AN INVESTIGATION INTO THE USE OF SATELLITE DATA TO DEVELOP A GEOMAGNETIC SECULAR VARIATION MODEL OVER SOUTHERN AFRICA

E. Nahayo[1, 2*], P. B. Kotzé[1], and M. J. Alport[2]

[1]Hermanus Magnetic Observatory, 7200, Hermanus, South Africa
[2]School of Physics, University of KwaZulu-Natal, 4000, Durban, South Africa
**Email:* enahayo@hmo.ac.za

ABSTRACT

There is a need to develop secular variation (SV) models using satellite data as the use of ground data is not always possible. Ground data has many limitations including limited data points and lack of data over ocean areas that are not easily accessible. Two regional geomagnetic field modelling techniques, namely polynomial surface modelling (PolyM) and Spherical Cap Harmonic Analysis (SCHA), were applied to CHAMP satellite data recorded between 2001 and 2005 to investigate the use of satellite data to develop a geomagnetic SV model over southern Africa. The resulting regional models of this investigation were validated against the two widely used global field models IGRF 10 and CHAOS-2 using the available ground survey data obtained during the same period over southern Africa. The results suggest that the regional field models can be derived based entirely on satellite data. However, the regional SV models can be improved using both high quality satellite and ground survey data, since they lack the high quality of a global field model like CHAOS-2.

Keywords*:* Geomagnetic field, Secular variation, Magnetic satellite data

1 INTRODUCTION

The major portion of the magnetic field measured at the Earth's surface has its origin in electrical currents flowing in the liquid outer core. These electrical currents result from a dynamo process where convective motions of the fluid outer core stretch and distort field lines in a self-sustaining manner. This field is known as the *main* or *core field* (Mandea et al., 2007). The temporal variation of the geomagnetic field covers a large range of time-scales, from seconds to millennia. Variations on short time scales are mostly dominated by external sources while variations on longer timescales (~ 1 year and longer) are collectively known as *secular variation* (SV) and are predominantly of internal origin (Kotzé, 2003).

It has been known that secular change is a comparatively local phenomenon and that it does not proceed in a regular way all over the Earth, giving rise to regions where the field changes more rapidly than elsewhere. One region where the most rapid decrease of field intensity is observed at the Earth's surface stretches across southern Africa and the South Atlantic Ocean (Korte et al., 2007). An urgent need therefore exists to monitor the time-variation of the geomagnetic field over southern Africa. Two regional modelling techniques (polynomial surface modelling (PolyM) and Spherical Cap Harmonic Analysis (SCHA)) were applied to CHAMP satellite data recorded between 2001 and 2005 to investigate the possibility of developing geomagnetic SV field models over southern Africa. The accurate regional SV models can help to understand the time-variation of the geomagnetic field over this region and play an important role in studying core-mantle interactions to understand better the geomagnetic polarity reversals (Gubbins, 1994).

2 DATA: SOURCE AND SELECTION

The investigation of the use of satellite data to develop a geomagnetic SV model was done using the CHAMP satellite data for the period 2001-2005 over the southern Africa region, covering the area between 10°S and 40°S in latitude and 10°E and 40°E in longitude.

The focus was on the months of January and December of each year. In particular, only quiet time data corresponding to a Dst index between -20 nT and +20 nT measured during the universal time intervals 16:00 - 24:00 and 00:00 - 05:00 were considered. The validation of the developed regional models was done using the global field models (IGRF 10 and CHAOS-2) together with the ground survey data from 13 ground points of the Hermanus Magnetic Observatory (HMO) magnetic repeat stations network and permanent observatories (Hermanus (HER), Hartebeesthoek (HBK), and Tsumeb (TSU)) (Figure 1).

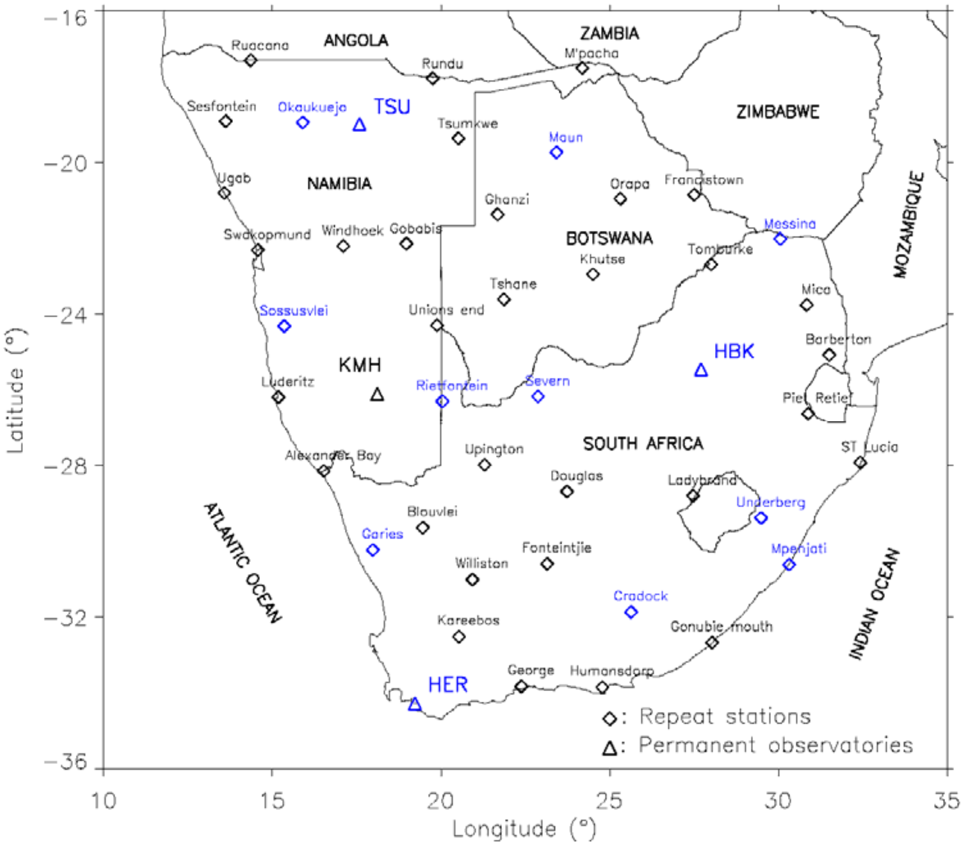


Figure 1. The map showing the HMO network of magnetic repeat stations and permanent observatories. The blue points are the only ones used in the validation of the developed geomagnetic SV models.

3 DATA MODELLING TECHNIQUES

3.1 SURFACE POLYNOMIALS (PolyM)

In this present study, the following general surface polynomial was used:

$$B(\varphi,\lambda)=\sum_{n=0}^{N}\sum_{m=0}^{N}k_{mn}\times(\varphi-\varphi_0)^n\times(\lambda-\lambda_0)^m,$$

where B is the magnitude of the main field (or SV) for each element (declination D, horizontal component H, vertical component Z, and total field F) at the point with geographic coordinates φ (latitude) and λ (longitude), k_{mn} is a numerical coefficient, and φ_0 and λ_0 are the coordinates of the center of the modelled area: $\varphi_0=25^\circ S$ and $\lambda_0=25^\circ E$. The degree of the polynomial is determined by the value of integer N (N = 1, 2, 3, 4, 5 ...).

By assuming that $B(\varphi,\lambda)$ is the measured magnitude of the main field element or a SV value at a given point with coordinates (φ,λ) and k_{mn} is unknown, a redefined system of conditional equations is obtained and solved by the least squares method. A 5th degree polynomial was used for main field models while a 3rd degree polynomial served to derive SV models.

3.2 SPHERICAL CAP HARMONIC ANALYSIS (SCHA)

SCHA is a mathematical technique developed by Haines (1985) to model a potential field and its spatial derivatives, or a general function and its surface derivatives, on a regional scale in order to overcome the non-orthogonality problem in the case of global spherical harmonic models when applied to restricted areas. In this study, the only part of the Laplace's equation solution for internal sources without the time-varying part was used.

$$V(r,\theta,\lambda) = a\sum_{k=0}^{KINT}\sum_{m=0}^{k}\left(\frac{a}{r}\right)^{n_k(m)+1} P_{n_k(m)}^{m}(\cos\theta)\left[g_k^{m,i}\cos(m\lambda) + h_k^{m,i}\sin(m\lambda)\right],$$

where $KINT$ is the maximum index of spatial expansion of internal sources, a the Earth's radius, and r, θ, and λ are radial distance, colatitude and longitude, respectively. The g_k^m and h_k^m are the Gauss coefficients, and the $P_{n_k(m)}^m(\theta)$ are the associated Legendre functions with order m and real degree n_k where k is the integer degree index. A half-cap angle of 18° was chosen for SCHA modelling, and the IGRF 10 model was used as a known spherical harmonic potential for the reference field which was calculated at an epoch of 2003.5. The resulting residual data were converted from a geocentric coordinate system to a new pole at 25°S, 25°E. In addition, the selected low maximum index of expansion of internal sources ($KINT = 5$ yielding a minimum wavelength of approximately 1300 km) produced the best SV models.

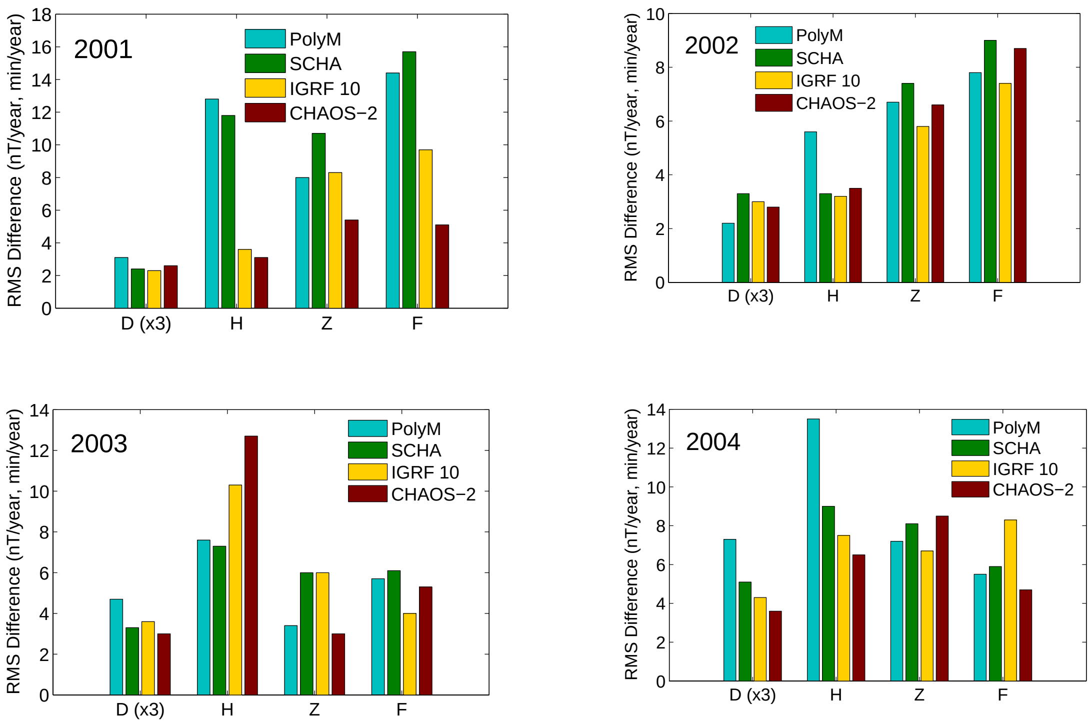
4 DATA MODELLING AND RESULTS

For both modelling techniques (PolyM and SCHA), data was first reduced to the ground level (0.8 km, the mean altitude of the 13 ground points) so that the derived models can be validated using the ground survey data. The correction was done using the IGRF 10 model. For a data point value D at a given geodetic coordinate (φ, λ, S), the data point value at a new altitude N is given as follows:

$$D(\varphi,\lambda,N) = D(\varphi,\lambda,S) + \left(IGRF\ 10(\varphi,\lambda,N) - IGRF\ 10(\varphi,\lambda,S)\right),$$

where S is the satellite altitude.

The SV models were developed by calculating the time variation in the geomagnetic field between January and December in each year. The results are shown in Figure 2 and Table 1.



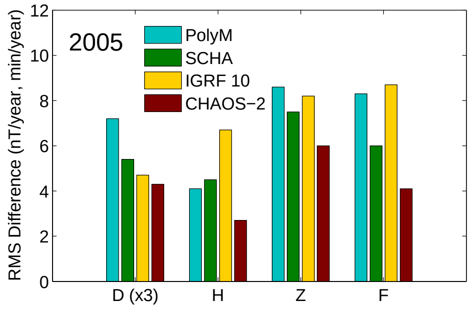


Figure 2. Comparison of RMS differences between field survey data and the regional models (PolyM and SCHA) and field survey data and two global models IGRF 10 and CHAOS-2. The RMS values in the D component are multiplied by 3 for the plotting purpose, and they are in minutes of arc/year. The RMS values were calculated using only the 13 ground reference points (Figure 1).

Table 1. A comparative evaluation among the RMS differences given in Figure 2. Negative values indicate that a regional field model is to be preferred to a global field model.

Epoch	Component/ Total field	PolyM - IGRF 10	PolyM - CHAOS-2	SCHA - IGRF 10	SCHA - CHAOS-2
2001.5	D (min/year)	0.2	0.1	0.0	-0.1
	H (nT/year)	9.2	9.7	8.2	8.7
	Z (nT/year)	-0.3	2.6	2.4	5.3
	F (nT/year)	4.7	9.3	6.0	10.6
2002.5	D (min/year)	-0.3	-0.2	0.1	0.2
	H (nT/year)	2.4	2.1	0.9	0.6
	Z (nT/year)	0.9	0.1	1.0	0.2
	F (nT/year)	0.4	-0.9	0.2	-1.1
2003.5	D (min/year)	0.3	0.5	-0.1	0.1
	H (nT/year)	-2.7	-5.1	-3.0	-5.4
	Z (nT/year)	-2.6	0.4	0.0	3.0
	F (nT/year)	1.7	0.4	2.1	0.8
2004.5	D (min/year)	1.0	1.2	0.3	0.5
	H (nT/year)	6.0	7.0	1.5	2.5
	Z (nT/year)	0.5	-1.3	1.4	-0.4
	F (nT/year)	-2.8	0.8	-2.4	-1.2
2005.5	D (min/year)	0.8	1.0	0.2	0.4
	H (nT/year)	-2.6	1.4	-2.2	1.8
	Z (nT/year)	0.4	2.6	-0.7	-1.5
	F (nT/year)	-0.4	1.9	-2.7	2.1

5 CONCLUSIONS

The results obtained show that it is indeed possible to derive SV models over southern Africa based entirely on satellite data as illustrated in Figure 2 and Table 1. The unexpected poor performance in 2001, particularly in H, Z, and F, can mainly be attributed to the poor data coverage in December 2001. For the remaining 4 years (2002-2005) there is a good agreement with global field models.

However, the regional SV models can be substantially improved using both high quality satellite and ground survey data. In this case, the Revised SCHA (R-SCHA) technique is recommended as it correctly takes into account the radial dependence, unlike SCHA (Thébault, 2004).

6 ACKNOWLEDGEMENTS

The support of the CHAMP mission by the German Aerospace Center (DLR) and the Federal Ministry of Education and Research are gratefully acknowledged.

7 REFERENCES

Gubbins, D. (1994) Geomagnetic polarity reversals: A connection with secular variation and core-mantle interaction. *Reviews of Geophysics* 32(1), 61–83.

Haines, G. V. (1985) Spherical cap harmonic analysis. *Journal of Geophysical Research* 90, 2593-2598.

Kotzé, P. B. (2003) The time-varying geomagnetic field of southern Africa. *Earth Planets Space* 55, 111-116.

Korte, M., Mandea, M., Kotzé, P. B., Nahayo, E., & Pretorius, B. (2007) Improved observations at the southern African geomagnetic repeat station network. *South African Journal of Geology* 110, 175–186.

Mandea, M., Korte, M., Mozzoni, D., & Kotzé, P.B. (2007) The magnetic field changing over the southern African continent: a unique behaviour. *South African Journal of Geology* 110, 193-202.

Thébault, E., Schott, J. J., Mandea, M., & Hoffbeck, J. P. (2004) A new proposal for spherical cap harmonic modelling. *Geophysical Journal International* 159, 83-103.