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ANALYSIS OF SINUSOIDAL CODED MODEL: ANALYSIS OF CODE

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Abstract

This article presents a procedure for transformation of measured data and application of the proposed sinusoidal coded model to fit better seasonal stable isotope variations in precipitation and stream water. The utility of proposed model was validated by the comparison between measured data and numerical evaluations for oxygen isotopic content in precipitation over the period 2004-2008. The proposed sinusoidal coded model offers an accurate fit with low standard deviation per month only with one fitting parameter.

Introduction

Oxygen isotope composition (^{18}O) is an ideal tracer for characterizing hydrological processes because it can be reliably measured. Surface waters (precipitation and stream water) exhibit $\delta^{18}O$ seasonal variations which are usually generalized by an expression of the sine function equation (1):

$$\delta^{18}O = mean(\delta^{18}O) + A\sin[(2\pi t / b) + c] \qquad (1)$$

where $mean(\delta^{18}O)$ is the annual mean $\delta^{18}O$ expressed in ‰, A is the seasonal amplitude of $\delta^{18}O$, b is the period of the seasonal cycle (i.e. 365 days), t (days) is time, and c (radians) is the phase lag [1]. A typical sinusoidal model neither provides a satisfactory fit to the data of isotope content of precipitation nor meets Fisher's condition for the existence of periodical processes. Although, this model treats one year in the same way as the following, statistical noise is too large that the variations caused by non-periodic natural processes would be analyzed. As long as the obtained correlation coefficients for the assumed p = 95% are low ($r^2 <$ 0.76), which is common in hydrologic investigations, this model is inadequate. It is important to note that most authors do not generally use statistical test to confirm the existence of periodicity (equation 2).

$$q_{\mathrm{var}} = \frac{A_1^2}{\sum_{i=2}^{n} A_i^2} \geq 0.638 \quad \textit{for } 95\% \textit{ significance level} \qquad (2)$$

where A_1 is the amplitude of basic frequency with the period of 12 months, and A_i stands for i-th harmonic in Fast Fourier Technique (FFT) series [2] for the total number of measurements, *n*. The q_{var} is a variance ratio, which in our cases exhibit rather low values of around 0.219. Therefore, the coded sinusoid method has been proposed [3]. This method represents a new technique for a better fitting of periodic data. It is based on two assumptions. The first one is in advance known a period of time (t), which is usually one year in the case of hydrological data. It is implicit in all cyclical hydrologic models, and until recently it was the default, and neither examined nor criticized. Basically, it is assumption that all hydrologic processes on Earth are coordinated with its revolution. The second assumption concerns the shape of the observed periodic function. The basic idea is that parts of the original sinusoids (12 parts) are shifted along the time axis, of unequal value. These shifted values we call codes, by which the sine-coded model was named. The objective of this paper is to present a procedure for transformation of measured data and application of the proposed sinusoidal coded model.

Results and discussion

Our observed data are measured monthly values for period of N years (2004-2008). The application of sinusoidal coded method requires performing mathematical transformations to the measured data set (n). The first step is a subtraction of the trend line (list square line, LSQL) from all original data along the time axis. Then, monthly mean values (or weighed averages) are calculated by summing all transformed data for N years. The result is a set of 12 data. Next, the most important step is coding procedure shown in Table 1. In order to achieve the sine waveshape, calculated maximum and minimum monthly mean values are set at the position of maximum and minimum of a **s**inus function, respectively. A shift lag code should be noted for each month. Lagged data (CodD, Table 1) should be subjected to Fisher's condition for sinusoidal periodicity (2). If they pass, the procedure should be continued.

Table 1. The arrangement for coding procedure

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Data	-1	-0.8	-0.81	-0.5	-0.5	0	0.1	0.5	0.51	0.8	0.9	1
xi	0π/6	1π/6	2π/6	3π/6	4π/6	5π/6	6π/6	7π/6	8π/6	9π/6	10π/6	11π/6
sin x_i	0	1/2	0.87	1	0.87	1/2	0	-0.5	-0.87	-1	-0.87	-0.5
Cod**D**	0	0.5	0.8	1	0.9	0.51	0.1	-0.5	-0.8	-1	-0.81	-0.5
Cod	-5	-6	-7	-8	-6	-3	0	+4	+7	+9	+8	+7

Data - transformed monthly mean values, x_i - x -axis , Cod**D** – coded data (Y^{cod})**, Cod** - noted shift code

The amplitude of coded sinusoids is computed by the formula (3) which is obtained with minimization of simple non linear sine function with one parameter, A.

$$A^{cod} = \frac{1}{6}\sum_{i=0}^{11} Y_i^{cod} \cdot \sin x_i \qquad (3)$$

where A^{cod} is coded amplitude and x_i is the time expressed in 2π/12. Coded sinusoid is calculated using equation 4 in which Y_i^{cf} stands for fitted coded data.

$$Y_i^{cf} = A^{cod} \cdot \sin x_i \quad (4)$$

The following step is a decoding of generated sinus function. Fitted values are displaced to their coded positions according to their noticed order. Then, twelve obtained data should be repeated N-1 times. One set of data is produced for each year giving a coded fit. The final step is the addition of the trend line to the data obtained by decoding algorithm. The obtained periodical curve fits well measured data with the low standard deviation per month (σ_k) as the measure for a good fit (Fig. 1). Calculated efficiency index [4] for a simple sinusoidal and coded model is about 46% and 87%, respectively.

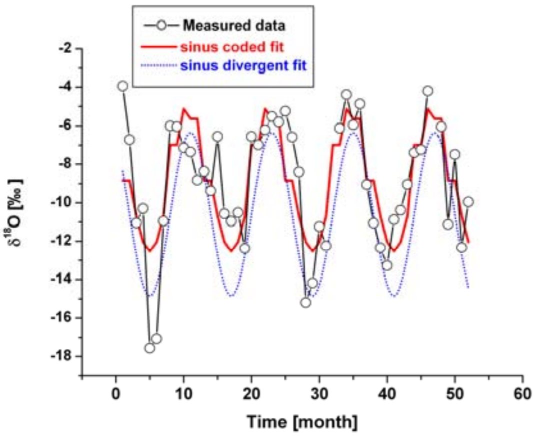

Fig.1. Measured and calculated oxygen-18 content of precipitation over the Velika Morava catchment using sinusoidal coded model for the period 2004-2008

Conclusion

In conclusion, the proposed sinusoidal coded model is established on basic hydrological assumption that neither the annual average nor the magnitude of isotopic variations in meteoric precipitation remains constant year to year. The amplitude of the isotopic variations of the system of interest is the only one fitting parameter, which can provide an accurate fit with low standard deviation per month.

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