Secular variation modeling at Trelew Magnetic Observatory (Chubut, Argentina)

J. C. Gianibelli, I. R. Cabassi
Department of Geomagnetism and Aeronomy, Faculty of Astronomical and Geophysical Sciences, La Plata National University[1]

A b s t r a c t: In this study we analyse the nocturnal reference level of total magnetic intensity at Trelew Magnetic Observatory in the interval 00 - 03 UT hours using 1-minute digital records of Q days from 1993 to 1999. Fitting these data with the 2nd degree polynomial, we propose a model of the geomagnetic field secular variation at the observatory. The residual time series are studied by various methods of the spectral analysis. A linear additive harmonic model is applied to represent periodic variations in each residual time series. Using this model, we were able to obtain the amplitudes of the annual and semiannual variations. The daily mean values for the first three months of the year 2000 were succesfully forecasted.

Key words: secular variation, annual and semiannual variations, nocturnal reference level, Q-days

1. Introduction

Trelew magnetic observatory (Chubut, Argentina, $\varphi = 43°\ 16'1$ S; $\lambda = 65°\ 22'9$ W) started to record 1-min digital geomagnetic data (declination, inclination, and total intensity) in September 1993 (*Rasson et al., 1996*). However, the recording system experienced various problems, such as changes in the protecting system (to prevent cutoffs of the electricity), breakouts of recording computers and absolute instruments, etc. An important progress has been achieved at the beginning of May 2000, when a new digital system has been installed (in parallel to the existing one) in order to meet the requirements of the INTERMAGNET network. At present, the information is transmitted via Internet (with a delay of 24 hours) to the Geomagnetic Information Node (GIN) at Edinburgh (UK).

2. Data analysis

Magnetically Quiet International Days (Q-days) were selected from the records of the absolute total intensity (F) of geomagnetic field for the period

[1] Paseo del Bosque s/n, 1900 La Plata, Province Buenos Aires, Argentina
e-mail: jcg@fcaglp.fcaglp.unlp.edu.ar, rosy@fcaglp.fcaglp.unlp.edu.ar

1993.6-1999.9. We applied various digital filters to eliminate the spikes and found out that the "median" 9-points filter turns to be suitable (*Gianibelli and Cabassi, 1999; 2000*). Then mean values over the intervals 00 - 03 UT hours (21 - 24 LT) and 00 - 06 UT hours (21 - 03 LT) were selected as the Nocturnal Reference Level of low geomagnetic activity.

Fig. 1 shows the standard deviation of the averages computed on the intervals mentioned. The best standard deviations belong to the interval 00 - 03 UT hours. The time series was mathematically modeled by means of a non-linear approximation as:

$$F(t) = A + B*t + C*t^2 + \sum Cn\, e^{i(\omega n\, t + \varphi n)}; \quad n = 1, ..., N \qquad (1)$$

where the first three terms represent the secular variation, and the last term includes some other varaitions, such as annual and semiannual ones, quasi-biannual oscialltions (QBO, if exist), etc.

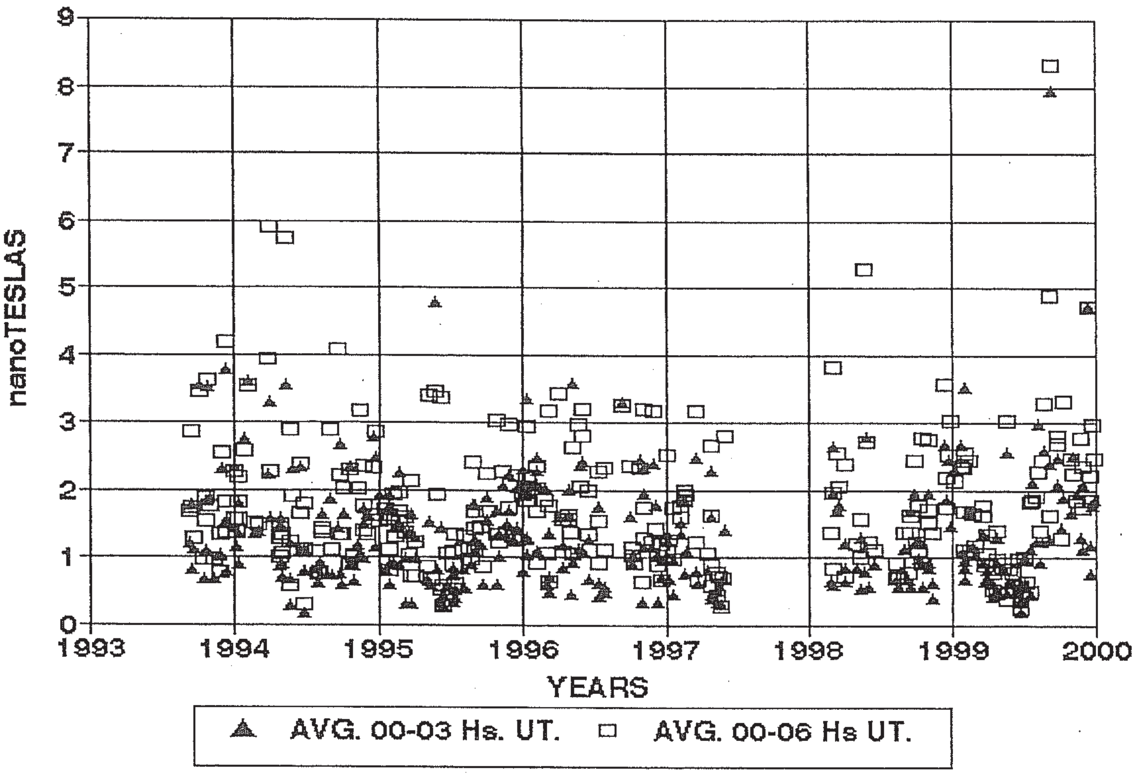

Fig. 1. Standard deviation of the mean values in the intervals: 00 – 03 UT and 00 – 06 UT (deduced from the means the Nocturnal Reference Level of low geomagnetic activity).

Fig. 2 shows the time series of the nocturnal means (00 – 03 UT). According to the proposed nonlinear approximation, the 2nd-order model was chosen as the best one and only the annual and semiannual variations were adjusted. This polynomial model is valid until 2001; then it should be adjusted again to the maximum of the 23rd solar activity cycle.

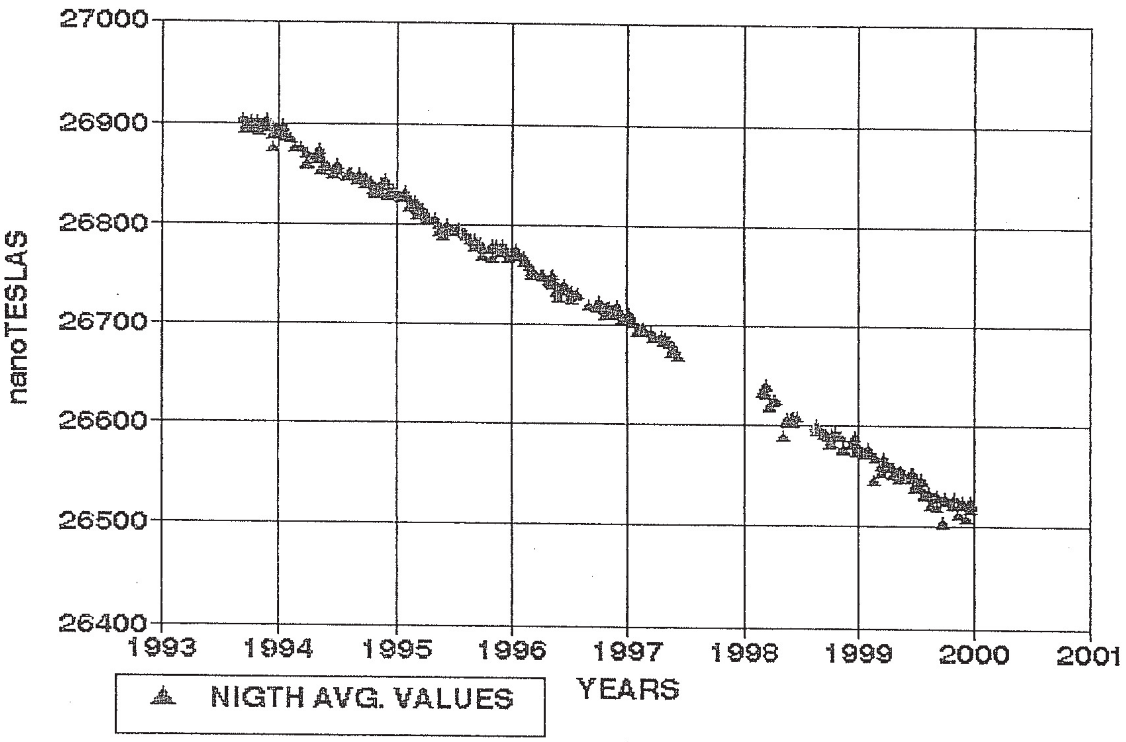

Fig. 2. Nocturnal mean values (the 00 - 03 UT intervals) of 1-minute data of the F total intensity recorded in the period 1993.6 - 1999.9.

3. Method

For the complete polynomial fitting of the annual and semiannual variations, we used the least-square method as it was applied to heterogeneous time series (*Montgomery* and *Johnson*, 1976). The approximation was realized in a generic model as follows:

$$Fj = b_1 + \sum b_j Z_{ij} \qquad i = 2,\ldots,k;\; j = 1,\ldots,n \qquad (2)$$

For the non-equidistant j points, Zj are the functions that exist near Fj at each point. The following system of equations should be solved for the proposed model:

$$G = \begin{bmatrix} N & \Sigma Z_{2j} & \cdots & \Sigma Z_{kj} \\ \Sigma Z_{2j} & \Sigma Z_{2j}^2 & \cdots & \Sigma Z_{2j} \cdot Z_{kj} \\ \cdots & \cdots & \cdots & \cdots \\ \Sigma Z_{kj} & \Sigma Z_{kj} \cdot Z_{2j} & \cdots & \Sigma Z_{kj}^2 \end{bmatrix}$$

$$n\, b_1 + (\Sigma Z_{2j})\, b_2 + \ldots + (\Sigma Z_{kj})\, b_k = \Sigma X_j \qquad j = 1,\ldots,n \qquad (3)$$
$$(\Sigma Z_{2j})\, b_1 + (\Sigma Z^2_{2j})\, b_2 + \ldots + (\Sigma Z_{2j} Z_{kj})\, b_k = \Sigma Z_{2j} X_j.$$

$$(\Sigma Z_{kj})\, b_1 + (\Sigma Z_{kj} Z_{2j})\, b_2 + \ldots + (\Sigma Z^2_{kj})\, b_k = \Sigma Z_{kj} X_j$$

Therefore, $G * b = g$ and $b = G^{-1} * g$ where

$$b = \begin{bmatrix} b_1 \\ b_2 \\ \vdots \\ b_k \end{bmatrix} \qquad g = \begin{bmatrix} \Sigma X_j \\ \Sigma Z_{2j} \cdot X_j \\ \vdots \\ \Sigma Z_{kj} \cdot X_j \end{bmatrix}$$

(4)

and $Z_{2j} = b_2\,(t_j - 1993.0)$; $Z_{3j} = b_3\,(t_j - 1993.0)^2$;
$Z_{4j} = b_4 \sin(W_j)$; $Z_{5j} = b_5 \cos(W_j)$;
$Z_{6j} = b_6 \sin(2\,W_j)$, $Z_{7j} = b_7 \cos(2\,W_j)$, where
$W_j = 2\pi\,(t_j - 1993.0)/(1\ \text{year})$.

4. Results

The proposed deterministic additive model allows to divide the time series in polynomic and periodic parts. Fig. 3 shows the residual values of the adjustment and the synthesis of the model to obtain the annual and semiannual variations.

One can see in this figure that the dispersion of residuals increases near the maximum of the 23rd solar activity cycle.

The parameters of the definitive mathematical model, which is valid for the interval from 1993.6 up to 2001.0, are the following:

$$F(t) = 26{,}944.235 - 58.372\,(t - 1993.0) - 0.521\,(t - 1993.0)^2 + 0.307 \sin(W) + 3.749 \cos(W) + 0.024 \sin(2W) + 2.085 \cos(2W) \quad [\text{nT}], \qquad (5)$$

where W = 2π (t – 1993.0)/(1 year), and t is in years and decimal fraction of year. The obtained RMS error is 5.4 nT.

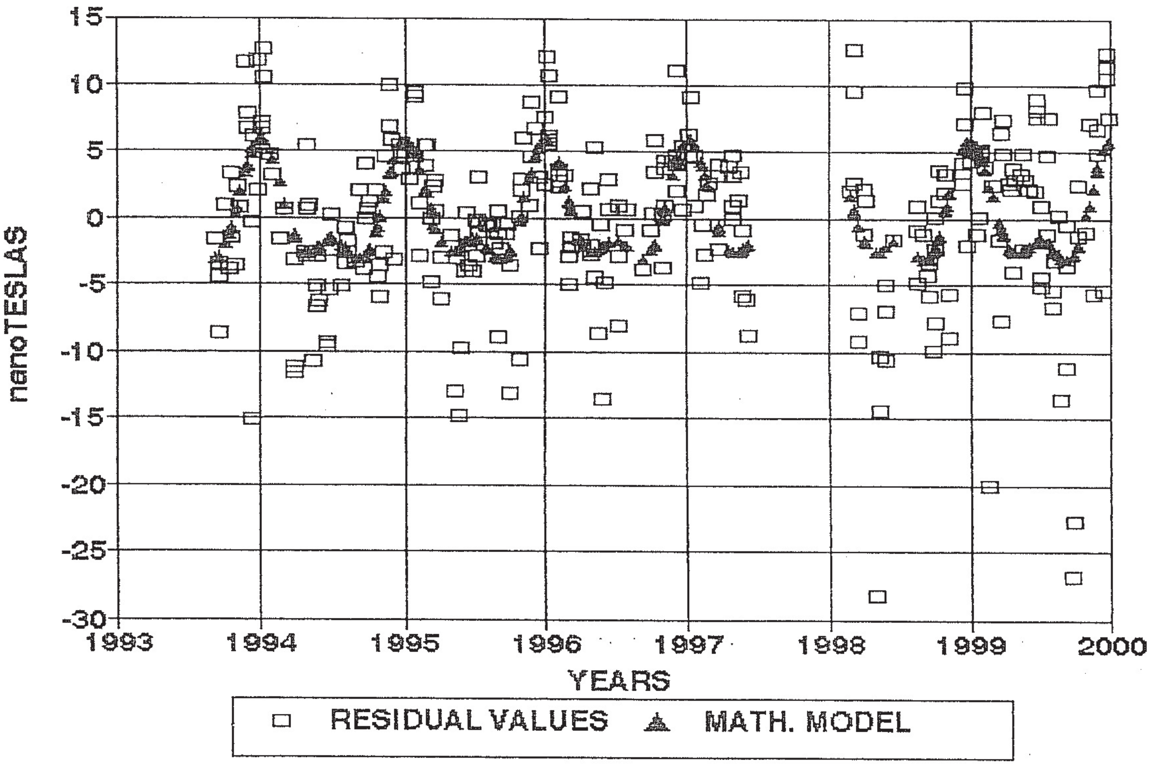

Fig. 3. Residual values and simulation obtained from the mathematical model to compute the annual and semiannual variations.

Fig. 4 shows the time evolution of the mathematical model and the values for the Q-days corresponding to the months of January, February, and March of year 2000. It is confirmed that the prediction of Q-days for the first quarter of the year is satisfactory.

5. Conclusions

The proposed method allows us to revise the model at the end of the studied period recalculating the parameters and entering the daily averages in the interval 00 - 03 UT for the recorded Q-days. At the end of 23rd solar cycle, we should revise the model incorporating the effect of the solar cycle into the mean values of the nocturnal level. The obtained square mean error of 5.4 nT is satisfactory because of the good quality of digital recording, specifically if there are no Q-days records during some disturbed intervals.

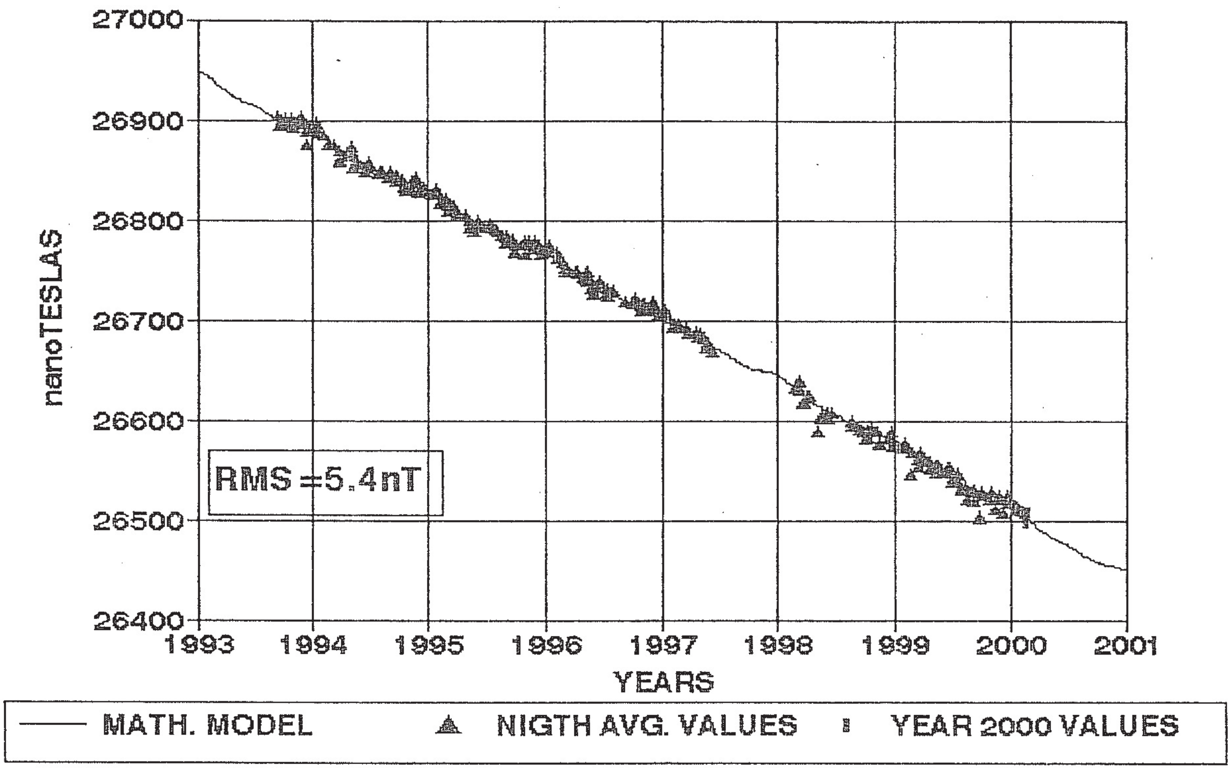

Fig. 4. Temporal evolution of the mathematical model, of the nocturnal averages in the 00 - 03 UT interval, and values for the Q- days predicted for the first quarter of year 2000.

The nocturnal level in the 00 - 03 UT interval of the international quiet days (for example, used to correct magnetic surveys) is more appropriate as a reference of the minimum activity.

The proposed method is simple and appropriate, and it allows us to quickly revise the model parameters as new data become available. For example, this method is applicable to determine the functions for better fitting of baselines at a magnetic observatory. On the other hand, this methodology is used to study temporal variations recorded in each geomagnetic observatory, which is in the direct relation with both the correction of magnetic surveys and reduction to a common epoch of magnetic charts. The method considered allows us to obtain a better model of the secular variation.

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