SCIENCE OF THE TOTAL ENVIRONMENT 407 (2009) 2361–2371

available at www.sciencedirect.com

ScienceDirect

www.elsevier.com/locate/scitotenv

ELSEVIER

Science of the Total Environment

Temporal variations of radon concentration in the saturated soil of Alpine grassland: The role of groundwater flow

Frédéric Perrier[a,*], *Patrick Richon*[b,c], *Jean-Christophe Sabroux*[d]

[a]*Equipe de Géomagnétisme, Institut de Physique du Globe de Paris and University Paris Diderot, UMR7154, 4, Place Jussieu, F-75005 Paris, France*
[b]*Département Analyse, Surveillance, Environnement, CEA, DAM, DIF, F-91297 Arpajon, France*
[c]*Equipe Géologie des Systèmes Volcaniques, Institut de Physique du Globe de Paris, UMR7154, F-75005, Paris, France*
[d]*Institut de Radioprotection et de Sûreté Nucléaire, Centre de Saclay, B.P. No 68, F-91192 Gif-sur-Yvette, France*

ARTICLE DATA

Article history:
Received 6 July 2008
Received in revised form
26 November 2008
Accepted 3 December 2008
Available online 20 January 2009

Keywords:
Radon-222
Meteorological effects
Temperature effect
Water infiltration
Transit time
Soil water content
Soil hydrology

ABSTRACT

Radon concentration has been monitored from 1995 to 1999 in the soil of the Sur-Frêtes ridge (French Alps), covered with snow from November to April. Measurements were performed at 70 cm depth, with a sampling time of 1 h, at two points: the summit of the ridge, at an altitude of 1792 m, and the bottom of the ridge, at an altitude of 1590 m. On the summit, radon concentration shows a moderate seasonal variation, with a high value from October to April (winter), and a low value from May to September (summer). At the bottom of the ridge, a large and opposite seasonal variation is observed, with a low value in winter and a high value in summer. Fluctuations of the radon concentration seem to be associated with temperature variations, an effect which is largely delusory. Indeed, these variations are actually due to water infiltration. A simplified mixing model is used to show that, at the summit of the ridge, two effects compete in the radon response: a slow infiltration response, rich in radon, with a typical time scale of days, and a fast infiltration of radon-poor rainwater. At the bottom of the ridge, similarly, two groundwater contributions compete: one slow infiltration response, similar to the response seen at the summit, and an additional slower response, with a typical time scale of about a month. This second slower response can be interpreted as the aquifer discharge in response to snow melt. This study shows that, while caution is necessary to properly interpret the various effects, the temporal variations of the radon concentration in soil can be understood reasonably well, and appear to be a sensitive tool to study the subtle interplay of near surface transfer processes of groundwater with different transit times.

1. Introduction

Radon-222, radioactive daughter with half-life 3.8 days of radium-226, is found in groundwater and the air space of rocks and soils, from where it is transported to the open atmosphere, surface dwellings and underground cavities (Nazaroff, 1992). It causes more than half of the radiation dose to the general population (Porstendörfer, 1994) and thus can be considered as a major health issue. In the soil, radon concentration can reach high values, 50×10^3 Bq m^{-3} or larger, and thus the soil represents a large fraction of the radon source into buildings. It is therefore important to better understand the factors controlling radon generation in the soil and its transport properties, from the soil to the atmosphere, and, similarly, from the bedrock to the atmosphere across the soil layer.

* *Corresponding author.* Tel.: +33 1 44272411; fax: +33 1 44273777.
E-mail address: perrier@ipgp.jussieu.fr (F. Perrier).

0048-9697/$ – see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.scitotenv.2008.12.018

Radon concentration in the soil is affected by large temporal variations due, for example, to atmospheric pressure (Clements and Wilkening, 1974) or to temperature and moisture variations (Washington and Rose, 1990, 1992). While long radon time series remain rare, seasonal variations of the radon concentration have been observed to exhibit various patterns. In Germany, high concentrations are observed in winter due to a frozen top soil layer (Winkler et al., 2001) while low concentrations are reported during dry periods. By contrast, in Slovenia (Zmazek et al., 2003) or in Jordan (Al-Shereideh et al., 2006), radon concentration tends to show a high value in summer. In Greece, both high and low summer levels are observed (Richon et al., 2007). In the soil of permeable glacial sediments in Norway, large seasonal variations have been linked to temperature driven convection currents, with high and low levels in summer depending on the position with respect to the air circulation (Sundal et al., 2008).

These various examples indicate that it is difficult to recognize general features; various factors are at play to control the radon concentration in the soil. The first factor is the radon source, namely the radium-226 concentration multiplied by the probability of releasing the radon atom in the pore space, called the emanation factor. Once in the pore space, radon is transported, in the water or the air phases, by diffusive or advective modes having vastly different properties and seasonal dependences. In addition, the ratio between the radon concentration in water and in air, referred to as the partition coefficient, depends on temperature. The transport of radon in the soil, in general, is therefore a complex combination of elementary processes in the water and in the air phases. To improve our understanding of the temporal variability of the radon concentration in the soil, it is interesting to concentrate on sites where a single transport mechanism dominates.

In this paper, we present the results of monitoring the radon concentration in the soil over significant durations, from 1995 to 1999, at two points located in Alpine grassland. This site is covered by 1 to 2 m of snow from October to April and, over the whole year, is subject to intense precipitation of the order of 1400 mm per year. The soil in such conditions is expected to remain saturated and, therefore, offers an interesting possibility to isolate temporal variations due to groundwater transport.

2. Site and experimental methods

The two radon measurement points (SF and CH) are located on the Sur-Frêtes east–west trending ridge (Fig. 1), located in the French Alps (Trique et al., 1999, 2002). The ridge separates two artificial lakes (Fig. 1): La Gittaz lake to the north and the Roselend lake to the south. The SF point is located on the top of the ridge, at an altitude of 1792 m above sea level (a.s.l.). The CH point is located at the bottom of the south flank of the ridge, at an altitude of 1590 m a.s.l., 15 m below an old chapel and 35 m

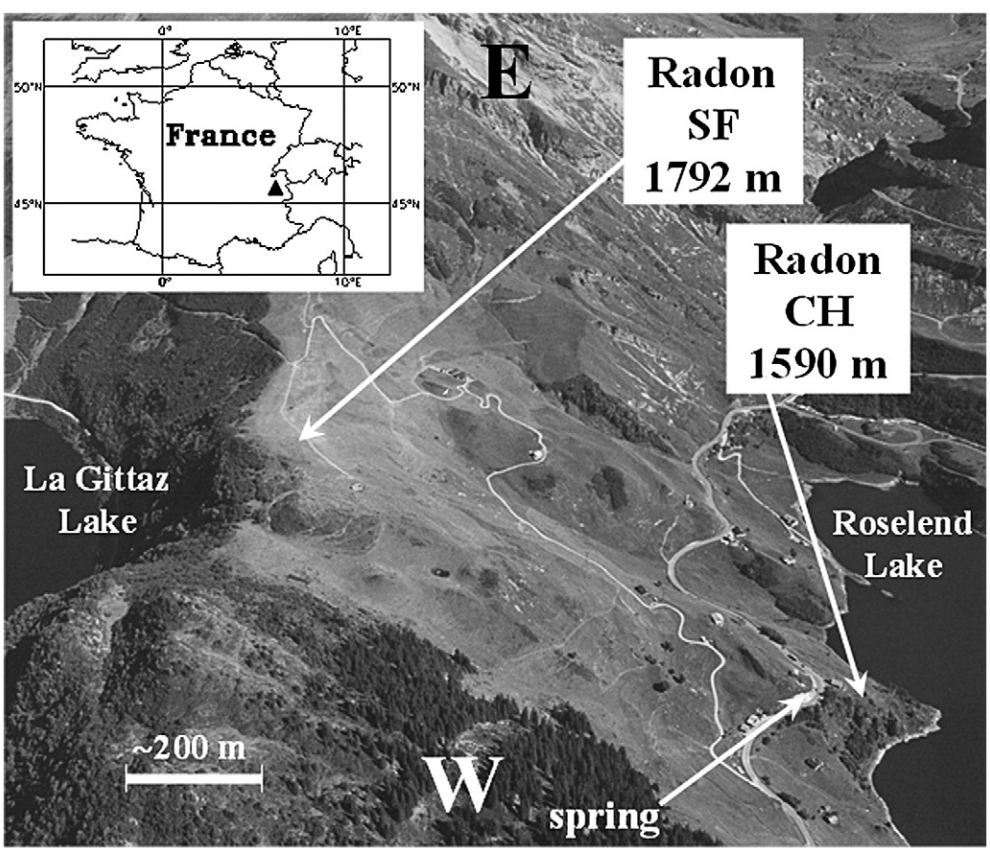

Fig. 1 – View of the Sur-Frêtes ridge (French Alps). Radon concentration is monitored at the summit (point SF) and below the Roselend chapel (CH point), above the shore of the Roselend lake.