УДК 550.837.21 (575.2) (04)

MAGNETOTELLURIC MONITORING EXPERIMENT IN THE NORTHERN TIEN SHAN SEISMOGENIC ZONE: FIRST RESULTS

A. Rybin – PhD
V. Batalev – PhD
L. Fox – PhD, President Phoenix Geophysics Limited, Toronto, Canada,
A. Ingerov – PhD, Vice President Phoenix Geophysics Limited, Toronto, Canada,
G. Schelochkov – Deputy Director

The analysis of results for two-year duration (September, 2003 – October, 2005) observations of experimental magnetotelluric (MT) continuous measurements is presented. In this paper we focus exclusively on some aspects of study the temporal stability of magnetotelluric transfer functions (TFs) as indicators of resistivity changes in concrete geoelectrical environment of the Northern Tien Shan.

Introduction. The Tien Shan Mountains in Kyrgyzstan are an active geodynamic region. Experimental pilot program of creating Central Asia MT monitoring system was started in 2003. As a first step Research Station in Bishkek (Kyrgyzstan) and Phoenix Geophysics (Toronto, Canada) jointly installed near Bishkek two monitoring stations for measuring natural and artificial electromagnetic fields, using new generation of Phoenix MT equipment. The both sites are located at the territory of Bishkek Geodynamical Poligon (BGP) which is a part Northern Tien Shan seismogenic zone (Fig. 1). The main goal of the joint project was to install experimental wideband EM monitoring system in the North Tien Shan seismic active zone for studying different tectonic processes.

Field experiment. The field experiment was performed at the facilities of BGP in Kyrgyzstan; the polygon has 7 permanent monitoring stations in the Northern Tien Shan Mountains (Fig. 1).

Wideband EM field measurement was performed using Phoenix MTU-5D fifth generation MT/multifunction EM equipment [1]. With a special modification for long duration monitoring records, this equipment can be used for monitoring natural field as well as artificial fields. Two sets of 5-channel equipment with frequency band 400 Hz–10,000 s were used. In Stage 1, repeatable synchronized MT measurements were done at seven sites shown in Figure 1 (red star and triangles). After analysis, sites Chon and Aksu were chosen as the sites for permanent monitoring (Fig. 1). The main criteria were the accuracy of the obtained MT transfer functions.

In parallel with the natural field monitoring with Phoenix equipment, the powerful Russian RGU-600-2 artificial source was also used for EM field monitoring during a one-month period in 2003. This stationary Lotem system (transmitting dipole marked as a red star in Fig. 1) has been functioning at the Bishkek polygon since 1982. The red triangles in Fig. 1 show 6 receiving sites. The RGU system uses the 50 Hz, 380 V mains power supply as its energy source. It can transmit positive or negative polarity impulses with a current amplitude of 600 A [2].

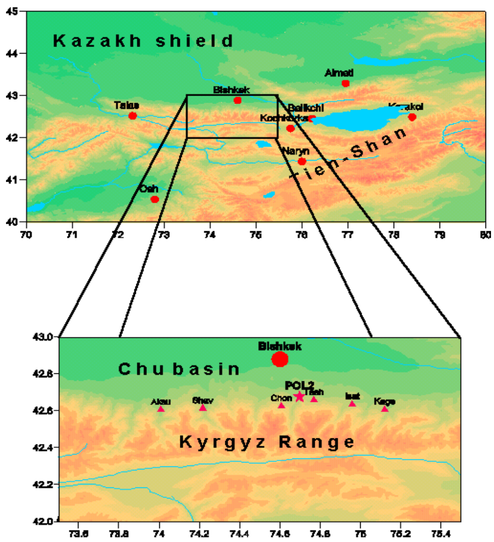

Fig. 1. Topographic map of the Central Tien Shan based on 1 km DEM (upper image). Inset box shows location of Bishkek Geodynamic Polygon (BGP) area. Locations of MT and TDEM continuous sounding sites are shown by red triangles in lower image.

Data processing and accuracy of MT transfer functions. Undoubtedly, the question of accuracy of EM-parameters determination is basic for creation concrete monitoring system and its decision defines as far as MT-method can be effective for research of seismotectonic processes in the Earth's crust for the investigated region. First point in "accuracy question" for installed Phoenix stationary MT-system was a stability of the hardware response. Very stable contact resistance and DC offset were observed on all electrodes. System response variations of all channels with sensors were very small not exceeded 0.2 % during two month period between their calibrations [3].

The coherencies are used in evaluating data quality and identifying the source of noise in the raw data. For any two measurements A and B (in the temporal frequency domain), the coherency between A and B is defined as:

$$CohAB = \frac{(A\boldsymbol{B})}{(A\boldsymbol{A})^{1/2}(B\boldsymbol{B})^{1/2}},$$

where A and B are commonly the orthogonal electric and magnetic fields, **A** and **B** – conjugate complex numbers.

Since the impedance estimation is directly proportional to coherency value, we have possibility to evaluate the accuracy of obtained MT transfer functions using coherency factor.

Let us consider results of application coherency criterion for an estimation of MT monitoring data quality. Temporal analysis of impedance estimations by MT materials, received at the Baltic shield [4], has shown, that intensive amplitude-phase pulses in the impedance estimations, which are observed in a wide range of periods, clearly coincide with record segments of the lowered values (level below 0.8) of coherency factor. That is time windows with abnormal values of impedance estimations were characterized by sharp reduction of linearity quality between electromagnetic field components.

In our case it is applicable coherency criterion of impedance estimations for diagnostics of quality (distortions) of the MT transfer functions estimations received during monitoring at site Chon. The pseudosection of Ex-Hy coherency values corresponding to Zxy impedance estimations for one-month duration is showed in Fig. 4. We can see from this figure, that there is no essential reduction of coherency factor values practically in the whole period range, i.e. quality of researched linear relations does not decrease, that denote a reliability of obtained impedance estimations and an opportunity to use coherencies for analysis of the changes for parameters of geoelectric cross-section in the vicinity of monitoring site.

Results and discussion. The focus of this paper is to show results of study the temporal behavior of MT transfer functions in the wide frequency range (0.0005–400 Hz).

For analysis of short-term variations of apparent resistivity we shall analyze apparent resistivity estimates obtained as 1-hour sampling segments of time series recorded at the site Aksu (Fig. 2) in more detail. Let us compare MT data obtained at site Aksu with modeled tidal deformations at the same site. Calculations of gravity variations was produced with the help of the program Tides (author – B.I.Demchenko).

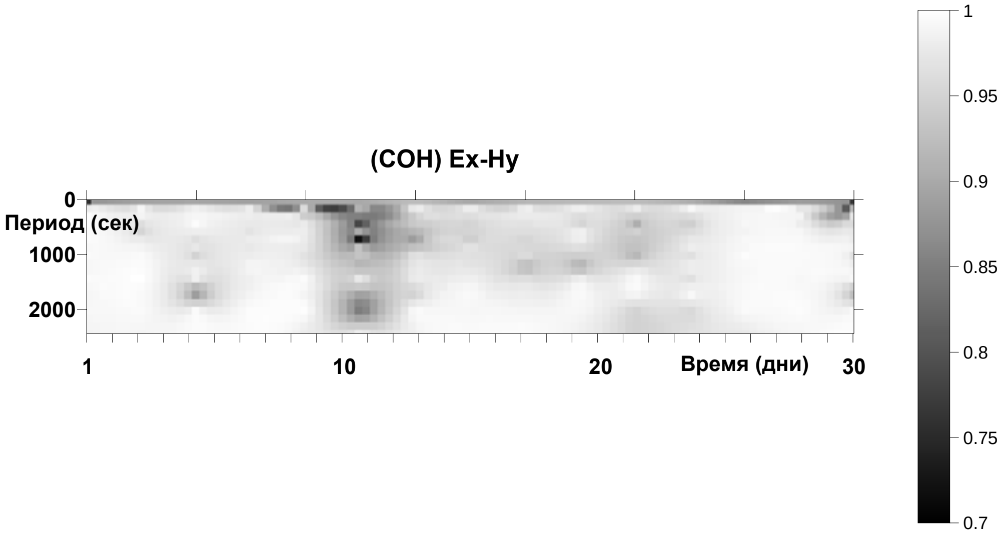

Fig. 2. Ex-Hy coherence pseudosection at the site Chon for one month duration.

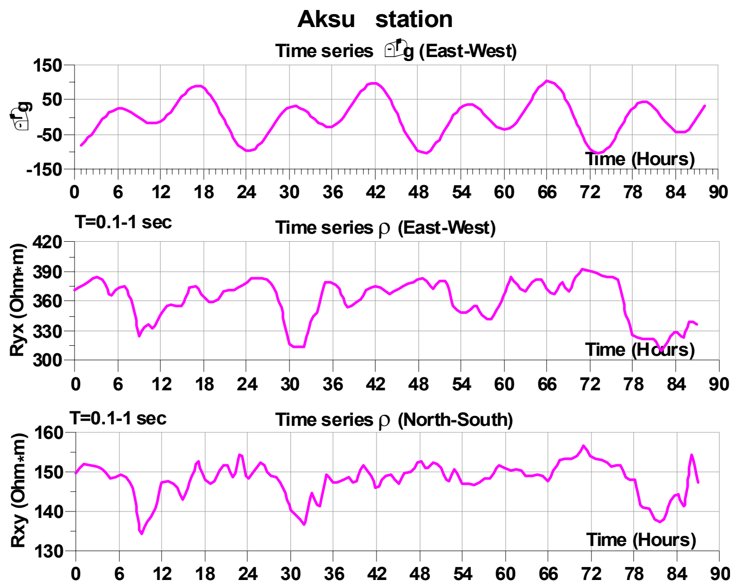

Fig. 3. Comparison of an average apparent resistivity (ρxy, ρyx) in the band 10-1 Hz and calculated gravity variation (in μGal) at the site Aksu. Beginning of comparison – August 12, 2004 at 16-00 of local time.

From analysis of the graphics of apparent resistivity for frequency band 10-1 Hz (Fig. 2) and calculated gravity variations at the monitoring site Aksu we conclude that:

(1) The periodicity about 24 hours is clearly presented in apparent resistivity estimates from 4 days observation of MT field. This fact can be explained by an effect of the electrical resistivity modulation apparently due to lithosphere deformations concerned with solar-lunar tides. It is known, there are two (23.9 and 24.1 hours) and 12.0-hourly components in spectrum of solar-lunar tides. (2) Action of tide force causes a decrease of stress and opening of microscopic fractures (high tide phase). As a result of this action the fluids are partly migrated from closed

pore spaces to opening cavities. It results in increasing number of coupled conductive channels for current and higher electrical conductivity of rocks. The inverse effect is observed during low tide phase. (3) With small delay the peaks of the max magnitude of apparent resistivity coincide with peaks of the max magnitude of tide force related to Sun influence. Apparently, in these time moments the maxima of deformation action on investigated geologic volume of medium is realized.

Thus, the variations detected in geoelectrical parameters (apparent resistivity) with periods about 24 and 12 hours can testify to correlation of geoelectric section characteristics of the Earth's crust and parameters of stress-strain state due to solar-lunar tides. And complicated character of relations between apparent resistivity and vertical tidal deformation possibly can be explained by peculiarities of fluid flow reorganization under pressure changes in concrete geodynamical settings, including factors of specific geometry of pore space as network system and various degrees of rocks water saturation.

To study long-time variations of apparent resistivity and phase we consider deviations of the daily estimates from the long-time average: $\Delta\rho_{xy}=(\rho_{xy} - \overline{\rho}_{xy})/\ \overline{\rho}_{xy}$ and $\Delta\varphi_{xy} = \varphi_{xy} - \overline{\varphi}_{xy}$. We regard the averaged apparent resistivity and phase curves which were calculated with median of the 740 daily estimates for two monitoring sites as reference MT curves (Fig. 4).

Let us analyse the temporal behavior of magnetotelluric transfer functions obtained in monitoring experiment at sites Aksu and Chon for two years of MT measurements (September, 15, 2003 – October, 2005) on the base of spectra-time presentation for data.

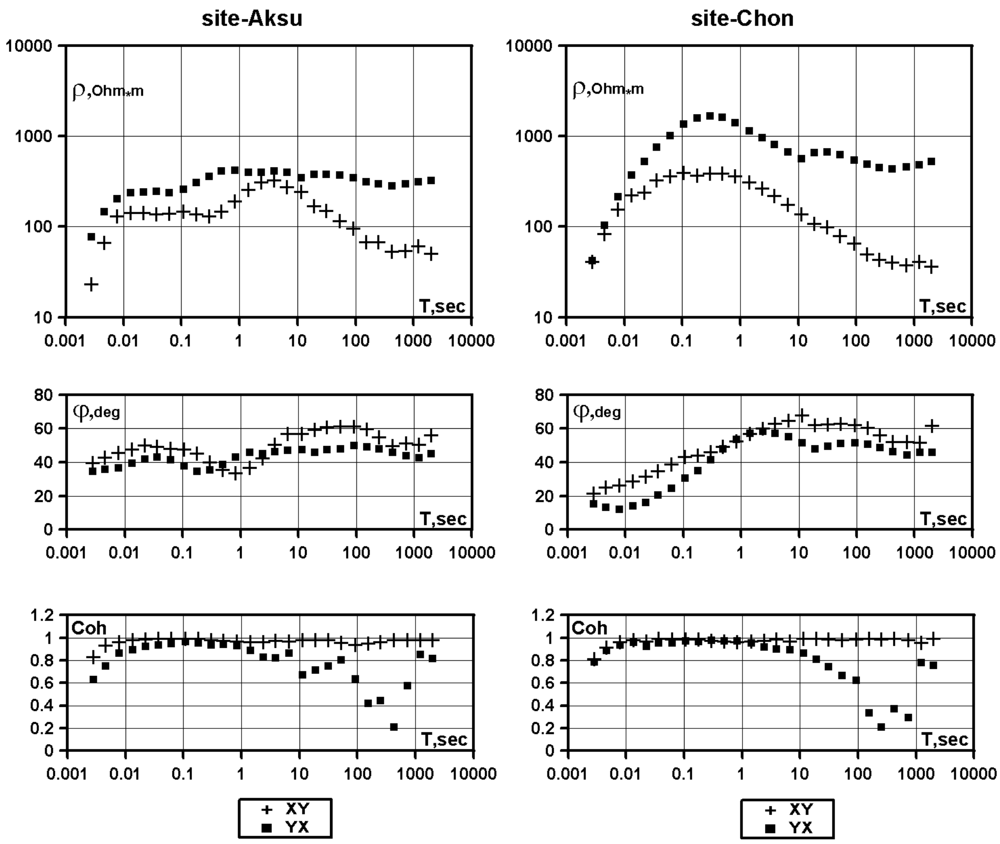

Fig. 4. Reference MT curves (amplitude and phase) and local coherences for monitoring sites were calculated as the median of the 740 daily estimates for two monitoring sites (xy: north-south; yx: east-west)

Fig. 5, 6 show the frequency-time diagrams (dynamic spectra) of apparent resistivity deviations in percents and phase deviations in degrees at sites Aksu and Chon. In the dynamic spectrum, the easily-seen white and pale color zones correspond to changes in resistivity ±3%. The dark color shows changes exceeding 10%, mainly arising from instability and disorder of TFs. Visual analysis of Fig. 5, 6 permit a tentative conclusion that dynamic changes of apparent resistivity in the YX (west–east) component are the most informative than YX (north-south) mode.

Note that fig. 5, 6 allow useful visual estimation of raw data quality at the Chon and Aksu sites, since only standard basic processing has been applied without any additional filtering. Note that our sections of log resistivity and phase variations have consistent scale (variation 1 percent in $\Delta\rho$ corresponds to 0.286° in $\Delta\varphi$). So we can see in practice that phase variations are always slightly below the amplitude variations on this common scale.

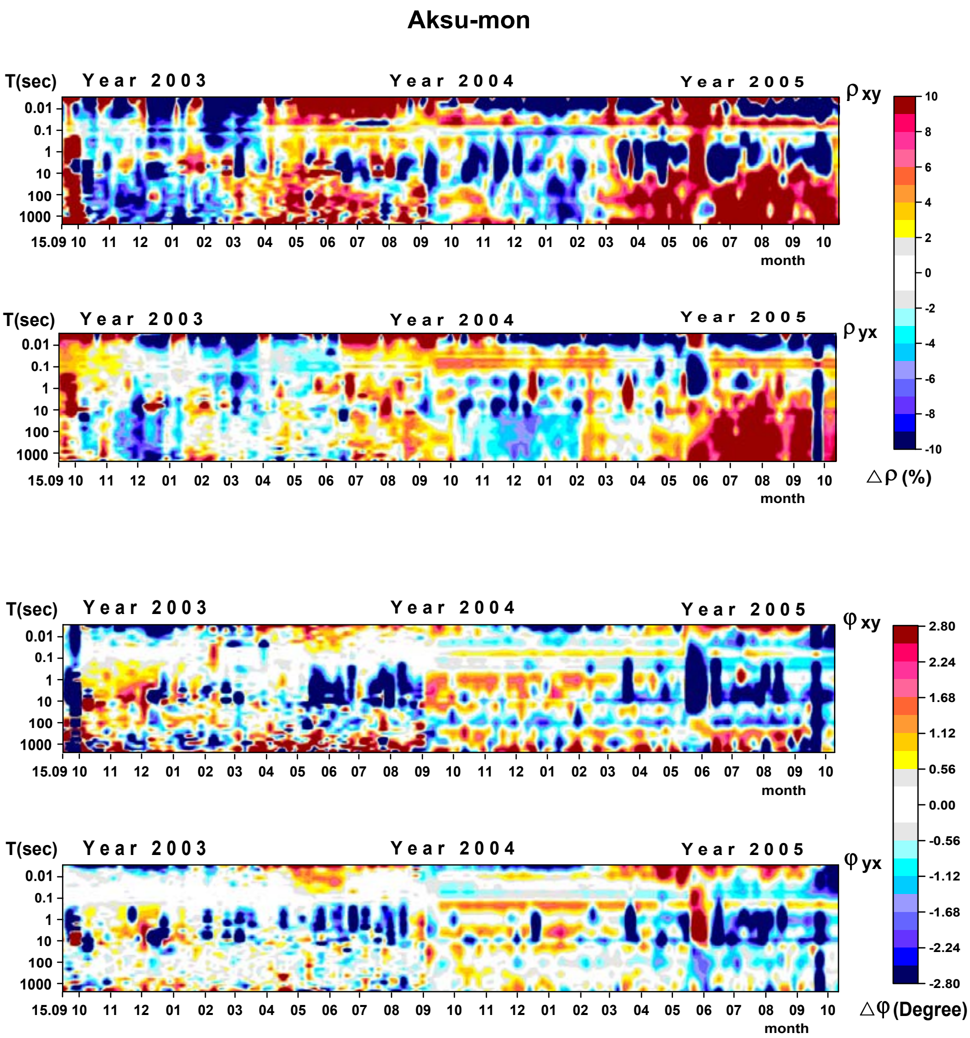

Fig. 5. Frequency-time diagrams of apparent resistivity and phase daily average values obtained at site Aksu. Dynamics of time series is presented by relative differences (in percent and degree) between current and reference MT curves for full set of sounding periods at the given site during September, 2003 – October, 2005. **xy** – direction in north-south; **yx** – direction in east-west.

Chon-mon

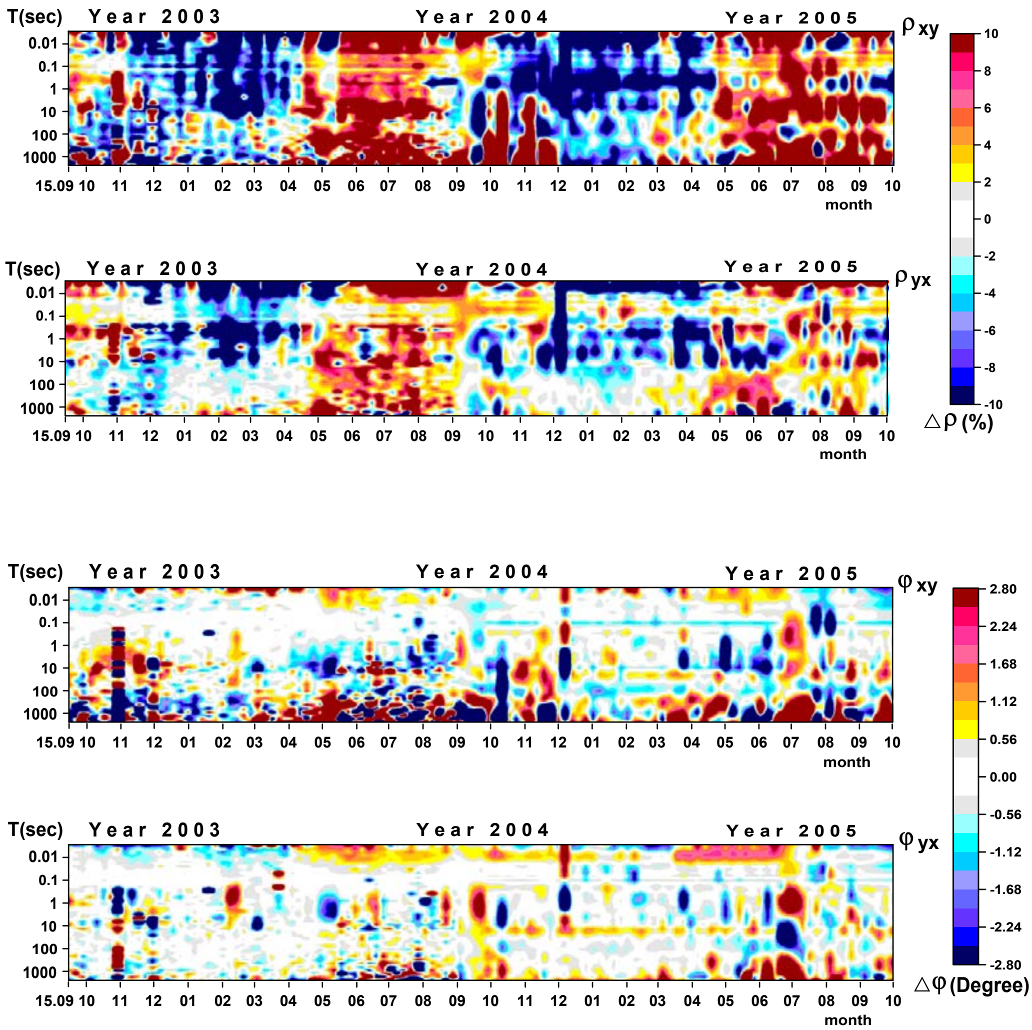

Fig. 6. Frequency-time diagrams of apparent resistivity and phase daily average values obtained at site Chon. Dynamics of time series is presented by relative differences (in percent and degree) between current and reference MT curves for full set of sounding periods at the given site during September, 2003 – October, 2005. **xy** – direction in north-south; **yx** – direction in east-west.

To emphasize possibly systematic (long-time) variations in MT transfer functions we applied a median filter to the array of resistivity differences in time domain with smoothing window 11 days. The filtered and initial variations in resistivity at the site Aksu are shown for xy- and yx- modes in Fig. 7.

Frequency-time sections in Fig. 7 clearly show a decrease in apparent resistivity Ryx (west-east) in low-frequency range (T>10сек) in observation period November, 2003 – January, 2004; a sharp increase in Ryx within July – September 2004, and some instances of persistent biases at the longest periods. Long-term variations of phases are generally smaller, consistent with the generally smaller total variability of phases seen in Fig. 5, 6.

There is no clear evidence of any seasonal variations in any of observed MT parameters, as might be expected due to seasonal variations in near-surface hydrology.

For more evident graphic visualization of time series of monitoring data the daily average values of the apparent resistivity module and impedance phase are shown in Fig. 8 separately on the periods. Here arrows mark the strong seismic events which have occurred in region for the monitoring period.

The strongest earthquakes with energy class K> 11 which epicentres are located from monitoring points on distance no more than 100 km and also destructive earthquake with magnitude 7.6, occurred on October, 8, 2005 in Pakistan have been chosen for comparison MT monitoring data with seismic activity.

In Fig. 8 it is distinctly manifested the "precursor" character of variations for apparent resistivity since June, 2005. Our opinion is that these variations can reflect the period of activation of structures of the Northern Tien Shan Earth's crust and, undoubtedly, have concerned the earthquakes occurred on June, 20 and on October, 8, 2005.

Conclusions. MT parameters computed daily for 2003-2005 have been generally stable with high accuracy of MTU-5D recorded data (generally, 1–2% in amplitude and 0.5 degree in phase). Such accuracy permits identification of harmonics of solar-lunar tidal variations of the lithosphere with the help of MT transfer function, as well as similar-magnitude changes of EM parameters caused by other processes. Practical approval of this conclusion can be illustrated by the revealed abnormal behaviour of MT apparent resistivity, registered at monitoring sites in the Northern Tien Shan, before the strongest earthquake in Pakistan with magnitude 7.6.

Typical deviations of estimates based on a single day of data differed from the long term average transfer function by 2–3% for T<100s and increasing to about 6–8% for T=1000–2000s. Note that long-term phase variations are smaller than amplitude ones. It is necessary to find a reasonable explanation for this peculiarity of MT transfer function behavior for long periods with the help of our future observations. Because variations between contiguous days were nearly random, so significantly smaller variability can be obtained by longer averaging times.

Site AKSU: 15.09.2003.r.-03.09.2004.r.

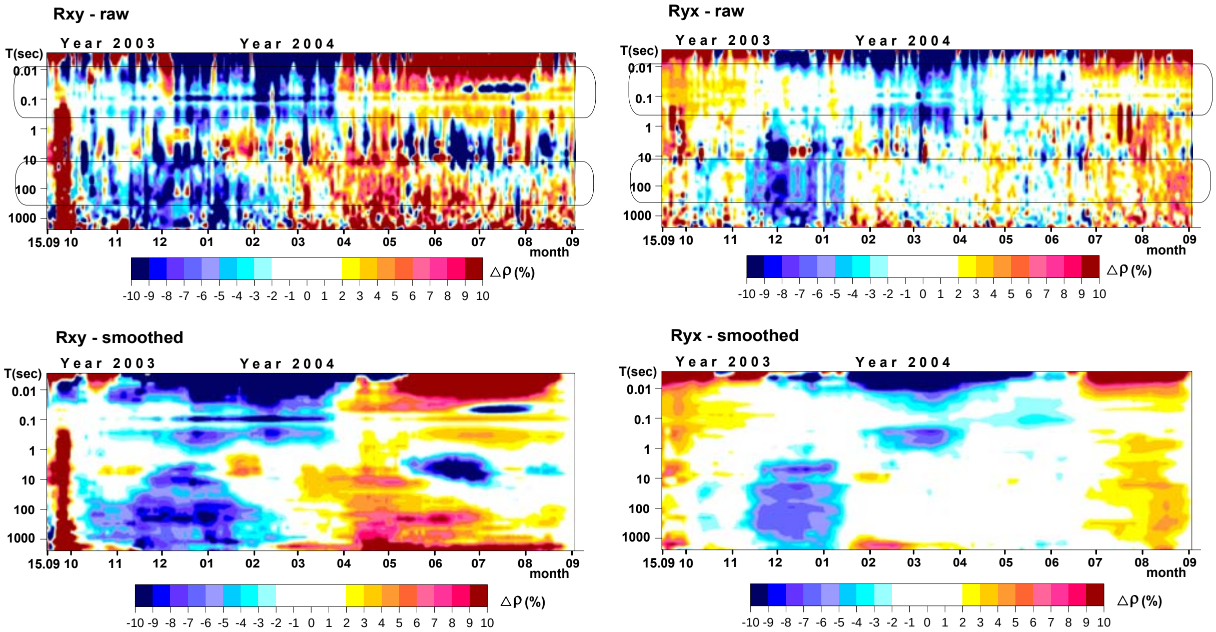

Fig. 7. Raw and low-pas filtered variations of daily averaged estimates of apparent resistivity expressed in percent. The median filter with smoothing window of 11 days was applied in time domain. Contours indicate the most informative frequency ranges.

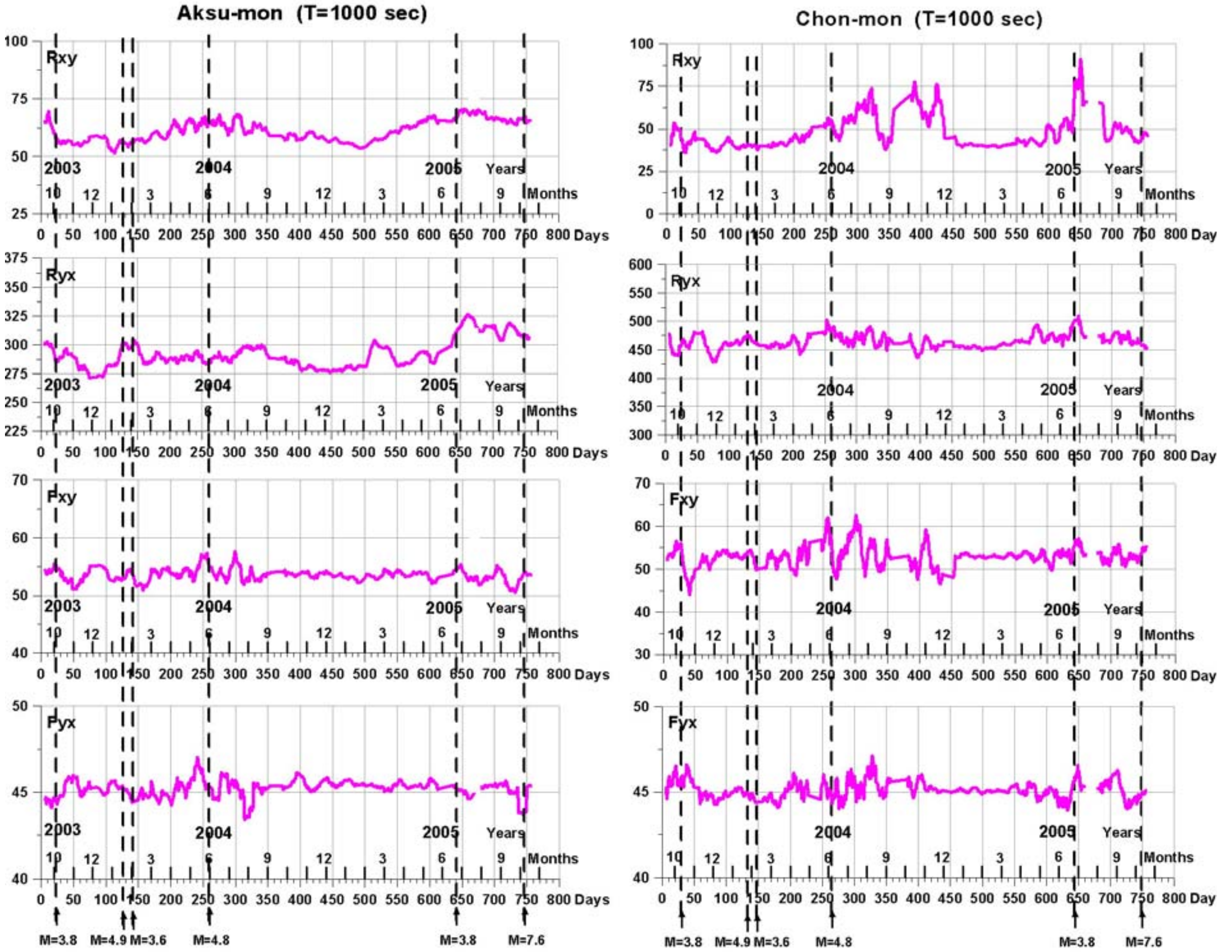

Fig. 8. Resistivity and phase at different periods based on the continuous monitoring of the MT fields. Site Aksu (left panel), site Chon (right panel)

Next step of our analysis will be connected with estimation of temporal variations in static electric field distortion and contribution of seasonal component in observed data variations.

References

1. *Fox L.* Satellite-Synchronized 3-D Magnetotelluric System U.S. Patent No. 6 191 587 B1, issued Feb. 20, 2001.
2. *Batalev V.J., Bragin V.D., Zejgarnik V.A., Zubovich A.V., Matiks A.I., Orlenko N.N., Rybin A.K., Trapeznikov J.A., etc.* Monography: Imaging of geodynamic processes in the geophysical fields. – Moscow: Science, 1993. – 158 p. (in Russian).
3. *Rybin A.K., Batalev V.Yu., Tshelochkov G.G., Bataleva E.A., I.V. Safronov, Leo Fox, Olex Ingerov.* About magnetotelluric monitoring on the Bishkek Geodynamic Poligon // Abstracts The Fifth Kazakhstan-Chinese International Symposium "Modern geodynamics and seismic risk of Central Asia". – Almaty, Kazakhstan. – September-2003. – P. 148–150.

4. *Varentsov Iv.M., Sokolova E.Yu. and BEAR WG.* Diagnostics and suppression of the auroral distortions in the transfer operators of the EM field in the BEAR experiment // Izvestiya, Phys. the Solid Earth. – 2003. – V. 39(4). – 28 p.