Fast Fourier Transform power spectrum of radon activity

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Abstract
Measurement of outdoor Radon-222 (222Rn) activity at National Atmospheric Research Laboratory (NARL), Gadanki, India, is carried out using Alpha GUARD PQ 2000 PRO from October 2011 to July 2014 and analyzed. The general inspection of time series reveals the decomposition of periodicity, significant diurnal and seasonal trend, and correlation between the measured and dependent variables. Detailed analyses have revealed that the Fast Fourier transform power spectrum of 222Rn has several energy peaks at different time scales that indicate the daily evolution of radon concentration. The composite seasonal plot shows that at least 21% of the average monthly radon concentration can be attributable to nonlocal effects. In a case study, it is observed that the time evolution of precipitation is one of the important governing factors of radon concentration near the surface. The activity of radon varies from 2 to 65 Bq/m³ with a mean of 12.35 Bq/m³ and ambient gamma dose levels varied between 141.8 and 244 nSv/h with a mean of 188.8 nSv/h.

Keywords: Gadanki, natural tracer, radiation dose, radon

INTRODUCTION
Radon-222 (222Rn) (an inert and naturally occurring radioactive gas with a half-life of 3.823 days) emission from the surface of the earth has long been studied over the several decades from different perspectives. Its epidemiological effects are well reported; radon and its daughters deliver the highest radiation dose to human beings among all natural radioactive sources.[1,2] Apart from its own radiological significance, 222Rn being a natural tracer is also a potential candidate for its use in several research applications such as environmental processes, tectonic, hydrogeologic, atmospheric dispersion, and climate change studies. Anomalous changes in radon activity before earthquakes (tectonic movements) have also been reported by several authors.[3-5] The strong dependence of 222Rn activity on meteorological parameters such as temperature and relative humidity makes radon as a convenient passive tracer of vertical mixing[6-8] and horizontal transport[9] from and within the atmospheric boundary layer. Radon measurement is also efficiently utilized for the classification of nocturnal stability regimes[8] and demonstrates the multiple uses as a tracer to explain observed diurnal characteristics of several trace gases such as NOₓ, O₃, and air pollution levels.[10,11] Hence, the long-term measurement of outdoor 222Rn has been carried out from October 2011 to July 2014 along with the relevant meteorological parameters at National Atmospheric Research Laboratory (NARL), Gadanki, India, to study the decomposition of periodicity and possible trend, correlation between the measured variables, dependence of near-surface radon activity on...
meteorological parameters, effect of precipitation on the radon concentration, and its recovery after precipitation.

Experimental methodology

Outline of the study site

Figure 1 shows the geological location, where continuous measurements of activity of radon and meteorological parameters were carried out in the premises of NARL (13.5°N and 79.2°E), Gadanki, India. The site is about 2 km away from the main residential areas with no major industrial activities, and it is surrounded by rocky terrains and dense vegetation. Overall wind direction is southerly and southeasterly during April, westerly from May to September, and North-Easternly during October and November. All the measurements are carried out for the outdoor environment at a height of 1 m.

Experimental setup

Many techniques are adopted for measuring the concentration of radon in air which are mainly based on the detection of emissions from radon or its radioactive decay products. However, due to low concentrations of environmental radon, the precision, accuracy, and detection efficiency of the techniques are of important issues. Alpha GUARD PQ2000 PRO is a compact portable measuring system for the continuous monitoring of the radon concentration. The pulse ionization chamber principle is incorporated in this equipment and measures radon by three-dimensional alpha spectroscopy technique with DSP technology. The time period of measurements is 10 min and fed to a memory module for data acquisition. The Alpha GUARD was placed inside a Stevenson’s screen (well-ventilated and weatherproof enclosure) to protect it from precipitation and high winds. The meteorological variables are obtained from automatic weather station and mini boundary layer mast.

RESULTS AND DISCUSSIONS

Time evolution of Radon and meteorological variables

An effort is made to analyze 30 months of data on radon, meteorological parameters with 10 min resolution. The sampling location NARL is a typical rural warm location in South India. The radon measurements were conducted specifically over the period October 2011 to July 2014. The instrument detects directly $^{222}$Rn that is therefore not inferred from the analysis of its daughters as in other cases. Figure 2 shows the time evaluation of the all the variables at 10 min frequency (black lines, red lines – 24 h running mean) measured at NARL that provides clear characterization of the sampling location for the data analyzed. The most important aspects observed are (a) pronounced monthly variations in all the measured parameters, (b) the temperature and relative humidity evolution throughout the year is comparable to similar environments with fairly cold winters and warm summers, (c) radon concentration is high ranging from a minimum value of few Bq m$^{-3}$ in May to a maximum of 65 Bq m$^{-3}$ in January.

The evaluation of Pearson’s correlation coefficient of radon with temperature and relative humidity (between monthly means) is shown in Figure 3. In general, the largest values are found in the first part of the year. For temperature, anticorrelation exists with radon activity and maximum value of $-0.76$ was found in February. However, in case of relative humidity, a strong positive correlation is found in all months, with highest of 0.7 in January (winter).

Fourier transform analysis for periodicity

In the present study, the Fast Fourier Transform (FFT) technique was used for the analysis of radon data in frequency domain to see the periodicity hidden in the time series. The frequency domain is the square of FFTs magnitude since in physics that energy is proportional to the amplitude squared. This option is the simplest of the Fourier spectral procedures with no data window tapering, no averaging of segments, and the only requirement is the data stream to be uniformly sampled (constant sample increment with a time interval of 10 min). Frequency domain information is in the amplitude format with N as data size is given by equation (1):

$$\text{Amplitude} = \frac{\text{Magnitude}[\text{FFT}(A)]}{N} = \sqrt{\left(\text{real}[\text{FFT}(A)] + \text{image}[\text{FFT}(A)]\right)^2}$$

The continuous time series and FFT power spectrum for 1-month (August 2013) radon activity are presented in Figure 4a and b. A well-defined diurnal variation in radon
activity can be observed in time series. When the FFT analysis is carried out for the same data set, prominent peaks at 12 h and 24 h is observed. This may be attributed to the well-known frequencies of solar radiation tide.\(^ {26,27}\)

Figure 5 shows the power spectrum of the all meteorological variables (upper part) and radon (lower). The similarities in the several energy peaks were observed for radon, wind speed, temperature, and relative humidity, which indicates the significant correlation between variables. For radon, within this range of scales, one can clearly distinguish the presence of four energy peaks positioned at 23.99, 12.00, 8.00, and 6.00 h. All the peaks refer to the daily evolution of radon concentration which is governed by the nocturnal accumulation and mixing of atmospheric boundary layer constituents and the constant emission from the surface.

The shortest time scales (12 h and less) could be due to the night time boundary layer formation/evolution and growth of radon activity,\(^ {24}\) whereas 24 h complete cycle is due to the formation of temperature inversions during early morning hours, breaking of inversion after sunrise, and increase in vertical mixing till late afternoon hours.\(^ {26}\) The result presented is not completely surprising as the mechanism of radon emission and dispersion in the boundary layer is well established. The spectrum of temperature, relative humidity, and radon are comparable as they are all atmospheric tracers transported and diffused in a similar way. They all show the presence of significant peaks at 24, 12, 8, and 6 h (small peaks in smaller time scales).\(^ {24-27}\)
Seasonal variations

The diurnal variation of activity of $^{222}\text{Rn}$ and its correlation with meteorological parameters at NARL are already reported. [28] Hence, the composite seasonal cycle of $^{222}\text{Rn}$ is concentrated [Figure 6], and it is observed that the activity of $^{222}\text{Rn}$ is characterized by low concentrations in June through August and higher concentrations November through February. [14] It is found that, at least 21% of the 12.35 Bq m$^{-3}$ (average monthly radon concentration) seen in Figure 6 can be attributable to nonlocal effects, which is the difference between afternoon minimums of different seasons. [11,16] The activity of radon during afternoon near the surface represents the mean concentration through the depth of the daytime convective boundary layer (CBL) and changes slowly from day to day in response to the passage of synoptic scale weather systems.

The remaining 79% of the above concentration at NARL is attributable to local diurnal effects. The composite
diurnal cycle of radon at NARL is characterized by a strong peak before sunrise when the nocturnal boundary layer is at its lowest, smaller wind speeds, and the influence of local sources dominate. Minimum values are found in the late afternoon when the CBL is at its deepest (maximum dilution), and radon source influences are dominated by the increased vertical mixing.

The period of the diurnal cycle of radon activity changes according to seasonal variation of the incident solar radiation. It can be noticed from Figure 7 that the colder drier conditions in autumn and winter (December–February) generate weaker mixing, leading to shallower nocturnal inversions with high radon levels.\[^{14}\]

**Behavior of Radon during precipitation event**

The analysis of the time series of the radon activity has several interesting results. It outlines the presence of specific periods during which the radon concentration behaves in a special way, especially during monsoon period.\[^{24}\] One such case is discussed in this section, observed during August 27 –September 5, 2012 [Figures 8a and b]. During August 28–30, 2012, several precipitation events (black lines) are registered, and a significant decrease in radon concentration (gray lines) occurs coinciding with a period with precipitation stopping at August 31. From that moment on and for the following 4 days, the radon concentration shows the usual daily evolution though superimposed to a linear growth. From Figure 8b, it is clear that, apart from temperature and relative humidity, the precipitation events clearly affects the dynamics of radon activity near the surface of outdoor environment and time evolution of precipitation can be considered as one of the important governing factors of radon concentration near the surface.

The statistical analysis of all the measured variables is performed and presented in Table 1. The observed activity of radon over NARL is between 2 and 65 Bq/m\(^3\) with a mean of 12.35 Bq/m\(^3\), and the mean ambient gamma dose rate was 188.8 nSv/h. Both the values are within the permissible limit and comparable to the earlier results of similar environments in India.\[^{29}\]

**CONCLUSIONS**

The analysis of 30-month data of outdoor \(^{222}\)Rn activity at NARL, Gadanki, India, is carried out. The detailed results

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**Table 1: Descriptive statistic**

<table>
<thead>
<tr>
<th>Radon (Bq/m(^3))</th>
<th>Gamma dose (nSv/h)</th>
<th>Temperature (°C)</th>
<th>Relative humidity (%)</th>
<th>Pressure (mbar)</th>
<th>Wind speed (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data points</td>
<td>16,777</td>
<td>16,465</td>
<td>17,050</td>
<td>12,599</td>
<td>16,629</td>
</tr>
<tr>
<td>Maximum</td>
<td>65</td>
<td>244</td>
<td>46</td>
<td>99</td>
<td>981</td>
</tr>
<tr>
<td>Minimum</td>
<td>2</td>
<td>141.83</td>
<td>10.9</td>
<td>15.5</td>
<td>908</td>
</tr>
<tr>
<td>AM</td>
<td>12.35</td>
<td>188.8</td>
<td>28.3</td>
<td>67.7</td>
<td>967.33</td>
</tr>
<tr>
<td>SD</td>
<td>8.10</td>
<td>23.9</td>
<td>5.9</td>
<td>19.9</td>
<td>14.43</td>
</tr>
<tr>
<td>SE</td>
<td>0.12</td>
<td>0.6</td>
<td>0.10</td>
<td>0.4</td>
<td>0.27</td>
</tr>
<tr>
<td>GM</td>
<td>10.25</td>
<td>187.6</td>
<td>27.6</td>
<td>64.4</td>
<td>967.22</td>
</tr>
<tr>
<td>GSD</td>
<td>1.84</td>
<td>1.1</td>
<td>1.2</td>
<td>1.3</td>
<td>1.02</td>
</tr>
<tr>
<td>Median</td>
<td>9.67</td>
<td>185.3</td>
<td>28.08</td>
<td>67.5</td>
<td>970.00</td>
</tr>
<tr>
<td>CV</td>
<td>0.54</td>
<td>0.2</td>
<td>0.2</td>
<td>0.27</td>
<td>0.01</td>
</tr>
</tbody>
</table>

AM: Arithmetic mean, SD: Standard deviation, SE: Standard error, GM: Geometric mean, GSD: Geometric standard deviation, CV: Coefficient variation
show that FFT power spectrum of $^{222}$Rn has identified the presence of several energy peaks in the time series that range from 4 to 24 h indicating the periodicity at different time scales. A well-defined diurnal and seasonal trend in radon prove its strong dependence on meteorological parameters. A significant effect of precipitation on the radon concentration and its linear growth recovery after rainfall was observed. Hence, the time evolution of precipitation can also be considered as one of the important governing factors of radon concentration near the surface. The composite seasonal plot shows that at least 21% of the average monthly radon concentration can be attributable to non-local effects. The mean radon activity over NARL for the study period was found to be 12.35 Bq/m$^3$ and ambient gamma dose of 188.8 nSv/h. In future, with the help of simultaneous measurements of micrometeorological parameters and boundary layer height measurements in combination to radon concentration, it is planned to study the effect of precipitation intensity on the radon surface flux and surface layer concentration, use of radon as a tool for quantifying atmospheric stability, dispersion, and boundary layer properties over NARL.

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Conflicts of interest
There are no conflicts of interest.

REFERENCES
Kumar, et al.: FFT of Rn activity


