The Influence of Meteorological Parameters and Other Factors on Soil Radon Dynamics

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Abstract. The paper presents the results of the research in the degree of the effect of space weather meteorological parameters and factors on the dynamics of soil radon levels and α- and β-radiation flux densities in a seismically passive region. The cross-correlation analysis showed a significant correlation of β-radiation flux density with temperature in summer, and no correlation in winter. A significant relation between α- and β-radiation flux densities and pressure within the intra-annual range was not observed. The investigation of the high-intensity precipitation effect on radon volumetric activity and α- and β-radiation flux densities showed their abnormal increase. The dependence of the anomaly duration on the depth was revealed. The abnormal jumps in α- and β-radiation flux densities data series occur in the snow-melting periods as well. Low-intensity precipitations significantly violate the standard "diurnal variations" of α- and β-radiation soil fluxes and radon volumetric activity. Fourier analysis showed the diurnal (24 hours) and semidiurnal (12 hours) harmonics for the observed radiation values at a depth of 0.5 m. The obtained results can be used for interpretation of the data on the soil radon monitoring in order to predict earthquakes, etc.

1. Introduction
Zones of strains and compressions occurring in the lithosphere cause changes in the intensity of the gas flow (including radon) from the earth interior into the atmosphere [1–10]. Thus, variations of soil radon are an indicator of changes in stresses in the lithosphere and they are used as a precursor of earthquakes. The interpretation of the monitoring data on radon in seismic areas is a complex problem since the variations related to the change in stresses in the lithosphere are affected by "background" variations due to meteorological or other factors. These "background" variations are interferences and the spectrum and the factors affecting them are far from being fully studied. These background variations should be explored in seismically passive areas [11−12]. Therefore, the main research aim was to study the degree of the effect of meteorological parameters and space weather factors on the dynamics of soil radon in a seismically passive region.

2. Materials and methods

The investigation of the influence of meteorological parameters and other factors on soil radon dynamics was started from the end of 2008 at Tomsk Observatory of Radioactivity and Ionizing Radiation [13, 14]. Volumetric activity (VA) of soil radon was measured with help of highly sensitive intellectual scintillation α- and β-radiation detectors BDPA-01 and BDPB-01 (ATOMTEX, Republic of Belarus), respectively, with high time resolution of data series (10 min). Ionizing radiation (IR) detectors were mounted into boreholes of 0.5 and 1 m depths. The distance between boreholes was about 1.5 m. Radon isotopes and its decay products (DPs) radiometer EQF 3200 (SARAD, Germany) was used for calibration to convert the measured α- and β-radiation flux densities (FD) into soil radon VA [15].

In order to determine the degree of external factors influence the monitoring of meteorological (air temperature, pressure, air relative humidity, wind speed and direction, surface temperature and soil temperatures), actinometrical and atmospheric-electrical values was performed via automated information measuring system of IMCES. The precipitation data were taken from http://rp5.ru/8218/ru.

3. Results and analysis

The analysis of seasonal variations of α- and β-radiation FDs showed that, on the whole, seasonal changes by both types of IR measured at 2 depths are very close. However, variations of β-radiation FD in soil have more dispersion compared to the α-radiation FD. The dispersion of variations at a depth of 0.5 m for both types of radiation is greater than that at a depth of 1 m.

The following seasonal pattern has been identified. After melting of the snow cover all the IR detectors recorded a significant increase in α- and β-radiation FDs: at a depth of 1 m, it was ~2-fold, and at a depth of 0.5 m, it was 2.5–3-fold. This is due to the filling of the top layer pores with the soil water, which reduces the exhalation of soil radon into the atmosphere and causes it to accumulate in the soil.

It is well known that pressure and temperature have a significant impact on the variation of soil radon. A decrease in temperature is accompanied by gas compression, whereas, an increase is followed by its extension, therefore, when the temperature of the soil decreases, new portions of the atmospheric air enter the soil, and quite the opposite process occurs when heated. These processes have distinct diurnal variations.

To study the dependence of the α- and β-radiation FDs on meteorological parameters a cross-correlation analysis was performed using MATLAB. The example of cross-correlation between β-radiation FDs at depths of 1 and 0.5 m and the temperature in winter and summer of 2013 is shown in Fig. 1 a–d. It shows that in summer, there is a correlation of the β-radiation FD with temperature, and in winter, no correlation is observed. An interesting pattern can be observed when considering different depths in summer: the correlation with temperature at a depth of half a meter is significantly greater than that at a depth of 1 meter. Moreover, at a depth of 0.5 m, the correlation is positive with an average coefficient of 0.6, and at a depth of 1 meter, the correlation is negative with the same coefficient. The obtained result is important both to interpret the data on soil radon monitoring and to improve the models of radon transport.

The example of cross-correlation between α-radiation FDs at the depths of 1 m and 0.5 m and the temperature in winter and summer is shown in Fig. 2 a-d. The relation of α-radiation FDs and the temperature of the atmosphere can be observed only at the depth of half a meter during the summer months. The average value of correlation coefficient is about 0.6. The relation between alpha-field at a depth of 1 m and the temperature was not significant. In the winter months, the effect of the atmosphere temperature on the dynamics of the soil alpha and beta fields was not observed.
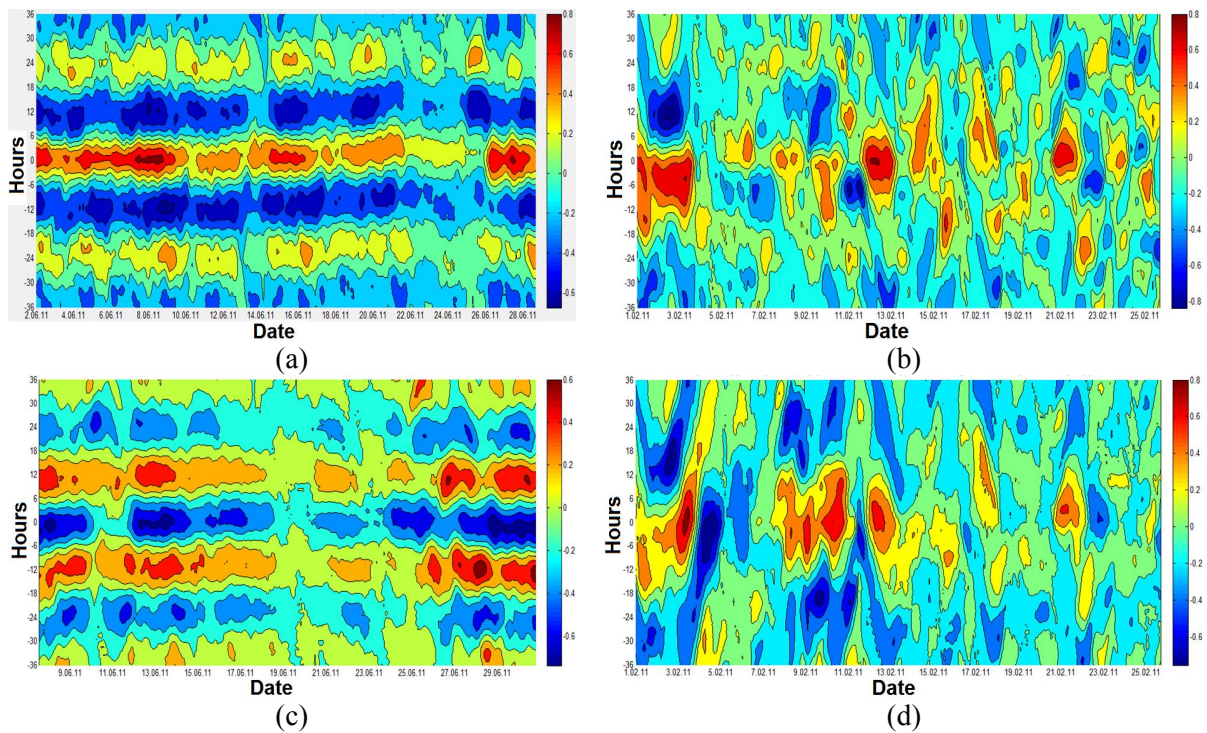
Figure. 1. Cross-correlation between β-radiation FD at: a) 0.5 m depth in June; b) 0.5 m depth in February; c) 1 m depth in June; d) 1 m depth in February and air temperature
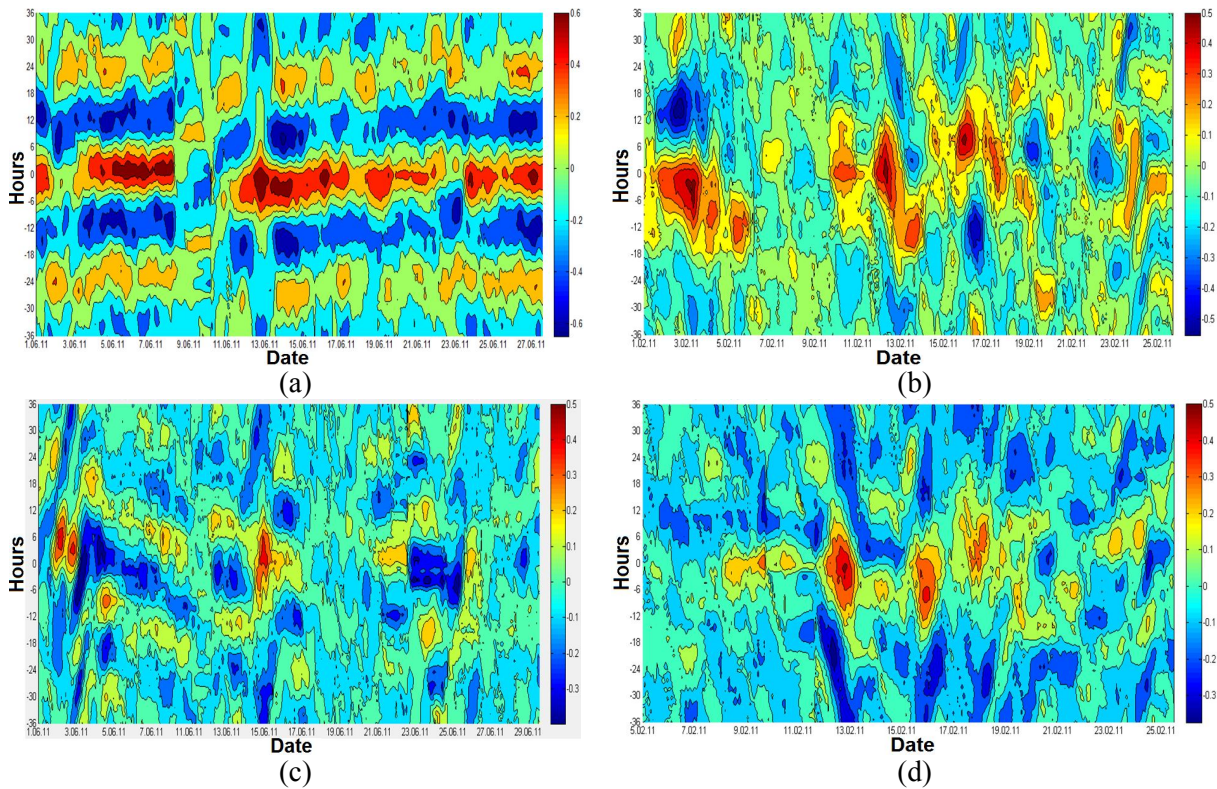

Figure. 2. Cross-correlation between α-radiation FD at: a) 0.5 m depth in June; b) 0.5 m depth in February; c) 1 m depth in June; d) 1 m depth in February and air temperature

The cross-correlation analysis also did not confirm a significant relation between α- and β-radiation FDs and pressure within the intra-annual range.

Consider the influence of precipitations on the variations of soil radon VA and α-, β-radiation FDs. Fig. 3 presents variations of radon VA at a depth of 1 m measured by the radiometer EQF 3200 (Rn 1 m), the series of β-radiation FD at 1 m depth and α-radiation FDs at 0.5 m and 1 m depths, recovered through multiplication by calibration coefficients. All radiation values showed abnormal abrupt increase for the precipitation intensity of 47 mm (13 of July, 2011). The abnormal increase in the radon VA was ~4.5-fold, α- and β-radiation FDs at the depth of 1 m increased by a factor of ~2.5 and ~1.6, respectively; α-radiation FD at the depth of 0.5 m went up by a factor of ~2.8. It can also be seen that the anomaly duration depends on the depth. The flux of α-radiation at a depth of 0.5 m recovered to its original value after 2 days, and the flux of α-radiation, as well as the flux of β-radiation and radon VA, at a depth of 1 m recovered only after 5 days. It is reasonable to assume that the anomaly can be even greater, and its duration can be shorter at the depths up to 50 cm. These abnormal jumps could be misinterpreted as the earthquake precursors in the seismic zone.
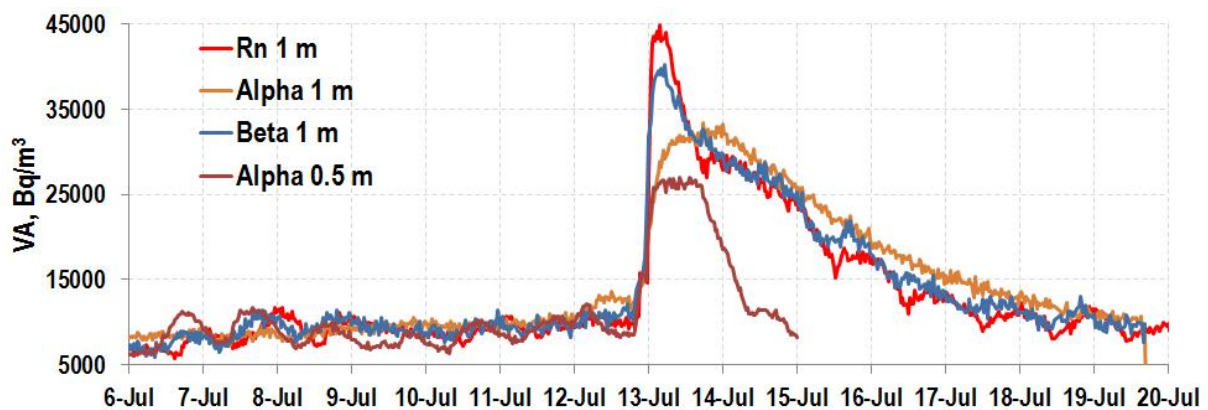
Figure. 3. The influence of high-intensity precipitations on dynamics of soil radon volumetric activity, α- and β-radiation FDs

It was found that low-intensity precipitations do not cause the abnormal jumps but significantly violate the standard "diurnal variations" of α- и β-radiation soil fluxes at a depth of 0.5 m, leading to its insignificant increase.
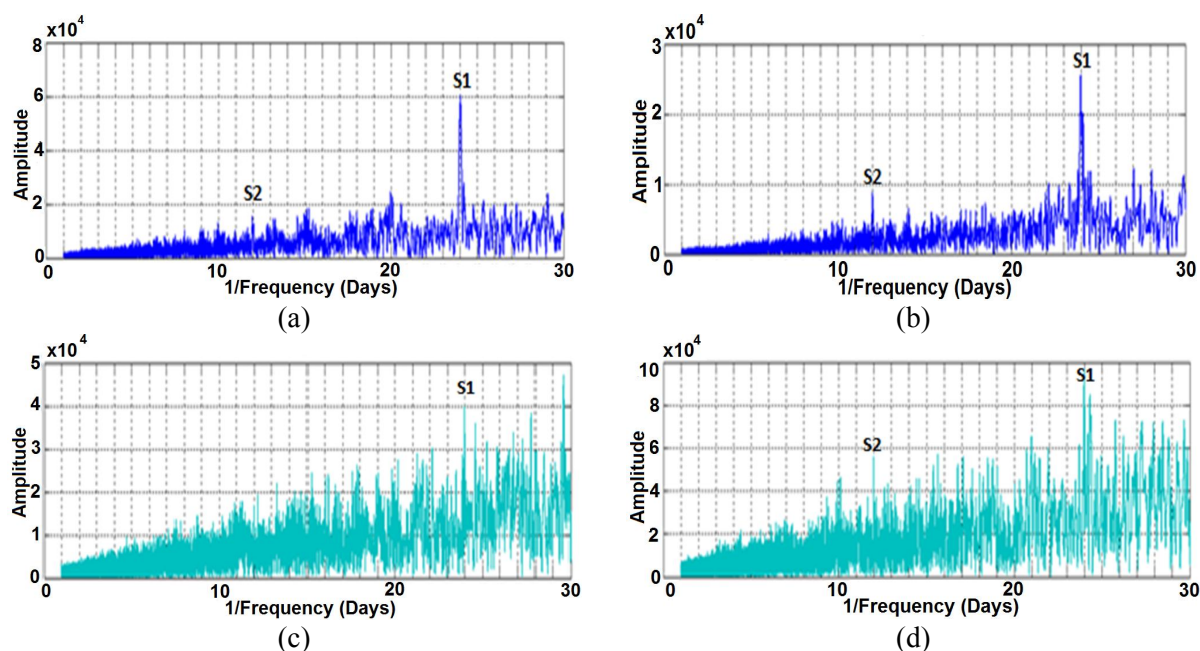
Consider the results of Fourier analysis for the time series of α- and β-radiation FDs at different depths. The examples are presented in Fig. 4. In the series of α- and β-radiation FDs at half a meter, the diurnal harmonic (24 hours) associated with solar tides can be clearly observed. The peak of the solar tide is caused by non-uniform heating of the atmosphere and the ground surface by solar radiation. The semidiurnal harmonic (12 hours) for β-radiation FD, which is also caused by the influence of the solar radiation reaching the earth's surface, can be clearly observed. It is difficult to distinctly identify the periodicals corresponding to the solar and lunar tides in the series recorded at a depth of 1 m. This fact confirms the minor effect of the tides on the radon dynamics at a depth of 1 m.

4. Conclusion

The analysis of the study results on the influence of meteorological parameters and space weather factors on the soil radon dynamics in a seismically passive region allows making the following conclusions:

−   It was revealed a significant correlation of the β-radiation flux density with temperature in summer, but in winter, no correlation is observed. The cross-correlation analysis also did not confirm a significant relation between α- and β-radiation FDs and pressure within the intra-annual range.

- When processing the results of monitoring in the earthquake zones, it is essential to consider that high-intensity precipitations of more than 20 mm may cause abnormal jump of the soil α- and β-background and radon concentration at a depth of up to 1 m. The shape and duration of the anomalies are similar to the geochemical precursors of earthquakes.
- The low-intensity precipitations significantly violate the standard "diurnal variations" of the soil α- and β-radiation flux densities at a depth of 0.5 m, and lead to radiation increase.
- The abnormal jumps caused by high soil moisture can also occur in the snow-melting periods.
- Fourier analysis revealed the diurnal (24 hours) and semidiurnal (12 hours) harmonics in the time series of α- and β-radiation flux densities at a depth of 0.5 m.

Figure. 4. Results of Fourier analysis for: a) α-radiation FD at 0.5 m depth; b) β-radiation FD at 0.5 m depth; c) α-radiation FD at 1 m depth; d) β-radiation FD at 1 m depth

The obtained results could be useful for interpretation of soil radon monitoring data with an aim of prediction of the stress-deformed state of the Earth's crust.

Acknowledgments

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