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# New Predictive Models of Seismic Activity Based by Monitoring Data of Radon Variations in the Surface Atmosphere

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***Annotation.*** *In the article are reviewing issues of short-term forecast of local earthquakes. Based by two-year monitoring data of radon volumetric activity variations in the surface atmosphere, the predictive models of Hauksson, Goddard, and Rikitake, linking the earthquake magnitude, radon anomaly, distance to the epicenter, and precursor time, were verified and corrected.*

**Keywords:** *seismic activity, radon anomaly, earthquake magnitude, predictive models, precursor time*

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The fact the radon concentration in the surface air is an indicator of seismic activity has been known long time. First radon measurements as a precursor to earthquakes date back to 1927. However, the first published record linking radon fluctuations to seismic events appeared in 1966 only, after Tashkent earthquake. This event was the impetus for the development of the science direction, in which to radon assigned the role of an indicator-harbinger of earthquakes. All over world began radon investigations, included discrete and continuous measurements, measurements in soil, water, and air [1]. An overview of radon measurement methods and modes been given in [2]. The extreme importance of long-term continuous monitoring of radon fluctuations emphasized in [3] and [4].

This paper presents some results of monitoring measurements of radon volumetric activity (RVA) in surface air, which began in January 2016. The main object of research is the coastal zone of the Azov and Black seas of the Crimean-Taman region, where submeridional faults affected to the geological structures significantly. Regional discontinuities are located here between differently developing blocks of foundation, and represent zones of the earth's crust crushing, providing autonomy development of the foundation blocks and are mobile areas of their interface. The region characterized by both high speeds of vertical movements of the earth's crust (from -1.6 to +0.8 mm/year) and high speeds of horizontal movements (up to 12.9 mm/year). Activity of tectonic processes contributes to creation of prerequisites for the occurrence of extreme situations.

To obtain the announced research results, a non-standard method of radon registration used: fixing the energy of daughter short-lived products of beta lines decay. This approach allowed us to solve the problem of filtering the influence of weather parameters and other extraneous noise to readings of measuring equipment. Sensitivity of the radon detector increased about four times compared to classical meters [5]. Data of radon measurements are recording continuously, hourly and automatically since January 2016. The phenomenon of radon anomalies depends on the type of tectonic disturbances and geological structures [6]. If the anomalies occur far from the epicenters of earthquakes, they reflect changes of regional tectonic stress fields. Such anomalies most effectively detected in zones of seismically active faults. When choosing the location of the recording equipment, the results of ground monitoring of radon anomalies have taken into account [5]. The graph of radon volumetric activity fluctuations in the region during year 2016 has shown in fig. 1.

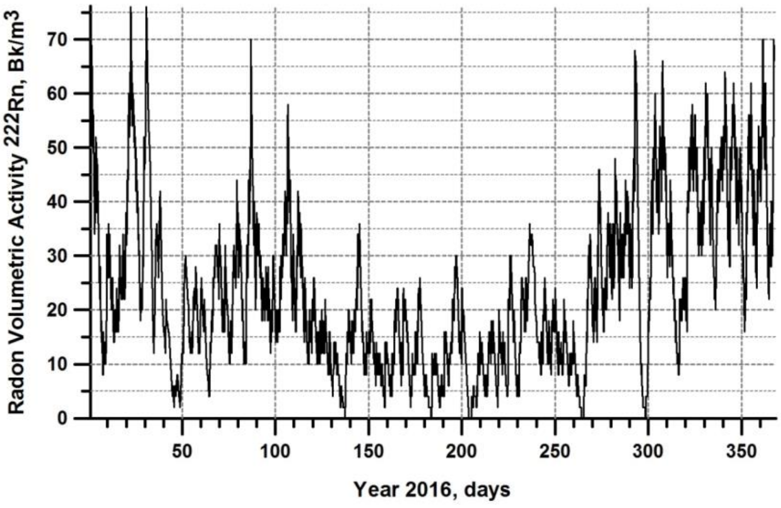


Fig. 1. **Graph of RVA fluctuations in the surface air during year 2016**

Spectral analysis of the annual series of radon fluctuations and meteorological parameters showed that the peaks of the energy spectra of processes lie at different frequencies (fig. 2). This confirmed the correctness of the decision in choosing the method of radon measurement in the surface air. Meteorological measurements were doing synchronously by an autonomous UT330C weather station installed at the data collection point.

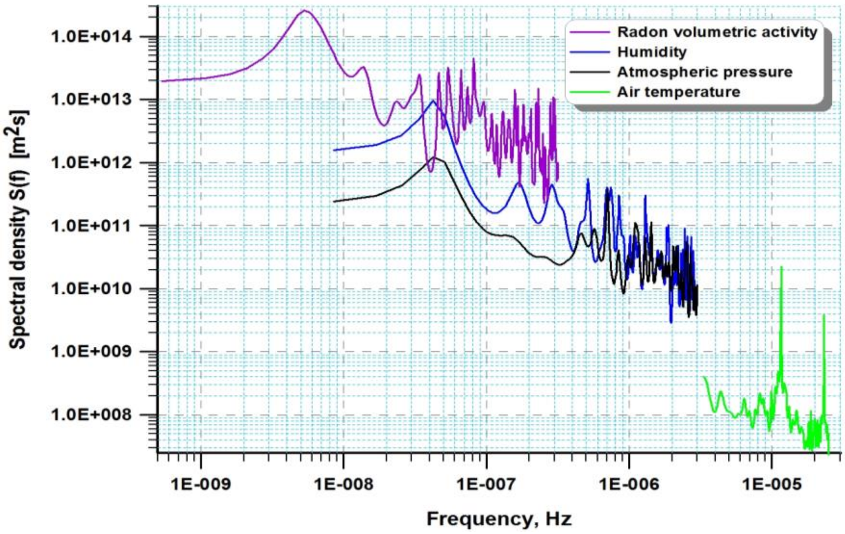


Fig. 2. **Spectral densities graphs of radon, humidity, atmospheric pressure, and air temperature fluctuations over on annual interval**

In the course of monitoring, the variation of radon were comparing with the ongoing earthquakes, information about which received from the European-Mediterranean Seismological Centre. At the measurement point, according to the Aptikaev relations [7], the physical parameters of seismic impacts have calculated: peak accelerations, ground velocity and displacement, and induced seismic magnitude. The graph of radon fluctuations for the 3-month period of 2017 relative to the average value for the entire monitoring period has shown in fig. 3. At the graph are numbered marks for eleven selected earthquakes. Shown in fig. 3 earthquakes have selected by principle of having a minimum number of other powerful sources disturbances of seismic stability.

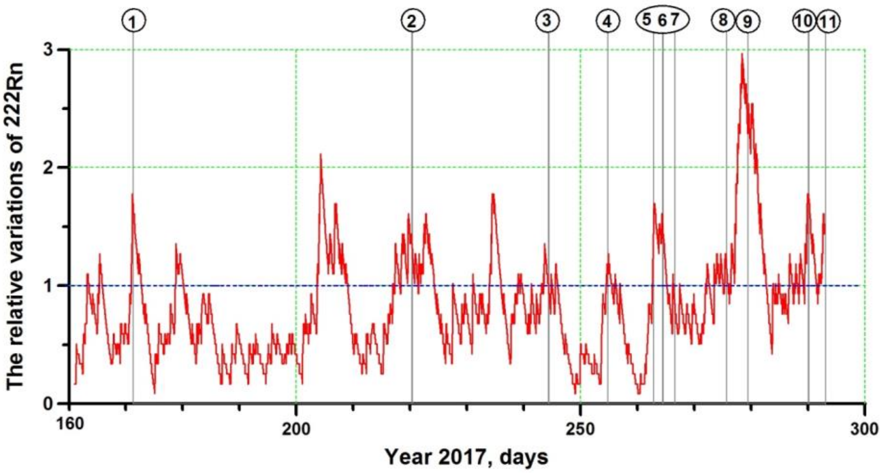


Fig. 3. **Graph of radon variations for the 3-month period of 2017 relative to the average value for the entire monitoring period. Vertical lines with digital designations - are selected earthquakes**

Parameters of the earthquakes marked in fig. 3 have shown in fig. 4. The letters in the fig.4 are *M*, *E* – magnitude and energy of the earthquake in the hypocenter; *H* – depth of the earthquake source; *D* – distance from the epicenter to the data collection point; PGA, *Mi* – peak acceleration and induced magnitude in the monitoring zone.

| № | Date | Time, UTC+3 | *M* | *E*, J | *H*, *km* | Epicenter coordinates | *D*, km | *PGA*, *cm/s²* | *Mi* |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 20.06.2017 | 06.16 | 3.6 | $1.58\cdot10^{10}$ | 10 | 44.62N; 36.95E | 81 | 2.31 | 3.58 |
| 2 | 08.08.2017 | 08.30 | 3.5 | $1.12\cdot10^{10}$ | 10 | 44.82N; 36.76E | 101 | 1.31 | 3.49 |
| 3 | 01.09.2017 | 09.37 | 3.9 | $4.47\cdot10^{10}$ | 10 | 41.30N; 46.25E | 833 | 0.04 | 1.09 |
| 4 | 11.09.2017 | 19.20 | 5.0 | $2\cdot10^{12}$ | 10 | 39.13N; 21.53E | 1490 | 0.07 | 1.42 |
| 5 | 19.09.2017 | 21.15 | 7.1 | $2.82\cdot10^{15}$ | 51 | 18.59N; 98.47W | 11700 | 0.03 | 0.80 |
| 6 | 21.09.2017 | 12.06 | 4.2 | $1.26\cdot10^{11}$ | 2 | 41.61N; 46.58E | 776 | 0.07 | 1.49 |
| 7 | 23.09.2017 | 14.40 | 4.2 | $1.26\cdot10^{11}$ | 12 | 41.15N; 47.30E | 858 | 0.06 | 1.36 |
| 8 | 02.10.2017 | 16.59 | 3.6 | $1.58\cdot10^{10}$ | 40 | 42.55N; 36.22E | 227 | 0.32 | 2.51 |
| 9 | 06.10.2017 | 10.59 | 6.0 | $6.31\cdot10^{13}$ | 10 | 37.45N; 143.98E | 8270 | 0.01 | 0.16 |
| 10 | 17.10.2017 | 04.59 | 3.9 | $4.47\cdot10^{10}$ | 10 | 44.22N; 41.50E | 281 | 0.33 | 2.53 |
| 11 | 20.10.2017 | 01.37 | 3.9 | $4.47\cdot10^{10}$ | 4 | 40.76N; 33.87E | 544 | 0.09 | 1.66 |

Fig. 4. **Parameters of earthquakes, which have marked in fig. 3**

The scientific world, based on the world experience of research, believes that the early manifestation of radon anomalies is associated with the scale of the brewing situation and the epicenter distance. Empirical relations based on the theory of radon diffusion are widely used. The Hauksson and Goddard model [8] relates the minimum earthquake magnitude $M$ required for the radon anomaly to manifest at the epicentral distance $D$:

$$M \geq 2.4 \log_{10} D - 0.43 \quad (1)$$

Fig. 5 illustrates the results of calculations performed using the model (1). In fig. 5 also presents data on actual earthquakes (from the table in figure 4), to which were preceded radon anomalies shown in fig. 3.

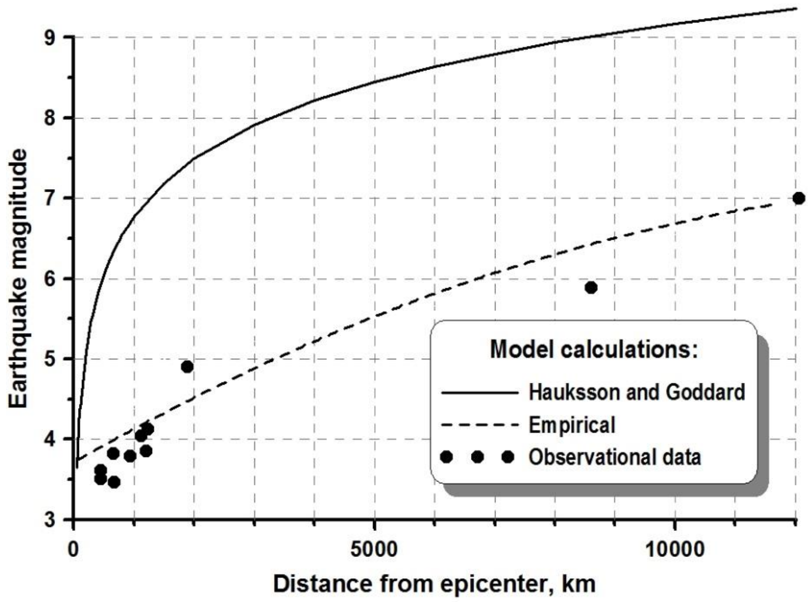


Fig. 5. **Graph of relationship between the distance to epicenter and required of earthquake magnitude that can cause radon anomalies. The dotted line shows the result of calculations performed using the empirical model (2)**

The empirical model, calculated according to the results of the monitoring:

$$M = 3.716300113 + 4.282533138 \cdot 10^{-4} D - 1.311840954 \cdot 10^{-8} D^2 \quad (2)$$

One of the first models linking the time-harbinger $t$ and the magnitude $M$ of an impending extreme situation became the Rikitake equation [9]:

$$\log_{10} t = 0.76M - 1.83 \quad (3)$$

Based on the monitoring data, we have calculated a new empirical model:

$$t = 6.267984634 - 0.1306085548M + 1.103283014M^2 \quad (4)$$

In fig. 6 and fig. 7 illustrates the results of calculations using mathematical models (3) and (4).

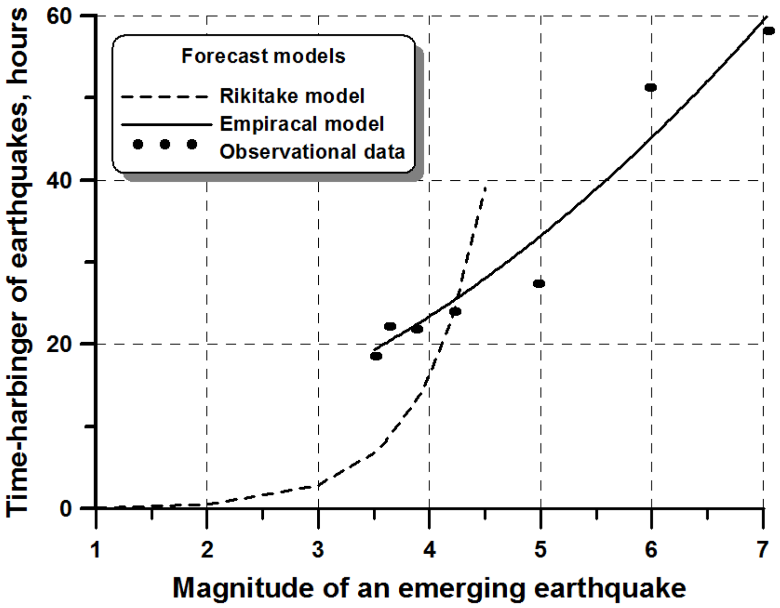


Fig. 6. **Graphs of the dependence the harbinger time on the magnitude of the emerging earthquake. The Rikitake model built only for magnitudes 1 – 4.5**

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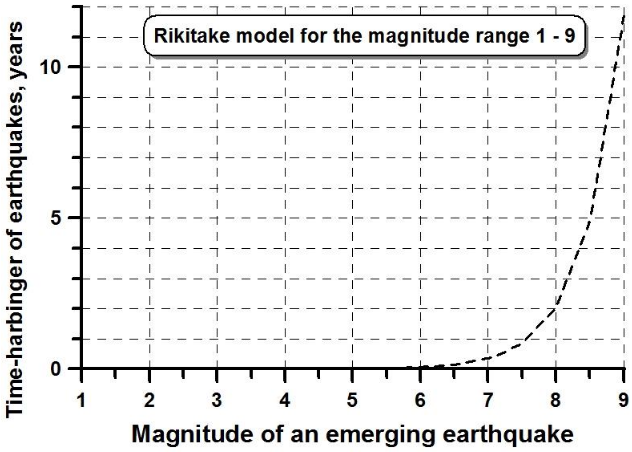


Fig. 7. **Rikitake model built for magnitudes 1 – 9**

**Conclusions**

Comparison of the results of calculations based on the Hauksson and Goddard model (1) and the found empirical model (2) shows a match only for epicentral distances less than 100 km. It makes the model untenable for large-scale investigations. Calculations based on the Rikitake model (3) coincide with calculations based on the empirical model (4) only for magnitudes less than 4.5.

Increased radon emanation when seismic instability occurs triggers a chain of physical processes that result in changes in the conductivity and temperature of atmospheric air. This fact opens the way for the development of methods for remote monitoring of radon anomalies and forecasting regions of nascent earthquakes.

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