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Regional Geomechanical-Geodynamic Control Geoinformation System with Entropy Analysis of Seismic Events (In Terms of Kuzbass)

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自然和采矿诱发的地震事件云服务分类

Abstract—The presented geoinformation system is based on cloud service classification of natural and mining-induced seismic events. The data entropy-based models treat seismic signals as functions of a “waveguide” led from a seismic source to a seismic station. The quality similarity or distinction of the models is related with the genesis of seismic events. The service includes Google App Engine cloud calculating technologies, IRIS Data Management Center web-services and local seismic monitoring databases. The application of the cloud service to classifying unknown-genesis seismic events is illustrated by the examples.

Key words: Industrial and regional seismicity, seismic signals, classification, cloud service, geoinformation system.

总结：采用Google App Engine云计算技术，结合IRIS数据中心网络服务和本地地震数据监测数据库，实现云服务在未知成因地震事件中的应用。

INTRODUCTION

Monitoring and analysis of regional geodynamic situation is a very responsible and complex mission. It is required to interpret and classify powerful peturbances in the known sites as well as other, different nature, power and occurrence depth events, among which there are industrial blasts, rock bursts and landslides [1–3]. It is also important to confirm or refute the connection of the local and regional seismic events with the ecological impact. It is a critical task to develop and introduce accessible and ergonomic services for classification of seismic events, estimation of cause and effects, assessment of geomedium stress state and control of abidance by mining rules and safety procedures.

总结：阐述了系统开发的重要意义

采矿规则和安全程序

1. ESSENTIAL MATHEMATICAL MODELS

The offered algorithms are based on informative models [4, 5]. The models involve entropy image of observation and experimental data:

$$\mathbf{E} = -\mathbf{q}\ln(\mathbf{q}), \tag{1}$$

where $\mathbf{q} = \mathbf{x}/S$—vector of likelihood ratios of opting an i-th element out of vector $\mathbf{x} = \{x_1, \ldots, x_m\}$ of data on values of an index X; $S = \sum_i x_i$—sum of elements of the vector $\mathbf{x}$.

Entropy image (1) reduces the data vector to a model of distribution of the total system entropy [5, 6] by elements-experiments in the chosen X and, according to theory of information, unambiguously defines the state of the i-th element. Elements of equal and/or ordered contribution into the total entropy condition the structure of the system as a set of subsystems with specific properties. The demandable property of an image is additivity of the elements-experiments inside an index and several indexes. This property ensues from a presentation of the set of images $\{\mathbf{E}_1, \ldots, \mathbf{E}_n\}$, built in the indexes $X_1,\dots,X_n$, as the model of total entropy of the experiment system represented by independent messages (channels) $\{\mathbf{x}_1,\dots,\mathbf{x}_n\}$.

Diagnostics using the set of the indexes $X_1,\dots,X_n$ is made using the generalized entropy model:

$$\mathbf{E}_{\Sigma,V} = \left\{ -\sum_{j\in V} q_{i,j} \ln(q_{i,j}) \right\}_{i=1,\dots,m}, \tag{2}$$

where V—generalized subset of indexes, i.e., we have an algorithm of a complex characteristic using signals on orientations, events and stations. 熵模型，该模型通过提取索引的部分熵值的向量来构建系统的选定元素

Additivity of elements in entropy models reveals another type of informativeness models constructed by extracting vector of values of partial entropy of indexes for a chosen element of the system, i.e., at $i = \text{const}$, and further standardization:

$$\mathbf{E}_i = \frac{\{E_{i,j=1},\dots E_{i,j=n}\} - M[\{E_{i,j=1},\dots E_{i,j=n}\}]}{\sigma[\{E_{i,j=1},\dots E_{i,j=n}\}]}. \tag{3}$$

It is easy to interpret such model: each element $\mathbf{E}_i$ is entropy of a *j*-th index of an *i*-th element. So, we have a model of increment rate for the *i*-th object with respect to every index and, thus, can estimate and compare informativeness of each index for every object.

Analyzing systems assigned by outlet signals must take into account their difference from samplings: *i*-th counting of an index with respect to time is neither an independent object nor the system condition characteristic. The characteristic of the system condition is amount of information produced by the system by the time t from the counting start [4–6]. Based on physical principles of seismic signal recording, we replaced original forms by the vector of modules of peak-to-peak values:

$$s_i = |x_{i+1} - x_i| \tag{4}$$

of the *i*-th and $i+1$-th countings. This transformation of the signal leads to the definition of an additive value as the length of material point movement trajectory (material point is a mass center of a measurement system).

Then, the amount of information by the *i*-th counting is the cumulative function of entropies of the peak-to-peak values:

总结：这部分主要阐述了提供的熵模型，熵模型中元素的可加性揭示了另一种类型的信息模型，该模型是通过提取索引的部分熵值的向量而构建的系统的选定元素。

$$\mathbf{H}_C = \left\{ -\sum_{k=1}^{i} \frac{s_k}{\sum_{i=1}^{m-1} s_i} \ln\left(\frac{s_k}{\sum_{i=1}^{m-1} s_i} \right) \right\}_{i=1,\dots,m-1}. \tag{5}$$

Algorithms of analyzing conditions of dynamic systems, based on such models, have no limitations with respect to time and time invariance of signals, since the reference imaging does not impose such requirement on the data of observations and experiments.

开放且可扩展

重点研究这部分，系统是如何构建的

2. SOFTWARE IMPLEMENTATION

It was required that the developed applied programming support was open and scalable, ergonomic and provided with actual and reliable seismic data. We studied specifications of the present-day key cloud technologies Microsoft Windows Azure, Google App Engine (GAE) and Amazon Web Services (AWS) that are on the same level of server implementation and development, API and programming language. Considering minimized investment in web-project location and its functioning in a cloud, we selected Google App Engine. In favor of choosing IRIS DMC (Incorporated Research Institutions for Seismology Data Management Center) as a source of seismology information [7] spoke worldwide extensive network of seismic stations that feed seismic data bases in real time. IRIS grants free access to API and web-services [8–12] that inform on objects of the database (seismic station, seismic event, seismic signal, etc) upon an HTTP request. The answers come back in XML (QuakeML) for events in the form of integer-valued array of time-series in ASCII format. This property totally satisfies the used mode of observations and experiments.

总结：系统开发技术需求，选用Google App Engine，数据库对象（地震台站、地震事件、地震信号），数据的表达形式XML

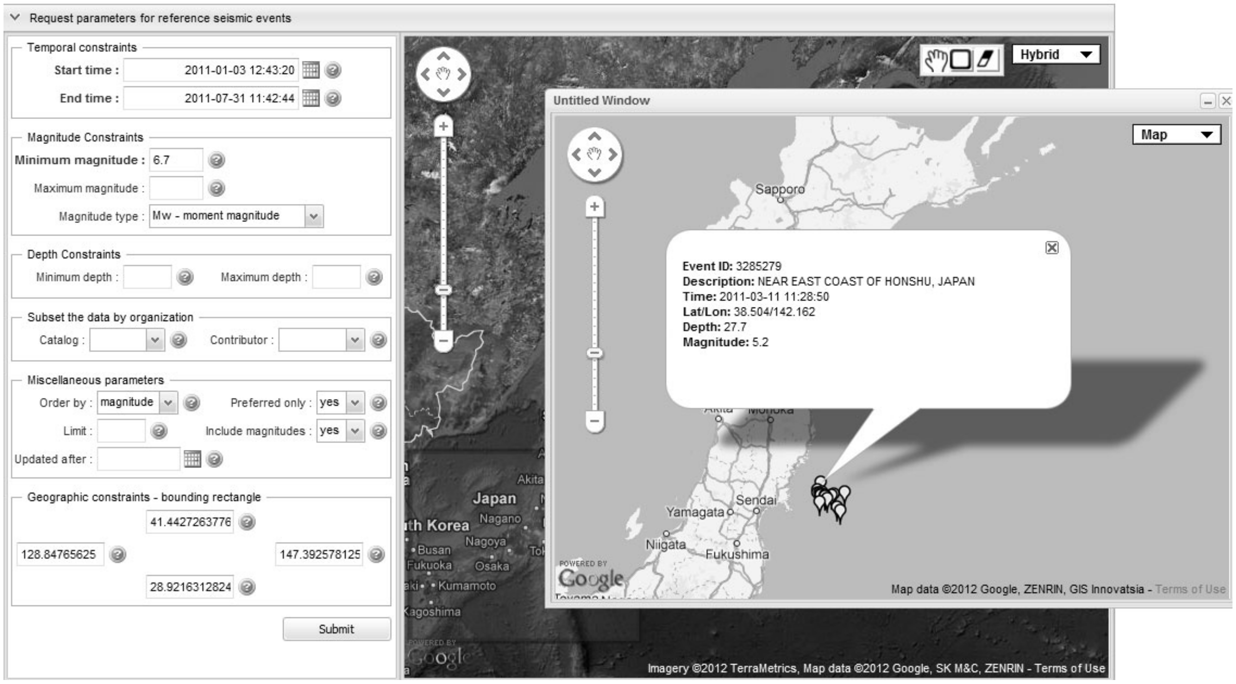

Fig. 1. Interface arrangement to select parameters of seismic events and display location of the events and seismic stations.

系统所涉及到的技术

The resultant cloud services "Seismatica" involved Google Web Toolkit (GWT), GWT-RPC, Google Map APIs (GMap), Google Chart API (GChart), Google Users API and IRIS Web Services (IRIS WS). The services are available at http://seismatica.appspot.com.

了解一下

The graphics GUI of the services used GWT, GMap, GChart. GUI allows a user to formulate boundary conditions of mathematical model in the form of parameters-requests submitted to the services IRIS WS and the list of time-series that form a matrix of values, to display seismic objects in Google Maps (see Fig. 1) and visualize the results using GChart. 使用Chart可视化结果

The technology GWT-RPC supports interaction between a user and the server by means of asynchronous outputs of remote servlets with programs of mathematical models and matrixes of values of time-series, and by http-requesting IRIS WS without the graphic interface rebooting. This approach eliminated the problem of saving the data both by the user and server, which enabled incapsulating the functional and making the services behave like a nonremovable software application.

The interface changes, model calculation and the calculated results visualization take place in the same context, which allows setting various initial conditions and obtaining a pool of results per session for the comparative analysis later on. 系统用户操作顺序的四个阶段

The sequence of user's operations, starting from setting boundary conditions and ending with getting final analytical result of the operation with "Seismatica" cloud services, can be grouped into 4 stages:

(1) choice of parameters of seismic events (time period, minimum/maximum magnitude, type, occurrence depth, etc. [11]) to compile a list of reference seismic events (Fig. 1);

(2) choice of a reference event and parameters of seismic events and stations—distance from the reference event site and magnitudes, to compile a list of closest-located events;

(3) choice of a seismic station, group of the closest-located seismic events and time-series;

(4) display of initial data and construction of models of signals (Fig. 2).

The Seismatica has a system of prompt messages and warnings in case a user takes incorrect actions. All the terms, symbols and units of measure used in either graphic interface or in prompt messages are drawn from the IRIS WS services documentation.

开发的系统Setsmatica具有一个提示消息和警告系统，以防用户采取错误措施。

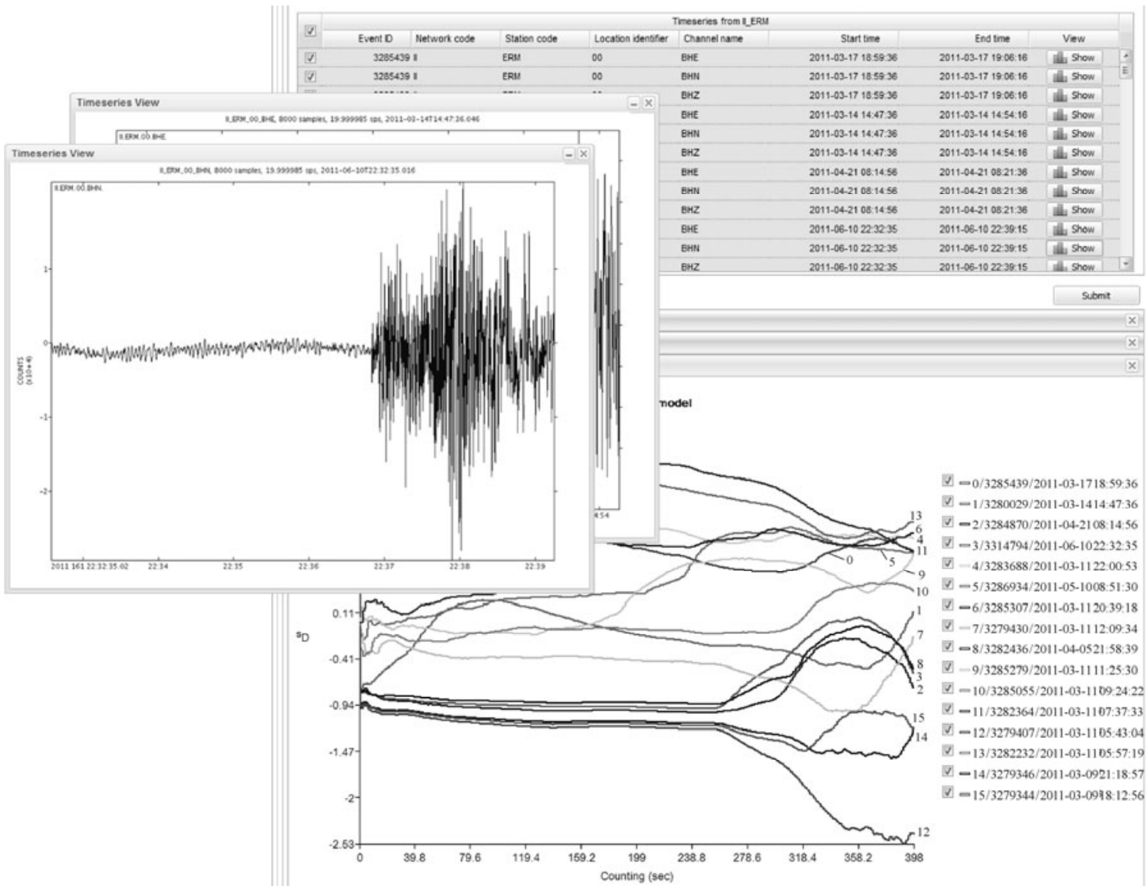

Fig. 2. Display of seismic signals and calculations of characteristic functions.

地震事件的例子

3. SOFTWARE EXPERIENCE

As a reference seismic event, we chose the Altay-Sayan earthquake September 27, 2003. It featured the absence of the pre-history, i.e. IRIS DMS-recorded and energy-comparable pre-events to take place in the same locality within previous 5 years. In this case, we compared the reference event with the next powerful quakes in the same region. 利用所描述的技术，可以随时随地跟踪地球动力学情况的发展。

With the described technology, we can follow development of geodynamic situation across any time and space interval. The validity of the conclusion is based on the obedience of the pre-set rule of choice and filtration of the events in IRIS DMS.

The table below reports the events recorded after the reference event (in bold). These events were chosen based on the following criteria: the magnitude is equal / above 5; the absence of strong aftershocks inside the time window of the reference event. The observation point was chosen the seismic station in Ulan-Bator, Mongolia (code IU-ULN, Ulaanbaatar, Mongolia, Lat: 47.8651; Lon: 107.0532). Figure 3 shows the location of the station and chosen events obtained using the described services.

Seismic events chosen for the analysis

Order number	Number of the event	Data (yy-mm-dd) and time of the event	Longitude	Latitude	Magnitude
0	1646230	2003-11-11 22:42:31.5300	50.1050	87.8364	5.0
1	1667932	2003-10-17 05:30:20.6800	50.1579	87.7116	5.0
2	1654214	2003-10-13 05:26:38.1500	50.2522	87.6298	5.3
3	1640547	2003-10-09 16:06:03.7700	50.0524	87.8312	5.1
4	1594940	2003-10-01 01:03:26.3100	50.1599	87.7071	6.3
5	1647584	2003-09-27 18:52:46.0600	50.0871	87.7632	6.6
6	1646446	2003-09-27 15:31:22.0700	50.0738	87.8570	5.0
7	**1645208**	**2003-09-27 11:33:25.1300**	**50.0089**	**87.7788**	**7.4**

(a)

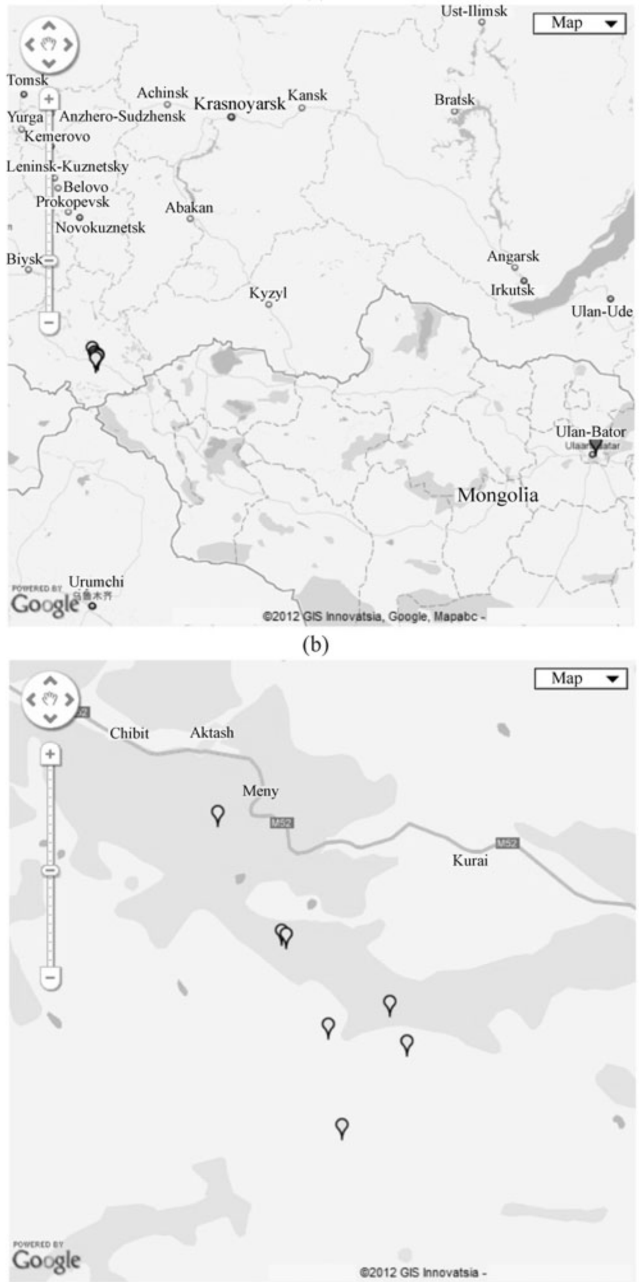

Fig. 3. (a) Location of seismic events; (b) location of seismic stations.

Figure 4 shows characteristic functions of the analyzed seismic events. Comparing the time domain isolates a few representative areas: area of margin effect (up to marker 1); “shock wave” front area (between markers 1 and 2); “shock wave” tail area (between markers 2 and 3); and area of residual vibration (noise) in lithological structures in the vicinity of the seismic station (behind marker 3).

It is interesting to see that events nos. 4, 5 and 7 apparently make a group. Event no. 7 is the reference event; thus, we can conclude that after the reference event, the two lower energy events took place in its source area.

The other events are reckoned among strong aftershocks. Events nos. 3 and 6 exhibit independent behavior and may be classified as specific processes. The developed technology shows its capacity in full extent in processing seismic events of different and previously unknown genesis, or unclassified events.

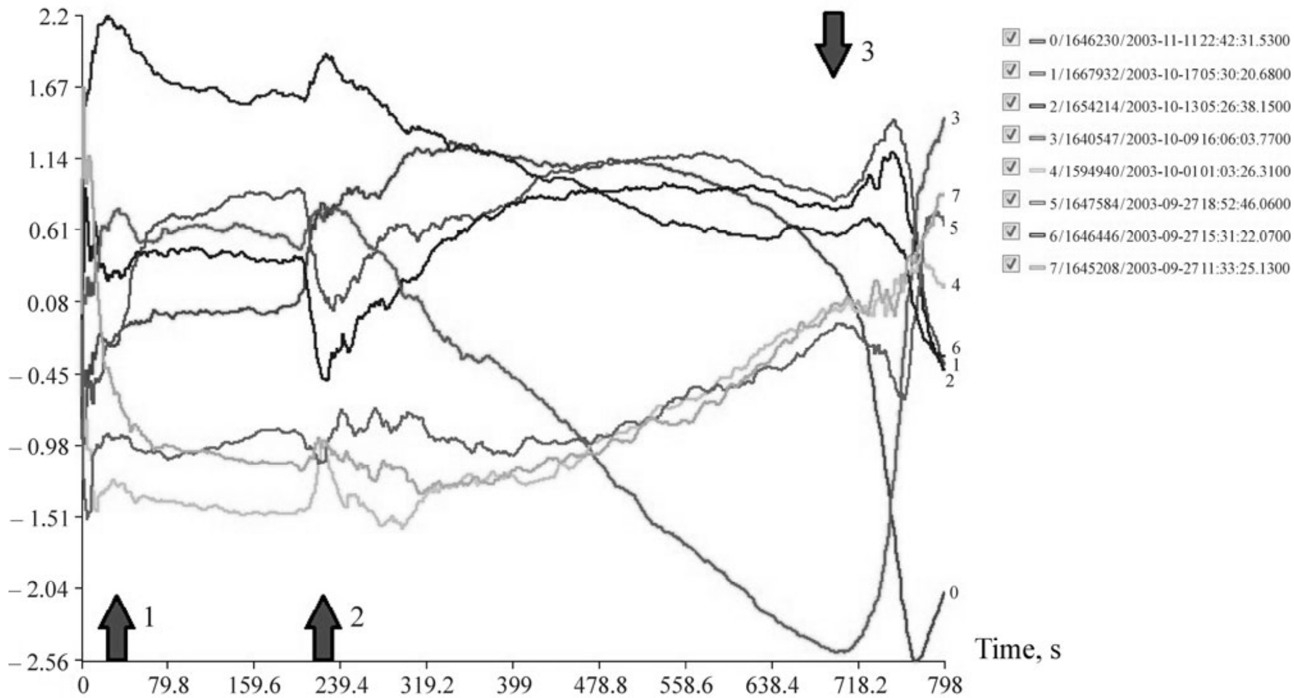

Fig. 4. Characteristic functions of seismic events in the vicinity of the Altay-Sayan earthquake source site.

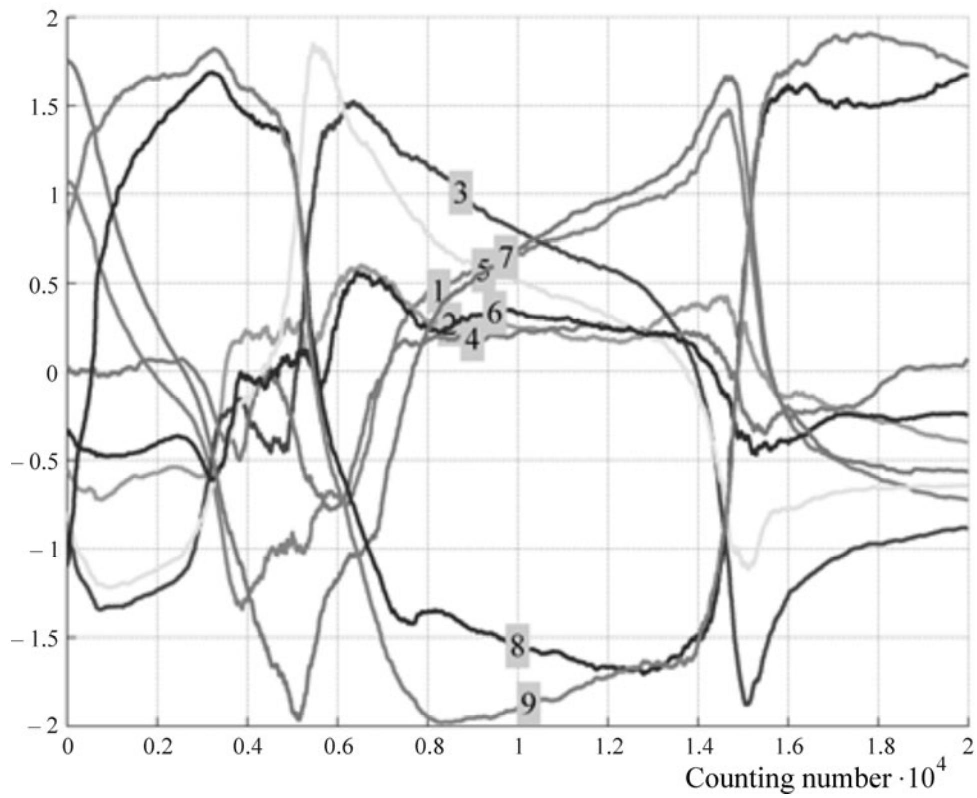

Fig. 5. Characteristic functions of seismic events in the Belovo district, Kemerovo Region: 1, 4, 7—industrial blasts in Bachatsky OPM; 2—industrial blasts in Krasnobrodsky OPM; 5—industrial blast in Sartakinsky OPM; 6—industrial blasts in Mokhovsky OPM; 8, 9—natural earthquakes; 3—unknown genesis event.

Figure 5 shows characteristic functions of seismic events recorded in the territory of Belovo district, Kemerovo Region, in January–February 2012. This set of events includes natural earthquakes, confirmed industrial blasts in open pit mines and an unknown genesis event geographically linked with

这组事件包括自然地震，露天矿中已确认的工业爆炸以及与地球相关的未知成因事件。

the industrial zone. The conclusion made after having compared the characteristic functions is that event no. 3 is the industrial blast in the Sartakinsky OPM (no. 5 in Fig. 5), and that event no. 3 and the other blast have nothing in common with natural earthquakes nos. 8 and 9.

The developed tool of the prompt classification of seismic events offers wide options of geodynamic monitoring for the convenience of regional services within civil defense and critical emergency, governmental supervision of mining and other industries as well as environmental protection.

系统开发的意义：开发的地震事件快速分类工具，提供了广泛的地球动力学监测选项，以方便在民防和紧急事件中的区域服务，政府对采矿和其他行业的监管以及环境保护。

CONCLUSIONS

The algorithm and programming software are presented in the article as a new tool of monitoring regional geodynamic situation. Conditionality of the conclusions can be overcome by expanding the set of analyzed seismic events in a region of interest. The present day efforts are directed toward elaboration of database of characteristic functions for natural and industrial-induced seismic events in the territory of the Kemerovo Region.

本文主要介绍了熵模型算法和编程软件，作为监测区域动力学情况的新工具。

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思考：
1、在开发系统时，要考虑的可扩展性；

2、了解以下Google App Engine云计算技术；

3、本文系统采用的时熵模型进行地震数据信息分类，开发的系统采用什么样的方式进行数据分类？

4、按照行业标准（本文是采矿准则和安全程序），自己开发的系统，我们的系统应该采用什么样的行业标准？

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