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The Research of Geophysical Fields of South Yakutia

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ABSTRACT

The data analysis of observations of seismic activity was conducted over the period of 2008-2012. The information about the quantity of seismic events which took place, the released seismic energy, and the distribution of parameters within the periods has been estimated. The lgN (K) dependency graph for the earthquake K = 11-15 ahs been plotted for South Yakutia region. The data resulting observations and the analysis conducted allow to identify the potential geophysical forerunners of earthquakes, determine their relationship to seismic activity in South Yakutia. The reliable forerunners of earthquakes have been indicated for the rapid assessment of seismic hazard. It is concluded that the anomalous distribution of seismic events in time leads to the possibility of constructing a model of seismic events with the necessary condition for the significant number of experiments conduct in order to obtain more reliable estimates of random variables in the model. Conducting a comprehensive interpretation of the observed geophysical forerunners, comparison of graphs of geophysical parameters, taking into account previous earthquake foreshocks make possible to forecast the approximate place of occurrence and the strength of earthquakes.

KEYWORDS
Construction of pipelines, Seismic activity, Classes of seismic events, Seismic events, Magnetic field

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Introduction

Due to the next stage in the development of South Yakutia, and taking into account the structure of industry and transport infrastructure in the 20th century: the Baikal-Amur Railway, the southern section of the Amur-Yakutsk highway (the Lesser BAM), industrial and civil objects of the City of Neryungri the issue of evaluation of seismic activity in this region has been relevant for several decades.

Construction of the "Eastern Siberia – Pacific Ocean" pipeline and the development of the Elga coal deposit, the northern section of the AYH (Amur-Yakutsk highway) and the rail connection Ulak-Elga tasks to ensure their further seismic safe functioning to a new level, as far as taking into account the

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potential environmental consequences and the development of exogenous processes (Erhabor & Don, 2016).

Over 20% of the territory of the Russian Federation is referred to the earthquake endangered zones, where the earth shocks exceeding 7 scores on the Richter scale are possible. More than 5% of the territory of Russia is occupied by extremely dangerous 8-9-scored zones. (Zavyalov, 2006). These include the North Caucasus, Altai, Sayans, the Baikal region, the Stanovoy Highlands, Yakutia and the entire Far East, including Kamchatka, Sakhalin and the Kurile Islands. The rest of the country is considered to be moderate seismically quiet, but bevertheless the echoes of earthquakes can cause earth tremors up to 5 scores (Shebalin, 2006).

The recent studies and observations have shown that in many countries, as well as in Russia, the estimated assessment of the level of seismicity is low (Tsapanos, 2008). Also, the technique that allows to forecast with high accuracy the place and the time of an earthquake is not yet developed. The recent examples – the earthquake in Tuva which took place in December. The catastrophic earthquake which occurred in Japan in 2011, to which the great number of scientific works is dedicated (Garcia et al., 2014). The Japanese earthquake in 2011 caused the electromagnetic, atmospheric, gravity anomalies that make it possible to analyze the detector response and draw conclusions about the most efficient algorithms to forecast the new periods of increased seismic activity, as far as the new earthquakes (Klausner et al., 2015).

The earthquake in Chile in 2012 is described in detail and studied in terms of the assessment of the previous micro-seismic activity, which could be a signal of impending seismic event (Wang et al., 2012).

According to the experts, the presence on the territory of Russia of such a great number of zones where the destructive earthquakes are potentially possible, makes the forecasting of seismic activity and the development of specific measures for construction in seismic zones one of the most important objects of attention by the state (Sobolev, Ratushny & Kushnir, 1990).

The meteor overflying the city of Chelyabinsk (Russia) in 2013, caused the electromagnetic and gravity anomalies, and also there have been recorded significant changes in the ionosphere. This event is related to the study and forecasting the periods of increased seismic activity due to the fact that the similar anomalies are also observed at notable earthquakes (Yang et al., 2013).

The seismicity and volcanism of the Earth, as well as the methods for their implementation – the tectonic earthquakes and volcanoes intended to "reset" the tectonic energy accumulated in the Earth – are the all-planetary feature. These grand dissipative processes are based on two different elementary acts: the formation of a crack and the occurrence of a melt. One and the other is the reaction of the environment to an external load. The first leads to the seismic activity, the second – to the volcanism. The main reason for these phenomena on the Earth is in the implementation of the principle of minimizing its potential gravitational energy (Chao, Gross & Dong, 1995).

However, not only volcanism "monitors" the compliance of the shape of the Earth to the principle of energy minimization. More recently the scientists came to the conclusion that the earthquakes may lead to the fact that our planet becomes increasingly more compact and spherical, and its gravitational energy reduces and converts into the heat energy. Moreover, these authors argue that earthquakes not so much "reset" tectonic stresses as redistribute their impact over the lithosphere of the Earth (Chao & Gross, 1987).

Nowadays there is hardly any reliable method for the earthquake forecast. Moreover, it is generally not possible without reaching a clear understanding of the physics of the earthquake. The problem of the earthquake physics has not found its decision, and this remains one of the most important tasks of Physics of the Earth.

A long-term earthquake forecast is one of the most important fields of research and works on the forecast and assessment of seismic hazard (Gao et al, 2014). The scientists of all countries work hard to develop an algorithm for long-term forecasting and short-term forecasting of earthquakes (Gao et al., 2014).

South Yakutia is a seismically active region of Russia. In the other highly seismically active regions of Russia, the methods of cyclic long-term forecasting of earthquakes and long-term forecasting of earthquake are used, which are based on the patterns of distribution of approximate places of the further strongest earthquakes ("seismic gaps") and the seismic cycle (Fedotov, 1968).

A huge progress of seismology for 100 years has been stimulated basically by obtaining the constantly improving data (Berkhemer, Zschau & Ergunay, 1988). The most important steps in this direction have been made by scientists fluent in the methods of mathematical physics. Each generation of seismologists progressed to obtaining the quantitative data, overcoming the barriers to first calculations using mechanical calculators, and more recently, due to the advances in digital microprocessors and enhanced sensors for monitoring (Shoda et al., 2014). During the past two decades the electronic computers have become efficient enough to use them to extract a large share of the information contained in the seismograms (Gao et al., 2014). Thus, the quantitative picture of modern seismology consists of close cooperation between high-quality source material, the detailed mechanisms of seismic wave sources and the models of internal structure of the Earth. H should be noted the works on improving the systems for monitoring and identifying the changes in gravity, seismic, electromagnetic, atmospheric and ionospheric anomalies connected with the seismic activity and the events related (Shoda et al., 2014).

These seismic observation data and recording of potentially dangerous events demonstrate the need to study the seismic activity in South Yakutia, the parameters and the degree of hazard of the recorded earthquakes for the further evaluation, zoning and forecasting of seismic medium.

The scientists from different countries use the most varied methods of gravity, seismic, electromagnetic, and geochemical methods to forecast the earthquakes (Uyeda, Nagao & Kamogawa, 2009). There are also the scientific studies on groundwater level changes to forecast the upcoming increase in seismic activity (Singh et al., 1999).

The task of the time and location of occurrence of large earthquakes forecast is central in seismological studies (Tsapanos, 2008). It is obvious that this problem can only be solved in the formulation of detailed complex observations of seismic and geophysical fields by establishing the regularities of their changes in time and space in the zones of high seismic activity.

Here should be noted the achievements and the results of studies of changes and anomalies of geophysical fields caused by the tsunami which are the consequences of strong earthquakes (Klausner et al., 2014).

In solving the problem of forecasting the degree of seismic hazard of catastrophic earthquakes not only the results of instrumental observations in Table 1, but also the assessment of the potential earthquake energy for a specific zone, its magnitude, intensity and radius of influence of seismic events on the geophysical parameters are of particular interest (Chao, Gross & Dong, 1995).

Table 1. Recorded seismic events for the energy class K≥8, 1st quarter of 2012

S.R. No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Date	22.01	23.01	27.01	13.02	15.02	17.02	20.02	22.02	25.02	08.03	09.03	19.03	23.03	25.03	27.03	29.03
K	11.5	10.3	8.5	9.9	9.5	8.8	8.3	9.2	9.2	9.5	9.2	10.8	10.1	9.2	9.4	9.7

Method

In the City of Neryungri there is a scientific – research laboratory for monitoring and forecasting of seismic events equipped with modern geophysical equipment. The regular monitoring of variations of geophysical fields in the area of the city (gravimetric and magnetometric observations, electromagnetic, barometric, temperature) is established. According to the results of long-term observations of various geophysical fields, their abnormal behavior is observed before strong earthquakes.

The formed statistics of observations allows to present and evaluate the available information on the number of seismic events that took place, the released seismic energy, the distribution of parameters by periods (Fig. 1), set the presence of correlation.

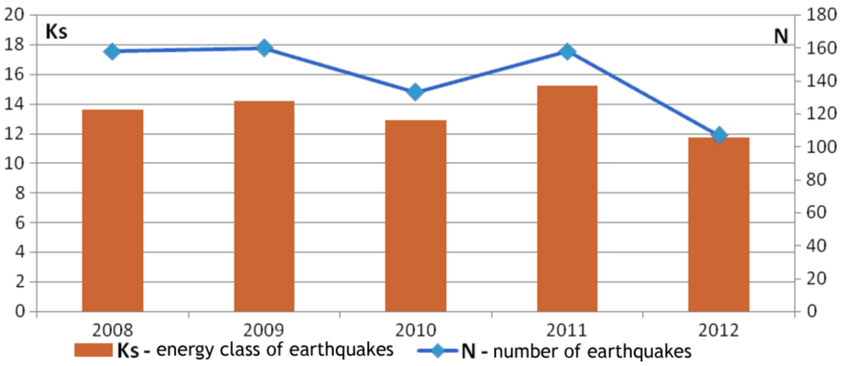

Figure 1. Total annual released energy and the number of earthquakes per year

During the period of 2008-2012 the following values have been obtained:

– The average annual total released energy is $K_{srg} = 11.0$;

– Maximum total released energy $K_{max} = 15.2$ in 2011; while in the same year there were recorded earthquakes with Ks_{max}: 15.0 and 14.6;

– Minimal total released energy $K_{min} = 11.7$ in 2012, thus, a maximum released energy of an individual event in 2012 was 11.5.

Pearson correlation coefficient for the annual values of N and K was r = 0.89.

It should be noted that the energy values K and M (magnitude) are not completely independent, and are correlated with each other. The most frequently used is the following relationship:

$$K = 4 + 1.8M$$

Thus, the correlation coefficient is ≈ 90%.

Data, Analysis, and Results

The evaluation of non-periodic changes of geophysical parameters, identification of possible dependencies obtained from the observations is a non-standard task, as far as non-periodic changes of the above data during the change of seismic activity are often caused by not only local, but also regional factors. It should be noted that to conduct a correct analysis of the identified anomalies the normal seismic background, its dynamics in time shall be considered. Thus, there are situations when it is possible to obtain various combinations of forerunners of seismic events from one set of data i.e. each stage of the forecasting process is based on a relevant set of forerunners prior to the occurrence of earthquakes (Chao, Gross & Dong, 1995).

One of the main parameters of the seismic regime is the change of the recurrence curve (angle) in time : γ or b-value depending on the parameter used as a characteristic of earthquake magnitude: K or M, respectively (see fig. 3). Numerous measurements of the γ parameter showed that its values for the specified K range are within 0.44–0.56.

The corresponding dependence is approximated by a straight line represented as:

$$\lg N = \lg A - \gamma K = a - bM,$$

wherein $b = 1.8\gamma$ (Tsapanos, 2008).

The recurrence curve for a specific region built on the basis of long-term observational data makes it possible to speak with a certain degree of probability about registration of earthquakes of a certain class in the future.

Given the accepted view of the fact that the seismic event takes place in the aftermath of seismic quiescence or after foreshock activation, in order to identify the anomalies of geophysical parameters it is possible to use the following approach (Stein et al., 2006). It is necessary to experimentally highlight the so-called anxiety level ξ_{tr}, and in this case the seismic quiescence anomaly is defined as $\xi_n \leq \xi_{tr}$, and the seismic activity anomaly $\xi_n \geq \xi_{tr}$. The anomaly is defined as false or implemented depending on whether the earthquake took place in the data sampling period $T_{ozh} + |\sigma|$.

The data resulting observations and the analysis conducted allow to identify potential geophysical forerunners of earthquakes, determine their relationship to seismic activity in South Yakutia.

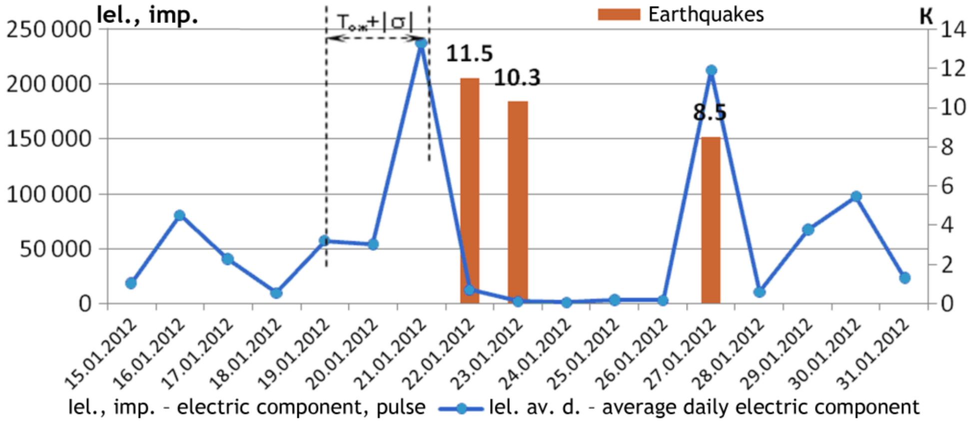

Figure 2. Variations of the pulsed natural electromagnetic field of the Earth, January 2012

The figures above show the variations of natural pulsed electromagnetic field of the Earth (the electric component Iel) related to seismic activity; thus, the abnormal changes of the specified field are observed in the final stages of preparation of the earthquake (Fig. 2). Based on data analysis, it can be concluded that an earthquake occurs during the period of registration of anomalies or no later than 2-4 days after their completion.

Consider the variations of the full vector of the magnetic field (T, nTl) in Fig. 4. Observational data in the 1st quarter of 2012 show that abrupt changes of the (T) parameter are recorded before the seismic events. In January, two days (T_{ozh}) before the earthquake of 11.5 class the magnetic field increased by 171 nTl, and then after the earthquake it decreased by 155 nTl. Thus, in March the T_{ozh} ranges from 2 to 4 days ($T_{ozh}+\sigma$). Separately, it should be noted that the dynamics of the gravimeter records is identical to the changes in the magnetic field of the Earth. Fig. 3 shows abnormal variations of Δg gravity, mGal before earthquakes.

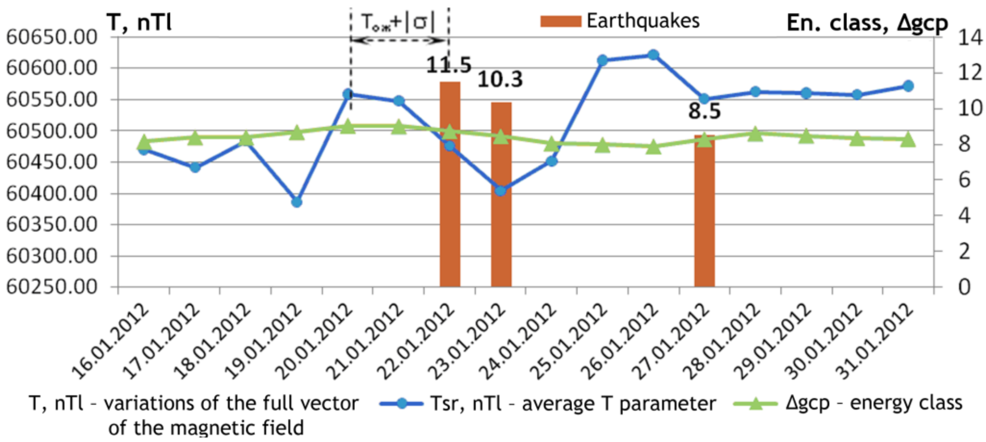

Figure 3. Abnormal changes in the full vector of the magnetic field, the gravity

A separate issue is the variations of the full vector of the magnetic field in February, which in addition to an abrupt change of T is characterized by the total increase of the parameter values comparing to the normal values (with an average of 60 470 to 61 200 nTl) against the sequence of seismic events from the energy class of 8.3 to 9.9.

Discussion

Given the results of the monitoring of seismic activity considered above, the following (non-exhaustive list) reliable forerunners of earthquakes can be emphasized for the rapid assessment of seismic hazard:

– abnormal changes of pulsed electromagnetic field of the Earth;

– an abrupt change of the full vector of the magnetic field of the Earth and the increase of T, nTl parameters from the average values;

– variations of Δg gravity.

However, when forming conclusions about the upcoming seismic event on the basis of certain forerunners, the probabilistic nature of the forecast shall be taken into account, as the abnormal changes of the forerunners do not appear before each of the earthquakes; and not every abnormal change of some of the geophysical parameters can be related to the change in seismic activity.

In addition, the available limited statistics of strong earthquakes is insufficient to properly assess the probability of strong earthquakes. Consequently, the statistics of weaker seismic events and extrapolation on the recurrence curve shall be applied (Tiampo et al., 2002).

Consider the distribution of the number of seismic events and the energy released in time with distribution by months of the year. The values of N and Ks are defined as the average monthly values for the period of 2008-2012 (Fig. 4).

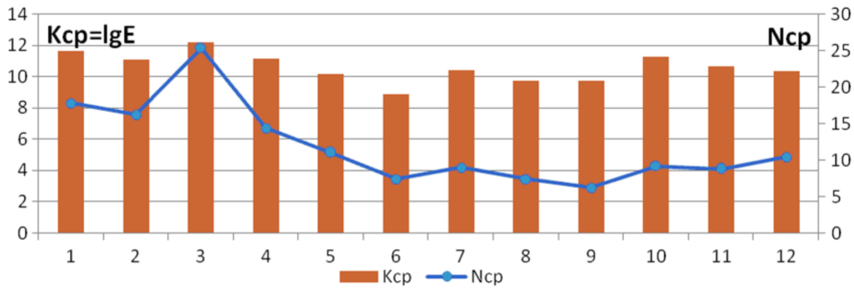

Figure 4. The distribution by months of the year Kcp and Ncp for the period of 2008-2012

At the same time, the analysis of seasonal fluctuations in the studied data in order to identify patterns of recurring differences in the dynamics of the series, depending on the time of the year, shows that in the considered period the following is obtained per month at averaging the tested values:

– Average total released energy is K_{srm} = 10.6;

– Maximum total released energy K_{max} = 12.2 in March; at the same time, it shall be noted that the maximum released energy is in January-April, October;

– Minimum total released energy K_{min} = 8.9 in June; while a reduction of the energy released is noted from May to September.

Pearson correlation coefficient for N and K average monthly values was r = 0.83.

One shall consider the international experience in improving the systems for monitoring and identifying the changes in gravity, seismic, electromagnetic, atmospheric and ionospheric anomalies related to the increased seismic activity and the events paragenetically-related hereto (Shoda et al., 2014). It is necessary to develop and introduce new technologies to monitor the increased seismic activity on the territory of South Yakutia and Russia as a whole. For the regions adjacent to the seas and oceans, it is advisable to introduce a system to monitor the changes and anomalies of geophysical fields caused by the tsunami as the events of paragenetically-related to the seismic events (Klausner et al., 2014). In Russia as a whole it is advisable to consider the large-scale introduction of ionospheric anomalies monitoring system in the context of seismic activity and its forecasting (Yang et al., 2014).

Conclusion

Thus, the abnormal distribution of seismic events in time leads to the possibility of constructing a model of seismic events with the necessary condition for the significant number of experiments in order to obtain more reliable estimates of random variables of the model.

However, the evaluation of abnormal changes of only one of the identified earthquake forerunners to draw conclusions about the state of the estimated seismic zone can lead to false alarms. Therefore, the evaluation dynamics of several parameters at the individual seismic events, their interdependence and anomalies are of particular interest.

Through a comprehensive interpretation of the observed geophysical forerunners, comparing the graphs of geophysical parameters, and taking into account foreshocks forerunning the earthquakes, an approximate location and the strength of the earthquake is forecasted.

This work consists of additional observations and conclusions, which are very necessary for the statistical analysis of seismic activity of a worldwide basis, for the analysis and forecast of seismic activity of regional and local bases. Further studies and works shall complement the forming database and increase the accuracy of the statistically determined data, and shall increase the quality of the forecasted estimates.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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