The joint seismic-and-electromagnetic monitoring with electromagnetic field separation

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Abstract. The magnetotelluric soundings (MTS) are a common tool in applied geophysics. The guidelines for electromagnetic (EM) monitoring should be updated because of new tools and software developed. Some techniques paragraphs have outdated sections. Some essential equipment requirements and its' allowable parameters, MTS acquisition, are defined. We involve Research Station RAS patents (RU 175972 U1, 2017; RU 2701876 C1, 2018) to increase the long-term stability of electrical parameters of non-polarizable electrodes. We consider the irreversible rock deformations form sources of the electromagnetic field of endogenous origin as geodynamic processes. We offer MTS with an additional algorithm with electromagnetic field separation for studying the endogenous component of EM field as a lower half-space impedance. We explain the technology of MTS in seismically active zones with remote access on the example of the Tien Shan. We introduce these guidelines acquiring data system for the joint seismic-and-electromagnetic monitoring for the modern geodynamic processes. We show a result diagram for the energy characteristic of the endogenous component of EM field.

1 Introduction

Magnetotellurics (MT) is a passive geophysical method used to infer the Earth's resistivity structure from the measurements of the natural electric (telluric) (TE) and magnetic field (TM) components either at Earth's surface or at the seafloor. The basic regional electromagnetic (EM) method is the MT method is mobile, as it does not require an artificial field source MT investigations essentially expand the existing ideas about the structure and geodynamics of the Earth's interior fluid-saturated crustal zones. The Research Station of the Russian Academy of Sciences in Bishkek (RS RAS) is a complex geophysical station. It holds a wide network of sites in the seismically active zone of the Tien Shan. The geoelectrical data based on magnetotelluric soundings (MTS) and magnetovariational soundings (MVS), created in the Tien Shan region, has been constantly updated [2, 3]. The network with the regime and stationary stations are suitable for electromagnetic monitoring rather than a series of regional and local profiles in the range of

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periods from 0.06 to 1800 s. The MTS was carried out at altitudes from 800 up to 3350 meters above sea level.

The theoretical part of EM methods as part of geophysical prospecting is based on [4-7]. In Russian references, it was largely populated by. The flowchart of MT field operations is standard upon; equipment and procedures were explained firstly. But the technical guidelines for MTS are outdated because of the new generation of MT 5-channel equipment such as Phoenix MTU-5/5A.

The new step in the development of MT theory was made by. Especially for on the surface of a layered anisotropic half-spaces. The direct MTS problem for layered space and fields from the sources located in the corresponding areas of space has been solved by. The separation of the electromagnetic field at the position of the sources in the magnetotelluric method was withdrawn as the impedances of the upper and lower half-spaces. Using the electromagnetic field extension through the horizontally layered medium, a formula showing the relationship between the tangential components of impedance tensor registered on the Earth's surface has been determined. This solution allows efficient for the implementation the passive electromagnetic monitoring from a new scientific point of view.

Usually, MTS is used in applied geophysics for prospecting and deep investigations of the sedimentary cover and consolidated crust for large areas [20] and for other environmental purposes. The modern MTS application is close to studying tectonic disturbances in rock masses. The potency of geodynamic predictions is based on a monitoring of geodynamic processes. The technology of informative support of systems of the automated electromagnetic monitoring of geodynamic objects is an up-to-date issue. Also, the theory of seismic-and-electromagnetic monitoring of the modern geodynamic processes could be improved [24]. The methodological experiment results show a link between variations in seismic and electromagnetic parameters during long-term monitoring of cracking processes [27]. There are also some relationships under lunar-solar tides and earthquakes. In work, we introduce a modified joint seismic-and-electromagnetic monitoring with EM field separation.

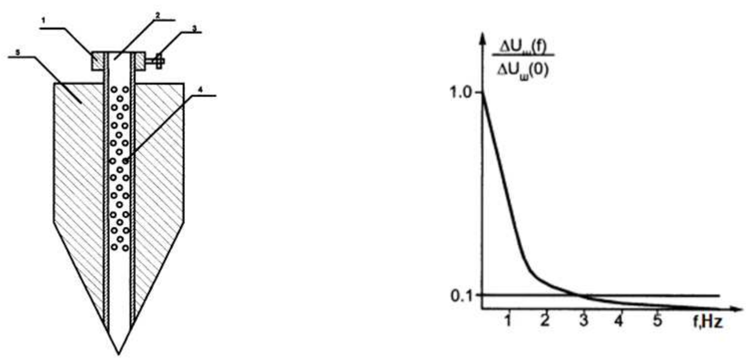
2 Materials and methods

The common flowchart of MTS measurements consists of:
- Geological setting.
- Data acquisition.
- Data processing.
- Data interpretation.

The first step is anticipated by the stationary and regime sites of RS RAS network. The second step is one of the most important tasks and needs to be done carefully. We analyze raw data in special software, trying to avoid any noise involving into the next processed data. For the EM monitoring purposes, the last step is changed for the endogenous component extraction according to [17, 26, 27]. Because a geodynamic processes manifest itself in two interrelated phenomena: changes in the resistivity of the rock and generation of sources of electromagnetic field. So the best practice is to look at the detailed roll of the hours-long stationary (or regime) site. The EM monitoring could be provide with the typical instruments the 5-channel 4-D electromagnetic system. The best instrument for these purposes is the Phoenix V5 System 2000™ (Phoenix Geophysics Limited, Toronto, Canada). This instrument consists of a lightweight battery, GPS antenna with coordination with Universal Time (UTC), carrying case, electrodes, cables, MTU-5 station, and MT induction coils. There are obviously three induction coils for acquiring three channels of magnetic data (H_x, H_y, H_z) and two electrical channels (E_x, E_y). Each sensor is installed for measuring one spatial coordinate. We also get two channels of telluric data from porous pot electrodes. The advantage of this instrument is logistic flexibility in field measurements: light configuration and rather small spacing without the great physical impact on the land (because of vehicle access, shallow holes and/or trenches for the electrodes and sensors). Station spacing is restricted by the network meanings of Research Station RAS. As usual, a maximum distance should be less than 1000 m, even in the most favorable environments. The field group should include 3 persons: chief leader and two engineers. An experienced crew can settle a site in about 1 hour. The travel time must also be taken into account. All surveys should be done under the surveillance of the customer.

Equipment and procedures: pot electrodes.

We measure electric fields by burying electrodes as a cross-shaped array with spacings from the centre 50 or 100 m. Traditionally, the legs of the array should be exactly equal and perfectly orthogonal [13]. Geography and topography should be taken into account. The conventional non-polarization electrodes used to measure the E-field have a significant achievement [29]. These electrodes must be refurbished or replaced after about a year of regular use. That is why the engineers' staff has patented an electrode for high-frequency geophysical electrical exploration [30] by Dzalba A.L. & Batalev V.Yu., and moisture saturation stabilization of non-polarizing electrodes by Dzalba A.L., Matyukov E.K., & Timonin G.N. [31]. It is about high importance to admit low noise, temperature coefficient, and long-time stability of electrodes for telluric observations [32].



a b

Fig. 1. The electrode for high-frequency geophysical electrical exploration: a) The electrode consists of a metal pipe (2) with a plumage of an arrow-shaped shape (5), covered with a layer of lead. Through the surface of the pipe there are through holes (perforation) (4) for moistening the soil with liquid at the point of contact through the upper end hole. To connect to the dipole, there is a threaded clamp (3) located on the tip of the electrode (1). b) the amplitude-frequency response spectra. Source: [30].

The inventions [30, 31] are ready to increase the long-term stability of electrical parameters non-polarizable electrodes with any water-containing depolarizers. The quantitative stabilization of the inside moisture is made by colored salts metals (e.g. copper sulfate $CuSO_4$) and coating its body with bentonite clay. "To maintain a sufficient amount of water in the depolarizer, it is sufficient to introduce similar absorbents into its composition in ratios of less than 1/200 of the volume of graphite and 1/100 of electrolyte depolarizers" [31]. The proposed electrode (Figure 1) has a larger square of contact with the soil due to the steel pipe perforated with holes. This design of the electrode as a plumage from arrow-shaped ribs, coated with a lead layer throughout the structure, obeys a very significant mechanical strength. It leads to a decrease in contact resistance. Each dipole consists of two lead-chloride porous pot electrodes buried about 0.25 m deep in the ground in the installation places of electrodes, a polymer absorbent is introduced. When measuring contact resistance, use an analog ohmmeter. High DC potentials indicate a faulty electrode or closeness to power lines. When measuring dipole voltages, use a digital voltmeter. Self-potential should be <10 mV (<2 mV when new).

2.1 Equipment and procedures: magnetotelluric station

MT station is presented by V5 System 2000 MTU-5/A of 24-bit analog-to-digital converters, which records data to the compact flash card. MT techniques acquire data in frequencies ranging from about 400 Hz to 0.0000129 Hz (a period of about 21.5 h). According to [3], in an ordinary observation point on a profile, the duration of an MT-field recording is a time interval from several hours to several days, which is determined by the depth of soundings. To configure a standard set of parameters the MTU station at each site a binary file STARTUP.TBL could be used repeatedly. The file contains information for tags. MT station is placed exactly at the site centre. GPS antenna power mode contacts with at least four GPS satellites. MTU instrument must be calibrated before acquiring data or calibrating sensors. Because calibration requires GPS satellite lock, it is usually done outdoors. Each calibration must be completed in a single session; it cannot be interrupted and resumed. The resulting calibration file in the \CAL directory on its internal disk. The file is named NNNN.CLB, where NNNN is the serial number of the instrument.

2.2 Equipment and procedures: induction coils

The induction coil is a magnetic sensor MTC-50. Each sensor weighs approximately 8 kg, and measure 1.41 m. We use three of them for each spatial direction. Research on the comparison testing technique of the induction coil sensor was investigated [33] and its' indoor testing [34].

Induction coils are installed in shallow (0.40 m deep) trenches and pits on stable solid foundations, at a distance of at least 3 m and oriented using a survey compass with an error of ±0.5° (Figure 2).

Fig. 2. The survey compass positioning for the MTC-50 device into the trenches (Photo by ©Research station RAS in Bishkek).

The horizontal coils are normally aligned with the telluric dipoles, as carefully oriented and level as possible. The azimuth of the sensor for measuring H_x placed with its free end pointing and should coincide with the azimuth of the X axis, the azimuth for measuring H_y should fit with the azimuth of the Y axis respectively. The hole for H_z is made so deep that it is possible to install the sensor in it and close the hole with shields or cloth from moisture, which should not touch the instrument case. After the end of the work, the trenches are covered with an early dug and laid with the previously removed sod.

2.3 Equipment and procedures: calibrating the equipment

Calibration should take place, preferably at the beginning of every survey. In case of equipment problems (e.g. damaged cables), the calibration procedure could be repeated during a survey. Usually, the reference site is the best location for calibration because you have chosen it for its low noise characteristics, and you have permission to use it for a longer period of time. The calibration of an MTU-5 instrument takes about 10 minutes. The calibration of magnetic sensors requires a calibrated MTU-5 station and takes at least an hour. To check the performance of the station, a test recording of about an hour is made.

Besides, before the start of fieldwork, synchronous registration of the components of the total magnetic field vector is carried out at the field and reference sites, and after completion, the on/off operation is checked. The delay of marks, times when two stations switches work together, should not exceed 0.1 s. When checking the identity of the sets of equipment, rectangular receiving installations are laid out parallel to each other at a distance of 5–6 m. The result of processing a joint record (special parameter $\aleph$) should not differ from one by more than 5%. The root-mean-square discrepancy between the values of the effective impedance moduli $|Z_{eff}|$ of the control and controlled observations should not exceed ±5%. All data characterizing the field records of the magnetotelluric field are entered into field journals. Each oscillogram and tellurogram is supplied with a digital passport and label.

Equipment and procedures: Software.

For MT data processing and interpretation, we refer to [35-37]. The data streams in magnetotelluric (MT)-monitoring is standard [3]. The data storage is written to a file with the extension EDI (Electrical Data Interchange), which we get through the MT-Correct program developed by the Nord-West Ltd., Russia [38-40]. With new tools of MT-Corrector [38, 40]. We improve raw data. After that, we subject data to a program for processing, analysis and interpretation on azimuthal directions through roll volume of time-frequency series [41]. The results could be found at [28].

For MT data processing, other software could be used, such as: WinGLink [42], SSMT2000 (Phoenix Geophysics Ltd., Canada), Epi-Kit software (Nord-West Ltd., Russia), etc.

The processing is also related to checking the data consistency by the dispersion relations curves of MT tensor Z, which are useful in many MT investigations. The recording can be split into several parts after deleting such sections. At the same stage, files are prepared for further processing (creation of the structure of output file names, the introduction of service information, etc.). At the first stage, the parameters of the recording equipment are also monitored. At this stage, we could work in both interactive and automatic modes.

3 Results and Discussion

The essence algorithm is that according to the known impedance of the lower half-space needs to find the difference registered on the daylight surface of tangential components of the EM field. To implement the algorithm MTS data processing program developed in order to separate the sources of the electromagnetic field of endogenous origin. A stable solution for the layered laterally homogeneous arbitrary anisotropic model of the geoelectrical medium was given in [17]. Under the energy characteristic of the

electromagnetic field of endogenous origin, we mean the integral $\int_0^{\Delta\omega} |Y(\omega) d\omega|$ over frequency (ω) (Y – EM field of sources, located in the lower half-space) obtained after Fourier transform recorded signals in the time domain for 1-hour research related to the development of azimuthal EM monitoring techniques. It consists of analyzing the obtained time-frequency series of EM parameters in order to determine the contribution of each of the components of the impedance tensor to the informativeness of monitoring studies.
The detailing of the main process is carried out, including 3 main subprocesses (Processing of primary files, Processing of daily average files, Processing of EDI files) and 2 auxiliary subprocesses (Construction of correlation diagrams and MT time-frequency monitoring), interacting with the Server.

4 Conclusions

After calculations of the energy characteristic of the endogenous component of EM field for some range of frequencies, we get a diagram (Figure 3). As a result of the research, some patterns reveal in the behavior of the parameters: there is a stable relationship between the anisotropy of electrical resistivity and the energy characteristic of the electromagnetic fields of endogenous origin.

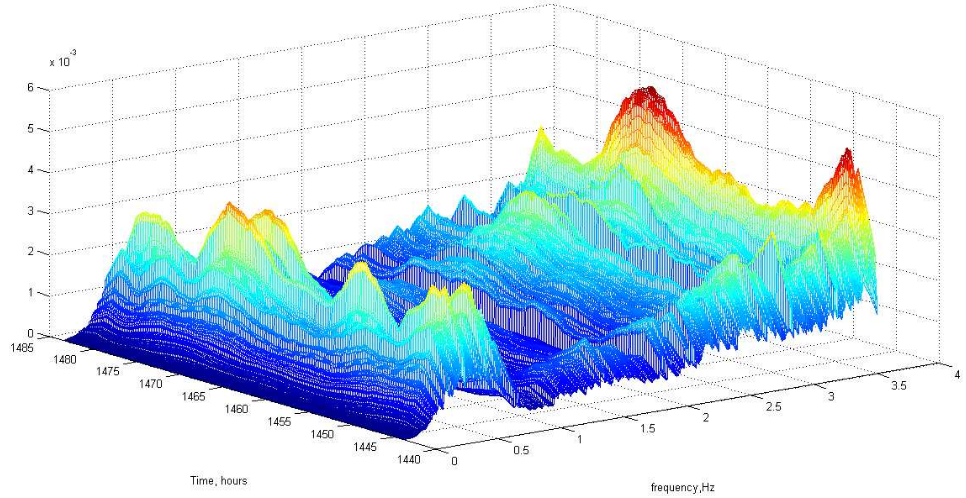


Fig. 3. The energy characteristic of the endogenous component of EM field for the range of MTS frequencies for the period 27/06/2019 11.00-01/07/2019 4.00 (UTC) at the Ukok 2 test site.

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References

1. E. Sokolova, M. Berdichevsky, I. Varentsov, A. Rybin, N. Baglaenko, V. Batalev and P. Pushkarev, *Advanced Methods for joint MT/MV Profile Studies of Active Orogens: the Experience from the Central Tien Shan*, ed. O. Ritter and H .Brasse, in Protokoll zum 22 Kolloquium "Elektromagnetische Tiefenforschung", 132 (2007)
2. E.A. Bataleva, IOP Conf. Ser. Earth Environ. Sci., **350**, 012053 (2019)
3. E. Bataleva, A. Rybin, V. Matiukov, Data, **4**, 99 (2019)
4. L. Cagniard, Geophysics, **18**, 605 (1953)
5. G. Fischer, Eos, Trans. Am. Geophys. Union, **63**, 578 (1982)
6. J. F. Hermance, in Geophysics (Kluwer Academic Publishers, Dordrecht, 1989)
7. K. Vozoff, in Electromagn. Methods Appl. Geophys (Society of Exploration Geophysicists, 1991)
8. M.N. Berdichevsky, Surv. Geophys., **20**, 341 (1999)
9. M.N. Berdichevsky, V.I. Dmitriev, Models and Methods of Magnetotellurics (Springer Berlin Heidelberg, Berlin, Heidelberg, 2008)
10. V.V. Spichak, Surv. Geophys., **11**, 271 (1990)
11. L. B. Pedersen, Surv. Geophys., **9**, 245 (1988)
12. A Guide to Safe Field Operations, U.S. Geological Survey Open-File Report, https://pubs.usgs.gov/of/1995/of95-777/gw_act.html
13. J. Clarke, T.D. Gamble, W.M. Goubau, R.H. Koch, R.F. Miracky, Geophys. Prospect, **31**, 149 (1983)
14. Phoenix Geophysics User Guide Version 2.0. 2010 (Toronto), http://www.phoenix-geophysics.com/Support/user_guides/guides/mtu_ug_2.0.pdf
15. M.S. Zhdanov, Geophysics **75**, 75-49 (2010)
16. D. Loewenthal and M. Landisman, Geophys. J. R. Astron. Soc., **35**, 195 (2009)
17. P.N. Alexandrov, A. K. Rybin, O. B. Zabinyakova, Uchenye Zapiski Kazanskogo Universiteta, Seriya Estestvennye Nauki, **160**, 2, 339 (2018)
18. E.D. Aleksanova, I.M. Varentsov, M.I. Vereshchagina, V.A. Kulikov, P.Y. Pushkarev, E.Y. Sokolova, N.L. Shustov, V.K. Khmelevskoi, A.G. Yakovlev, Izv. Phys. Solid Earth, **46**, 707 (2010)
19. N.A. Palshin, E.D. Aleksanova, A.G. Yakovlev, D.V. Yakovlev, R.B. Vianna, Geophysical Research, **18**, 27 (2017)
20. N. Palshin, R. E. Giraudo, D. Yakovlev, S. Zaytsev, E. Aleksanova, R. Zaltsman, and S. Korbutiak, J. Appl. Geophys, **181**, 104136 (2020)
21. V. Spichak, in Geophys. Potential Fields (Elsevier, 2019)
22. E.A. Bataleva, A.K. Rybin, V.Y. Batalev, I.V. Safronov, J. Min. Sci, **41**, 225 (2005)
23. A. Bykov, O. Kuzichkin, N. Dorofeev, A. Koskin, Procedia Comput. Sci., **103**, 253 (2017)
24. P.N. Aleksandrov, Bull. KRAESC, Earth Sci., **2**, 14, 49 (2009)
25. The Acoustic-Electromagnetic Analogy in *Wave Fields Real Media*, Elsevier, 321–383 (2015)

26. V.Yu. Batalev, E.A .Bataleva, V.E. Matyukov, A.K. Rybin, Bull. KRAESC, Earth Sci. **42**, **2**, 42 (2019)
27. A. Rybin, E. Bataleva, K. Nepeina, V. Matiukov, P. Alexandrov, P. Kaznacheev, J. Appl. Geophys., **181**, 104144 (2020)
28. E. Bataleva, E3S Web Conf., **127**, 02019 (2019)
29. G. Petiau, Pure Appl. Geophys., **157**, 357 (2000)
30. A.L. Dzalba, V.Yu. Batalev, RU 175972 U1 (2017)
31. A.L. Dzalba, E.K. Matyukov, G.N. Timonin, RU 2701876 C1 (2018)
32. G. Petiau, A. Dupis, Geophys. Prospect., **28**, 792 (1980)
33. X. Luo, Z. Wu, M. Deng, M. Wang, K. Chen, in *Eng. Technol. Appl.*, CRC Press, 177–182 (2014)
34. S. Ge, M. Deng, K. Chen, X. Shi, J. Geophys. Eng., **13**, 612 (2016)
35. G. Egbert, in Springer, Dordrecht, 816–822 (2011)
36. G.D. Egbert, Geophys. J. Int., **130**, 475 (1997)
37. J.F. Hermance, in *Encycl. Solid Earth Geophys. Encycl. Earth Sci. Ser.*, Springer, Dordrecht, 822–829 (2011)
38. D.V. Epishkin, Moscow Univ. Geol. Bull., **71**, 347 (2016)
39. N.I. Zorin, D.A. Alekseev, Russ. Geol. Geophys., **59**, 313 (2018)
40. N. Zorin, E. Aleksanova, H. Shimizu, D. Yakovlev, Earth, Planets Sp., **72**, 9 (2020)
41. E.A. Bataleva, V.Yu. Batalev, Vest. Kyrg.-Sl. Uni., **14**, 8 (2014)
42. WinGLink User’s Guide, version 2.07.04. (Geosystems SRL, Milan, 2004)