Development and verification of long-range atmospheric transport model of radon-222 and lead-210 including scavenging process

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Abstract. A three-dimensional Eulerian atmospheric long-range transport model of radon-222 (^{222}Rn) and lead-210 (^{210}Pb) coupled with meteorological model MM5 was developed. The model calculates advection, diffusion, radiation decay and deposition processes in a horizontal scale of several thousand kilometers. This model was applied to East Asia. Performance of the model was evaluated with measured hourly surface air ^{222}Rn concentration and monthly ^{210}Pb deposition. The model verification was done with respect to the following points: 1) the sensitivity of vertical distribution of turbulent diffusivity and 2) the accuracy of spatial distribution of precipitation. In this report, improvement of the model performance is also discussed.

Keywords: radon-222 concentration, lead-210 deposition, atmospheric transport model, long-range transport, wet deposition, MM5, East Asia.
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INTRODUCTION AND MEASUREMENT

Radon-222 is a naturally occurring radioisotope, a chemically inert gas, and has a suitable half-life (3.82 days) to be used as a tracer for regional transport in the atmosphere. Lead-210 is one of decay products of ^{222}Rn and has relatively long half-life (22.3 years) to be used as a tracer for dry and wet deposition of aerosol particles. Recently high-level gamma dose rates are observed around nuclear power plants when precipitation is recorded. The decay products of long-range transported ^{222}Rn are considered to be one of their causes. Therefore, range of gamma dose rate variations caused by decay products need to be investigated.

It has been widely recognized that the numerical models are very useful for better understanding of atmospheric transport. Many researchers have developed local and regional atmospheric transport models and used ^{222}Rn to validate the models [1].

The objective of this study is 1) to develop a long-range atmospheric ^{222}Rn and ^{210}Pb transport and 2) to evaluate and improve the model performance. For model verification, ^{222}Rn concentration data from our measurement deployed in East Asia were used. Hourly atmospheric ^{222}Rn concentrations were measured using a continuous electrostatic radon monitor (ERM) [2]. In this report, ^{222}Rn concentrations at Hachijo and Nagoya during February 2004 were analyzed to evaluate the model. Hachijo is 200 km to the south of main island of Japan. Because of small island, it can be assumed that there is negligible effect of locally exhaled ^{222}Rn. Nagoya is located on the Pacific Ocean side of the main island of Japan. This measurement point at Nagoya is chosen to

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check the model under conditions where the contribution of local source of ^{222}Rn is substantial.

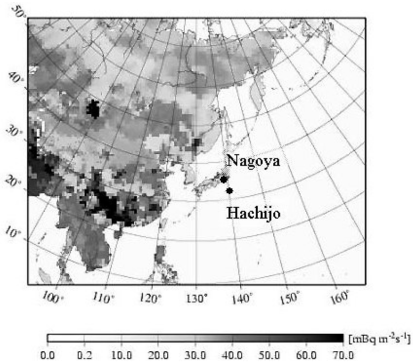


FIGURE 1. Horizontal distribution of ^{222}Rn exhalation rate calculated by Schery's model [3] in the calculation domain.

MODEL

The three-dimensional (3-D) long-range atmospheric transport model consists of two models, an atmospheric dynamic model, Mesoscale Model version 5 (MM5) [4], and an originally developed advection-diffusion model (HIRAT). The model calculates the movement of ^{222}Rn and ^{210}Pb in the atmosphere due to advection, diffusion, radiation decay and dry/wet deposition processes. HIRAT uses a low numerical diffusion scheme for advection terms [5] and an implicit method for diffusion terms. Input data sets for HIRAT are 3-D distributions of wind and turbulent diffusivity and surface precipitation from MM5. In the present application, the MRF (Medium Range Forecast) scheme for planetary boundary layer (PBL) was used to calculate vertical turbulent diffusivity. MRF scheme is a 1st order closure model that solves a diagnostic equation based on K-theory.

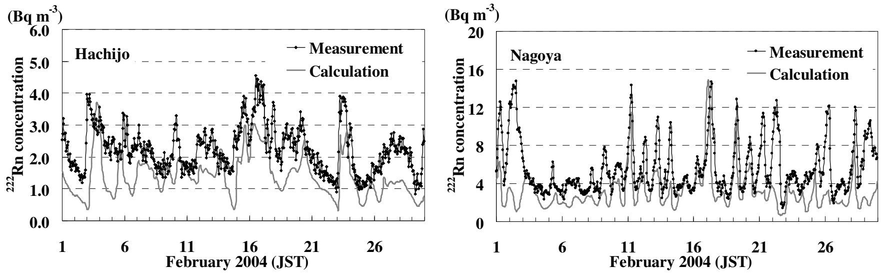
The ^{222}Rn source distribution calculated by Schery and Wasiolek [3] was used (**Figure 1**). Lead-210 is modeled to be directly produced by decay of ^{222}Rn in the atmosphere. Dry and wet depositions are formulated according to conventional models [6]. Wet deposition is a function of precipitation intensity.

The calculation domain was 9792 km (W-E) by 7776 km (N-S) as shown in **Figure 1** and the gird size was 72 km. The vertical domain was 10 km, and divided into 20 layers. The smallest spacing at bottom was 50 m. Meteorological input data used were analysis data from Japan Meteorological Agency (JMA), which was available at a time interval of 6 hours.

RESULTS AND DISCUSSIONS

Verification of ^{222}Rn calculation

The calculated ^{222}Rn concentration is compared with the hourly measured value at Hachijo and Nagoya (**Figure 2**). The calculation results show a good agreement with measurement. The model calculated onset times and durations of high concentration periods very well. Furthermore, calculated temporal variation of ^{222}Rn concentration reproduced the measured several-days cycle variation at Hachijo and diurnal variation at Nagoya. However, the model underestimated the concentration for the whole comparison period. The overestimation of vertical transport by turbulence diffusion was considered to be one of the causes of underestimation. Analysis of a meteorological data showed that the PBL height was overestimated by MM5. To solve this overestimation, MRF scheme was replaced by GS (Gayno Seaman) scheme, which is a 2nd order closure model that solves a prognostic equation for turbulence kinetic energy. As a result, PBL height calculated by the GS scheme was substantially shallower than that of original model and underestimation of ^{222}Rn concentration at surface was solved. The Bias, an index of model performance that indicates a tendency of over- or under-calculation, improved from –0.83 to –0.37 Bq m^{-3} for Hachijo and from –2.5 to –1.3 Bq m^{-3} For Nagoya.



(a) (b)

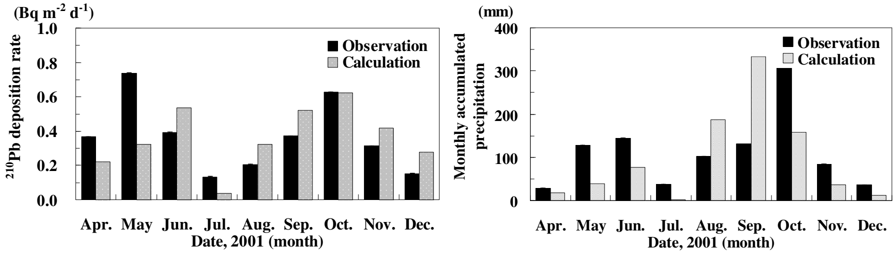
FIGURE 2. Comparison of temporal variation in surface ^{222}Rn concentration between measurement and calculation at Hachijo and Nagoya.

Verification of ^{210}Pb calculation

The calculated ^{210}Pb deposition is compared with the monthly measured data at Tokai-mura [7] in **Figure 3 (a)**. The result showed that seasonal trend of calculated ^{210}Pb deposition was in good agreement with measured data. However, substantial disagreements were found in some months. **Figure 3 (b)** shows monthly-accumulated precipitation results. The calculation is in poor agreement with observation.

To exclude the uncertainty in the calculated precipitation, Radar-AMeDAS (Automated Meteorological Data Acquisition System) analysis data from JMA were introduced to the model. The Radar-AMeDAS data are nation-wide hourly-accumulated grid data analyzed from dense observation data.

Introduction of Radar-AMeDAS largely contribute to improve the calculation accuracy of ^{210}Pb deposition. Lead-210 deposition calculation was largely improved in April, May and September. ^{210}Pb deposition calculation was calculated with errors less than 16%.



(a) (b)

FIGURE 3. Comparison of monthly accumulated in ^{210}Pb deposition and precipitation between observation and calculation.

CONCLUSIONS

A 3-D Eulerian long-range transport model of ^{222}Rn and ^{210}Pb coupled with meteorological model, MM5, was developed. The model was applied to East Asia and evaluated by the hourly surface air ^{222}Rn concentration at Hachijo and Nagoya, and monthly ^{210}Pb deposition at Tokai-mura. As a result of verification and improvement, it is concluded that 1) the model can calculate ^{222}Rn concentration at surface with high accuracy when vertical structure of turbulent diffusion in PBL is sufficiently calculated by MM5 and 2) the calculated ^{210}Pb deposition shows in good agreement with observation if precipitation used is accurate. The developed model realistically calculated atmospheric transport of ^{222}Rn and ^{210}Pb in a synoptic scale.

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