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Earthquake Precursors Identification on the Base of Statistical Analysis of Hydrogeochemical Time Series

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Abstract

Algorithm and computer programm for earthquake precursors identification on the base of nonparametric statistical methods for detections of random sequences characteristics changes are described. The results of analysis of hydrogeochemical time series are presented.

1 Introduction

Long periods associated with complex processes in the earth crust, precede strong earth - quakes. Changes of tension, porosity and earth crust permeability reflect on the dissolving of chemical elements and gases in underground liquids during the earthquakes' preparation. During the observations of underground water in special holes, anomalies of chemical composition are marked already several months before the earthquake. Hence anomalies can be used as precursors for middle-time prediction.

The comparison of hydrogeochemical precursors with others provides the theoretical interpretation of the eartquake preparation processes and also elaboration of scientifically substantiated complex of protection actions [1,2].

The [3] is devoted to investigations and statistical assertion of various model equations connecting the seismicity regime changes and geochemical characteristics occilations. Also there is an attempt to formalize the decisive rules of forecasting in parametrical model boards.

The approach developed in this article consists of analysis of underground water chemical composition for precursors identification and forecasting algorithms synthesis by nonparametrical statistical methods of detection of random sequences property changes [4,5].

Various technical applications of parametrical methods of detection of changes of properties in random sequences in, particular, detections of seismic waves are presented in [6]. Interesting application of nonparametric methods, particularly in medicine, are developed by a number of authors in [7].

The computer programm discussed in this article is tested on data of observations on some chemical micro- and macroelements in underground waters in Armenia during the 80-th. The experimental results partially were represented in the V School-Seminar of C.I.S [8] on programm- algorithmic software of statistical analysis.

The results of experimental data analysis show the efficiency of the suggested algorithm.

2 Time Series Analysis by Rank Test Statistics

The working hypothesis during the geochemical data analysis was that the ranges of time series of each of 8 components: Mg^{2+}, Ca^{2+}, HCO_3^-, SO_4^{2-}, Cl^-, He, F, pH, some time before the earthquake it is possible to distinguish at least three parts, which differby their statistical properties. The first of them can be named as the period of phone value (or the "non-decomposed" state of the process), the second – the period of changes accumulation and the third – the calm period before the earthquake (or the "decomposed" state of the process). During the period from 1982 to 1993 in the region within 42°00′00″ and 47°00′00″ longitude and 30°00′00″ and 42°00′00″ of latitute seven strong earthquakes (by the energetic class above 11.0) take place. In [9] geochemical quiescence approximately 3-4 month before earthquake called stable geochemical precursors. Data concerning these earthquakes are given in Table 1.

Date of earthquake	Energetic class	Coordinates of earthquake
02.11.83	11.8	42°12′00″; 39°30′00″
02.11.83	11.6	42°00′00″; 40°12′00″
18.09.84	12.5	42°18′36″; 40°28′48″
13.05.86	13.7	43°51′00″; 41°27′00″
14.07.87	11.1	47°46′12″; 41°01′12″
07.12.88	11.6	44°13′48″; 40°55′12″
02.12.89	11.4	45°19′48″; 38°30′00″
06.10.91	12.7	43°36′00″; 41°07′48″

Table 1.

As it is seen on Fig. 1, where the Helium time series is shown, during 10 months before the earthquake 02.12.1989, characteristic changes of the series preceeding to the earthquake, which differs from the seasonal or occasional oscillations, sometimes is possible to detect visually.

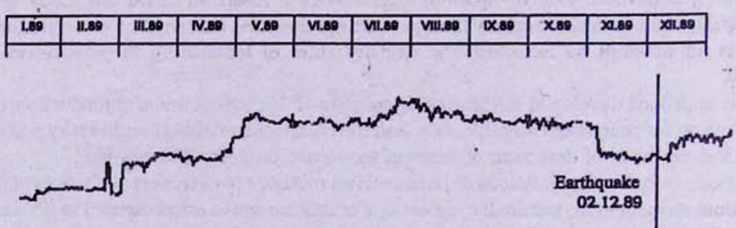

Fig. 1. Time series of Helium during the period of 01.01.89.-31.12.89.

Let us apply the following statistical model: in the series of observations $\{X_1, X_2, ...\}$, each observation X_n, has a distribution function $F_1(x)$, when $n \leq n_1$; distribution function $F_2(x)$, when $n > n_2$; and distribution function

$$G_n(x) = \left(1 - \frac{n - n_1}{n_2 \quad n_1}\right) F_1(x) + \frac{n - n_1}{n_2 \quad n_1} F_2(x). \tag{1}$$

when $n_1+1 \le n \le n_2$. We assume that the distributions $F_1(x)$ and $F_2(x)$ are unknown and continuous.

The identification of the precursor means detection of the moments n_1 and n_2.

Therefore we calculate the sequence of Chernoff - Savage statistics $W_N(n/N)$ in a scanning window of width N, by scanning step h.

As it is shown in [4,5], the diagram of $W_N(n/N)$ is oscillating near a function $w(n/N)$, which shape depends on the window's position with respect to the points n_1 and n_2.

Namely:

- $w(n/N) \equiv 0$, when the window is out of the interval (n_1, n_2);
- $w(n/N)$ has a unique minimum at the point n_1 (or n_2), if the point n_1 (or n_2) is within the window, or, both of them are within the window and one of them is near to the middle of the window.
- $w(n/N) = \text{const} < 0$ if $n_1 < n < n_2$, when n_1 and n_2 are at the same distance from the bounds of the window.

As it follows from [4], if $w(n/N)$ has a unique minimum, then the statistics

$$n/N = \arg \min_{1 \le n < N} W_N(n/N)$$

approaches by probability to the minimum of the function $w(n/N)$.

This allows to obtain estimations $\hat{n}_1$ and $\hat{n}_2$ of the moments n_1 and n_2, when the window moves from left to right.

If in two or three successive windows the minimum of statistics hits on the same value of n and the point of minimum is shifted from the right bound of the window to the middle, then that value of n we consider as the estimation $\hat{n}_1$ of n_1. If for further movement of the window there appeares the second minimum, the point of which is shifted from the middle to the left bound of the windows, then such n we consider as the estimation $\hat{n}_2$ of n_2.

If the diagram of the statistics is within the limits $\pm z_\alpha$, then by probability equal to $1-\alpha$ one can consider, that there is no one moment of change in the window. The limits $\pm z_\alpha$ are choosen from the condition, that if there are no changes then the statistics $W_N(n/N)$ has a standard normal distribution for sufficiently great values of N.

3 The Result of Experimental Data Processing

The process of detection the moments n_1 and n_2 by the He time series, which precedes the earthquake 13.05.86., based on Wilcoxon statistics is shown on Fig. 2. The upper series of diagrams represents the behaviour of the statistics calculated in the window $N = 300$ with the step $h = 45$, the lower series of diagram is the same for $N = 100$ with the step $h = 45$. By the upper series of diagrams one can be convinced that the behaviour of statistics in the scanning window corresponds to the behaviour described above. Comparison of the diagrams (a) and (b) on Fig. 2 shows that the minimum shifts from the right bound of the window to the middle, on the diagram (c) the statistics has two minimums, between which its value is approximatelly constant, and the comparison of the diagrams (d) and (e) shows that later on the minimum shifts from the middle to the left bound of the window.

There are obtained the following estimations of the points n_1 and n_2: $n_1 = 06.07.85$, $n_2 = 30.09.85$, when $N = 300$ and $N = 100$ the estimations coincide.

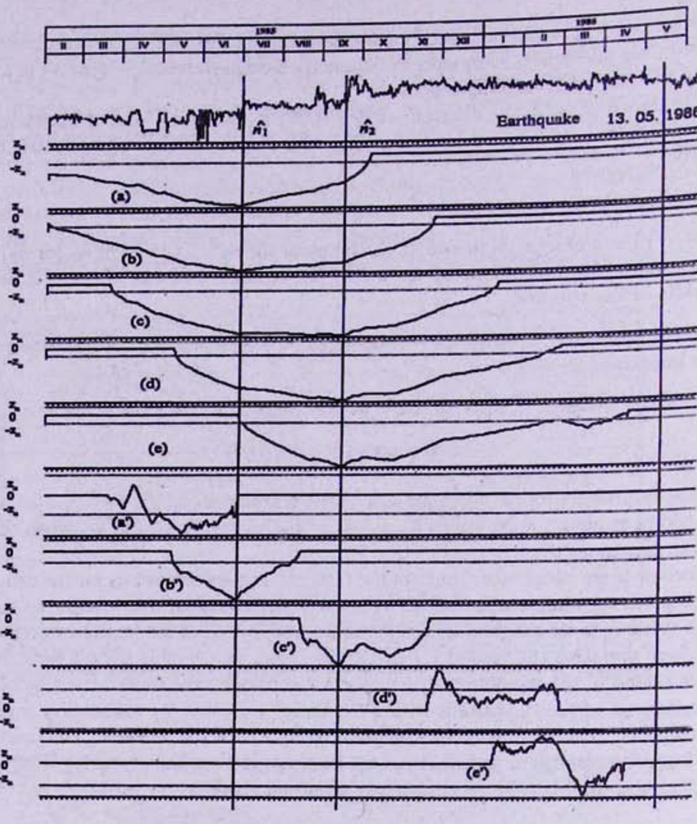

Fig. 2. Time series of Helium during the period 01.02.85.-01.06.86. and the Wilcoxon statistics behaviour in scanning windows N = 300 (diagrams (a) - (e)) and N = 100 (diagrams (a') - (e')).

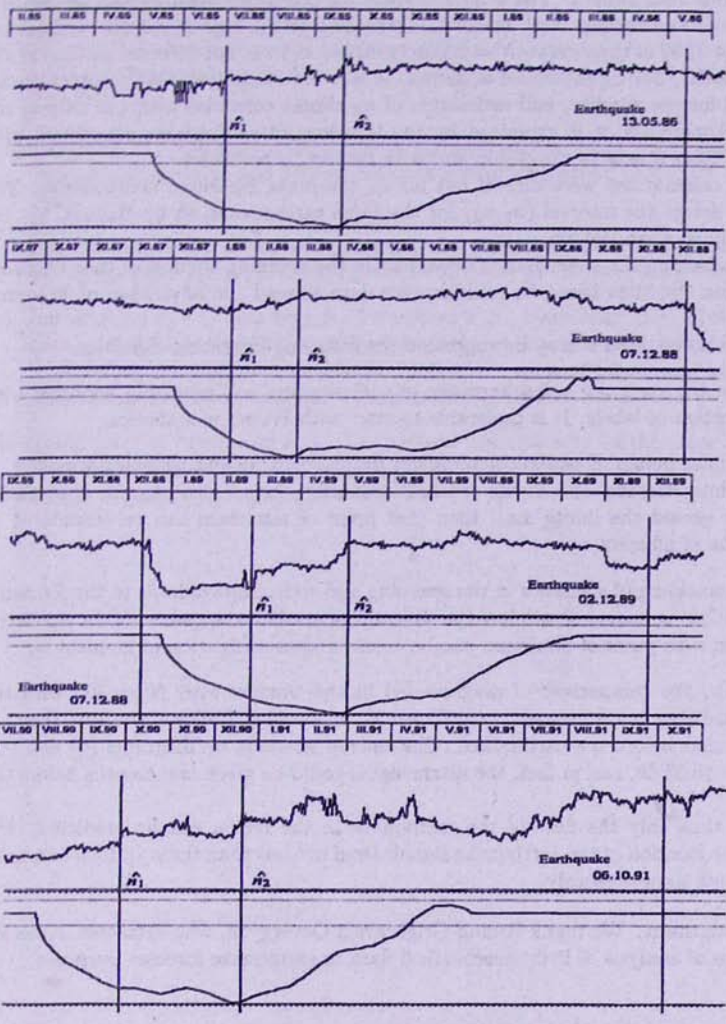

Fig. 3. Comparison of Wilcoxon statistics behaviour for four carthquakes

Simalar calculations are carried out for the sections of time series of Helium for other earthquakes data from Table 1. The Wilcoxon statistics behaviour calculated in the window $N = 300$ for some earthquakes from Tables 1, is presented on the Fig. 3. For the earthquakes 02.11.83 and 14.07.87 in the window $N = 300$ interval (n_1, n_2) was not detected neither by the Wilcoxon statistics, nor by the Mood statistics. It was detected by the Wilcoxon statistics with $N = 200$ for the window, and estimation of n_2 almost coincides with the date of the earthquake. Apparently, it is explained by the locations of earthquakes epycenters with respect to the main breaks in the region and with respect to boreholes.

Analogous calculations were carried out for all the other measured components. The most of them detect the interval (n_1, n_2) for the same earthquakes, as by Helium, but for 1.5–2 months later, than Helium.

The comparison on the same data of behaviour in the scanning window of the Wilcoxon, Mood and other statistics based on rank degrees data showed the advantage of Wilcoxon statistics.

In view of above stated it may be suggested the following forcasting algorithm:

- Calculate the statistics simultaneously in the scanning and widening windows with some function of labels. It is preferable to start with Wilcoxon statistics.
- Compare the points of statistic's minimum in the scanning and widening windows. If these points coincide, and in the previous scanning window the diagram of statistics does not exceed the limits $\pm z_\alpha$, then that point of minimum can be considered as estimation of moment n_1.
- If after coinciding of statistics in the scanning and widening windows, in the following in the following scanning window the diagram of statistics appears within the limits $\pm z_\alpha$, then such point of minimum can be considered as estimation of moment n_2.

For example, the comparison of diagram (d) in the window with $N = 300$ with the diagram (c') and (d') in the window with $N = 100$ on the Fig. 2 allows to assert that the calm period comes before the earthquake. The ends of windows on diagrams (d) and (d') come to a date 15.03.86, i.e., in fact, the alarm signal could be given two months before the earthquake.

Of course, thus only the date of the earthquake in the region can be predicted. For forcasting of the location of the earthquake signals from not less than three various boreholes must be obtained simultaneously.

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