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Seasonal emanation of radon at Ghuttu, northwest Himalaya: Differentiation of atmospheric temperature and pressure influences

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HIGHLIGHTS

- Seasonal variability of radon in borehole.
- Influence of atmospheric temperature and pressure on radon variability.
- Partial correlation coefficient.

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ABSTRACT

Continuous monitoring of radon along with meteorological parameters has been carried out in a seismically active area of Garhwal region, northwest Himalaya, within the frame work of earthquake precursory research. Radon measurements are carried out by using a gamma ray detector installed in the air column at a depth of 10 m in a 68 m deep borehole. The analysis of long time series for 2006–2012 shows strong seasonal variability masked by diurnal and multi-day variations. Isolation of a seasonal cycle by minimising short-time by 31 day running average shows a strong seasonal variation with unambiguous dependence on atmospheric temperature and pressure. The seasonal characteristics of radon concentrations are positively correlated to atmospheric temperature ($R=0.95$) and negatively correlated to atmospheric pressure ($R=-0.82$). The temperature and pressure variation in their annual progressions are negatively correlated. The calculations of partial correlation coefficient permit us to conclude that atmospheric temperature plays a dominant role in controlling the variability of radon in borehole, 71% of the variability in radon arises from the variation in atmospheric temperature and about 6% of the variability is contributed by atmospheric pressure. The influence of pressure variations in an annual cycle appears to be a pseudo-effect, resulting from the negative correlation between temperature and pressure variations. Incorporation of these results explains the varying and even contradictory claims regarding the influence of the pressure variability on radon changes in the published literature. Temperature dependence, facilitated by the temperature gradient in the borehole, controls the transportation of radon from the deep interior to the surface.

1. Introduction

Anomalous changes in radon in association with earthquake occurrences are among the most widely researched parameter (Igarashi et al., 1995; Virk et al., 2001; Walia et al., 2005; Ghosh et al., 2009). Increased diffusion of radon from rocks in response to the stress-induced deformation or due to the opening of micro-cracks and influx of fluids (Scholz et al., 1973) are considered possible mechanisms for the generation of a precursory signal in radon accompanying seismic activity (Thomas 1988; Ghosh et al., 2009; Chyi et al., 2010). Recognising these potential roles in earthquake precursory programs, a radon monitoring was initiated at Ghuttu, northwest Himalaya in 2007. This monitoring is part of the Multi-Parameter Geophysical Observatory (MPGO) set-up to study multiple precursors, including seismic velocity changes, space time pattern in seismicity, small scale changes in gravity, resistivity, magnetic field, EM-ULF emission, ground water level changes etc. in a collective manner from a single platform (Arora et al., 2012). Despite the clear realisation that simultaneous measurements of inter-disciplinary parameters and their cross-validation may enhance their use in real time forecast, characterisation of weak precursory signals continues to be a challenge as each

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measured time series has characteristic time variability related to hydrological, environmental and tectonic sources. Therefore, the applications of data-adopted numerical techniques are critical to understand the sources and the nature of time variability of different geophysical time series. Several numerical methods are being used to characterize, the site specification, background variability and isolate earthquake-related changes with varying success (Zmazek et al., 2005; Finkelstein et al., 2006; Francesco et al., 2010). The examination of radon data collected at Ghuttu over the years has shown complex time variability, including, periodic, aperiodic and transient changes. The early study by Choubey et al. (2009) reported a bell-shaped transient anomaly, marked by the sharp negative-positive impulse, in association with an M 4.9 Kharsali earthquake of July 22, 2007. Later Choubey et al. (2011), Arora et al. (2012), and Kamra et al. (2013) reported the season-dependant diurnal variations in radon, which were related with the saturation of the top soil layer and the temperature gradient in a borehole environment. There is growing evidence that emanation and transport of radon in the rock matrix is also affected by meteorological parameters like rainfall, soil moisture, pressure, temperature, both at transient and at seasonal time scales (Clements and Wilkening, 1974; Mogro-Campero and Fleischer, 1977; Ball et al., 1991; Pinault and Baubron, 1997; Muramatsu et al., 2002; Finkelstein et al., 2006; Adler and Perrier, 2009; Barbosa et al., 2010; Choubey et al., 2011; Gregorič et al., 2011; Zafrir et al., 2013). The nature and extent of such influences hamper the utilisation of radon as a seismic precursor and, therefore, characterisation of the complex temporal pattern and their sources remain an active area of research. In the present communication, using long term radon time series data of 6-years, we first try to establish the nature of seasonal variations and then proceed to quantify the influence of meteorological parameters. The study draws special significance because in addition to meteorological parameters, it has also been suggested that seasonal variations are influenced by a component from solar irradiation (Steinitz et al., 2011; 2013; Sturrock et al., 2012).

2. Data

Radon monitoring is continuously being carried out in a 68 m deep borehole as a part of MPGO that is established at Ghuttu (30.53°N, 78.74°E) at an altitude of 1835 m above sea level in the NW Garhwal Himalayan region (Fig. 1). The observatory is located in a narrow belt of high seismicity, just south of the Main Central Thrust (MCT). Radon measurement is performed by using a gamma PM-11 detection system 2 in. × 2 in. NaI (TI activated) scintillator, equipped with an electronic total count Single Channel Analyzer (SCA) Rotem Industries, Israel. The gamma detector counts the photons emitted from Pb-214 and Bi-214. The radon sensor probe is placed at a depth of 10 m; recording radon counts from the air column above the water level at 15 min intervals. Furthermore, meteorological parameters including atmospheric temperature, pressure and rainfall were measured at the same site with the same temporal resolution (Kamra et al., 2013). In addition, the temperature inside the borehole at 10 m depth is also recorded which shows nearly a steady value at 19.4 ± 0.3 °C throughout all seasons of the year. The measured radon data (as counts) and other time synchronous meteorological parameters at predefined 15 min intervals are stored in a Campbell (10 ×) data logger and periodically transferred to the personal computer for further evaluation and processing. The time series of all parameters spanning 6 years, 2007–2012 are used. The measured time series of radon concentration at Ghuttu acquired with 15 min sampling exhibited complex temporal variability marked by short term (diurnal) and long (multi-day to seasonal) periods (Arora et al., 2012; Choubey et al., 2011; Kamra et al., 2013). With an objective to suppress the influence of strong diurnal variations measured radon counts were pre-processed by aggregating 15 min sample values to daily averages. Afterward the time series was analysed by using a 31 day running average in order to separate the daily and multiday variations.

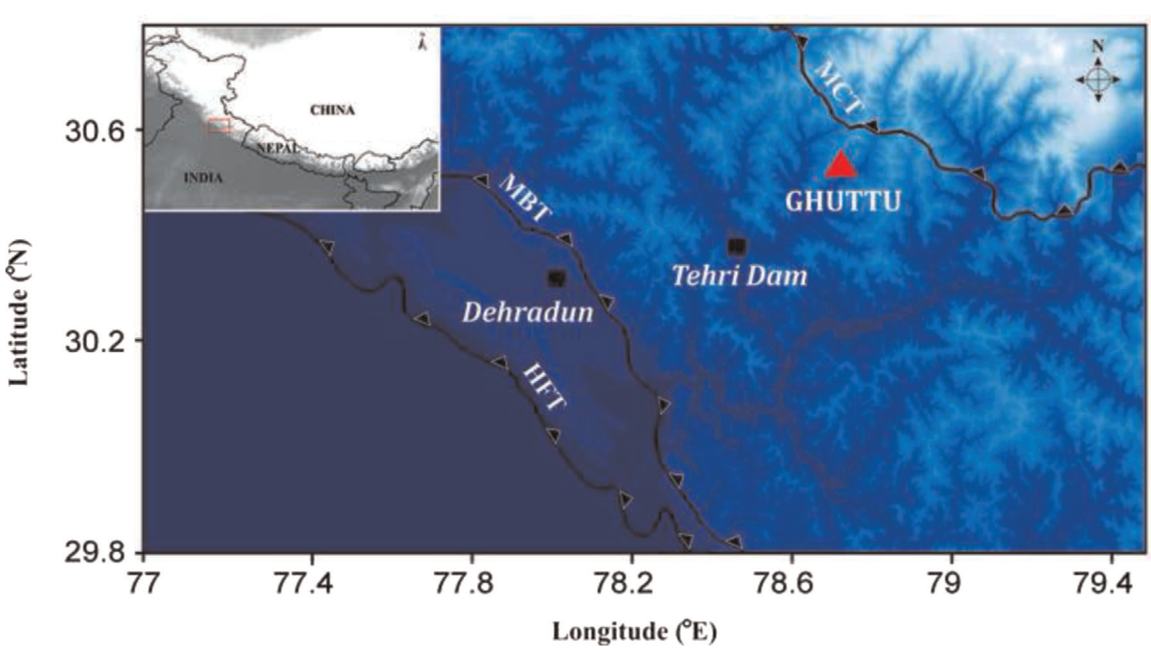

Fig. 1. The SRTM image shows the major tectonic features in the Garhwal Himalaya, where the location of MPGO observatory at Ghuttu is shown by red triangle. The major tectonic features viz., Himalayan Frontal thrust (HFT), Main Boundary Thrust (MBT) and Main Central Thrust (MCT) are delineated by black line. Inset shows the location of the study area (red rectangle) in the NW-Himalaya, India. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)