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Spectral Analysis of Tree Ring Width Time Series from Chile (1587-1994 A.D.)

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Abstract: Tree growth rings are an important natural record of past climate variations and solar activity effects on it. We perform in this study a spectral analysis of tree ring samples from the *Pilgerodendron cupressoides* species, at Glaciar Pio XI (Lat: 49° 12' S; 74° 55'W; Alt: 25 m), Chile. We have obtained an average chronology of ~400 years from these trees. A large number of short term periods, around 2-7 years, were found which are most likely associated with ENSO effects. Further, we have found significant periods around 9-14, 20-22 and 80-100 years. These periodicities are coincident with the well known Schwabe (11 yr), Hale (22 yr) and Gleissberg (~80-100 yr) solar cycles. Therefore, the present analysis shows evidence of solar activity effect/modulation on climatic conditions that affect tree ring growth. Although we cannot say with the present analysis if this effect is on local, regional or global climate, these results add evidence to an important role of solar activity over terrestrial climate over the past ~400 years.

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

Introduction

Tree growth rings have been widely used both to reconstruct past climate and solar variability. Douglas (1928) first showed evidences that tree ring width patterns may represent reliable records of environmental conditions and that they could also reflect environmental factors occurring over a whole region, such as climate variations. There are also evidences that possible variations in tree growth ring thickness may be related to solar activity, from different tree ring series studies conducted on several trees species from locations around world with clear climatic contrast. Several studies have showed a possible 11 year (yr) solar cycle signal in tree rings. Murphy (1991) has found periods of 11.1 and 13.6 yr in tree rings from Taiwan. Dutilleul and Till (1992) have observed periods of 9.3 and 13.3 yr in tree rings from Morocco. Kurths *et al*. (1993) found periods around 11 yr in fossil (20 million years) tree rings from Germany. Rigozo *et al*. (2004a) reported periods around ~11 yr in tree rings from southern Brazil.

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The growth of tree rings depends, among other factors, on the air temperature and on the amount of water precipitation. Thus, it is expected that precipitation and temperature fluctuations caused by ENSO and other natural forcing mechanisms, could have recorded their signal in tree ring growth rings. In the South America region, researches with tree ring chronologies were most conducted for the study of climate records in sample from Chile and Argentina (Hughes *et al*., 1982). It is also known that ENSO has a very strong influence on the climate of South America (Neelin and Latif, 1998).

A new methodology was developed by Rigozo (1998) and presented in Rigozo *et al*., (2004b) to study the solar activity and geophysical signals in tree ring samples. This methodology has been applied to study natural signals recorded in tree rings from Southern Brazil (Rigozo *et al*., 2002; 2003; 2004a, c) and Chile (Nordemann *et al*., 2001; Rigozo *et al*., 2004c). In this study, a spectral analysis was conducted on *Pilgerodendrum cupressoides* tree ring samples from Chile, using the iterative regression methods. Periods associated with ENSO and some solar activity cycles were found and are described in this work.

Data Set and Spectral Analysis

The tree samples used in this study were obtained from trees that grew up at Glacier Pio XI, Chile (Lat: 49° 12' S; 74° 55'W; Alt: 25 m). A total of 6 samples were used in this study. These trees were native *Pilgerodendron cupressoides* species of ages ranging from 300 to 450 yr. The methodology used for sample polishing and treatment, as well as digital image analysis of the scanned samples is described in Rigozo *et al*. (2004b). Tree growth ring series were detrended using wavelet scaling levels. This procedure consists in decompose the original data series in wavelet frequency level through the multiresolution analysis (Percival and Walden, 2000). It works as a bandpass filter and the scaling level contains only the long term trend of data. This scaling level was applied to each tree ring time series to estimate its long term growth trend and to remove its effects from the data. This is necessary to eliminate the different growth rate of trees with their ages. Trends and periods longer than 200 yr are removed (Fig. 1). A tree growth ring detrended curve for each radius time series and the average of the six examples is shown in Fig. 2.

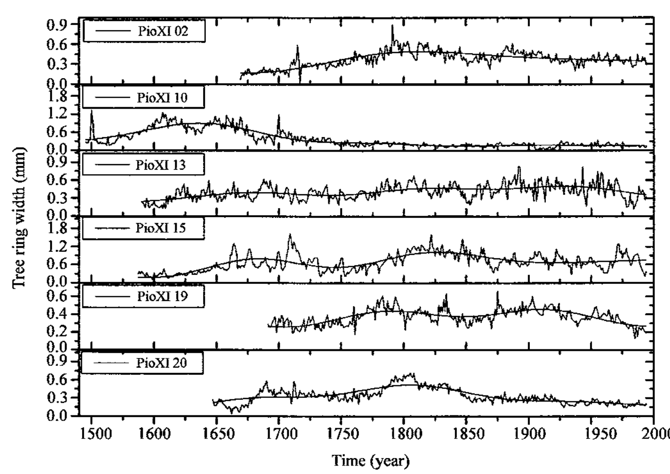

Fig. 1: Tree ring width time series and long term trends

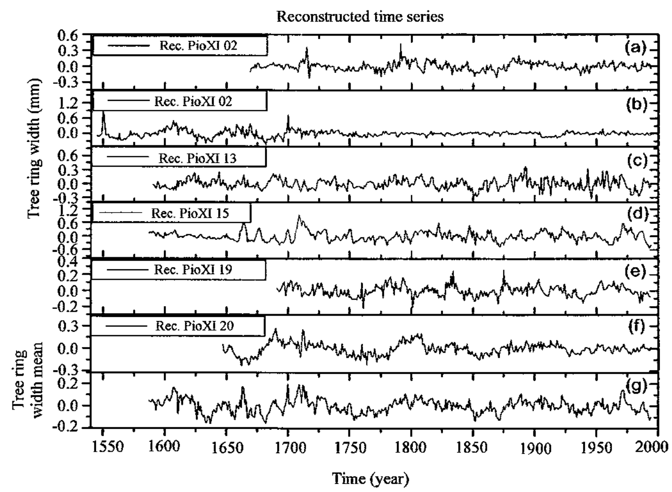

Fig. 2: Reconstructed tree ring width time series without long term trends

In order to identify the main periodicities, their amplitude in phase in each individual tree ring series and in their average, an iterative multiple regression model was applied (Wolberg, 1967). This technique is called Iterative Regression Analysis of Time Series (ARIST-Análise por Regressão Iterativa de Series Temporais) (Rigozo and Nordemann, 1998; Rigozo *et al*., 2005). This method can be applied to the fit of any function, including the search for periodicities in time series, using, for each period, a sine function with three unknown parameters, amplitude, period and phase. The starting point of the method is to define the conditional function:

$$F = Y - r_n \sin(w_n t + \phi_n) \tag{1}$$

where, Y is the observed signal, filtered or not, r_n, w_n and ϕ_n are amplitude, frequency and phase, respectively, t is time. F is the conditional function, which represents the difference between the measured value Y and the fit curve for the corresponding abscissa. As the method is iterative, at every step corrective terms are calculated. These are repeatedly applied to the parameters r_n, w_n and ϕ_n.

In this study the ARIST was applied to every tree sample and the most significant periods at 95% (amplitude higher than two times the standard deviation) were analyzed.

Results and Discussion

After the removal of the long range trends from the tree ring samples, the ARIST spectral analysis was done. Figure 3 shows the amplitude spectra obtained with ARIST for the tree ring samples (Fig. 2-f) and average (Fig. 2g). The presence of peaks at both low and high frequencies suggests that this species is very sensible both to long and short periods and to climatic factors influencing growth patterns.

The statistical estimate of the significance of the periods found is calculated considering that the periods which amplitude is higher than 2 times its standard deviation, are significant at 95% confidence level. Only these periods are shown in Fig. 3. It may be observed in these spectra that there are peaks close to 80, 22 and 11 yr. This represents a possible response of tree rings to solar influences, through

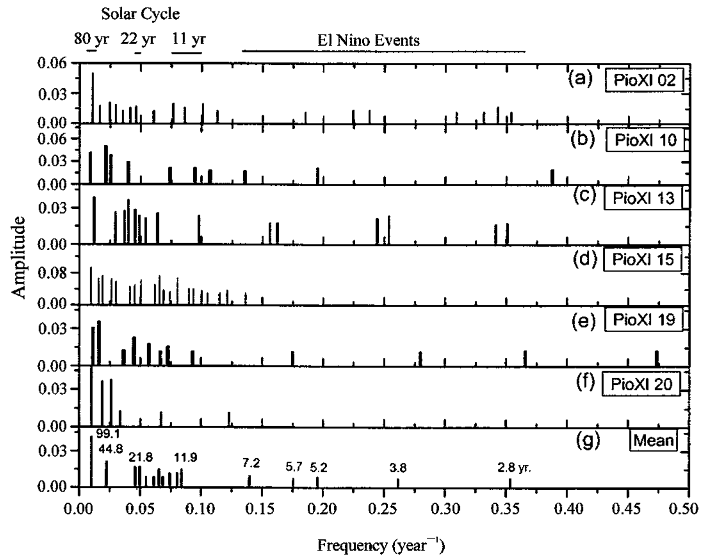

Fig. 3: Amplitude spectrum of the reconstruction tree ring width time series

climatic modulation. In addition, in these spectra we can noticed short periods of 7.2, 6.2, 5.5, 5.0, 4.4, 3.5, 3.1, 2.7, 2.3 and 2.0 years. These periods most likely represent the forcing of local environmental influences, as ENSO.

We can see that these solar related periods are present in all the tree ring samples, which show they are persistent. From tree to tree sample there is some differences in the spectrum (Fig. 3-f), but the general characteristics seen in all spectra and on the average series spectrum (Fig. 3g) are: low periods, 2-7 years (ENSO); periods around 9-14 yr; periods around 20 yr; periods around 80-100 yr.

It is well known that ENSO affects the climate of South America and Chile in special (Neelin and Latif, 1998). This effect seems to be mainly due to rainfall variability (Dai *et al.*, 2000). This signal was expected to be recorded in tree growth rings. The periods found here (Fig. 3g), around 2-7 years, may be related to ENSO, although some of them are caused by random natural variations or other geophysical phenomena (QBO). However, ENSO period of occurrence is erratic, varying around 3-7 years (Gray *et al.*, 1992). These ranges of periods has been found in tree rings from Alaska (Wiles *et al.*, 1998), southern Brazil (Rigozo *et al.*, 2004c) and other locations in Chile (Nordemann *et al.*, 2001).

Regarding solar activity periods, a number of studies has found them in tree ring samples (Fig. 3). The Schwabe 11 yr solar cycle has been found in tree rings from southern Brazil (Rigozo *et al.*, 2002; 2004a), Australia and Taiwan (Murphy, 1990, 1991) and in fossil trees from Germany (Kurths *et al.*, 1993). The Hale 22 yr and the 80-100 yr Gleissberg solar activity cycles have been found in samples from Russia and Scandinavia (Raspopov *et al.*, 2000), Australia and Taiwan (Murphy, 1990, 1991) and southern Brazil (Rigozo *et al.*, 2004a).

These periods should be recorded on tree rings most likely through solar modulation of local/regional climate. It is not expected that direct solar influence, e.g., solar radiation-can affect the tree growth, since satellite observations have showed a very small (0.1%) variation of solar activity with solar cycle (Frolich and Lean, 1998). The climatic parameters that control most of tree growth are heat/temperature and water/rainfall. We have found evidence here that one (or both) of these climatic parameters may have a solar influence.

Conclusions

We have performed spectral analysis on a ~450 yr tree ring width series from Chile. The amplitude spectrum showed the presence of various periodicities around 2-7 yr, which may be related to climatic/ENSO factors. In addition, periodicities close to the 11, 22 and 80 yr solar cycles were found. This study showed then evidence of solar activity effect on the climatic factors (rainfall and temperature) that affect tree growth.

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