Contribution to analysis of time courses of soil radon concentration (year 2004)

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Abstract: The article is devoted to evaluation of dependence between measured values of volume activity of ^{222}Rn and ^{220}Rn in soil air and some meteorological parameters (temperature, humidity and pressure of atmospheric air) in an annual cycle from 13.1.2004 to 26.1.2005. In addition to year-around assessment of observed dependencies by means of linear regression (Table 1) there is also presented more detailed statistical analysis of variability of daily (weekly) measurements files. Based on these results several shorter time periods (seasons) are detached within a year which differ from each other by weather character and during which single meteorological parameters get determining influence on measured concentrations of ^{222}Rn and ^{220}Rn (Table 2). The results document a tight dependence between radon content in pore space of soil cover and meteorological parameters of atmospheric environment in dependence on weather changes in a year cycle.

Key words: volume activity of ^{222}Rn and ^{220}Rn, soil air, seasonal variations of radon, temperature, humidity, pressure of atmospheric air

1. Introduction

Monitoring measurements of ^{222}Rn and ^{220}Rn volume activity in soil air were carried out manually in single place at the depth of 0.8 m once per week. This kind of weekly, resp. daily statistical file (set) is mostly represented by 5 values (quintuplet) acquired by immediate measurements of soil air samples taken from the same probe in 10–13 minutes' intervals. Whole day's, resp. week's measurements were covering in this manner a time period of approx. 1.5 hours' long and usually were carried out between 8:00 and 10:00 in the morning. At the same time intervals also temperature, humidity and pressure of atmospheric air were registered.

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All processed values were taken from one measuring station – probe installed inside the Faculty of Natural Sciences campus. The area lies on the southward oriented slope of the Little Carpathians Mts. with easy gradient to the Danube River terrace in the SW part of Bratislava. The basement is built by mixture of slope loams and sandy-gravel old terrace sediments. But the uppermost layer is a heterogeneous building made-up ground. The clay particles content is approx. 49% what means a middle permeable environment for radon gas moving.

2. Object of study

The target is to give statistical assessment of measured data within the year 2004 (exactly from 13.1.2004 to 26.1.2005) and to find out the most important dependencies between the values of ^{222}Rn, resp. ^{220}Rn volume activity in soil air and single meteorological parameters.

3. Results of study and discussion

3.1. General view – year-around courses and relations

There were 263 measurements carried out during 52 days (weeks) in the period from 13.1.2004 to 26.1.2005. Time courses of measured content of ^{222}Rn, resp. ^{220}Rn isotopes in soil air are presented in Figs. 1 and 2 in bottom part (the ^{222}Rn, resp. ^{220}Rn volume activity in kBq·m^{-3}). The polynomial curve (bold line) fitted through measured values underlines seasonal course of both isotopes' changes (variations) in good correlation with description in research literature and former works. The ^{222}Rn curve (Fig. 1) falls from its winter maximum (January 2004) to spring minimum (March – April/May 2004) with relatively high scatter of values and next in May – June 2004 it forms a compact maximum after which in period July – September 2004 a relatively stable plateau comes that in autumn and winter months 2004/2005 passes to the highest values within a year *(Holý et al., 1995; Mojzeš, 2004)*. The ^{220}Rn course (Fig. 2, bottom) is more uniform with minimum values in colder months February – April 2004 and with maximum in warmer period August – October 2004. At the same time its phase delay behind the curve of atmospheric air temperature is evident *(Mojzeš, 2004)*.

For the possibility to compare the time courses of radon volume activity

Table 1. Coefficients of linear correlation between measured variables in whole measured period 13.1.2004 – 26.1.2005

	$a_V(^{222}Rn)$	$a_V(^{220}Rn)$
Temperature of atm. air	0.17	0.24
Humidity of atm. air	-0.26	0.03
Pressure of atm. air	0.20	0.28
Number of measurements	263	

Legend: $a_V(^{222}Rn)$ - volume activity of ^{222}Rn in soil air [kBq·m^{-3}],
$a_V(^{220}Rn)$ - volume activity of ^{220}Rn in soil air [kBq·m^{-3}]

with their probable reasons there are also presented the time courses of observed atmospheric air parameters, i.e. temperature, humidity and pressure in the top of Figs. 1 and 2. Their dependence is well known from former works, e.g. (*Matolín and Prokop, 1992; Holý et al., 1995; Mojzeš, 2004*). For completeness the dependence of the ^{222}Rn and ^{220}Rn volume activity on single meteorological parameters by the coefficients of linear correlation is presented in Table 1.

3.2. Detail view – daily measurements' analysis

The detail view on the ^{222}Rn, resp. ^{220}Rn volume activity curve (Figs. 1, 2) shows that it consists of a chain of 5-points' clusters of values measured within a single day (week) which are separated from each other by approx. one week. The clusters of daily measurements (quintuplets) have different consistence – the points in some quintuplets are near to each other but in another ones they are more scattered. Based on own experience with measurement it can be stated that the compactness, resp. the variability of values measured within fixed daily period was to certain extent depending on actual weather character within longer or shorter time range. For example, if the measurement was performed in a time range with relatively

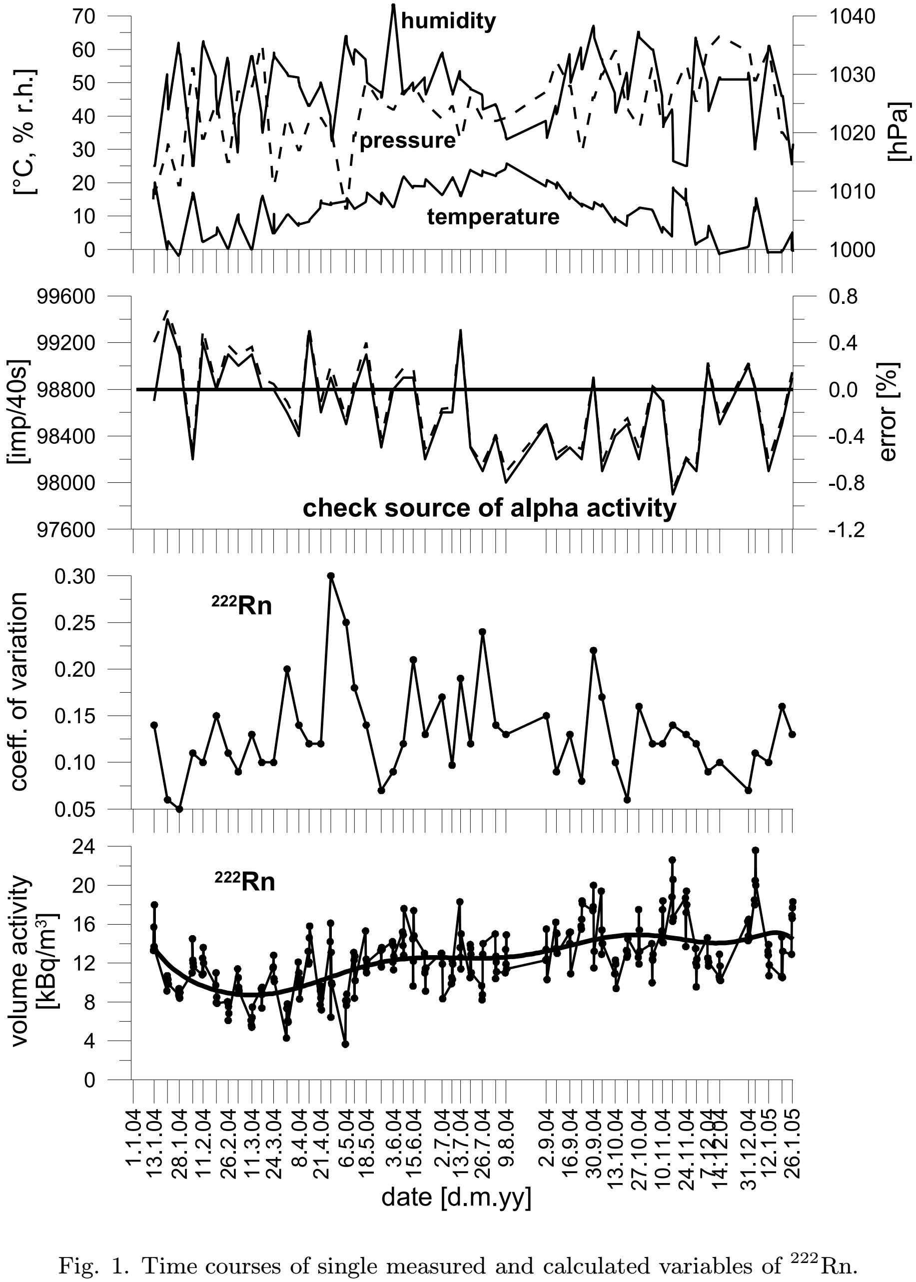

Fig. 1. Time courses of single measured and calculated variables of ^{222}Rn.

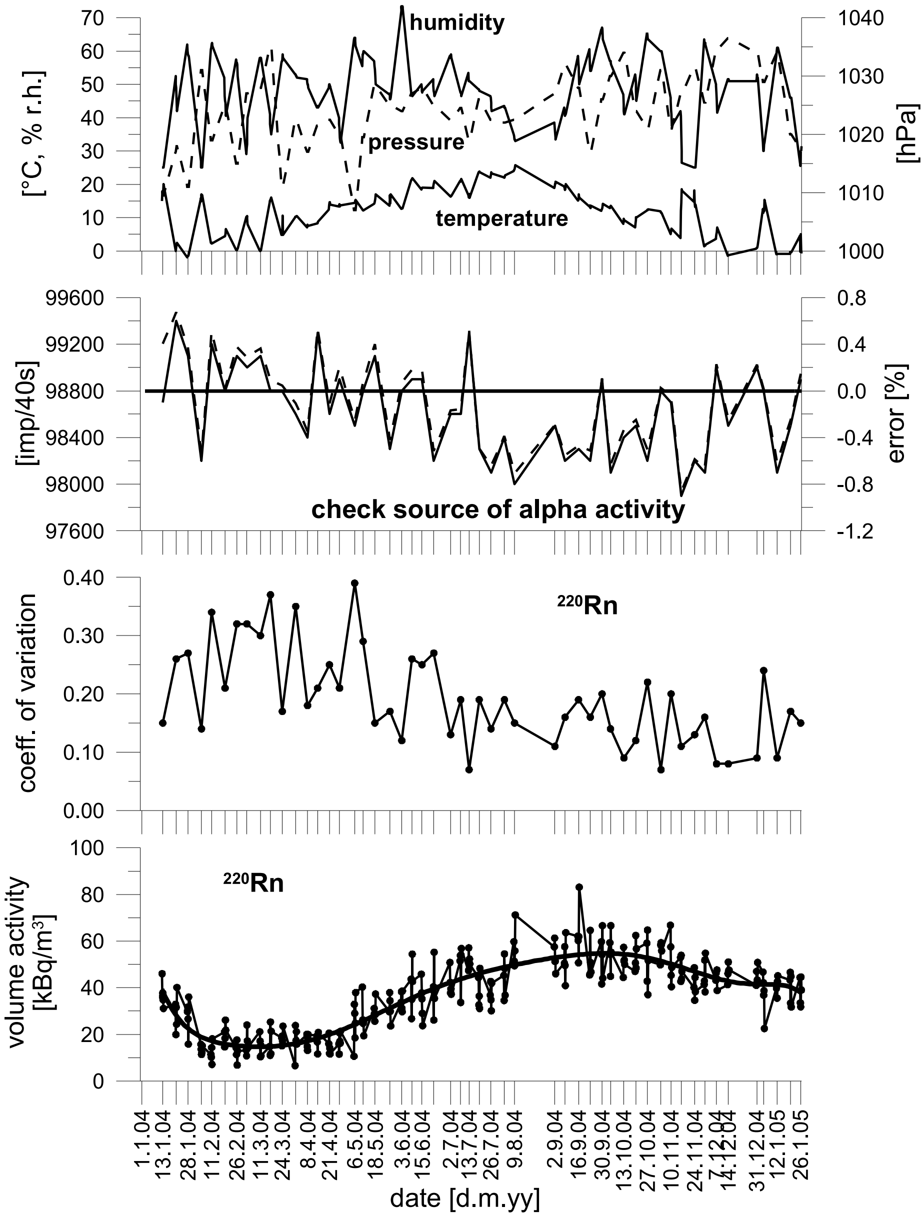

Fig. 2. Time courses of single measured and calculated variables ^{222}Rn (thoron).

long-lasting stable weather state, no matter if the weather was nice or bad, it could be observed that the quintuplets had values more compact with lower statistical variance. On the other hand, in the case of varied and unstable weather, e.g. during the transition from nice weather to bad or conversely, less stable values with higher variance were observed. These observations led us to an idea of statistical valuation of values inside clusters of daily measurements and based on it to try to do some conclusions on an influence of meteorological parameters on physical field of soil radon concentration in a year cycle. For the evaluation of variability of the radon volume activity inside 52 quintuplets of daily measurements the coefficient of variation $\mathrm{V_k}$ was used

$$V_{\mathrm{k}} = \sigma/\emptyset\,, \qquad (1)$$

where σ – standard deviation, $\emptyset$ – average.

Time course of the coefficient of variation is presented as the second graph from bottom up in Fig. 1 for the ^{222}Rn volume activity and in Fig. 2 for the ^{220}Rn volume activity.

3.2.1. Daily measurements and instrument stability

We suppose that the stability of instrument measurements by itself has no significant influence on value of the coefficient of variation of the radon volume activity. This could be illustrated by the time course of instrument function stability presented as the second graph from above in Figs. 1 and 2 in the form of number of impulses in 40 seconds (imp/40 s) from measurements of radiation check source and check measurements' error in %. Starting from zero error at the level of 98800 imp/40 s the value of check field was being continuously decreased during measurements as a result of check source activity loss and the curve shows neither significant similarity nor relation to the curves of the coefficient of variation of the radon volume activity (the value of the coefficient of linear correlation between the coefficient of variation of the ^{222}Rn volume activity and the check source activity –0,07 indicates an absence of dependence). Thus, the strongest influence on the course of coefficients of variation of the ^{222}Rn and ^{220}Rn volume activity has, in our opinion, exactly seasonal character of weather and its changes.

3.2.2. Daily measurements' variability during a year cycle

It is possible to assign two different parts in a year cycle of the coefficient of variation of the ^{222}Rn volume activity by visual evaluation of its time course (Fig. 1, 2nd graph from bottom): part April – September which covers values with wide variance and the highest maxima and part October – March with considerably more balanced and also lower values of variability. The maximal values in these parts' boundaries (on 1.4., resp. 27.4.2004 and 30.9.2004) indicate substantial weather character change – from colder and wetter season to warmer and drier one and back. Higher and more frequent variances of values in the period April – September (27.5., 15.6., 26.7.2004) could be caused by short-time-lasting dry or rainfall intervals which can manifest themselves more intensively in conditions of hay soil horizon in summer season than in case of wet water saturated one in winter season.

Also in case of time course of the coefficient of variation of the ^{220}Rn volume activity (Fig. 2, 2nd graph from bottom) it is possible to assign two parts in a year cycle: part January – May/June which covers values with higher amplitudes and higher variance and part June – December with lower amplitudes and more balanced course. Unlike ^{222}Rn we suppose that the reason is a demonstration of ^{220}Rn measured quantity – higher and unstable values of the coefficient of variation are connected with low ^{220}Rn content in soil air but lower and more balanced ones are in period with sufficient ^{220}Rn production in soil air which shows expressive dependence on environment temperature probably through the coefficient of emanation.

3.3. Time courses and relations within determined periods of the year – results and discussion

Based on own practical experience with manual measurements of radon content in soil air we know that measured values were closely connected with changes of single meteorological parameters whereby the power of influence of each of them changed in different periods of year, e.g. sometimes the temperature changes had prevailing influence on the radon content variations, at other time the humidity changes, etc. One of the most notable influence was a strong positive dependence of the ^{222}Rn content on the temperature in winter and early spring period (January – March) the reason for which could be a fluctuation of free pore moisture content in soil horizon as a result of its repeated melting and freezing meaning: higher temperature → melting of pore water → water infilling pores in near surface layer → horizon sealing-off → higher ^{222}Rn values as a result of its accumulation under drenched impermeable layer and conversely: lower temperature → freezing of pore water → higher gas permeability of nearsurface horizon → better soil ventilation → lower ^{222}Rn contents in measured depth. But this dependence was lost after accession of warm summer mode of media exchange between pore and atmospheric environment and, on the contrary, an influence was obtained by terminable rainfalls during relatively drier summer season which started to carry a function of nearsurface horizon tightening through its drenching. We suppose that exactly these influences were manifested on curves of the coefficients of variation of the ^{222}Rn and ^{220}Rn volume activity and they allowed to select the mentioned time periods.

The values of the coefficient of linear correlation between the ^{222}Rn and ^{220}Rn volume activity and temperature, humidity and pressure of atmospheric air are listed in Table 1 for the study area. These values are computed from all 263 measurements during the whole year cycle 13.1.2004 – 26.1.2005. From the statistical point of view their values are relatively low and the dependencies are not significant, but this could just be a result of total evaluation in which single seasons are suppressed in favour of the whole. Therefore we tried to plot the time course of the coefficient of linear correlation for selected couples of variables during measured period (Fig. 3). Also on these curves it is possible to see a seasonal character of some relations in a year cycle. To the most statistically significant dependencies (according to maximum values) belong:

- positive dependencies:	^{222}Rn vs. temperature (up to +0.9),
	^{220}Rn vs. temperature (up to +0.65),
- negative dependencies:	^{222}Rn vs. humidity (up to –0.9),
	^{220}Rn vs. pressure (up to –0.75).

To the least statistically significant dependencies belong the relations with the coefficients of linear correlation oscillating around zero:
- ^{222}Rn vs. pressure (from –0,3 to +0,23),
- ^{220}Rn vs. humidity (from –0,3 to +0,1).

The time course of the coefficient of linear correlation for the most important relation between the ^{222}Rn volume activity and temperature (which is also determining for the second most important relation between ^{222}Rn and humidity, based on logic inversely proportional relation between temperature and humidity of atmospheric air) is presented also in "backward" order when the time interval, in which the coefficient was calculated, was step by step shortened from maximal length 13.1.2004 – 26.1.2005 to minimal 20.1.2005 – 26.1.2005 (Fig. 4).

Table 2. Coefficients of linear correlation between study variables in single time periods

	^{222}Rn vs. temper.	**^{222}Rn vs. humidity**	**^{222}Rn vs. pressure**	**^{220}Rn vs. temper.**	**^{220}Rn vs. humidity**	**^{220}Rn vs. pressure**	**No. of meas.**
13.1. – 27.4.2004	0.36	-0.46	-0.25	0.02	-0.22	-0.45	82
27.4. – 15.6.2004	0.37	-0.23	0.69	0.48	0.20	0.39	36
15.6. – 30.9.2004	-0.53	0.31	-0.05	-0.23	-0.03	0.05	65
30.9.04– 26.1.2005	0.40	-0.45	-0.20	0.27	0.39	0.02	80
13.1.04– 26.1.2005	0.17	-0.26	0.2	0.24	0.03	0.28	263

Through visual evaluation of the time course curves of the coefficients of linear correlation for selected dependencies in selected time intervals (Figs. 3 and 4) based on notable changes of their course shape we tried to identify actual time periods and their boundary dates on which some important weather changes occurred which subsequently affected the course of the ^{222}Rn and ^{220}Rn volume activity values in soil air. To the most important time breaks belong these short time intervals:
27.4.2004 – 6.5.2004,
3.6.2004 – 15.6.2004,
16.9.2004 – 30.9.2004.

All these dates correspond with time localization of extreme values of the coefficient of variation mainly of the ^{222}Rn volume activity but also ^{220}Rn in Figs. 1 and 2. It seems logical that the first time landmark (27.4. – 6.5.) corresponds to the beginning of the warmer and drier summer season, the second time landmark (3.6. – 15.6) probably relates to the period of more intensive summer rainfalls which are in this period (June – July) typical for the latitude of the study area *(Holý et al., 1995; Mojzeš, 2004)* and the third one (16.9. – 30.9) with the end of the summer drier weather and the beginning of colder and wetter autumn weather. The year cycle could be

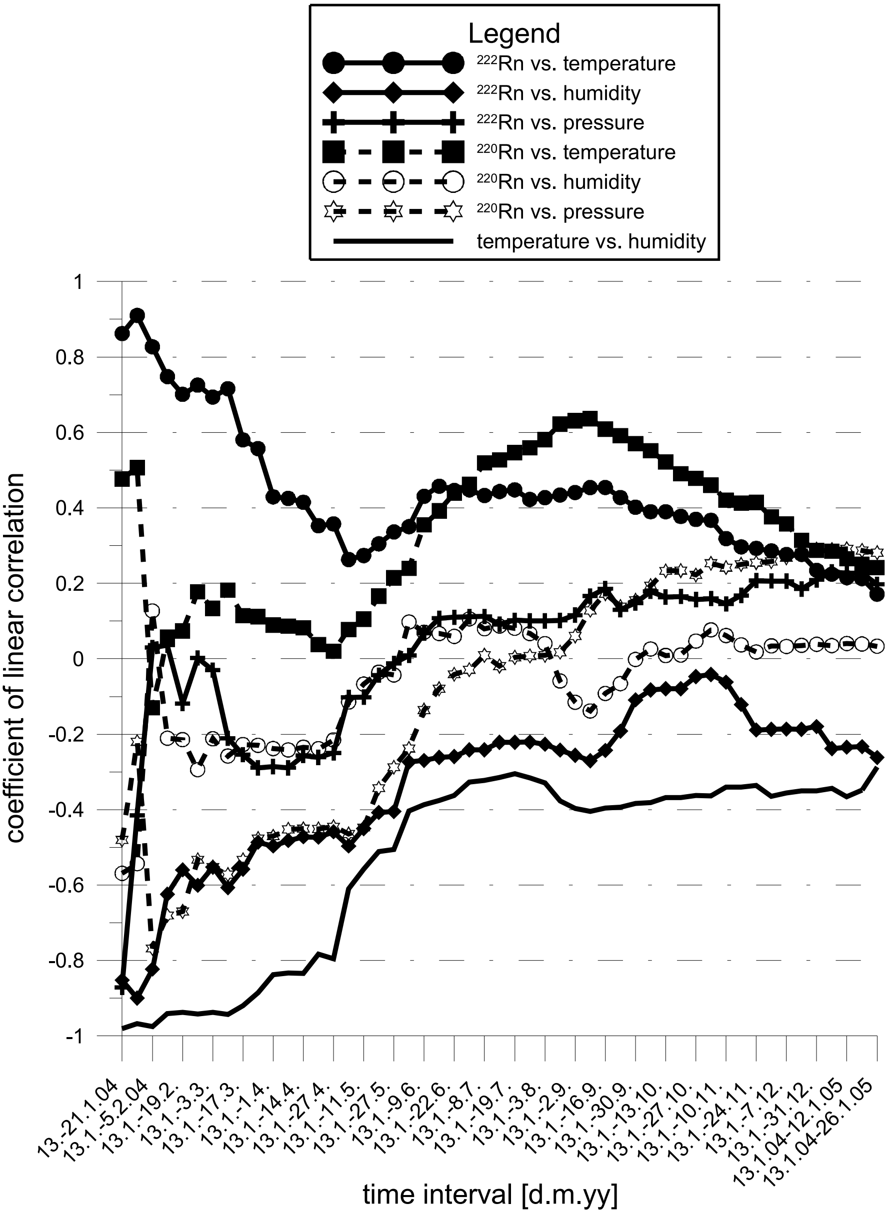

Fig. 3. Time courses of the coefficients of linear correlation between selected variables.

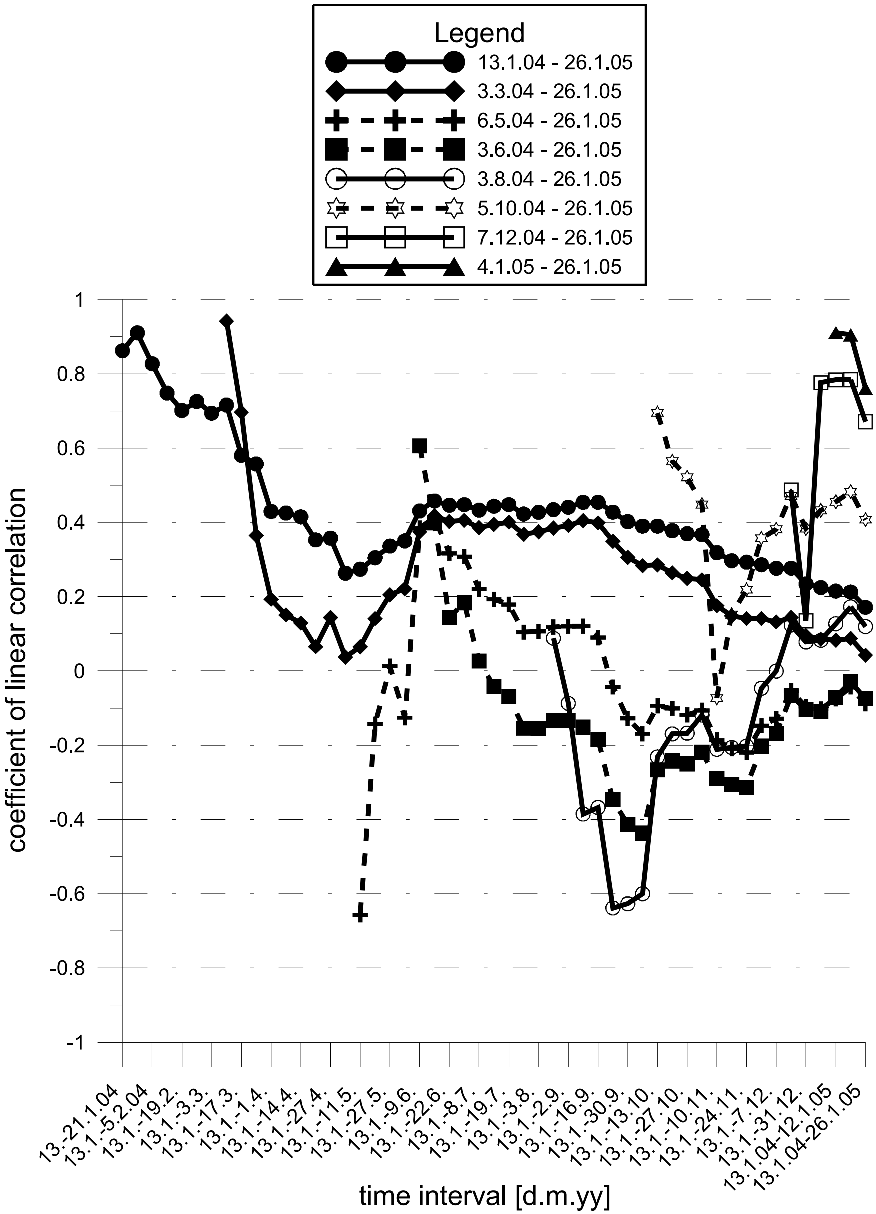

Fig. 4. Time courses of the coefficients of linear correlation between the ^{222}Rn volume activity and air temperature in selected time intervals.

thus divided into several shorter periods:
13.1.2004 – 27.4.2004,
27.4.2004 – 15.6.2004,
15.6.2004 – 30.9.2004,
30.9.2004 – 26.1.2005.

There are calculated coefficients of linear correlation for selected couples of variables in these time periods, cf. Table 2. It follows from the table that different meteorological parameters get prevailing influence on the value of the radon volume activity in soil air in single time periods in directly or inversely proportional meaning.

This is very well notable in the case of ^{222}Rn - on its relation with temperature - where the positive correlation during autumn, winter and spring periods (13.1. – 27.4.2004 = 0.36 and 30.9.2004 – 26.1.2005 = 0.40) can be well documented on curves in Fig. 1 on days 13.1., 5.2., 3.3., 24.3., 16.11., 7.12.2004, 4.1. and 26.1.2005 where, except others, also already mentioned nearsurface soil horizon drenching as result of pore water melting (only in winter months) was manifested. Absolutely different character has the dependence of these two variables during summer and dry period 15.6. – 30.9.2004 when they have negative correlation (-0.53) which should be explained through the generation of ^{222}Rn concentration maxima as result of drenching and thereby also through the tightening of nearsurface soil layer, which is normally hay and seamy, in consequence of short-time-lasting thundery summer rainfalls. In this period, accordingly, also the relation between ^{222}Rn and humidity of atmospheric air gets the highest positive correlations (0.31). Relatively questionable is the evaluation of high correlation between ^{222}Rn and atmospheric air pressure (0.69) in period 27.4. – 15.6.2004. We suppose that it is an attendant manifestation of primary dependence of ^{222}Rn on temperature and rainfalls.

In case of ^{220}Rn the strongest correlation is its correlation with the atmospheric air temperature just in period 27.4. – 15.6.2004 (0.48) that can be explained through permanent increase of temperature during weather transition process from spring to summer season that resulted in the same gradual and permanent increase of the ^{220}Rn volume activity values which show, as it was already mentioned, the strongest year-around dependence on temperature (see Fig. 2 – noticeable visual correspondence of curves of the ^{220}Rn volume activity and temperature). Inadequacy between values of the coefficient of correlation and this curves' coincidence could be explained through the lag effect of the ^{220}Rn volume activity curve behind the temperature curve which logically misrepresents (decreases) the calculated values of the coefficient of linear correlation. The existence of certain time delay between dependent and independent variable cannot be excluded even in the case of ^{222}Rn.

4. Conclusions

The results document a close connection between radon content in pore space of soil cover and some meteorological parameters of aerial atmospheric environment in dependence on weather changes in a year cycle. Table 1 presents the coefficients of linear correlation between observed variables during whole year-around cycle from 13.1.2004 to 26.1.2005. More detailed statistical analysis of variability of daily (weekly) measurements' sets allowed the assignment of 4 shorter time periods within the study year which differ from each other by weather character and in which single meteorological parameters get prevailing influence on measured ^{222}Rn and ^{220}Rn concentrations (Table 2). Even though there is a generally established and accepted year cycle division to warmer (summer) and colder (winter) seasons based on the determined dependencies between observed variables, the date definition of single time periods (13.1. – 27.4.2004, 27.4. – 15.6.2004, 15.6. – 30.9.2004 and 30.9.2004 – 26.1.2005) is apparently valid only for the study year cycle 2004/2005. Therefore it could be interesting to evaluate measurements of other year cycles and the mutually compare time landmarks of the obtained time periods.

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