Institute of cosmophysical research and radio wave propagation FEB RAS

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SPACE WEATHER AND EARTHQUAKES

An overview of the problem and future research

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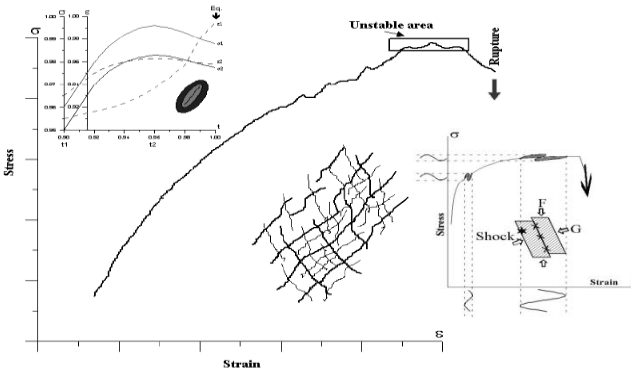
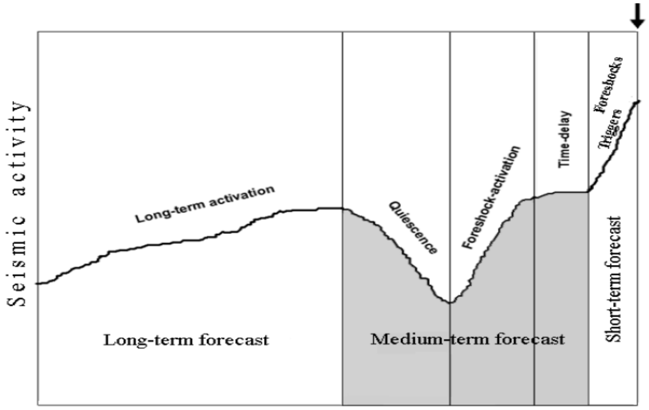
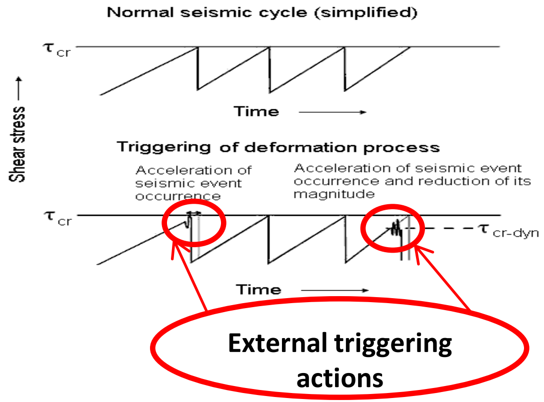
Motivation:

1) Earthquakes represent one of nature's major challenges to humanity. **Since 1900, 2234 catastrophic earthquakes on the globe have killed more than 2 million 320 thousand people** [James E. et al, (2017), Frontiers in Built Environment], while direct and indirect economic losses, according to UNESCO estimates, amount to billions of dollars annually.
2) *According to the China Earthquake Administration (CEA), catastrophic seismic events are beginning to threaten the sustainable development of China's economy.*
3) There is currently no reliable method for short-term earthquake prediction based on precursors (Parkfield EQ prediction failure).
4) The concept of earthquake prediction based on triggering impacts on the earthquake source is proposed [Sobolev G.A.(2010), NHESS].

The following steps towards predictability of earthquakes look reasonable:
(a) Determination of the volume of an unstable area (systems of local unstable areas of various scales);
(b) Monitoring of triggering effects and assessment of their impact on unstable areas;
(c) Estimation of probability of the place, time, and magnitude of the impending earthquake.



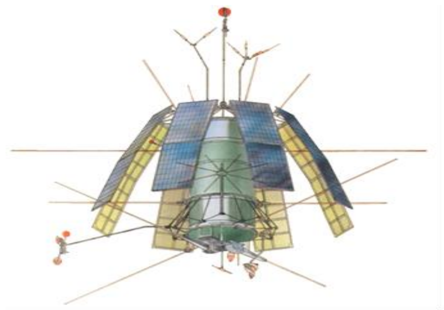




Russian-Chinese cooperation project # 21-51-53053 funded by RFBR and NSFC

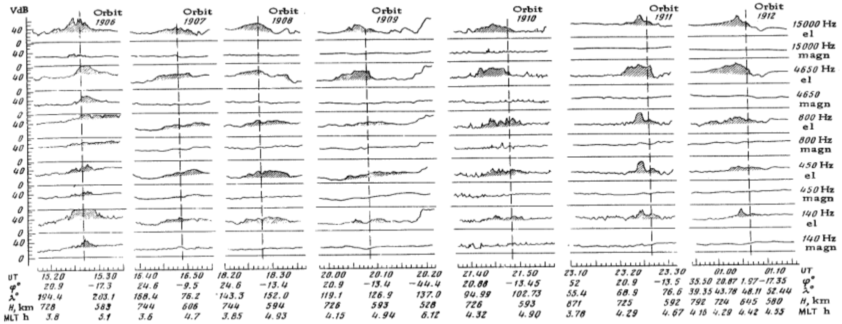
- The project is directed to further study the interconnection of processes in the "ionosphere-atmosphere-lithosphere" system in seismic-prone regions for solving the problem of seismic hazard mitigation relevant for Russia and China.
- The specific objectives of the project are to refine existing models of the relationship between the earthquake source and space weather parameters based on data of space monitoring by Chinese satellite CSES-1, as well as to analyze the degree of an influence of variations of the space weather parameters on deformation processes in the earthquake source and the possibility of triggering the seismic events by strong ionospheric disturbances.
- The scientific novelty of the project is to obtain new results on possible ionospheric precursors of strong earthquakes according to new data from the CSES-1 satellite and their theoretical justification, as well as the physical justification (or refutation) of the possibility of earthquake triggering by strong bursts of geomagnetically induced currents in conducting seismogenic faults of the Earth crust.
- The project provides for an analysis of satellite observations over the seismic-prone regions of Russia and China, the refinement of the model of ionospheric-lithospheric relations, a numerical analysis of induction of telluric currents in the conducting zones of the Earth crust (faults) by strong geomagnetic disturbances and their effect on deformation processes in the earthquake sources.
- Physical modeling will be performed at laboratory set-ups for a study of generation of telluric currents and their concentration in the conductive model fault, triggering of a laboratory "earthquake" by electric pulses at spring-block models of seismogenic fault, and rock failure under electromagnetic impact. The obtained laboratory data will be compared with the impact of space weather on the parameters of repeating earthquakes observed in China, Russia, Japan, and the USA.
- The results of the project will have a fundamental importance in terms of understanding the relationship between space weather and Earth seismicity and possibly may be used in future technologies of the short-term earthquake prediction.

Satellites detected the pre-earthquake signals

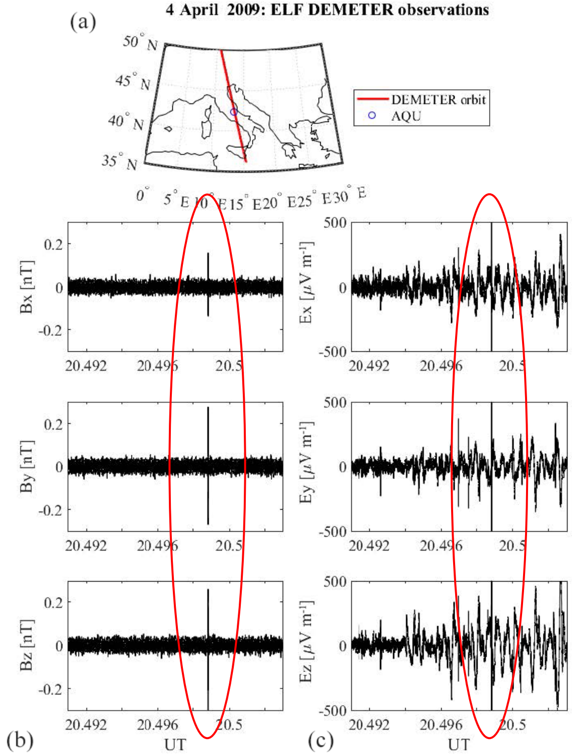


INTERCOSMOS-19, 1979-1982

Detection of an anomalous increase of VLF emission in the upper ionosphere by INTERCOSMOS-19 satellite



An anomalous increase in the intensity of VLF emission in the upper ionosphere over a period of tens of minutes to hours before and after earthquake M=5.7, July 9, 1979 has been observed. The maximum effect corresponds to frequency of ~15 kHz. [Larkina et al, 1983]



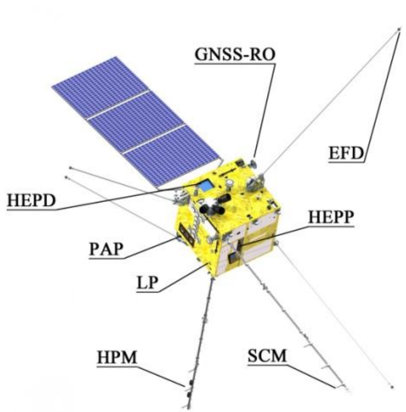
DEMETER satellite (Detection of Electro-Magnetic Emissions Transmitted from Earthquake Regions) 2004-2010

Bertello et al. Electromagnetic emission during the 2009 L'Aquila earthquake (2018)

DEMETER electromagnetic observation on 4 April 2009 in the ELF band. (a) shows the satellite orbit (red) as a function of the geographic latitude and longitude. Lower panels show the electric(c)and magnetic (b) field observations as a function of the universal time (UT). The blue circle identifies the L'Aquila geographic position

China launched electromagnetic satellite on February 2, 2018 to study earthquake precursors

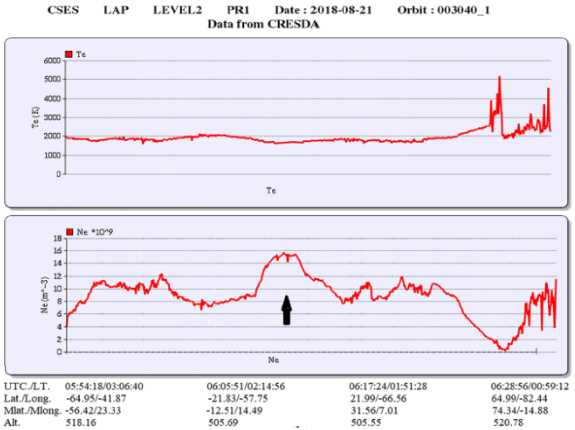
CSES-1 on-board instruments



The payload onboard consists of two High-Energy Particle Detectors (HEPD, HEPP) to measure the particle flux and energy spectrum, a Search-Coil Magnetometer (SCM) and a High Precision Magnetometer (HPM) to measure the components and the total intensity of the magnetic field, respectively, an Electric Field Detector (EFD) to measure the electric field, a Plasma analyzer and a Langmuir probe to measure the disturbance of plasma in ionosphere, a GNSS Occultation Receiver and a Tri-Band Beacon to measure the density of electrons.

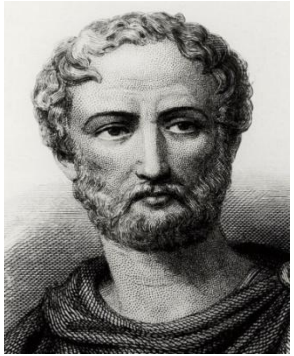
China's first seismo-electromagnetic satellite Zhangheng-1 launched on Feb. 2, 2018 is a significant complementary to the country's ability in the study of seismic precursors. The specific objectives of the project are to refine existing models of the relationship between the earthquake source and space weather parameters based on data of space monitoring by Chinese satellite CSES-1.

Variations of electron data recorded by Langmuir probe onboard the CSES-1 15 h before a M_W *7.3 EQ*



The top panel is the electron temperature (Te) and the bottom one is the electron density (Ne) with an apparent 21.9% increase labeled by a black arrow. The parameters below the plots indicate the time in UT/LT and the position of the satellite along its orbit.

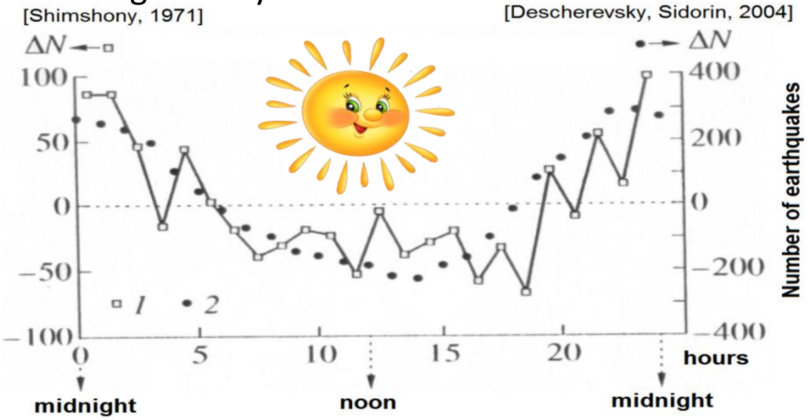
Prehistory of a question of a possible impact of solar processes on the Earth seismicity

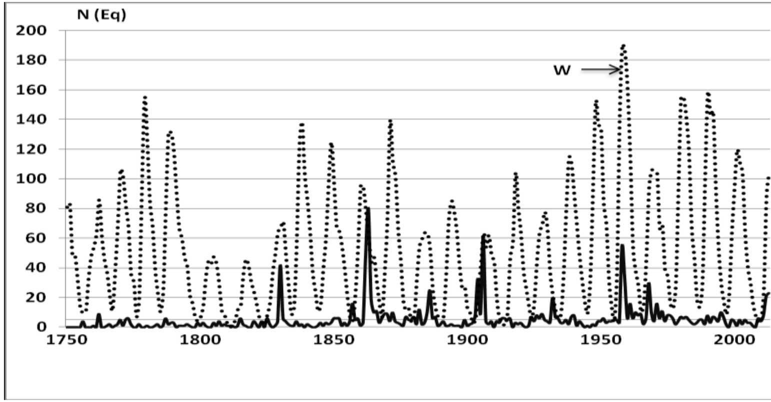


In 1853 the Swedish astronomer Rudolf Wolf indicated that the sun spots may have an influence on the earthquake occurrence [Wolf, 1853].

Even Pliny in the first century AD, in his Natural History [Murphy, 2004], noted that earthquakes in the Mediterranean region occur more often at night than during the day.

Rudolf Wolf (1816 - 1893)



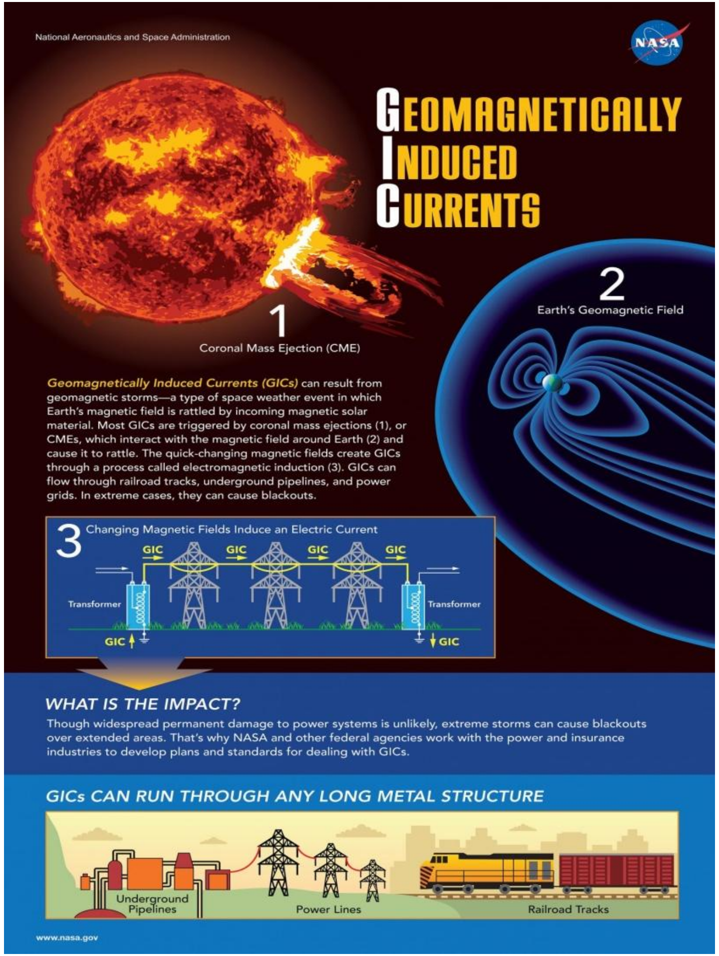


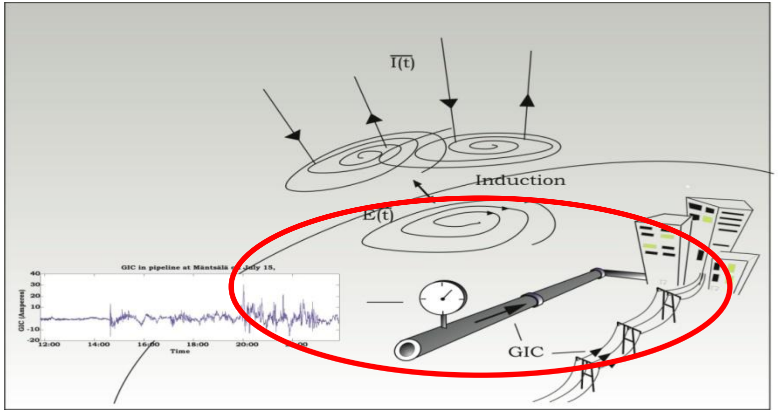
Investigations of possible influence of solar activity on the Earth seismicity

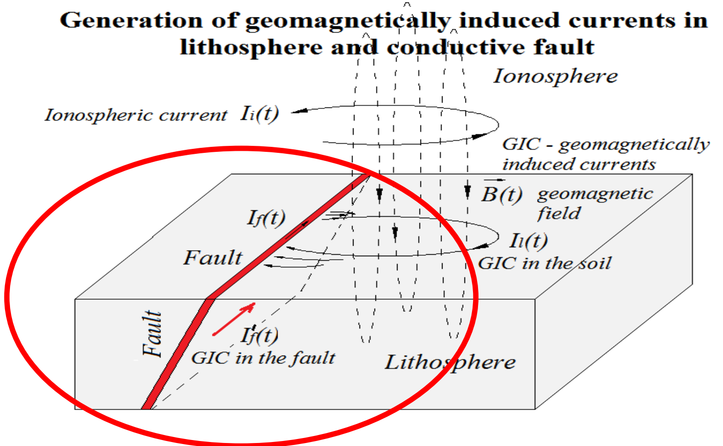
- Search of correlation of the Earth seismicity and solar activity (Wolf number) [Gribbin, 1971; Takayama, Suzuki, 1990; Zhang, 1998].
- **The studies completed to-date on a relation of the Earth's seismicity and solar processes provide the fuzzy and contradictory results.**
- Certain dependence of global seismicity on 11-year solar cycle was noted: positive correlation of a number of earthquakes and phases of 11-year solar cycle [Sytinsky, 1973, 1989, 1997].
- There is converse proposition that the 11-year cycles of seismic activity have inverse correlation with cycles of solar activity and geomagnetic disturbances [Sobolev et al, 1998; Tarasov, 2017].
- Love &Thomas (2013), Kozyreva & Pilipenko (2020) indicated to insignificant solar-terrestrial triggering of earthquakes.

The results obtained to-date are statistical only, without consideration any physical mechanism of earthquake triggering by severe space weather.

Geomagnetically induced currents as a possible trigger of earthquakes

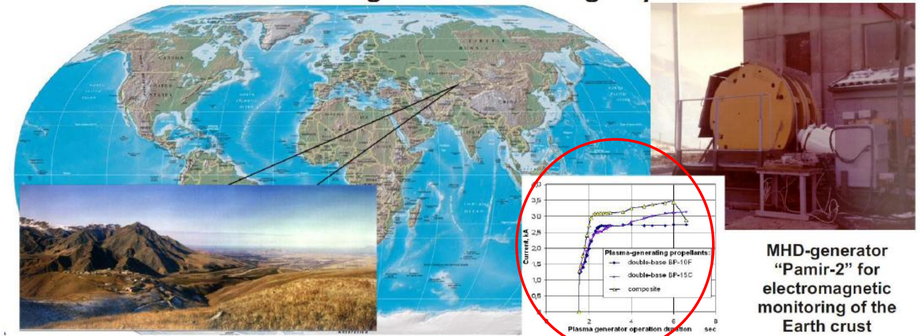






Earthquake triggering by electromagnetic impact on the Earth crust

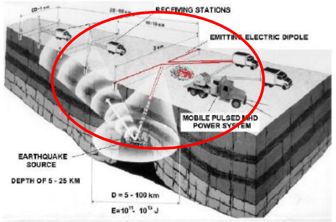
Active Electromagnetic Monitoring Experiment

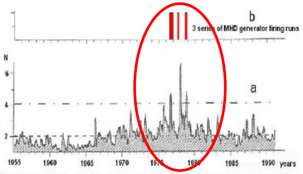


MHD-generator "Pamir-2" for electromagnetic monitoring of the Earth crust

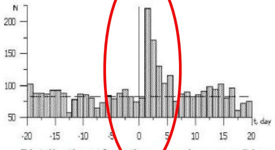
Pulsed MHD generator for earthquake prediction program

An impact of electromagnetic pulses produced by MHD generator on seismic activity of Pamir and Northern Tien Shan





Daily number of earthquakes in upper layer (0-5 km) of Tajik depression (a) and period of three series of MHD generator firing runs at Garm geophysical proving ground (Tajikistan) (b).



Distribution of earthquakes in upper 5 km layer of the Earth crust in the Northern Tien Shan for energetic class K > 8 (K = 2.5 Mb-0.5) 0 - firing run of pulsed MHD generator, N - number of earthquakes per

Current density produced by MHD generator: $10^{-7 \ldots -8}$ A/m^2

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A possible mechanism of stimulation of seismic activity by ionizing radiation of solar flares*

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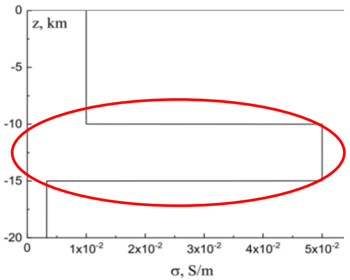
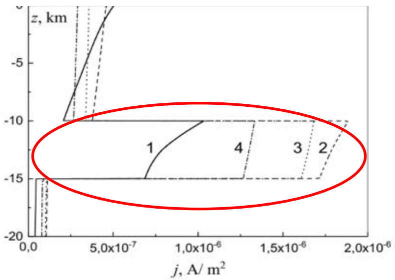




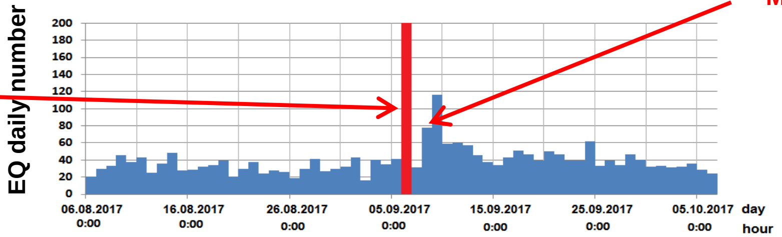
Estimation of current density produced by solar flare:

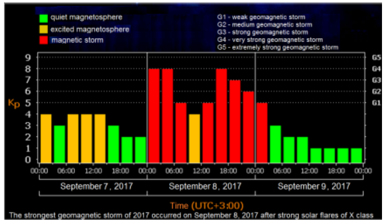
10^{-6} A/m^2

Global daily number of earthquakes before and after a solar flare of X9.3 class on September 6, 2017 (11:53 UTC)

Solar flare of X9.3 class

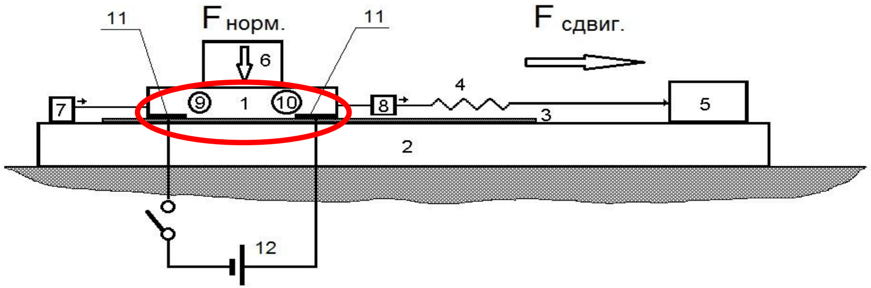
Magnetic storm Kp=8

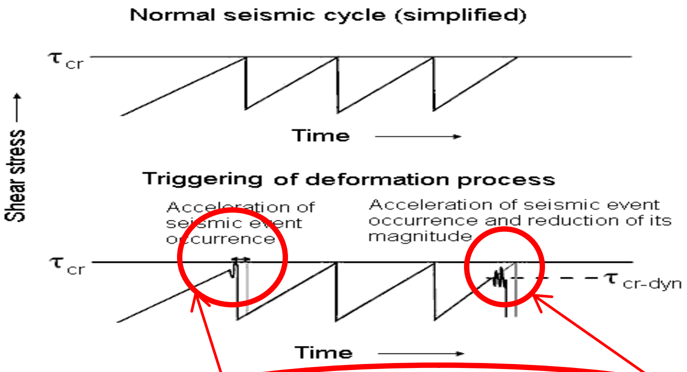




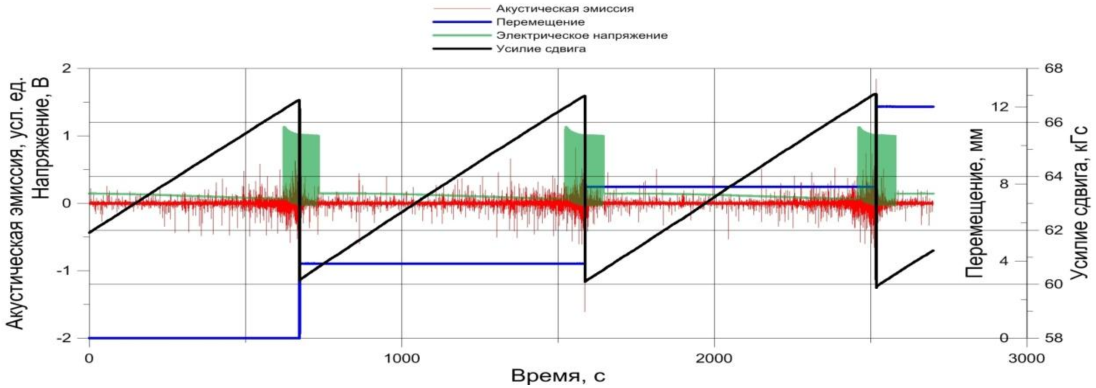
Na/Nb =
a) 1.967
b) 1.678
c) 1.610
d) 1.371
Nb – EQ daily number before SF
Na – EQ daily number after SF
a, b, c, d – time window of 5, 10, 20, and 30 days

Results of deformation of inter-block contact at the C-1 spring-block model under electric current injection into the simulated crust fault





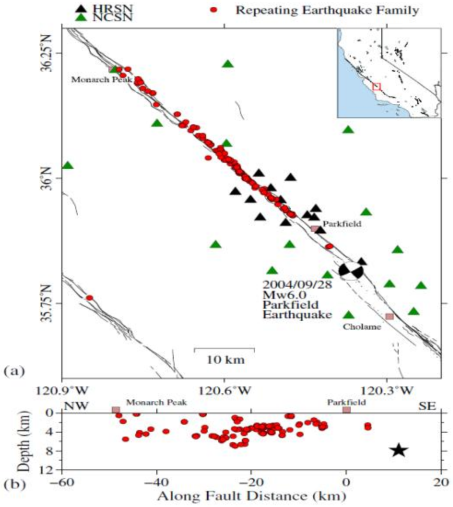
Triggering impact

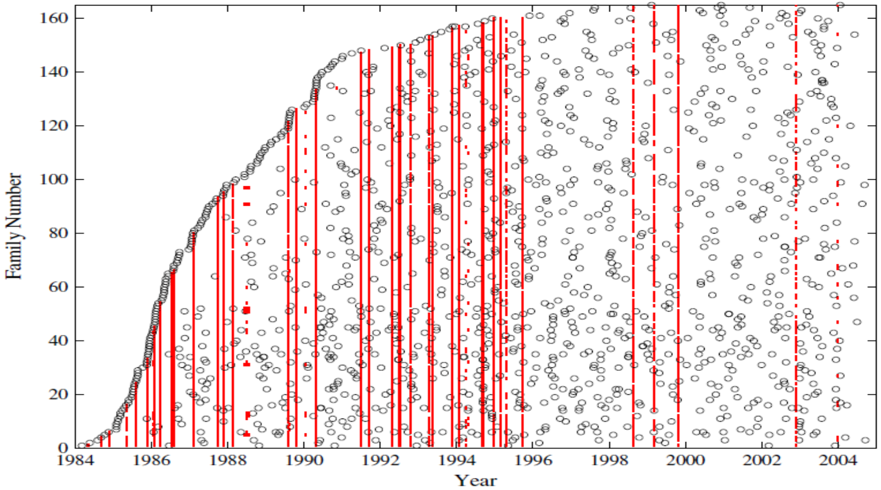


Shortening of recurrent period by ~ 20%

Test conditions:
Concrete running block 227x112x53 mm, granulated gouge (quartz sand with grain size of 0.2-0.5 mm and thickness of 2 mm). The contact normal load is 113.76 kgf, normal stress in the granulated layer is 43.9 kPa. Spring stiffness is 16.57 N/mm. Contact area is water saturated, fluid injection rate is 0.05 – 0.1 g/s.

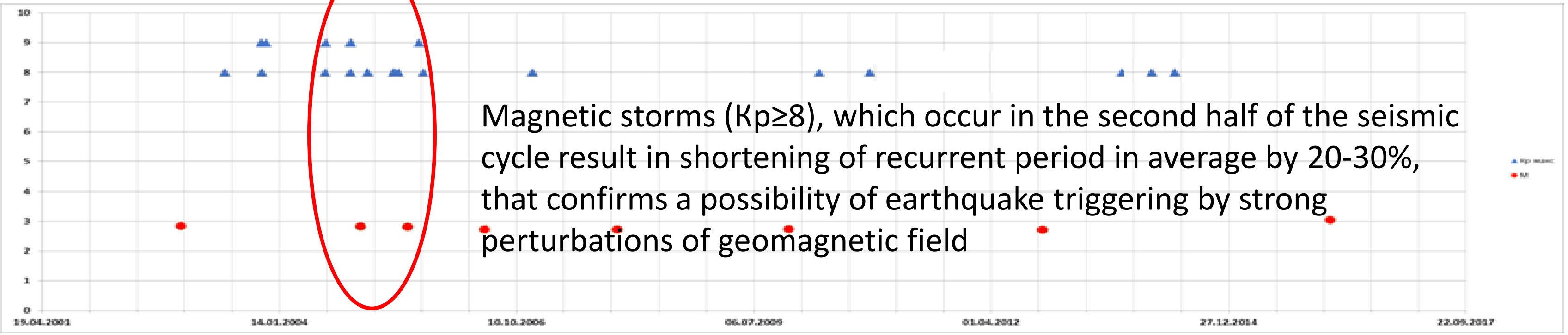
An impact of strong magnetic storms (Кр≥8) on the recurrent period of repeating earthquakes





(Wu et al, 2014, GRL)

Кр



Magnetic storms (Кр≥8), which occur in the second half of the seismic cycle result in shortening of recurrent period in average by 20-30%, that confirms a possibility of earthquake triggering by strong perturbations of geomagnetic field

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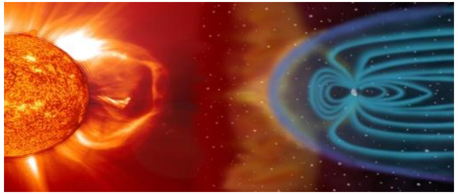
Summary conclusions (to be continued)

- Space weather phenomena like solar flares and geomagnetic storms can generate telluric current density similar to artificial power sources which provide earthquake triggering
- Behavior of seismic activity after solar flare and geomagnetic storm is similar to increase a number of local earthquakes after injection of DC pulses into the Earth crust.
- Reliable physical models explaining the electromagnetic earthquake triggering phenomena are required.
- Before earthquake alert after strong perturbation of space weather we need to select the areas favorable for electromagnetic earthquake triggering from point of view of the fault maturity to the dynamic rupture, its electric conductivity and orientation for induction of extreme geomagnetically induced currents

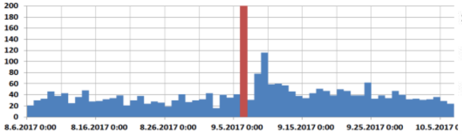


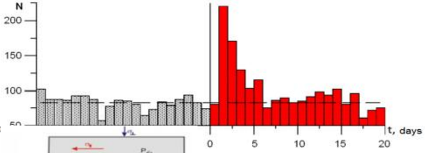
MHD generator:

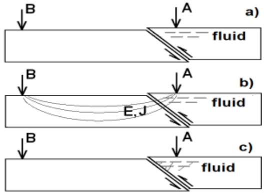
$10^{-7...-8}$ A/m^2

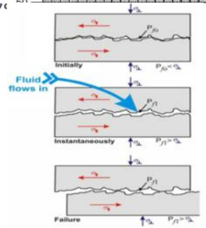
Solar flare:

10^{-6} A/m^2

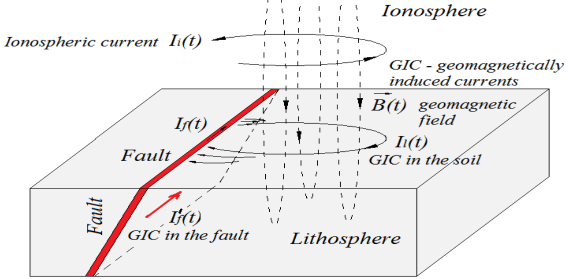








Generation of geomagnetically induced currents in lithosphere and conductive fault



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