NUKLEONIKA 2010;55(4):507–511

ORIGINAL PAPER

A radon anomaly in soil gas at Cazzaso, NE Italy, as a precursor of an $M_L = 5.1$ earthquake

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Abstract. At Cazzaso (Friuli) in northeast Italy, radon (^{222}Rn) activity concentration in soil gas in a borehole at a depth of 80 cm has been monitored continuously (at a frequency of once an hour) since May 2004, using a Barasol probe (Algade, France). In addition, environmental parameters (air and soil temperature, barometric pressure) have been recorded. The results have been evaluated and the relationship between radon levels and seismic activity is discussed. Correlation between radon concentration and barometric pressure has been observed. Preliminary results have shown a distinct radon anomaly prior to some earthquakes.

Key words: radon • soil gas • Barasol probes • anomalies • earthquakes

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Received: 13 August 2009
Accepted: 30 December 2009

Introduction

Since earthquakes are physical phenomena, most of the techniques currently used for prediction purposes are based on geophysical approaches, including seismology, magnetism, electricity, and geodesy. Seismically active faults are characterised by relatively high values of permeability. Many terrestrially generated gases such as CO_2, He, H_2, Rn, CH_4, N_2, and highly volatile metals such as Hg, As, Sb [4, 9] exhale from active faults. Deep geodynamic processes in the earth's crust may simultaneously produce anomalies in gas composition, changes in water temperature and level, electrical conductivity, etc. In principle, all changes observable prior to an earthquake could be useful for a better understanding of earthquake precursors.

Radon (^{222}Rn) has often been studied as one of the earthquake precursors. It is an inert gas generated by radioactive decay of ^{226}Ra in the uranium decay chain. Variations in radon concentrations in thermal water and soil gas associated with earthquake activity have been known for almost half a century. In the year 1966, in water from a Russian well an increase of radon concentration was observed prior to the Tashkent earthquake [10]. In 1974, the first station was installed to measure radon gas concentration in soil to study its relation to earthquakes [1, 2]. Since then, variations of radon concentration in both soil and groundwater have been considered as potential precursors for earthquakes.

Our study area is in NE Italy, close to the Italy-Slovenia-Austria border, a seismic-prone area due to the interaction between the Eurasian and African plates (with the Adriatic microplate). To the east, the contact with NW-SE trending Dinaric structures occurs [6, 7].

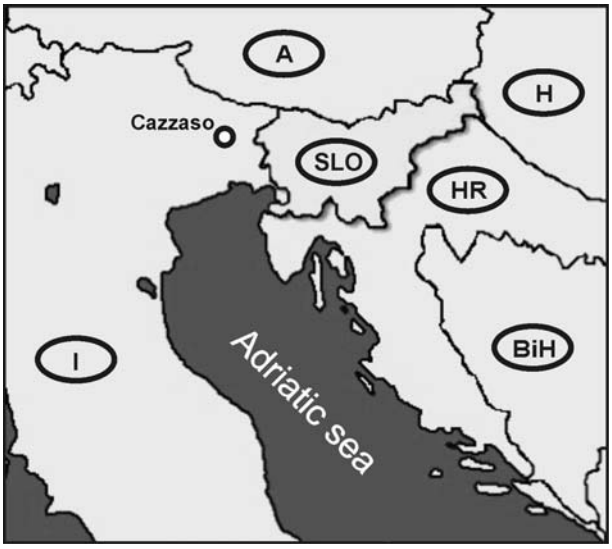

Fig. 1. Location of the measurement site at the town of Cazzaso in Friuli, NE Italy.

The aim of the work is to verify the relations between the geochemical variations and the geodynamic process of the study area. The continuous radon monitoring in soil gas has been carried with the Barasol MC 450 probe (Algade, France) designed to measure radon in soil and water. The sensitivity of the device is 50 Bq·m^{-3} and its sampling and analysing intervals 1 h.

Measurements and data evaluation

Radon concentration, barometric pressure, soil and air temperatures have been measured continuously, using a Barasol probe, at the town of Cazzaso in Friuli, NE Italy (Fig. 1) since May 2004, with some breaks in 2006 because of probe calibration. Based on earthquake magnitudes M_L, the so-called Dobrovolsky radius R_D of the effective precursory manifestation zone was calculated [3], i.e., $R_D = 10^{0.43M}$, where M is the earthquake magnitude and R_D, the radius in km of the zone within which precursory phenomena may be manifested. In data evaluation, those earthquakes have been taken into account for which the distance R_E between our measurement point and the epicentre was within 1.5 R_D and $M_L > 2.4$.

In the time series of the measured parameters, radon anomalies were sought, defined as: (i) a radon concen-

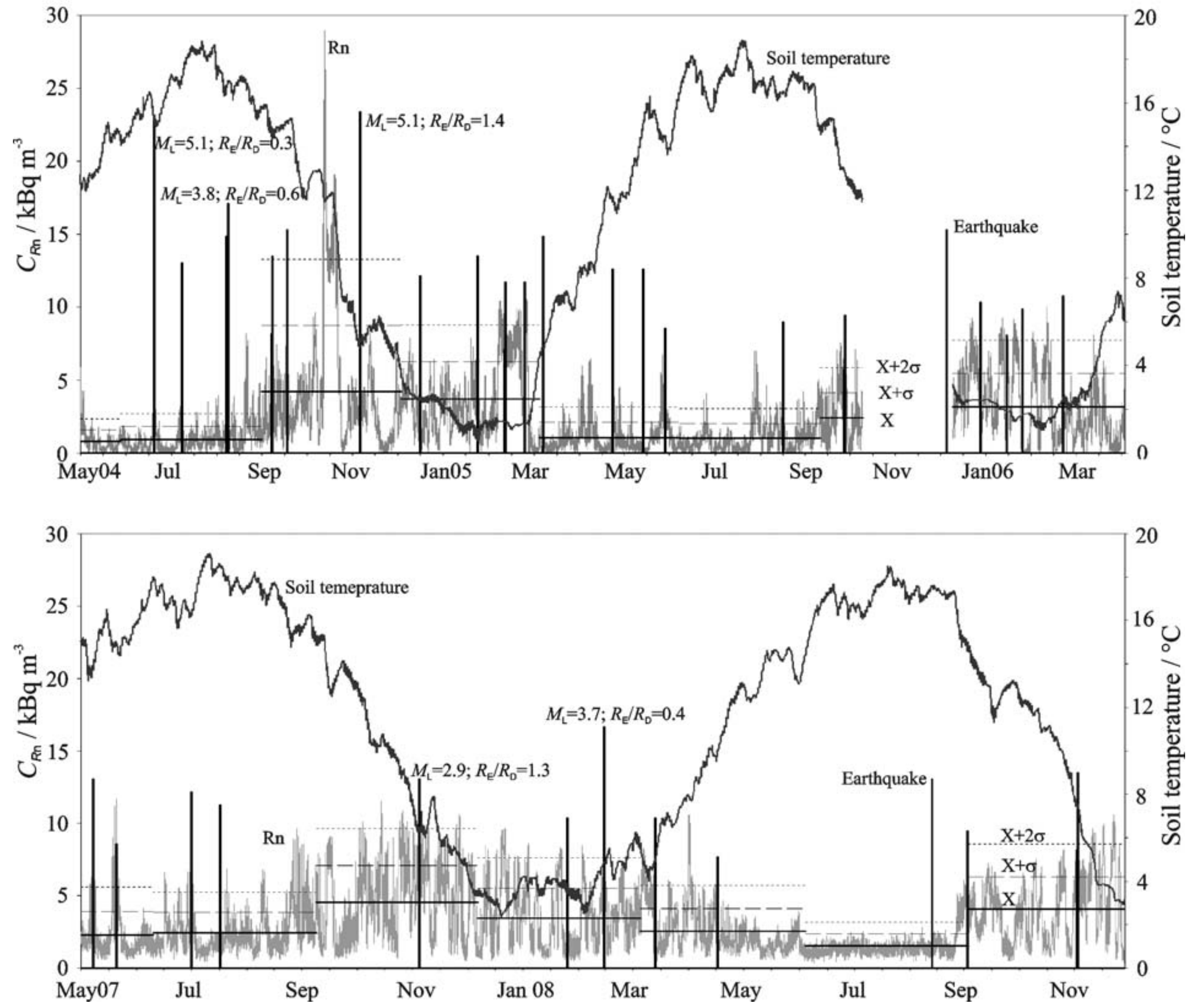

Fig. 2. Time series of hourly radon concentration in soil gas and soil temperature for two period: upper graph from May 2004 to April 2006, and lower graph from May 2007 to December 2008. Also earthquakes are drawn as bars. Full lines indicate average seasonal radon concentration, dashed lines, +1σ deviation, and dotted lines, +2σ deviation from the seasonal average value.

tration that deviates for more than twice the standard deviation (± 2σ) from the seasonal average radon concentration (ii) all radon concentrations appearing when the time gradient of barometric pressure, $\Delta P/\Delta t$, and the time gradient of radon concentration, $\Delta C_{Rn}/\Delta t$, in soil gas have the same sign. These anomalies have been considered to be related to seismic activity and not to environmental parameters. The latter definition of an anomaly is based on the well known inverse relationship between radon exhalation and barometric pressure [5]. A decrease in barometric pressure, with values of other environmental parameters remaining constant, generally causes an increase in radon exhalation from the ground [8].

From the measured radon concentration (C_{Rn}) and barometric pressure (P), time gradients $\Delta C_{Rn}/\Delta t$ and $\Delta P/\Delta t$ were calculated. Values of 6, 12 and 24 h have been taken for Δt. For radon data fluctuations, Δt = 24 h appeared to be optimal and has eventually been used in this paper. Time intervals with both gradients having the same sign, either positive or negative, i.e., $(\Delta C_{Rn}/\Delta t) \times (\Delta P/\Delta t) > 0$, were considered as radon anomalies, possibly related to seismic activity.

Results and discussion

The upper plot of Fig. 2 shows the radon concentration in soil-gas from May 2004 to April 2006 and the lower one, from May 2007 to December 2008. Earthquakes, barometric pressure and soil temperature are also shown. To some earthquakes, magnitude M_L and R_E/R_D ratio are attached. Full lines represent seasonal average radon concentrations, dashed ones, +1σ and dotted ones, +2σ deviation from the seasonal average. In this period radon concentration varied from several kBq·m^{-3} to about 30 kBq·m^{-3}. Temperature of the soil varied from 2 to 19°C. Lower radon concentration appears in summer and higher in winter. Anomalies, radon concentration beyond ± 2σ are seen before the majority of earthquakes. A pronounced radon anomaly with radon concentration of about 30 kBq·m^{-3}, is seen in the period from October 31 to November 9, 2004, thus appearing about three weeks prior to the M_L = 5.1 earthquake, that occurred on November 24 with the epicentre at the Lake Garda, about 250 km away. This anomaly is shown in the upper plot of Fig. 3 where the period from September 2004 to April 2005 is pre-

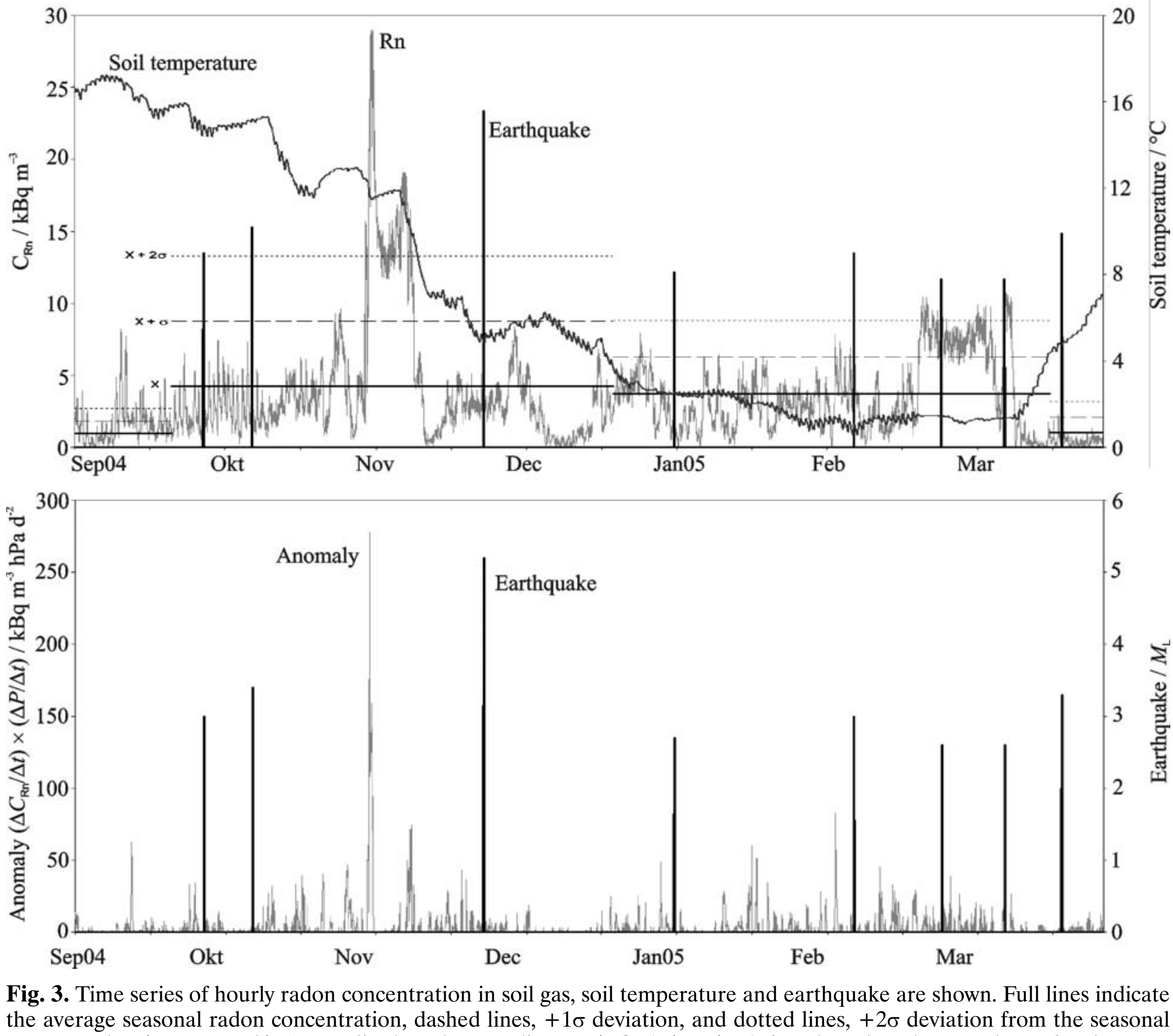

Fig. 3. Time series of hourly radon concentration in soil gas, soil temperature and earthquake are shown. Full lines indicate the average seasonal radon concentration, dashed lines, +1σ deviation, and dotted lines, +2σ deviation from the seasonal average value (upper graph). Anomalies based on gradient as $(\Delta C_{Rn}/\Delta t) \times (\Delta P/\Delta t)$ and earthquakes are shown for the same period: from September 2004 to April 2005.

Table 1. Earthquakes listed with: 1 – the date of occurrence; 2 – M_L magnitude; 3 – R_E/R_D value (R_E, distance of the measuring site from the epicentre; R_D, Dobrovolsky's radius [3]; 4 – day of the maximum of the radon anomaly defined as +2σ (σ, standard deviation) deviations of radon concentration from the seasonal average value; 5 – duration time of the anomaly in days; 6 – how many days the anomaly appeared before the earthquake; 7 – day of the maximum of the radon anomaly defined with gradients; 8 – maximum size of the anomaly obtained as a product $\Delta C_{Rn}/\Delta t \times \Delta P/\Delta t$; 9 – how many days the anomaly appeared before the earthquake. (In columns 4 and 7 dates in italics are for the earthquakes taken into account for the analysis, based on the Dobrovolsky's radius)

Earthquakes (EQ)			2σ			Gradients		
1	2	3	4	5	6	7	8	9
Date	M_L	R_E/R_D	Day of max	Duration time (d)	Start time before EQ (d)	Day of max	Max size	Start time before EQ (d)
12.07.2004	5.1	0.3	27.05.2004	8	48	21.06.2004	19	21
30.07.2004	2.9	0.5	*29.07.2004*	2	2	*27.07.2004*	12	3
28.08.2004	3.3	0.5	*23.08.2004*	13	14	*24.08.2004*	22	5
29.08.2004	3.8	0.6						
27.09.2004	3.0	0.7	*10.09.2004*	11	19	*12.09.2004*	63	15
07.10.2004	3.4	0.4	–	–	–	24.09.2004	33	13
24.11.2004	5.1	1.5	*01.11.2004*	11	25	*30.10.2004*	278	25
02.01.2005	2.7	0.9	–	–	–	30.12.2004	49	3
08.02.2005	3.0	0.9	–	–	–	04.02.2005	83	4
26.02.2005	2.6	0.5	23.02.2005	5	5	13.02.2005	45	13
11.03.2005	2.6	1.4	06.03.2005	8	7	28.02.2005	39	11
23.03.2005	3.3	1.3	–	–	–	12.03.2005	26	11
08.05.2005	2.8	0.3	*23.04.2005*	18	22	*25.04.2005*	47	13
28.05.2005	2.8	0.9	12.05.2005	8	14	19.05.2005	17	9
11.06.2005	1.9	0.4	*09.06.2005*	4	4	*08.06.2005*	38	4
27.08.2005	2.0	0.6	*08.08.2005*	10	20	*08.08.2005*	29	19
06.10.2005	2.1	1.3	04.10.2005	7	7	29.09.2005	31	8
03.01.2006	2.3	0.5	*29.12.2005*	6	9	*29.12.2005*	74	5
30.01.2006	2.2	0.8	*17.01.2006*	7	16	*18.01.2006*	58	12
26.02.2006	2.4	1.3	16.02.2006	2	12	10.02.2006	191	16
18.05.2007	2.9	1.3	17.05.2007	2	3	11.05.2007	53	7
31.05.2007	1.9	0.5	*31.05.2007*	3	3	*29.05.2007*	138	2
12.07.2007	2.7	0.9	10.07.2007	5	3	27.06.2007	43	15
28.07.2007	2.5	0.8	15.07.2007	1	13	24.07.2007	16	4
17.11.2007	2.9	1.3	26.10.2007	19	22	08.11.2007	123	9
08.02.2008	2.3	0.4	04.02.2008	2	5	05.01.2008	76	33
29.02.2008	3.7	0.4	*16.02.2008*	3	14	*16.02.2008*	118	13
29.03.2008	2.3	1.1	*22.03.2008*	8	9	*20.03.2008*	91	9
02.05.2008	1.7	0.9	17.04.2008	4	17	22.04.2008	69	25
20.09.2008	2.1	0.9	*18.09.2008*	7	7	*15.08.2008*	32	5
21.11.2008	3.0	1.0	–	–	–	31.10.2008	73	21

sented. The same magnitude of earthquake ($M_L = 5.1$), appear on July 12, this is just after Rn concentration measurements start in this area, so the anomalies in Rn concentration in this period are not detected.

The lower plot of Fig. 3 shows anomalies based on gradients of pressure and radon concentration for the same period. The maxima of these anomalies (product $\Delta C_{Rn}/\Delta t \times \Delta P/\Delta t$) coincide with maxima of anomalies based on ± 2σ deviation. The largest anomalies for both types of anomaly (2σ and gradients) coincided before the largest earthquake of $M_L = 5.1$. The maxima of both types of anomaly also coincide prior to the majority of other earthquakes. In Table 1, earthquake data are shown with data for both types of anomalies. Anomalies observed at the same time (with up to three days difference) have been indicated in italics.

Conclusion

Anomalies based on either 2σ or gradient definition, have been observed prior to the same earthquakes. A clearly visible and the largest anomaly was observed three weeks prior to the $M_L = 5.1$ earthquake on November 24, 2004. It has been found that the majority of anomalies are observed by both methods (2σ and gradients) at the same time. In future, machine learning methods (decision trees and neuron networks) will be applied to distinguish the anomalies, possibly caused by earthquakes, from those simply ascribed to environmental parameters.

Acknowledgment. The study was financed by the Slovenian Research Agency (Slovenia) and the Ministry of Foreign Affaires (Italy) within the bilateral collaboration no. BI-IT/05-08-027.

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