The 9th IEEE International Conference on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications
21-23 September 2017, Bucharest, Romania

Spatio-temporal Data Processing of Automated Geodynamic Monitoring System

Nikolay V. Dorofeev [1], Oleg R. Kuzichkin [1], Roman V. Romanov [3], Alexander V. Koskin [4]
[1] Murom Institute of the Vladimir State University
23 Orlovskaya str., Murom, Vladimir region, Russia
dorofeevnv@yandex.ru, www.mivlgu.ru
[2] Orel state University by I. S. Turgenev
95 Komsomolskaya str., Orel, Russia

Abstract—**In this paper, an approach to the organization of spatial-temporal processing of geoelectrical data in the system of automated geodynamic control is considered. It allows combining methodical, algorithmic, program and information support of the processes of collecting and processing of geodynamic information at subjects to control. Use of the relations obtained simplifies the geodynamic estimation of the variations of individual isolated research objects on the basis of an analysis of model coefficients in the transfer function of the geoelectrical section.**

Keywords—geodynamic control; geoelectric methods; transfer function; data processing; automated system.

I. Introduction

Currently there are significantly increased loads on the environment in the natural – technical systems (NTS). This leads to the need for the development and implementation of automated systems of geodynamic systems controls, which are designed to solve the problems of protection and the prevention of accidents on the technical and life-supporting objects of NTS [1]. Construction of geodynamic automated control systems is based on the concept of the possibility to assess and forecast NTS based on local observations of individual dedicated geodynamic activity areas [2-4]. Some media volumes have their own natural rhythm and their and by geodynamics are determined by its natural regimes, complicated technogenesis [5]. They have certain properties and characteristics allowing to allocate them as the separate geodynamic objects belonging to a certain class of models. The geological environment is represented as a set of large and small volumes of the environment (objects), and it is possible to allocate separate geodynamic objects defining this or that process in NTS. It gives the chance to focus our attention on the allocated local geodynamic indignations at the generalized assessment of geodynamics of the geological environment.

It is known much less about both manner and intensity of changes in local climate systems in time [6] and space scales [7] in comparison with the intensity of local geodynamic changes. Therefore, control of the allocated geodynamic objects provides information about the possible catastrophic changes earlier than when tracking geodynamics environment as a whole. Accordingly, control of the allocated geodynamic objects provides information about the possible catastrophic changes earlier than when tracking geodynamics environment as a whole. They provide efficient organization of observations of geological objects, assessment of the status and development forecast. The main model used in the analysis of data obtained by geoelectrical methods is the geoelectrical section. Geoelectrical section is a set of electrical and geometric characteristics of the rocks under study.

The main problem of their application for the geodynamic control in NTS is that the currently existing automated geoelectric monitoring systems designed for scientific research are based on a comparative analysis of time series with the filtration of natural and man-made rhythms and on the allocation of the useful geodynamic component [8].

In most cases, this approach is useful for research purposes and is extremely effective when implementing control functions designed for rapid response to critical geodynamic changes in NTS.

The purpose of this work is to consider the analysis of methods of existential handling of geoelectric data in the systems of the automated geodynamic control of the processes of collection and handling of geodynamic information providing methodical, algorithmic, program and technical and information maintenance[1].

II. Structure of the Distributed Information Data Processing of the Automated Geodynamic Monitoring

The structure of the distributed information data processing at the automated geodynamic is presented in the Fig. 1.

In this structure, it is possible to allocate subject to control, the studied geological environment. The structure

[1] Work is performed within the state task of the Ministry of Education and Science of the Russian Federation №5.3606.2017/PC

includes a necessary quantity of measuring systems which cover the controlled territory.

Collection of data on the current parameters of the geological environment is carried out by means of basic geoelectric measuring systems in stationary and temporary points. Electrolocational installations are applied as geoelectric measuring systems [9].

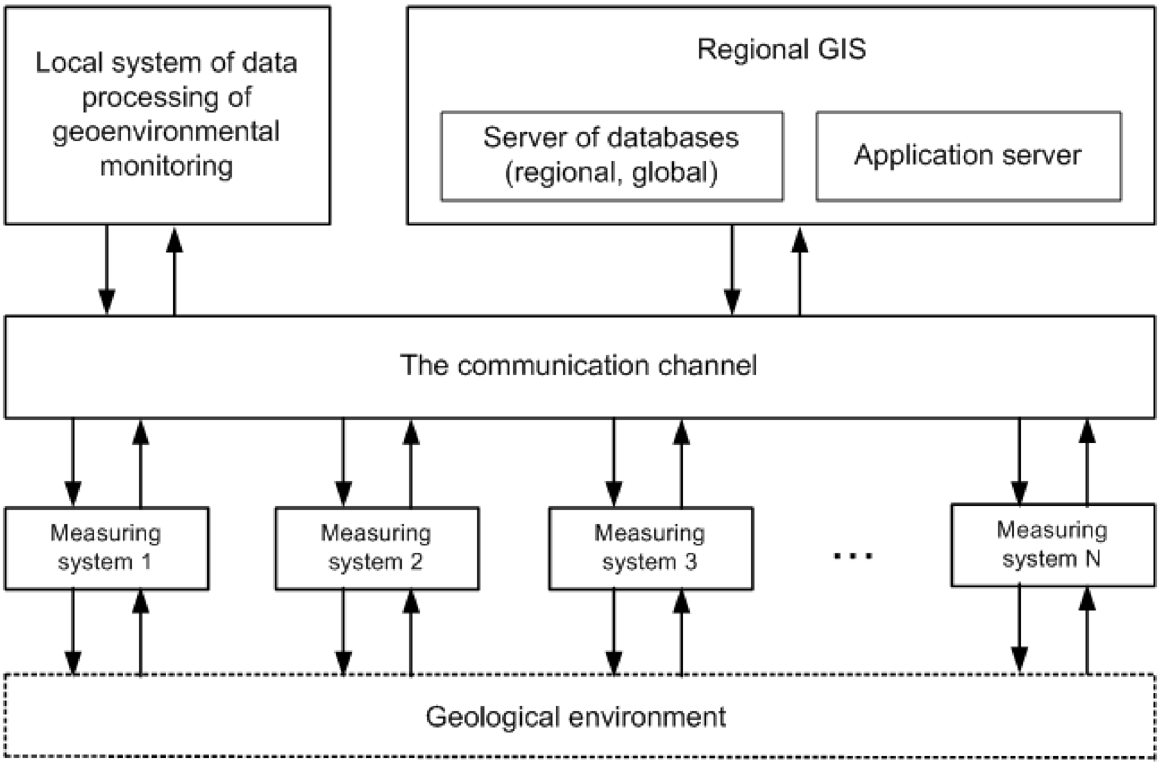

Figure 1. The network structure of a distributed information processing geodynamic monitoring data

Basic geoelectric measuring systems interact with the local data processing system of geodynamic monitoring through a communication channel. The communication channel is under stood as the physical transmission medium, comprising connection lines or a space in which electrical signals propagate, and data transmission equipment. Systematics of primary data and accounting data collection settings (the metrological characteristics of measuring systems, in which the parameters were measured, the spatial coordinates of the object, the characteristics of the surrounding area) takes place all these parameters are passed by the measuring system to the central server of the local data processing system [10].

Local system of geodynamic monitoring data processing interacts via a communication medium with regional GIS using an Ethernet data transmission technology. Data of obtained and processed measurements from checkpoints measuring systems, thematic maps with highlighted areas of particular risk of negative geodynamics, and reports a retrospective analysis of hydrogeological condition of using the accumulated data bank, etc. is transmitted and processed to the regional GIS.

III. SPACE-TIME DATA PROCESSING

Geodynamic variations of the environment in the area of NTS actions have considerable complexity and diversity, which leads to the need to increase the number of monitored parameters of spatially distributed geodynamic objects. This fact significantly increases the flow of information in the geoelectric data acquisition system. The main purpose of the space-time processing of geoelectric data consists in the fact that, in the solution of geodynamic control tasks it is necessary to substantially reduce the processing time for forming the operational reaction to critical changes of the research object [11]. Improvement of quality indicators, the reduction development time of forward-looking solutions that increase the efficiency of the geodynamic control in NTS – is the main goal of the development and application of automated systems of space-time processing of geoelectric data.

Fig. 2 shows a generalized structure of a system of space-time processing of geoelectric data showing the basic processes of information processing of geoelectric data at geodynamic control in NTS.

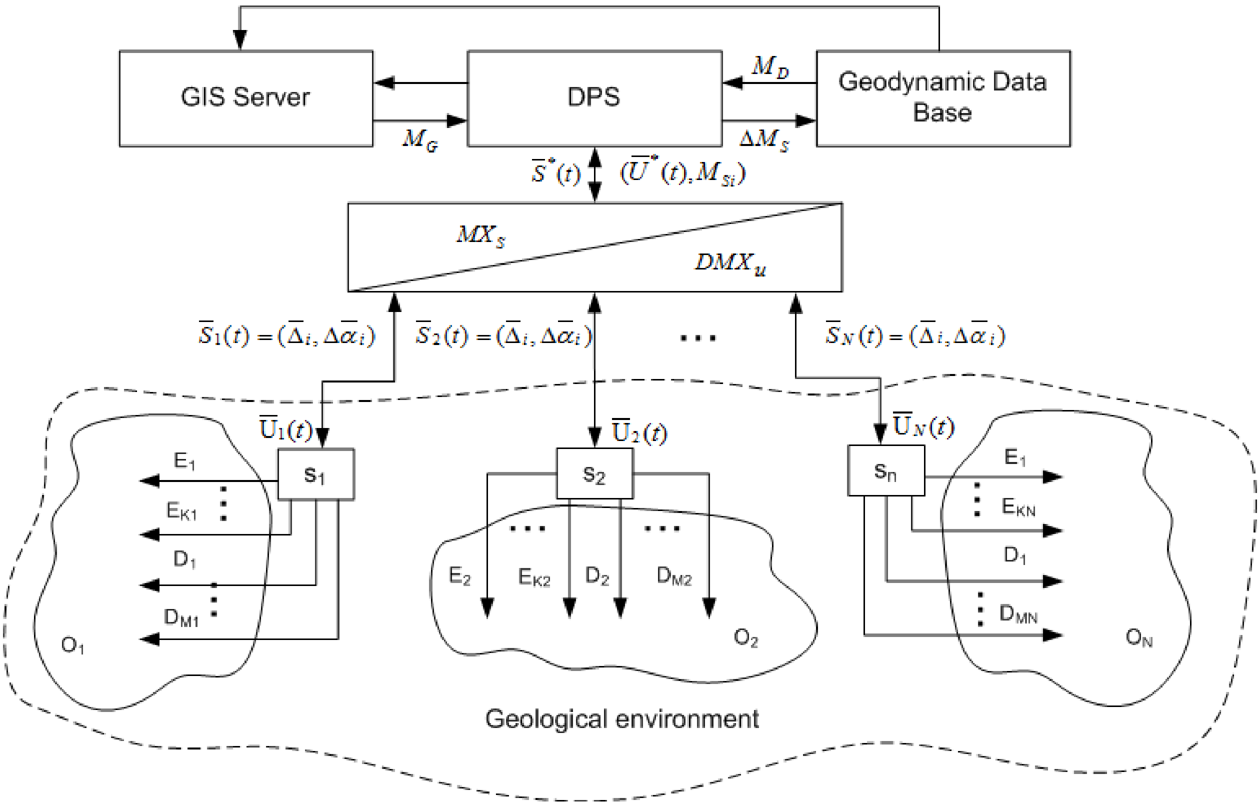

Figure 2. The system of space-time processing of geoelectric data geodynamic control

System Initialization of space-time processing of geoelectric data of geodynamic monitoring on the basis of formation of the vector model M_S parameters for monitoring the geological environment area (Geological environment). At the same time, these model parameters are defined on the basis of preliminary prospecting data according to base of geodynamic models (Geodynamic Data Base) M_D and data of GIS – server (GIS Server) M_G:

$$M_S = F_M(M_D, M_G) \quad (1)$$

On the basis of GIS data, points of geodynamic control are determined (geodynamic control objects) O_i and produced decomposition model parameters M_S on the model parameters of objects M_{Si} are produced:

$$M_S \rightarrow (M_{S1}, M_{S2}, ..., M_{SN}) \quad (2)$$

where N – total of subjects to control.

Control signals to the initial installation and positioning of the measuring systems geoelectric are generated:

$$\overline{U}_i(t_0) = F_U(M_{Si}, \overline{U}^*(t_0)) \quad (3)$$

where F_U – forming functional initial positioning control vector $\overline{U}^*$ system of space-time processing of geodynamic monitoring data at the time of launch $t=t_0$. Later geoelectric measuring systems operate directly in the semi-automatic mode according to the following algorithm:

$$\overline{U}_i(t) = \overline{U}_i(t_0) + \Delta U(M_{Si}, \Delta\overline{\alpha}_i) + F_U(\Delta M_{Si}, \overline{U}^*(t)) \quad (4)$$

where $\Delta U(M_{Si}, \Delta\overline{\alpha}_i)$ – current electrical installation for positioning control vector geodynamic variations $\Delta\overline{\alpha}_i$; ΔM_{Si} – model correction.

Information processing in the geodynamic control points O_i is built in accordance with the basic principles of solving the inverse problem of the geodynamic control [12]:

$$(M_{Si}, \Delta\overline{\alpha}_i, E_i) = A^{-1}(D_i) \quad (5)$$

where D_i – the observed data vector;

$E_i = \Psi(\overline{U}_i(t), M_{Si})$ – source parameters of probing defined fields are given by the model and the control signal;

A^{-1}- operator of the return task.

Geoelectrical data is always recorded with noise, defined as interference in the measurement channels, and specific climatic and anthropogenic factors. In that case the solution of the return task consists in definition of such geodynamic changes $\Delta\overline{\alpha}_i$ of an object model M_{Si}, and forms expected data $\widetilde{D}_i$, with the best accuracy:

$$\widetilde{D}_i = A\ (M_{Si}, \Delta\overline{\alpha}_i),\ \left\|D_i - \widetilde{D}_i\right\|^2_{L_2} = \overline{\Delta}_i \to \min \quad (6)$$

where A – operator of a direct task.

Purpose and operation of virtual multiplexer (MX_S,DMX_U) is to harmonize the flow of geodynamic data $\overline{S}^* = ((\overline{\Delta}_i, \Delta\overline{\alpha}_i)\ i = \overline{1,N})$ and system control signals of spatio-temporal processing of geodynamic control data processing unit (DPS).

IV. Decomposition of Model Parameters based on Approximation of Equivalent Transfer Function of Geoelectric Section

Approximation of transfer functions is used when using geoelectric methods of control as the base model in the control points.

The approximation is carried out equivalent to a rational function of the complex variable p=jω, physically realized by discrete circuits [13]. For the decision of tasks of geodynamic monitoring, equivalence of functions of a geoelectric section shall provide coincidence of characteristics not on all infinite range of frequencies and times but only on a limited segment. Therefore, the procedure of decomposition of model parameters according to ratios (1,2) can be presented in the form of operator expression for transfer function of a geoelectric section in a control point. It can be presented for the fixed provision of a source of the probing signal of X (p) and a point of registration of a signal of geodynamics of an object of Y(p) concerning a surface:

$$H(p,x,y,z) = \frac{Y(p)}{X(p)} = \frac{W(p,x,y,z)}{V(p,x,y,z)} = \\ = \frac{b_0(x,y,z) + b_1(x,y,z)p + ... + b_n(x,y,z)p^n}{a_0(x,y,z) + a_1(x,y,z)p + ... + a_m(x,y,z)p^m} \quad (7)$$

where n ≤ m; V(p,x,y,z) – Gurvits's polynom.

When changing the position of the electromagnetic field source the studied geoelectric section will change the real coefficients of the transfer function (7), without changing the order used in the approximation function. Geodynamic variation research facilities will also be expressed in variations of valid coefficients. Therefore, to solve the problem of approximation it is always possible to set such an order function m, which will provide the required accuracy geodynamic approach to any group of geoelectric section models M_{Si}.

The transfer function (7) defines a set of discrete electrical circuits that determine the geodynamic model of the geoelectric section. Geodynamics individual selected objects is described in the presentation of the transfer function in the form [14]:

$$H(j\omega,x,y,z) = \sum_{i=1}^{m} \varphi_i(x,y,z) A_i/(B_i + j\omega) \quad (8)$$

Where the coefficients A_i, B_i and φ_i are functional dependencies of spatial and electromagnetic parameters of environments composing section at the point of control.

In particular, in the construction of the control system of geodynamic locally multifrequency method using vertical electric sensing transfer function approximation of geoelectric section can be expressed in the form [15,16]:

$$H(j\omega,r,h)) = \\ = \frac{\rho_1(j\omega)}{2\pi}\left[\frac{1}{r^2} + 2\frac{\rho_2(j\omega) - \rho_1(j\omega)}{(\rho_2(j\omega) + \rho_1(j\omega))(r^2 + (2h))^{3/2}}\right] \quad (9)$$

where ρ_1 and ρ_2 – specific complex of the upper layer of geoelectric section resistance; h- depth of occurrence; r- distance between radiating and reception electrodes.

V. Control the Initial Setting and Positioning of Geoelectrical Measuring Systems

Algorithms control of the initial setting and positioning of geoelectric measuring systems and data processing are based on the following assumptions in accordance with relations (3,4):

- geodynamics of the object can be determined with sufficient accuracy of the results of the registration fields on the N points with coordinates (x_i,y_i);
- quantity of poles (sounding points) M.

In accordance with the principle of superposition in each i – th measuring point source j creates a vector signal of the electric field of the following form:

$$\overline{e}_{xij} = [\psi^x_{ij} + G_j(j\omega)\sum_{k=1} \beta^x_{ijk}] I_j \exp(j\varphi_j),$$

$$\bar{e}_{yij} = [\psi^{y}_{ij} + G_j(j\omega)\sum_{k=1} \beta^{y}_{ijk}] I_j \exp(j\varphi_j) \qquad (10)$$

where ψ^{x}_{ij}, ψ^{y}_{ij} – spatial functions of a relative positioning of a source of a locational signal and measuring sensors; β^{x}_{ijk}, β^{y}_{ijk} – spatial functions of a relative positioning of an imaginary source *k*, define the studied geodynamic object; I_j, φ_j – amplitude and phase of the probing signal.

Transfer coefficient (contrast) in an imaginary sources $G_j(j\omega)$ characterizes the difference in the electrical parameters of the inhomogeneity and the environment.

To ensure a high sensitivity to small changes in geodynamic object, the installed system must be balanced by a recorded electric field vector. This will eliminate the constant component of the detected signals.

Highlighting real a_{ij} and imaginary b_{ij} of the spatial functions in the equation (10), you can record the condition of the balance of the measuring system under the action of a multipolar probing signal $\bar{e}_x = \bar{e}_y = 0$ and conditions of formation of the first impacts of the probing source $I_1=1$, $\varphi_1=0$:

$$a^{x}_{i1} + jb^{x}_{i1} + \sum_{j=2}^{M}(a^{x}_{ij} + jb^{x}_{ij})(I_j \cos\varphi_j + jI_j \sin\varphi_j) = 0,$$

$$a^{y}_{i1} + jb^{y}_{i1} + \sum_{j=2}^{M}(a^{y}_{ij} + jb^{y}_{ij})(I_j \cos\varphi_j + jI_j \sin\varphi_j) = 0 \qquad (11)$$

Spatial features in equations (10), (11) can be defined at initialization by series connection of the probing signals system on selected poles.

When the time comes, geoelectric measuring system comes to imbalance due to natural changes in the object under study and there is a need for re-balancing. The moment of balancing is determined by some criterion which can be set from conditions of carrying out geodynamic control and according to an algorithm of work of system. The measurement procedure of spatial functions at system initialization gives a balanced trend of geodynamics object signal according to the ratio (4).

VI. Results of Observations and Spatio-Temporal Data Processing

Increase in the concentration of groundwater mineralization indicates negative geodynamic processes occurring in the geological environment (for example, karst formation). In this work, to measure the mineralization of the aquifer, measuring systems of geoecological monitoring were used. The measuring system of geoecological monitoring includes an electrolocating installation and special software developed by our team. The electrolocating system consists of a generator, eight non-contact transformer sensors (NCS 1- NCS 8), temperature sensors (T1-T4) and a level gauge.

In the period from January to November 2016, we conducted observations on the lake "Svyato" (Russia, Nizhny Novgorod region). Collection and processing of data on current geodynamic processes were carried out at stationary points P1-P4 (Fig. 3).

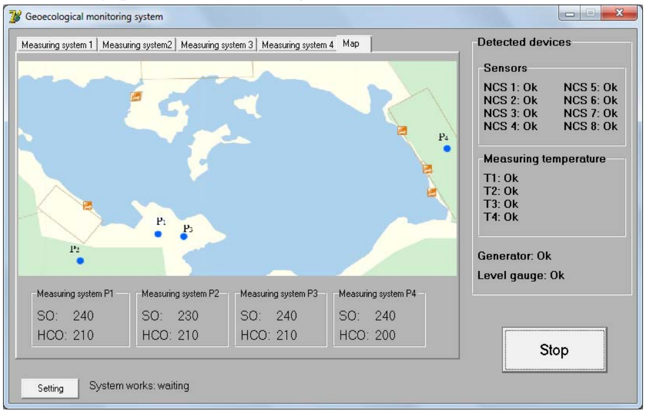

Figure 3. The window of the program with a map of control points in the observing area

Fig. 4 shows the main window of the program after initialization of all devices. The program window displays the current content of sulfates and hydrocarbons in the groundwater at observation posts from 9:00 to 17:00 o'clock. 30.04.2016.

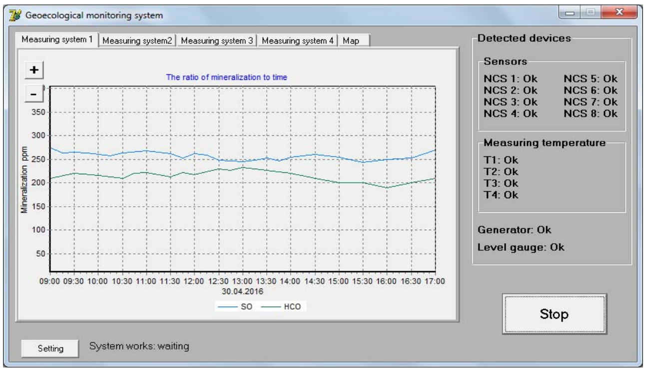

Figure 4. The main window of the program. The ratio of aquifer mineralization on time

Measuring systems operated around the clock in automated mode throughout the observational period (Fig. 5a.).

In the measuring system of geoecological monitoring and control of geodynamic objects, separate spectral components of signals with certain properties are singled out. The main method of signal preprocessing is spectral-temporal analysis, which allows to identify the main frequency components of the signal in a distributed monitoring system (Fig. 5b.). This method consists in synchronous transmission of the input signal through a system of narrow-band filters and analysis of the amplitude values of the envelopes and their phases at the output of the filters.

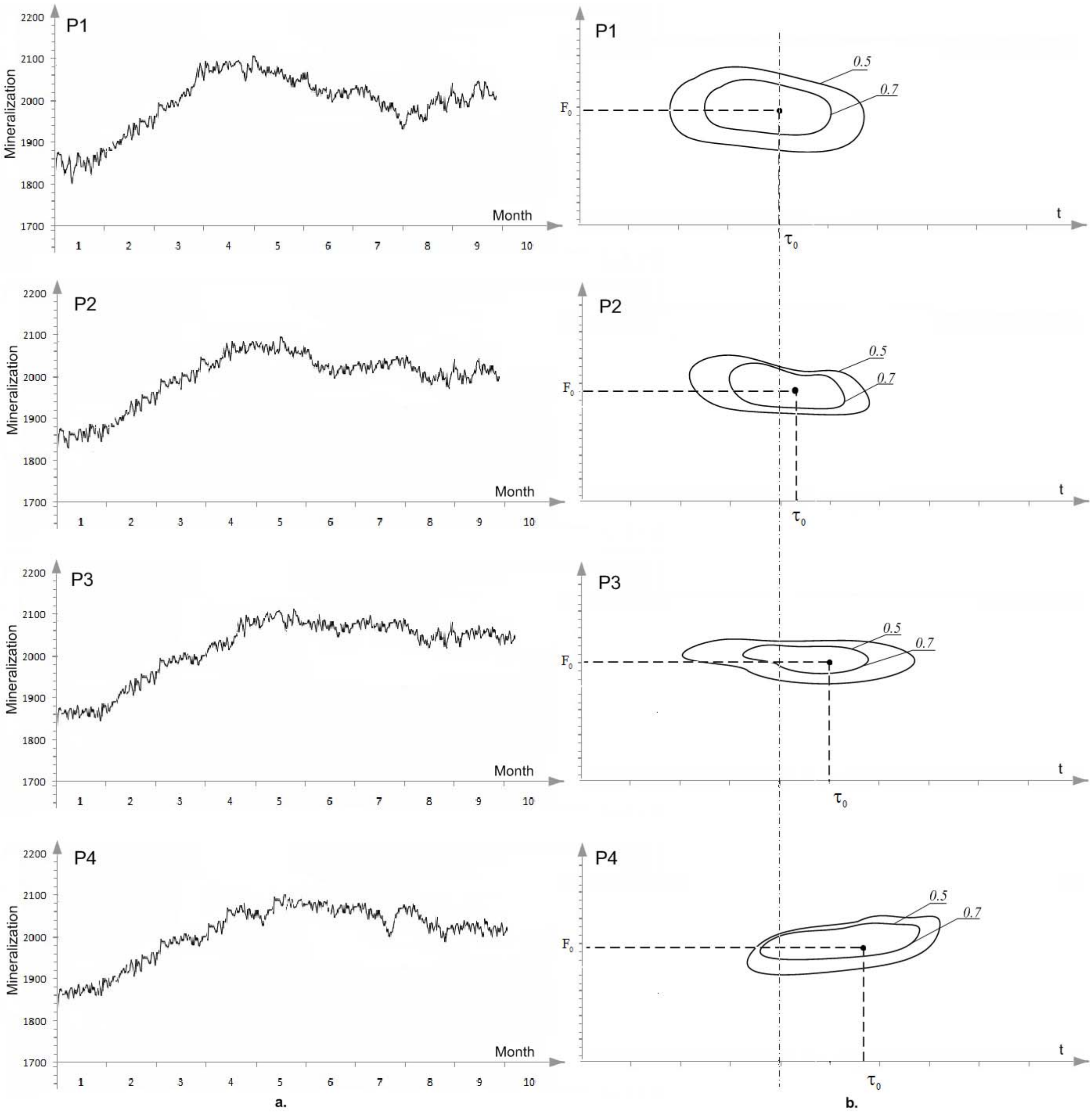

Figure 5. Spatio-temporal analysis of geoelectric data of geodynamic monitoring

As a result, spatio-temporal dependencies were revealed in the controlled territory. It was recorded an increase in the mineralization of groundwater at all observation points in the spring period. First, the increase in mineralization was recorded at observation point P1, then the increase in mineralization began to appear at observation points P2, P3, P4 with a delay of 7-8 days. This fact indicates that there is an activation of karst processes that affect the geodynamics of the environment.

VII. CONCLUSIONS

An approach to the organization of space-time processing of geoelectric data in automated systems geodynamic control, considered in this paper allows one to combine methodical, algorithmic, program and technical and information support for the collection and processing of information on geodynamic locally allocated NTS control objects into a single unit.

The proposed method of positioning and work of geoelectric measurement systems allows to determine the geodynamic changes at NTS with improved accuracy by separating trend signal component and independent signal processing of small displacements fictitious sources of the electric field.

Using these relations simplifies evaluation of geodynamic variations of individual allocated objects of study based on the analysis of the coefficients of model changes in the transfer function of the geoelectric section.

ACKNOWLEDGMENT

Work is performed within the state task of the Ministry of Education and Science of the Russian Federation №5.3606.2017/PC

REFERENCES

[1] A. A. Bykov, O. R. Kuzichkin, I. A. Kurilov, "Organization of electrolocation systems of geodynamic monitoring on the basis of the single-crystal microcomputer," in *Proceedings of the 8th IEEE International Conference on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications (IDAACS'2015),* Warsaw, Poland, 24-26 September 2015, pp. 582-586.

[2] I. Uchytel, B. Kapochkin, "Need to consider damaging aseismic geodeformations when developing construction technologies," *Eastern European Journal of Enterprise Technologies*, vol. 1(7), pp. 52-57, 2015.

[3] R. V. Sharapov, O. R. Kuzichkin, "Geodynamic monitoring in area of nuclear power plant," *Applied Mechanics and Materials*, vol. 492, pp. 556-560, 2014.

[4] R. V. Sharapov, O. R. Kuzichkin, "Monitoring of karst-suffusion formation in area of nuclear power plant," in *Proceedings of the IEEE 7th International Conference on Intelligent Data Acquisition and Advanced Computing Systems (IDAACS'2015),* Berlin, Germany, September 12-14, 2013, pp. 810–813.

[5] P. Schindler, T. Jahr, G. Jentzsch, N. Kukowski, "High precision deformation monitoring at the geodynamic observatory moxa/thuringia," *Germany: The three-component strainmeter assembly. International Association of Geodesy Symposia 139*, 2014, pp. 141-147.

[6] Yu. Kolokolov and A. Monovskaya, "Guess-work and reasonings on centennial evolution of surface air temperature in Russia: Is it possible to build bifurcation diagrams based on extra-short local observations?" *Int. J. of Bifurcation and Chaos*, vol. 25, no. 6, 1550084, 2015.

[7] Yu. Kolokolov and A. Monovskaya, "Guess-work and reasonings on centennial evolution of surface air temperature in Russia. Part II: is it possible to research both local peculiarities and regional tendencies from the bifurcation analysis viewpoint," *Int. J. of Bifurcation and Chaos*, vol.26, no. 4, 1650071, 2016.

[8] A. A. Kaufman, *Introduction into Theory of Geophysical Methods, Gravitational, Electrical and Magnetic Fields*, Moscow, Nedra, 1997, 520 p. (in Russian)

[9] M. Blome, H. Maurer, S. Greenhalgh, "Geoelectric experimental design – Efficient acquisition and exploitation of complete pole-bipole data sets," *Geophysics,* vol. 76, no. 1, pp. F15-F26, 2011.

[10] R. V. Romanov, "Development of geographical information – analytical system for magnetotelluric geodynamic monitoring," *Proceedings of the IEEE 7th International Conference on Intelligent Data Acquisition and Advanced Computing Systems (IDAACS'2013),* Berlin, Germany, September 12-14, 2013, pp. 824-827.

[11] I. S. Konstantinov, O. R. Kuzichkin, "Organization of systems of avtomated electromagnetic control of geodinamical objects," *Information Systems and Technologies*, vol. 4, pp. 13-16, 2008. (in Russian)

[12] M. S. Zhdanov, *Theory of Inverse Problems and Regularization in Geophysics*, M.: Nauchnyy mir, 2007, 712 p. (in Russian)

[13] A. Bykov O. Kuzichkin, "Approximation of equivalent transfer function of the geoelectric section in geodynamic inspection," *Proceedings of the International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management*, 2014, pp. 615–622.

[14] O. Kuzichkin, N. Chaykovskay, "Spectral processing of the spatial data at geoelectric monitoring," *Proceedings of the International Conference on Multimedia Technology*, Hangzhou, China, 2011, pp. 765-768.

[15] R. V. Romanov, O. R. Kuzichkin, A. V. Grecheneva, "Geoecological control of the aquifer in a non-centralized water supply system at the local level," *Fundamental and Applied Problems of technics and technology*, vol. 3 (311), pp. 137-142, 2015. (in Russian)

[16] R. V. Romanov, O. R. Kuzichkin, A. V. Tsaplev, "Geoecological control of the aquifer in the decentralized water supply systems of the local level," *Proceedings of the 8th IEEE International Conference on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications (IDAACS'2015),* Warsaw, Poland, 24-26 September 2015, pp. 42-46.