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Synoptic global tendencies of solar background magnetic fields at the 19th cycle

I. Ferro Ramos
Institute of Geophysics and Astronomy
Cuban Academy of Sciences, Havana, Cuba.

RESUMEN

Sobre la base de los mapas sinópticos en H para el ciclo 19 se construyeron superficies polinomiales de tendencia para representar el campo que es proporcional al flujo magnético positivo. Se muestra que mediante las superficies polinomiales de primer orden es siempre posible representar el campo, excepto para el mapa que precisamente antecede al proceso de inversión de polaridades en el Sol, y además, que el "gradiente superficial" de esa magnitud indica que la inversión de polaridades en el Sol como un todo ocurre mucho antes (13 rotaciones) de que las zonas polares la experimenten. Los mapas cuya superficie de tendencia mejora con el incremento del orden de la superficie, son los situados en los comienzos, en el máximo e inmediatamente después del máximo del ciclo. En particular, los dos únicos mapas que requieren una superficie de cuarto orden o más son los de comienzo y los de la fase media del ciclo. En ellos, los de las bandas proporcionales al flujo neto igual a cero son antisimétricas. La redistribución en los patrones del campo a mitad del ciclo, aproximadamente unos dos años después del máximo, puede estar relacionada con el segundo máximo de actividad descubierto por Gnievishev. Las tendencias observacionales obtenidas pueden ser usadas con propósitos predictivos.

PALABRAS CLAVE: campo magnético solar, ciclo solar.

ABSTRACT

On the basis of H synoptic maps of background magnetic fields for the 19th cycle, we take one map for every ten rotations and in a continuous manner for the maximum of the cycle, where we take for the analysis all maps within the maximum of the cycle. We constructed tendential polynomial surfaces to represent the field that is proportional to the positive magnetic flux.

It is shown that with the polynomial surfaces of first degree it is always possible to represent the field, except for the map immediately preceding the process of polarities' inversion at the Sun. In addition, the "surface gradient" of that magnitude shows that inversion of polarities at the Sun as a whole occurs earlier (13 rotations) than the onset of the change of polarities at the Sun's poles. Maps whose tendential surfaces improve with increasing order of the surface are those at the beginning, at maximum and immediately after maximum of the cycle. In particular, the two only maps whose representation becomes better with a surface of fourth degree or more occur at the beginning of the cycle and at the medium phase of the cycle. In those maps, the ribbons proportional to net flux equal to zero are antisymmetric.

KEY WORDS: solar magnetic field, solar cycle.

INTRODUCTION

The study of background magnetic fields discovered by Babcock and Babcock (1955) has become very important as it was discovered that filaments, filament canals and quiet protuberances follow the null line of the longitudinal magnetic field. It was found that the H_α synoptic charts show the inversion of the line of polarities with more precision than the magnetograph (Duvall, 1977).

These zones of background magnetic fields that occupy more than 80% of the solar surface (Kotov *et al.*, 1977) contribute to the Sun's general magnetic field more than the magnetic fields of sunspots and active regions.

If we consider (as stated by Severny and others) the relation between the Sun's general magnetic field and sectorial structure of the interplanetary magnetic field (Kotov *et al.*, 1977), then the importance of the study of background magnetic fields can be understood as a means of forecasting the solar wind, geomagnetic storms, etc. (Bumba and Howard, 1966).

DATA AND METHODS

Source data are the Sun H_α Synoptic Maps for the 19th cycle compiled by V. I. Makarov and K. R. Sivaraman. Each map represents a solar rotation and the Atlas covers the interval from Rotation Num. 1355 (Dec., 1954 - Jan., 1955) to Rotation Num. 1486 (Oct., 1964).

Each map was digitized for 162 squares of 20° x 20° beginning from SW to the North. In each square we count the fraction of positive area with a precision of 1/16. It represents a magnitude proportional to positive flux, if it is taken into account that background magnetic fields are approximately constant with a medium value of about 2.5 Gauss (Kotov *et al.*, 1977).

Fourteen maps were analyzed, one every 10 rotation and additionally 9 maps corresponding to rotations Num. 1386 to 1394 (year 1957). The objective of this paper is to construct a tendential surface for each one. The method is an adaptation of multiple regression and is employed in geology to separate the data in maps into two components,

one of regional nature (tendency) and the other of fluctuating nature or local anomalies.

A tendency of our magnitude (in our case a magnitude proportional to positive flux) is a function of geographic coordinates - in this case solar coordinates - of a data group such that square deviations from tendency are minimized.

In the particular case of first degree, it is necessary to achieve a plane surface of the form:

$$Y = b_0 + b_1 X_1 + b_2 X_2$$

where Y is the observation of the magnitude
b_0 is a coefficient related to the mean of observations
b_1 id. with the E - W coordinates
b_2 id. with the N - S coordinates.

Since this equation has three unknowns, three equations are necessary to find the solution, which in matricial form is written as follows:

$$\begin{bmatrix} n & \Sigma X_1 & \Sigma X_2 \\ \Sigma X_1 & \Sigma X_1^2 & \Sigma X_1 X_2 \\ \Sigma X_2 & \Sigma X_1 X_2 & \Sigma X_2^2 \end{bmatrix} \cdot \begin{bmatrix} b_0 \\ b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} \Sigma Y \\ \Sigma X_1 Y \\ \Sigma X_2 Y \end{bmatrix}$$

In an analogous way other surfaces of higher degree can be found, up to 4th degree in our case, e.g.

$$Y = b_0 + b_1 X_1 + b_2 X_2 + b_3 X_1^2 + b_4 X_2^2 + b_5 X_1 X_2 \qquad \text{(2nd. order)}$$

DISCUSSION AND RESULTS

Maps of first degree

It is obvious that tendency maps of higher degree will represent better the surface of positive fluxes. At the same time, and if the coefficients of the regression equation are significant, surfaces of first degree will smooth better the field and will show its tendency.

At first we tried to test if coefficients of the regression equation were significant and then maps of first degree were analyzed in an evolutive way.

The corresponding analysis of the variance at 1% level showed that all maps can be represented by first degree surfaces (planes) except the map corresponding to Rotation Num. 1391. In this case it is not significant either for 1% nor 5%. This map corresponds precisely to the rotation previous to that when the Sun's poles begin to mix their polarities; i.e. at Rotation Num. 1392 the North pole of the Sun begins to present zones with both positive and negative polarity and the South pole continues with negative polarity as before. If this is true for other cycles, it can be an indicator of short-term type for the change of polarities of the Sun's poles.

For the first degree tendency maps (Fig. 1) we localized the situation of the ribbon that corresponds to net flux equal zero (this is represented in the maps by the number 8) and for each the direction of increase of positive fluxes is noted. The result is shown in Fig. 2. It is seen that there is a total symmetry after the maximum of the Wolf number (maps corresponding to Rot. 1390 and 1391), with the feature that field patterns are longer when they are nearer to a minimum. Note the correspondence between maps corresponding to Rot. 1485 and 1395; 1465 and 1475 with 1405; 1455 with 1415 and those maps with Rotation numbers 1425, 1435 and 1445 are intermediate.

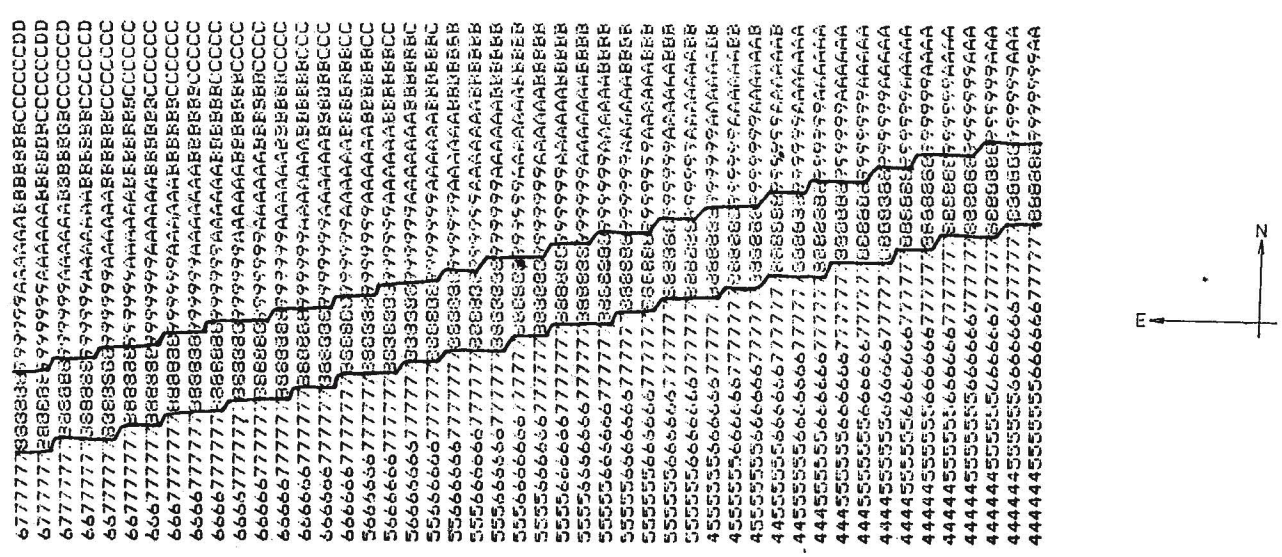

Fig. 1

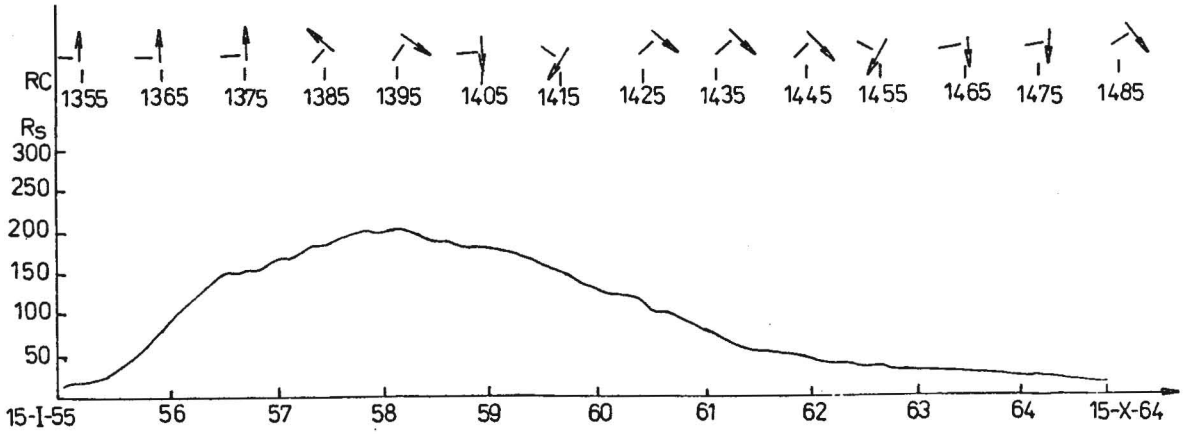

Fig. 2.

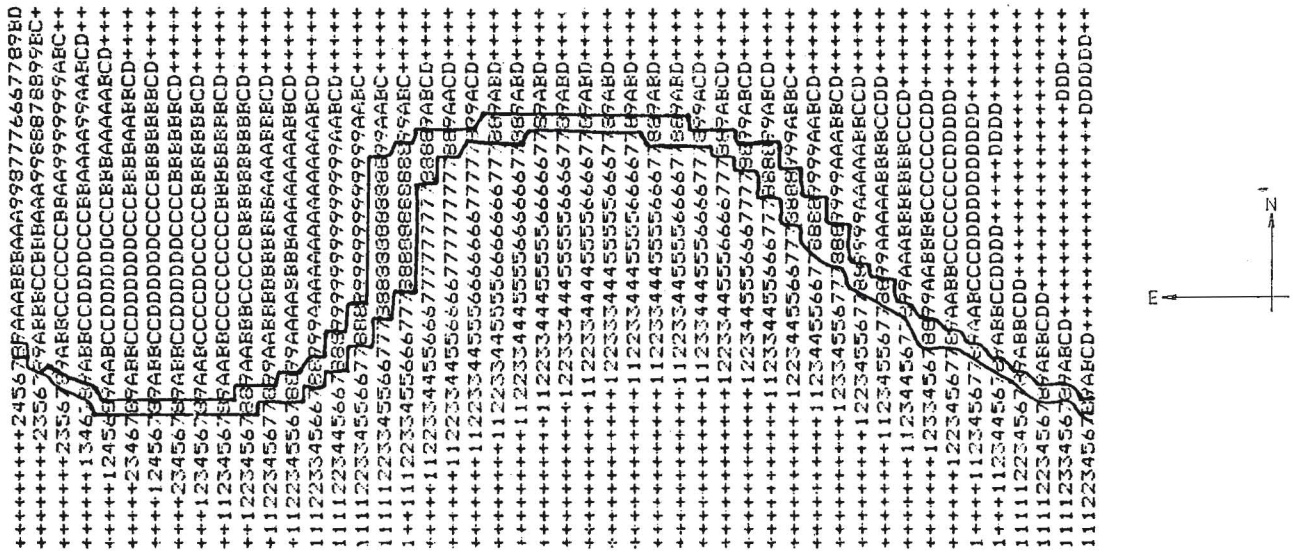

Fig. 3

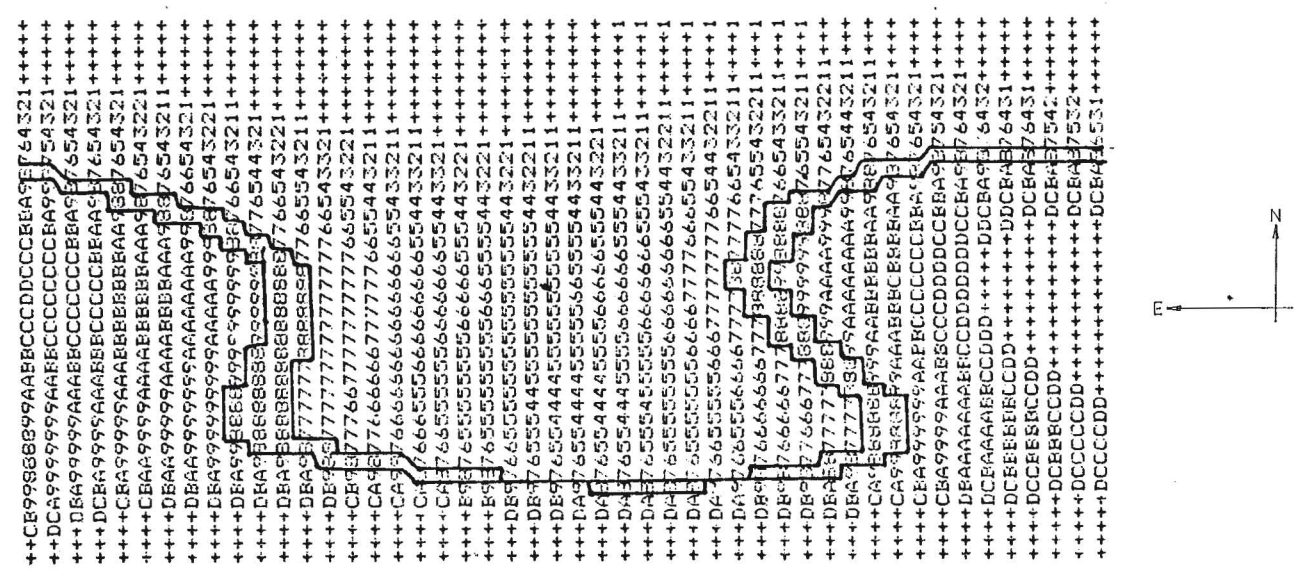

Fig. 4

It is noticed that between the maps corresponding to Rotation numbers 1385 and 1395 the "surface gradient" of positive fluxes radically changed. Hence we analyzed separately the maps corresponding to Rotation 1386 to 1394.

The results of the analysis show that the change of the "surface gradient" as well as the change of polarities at the Sun poles precisely begins at Rotation Num. 1392 although the South pole continues as before (with negative polarity) and will not acquire a completely positive polarity until after 13 rotations. In addition, the North pole only presents mixed polarities. This fact indicates that the effect of change of polarities occurs itself at the Sun as a whole much earlier than the polar zones show it.

In all cases the correlations between the original maps and tendency surfaces are low but significant except for Rotation Num. 1391.

Tendency maps of higher degree

Although the coefficients of tendency polynomial equations of first degree are significant, we tried to find out whether the use of a polynomial of higher degree fits the maps better.

Analysis of variance for a significance level of 5% shows that the maps that can be represented best with a polynomial surface of higher degree are those corresponding to Rotation Num. 1355 (needs 4th degree or more), Rotation 1395 (2nd degree), Rot. 1405 (3rd degree), Rot. 1415 (2nd degree) and Rot. 1425 (4th degree or more). Note that these maps are at the beginning, at the maximum and immediately after the maximum of the cycle. In particular, the only two maps whose representation improves with a surface of 4th degree are those corresponding to Rot. 1355 and 1425. The first one opens the cycle and the second is situated at the middle of the cycle in accordance with monthly smoothed Wolf number. In these maps (figures 3 and 4) the ribbons that represent magnitude proportional to the net flux equal to zero are disposed in completely antisymmetrical ways. This redistribution in the pattern of solar fluxes halfway through the cycle, but not at the maximum of Wolf number (approximately two years after maximum) may be related with the second maximum of activity discovered by M. Gnievishev.

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I. Ferro R.
Institute of Geophysics and Astronomy
Cuban Academy of Sciences,
Av. 212 No. 2906, Havana, Cuba.