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SENSING AIR POLLUTION FIELD STRUCTURE IN THE INDUSTRIAL CITY'S ATMOSPHERE: STOCHASTICITY AND EFFECTS OF CHAOS

A. V. Glushkov, Yu. Ya. Bunyakova, V. N. Khokhlov,
G. P. Prepelitsa and I. A. Tsenenko

Institute of Applied mathematics OSEU,
P. O. Box 108, Odessa-9, 65009, Ukraine
Phone: +380-482-637227 E-mail: glushkov@paco. net

Abstract

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A. V. Glushkov, Yu. Ya. Bunyakova, V. N. Khokhlov, G. P. Prepelitsa and I. A. Tsenenko

A new scheme for sensing temporal and spatial structure of the air pollution fields in the industrial city's atmosphere is considered and applied to an analysis of the Odessa atmosphere aerosol component data. Effects of stochasticity and chaotic features in the dusty air pollution field structure are discovered on the basis of the correlation dimension approach to empirical data.

Key words: sensing, city's air pollution, correlation dimension, stochasticity, chaos

Резюме

ДЕТЕКТУВАННЯ СТРУКТУРИ ПОЛЯ ЗАБРУДНЕННЯ АТМОСФЕРИ ПРОМИСЛОВОГО МІСТА: СТОХАСТИЧНІСТЬ І ЕФЕКТИ ХАОСУ

А. В. Глушков, Ю. Я. Бунякова, В. М. Хохлов, Г. П. Препелица, І. О. Цененко

Розглянуто нову схему детектування просторово-часової структури полів забруднення повітря в атмосфері промислового міста. Схему протестовано на даних по аерозольному пилу в атмосфері м. Одесси. На підставі аналізу емпірічних даних в межах методу кореляційної розмірності виявлені стохастичність та ефекти хаосу у динаміці і структурі поля забруднення атмосфери промислового міста.

Ключові слова: детектування, забруднення повітря, промислове місто, кореляційна розмірність, стохастичність, хаос

Резюме

ДЕТЕКТИРОВАНИЕ СТРУКТУРЫ ПОЛЯ ЗАГРЯЗНЕНИЯ АТМОСФЕРЫ ПРОМЫШЛЕННОГО ГОРОДА: СТОХАСТИЧНОСТЬ И ЭФФЕКТЫ ХАОСА

О. В. Глушков, Ю. Я. Бунякова, В. Н. Хохлов, Г. П. Препелица, И. А. Цененко

Рассмотрена теоретическая схема детектирования пространственно-временной структуры полей загрязнения воздуха в атмосфере промышленного города. Схема протестирована на данных по аэрозольным взвесям в атмосфере г. Одессы. На основе анализа эмпирических данных в рамках метода корреляционной размерности обнаружены стохастичность и эффекты хаоса в динамике и структуре поля загрязнения атмосферы промышленного города.

Ключевые слова: детектирование, загрязнение воздуха, промышленный город, корреляционная размерность, стохастичность, хаос

One of the actual problems of modern atmosphere and environmental physics is carrying out new, effective schemes for sensing air pollution field structure in atmosphere in general and atmosphere of industrial cities in particular (c. f. [1-15]). A great number of different experimental methods are used in studying the atmosphere pollution. Besides standard physical-chemical analysis, in last years a great interest attracts using laser emission analysis schemes. They are based on using different linear and non-linear optical phenomena. In particular, an effect of the low threshold laser clamp on the solid ingredients of the disperse medium [1,2]. This effect is technically realized in real atmosphere on the distances of hundred meters from emitter. As emitters the pulsed laser (CO_2, HF, DF etc.) are used. Generating the optical emission spectra, electric and magnetic pulses and also acoustical emission follows the distant laser clamp.

Within scheme of the distant spectral chemical analysis laser source must provide evaporation of the aerosol component (soil particles, products of the metallurgical and other productions, organic substances etc.) and exciting intensive emission spectra in the corresponding vapours simultaneously. Here it is arisen a class of tasks, connected with studying the key features of the corresponding aerosol components. In last years it has been shown that the aerosol particles are created in many natural processes (coagulation of the smoke particles, clusters in the clouds, ceramic materials etc.). and possessed by the fractal structure (c. f. [2]).

This paper goes on our work on development of the new, effective theoretically optimal technological schemes for sensing temporal and spatial structure of the air pollution fields in the industrial city's atmosphere and creation of the corresponding laser emission analysis methodises. The first task is to carry out studying the key features of the air pollution fields in the industrial city's atmosphere. The next problem is connected with searching optimal laser emission spectrum analysis methodises. Here we present new theoretical approach to sensing temporal and spatial structure of the air pollution fields in the industrial city's atmosphere and applied to an analysis of the Odessa atmosphere aerosol component data. On the basis of the correlation dimension approach to empirical data we have discovered the effects of stochasticity and fractal features in the dusty air pollution field structure.

Further let us note that the atmosphere as many other physical, geophysical, biological systems (and the dynamics of their key characteristics fluctuations) can be described as a mechanical dissipative multi-level system, which are fundamentally nonlinear (c. f. [2-10]). It is well known that the similar dynamical dissipative systems very often have parameter ranges, in which the dynamics is chaotic. Non-linear systems typically have a long-term behaviour, which is described by an attractor in phase space. At the same the chaotic dynamics in details is often unknown. It is well known that an attractor is called strange attractor if its dimension is non-integer, i. e. fractal. Non-linear systems of fractal objects like interfaces or time-series is their scaling property related to invariance under magnification. For uniform fractals one-fractal exponents, the so-called fractal dimension, uniquely describe the scaling. For non-uniform fractals one must say about multi fractal dimension spectrum. This phenomenon was discovered in many systems (c. f. [2]). Here we will find it in the temporal and spatial structure of the dusty air pollution fields in the industrial city atmosphere. The presence of chaos in the dusty air pollution dynamics is investigated by employing the correlation dimension method (c. f. [3]). The correlation dimension is a representation of the variability or irregularity of a process and furnishes information on the number of dominant variables present in the evolution of the corresponding dynamical system. It can indicate not only the existence of chaos in the air pollution variability process, if any, but also reveal whether the process is deterministic or stochastic, if not chaotic.

The correlation dimension method uses the correlation integral (or function) to distinguish chaotic and stochastic systems. The Grassberger-Procaccia algorithm [3] employed in the present study for estimating the correlation dimension of the dusty air pollution series, uses the concept of phase-space reconstruction. For a scalar time series $X\,i$, where $i = 1$, 2,..., N, the phase-space can be reconstructed using the method of delays, according to (e. g. Takens, 1981):

$$Y_j = (X_j, X_{j+t}, X_{j+2t},..., X_{j+(m-1)\,t}), \tag{1}$$

where $j = 1, 2,...., N-(m-1)t/Dt$; m is the dimension of the vector Yj, also called the embedding dimension; and t is a delay time.

For an m-dimensional phase-space, the correlation function C(r) is given by

$$C(r)= \lim_{N\to\infty} \frac{2}{N(N-1)} \sum_{i,j} H(r-|Y_i-Y_j|)\,. \tag{2}$$

Here H is the Heaviside step function, with $H(u) = 1$ for $u > 0$, and $H(u) = 0$ for $u \le 0$, where $u = r-|Y_i-Yj|$; r is the radius of sphere centred on Y_i or Y_j and $1<i<j<N$. If the time series is characterised by an attractor (a geometric object which characterises the long-term behaviour of a system in the phase-space) then, for positive values of r, the correlation function $C(r)$ is related to the radius r by: $C(r) \sim ar^n$, where a is constant and n is the correlation exponent or the slope of the $\log C(r)$ versus $\log r$ plot given by

$$\nu= \lim_{r_i \sim 0, N \sim A} \frac{\log C(r)}{\log r}\,. \tag{3}$$

The slope is generally estimated by a least-squares fit of a straight line over a certain range of r, called the scaling region. The presence/absence of chaos can be identified using the correlation exponent versus embedding dimension plot. If the correlation exponent saturates and the saturation value is low, then the system is generally considered to exhibit low-dimensional chaos. The saturation value of the correlation exponent is defined as the correlation dimension of the attractor. The nearest integer above the saturation value provides the minimum number of variables necessary to model the dynamics of the attractor. On the other hand, if the correlation exponent increases without bound with increase in the embedding dimension, the system under investigation is generally considered as stochastic.

Further we present the results of the applying correlation dimension method to an analysis of the Odessa atmosphere aerosol (dusty) air pollution data and sensing the effects of stochasticity and fractal features in the air pollution field structure. As a first step, the present study investigates the dusty air pollution variability series of different (temporal) scales. Data of four different temporal scales, i. e. daily, 1-week, 0,5-month, and 1-month, over a period of about 20 years observed at the Odessa city are analysed (independently) to investigate the existence of stochasticity (chaos). The underlying assumption is that the individual behaviour of the dynamics of the processes at these scales provides important information about the dynamics of the overall dusty air pollution transformation between these scales. More specifically, if the dusty air pollution variability processes at different scales exhibit chaotic behaviour, then the dynamics of the transformation between them may also be chaotic.

Figure 1 shows the variation of the air pollution dusty component series at the Odessa city from 1976 till 200 years. Statistics of the Odessa dusty air pollution data is as follows: Statistics of signal <Dust>: number of data points: 3324; sample distance: 1Dust; Min. Value 0. 1 at 202Dust, and Max. Value 2. 5 at 65Dust; mean: 0. 549012; median: 0. 4; standard Dev.: 0. 396051; mean abs. dev.: 0. 307072; variance: 0. 156857^2; skewness: 1. 60913; kurtosis: 2. 6079;center of Mass: 113. 502Dust; Integral: 177. 88Dust; Absolute integral: 177. 88Dust; Linear Regression: y-offset: 1. 0355 slope: -0. 00301231Dust. The correlation functions and the exponents are computed for the four series. The delay time, t, for the phase-space reconstruction is computed using the auto correlation function method and is taken as the lag time at which the auto correlation function first crosses the zero line.

For the daily air pollution dusty component series, figure 2 shows the relationship between the correlation integral, C(r), and the radius, r, for embedding dimensions, m, from 1 to 10. For all the series, the correlation exponent value increases with the embedding dimension up to a certain dimension, beyond which it is saturated; this is an indication of the existence of deterministic dynamics. The saturation values of the correlation exponent (or correlation dimension) for the four daily air pollution dusty component series are respectively, 2. 72, 3. 42, 4. 15, and 5. 92. The finite correlation dimensions obtained for the four series indicate that they all exhibit chaotic behaviour. The presence of chaos at each of these four scales suggests that the dynamics of transformation of air pollution dusty component between these scales may also exhibit chaotic behaviour. This, in turn, may imply the applicability (or suitability) of a chaotic approach for transformation of the air pollution dusty component data from one scale to another.

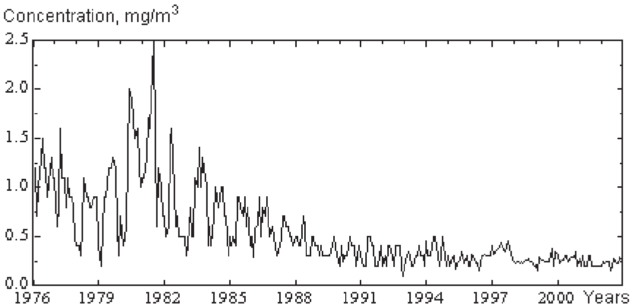

Figure 1. The variation of the air pollution dusty component series at the Odessa city

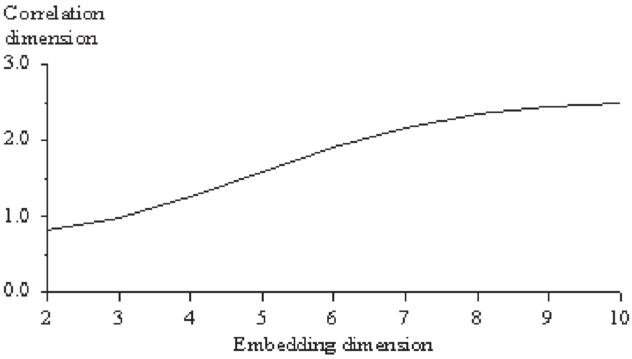

Figure 2. Relationship between correlation dimension and embedding dimension for daily series (2000-2002)

Discovered features allow making conclusion about fractal properties of the dusty air pollution component series, as it was indicated in ref. [14,15]. How to use this effect in the modern laser emission sensor technologies, we consider in the next paper. Here we only note that obtained information about dynamics and structure of the dusty air pollution component may be very useful and important under searching optimal laser emission spectrum analysis methodises. Naturally this is regarding further technological realizations for laser emission sensor of the air pollution field structure in the industrial city's atmosphere.

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