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On the construction of a time base and the elimination of averaging errors in proxy records

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Proxies are sources of climate information which are stored in natural archives (e.g. ice-cores, sediment layers on ocean floors and animals with calcareous marine skeletons). Measuring these proxies produces very short records and mostly involves sampling solid substrates, which is subject to the following two problems:

Problem 1: Natural archives are equidistantly sampled at a distance grid along their accretion axis. Starting from these distance series, a time series needs to be constructed, as comparison of different data records is only meaningful on a time grid. The time series will be non-equidistant, as the accretion rate is non-constant.

Problem 2: A typical example of sampling solid substrates is drilling. Because of the dimensions of the drill, the holes drilled will not be infinitesimally small. Consequently, samples are not taken at a point in distance, but rather over a volume in distance. This holds for most sampling methods in solid substrates. As a consequence, when the continuous proxy signal is sampled, it will be averaged over the volume of the sample, resulting in an underestimation of the amplitude. Whether this averaging effect is significant, depends on the volume of the sample and the variations of interest of the proxy signal. Starting from the measured signal, the continuous signal needs to be reconstructed in order eliminate these averaging errors.

The aim is to provide an efficient identification algorithm to identify the non-linearities in the distance-time relationship, called time base distortions, and to correct for the averaging effects.

Because this is a parametric method, an assumption about the proxy signal needs to be made: the proxy record on a time base is assumed to be harmonic, this is an obvious assumption because natural archives often exhibit a seasonal cycle. In a first approach the averaging effects are assumed to be in one direction only, i.e. the direction of the axis on which the measurements were performed.

The measured averaged proxy signal is modeled by following signal model:

$$\overline{y}(n,\theta) = \frac{\Delta}{\delta}\int_{n-\frac{1}{2}\frac{\Delta}{\delta}}^{n+\frac{1}{2}\frac{\Delta}{\delta}} y(m,\theta)dm$$

where m is the position, $x(m) = \Delta m$; θ are the unknown parameters and $y(m,\theta)$ is the proxy signal we want to identify (the proxy signal as found in the natural archive), which we model as:

$$y(m,\theta) = A_0 + \sum\nolimits_{k=1}^{H} \left[A_k \sin(k\omega t(m)) + A_{k+H}\cos(k\omega t(m))\right]$$

With $t(m)$:

$$t(m) = mT_S + g(m)T_S$$

Here $T_S = 1/f_S$ is the sampling period, f_S the sampling frequency, and $g(m)$ the unknown time base distortion (TBD). In this work a splines approximation of the TBD is chosen:

$$g(m) = \sum\nolimits_{l=1}^{b} b_l\phi_l(m)$$

where, b is a vector of unknown time base distortion parameters, and ϕ is a set of splines.

The estimates of the unknown parameters were obtained with a nonlinear least squares algorithm.

The vessel density measured in the mangrove tree *R mucronata* was used to illustrate the method. The vessel density is a proxy for the rain fall in tropical regions. The proxy data on the newly constructed time base showed a yearly periodicity, this is what we expected and the correction for the averaging effect increased the amplitude by 11.18%.