

ON THE CAUSES OF THE SUDDEN INCREASE OF SOLAR DYNAMO MAGNETIC FIELD AFTER 1923

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Hemos encontrado que la relación de largo plazo entre el número de manchas solares, R_z , y el índice geomagnético aa no es lineal, ni lo es su incremento durante el último siglo. En particular hemos hallado un evento corto – 30 años- que comenzó en el año 1923, durante el cual R_z y aa aumentaron sustancialmente, comenzando luego a oscilar alrededor de un nivel sustancialmente más alto que el previo. Así es como esos índices han alcanzado recientemente sus valores históricos más altos. En el presente trabajo investigamos este evento y demostramos que el mismo puede explicarse mediante la eyección de nuevo flujo magnético a la región del dinamo solar que comenzó en el año 1923 (comienzo del ciclo solar 16) y terminó en el año 1949 (dos años después del año de ocurrencia del máximo del ciclo solar 19) y que dicha eyección produjo una desestabilización del dinamo durante los ciclos solares 16 a 21 que excitó la periodicidad de 158-días en las manchas solares y en las llamaradas solares de muy alta energía durante el máximo de dichos ciclos..

We have found that the long-term relationship between sunspot number, R_z , and geomagnetic index aa as well as the increases of both indexes in the last century are not linear. In particular we have found a short event of increases – 30 yr. long - that started at year 1923 and after which the average value of R_z and aa indexes beginning to oscillate around a fixed level substantially larger than the previous one. In that way R_z and aa indexes have recently reached the highest measured values. Here we investigate this event. We find that it may be explained by the ejection of new magnetic flux to the dynamo system that started at year 1923 (the beginning of solar cycle 16) and ended at year 1949 (two years after sunspot cycle 19 maximum). We demonstrate that this ejection has produced a destabilization of the dynamo layer along solar cycles 16 to 21 that excited the 158-days periodicity in sunspot and in highly energetic solar flares during the maxima of those cycles.

I. INTRODUCTION

According to the dynamo mechanism, at the start of a sunspot cycle, the dynamo process transforms the sun's polar field, into an internal toroidal field that increases during the maximum phase of the sunspot cycle¹. Therefore, long-term changes in geomagnetic and solar activities are related as both are linked to changes in solar magnetic field strength^{2,3,4}. Oliver et al.⁵ examined the sunspot areas of 1874-1993 via a wavelet technique and found that the 158-day periodicity in sunspot is coincident with the appearance of the same periodicity in energetic solar flares during sunspot cycles 16-21. These authors suggest that the emergence of new magnetic flux near the peak of a sunspot cycle destabilizes active regions and causes energetic solar flares.

If new magnetic flux were expelled to the sun's dynamo layer during the toroidal phase of sunspot cycles 19-21, solar activity would increase as well. And, according to the dynamo theory polar magnetic field and so geomagnetic activity would increase too. In fact, by a multi-resolution wavelet analysis³, Duhau and Chen⁴ found that long-term modulations of geomagnetic index aa and sunspot number R_z , oscillate around constant levels that have increased to be 1.9 and 1.6, respectively

of its values prior 1923. Also, the oscillations of the aa and R_z long-term modulations appear to be well represented by the superposition of a decadal cycle and the Gleissberg cycle^{3,4}. The amplitude ratio and the phase shift between the R_z and aa decadal cycles changed sharply at year 1923^{2,3}, as well as the spectral distribution³. And the Gleissberg cycle was interrupted at that year to be restarted at year 1949⁴. The synchronicity of these changes with temporal changes in several solar and solar-terrestrial variables indicates that the non-linear nature of the solar dynamo has led to a major change of its background state after 1923⁴.

In this paper, we investigate the origin of this major change in solar dynamo by examining the relationship between long-term changes of solar and geomagnetic activity and related changes in the Schwabe scale (periods smaller than 15 years). We find that these changes are synchronic with the appearance of the 158-days periodicity in sunspot number and energetic solar flares during sunspot cycle maximum 16 to 21. The significance of this finding is also analyzed.

II. METHOD AND RESULTS

We have performed a multi-resolution wavelet analysis of the relationship between the Zurich sunspot

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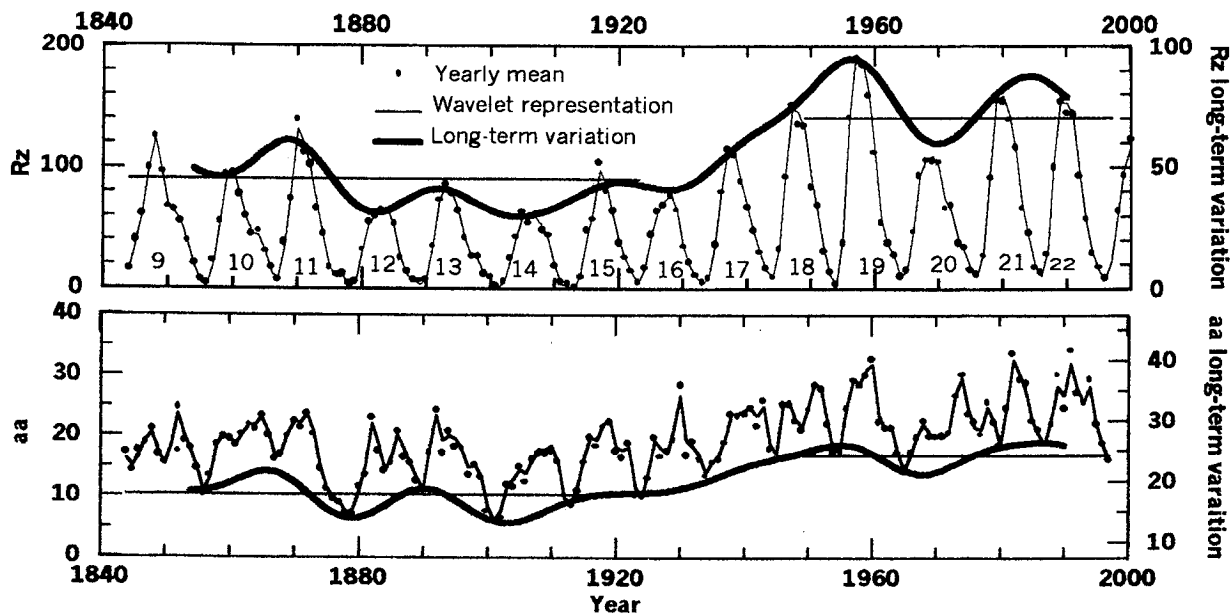


Figure 1. Rz (upper panel) and aa (lower panel) yearly means together with their wavelet representations and long-term variation). The straight lines are the values around which Rz and aa long term variation oscillate prior 1923 and after 1949, respectively⁴.

number (Rz) and geomagnetic index aa for 1844-2000. The National World Data Center A supplied Rz and aa for 1968-1997 and Nevalinna and Kataja⁶ provided aa for 1850-1967. The long-term variation of Rz and in aa may be found from the addition of the linear trend and the 7 wavelet components which Fourier periods are equal or larger than 21.4 (that we have denominated the long-term scales as listed in Table 1). From the long term variation of Rz maxima and aa minima is found by duplicating, in the case of Rz, and by subtracting 7.2, in the case of aa, respectively⁴ (compare the left with the right scales in figure 1). The constant levels around which the envelope oscillates have been found in ref. 4

The oscillations around the constant levels (straight lines in figure 1) are composed by two well separated cycles: the decadal and the Gleissberg cycle. The first is apparent in figure 1 as the short fluctuations in the envelope while the second is apparent, for example, in the fact that the short fluctuations are always below the constant level during the interval 1875- 1923. The multi-resolution wavelet analysis has allowed a quantitative representation of these cycles^{3,4}

It has been shown that for each 11-year sunspot cycle, a minimum in aa is a measure of the polar magnetic field^{7,8,9,10} while a maximum value of Rz indicates the strength of the toroidal magnetic field^{1,8,11}. Therefore we have interpreted long-term changes in Rz and aa in terms of long-term changes in the strength of the polar and toroidal solar magnetic flux, respectively^{3,4,12}. In the framework of this interpretation the fact that Rz and aa envelopes track with each other, (compare heavy lines in upper and lower panel in fig. 1), supports the presence of the dynamo mechanism¹, since according to this mechanism the strength of the poloidal

TABLE 1: FOURIER PERIODS OF THE MORLET WAVELET COMPONENTS OF THE Rz AND AA YEARLY MEANS REPRESENTATION. (1844-2000)

Scales	Fourier Period (yr.)						
Schwabe	2.7	3.8.	5.3	7.6	10.7.	15.1.	
Long-term	41.4	30.3	42.8	60.5	85.5	123.	171

and the toroidal components of the magnetic field during each sunspot cycle must be related

Prior 1923 the envelopes oscillate around constant levels, during the interval 1923-1949 Rz and aa envelopes steadily increases to reach a new level around which the oscillations are re-started. This is even more evident in figure 2, were we show a plot of Rz versus aa long-term variations. For sunspot cycles 10-15, Rz versus aa yields closing ellipses (path I) that collapse toward the center at 1923 - the start of sunspot cycle 16 - after which they increase to the highest Rz value at sunspot cycle 19 maximum. After that Rz versus aa re-assume a quasi-cyclical path (path II) at higher values. The slope of the mayor axis of the ellipses has increased and the wide of the minor axis has decreased after year 1923. This means that the ratio of Rz to aa amplitude and the phase delay of Rz to aa oscillations has appreciably increased and decreased, receptively. Therefore the relationship between Rz and aa is non-linear. For path I sunspot cycle maxima systematically occur near the vertices of the major axis of the ellipses, odd numbered sunspot cycles are more intense than even ones. This behavior is called the odd-even rule^{13,14}. Odd-even rule is broken since the starting of sunspot cycle 16 (1923) on, and is apparently re-assumed after sunspot cycle 19. However, this situation endured only two sunspot cycles, since the odd

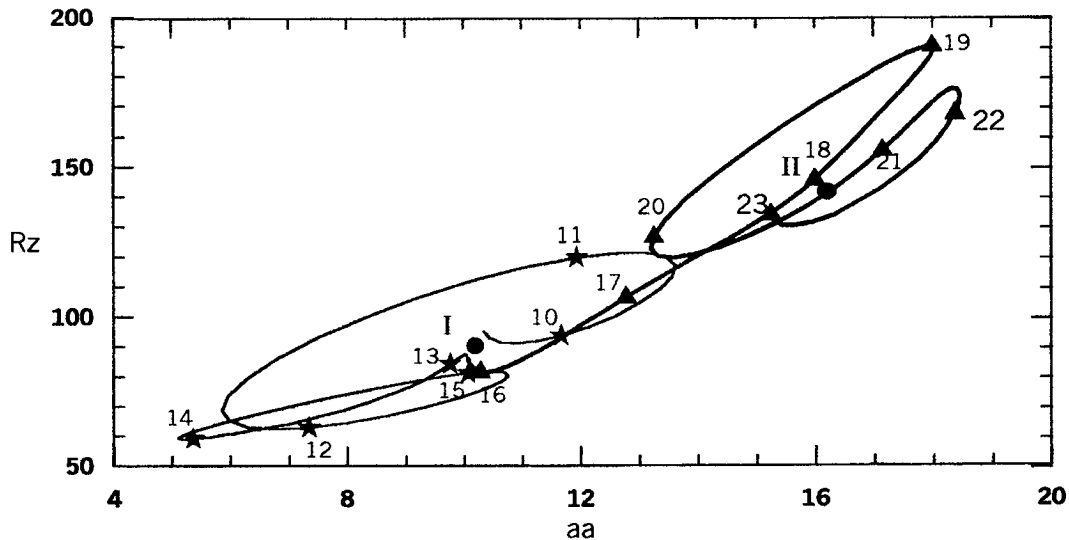


Figure 2: *Rz vs. Aa long-term variations prior (light line) and after (heavy line) 1923. The stars (triangles) indicate the time of occurrence of Rz maximum for each sunspot cycle cycle prior (after) 1923. The points represents the constant levels around which Rz and aa envelopes oscillate (see fig. 1)*

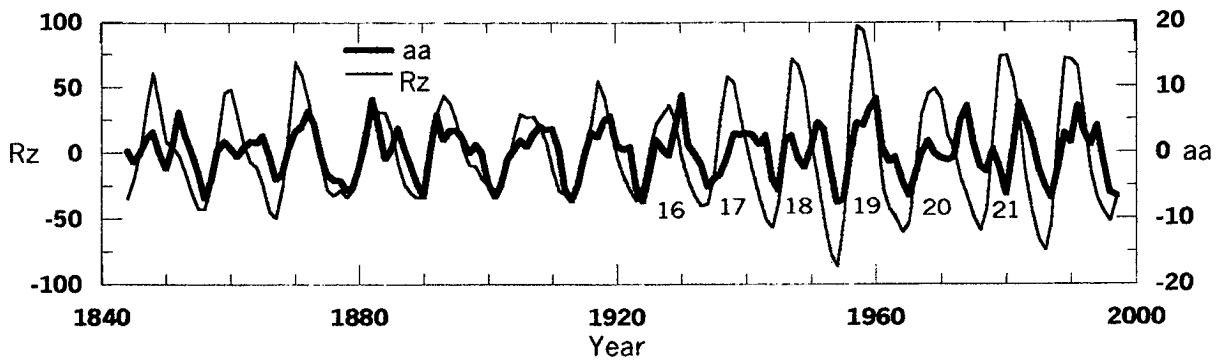


Figure 3: *The Rz and aa Schwabe cycle as obtained by adding the respective (see table 1) wavelets components.*

even rule was broken again after sunspot cycle 21 to our days (see also fig 1.) and, simultaneously, the direction of circulation of the quasi-cyclical path changed from counter-clockwise to clockwise.

Figure 3 shows the Schwabe cycle as determined by superposing the wavelet components in the respective scale (see Table 1). Prior cycle 16 each aa minimum is delayed at the most 1 year with respect to the previous Rz minimum, but the delay increases more and more after that year being maximum for the minimum between cycles 20 and 21. The cycle seems to come back to the previous behavior after sunspot cycle 21.

Therefore the regular behavior of the Schwabe cycle was interrupted during sunspot cycles 16 to 21. This interruption is synchronous with the apparition of the 158-day sunspot periodicity that occurred only at the peaks of sunspot cycles 16-21 reaching its maximum intensity at sunspot cycle 19 and disappearing after sunspot cycle 21 (see Figure 1 in ref 5).

III DISCUSSION AND CONCLUSIONS

We have found that before year 1923 and after year 1949, the amplitude of the sunspot cycle was modulated around two different constant levels⁴. The relative strength of the toroidal as compared with the poloidal magnetic field has increased^{3,4}, indicating that a major change in the sun dynamo system has occurred as a result of a short event that started at year 1923, leading to a non-linear relationship between long-term variations in aa and Rz and so, between minima in aa and maxima in Rz⁴.

We have found that Rz and aa are proxy data for the toroidal and the poloidal components of the solar magnetic field^{3,4}, therefore we may interpret Rz and aa evolution in terms of the evolution of solar magnetic field strength

Therefore, the strength of the sun magnetic field steadily increased from the beginning of sunspot cycle 16

(19n23) to the maximum of sunspot cycle 19 (1949) (see figure 1 and 2) and the regular behavior of the Schwabe cycle was interrupted along cycle 16-21 (see figure 3). In synchronicity with this phenomenon, the 158-days periodicity was seen for the first time at sunspot cycle 16 maximum and reached its peak intensity at sunspot cycle 19 maximum, completely disappearing after sunspot cycle 21 maximum. This synchronicity supports the suggestion of Oliver et al.⁶ that the 158- days periodicity is due to the emergence of new magnetic flux. However, our results indicate that the new magnetic flux was entirely ejected from the starting of sunspot cycle 16 to sunspot cycle maximum 19 leading to a destabilization of the dynamo region that endured until sunspot cycle 21. Therefore we conclude that the 158-days periodicity is due to the destabilization of the Schwabe cycles during sunspot cycles 16-21 produced by the ejection of new magnetic flux in the interval 1923-1949.

The ejection of new flux at sunspot cycles 16 to 19 maxima may explain also the increases of the time delay of the appearance of the aa minimum with respect to the Rz minimum during sunspot cycles 16 to 21 as seen in fig. 3. Namely: during each sunspot cycle, dynamo effect converts poloidal field into toroidal field and vice-versa. For a regular cycle the toroidal field comes entirely from the conversion of the poloidal field of the previous minimum, but after the event of magnetic flux ejection, new toroidal field is produced during each sunspot cycle maximum. This field needs some extra time to convert into poloidal field, so delaying the apparition of the forthcoming aa minimum. The strongest ejection of magnetic flux occurred during sunspot cycle 19 maximum (see figure 1 in ref 5). Therefore the quite anomalous behavior of aa Schwabe cycle 20, that has a 6 yr. delayed sharp peak and two forthcoming minima, one at the regular delay, and the other three years later, may be explained on the above framework. Also, according to our result the last ejection was at cycle 19 maximum, consequently cycle 21 ended at the regular delay (not larger than one year). We conclude that the Schwabe cycle have recuperated its regular behavior only when the ejected magnetic flux was evenly re-distributed between the poloidal and the toroidal magnetic field components.

The sunspot cycle has a 11-year length but the magnetic cycle duplicates this length due to the inversion of the polar field after each successive sunspot cycle. During the odd cycles the polar field points southward, therefore the odd-even rule might be explained by the existence of a relic polar field pointing southward^{15,16}.

The fact that the odd-even rule was broken at sunspot cycles 16 to 19 might be due to the masking of this rule by the ejection to the dynamo layer of new magnetic flux during these cycles. However, odd-even rule is lost again when the Schwabe cycle re-starts its regular behavior after sunspot cycle 21, in synchronicity with a change in the direction of circulation of the path

of Rz versus aa long-term variation (see figure 2). If the odd-even rule were due to a relic field pointing southward as suggested by Sonett¹⁵ these change might be associate with a change of orientation of this relic field. Evidence is still scarce to go further with this argument.

Therefore the origin of the change in the path of Rz versus aa long term variation after sunspot cycle 21 and its possible synchronicity with the loss of the odd-even rule must be further investigated. The understanding of these changes will give clues about the nature of the mechanism that has produced the sudden increases of solar magnetic field strength during sunspot cycles 16-19. Our result indicates that these larger values will be maintained until a new short event would lead to an increase or, eventually a sudden decrease, of the energy contained in the dynamo magnetic field.

Acknowledgments

This work was supported by the Buenos Aires University, the Agencia Nacional de Promocion Cientifica y Tecnica and the Consejo nacional de investigaciones Cientificas y Tecnicas under grands UBACYT II05, PICT97-00551 and PID 4490, repectively.

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