Paper from: *Development and Application of Computer Techniques to Environmental Studies*, CA Brebbia and P Zannetti (Editors).
ISBN 1-85312-909-7

Radon concentration in the atmosphere as an indicator of the height of the mixing layer in the region of mining activity

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Abstract

The main objective of this work was examination whether measurement of polonium ^{218}Po concentration in the atmosphere could be useful to evaluate the height of the mixing layer as an alternative method in relation to the theoretical or remote sensing methods. Data analysis based on study of variation of chosen meteorological parameters and its comparison with changes of the radon emanation power. The Fourier-, Wavelet- and Regression analysis were used for this aim. Finally one has been ascertained that meteorological conditions indirectly influenced the radon emanation power however its consequences had an essential meaning. On the other hand the relationship between the daily variation of the mixing height and polonium ^{218}Po concentration in the atmosphere at the ground level was determined. As a result one has been stated that the polonium concentration could be an indicator of the mixing layer.

1 Introduction

A feedback occurs between air pollution and meteorological conditions. The meteorological conditions at the ground level are characterised by dynamic instability of the atmosphere and the so-called height of the mixing layer is an effectiveness measure of the transport of pollution by the turbulent mixing of air.

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One possibility to monitor the mixing layer is measurement of the concentration of the short-lived radon daughters in air. Radon is a gaseous daughter of radium ^{226}Ra that is a member of the uranium series. Production of radon proceeds in soil with the stable rate depended on the half-life of radium. Therefore radon concentration in soil gas is related to radium concentration but also depends on geological structure. Radon concentration in soil affects the concentration of these isotopes in atmospheric air. Short-lived isotopes of polonium, lead and bismuth (^{218}Po, ^{214}Pb, ^{214}Bi, ^{214}Po) originate as a result of the radon decay in atmospheric air [1]. Migration of radon between the lithosphere and atmosphere results from the molecular diffusion that is caused by concentration gradient and on the other hand from convection motion of radon caused by pressure gradient [2, 3, 4]. Radon is a noble passive and water-soluble gas. Its short-lived daughters however generate so-called clusters together with gaseous atoms or radioactive aerosols after its catching by air pollution.

In order to establish the quantitative and qualitative relationship between the height of the mixing layer and concentration of radon and its short-lived daughters, the influence of meteorological conditions, which characterise the physical state of the atmosphere, on the radon emanation power and daily changes of the radon concentration at the ground boundary level has to be defined. In the region of mining activity strong time variations of the radon emanation power can occur. This changeability can make it difficult to use the above-mentioned method for parameterisation of the height of the mixing layer. In this work we have examined thesis about possibility of use this method in such region.

2 Methodology

The measurement method and method of data analysis is presented below.

2.1 Radon emanation power

The measurements of the radon concentration in soil gas were performed on the depth of 1m with use of the Barasol probe. The probe is adjusted to long-term measurements under hard environmental conditions. This device is equipped with a silicon detector of the PIPS type. A measuring position was located in the South part of Katowice town in the Upper Silesia district. The measurements were performed in 1999-2000 and the results were averaged over period of 15minutes. The meteorological data were collected by local meteorological station located in the distance of about 1km to the North of the measuring position. Analyse of the time variation of meteorological conditions was performed on the base of following parameters: atmospheric pressure, air temperature, wind velocity, relative humidity, precipitation.

2.2 Concentration of polonium ^{218}Po

Measurements of the polonium concentration in air were performed with help of alpha spectroscopy. Air stream was drawn through a nucleopore filter with pores

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of 0.8μm and effective diameter of 20mm. Its activity was measured continuously during sampling by a semiconductor silicon detector of the ULTRACAM type with effective area of 1700mm^2. That detector was placed above the filter at a distance of 4.4mm. Air was pumped 1 hour long with a flow rate of 60 litres/min so the evaluated polonium concentration was averaged over this time period. For such conditions the lower limit of detection was around 0.15Bq/m^3 at the confidence level of 0.95.

2.3 Evaluation of the height of the mixing layer

A monostatic sodar of SAMOS was used to collect data related to the depth of the mixing layer. This device was located on an airfield near to a local meteorological station. Frequency of the emitted audible signal was equal 1.6 kHz. Data related to the physical parameters of the boundary layer were collected in real time every 6 seconds. However these results were averaged over a period of 1 hour to harmonise it with measurements of the polonium concentration in air.

2.4 Methods of data analysis

The diurnal and annual variations of the radon emanation power were compared with the meteorological data. The Fourier analysis was used to separate the main components of the season variations of the examined parameters and the wavelet method to find the short-term components. The regression method made it possible to find the relationship between the radon emanation power and meteorological conditions. On the base of the same method time variation of the polonium concentrations was compared with data related to the height of the mixing layer obtained with help of the monostatic sodar.

3 Results

3.1 Radon in soil gas

As above mentioned the radon emanation power in soil can be a measure of radon concentration in atmospheric air. In this connexion we examined whether the radon emanation power in soil was a time function and what physical factors influenced this quantity. The assumption was accepted that the radon emanation power depends on the following parameters:

- geodynamic events caused by mining activity,
- variation of meteorological conditions at the ground level,
- changes of measurement conditions (e.g. caused by exchange of measuring device).

First of all the discontinuities related to geophysical effects were eliminated. They disturbed measurements of radon concentration in soil gas [5]:

- influence of stress field in the crust of the earth on migration of radon,
- occurrence of elevated fissuring related to faults.

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On the figure 1 the annual variation of radon concentration in soil gas is presented. These measurements were done in 2000. Furthermore the influence of meteorological conditions on this quantity was examined. For this aim the wavelet method using Morlet's wavelet [6] and regression analysis were used. As a result we obtained the following conclusions:

- analysis of the wavelet transform amplitude doesn't warrant separation of time function with a period of one day in relation to diurnal variations of meteorological conditions. Therefore these short period meteorological changes didn't affect the radon emanation power and its course line is nearing the "white noise" (fig. 2),
- the long term variations of meteorological conditions indirectly influence the radon emanation power. Among the examined meteorological parameters the following consecutive quantities averaged over a period of 21 days have the utmost meaning: temperature (t_{21}), wind velocity (v_{21}), total precipitation (P_{21}) (fig.3, 4, 5). The obtained correlation coefficients 0.49 are statistically essential at significance level of 0.05. As a result of the regression analysis a meteorological indicator related to the radon emanation power was calculated IM_{Rn}:

$$IM_{Rn} = -730 - 16.6 \cdot P_{21} + 182 \cdot t_{21} + 1061 \cdot v_{21}$$

This indicator approximately characterises the state of the ground during radon emanation.

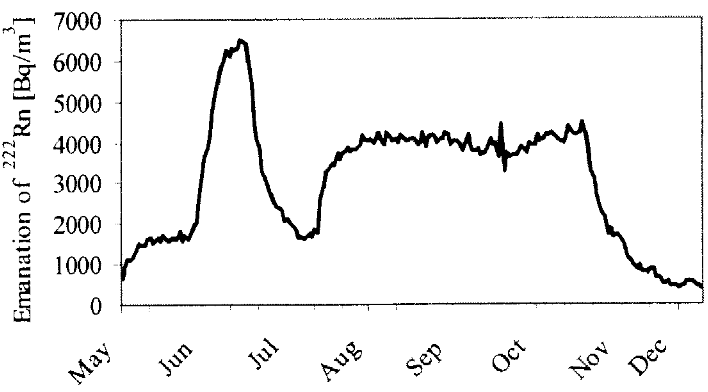

Figure 1: Concentration of radon ^{222}Rn in soil gas in 2000 year.

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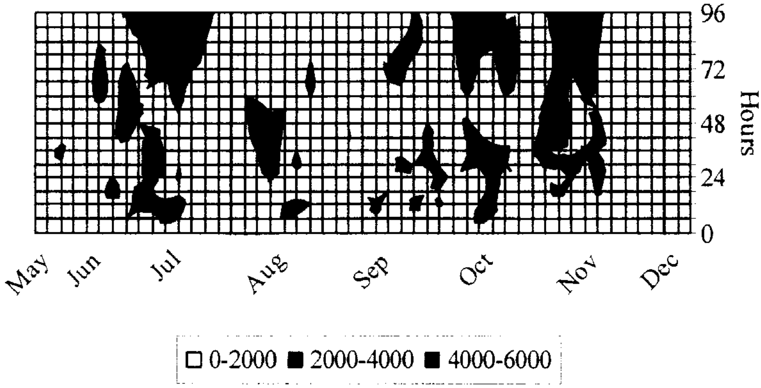

Figure 2: Amplitude of Morleta vavelet emanation of radon ^{222}Rn in years 1999 - 2000.

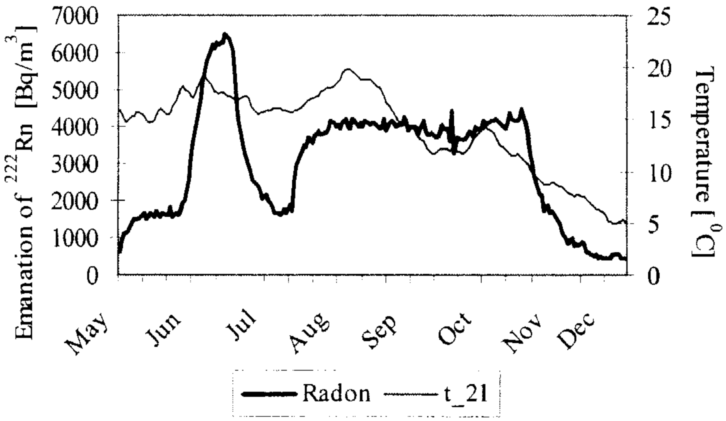

Figure 3: Dependence of 21 daily mean consecutive temperature air and emanation of radon ^{222}Rn in years 1999-2000.

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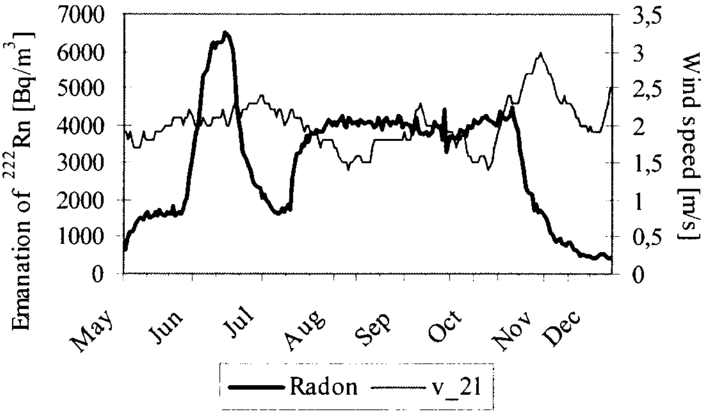

Figure 4: Dependence of 21 daily mean consecutive wind speed and emanation of radon ^{222}Rn in years 1999-2000.

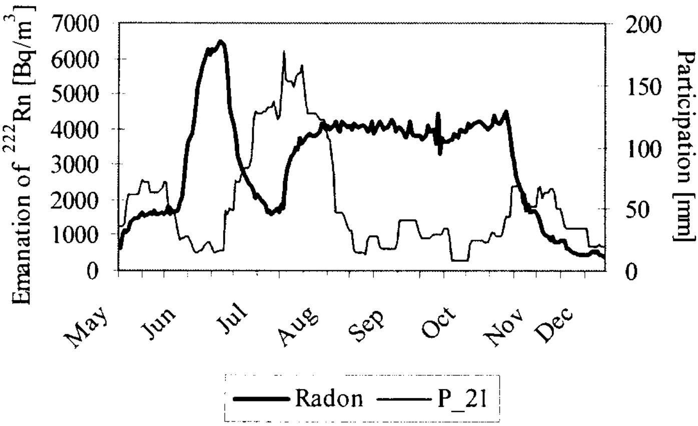

Figure 5: Dependence of 21 daily mean consecutive participation and emanation of radon ^{222}Rn in years 1999-2000.

3.2 Mixing layer and polonium concentration near the ground

In 2000-2001 anywhere from ten to twenty one-day measurements of polonium concentration were performed at the ground level. These measurement companies took place in the region of mining activity. At this stage the experiments were done when the depth of the mixing layer was well-defined (hot season, radiational and sunny weather). The meteorological state during these measurements was compared by evaluation of the meteorological indicator IM_{Rn}. Only these situations were analysed when the quantity was in the range (3200-3600). Under such assumptions the following conclusions can be drawn (fig. 6):

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- in the region of mining activity like other "normal" areas a typical diurnal variations of the polonium activity in the atmospheric air can be observed with a maximum during the small hours and a minimum near the noon,
- a statistically essential relationship at significance level of 0.05 occurs between the polonium concentration in the air (C_{Po}) and the depth of the mixing layer (h_{mix}). This relationship is as follow:

$$C_{Po} = 75.6 \cdot h_{mix}^{-0.65}$$

- correlation coefficient is better in case when the depth of the mixing layer is averaged over a period longer than 1 hour. This observation can manifest occurring of inertia of the polonium concentration changes in relation to changes of the mixing height.

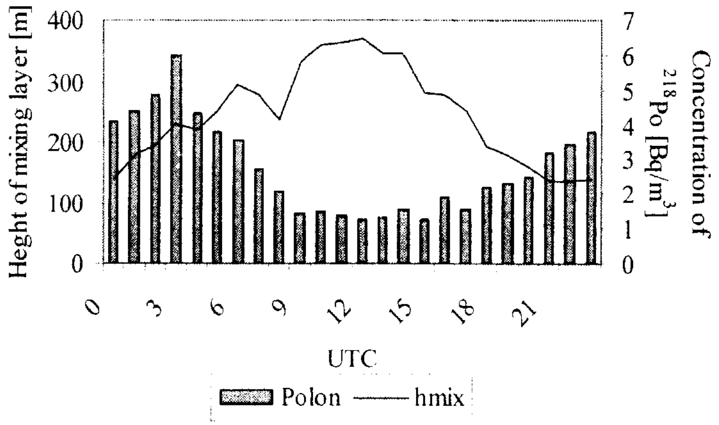

Figure 6: Dependence of the concentration of polon ^{218}Po and height of the mixing layer in mining area.

4 Discussion and conclusions

The diurnal and annual variations of the radon and radon daughters concentration in the region of mining activity are the same as reported elsewhere on "normal" areas [2]. There was no direct relationship between the radon emanation power and current meteorological conditions. A possible relationship is a secondary effect and relies on a long-term complex influence related to these meteorological conditions. Such indicators of the meteorological conditions influence the physical state of the ground (soil moisture, porosity). When soil is wet, the diffusivity and permeability are greatly reduced and migration of radon is difficult. On the other hand, high temperature and enhanced wind velocity facilitate the soil aeration making easier transport of radon into the atmosphere [5]. However the delayed reaction of the polonium concentration in relation to the evaluated depth of the mixing layer calls for explanations.

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Basing on the performed measurements one can be stated that data concerning the radon and polonium concentration in the air can be used also for investigation of the atmosphere dynamics in the region of mining activity. However the radon emanation power in relation to the physical state of soil has to be taken into account to develop such model.

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Acknowledgement

This research company was performed within the Grant No. 3 T09C 039 19 sponsored by the Polish National Committee of Scientific Research.