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Annual variation in the atmospheric radon concentration in Japan

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A B S T R A C T

Anomalous atmospheric variations in radon related to earthquakes have been observed in hourly exhaust-monitoring data from radioisotope institutes in Japan. The extraction of seismic anomalous radon variations would be greatly aided by understanding the normal pattern of variation in radon concentrations. Using atmospheric daily minimum radon concentration data from five sampling sites, we show that a sinusoidal regression curve can be fitted to the data. In addition, we identify areas where the atmospheric radon variation is significantly affected by the variation in atmospheric turbulence and the onshore-offshore pattern of Asian monsoons. Furthermore, by comparing the sinusoidal regression curve for the normal annual (seasonal) variations at the five sites to the sinusoidal regression curve for a previously published dataset of radon values at the five Japanese prefectures, we can estimate the normal annual variation pattern. By fitting sinusoidal regression curves to the previously published dataset containing sites in all Japanese prefectures, we find that 72% of the Japanese prefectures satisfy the requirements of the sinusoidal regression curve pattern. Using the normal annual variation pattern of atmospheric daily minimum radon concentration data, these prefectures are suitable areas for obtaining anomalous radon variations related to earthquakes.

1. Introduction

Globally, one-tenth of the total number of earthquakes with magnitudes greater than 4.0 have occurred in and around Japan (Ukai, 1996). The occurrence of anomalous changes in radon concentrations prior to earthquakes has been studied in Japan (Wakita et al., 1980; Igarashi et al., 1995; United Nations Scientific Committee on the Effects of Atomic Radiation, 2000). Variations in atmospheric radon in Fukushima, Japan before the Tohoku-Oki Earthquake (Mw = 9.0) have been previously reported (Hatanaka et al., 2013; Hayashi et al., 2014). Atmospheric radon concentrations are determined by collecting data using exhaust monitors at radioisotope (RI) institutes in Japan. Seismic anomalous radon variations have been observed by comparing variations in radon around seismic events with normal radon variations identified using exhaust-monitoring data (Hatanaka et al., 2013; Hayashi et al., 2014). However, further studies of seismic changes are still required.

We previously reported the normal variation in the radon concentration required to extract the anomalous variation that occurred prior to the Tohoku-Oki Earthquake (Hayashi et al., 2014; Nakamura et al., 2013). First, data on the daily minimum atmospheric radon concentration in areas near Fukushima were used as representative concentrations to reduce the effects of topography. Next, we determined that applying a sinusoidal model with a phase shift of approximately 70 days to the annual (seasonal) radon variation was possible. That is, the annual variations during the normal period, which the data was collected at four sites in Japan, were found to be similar to the annual variation observed in Fukushima by applying a sinusoidal model with a phase shift ranging from 70 to 85 days (Table 1 of Nakamura et al., 2013). At all four sites, the radon concentration was low in the summer and high

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Table 1
Radon data measuring conditions: a) data obtained at five sampling sites; and b) data reported in Oikawa et al. (2003).

a) Location	Normal period of measurement	Operating data	Height (m) (Fig. 1a)	Air change rate (h^{-1}) (Fig. 1a)
FMU	2003–2007[a]	Hourly continuous	7	5
IMSUT	2005–2010		6.5	10
WMU	2000–2010		18.25	26
SMU	2005–2009[a]	Hourly 9:00–17:00	61	16
NINS	2003–2011		15	16

b) Location	Measurement period	Operating data	Height (m)
Fukushima	1997–1999	Every 3 month	2
Tokyo	1997–1999	4 data/year	
Wakayama	1997–1999		
Hokkaido	1997–1999		
Aichi	1997–1999		

[a] Measurement period: FMU (2003–11 March 2011), SMU (2000–2009).

in the winter. Note that all four sampling sites were located on the tops of hills or on plains. Furthermore, in the data sets for two of the sites, anomalous radon changes were observed before and after earthquakes (Hatanaka et al., 2013).

The time-series variation in the atmospheric radon concentration in Japan was found to be affected by atmospheric turbulence (Sesana et al., 2003) and the onshore-offshore pattern of Asian monsoons (Chambers et al., 2009), which was linked to the variation in surface temperature. The radon concentration was mainly affected by atmospheric turbulence and was inversely related to the variation in surface temperature. When the normal annual radon variation pattern obtained by applying a sinusoidal model is close to the inverse correlation (the phase shift of the sinusoidal model was approximately (70 + 365/2) days (Trenberth, 1983)) of the annual variation pattern for the surface temperature, it is reasonable to assume that the normal annual variation in radon concentration is matched by inverse variations in atmospheric turbulence and the onshore-offshore pattern of Asian monsoons. This normal variation of the daily minimum radon concentration was estimated by determining the amplitude in the sinusoidal model with a phase shift of approximately 70 days (Hayashi et al., 2015). Thus, for simple variations in the daily minimum radon concentration, estimating the variation pattern is easy.

The results of a nationwide survey of atmospheric radon concentrations were reported by the Japan Chemical Analysis Centre (hereafter JCAC report) (Oikawa et al., 2003). The average radon concentration for each four-quarter period was determined using the average value for each three-month period. However, it is not clear if it is possible to fit a sinusoidal curve to the data in the JCAC report.

The climatic conditions of Japan differ between the Pacific side and the Sea of Japan side. The heavy precipitation on the Sea of Japan side may mean that dry conditions prevail in the Pacific region (Maejima, 1967). The air mass fetch regions of a site vary seasonally, especially in Japan, which is strongly influenced by Asian monsoons. Japan has four distinct seasons with a climate ranging from subarctic in the north to subtropical in the south. Northern Japan has warm summers and very cold winters. Eastern Japan has hot and humid summers and cold winters. The Sea of Japan side has heavy snow in winter.

The purpose of this study is to determine whether the JCAC report data can be used to determine the best locations for gathering exhaust-monitoring data in Japan (where simple variation of the radon concentration similar to that observed at five sites, including the four above-mentioned sites (Table 1 of Nakamura et al., 2013)). This variation is hereafter referred to as "simple variation". First, the annual variations in the daily minimum radon concentrations, which were used to remove the effects of meteorological and geographical conditions, were calculated using the exhaust-monitoring data at the five sites for a period greater than five years. The sinusoidal regression curves obtained by fitting a sinusoidal model to the daily minimum data from the five sites

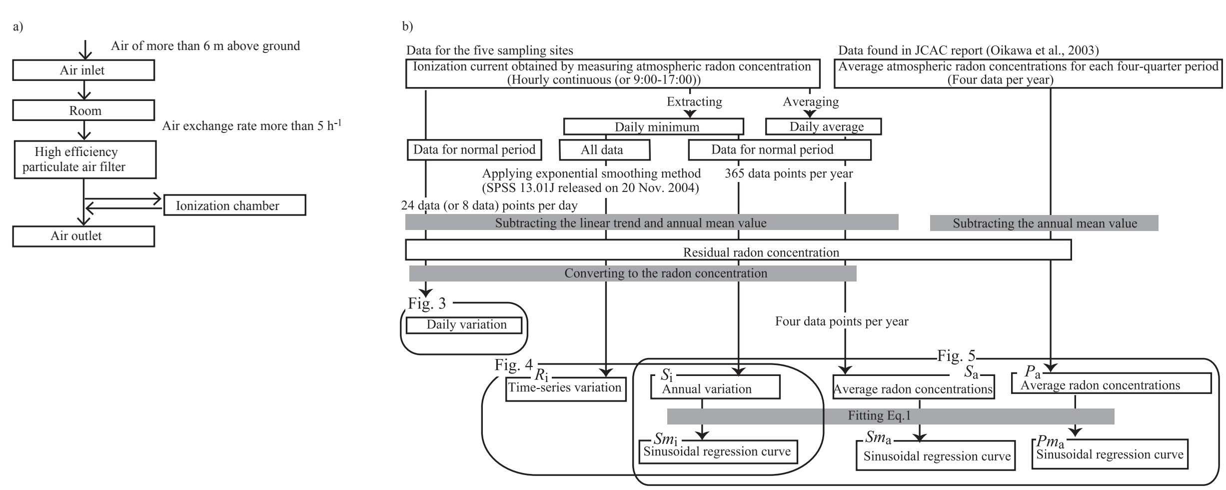

Fig. 1. Schematic block diagrams showing (a) the radon measurement system and (b) the analysis and calculation methods.