Estimation of global radon exhalation rate distribution

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Abstract. A radon exhalation rate distribution model was developed, which considers dependency on soil water saturation, soil temperature and soil texture. The global averages of the radon exhalation rates were calculated to be 17.5 and 18.0 $mBq.m^{-2}.s^{-1}$ by the model with different input soil moisture data. These values were slightly smaller than the widely-accepted value. Although the calculated radon exhalation rates were smaller than the measured ones in the East Asia, the estimated latitudinal distributions of the radon exhalation rate agreed fairly well with that reported by Conen et al. (2002).

Keywords: radon exhalation rate, radium content, soil water saturation, soil temperature
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INTRODUCTION

Radon-222 (radon) is a naturally occurring radioactive gas with half-life of 3.82 d generated by alpha decay of Ra-226 (radium) in soil grains. Since radon is chemically inert, it has been used as a tracer for validation of global chemical transport models. For the test of these transport models, the radon exhalation rate from land surface is assumed to be constant. However, it exhibits both spatial and temporal variation depending on radium content and conditions of soil. It has been therefore required to develop a model that can quantitatively estimate spatial and seasonal variation of radon exhalation rate in global scale.

RADON EXHALATION MODEL

A model of radon exhalation rate from ground surface was developed as follows (Zhuo, 2006). Assuming that soil is a homogenous porous medium, one dimensional diffusion equation for radon is expressed as

$$\frac{\partial}{\partial z}\left(D\frac{\partial C}{\partial z}\right)+R\varepsilon\rho\lambda-\lambda C=0\,, \tag{1}$$

where z is the vertical coordinate in soil having positive values (m), D is the effective radon diffusion coefficient ($m^2.s^{-1}$), C is the radon concentration in soil air ($Bq.m^{-3}$), λ is the radon decay constant (s^{-1}). The term in the left-hand side $R\varepsilon\rho\lambda$ is the radon production rate where R is the radium content in soil ($Bq.kg^{-1}$), ε is the radon emanation power having a value of 0 to 1 and ρ is the dry bulk density ($kg.m^{-3}$).

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Assuming a steady state and the boundary conditions as $C|_{z=0} = 0$ and $\partial C/\partial z|_{z=\infty} = 0$, the solution for Eq. 1 gives the depth profile of the radon concentration as

$$C(z) = R\varepsilon\rho\left[1 - \exp\left(-\sqrt{\lambda / D} \times z\right)\right]. \quad (2)$$

Substituting the concentration gradient at the ground surface (z = 0) to Fickian law, the radon exhalation from the ground surface F ($Bq.m^{-2}.s^{-1}$) can be expressed as

$$F = R\varepsilon\rho\sqrt{\lambda D}\ . \quad (3)$$

Here, we will model the effective radon diffusion coefficient. Combining an empirical formula reported by Rogers and Nielson (1991) and temperature dependency of gas diffusivity, we can model the effective radon diffusion coefficient as

$$D = D_0 p (T / 273)^{3/4} \exp\left\{-6Sp - 6S^{14p}\right\}, \quad (4)$$

where D_0=1.1×10^5 $m^2.s^{-1}$ is the radon diffusion coefficient in air, p is the porosity of the soil, T is the soil temperature and S is the water saturation.

Zhuo (2006) reported the radon emanation power as a function of soil water saturation and soil temperature as

$$\varepsilon = \varepsilon_0\left[1 + 1.73(1 - \exp(-19S))\right] \cdot \left[1 + 0.011(T - 298)\right], \quad (5)$$

where ε_0 is the emanation power of dry soil.

Finally, we can calculate the radon exhalation rate F by using Eq. 3-5.

CALCULATION CONDITIONS

The radon exhalation rate was calculated for two conditions with different dataset of soil water content. In the case 1, the soil water saturation was calculated from precipitation and atmospheric temperature. The meteorological dataset from Japan Meteorological Agency was used for the calculation in case 2.

The calculation was carried out monthly with a grid internal of 1° of latitude and longitude.

For the calculation of winter season, influence of snow and frozen of soil was considered as follows. Yamazawa et al. (2005) reported that the radon diffusion coefficient in frozen soil is lower than that in unfrozen one. Therefore, the effective diffusion coefficients were reduced by a factor of 0.5 if soil temperature was lower than 0 $^\circ$C. In addition, influence of snow cover layer was also considered in such a way that the radon exhalation rate was reduced depending on snow depth.

TABLE 1. Calculation conditions for two cases

	Case1	Case2
S	Calculated from precipitation and atmospheric temperature [a)]	JRA-25 dataset [b)]
p	0.5	JRA-25 dataset [b)]
T (K)	Surface air temperature	JRA-25 dataset [b)]
R (Bq kg^{-1})	A dataset of measurement data for China 30 for rest	
ρ (kg m^{-3})	1600	

a) Calculated with method by Zhou et al.(2006)

b) The datasets are provided from the cooperative research project of the JRA-25 long-term reanalysis by the Japan Meteorological Agency (JMA) and the Central Research Institute of Electric Power Industry (CRIEPI).

RESULTS AND DISCUSSION

The latitudinal distribution of annual average of radon exhalation rate is presented in Figure 1. The global, annual average of the radon exhalation rates was calculated to be 18.0 and 17.5 mBq.m^{-2}.s^{-1} for case 1 and 2, respectively. These values were slightly less than widely used values such as 20.8 mBq.m^{-2}.s^{-1}. Conen (2002) reported that radon exhalation rate decreases linearly with increasing latitude in the northern hemisphere, which corresponds to our calculation results. The main reason of this tendency is that higher latitude is characterized by higher water saturation and longer period of freezing and snow.

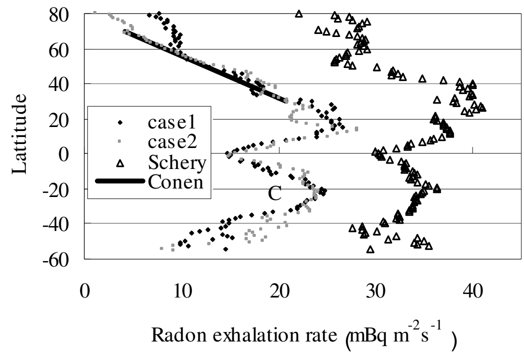

FIGURE 1. The latitudinal distribution of annual average of radon exhalation rate. Data reported by Schery (1998) and Conen (2002) were also adopted.

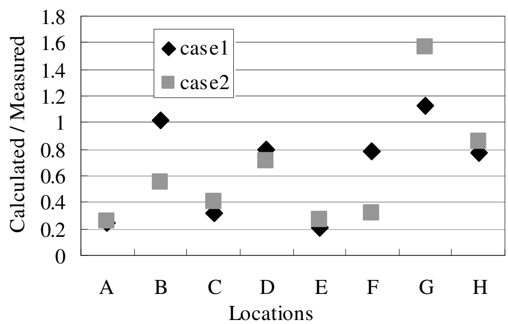

FIGURE 2. The comparison of calculated and measured radon exhalation rate in Japan and Korea by Zhuo (2006).

The comparison of calculated and measured radon exhalation rate in the East Asia regions is shown in Figure 2. The calculated exhalation rates in case 1 were generally smaller than the measured ones. This is probably due to the overestimation of soil water saturation for case 1. The calculated radon exhalation rates for case 2 were still smaller than the measured one. The use of water saturation data from Japan Meteorological Agency did not substantially improve the underestimation by the model because of the overestimation of soil water content.

CONCLUSION

A radon exhalation was developed. The global average of the radon exhalation rates was calculated to be 17.5 and 18.0 $mBq.m^{-2}.s^{-1}$. The latitudinal distribution decreasing linearly with increasing latitude in the northern hemisphere was in agreement with the known feature reported by Conen (2002). The estimated exhalation rate was smaller than measured data in the East Asia region probably due to overestimation of water saturation of soil. For the improvement of the model calculation, more realistic data of soil water content are necessary.

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