Towards closer cooperation between space & seismology communities: To avoid errors in hunting for earthquake precursors

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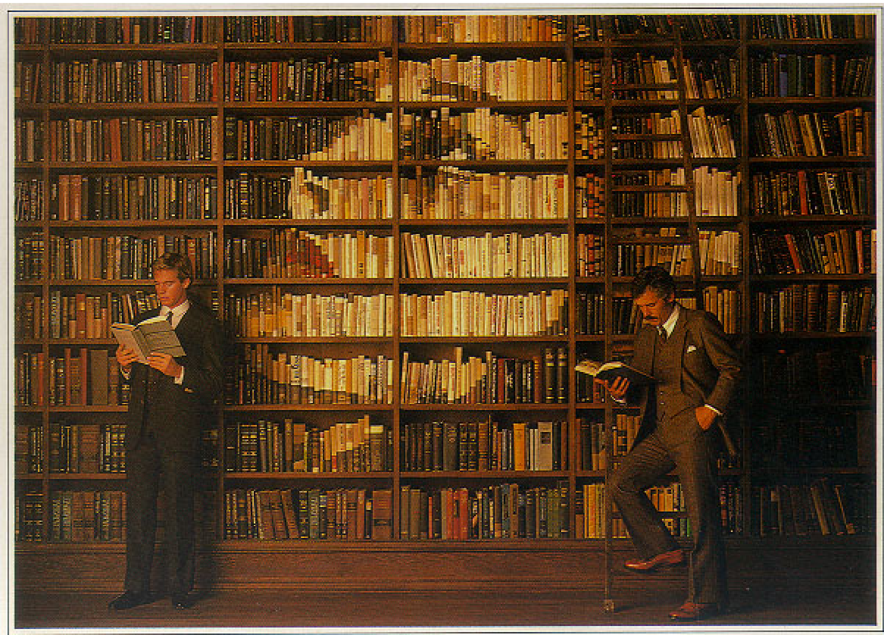
The space physicists and the EQ prediction community exploit the same instruments – magnetometers, but for different tasks. However, the lack of deep collaboration between those communities may result sometimes in misleading conclusions.

In this critical review, we demonstrate some incorrect results by highly professional research teams caused by a neglect of specifics of geomagnetic field evolution during space weather activation:

- Magnetic storms as a trigger of EQs;
- Geomagnetic impulses before seismic shocks;
- Discrimination of underground ULF sources by amplitude-phase gradients;
- Depression of ULF power as a short-term EQ precursor;
- Detection of seismogenic emissions by satellites.

References (~5-15 for each topic) – in the draft upon request (*pilipenko_va@mail.ru)*



The possibility of a triggering effect of magnetic storms on the Earth's seismicity

When accumulated stress along the fault is close to critical level, even a weak impact can provoke instability of lithospheric blocks and serve as EQ trigger. It was reported that after magnetic storms: increase of weak EQs in Tajikistan and Kyrgyzstan by 3-4 per day; increase in the daily number of local EQs in Kyrgyzstan and Carpathians on the 2nd day after the solar flare, high correlation between the diurnal variation of weak seismicity and geomagnetic Sq variation, …

The possibility of a triggered release of energy accumulated in the crust was verified in Tajikistan, Kyrgyzstan, and Tien Shan with the MHD generator. Powerful e/m pulses were found to cause an activation of weak seismicity 5–6 days after the impact, though the release of seismic energy was ~5 orders of magnitude greater than the pulse energy.

Magnetic storm as EQ trigger was tested for Alaska region with high seismicity, where magnetic variations are ~2 orders of magnitude stronger than at low latitudes.

2014-2016

Strong EQs (M>5) - 25

Weak (M=3-5)

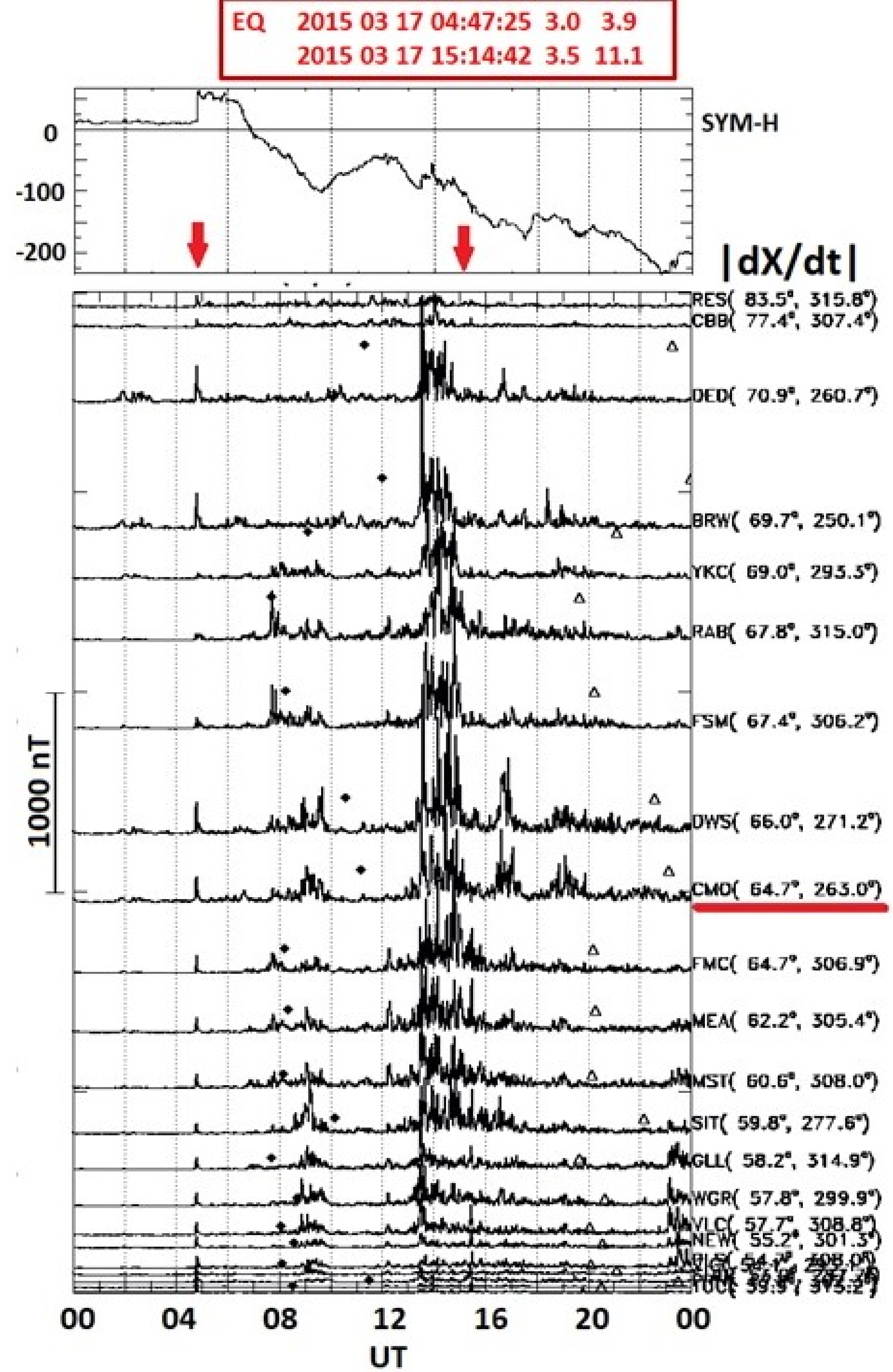
H<5 км	H=5-10 км	H=10-30 км
100	177	497

Example of misleading case study

The magnetic storm on March 17, 2015, was the largest in the 24th solar cycle. Immediately after SC, a weak local EQ (M=3.0, H=3.9 km) occurred in Alaska. When the geomagnetic field variability |dX/dt| sharply increased, another local EQ (M=3.5, H=11 km) occurred.

The effect of triggered excitation of weak EQs by a strong magnetic storm?

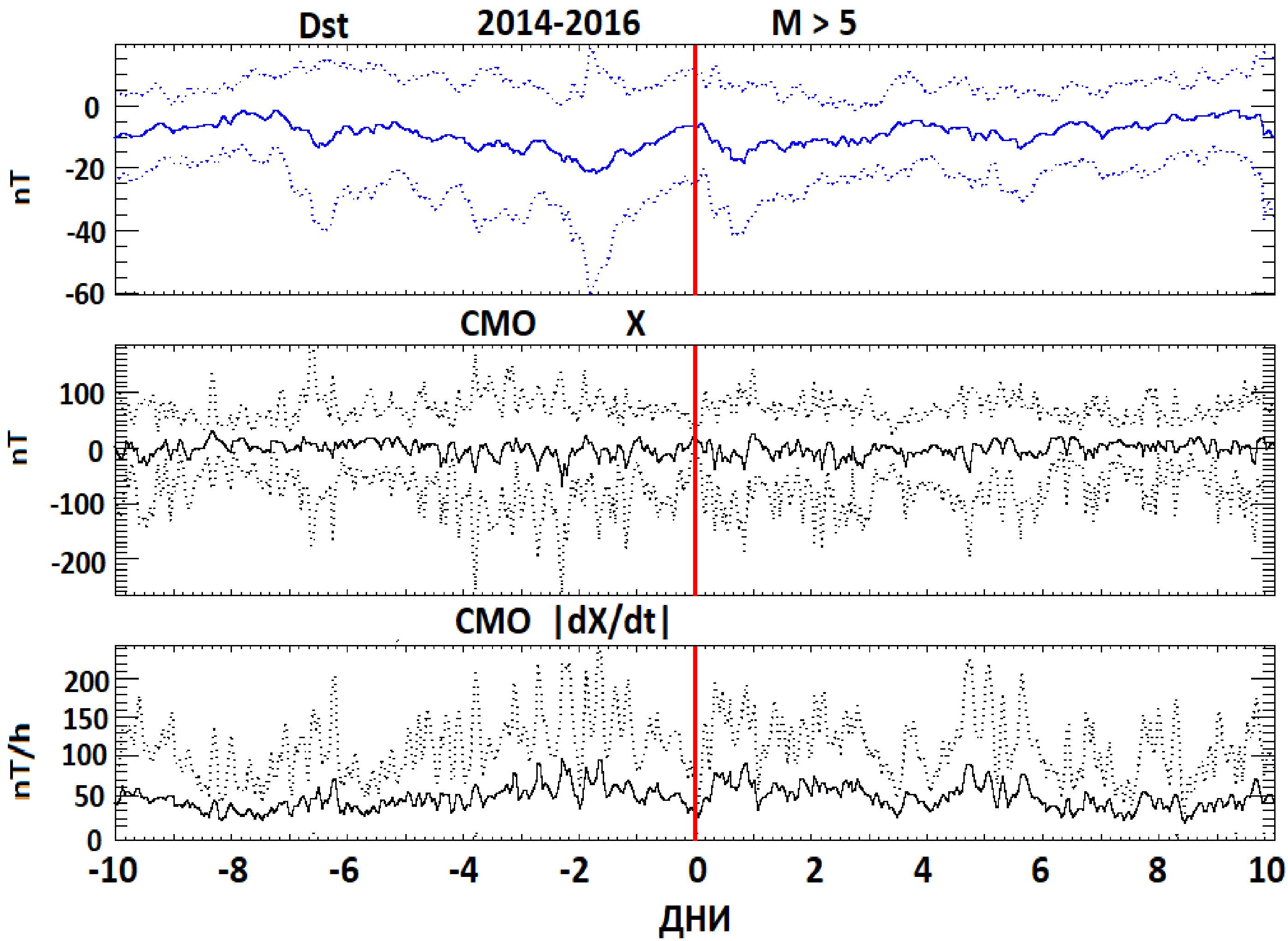
Despite the importance of case studies, statistical analysis should supplement this approach.



The super-posed epoch (SPE) method for the Alaskan magnetometer data

Quake moment has been chosen as a 0, and median values have been used, which are resistant to outliers. If strong B-field variations are EQ trigger, then their dynamics in previous 10 days must show a systematic increase in the variability.

SPE graphs of Dst, |ΔX|, |dX/dt|, before "strong" (M>5) EQs do not show a statistically significant enhancement that goes beyond dispersion. Similar negative results are seen for weak (3<M<5) near-surface (H<5 km), weak small-depth (H=5-10 km), and weak shallow (H = 10-30 km) EQs.



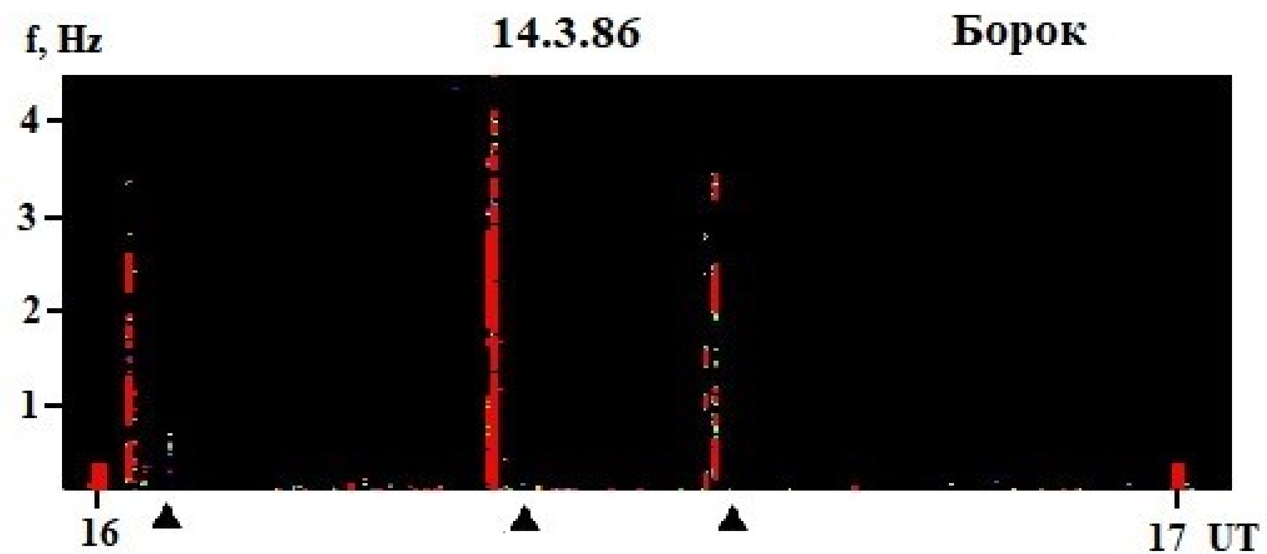
The negative result casts doubt on the hypothesis of storm as an EQ trigger.

Geomagnetic impulses before quakes

An amazing phenomenon was described in a series of papers - the appearance of global magnetic impulses a few minutes before the seismic shock!

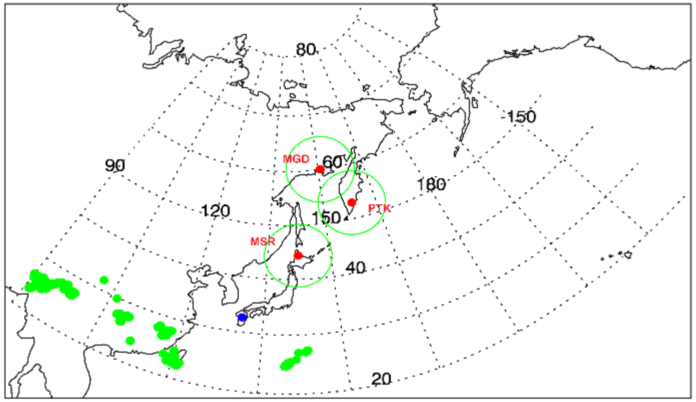
The effect was found from the data of induction magnetometers at stations Borok and College, separated by 12 h in longitude and 10° in latitude.

This intriguing hypothesis may be a truly major discovery in geophysics, so its critical consideration should be taken carefully.

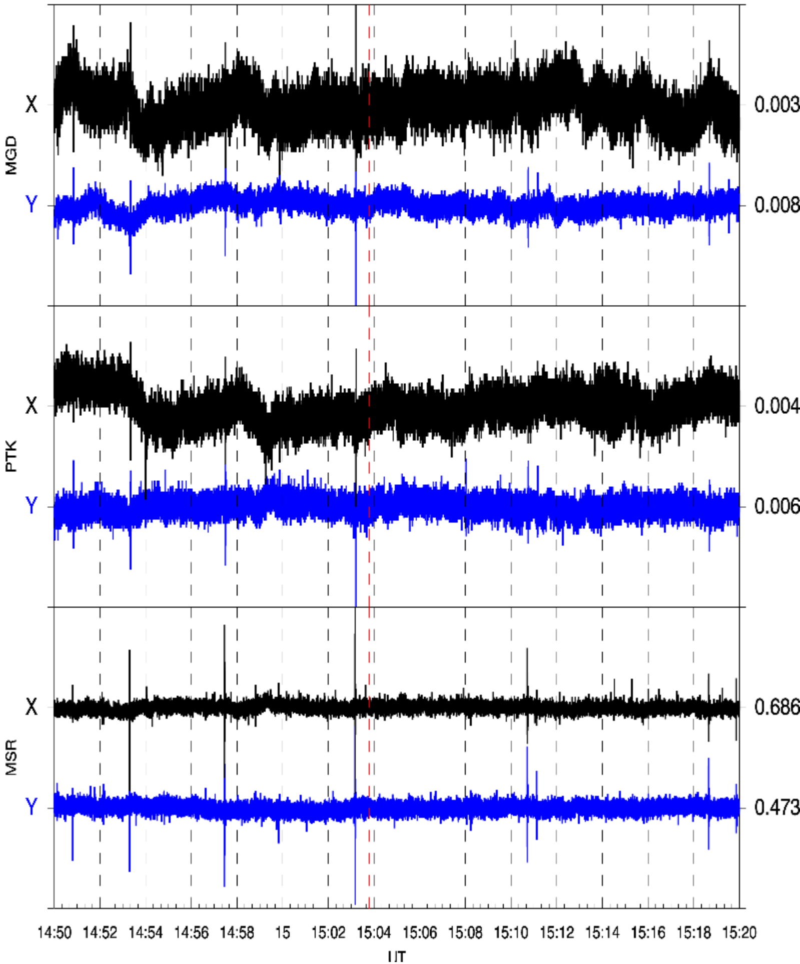


UT	φ	λ	*h*	*M*
16:05:13	-5.286	154.379	233	5.2
16:25:45	24.780	122.873	23	4.3
16:35:27	-41.136	174.642	31	3.4

Validation of the hypothesis about an impulsive magnetic precursor using the search-coil magnetometers PWING.



2016 0414 (105) 15:03:47UT H: 10.2km M: 6.0



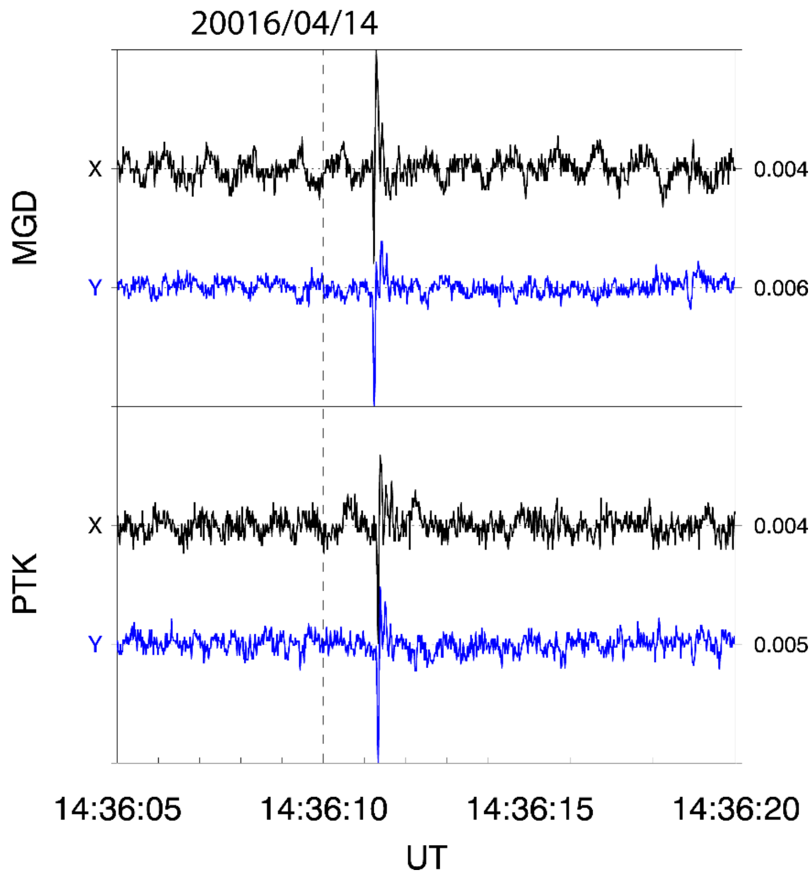
Indeed, the appearance of impulse disturbances synchronously at several stations around EQ (blue dot) was detected!

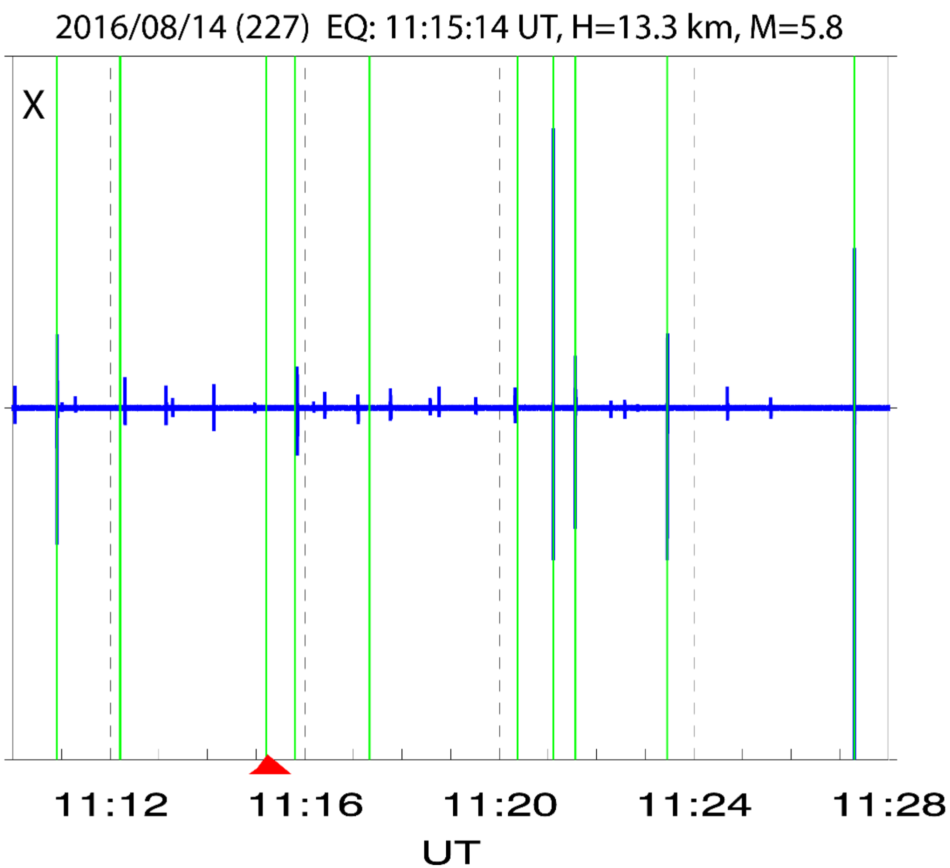
Green dots denote lightning discharges in the region under study as recorded by the WWLLN system.

Pulse waveforms (~8 Hz transients) indicate that they can be associated with the Schumann Resonance excitation.

At least a part of these pulses is a response to lightning discharges recorded by the WWLLN system.

Statistics based on automatic calculation of the number of impulses ±5 mins before/after a seismic shock did not show the predominance of impulse occurrence before local EQs.





Although the detailed analysis did not confirm the hypothesis of ultra-short ULF pulses as a precursor of EQs, their physical nature was established – they are caused by electric discharges in the atmosphere!

Discrimination of underground ULF sources by amplitude-phase gradients

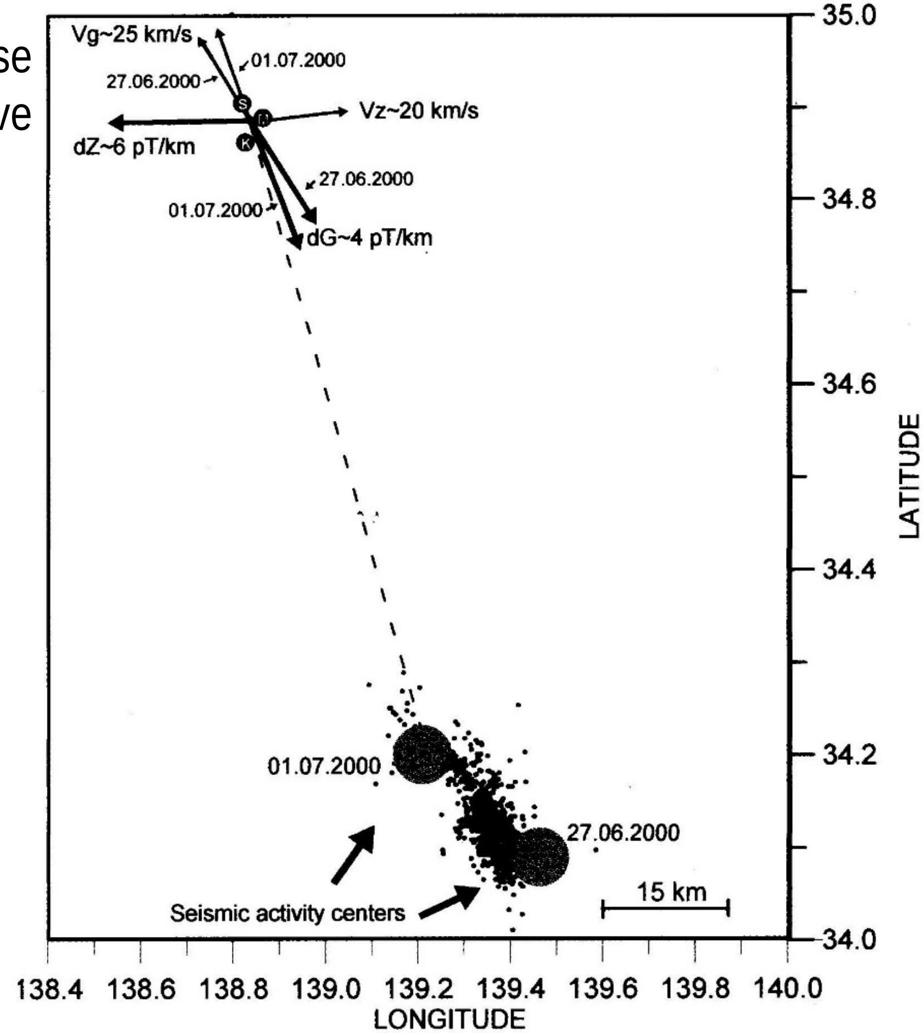
There were proposals to use gradient measurements with a small baseline (~5-7 km), which would suppress contribution of large-scale ionospheric disturbances, for the discrimination of weak seismogenic disturbances.

Approach is based on premise that amplitude/phase gradient is due to e/m field propagation in conductive Earth as wave with velocity

$$U_g = \lambda / T = \sqrt{10\rho / T}$$

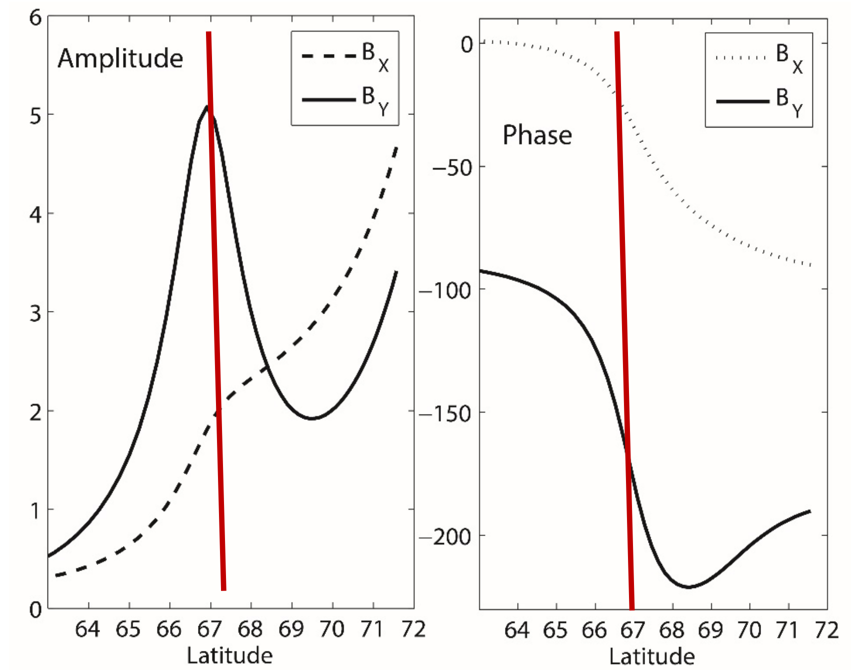
This approach made it possible to seemingly successfully retrieve anomalous signals several months before nearby EQs with M=5-6.

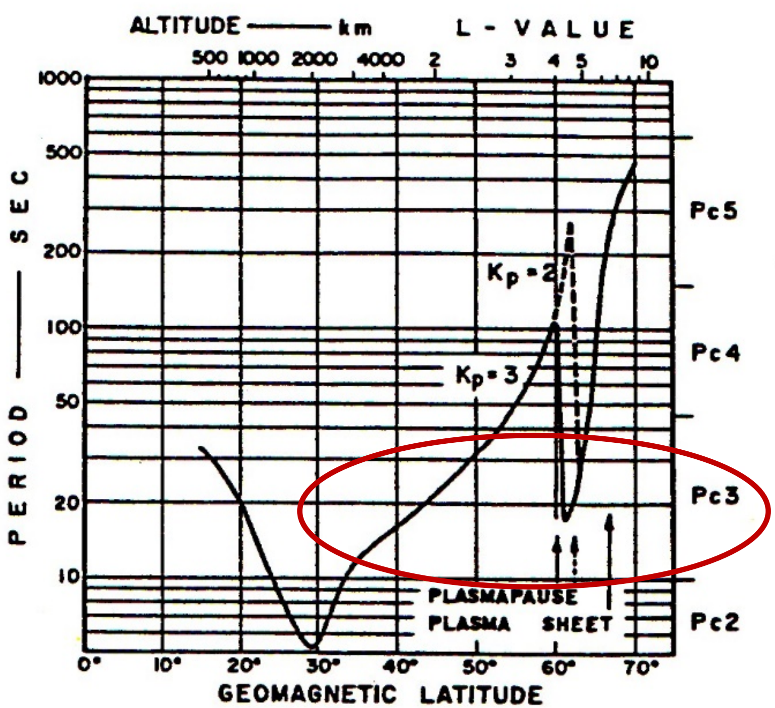
Amplitude gradient in band 0.03-0.1 Hz (Pc2-3) was around *G*≈0.1-1 pT/km, and phase velocity *U*g≈20-100 km/s.



However, latitudinal structure of magnetospheric ULF waves with amplitude/phase gradients (poleward propagation) is formed in the resonance region $T \sim T_A(\Phi)$. The phase jump across the resonant region $\Delta\phi \leq 180^o$.

Thus, the phase and amplitude gradient values similar to observations may occur in the resonant region!





Therefore, gradient method of the seismogenic pulsations detection must be applied only in frequency band far from the magnetospheric field-line resonator frequency.

The properties of an electromagnetic disturbance with frequency ω in a conductive medium are characterized by the skin-depth δ_g

$$\delta_g^2 = k_g^{-2} = D / \omega$$

D is the diffusion coefficient

$$D = \left(\mu_0 \sigma\right)^{-1}$$

ULF signal propagation inside the Earth crust occurs in diffusive manner, but not as a wave! A seismogenic source may be an impulsive one, e.g., accompanying stick-slip movement along a fault. The magnetic field disturbance should propagate diffusion-like as follows

$$\Delta\rho \approx \sqrt{Dt}$$

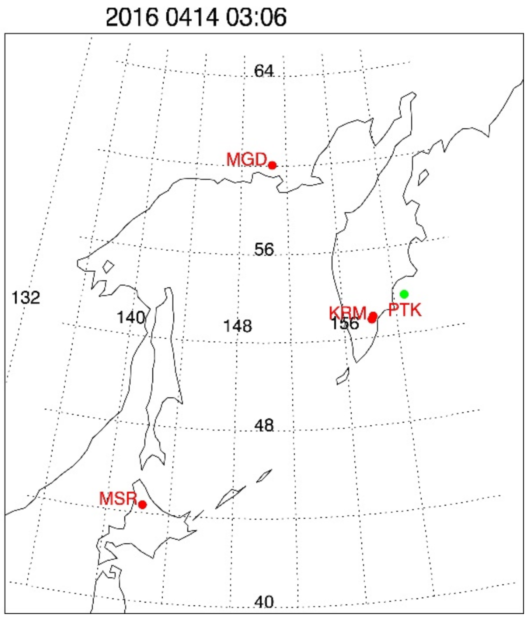
The maximal response at distance R from a source is observed at delay time $\tau \sim R^2/D$

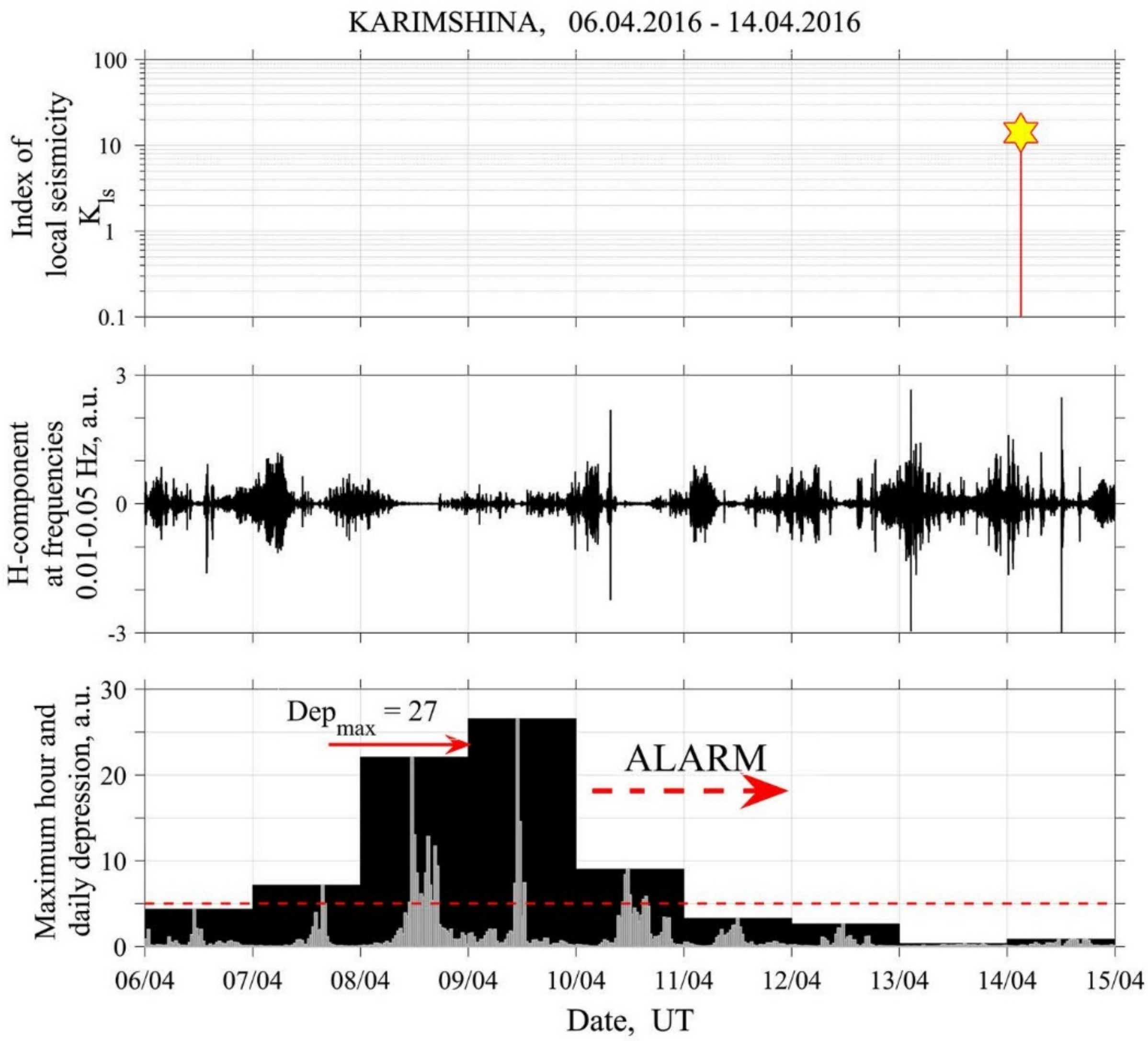
The apparent propagation velocity is distance-dependent and differs from *U*g!

Depression of ULF power as a short-term EQ precursor

Unexpectedly discovered phenomenon - depression of ULF noise intensity in the band 0.01–0.1 Hz a few days before EQ. The ULF depression was supposed to be caused by an increase of the ionospheric turbulence before an EQ, which leads to additional absorption of magnetospheric noise.

06-14 April, 2016, depression of ULF noise intensity ~4 days before EQ (M=6.2, H=32 km) in Kamchatka was detected. To identify anomaly, the parameter ΔS~1/W was used (W is spectral density over 3-h nighttime intervals).

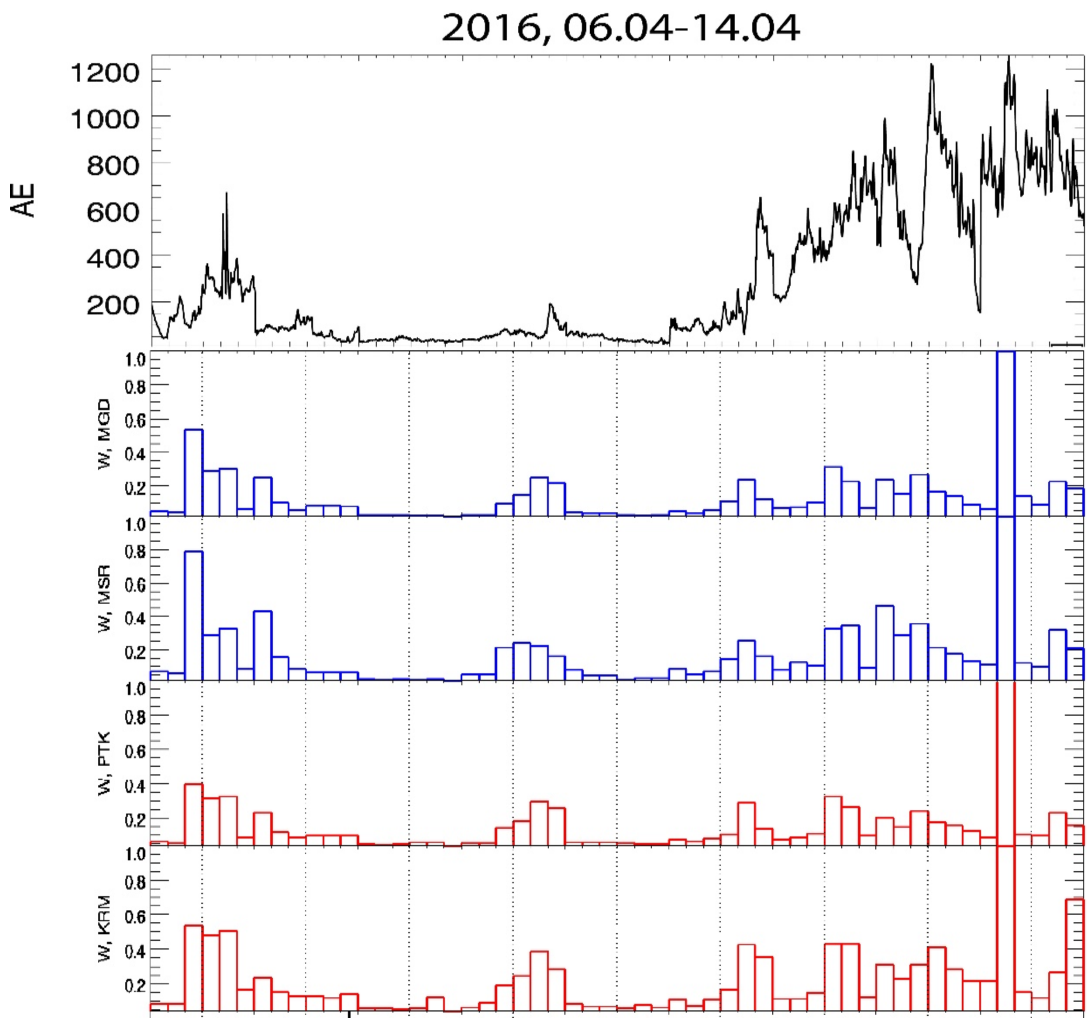




If the effect of geomagnetic depression is really associated with EQ preparation, then the same effect should be absent far from the epicenter?! To test this assumption, PWING data were re-analyzed. The normalized hourly spectral power W in the band 0.01–0.8 Hz (Y component) at night hours was calculated for **all** magnetometers.

At two nearby stations KRM and PTK, located not far from the epicenter, the depression was most clearly observed on April 8–9 and April 10–11.

At distant MSR and MGD stations (1514 km and 915 km away from the epicenter) the noise intensity depression is observed as well!



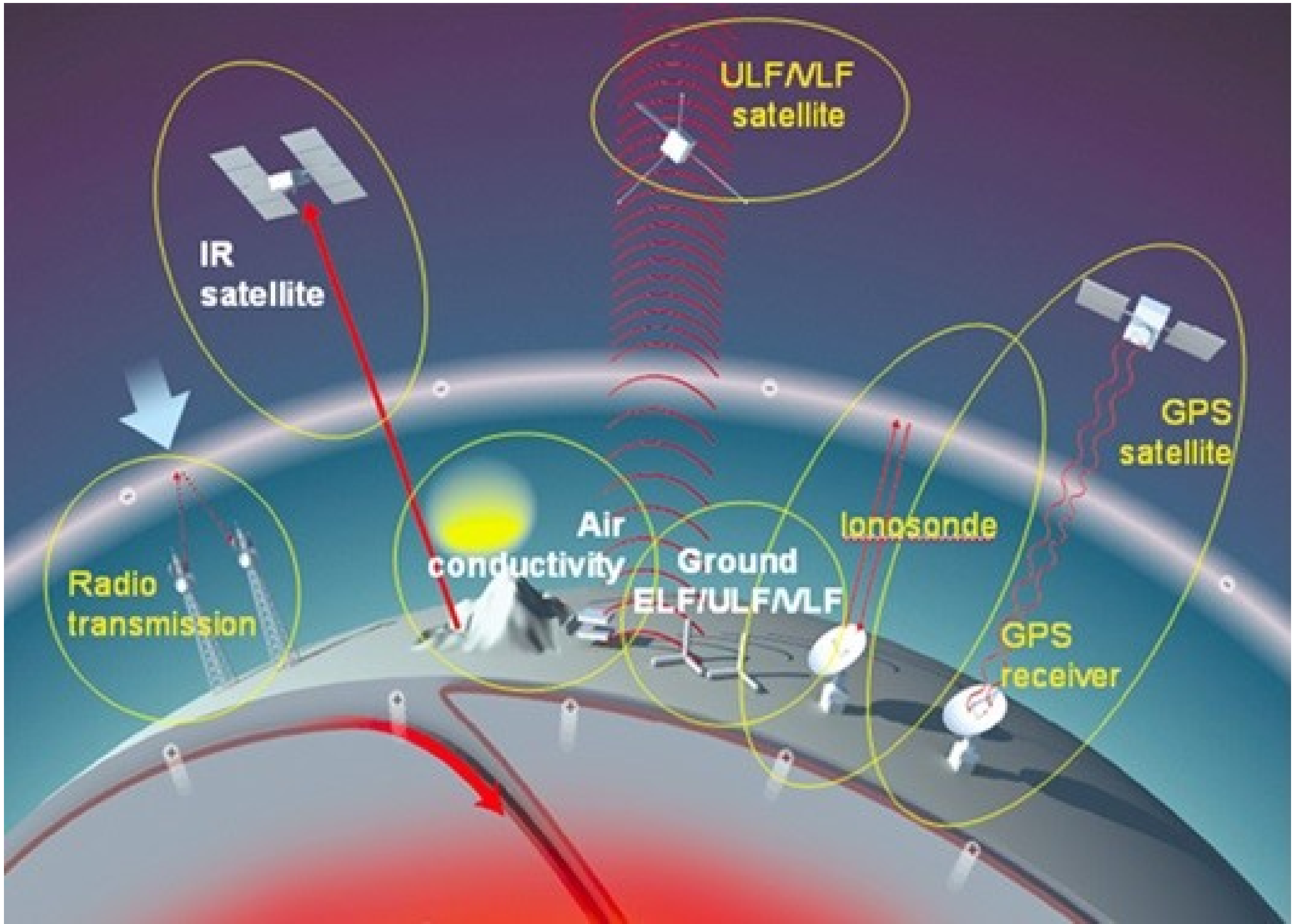
Variations in spectral power occurred synchronously both at nearby and remote (>1000 km) stations. Depression turns out to be a general magnetospheric process, apparently unrelated to seismic activity.

The reason for the global depression of ULF noise is evident from the AE-index: During April 8–9 and April 10–11, the planetary magnetic situation was exceptionally calm!

Feasibility of the seismogenic ULF disturbance detection by satellites

Attempts are being made to detect seismogenic ULF (<10 Hz) disturbances on LEO satellites. Encouraging results of early missions, when "anomalous" E-field disturbances >several mV/m were detected during nighttime before EQs, have stimulated dedicated missions: DEMETER (~660 km), CSES (~500 km). Other missions are being developed: TwinSat, ESPERIA, …

It is implicitly assumed that the emission from an underground ULF/ELF source reaches the satellite.



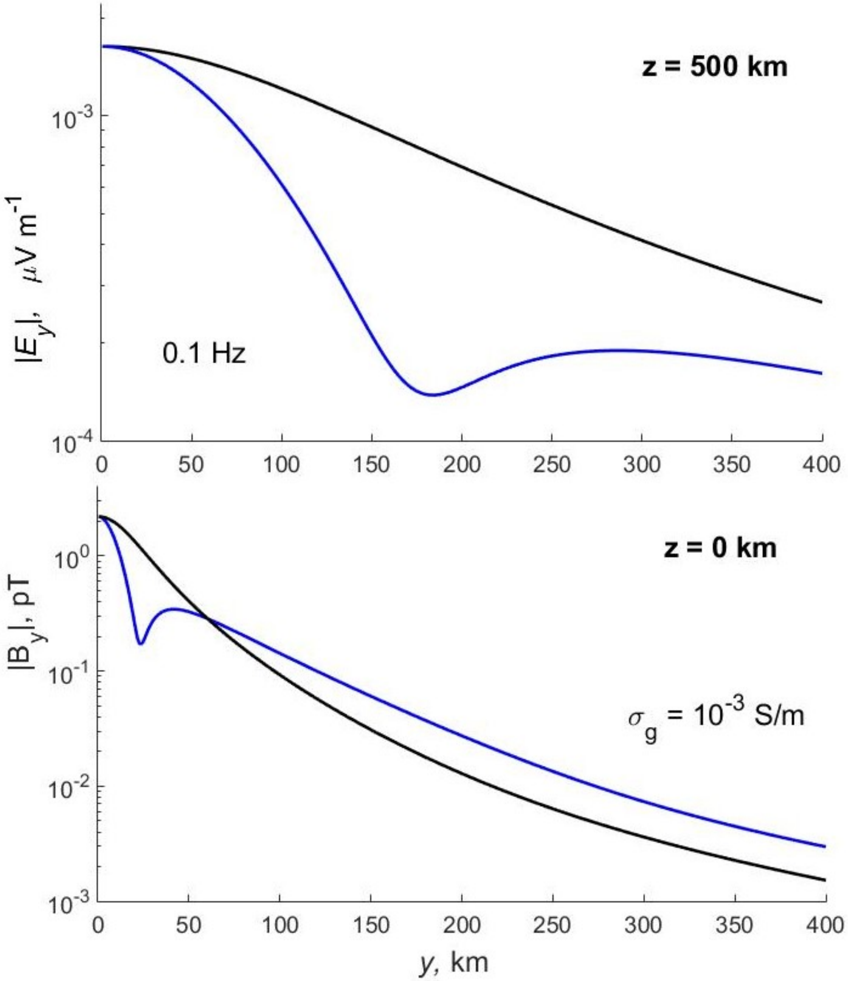
To estimate the necessary intensity of a seismic source of radiation that can be detected at LEO, it is necessary to model the response of the ionosphere to a large-scale underground emitter. We have elaborated a numerical model that makes it possible to estimate ULF fields generated by an underground horizontal current of finite length both on earth and in the upper ionosphere.

Model accounts for atmospheric conductivity profile and structure of ionospheric parameters derived from IRI model.

Spatial structure of 0.1-Hz e/m field, radiated by underground current with J=1 A, L=20 km, H=20 km, is calculated for upper ionosphere (z=500 km), and on the ground (z=0). Maximum disturbance of E-field above source reaches ~2 mV/m for current J~10^6 A.

In this case, perturbation of $B \sim 10^3$ nT arises on earth! Such geomagnetic disturbances would be detected by existing network of magnetometers!

ULF disturbances before EQs recorded on early satellites can hardly be associated with radiation from underground sources!



- ❖ We believe that a critical analysis of all published results is as important as a search for new effects. This may help to shut down unpromising and misleading directions and thus save time and resources.

- ❖ Weak point of the seismo-e/m studies is the lack of quantitative physical models. Theoretical modeling would make it possible to discard unrealistic physical mechanisms, otherwise, random coincidences can be perceived as reliable evidence. A new theoretical model is needed for calculating e/m fields in the Earth-atmosphere-ionosphere system, created by an underground current source.

- ❖ A re-analysis is necessary to validate earlier results on:

- Magnetic storms and interplanetary shocks as a trigger of EQs;
- Discrimination of underground ULF sources by amplitude-phase gradients and polarization features;
- Depression of ULF power as a short-term EQ precursor;
- Feasibility of detection of seismogenic ULF-ELF emissions by satellites.

Most geomagnetic field “anomalies” can be explained by global magnetospheric activity and are apparently not associated with seismic processes. The considered issues are a clear illustration of the fact that the analysis of anomalous disturbances should be carried out jointly by specialists in EQ physics and space weather. We suggest that both communities must cooperate their studies more tightly.