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Accurate extraction of multiple periodic variations in Himalayan tree-ring widths through wavelet transform

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Abstract : We report here the observation of multiple periodic variations in the tree ring widths of the Himalayan region, through the continuous wavelet transform analysis. Ring width chronology of deodar tree from Joshimath (1584-1999 years) and Uttarkashi (1500-2002 years) in the western Himalayas, reveal wavelet amplitude variations in time periods of 11, 22 and 42 years, some of which are correlated with solar flares. Similar analysis of the pre-monsoon (March-April-May) temperature anomalies (1876-2003) relative to 1951-1980 mean, clearly show anti-correlation with the tree ring chronology data. Two different continuous wavelets (Morlet and Mexican) have been used, in order to ensure that, the observed variations are genuine and not an artifact of wavelets employed. In continuous wavelet transform, the scale intervals range from 1 - 64 years, since the trees growing on moisture stressed sites are not sensitive to record centennial time scale variations in their tree ring growth patterns. Very interestingly, the study of continuous wavelet transform maxima reveals inversion behavior in the periodic variations at around the year 1750.

Introduction:

Our understanding on variability of climate is largely hampered by limited length of instrumental weather records, spanning in most cases to past 100 years. High-resolution proxy climate records, with precise dating control, provide very good tool to supplement the weather records back by several centuries and millennia. Of these records, tree rings provide valuable proxy, as annual growth rings could be precisely dated to calendar year of their formation and the overlapping template of tree ring chronologies could be calibrated with weather data to hind cast the climate variables. Such long-term records could be used to understand the mode of climate variability in longer perspective.

The possibility of temporal variations in the weather pattern, at multiple time scales, necessitates a method of analysis, which is well-suited for the same. Wavelet transform, a procedure of recent origin, is ideal for the above purpose, since the mathematical microscope nature of this transform naturally enables one to see variations at multiple scales. Furthermore, the fact that, wavelet basis set consists of members which are sufficiently localized, makes one to pin point the location of the observed variation. We employ continuous wavelet transform, to extract multiple periodic behavior in the tree ring widths and correlate it with the temperature variations information.

Tree Ring Materials and Chronology Preparation:

Tree ring samples in the form of increment cores were collected from Himalayan cedar trees growing at moisture stressed sites in Juma near Joshimath and Gangotri in Uttarkashi. Increment borers were used to extract 4mm diameter cores from trees at 1.4m stem height from ground. The increment cores were processed to cross date the sequence of growth rings in trees to exact calendar year of their formation. The ring widths of precisely dated growth rings were measured using linear encoder with the accuracy of 0.01mm. Long-term growth trends inherent in trees due to increasing age and stem girth were removed by standardizing the ring width measurement series. Individual tree ring width measurement series were fitted with negative exponential or linear regression line with negative slope or no slope and indices calculated as quotient of actual measurement and curve value. The individual tree series after standardization were averaged using biweight robust estimation of the mean to develop mean chronology using program ARSTAN. The chronology dynamics assumed to be climate driven could be used to examine the possible low frequency modes and how these might have varied over time [1-3].

The climate dynamics is affected by a large number of factors, which in turn is reflected on a variety of proxy records, such as tree ring widths, ocean and lake deposits etc. The tree ring data has a much higher resolution as compared to the later ones. Recently, these two class of data have been combined through the multi-resolution capability of the wavelets [4], for reconstructing millennial-scale climate variability, in the northern hemisphere. Multi-centennial variations in temperature, possibly arising out of natural phenomena, have been inferred from the above study, which correlates well with a general circulation model. The variations in temperature naturally introduces variations in precipitation patterns, which are truthfully recorded in the tree ring data. At present, global temperatures are increasing; the last century in particular has seen substantial variations in temperature and precipitation rates, which may be arising due to anthropogenic forcing or natural causes.

The goal of the present work is to study the tree ring data much more carefully, through two different continuous wavelets, in order to capture the variations at different scales, in a consistent and reliable manner. Since, it is known that, this data has difficulty quantifying multi-centennial temperature variability, the highest wavelet windows are adjusted accordingly.

A number of clear time scales of variations emerge from our study, which includes, the natural solar variability time periods. Wavelet transform analysis is performed over the time series of temperature record data and the tree ring-width data from 1700-2001 years. The temperature variations show clear anti-correlation with the tree ring chronology data and inversion behavior in the periodic variations at around the year 1750.

Results and Discussion:

The difficult task is to find a suitable wavelet for analyzing data which are non-stationary. In the present case, both the tree ring and temperature data belong to this class. We have employed both Morlet and Mexican hat wavelet for analysis. The purpose of employing these two wavelets is to ensure that the observed variations are not due to any artifacts. We have confined ourselves to centennial scales, since the tree-ring data is not sensitive beyond the same. Furthermore, in this case the boundary artifacts are minimal. The continuous wavelet coefficient W(a,b) is defined as,

$$W(a,b) = K\int_{-\infty}^{+\infty} \psi^*(\frac{x-b}{a}) f(x)dx$$

Here, 'a' is the scaling and 'b' is the translation parameter; 'K' is the normalization constant [5]. Figure 1 depictis the time series of the tree ring data from Uttarkashi (top) and the contour plot of the modulus of the wavelet coefficients as a function of time and scale. The scalogram clearly reveals multiple periodic variations at different scales (bottom). Figure 2, depicts the plot of log of wavelet power summed over all time at different scales. One clearly observes the variations at 11, 22 and 42 years clearly. The figures 3 and 4 illustrate the same of the tree ring width time series from Joshimath. One clearly observes an inversion in the periodic behavior approximately around the year 1750, and a small periodic variation in the time scale of 7 years.

Figure 5: (top) shows the time series of pre-monsoon (March-April-May) temperature relative to 1951-1980 mean (1876 -2003) and its scalogram using Morlet wavelet (bottom). The semi-log plot of the wavelet power versus scale clearly shows an anti-correlation effects with the tree ring variations of figures 2 and 4.

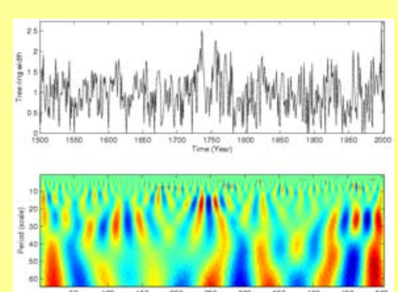

Figure 1, the plot of time series of the tree ring data from Uttarkashi (top) and the contour plot of the modulus of the wavelet coefficients as a function of time and scale. The scalogram clearly reveals multiple periodic variations at different scales (bottom).

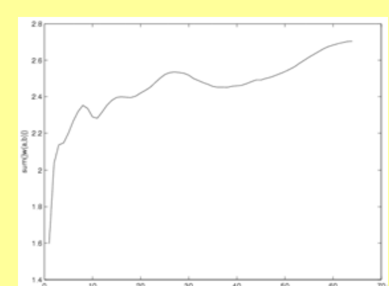

Figure 2, the plot of log of wavelet power summed over all time at different scales. One clearly observes the variations at 11, 22 and 42 years clearly.

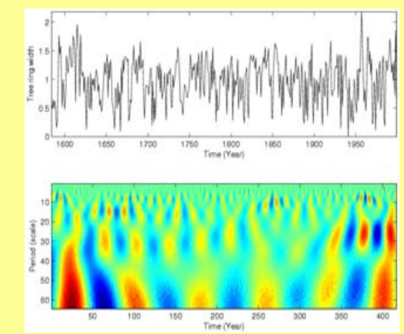

Figure 3, the plot of time series of the tree ring data from Joshimath (top) and the contour plot of the modulus of the wavelet coefficients as a function of time and scale. The scalogram clearly reveals multiple periodic variations at different scales (bottom).

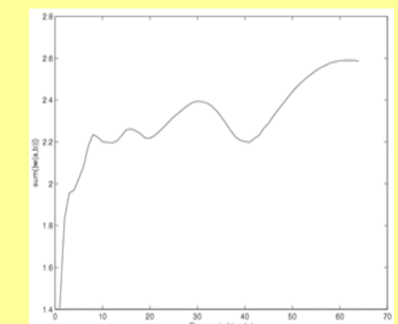

Figure 4, the plot of log of wavelet power summed over all time at different scales. One clearly observes the variations at 11, 22 and 42 years clearly.

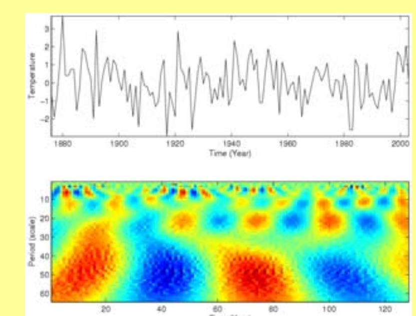

Figure 5: (top) the plot of time series of the pre-monsoon (March-April-May) temperature relative to 1951-1980 mean (1876 -2003) and its scalogram using Morlet wavelet (bottom).

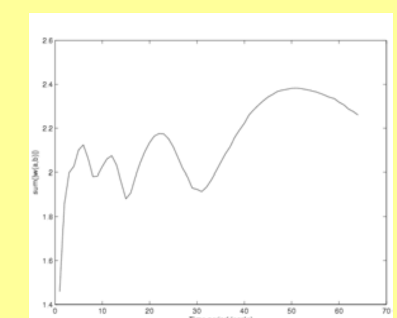

Figure 6: The semi-log plot of the wavelet power versus scale for the temperature data. An anti-correlation effects clearly showing an anti-correlation effects with the tree ring variations of figures 2 and 4.

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