The 120-yrs solar cycle of the Cosmogenic Isotopes

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Abstract: The solar periodicities of 80-90 yrs (Gleissberg cycle) and 205 yrs (de Vries or Suess cycle) using different time series of proxies of solar activity and cosmic ray flux have been reported in a great number of papers. In this work we present the spectral analysis of cosmogenic isotopes series applying the wavelet transformation based on the Morlet wavelet to obtain the long-term periodicities related to the solar activity and cosmic ray flux long period changes. We use the INTCAL98 for ^{14}C time series and ^{10}Be time series for both the South and North Poles. The results obtained from the wavelet transformation show that there are no periodicities either 80-90 or 205 yrs. Instead significant periodicities are the 60 (Yoshimura cycle), 120 and 240 yrs (de Vries or Suess cycle). The solar activity secular minima periodicity is of 120 yrs and this is the sunspot series modulator. The 120-periodicity could possibly be one of the principal periodicities of solar activity. The solar secular variability is not a stochastic or/and intermittent processes.

Introduction

The sunspot are the oldest source of direct records of solar activity. In the western hemisphere the Greeks reported them since the year 28 B.C., observed by Aristotles pupil Teofrastro of Athens. The study of these documents shows observations of three to four spots per century in average. In the eastern hemisphere there are records since the Han dynasty (200 B.C.- 200 D.C.). From Korea, similar information is available since the 16th century [1]. As observations were not performed regularly, the records of celestial phenomena in those ages and countries should be taken with caution.

Galileo observations since 1610 (with the construction of a telescope aiming at the Sun) motivated a rise in the study of sunspots in European countries. Its cyclical behavior was not noticed until 1843. The discoverer was Heinrich Schwabe who reached this conclusion based on the study of 17 yrs of observations.

Richard Wolf organized the records of number of sunspots on a systematical basis. It is known as the Wolf Sunspot Number. After a careful work, he compiled the existing data between 1610 and 1843, concluding that the cycle of approximately 11-yrs (Schwabe cycle) was present at least since 1700 [2].

Wolf also worked to find if the Schwabe cycle had been presented in the past, but due to the scarcity of sunspot series it was not possible to perform this study. However, even with the great limitations in the eyesight observations these testimonies are useful to reveal us extended periods of high and low solar activity.

The solar activity presented a reduced number of sunspots between 1645 and 1715 reported by Walter Maunder and Gustav Spörer [3], a period later named the Maunder minimum. One of the main questions in the study of solar variability is if the Solar Dynamo and the Shchwabe cycle were present or absent during the Maunder minimum.

Whether the solar variability is due to a stochastic, chaotic, intermittent or quasi-periodical processes is one of the questions of more interest to Solar Physics, of great importance also to the predictions of solar activity and to solar-terrestrial relationships. Unfortunately there is not a complete theory of the Solar Dynamo that explains the origin of the observed solar magnetic fields, their properties, their evolution and how they relate to each other [4].

The analysis of the sunspots series is a tool to study the solar magnetic field and the solar dynamo. Since there are no direct observational data to study the solar variability over long time scales we have to rely on proxy data such as cosmogenic isotopes.

The cosmogenic isotopes are produced mainly by galactic cosmic rays flux modulated by the change in interplanetary magnetic field and geomagnetic field.

The analysis of cosmogenic isotopes such as $Beryllium - 10$ (^{10}Be) in polar ice cores and $Carbon - 14$ (^{14}C) in tree rings stored in natural archives, provides a mean to extend our knowledge of solar variability over much longer periods [5].

The analysis of the cosmogenic isotopes record is more dificult thant the analysis of sunspot numbers. This is due to the fact the ^{14}C and ^{10}Be concentration not only reflects the production rate, which is modulated by the solar activity, but also by atmospheric transport and deposition processes [5].

In this work we apply the wavelet transform to long data series of ^{14}C and ^{10}Be to extract from them the major periodicities. They are long-term proxies of the solar activity and cosmic ray flux changes.

Data and Analysis Tecnique

We work with the data for ^{10}Be in polar ice core from the Greenland Dye-3 record for the period 1424-1985 [6]. We also examined the Antarctic ^{10}Be for 860-1975 [7] and INTCAL98 calibration record of atmospheric ^{14}C abundance between 0-1955 [8].

The simplest technique to investigate periodicities in solar activity and cosmic ray flux is the Fourier Transform. Although useful for stationary time series, this method is not appropiate for time series that do not fulfill the condition of stationarity. In order to find the time evolution of the main frequencies of the time series, we apply the wavelet method using the Morlet wavelet [9].

Wavelet analysis can be used to analyse localized variations of power within a time series at many different frequencies. To determine the significance levels of the wavelet power spectrum, first it

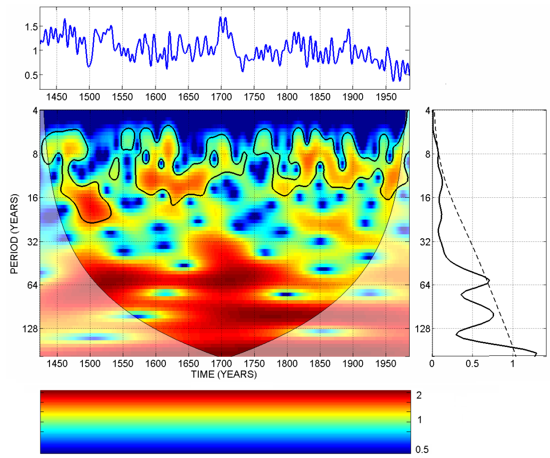

Figure 1: Wavelet analysis of the North pole ^{10}Be

is necessary to choose an appropriate background spectrum. For many geophysical phenomena such background spectrum is either white noise (with a flat Fourier spectrum) or red noise (increasing power with decreasing frequency). The dashed curve in the panel for the global power spectrum density indicates the red noise level at the 95% confidence level. We then estimate the significance level for each scale using only values outside the cone of influence (COI) [9] .

Results

We show in the top panel of each of the Figures $1, 2$, and 3, the time series of the cosmogenic isotopes: the right panel shows the global wavelet spectrum, and the central panel presents the Morlet wavelet spectrum.

Fig. 1 shows the wavelet spectral analysis of the North pole ^{10}Be; the global wavelet spectrum shows three periodicities with more of 95% confidence level: $7, 60$ and 240 yrs, and two periodicities close to the of 95% confidence level, 11 and 120 yrs.

As it can be seen from the Morlet spectrum, the 11 yrs periodicity is present during the secular minima of solar activity, known as Spörer, Maunder, Dalton and Modern (Table 1). It is attenuated since the end of one secular minima to the beginning of the

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next secular minimum (i.e. 1530-1580, 1715-1785 and around 1850).

In the cosmogenic isotopes there is an absence or attenuation of the 11 yrs periodicity in $1530-1580, 1715-1785$ and around 1850, while the 11 year periodicity for Sunspots is present.

The 60-yrs (Yoshimura cycle) and 120-yrs periodicities are prominent practically during the whole time interval. The 240 yrs is prominent but unfortunately is practically out side of the COI.

In Figure 2 we present the wavelet analysis of the ^{10}Be data from the South Pole. The global wavelet spectrum shows two periodicities with more than 95% confidence level: 128 and 235 yrs. The periodicity of 60 yrs has less than 95% confidence level. The Morlet wavelet spectrum shows that the 128 and 230 periodicities are prominent during the whole time interval.

In Figure 3 the wavelet analysis of the ^{14}C is shown, the global wavelet spectrum shows three periodicities with more than 95% confidence level: 128, 230 and 340 yrs. The periodicity of 60 yrs has less than 95% confidence level.

The Morlet wavelet spectrum shows that the periodicities of 128, 230 and 340 are prominent during the whole time interval.

In the spectral wavelet analysis of the three time series of the cosmogenic isotopes an $80-90$ yrs periodicity is not shown (Gleissberg cycle).

The importance of knowing with greater accuracy the solar activity periodicities is to be able to reconstruct the solar magnetic variability and its prediction.

In Table 1 a reconstruction of the solar magnetic minima of the last two millennia is shown. In the first column the name of the solar toroidal secular minimum is listed, in the second column every row differs to the next by 120 yrs, in the third, fourth and fifth columns the corresponding years of the so called Gleissberg cycle for 80, 88 and 90 yrs respectively are shown.

We take as reference point the Maunder minimum (1680 for all periodicities) in the solar magnetic secular minima reconstruction. As may be observed, the Gleissberg cycle (80-90) yrs cannot reproduce satisfactorily the solar magnetic minima.

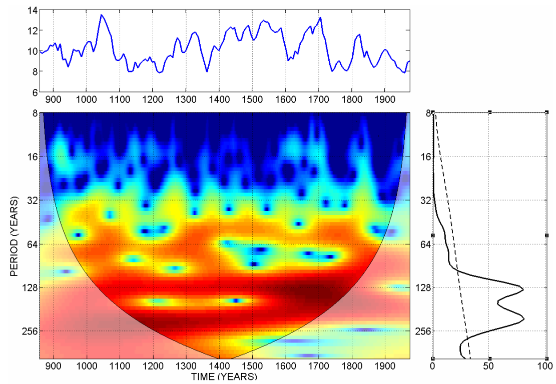

Figure 2: Wavelet analysis of the South pole ^{10}Be

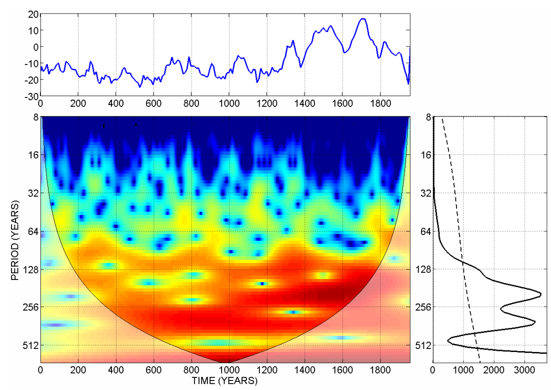

Figure 3: Wavelet analysis of the ^{14}C

That is why a solar activity prediction done based on the Gleissberg cycle is not possible.

The 120 yrs periodicity rebuilds with greater precission the solar minima and predicts the following secular minima appear around the 2040 and 2160.

Conclusions

We use the INTCAL98 for ^{14}C time series and ^{10}Be time series for both the South and North Poles. The results obtained from the wavelet transformation shows that there are no periodicities of 80-90 yrs (Gleissberg cycle) or 205 yrs (de Vries or Suess cycle) in these series.

This suggests that these periodicities may be the result of applying transformations (for example

	120-yrs Cycle	Gleissberg Cycle		
		80 yrs	88 yrs	90 yrs
Jesus	0	560	448	420
	120	640	536	510
	240	720	624	600
Late Roman maximum	360	800	712	690
	480	880	800	780
Byzantine maximum	600	960	888	870
Dark Age minimum	720	1040	976	960
Maya	840	1120	1064	1050
	960	1200	1152	1140
Oort minimum $[1010, 1050]$	1080	1280	1240	1230
Medieval maximum	1200	1360	1328	1320
Wolf $[1280, 1340]$	1440	1320	1416	1410
Late Medieval maximum	1440	1520	1504	1500
Spörer minimum $[1420, 1530]$	1560	1600	1592	1590
Maunder minimum $[1645, 1715]$	1680	1680	1680	1680
Dalton minimum $[1790, 1830]$	1800	1760	1768	1770
Modern minimum $[1890, 1930]$	1920	1840	1856	1860
Minimum XXI	2040	1920	1944	1950
Minimum $XXII$	2160	2000	2032	2040

Table 1: Reconstruction of the solar magnetic minima of the last two millennia, taking as reference point the Maunder minimum (1680 for all periodicities).

Fourier) to time series that do not fulfill the condition of stationarity:

I) The significant solar periodicities obtained from the Morlet wavelet are: 60 yrs (Yoshimura cycle), 120 yrs and 240 yrs (de Vries or Suess cycle).

II) The decrease in the cosmogenic isotopes for most of the 20th century and other inter minima periods reveal the corresponding increase in solar activity.

IV) The solar activity secular minima periodicity is of 120 yrs and this is the sunspot series modulator.

V) The 120-yrs periodicity could possibly be one of the principal periodicities of magnetic solar activity.

VI) Quite possibly the 240 yrs periodicity (de Vries or Suess cycle) is a 120 yrs periodicity subharmonic.

VII) The 120-yrs periodicity predict that the following solar secular minima, should be around 2040 and 2160.

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