Anamolous modulations of electromagnetic field during increased seismic activity

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Abstract. The article presents the results of electromagnetic monitoring and geomagnetic observation during increased seismic activity in eastern part of Bishkek geodynamic range (Northern Tien-Shan) in 2017. It includes brief description of seismic conditions of the territory being researched, as well as analyses of the correlation between changes in geophysical field parameters and the earthquakes.

1. Introduction
Anomalous modulations of the electromagnetic field manifest stress-strain condition in the environment due to, among other things, earthquakes. The experience of the perennial monitoring indicates that electromagnetic field modulations may accompany the onset of an earthquake, earthquake itself, and post-seismic activity.

2. Results of electromagnetic monitoring
Long-term (since 1987), far-field transient electromagnetic (TEM) sounding of the Bishkek Geodynamic Range (BGR) carried out at 6 stationary and 14 mobile measuring stations (Figure 1, Figure 2) provided information on how, such an important field characteristic as apparent electrical resistivity \( \rho_T \), changes with distance and time.

Figure 1. Areal map of Kyrgyzstan showing locations for the electromagnetic monitoring stations in KNET network and geomagnetic measuring stations.
Figure 2. Electromagnetic monitoring network stations overlaid on geomagnetic measuring stations. Stationary stations: 1-Aksu; 2-Shavai; 3-Chonkurchak; 4-Tash-Bashat; 5-Issyk-Ata; 6-Kegety. Mobile sites: 11-Noruz; 13-Kashkasu; 14-Ala-Archa middle; 17-Ala-Too; 18-Toguzbulak; 19-Skvazhina 11520; 21-Dachi; 22 – Lower Serafimovka; 23 – Upper Serafimovka; 35-Ala-Archa upper; 61-Shlagbaum; A-Almaz; B-Basa.

Analyses of the apparent electrical resistivity time series presented certain difficulties when it came to data interpretation: quite often anomalous values of $\rho_t$ had nothing to do with the seismic events. Time series data persistently contained insignificant variations due to large number of small earthquakes $K=6÷8$. In some cases, it is impossible to unambiguously determine which event brought about anomalous modulations of the electric field.

Figure 3. Tectonic map of BGR depicting seismic conditions April – May 2017 including locations of electromagnetic measuring stations (yellow star represent the epicenter of the historic Balasagun earthquake (1475, $M=6.4$)).

However, the data from some measuring periods contained significant changes in $\rho_t$ that can be linked to specific seismic activity for Example, to a series of Kegetynsky earthquakes in April 2017 (named after settlement Kegety located in extreme eastern part of electromagnetic monitoring area (see Figure 3).
It should be noted, this article uses earthquake energy characteristic called “Class” instead of magnitude as was customary in the territory of the former USSR. For further details see reference document [1].

Seismic conditions near Kegety on April 21, 2017 were unique: there were two earthquakes with $K=11.68$ (00:41:52 UTC) and $K=11.55$ (00:55:44 UTC) accompanied by series of fore- and aftershocks. For 224 days after the primary earthquakes there were a total of 76 aftershocks (62 within first 24 hours) registered as having power classes ranging 6 to 10.5 [2].

It should be noted, that until than the observed area had weak seismic activity. It start increasing at the end of 2015, continued in 2016 and peaked in spring 2017 (Figure 4).

The hypocenters of the primary earthquakes and aftershocks (Kegety, April 21, 2017) were located primarily within the depth interval 11 to 15 km along the plane of the Shamsi-Tyundyuk fault, but the epicenters were concentrated mainly in the abandoned south wing of the fault.

It appears that increased seismic activity at the beginning of 2017 in Kegety area of Kirghiz Ridge piedmont was due to the adjustment movements along Shamsi-Tyundyuk fault and the discharge of the strain accumulated within the earth crust.

Changes in the condition of geological medium due to preparation and subsequent seismic activities near Kegety were registered in the form of anomalous unlike signs variations of $\rho_T$ with various degrees of intensity and duration on all stationary and mobile sounding stations.

The framework of this article does not allow for detailed analysis of $\rho_T$ time series for all 6 stationary and 14 mobile measuring stations, therefore below please find excerpts from analyses made for stations located at different structural zones: mountainous regions of developing Paleozoic formations (Figure 5, a, b); in piedmont (along junction Kyrgyz ridge -Chui depression, Figure 5, c) and within Chui depression (Figure 5, d).

As seen on Figure 5, data trends from for stationary stations started changing as early as February, at least 3 months prior to the events under consideration, majority of changes were gradual decrease in value of apparent electrical resistivity until May-June, primarily on early stages of field formation ($t=0.14$ c, corresponds to upper portion of cross section).

It should be noted, several stationary stations saw changes in value of $\rho_T$ along entire geo electrical cross section either increasing with depth ($t=3.14$ c, Skvazhina 11520), or decreasing (Shavai). Narrow, localized anomalies in unlike sign values of $\rho_T$ observable on $\rho_T$ charts against background of general
decrease of electrical resistance, as a rule are associated with the local weak earthquakes that have epicenter within measuring network.

Figure 5. Segments of the apparent electrical resistivity $\rho_T$ time series for several stationary measuring stations with submeridional (a, b) and sublatitudinal (c) orientation of MN dipole, and for one of the mobile measuring stations (d).

The most significant variations of $\rho_T$ were observed on Almaz and Basa stations that have radial and x-type configuration of receiving devices respectively (each site has 4 MN dipoles oriented to cardinal points 45° apart).

An example of $\rho_T$ time series for the lower horizons of cross-section ($t=3.14$ c) at all receiving dipoles $\varphi$ orientations presented in Figure 6.
Figure 6. Fragment of time series for lower, deeper levels of cross sections ($t=3.14$ c) at various MN dipoles ($\phi$) orientation received from mobile stations Almaz and Basa.

One can get the overall picture on how geo medium electrical characteristics change with time and depth for stations Almaz and Basa after building polar graph using relative values of apparent electrical resistivity $\Delta \rho_\tau (t)/\rho_\tau$ (where $\rho_\tau$ – initial value in each time series) from all 4 receiver lines.

After describing an ellipse around the data and determining orientation of the anisotropy bigger and lesser axis or direction of the bigger and lesser changes in apparent electrical resistivity, it’s possible following the model in reference document [2] to identify direction of compression and tensile forces at different time intervals (Figure 7).

Figure 7. Orientation of the big and small axis of the ellipse for anisotropy $\rho_\tau$, based on data from Almaz and Basa stations. The red outline highlights time of the biggest seismic activity.

Changes in the stress-strain state of the medium leading up to the Kegety earthquakes were also manifested through anomalous modulations of the geomagnetic field (Figure 8).

Prior to the noted events in Kegety, the changes in the magnetic field were observed on all monitoring sites, no exclusions. Approximately one week prior to the primary shocks (class 11 events) $\Delta T$ charts coming from all network stations show minim delta in magnitude of the magnetic field full vector, in other words $\Delta T$ values decline 0.6% to 10% relative to the values at the beginning of 2017. Sharply
increased values of $\Delta T$ reached their maximum in the middle of May, which can be attributed to the aftershock process following two primary shocks and reflect unspecified total effect from more than 60 aftershocks.

![Figure 8. Time series (fragments) for magnetic field full vector differential based on data from a number of stationary geomagnetic measuring stations in 24-hour observation mode.](image)

Seismic events in April 2017 near Kegety brought along magnetic field modulations and set a new level of $\Delta T$ in the farthest point of the geomagnetic monitoring network - station Karagai-Bulak. It is located on the north shores of the lake Issyk-Kul, 150 kilometers from the epicenter of the earthquakes under review.

3. Conclusion
Proceeding from the above, it appears that changes in $\rho_t$ time-domain data manifested Kegety earthquakes preparation phase and took place way before the earthquakes in April-May 2017. The changes in medium stress-strain state induced by the upcoming seismic events were registered throughout entire territory covered by the electromagnetic measuring stations.

Manifestation of the above-mentioned events, primarily April-May 2017, brought about in some cases significant changes in physical characteristics of the medium and established a new level of apparent electrical resistivity and $\Delta T$.

4. References
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