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Chile Tree Ring Chronologies as Proxy Data for Solar Variability

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Abstract: Tree ring index chronologies, representing standardized annual growth rates for *Fitzroya cupressoides* at Cordillera de la Costa de Osorno in Chile, have been employed for the search of solar periodicities during the last 400 years. Spectral analysis of tree ring series by multitaper method has determined significant periodicities at about 21 and 10.7 years. These values are close to two known basic solar activity periods at 22 and 11 years (Hale and Schwabe cycles). Other periodic component appears at 5 years, which may also be related to solar variations. The short periods found probably may be due to the environmental and climatic influences. The application of band pass filter techniques shows that the 11 year cycle present in tree ring series correlates with the sunspot numbers with a time lag of about two years, since AD 1700, the extent of accurate sunspot record interval.

Key words: Signal processing, tree-ring data, biosphere-atmosphere interactions, sun-climate relationships

Introduction

Dramatic variations such as sunspots numbers have been observed for more than a century in solar phenomena. Unambiguous confirmation of real variations in the Sun's radiation at the Earth is, however, relatively recent; only during the past decade have satellite measurements revealed the variability of the solar constant. During the last centuries, maxima and minima in solar activity have occurred approximately every 11 years. This is demonstrated clearly by the sunspot data. The Sun also exhibits variability over time scales both longer and shorter than its dominant 11 year cycle (Hudson, 1988; Foukal, 1990). Techniques using cosmogenic isotopes have reconstructed solar activity variations on longer time scales. Two isotopes are commonly used, carbon-14 and beryllium-10, both produced by cosmic rays. Galactic cosmic rays are modulated by changes in the strength of the interplanetary magnetic field arising from changes in solar activity (Hoyt and Schatten, 1997). The existence of century scale variations caused by solar activity has been confirmed from ¹⁴C dating (Stuiver and Quay, 1980) and ¹⁰Be ice-core data (Beer *et al.*, 1988). The sun's long-term behavior also shows transient dynamics such as the Maunder minimum from AD 1645 to 1715 (Eddy, 1976), characterized by a striking decrease of solar activity.

Recent techniques have been using tree rings as a possible proxy of the solar activity variations in the past, but it was not still possible to observe clearly a correspondence between tree rings and the solar activity, due to overlap of the climatic signs masking the signs of solar origin. Mori (1981) also found strong evidence for a 11 year solar cycle signal in a tree ring series from Formosa. Cross spectral

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analysis with solar data demonstrated a high coherence level at a frequency near 11 years with time lag of about 2.8 years. More recently Murphy and Veblen (1992) have reported a dominant cycle of 11 years existing in tree ring index from Colorado. Although the casual connection between solar variations and growth-rings is more complex than that between solar variations and cosmogenic isotopes, several studies suggest that such connections may exist (Kurths *et al.*, 1993).

The presence in tree growth ring thickness series of periodical signals that may be associated to some effects of solar activity, climatologic and environmental conditions suggest that specific comparative studies of these signals in observational and tree records may contribute to better know their relations and to promote the use of the ring-width record as a proxy of solar activity and other atmospheric phenomena. In the present study, the spectral analysis by multitaper method is used to identify periodicities contained in Chile cypress tree ring width series of 419 year life time. Periods associated with ENSO and some solar activity cycles were found and are described in this study.

Materials and Methods

The tree ring width data set used in this investigation-this study was conducted in 2005 in Brazil-has been obtained by Tree Ring Image Interactive Treatment (TRIIT) (Rigozo *et al.*, 2004). The *Fitzroya cupressoides* native species was studied and presents a 419 year chronology from 1575 to 1993 AD, as determined by the Department of Botany, University of Chile according to standard dendrochronological procedures. This chronology has been used to investigate the possibility that solar activity induces periodical signals in growth rings at Cordillera de la Costa de Osorno in Chile (Lat: 41°00' S; Long: 73°50' W; Alt: 1000 m). The tree ring series has been standardized by a two-peak gaussian function. The tree ring index time series is illustrated in Fig. 1 along with an indication of the period of Maunder-minimum of low solar activity.

The spectral estimate is a powerful method to analyze data and it is frequently used to study geophysical processes. Many techniques have been developed to analyze long and stationary time series. However, these techniques are not universally applied for time series that involve non-stationary processes of short duration. The main problem has been to isolate spectral frequencies amid a noise, to obtain spectrum estimation with a low spectral leakage and minimum variance (Stearns and Ruth, 1993). A new technique of spectral estimate, known as spectral analysis by multitaper, firstly presented by Thomson (1982), has been applied in the analysis of time series, mainly in seismology

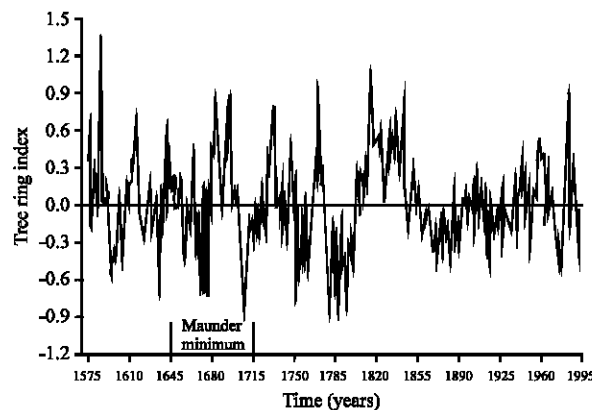


Fig. 1: Tree ring index time series extending from 1575 to 1993 AD with zero mean. The Maunder minimum period (1645 to 1715 AD) of very low solar activity, as determined by carbon-14 dating, has been indicated

(Park *et al.*, 1987) and climatology (Thomson, 1990) areas. In this method, the data are multiplied by a window function, as it happens in the conventional methods, but for several resistant functions to spectral leakage. By this, several spectral estimates are obtained from a time series, that can be combined to form only one spectral estimate. The routine used in this study to determine the spectral estimate by multi-tapers was improved from former ones and used by Vieria (1998).

Results and Discussion

After the removal of the long range tendencies, as above described, from tree ring time series, the spectral analysis is performed. Figure 2 shows a statistical estimate of significance of the frequency registered in the growth rings, in which the spectral probability has been calculated using the multitaper method. The significant peaks at both lower and high frequencies suggests that this species, growing at high altitudes sites, is very responsive to longer and shorter periods and to climatic factors influencing growth patterns.

Figure 2 shows the probability spectrum from the Chilean tree ring index series. It is seen that long periods have a high statistical significance. This represents most likely a strong response of tree rings to solar activity in the past. The periods observed representative the solar activity were 140.0, 38.0, 20.9 and 10.7 year. It may be observed that there exist two peaks, with a high statistical estimate, close to the 11 years, 13.1 and 10.7 years. Figure 2 also shows highly statistical estimates for the short periods, this represents a strong response of the tree rings to environmental influences. Some of these observed periods present estimated statistical significance above 95%, as it is the case of 6.3, 4.3, 4.0, 2.7, 2.6, 2.3 and 2.03 years.

Assuming that signals close to ~11 year period have a solar origin, it would appear that the length of the solar cycle over this period was near 10.7 years and less than the current average of 11.1 years obtained by Murphy (1990). The same result was observed in tree rings by Murphy and Palmer (1992), who found between 426 years (close to AD 177), a mean period of 10.5 years for the length of the 11 year solar cycle. An equivalent result was observed by these authors, for the 22 year solar cycle, who obtained for the length of this solar cycle in the tree ring index, for the same time interval, a value of 20.9 years.

Confirmation of tree ring width variations may be attributed, at least in part, to anomalous solar activity. Many early spectral studies failed to find any significant evidence of solar periodicities (La Marche and Fritts, 1972). However, recent spectral studies have shown strong evidences of a 11 year period in tree ring data. Murphy (1990) found evidences of a 11 year solar signal in tree ring data

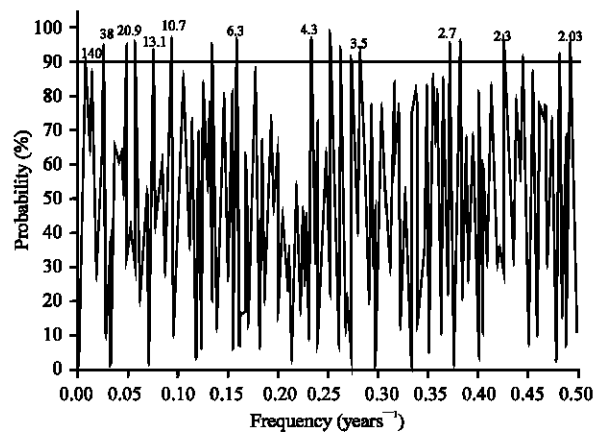


Fig. 2: Spectral probability at tree ring index time series over AD 1575-1993

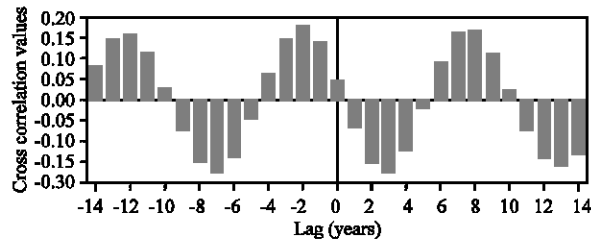


Fig. 3: Cross correlation of tree ring index and sunspot numbers over the common period of AD 1700 to 1993

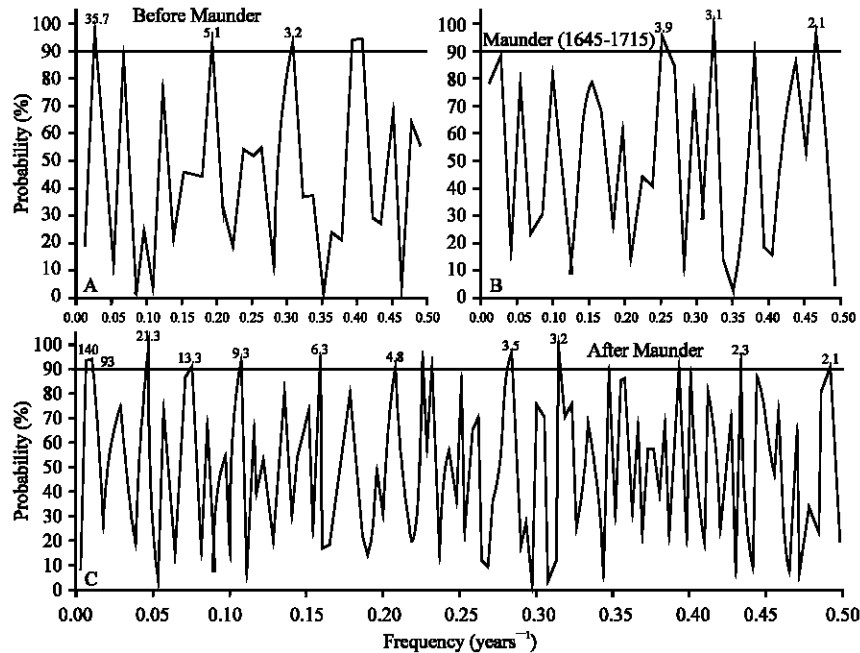


Fig. 4: Spectral probability obtained at (A) before the time of Maunder minimum AD 1575-1645, (B) during the time of Maunder minimum ad 1645-1715 and (C) after the period of the Maunder minimum AD 1715-1993

from Australia, with a time lag of 3 years. He also found periods close to the 22 year and 90 year (Gleissberg cycle) solar cycles. We also found a period close to the 11 year-old solar cycle, but with a time lag of 2 years for the sample of Chile and a strong evidence of the signal of the 22 years cycle. These same results were found by Kurths *et al.* (1993) in samples of trees of Miocene from Germany, where they observed periods of 12.5 years and the second harmonic of 11 year cycle in 5.5 years. We observed the second harmonic at 5.1 years for the period before Maunder minimum. For the period after the Maunder minimum, it was found at 4.8 years but this periodicity is not clearly related to a solar signal.

The cross correlation between the two time series, tree ring index and relative sunspot number (NOAA, 1994), can demonstrate the periodic equivalence of two time series and establish their phase relationship along with an indication of the common interval over which the periodicity has persisted. Figure 3 which gives the magnitude of the correlation coefficient at various time lags illustrates this situation. Here at lag-2 the value of cross correlation is approximately 0.18. Thus a positive correlation

clearly exists with a growth response time lag of about 2 years in relation to solar activity phase.

The attention has been directed towards identifying epochs of very low solar activity, based on information derived from indirect sources. One of these epochs is the Maunder minimum from AD 1645 to 1715 (Eddy, 1976). Figure 4 presents the spectral analysis for three periods, (A) before Maunder from AD 1575-1645, (B) during Maunder from AD 1645-1715 and (C) after Maunder from AD 1715-1993.

In Fig. 4A only a long period, 35.7 years, has been found with an estimated probability above 95% and three short periods, 5.1, 3.2 and approximately 2.5 years, have been found with an estimated probability above 93%. In Fig. 4B only short periods show a high estimated statistical significance, 3.9, 3.1 and 2.1 years, above 95%. The interesting fact is a period found close to the 11 year solar cycle but with a low estimate of probability, which turns that result not reliable. Figure 4C shows periods due to the solar cycles of 22 and 11 years with an estimated probability of 99% for 21.3 years, 91% for 13.3 years and 94% for 9.3 years. It was also found a high estimated statistical significance of 94% for periods between 93 and 140 years. Short periods were also found with an estimated statistical significance above 93%, 6.3, 4.4, 3.5, 3.2 and 2.3 years. This represents that the signals of solar origin are dominant after Maunder minimum.

The long-standing suggestion that variations in the Sun's total irradiance (the solar constant) on time scales of decades to millennia may have been the cause of long-term climate variations has been revived in recent years by spacecraft radiometric measurements (Wilson and Hudson, 1991) showing that the Sun's total irradiance has varied more or less in phase with solar magnetic activity as measured by the sunspot number since peak of solar cycle 21 in 1980. As was originally pointed out by Eddy (1976), the Maunder minimum coincided roughly with one of the coldest episodes of the Little Ice Age, when global temperatures have been estimated to have been 1 to 1.5°C colder than modern temperatures (Crowley and Noth, 1991; Bradley and Jones, 1993). Thus, it may be thought that variations in the total irradiance from the Sun can induce variations in tree growth by some mechanisms which involve sun induced global and regional climatic variations and specific sensitivity of trees to ambient variations which intervene as limiting factors when in stress conditions.

Evidence shows that during the Maunder minimum from 1645 to 1715, the climate was anomalous. Studies of tree rings in the American Southwest suggested that the late 1600s was a period of drought although the Scandinavian tree rings show the Maunder minimum was a period of relative warmth (Douglas, 1936). The same author also wrote that during the Maunder minimum the 11 year tree ring cycle disappeared. All these anecdotal and regional accounts give a confusing and contradictory picture of the Maunder minimum climate. Rind and Overpeck (1993) used the Goddard Institute for Space Studies General Circulation Model (GISS/GCM) to model the consequences of prolonged decrease in solar irradiance such as which may have occurred during the Maunder minimum. They found that while most of the world cooled, certain regions were actually warmer. This simulation revealed warmer regions east of Scandinavia where the tree rings data shows a warmer climate. This model also evidenced a cold period in South America and particularly in Chile, where we found no significant statistical evidence for the 11 year solar cycle in the tree ring series from Chile, during the Maunder minimum, but this negative result does not allow to conclude that chronology intervals without 11 year solar cycle correspond systematically to cold weather periods.

Conclusions

The spectral analysis of tree ring data from Chile presented evidences for the 11 year solar cycle, with a time lag of about 2 years and the cycle of Hale and these are dominant after Maunder minimum, 1715-1993 AD. We observed also the second harmonic at 5.1 years for the period before Maunder

minimum. The Gleissberg cycle presents a periodicity of 93 to 140 years, for the post-Maunder minimum period. The short periods observed can be due the environmental influences and climatic. The results found are in agreement with other record studies of the solar activity in the past, such as the concentrations of the cosmogenic isotopes carbon-14 (Stuiver and Quay, 1980) and beryllium-10 (Beer *et al.*, 1988). More studies of regional tree ring data, as this, become necessary to determine the relative importance of the solar influences in the Sun-Earth system, in the past, since tree rings are seemingly becoming an excellent proxy data base for solar variability.

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