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ATMOSPHERIC POLLUTANTS CONCENTRATIONS TEMPORAL DYNAMICS FOR THE INDUSTRIAL UKRAINIAN CITIES

Dynamics of time variations of the air pollutants (dioxide of nitrogen, sulphur etc) concentrations in an atmosphere of the ukrainian industrial cities (Mariupol) with using advanced non-linear analysis, prediction and chaos theory methods is studied.
***Keywords**: methods of the theory of chaos, industrial city, atmosphere, time series of concentrations, pollutants*

The present paper concerns the results of the research for dynamics of variations of the atmospheric pollutants (dioxide of nitrogen, sulphur etc) concentrations in an air basins of the large ukrainian industrial cities by using the non-linear prediction and chaos theory methods [1-12]. A chaotic behaviour in the nitrogen dioxide and sulphur dioxide (sulphurous anhydride) concentration time series at several sites in the Mariupol city numerically investigated. Using the non-linear prediction and chaos theory methods includes the chaos tests, reconstruction of the corresponding attractors, determination of the time delay and embedding dimension. The former is provided by using the methods of autocorrelation function and average mutual information. Besides, during the total investigation one should use the correlation dimension method, an algorithm of false nearest neighbours, the Lyapunov's exponents analysis and determination of the Kaplan-Yorke dimension and Kolmogorov entropy etc [1,3,9,13-19]. Under availability of an existence of the low-dimensional chaos in the studied system, it would be possible the further short-terminal forecast of the atmospheric pollutants fluctuations dynamics.

As a useful indications regarding the topics studied, let us remind about satisfactory results during investigation of the time fluctuation dynamics, for example, for O_3 concentrations in Cincinnati (Ohio) and Istanbul, when it has been proved the chaotic feature of the cited dynamics [20,21].

In ref. [14] there is an analysis of the NO_2, CO, O_3 concentrations time series in a Gdansk region and it has been definitely received an evidence of chaos. Further it has been developed principally new effective approach to a short-range forecasting the atmospheric pollutants fluctuation dynamics using non-linear prediction method. These studies show that a chaos theory methodology can be successfully applied to investigation of the air pollution dynamics in atmosphere of the industrial cities. At the same time, one could remember about the fact that not all time series of concentrations are always chaotic, and, as a rule, the availability of chaotic behaviour for each time series should be preliminary proved.

In this paper we present the results of studying a dynamics of the time variations of the air pollutants (dioxides of the nitrogen and the sulphur) concentrations in an atmosphere of the ukrainian industrial cities (on the example of Mariupol) with using advanced non-linear analysis, prediction and chaos theory methods [1-12].

In our study, nitrogen (NO_2) dioxide and sulphurous anhydride (SO_2) concentration data observed at the above cited Ukrainian industrial cities (Mariupol) from 1985 till 2004 years. There are eight and five sites (N8-N20) in the region of the investigated cities [1]. In our studying we use the multi year hourly concentrations (one year total of 20x61440 data points). The temporal series of concentrations (in mg/m^3) of the NO_2 and SO_2 are presented in figures 1 and 2.

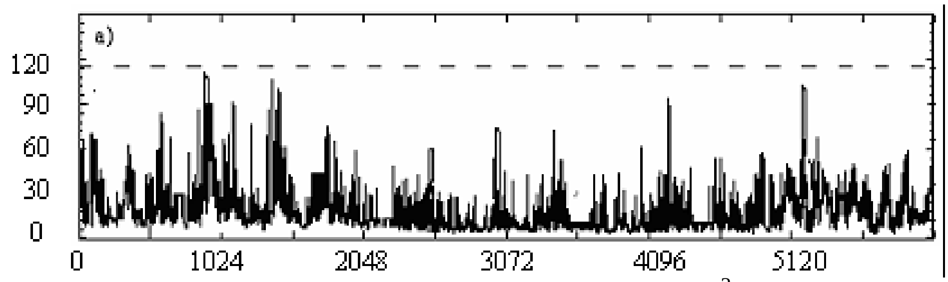

Figure 1. The temporal series of concentrations (in mg/m^3) of the of the NO_2

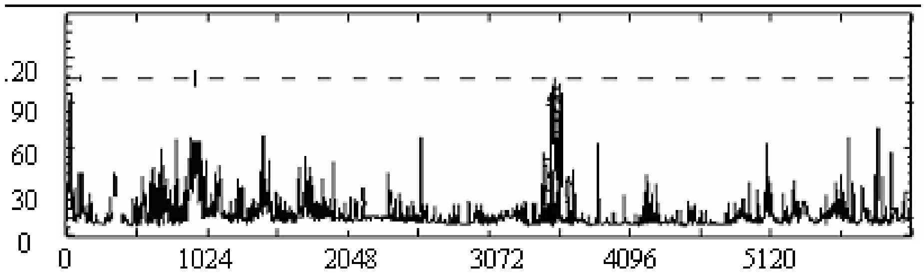

Figure 2. The temporal series of concentrations (in mg/m^3) of the of the SO_2

Table 1 summarizes the results for the time lag calculated for first 10^3 values of time series. The autocorrelation function crosses 0 only for the NO_2 time series at the site 15, whereas this statistic for other time series remains positive. The values, where the autocorrelation function first crosses 0.1, can be chosen as τ, but in [1] it's showed that an attractor cannot be adequately reconstructed for very large values of τ. So, before making up final decision we calculate the dimension of attractor for all values in Table 1.

Table 1 - Time lags (hours) subject to different values of C_L, and first minima of average mutual information,I_{min1}, for the time series of NO_2 , SO_2 at the sites of the Mariupol

	Site 10	
	NO_2	SO_2
$C_L = 0$	—	—
$C_L = 0.1$	138	228
$C_L = 0.5$	6	13
I_{min1}	9	18

The outcome is explained not only inappropriate values of τ but also shortcomings of correlation dimension method [2]. If this algorithm is used, then a percentages of false nearest neighbours are comparatively large in a case of large τ. If time lags determined by average mutual information are used, then algorithm of false nearest neighbours provides $d_E = 6$ for all air pollutants.

Table 2 shows the calculated parameters: correlation dimension (d_2), embedding dimension (d_E), Kaplan-Yorke dimension (d_L), two Lyapunov exponents, E(λ_1,λ_2), Kaplan-Yorke dimension (d_L), and average limit of predictability (Pr_{max}, hours) for time series of NO_2,SO_2 at sites of Mariupol (Jan.-Dec.1985). From the table 2 it can be noted that the Kaplan-Yorke dimensions, which are also the attractor dimensions, are smaller than the dimensions obtained by the algorithm of false nearest neighbours.

Table 2. The correlation dimension (d_2), embedding dimension (d_E), first two Lyapunov exponents, E(λ_1,λ_2), Kaplan-Yorke dimension (d_L), and average limit of predictability (Pr_{max}, hours) for time series of NO_2,SO_2 at sites of Mariupol (Jan.-Dec.1985).

	Site 13 NO_2	Site 13 SO_2	Site 9 NO_2	Site 9 SO_2
λ_1	0.0176	0.0161	0.0185	0.0146
λ_2	0.0058	0.0057	0.0045	0.0043
d_2	5.31	1.65	5.29	3.53
d_E	6	6	6	6
d_L	4.12	5.08	3.97	4.68
Pr_{max}	39	44	41	46

The presence of the two (from six) positive Lyapunov exponents λ_i suggests the investigated air pollutants fluctuation temporal dynamics system broadens in the line of two axes and converges along four axes that in the six-dimensional space. The time series of SO_2 at the site 9 have the highest predictability (more than 2 days), and other time series have the predictabilities slightly less than 2 days.

List of Literature

1. Bunyakova Yu.Ya. and Glushkov A.V. Analysis and forecasting effect of anthropogenic factors on air basin of industrial city.-Odessa: Ecology, 2010.-256p.
2. *Glushkov A.V., Svinarenko A.A., Buyadzhi V.V., Zaichko P.A., Ternovsky V.B.* Adv.in Neural Networks, Fuzzy Systems and Artificial Intelligence, Series: Recent Adv. in Computer Engineering, ed. by J.Balicki (WSEAS, Gdansk).-2014.-Vol.21.- P.143-150.
3. *Khokhlov V.N., Glushkov A.V., Loboda N.S., Bunyakova Yu.Ya*. Short-range forecast of atmospheric pollutants using non-linear prediction method// Atmospheric Environment (Elsevier; The Netherlands).-2008.-Vol.42.-P. 7284–7292.
4. *Glushkov A.V., Khokhlov V.N., Prepelitsa G.P.,Tsenenko I.A.* Temporal changing of the atmosphere methane content: an influence of the NAO// Optics of atmosphere and ocean.-2004.-Vol.4,№7.-C.593-598.
5. *Glushkov A.V., Khokhlov V.N., Bunyakova Yu.Ya.* Renorm-group approach to studying spectrum of the turbulence in atmosphere// Meteor.Climat.Hydrol.-2004.-N48.-P..286-292.
6. *Glushkov A.V., Khokhlov V.N., Tsenenko I.A.* Atmospheric teleconnection patterns and eddy kinetic energy content: wavelet analysis// Nonlinear Processes in Geophysics.-2004.-V.11,N3.-P.285-293
7. *Glushkov A.V., Khokhlov V.N., Serbov N.G Bunyakova Yu.Ya., Balan A.K., Balanjuk E.P.* Low-dimensional chaos in the time series of the pollution substances concentrations in atmosphere and hydrosphere// Herald of Odessa State Environmental University.-2007.-N4.-C.337-348.
8. *Glushkov A.V., Khokhlov V.N., Loboda N.S., Ponomarenko E.L.* Computer modelling the global cycle of carbon dioxide in system of atmosphere-ocean and environmental consequences of climate change// Environmental Informatics Arch.-2003.-Vol.1.-P.125-130
9. G*lushkov A.V., Khokhlov V.N., Loboda N.S., Khetselius O.Yu., Bunyakova Yu.Ya*. Nonlinear prediction method in forecast of air pollutants CO_2, CO. *Transport and Air Pollution*. – Zürich: ETH University Press (Switzerland). 2010.-P.131–136.

10. *Serga E.N., Bunyakova Yu.Ya., Loboda A.V., Mansarliysky V.F., Dudinov A.A.* Multifractal analysis of time series of indices of the Arctic, the Antarctic and the Southern Oscillation. // Ulrainian Hydrometeorology Journal.-2013.-N13.-P.41-45.
11. *Rusov V.D., Glushkov A.V., Prepelitsa G.P., et al.*On possible genesis of fractal dimensions in turbulent pulsations of cosmic plasma- galactic-origin rays-turbulent pulsation in planetary atmosphere system// Adv. Space Research (Elsevier).-2008.-Vol.42.-P.1614-1617.
12. *Khokhlov V.N., Glushkov A.V., Loboda N.S., Serbov N.G., Zhurbenko K.,* Signatures of low-dimensional chaos in hourly water level measurements at coastal site of Mariupol, Ukraine// Stoch.Environment Res. Risk Assess. (Springer).-2008.-Vol.22,N6.-P.777-788.
13. Kennel M.B., Brown R., Abarbanel H.: Determining embedding dimension for phase-space reconstruction using a geometrical construction. *Physical Review* A 45, 1992, 3403-3411.
14. *Schreiber T.* Interdisciplinary application of nonlinear time series methods // Phys. Rep.-1999.-Vol.308.-P.1-64.
15. *Grassberger, P. and Procaccia, I.* Measuring the strangeness of strange attractors// Physica D.-1983.-Vol.9.-P.189–208.
16. *Havstad, J.W. and Ehlers, C.L.* Attractor dimension of nonstationary dynamical systems from small data sets//Phys. Rev. A.-1989.-Vol.39.-P.845–853.
17. *Berndtsson, R., Jinno, K., Kawamura, A., Olsson, J. and Xu S.* Dynamical systems theory applied to long-term temperature and precipitation time series//Trends in Hydrol.-1994.-Vol.1.-P.291–297.
18. Gallager R.G. : *Information theory and reliable communication*, N-Y., Wiley, 1986.
19. *Nason G., von Sachs R., Kroisand G.* Wavelet processes and adaptive estimation of the evolutionary wavelet spectrum // J. Royal Stat. Soc. – 2000. – Vol. B-62. – P. 271-292.
20. *Lanfredi M., Macchiato M.* Searching for low dimensionality in air pollution time series// Europhys.Lett.-1997.-.-Vol.57.-P.589-594.
21. *Koçak K., Şaylan L., Şen O.* Nonlinear time series prediction of O_3 concentration in Istanbul.// Atmospheric Environment (Elsevier).-2000.-Vol.34.-P.1267-1271.
22. *Grassberger P., Procaccia I.* Measuring the strangeness of strange attractors// Physica D. – 1983. – Vol. 9. – P. 189-208.
23. *Inhaber H.* A set of suggested air quality indices for Canada// Atmos. Environ.-1975.-Vol. 9.-P.353–364.
24. *Schreiber T.* Interdisciplinary application of nonlinear time series methods // Phys. Rep. – 1999. – Vol. 308. – P. 1-64.
25. *Mandelbrot B.B.* Fractal Geometry of Nature.-N.-Y., W.H. Freeman, 1982.

Часова динаміка концентрацій забруднюючих атмосферу промислових міст України речовин

Сєрга І.М., Бунякова Ю.Я., Грушевський О.М., Щахман І.О.

Вивчається динаміка тимчасових змін концентрацій забруднюючих (діоксид азоту, сірки) атмосферу українських промислових містах (Маріуполь) речовин з використанням узагальнених нелінійних методів аналізу, прогнозу та теорії хаосу ..

Ключові слова*: методи теорії хаосу, промислове місто, атмосфера, екологічний стан, часові ряди концентрацій, забруднюючі речовини*

Временная динамика концентраций загрязняющих атмосферу промышленных городов Украины веществ

Серга И.Н., Бунякова Ю.Я., Грушевский О.Н., Щахман И.А.

Изучается динамика временных изменений концентраций загрязняющих (диоксид азота, серы) атмосферу украинских промышленных городах (Мариуполь) веществ с использованием обобщенных нелинейных методов анализа, прогноза и теории хаоса..

***Ключевые слова:** методы теории хаоса, промышленный город, атмосфера, экологическое состояние, временные ряды концентраций*