Analysis of the data of electromagnetic monitoring of earthquakes at the territory of China: A new approach

A.S.Alekseev, A.V.Avdeev, E.V.Goruynov, V.V.Skazka

Computing Center, Siberian Branch of Russian Academy of Sciences, Novosibirsk 630090, Russia.

Abstract

An attempt is made to use the data of monitoring of electromagnetic precursors of earthquakes for reconstructing the time dynamics of some characteristics of the medium in the regions under observation. The results obtained show that, although the data are designed for statistical analysis, some parameters of the medium associated with the development of cracking can be estimated with a good accuracy.

Keywords: Earthquake, Electromagnetic Precursors, Cracking Zone.

1 Introduction

Seismologists in different seismically active regions of the Earth use, as a rule, the whole set of geophysical methods, taking into account the complex character of the seismicity processes. It is well known that anomalous changes of different geophysical fields taking place before many strong earthquakes can apparently be considered as precursors of earthquakes. However, there are always contradictory data about the possibility of an earthquake and its parameters in the large set of such precursors.

One significant limitation of the algorithms of prediction available now based on studying the development of anomalies of various nature is basically the statistical character of these algorithms. They practically do not take into account the quantitative characteristics of the physical process of earthquake preparation itself.

Rich material on complex study of the process of seismicity ([2], [8]) has been accumulated in the world in the last few decades. Some Russian institutes (Institute of Geology and Geophysics of SB RAS, Computing Center of SB RAS, Institute of the Earth's Physics of RAS and others) have contributed significantly to this problem. More than a thousand of anomalies which can be considered precursors of earthquakes have been detected in China by investigating approximately a hundred of large earthquakes [7], [9]. They form a data base of multidisciplinary investigations.

The procedure of prediction of the magnitude, place and time of earthquakes has been developed by the Chinese scientists. Some real predictions have been successful. The Chinese scientists note, however, that these works are still at the initial stage and need theoretical development [5]. The theoretical foundations of the quantitative estimate of contradictory sets of precursors must be found.

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The degree of cracking of rocks is one of most important parameters influencing different geophysical fields and rheological properties of the Earth's crust. A cracking zone occurs in the forming earthquake source. Some dynamic characteristics of this zone can serve as precursors of an approaching earthquake [1]–[3].

The propagation of electromagnetic waves and currents is known to be described by the Maxwell system of equations. In practice, simplified models (for specific cases) are used to solve various problems, which describe the process of distribution of currents in media. Then, numerical calculations are carried out for these simplified models.

In our case, when the medium's structure is not known, we are forced to construct a medium's model, in which the apparent specific resistance is most similar to the resistance measured in the process of monitoring. An attempt of answering the question of a preparing earthquake can be made by analysing the time variations in the medium model obtained.

Such problems of reconstruction of the parameters of a medium by using recorded data have been investigated for a long time. These are the so-called INVERSE PROBLEMS.

In the present paper we are interested in the variation of only one parameter of the medium under study, namely, cracking. This parameter influences other geophysical fields, for example, the gravitational field, the elastic wave field, etc. This makes necessary investigation of the multidisciplinary inverse problems (i.e., the problems of reconstruction of parameters of the medium using all available information of various physical nature). Solutions to these problems may allow more accurate reconstruction of the medium's parameters and, consequently, more accurate prediction of time of place of earthquakes [3]. Investigation of the multidisciplinary inverse problems has begun recently. Therefore, we do not dwell on the details of these problems in our paper.

2 The development of an approach to using the data of electromagnetic monitoring of earthquakes

An analysis of the data of electromagnetic monitoring made available to us by the Chinese specialists, allowed us to make the following preliminary conclusions:

- Routine observations are carried out with the help of the four-electrode unit AMHB (AB = 1000m, MH = 300m). The voltage difference in the line MH and the current strength in the line AB are measured every day. Using the results of these measurements, the apparent resistance is computed in a standard way, and the time series representing the variations of the observed signal are constructed;
- It follows from the data presented that the amplitude of variations of the apparent resistance relative to the normal noise background is small (1–2 per cent) and is comparable to the error of measurements;
- There are practically no data on geoelectric structure of the region. It is fair to note that the Chinese technology based on the statistical analysis of earthquake precursors does not need these data.
- The basic limitation of the data presented is the fact that it is difficult to use them for solving the inverse problems of geoelectrics.

In this connection, of interest is an analysis of a possibility of using the data of the Chinese researchers for solving the "adapted" inverse problems of geoelectrics to attempt the prediction of earthquakes. Besides, if the classically understood inverse problems are not solved satisfactorily, it would be interesting to try to get an answer to the question: what parameters of the medium can be reconstructed, or at least estimated with the help of the chosen cost functions on the basis of the optimization method using the material available?

The well known Archie's law [4], [6] relates electric conductivity and cracking by the law $\sigma = a \cdot \sigma_\omega \cdot \phi^m$, where σ_ω is the electric conductivity of the fluid, ϕ is porosity, m is the "cementation index". In our investigations, we mainly tried to estimate the variations in m versus time. As the data were not adapted to the reconstruction of the geoelectric cross-section (the measurements were made not on the profile, but only between two points), we have chosen the simplest model as a basis. Namely, the whole half-space in the region under study was considered homogeneous. This means that the "averaged characteristics of the medium" were reconstructed [1].

When solving the inverse problem we use the method of minimization of the cost function. We assume that in the time interval considered (t_0, t_1) the parameter m varies by the law $m = m_0 + \alpha * t$, where t is time. The cost function $\Phi = \int_{t_0}^{t_1} |\rho(t) - \rho_{mod}(t)|^2 \, dt$ is considered. Here $\rho(t), \rho_{mod}(t)$ is the measured and calculated apparent resistance, correspondingly, at the given m_0 and α. Then m_0 and α are found, at which Φ reaches a minimum. The parameter α is most informative, because it shows the dynamics of the process. Moving the "window of observation", namely, the interval (t_0, t_1) along the whole data array of monitoring, we reconstruct "the evolution of the dynamics" of the parameter α.

The following comparisons have been made:

- A series of test solutions of the direct problems has been carried out. The behavior of solutions at varying model parameters of cracking has been studied within the framework of the Archies law to understand what model adequately describes the variation of the observed data versus time;
- After a series of numerical experiments, the cost functions most suitable for solving the inverse problems have been chosen;
- Test calculations for solving the inverse problems using synthetic data have been carried out;
- It has been concluded, on the basis of the results of work using real data, that the available experimental material and the data on the medium under study are suitable for solving the inverse problems in "adapted" statements.
- The possibility of using the data made available by the Chinese side for solving the inverse problems in combined statements has been analyzed.

The analysis and study of the real data have shown that the effective parameters of cracking can be reconstructed within the framework of the Archies law with some certainty. In any case, the obtained estimates of the effective parameters associated with the cracking of the medium correlate well with the time of earthquakes.

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