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TECHNICAL NOTE

Spectral analysis on mountain pine tree-ring chronologies

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Abstract

The present study applies classic spectral analysis techniques to investigate cyclic patterns in four tree-ring chronologies of *Pinus montana* Miller from the Central Italian Alps (Valle del Gallo). Three of the chronologies were derived from mountain pine populations located in relatively undisturbed areas of the valley bottom and valley slopes, and one from a population located in an area of the valley bottom occasionally affected by sheetfloods. Each chronology consists of raw, standard, and residual data. We estimated power spectra by applying the Blackman–Tukey Method, the Maximum Entropy Method, the Multitaper Method, and the Lomb–Scargle Fourier transform, and tested the results against appropriate red noise models. The power spectra of the standard chronologies from undisturbed areas yielded statistically significant and reproducible interdecadal-scale cyclicities with main peaks closely spaced around a mean value of ~0.05 cycle/year, in association with statistically non-significant albeit reproducible peaks at higher frequencies. The chronology of trees affected by sheetfloods yielded no statistically significant cyclicities, probably because sheetfloods altered tree growth. Raw chronologies, instead, yielded power spectra dominated by the growth trend, while residual chronologies yielded flat power spectra. Our analysis suggests that tree growth, if not disturbed by external geomorphological factors, was controlled by environmental and/or climatic conditions that oscillated in the last ~150 years on interdecadal (~20 years) to decadal scales.

Keywords: Mountain pine; Spectral analysis; Sheetfloods; Central Italian Alps

Introduction

Tree-ring width time series are natural archives of past regional climatic conditions, which commonly oscillate with interdecadal to decadal periodicities. Although, the existence of a relationship between climate and tree rings is well established, the origin of the observed periodicities remains controversial (Fritts, 1976). Several hypotheses have been put forward in the literature that relate these periodicities to, for example, solar activity (Douglass, 1928; Vercelli, 1949; Bitvinskas, 1990; Cecchini et al., 1996), ocean–atmosphere dynamics (Linderholm, 2001; D'Arrigo et al., 2003; Gray et al., 2004), or an interplay of both mechanisms (Rigozo et al., 2005).

In many areas of the physical and natural sciences, spectral analysis is commonly used to detect periodic or quasi-periodic components of time series, as well as to

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compare different time series and investigate how they differ or relate (Percival and Walden, 1993).

Both periodic and quasi-periodic natural processes can be characterized by estimating the power spectrum of a time series – a measure of the relative amplitudes and periods of the different frequencies that form the signal. For example, a random process like white noise (a random noise signal that has an equal amount of energy at all frequencies) has a power spectrum homogeneously distributed across all frequencies, whereas a periodic process like radioactive decay allocates all power to single spectral line(s). Power peaks that rise from a continuum of background red noise (a noise signal with energy monotonically decreasing as the frequency increases) realistically characterize deterministic natural processes.

In the field of climate studies, spectral analysis is one of the methods used to reconstruct past climate variability (Schulz et al., 2000; Ghil, 2002; Ghil et al., 2002; Wunsch, 2003).

In this paper, we investigate to which extent classic spectral analysis methods are efficient in revealing the cyclic signature of tree-ring data with the aim, on a longer-term scientific commitment, to contribute to the development of climatic models capable to explain any such potentially present variability. Our study is focused on tree-ring chronologies of mountain pine from the Central Italian Alps and on climatic time series.

The study area

The study area is located in Valle del Gallo (Lombardy, northern Italy) at altitudes between 1900 and 2200 m a.s.l (Fig. 1). A mountain pine forest (*Pinus montana* Miller) dominates the vegetation of the valley. In this high mountain environment, instability processes are very common, and consist especially of debris flows that constructed several fans now dominating the landscape of the valley bottom (Santilli et al., 2002). One of these debris flow fans is also affected by sheetfloods that, descending from a small tributary valley, deposited silt material at the stems base, without however inducing any evident mechanical damage (Pelfini et al., 2005a; Santilli et al., 2002). In any case, these processes frequently altered tree growth, and only in some undisturbed areas of the valley slopes and valley bottom trees growth is undisturbed.

In the last years, some reference chronologies of mountain pine were built in Valle del Gallo for dendrogeomorphological dating of debris flows (Pelfini and Santilli, 2003; Santilli and Pelfini, 2002, 2005), as well as to study stream erosion processes (Pelfini et al., 2005b) and to perform dendroclimatic analysis (Pelfini et al., accepted).

Materials and methods

Dendrochronological data

The four tree-ring chronologies of mountain pine considered in this study come from four different locations (Fig. 1): trees located on undisturbed areas of the valley bottom (chronology c200), on undisturbed areas of the two opposite valley slopes (chronology c300 on the western slope, and chronology c400 on the eastern slope), and trees located in an area of the valley bottom occasionally affected by sheetfloods (chronology c500).

For each population, we sampled 30 dominant trees showing regular growth and crown, taking two or three cores from each stem. Samples were prepared for measurement according to standard methods (Schweingruber, 1988). The growth curves of all samples were constructed by measuring the ring width with accuracy of 0.01 mm using the software TSAP (Rinn, 1996) and by means of image analysis using the software WINDENDRO. We checked date accuracy and measurement quality of each series both statistically and visually by using the software COFECHA (Holmes, 1983; Grissino-Mayer, 2001) and TSAP-Win (Sander, 2004), respectively. For each population, we selected the growth series showing a good correlation ($r > 0.5$) with their mean chronology (Hofgaard et al., 1999). In order to remove long-term growth trends, like the age trend and non-climatic trends related to stand dynamics (Fritts, 1976; Schweingruber, 1988), all selected series were standardized by using a cubic smoothing spline function with a 50% cut-off at 60-year wavelength using the software ARSTAN (Cook and Holmes, 1986; Holmes, 1994). By applying a biweight robust mean to the time series, the program output supplied both standard and residual chronologies, the latter derived by using an autoregressive (AR) model (Cook and Briffa, 1990) that removes the autocorrelation, resulting in a series of independent observations. In this study, we used raw-data, standard, and residual chronologies. The standard tree ring chronologies are shown in Fig. 2.

Climatic data

Some meteorological stations exist close to the study area. Temperature and precipitation data from Cancano, Bormio, and Livigno stations were used in a previous study on the influence of climate on mountain pine growth (Pelfini et al., accepted). However, the shortness of these data time series, in particular temperature, hampered the applicability of spectral analysis methods. For this reason, we utilized annual and monthly average temperature and precipitation values collected in the city of Milan (about 150 km to the