Improvements in real time ^{222}Rn monitoring at Stromboli volcano

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Abstract

Monitoring gas emissions from soil allows to get information on volcanic activity, hidden faults and hydrothermal dynamics. Radon activities at Stromboli were collected by means of multi-parametric real-time stations, that measure radon as well as environmental parameters. The last improvements on the detection system are presented and discussed.

Keywords: radon, volcanic activity, real-time measurements

1. Introduction

The analysis of temporal and spatial variations of soil gases flux is a useful tool to investigate geophysical processes associated to volcanic activity. One of these gases is radon that shows an unique properties: it belong to the decay chains of the three major primordial radionuclides of the Earth crust such as ^{238}U, ^{235}U and ^{232}Th. Radon is a natural occurring noble element, chemically inert, constantly generated in the rock matrix and in the crustal material. Being monoatomic it could easily enter the rock pores and migrate to significant distances from the site of generation in a surprising short time. Measuring the variations of radon flux, that are only induced by physical factors since it is not a reactive species, could give valuable information on dynamical transport processes, associated with the ascent of hydrothermal fluids. ^{222}Rn isotope is an α-emitter (E_α=5.5 MeV) with half-life of 3.82 days, widely used as a precursor of earthquakes and variations in volcanic activity. In active volcanoes like Stromboli, sharp variations in ^{222}Rn concentrations may be related to magma rise, changes in temperature and/or depth of hydrothermal system, stress variations associated with seismic transients. Radon values are also affected by environmental parameters, namely atmospheric pressure and temperature, soil temperature, soil moisture and humidity. Hence, the environmental modulation on the ^{222}Rn signal could mask variations related to volcanic activity if the raw data are not opportunely filtered. Since 2007 two real-time stations are operative at Stromboli volcano. The in-soil radon concentrations are collected together with atmospheric pressure and soil temperature. Automatic measurements of these parameters give us the opportunity to filter the radon data for improving volcano surveillance.

2. Experimental

Improvements in real-time measurements were carried out by a measurement box equipped with a radon detector (DOSEMan, SARAD Gmbh). The measurement box is placed inside a PVC container buried 60 cm depth in the ground [1]. This arrangement minimize the effects of meteorological changes, enhancing the efficiency of the system. Radon diffuses inside the container and then inside the measurement box (see Fig. 1) until reaches equilibrium concentration. The effective volume of the measurement chamber is 12 cm^3 [2]. The measurement chamber hosts a silicon doped detector that is able to analyze the α-particles related to the radon progeny. This equipment efficiently measures α-particles within an energy windows of 4.5 to 10 MeV (able to includes the ^{222}Rn, ^{218}Po and ^{214}Po energy peaks). A fine pored membrane filter, fully radon permeable, is protecting the entrance of the measurement chamber of the detector. ^{222}Rn mostly decays in the air inside the box and usually only a small fraction on the surface or close to the detector. A decaying ^{222}Rn atom within the chamber leaves behind a positively charged ^{218}Po which is electrostatically accelerated and concentrated on a very thin aluminum foils at high voltage placed just in front of the silicon detector. ^{218}Po nucleus has a short half-life (3.11 min) and when it decays, if electrostatically captured by aluminum foils, it will have 50% chance of striking with the emitted α particles the detector. Full spectra of α decays are recorded and subdivided in five energetic sectors (ROIs) each ones related to a single nuclide of interest. However, the counts for ^{214}Po (peak at 7.69 MeV) needs to be corrected since the ^{220}Rn spectrum generally may overlap the ^{214}Po peak. Instrumental calibrations suggest that approximately 7.5% of the counts may be related to thoron (e.g. ^{220}Rn) [3]. Thus, radon concentrations are correlated to the intensity of the detection peaks, to the volume of the detection chamber and to the sampling rate. Radon activities has been computed taking into account the counts for ^{222}Rn and ^{218}Po (Fast Mode, the detector sensitivity has been observed to be 0.22 counts/(min/kBq/m^3)) and in Slow Mode that includes the counts of ^{214}Po (sensitivity of 0.38 counts/(min/kBq/m^3)) too. The statistical error for 1 hour measurement at 1000 Bq/m^3 is

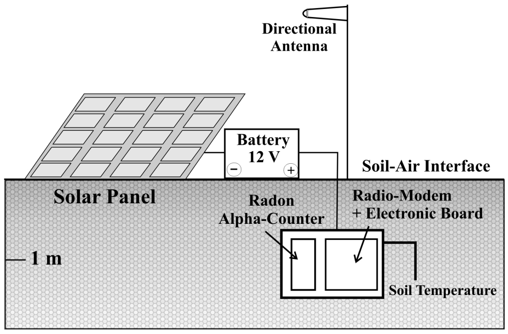

Figure 1: Sketch of the ^{222}Rn real-time monitoring station placed at Stromboli volcano. The station (contained in the polycarbonate case) with the dosimeter and the electronic board. This case has been inserted in the PVC box at about 30 cm from the bottom soil (see text for details). Sensors are connected with the radio-modem placed near the radon detector inside the buried container, being protected from atmospheric agents. The radio-modem is linked to the directional antenna for data transfer at the Stromboli Observatory (COA).

±25% significantly decreasing at higher activities [2], an average concentration of 200 Bq during eight hours measurements gives an error of ±20%. In the reported data (Fig. 2) we utilized the Fast Mode counting since ^{214}Po tends to cluster with aerosol particles. Moreover, this option bypasses the uncertainties related to thoron interferences on the ^{214}Po peaks. Inside the container it has been placed a desiccant to avoid the accumulation of humidity in the buried volume, keeping the air inside relatively dry. In addition, a sensor measures permanently the soil temperature at 1 m depth under the measurement box. A digital barometer is collecting atmospheric pressure data. All the data are automatically acquired every 15 minutes and automatically transferred through a directional antenna to the receiving station placed at the Stromboli Volcano Observatory (COA-Centro Operativo Avanzato; Dipartimento Protezione Civile). The container-box system has been shown to be particular effective in detecting a more coherent radon signal [4].

3. Results and discussion

At LSC station, the one placed at the Liscione site, the average sum of daily counts, considering the entire energy window (4.5-10 MeV, which includes all the 5 ROIs), is about 700 cts; where a 6% is represented by ^{220}Rn, the 55% corresponds to the sum of the few ^{222}Rn αs directly striking to the silicon and ^{218}Po counts, and the remaining is stored as ^{214}Po. As cited above, in order to analyze radon concentration, we use the sum of the ^{222}Rn and ^{218}Po contributions to α spectra. The time series for the radon data collected at the LSC site (Fig. 2) exhibits a clear negative correlation between ^{222}Rn concentration and soil temperature. The relationship with atmospheric pressure are more complex to analyze. The correlation coefficients between radon and the above environmental parameters are -0.8 and -0.4, respectively, considering daily average values. Occasionally, positive short-time peaks in radon are related to the occurrence of rainfall episodes (Fig. 2). This behavior seems to be linked to the capability of water in the porous medium to increase the radon emanation factor, drastically enhancing its mobility trough the soil pores. Hence, at Stromboli, this process is associated with general decreases in soil temperatures accompanied by a marked increase in radon emissions. In order to minimize short-time variations, partially related to the sensitivity of instruments, we analyzed radon data in terms of daily average concentrations. Higher ^{222}Rn activities were measured during fall-winter periods with maximum values approaching 5000 Bq/m^3, and average emissions throughout the whole period of 2330 Bq/m^3 (±990). Conversely, during the spring-summer season radon concentrations show minor variations, mainly related to the absence of change in soil humidity (e.g. rainfall episodes) with daily average activities of 1040 Bq/m^3 (±580). This variability is essentially related to the summer time heating of the Earth's surface: a seasonal inversion in the near surface temperature gradient affects the flow geometry of the convective cells, by creating a barrier to the upward migration of radon [5]. We finally emphasize that a statistical treatment of radon data is crucial to be able to remove the contribution of the environmental parameters (such as soil temperature, atmospheric pressure and tidal forces) on the recorded radon signals [4]. Our goal is to test the capability radon monitoring as potential tracer for forecasting variations in volcanic activity.

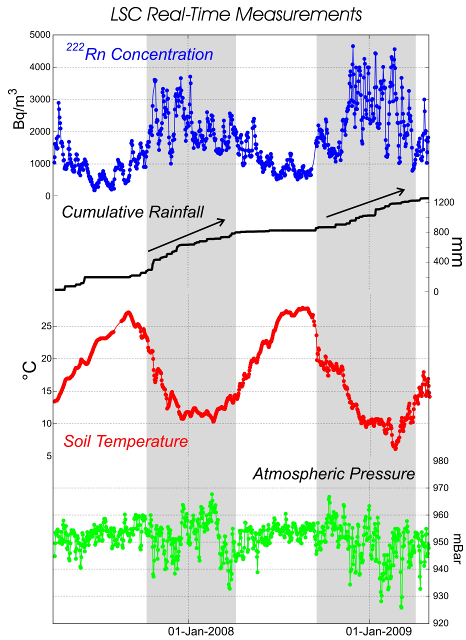

Figure 2: Time series of ^{222}Rn concentration (upper curve) at the Liscione site (LSC) together with the cumulative curve for rainfalls (obtained from the data of the Messina station - Servizio Metereologico Aeronautica), soil temperatures (at 1 m depth) and atmospheric pressure (mbar).

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