Utility of the Absolute Observations of the Terrestrial Magnetic Field at "Las Acacias" Magnetic Observatory (Buenos Aires Province, Argentina)

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Resumen

Se estudiaron las determinaciones absolutas con los magnómetros QHM y BMZ en el observatorio magnético "Las Acacias", durante el periodo de 1961-1997, utilizando el Análisis de Espectro No Lineal, basado en el Método de Entropía Máxima (MEM).

El MEM se aplica a las series residuales de D, H y Z, por medio del análisis de densidad del poder espectral. Se determinan los periodos característicos para la predicción del error (LFPE), entre el 50 y el 95% de la longitud de cada serie de tiempo. La amplitud y la fase de la onda en cada periodo son computados por medio de un modelo aditivo. Se sugiere una elección final de LFPE de 240 meses, debido a que para mayores longitudes, el periodo se divide en ondas no coherentes.

Abstract

The absolute determinations with QHM and BMZ magnetometers at "Las Acacias" magnetic observatory, during the period 1961-1997, were studied using Non-Linear Spectral Analysis, based in the Maximum Entropy Method (MEM).

MEM is applied to the residual series of D, H, and Z, by means of the density function analysis of the spectral power. Characteristic periods for error predictor filter lengths (LFPE) between 50 and 95% of the length of each time series are determined. Amplitude and phase of the wave in each period are computed by means of an additive model. A final choice of LFPE of 240 months is suggested because for greater lengths the period is divided into non-coherent waves.

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Introduction

Classical instruments for "absolute" determinations of Magnetic Declination (D) and horizontal (H) and vertical (Z) components of the terrestrial magnetic field were, and in several cases, still continue to be used. Quartz Horizontal Magnetometer (QHM) to measure D and H, and the Balance Magnetometer Zero (BMZ) to measure Z, both by La Cour. These instruments are semi-absolute from the Gauss' criteria. They need calibration at regular intervals.

At "Las Acacias" magnetic observatory, Buenos Aires Province, Argentina ($\varphi = 35° 00' 5$ S; $\lambda = 57° 41' 65$ W) QHM- and BMZ- magnetometers were utilized from 1961 September, until 1997 March.

One of the questions of interest is what utility has the monthly observations in the context of the earth magnetic field evolution? To respond this question it is important to answer two additional questions:

1) What precision the instruments have to determine the absolute values?, and
2) What sources of external and internal origin, like induction, have these determinations?

The precision of the determination of D is of 0.1 arc minute, while for H it varies between 1 and 2 nT with QHM- magnetometer. On the other hand, the measures realized with BMZ have less precision, between 2 and 4 nT.

The more interesting feature is that an absolute determination of the three elements of the terrestrial magnetic field (D, H and Z) have contributions of different sources, such as the geodynamo and the crust field of internal origin and from sources of external origin which are influenced by magnetospheric and ionospheric current systems.

In a magnetic storm recorded at "Las Acacias" observatory (LAS), 97.4% of the absolute values measured of either component is due to sources of internal origin, while 2.5% is of external origin and only 0.1% is due to induction of magnetospheric and ionospheric current systems acting on the crust and hydrosphere around the observatory, because 10 km northward from it, there is a vast La Plata River with fresh water, wherein the currents are induced too.

Thus, the absolute observations help in assessment of the secular variation with the passage of time.

Data and Observations

The observations at "Las Acacias" Magnetic Observatory were made by means of two QHM —magnetometers (numbers 622 and 623) and a BMZ— magnetometer (number 189), both fabricated by Andersson-Sörensen at Copenhagen. Periodic observations were made during all months in the interval 1961-1997. Three time series of averaged monthly values were generated from these observations.

All the absolute observations have contributions of inductive, internal and external sources. The contribution of internal origin has a trend modelled by a polynomial upto 3- degree. The residual part —obtained from model minus the observational data— has still some contribution of internal origin with periods between 30 and 60 years. The rest of the periodic composition is due to components of external origin and, to a small extent, due to induction. In the monthly mean series, there are the annual and semiannual variations, the solar cycle of 11 and 22 years, and a possible wave of 18.6- year of lunar origin.

So, any composition of the mathematical model representative of the D-, H- and Z- series would be a characteristic polynomial of secular variation, and superposed periodic variations.

Figures 1 (a, b and c) show the temporal trend of D, H and Z respectively. The polynomial fits (degree 2 for D, degree 1 for H, and degree 3 for Z) and the residual parts have been analyzed by MEM. The determination of the 'best-fit' polynomial was realized by means of the Square Minimum Method (Gianibelli 1995).

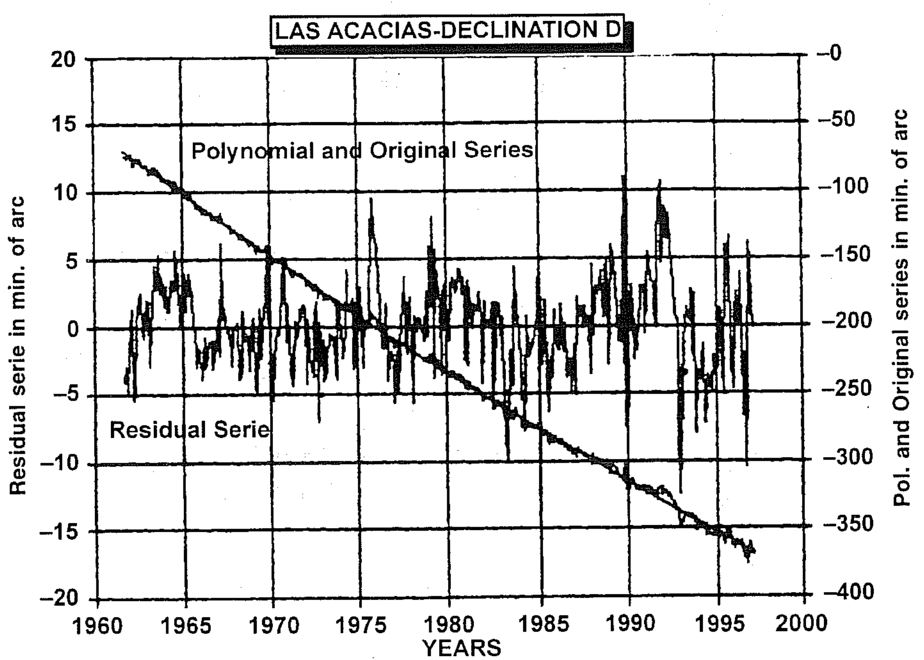

Figure 1a. Temporal Trend of D- magnetic declination. Residual Series and Polynomial fit and Original Series, both in minute of arc.

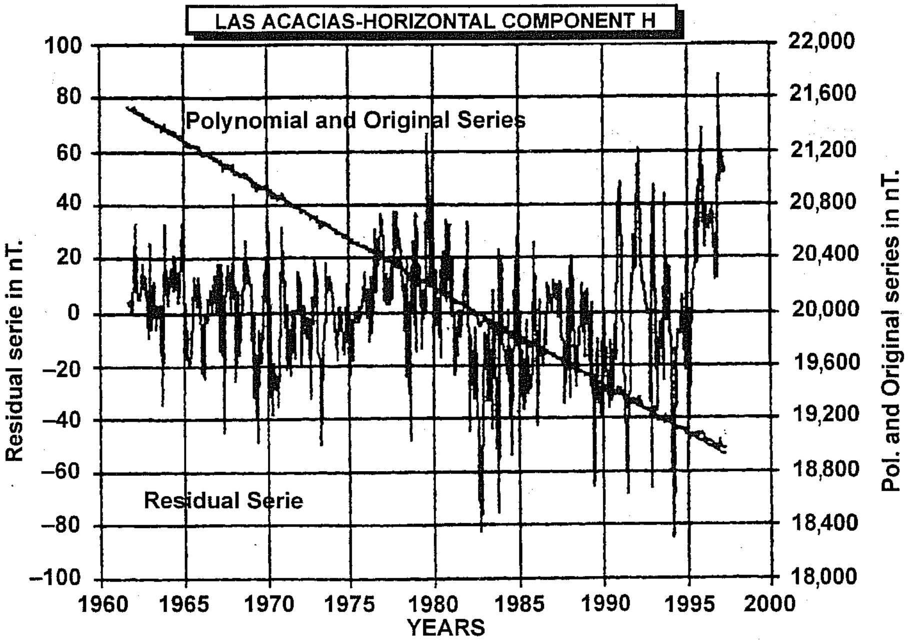

Figure 1b. Temporal Trend of H- magnetic horizontal component. Residual Series and Polynomial and Original Series, both in nT.

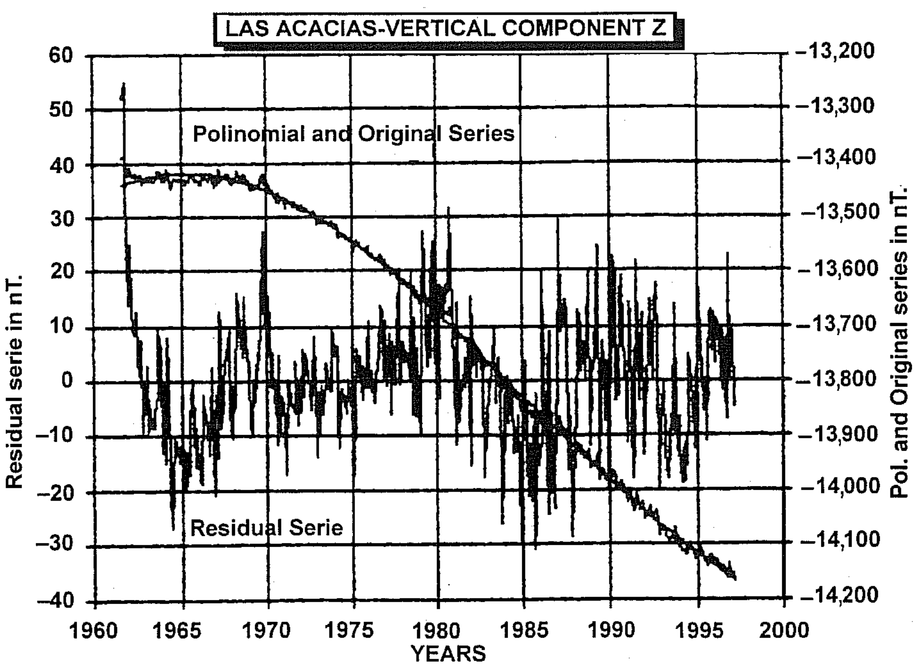

Figure 1c. Temporal Trend of Z- magnetic vertical component. Residual Series and Polynomial and Original Series, both in nT.

Figures 1 (a, b, and c) show original data, the best- fit polynomial representing the secular variation, and the residual part of the difference between the observed data and this polynomial. It is possible to see that the vertical component is approximated better with a polynomial of third degree, due to an anomalous behavior compared with other magnetic observatories of the South Hemisphere (Gianibelli and Suárez 1994). It is possible to see a change before 1970, due to a "pulse" of the geomagnetic field of internal origin, perhaps produced by a variation of the coupling between the upper mantle-external core limit (Gianibelli and Perdomo 1993; Merril and McElhinny 1983; Jill and Thomas 1974). Declination D and H components (Figures 1a and 1b) do not show this effect clearly but from the residual parts, it is possible to deduce changes in the behavior around 1970. Thus, it can be related to the geomagnetic "pulse" observed elsewhere also.

Methodology of the Spectral Analysis

Geomagnetic time series can be prepared with annual, monthly, hourly, and each minute means. Various techniques to study the spectral structure have been developed: i) Fourier harmonic analysis, ii) Fast Fourier Transform (FFT), periodogram and spectral analysis; and iii) Non-Linear Spectral Analysis, i.e. Maximum Entropy Method (MEM). We consider that the appropriate method to determine the characteristic frequencies is the Non-Linear Spectral Analysis, based on the Maximum Entropy Theory.

MEM is applied to the residual series by means of the analysis of the density function of the spectral power (Burg 1968). Ulrich and Bishop (1975) have presented appropriate softwares for the algorithms. Lacoss (1971) and Ulrich (1972) have shown that this method is good to estimate the spectral power density in periods embedded in a time series. This is possible when the non-periodic tendency is subtracted from the observed data as it can be represented by a suitable polynomial.

For a discrete stochastic process and a frequency f, the spectral density is:

$$P(f) = P_{M+1}\,[f_N \,|\, 1 + \sum_{k=1}^{M} A_{MK} \exp(-i\, 2\pi\, k\, f\, \Delta\, t)\,|^2]^{-1} \qquad (1)$$

where P_{M+1} represent the mean output power for the (M+1) point of the Error Predictive Filter (FPE), used to whiten the series. A_{MK} represent the FPE coefficients determined from the data; t is the uniform interval of sampling (i.e. 1 month); f_N is the Nyquist frequency = 1/(2 * t) and f is the frequency between ($-f_N$, $+f_N$) for which the spectral power density is determined. The coefficients A_{MK} are calculated by means of the Burg algorithm, used by Ulrich and Bishop (1975), which assumes no periodic extension or padded zeros in the data.

We detected the characteristic periods (1) for the length of the error predictor filter (LFPE) between 50 and 95% of the length of each time series. Then, we determined the amplitude and phase of the wave in each period by means of an additive model as:

$$Z_r(t) = \sum_{n=1}^{N} C_n \exp[i(2\pi f_n t + \phi_n)], \; f_n = 1/T_n \tag{2}$$

where C_n is the amplitude and ϕ_n, the phase of the waves of period T_n, determined by MEM. The errors of C_n and ϕ_n were determined as the square root of the elements of the principal diagonal of the inverse matrix in the normal equation system, divided by the standard deviation of the bestfit data.

Results and Conclusions

In Figures 2 (a, b, c, d, e, and f) the detected periods for each component are shown as a function of the LFPEs, with increments in steps of 20 months between 200 and 380

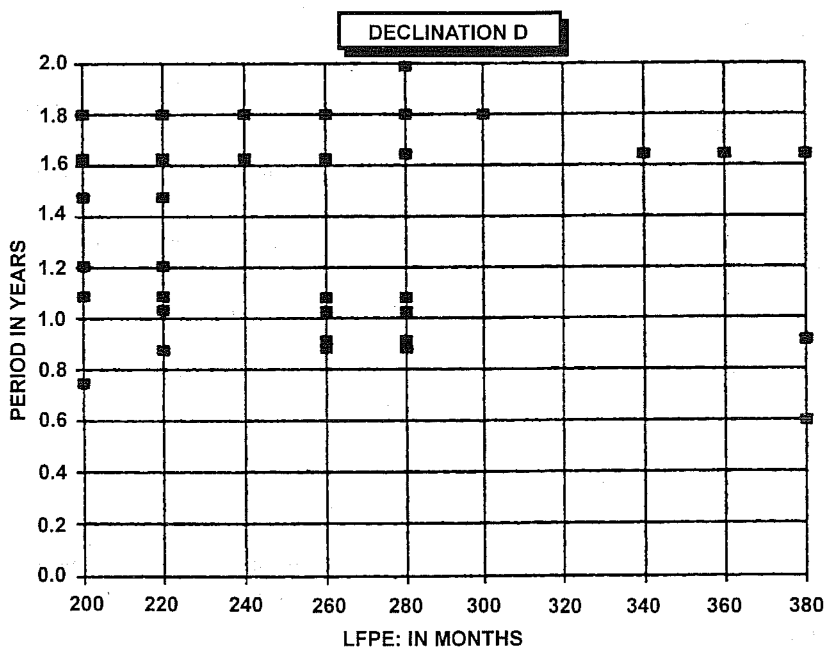

Figure 2a. Detected Periods (years) vs. Error Predictor Filter Length (LFPE in months) D-magnetic declination, sampling each 20 months. Periods less than 2 years.

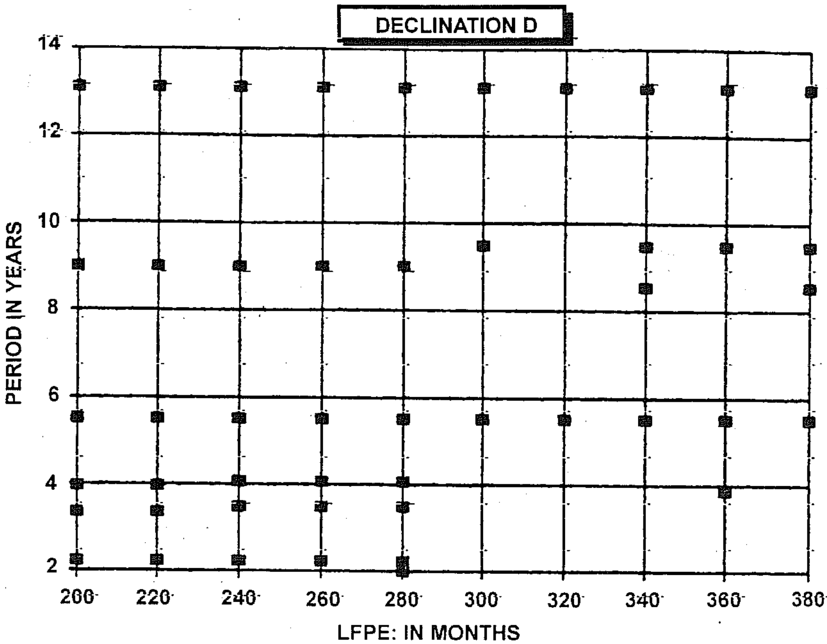

Figure 2b. Detected Periods (years) vs. Error Predictor Filter Length (LFPE in months) D- magnetic declination. Periods greater than 2 years.

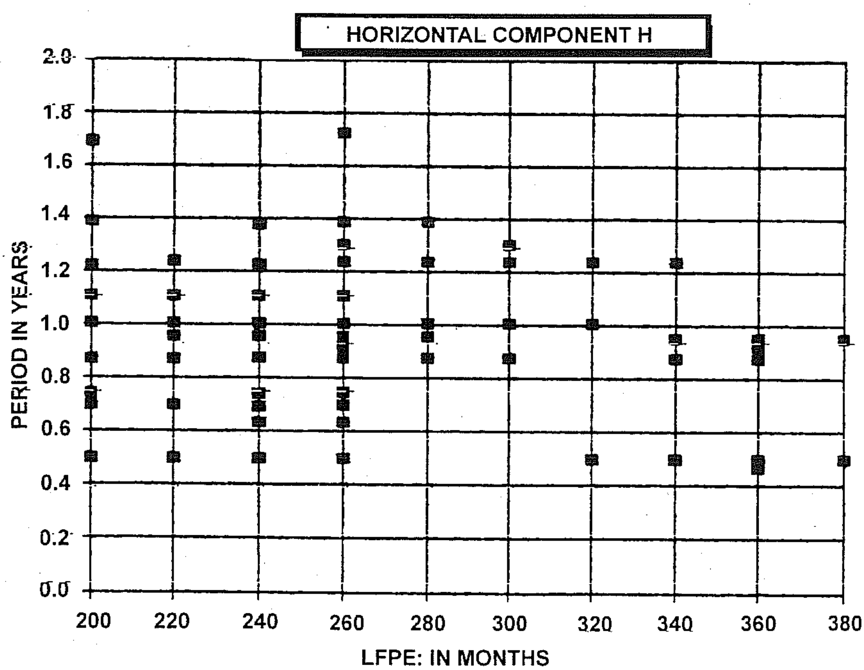

Figure 2c. Detected Periods (years) vs. Error Predictor Filter Length (LFPE in months) H-magnetic horizontal component. Periods less than 2 years.

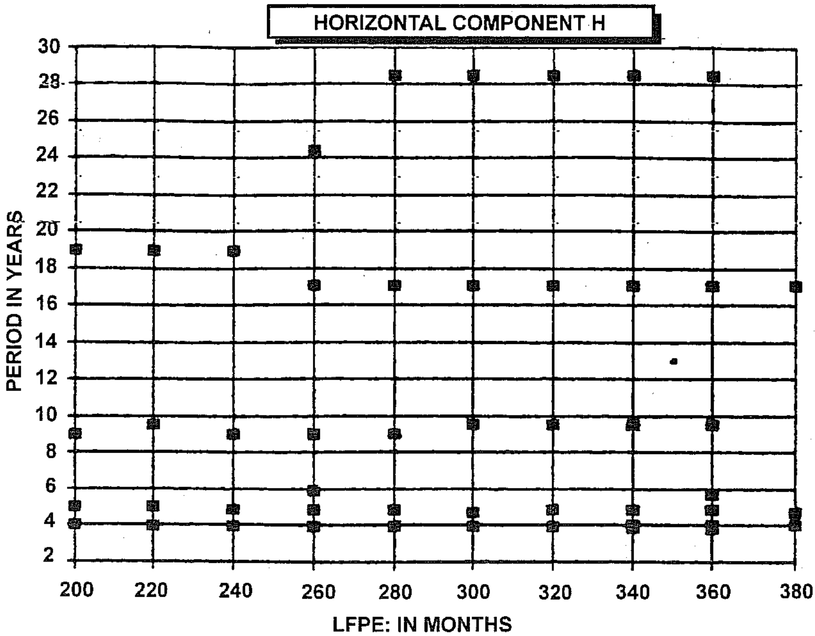

Figure 2d. Detected Periods (years) vs. Error Predictor Filter Length (LFPE in months) H-magnetic horizontal component. Periods greater than 2 years.

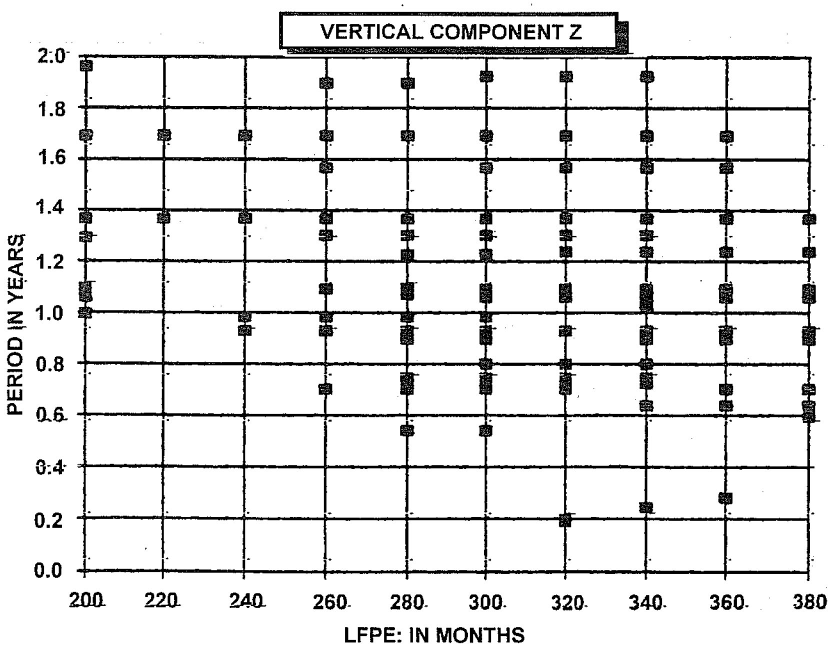

Figure 2e. Detected Periods (years) vs. Error Predictor Filter Length (LFPE in months) Z-magnetic vertical component. Periods less than 2 years.

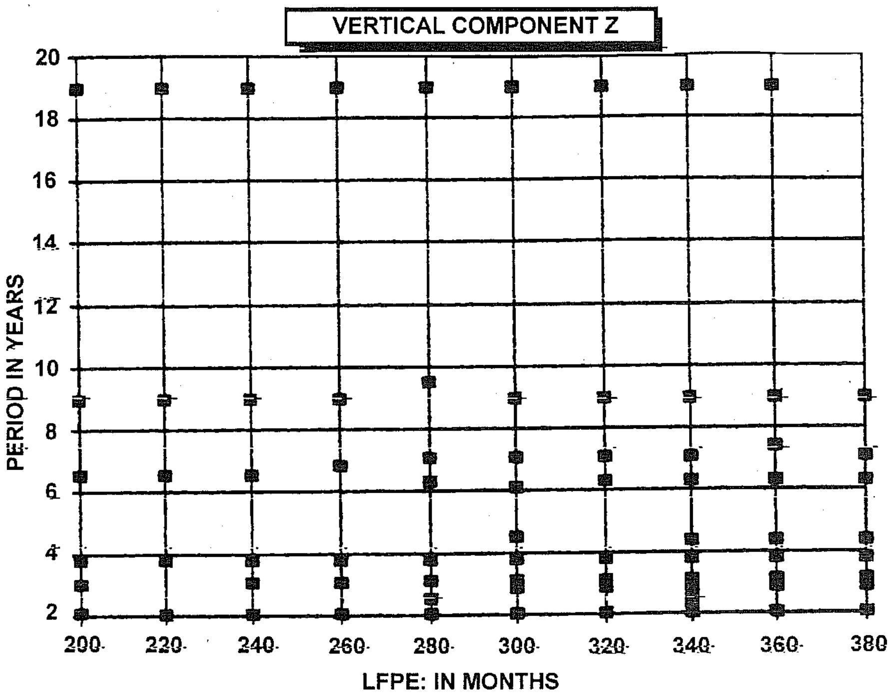

Figure 2f. Detected Periods (years) vs. Error Predictor Filter Length (LFPE in months) Z- magnetic vertical component. Periods greater than 2 years.

months. The total length of the series was 427 months in the studied period (1961-1997). Figures 2 (a, c, and e) correspond to the periods less than 2 years, while Figures 2 (b, d, and f) show periods greater than 2 years.

A length of about 240 months for FPE seems more appropriate because for greater lengths, the period is divided in non-coherent waves with the physical process representing each component being missed. For example, in Figure 2d it is observed that the 18.6- years wave, corresponding to the Mn- Lunar Tide wave (Melchior 1966), is not present, but appear split as two other waves: 17- and 28.3- years.

The more representative periods, determined by means of an additive model, are shown in Tables II, III, and IV.

Table I

Periods, amplitudes, and phases (with errors) of D- the magnetic declination, and H- the horizontal component respectively. Root Mean Square Error (rms) of the Synthesized D is 2.77, and for H it is 19.1 nT

Declination *Table I*

Period Years	*Amplitude Min. of arc*	*Error Min. of arc*	*Phase Degrees*	*Degrees*
13,13	1,26	0,27	320,778	12,424
8,98	0,89	0,26	331,926	16,884
5,51	1,12	0,22	170,840	11,349
4,06	0,89	0,27	125,137	17,490
3,48	0,88	0,22	7,666	10,826
2,22	0,68	0,20	4,047	14,885
1,80	0,71	0,26	152,855	20,556
1,63	0,68	0,21	174,927	17,454

RMS of the synthesis: 2.77 Min. of arc.

Table II

Periods, amplitudes, and phases (with errors) of D- the magnetic declination, and H- the horizontal component respectively. Root Mean Square Error (rms) of the Synthesized D is 2.77, and for H it is 19.1 nT

Horizontal Component *Table II*

Period Years	*Amplitude nT*	*Error nT*	*Phase Degrees*	*Degrees*
18,96	10,42	1,63	104,897	8,689
8,98	6,81	1,73	66,509	5,775
4,88	5,88	1,44	275,514	14,300
3,97	7,47	1,85	35,047	2,482
1,38	3,42	1,75	25,497	10,367
1,23	4,46	1,81	32,286	5,241
1,11	5,59	1,59	76,354	9,925
1,00	9,89	1,84	148,420	10,641
0,96	3,93	1,81	331,447	26,368
0,88	5,15	1,64	253,483	9,923
0,74	4,03	1,86	222,193	1,280
0,69	3,54	1,80	239,280	7,443
0,63	2,41	1,42	5,067	28,306
0,50	3,73	1,75	64,231	9,385

RMS of the Synth.: 19.1 nT.

Table III
Periods, amplitudes, and phases (with errors) of Z- the vertical component respectively. Root Mean Square Error (rms) of the Synthesis 9.58 nT

Vertical Component *Table III*

Period Years	*Amplitude nT*	*Error nT*	*Phase Degrees*	*Degree*
18,96	3,82	0,90	117,549	13,250
8,98	5,92	0,84	16,493	4,354
6,56	2,58	0,82	346,330	18,162
3,79	2,44	0,90	300,025	21,202
3,05	1,56	0,93	222,713	1,386
2,06	3,09	0,93	128,858	17,147
1,69	2,52	0,93	45,057	0,072
1,37	1,89	0,90	29,951	7,310
0,99	2,25	0,86	201,805	9,346
0,93	1,69	0,85	20,316	13,215

RMS of synth.: 9.58 nT.

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