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Discrimination between induced and natural seismicity by means of nonlinear analysis

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The effect of human activity on the Earth's interior often causes activation of seismic processes, i.e. generates induced seismicity. Nowadays, the problem of distinguishing between the natural and induced seismicity have become important. The increasing interest to this problem is caused by the issues which seem to be far from related to seismicity, for examples, the reduction of greenhouse gas emissions into the atmosphere through the transition to the so-called green energy sources (such as hydrothermal power plants). Some geothermal power plants are located in the seismically active regions, which impedes referring the increase in seismic activity to the induced effects or natural variations.

Efficient methods for analyzing the behavior of complex dynamical systems (to which the geophysical systems pertain) were developed in the field of nonlinear dynamics. In particular, these methods allow one to identify the changes in the state of the system, which are caused by external action. If a system exposed to some impact has changed its state, the processes in this system will contain a deterministic component defined by the external factor. The appearance of the deterministic component should decrease the fractal dimension of the attractor in the phase space of the system states (if such attractor is distinguished) and decrease the dimension of the embedding space (the number of the key parameters required for describing the behavior of the system).

The Grassberger-Procaccia method is the widest-adopted approach for estimating the dimensions of the attractor and the embedding space. In the presented work, we use this method for analyzing the seismicity in several regions that suffered from technogeneous impacts. In some cases considered, the seismicity was not obviously induced.

Four data sets were analyzed: (1) the seismicity in the region of the Romashkino oil field, Russia; (2) the seismic activity before and after the large-scale explosions on Burlykiya and Uch-Terek Rivers in Kyrgyzstan; (3) the seismicity in the region of the Geysers geothermal complex in California, US; (4) the seismicity in the region of Bishkek geophysical test site, Kyrgyzstan, recorded before and after strong electromagnetic discharges.

The nonlinear analysis of the data sets on seismicity showed that technogeneous action on the geophysical medium increases the regularity of the seismic regime. It looks like the formation of stable states characterized by a finite fractal dimension of the attractor and reasonable small dimension of the embedding space. The presence of the stable states opens the possibility of forecasting the development of induced seismic activity.

We also present the results of nonlinear analysis of the rate-and-state model, which allows us to describe the mechanics of the studied phenomenon. In this context, the model of motion in the fault zones that obey the two-parameters friction law suggests that if the external action causes the critical stresses to decrease e.g. due to the growth of the pore pressure or due to heating of the fault zone, we should expect the deterministic component of the seismic process to increase.