

# POLYNOMIAL MODELLING OF SOUTHERN AFRICAN SECULAR VARIATION OBSERVATIONS SINCE 2005

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## ABSTRACT

*The COMPASS (COMprehensive Magnetic Processes under the African Southern Sub-continent) program forms part of a collaboration project between Germany and South Africa, called Inkaba ye Africa, and aims to investigate the regional geomagnetic field in this area, particularly its evolutionary behaviour. Results obtained from field surveys conducted by the Hermanus Magnetic Observatory (HMO) and the Helmholtz GeoForschungsZentrum (GFZ) in South Africa, Namibia, and Botswana, in addition to geomagnetic field data from the 4 continuous recording magnetic observatories in southern Africa at Hermanus, Hartebeesthoek, Keetmanshoop and Tsumeb, were used to model the geomagnetic field time variation by means of a polynomial approach.*

## 1 INTRODUCTION

It is well known that secular change is a comparatively local phenomenon and that it does not proceed in a regular and uniform pattern all over the Earth, giving rise to regions where the field changes more rapidly than elsewhere, such as southern Africa.

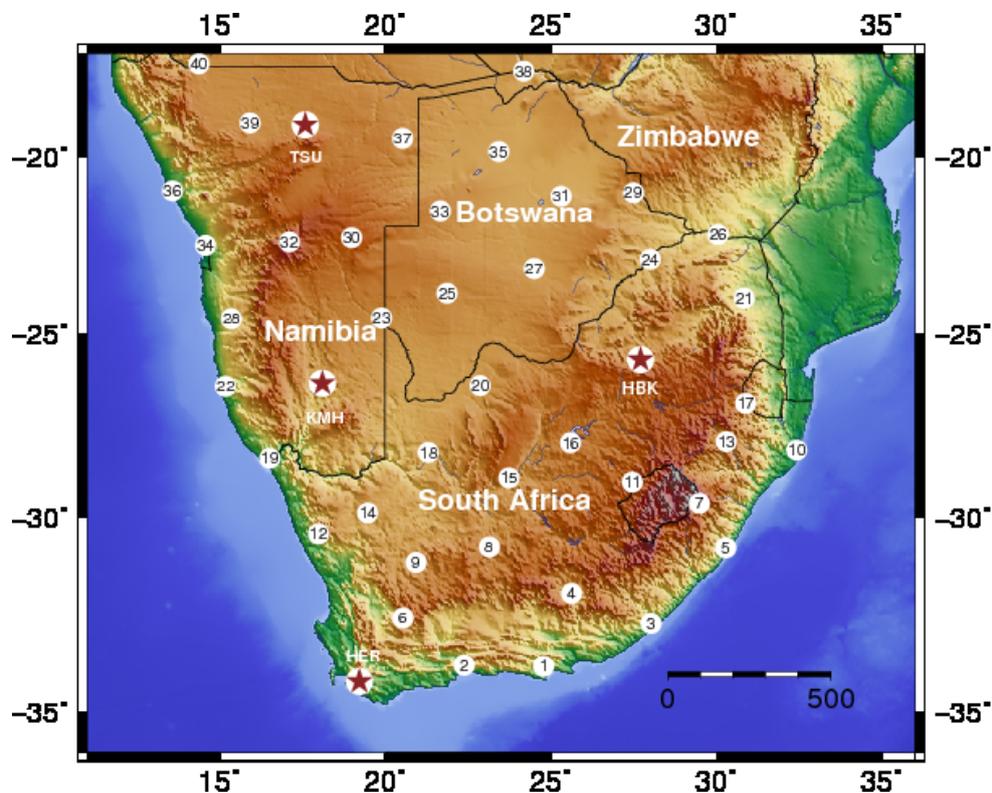
COMPASS (COMprehensive Magnetic Processes under the African Southern Sub-continent), a sub-project forming part of the Inkaba yeAfrica project (<http://www.inkaba.org/>), aims at a better understanding of the regional geomagnetic field behaviour. Secular variation observations over southern Africa, including countries like South Africa, Namibia, and Botswana, have been conducted since 2005 as part of this collaboration between the Hermanus Magnetic Observatory (HMO) in South Africa and the German Research Centre for Geosciences in Germany. For this purpose, a total of 40 repeat stations, separated by distances ranging between 300 and 400 km, were identified. These stations form part of a network of 75 repeat stations, established by the HMO during the last 60 years and visited at regular 5 year intervals until 2000. Due to the rapid secular variation change over this area, it was necessary to conduct annual surveys at a reduced number of repeat stations. The stations were also selected to form two independent sets of 20 beacons each, enabling one to visit these at alternative years respectively.

During these field surveys, 2 teams, consisting of both HMO and GFZ observers, using similar DI Flux theodolites and fluxgate variometers, obtained geomagnetic field data over southern Africa. These measurements were processed to remove daily variations etc. and then modelled by polynomial fitting as a function of latitude and longitude to derive geomagnetic field secular variation models for southern Africa.

## 2 FIELD SURVEYS AND DATA

Continuous recording of geomagnetic field variations are conducted at Hermanus (34° 25.5' S, 19° 13.5' E), Hartebeesthoek (25° 52.9' S, 27° 42.4' E), Tsumeb (19° 12' S, 17° 35' E), and Keetmanshoop (26° 32.5' S, 18° 6.5' E). All these observatories comply with INTERMAGNET standards (<http://www.intermagnet.org/>). The primary instrument for recording of magnetic field variations is the FGE fluxgate magnetometer, manufactured by the Danish Meteorological Institute in Copenhagen, Denmark. This instrument is based on three-axis linear-core fluxgate technology, optimised for long-term stability, and records the components H, D, and Z. An Overhauser-type magnetometer further provides absolute total field information while baselines for the other components are obtained using a DI (Declinometer-Inclinometer) Flux theodolite ([www.bartington.com/flux1](http://www.bartington.com/flux1)).

For field survey purposes, field stations are marked by concrete beacons, ensuring that all observation points are exactly reoccupied during surveys. Most measurements are taken on a standard 1.2m pillar while in a few cases observers had to use a tripod mounted above a clearly marked shorter beacon. The field surveys of 2005, 2006, 2007, 2008, and 2009 were separated into three different sectors. At first a survey was done by only HMO field surveyors. Thereafter, two independent teams, each consisting of a staff member from HMO and GFZ, conducted a simultaneous field survey in southern Africa. A map showing the repeat station beacons visited during the 2009 survey is shown in Figure 1.



**Figure 1.** Map of distribution of observatories (red asterisks) and repeat stations (numbered white dots) in the southern African region. Observatories are situated in Hermanus (HER), Tsumeb (TSU), Keetmanshoop (KMH), and Hartebeesthoek (HBK). (Figure courtesy of A Geese, GFZ)

More information on the repeat station methodology is given by Korte et al. (2007). A DI fluxgate magnetometer was used as primary instrument during field surveys to obtain values of declination and inclination while an Overhauser magnetometer delivered values of total field intensity ( $F$ ). Corrections for diurnal variation and other disturbing effects were made by comparing field station observations with magnetic data recorded on site with a LEMI suspended tri-axis fluxgate instrument.

The data reduction to quiet internal field values according to the standard procedures described, e.g., by Newitt et al. (1996) is done in two steps. First the measured values are reduced to the quiet night time level by means of the local variometer recording. For quiet up to moderately disturbed magnetic conditions, the average of several night time hours represents the quiet internal field reasonably well (Korte et al., 2007). In order to obtain data for a common time, the quiet night time values are then further reduced to annual means utilizing the recordings of the nearest observatory and taking into account estimates of secular variation differences.

### 3 POLYNOMIAL MODELLING

Historically, polynomial models are among the most frequently used empirical models for curve fitting and to determine the parameters that have a profound effect on a particular response function. This type of modelling is popular as polynomial models have a simple form, have well known and understood properties, have moderate flexibility of shapes, and they are computationally easy to use. However, polynomial models also have limitations such as weak interpolatory and extrapolatory properties. Polynomials may provide good fits within the range of data, but they will frequently deteriorate rapidly outside the range of the data.

Different methods to model the geomagnetic field on a regional scale were reviewed by Haines (1990). In geomagnetism, polynomials have been applied with great success to derive regional models of secular variation (Shu et al., 1996).

Polynomials have been used extensively to model ground magnetic field measurements to derive secular variation models for southern Africa (Kotzé, 2003). The field surveys conducted since 2005 however enabled polynomial-based secular variation models to be derived. We selected a two-dimensional polynomial presentation (Xu et al., 1992):

$$\frac{dB}{dt}(\theta, \gamma) = \sum_{n=0}^N \sum_{m=0}^M a_{nm} (\theta - \bar{\theta})^n (\gamma - \bar{\gamma})^m$$

Where  $\frac{dB}{dt}$  is the magnitude of secular variation for each component of the geomagnetic field at the point with geographic coordinates  $\theta$  and  $\gamma$ ,  $a_{nm}$  is a numerical coefficient, and  $\bar{\theta}$  and  $\bar{\gamma}$  are the coordinates of the centre of the modelled area:  $\bar{\theta} = 26^\circ\text{S}$  and  $\bar{\gamma} = 24^\circ\text{E}$ .

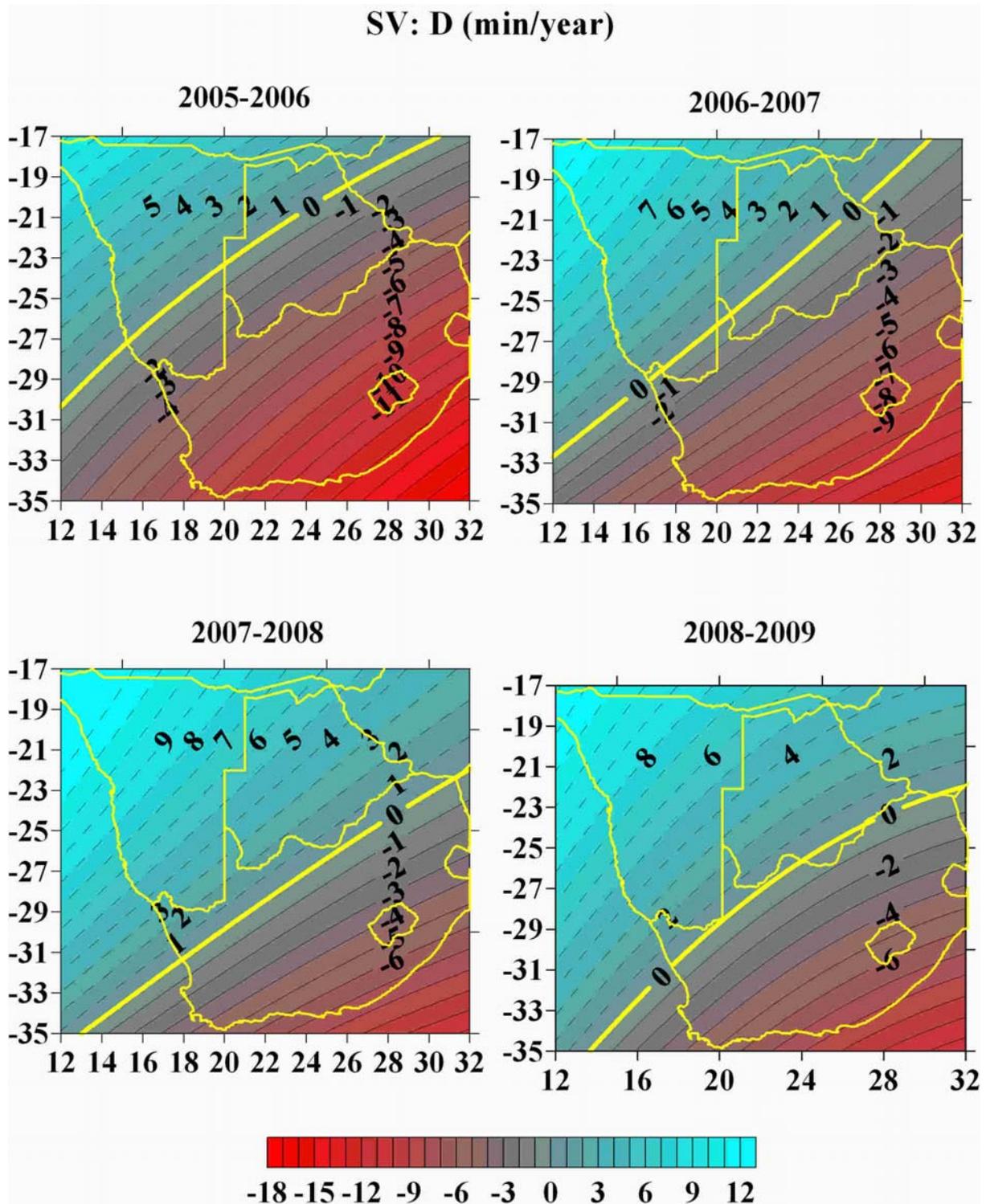
Since secular variation is not measured directly but is derived as a time derivative of the geomagnetic field, one can model the main field and then differentiate the corresponding field model to get a secular variation model, or one can numerically differentiate the main field data and then fit a secular variation model directly. The latter derivative-fit approach has been applied in this study of observatory and repeat station data. First central differences from annual mean observatory data as well as repeat stations, divided by their respective time intervals in years, are used as input data to our secular variation model. As observatory data, in general, are more accurate than repeat survey data (because of better baseline control and because seasonal and other short-term variations are more effectively removed by using annual means), we weighted observatory and repeat station secular variation data in a ratio 1:0.7 in the least-squares solution. This ratio was determined by minimizing the RMS difference between model fits and survey data. There are 120 vector differences from 40 repeat stations and 12 vector differences from the 4 observatories, providing a total of 132 data values for a particular time interval. Secular variation models for the periods 2005-2006, 2006-2007, 2007-2008, and 2008-2009 were subsequently derived. The least-squares routine used to fit the data is the stepwise regression procedure described by Efroymson (1960) that has the ability of both entering and removing variables at given levels of statistical significance. The scatter about the fit for declination secular variation is less than 1 min/y.

## 4 RESULTS AND DISCUSSION

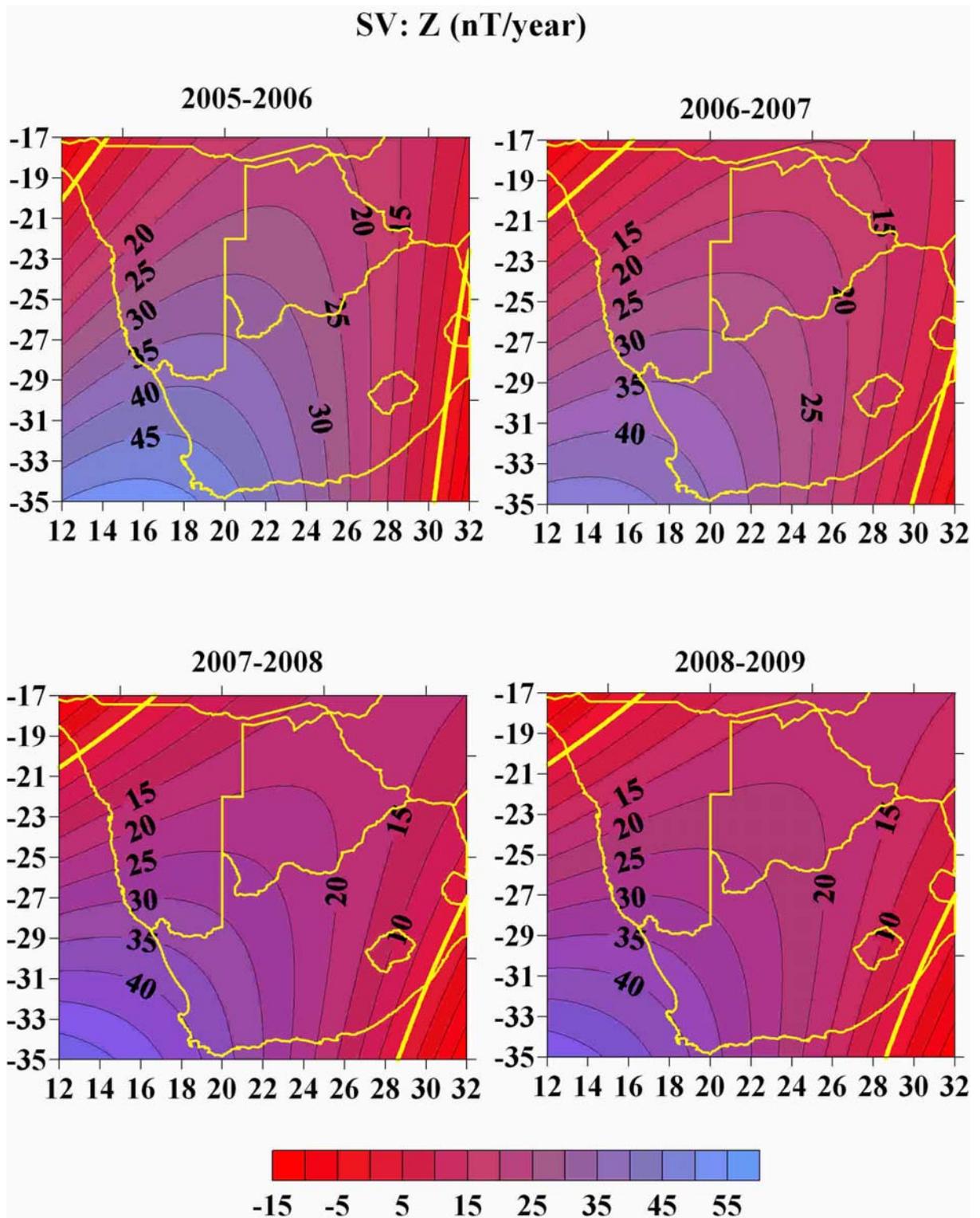
Results obtained in this investigation by modelling secular variation over southern Africa for the period 2005 – 2009 by means of a polynomial modelling approach reveal a very dynamic geomagnetic field pattern. In particular, the declination secular variation is dominated by an eastward changing pattern in the north-western part of the region while the south-eastern region of southern Africa is under the influence of a westward variation (Figure 2). The annual field survey results reveal a rapid change from year to year. This is quite evident when observing the annual movement of particularly the zero secular variation contour line as displayed in Figure 2. Of particular interest is to note that the westward change in declination secular variation in the southern part of the region, centred around Cape Agulhas, has slowed down from 8 min/year in 2006.5 to approximately 4 min/year in 2008.5. In contrast to this, the eastward change in the declination secular variation as displayed in the northern part of Namibia stayed constant around 8 min/year. This indicates a decreasing gradient in the orientation of the geomagnetic field of southern Africa in a north-west, south-eastern direction as revealed during the period 2005 – 2009.

The pattern displayed by the Z-component secular variation (Figure 3) clearly indicates that southern Africa is dominated by a central region where the vertical component of the magnetic field is declining at a rapid rate between 20 and 40 nT/year. Over the south-western part of the subcontinent, the decay of Z is the most prominent, characterised by a rapid change between 2007 and 2008, reminiscent of a geomagnetic jerk that occurred in this time interval (Kotzé, 2010). A plot of  $dY/dt$  and  $dD/dt$  versus time (Figure 4) for the Hermanus (HER) observatory confirms that indeed an extremely strong secular variation impulse occurred around 2007.5 following a linear fit to the data. For the Y-component in particular, the secular variation changed from -15 nT/y at 2006.0 to -2 nT/y at 2007.4 and then started to change back to -10 nT/y at 2009.0. The strength of this jerk is

more than  $15 \text{ nT/y}^2$ , which is more than 3 times stronger than the global geomagnetic jerk of 1982/3. A similar pattern can be observed for D during 2007.

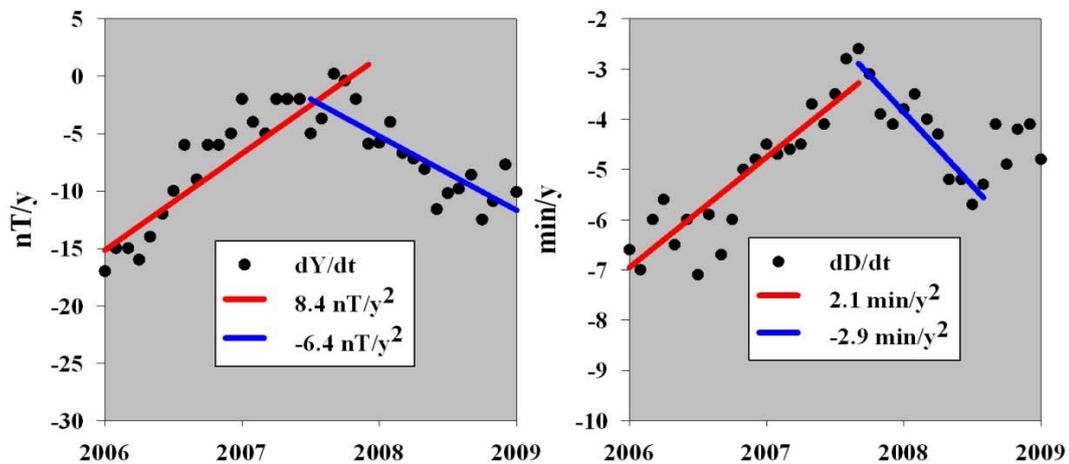


**Figure 2.** Secular variation of Declination for the periods 2005-2006, 2006-2007, 2007-2008, and 2008-2009 for southern Africa



**Figure 3.** Secular variation of Z for the periods 2005-2006, 2006-2007, 2007-2008, and 2008-2009 for southern Africa

### Hermanus Secular Variation: Y and D (2006 - 2009)



**Figure 4.** Plots showing the occurrence of a geomagnetic jerk as observed during 2007 at the Hermanus Magnetic Observatory in the secular variation patterns of both the Y and D field components.

Since the first magnetic field measurements started in the nineteenth century, a continuous decrease of the Earth's magnetic dipole moment has been observed. The change in the field strength is, however, not evenly distributed over the globe. In particular, the most rapid decrease of the core field is observed across the Southern Atlantic region. The southern African and south Atlantic regions have shown a particularly striking geomagnetic field behaviour over the last decades (Bloxxham & Gubbins, 1985; Manda et al., 2007). Therefore southern Africa provides an ideal opportunity to study these geomagnetic field changes, as confirmed by the field surveys since 2005. Since the establishment of the Hermanus Magnetic Observatory in South Africa in 1941, the total field intensity across southern Africa has decreased by 20%. This rapid and substantial changes observed across the southern African region can largely be attributed to the close proximity of the South Atlantic Anomaly.

The growth and position changing of patches of the reverse flux under the southern African region, from 1840 onwards, may be responsible for changes in dipole moment (Gubbins & Bloxxham, 1985; Bloxxham & Jackson, 1992; Jackson et al., 2000). Most interestingly in this regard, it has been shown recently (Dormy & Manda, 2005) that patches of intense secular variation appear in the South Atlantic hemisphere that are very rapidly displaced in a south-east – north-west direction, consistent with observations of the present study.

## 6 ACKNOWLEDGEMENTS

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