IRSN
INSTITUT DE RADIOPROTECTION ET DE SÛRETÉ NUCLÉAIRE

Faire avancer la sûreté nucléaire

Radon production and migration in karstic environment: experimental data and numerical modelling (Fourbanne site, French Jura Mountains)

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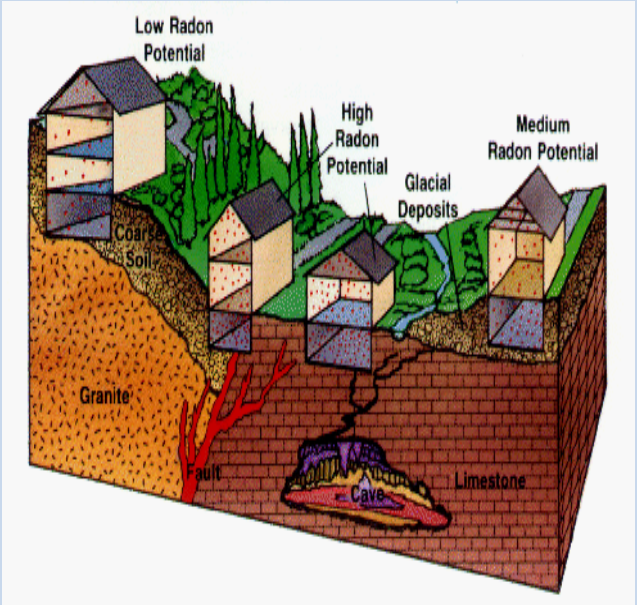

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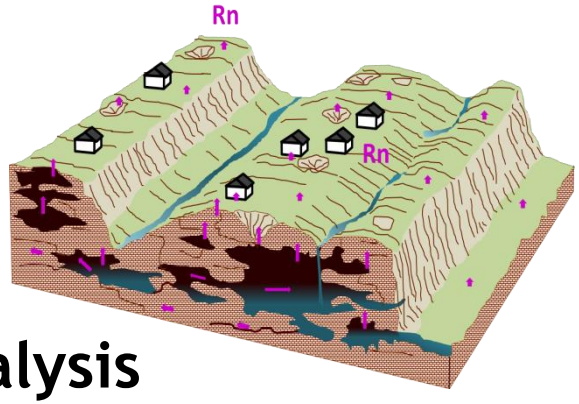


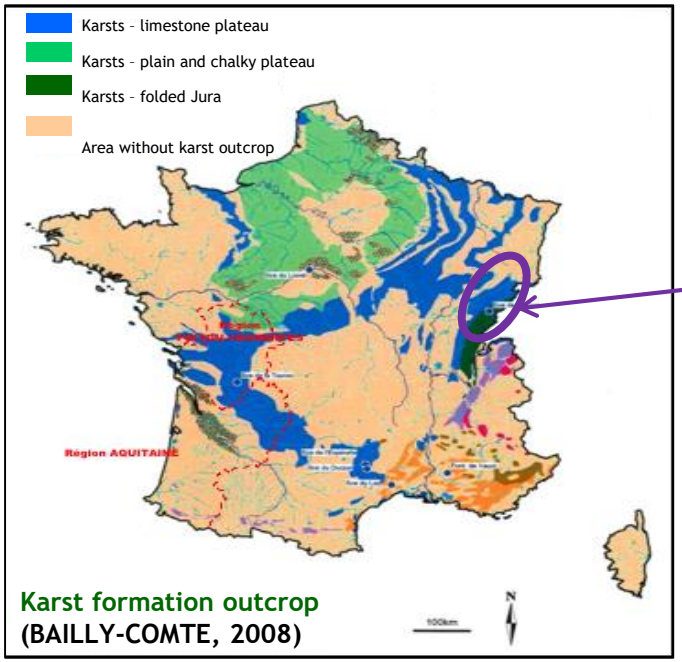
- Context
- Objectives
- Experimental study and data analysis
- Numerical modelling
- Conclusions
- Perspectives

Context

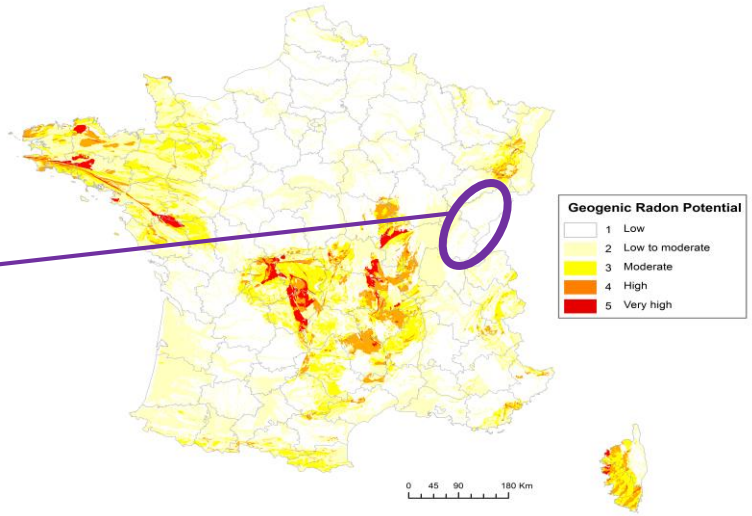
Mapping of geogenic radon potential for France (IRSN, 2010):

to determine the ability of geological formation to produce and transport radon towards surface

Higher radon potential are generally observed in areas characterized by Hercynian granitic or metamorphic rocks, Permian sandstones/pelites, coal-rich sedimentary rocks, acid volcanites (trachytes…) for examples, and/or by major faults and mines.



Karst formation outcrop
(BAILLY-COMTE, 2008)



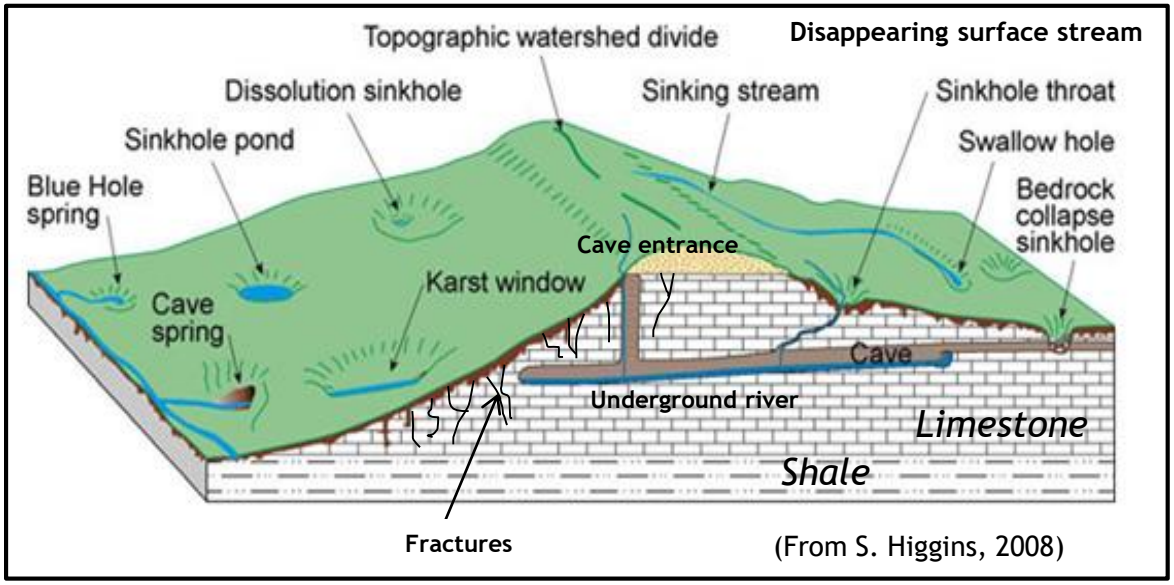
Jura Mountains, at the border with Switzerland

- High indoor radon levels (>300Bq/m^3) are observed in one karst region (Franche-Comté)
- Karstic areas are represented with low geogenic radon potential (limestone)

Objectives

- To evaluate the potential influence of karstic area on the radon levels in soils
  - To evaluate the impact of karst on the geogenic radon potential

Diagram of karst features :



- Strong heterogeneity of karsts typology over French territory (fractures, cave,..)
- Complexity of the geological structures of karst environments.
- Air exchange between the cave and the outside atmosphere

→ Experimental data acquisition

→ Numerical modelling

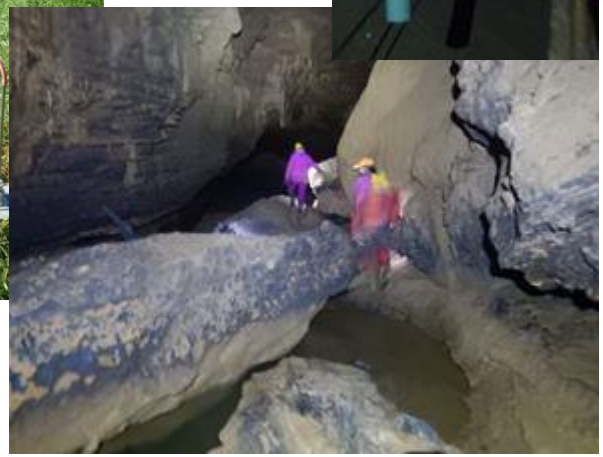
Experimental study and data analysis

Jura Mountains, at the border with Switzerland

- In situ measurements in the cave
- In situ measurements in the soil
- In situ measurements across faults

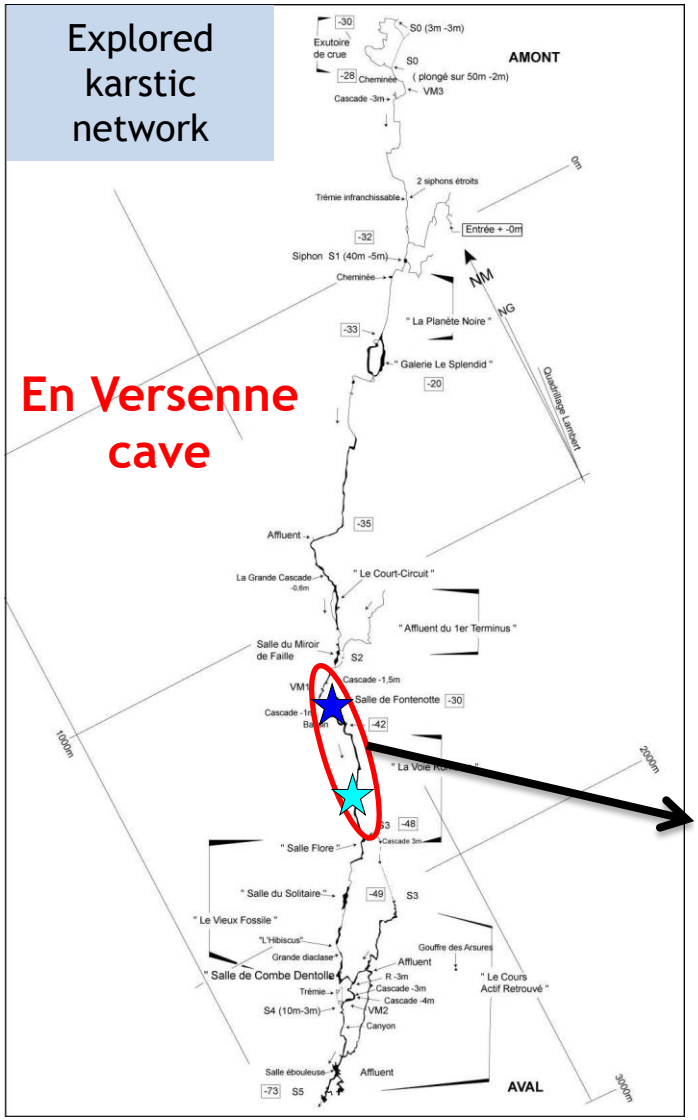






Measurements in the cave

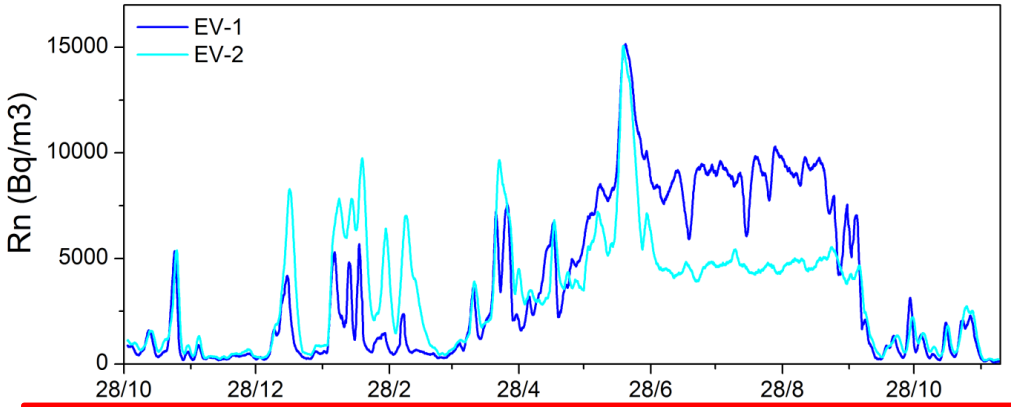
Explored karstic network



- Continuous hourly measurement over one year (Rn-222, pressure, temperature) with BMC2
- Ra-226 in rocks and sediments
- Hydrological and hydro-chemical measurements: water turbidity, water conductivity, water height, ..

^{226}Ra (limestone) = 10-20 Bq/kg

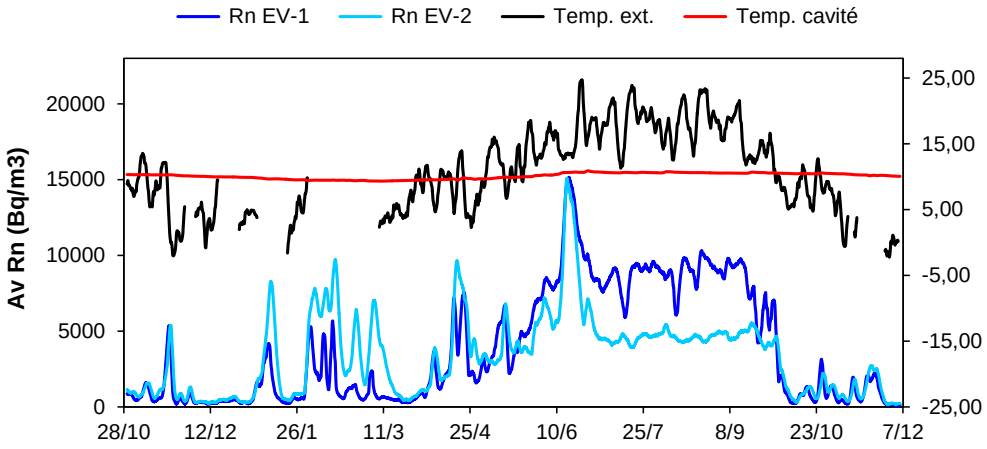
^{226}Ra (sand) = 60-120 Bq/kg

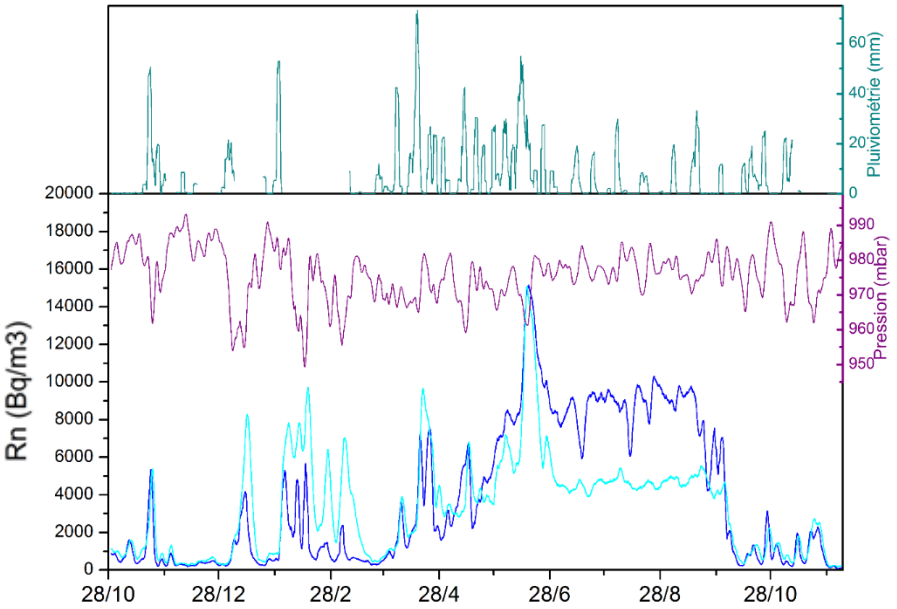


No significant spatial variations of Rn signal in the cave

Rn concentrations in the cave

Important seasonal fluctuation :
higher Rn activity concentrations in summer



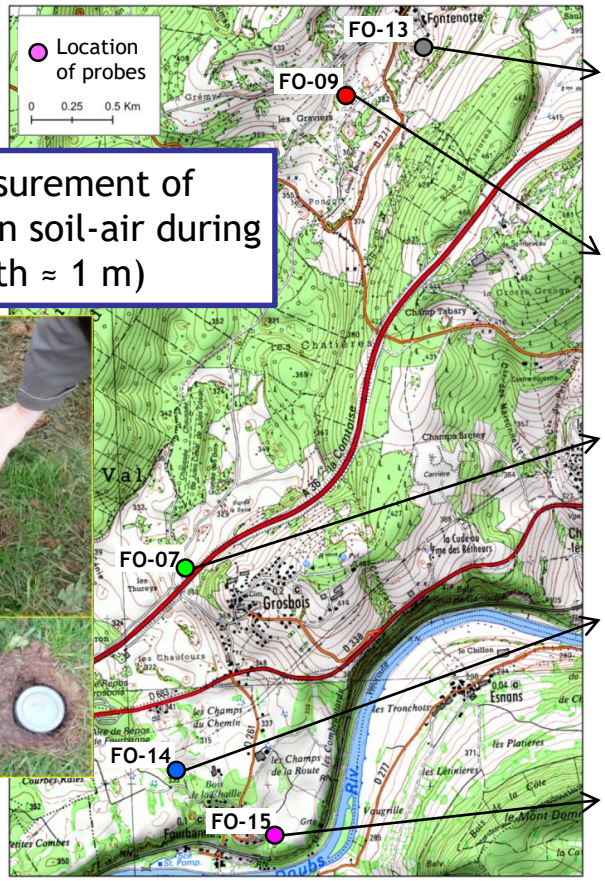


Radon content increase when temperature outdoor > temperature indoor
Less natural ventilation in summer

Several Rn anomalies in cave are correlated with pressure drops and heavy rains period

Measurements in soil air

Hourly measurement of ^{222}Rn level in soil-air during 1 year (depth ≈ 1 m)



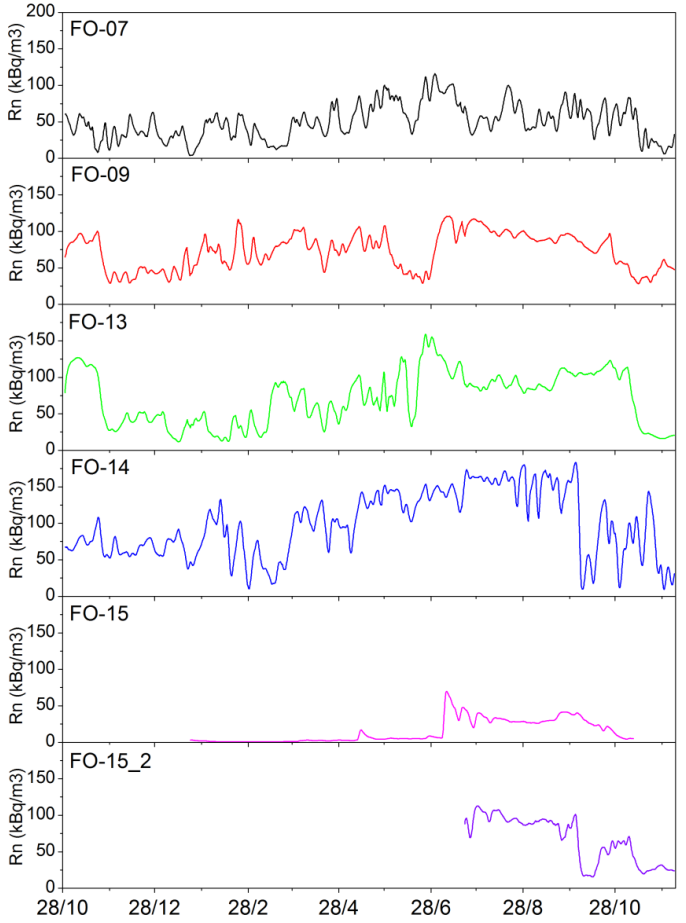
^{226}Ra = 74 Bq/kg
$^{222}Rn_{avg}$ = 71 546 Bq/m^3

^{226}Ra = 83 Bq/kg
$^{222}Rn_{avg}$ = 72 906 Bq/m^3

^{226}Ra = 79 Bq/kg
$^{222}Rn_{avg}$ = 50 081 Bq/m^3

^{226}Ra = 96 Bq/kg
$^{222}Rn_{avg}$ = 98 891 Bq/m^3

^{226}Ra = 54 Bq/kg
$^{222}Rn_{avg}$ = 66 875 Bq/m^3



- Very significant fluctuations of radon concentrations
- The radon concentrations can be very important

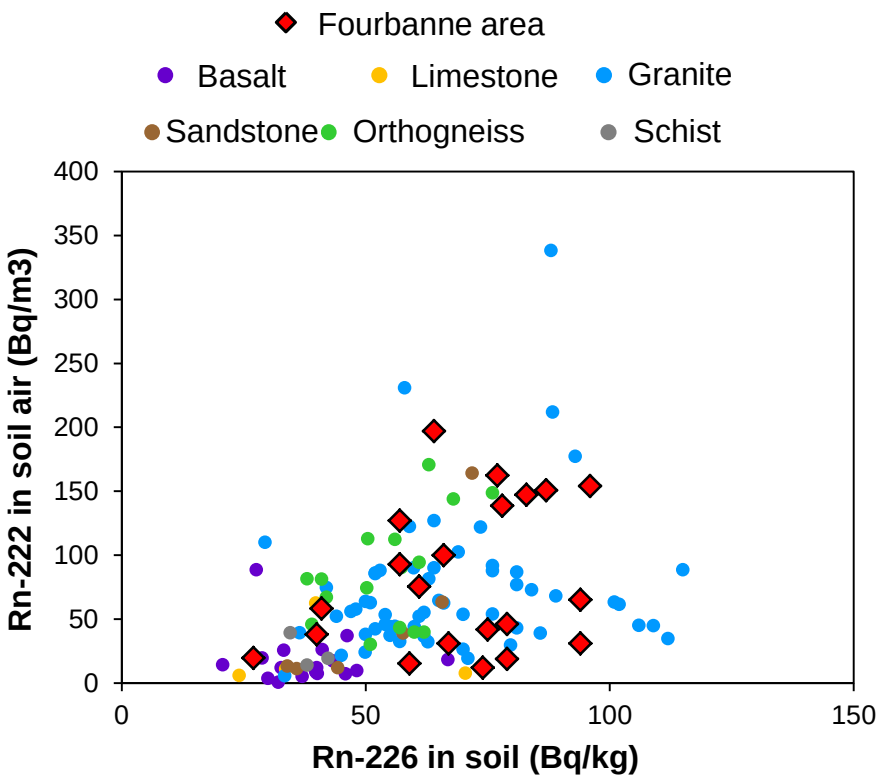
Rn concentrations in soil air

- Comparison of measurement results with other data previously acquired by IRSN in France

→ Radon levels consistent with measured soil radium-226 content

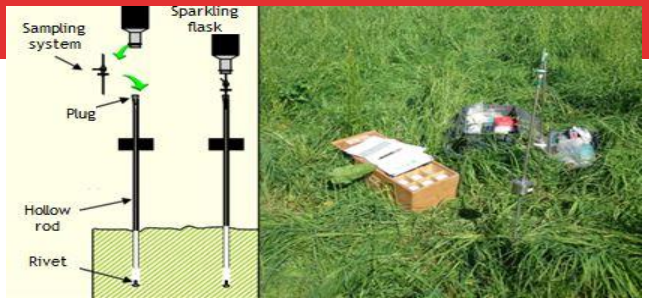
- Soil radium-226 contents similar to those observed in granitic soils

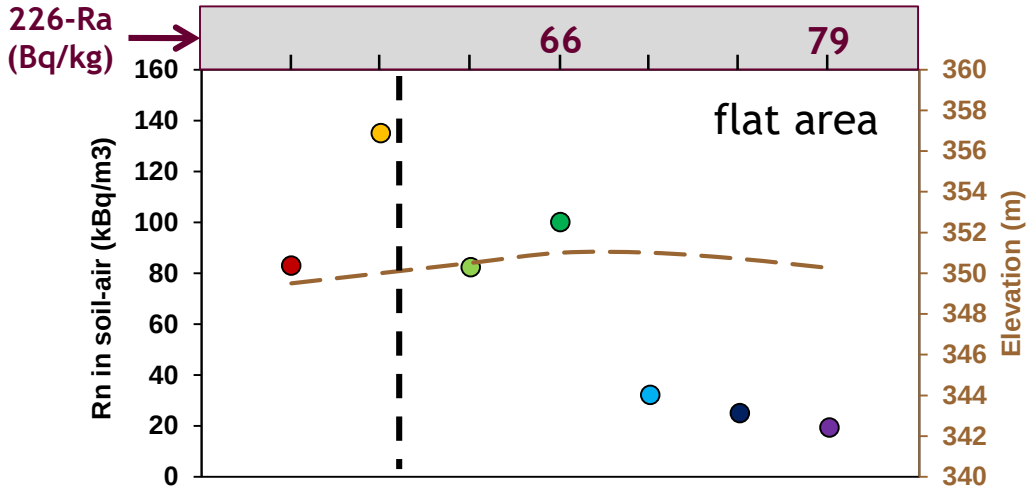
→ Existence of a relative enrichment in radium in the soil of this karstic area



Measurements across faults

- Single-time measurement of ^{222}Rn level in soil-air (depth ≈ 50 cm)
- ^{226}Ra of soil measured in different part of the profiles

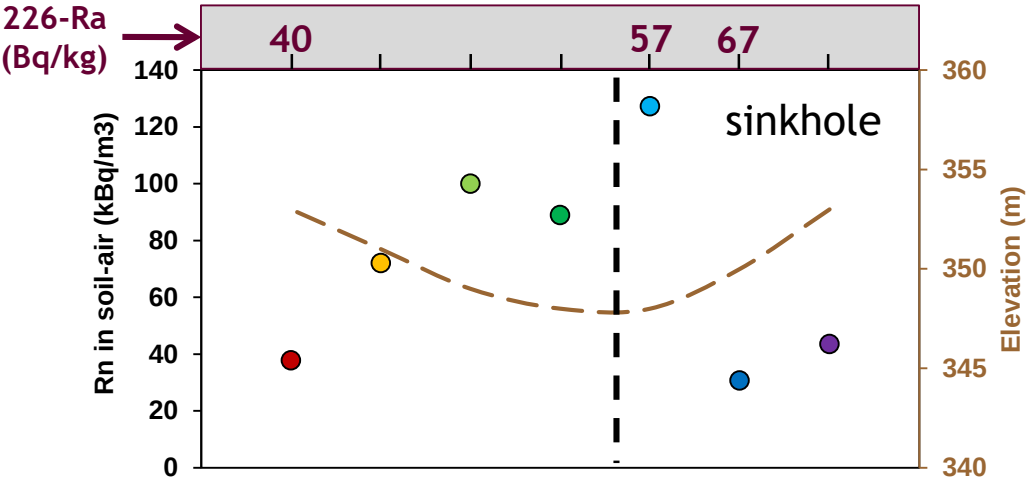




- 7 Rn measurements made in a flat area
- Total length of profile = 100 m
- Space between measurements = 15 m

- Larger Rn fluctuations
- Radon content in soil air increases near the fault

→ no topographic effect

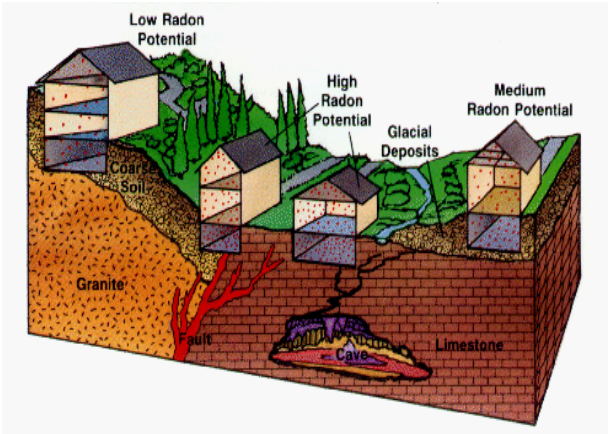


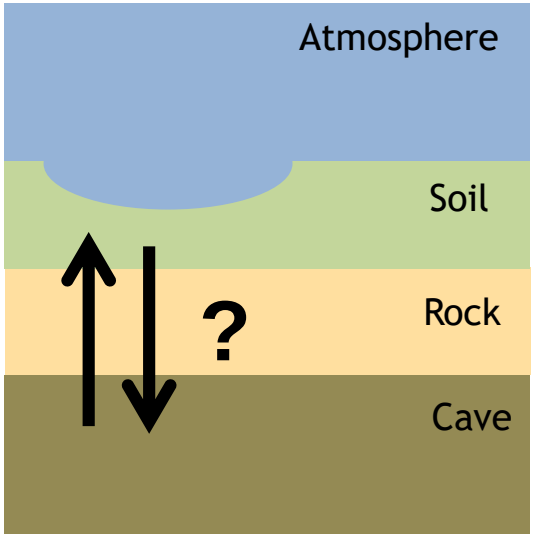
- 7 Rn measurements made in Fontenotte sinkhole (FO-13)
- Total length of profile = 70 m
- Space between measurements = 12 m

- Significant Rn fluctuations over a short distance
- Radon content increases in soil air near the fault corresponding to the bottom of sinkhole

Numerical modelling

- Numerical tool: T2Rn
- Mathematical model
- Periods of interest
- Results





Numerical tool: T2Rn

- **T2Rn**: Rn flow and transport in soil and rock with matrix-fracture interaction (IRSN, Saadi et al. 2016)
- **TOUGH2**: transport of unsaturated groundwater and heat (Lawrence Berkeley National Laboratory (LBNL), Pruess et al. 1999)
- **EOS7R**: module for radionuclide transport

Multidimensional	1D, 2D, 3D
Two-phase	liquid, gas
Three-components	water, radon, air
Non-isothermal	Heat transfer
Flow and transport	Darcy and Fick laws
Fractured porous media	dual-ϕ, dual-k, MINC, ECM

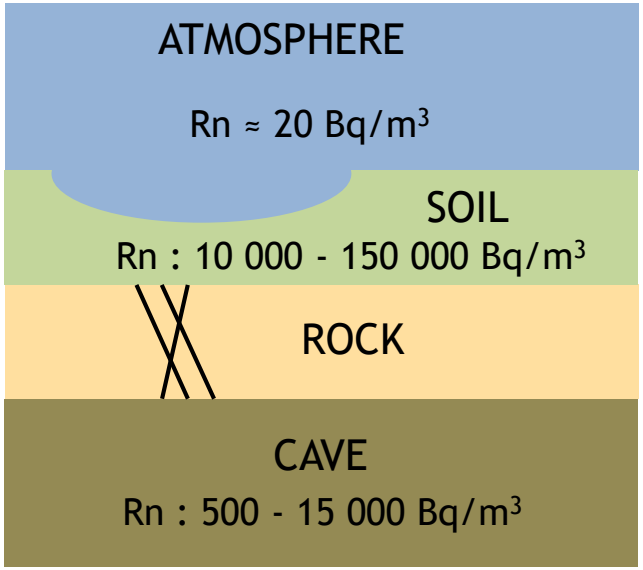
Radon physical properties: Diffusion; Dissolution; Adsorption; Emanation

Mathematical model

Initial condition:
position of water table

Physical properties:
porosity + soil permeability

Geometrical characteristics of the domain:
Layer thichness, Width, …



Soil radon source and transport properties:
Emanation coef., Diffusion coef., Henry low coef., Radium-226 activity mass content

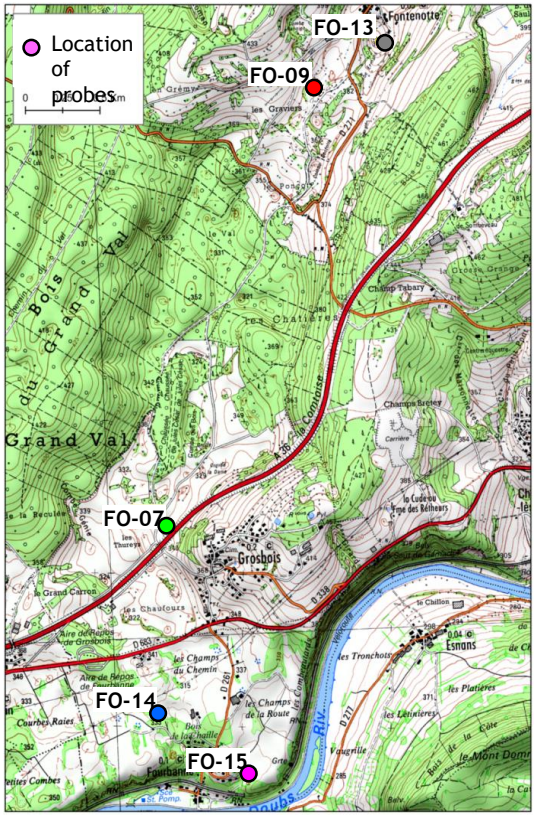
Boundary conditions:
Rn concentration in the cave,
Cave air Pressure,
Atmospheric air pressure,
Rainfal

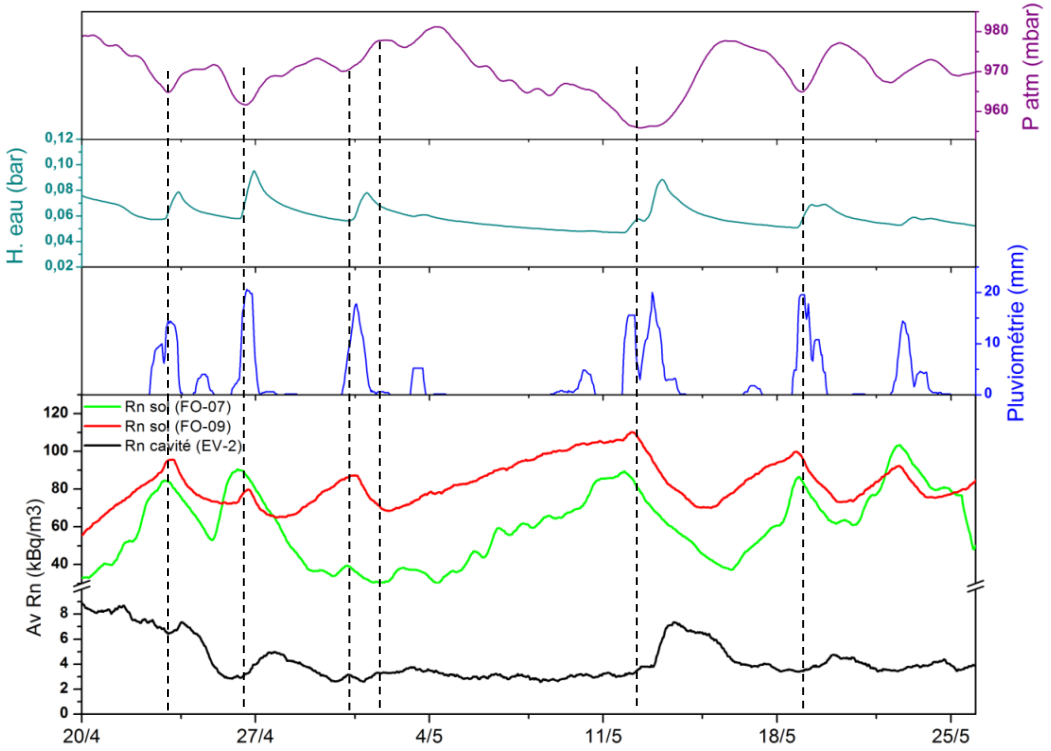
Hydrodynamic properties:
Capillary pressure, relative permeability,

- What are the factors influencing radon levels in the soil?
- Is there a transfer between the cave and the ground?
- What is the impact of sinkholes and fractures?

Periods of interest

- Analysis of variations in the soil (FO.09)
  - Selection of periods of interest : April – May 2016





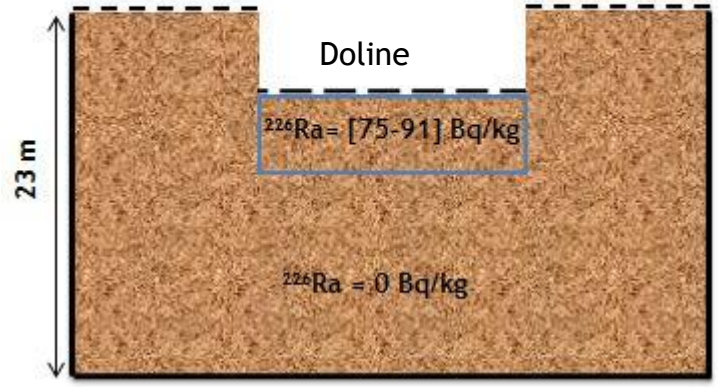
→ Radon peaks in soil also correlated with pressure drops and rain events

→ Effect of pressure or rainfall?

1st model configuration

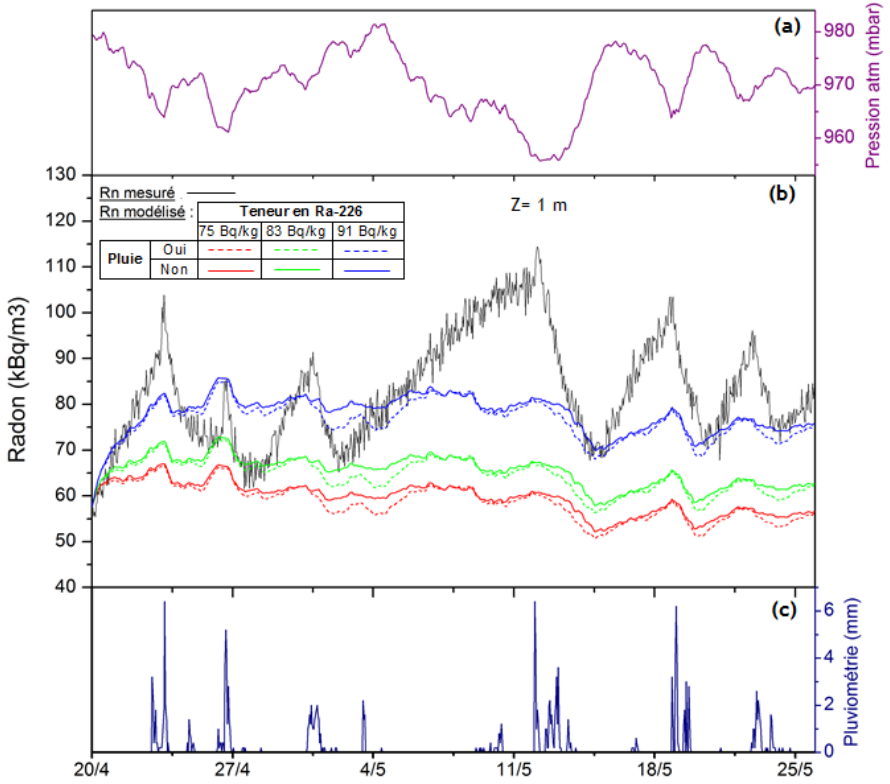
→ Quantification of soil impact

Temporal variations:
air pressure, rainfall, evapotranspiration



- Influence of surface temporal variations
- Not taking into account the physical parameters of the underlying rock
- With and without rainfall

2 m of soil : Ra = 75 - 91 Bq/kg

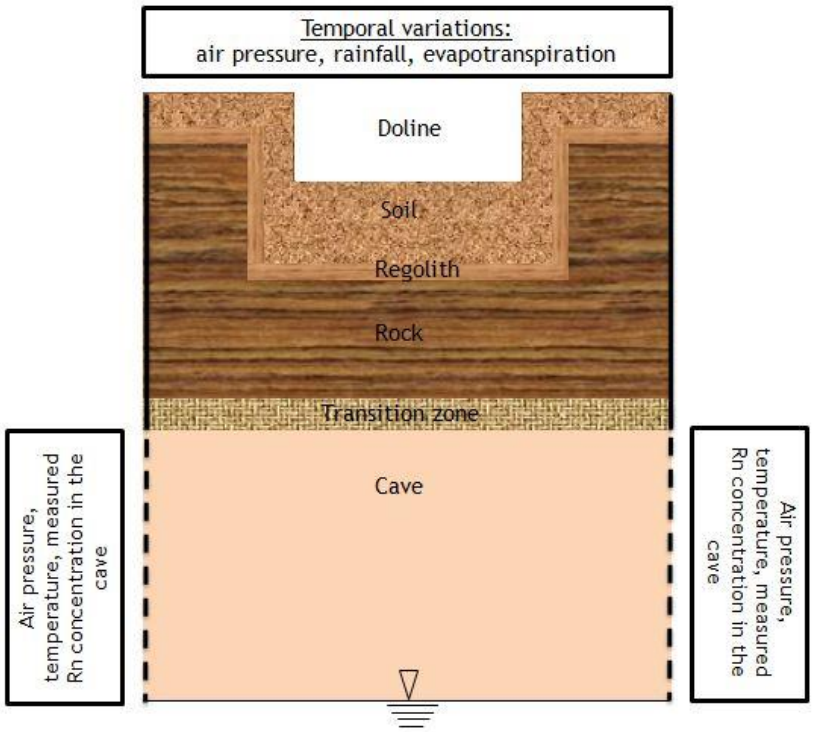


→ Average levels of radon result from radium-226 emanation from the soil

→ The sole consideration of the soil does not explain the fluctuations observed

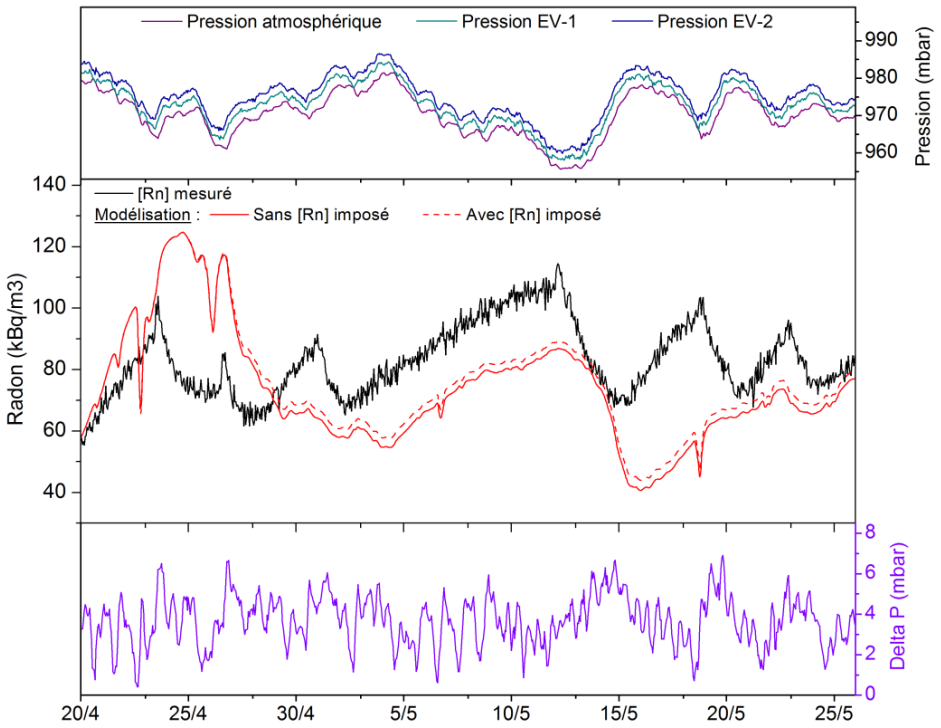
2nd model configuration

→ Quantification of the impact of the cave



- Influence of surface temporal variations
- Influence of the depression created by the cave

2 m of soil : Ra = 75 - 91 Bq/kg
16 m of rock : Ra = 17 - 19 Bq/kg
0.5 m of transition zone
16 m of cave



→ Amplitudes of Rn fluctuations related to soil pressure gradients caused by pressure fluctuations in the cave

→ Minimal cave impact on Rn levels: confirms that average radon levels result from soil radium

Conclusions

- This study confirmed that karstic environments could be the source of locally high radon contents in the soil
- Observation of a strong radon variability both spatial and temporal
- Lessons from the data analysis:
  - Measured radon-222 levels in soil air are consistent with soil radium-226 levels
  - In the cave, the seasonal variations are related to the difference in temperature with the surface which causes a flow of air and a dilution of the activities of volume of radon in winter
- Lessons from numerical modelling:
  - The average levels of radon activity in the soil are essentially the result of radium-226 emanation from the soil.
  - Fluctuations in radon volume activity observed in the soil appear to be related to the existence of pressure gradients from the cave to the ground generated by pressure variations in the cave.

Perspectives: new data

- Conduct a measurement campaign in the habitat
  - Distribution of radon measurement kits in the study area and at the Swiss border
- Complete the knowledge on the relationships between the radon activities in soil air and the radium-226 levels of soils in calcareous areas
  - Measurements in other karstic areas (Franche Comté, Causse, Provence ...) + measurements in non karstic areas
- Refine the results obtained by numerical modelling
  - Geophysical measurements: to know the structure of a sinkhole
  - Measurement of effective radium-226 concentrations (ECRa) of soil samples
  - Measurements of the physical properties of limestone (porosity and permeability)
- Make the model of radon transport in the study area over a second period

THANK FOR YOUR ATTENTION !