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First results for the selection of repeating earthquakes in the Eastern Tien Shan (China)†

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Abstract: This research of repeating earthquakes is aimed at the possible influence of space weather parameters on the seismic process. I make attention to the behavior of specific faults and active tectonic zones. Repeating EQs were found in the Eastern Tien Shan (region of China), on the border with Kazakhstan and Kyrgyzstan. In this work, an earthquake catalog (NEIC) of 400 earthquakes with 2.5+ magnitude from 2015 to 2020 was used. The areas of shear zones with small nucleating are found. These droplets could lead to the process before the nucleation of the macroscopic phase. Especially, to detect slip faults areas, the Google Earth tools are effective.

Keywords: repeating earthquakes; earthquake cycle; Earth structure changes.

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1. Introduction

Recent studies indicate that the repeated earthquakes occur all over the world [1-5]. Authors report repeating earthquakes at Parkfield in [5] and say, comparing to [e.g., 6-8]: "A characteristic repeating earthquake sequence (RES) is defined as a group of events with nearly identical waveforms, locations, and magnitudes that represent repeated ruptures of effectively the same patch of fault". The result shows that the sequence of earthquakes could be extended in time, even low magnitude. The observations of RES prove that there are aseismic slips at depth loads the repeating ruptures. In this case, the view of China Mainland is very attractive to be an example, especially the northern-western mountainous part. The hazard map for PGA corresponding to a 10% probability of exceedance in 50 years is presented in Fig. 1.

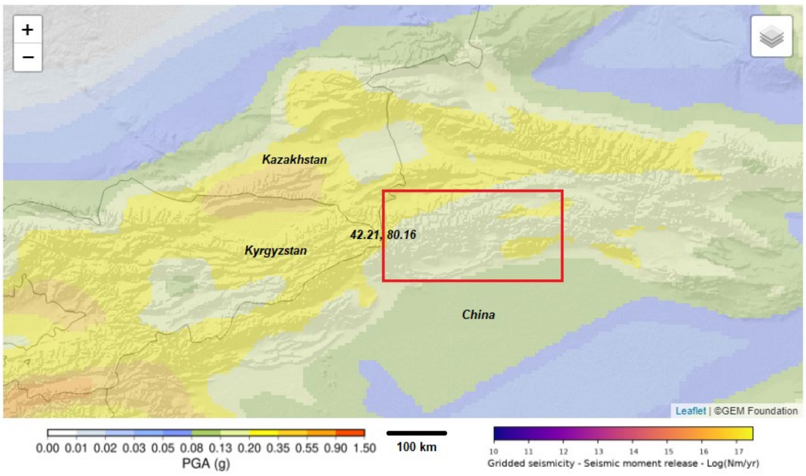


Figure 1. The Global Hazard Mosaic coverage of China, based on the 2015 seismic hazard model of China (GB18306-2015) for peak ground acceleration (PGA) and spectral acceleration (SA) at 0.2s, 0.5s, 1.0s, and 2s [9].

Some research about repeating earthquake sequences (RES) is able to monitor volcanic activity [10]. The RES comparison results from different authors we could find in [1]. Sometimes repeating earthquakes called duplet events, and families or clusters if they are located inside the same area. Upon research from Uchida and Bürgmann [7] well-characterized RES are mostly small (M < 4) but can be larger than M6 and show long-term slip rates increased for several years to a decade.

For the seeking process of RES events, the accurate hypocenter determinations are of high importance. Hypocenter location and waveform similarity are two main methods to identify repeating earthquakes to obtain the highest cross correlation coefficient (CC) between each waveform pair [1]. The most popular method is cross correlation of regional seismic waveforms. Their waveform characteristics provide important insights into frictional fault mechanics, earthquake source heterogeneity, and Earth structure changes. That is the reason why for the China catalogs from 1985 to 2005 near 5623 events were relocated by Schaff et al. [11]. In such way, Schaff and Richards [12] found that 10% of seismic events in and around China are repeating earthquakes (with no more than 1 km from each other), whereas 64% of postshocks have smaller magnitudes than the preceding RES events [5]. Recent novelty in epicenter location is satellite data usage to reduce uncertainty. Geodetic observations and imaging geodesy observations complete the NEIC catalogs [13, 14]. China statistical correlation of seismicity and geodetic strain rate in the Chinese Mainland is given in [15].

The aim of this research is to provide number of samples of repeating earthquakes to study the "ionosphere-atmosphere-lithosphere" system in seismic-prone regions and the relationship between the earthquake source, effect on deformation processes and space weather parameters based on data of space monitoring by Chinese seismo-electromagnetic satellite CSES-01, the possibility of earthquake triggering by strong bursts of geomagnetically induced currents in conducting seismogenic faults of the Earth crust. Because there are some proofs of the space weather influence in triggering of seismic activity [16, 17].

2. Materials and Methods

For the RES catalog forming, firstly, we need to use open worldwide catalogs, e.g. NEIC [14]. Than we need to choose the interesting area and form a text format catalog and save for further analyzing. Afterwards, we need to compare hypocenter locations and find any clusters or repeating sources. Usually, the RES distance is no more than 1 km from each other. The next step is to find any close seismic stations, where the seismograms for these cluster events are recorded. As I said before, the only reason to collect waveforms is to correlate them with each other. Thus, I need to download earthquake waveforms for each event recorded by the seismic long-term segment. Usually, they should have 100 Hz sampling rate. Eventually, we group repeating pairs into clusters using median CC value ≥ 0.9 with a number of at least 2 stations upon [1, 18]. The additional information (e.g., the number of stations, station distribution, and timing accuracy of station clocks) is outside our attention. The CC time windows are very sensitive [19]. The CC time length are compared to ~5000 samplings, starting 0.5 s before the P/S wave onset [18, 20]. The process and results should be similar to the research by Deng et al. [21, 22].

Actually, for all those steps, firstly, we need to find and accumulate information about seismic and observatories, monitoring the Earth's magnetic field. The previous data for China Digital Network was reviewed in [23]. Permanent stations on China’s National Digital Seismograph Network (CNDSN) are: Beijing (BJI), Enshi (ENH), Hailar (HIA), Kunming (KMI), Lhasa (LSA), Lanzhou (LZH), Mudanjiang (MDJ), Qiongzhong (QIZ), Shanghai (SSE), Urumqi (WMQ), Xi'an (XAN) [23]. There is also the China National Seismic Network at Institute of Geophysics [24]. There were only two permanent stations in China near the chosen region that are useful for the study: Urumqi (ENH), Kashi (KSH).

The other seismic stations are located in Kyrgyzstan and Kazakhstan for studying seismicity [25-30]. I select for further analysis nine seismic stations with their coordinates are given in Table 1.

Table 1. The nearest seismic stations to the selected area.

Station Code	Station Name	Country	Latitude, °N	Longitude, °E	Network Name / Data Center(s)
ASAI	Aksay	Kyrgyzstan	40.9178	76.521	CAIAG / GEOFON
ENEL	Enylcheck	Kyrgyzstan	42.1529	79.455	CAIAG / GEOFON
MRZ1	Lake Merzbacher	Kyrgyzstan	42.2246	79.8597	CAIAG / GEOFON
TARG	Taragay	Kyrgyzstan	41.7291	77.8048	CAIAG / GEOFON/ IRISDMC
PRZ	Prjevalsk	Kyrgyzstan	42.5	78.4	KRNET / IRISDMC
PRZ1	Karakol	Kyrgyzstan	42.5	78.400002	KRNET / IRISDMC
PDGK	Podgonoye	Kazakhstan	43.3276	79.4849	KNDC / IRISDMC
WMQ	Urumqi	China	43.821098	87.695	CDSN / IRISDMC
KSH	Kashi	China	39.516998	75.922997	CNDSN / IRISDMC

After RES searching in the catalog and waveform CC, as mentioned before, we are interested in solar storms, and consequently, strong bursts of geomagnetic indices. Therefore, I list below geomagnetic stations (Tables 2-4), which could be potentially useful to find any relationship between RES and indices variations.

Table 2. Local stationary geomagnetic stations in Kyrgyzstan [27].

Station	**Latitude, °N**	**Longitude, °E**	**Type**
Ak-Suu	42.603	74.008	transient electro- magnetic sounding method (TEM) geomagnetic-variation modular system “MB-07” developed by RS RAS
Shavay	42.617	74.222	
Chonkurchak	42.626	74.608	
Tash-Bashat	42.667	74.770	
Issyk-Ata	42.638	74.960	
Kegety	42.613	75.157	

Table 3. INTERMAGNET observatories (the global network of observatories, monitoring the Earth's magnetic field) near the target area [31].

Code	**Name**	**Country**	**Latitude, °N**	**Longitude, °E**	**Institute**	**Elevation, m**	**Instruments**
AAA	Alma Ata	Kazakhstan	46.8	76.9	IIRK	1300	Variations: Fluxgate magnetometer LEMI-008, Overhauser proton magnetometer POS-1 Absolutes: DI-fluxgate 3T2KP LEMI-203, Overhauser Proton Magnetometer POS-1
WMQ	Urumqi	China	46.19	87.71	CEA	908	Variations: Continuously Recording • Vector Magnetometer DMI FGE • Scalar Magnetometer GSM-90F Absolutes: DI Fluxgate Theodolite, Minregion DIM, Hungary and Proton Magnetometer G856AX

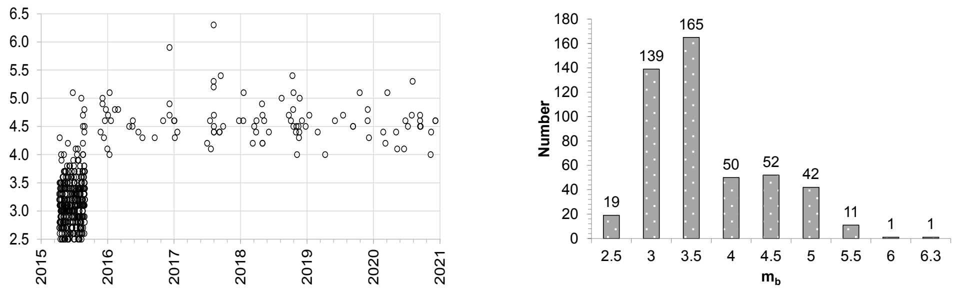
Table 4. Meridian project station locations in China, along with the types of observations and instruments deployed at each [32].

Station	Latitude, °N	Longitude, °E	Instruments
Mohe	53.5	122.4	magnetometer, digisonde, TEC[a] monitor/ ionospheric scintillation monitor
Manzhouli	49.6	117.4	magnetometer, ionosonde
Changchun	44.0	125.2	magnetometer, ionosonde
Beijing	40.3	116.2	magnetometer, digisonde, lidar,[b] all-sky imager, Fabry-Perot interferometer, mesosphere-stratosphere-thermosphere radar, interplanetary scintillation monitor, cosmic ray monitor, TEC monitor/ionospheric scintillation monitor, high-frequency Doppler frequency shift monitor
Xinxiang	34.6	113.6	magnetometer, ionosonde, TEC monitor/ ionospheric scintillation monitor
Hefei	33.4	116.5	lidar
Wuhan	30.5	114.6	magnetometer, digisonde, lidar, mesosphere-stratosphere-thermosphere radar, meteor radar, TEC monitor/ ionospheric scintillation monitor, high- frequency Doppler frequency shift monitor
Guangzhou	23.1	113.3	magnetometer, ionosonde, cosmic ray monitor, TEC monitor/ionospheric scintillation monitor
Hainan	19.0	109.8	magnetometer, digisonde, TEC monitor/ ionospheric scintillation monitor, lidar, all-sky imager, very high frequency radar, sounding rockets, meteor radar
Zhongshan	69.4	76.4	magnetometer, digisonde, high-frequency coherent scatter radar, aurora spectrometer
Shanghai	31.1	121.2	Magnetometer, TEC monitor
Chongqing	29.5	106.5	magnetometer, ionosonde
Chengdu	31.0	103.7	magnetometer, ionosonde
Qujing	25.6	103.8	incoherent scatter radar
Lhasa	29.6	91.0	magnetometer, ionosonde

[a]Total electron content.
[b]Light detection and ranging.

3. Results

In this work, an earthquake catalog (NEIC) 2015-2020 from [14] of 400 earthquakes with magnitudes m_b 2.5-6.3 was used. The magnitude consistency is shown in Fig. 2.



(a) (b)

Figure 2. Final locations for 5623 events well distributed throughout China—3689 for all of China from 2015 to 2020.

The overview of the events' coordinates gives an impression of seismic areas by distribution density. By K-means clustering algorithm in Origin 9 [33], I got six main clusters after ten iterations (Fig. 3a). For the detailed analysis, I decided to look in clusters 3, 4 and 6. I applied K-means clustering again to separate small families of adjacent events (Fig. 3b). I zoom in to the area from 41.5° N, 81° E to 43° N, 85° E (118 events). This procedure helps separate each location and group them into families. Inside these 28 families, I could start to download seismic waveforms for cross-correlation for repeated earthquakes.

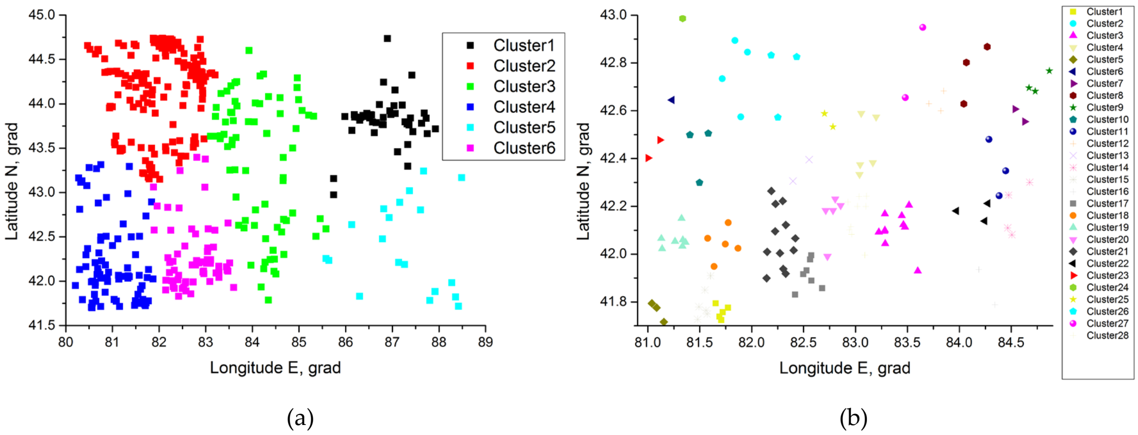


Figure 3. Clustered epicenters locations for events from 2015 to 2020 distributed throughout China: (a) all events for the target area; (b) only events for 3, 4, 6 clusters from (a).

On the Landsat image, the epicenters distribution is sparse (Fig. 4). The hypocenter depth is shown in color. It is obvious, that some epicenters group near trench zones and orogenesis.

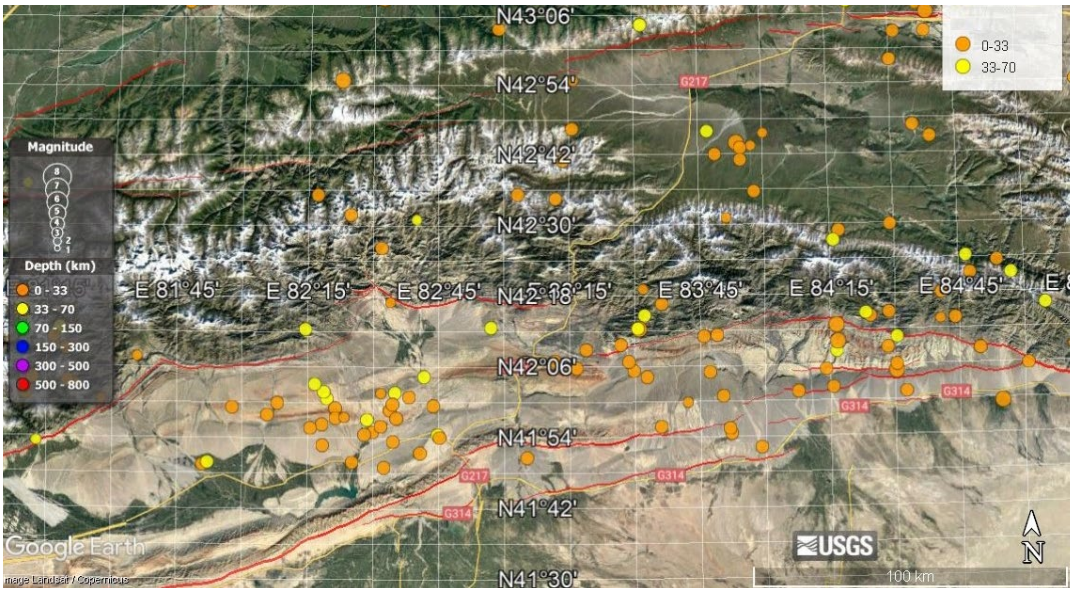


Figure 4. Earthquakes epicenters on ©Google Earth Landsat image [34]. Red lines – fault from database [35].

Finally, by checking each of 28 families we could find potential RES events. For example, for the first cluster K-means creates cluster of 5 events. Only 2 of them (04.12.2019, T_0=12:48:30 λ=41.7243° N, φ=81.7066° E, and 17.01.2019, T_0=13:32:37, λ=41.7386 ° N, φ=81.6901° E) are close to each other (distance ~2.5 km) (Supplement Table S1). Both have occurred at the same depth 10 km, which intermediately indicates the similarity of sources.

4. Conclusions

I present here principle moments in the repeating earthquake sequences search using K-means algorithm to epicenter coordinates from NEIC seismic catalog. The first results give us give an idea of the possibility of finding similar events over a long period of time. The hypothesis about the "ionosphere-atmosphere-lithosphere" relation as the possibility of earthquake triggering by strong bursts of geomagnetically induced currents requires additional analysis, using data from geomagnetic stations indicated in the study and Chinese seismo-electromagnetic satellite CSES-01 data.

Supplementary Materials: The following are available online at www.mdpi.com/xxx/s1, Table S1: K-means clustering results for the area from 41.5° N, 81° E to 43° N, 85° E (118 events).

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