The capabilities of analyzing the seismo-electromagnetic satellite CSES-01 data for monitoring of seismic activity of the Northern Tien Shan

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Abstract. The relationship between space weather and earthquakes occurring in seismically active areas with the seismo-electromagnetic satellite CSES-01 data are observed. The study assumes the presence of possible ionospheric precursors of strong earthquakes. The sets of measuring instruments of the satellite and data are considered. Subsequently, to prove the non-random nature of the space weather effects, the results of ground-based geomagnetic or electromagnetic observations should be used, for example, magnetotelluric soundings (MTS). Stationary and regime points of the MTS network of the Research Station RAS in Bishkek (RS RAS) are suitable for these purposes in the Northern Tien Shan. The MTS data are presented in the form of hourly frequency-time series with system rotation from 0° to 180°. To obtain information on earthquakes, it is proposed to use data from the NEIC or ISC seismic catalog, since they aggregate data from regional catalogs, including the KNET seismological network maintained by the RS RAS. It is concluded that it is necessary to select the CSES-01 trajectories and times of flight over the territory of Kyrgyzstan and download the electric field detector (EFD) data. The results of comparing satellite and ground-based observations can be used in future technologies for short-term earthquake prediction.

1. Introduction
Since the 80s of the twentieth century in the Northern Tien Shan, geophysical observations are carried out on the basis of the International Research Center “Geodynamic Test Site” (IRC-GPG) [1, 2]. An important part of the performed geophysical research related to predicting the dynamics of seismic activity is the collection, archiving and construction of geoelectric models of the Northern Tien Shan [3-5]. Observations of the behavior of seismolectric signals (SES) are carried out in Kyrgyzstan in the course of cooperation of the Research Station of the Russian Academy of Sciences in Bishkek (RS RAS) with the Association “Electromagnetic Studies of Earthquakes and Volcanoes” (EMSEV) [6]. Much attention is paid to both active and passive electromagnetic monitoring [7, 8]. When analyzing the anomalies of the electromagnetic parameters of stationary MTS points on the obtained geoelectric azimuthal hourly data (time-frequency sections), information on the redistribution of electrical resistivity anomalies can be obtained [9]. Such fluctuations are best viewed in conjunction with the distribution of seismicity in the region. On the azimuthal time-frequency series (TFS) from magnetotelluric soundings (MTS), the dependencies of the apparent resistivity changes during the seismic events occurred [10].
It is assumed that the use of satellite data in the analysis of the behavior of variations in geophysical fields can lead to the identification of possible physical mechanisms of lithosphere-ionospheric connections, for example, when comparing the wind speed of the upper troposphere with variations in seismic activity [11-15]. Satellite measurements of electromagnetic phenomena (ionospheric waves) can characterize the relationship between the lithosphere-atmosphere-ionosphere-magnetosphere and electromagnetic radiation. In the study [16], it was shown that there is a connection between the processes in the atmosphere and the ionosphere before the earthquake based on temperature measurements in the upper troposphere/lower stratosphere, when macroscale positive ionospheric irregularities occur 10-15 hours before strong earthquakes (M ≥ 5). Moreover, anomalies in the behavior of the ionosphere can be observed even 2 weeks before a strong earthquake [17].

In this paper, it is proposed to use the records of the seismo-electromagnetic satellite CSES-01 (Chinese Seismo-Electromagnetic Satellite) [18], since the satellite allows measuring the electromagnetic field in a wide frequency range. An analysis of the degree of influence of variations in space weather parameters on deformation processes and the possibility of initiating seismic events by strong ionospheric disturbances using CSES-01 are carried out in [13]. For joint consideration, it seems possible to use the data on the seismicity of the Northern and Central Tien Shan in comparison with the records of stationary and regime points of magnetotelluric monitoring of the RS RAS, since the relationship between seismic events and variations in the geoelectric parameters of the Earth has been proven [4, 10]. Anomalies in electrical resistivity were accompanied by stretching of the upper cortex. The most noticeable resistivity decrease was observed at sites around the earthquake epicentre (Northern Tien Shan, M=4.7) at a distance of 15–20 km [5]. This change began 1.5–2 months prior to the earthquake, and reached a maximum immediately before the event, and then the values returned to the initial level 1 month after the earthquake. Thus, the maximum amplitude of the drop in resistivity was observed within the crustal conductive horizon of the earth's crust, where most of the hypocenters were located.

2. Materials and methods

The papers [19-21] indicate that satellite measurements are widely used in seismology both for ionosphere sounding and for detecting the Earth's surface movements. For example, the DEMETER satellite (Detection of Electro-Magnetic Emissions Transmitted from Earthquake Regions) was launched in 2004 to study ionospheric disturbances associated with the seismic activity of the Earth's lithosphere. In addition to all existing satellite missions, a new one has appeared in 2018 - China Seismo-Electromagnetic Satellite “Zhangheng 1” (CSES-01). The satellite's mass is about 730 kg, the trajectory height is ~507 km, and the inclination angle is about 97.4°. The expected service life is 5 years. The main goal of the CSES mission is to detect the anomalous electromagnetic field associated with earthquakes, based on the assumption of the presence of ionosphere-magnetosphere-lithospheric interactions. The CSES-01 operating mode covers the latitude range from 65° S up to 65° N [22].

A set of instruments included in the CSES-01 satellite [23, 24]:

- A Search-Coil Magnetometer (SCM) for measuring the three components of the magnetic field at higher frequencies;
- An Electric Field Detector (EFD), including four probes installed on as many booms, aimed at the measurement of the three components of the electric field;
- Fluxgate magnetometer;
- A global navigation satellite system (GNSS);
- Occultation receiver for studying the ionospheric plasma profile;
- A Plasma Analyzer Package (PAP) and a Langmuir probe (LAP), to observe ion/electron density and temperature, ion drift velocity and plasma composition;
- Tri-band beacon (TBB);
- Two particle detectors, the High-Energy Particle Package (HEPP) and the High-Energy Particle Detector (HEPD), for measuring high-energy charged particles and X-ray flux.

Mission scientific objectives:
• Monitoring electromagnetic field and waves, plasma and particles perturbations induced in the ionosphere and magnetosphere;
• Monitor space weather phenomena;
• Study possible spatial and temporal correlation between electromagnetic disturbances in the topside ionosphere and the occurrence of seismic and volcanic events;
• Study solar physics.

According to [25], to verify the observed phenomena on the CSES-01 electromagnetic data, a standard ground cross-form setup can be used, oriented in the North direction and measuring the electromagnetic field on the ground surface. Therefore, it seems possible to use the data from the MTS network in the Northern and Central Tien Shan. RS RAS process MTS monitoring using the following equipment:

• Standard five-component MTS installation for measurements in passive mode Phoenix MTU-5 [26] complete with non-polarizable electrodes [27], GPS antenna, electric dipoles - components (Ex, Ey), and three inductive coil sensors MTC-50 - components (Hx, Hy, Hz) (Fig. 1). The connection and registration is made via a laptop.

Figure 1. A set of equipment for electromagnetic field registration on the ground surface: a) Phoenix MTU-5 with inductive coil sensors MTC-50; b) MTS cross-form setup

3. Results
To select data from a seismo-electromagnetic satellite, we need to refer to the server http://leos.ac.cn/#/dataService/auxiliaryDownloadList [18]. The server view is presented in Fig. 2. It should be noted that the following restrictions are imposed on data loading:
1. You can download data recorded earlier than 180 days ago;
2. The duration of the data array should not exceed 12 months.
The RS RAS database during the satellite operation in 2018-2021 contains the results of monitoring for the network of MTS points: stationary points Aksu and Chon-Kurchak 2018-2020 (year-round), mini-polygon Kentor - spring and autumn sessions, each of which lasts 21 days (2018, 2019, 2020, 2021); and points of deep magnetotelluric soundings (GMTS) in 2018 (registration time 500 hours) (Fig. 3). The NEIC catalog [28] was used to show the earthquake epicenters on the map, since it contains data from regional catalogs, including the seismological network KNET, which is under the supervision of the NS RAS.

Figure 3. Map of the earthquake epicentres distribution according to the NEIC catalog [28] for the territory of Kyrgyzstan with magnitudes: 1 - 2.5 <M <3.5, 2 - 3.5 <M <4.5, 3 - 4.5 <M <5.5, 4 - 5.5 <M <6.5; 5 - points of magnetotelluric monitoring (stationary points: Aksu and Chon-Kurchak, regime points: GMTS 900-920, Ukok-2), 6 – cities
The standard view of the MTS monitoring results and the temporal distribution of seismic events on the MTS records is presented as the form of time-frequency series (TFS) of variations in electromagnetic parameters (Fig. 4), calculated with a rotation angle step 15° [29].

Figure 4. Variations in apparent electrical resistivity in the form of time-frequency series for the stationary point Aksu from October 11 to October 30, 2018 with plotted vertical lines with the times of earthquakes, that occurred on the territory of Kyrgyzstan [30]

Based on the analysis of the time-frequency series (TFS) of variations in the apparent resistivity in 12 azimuthal directions for different points of the MTS it is known [29, 30]:
- The most important result of the TFS analysis is the pattern of sign change in electromagnetic parameters variations;
- There is a fact of connection between seismic events focal time and areas of TFS with high gradients of electromagnetic parameters;
- There is a relationship between changes in the parameters of the electromagnetic field at the extremes of lunar-solar tides for earthquakes with magnitudes M<6.

4. Conclusions
Based on a review of the available data, it becomes clear that the CSES-01 satellite flies over the selected area (limits of the rectangular area: northern - 43.27° N, southern - 39.27° N, western - 69.25° E, eastern - 80.3° E) approximately once every 5±2 days at a speed of ~5 km/s. The satellite is located over the territory of Kyrgyzstan for about 3 minutes: on the ascending trajectory at about 08-09 hours UTC, on the descending trajectory at 20-21 hours UTC. Considering the data on the occurring seismic events, the choice of records with the simultaneous registration of earthquakes is difficult.

First of all, we need:
- Select Langmuir Probe (LAP) and Electric Field Detector (EFD) for further analysis;
- Select datasets for the time of satellite flight over the object under study;
- Select suitable earthquakes, the time in the source of which falls on the time of the satellite's passage (for strong earthquakes ± 1 month) for a territory of Kyrgyzstan;
• Compare the results of satellite observations and variations of electromagnetic observations in ground-based magnetotelluric soundings data.

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