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Exploring Urban Air by the Technologies of Statistical and Wavelet Analysis

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Abstract

The problem of getting operative, adequate and comprehensive information about urban air pollution is very important today. To solve this problem, much attention is paid to the distant optical methods of sounding both at regional and interregional levels [1-5].

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1 Introduction

The way the monitoring system acts is closely related to its purposes and the mission it has to complete. Atmospheric air is the most variable and most vulnerable-to-pollution component of environment. Level of air pollution in urban areas is very liable to variations depending on the degree of anthropogenic impact and meteorological conditions. Distant optical methods are currently the most often used for ecological monitoring of atmospheric air [2-5].

Distant monitoring of atmospheric air is based on the measurements of radiation characteristics (such as luminous flux, clearness of weather) transformed inside it. In this work, we explore the radiation variations in the atmospheric air in the city of Baku by the technologies of wavelet analysis. Primary information is the actinophotometric measurement data provided by ground-based measurement complex Peleng SF -06.

2 Methodological aspects of the problem

Ecological monitoring is a system of observation, evaluation and forecasting of changes in nature caused by the anthropogenic impact. The largely adopted scheme of subsystems of this system is shown in Fig.1 [2,5]. As seen from Fig.1, the major role is played here by the observation. Optical observations provide adequate, operative and comprehensive information. That's why the distant optical methods are widely used today for examination of the current state of environment and, in particular, of air [3,4]. The main purpose of the monitoring system is to provide diagnostic and prognostic information that would help to regulate the quality of environment.

Distant monitoring of atmospheric air is based on the measurements of radiation characteristics (such as luminous flux, clearness of weather) transformed inside it.

There exist various systems for the control of air quality in industrial facilities. Various algorithms have been developed for processing of data on urban air pollution in the form of time series. For more information we refer the reader to [1-4].

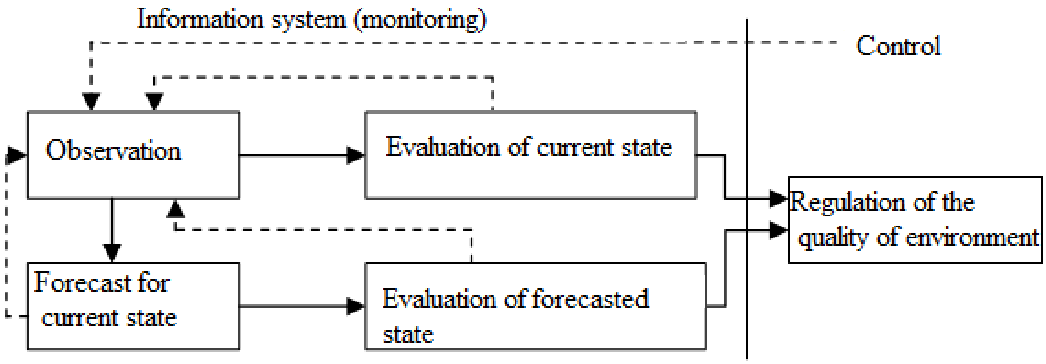


Figure 1. Scheme of monitoring system

The existing monitoring systems are engaged in gathering data and making forecasts. To do so, they usually use statistical methods. But they often neglect the change dynamics of polluters. To eliminate this defect, mathematical models are required which would take into account the variability of time series parameters during the processing of information. The methods of wavelet analysis are widely used for processing of information in the form of time series.

In the analysis of non-stationary signals, the most important thing is the time period when the variations are biggest.

Dynamic processes in atmospheric aerosol are hard to explore as they are most variable (both in time and space) component of the atmosphere. This is especially true about the aerosols of anthropogenic origin.

All the real ecosystems are under the influence of external environment that may change randomatically. In other words, some of the parameters of external environment have random components. Every phenomenon (for example, meteorological or hydrological phenomenon) includes regular and random components in the course of time. As regular components, one can consider the time-averaged and realization-averaged quantities, while the mean deviations can be regarded as random components. Of course, the behaviour of random components is most hard to describe as in many processes they act like noise. Fig.2 presents the values of total radiation at 0.3 mkm-2.4 mkm wavelength range provided by Peleng SF-06 pyranometer in Baku.

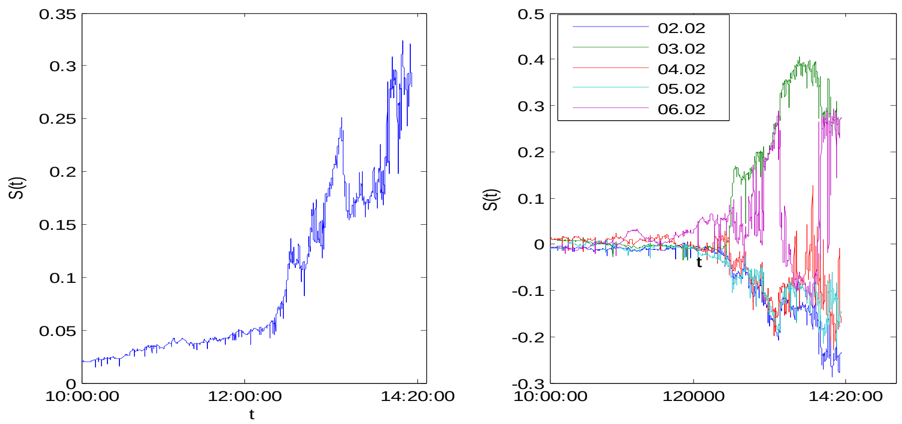


Figure 2. Random components of total radiation in regular and different days (from February 2, 2015 to February 6, 2015, Baku)

Usually the experimental data are entered in wavelet analysis and statistical processing blocks in the form of time series – as signal S(t), which is considered as a quasi-random process. Because, in addition to determinantal component, the signal *S(t)* includes also noise component *x(t)*. Noise *x(t)* perceptibly reduces the accuracy of *S(t)*.

In this work, the values of the signal function *S(t)* are considered as the values of total radiation provided by Peleng SF-06 from February 2, 2015 to February 6, 2015.

Factors that influence the measurable parameters of solar radiation include the availability of small gas admixtures, the state of underlaying surface, the air humidity, the speed and direction of wind, the characteristics of the sources of aerosol particles and other meteoparameters. It is absolutely clear that in treatment of experimental data it is almost impossible to take into account all these numerous processes that affect the object of research. Therefore, you have to restrict yourselves to some of the most important of these processes, or to make some hypotheses to explain the observed phenomena.

There is a great variety of statistical approaches based on the processing of observation data on environmental pollution. Usually, the primary data are treated as a uniform time series [7]. We assume that the time series is given by the values of a function following each other with a constant time step Δt:

$$S_k(t) = S(t_k) \quad t_k = \Delta t * k \quad k=0,1,2,\ldots,N\text{-}1$$

where N is the number of points of the series.

In this work, the measurements are made with an interval of $\Delta t = 2$ seconds. Various statistical characteristics are used to process and analyze time series and other data. The most frequently used ones are histograms, elementary probability laws (EPL), correlation functions and covariance functions.

Today, wavelet analysis is one of the most powerful and most flexible tools for treatment of data. Wavelet functions have the property of time-frequency localization. The structure of wavelet analysis has a tree form (see Fig.3). At first, the signal is decomposed into approximating and detalizing components using the given function basis. Then, the approximating component is in turn decomposed into second level approximating and detalizing components. There are $n+1$ possible ways for n^{th} level decomposition [6].

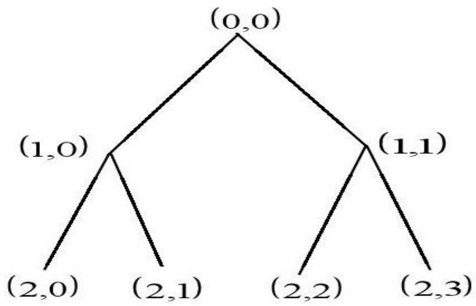


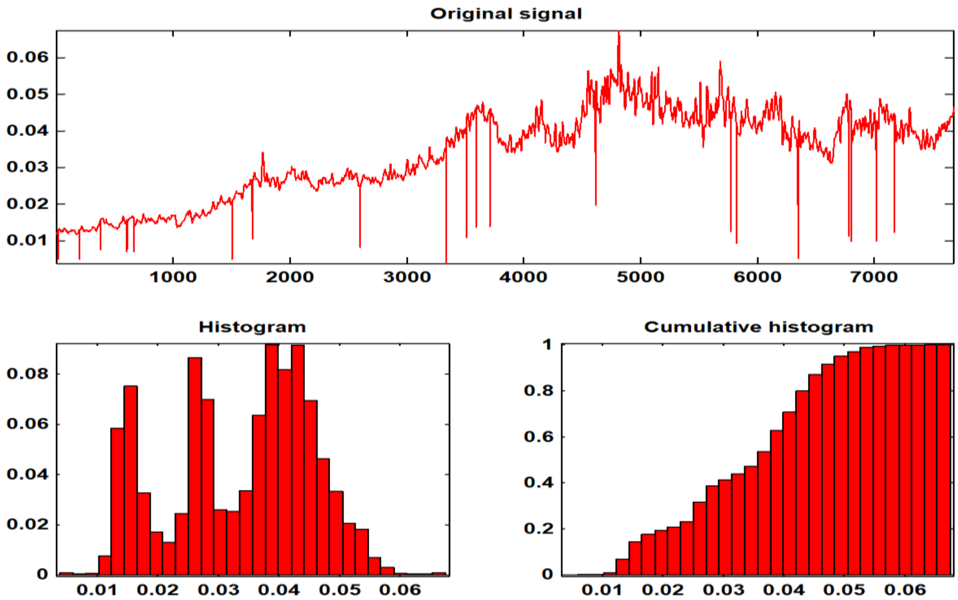
Figure 3. Wavelet tree structure

In this work, we present a comparative analysis of statistical characteristics of signal function *S(t)* for different days, second level wavelet tree coefficients and entropy values. For this purpose, we use the following Shannon entropy equation: $E(s) = -\sum_j s_j^2 \log(s_j^2)$.

3 Results of Calculations

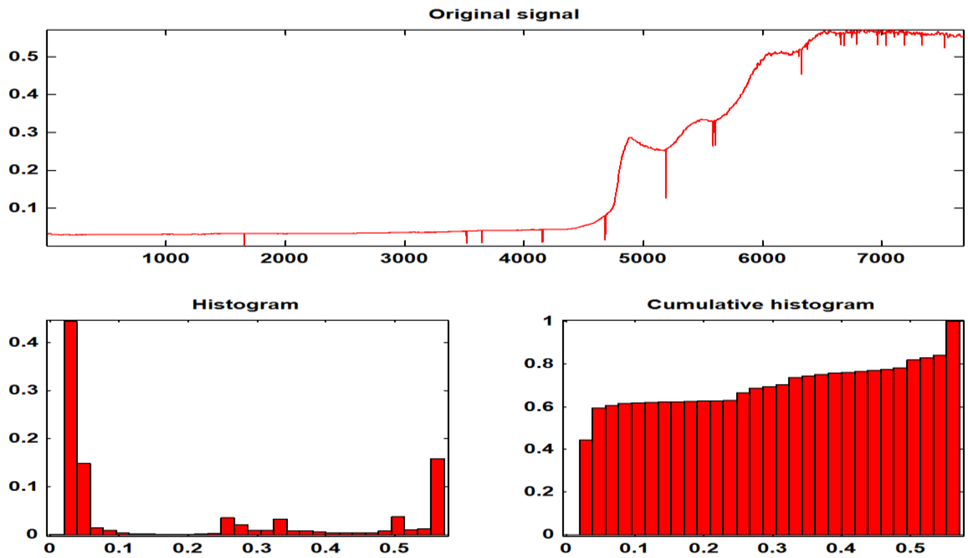
First, we analyze the statistical characteristics of signal elements. Figures 4-9 present the instantaneous values and statistical characteristics of total radiation for different days.

The measurements are made by Peleng SF-06 pyranometer from 10.00 a.m. to 2.20 p.m. with an interval of 2 seconds in Baku.



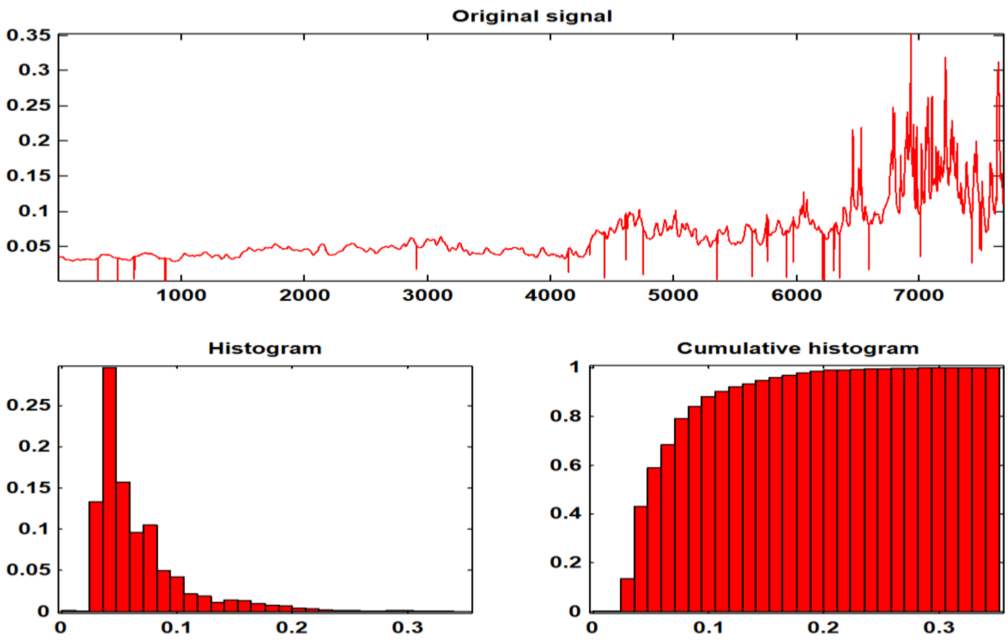
Mean	0.03372	Maximum	0.0675	Standard deviation	0.01181
Median	0.0365	Minimum	0.0038	Median absolute deviation	0.0089
Mode	0.03884	Range	0.0637	Mean absolute deviation	0.01019

Figure 4. Statistical characteristics of total radiation (February 2, 2015, Baku)



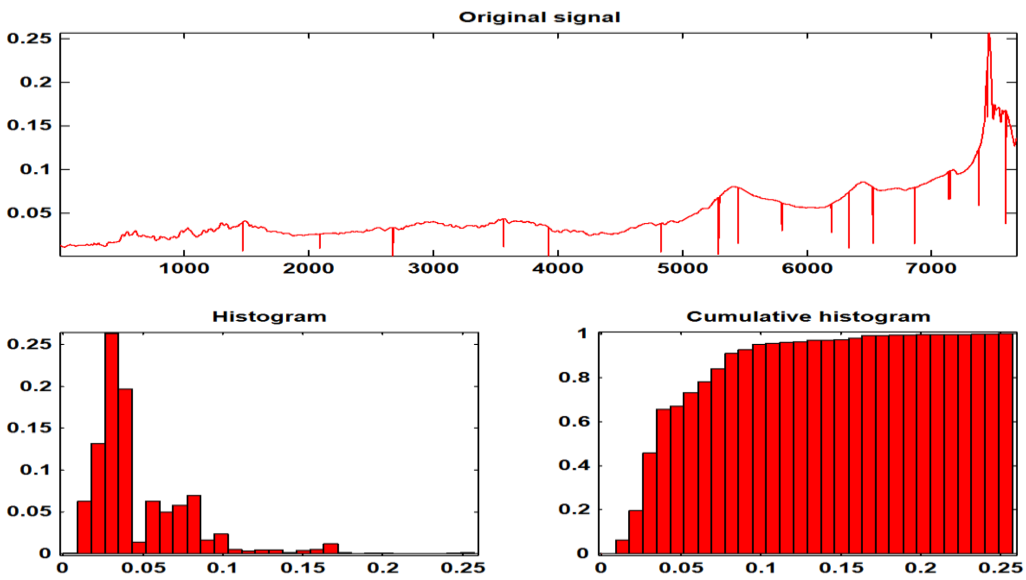
Mean	0.1948	Maximum	0.5709	Standard deviation	0.2154
Median	0.0416	Minimum	0.0006	Median absolute deviation	0.0105
Mode	0.02911	Range	0.5703	Mean absolute deviation	0.1955

Figure 5. Statistical characteristics of total radiation (February 3, 2015, Baku)



Mean	0.06625	Maximum	0.3522	Standard deviation	0.0405
Median	0.0508	Minimum	0.0008	Median absolute deviation	0.0148
Mode	0.0418	Range	0.3514	Mean absolute deviation	0.02861

Figure 6. Statistical characteristics of total radiation (February 4, 2015, Baku)



Mean	0.0485	Maximum	0.2571	Standard deviation	0.03327
Median	0.0362	Minimum	0.0008	Median absolute deviation	0.0107
Mode	0.0307	Range	0.2563	Mean absolute deviation	0.02454

Figure 7. Statistical characteristics of total radiation (February 5, 2015, Baku)

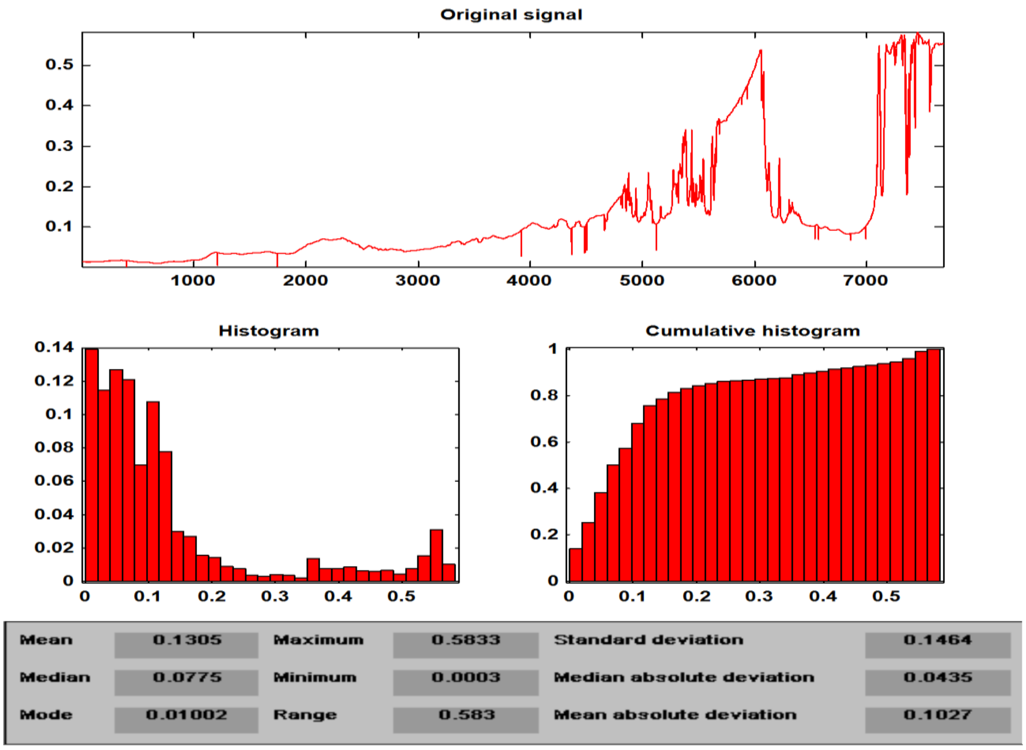


Figure 8. Statistical characteristics of total radiation (February 6, 2015, Baku)

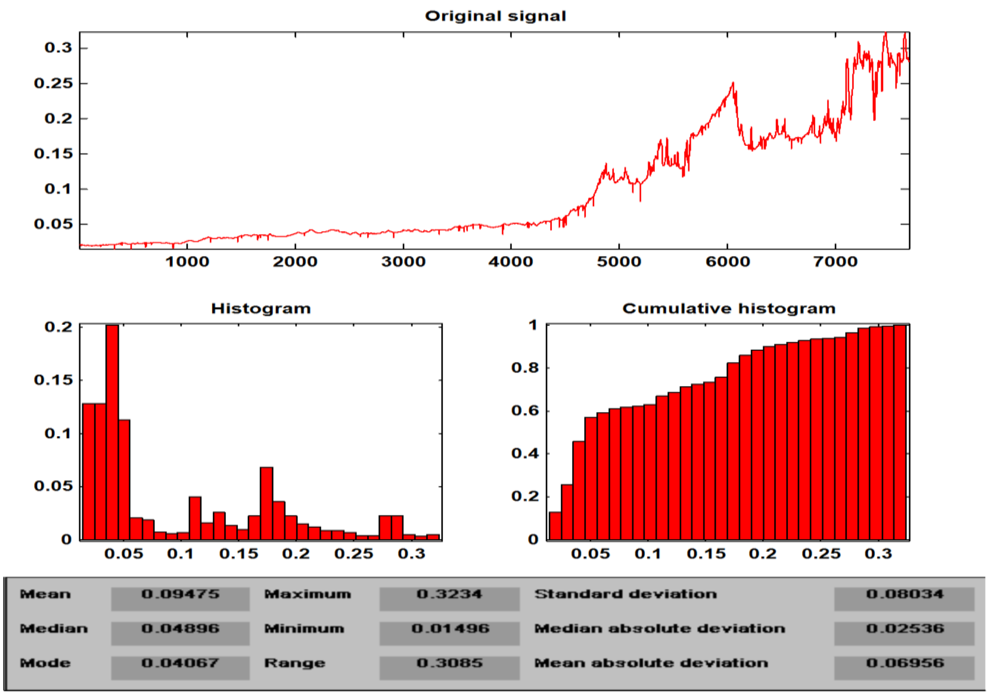


Figure 9. Statistical characteristics of regular components of total radiation

Table 1 presents the entropy values corresponding to the Haar wavelet in terminal nodes of wavelet tree for different days, and Table 2 presents the entropy values for different days as compared to the background entropy values.

Table 1. Entropy values in terminal nodes of wavelet tree for different days

Terminal node indices of wavelet tree	02.02.2015	03.02.2015	04.02.2015	05.02.2015	06.02.2015	Regular components
0.0	63.369	934.36	205.92	129.96	575.43	392.1
1.0	56.559	485.58	173.77	111.55	371.95	310.08
1.1	0.03272	0.11028	0.1813	0.092296	0.26227	0.037831
2.0	49.778	36.342	141.82	93.227	166.34	228.07
2.1	0.024626	0.03714	0.26911	0.067296	0.57778	0.060839
2.2	0.018316	0.061409	0.11349	0.062211	0.18669	0.022236
2.3	0.01623	0.049926	0.68943	0.030977	0.0825	0.01411

Table 2. Entropy values in terminal nodes of wavelet tree for different days as compared to background entropy values (Here ENT denotes the entropy value (different for different days), and ENTR stands for the background entropy value)

Terminal node indices of wavelet tree	$\frac{ENT}{ENTR}$				
	02.02.15	03.02.15	04.02.15	05.02.15	06.02.15
0.0	0,161614384085692	2,38296352971181	0,525172149961744	0,331446059678653	0,00374281891379223
1.0	0,182401315789474	1,56598297213622	0,560403766769866	0,359745872033024	0,00386845057329325
1.1	0,864899156776189	2,91506965187280	4,79236604900743	2,43969231582565	183,253793498685
2.0	0,218257552505810	0,159345814881396	0,621826632174332	0,408764852896041	0,00319786681328433
2.1	0,404773253998258	0,610463682835024	4,42331399266918	1,10613257943096	156,098370861216
2.2	0,823709300233855	2,76169275049469	5,10388559093362	2,79776038855909	377,578907013971
2.3	1,15024805102764	3,53834160170092	48,8610914245216	2,19539333805812	414,381082925942

4 Conclusion

Optical diversity of urban air in Baku is analyzed by the statistical methods. Entropy values in Table 2 are important from the diagnostic point of view.

5 Acknowledgment

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