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Decadal and centennial cycles revealed in two climate isotopic records

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Abstract. We measured the $\delta^{13}C$ profile of *Globigerinoides Ruber* in a shallow water Ionian sea core dated with high precision by means of radiometric and tephroanalysis methods. The time series, covering the period 200-1979 AD with a resolution of 3.87 years, is analyzed using the Wavelet Transform (WT). The same analysis is performed also on another climatic record, the tree-rings $\delta^{13}C$ of a Japanese cedar, spanning a similar time interval (125-1952 AD). The Wavelet Spectra (WS) of the two series and the Cross Wavelet Spectrum (CWS) between them allow highlighting the common spectral content on different time scales and investigating a possible link between climate and solar variations.

Key words. Solar-terrestrial relationships – Isotopic measurements – Marine sediments

1. Introduction

Sediments with high sedimentation rate, allowing high resolution studies, offer the opportunity to investigate the climate variability over the last millennia. A fundamental requirement is the accurate dating of the cores. For many years we have been studying sediment cores taken from the Gallipoli Terrace (Gulf of Taranto, Ionian Sea) because of the very particular characteristics of this area. In fact, the presence of clear volcanic markers along the cores allowed us to determine the sedimentation rate with high accuracy, better than 1% (Cini Castagnoli et al. (1990), Cini Castagnoli et al. (1992)). The high resolution of the measured series (3.87 y, corresponding to a 2.5 mm sampling interval) allows studying also interdecadal time scales of climate variability.

In this paper we present the Wavelet Transform (WT) analysis of the isotopic $\delta^{13}C$ record, measured in *Globigerinoides Ruber* selected from the GT90/3 core. The carbon-isotope fractionation in the skeletons of foraminifera dwelling at the sea-surface and subsequently deposited in shallow water sediments depends on the photosynthetic activity of the symbiontic algae living on the shells, strictly related to the illumination of the sea surface. The same WT analysis is also performed on another climatic record, the $\delta^{13}C$ in the tree-rings of a Japanese cedar, which is related to the environmental temperature (Kitagawa and Matsumoto 1995).

The aim of the present work is to compare the spectral content of the two series and to

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reveal possible connections between these climate records and the solar activity.

2. Experimental procedures

We sampled the GT90/3 core at 2.5 *mm* in a continuous sequence. The carbon isotope compositions were measured accordingly to the method of McCrea (1959). Samples of about 5 g of sediment were soaked in 5% calgon solution over night, then treated in 10% H_2O_2 to remove any residual organic material and subsequently washed with distilled water jet through a sieve (150 μm). The fraction > 150 μm was kept and oven-dried at $50^0 C$. *G. Ruber* were picked up under microscope. For each sample, 20-30 specimens of *G. Ruber* were selected for $\delta^{13}C$ and $\delta^{18}O$ determination. The stable isotope measurements were performed using a VG-PRISM mass spectrometer fitted with an automated ISOCARB preparation device. Analytical precision based on internal standards was better than 0.1 per mil. Calibration of the mass spectrometer to VPDB scale was done using NBS19 and NBS18 carbonate standards.

The experimental procedure used for $\delta^{13}C$ determination in the Japanese tree are reported in Kitagawa and Matsumoto (1995).

3. Analysis and results

The $\delta^{13}C$ profile (mean value $x_m = 0.72$ per mil; $s = 0.23$ per mil) consists of a continuous record of 460 points from 200 to 1979 AD, with time resolution $\Delta t = 3.87$ *y*. In Fig.1 we show the raw data points as a function of time (light line). The tree-$\delta^{13}C$ profile (heavy line in Fig.1; $x_m = -22,04$ per mil; $s = 0.36$ per mil) spans the interval 125-1952 AD. In order to compare the tree-rings series with the forams one, we linearly interpolated the tree-rings data to the sampling time of 3.87 *y*.

The two trends in Fig.1 are the Inverse WT-reconstructed series based on scales exceeding ~600 *y*. We decided to reconstruct the trends using these scales on the basis of the Global Wavelet Spectra (GWS) of the two series (see

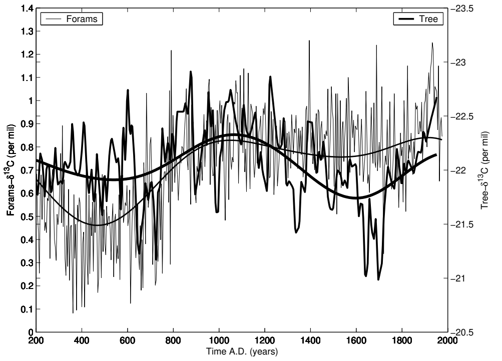

Fig. 1. Forams-$\delta^{13}C$ (light line) and tree-$\delta^{13}C$ (heavy line) time series and corresponding long-term trends from WT analysis. Tree-$\delta^{13}C$ is plotted on a reversed scale, according to its relation with temperature (see Kitagawa and Matsumoto (1995)).

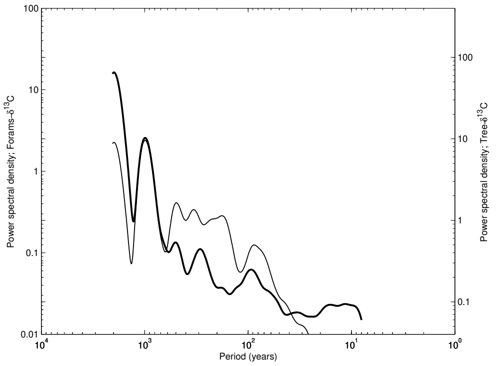

Fig. 2. Global Wavelet Spectra of forams-$\delta^{13}C$ (heavy line) and tree-$\delta^{13}C$ (light line).

Fig.2). In fact, for scales >600 *y* the two spectra are very similar.

This similarity suggests a global climate variability on these long time scales.

Between the factors influencing tree- and forams-$\delta^{13}C$, there are light intensity, temperature, precipitation, etc. For the forams-$\delta^{13}C$, changes in sea-surface illumination seem to be the most effective direct forcing. The dominant one for the Japanese cedar has been recognized to be the temperature, with an inverse correlation (Kitagawa and Matsumoto 1995). According to this, from Fig.1 we recognize high illumination and temperature during the Medieval Warm Period (MWP), while we rec-

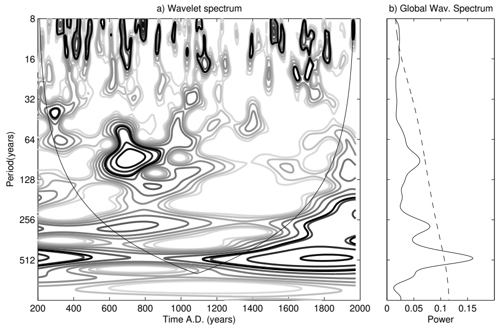

Fig. 3. Wavelet Spectrum and Global Wavelet Spectrum of detrended forams-$\delta^{13}C$.

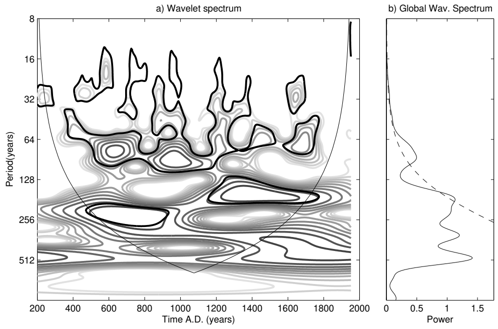

Fig. 4. Wavelet Spectrum and Global Wavelet Spectrum of detrended tree-$\delta^{13}C$.

ognize low illumination and temperature during the Little Ice Age (LIA). Also the modern temperature increase, starting from about 1700 AD, is well indicated by both time series.

Before performing the WT analysis on both series, we detrended them using the trends shown in Fig.1.

The WT analysis is performed according to the guidelines given in Torrence and Compo (1998), by computing the WT on a dense set of scales and at every time step. As a mother wavelet, a complex Morlet wavelet with parameter $\omega_0 = 6$ is chosen (for which scale and Fourier period are nearly coincident). In Fig.3 and Fig.4 we show the Wavelet Spectra (WS), or *scalograms*, and the GWS for the forams-$\delta^{13}C$ record and for the tree-$\delta^{13}C$ record, respectively. Each GWS is derived from the WS by averaging the scalogram values over time. The black cup-shaped line in these figures represents the cone of influence, outside which scalogram values are affected by zero padding at the edge of the series, which is performed before computing the WT convolution in the frequency domain via FFT, in order to avoid aliasing in the time domain. In the scalograms, the areas of the time-period plane surrounded by a heavy black line correspond to power which is significant at 90% confidence level, according to the statistical test described in Torrence and Compo (1998). The dashed line in the GWS plots gives the corresponding significance level for the GWS, computed according to Torrence and Compo (1998).

In Fig.3 (forams-$\delta^{13}C$) we notice high power around the 11 y period along the entire duration of the series ($\sim$1800 y). This is in agreement with the reconstruction obtained by Singular Spectrum Analysis (SSA) in Cini Castagnoli et al. (2002), in which we showed also that this oscillation is in phase with the sunspot number series in the last 250 y, what reveals a solar imprint on the 11 y scale. We moreover notice high power at $\sim$100 y, with maximum values in the interval 500-1000 A.D., confirming previous results obtained by SSA (see Fig. 2 in Cini Castagnoli et al. (2005)). High power is present also at $\sim$300 and $\sim$500 y, expecially at the beginning of the record and after $\sim$1200 A.D.

For the tree-$\delta^{13}C$ (Fig.4) high power is found at $\sim$100, $\sim$200, $\sim$300 and $\sim$500 y. The centennial component is particularly strong between 500 and 1000 A.D., as for forams-$\delta^{13}C$.

It must be noticed that although some peaks in the GWS do not attain the significance level, the corresponding power is nevertheless significant locally in the scalograms.

The Cross Wavelet Spectrum (CWS) between the two series and its time-averaged counterpart, the Global Cross Wavelet Spectrum (GCWS), shown in Fig.5, put into evidence the spectral components shared by the two series: the centennial variability ($\sim$90 y), the 300 and 500 y oscillations. This suggests a global character of these climatic components too.

In order to highlight a possible link between the two records and the solar activity,

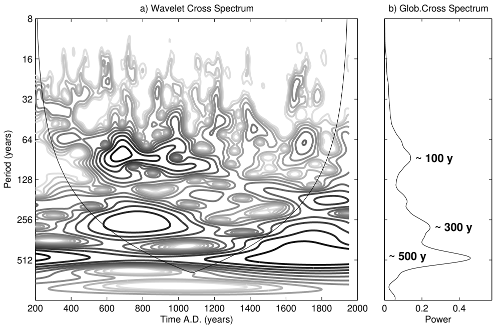

Fig. 5. Cross Wavelet Spectrum and Global Cross Wavelet Spectrum between detrended forams- and tree-$\delta^{13}C$.

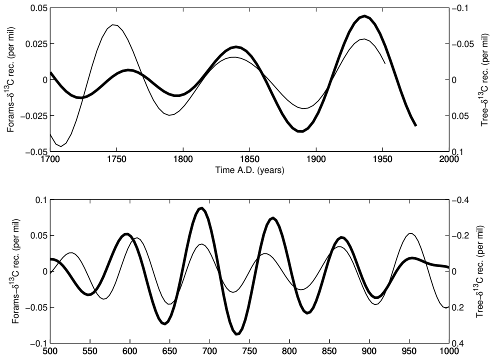

Fig. 6. Forams-$\delta^{13}C$ (heavy line) and tree-$\delta^{13}C$ (light line) centennial components, a) over the last 300 y, b) over the interval of maximum wavelet power (500-1000 A.D.).

we reconstruct the 100-*y* oscillations revealed in the two records. Here the WT is used as a filter: a scale interval is chosen, spanning ±15% around the scale of each maximum in the GWS, and the corresponding cycles are reconstructed by Inverse WT (Torrence and Compo 1998) on the basis of the scales included in that interval only. These centennial components are shown in Fig.6.

The forams-$\delta^{13}C$ and the tree-$\delta^{13}C$ reconstructed oscillations in the last 300 y (Fig.6.a) are in phase with one another and pick out the well-known shape of the Gleissberg solar cycle and in particular the Maunder Minimum (~1700 A.D.), the Spörer Minimum (~1800 A.D.) and the Modern Minimum (~1900 A.D.). The presence of similar 100-*y* cycles in records measured in two different archives from geographical areas very far apart supports the hypothesis that the 100-*y* oscillation revealed in these records is global and connected to the solar activity.

We finally notice that the two reconstructed oscillations are in phase with one another also in the interval of maximum spectral power, i.e. ~500-1000 A.D. (Fig.6.b; see also Fig.s 3-5).

4. Conclusions

Two 1800-years long $\delta^{13}C$ time series, one recording the environmental conditions of the sea surface and the other one recording those of the atmosphere, have revealed a common centennial oscillatory component of climate variability, together with ~200, ~300 and ~500 *y* waves and a long-term trend which describes the major climate features of the last two millennia, the MWP and the LIA. Moreover, the agreement between the 100-*y* components and the Gleissberg cycle suggests a solar forcing on the Earth's climate at centennial scale.

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