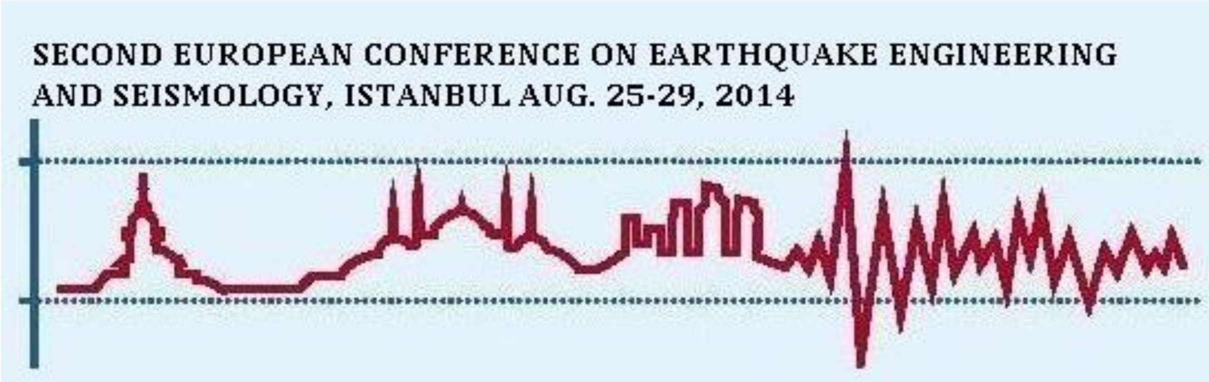

A WEB PLATFORM FOR SPATIO-TEMPORAL ANALYSIS OF SEISMOTECTONIC PROCESS

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Big volume of datasets and increasing the analysis complexity make ineffective traditional methods discovering hidden regularities. This is one of reasons why geoinformation technologies have been widely applied in the research of natural processes. Modern Geographic Information System (GIS) is a well-established tool for analyzing the processes presented by big sets of multimodal spatial and spatio-temporal geo-data.

We present a web platform involving interactive spatio-temporal data mining and knowledge acquisition tools, suited to coping with the inherent analysis complexities of seismotectonic processes. The platform implements real-time analysis of seismic activity fields and gives user a set of tools for comprehensive spatio-temporal analysis of seismotectonic process.

The platform consists of two GISs: SeismoMap и GeoTime 3.

GIS SeismoMap (http://dcs.isa.ru/geo) is intended to summarize the evolution of seismic processes. GIS is designed for a wide range of users. It monitors and analyzes the dynamic fields of seismic activity. We can compare fields of seismic activity with maps of seismic weather. Changes of seismic activity fields, defined as difference between current seismic activity, which is calculated for two-month temporal interval in the present, and background seismic activity, which is calculated for sufficiently large temporal interval in the past, show areas of seismic quiescence and intensification. Areas of statistically significant (abnormal) variations of seismic activity indicate essential changes in the seismic process. Decreased activity indicates seismic energy accumulation process and an increased activity indicates intensification of seismic process. It is known that both spatio-temporal anomalies may be precursors of strong earthquakes.

Every day SeismoMap reads regional seismic catalogs for T_1+T_2+$T\varepsilon$+$T_0 \times N \approx 2.5$ years from one of the sites www.isc.ac.uk, http://earthquake.usgs.gov/earthquakes/feed/, http://geonet.org.nz/, http://www.emsd.ru/ts/alldemo.php. Next the system calculates the following fields: a field of average seismic activity A_1 over the past T_1=2 years (Background interval), a field of average seismic activity A_2 for the resent T_2=2 months (Front interval), and the field of t-statistics, which detects changes (disorder) of seismic activity. The maps of these fields for recent N=10 weeks are displayed using API Google Maps. GIS can show the epicenters of earthquakes occurring within two months from the date of the current seismic activity map. The interface allows the user to read the time and magnitude of each earthquake.

SeismoMap's algorithm for computing the 3D seismic activity fields consists of two steps: (1) Estimating the spatio-temporal field of earthquake density for a given representative magnitude, (2) Calculating the field of seismic activity for a given b-value.

A method of kernel regression is applied to estimate spatio-temporal 3D grid-based fields of earthquake density:

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$$\lambda = \frac{1}{\pi R^2 T th(\varepsilon^2) th(\varepsilon)} \sum_{m_n \ge m_0} \frac{1}{ch^2(\frac{r_n}{R})^2 ch^2(\frac{t_n}{T})}$$

where λ is the value of earthquake density in a grid point, m is earthquake magnitude that is more then the representative earthquake magnitude m_0, $r_n<R\varepsilon$ and $t_n<T\varepsilon$ are the distance and time between earthquake epicenter and 3D grid point correspondently. The field of seismic activity is calculated for the base magnitude m_A and the magnitude interval δm by the standard formula.

In order to estimate time variation of seismic activity we use t-statistics:

$$t = (A_2 - A_1)\sqrt{\frac{n_1 n_2 (n_1 + n_2 - 2)}{(n_1 + n_2)(s_1^2 + s_2^2)}}$$

where: n_1 and n_2 are the numbers of seismic activity fields in time intervals T_1 and T_2 , A_1 and A_2 are the averages of seismic activity within T_1 and T_2 intervals, s_1 and s_2 are the sums of squares of deviations from the averages. If the values of seismic activity in the spatial grid node are realizations of the sequence of independent Gaussian variables and variance of sequences at intervals T_1 and T_2 are identical, then the statistics t has a standard Gaussian distribution. Therefore, if t takes values close to 0, then the seismic activity in the interval T_2 is the same as within T_1. If the value of the statistic $t > 3$, then we can assume that the seismic regime in T_2 is significantly changed.

GIS GeoTime 3 is multiuser, multifunction systems intended for an interactive presentation, comprehensive analysis and modeling of vector and grid-based geographic information on spatio-temporal processes. GeoTime is largely focused on the analysis of precursors of natural disasters. The analysis is based on the assumption that the earthquake preparation is accompanied by spatio-temporal anomalies of the characteristics of geological environment in the vicinity of a future event. GeoTime 3 can start autonomously (http://www.geo.iitp.ru/GT3/) or from GIS SeismoMap. In the latter case SeismoMap automatically loads in GeoTime 3 seismic and geographical data referring to the region selected in SeismoMap. After that the user can load in GeoTime 3 additional 2D, 3D and 4D grid and vector data in ESRI and/or ASCII formats from a remote server or user's computer.

Foundations of GeoTime 3 approach to analysis of spatio-temporal processes are described in Gitis and Derenyaev (2011) and Metrikov et al (2012). Three methods are used in the analysis of earthquake precursors: (1) evaluating of dynamic characteristics (features) of the process under study in the form of spatio-temporal 3D fields, (2) detection of spatio-temporal anomalies (possible precursors of accidents) in 3D fields, and (3) estimation of parameters of the anomalies (Gitis et al, 2012).

Spatio-temporal dynamic fields of features in GIS GeoTime 3 are calculated by geo-monitoring temporal sequences and earthquake catalogues. In the first case, to calculate the 3D feature fields the methods of spatio-temporal interpolation are used. In the second case, 3D fields of seismic flow parameters , such as density of earthquakes, b-value, seismic activity, fractal dimension, RTL criterion and their modifications, are estimated from earthquake catalogs. To calculate these fields GeoTime 3 uses known methods of kernel regression as well as a new method of nonparametric adaptive smoothing (PS-approach), developed in a series of papers Polzehl and Spokoiny (2000, 2006). This method is considered as the result of smoothing the local likelihood estimation for a broad class of probabilistic models (exponential family distributions). The peculiarity of PS-approach is to look for and the union of statistically homogeneous zones, which improves the accuracy of estimating the fields. When applying PS-approach for estimating the density field of earthquakes, the model of an inhomogeneous Poisson point field is considered. Observed data is the number of epicenters of earthquake with magnitude greater than specified, occurred in a fixed time in regular spatio-temporal cells. The result is 3D spatio-temporal field of the estimates of the Poisson distribution parameters, satisfying the locally-weighted maximum likelihood function. Experimental study made on artificial point fields and the fields of earthquake epicenters shows that PS-method restores the point density fields (the fields of earthquake epicenter density) at about with the same accuracy as the kernel methods with optimally matched the width of smoothing window. At the same time, it should be noted that the PS-method does not require the selection of the width of the smoothing window, which is an additional problem in the application of kernel techniques.

Anomaly detection in scalar 3D fields is based on the assumption that geological environment is heterogeneous in space, and in the normal state has a stationary dynamics, which is violated in course of the preparation of a geological disaster. In order to detect an anomaly, the time series at a grid node are analyzed. The current time interval of the time series is divided into two consecutive subintervals. The lengths of subintervals are set by the user, in accordance with the context of the problem under consideration. The techniques of anomaly detecting are based on methods of statistical hypothesis testing.

The existence of a spatio-temporal anomaly gives only a qualitative idea about the disaster's precursor. However, to predict a disaster with a given energy, it is necessary to formally indicate the location and time of the event. We assume that maximum of the anomaly is located in the center of the disaster zone and decreases exponentially in space towards the boundaries. In order to estimate parameters of the anomaly, the projection of the 3D anomaly field to each spatial slice is approximated by a Gaussian. The coordinates of the center, the height and the damping are tunable parameters of the Gaussian. A normalized value of the Gaussian approximation accuracy, which varies from 0 to 1, is used to evaluate the degree of confidence of the presence of an anomaly on the slice.

We discussed new methods of monitoring and spatio-temporal data mining of the seismic process. The methods are implemented on a web-GIS platform consisting of GISs SeismoMap and GeoTime, which are openly accessible. GIS SeismoMap performs real-time monitoring and analyses spatial dynamics of seismic activity. GIS GeoTime allows one to perform more sophisticated analysis of the seismic process. The user can use the additional information loading it from a remote server or local network. GIS platform can be customized for any regions.

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