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Solar and climate signal records in tree ring width from Chile (AD 1587–1994)

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Abstract

Tree growth rings represent an important natural record of past climate variations and solar activity effects registered on them. We performed in this study a wavelet analysis of tree ring samples of *Pilgerodendron cupressoides* species, from Glaciar Pio XI (Lat: 49°12′S; 74°55′W; Alt: 25 m), Chile. We obtained an average chronology of about 400 years from these trees. The 11-yr solar cycle was present during the whole period in tree ring data, being more intense during Maunder minimum (1645–1715). The short-term periods, around 2–7 yr, that were found are more likely associated with ENSO effects. Further, we found significant periods around 52 and 80–100 yr. These periodicities are coincident with the fourth harmonic (52 yr) of the Suess cycle (208 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 yr.

Keywords: Tree-ring data; Solar–planetary relationships; Solar activity; Wavelet analysis

1. Introduction

Quasi-periodical 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 relatively recent; only during the past decade satellite measurements have revealed the small variability of the solar constant. During last centuries, maxima and minima in solar activity have occurred approximately every 11 yr. This is demonstrated clearly by sunspot data. The Sun also exhibits variability over time scales both longer and shorter than its dominant 11-yr cycle (Hudson, 1988; Foukal, 1990).

Techniques using cosmogenic isotopes permitted the reconstruction of 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 ^{14}C dating (Stuiver and Quay, 1980) and ^{10}Be 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 used trees ring as a possible proxy of the solar activity variations in the past. 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.

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(1993) found periods around 11 yr in fossil (20 million years) tree rings from Germany. Rigozo et al. (2004) reported periods around 11 yr in tree rings from Southern Brazil.

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

In this paper, a wavelet analysis was conducted on *Pilgerodendrum cupressoides* tree ring chronology from Chile. Periods associated with ENSO and some solar activity cycles were found and are described in this work.

2. Data set and spectral analysis

The tree ring data used in this study were obtained from Rigozo et al. (2006a), who obtained a chronology (~400 yr) from Glacier Pio XI, Chile (Lat: 49°12′S; 74°55′W; Alt: 25 m). These trees were native *Pilgerodendrum cupressoide* species of ages ranging from 300 to 450 yr.

The indices used in this work were the Group Sunspot Number (Rg) for solar activity, and the Southern-Oscillation Index–SOI, for the El Niño-Southern Oscillation–ENSO (Enfield, 1989; Neelin and Latif, 1998). The Rg data set was taken from the National Geophysical Data Center (www.ngdc.noaa.gov) for the 1610–1994 intervals. At present time there are two different theories on the solar activity–climate relationship, one based on irradiance variations and the other one based on galactic cosmic ray-cloud cover (Herman and Goldberg, 1978; Nesme-Ribes and Ferreira, 1993; Hoyt and Schatten, 1997; Haigh, 1999; Lean and Rind, 1999). Thus, the utilization of the group sunspot number to represent solar activity seems to be more justified at present time than the reconstructed irradiances or cosmic rays variations (Ruzmaikin, 1999).

The SOI is calculated from the monthly or seasonal fluctuations in the air pressure difference between Tahiti (20°S, 150°W) and Darwin (Australia, 10°S, 130°E). Positive values of SOI indicate La Niña events and negative values of SOI indicate El Niño events (Enfield, 1989; Neelin and Latif, 1998).

The wavelet transform is a very powerful tool to analyze non-stationary signals. It permits the identification of main periodicities in a time series and the evolution in time of each frequency (Kumar and Foufoula-Georgiou, 1997; Torrence and Compto, 1998; Percival and Walden, 2000). The wavelet transform of a discrete data series is defined as the convolution between the data series with a scaled and translated version of the wavelet function chosen. By varying the wavelet scale and translating in time, it is possible to construct a picture showing the amplitude of any characteristic versus scale and how this amplitude varies with time.

In this work, the complex Morlet wavelet analysis was used because it is the most adequate to detect variations in the periodicities of geophysical signals in a continuous way along time scales. The Morlet wavelet is a plane wave modulated by a Gaussian function (Torrence and Compto, 1998; Percival and Walden, 2000):

$$\psi(0)_\eta = \pi^{-1/4} e^{i w_0 \eta} e^{-\eta^2/2}. \tag{1}$$

2.1. Cross-wavelet spectrum

If X, Y are time series and $W_n^X(s)$, $W_n^Y(s)$ are their wavelet transforms, the cross-wavelet spectrum is then (Torrence and Compto, 1998; Percival and Walden, 2000)

$$W_n^{XY}(s) = W_n^X(s) W_n^{Y*}(s), \tag{2}$$

where $W_n^{Y*}(s)$ is the complex conjugate of $W_n^Y(s)$. The power is then $|W_n^{XY}(s)|$

The cross-wavelet power indicates the scales of higher covariance between two time series (X, Y).

3. Results and discussion

The periods analyzed in this work are: (1) 1587–1994 in tree ring chronology, (2) 1610–1994 in Rg and (3) 1876–1994 in SOI. In order to identify the main periodicities in each time series and study its time variation, wavelet spectrum was determined for Rg, SOI and tree ring data using the 95% confidence level contour (Torrence and Compto, 1998).

Fig. 1 shows the wavelet spectrum for the Chile tree ring data. It shows a signal associated to the 11-yr solar cycle and fourth harmonic (52 yr) of the Suess cycle (208 yr), in the interval 1645–1715, and a strong signal associated with the Gleissberg (~80–100 yr) solar cycles between 1720 and 1860. Fig. 1 also shows others signals in the 2–8 yr band, which are visible with more intensity for interval between 1616 and 1742 and weaker for interval between 1830 and 1950, approximately. This may be an indication of the response of the tree rings growth to environmental conditions at their location.

Fig. 2 shows the wavelet spectrum for the Rg. The signal near 11-yr is the strongest feature and it is persistent during the whole period, with higher intensity in the period 1940–1994. It may be observed in the upper panel of Fig. 2 that in this period Rg have shown the highest amplitudes (higher group sunspot number), which indicates the non-stationary behavior of the Rg series. The signal near 11-yr do not appear in the period 1645–1715, the Maunder Minimum epoch.

Fig. 3 shows the wavelet spectrum for the SOI. In this case strong amplitudes are observed in the interval 2–8 yr, and the signal is clearly non-stationary, with periodicities alternating, present in some times and absent in others.

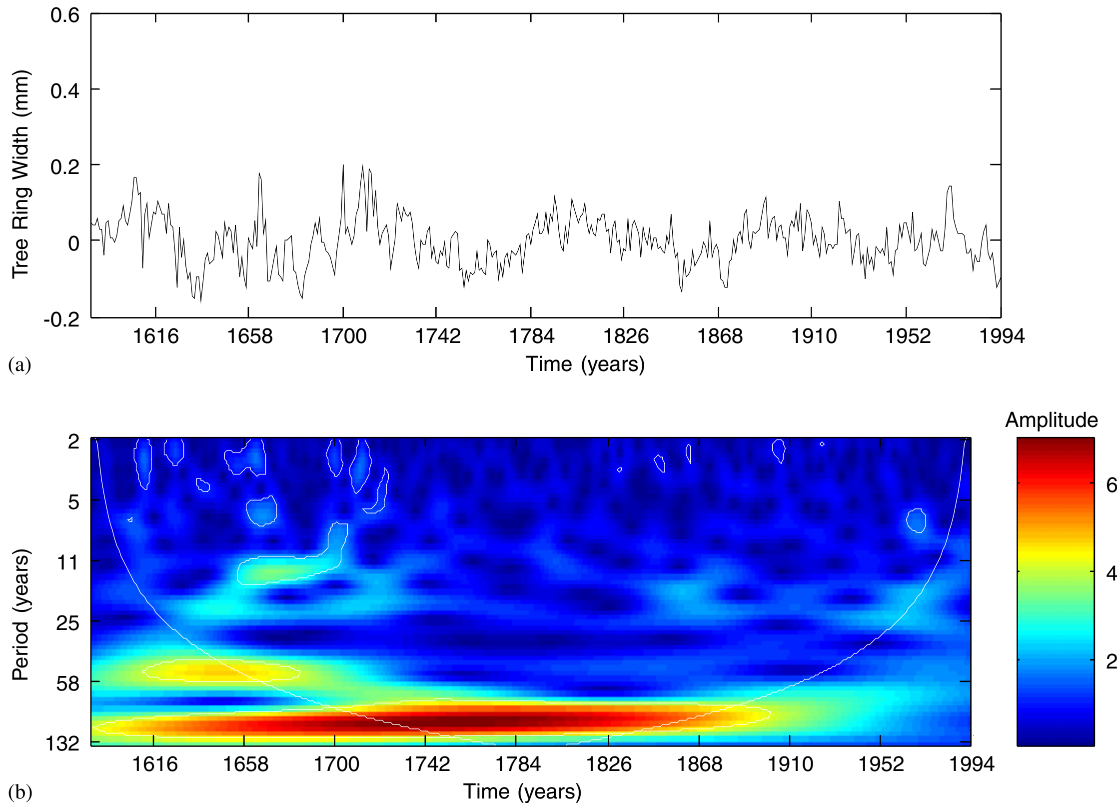

Fig. 1. Tree ring width time series (a). The wavelet spectrum with cone of influence (smooth curve) and significance levels contour for 95%. At right the legend indicates the wavelet spectral power in colors levels (b).

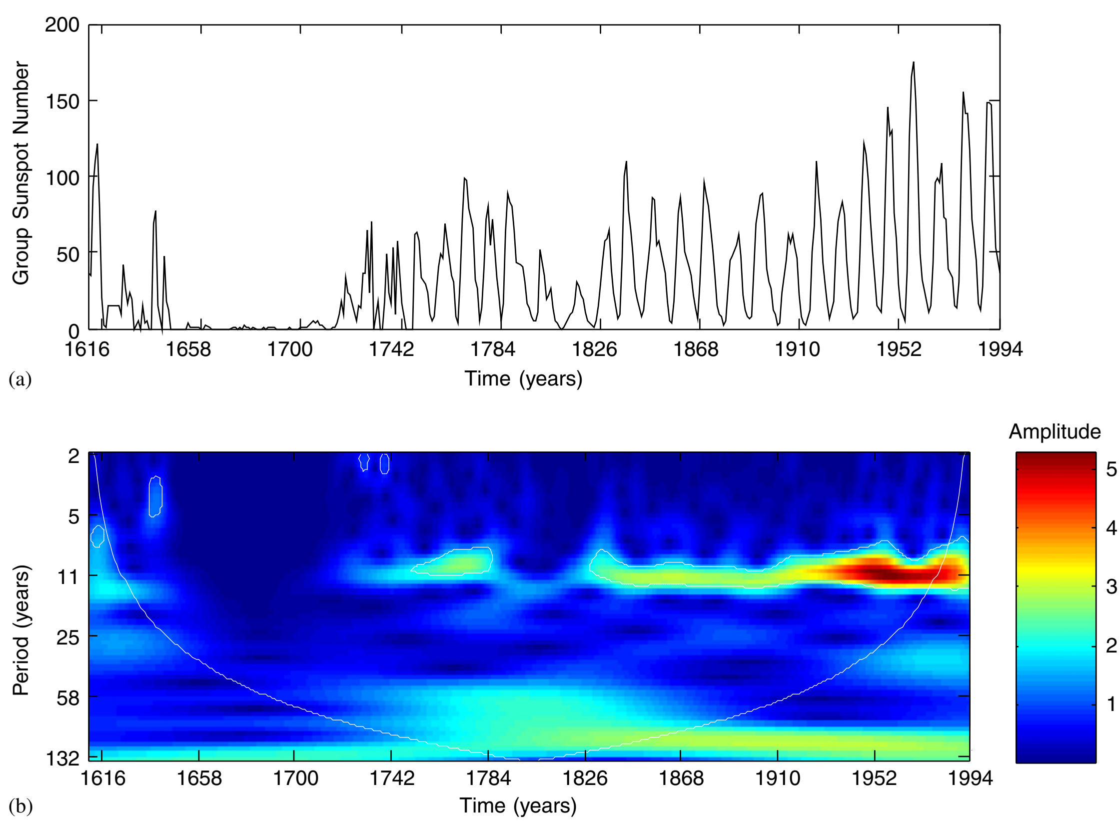

Fig. 2. The group sunspot number time series (a). The wavelet spectrum with cone of influence (smooth curve) and significance levels contour for 95%. At right the legend indicates the wavelet spectral power in colors levels (b).

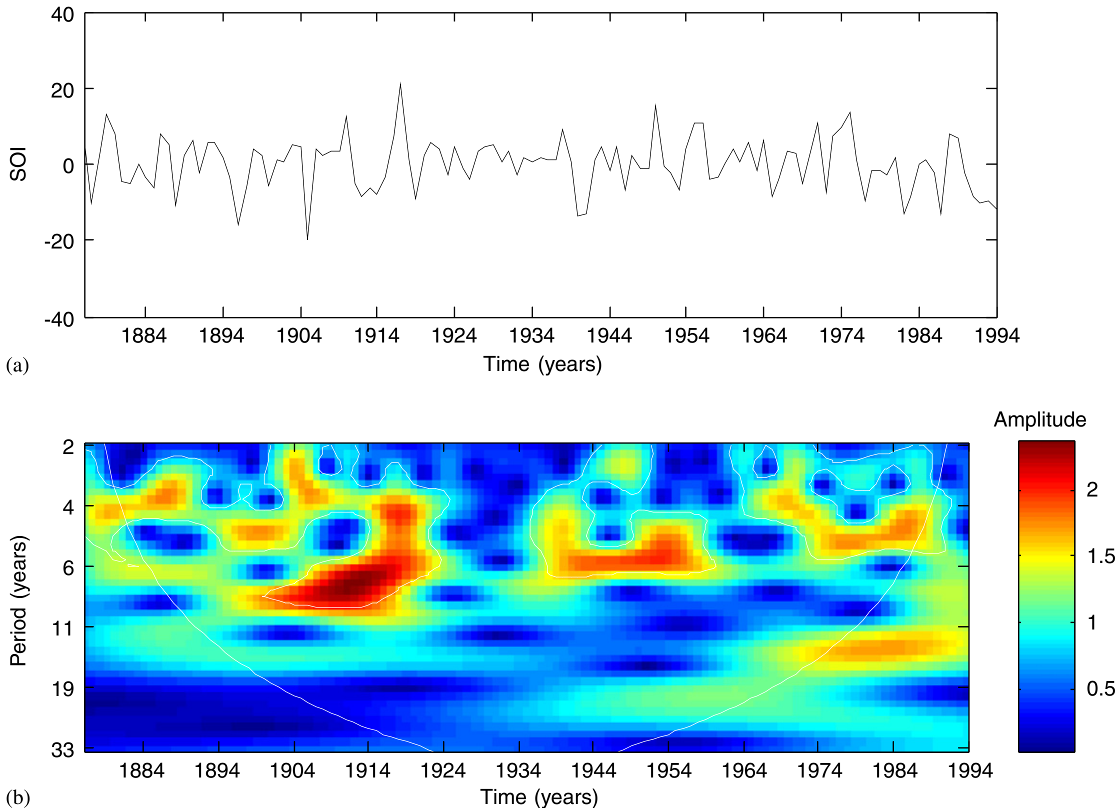

Fig. 3. The SOI time series (a). The wavelet spectrum with cone of influence (smooth curve) and significance levels contour for 95%. At right the legend indicates the wavelet spectral power in colors levels (b).

The non-stationary of ENSO was also observed by Trenberth and Hoar (1997), with an increase of ENSO frequency events for the last decades. 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 and Wigley, 2000).

This signal was expected to be recorded in tree growth rings. The periods found here (Fig. 3), around 2–7 yr, 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 yr (Gray et al., 1992). These ranges of periods have been found in tree rings from Alaska (Wiles et al., 1998), Southern Brazil (Rigozo et al., 2003) and other locations in Chile (Nordemann et al., 2005).

Regarding solar activity period, a number of studies have shown them in tree ring samples (Fig. 1). The Schwabe 11-yr solar cycle has been found in tree rings from Southern Brazil (Rigozo et al., 2002, 2004; Nordemann et al., 2005), Chile (Nordemann et al., 2005; Rigozo et al., 2006a), Australia and Taiwan (Murphy, 1990, 1991) and in fossil trees from Germany (Kurths et al., 1993). The fourth harmonic of Suess cycle (52 yr) has been found by Damon et al. (1998) studying a tree ring $\Delta^{14}C$ time series, for the time interval between 1065 and 1250 AC. This signal (52 yr) was also found in tree ring data from Concórdia, Brazil, by Rigozo et al. (2006b) and from Osorno, Chile, by Nordemann et al. (2005). 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), Southern Brazil (Rigozo et al., 2004) and Chile (Rigozo et al., 2006a). Nordemann et al. (2005) have observed that there has been an increase of Osorno tree ring thickness, in Chile, during the intervals with low sunspot numbers (1800–1835 and 1875–1935) and the contrary during the intervals with high sunspot numbers (1725–1800, 1835–1850 and 1950–1991). This evidence a long trend response of tree rings to solar activity decreases and increases.

In order to have a better visualization of similar periods in two time series, and to help the interpretation, cross-wavelet spectra are used. This analysis gives the correlation between two time series as a function of the period of signal and its time evolution also with a 95% confidence level contour (Torrence and Compto, 1998).

In Fig. 4 the cross-wavelet spectrum is shown for tree ring-*Rg* and in Fig. 5, for tree ring-SOI. At right the color scale shows the cross-wavelet power. Observing these cross-spectrum, it may be observed that: tree ring and *Rg* (Fig. 4) show a very high correlation with Gleissberg (~80–100 yr) solar cycles. The tree ring-SOI (Fig. 5) cross-correlation shows high values in the band 2–8 yr, and during some intervals.

A very interesting result is observed in the intervals 1903–1925 and 1959–1975, when strong amplitude is seen

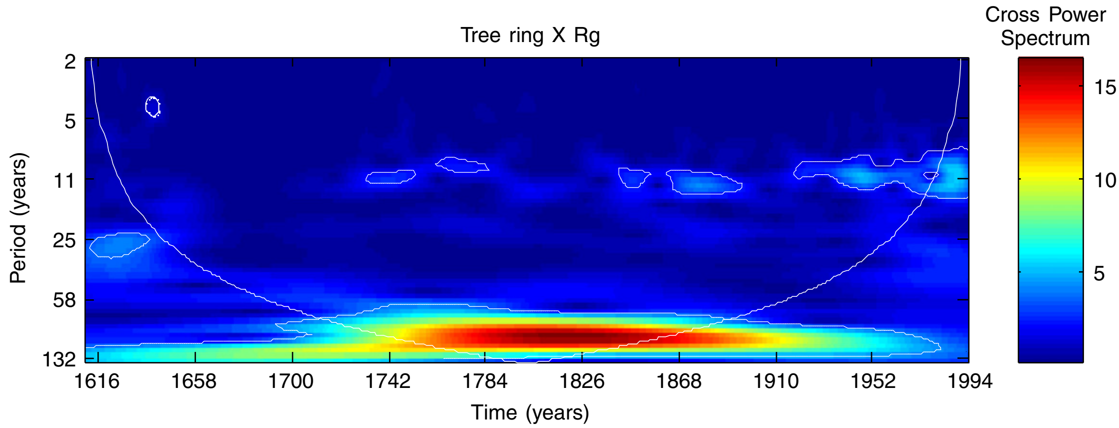

Fig. 4. Cross-wavelet spectrum between tree ring width and *Rg* with cone of influence (smooth curve) and significance levels contour for 95%. At right the legend indicates the cross-wavelet power in colors levels.

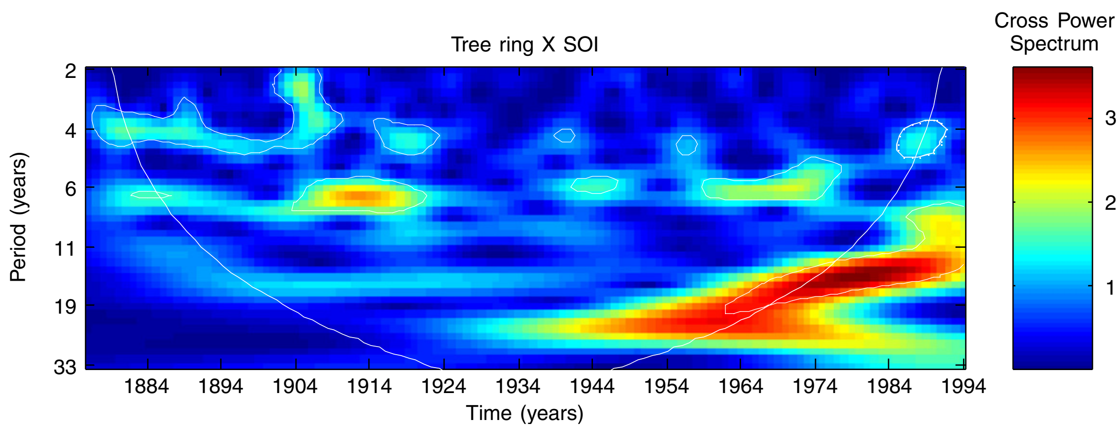

Fig. 5. Cross-wavelet spectrum between tree ring width and Southern Oscillation Index (SOI) with cone of influence (smooth curve) and significance levels contour for 95%. At right the legend indicates the cross-wavelet power in color levels.

in the SOI-tree ring Index cross-wavelet spectrum. The Rg-tree ring cross wavelet spectrum shows near-constant correlation around 80 yr and a varying correlation in the 11 yr period, with more intense cross-power around ~1740–1750, 1770–1780, 1830–1900 and 1920–1994 periods. Rigozo et al. (2002) have found a significant correlation between 1940 and 1970 for 11 yr solar cycle. The strongest El Niño and La Niña events in the period 1876–1991 are found in this interval, as it can be observed from the SOI variation in the upper panel of Fig. 5: the lowest value of SOI (the highest negative) was observed in 1905, which indicates a strong El Niño, and the highest value (positive) of SOI was observed near 1920 indicating strong La Niña. The results show that these large ENSO events have caused the high amplitudes in the band near 6–8 yr in 1903–1925, and the continuous high correlation seen in the cross-wavelet spectrum.

These results show that the *Rg* signal near 11 and 80 yr has a great influence on tree ring index (Fig. 4). It could be interpreted from this cross-spectrum relation that solar variations associated to *Rg* was one of the main factors influencing tree growth. Similar behavior is observed in SOI-tree ring data cross-wavelet spectrum (Fig. 5). Cross-wavelet spectrum of Sunspot-SOI studied by Rigozo et al. (2003) also presents a similar behavior, which could indicate some kind of solar modulation on ENSO as believed by many scientists (McCabe and Dettinger, 1999; Correge et al., 2001; White and Cayan, 1998; Quinn et al., 1993, 1998).

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 shown only a very small (0.1%) variation of solar activity with solar cycle (Frölich and Lean, 1998).

4. Conclusion

We have performed wavelet analysis on a ~400 yr tree ring width series from Pio XI, in Chile. The wavelet 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, 52 and 80-yr solar cycles were found. A growth in Pio XI tree ring was observed in the the Maunder Minimum period (1645–1715). This study showed evidence of solar activity effect on climatic factors (rainfall and temperature) that affected tree growth during the intervals of minimum and maximum solar activity.

These results indicate that solar activity is a very important agent responsible by the tree ring variability and it has visible influence on the climate on the $\sim$11 and 80 yr time scales. It is possible that other climatic factors could be operating together with the solar activity signal, and that this signal could have been amplified in the tree rings. Volcanic signal, through the aerosol optical depth enhancement (Sato et al., 1993), could act as a modulator factor on climate and have important impacts on decadal scale temperature variations (North and Stevens, 1998; Crowley, 2000). Further studies should be made on the extra climatic variables, such as volcanic activity indicators, temperature records and to be approached in future works.

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