TWO COUPLED 88 AND 22 YR. OSCILLATORS IN THE MODULATION OF SUNSPOT CYCLE

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Hemos encontrado que la eyección de nuevo flujo magnético a la superficie del sol durante el periodo 1923-1949 podría explicar los altos valores de la actividad solar que se están dando en el presente. Para profundizar en la investigación del origen de este fenómeno, realizamos un análisis multi-resuelto mediante la transformada ondeleta de Morlet, de la serie histórica del numero de manchas solares para los últimos 352 años (1650-2001). Encontramos que la intensidad del ciclo de manchas solares oscila alrededor de un nivel fijo que en los últimos 352 años sufrió dos incrementos de 55 manchas cada uno, uno el ya encontrado y otro que comenzó en 1705 y que duró 35 años. Dichos incrementos elevaron la actividad solar desde el pronunciado mínimo de Maunder hasta los valores mas altos del presente milenio.

Proveemos además evidencia de que los incrementos se deben al intercambio de energía entre dos osciladores, uno de 88-yr., asociado al ciclo de Gleissberg, y el otro el ciclo de 22-yr. del campo magnético, que se manifiesta en el ciclo de manchas solares de 11 años, y que dichos ciclos intercambiaron energía solamente durante dos cortas transiciones de 35 y 28 años que comenzaron en 1705 y 1923, respectivamente. Fuera de estas transiciones durante las cuales el ciclo de Gleissberg se detuvo, la amplitud del mismo se mantuvo casi constante y la del ciclo de 22-años estuvo modulada por dos oscilaciones cuasi - periódicas una semi-secular (~60 años) y la otra decadal (~28 años) que podrían deberse la desestabilización del ciclo de 22- años por la inyección súbita de energía a este oscilador desde el oscilador de 88 años.

We have found that the considerable increment in solar activity that is seen in our days is a consequence of a transient event of new magnetic flux ejection to the sun surface that started at 1923 and lasted 28 years. To further investigate this phenomenon we perform a multi-resolution analysis of the time series of sunspot number for the last 352 yr. (1650-2001) by means of the Morlet wavelet transform. We found that sunspot cycle intensity oscillates around a fixed level that in the last 352 yr. have had two increments, 55 spot each, one is the found previously and the other started at year 1705 and endured 35 yr.

Evidence is also provided that these sporadic increases are the manifestation of the coupling of a 88- yr. oscillator, associate to the Gleissberg cycle, and the 22-years oscillator that manifest itself in the 11-yr. sunspot cycle. These oscillators have interchanged energy only during the short 1705-1740 and 1923-1951 transitions. Otherwise, the amplitude of the Gleissberg cycle remained constant and the 22-yr. cycle was modulated by a semi-secular (~60 yr. long) and a decadal quasi-periodic (~28 yr. long) oscillations. These oscillations might be excited by the destabilization of the 22-yr cycle by the sudden injection of energy to that oscillator from the energy stored in the Gleissberg one.

I. INTRODUCCIÓN

Transient phenomena in solar activity[1-3] and in solar-terrestrial relationships[4] do exist. Also cyclical behavior in the modulation of the 11-yr. cycle undergoes time variations in amplitude and length[5,6]. On the other hand, Fourier analysis presupposes that the time series is the result of a stationary process. Therefore Fourier analysis of solar and solar terrestrial time series are likely to produce spurious periodicities and inconsistency in the results. This problem has lead to a "cycle-mania" that obscures the searching for solar-climate relationship[7]. A suitable tool to solve that problem is the wavelet transform formalism[1-7].

By a Morlet wavelet multi-resolution analysis[8] of solar sunspot number, Rz, and geomagnetic index aa, we have found an event of sudden rise of solar an geomagnetic activity, starting at year 1923[2]. Also we have found that the short event of rise of the average of sunspot cycle intensity may be due to the ejection of new magnetic flux to the dynamo system, which destabilized it during solar cycle 16 to 21[3]. This event of magnetic flux ejection was in concert with a temporary losing of the regular relationship between sunspot cycle intensity and global temperature[4], i. e. the lack of linearity in the sun's dynamo system is apparent in a climatic variables.

Therefore to find the causes of solar events such

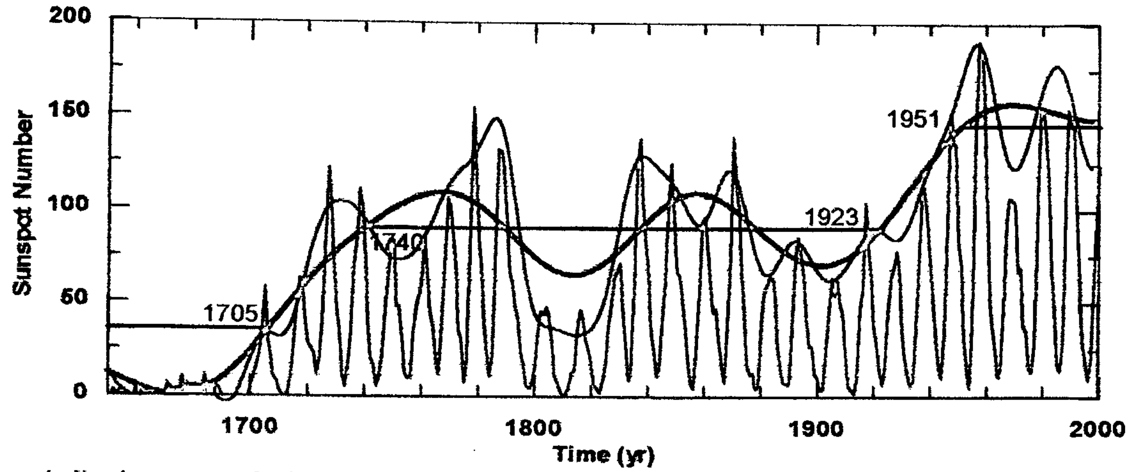

Figure 1: Yearly average of relative solar sunspot number (dashed line), the envelope of the maxima (light line) the secular variation (heavy full line). The meaning of the constants (straight lines) is discussed in section 2. The data since 1700 has been obtained from http//www.ngdc.gov.ar.} and fro 1650 to 1700 from Eddy[9]

as the one starting at 1923, may help to long-term forecasting of solar activity and related changes in solar-terrestrial variables.

The modulation of sunspot cycle intensity since year 1650 is analyzed here, by the same procedure based in wavelet analysis that we have used to unearth the 1923 event form the Rz and aa data[2,3]. We search, in particular, for the existence in the past of other events of sudden change of solar activity like the 1923 one.

2. THE MODULATION OF THE SUNSPOT CYCLE INTENSITY

In previous work[2,3,5] we have represented the Rz time series for the period 1844-2000 as the superposition of the linear trend and 13 wavelet components which Fourier periods are harmonic and sub-harmonic of the average period of the Schwabe cycle. Two additional sub-harmonic wavelet components have been added to represent the time series for the longer interval 1650-2001. The envelope of the maxima of the Schwabe cycle (see light line in fig. 1), i. e. the curve that track the modulation of Rz, is twice the values obtained by eliminating the 6 Schwabe wavelet components form the superposition[2,3]. The result is shown in figure 1 (light line)

In fig. 1 the heavy line represents the duplicate value of the secular variation found by adding the 5 secular wavelet components in the secular time scale, as defined in section 2.1, and the linear trend. The straight line that goes from 1740 to 1923 is determined by the value of the envelope (90 spots) at year 1923. This was the year at which the cyclical path of the envelope of sunspot cycle maxima versus geomagnetic index aa minima collapsed to the center of the path[3]. At year 1923 the secular oscillation was zeroing and the amplitude of the oscillations around the constant 90 spot level vanished[2].. The same condition happened at 1705, so we have selected the constant level prior 1705 as the value of the envelope (35 spot) at that year.

In the centuries before the Maunder minimum a well-established strong 88-yr. periodicity was found in solar activity as measured by auroral activity[10] and ^{14}C anomaly[11]. This indicates that the average length of the Gleissberg[12] cycle is 88 yr.. Two consecutive secular oscillations, 97 yr. and 85 yr. long, respectively, around the 90 spot level, occurred between 1740 and 1923. Therefore we may identify the secular oscillation with the Gleissberg cycle as suggested by Duhau and Chen[3], and have selected the constant level after 1951- 145 spot-such as the present Gleissberg cycle has a 85-yr. period. This value leads to an average of 88-yr. for the Gleissberg cycle in the last 352 years. Note that the ending time of the 1923 transition is 2 yr. later that the one determined in ref. 2, this difference is due to the fact that the new estimation is based in a longer time series

2.1 Quasi-periodic regimen in solar dynamo

The energy spectrum of a quasi-periodic signal is a resonant distribution that has its maximum at the average period of the signal[13]. In fig. 2 we show the energy spectrum of the Rz for the last 168 yr. (light line) and for the last 352 yr. (heavy line), respectively. The Morlet wavelet is a Gaussian wave-packet of a fixed Fourier frequency, in figure 2, k is the ratio of the Gaussian wide to the Fourier period.

The energy spectrum for the time interval 1844-2001 (157 yr. long) has three resonant distributions which peak at 10.7, 25 and 120 yr. period respectively (see light line in fig. 2). This has leaded us to define for that epoch three time scales: the Schwabe, the decadal and the secular time scales[2,5].

Within the Schwabe and the secular time scales the spectrum for the longer 1650-2001 yr. time interval (352 yr. long) is quite alike to the 168 yr. one. The spectrum for Fourier periods in the interval 40 to 60 yr. is very weak for the 157 yr. time series while for the larger 352 yr. interval has a peak at about the 60 yr

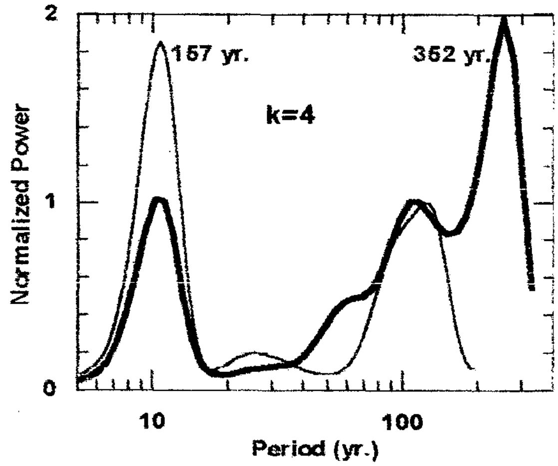

Figure 2: Energy spectrum of Rz time series for the last 168 yr.(light line) and for the last 352 yr. (heavy line) normalized to be unity at the Gleissberg peak.

period. This indicates that there is a cycle with an average period of about 60 yr. that was strong prior 1844 but very weak or non-existent after that. Inversely, the spectrum for Fourier periods between 20 and 30 yr. is weaker in the longer time interval. There is a new peak at the 250 yr. period, however, the time series is not long enough to allow the separation of the corresponding cycle from the Gleissberg cycle and the linear trend. Therefore we have included this periods together with that on the Gleissberg time scale in the secular time scale, and, so for the last 352 yr. we have defined four time scales as given in Table 1.

In fig. 3 we show the semi-secular (heavy line in the upper panel) and the decadal (lower panel) cycles as determined by superposing the wavelet components with Fourier periods in the respective time scale (see TABLE 1). The Gleissberg cycle as isolated from the secular variation is also shown on that figure (light line in the upper panel). The length of the semi-secular oscillation changes with time form 58 yr., at the end of the 17th century, to 60 yr. at the second half of the 19ht century, when suddenly stopped for more than 50 yr.. The length of the decadal oscillation decreases form 30 yr. at the beginning of the 90 spot constant level epoch to 26 yr. at the end, to be restarted after the 1923 event with a 29-yr. length. The time series is not long enough to allow us to know the average length of the semi-secular and decadal oscillations in the long term.

TABLE 1. FOURIER PERIODS OF THE MORLET WAVELET COMPONENTS OF THE RZ YEARLY MEANS REPRESENTATION. (1650-2000))

Scales	Fourier period (yr.)					
Schwabe	2.7	3.8.	5.3	7.6	10.7.	15.1.
Decadal	21.4	30.3				
Semi-secular.	42.8	60.5				
Secular	85.5	123	171	242	342	

The semi-secular cycle has its stronger minimum near 1810 almost coincident with a minimum in the Gleissberg cycle. This coincidence has lead to the very weak sunspot cycles in the interval 1800-1820, known as Dalton minimum. Therefore this minimum is produced by the superposition of these two cycles

2.2. The modulation of the sunspot cycle as a signature of two coupled 88 and 22 yr-oscillators

The amplitude of the Gleissberg cycle has been

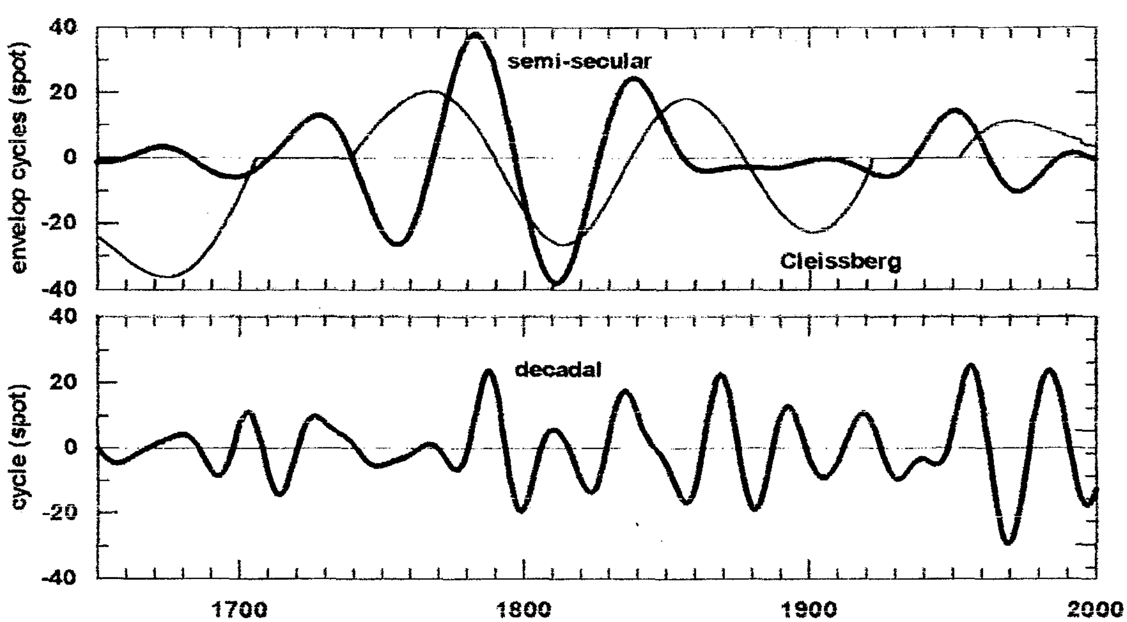

Figure 3: The Gleissberg, semi-secular and decadal cycles on which the envelope of Rz maxima (light line in fig. 1) may be decomposed.

quite constant during the 90 yr. constant level state, i. e. during more than 200 yr and has substantially decreased after each transition. Also, this cycle has stopped during the transitions. These facts provide evidence that the Gleissberg cycle interacts with the 22 yr. magnetic cycle exclusively during the short transitions. Therefore the Gleissberg cycle is not merely the manifestation of amplitude variations of the 22-yr. cycle but might be the signature of a distinct oscillator that is coupled to the 22-yr. one.

On the other hand, during quasi-periodic regimen the amplitude of the 59-yr. oscillation increases to reach it maximum around the pronounced 1800-1820 Dalton minimum decreases sharply after that. This behavior indicates that this oscillation is due to amplitude variations of the 22-yr. oscillator excited by the sudden injection of magnetic flux to this oscillator.

The amplitude of the decadal oscillation has strengthened after each transition following the increases of the fixed levels, i. e following the sudden increases in the average sunspot cycle intensity Also, the decadal oscillation is the cause of the odd –event effect in the sunspot cycle. Therefore this oscillation might be the manifestation of the north-south asymmetry in the 22 yr. sun magnetic cycle,

By means of a wavelet multi-resolution analysis similar to that used here we have compared the length of day (LOD) and the sunspot number yearly means time series for the last 350 years[6]. We found that while LOD Rz semi-secular and longer periods wavelet components track each other closely, there is not a relationship between them in the decadal scale. This lack of relationship may be due to the fact that higher order multi-poles components of the polar field die away from the sun faster than the dipolar one and so are not seen by the earth. Therefore it seems that the Gleissberg and the semi-secular oscillations are linked to the dipolar component of the polar field and that the decadal cycle is linked to higher order multi-poles of that field.

Based in the above consideration we suggest that the sudden increases of the average level of solar activity after 1705 and 1923 are manifestations of the coupling of the Gleissberg and the 22-yr. oscillators that interchanged energy during the short 1705-1740 and 1923-1951 transitions. In that framework the semi-secular and the decadal cycles are due to amplitude oscillations of the 22-yr cycle excited by the sudden injection of energy to that oscillator from the Gleissberg oscillator.

More work is needed to fully understand the nature of the cycles in the modulation of sunspot cycle intensity. Meanwhile our empirical findings indicate that there are two coupled oscillators which interaction leads to the modulation of sunspot cycle, one is a 88-yr. period (that manifest itself in the Gleissberg cycle) and other the 22-yr. sun's magnetic cycle (that manifest in the sunspot cycle).

Acknowledgments

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