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Global temperatures and sunspot numbers. Are they related?

Luis A. Gil-Alana [a,b,*], OlaOluwa S. Yaya [c], Olanrewaju I. Shittu [c]

[a] *University of Navarra, Pamplona, Spain*
[b] *ICS, Navarra Center for International Development, Pamplona, Spain*
[c] *University of Ibadan, Ibadan, Nigeria*

HIGHLIGHTS

- We relate global temperatures and sunspot numbers.
- Long range dependence techniques are used.
- Temperatures are $I(d)$ with d about 0.46.
- Sunspots are cyclical with periodicity of 11 years and d about 0.40.
- The two series have poles at different frequencies in the spectrum.

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ABSTRACT

This paper deals with the analysis of global temperatures and sunspot numbers and the relationship between the two. We use techniques based on the concept of long range dependence. For the temperatures, the best specification seems to be a fractionally integrated or $I(d)$ model with an order of integration d of about 0.46 and an estimated time trend coefficient that suggests that temperatures have increased by about 0.57 °C over the last one hundred years. However, for the sunspot numbers, a cyclical fractional model seems to be more appropriate, with a periodicity of 11 years per cycle and an order of integration of about 0.40. Thus, the two series display long memory and fractional integration. However, the fact that both series display poles in the spectrum at different frequencies implies that we fail to reject the null hypothesis of no relationship between the two variables in the long run. Moreover, assuming that the sunspots are exogenous, the results show no statistical significance of this variable on the global temperatures, which is one of the main contributions of the present work.

1. Introduction

Determining the sunspot cycle period is important among other things in order to compare the period estimate with cycles in temperatures. Thus, cooling and warming of the Earth might be due to the changes in the number of observed sunspots. From the historical data available to Rudolf Wolf in 1848, he estimated a cycle period of above 11.1 years/cycle. This result was also confirmed by Schuster [1] who employed techniques based on the periodogram and found an estimate of 11.125 years/cycle. Nowadays, it is widely accepted that the number of sunspots fluctuate with apparently regular intervals and a period length averaging 10–11 years [2]. Nevertheless, the modelling of the time series of sunspots is still an open issue. According to Aguirre et al. [3], there are two main practical difficulties concerning this series: one, the apparent nonstationary nature of the series, and two, the complex dynamics underlying the fluctuations in the cycle amplitude.

* Corresponding author at: University of Navarra, Pamplona, Spain. Tel.: +34 616964080.
E-mail address: alana@unav.es (L.A. Gil-Alana).

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The issue under investigation in this paper deals with the following question: can we obtain a long term equilibrium relationship between number of sunspots and global temperatures? Friis-Christensen and Lassen [4] showed that sunspot numbers between 1861 and 1989 display a significant relationship with the Northern Hemisphere mean temperatures.[1] They further showed that temperatures presented a better correlation with the length of the solar cycle between the years of the highest numbers of sunspots. According to these authors, it is noticeable that the total solar irradiance over the years increases as the number of sunspots increases. This is so because more sunspots release energy into the atmosphere causing global temperatures to rise. Willson [7] concludes that if the current rate of increase in solar irradiance continues until the mid 21st century, the surface temperatures will rise by about 0.5 °C. This may be insignificant but not a negligible fraction of the expected greenhouse warming. Other authors finding significant relationships between sunspots and global temperatures include Lean and Rind [8,9], Folland et al. [10] and Zhou and Tung [11], and relating sunspots with regional climate we found the papers by Shindell et al. [12] and Ineson et al. [13] among many others. On the contrary, there are several papers showing that sunspot numbers and temperatures are not correlated ([14–17]; etc.). Pittock [14,15] is of the opinion that those authors that obtained significant relationships between sunspot numbers and temperatures such as Scafetta and West [18], Scafetta et al. [19] and West and Grigolini [20] might have produced errors due to data handling and other statistical problems, though similar arguments are claimed by those authors arguing just the contrary. Usoskin et al. [21], using a long span of data of about 1150 years showed that solar activity might be highly correlated with climate. Nevertheless, these authors claim that sunspot numbers cannot explain the warming effect in the temperatures in the last 30 years, whereas they find a significant correlation between sunspot number and geomagnetic activity. Thus, there is no consensus about the possibility of a relationship between sunspot numbers and global temperatures.[2]

This article therefore seeks to study the cycles and trends in global temperatures and sunspot numbers. For this purpose we use techniques based on the concept of long range dependence. There are several contributions in the present work. First, we show that global temperatures can be adequately modelled in terms of a fractionally integrated or $I(d)$ model, with d being estimated about 0.47. Moreover, the estimate of the time trend under this specification indicates that temperatures have increased by about 0.57° over the last one hundred years. This value is slightly different than the one that would be obtained under other more classical representations that impose $d = 0$ or $d = 1$ in the analysis. Our results, in fact, strongly reject these two hypotheses in favour fractional degrees of differentiation. For the sunspot numbers, our results indicate that the best specification is the one formed by a fractional cyclical model, with a periodicity of about 11 years and an order of integration of 0.4.[3] Due fundamentally to the different stochastic nature of the two series we reject the hypothesis of a long term equilibrium relationship between the two variables. Finally, using sunspot numbers exogenously, our results reject the hypothesis that they affect global temperatures.

The rest of the paper is structured as follows: Section 2 describes the methodology used in the article. Section 3 is devoted to the empirical results, while Section 4 concludes the paper.

2. Methodology

This paper focuses on long range dependence or long memory processes. Given a covariance stationary process $\{x_t, t = 0, \pm 1, \ldots\}$, with autocovariance function $E(x_t - Ex_t)(x_{t-j} - Ex_t) = \gamma_j$, according to McLeod and Hipel [26], x_t displays the property of long range dependence, or long memory, if

$$\lim_{T\to\infty} \sum_{j=-T}^{T} |\gamma_j|$$

is infinite. An alternative definition, based on the frequency domain, is the following. Suppose that x_t has an absolutely continuous spectral distribution function, so that it has a spectral density function, denoted by $f(\lambda)$, and is defined as

$$f(\lambda) = \frac{1}{2\pi} \sum_{j=-\infty}^{\infty} \gamma_j \cos \lambda j, \quad -\pi < \lambda \le \pi .$$

Then x_t displays the property of long memory if the spectral density function $f(\lambda)$ has a pole at some frequency λ in the interval $[0, \pi]$, i.e.

$$f(\lambda) \to \infty \quad \text{as } \lambda \to \lambda^*, \ \lambda^* \in [0, \pi] .$$

Most of the empirical literature has focused on the case where the singularity or pole in the spectrum occurs at the smallest (zero) frequency. This is the standard case of $I(d)$ models of the form:

$$(1 - L)^d x_t = u_t, \quad t = 0, \pm 1, \ldots, \tag{1}$$

[1] This paper was later strongly criticised by authors such as Laut [5] and Damon and Laut [6].

[2] A recent review on these issues can be found in Ref. [22].

[3] These results are completely in line with those previously obtained by Gil-Alana [23–25].