DSTA 2021 dys-ta.com
16th INTERNATIONAL CONFERENCE
Dynamical Systems – Theory and Applications
December 6-9, 2021, On-line

Chaos in Environmental Radioactivity Dynamics of Some Geosystems: Analyses of the Radon Time Series

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Abstract: The paper is devoted to development and application of an effective universal complex chaos-geometric approach to studyinh of a deterministic chaos, the strange attractors in dynamics of the environmental radioactivity systems. In particular, the atmospheric radon ^{222}Rn concentration temporal dynamics is studied and computed. The analysis methods include advanced versions of the correlation integral, fractal analysis, algorithms of average mutual information, false nearest neighbors, Lyapunov exponents, surrogate data, predicted trajectories algorithms, spectral methods etc. to solve problems of modeling the atmospheric ^{222}Rn time series. The topological and dynamical invariants for the ^{222}Rn concentration time series for some regions of the USA are computed and analysed.

Keywords: deterministic chaos, attractors, dynamics of geosystems, radon time series

1. Introduction. Universal Chaos-Geometric Approach to Dynamics of Geosystems

A study of the phenomenon of stochasticity or chaos in different dynamical systems is provided by a great importance for a whole number of applications, including a necessity of understanding chaotic features in different geophysical (hydrometeorological, environmental etc) systems. New field of investigations of the similar systems has been provided by a great progress in a development of a chaos and dynamical systems theory methods [1-5]. In our previous papers [2,4,5] we have given a review of new methods and algorithms to analysis of different systems of environmental and Earth sciences. In this paper the fundamentals of an universal complex chaos-geometric approach to Des of the deterministic chaos, strange attractors in dynamics of the environmental radioactivity systems are presented. In particular, the atmospheric radon ^{222}Rn concentration temporal dynamics for some US regions is studied and computed. As many blocks of the used approach have been developed earlier and need only to be reformulated regarding the problem studied in this paper, here we are limited only by the key moments following to Refs. [2,4,5]. In our problem the approach inludes a realization of the following blocks: I. Analytical and numerical study of of convective transport in a general circulation model; II. Analysis and processing of a number of basic dynamic characteristics of the system, including application of general criteria for the existence of chaos in dynamics (e.g. the known Gottwald- Melbourne test, use of Fourier expansions, spectral methods); III. Reconstruction and determination of the phase space of the system (choice of time lag using the methods of autocorrelation function, average mutual information, application of the methods of correlation integral and nearest neighboring points, fractal geometry); IV. Chaos-cybernetic study of chaos in dynamics and construction of the prediction models: a) determination of chaos parameters, incl. topological, dynamic invariants (such as the Lyapunov's exponents, Kolmogorov entropy etc; b) forecasting temporal evolution of chaotic systems using novel prediction models [2]

2. Results and Discussion

The time series of the atmospheric Rn concentrations extending for a least one year are available from five sites in the Unites States (Environmental Measurement. Lab., USA Dept. of Energy). The record of the radon concentrations at the Chester cite is by far the most extensive. Measurements had been made round-the-clock 10 m above ground in a open field and data from July 1977 to November 1983 are available as continuous time series of 0.5-3 hour average concentrations (Harlee, 1978,1979; Fisenne, 1980-1985) (see details in [5,6]). Table 1 shows the results of computing a set of the dynamical and topological invariants, namely: correlation dimension (d_2), embedding dimension (d_E), first two Lyapunov's exponents, (λ_1,λ_2), Kaplan-Yorke dimension (d_L), and the Kolmogorov entropy, average limit of predictability (Pr_{max}, hours) for the studied ^{222}Rn time series.

Table 1. The correlation dimension (d_2), embedding dimension (d_E), first two Lyapunov's exponents, (λ_1,λ_2), Kaplan-Yorke dimension (d_L), and the Kolmogorov entropy, average limit of predictability (Pr_{max}, hours) for the 1978 ^{222}Rn time series at the Chester site

d_2	d_E	λ_1	λ_2	K_{ent}	d_L	Pr_{max}
6,03	7	0,0194	0,0086	0,028	5,88	35

Analysis of the data shows that the Kaplan-Yorke dimensions (which are also the attractor dimensions) are smaller than the dimensions obtained by the algorithm of false nearest neighbours. It is very important to pay the attention on the presence of the two (from six) positive (chaos exists!) Lyapunov's exponents λ_i. One could conclude that the system broadens in the line of two axes and converges along four axes that in the six-dimensional space. Other values of the Lyapunov's exponents $\lambda_i$are negative.

3. Concluding Remarks

An universal chaos-geometric approach is appled to analysis, modelling and prediction of the atmospheric radon ^{222}Rn concentration time series with using the data of surface observations of the Environmental Measurements Laboratory (USA Dept. of Energy) for some sites in the United States (Chester site). The topological and dynamical invariants for the ^{222}Rn concentration time series are computed and analysed

References

[1] ABARBANEL H, BROWN R, SIDOROWICH J AND TSIMRING L: The analysis of observed chaotic data in physical systems. *Rev. Mod. Phys* 1993, **65**:1331-1392.

[2] GLUSHKOV AV: *Methods of a Chaos Theory*. Astroprint: Odessa, 2012.

[3] KENNEL M, BROWN R, AND ABARBANEL H: Determining embedding dimension for phase-space reconstruction using a geometrical construction. *Phys. Rev. A* 1992, **45**:3403-3411.

[4] KHETSELIUS O: Forecasting evolutionary dynamics of chaotic systems using advanced non-linear prediction method. In: AWREJCEWICZ J, KAZMIERCZAK M, OLEJNIK P AND MROZOWSKI J (EDS.) *Dynamical Systems Applications*. Politechniki Łódzkiej: Łódz, 2013, **T2**:145-152..

[5] GLUSHKOV AV, DUBROVSKAYA YV, BUYADZHI VV AND TERNOVSKY EV: Chaos and strange attractors in environmental radioactivity dynamics of some geosystems: Atmospheric radon ^{222}Rn. In: AWREJCEWICZ J, KAŹMIERCZAK M AND MROZOWSKI J (EDS.) *'Mathematical and Numerical Aspects of Dynamical Systems Analysis*. ARSA Publishing: Łódz, 2017, **2**:205-214.

[6] JACOB D AND PRATHER M: Radon-222 as a test of convective transport in a general circulation model. *Tellus*. 1990, **42b**:118-134.