SOLAR-TERRESTRIAL RELATIONS OBSERVED
IN SOUTH AMERICA TREE RING RECORDS

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ABSTRACT

This work presents a review of the results obtained by research on solar-terrestrial relationships developed by analyzing tree growth rings from Southern Brazil and Chile. These studies were performed using harmonic spectral and wavelet analysis. The time interval covered by the samples is 200 yr for Brazil and 2500 yr for Chile. It was observed that sample trees from Southern Brazil are showing a ring growth response favorable to the increase of solar activity. Although periodicities associated to the 11 yr solar cycle were observed in sample trees from Chile, this relation was not so favorable as in Brazilian trees. However, Chile tree ring widths have a much better response to low period, which indicates that they are more adequate to study El Niño events environmental variations than those from Brazil.

INTRODUCTION

The environment at the surface of the Earth, as we know it, only exist because of the energy flux that our planet receive from the Sun. A radiation solar influences atmospheric and oceanic circulations which also influence the biosphere (National Research Council, 1994). Without solar radiation, photosynthesis stops. Solar radiation and high energy particles collide continuously on gases and plasmas, components of the atmosphere and magnetosphere the role of which is to protect life at the surface of the planet (Raisbeck e Yiou, 1984). Changes in the quantity of total solar energy input in the planet system are caused by three mechanisms:

1. - Geometric factors related to the inclination of the Earth and orbit around the Sun (that alter the incidence and distribution of the radiation incident on the planet): The geometric conditions modulate the input of solar energy on the Earth. The season progressions are controlled by the inclination of the rotation axis of the Earth in relation to the direction perpendicular to the planet orbit plane and by the orbital eccentricity and precession. Small periodical variations of the Earth orbital parameters at a time scale of more than 10.000 yr (called Milankovitch cycles) associated to feedbacks and possible carbon dioxide changes produce significant Earth climate variations (Eddy, 1980).

2. - Processes inside the proper planet system (which regulate the quantity of energy received by the Earth): Processes inside the Earth system regulate the solar energy that penetrates through many feedback mechanisms including man made effects, which influence Earth warming such as the greenhouse effect. Some of these feedback processes include variations of the cloud thickness and snow cover that determine the planet albedo and by this way affect the solar energy input fraction available to the Earth system (Lean et al., 1992).

3. - Solar activity variations (that modulate the energy emitted by the Sun): Solar activity variations may also cause natural changes on the Earth system. There is no doubt that solar variability alters the energy incident on the global Earth system. The ultraviolet radiation, the solar wind and the
energetic particles from the Sun suffer important variations related to the presence of active regions of the solar atmosphere. These changes cause a dramatic variability at the top of the atmosphere, in the ionosphere and magnetosphere of the Earth. Only recently, satellite observations revealed that small variations (about 0.1%) also occur for the total electromagnetic energy emitted by the Sun (Wilson and Hudson, 1988). These radiation variations are also related to the presence of active regions in the solar atmosphere (sunspot and solar flares), and they occur at all observation time scales, from minutes to beyond the 11 yr solar cycle.

The study of solar variations related to their energy flux is completely observational and also very recent, which limits the understanding of their effects on climate and the possibility of long term climatic prediction for the future. For these reasons it became necessary to indirectly monitor solar variations and other geophysical phenomena at a much greater time scale in the past. This is possible thanks to the existence of natural records which cover wide time intervals of the past.

Tree growth rings represent records of chronological series which are witnesses of the environment and climate that influenced their growth in the past (Fritts, 1976). Tree growth which lasts from birth to death is influenced by several simultaneous environmental factors: solar radiation, temperature, water precipitation and soil content, humidity, nutrients, neighborhood, pests, illness, etc... Depending of conditions and species, some of these factors may prevail. Temperature, light and precipitation play an important role in regions with contrasted season and induce different growth rate caused by different cell size allowing direct visual recognition of the well known tree growth rings. The thickness variation of yearly rings reflects the tree sensitivity and the environmental factors at the place where it grows.

Polished sections or slices of dead tree trunks are digitalized either by high resolution scanner or digital camera. Pictures may be colored or black and white. Pixel values along several radii are transformed into time series by a semi-automatic interactive process. The time reference is usually the year of the tree death. Special care is taken when establishing dendrochronological chronologies from means of radius series and different trees from the same or different locations.

The mathematical analysis of these series intends to identify the spatial and geophysical phenomena which caused the variations recorded year by year during the tree life. The study described in this article is based on a mathematical analysis of the time series of growth rings of trees sampled in the Southern region of Brazil and in some regions of Chile, looking for characteristic features of the variations of their thickness such as periodicities, trends and events, in order to obtain a greater understanding of effects of solar activity, climatic and geophysical phenomena effects, on the South America continent. The method used includes spectral analysis by iterative regression and wavelet analysis.

**TIME SERIES AND ANALYSIS METHODS**

In the study described here, a spectral analysis by an iterative regression method was used to look for the periodicities embedded in tree growth rings. This method (Análise por Regressão Iterativa de Séries Temporais - ARIST) is an iterative least square fit and uses a simple sine function with three unknown parameters, $a_0$ = amplitude, $a_1$ = angular frequency and $a_2$ = phase (Wolberg, 1967; Rigozo and Nordemann, 1998). The starting point of the method is the so called conditional function:

$$ F = Y - a_0 \sin(a_1 t + a_2) $$

where $Y$ is the observed signal, $t$ is he time and $a_0$, $a_1$, $a_2$ are the three unknown parameters. Every periodicity embedded in the time series corresponds to a set of values of the three parameters which are determined once at a time by applying the iterative process to the original time series with the limiting condition of maintaining the angular frequency $a_1$ inside a restricted domain of the allowed interval of angular frequencies. For the determination of each parameter set, the maximum number of iterations used may be chosen between 50 and 200 (Rigozo and Nordemann, 1998). The advantage of the method is that it provides the standard deviation for each parameter, as...
determined from the statistical fluctuations and also, if desired, from the errors on every value of the
time series. This allows a selection of the periodicities with amplitudes above 95% confidence.

The wavelet transform is a powerful tool for non stationary signal analysis. It permits to identify
the main periodicities in a time series and their evolution (Kumar and Foufoulà-Georgiou, 1997;
Torrence and Compo, 1998; Percival and Walden, 2000). The wavelet transform of a series of
discrete data is defined as the convolution between the series and a scaled and translated version
of the wavelet function chosen. By varying the wavelet time scale and translating the scaled
versions of the wavelet, it is possible to build a graph showing the amplitudes versus frequency (or
scale) and how they vary with time.

In this work, a complex Morlet wavelet was used because it is the most adequate to continuously
detect variations of periodicities in geophysical signals. The Morlet wavelet is a plane wave
modulated by a gaussian function (Torrence and Compo, 1998; Percival and Walden, 2000):

$$\psi(0)_{\eta} = \pi^{-1/4} e^{i\omega_{\eta}t} e^{-\frac{\eta^2}{2}}$$  \hspace{1cm} (2)

X, Y being time series and $W_n X(s), W_n Y(s)$ their wavelet transform, the wavelet cross spectrum
(Torrence and Compo, 1998; Percival and Walden, 2000) is:

$$W_{n}^{XY}(s) = W_{n}^{X}(s) W_{n}^{Y*}(s)$$  \hspace{1cm} (3)

where $W_n Y^*(s)$ is the complex conjugate of $W_n Y(s)$. The power is $|W_n^{XY}(s)|$. The wavelet cross
power indicates the scale of high covariance between two time series (X, Y).

The time series used for Sun-Earth relationship studies represent the growth ring thickness of trees
from the Southern region of Brazil and Chile and sunspot numbers.

Tree samples from Brazil are *Araucaria angustifolia* species (local name: araucária or pinheiro) and
were collected at Concórdia, Santa Catarina State, lat.: 27°11'S - long.: 51°59'W - Altitude: 640m
(Rigozo, 1998).

Tree samples from Chile are *Fitzroya cupressoides* species (Cypress tree, local name: alerce), and
were collected at Costa Del Osorno, lat.: 40°S, long.: 73°50'W - altitude: 1000m (Nordemann et al.,
2001).

The sunspot time series were obtained from National Geophysical Data Center, Boulder, Colorado,

RESULTS AND DISCUSSION

These time series were studied by harmonic spectral analysis (maximum entropy analysis, iterative
regression and multitaper method) and by wavelet. For tree ring time series, before performing
spectral analysis, long trends representing the life time growth curve, were determined for each tree
and suppressed from the original time series. Then a mean time series is calculated for each
sampled location.

**Tree rings from Brazil**

Figure 01a presents the mean time series of growth ring thickness of trees from Concórdia – Santa
Catarina State, after removing its long trend curve.

Figure 01b presents the amplitude spectrum obtained by iterative regression spectral analysis.
Periodicities at 79.0, 51.3, 23.7 and 10.5 yr may be seen and may represent a possible influence of
solar activity and its Gleissberg cycle (80 yr), fourth harmonic of the 200 yr Suess cycle (52 yr),
Hale cycle (22 yr) and Schwabe cycle (11 yr), respectively. Also are observed low periods cycles
from 2 to 7 yr, which possibly represent local climatic factors and/or El Niño events. Other two
interesting periodicities found are at 18.5 yr period, that several authors associate to lunar tide influence, Saros cycle (O’Brien and Currie, 1993), and at 33.3 yr period that may be due to Brückner cycle (Brückner, 1890; Sazonov, 1979).

Fig. 01 – (A) Tree ring thickness time series from Concórdia - SC. (B) Tree ring thickness amplitude spectrum above 95% confidence.

Harmonic spectral analysis is an excellent tool to detect signals embedded in a time series. However, it only indicates that a given frequency exists but it does not indicate at what time this frequency began, how long it existed and when it ceased or if its frequency shifted. For Sun-Earth relationship studies, dealing with non stationary evolution, it is absolutely necessary to deal with these questions.

Figure 02 presents a wavelet spectrum of tree ring thickness where it may be observed that the periodicity close to 11 yr which was detected by the harmonic spectral analysis, is not constant in time: it presents two significant events (above 95%): between 1807 and 1828 and between 1912 and 1954, approximately. Also the short periodicities between 2 and 7 yr, also found by the harmonic spectral analysis, presents more significant sporadic events. This shows that local environmental factors may be predominant in time for this period band.
The relation between solar activity and tree growth is more evident in Figure 3 for the 11 yr period, where it may be observed that the solar signal is in phase opposition with tree rings between 1797 and 1860. From 1880 to 1970, approximately, the situation is inverse, i.e. signals are in phase.

The wavelet cross spectrum of sunspot number and tree growth ring (Figure 04) presents clearly a relation between both series, i.e. as well with signal in phase opposition (from 1797 to 1860) and in phase (from 1880 to 1970). This represents a good response of tree growth variation to an increase of solar activity, mainly for the 11 yr period during the interval between 1900 and 1964.
Tree rings from Chile

Figure 05a presents a mean time series of growth ring thickness of Fitzroya cupressoides trees from Costa del Osorno no Chile, as well as its long period trend (white curve). This species is sensible to temperature and precipitation (Lara et al., 2000) and its main advantage is that individual life time series are generally above 900 yr and represent an excellent resource for the study of low frequency signals (Wolodarsky-Franke et al., 2002).

Figure 05b shows a tree ring time series after long trend removal and its variance for growth ring before 88 and after 89 A.D. Figure 05c presents a tree growth ring time series normalized by its variance after 89 A.D.

Figure 05a evidences a sudden decrease of growth rings in 88 A.D. The cause of this phenomenon is not yet fully known. Wolodarsky-Franke et al. (2002) also found a sudden change of Chile tree growth at the beginning of the Christian era. They attributed this sudden growth variation to local environmental factors (climate and/or volcanism) which caused this growth decrease.
Fig. 05 – (A) Tree ring thickness time series from Chile and its long trend (white curve). (B) Detrended tree ring thickness time series and variances for the intervals before de 88 A.D. and after 89 A.D. (C) Normalized tree ring thickness time series.

Figure 06 shows the amplitude spectra versus frequency for the ring thickness, as determined by iterative regression. It may be observed in both spectra that there is no domination of long periodicities over low periodicities, i.e. long periods do not hide low periods. The nature of this result suggests a favorable response to environmental factors for long and shorts periods that influence tree growth at Costa Del Osorno, Chile.
Two interesting facts may be observed in Figure 06: (1) a great number of low periods embedded in the tree ring time series, due to local climatic conditions and to El Niño events. (2) Periodicities at 197.0, 89.6, 50.3, 11.8 and 10.5 yr which may be representative of solar activity through Suess (200 yr) and Gleissberg (80 yr) cycles, fourth harmonic of Suess cycle (52 yr) and Schwabe cycle (11 yr) respectively.

The signal variability at high frequencies (low periods) embedded in tree ring series indicates that local environmental conditions were extremely variable. These local climatic conditions probably suffered an intensification of its variability as well as the intensity of El Niño events.

An influence of these local environmental conditions, in the low period band, is better seen in the tree ring time series wavelet spectrum (Figure 07 and 08). It may be observed in Figure 07 and 08 a persistence in time of periods between 2 and 5 yr. This shows the high variability tree ring growth for this period band.

![Amplitude spectrum of tree ring width above 95% confidence.](image)

**Fig. 06 – Amplitude spectrum of tree ring width above 95% confidence.**

![Wavelet spectrum for periods from 2 to 132 yr, with confidence cone (white curve) and confidence level of 95% (white contour).](image)

**Fig. 07 – Wavelet spectrum for periods from 2 to 132 yr, with confidence cone (white curve) and confidence level of 95% (white contour).**
Fig. 08 – Wavelet spectrum for periods from 2 to 1058 yr, with confidence cone (white curve) and confidence level of 95% (white contour).

Only this variability in local conditions at low period probably does not explain the sudden decrease of tree ring growth at the beginning of the Christian era. It may be possible to explain the sudden decrease of tree ring growth by combining the low period effects and a possible influence of the 11 yr and perhaps 80 yr cycles of the solar activity.

The possible influence of these two solar cycles occurs very close to this interval. This may be seen on Figure 07, where the 11 yr solar cycle shows up significantly close to the beginning of the Christian era. The same occurs for the Gleissberg cycle (Figure 08).

It is possible to compare more accurately solar activity as measured by sunspot numbers and tree ring thickness for a more recent epoch. Figure 09 presents these two time series for the interval from 1700 to 1991. It may be observed that there has been an increase of Chile tree ring thickness during the intervals with low sunspot numbers (1800 to 1835 and 1875 to 1935) and the contrary during the intervals with high sunspot numbers (1725 to 1800, 1835 to 1850 and 1950 to 1991). This evidences a long trend response of tree rings to solar activity decreases and increases.
CONCLUSION

Sun-Earth relationship studies, based on tree growth rings from Brazil and Chile, present interesting results. The main result is the observation, in tree samples from Brazil and Chile, of periodicities associated to solar activity: Suess cycle (only for Chile), Gleissber fourth harmonic of the Suess cycle, Hale cycle (only for Concórdia-SC, Brazil) and Schwabe cycle. About the 11 yr cycle, it was seen that Concórdia (Brazil) tree ring growth was more favored by solar activity increase, for the interval between 1880 and 1960, than Chile tree ring growth which presented an inverse relation.

Furthermore low periods were observed in both tree growth ring series. They are due to local environmental conditions of both countries and possibly to El Niño events. It was also observed that Chile trees are more sensible to low period environmental variations than Brazil trees. For this reason, it is expected that Chile tree ring are better to study El Niño events than Brazil tree ring. Brazil tree rings are therefore much better for solar activity studies because of their clearer record in this period band.

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