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SENSING THE NONLINEAR INTERACTION BETWEEN GLOBAL TELECONNECTION PATTERNS: MICROS TECHNOLOGY "GEOMATH"

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Abstract

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It is carried out the micros computer data processing technology for sensing the chaotic behavior in the global climate system of the Earth and the nonlinear interaction between teleconnection patterns, based on the using technical devices observation data and the joint wavelet analysis PC programs complex "GeoMath".

Key words: micros computer technology "GeoMath", wavelet analysis , sensing the nonlinear interaction between teleconnection patterns

Резюме

ДЕТЕКТУВАННЯ НЕЛІНІЙНОЇ ВЗАЄМОДІЇ ТЕЛЕКОННЕКЦІЙНИХ ПАТТЕРНІВ: МІКРОС ТЕХНОЛОГІЯ "GEOMATH"

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Розроблено мікрос технологію обробки данних і детектування нелінійної взаємодії телеконнекційних паттернів в земній атмосфері, яка базується на використанні данних супутникових тощо спостережень та ПК комплексу програм вейвлет аналізу "GeoMath".

Ключові слова: мікрос технологія "GeoMath", вейвлет аналіз, детектування нелінійної взаємодії телеконнекційних паттернів

Резюме

ДЕТЕКТИРОВАНИЕ НЕЛИНЕЙНОГО ВЗАИМОДЕЙСТВИЯ ТЕЛЕКОННЕКЦИОННЫХ ПАТТЕРНОВ: МИКРОС ТЕХНОЛОГИЯ "GEOMATH"

А. В. Глушков, В. Н. Хохлов, Ю. Я. Бунякова, Г. П. Препелица, А. А. Свинаренко, Т. А. Цененко

Разработана микрос технология обработки данных и детектирования нелинейного взаимодействия телеконнекционных паттернов в земной атмосфере, базирующаяся на использовании данных спутниковых и др. наблюдений и ПК комплексе программ вэйвлет анализа "GeoMath".

Ключевые слова: микрос технология "GeoMath", вэйвлет анализ, детектирование нелинейного взаимодействия телеконнекционных паттернов

1. Introduction

Carrying out new, avanced sensors and mycrosystems technologies in the modern atmosphere and environmental physics is related to ine of the most important problems. Here we present an advanced micros data processing technology for for sensing the chaotic behavior in the global climate system of the Earth and the nonlinear interaction between some teleconnection patterns, based on the using technical devices observation data and the joint wavelet analysis PC programs complex "GeoMath" [1-3]. In our paper the processes of nonlinear interaction between teleconnection patterns are addressed. Evidence of chaotic behavior for the relationship between the Arctic Oscillation (AO), Southern Oscillation (SO), and Antarctic Oscillation is examined by using the cross-redundancy and Granger causality (c.f.[1,4-7]). The analysis is carried out for three epochs of twenty centuries with different trends of global temperature [8-14]. To study an influence of low frequency variations, the wavelet decomposition is applied. The results display many well-known features for feedbacks between climate changes and observed trends in the indices of teleconnection patterns.

The temporal variations of the global temperature (and some other meteorological values, e.g. precipitation) during last 150 years show the vibrations and intermittency of the climate and to some extent the variations of climate over longer periods. This pattern gives the impression of being chaotic and bring to mind the behaviour of the dynamic systems which (in the modern theory of chaos) evolve on complex-structured limit sets present in their phase spaces and have come to be known as "strange attractors". This concept was introduced by Lorenz (1963, 1970). In light of the above, the theory of climate variation ought to be the statistical dynamics of the climate system. The climate system must include other layers of the Earth, which interact with the atmosphere. First of all, this includes oceans and seas, and then the upper active layer of solid earth — mainly the land. At that, components of the climate system like the atmosphere and oceans exhibit some coherent variability. The main source of energy for the processes in the climate system of the Earth is incident solar flux. Its intensity at Earth's mean distance from the Sun, according to both terrestrial and extraterrestrial measurements, is equal to 1360 ± 20 W m^{-2}. However, the solar forcing of climate variations on decadal and centennial time scales is too small. Oh *et al.* (2003) showed that the solar irradiance variations due to the well-known 11-year Schwabe (sunspot) and the 80–90-year Gleissberg cycles amount to 1.5 W m^{-2} and 2.25 W m^{-2}, respectively. Thus, it is impossible to apply the solar forcing as the modulator of climate changes on the aforementioned time scales.

Modern numerical models utilize mainly two approaches allowing physical interpretation for the observed climate variations: the greenhouse forcing of the climate system and the response of the climatic system on tropical Pacific sea surface temperature (SST) anomalies [10-14]. The ability to represent the atmosphere–ocean interaction is also possessed other main teleconnection patterns such as the North Atlantic Oscillation (NAO) and the Pacific North American pattern (PNA), as well as the so-called annular modes — the AO and the Antarctic Oscillation (AAO).This remarkable feature of the teleconnection patterns allow to use the time series of their indices as an integrated indicator for the climate variations over extensive areas of the Earth. Thus, the forecast for the phase of particular oscillation on the decadal and centennial time scales allows to increase the reliability for the forecast of regional climate change. Another feature of the main teleconnection patterns consists in the interaction between particular oscillations. This interaction appears as the nonlinear one and seems, to some extent, the partially synchronized chaos (as it's found by Duane *et al.* for Northern and Southern Hemisphere blocks). For such a complex system, the only possibility for realistic modelling seems to be that only a few of various mechanisms become prevalent in process, so that system dynamics are simplified with corresponding reduction in the number of the effective degrees of freedom. Therefore, the notion of chaos theory, i.e. seemingly complex behaviour could be the result of simple determinism influenced by only a few nonlinear interdependent variables, and the related methods of nonlinear dynamics (e.g. nonlinear prediction) could contribute to an understanding of dynamics for the interaction between particular teleconnection patterns.

2. Data and methodology

2.1. Data

We use unsmoothed datasets for the indices AO, SO, and AAO, as well as for global temperature anomaly (T) from the base period 1961–90. All data were obtained via Internet (http://www.jisao.washington.edu/data_sets/aots/ao18992002, http://www.cru.uea .ac.uk/ ftpdata/soi.dat, http://www.jisao.washington.edu/data/aao/slp/aaoslppc19482002,http://www.cru.uea.ac.uk/ftpdata/ tavegl2v.dat, respectively). From the original datasets, we extract time series from 1910 till 2001 (except for the AAOI that starts from 1948). For further analysis, we divide time series into three epochs: 1910–47, 1948–77, and 1978–2001 (hereafter W1, C, and W2, respectively). Figure 1 shows the time series chosen for the analysis.

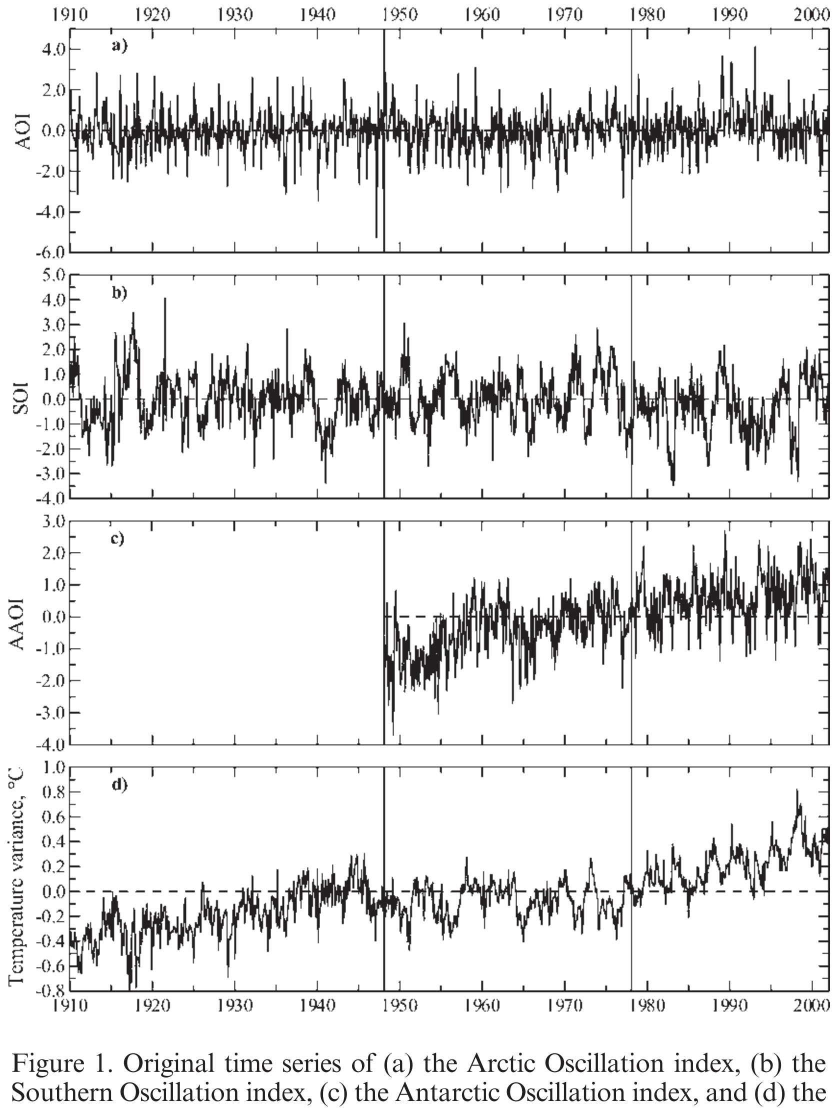

Figure 1. Original time series of (a) the Arctic Oscillation index, (b) the Southern Oscillation index, (c) the Antarctic Oscillation index, and (d) the global temperature anomaly during 1910-2001. The X-axis is calendar year

2.2. Mutual information and cross-redundancy

Consider two discrete variables X and Y with joint probability density functions (PDF) $f_{X,Y}(x,y)$, and marginal PDF $f_X(x)$ and $f_Y(y)$ respectively. The mutual information $I(X, Y)$ quantifies average amount of common information contained in the variables X and Y [6]:

$$I(X,Y)=\iint f_{X,Y}(x,y)\log\frac{f_{X,Y}(x,y)}{f_X(x)f_Y(y)}\mathrm{d}x\,\mathrm{d}y \quad (1)$$

When the discrete variables X and Y from continuous variables on a continuous probability space, then the mutual information depends on a partition chosen to discrete the space. The mutual information can be considered as a nonlinear analogue of the correlation between X and Y. The mutual information is symmetric, nonnegative and equal to zero if and only if X and Y are independent. A generalization of mutual information has been proposed by expressing it in terms of generalized correlation integrals $C_q(\varepsilon)$. In particular, it give:

$$\begin{aligned} I_q(X,Y;\varepsilon) &= \log C_q(X,Y;\varepsilon) - \\ &-\log C_q(X;\varepsilon) - \log C_q(Y;\varepsilon) \end{aligned} \quad (2)$$

This form enables convenient estimation by means of plug-in estimates of C_q. The choice $q = 2$, value which will be used throughout this paper, is particularly convenient since the estimation of the correlation integral for this case is straightforward. To estimate the correlation integrals, we use the algorithm of Grassberger-Procaccia [6], which uses reconstruction of the phase-space. For scale parameter we chose $\varepsilon = 0.5$. To examine the relation between two variables in more detail, we determine a mutual information of time series as a function of the delay (termed cross-redundancy).

2.3. Granger causality

By using the cross-redundancy, we only examine the dependence between two variables, but not obtain a behaviour of coupling. For example, if there is the nonlinear dependency between two variables, this might be because the first variable is driving the second, or the second is driving the first, or both (feedback). Such a causal relationship can be examined by testing for Granger causality. This is well-known concept used in econometrics is based on predictability. According to Granger (1969) (c.f.[1,6], the following sentence can be stated. Y is a Granger cause of X if past values of Y can improve predictions of future values of X, conditionally on past values X and Y, are distributed differently than future values of X only. In this case X conditionally (on past values of X) dependent on Y. This definition of causality is only operational and leaves open the possibility that causality is found between X and Y when they are in fact uncoupled. This can be the case if both X and Y are driven by a third variable (Diks and Mudelsee, 2000). The above definitions have assumed that only stationary series are involved. In the nonstationary case the existence of causality may alter over time. The definitions can clearly be generalized to be operative for a specified time. One could then talk of causality existing at this moment of time. The one completely unreal aspect of the above definitions is the use of series representing all available information. Let us to illustrate the above definition using model with two variables.Let X_t, Y_t be two stationary time series with zero means. The simple causal model is

$$\left.\begin{aligned} X_t &= \sum_{j=1}^{m} a_j X_{t-j} + \sum_{j=1}^{m} b_j Y_{t-j} + \nu_t, \\ Y_t &= \sum_{j=1}^{m} c_j X_{t-j} + \sum_{j=1}^{m} d_j Y_{t-j} + \eta_t, \end{aligned}\right\} \quad (3)$$

where ν_t, η_t are taken to be two uncorrelated white-noise series. In Eq. (3) m can equal infinity but in practice, of course, due to the finite length of available data, m is assumed finite and shorter than the given time series. The definition of causality given above implies that Y_t is causing X_t provided some b_j is not zero. Similarity X_t is causing Y_t if some c_j is not zero. If both of these events occur, there is said to be a feedback relationship between X_t and Y_t.

2.4. Non-decimated wavelet transform

Wavelets are fundamental building block functions, analogous to the trigonometric sine and cosine functions. Fourier transform extracts details from the signal frequency, but all information about the location of a particular frequency within the signal is lost. In comparison, the multi-resolution analysis makes wavelets particularly appealing for this study, because they are localized in time and the signals are examined using widely varying levels of focus. For detail about used version of the wavelet theory look references[1-5]. In this paper we consider periods with non-dyadic number of months. Therefore, whole periods are divided onto two sub-periods with dyadic length of months. Then the NWT is applied for these sub-periods and derived detail components are "glued" together to obtain the maximum possible length.

3. Cross-redundancy and Granger causality for unsmoothed time series

Figure 2 shows the cross-redundancy and Granger causality for unsmoothed, unfiltered time series of oscillations and global temperature anomaly. Before analyzing, let us note some particularities concerning the interpretation of results represented on the graphs. For the particular graph, the head notation reveals: (i) values for which results are presented; (ii) the lagged value; and (iii) the epoch under consideration. For example, "AOI-T (W1)" in Fig. 2(a) denotes that the cross-redundancy for the lagged AOI and T during the W1 epoch. Also, only positive values for the cross-redundancy indicate that there is the relationship between variables. In these graphs, the magnitudes for the Granger causality are denoted as triangles. If these values are located in the area of positive lags, then, e.g. for Fig. 2(a), the AOI is a Granger cause of the T and vice versa. Note that throughout this paper the Granger causality is estimated at 95% significance level. One can be noted

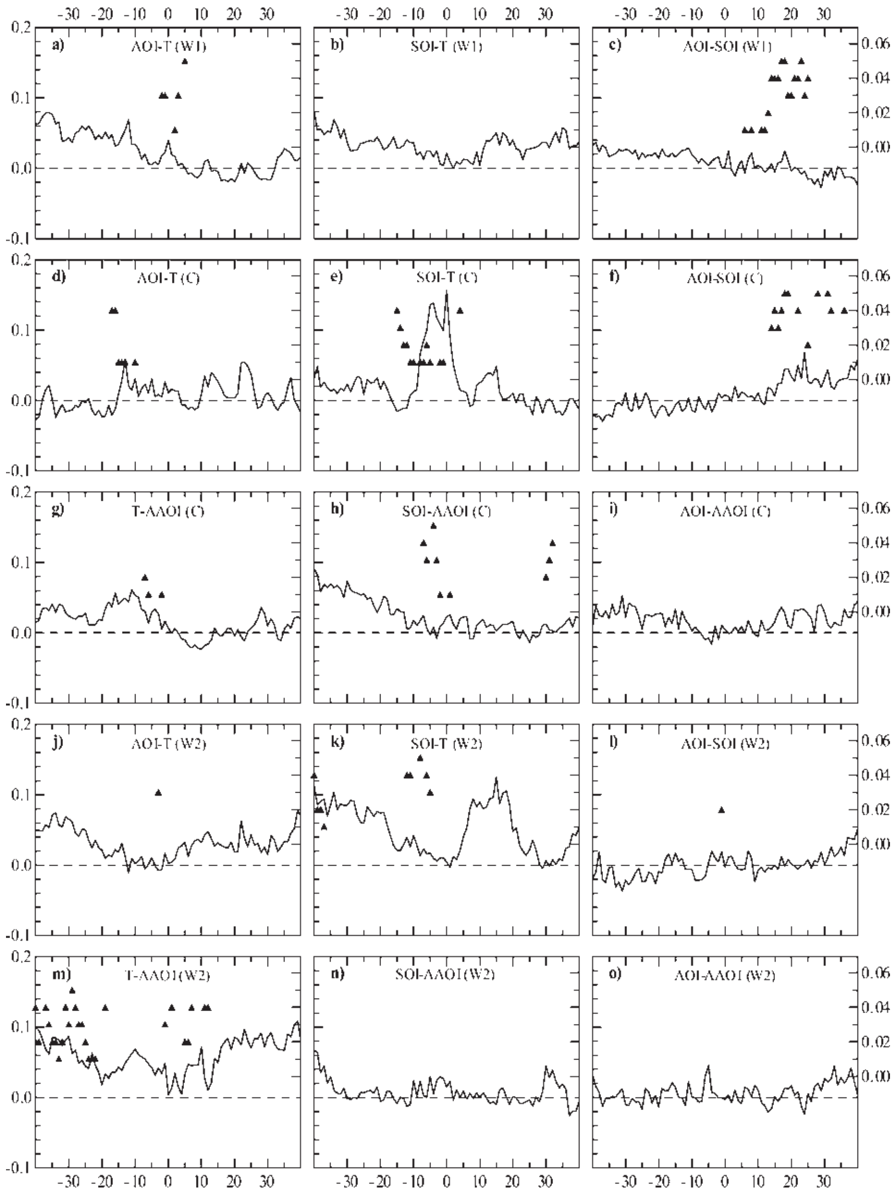

Fig 2.Cross-redundancies (solid lines; left Y-axis) 7 Granger causalities (triangles; right Y-axis) subject to the lag (X-axis) for different indices of oscillation and temperature anomalies during 3 epochs in 20century

that Fig. 2 shows many features for the interaction between the teleconnection patterns, which was described in section 2. For example, the AO–SO interaction occurs, though it is week. At that, during the C epoch the cross-redundancy for these oscillations tends to the increase with lags, whereas during the W1 and W2 epochs the cross-redundancies is rather insignificant. Here, it is surprisingly that the AO is the Granger causality of SO, it is observed at the almost same lags (12–24 months) both during the W1 epoch and during the C epoch. The largest cross-redundancy is registered for the T and SOI. During the C epoch, it is almost symmetric with regard to the maximum at the zero lag, whereas in the W2 epoch this maximum shifts towards positive lags (15 months approximately).

At that, the temperature anomaly is the Granger cause of SOI. Most interesting feedbacks are registered for the Antarctic Oscillation. First, during the C epoch the SOI is the Granger cause of the AAOI with lags close to 30 months, whereas the AAOI causes the SOI with lags less than 10 months. Second, during the W2 epoch the temperature anomalies force the AAOI with lag up to 12 months, but the AAOI itself is the Granger cause of the T with lags larger than 24 months.In some case, the cross-redundancies are small and the Granger causalities are insignificant at the prescribed significant level, e.g. for the relationship between the AOI and AAOI. So, the obtained results are mostly agreed with experimental and observational data, though by using known feedbacks it is difficult to explain some of them. In particular, it is related to that AOI is the Granger cause of the SOI. The latter can be rather referred to the deficient quality of unfiltered time series with the so-called “white noise”.

4. Conclusion

We examine the nonlinear interaction between some teleconnection patterns during different epochs of the twenty century and reveal the chaotic behaviour in the global climate system. The main advantage of the cross-redundancy and Granger causality, in contrast to other chaotic analysis, is relatively short time series used as input parameters for these approach. Our findings show that the aforementioned methods allow to display well-known mechanisms and feedbacks. Nevertheless, some our results require further elucidations. This is first related to the feedbacks between the AO and the Antarctic Oscillation, as well as the fact that the AO can be the Granger cause of Southern Oscillation. The wavelet analysis represents enough the known physical behaviour of large-scale dynamics in atmosphere and allows to detail the characteristics of this behaviour. So, our micros data processing “GeoMath” technology allows sensing the chaotic behavior in the global climate system of the Earth and the nonlinear interaction between teleconnection patterns and can be considered as quite powerful and effective tool in studying complex geosystems.

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