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Variability of radon distribution in the atmospheric surface layer over the land of middle latitudes

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Abstract. The variability of radon distribution in the surface atmosphere is investigated by numerical modeling of radon turbulent transport, based on the data of continuous field natural observations. The boundary conditions, including the radon flux from the surface and radon volumetric activity variation near the surface, were set according to the observations. Variations of turbulent diffusion coefficient altitude profiles were calculated by the observations of wind velocity pulsations at two altitudes made synchronously on the same location. The altitude profiles of radon volumetric activity typical for the atmospheric surface layer over the land of middle latitudes are obtained. It is shown that the radon volumetric activities at any altitudes vary concurrently, but the near-surface radon volumetric activity are greater than one at 10 m. The relative difference between them varies from 10 % (near local midnight) to 120 % (near local midday). The most considerable increase of the radon volumetric activity gradient occurs below 2 m.

1. Introduction

Radon (Rn^{222}) is a long-lived noble radioactive gas escaped from minerals into pore space of rocks and soil and then transported to the atmosphere by diffusion and advection [1–2]. The main source of atmospheric radon is land surface. Variations of the soil radon volumetric activity are considered to be earthquake precursors [3]. Studies of atmospheric radon are also important because of its radiation hazard to health of the population [4]. The inertness and long lifetime of radon make it to be a good tracer to study many atmospheric processes [5]. At last, atmospheric radon is one of the major natural ionizing agents in the lower atmosphere over the land [6–8].

It has been found experimentally and theoretically that the quasi-homogeneous distribution of radon is typical in the atmospheric boundary layer, but it does not take place in the surface layer. The variability of radon distribution in the surface atmosphere is caused, first of all, by its turbulent transport [8–9]. This paper presents the results of numerical modeling of radon turbulent transport in the surface atmosphere, based on the data of continuous observations at the experimental site of the Borok Geophysical Observatory of Schmidt Institute of Physics of the Earth of the Russian Academy of Sciences (BGO IPE RAS).

2. Measurement equipment and data

Continuous monitoring of radon volumetric activity as well as a turbulent regime of the atmospheric boundary layer was conducted at the experimental site of the BGO IPE RAS during the summer and fall seasons of 2014.



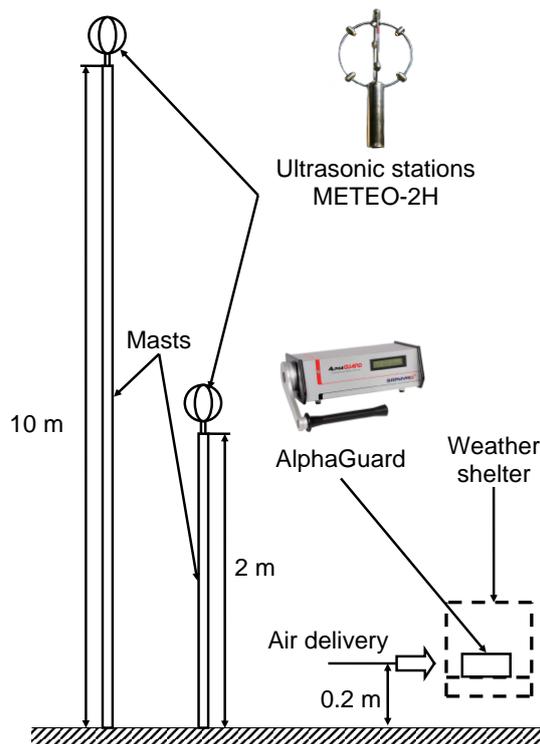


Figure 1. A configuration of the measuring instruments, installed on the experimental site of the BGO IPE RAS during the summer and fall seasons of 2014.

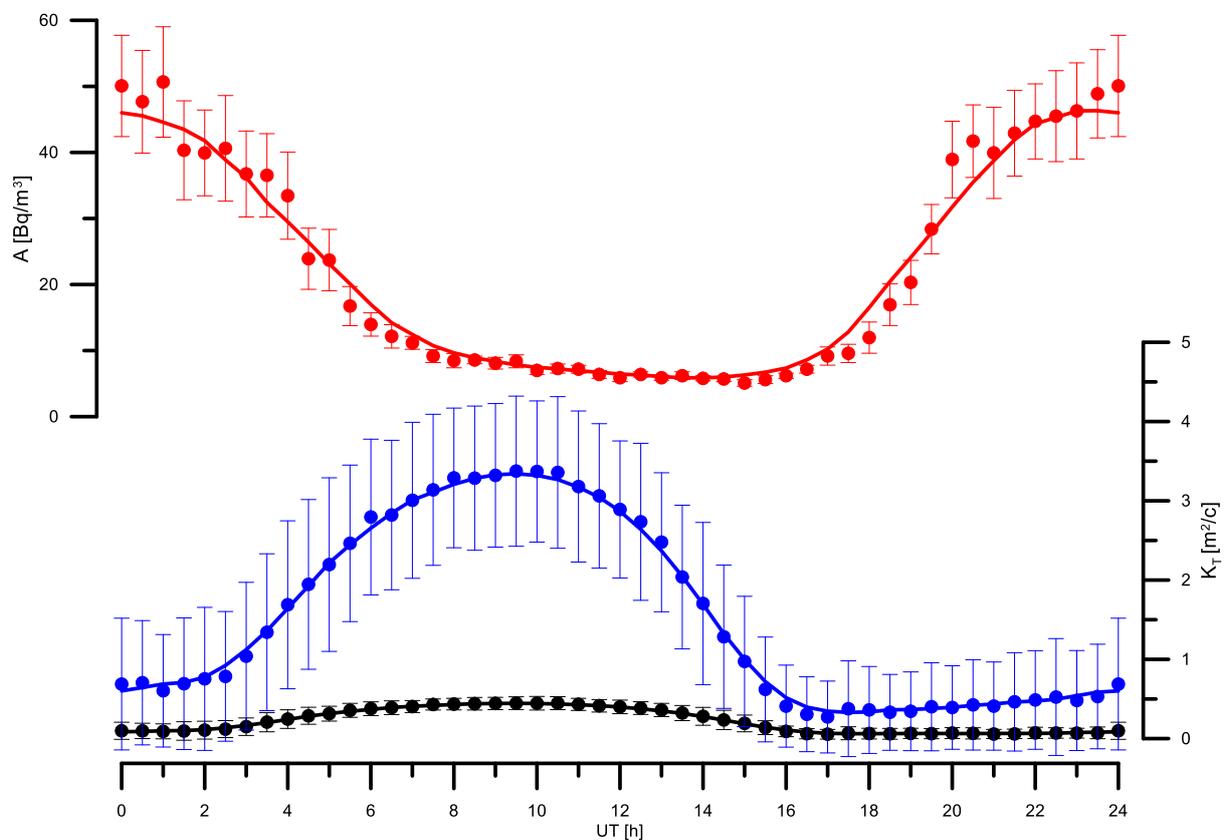


Figure 2. The mean diurnal variations of surface radon volumetric activity $A(t)$ (red) and turbulent diffusion coefficient $K_T(t)$ on 2 m (black) and 10 m (blue) altitudes, calculated by BGO IPE RAS observations in summer and fall seasons of 2014 under fair-weather conditions.

The AlphaGUARD PQ2000 radon monitoring system installed near the surface in the weather shelter was used as a sensor of the radon volumetric activity. The sensor has a sensitivity of at most 1 CPM (counts per minute) at 20 Bq/m^3 , the measurement range is $2 - 2 \times 10^6 \text{ Bq/m}^3$ and periodicity is one measurement per ten minutes.

Two ultrasonic stations METEO-2H [10] installed at heights of 2 and 10 m recorded the main meteorological parameters (air temperature, horizontal components of wind speed and wind direction, vertical wind speed, relative air humidity, and air pressure) with a 10 Hz sampling frequency. The software of these stations also enables evaluation of the vertical velocity variance, total energy of turbulent pulsations, friction velocity and the Monin-Obukhov length scale. It makes also possible to estimate the turbulent diffusion coefficient at the corresponding heights. A configuration of the measuring instruments is presented in figure 1.

The obtained data in the so-called fair weather days were chosen to be analysed. Fair weather implies the following conditions: (1) thunderstorms, precipitation, fog, mist and haze are absent; (2) wind speed does not exceed 6 m/s; (3) no low clouds are present, and the total cloudiness does not exceed three. There were 24 fair-weather days in summer and fall seasons of 2014, namely, June 4, 12, 16; July 1, 7, 8, 11–13, 31; August 3–7, 9, 11; September 9–11, 18, 20–22. The mean diurnal variations of the surface radon volumetric activity and the turbulent diffusion coefficient on both altitudes, calculated by BGO IPE RAS observations in summer and fall seasons of 2014 under fair-weather conditions, are presented in figure 2.

3. Atmosphere radon transport modeling

Radon transport in the atmosphere, taking into account its turbulent diffusion and radioactive decay, is described by the equation

$$\frac{\partial A}{\partial t} + \frac{\partial}{\partial z} \left(K_T(z, t) \frac{\partial A}{\partial z} \right) - \frac{1}{\tau} A = 0, \quad z \geq z_0, \quad (1)$$

where A is the radon volumetric activity in the atmosphere; $K_T(z, t)$ is the turbulent diffusion coefficient dependent on altitude z and time t ; τ is the radon lifetime ($4.74 \times 10^5 \text{ s}$), z_0 is the surface roughness parameter.

A mean diurnal variation of surface radon volumetric activity $A_0(t)$ and a mean surface radon flux density J_0 can be given as a boundary condition

$$A|_{z=z_0} = A_0(t). \quad (2)$$

The influence of radon turbulent transport on radon flux from the surface is negligible [11], so a mean surface radon flux density J_0 can be given as another boundary condition

$$\left(K_T(z_0, t) \frac{\partial A}{\partial z} \right) \Big|_{z=z_0} = J_0. \quad (3)$$

The dependence of the turbulent diffusion coefficient on altitude is assumed to be approximated by the power law [12]:

$$K_T(z, t) = K_0(t) \left(\frac{z}{z_0} \right)^{m(t)}. \quad (4)$$

where a factor $K_0(t)$ and an exponent $m(t)$ can be determined from observations.

The mean diurnal variations of $K_0(t)$ and $m(t)$, calculated from BGO IPE RAS observations in summer and fall seasons of 2014 under fair-weather conditions, are presented in a top panel of figure 3. The reconstructed turbulent diffusion coefficient altitude profile $K_T(z, t)$ is presented in a bottom panel of figure 3. The mean surface radon flux density J_0 at the experimental site of BGO IPE RAS location

is about 40 mBq/m^3 . The surface roughness parameter z_0 is 0.2 m according to tallgrass. Thus, all the parameters of the initial boundary value problem (1–4) may be given from the data observed.

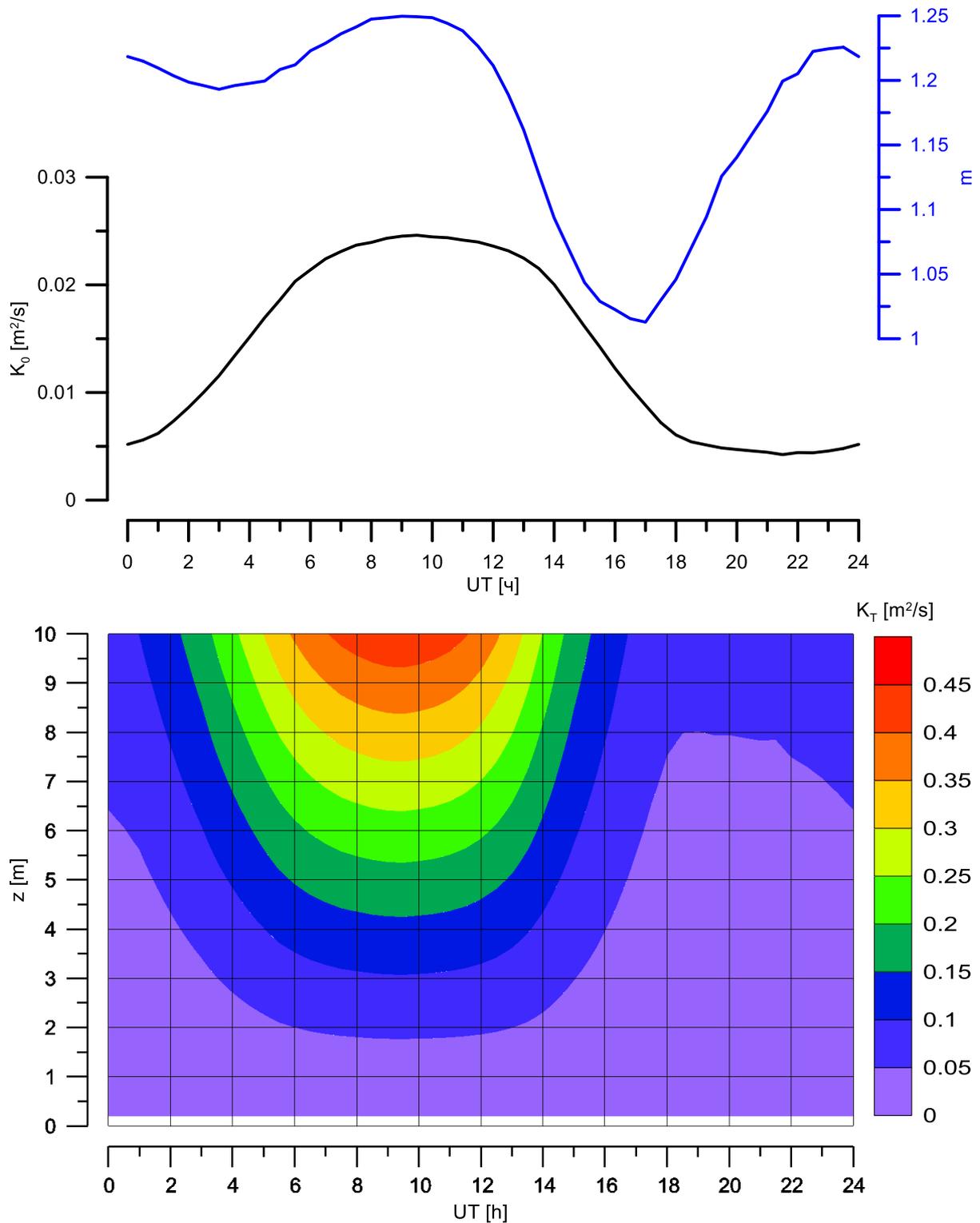


Figure 3. The mean diurnal variations of turbulent diffusion coefficient approximation parameters $K_0(t)$ and $m(t)$ (top panel) and turbulent diffusion coefficient altitude profile $K_T(z, t)$ (bottom panel), calculated from BGO IPE RAS observations in summer and fall seasons of 2014 under fair-weather conditions.

A solution of problem (1) – (4) must satisfy periodicity condition $A(0) = A(T)$, where $T = 24$ h. The solution can be found by means of numerical technique.

4. Results and discussion

The mean diurnal variation of radon volumetric activity altitude profile obtained through numerical solution of the problem (1) – (4) is presented in figure 4.

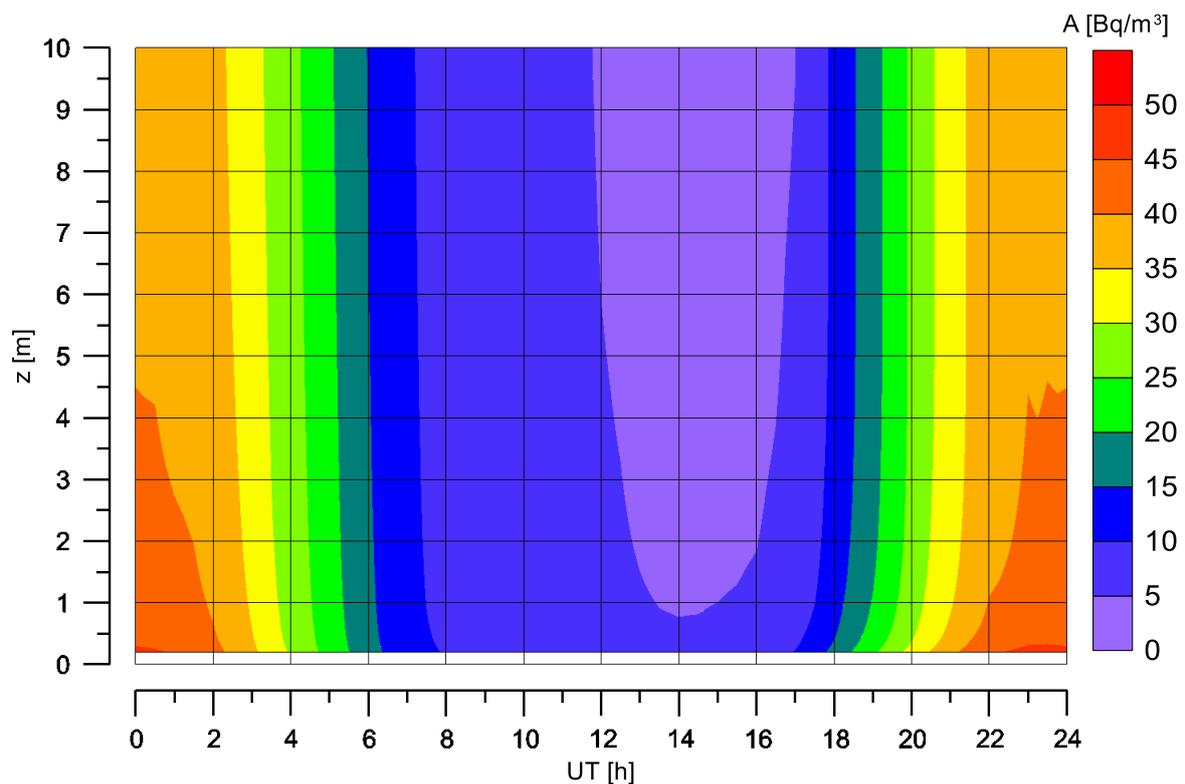


Figure 4. The mean diurnal variations of radon volumetric activity altitude profile calculated from BGO IPE RAS observations in summer and fall seasons of 2014 under fair-weather conditions.

It is easy to see that the radon volumetric activity at any altitude across the atmospheric surface layer varies with the near-surface radon volumetric activity. At the same time, the near-surface radon volumetric activity is always greater than one at 10 m. The relative difference between them varies from 10 % (near local midnight) to 120 % (near local midday). The most considerable increase of the radon volumetric activity gradient occurs below 2 m. It should be noted that most of atmospheric radon measurements are performed within 2-m-thick layer [13, 14]. So, these estimates need to be considered at the organization of atmospheric radon volumetric activity observations and interpretation of their results. The presented data agree with the results obtained by numerical modeling of radon activity altitude profiles in the atmospheric boundary layer [15] and by direct measurements using instrumented aircrafts [16]. But the proposed technique makes more exact and complete estimates of atmospheric radon distribution variability in the surface layer, based on the continuous surface observations.

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Acknowledgments

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