An aid to the study of the behavior of radon and air pollutants in the atmospheric boundary layer

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1 Introduction

It is suggested that observations of air pollutants can usefully supplement studies of the relation between the atmospheric activity concentration of ²²²Rn and the local nature of the atmospheric boundary layer [1]. In this paper, first, we discuss the relation between the atmospheric activity concentration of ²²²Rn and conditions of the atmospheric boundary layer at another site, where land and sea breezes are prevalent, namely Kabutonishi Town (34^o28'N, 133^o29'E), Kasaoka City, Okayama Prefecture in Japan. Next, we examine the relation between concentrations of NO, NO₂ and SO₂ and conditions of the atmospheric boundary layer at the site and within its vicinity.

2. Description of Study Site and Instrumentation

We selected another experimental site in Kabutonishi Town (34^o28'N, 133^o29'E), Kasaoka City, Okayama Prefecture in Japan (K-site) as a supplementary location and carried out intensive observation of the atmospheric boundary layer together with measurement of concentration of ²²²Rn at the location from 31 August to 15 September 1998 (see Figs. 1 and 2).

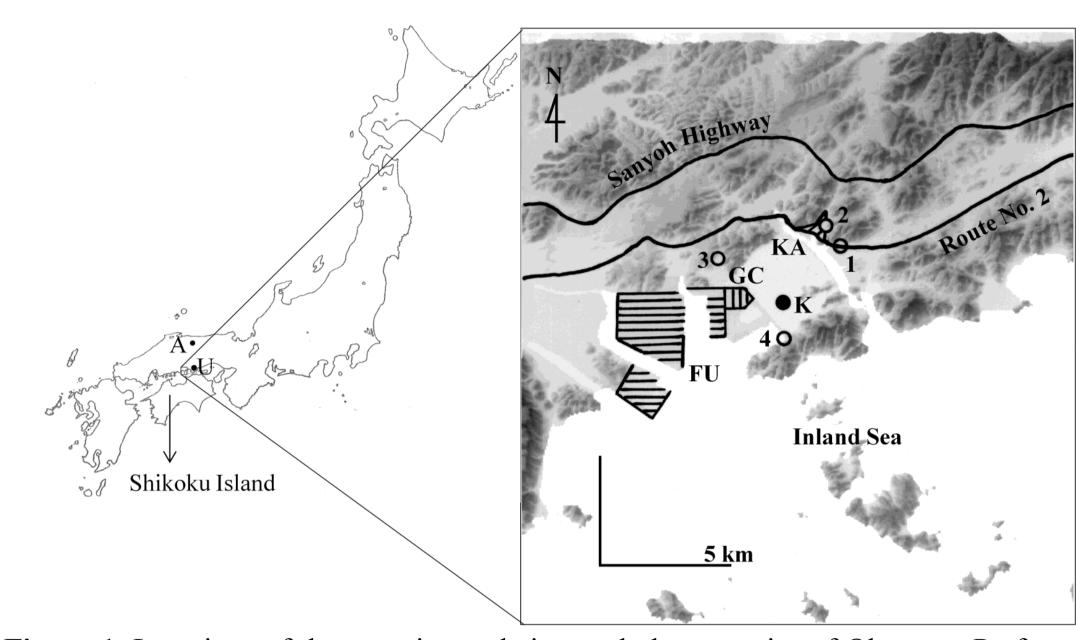


Figure 1. Locations of the experimental sites and observatories of Okayama Prefecture for monitoring air pollutants. ◆K: Experimental site in Kabutonishi Town (K-site), ◆A: Experimental site in Akawase (A-site), ◆U: Experimental site in Uchio (U-site), ○1: Observatories for monitoring air pollutants emitted from motor vehicles driving along route No. 2, ○2-4: Observatories 2-4 for monitoring air pollutants, ☑KA: Lightly populated region of Kasaoka City, ■FU: Fukuyama Industrial Complex, ■GC: Golf course

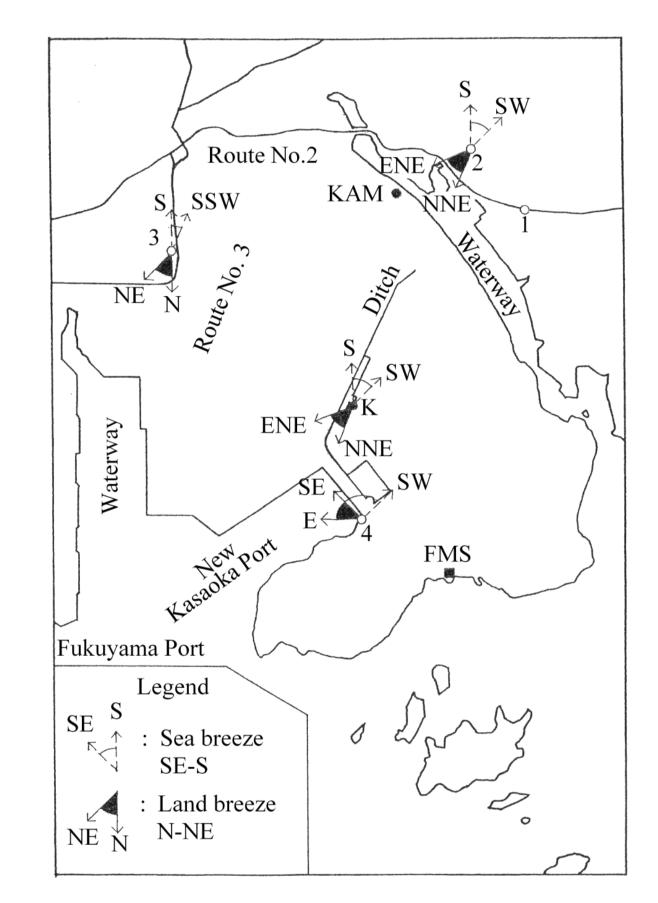


Figure 2. A sketch around the K-site showing observatories and predominant wind directions at the K-site during the period from 31 August to 15 September 1998. The wind directions shown are 10-minute averages. ●K: Experimental site in Kabutonishi Town (K-site), ○1: Observatories for monitoring air pollutants emitted from motor vehicles driving along route No. 2, ○2-4: Observatories 2-4 for monitoring air pollutants, ●KAM: Kasaoka station of Automated Meteorological Data Acquisition System, ■FMS: Factory manufacturing sulfuric acid. This sketch was made using JMC-Map of Japan Map Center.

The instruments used to obtain observations of ²²²Rn and of meteorology are given in a previous paper [2], except that an instrumented tethered balloon, low-level sondes and infrared thermal imagery were not used. The instruments used to obtain data on air pollutants (NO, NO₂ and SO₂), wind speed and direction at the observatories of Okayama Prefecture for monitoring around the K-site are the same as (or another version of) those used at the observatories around the U-site and are described in a previous paper [1]. Observations of ²²²Rn and air pollutants were obtained every hour.

3. Source of ²²²Rn for calculation of concentration of ²²²Rn

We start by making the following five points about our observations of exhalation rate of ²²²Rn and of the meteorological and site conditions:

1. The exhalation rates of ²²²Rn were measured at three points within the K-site during the intensive observation period. The average of the measured values is 0.0082 Bqm⁻²s⁻¹. These are within the

range of the exhalation rates of ²²²Rn measured elsewhere in Japan [3].

2. The amount of rainfall was 6 mm for the period of 0700–0900 JST on 6 September at the K-site during the intensive observation period. Soil moisture increased by rainfall reduces the exhalation rate

of ²²²Rn but the rate recovers within 1.5–2 days after the rainfall [4]. Therefore, when calculating the concentrations of ²²²Rn assuming that the exhalation rate of ²²²Rn is constant, we eliminate the period from 0700 JST on 6 September to 0900 JST on 8 September.

3. Atmospheric pressure varied between 1005.5 hPa and 1015.0 hPa at the K-site during the intensive

3. Atmospheric pressure varied between 1005.5 hPa and 1015.0 hPa at the K-site during the intensive observation period. We treat the exhalation rate of ²²²Rn as being independent of atmospheric pressure [5].

4. Other meteorological factors such as wind speed, temperature of the ground surface, and humidity

have only a minor effect on the exhalation rate of ²²²Rn [6].

5. The Inland Sea is shallow, and the exhalation rate of ²²²Rn from the surface of the Inland Sea is at least one order of magnitude lower than that from the ground surface near the shore of the Inland Sea [7]. The part of the Inland Sea where the K-site is located is 30–40 km (average about 35 km) in width with Shikoku Island to the south. It is considered that the Inland Sea affects the concentration of ²²²Rn at the K-site under such conditions, especially in the case of sea breeze. However, despite the fact that there is a substantial difference between exhalation rates, we assume here that the exhalation rate of ²²²Rn for the Inland Sea is the same as that for land in order that we might apply a

one-dimensional (1D) transport model.

Based upon the above five points, we treat the exhalation rate of ²²²Rn as a constant, the average value, for the periods when there is no effect of rainfall at the K-site during the intensive observation period.

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References

- [1] Kataoka, T., et al., A Study of the Atmospheric Boundary Layer Using Radon and Air Pollutants as Tracers, Boundary-Layer Meteorol. **101** (2001) 131-155.
- [2] Kataoka, T., et al., Diurnal Variation in Radon Concentration and Mixing-Layer Depth, Boundary-Layer Meteorol. **89** (1998) 225-250.
- [3] Hosoda, M., et al., In Situ Measurements of Radon and Thoron Exhalation Rates and Their Geological Interpretation, Jpn. J. Health Phys. **39** (2004) 206-214 (in Japanese).
- [4] Megumi, K., Mamuro, T., Radon and Thoron Exhalation from the Ground, J. Geophys. Res. 78, (1973) 1804-1808.
 [5] Kataoka T. et al. Concentrations of ²²²Rn. Its Short-Lived Daughters and ²¹²Ph and their Ratios under Complex
- [5] Kataoka, T., et al., Concentrations of ²²²Rn, Its Short-Lived Daughters and ²¹²Pb and their Ratios under Complex Atmospheric Concentrations and Topography, Boundary-Layer Meteorol. **107** (2003) 219-249.
- [6] Schery, S. D., et al., Factors Affecting Exhalation of Radon from a Gravelly Sandy Loam, J. Geophys. Res. 89(D5) (1984) 7299-7309.
- [7] Wilkening, M. H., Clements, W. E., Radon 222 from the Ocean Surface, *J. Geophys. Res.* 80 (1975) 3828.-3830
 [8] Beck, H. L., Gogolak C.V., Time-Dependent Calculations of the Vertical Distribution of ²²²Rn and its Decay Products in the Atmosphere, J. Geophys. Res. 84 (1979) 3139-3148.

4. Results and Discussions

It is noted, from Fig. 3a, that the measured concentrations of ²²²Rn lie from the midpoint of the concentrations calculated using the method of Beck and Gogolak [8] for the case of strong stability (IWN) and for the case of weak stability (WNN) to those for the case of weak stability (WNN) at night. These concentrations were lower than those at Akawase [2] and at Uchio [1]. At night, the concentrations of ²²²Rn at the K-site much more nearly approximated the concentrations calculated using the method of Beck and Gogolak [8] for the case of weak stability (WNN) than those at the U-site.

The measured concentrations of ²²²Rn were larger than the calculated ones in the daytime when the sea breeze was dominant after the morning calm (see Fig. 3a). This tendency is similar to that at the A-site which is located about 22 km south of the coast of the Sea of Japan and forms a basin at a ridge of the Chuhgoku mountains [2] and at the U-site which is located about 12 km north of the coast of the Inland Sea and is in the east of Okayama Plain [1].

We find from Figure 3a that the measured concentrations of 222 Rn started decreasing at 0800-1000 JST and reached a low level after about 1100 JST. Fig. 4 shows typical time variations of wind speed and standard deviation (σ_w) of vertical wind speed observed with the Doppler sodar at the K-site for the periods of 3–5 and 8–10 September 1998. The Doppler sodar may have detected the mixing layer developing more strongly at the location of the Doppler sodar. Therefore, it is believed that the relatively calm meteorological conditions during the transition period from land breeze to sea breeze are responsible for the observation that the concentration of 222 Rn decreased more slowly at the K-site than at the A-site (see Fig. 1) [2], despite development of the mixing layer after sunrise, as in the case of the U-site [1].

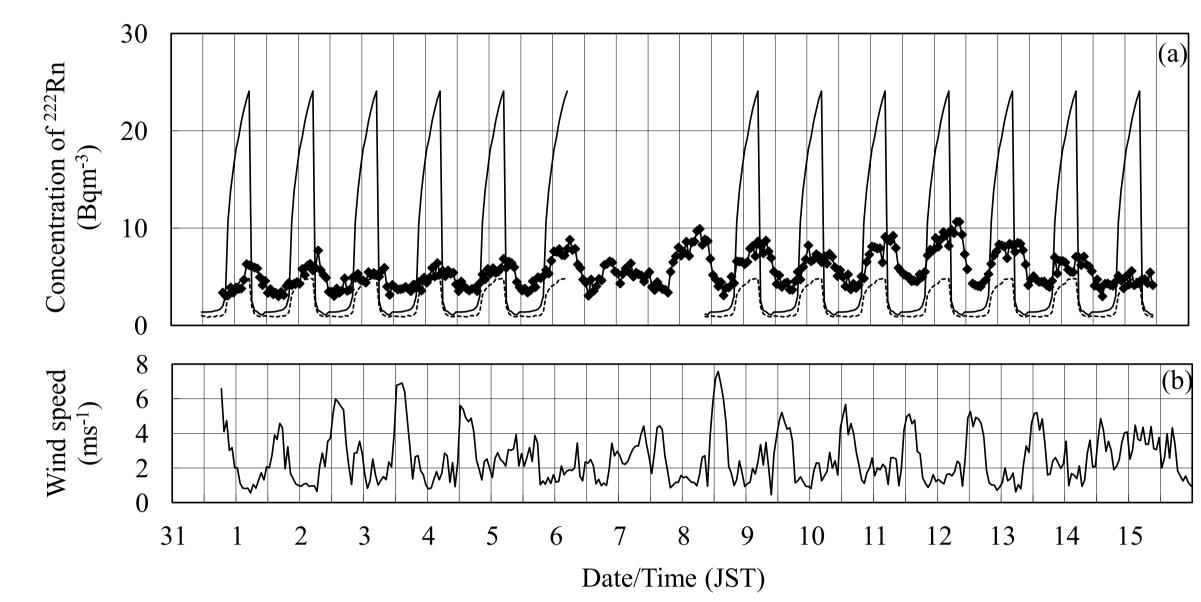


Figure 3. (a) Time variations of the concentrations of 222 Rn at the K-site. - - - : Measured concentration of 222 Rn, ——: Concentration of 222 Rn calculated using the method of Beck and Gogolak [8] for the cases ranging from neutral stability in the daytime (NNN) to strong stability at night (IWN), ----:: Concentration of 222 Rn calculated using the method of Beck and Gogolak [8] for the cases ranging from strong instability in the daytime (SSN) to weak stability at night (WNN). (b) Time variation of wind speed measured with an ultrasonic anemometer at the K-site. The readings of the wind represent 1-hour averages taken during the same intervals as those of the concentrations of 222 Rn.

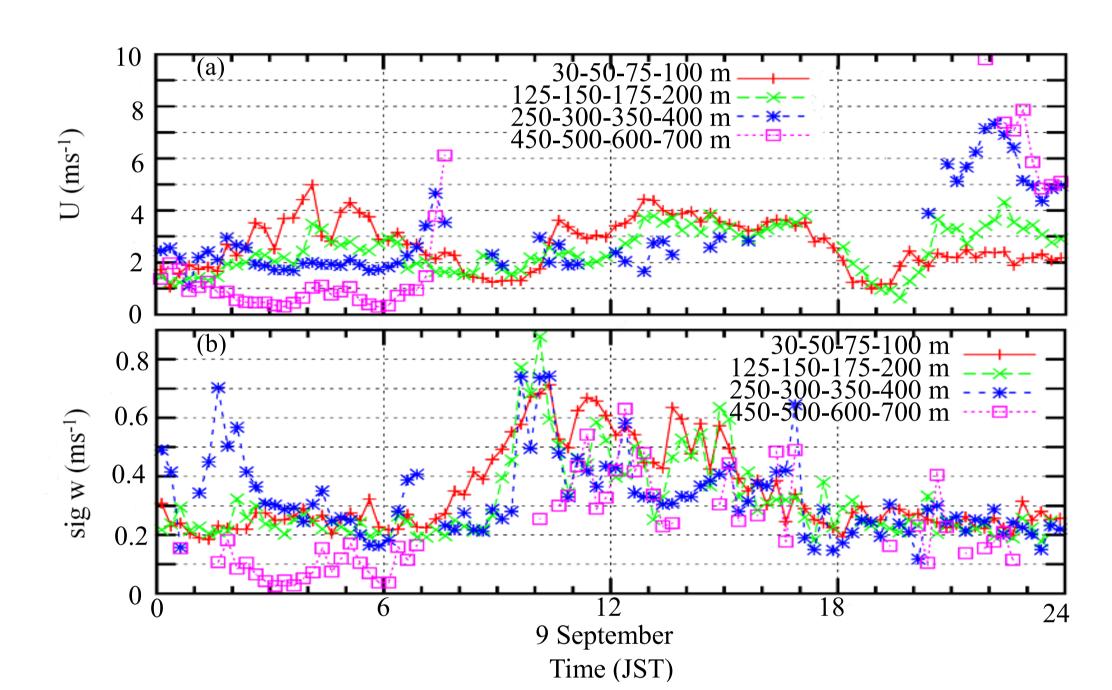


Figure 4. Time variations of (a) wind speed and (b) standard deviation of vertical wind speed obtained with a Doppler sodar at the K-site on 9 September 1998. 30-50-75-100 m: Average value of measurements at 30, 50, 75 and 100 m. 125-150-175-200 m: Average value of measurements at 125, 150, 175 and 200 m. 250-300-350-400 m: Average value of measurements at 250, 300, 350 and 400 m. 450-500-600-700 m: Average value of measurements at 450, 500, 600 and 700 m.

The wind direction was NE-NNE at observatory 2 and the peaks of NO, NO₂ and SO₂ that appear in Fig. 5a do not appear in Fig. 5b except by coincidence during each of these nights. Therefore, we conclude that the concentrations of NO, NO₂ and SO₂ at observatory 2 were not affected by traffic on route No. 2 during these nights.

From Fig. 5c, we notice that significant peaks appeared in the concentrations of NO and NO₂ at observatory 3 during the nights of 7–13 September. The timing of these peaks was a little different from those at observatory 1. It is considered, from these observations, that the effect of route No. 3 concealed any influence of route No. 2.

When peaks appeared in the concentration of SO₂ at observatory 4 (see Fig. 5d), the wind direction was, for the most part, SSE. There is a valley between observatory 4 and a factory manufacturing sulfuric acid, as shown in Fig. 2. Therefore, it is thought that the peaks were due to the factory.

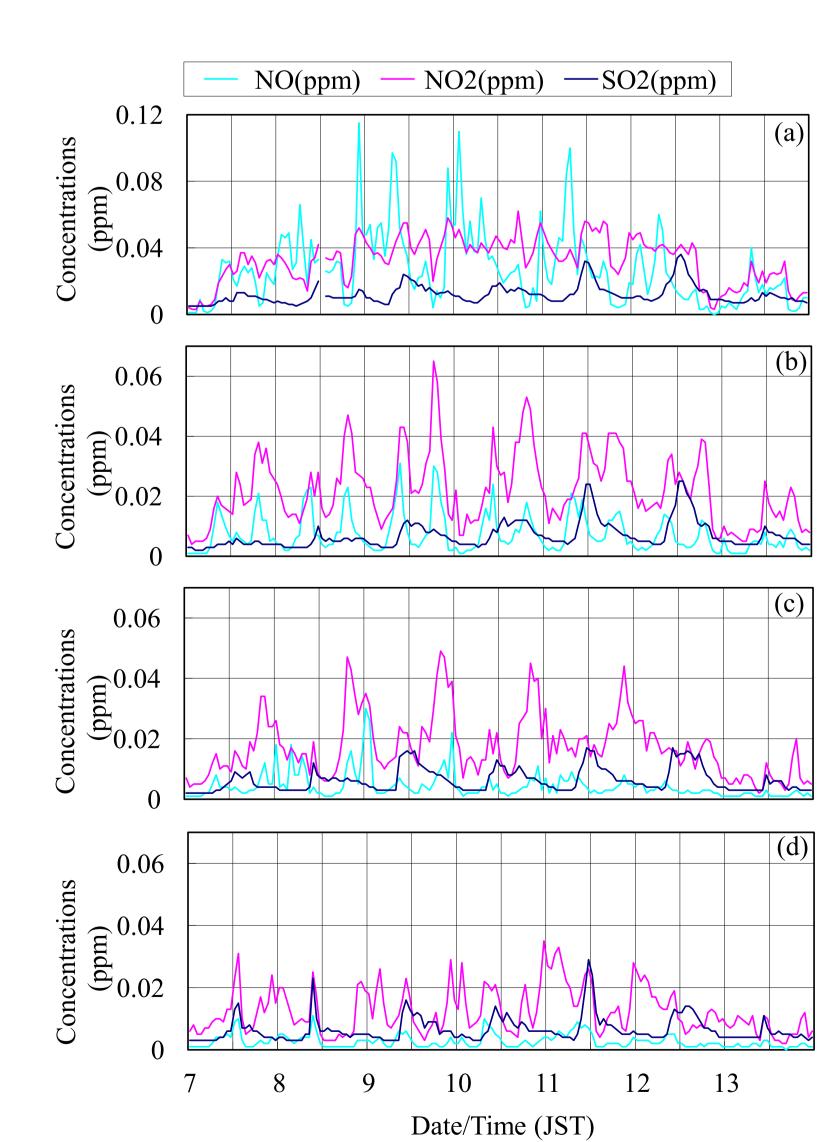


Figure 5. Time variations of the concentrations of NO, NO₂ and SO₂ at (a) observatory 1, (b) observatory 2, (c) observatory 3 and (d) observatory 4.

5. Conclusion

The concentrations of ²²²Rn at the K-site at night were lower than those at the A-site and the U-site reported in previous papers, and ranged from the midpoint of the concentrations calculated using the method of Beck and Gogolak for the case of strong stability and weak stability to those for the case of weak stability. Smaller increases of the concentration of ²²²Rn at night and slow decreases of the concentration of ²²²Rn during the morning calm, namely the transition period from land breeze to sea breeze could be also clearly explained by meteorological observations including Doppler sodar. In the daytime, the concentration of ²²²Rn was almost the same as those at the A-site and the U-site.

At night, although atmospheric conditions were near weak stability, advection of exhaust fumes

At night, although atmospheric conditions were near weak stability, advection of exhaust fumes originating from motor vehicles was identified from analysis of time variations of concentrations of NO, NO₂ and SO₂, and wind directions around the experimental site. In the daytime including the morning calm, exhaust fumes originating from factories and ships were also identified by the analysis. These results support a suggestion of a previous paper that a set of atmospheric ²²²Rn and air pollutants would be a useful indicator for the local nature of the atmospheric boundary layer.