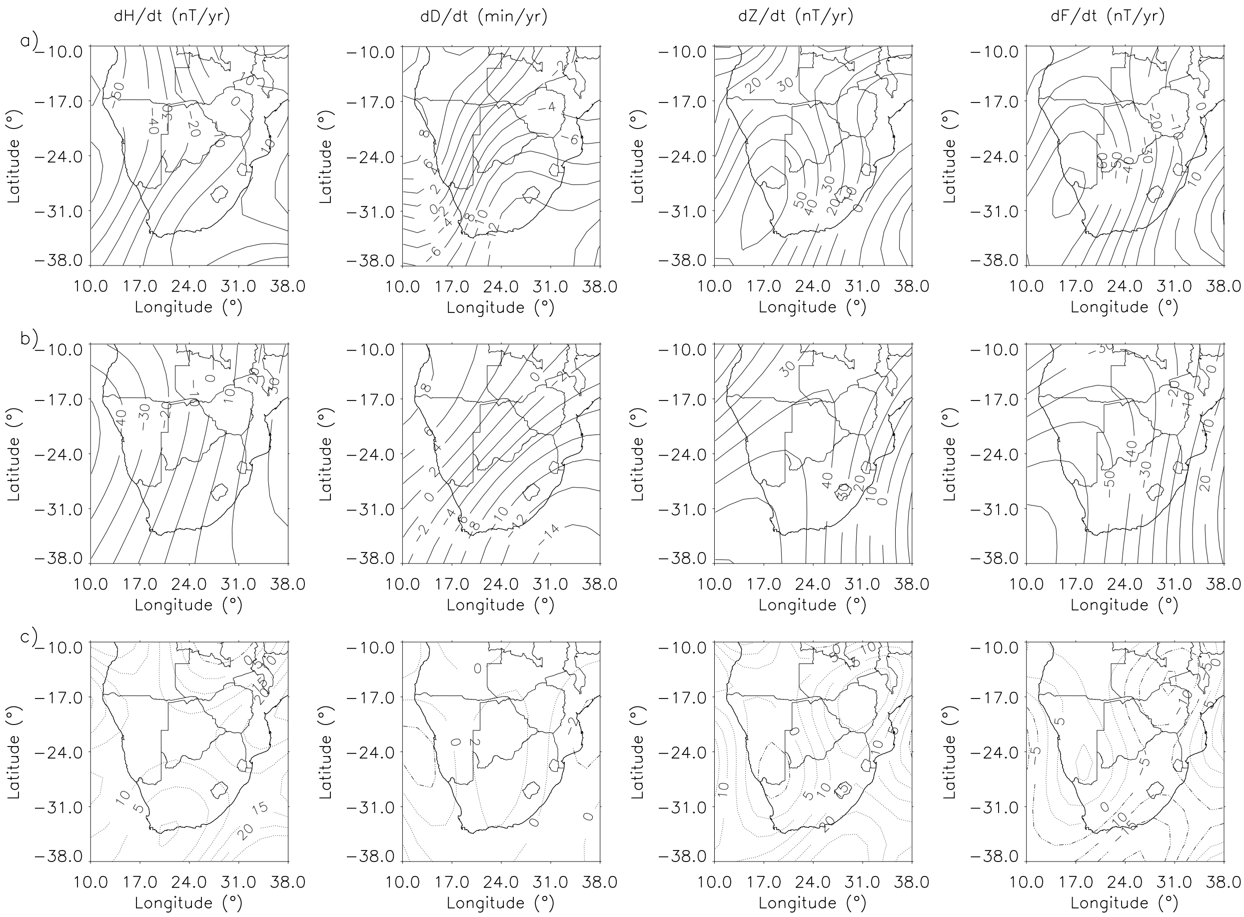

Figure 3. The comparison between (a) SACFM-1 (first row) and (b) IGRF-11 (second row) models for secular variation of H, D, Z and F (from left to right) at 1 km of altitude for epoch 2003.0. The third raw (c) represents the difference between the secular variation models of SACFM-1 and IGRF-11 for H, D , Z and F (from left to right).

Table 3. The RMS values of the differences between the SACFM-1 and IGRF-11 secular variation models and ground data at 10 reference points for epoch 2003.0.

Field component	SACFM-1 - Ground data	IGRF-11 - Ground data
dD/dt (min/yr)	1.7	1.3
dH/dt (nT/yr)	8.1	9.4
dZ/dt (nT/yr)	8.2	10.6
dF/dt (nT/yr)	6.1	6.4

5. Discussion and conclusion

The study of time variation of geomagnetic field was conducted applying the harmonic splines technique on CHAMP satellite data recorded between 2001 and 2005. Using the ground data measured at the 10 reference points, the developed regional model, SACFM-1, was compared with the global IGRF-11 model. For the secular variation models, the results presented in Table 3 show that SACFM-1 performs better than IGRF-11 in the H and Z components. In addition, both models SACFM-1 and IGRF-11 have a very similar performance in the D component and the total field intensity F.

The poor performance in H and Z components for main field models can be partially attributed to the external field contamination in satellite data and a poor data coverage. One would suggest that the model can be improved by reconsidering the data selection criteria or removing the unwanted contribution of external field from data. Furthermore, the increase of data centers to get a good data coverage would improve the model performance. The use of ground data together with satellite data should be considered, this would result in a regional model that can perform better than the global models and allowing the study of rapid variation of geomagnetic field in southern Africa.

Acknowledgments

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