Characterization of the spatial and temporal variations of radon in six sites representative of the Spanish geography. Methods for obtaining an average representative value.

J**. García-Rubiano**[1], H. Alonso[1], M.A. Arnedo[1], J. Bach[3], J.A. Carrasco[4], M. A. Duch[5], Ll. Font[2], I. Fuente[6], J. Garcia-Orellana[2], M. García-Talavera[7], J.G. Guerra[1], C. Grossi[5], J. L. Gutiérrez[6], A. Hierro[2], F.J. López-Acevedo[7], P. Martel[1], V. Moreno[2], E. Navarro[4], L. Quindós[6], A. Ramírez[4], V. Rodellas[2], M.D. Rodriguez-González[5], C. Sainz[6], A. Sánchez[8], E. Sanz[8], A. Tejera[1], A. Vargas[5]

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Prague. 18-20 de September de 2018

GARRM 2018

Geological Aspects of Radon Risk Mapping

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DEPARTAMENT DE FÍSICA
UNIVERSIDAD DE LAS PALMAS DE GRAN CANARIA
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LaRUC
Laboratorio de Radiactividad Ambiental
CSN Consejo de Seguridad Nuclear
geomnia
GEOCISA

Outline

UNIVERSIDAD DE LAS PALMAS DE GRAN CANARIA
Departamento de Física

Introduction

Spanish project for radon risk assessment in building - Objectives

4 university groups with experience on soil-gas radon measurements and radon metrology (UAB, UCAN, ULPGC, UPC)

Geologic assessment from 1 company (Geomnia) and collaboration from Geocisa.

Main goal: **Development and experimental validation of a methodology to obtain the soil-gas radon level representative of a piece of ground in Spain → radon risk assessment.**

Specific objectives

1. Establish a standard procedure to measure radon activity concentration in soil.
2. Provide guidelines for the determination of representative values of soil gas radon concentration and soil gas-permeability ("standard methodology")
3. Explore alternative methods when standard methodology cannot be used.
4. Explore applicability of radon-risk assessment based on in-situ measurements.
5. Provide recommendations on radon risk-assessment.

Font et al. Presentation

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Introduction

Spanish project for radon risk assessment in building - Methodology

WP1: Management & coordination   Ll. Font (UAB), M. García-Talavera (CSN)

WP2: Standard Procedure   Ll. Font (UAB)

WP3: Quality Control   A. Vargas (UPC), V. Moreno (UAB)

WP4: Representative value   J. Gª Rubiano and Héctor Alonso (ULPGC), and L. Quindós (UCAN)

Both spatial and temporal variations taken into account.

WP5: Alternative methods

- Rn exhalation.   V. Moreno (UAB)
- Ra content.   J. Garcia-Orellana (UAB), A. Vargas (UPC)
- Use of maps.   M. García-Talavera (CSN), C. Sainz (UCAN), C. Grossi (UPC)

WP6: Surveys in selected sites   All participants.

WP7: Geological studies   E. Sanz, A. Sánchez (Geomnia Natural Resources S.L.N.E)

Font et al. Presentation

Introduction

Objectives of WP-4 (Stablished at the beginning of the project).

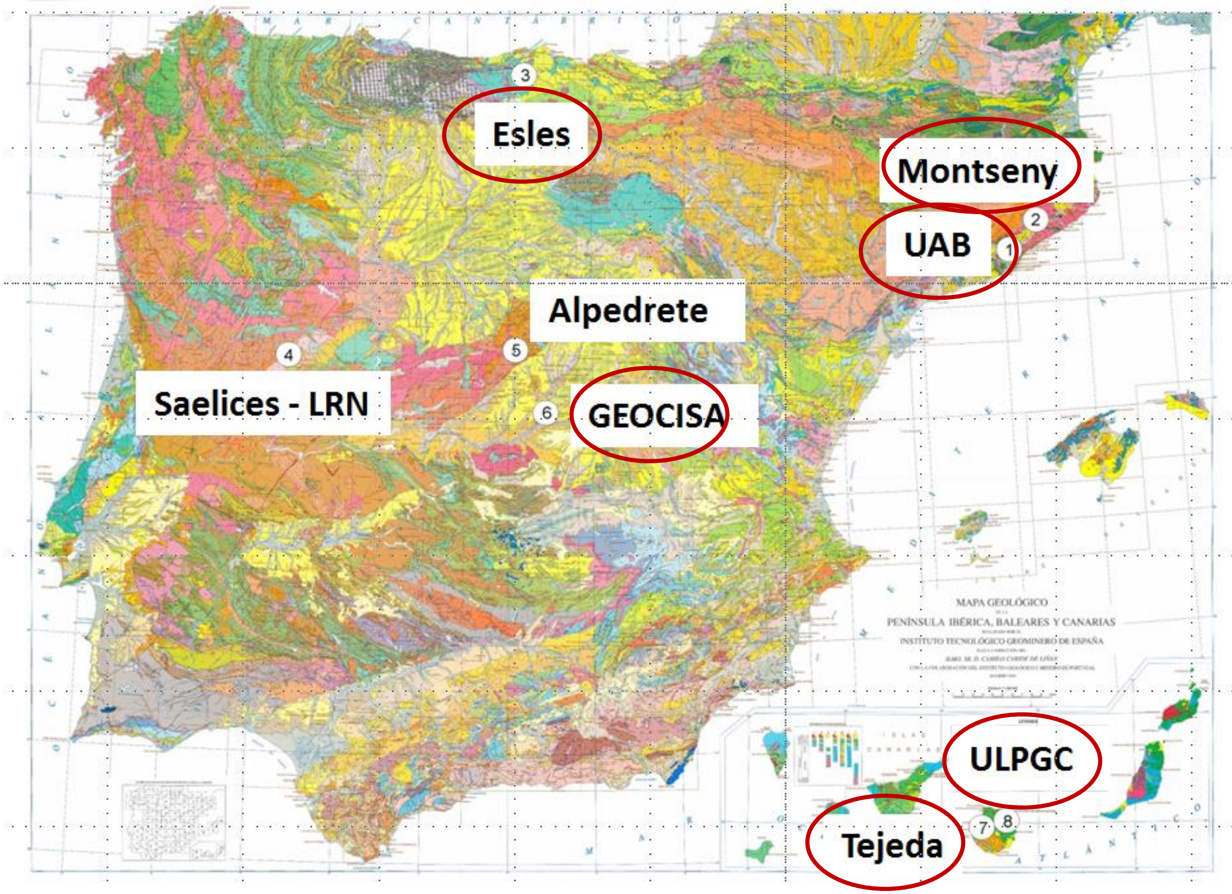
- Establishment of the statistical criterion for determining the representative average value of each site.
- Validation of the statistical criteria to establish the radon risk level of the sites.
- Analysis of the dispersions obtained according to the geological characteristics of each site.

Main goal: to study the spatial variability of radon gas in soils across the sites to propose a method that allows the classification of a 100 m^2 site used to built a dwelling using a minimum number of indicators.

These indicators should be simple to obtain, so that the protocol for soil radon measurement could be implemented realistically in a practical procedure. In this way, an additional objective of the work was to propose these indicators.

Introduction

Site selection: 8 sites have been selected trying to cover a significant part of the Spanish geological characteristics, taking into account available budget and practical considerations.



Experimental sites located in soils derived from distinct lithologies:

- Tertiary sedimentary basins (1,6)
- Paleozoic slates and sandstones (2,4)
- Mesozoic carbonates (3)
- Granites (5)
- Volcanic and volcaniclastic rocks (7,8)

Font et al. Presentation

Outline

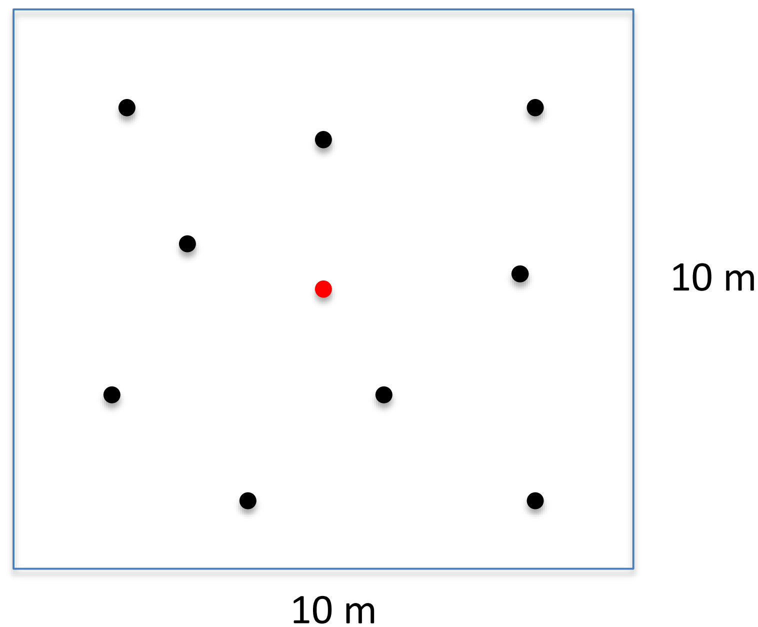
Material and methods

Survey design

The same dimensions in all sites (~100 m^2)

Soil-gas radon concentration:

- 9 measurement points that cover the site + 1 in the centre with a permanent steel rod.
- Unless 1 measurement at all points per season.
- 1 measurement/month at the central point.
- 1 specific soil radon profile measurement.



Important remark:

- At each site the responsible group performs Rn measurements with its own detectors and procedure → quality control required.

Material and methods

Procedure used for sampling Gal Radon in soil

- Standard method using a sampling depth of 80 cm. (ISO 11665-11:2016 Radon-222 - Test method for soil gas).
- Grab Sampling procedure
- In some of the sites (but not in all), the permeability of soils to gases has also been measured following the method established by Neznal et al.

Several Radon monitors and sampling systems

- Durridge RAD-7
- Saphymo AlphaGuard
- Sarad-Radon Scout
- RM-2 System (Radon v.o.s.)
- Several gas-sampling systems. (radon vos lost tip probes, AlphaGuard System probe, Durridge probe and self-constructed probes (UAB)

Material and methods

Spatial variability: To compare every pair of points taken in each land plot and determine which cannot be considered equals.

Procedures used to study the spatial variability

- **Variation coefficient** of spatial data samples: $CV_{Spatial} = \frac{\sigma_i^{Rn}}{\langle R_n(i) \rangle_{Spatial}}$ $i = 1,...10$ (number of samples through the site)
- Study of statistical distribution (normal, log normal, etc...) of all data (space and time)
- Use of **u-test** to analyse de differences between the values of the sampling points taking into account the instrumental uncertainties.

$$u_{test}^{avg} = \frac{|\langle Rn \rangle_{Spatial} - Rn(i)|}{\sqrt{u_{\langle Rn \rangle}^2 - u_{Rn(i)}^2}}; \qquad u_{test}^{GM} = \frac{|GM(Rn)_{Spatial} - Rn(i)|}{\sqrt{u_{\langle Rn \rangle}^2 - u_{Rn(i)}^2}}$$

u-test limits commonly used.

Condition	Status
$1.64 > u_{test}$	The reported result does not differ significantly from the expected value.
$1.64 < u_{test} < 1.96$	The reported result probably does not differ significantly from the expected value.
$1.96 < u_{test} < 2.58$	It is not clear whether the reported result differs significantly from the expected value.
$2.58 < u_{test} < 3.29$	The reported result is probably significantly different from the expected value.
$3.29 < u_{test}$	The reported result is significantly different from the expected value.

- Geostatistical analysis: **Contour plot by Kriging interpolation**.

Material and methods

Temporal variability: To compare every pair of months in each land plot and determine which cannot be considered equals.

Procedure used to study the temporal variability

- **Variation coefficient** of temporal data samples: $CV_{Spatial} = \frac{\sigma_j^{Rn}}{\langle Rn(j) \rangle_{Temporal}} \quad j = 1,\ldots n$ (number of samples through the time)

- Use of **u-test** to analyse the differences between the values of the sampling points in time.

$$u_{test}^{avg} = \frac{|\langle Rn \rangle_{temporal} - Rn(j)|}{\sqrt{u_{\langle Rn \rangle}^2 - u_{Rn(j)}^2}}; \qquad u_{test}^{GM} = \frac{|GM(Rn)_{temporal} - Rn(j)|}{\sqrt{u_{\langle Rn \rangle}^2 - u_{Rn(j)}^2}}$$

- **Welch test**: The Welch's t-test is utilized to prove the hypothesis that two populations have equal means. It is an adaptation of the t-student test but do not requires of the variances nor the samples size. The statistic of the Welch's t-test and the number of degrees of freedom are given by the equations:

$$t = \frac{\overline{x}_1 - \overline{x}_2}{\sqrt{\frac{s_1^2}{N_1} + \frac{s_2^2}{N_2}}} \qquad \upsilon \approx \frac{\left(\frac{s_1^2}{N_1} + \frac{s_2^2}{N_2}\right)^2}{\frac{s_1^4}{N_1^2 \upsilon_1} + \frac{s_2^4}{N_2^2 \upsilon_2}}$$

xi = arithmetic mean; si = standard deviations; Ni = number of data.

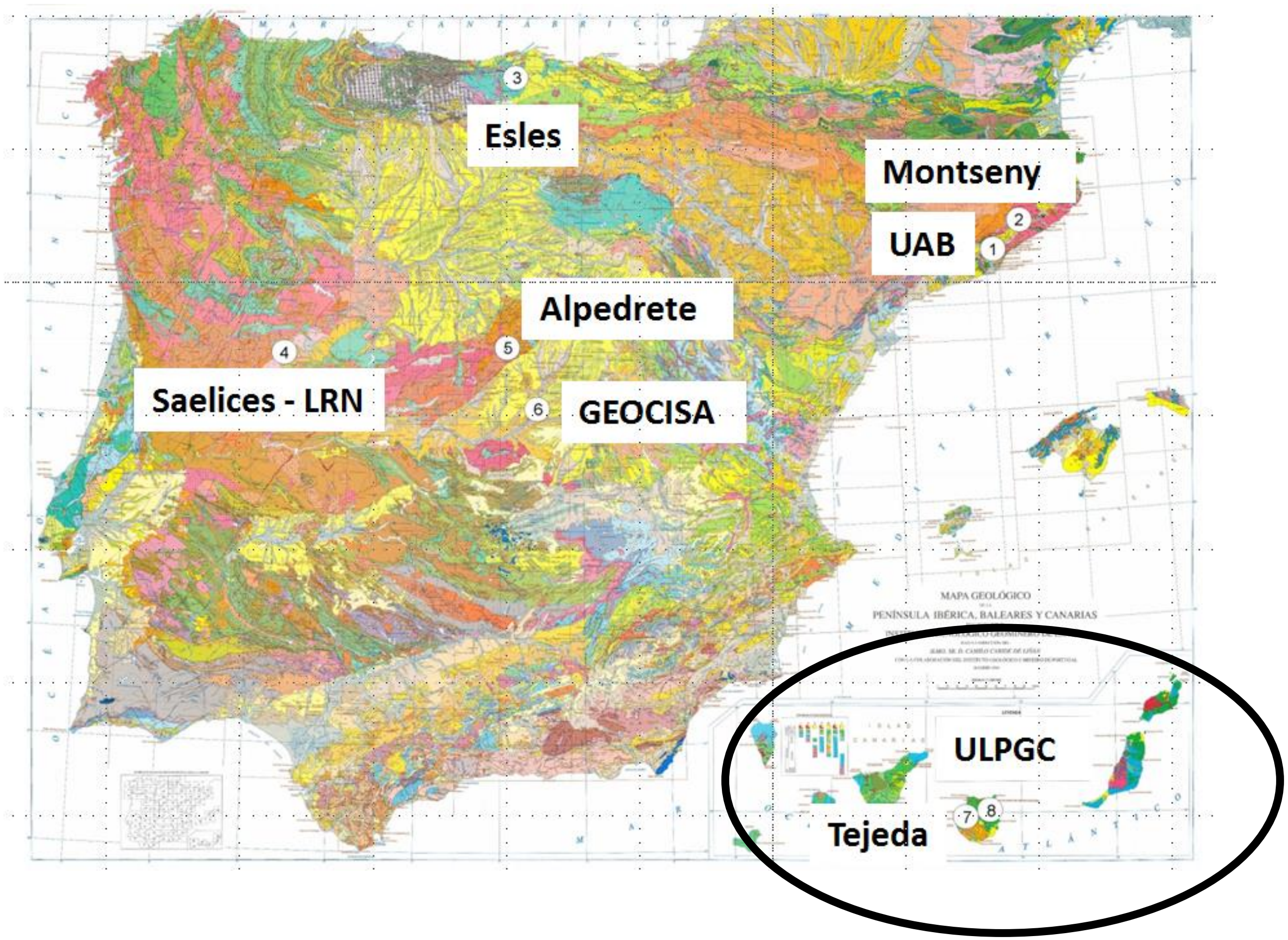
From t and υ, utilizing the t-student distribution, the p-value is obtained, indicating whether the null hypothesis can be accepted (p-value>=α) or must be rejected (p-value<α).

Outline

Results and discussion

Case study: ULPGC Sites

Results Site 1. Tafira.



Site 1. Campus of Tafira

Sites at Gran Canaria

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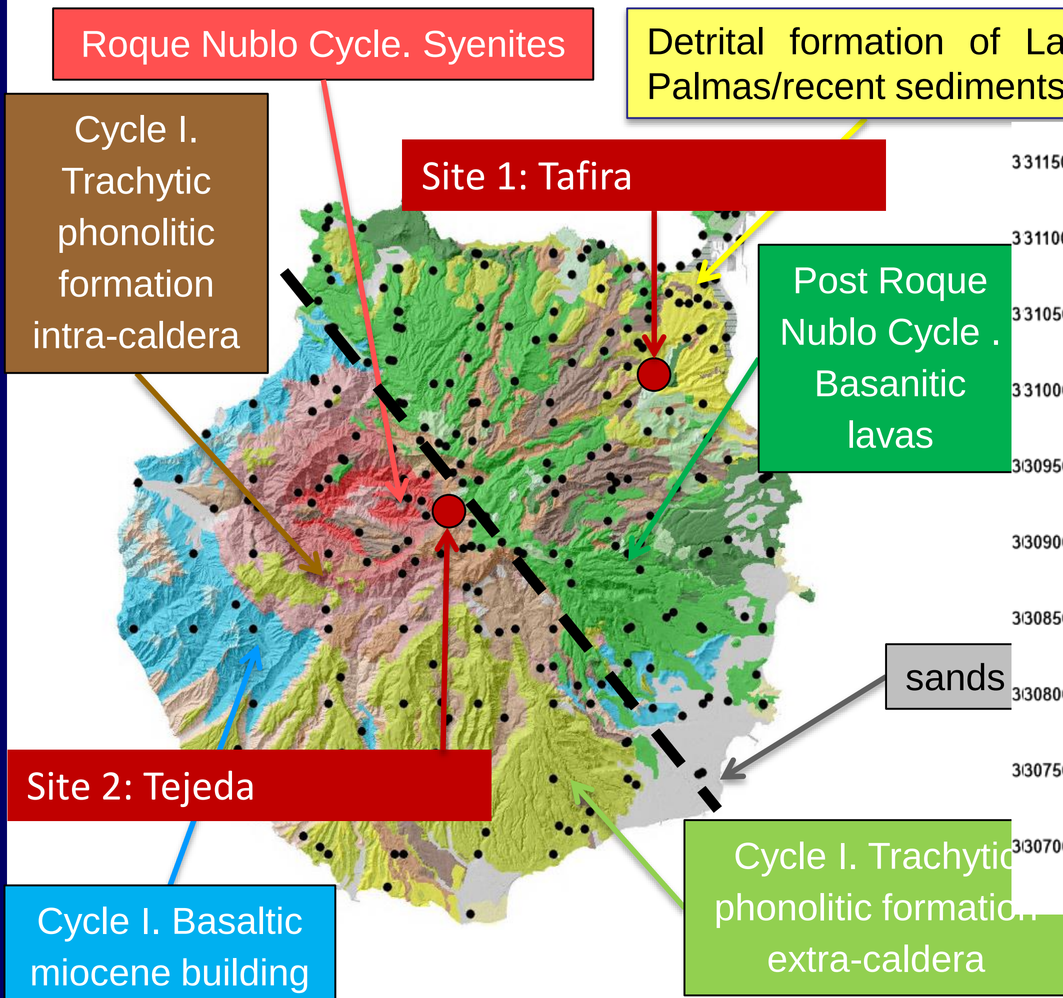
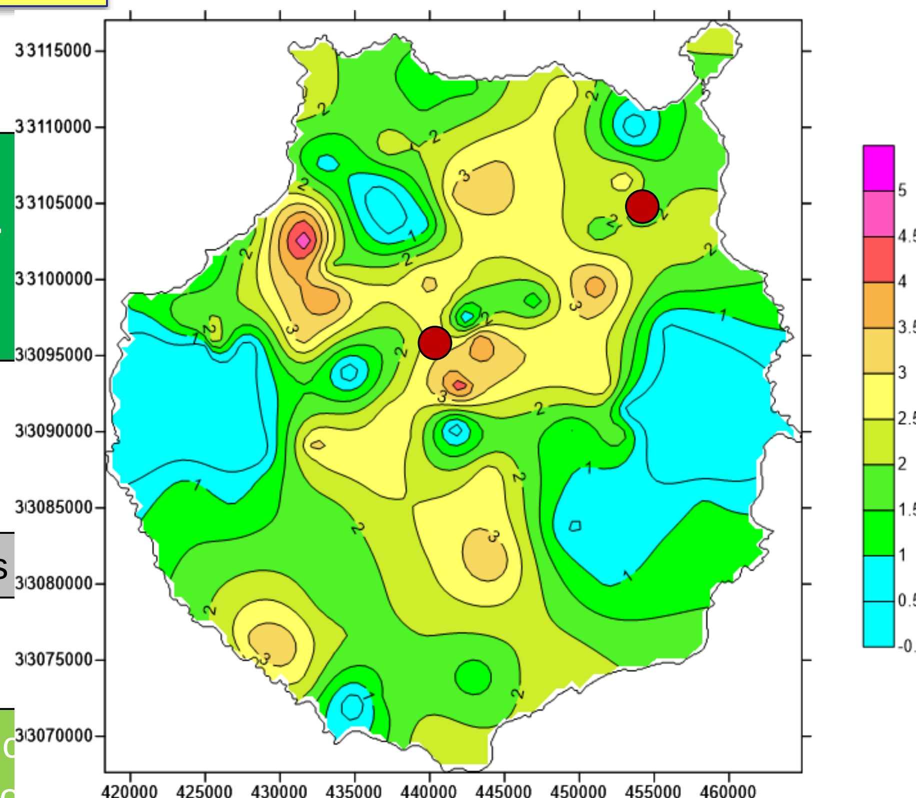
Following the criteria previously stablished, two sites were selected: one situated in the Campus of Tafira (low radon in soil level) and another in the Municipality of Tejeda (relatively high radon in soil level).



Radon prone area (Neznal)



ULPGC Site 1. Tafira

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ULPGC Site 1. Tafira

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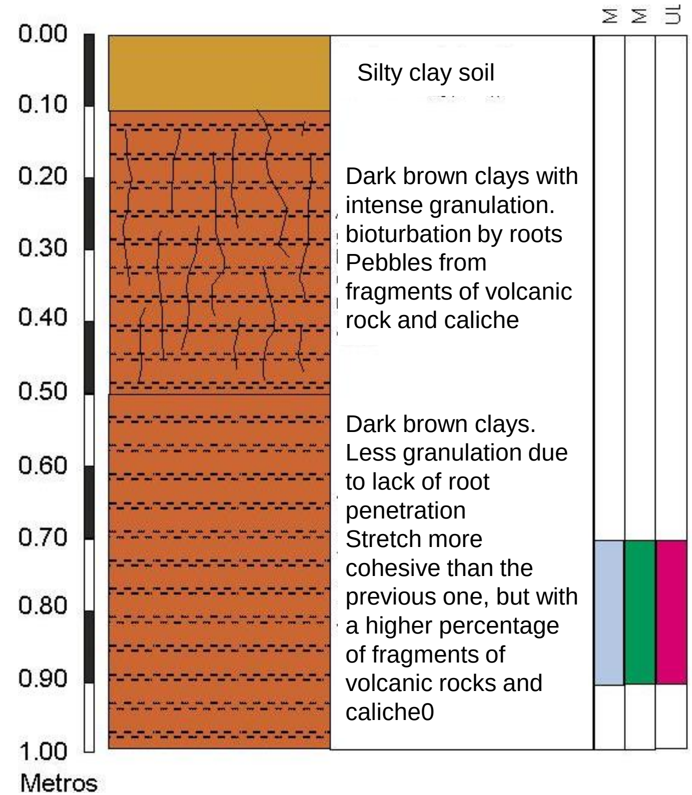
Land plot in rustic soil which has been employed for agriculture use. It has an approximated surface of 100 m^2 in rectangular shape. The soil is quite loose and deep in half the plot, which allows measuring at 80 cm of depth without difficulties. Solid rocks were found in the other half of the plot which allows only introducing the probe up to 30-40 cm of depth)



ULPGC Site 1. Tafira

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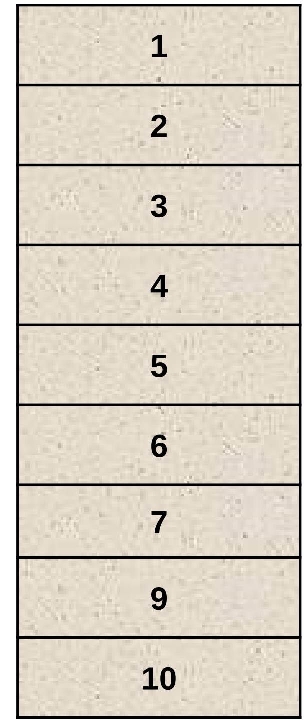
Survey plan

Located on campus it has been measured monthly.

- Twelve campaigns from June 2016 to May 2017 (on the 15th of each month).
- The plot has been divided into 10 rectangular sectors of 5 × 2 m in line.
- Radon probe, which is stuck every time (except the No. 6 that remains fixed)
- Depth of measurement 80 cm.
- Measurement of radon in soils, permeability and exhalation.



Sampling system

Radon vos RM-2 System (Main)

DURIDGE RAD7 (alternative).

RADON vos Probe

DURIDGE Probe (deep profile)

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Results Site 1. Tafira.

All sampling points exhibit **low permeability around 1.5·10^{-11} m^2**

Table. Results of measurement of concentration of radon in soil in the Campus of Tafira (kBq/m^3). Concentrations given with an uncertainty of 20%.

Subdivision	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY
1	9.9	10.1	8.2	8.5	10.6	10.3	11.1	12.9	12.4	8.4	10.5	10.1
2	9.4	11.1	8.6	9.3	8.8	8.9	11.4	9.6	11.1	6.9	6.3	9.8
3	9	8.4	11.4	9	9.4	10.4	13.1	6.7	8.4	6.1	9.7	8.9
4	7.2	7.8	7.6	8.4	9	8.6	6.4	7.2	7.3	7.1	7.4	9.8
5	8.1	7.9	5.5	7.4	5.8	7.4	10.1	6.9	8.6	9	10.1	8.6
6	10.9	11.7	11.5	10.9	7.2	11.4	8.8	8.8	8.9	8.1	8.8	10.5
7	8.5	9.7	10.3	12.6	10.2	9.3	11.7	10.6	9.9	11.8	11.7	8.9
8	9.2	9.2	9.9	10.2	11.8	9.9	9	10.5	10.2	10.9	9.3	8.6
9	10.1	9.4	9.6	10.1	10.2	10.1	11.5	10.9	9.9	10.6	8.1	9
10	10.2	9.4	11.7	10.2	11	11.2	8.8	9.8	8.9	11.4	9.7	9.4
mean	9.3	9.5	9.4	9.7	9.4	9.8	10.2	9.4	9.6	9	9.2	9.4
STD	1.1	1.3	2	1.5	1.8	1.2	2	2	1.5	2	1.6	0.7
CV(%)	11.9	13.4	21	15.3	19.2	12.5	19.2	21.3	15.3	22.6	17.2	7.1
GM	9.2	9.4	9.2	9.6	9.2	9.7	10	9.2	9.5	8.8	9	9.3
Mean error	0.59	0.6	0.61	0.62	0.6	0.62	0.66	0.61	0.61	0.58	0.59	0.59
GM error	0.58	0.59	0.58	0.6	0.58	0.61	0.63	0.58	0.6	0.56	0.57	0.59

Spatial variation Coefficient ∈ [7.1, 22.6] %

Temporal variation Coefficient ∈ [9.1, 20.6] %

Very homogeneous site in space and time.

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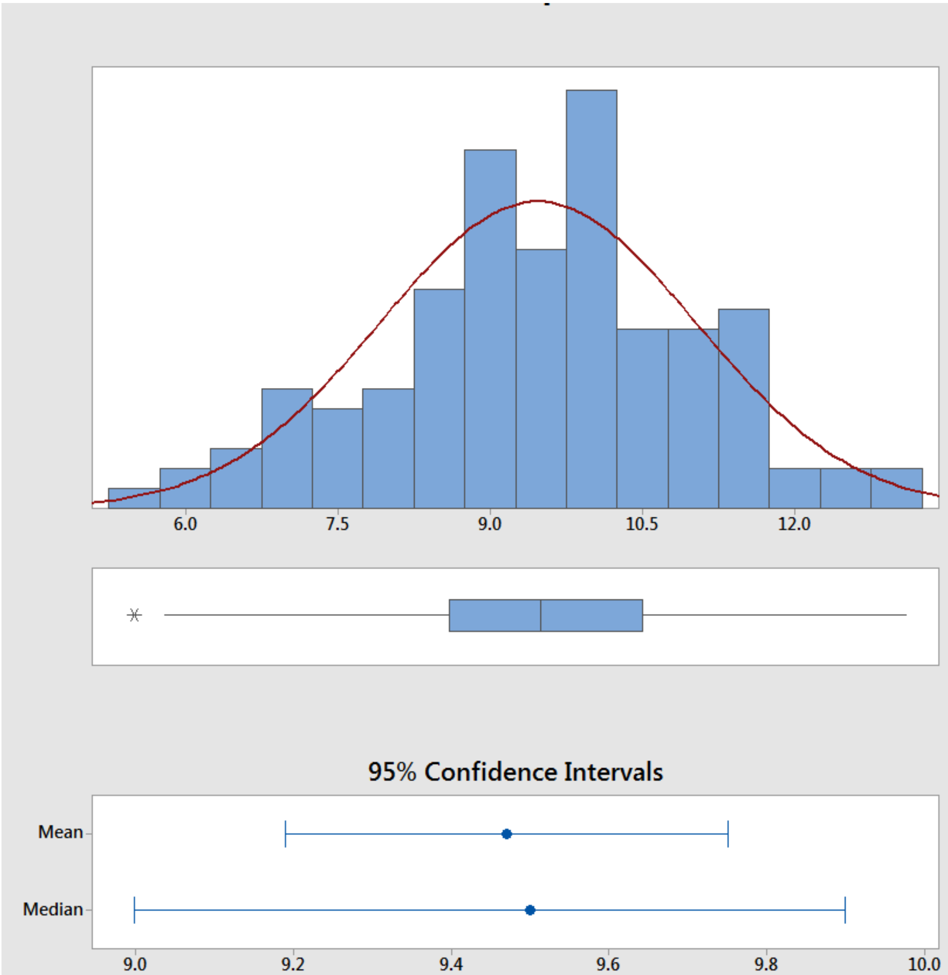
Results Site 1. Tafira.



Anderson-Darling Normality Test	
A-Squared	0.34
P-Value	0.504
Mean	9.4708
StDev	1.5520
Variance	2.4088
Skewness	-0.190614
Kurtosis	-0.139225
N	120
Minimum	5.5000
1st Quartile	8.6000
Median	9.5000
3rd Quartile	10.5000
Maximum	13.1000
95% Confidence Interval for Mean	
9.1903	9.7514
95% Confidence Interval for Median	
9.0000	9.9000
95% Confidence Interval for StDev	
1.3774	1.7778

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Results Site 1. Tafira.

Spatial Distribution. U- test statistical analysis

Arithmetic mean

Subdivision	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY
1	0.31	0.30	0.70	0.64	0.54	0.26	0.39	1.32	1.11	0.35	0.61	0.35
2	0.08	0.71	0.45	0.18	0.32	0.45	0.51	0.10	0.67	1.42	2.06	0.21
3	0.13	0.60	0.83	0.35	0.00	0.30	1.08	1.83	0.65	2.17	0.27	0.25
4	1.32	1.00	1.12	0.70	0.21	0.63	2.64	1.40	1.43	1.26	1.11	0.21
5	0.67	0.93	3.13	1.41	2.75	1.46	0.04	1.65	0.53	0.02	0.45	0.42
6	0.73	0.92	0.87	0.55	1.41	0.70	0.74	0.32	0.35	0.54	0.19	0.52
7	0.42	0.11	0.41	1.13	0.38	0.23	0.62	0.55	0.16	1.14	1.05	0.25
8	0.03	0.14	0.23	0.25	0.99	0.07	0.62	0.51	0.30	0.83	0.07	0.42
9	0.40	0.04	0.08	0.21	0.38	0.17	0.55	0.67	0.16	0.71	0.62	0.19
10	0.45	0.04	0.94	0.25	0.70	0.62	0.74	0.20	0.35	1.01	0.27	0.02

Geometrical mean

Subdivision	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY
1	0.34	0.34	0.58	0.59	0.63	0.29	0.47	1.40	1.15	0.24	0.68	0.36
2	0.11	0.74	0.34	0.13	0.23	0.41	0.59	0.20	0.71	1.29	1.97	0.23
3	0.10	0.56	0.93	0.30	0.09	0.33	1.15	1.71	0.60	2.03	0.33	0.23
4	1.28	0.96	0.99	0.65	0.12	0.59	2.52	1.28	1.37	1.13	1.03	0.23
5	0.63	0.89	2.99	1.35	2.64	1.42	0.04	1.53	0.47	0.10	0.51	0.41
6	0.76	0.96	0.96	0.59	1.30	0.73	0.64	0.21	0.30	0.42	0.12	0.53
7	0.38	0.15	0.51	1.17	0.46	0.19	0.70	0.64	0.21	1.23	1.11	0.23
8	0.01	0.10	0.33	0.30	1.06	0.11	0.53	0.60	0.35	0.93	0.14	0.41
9	0.43	0.00	0.19	0.26	0.46	0.20	0.63	0.76	0.21	0.81	0.54	0.18
10	0.48	0.00	1.03	0.30	0.78	0.66	0.64	0.30	0.30	1.10	0.33	0.03

Results Site 1. Tafira.

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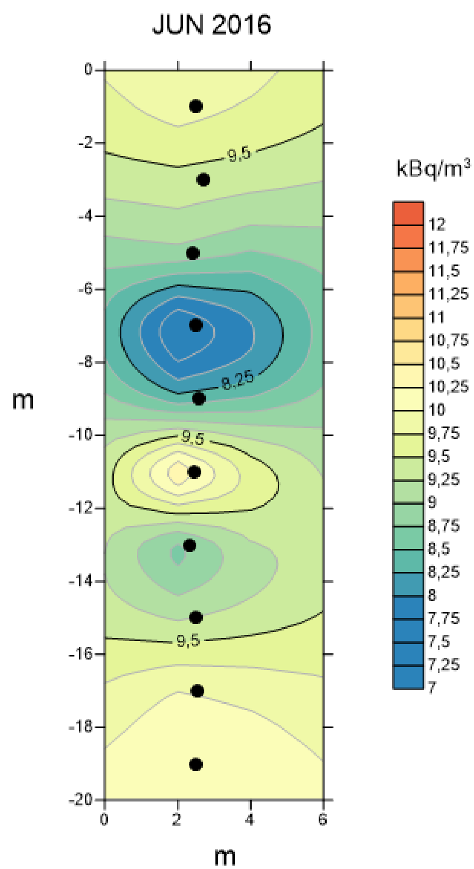
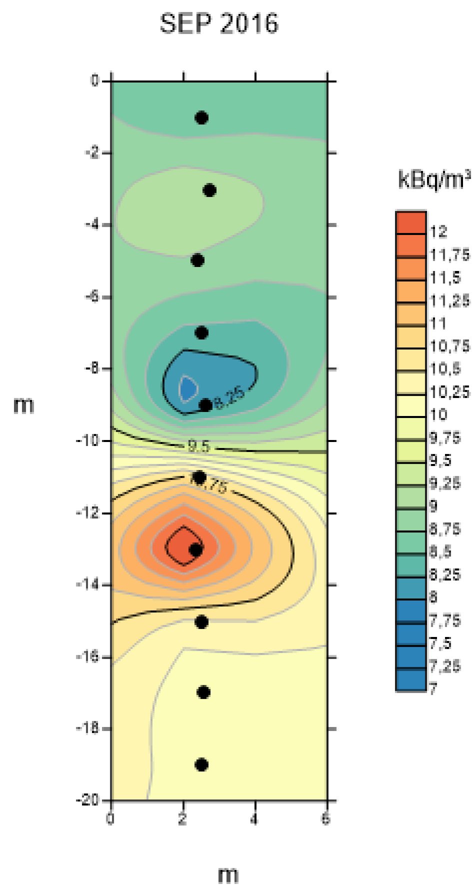
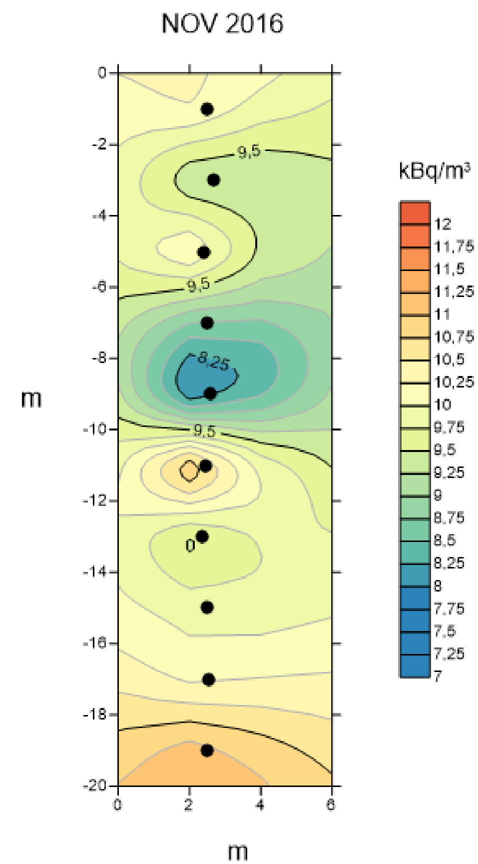
Geostatistical analysis. Kriging interpolation:







Mean= 9.3 kBq/m³
CV =11.9%

Mean= 9.7 kBq/m³
CV =15.2%

Mean= 9.8 kBq/m³
CV =12.5%

Results Site 1. Tafira.

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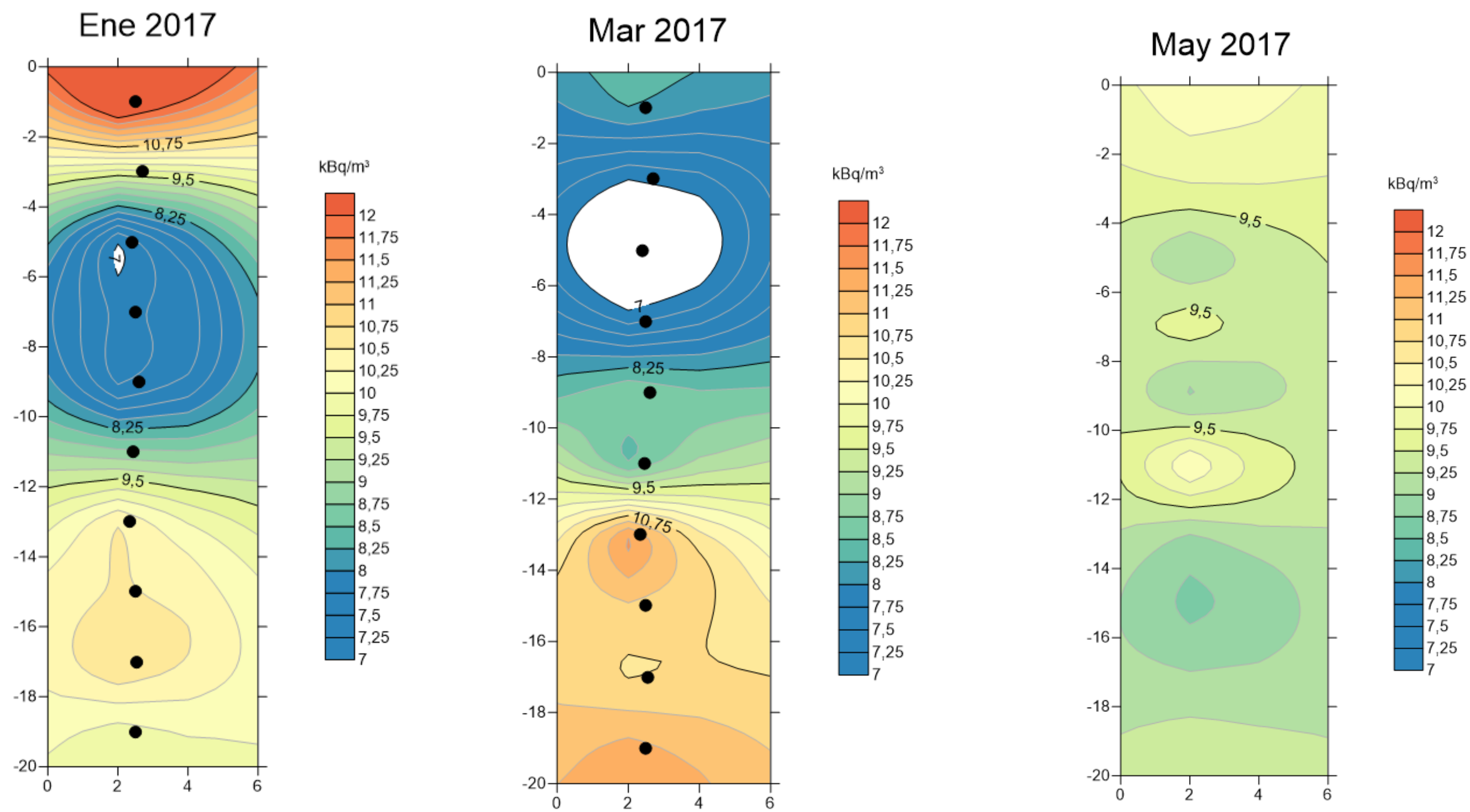
Geostatistical analysis. Kriging interpolation:



Mean= 9.4 kBq/m^3
CV =21.3%

Mean= 9.0 kBq/m^3
CV =22.6%

Mean= 9.4 kBq/m^3
CV =7.1%

Results Site 1. Tafira.

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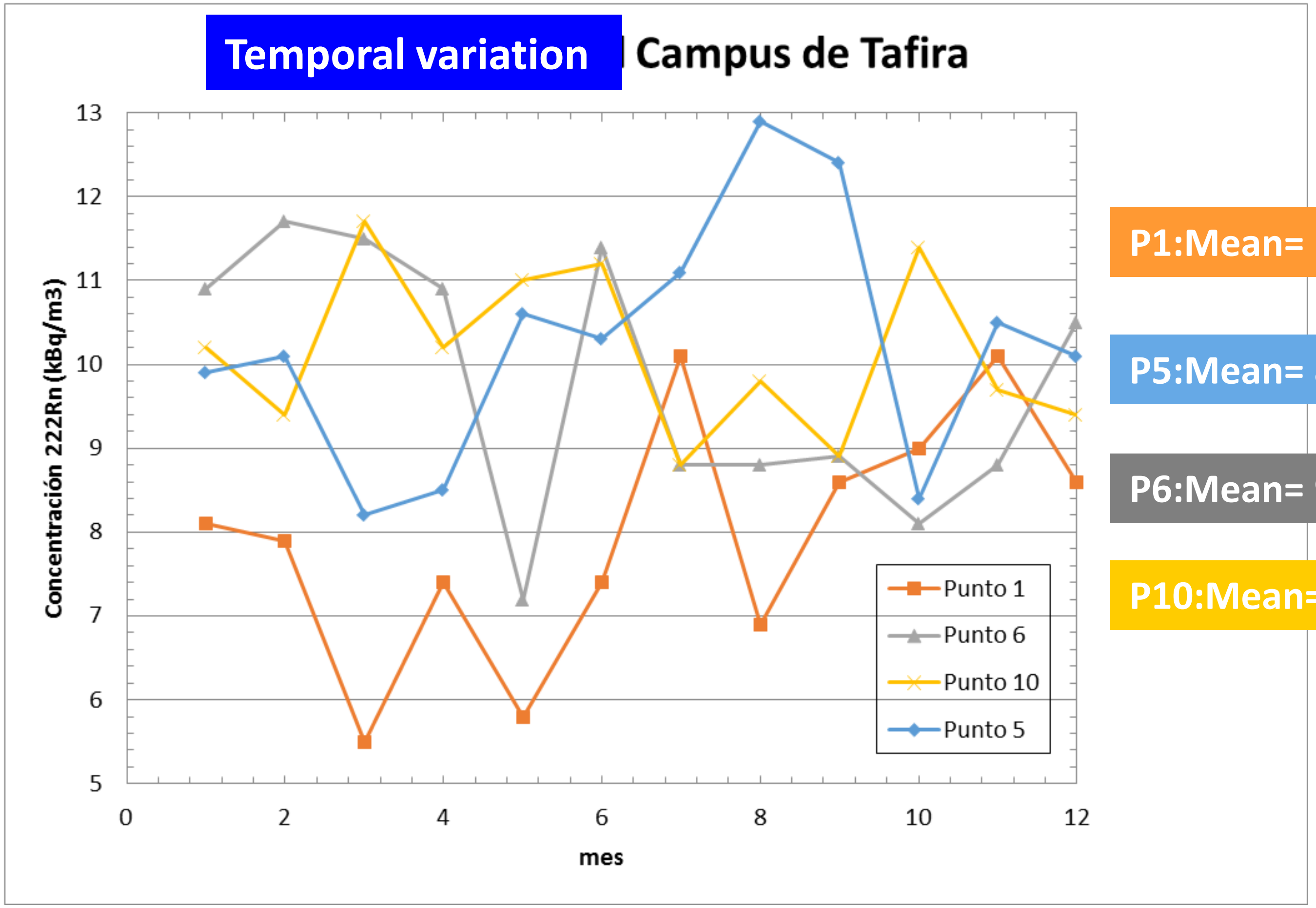
Temporal variation



P1:Mean= 10.3 kBq/m^3; CV =14.2%

P5:Mean= 8.0 kBq/m^3; CV =18.4%

P6:Mean= 9.8 kBq/m^3; CV =15.5%

P10:Mean= 7.5 kBq/m^3; CV =14.1%

Site 2. Tejeda

ULPGC Site 2. Tejeda

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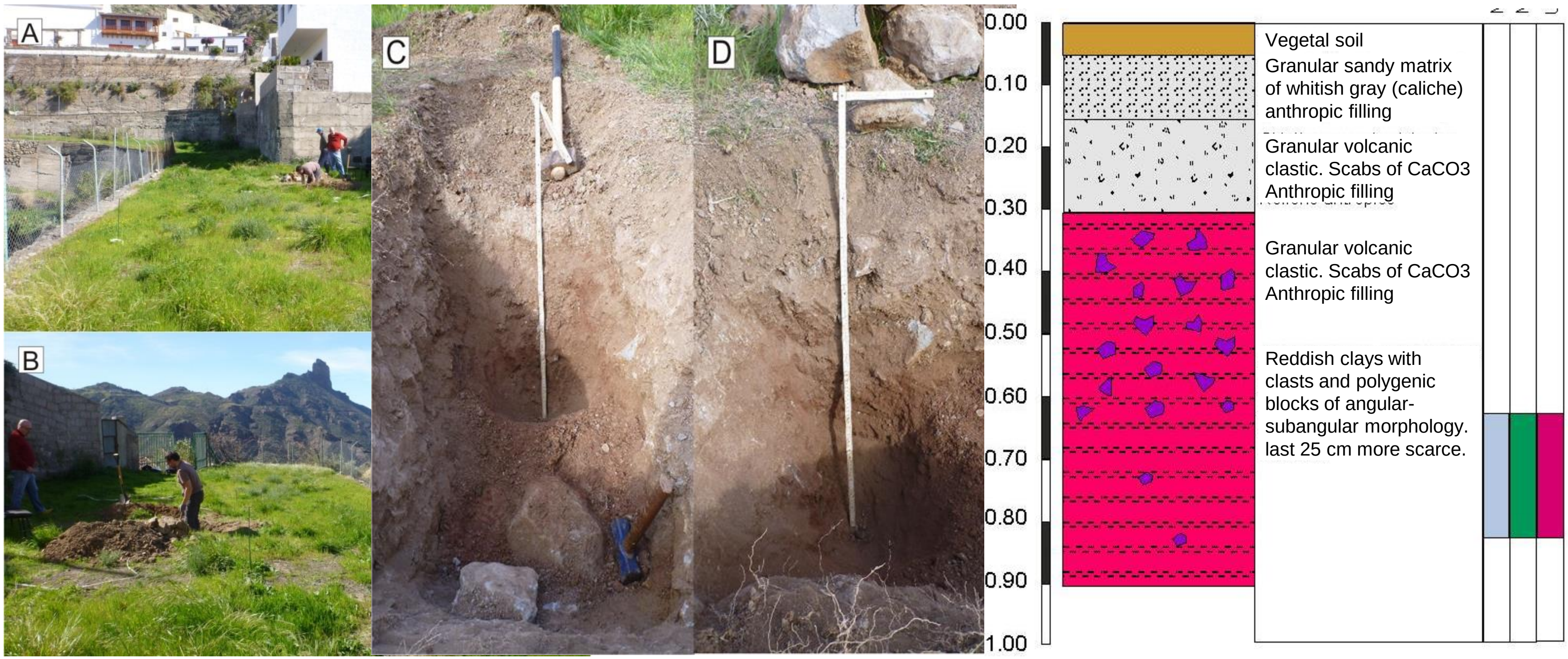
ULPGC Site 2. Tejeda

Rustic soil which has been used for agriculture, with an approximate surface of 100 m^2 with a shape of irregular quadrilateral, which can be divided into two parts with different characteristics, the southern part with a very compacted soil and the northern part with a very loose soil, and that besides presents a great surface of infiltration of air from a ravine.



ULPGC Site 2. Tejeda

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Survey plan

Being located in the center of the island with more complicated access has been measured once per station.

- Four campaigns: Spring (June), Summer (September), Autumn (December) and Winter (March).
- The plot has been divided into 10 sectors of 3 × 3.5 m
- Radon probe, which remain fixed at all times Depth of measurement 80 cm.
- Measurement of radon in soils, permeability and exhalation.

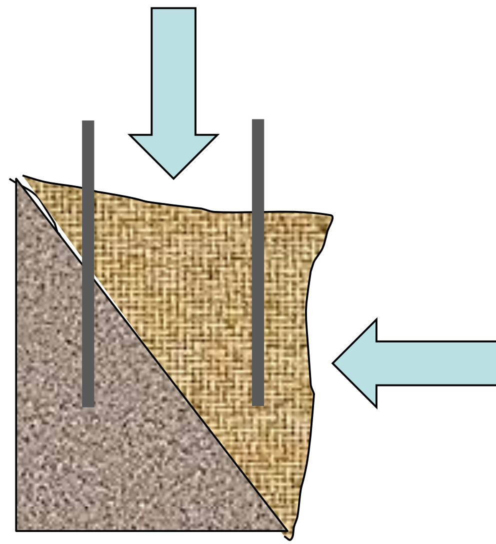
Sampling system

Radon vos RM-2 System (Main)

DURIDGE RAD7 (alternative).

RADON vos Probe

DURIDGE Probe (deep profile)



Results Site 2. Tejeda

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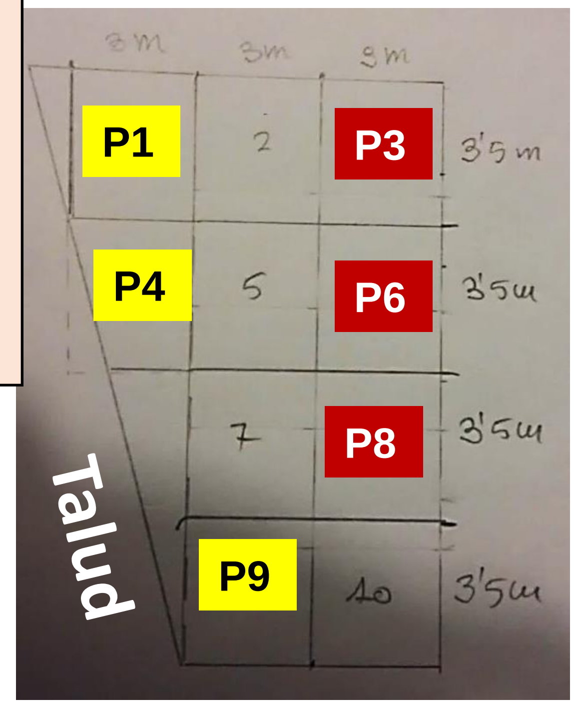
Large variation in permeability from one sampling point to another

Table. Gas Radon in soil activity concentration (kBq/m^3) ±20%

Subdivision	June	September	December	March	mean	STD	CV(%)
1	2.4	1.8	4	1	2.3	1.3	55.2
2	34.7	31	56.2	36.4	39.6	11.3	28.6
3	77.5	82	101	99.1	89.9	11.9	13.2
4	0.2	0.3	1.1	3.1	1.2	1.3	114.5
5	26	21.5	46.2	31.5	31.3	10.7	34.3
6	81.1	81.1	102	111	93.8	15.1	16.1
7	10.9	6.9	38.6	18.9	18.8	14.1	74.9
8	77.4	86.4	97.5	105	91.6	12.2	13.3
9	2.2	7.2	18.8	5.9	8.5	7.2	84.1
10	31.6	32.3	63.7	51.1	44.7	15.6	34.9
mean	34.4	35.1	52.9	46.3			
STD	32.9	35.0	38.5	43.5			
CV(%)	95.7	100.0	72.7	94.0			
GM	13.2	14.2	29.7	21.7			
Error mean	2.94	3.06	4.07	3.92			
Error GM	0.8	0.9	1.9	1.4			

Great inhomogeneity



Spatial Variation Coefficient∈[72.7,100] %

Temporal Variation Coefficient∈[13.2,114] %

Results Site 2. Tejeda

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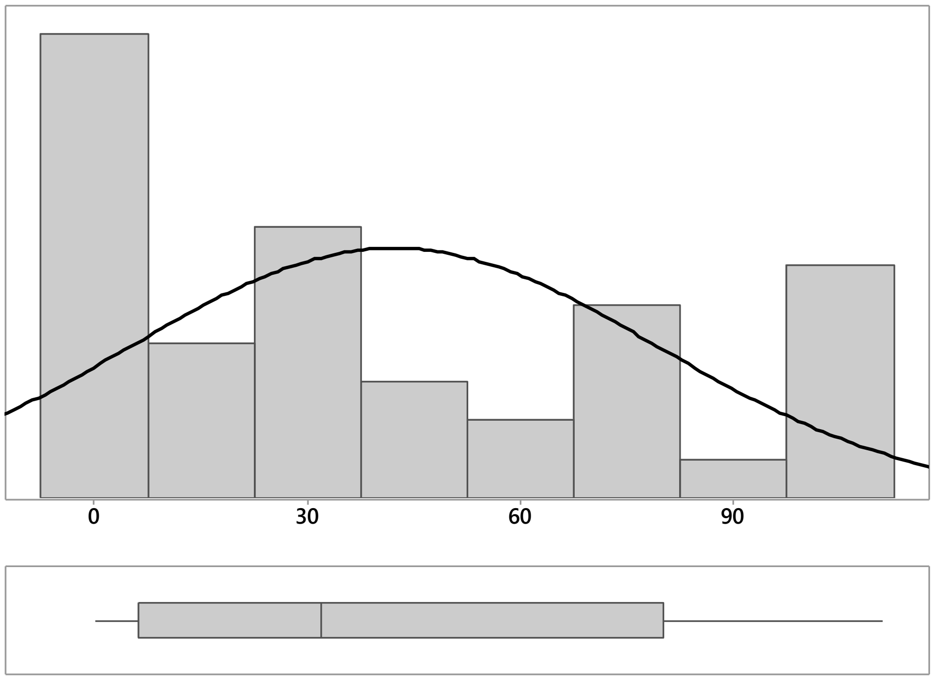
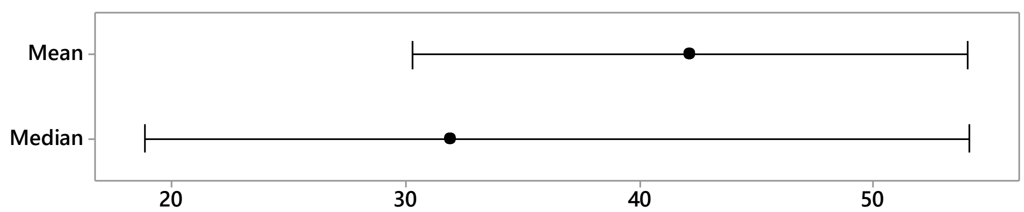


Anderson-Darling Normality Test	
A-Squared	1,56
P-Value	<0,005
Mean	42,165
StDev	37,080
Variance	1374,939
Skewness	0,48319
Kurtosis	-1,22514
N	40
Minimum	0,200
1st Quartile	6,150
Median	31,950
3rd Quartile	80,200
Maximum	111,000
95% Confidence Interval for Mean	
30,306	54,024
95% Confidence Interval for Median	
18,841	54,105
95% Confidence Interval for StDev	
30,375	47,612

95% Confidence Intervals



Results Site 2. Tejeda

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Spatial Distribution. U- test statistical analysis

Arithmetic mean

Subdivision	June	September	December	March
1	10.75	10.81	11.80	11.53
2	0.04	0.59	0.28	1.20
3	2.73	2.81	2.33	2.61
4	11.64	11.37	12.72	10.87
5	1.41	2.57	0.66	1.99
6	2.83	2.79	2.36	2.87
7	6.42	8.40	1.64	5.03
8	2.73	2.93	2.24	2.75
9	10.84	8.25	6.16	9.86
10	0.40	0.38	0.81	0.44

Geometrical mean

Subdivision	June	September	December	March
1	11.21	12.81	12.59	14.93
2	3.08	2.68	2.33	1.98
3	4.14	4.13	3.52	3.89
4	15.55	15.44	15.12	12.36
5	2.43	1.66	1.75	1.52
6	4.18	4.12	3.53	4.01
7	0.98	4.43	1.12	0.70
8	4.14	4.17	3.46	3.96
9	11.65	4.12	2.59	8.74
10	2.89	2.78	2.64	2.85

Results Site 2. Tejeda

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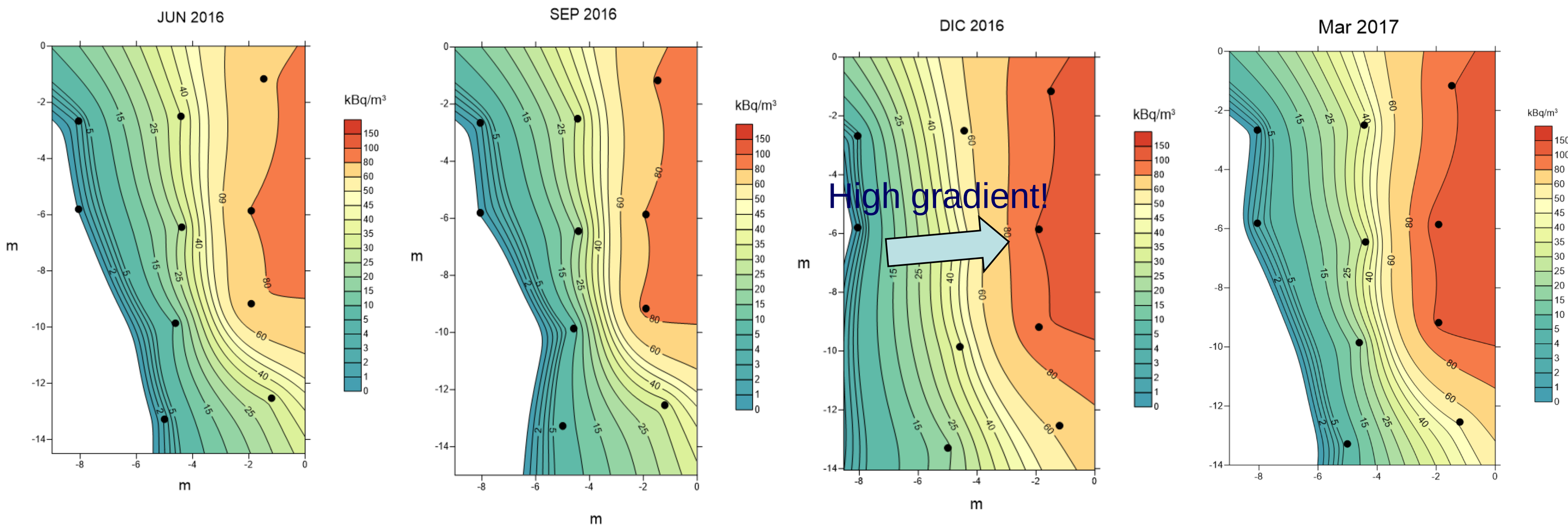
Geostatistical analysis. Kriging interpolation:



Mean= 34.4 kBq/m³ CV =95.7%	Mean= 35.5 kBq/m³ CV =100%	Mean= 52.9 kBq/m³ CV =72.7%	Mean= 46.3 kBq/m³ CV =92.0%

Results Site 2. Tejeda

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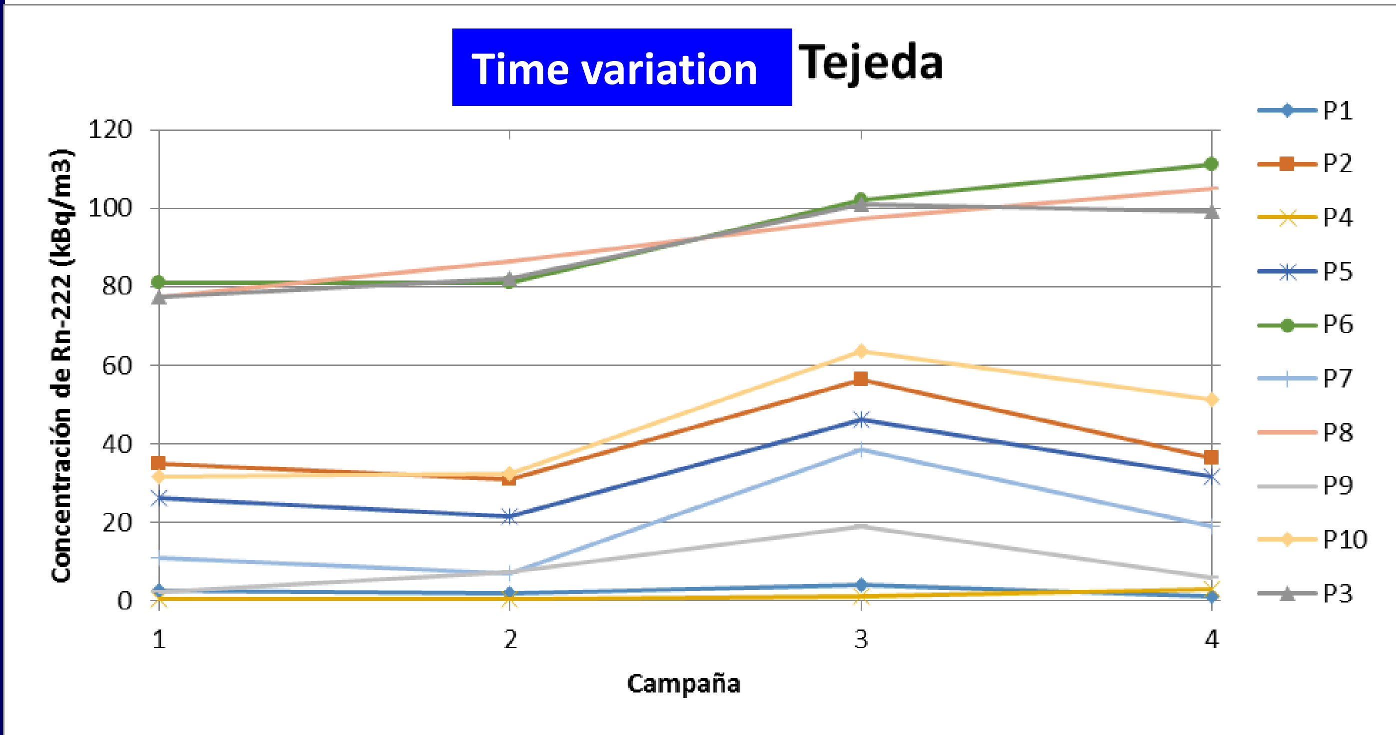


Media	STD	CV (%)
2.7	1.14	41.6%
40.6	13.61	33.5%
86.8	12.47	14.4%
0.5	0.49	92.5%
31.2	13.16	42.1%
88.1	12.07	13.7%
18.8	17.26	91.8%
87.1	10.07	11.6%
9.4	8.52	90.6%
42.5	18.33	43.1%

Results Site 2. Tejeda

Temporal Distribution. U- test statistical analysis.

Point	JUN	SEPT	DEC	MAR
1	0.20	1.34	2.11	5.79
2	0.68	1.34	1.46	0.43
3	0.78	0.47	0.54	0.46
4	12.61	9.80	0.33	3.09
5	0.99	2.18	1.60	0.03
6	0.76	0.76	0.40	0.76
7	3.36	7.24	2.54	0.02
8	0.89	0.29	0.30	0.63
9	10.38	0.88	2.72	2.09
10	1.98	1.84	1.48	0.62

Each value is compared to the arithmetic mean of the 4 temporal samples

Point	JUN	SEPT	DEC	MAR
1	0.73	0.62	2.42	4.37
2	0.52	1.13	1.54	0.28
3	0.72	0.42	0.56	0.48
4	8.09	5.07	1.91	3.91
5	0.73	1.82	1.71	0.22
6	0.68	0.68	0.43	0.79
7	1.85	4.99	2.99	0.92
8	0.82	0.25	0.32	0.64
9	7.11	0.48	3.26	0.46
10	1.61	1.48	1.61	0.80

Each value is compared to the geometrical mean of the 4 temporal samples

Outline

Radon Risk Classification

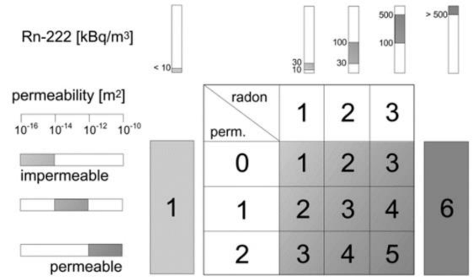
Table: Resume of Statistical indicators for each terrain

	CV(%)	Mean (kBq·m^{-3})	GM (kBq·m^{-3})	Q2 (kBq·m^{-3})	Q3 (kBq·m^{-3})	Maximum (kBq·m^{-3})	Characteristics
Campus of ULPGC	16.3%	9.5	9.3	9.5	10.5	13.1	homogeneous
Tejeda	90.60%	42.2	18.6	32	80.2	111	Non-homogeneous
Campus of UAB	30.4%	12.3	12.2	11.6	13.8	27.3	homogeneous
Montseny	149.7%	14.4	2.1	3.3	14.4	125.9	Non-homogeneous
Esles. UCAN	42.9%	85.7	75.3	80.7	114	138.8	homogeneous
Arganda	34.8%	9	8.3	8.4	11.1	18.6	homogeneous

Concluding remarks

Risk criteria

German Method (Kemsky et al., 2001)



radon ranking matrix

$$RP = \frac{c_a - 1}{-\log k - 10}$$

Czech Method (Neznal et al., 2004)

$$RAI = c_{Rn} \cdot \sqrt{k}$$

Swiss Method (Piller and Johner, 1998)

Swedish Method (Dubois, 2005)

Risk class	**Radon concentration (kBq·m⁻³)**	**Constructive techniques**
High risk	> 50	*Radon safe construction.* (Reinforced concrete foundation with forced ventilation)
Normal risk	10 - 50	*Radon protective construction* (without cracks, fissures, or gaps in the foundation)
Low risk	< 10	Traditional dwelling

Radon Risk Classification

	German Criterion	Czech Criterion	Swiss Criterion	Swedish Criterion	Permeability (m^2)	Q3 ($kBq\cdot m^{-3}$)
Campus ULPGC	Risk 3	RP Low-Medium	RAI =0.04 <0.2 $Bq\cdot m^{-2}$	Normal risk	$1.50\cdot10^{-11}$	10.5
Tejeda	Risk 4	RP Medium-High	RAI =0.19 <0.2 $Bq\cdot m^{-2}$	High Risk	$5.6\cdot10^{-12}$	80.2
Campus UAB	Risk 3	RP Low-Medium	RAI =0.04 <0.2 $Bq\cdot m^{-2}$	Normal risk	$1.12\cdot10^{-11}$	13.8
Montseny	Risk 3	RP Low-Medium	RAI =0.04 <0.2 $Bq\cdot m^{-2}$	Normal risk	$1.06\cdot10^{-11}$	14.4
Esles. UCAN	Risk 5	RP High	RAI > 0.2 $Bq\cdot m^{-2}$	High Risk	$6.99\cdot10^{-11}$	114
GEOCISA	Risk 3	RP Low-Medium	RAI =0.04 <0.2 $Bq\cdot m^{-2}$	Normal risk	$2.29\cdot10^{-11}$	11.1

Outline

Concluding remarks

- Six different 100 m^2 sites in Spain have been studied to obtain a representative value radon risk

- To obtain this representative value it is necessary to use statistical criteria to compare measurements for defining the degree of homogeneity (in space and time)

- Homogeneous sites can be represented by means of average values such as GM or arithmetic mean but this criteria fails to deal with inhomogeneous sites.

- Quartile 3 (Q3 or 75% percentile) seem to be a good estimator to be used as the representative value (in space and time). Combined with a representative value of permeability radon risk index can be defined.

- The criteria from different regulators applied to our data offer the same classification for all the sites. It also agrees with the Radon Risk map of Spain based on geology, gamma radiation map and indoor radon data.

Concluding remarks

Problem: what value to provide a value when concentration in the field is very variable? What number of measures to take?

Proposal of extremely simple guideline:

1. Perform at least two surveys one in winter and another one in summer.
2. Take the measurements in 15 stations as an initial number.
3. Analyze the Variation Coefficient (CV) if it is higher than 33% increase the number of measurements.
4. Analyze the distribution of the measures and take as representative value the 3rd quartile.
5. Combine these data with the average permeability of the site. Classify the risk with some of the already defined criteria (typically the Czech criterion)

Characterization of the spatial and temporal variations of radon in six sites representative of the Spanish geography. Methods for obtaining an average representative value.

J**. García-Rubiano**[1], H. Alonso[1], M.A. Arnedo[1], J. Bach[3], J.A. Carrasco[4], M. A. Duch[5], Ll. Font[2], I. Fuente[6], J. Garcia-Orellana[2], M. García-Talavera[7], J.G. Guerra[1], C. Grossi[5], J. L. Gutiérrez[6], A. Hierro[2], F.J. López-Acevedo[7], P. Martel[1], V. Moreno[2], E. Navarro[4], L. Quindós[6], A. Ramírez[4], V. Rodellas[2], M.D. Rodriguez-González[5], C. Sainz[6], A. Sánchez[8], E. Sanz[8], A. Tejera[1], A. Vargas[5]

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Geological Aspects of Radon Risk Mapping

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