Contribution to analysis of time courses of soil radon concentration (years 1997 – 1998)

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A b s t r a c t : The article is devoted to the evaluation of the dependence between measured values of ^{222}Rn and ^{220}Rn activity concentration in soil air and some meteorological parameters (temperature, humidity and pressure of atmospheric air) in an annual cycle from 5.3.1997 to 14.12.1998. In addition to year-around assessment of observed dependencies by means of linear regression (Table 1) a more detailed statistical analysis of the variability of daily (weekly) measurements is also presented. 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: ^{222}Rn and ^{220}Rn activity concentration, soil air, seasonal variations of radon, temperature, humidity, pressure of atmospheric air

1. Introduction

Monitoring measurements of ^{222}Rn and ^{220}Rn activity concentration in soil air were carried out manually in single place from the depth of 0.8 m once per week. This kind of weekly or 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, or week's measurements covered in this manner a time period

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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.

All processed values were taken from one measuring station – the probe installed at 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% which means a middle permeable environment for radon gas movement.

2. Subject of study

The target is to give statistical assessment of measured data within the years 1997–1998 (exactly from 5.3.1997 to 14.12.1998) and to find out the most important dependencies between the values of ^{222}Rn, resp.^{220}Rn activity concentration in soil air and single meteorological parameters.

3. Results of study and discussion

3.1. General view – year-around courses and relations

There were 591 measurements carried out during 80 days (79 weeks) in the period from 5.3.1997 to 14.12.1998. 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 activity concentration 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 the description in research literature and former works. The ^{222}Rn curve (Fig. 1, bottom) starts from its very expressive spring minimum (March – April/May 1997) with the lowest values, and next it forms in May – July/August 1997, on the contrary, very expressive summer maximum with the highest values in the study period. The reason of this shift dwells in weather changes: the spring 1997 was very dry while next three weeks of heavy rains resulted in river floods of the March and Danube Rivers (maximum of air humidity curve). But such rainy summer period is common in this region *(Holý et al., 1995; Mojzeš, 2004; Mojzeš and Putiška, 2006)* only it was very strong in 1997. The next ^{222}Rn course is not very typical for the region: the values are relatively stable with the only wider maximum in September 1998 and very tiny indication of maximum in February/March 1998 both probably as the result of short-time rainy periods (maximum of air humidity curve). There are no expected maxima neither in winter 1997 and 1998 nor in summer 1998 (except of 2 measurements on 17.6.1998). The ^{220}Rn course (Fig. 2, bottom) is more uniform with minimum values in colder months (March – April 1997, January – March 1998 and December 1998) and with maximum in warmer periods (August – October 1997 and July – September 1998). At the same time its phase delay behind the curve of atmospheric air temperature is evident *(Mojzeš, 2004; Mojzeš and Putiška, 2006)*.

For the possibility to compare the time courses of radon activity concentration 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 (the curves are shorter because the measurements started later on 1.7.1997). Their dependence is well known from former works *(e.g. Matolín and Prokop, 1992; Holý et al., 1995; Mojzeš, 2004; Mojzeš and Putiška, 2006)*. For completeness the dependence of the ^{222}Rn and ^{220}Rn activity concentration 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 activity concentration 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, or the variability of values measured within fixed daily period was to certain extent depending

Table 1. Coefficients of linear correlation between measured variables for whole measured period 1.7.1997 – 14.12.1998 and single years

1.7.1997 – 14.12.1998	**$a_V(^{222}Rn)$**	**$a_V(^{220}Rn)$**
Temperature of atm. air	0.23	0.25
Humidity of atm. air	0.28	0.03
Pressure of atm. air	-0.06	-0.10
Number of measurements	478	
1.7.1997 – 15.12.1997	**$a_V(^{222}Rn)$**	**$a_V(^{220}Rn)$**
Temperature of atm. air	0.13	-0.34
Humidity of atm. air	0.48	-0.08
Pressure of atm. air	-0.24	0.13
Number of measurements	174	
7.1.1998 – 14.12.1998	**$a_V(^{222}Rn)$**	**$a_V(^{220}Rn)$**
Temperature of atm. air	0.24	0.42
Humidity of atm. air	0.22	0.13
Pressure of atm. air	0.10	-0.03
Number of measurements	304	

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

on actual weather character within longer or shorter time range. For example, if the measurement was performed in a time range with relatively 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 activity concentration inside 80 quintuplets of daily measurements the coefficient of variation V_k was used

$$V_k = \sigma/\varnothing, \qquad (1)$$

where: σ – standard deviation; $\varnothing$ – average.
Time course of the coefficient of variation is presented as the second graph from bottom up in Fig. 1 for the ^{222}Rn activity concentration and in Fig. 2

for the ^{220}Rn activity concentration.

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 activity concentration. 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 per 40 seconds (imp/40 s) from measurements of radiation check source and check measurements' error in %. Starting from zero error at the level of 103240 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 activity concentration (the value of the coefficient of linear correlation between the coefficient of variation of the ^{222}Rn activity concentration and the check source activity –0,06 indicates an absence of dependence). Thus, the strongest influence on the course of coefficients of variation of the ^{222}Rn and ^{220}Rn activity concentration has, in our opinion, exactly seasonal character of weather and its changes.

3.2.2 Daily measurements' variability during a year cycle

The year course of the coefficient of variation of the ^{222}Rn activity concentration (Fig. 1, 2nd graph from bottom) is by its visual evaluation hardly interpretable. As it was mentioned above neither in case of the ^{222}Rn activity concentration course (Fig. 1, 1st graph from bottom) nor in case of its coefficient of variation there were expected expressive differences between warmer and colder seasons expressed. It is possible to assign seven different parts of the coefficient of variation of the ^{222}Rn activity concentration in a year cycle:

1st part (20.3.1997 – 21.5.1997) – is the most easily set as it is the most expressive one. This part is the most unstable one with the highest values of the coefficient of variation and is connected with the lowest measured values of the ^{222}Rn activity concentration during dry spring of 1997.

2nd part (21.5.1997 – 2.9.1997) – is the direct result of long-lasted rainfall period during summer season of 1997 (see the graph of relative humidity on the top of Fig. 1). This part is the most stable one with the lowest values of the coefficient of variation in 1997-98 period. It is similar to the 6^{th} part.

3^{rd} part (2.9.1997 – 15.12.1997) – is very unstable one with high variations. This part generally does not correspond to autumn and winter seasons. It is similar to the 5^{th} and 7^{th} parts.

4^{th} part (7.1.1998 – 23.4.1998) – is more stable part with lower variations.

5^{th} part (23.4.1998 – 16.7.1998) – is very unstable part with high variations.

6^{th} part (23.7.1998 – 9.11.1998) – is the second most stable part.

7^{th} part (20.11.1998 – 14.12.1998) – is short less stable part.

As it was outlined some parts are similar and create groups in which approximately the same periods of both 1997 and 1998 years occur, e.g. the 2^{nd} and 6^{th} parts (May – September 1997 and July – November 1998) or the 3^{rd}, 5^{th} and 7^{th} parts (September – December 1997, April – July 1998 and November – December 1998).

In the case of time course of the coefficient of variation of the ^{220}Rn activity concentration (Fig. 2, 2^{nd} graph from bottom) there is evident a negative correlation to ^{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 periods 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 the year, e.g. sometimes the temperature changes had prevailing influence on the radon content variations, at other times the humidity changes, etc. One of the most notable feature mainly in Fig. 1 is very strong expression of very dry spring 1997 (the lowest values of the ^{222}Rn activity concentration) followed by heavy rainy

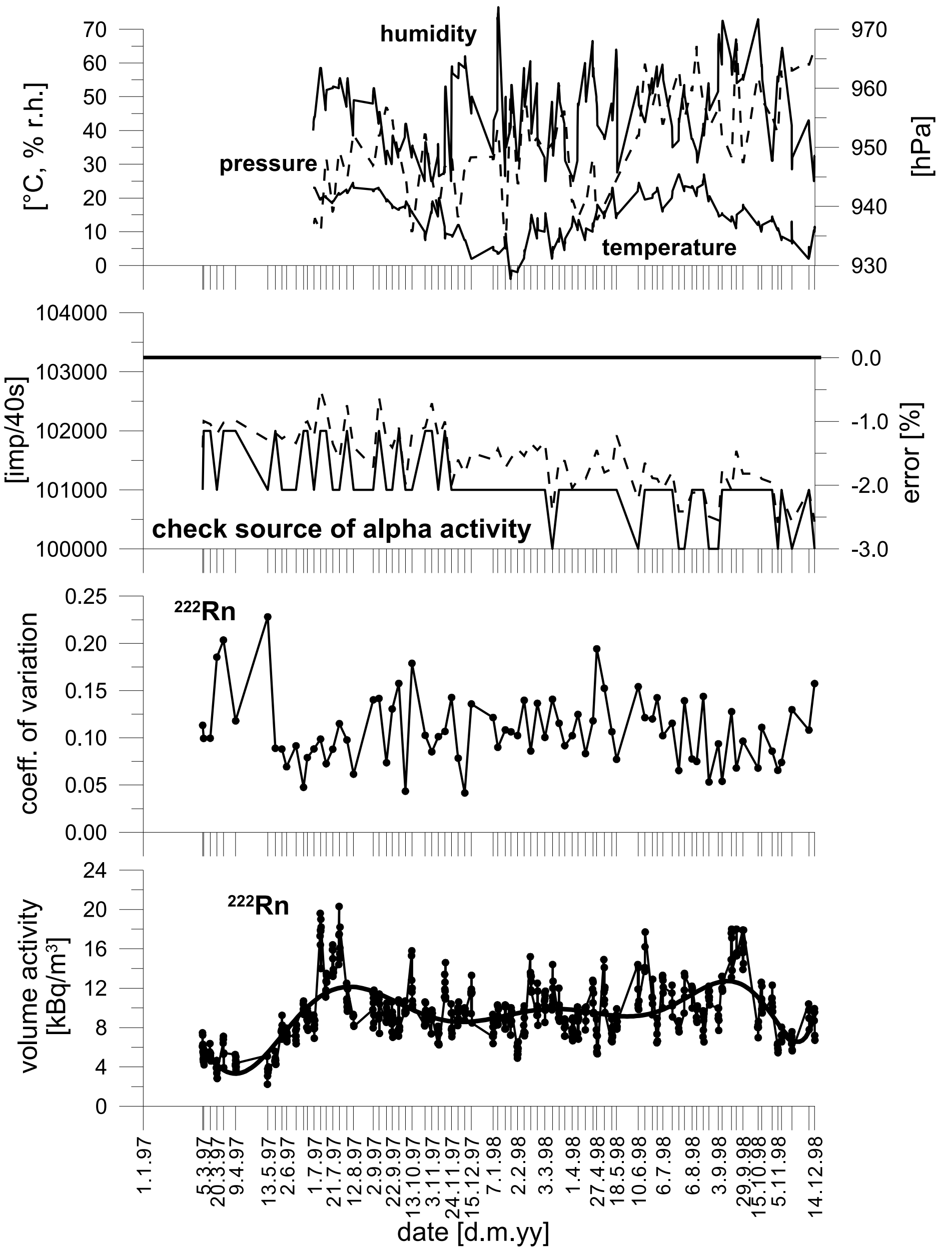

Fig. 1. Time courses of single measured and calculated variables of ^{222}Rn (radon).

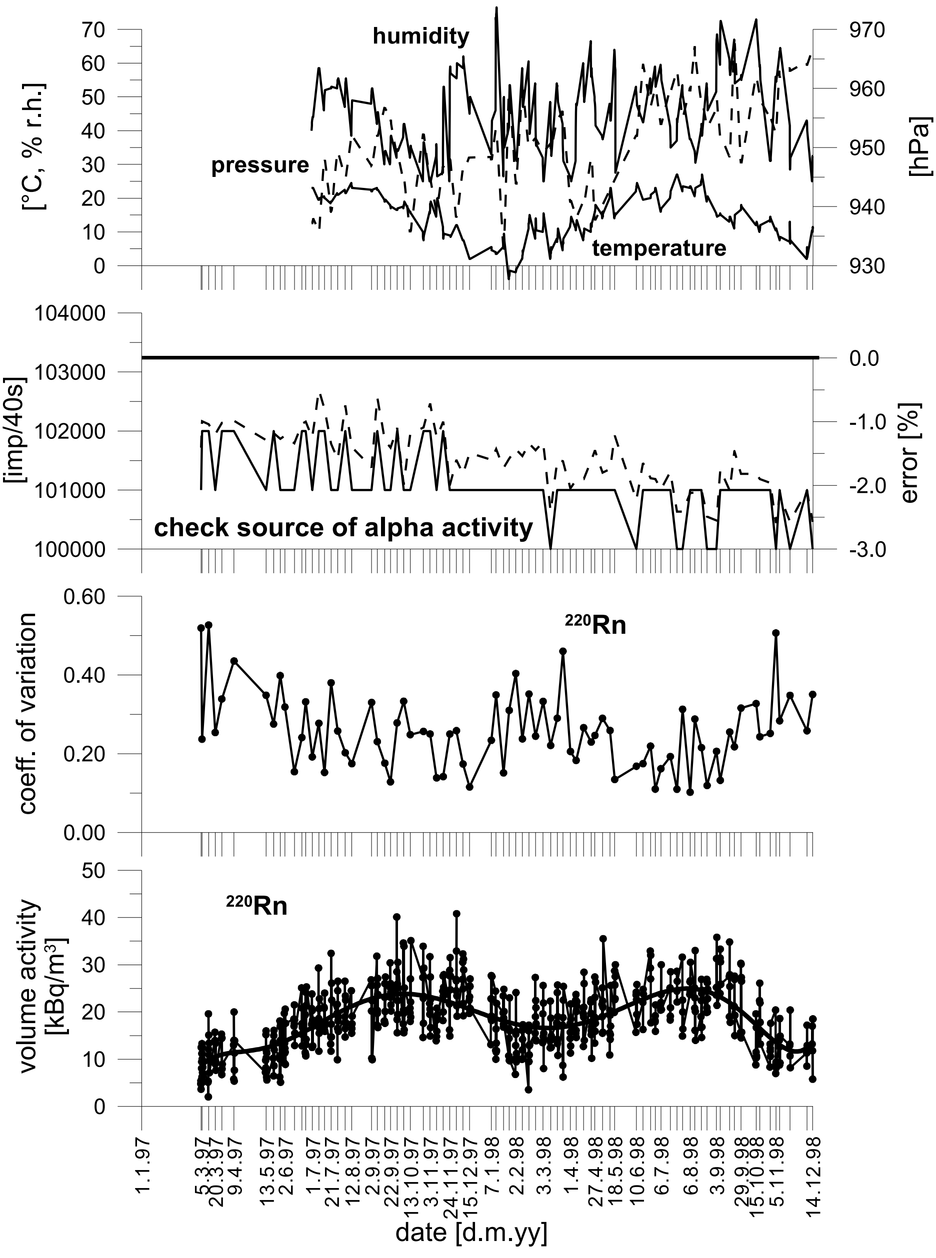

Fig. 2. Time courses of single measured and calculated variables of ^{220}Rn (thoron).

summer period (the highest values of the ^{222}Rn activity concentration) but their total absence in the 1998 year and also very weak expression of wet autumn and winter seasons in both the years (except of small maximum of the ^{222}Rn activity concentration in September 1998).

The values of the coefficient of linear correlation between the ^{222}Rn and ^{220}Rn activity concentration and temperature, humidity and pressure of atmospheric air are listed in Table 1 for the study area. These values are computed from all 478 measurements during the whole year cycle 1.7.1997 – 14.12.1998. 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 the 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. humidity (up to +0.95)
- negative dependencies: – ^{222}Rn vs. temperature (up to –0.95).

To the least statistically significant dependencies belong the relations with the coefficients of linear correlation oscillating around zero:

- ^{222}Rn vs. pressure (from –0.4 to +0.2),
- ^{220}Rn vs. humidity (from –0.35 to +0.15).

The time course of the coefficient of linear correlation for the most important relation between the ^{222}Rn activity concentration 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 1.7.1997 – 14.12.1998 to the length of 7.4.1998 – 14.12.1998 (Fig. 4).

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 activity concentration values in soil air. To the most important time breaks belong these short time intervals:
5.8.1997 – 22.9.1997,
8.12.1997 – 2.2.1998,
3.9.1998 – 9.11.1998.

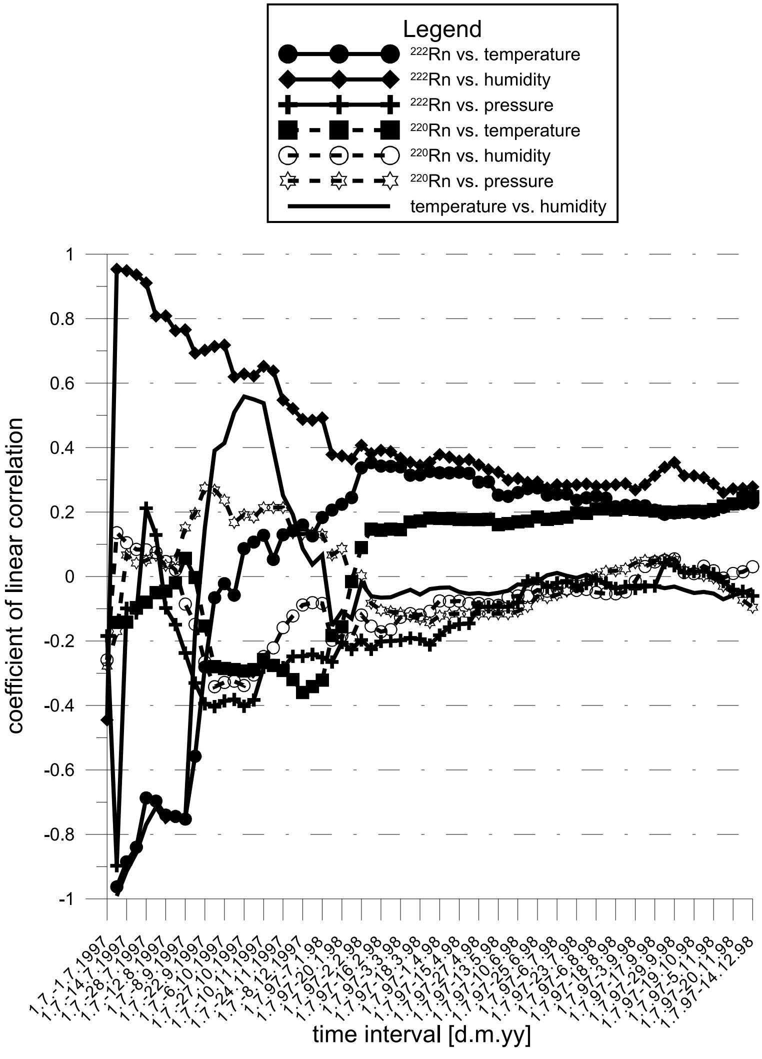

Fig. 3. Time courses of the coefficients of linear correlation between selected variables.

It seems to be logical that the first and third time landmarks correspond with the end of summer drier weather and the beginning of colder and wetter autumn weather, but the second time landmark is not very typical. The year cycle could be thus divided into several shorter periods:

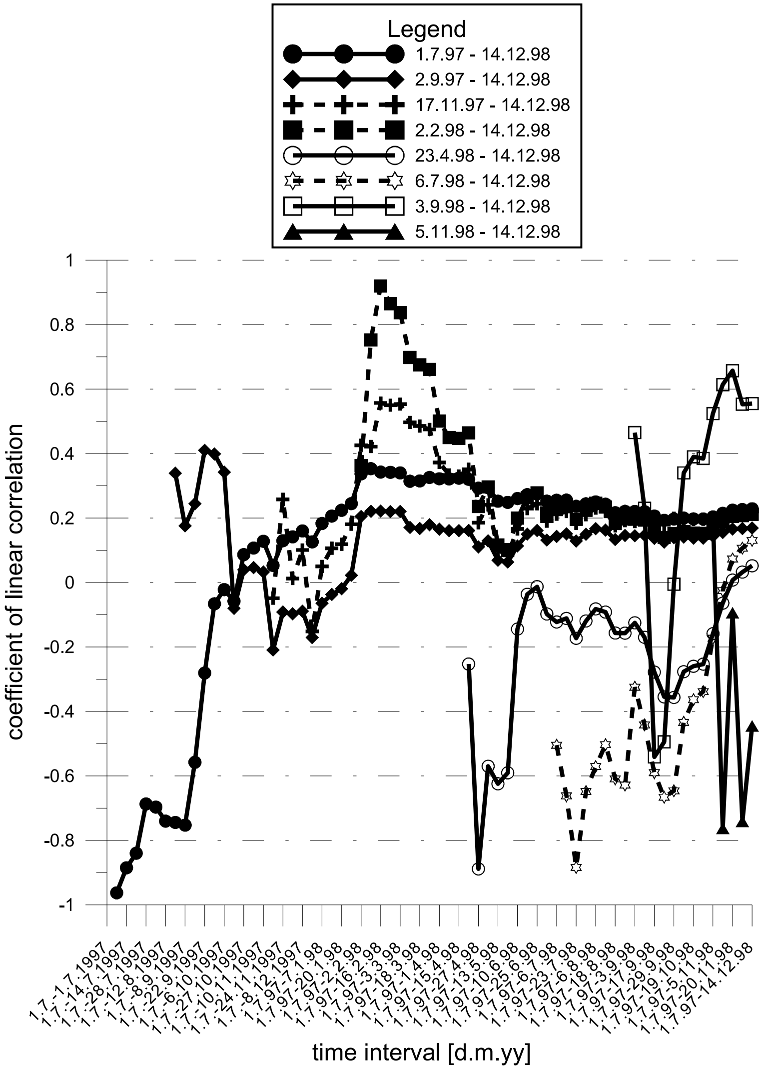

Fig. 4. Time courses of the coefficients of linear correlation between the ^{222}Rn activity concentration and air temperature in selected time intervals.

1.7.1997 – 2.9.1997,
2.9.1997 – 2.2.1998,
2.2.1998 – 3.9.1998,
3.9.1998 – 14.12.1998.

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

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.
1.7.97 – 2.9.1997	-0.74	0.81	-0.10	-0.05	0.05	0.03	56
2.9.97 – 2.2.1998	0.02	0.08	-0.13	0.17	-0.14	-0.11	148
2.2.98 – 3.9.1998	0.20	0.19	0.30	0.46	0.11	0.22	196
3.9.98– 14.12.1998	0.56	0.20	-0.43	0.52	0.42	-0.38	78
1.7.97– 14.12.1998	0.23	0.28	-0.06	0.25	0.03	-0.10	478

This is very well notable in the case of ^{222}Rn – on its relation with temperature and humidity – where its high positive correlation to humidity (0.81) and negative one to temperature (-0.74) during summer period (1.7.–2.9.1997) is connected with very expressive rainfall activity (floods of the March and Danube Rivers) mainly in the period 1.7.–5.8.1997. These huge precipitation were the reason of the tightening of nearsurface soil layer and next of ^{222}Rn accumulation in underlying pore spaces. As the following autumn 1997 and winter 1997/98 found expression in relatively dry weather the dependencies of ^{222}Rn on temperature (0.02) and humidity (0.08) are in the period 2.9.1997–2.2.1998 negligible. In the same way, the poor rainy period in summer 1998 also manifested itself inexpressively (Fig. 1, except of the narrow ^{222}Rn maximum on 17.6.1998) and therefore the dependencies of ^{222}Rn on temperature (0.20) and humidity (0.19) reached in the period 2.2.1998–3.9.1998 low values. Wetter early autumn 1998 (^{222}Rn and humidity maxima in September 1998) and the next dry autumn and winter months resulted in the period 3.9.–14.12.1998 in relatively very high correlation between ^{222}Rn and temperature (0.56) and low correlation between ^{222}Rn and humidity (0.20). Stable weather with gradual pressure increase resulted in relatively high anti-correlation between ^{222}Rn and pressure (-0.43).

In case of ^{220}Rn its strongest correlation to the atmospheric air temperature is expressive mainly during the 1998 year (0.46 in the period 2.2.–3.9.1998 and 0.52 in the period 3.9.–14.12.1998). This correlation is clearly seen in Fig. 2 via noticeable visual correspondence of curves of the ^{220}Rn activity concentration 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 activity concentration curve behind the temperature curve (this is more expressive in 1997 as in 1998) 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 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 the whole year cycle from 1.7.1997 to 14.12.1998. 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 (1.7.–2.9.1997, 2.9.1997–2.2.1998, 2.2.–3.9.1998 and 3.9.–14.12.1998) is apparently valid only for the study year cycle 1997/1998. Therefore it could be interesting to evaluate the measurements of other year cycles and mutually compare time landmarks of the obtained time periods.

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