ANALYSES OF ENVIRONMENTAL LONG TIME SERIES BY MULTISCALE WAVELET TRANSFORM

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ABSTRACT
Two ways of performing spectral analysis of time series are Fourier Transform (FT) and Wavelet Transform (WT). Multiscale Wavelet Transform in particular seems to be one of the best ways for spectral analysis of atmospheric time series, such meteorological data for instance. The analyzing function is a pseudoperiodic one in time and frequency localized, which shifts along the given time series. As a local indication, one can get a frequency contribution at a given date, with respect to Heisenberg uncertainty principle. The Milan time-series of temperature, pressure and rainfall (monthly values) were analyzed for the period 1858-1990. As far as rainfall is concerned, a periodicity of about 20 years stands out quite clearly either by using FT or WT. This is a common feature of many environmental time series. An obvious period between 8 and 16 months is found for temperature and pressure data.
A second application is presented to show the filtering power of wavelet analysis. from the coefficients it is possible to select a frequency range. Then a reconstruction of the time-series is possible by considering wavelets included in this range only, thus eliminating all phenomena with characteristic times outside the range. An example is provided consisting in a time series of aluminium concentrations in Corsican air samples. The series is affected by sporadic Saharan dust events which increase the concentration by a factor of hundred for short time periods. By means of a wavelet filtering, the pics may be removed or just pointed out by selecting appropriate frequency range.

KEY WORDS: Atmospheric time series, wavelets transform, spectral analyses, spectral filtration.

1 Introduction

The atmosphere is a physical system which is directed by exchange of energy with the earth (crust and oceans), with the space (heat input from the sun, heat release to the free space) and also between different parts of himself. If the astronomic forcing produce regular and coherent periodic variations, both internal and earth exchange give not coherent pseudo-periodic variations. As a first approach, it looks evident that a FT on time series related to atmospheric data will only point out pure astronomic forcing which is time coherent, and remove the other phenomena which are not time coherent. By opposite, WT produce a localized scan of frequencies and then can extract short and sporadic contribution of a phenomena with a given periodicity. Considering the form of the data, we use a spline cubic analyzing function ψ (figure 1) with a pseudoperiod of 2^j unit (month for Milanese meteorological data). This wavelet is then moved along the signal with steps of 2^j unit. The maximum extend allowed for the wavelet is obviously the duration of the time series.

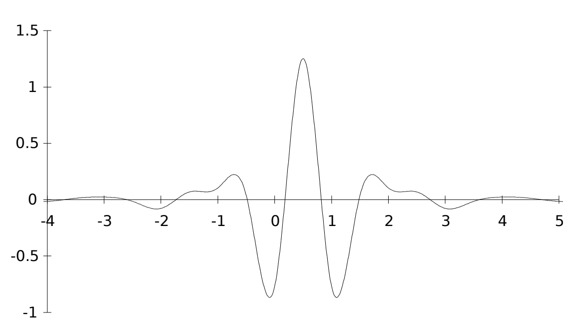


Figure 1: analyzing function y. Y an X axis are dimensionless.

2 Fourier Transform

We have worked on rainfall, pressure and temperature data from the meteorological station of Milan on monthly averages from 1858 to

1990, and on atmospheric aerosol aluminium concentration in Corsica, based on daily sampling from 14/02/1985 to 25/03/88 (Remoudaki, 1990). FT gives significant results only for meteorological Milanese data, showing an annual periodicity for pressure and temperature (figures 2 and 3) and clearly a 22 years periodicity for rainfall (figure 4). This last periodicity is a common feature of many geophysical and meteorological time series (sunspot numbers, pressure differences Madera-Iceland and Siberia-Iceland, westerly winds over Britain, southeasterly winds over North sea, and so on...).

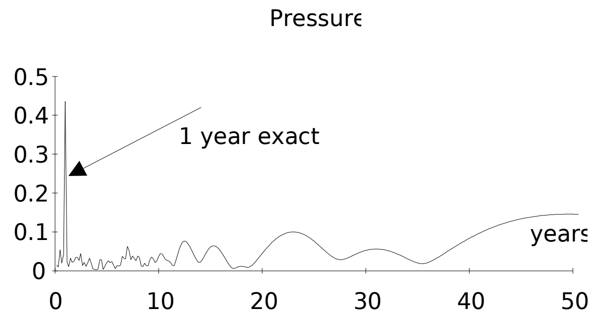


Figure 2: FT of pressure measurements at Milan.

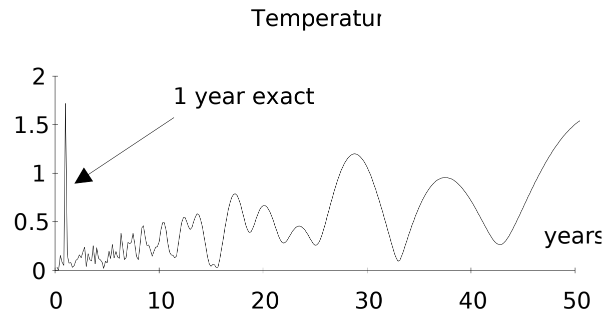


Figure 3: FT of temperature measurements at Milan

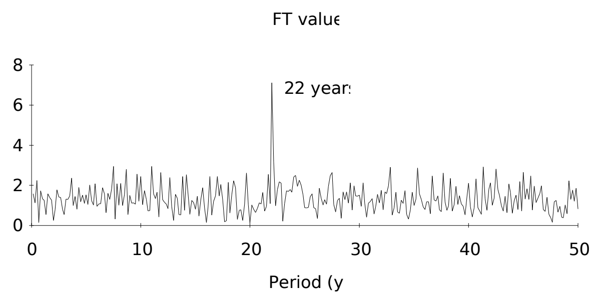


Figure 4: FT of rainfall measurements at Milan.

3 wavelet transform

3.1 Method

The time series investigated have a constant sampling rate (SR), 1 month for Milanese data and 1 day for Corsican aerosol measurements. The dimensionless X axis of the wavelet is multiplied by 2^j.SR and moved along the time series by 2^j.SR steps, by adding k.2^j.SR, where j and k are integers greater then zero. That produces as many $C_{j,k}$ wavelet coefficients than data measurements:

$$C_{j,k} = 2^{-j}$$

where t1 and t2 are the beginning and the end of the sampling period.

The time series recovered by the inverse operation is identical to the original shifted of the mean value of the time series.

$$f(t)_{recovered} =$$

If this mean value is large in regard of the variation of the signal (typically in the case of pressure measurements), edge effects will appear at the beginning and the end of the time series. For this reason, we have subtracted at each time series its mean value.

As an example of the reversibility of the wavelet transform, we show the phosphorus daily aerosol data in Corsica (figure 5).

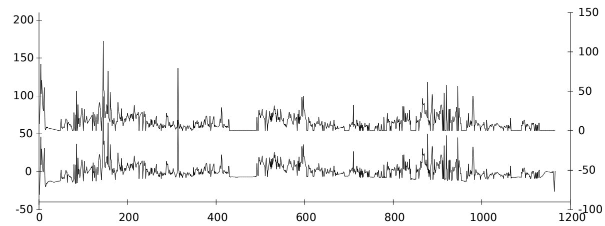


Figure 5: Original and reconstructed data of phosphorous atmospheric concentrations in Corsica (ng.m^{-3}). Dot line is original data and solid line reconstructed.

3.2 Rainfall at Milan

The results of the FT at Milan on rainfall seems to indicates that there are no annual variation. This curious aspect may be explained by changes of the rainy season along the year. Wavelet transform can shows that such a 1 year periodicity does exist because it looks just around the center of the wavelet and then can take acount of a long term variation of the phase of the maximum (figure 6b). By opposite, the long term 20 years rainfall intensity variation if as well obvious in figure 6a than in FT.

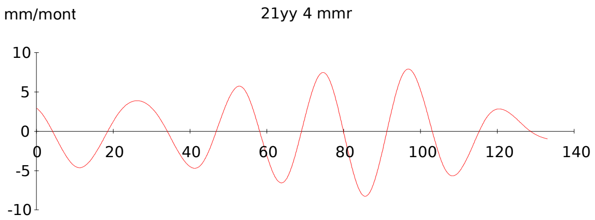


Figure 6a: Partial rebuilt of the rainfall variations at Milan with the 20 years period wavelett.

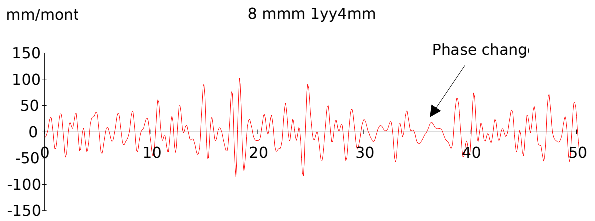


Figure 6b: Sample of the partial rebuilt of the rainfall variations at Milan with the 8 month and 16 months period wavelets.

3.3 Atmospheric release time.

As developped in previous papers, atmospheric aluminium concentration on Corsica is dominated by large Saharan dust inputs, which appears over a background which has a seasonal behaviour with a maximum in summer and a minimum in winter. We have proceed on wavelet transform and reconstruction on these aerosol daily data, and we can show very well the seasonal variation by selecting periods around 1 year (figure 7).

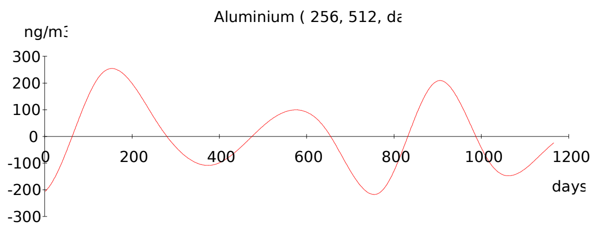
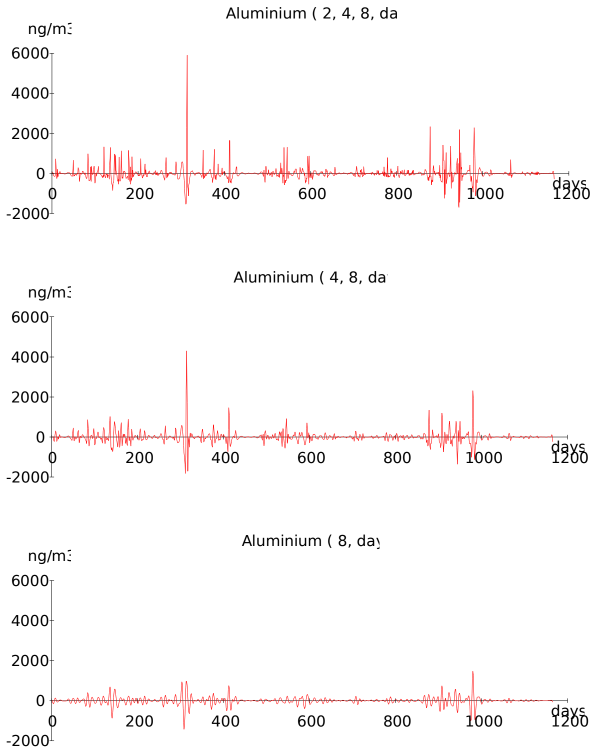


Figure 7: Evidence of seasonal variations of aluminium aerosol concentration in Corsica.

Moreover, if we proceed to partial reconstruction with first 2, 4, and 8 days periods (figure 8a) and then by removing 2 days (figure 8b) and 4 days (figure 8c) periods, the Saharan dust events disapeard between 4 and 8 days. It seems that we have pointed out a release time of 4 to 8 day of such atmospheric perturbation.



Figures 8a, b, c: partial reconstruction of aluminium daily variation in Corsica.