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The usefulness of the Radon signal for geophysical purposes highlighted through analytical procedures

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Content

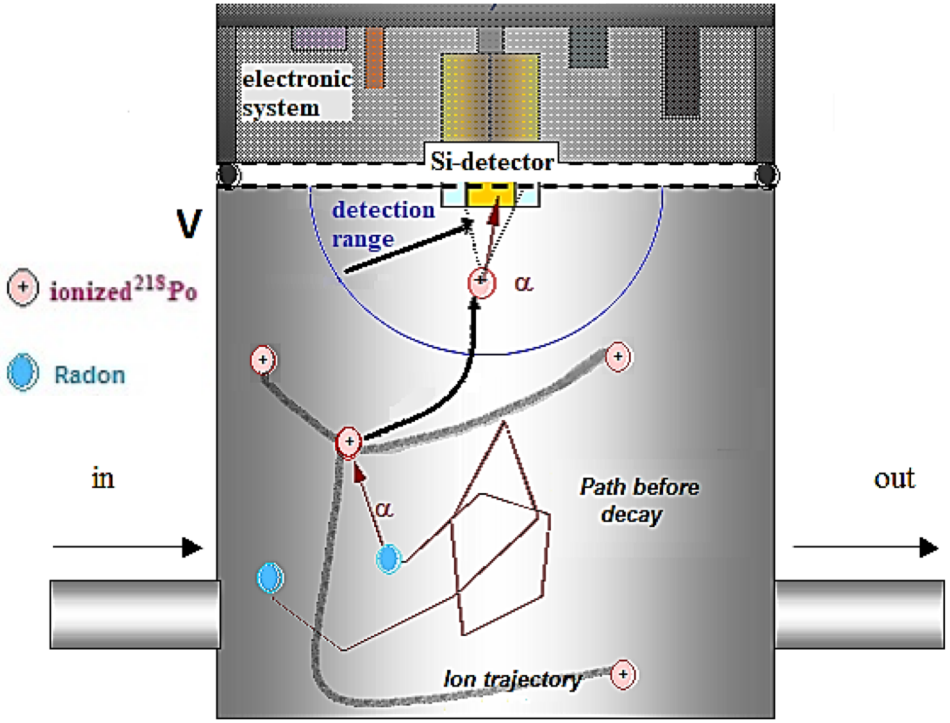
1. Recording of long-term Radon signal time series at various European sites using two types of devices;
2. Development of hybrid signal analysis methods;
3. Study of meteorological effects on the signals;
4. Comparison of the results obtained from hybrid methods at various European sites;
5. Search for cross-correlation between Radon and earthquake as well as Radon and fumarolic tremor and fault displacement;
6. Conclusions.

^{222}Rn continuous monitoring

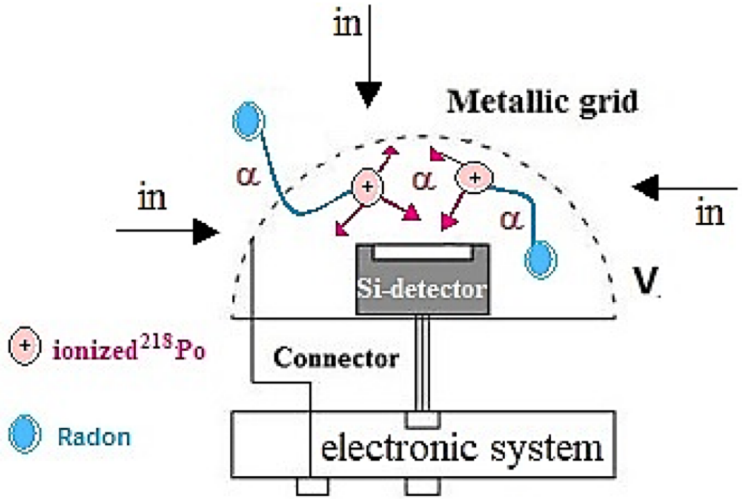
Performed by 2 devices based on:

- diffusion of gas inside a metallic chamber (spontaneously or conveyed by pumping);
- the electrostatic deposition of the decay product ^{218}Po on Si-semiconductor α-detector;
- subsequent spectrometric analysis of α-particles emitted with energy *6.002 MeV*.

RAMONA



RADIM-3A



Influencing parameters

1. seismic activity (local and remote earthquake);
2. change due to meteorological parameters
   (temperature, pressure, relative humidity, borehole water level, wind speed);
3. lithological characteristics of the soil, mainly porosity and permeability;
4. different seasonal and period trends, (CO_2,unknown variables).

GOAL

Analysis of continuous monitoring time series of ^{222}Rn recorded in EU underground sites, with the aim of identifying anomalies to find possible correlations with Earth's movements.

Monitored EU-sites

N°	SITES	TIME PERIOD
1	Mt. Olibano gallery – IT (pumice-pozzolana)	1/1/2016 – 31/12/2017
2	Zbrašov Cave - CZ (aragonite limestone)	29/9/2016 – 7/2/2018
3	Bozkov Cave - CZ (dolomite karst)	5/5/2017 – 28/2/2018
4	Županova Cave - SI (bedded limestone)	22/3/2017 – 5/10/2017
5	Ochtinská Cave - SK (aragonite limestone)	23/6/2016 – 23/5/2017
6	Driny Cave - SK (brown-grey limestone)	10/4/2014 – 28/10/2014

Time series analysis for anomaly detection

Hybrid forecasting method:

- aggregation of 2 individual methods (output of 1 one is input of 2 one);
- prediction of the starting signal (2° method);
- advantages combination of 2 methods;
- optimized algorithms;
- higher accuracy (lower uncertainty).

(1) EMD+SVR (Empirical Mode Decomposition + Support Vector Regression)

(2) MLR+ARIMA (Multiple Linear Regression + Auto-Regressive Integrated Moving Average)

(3) SSA+FM (Singular Spectrum Analysis + Forecasting Methodology)

Brief description of the methods

(1) EMD+SVR is a non-parametric method:

EMD → decomposition based on spline interpolation of min-max envelopes (trend, smooth, noise, periodicity, seasonality);

SVR → prediction of joint-prediction of each component with regression model.

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(2) MLR+ARIMA is a parametric statistical method:

MLR → links Rn signal and environmental parameters using regression model (z);

ARIMA → forecast on residue (Rn signal-z) based on linear and moving-average combination of previous data.

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(3) SSA+FM is a parametric spectral method:

SSA → eigendecomposition and reconstruction on the converted MD signal matrix (equal pairs of eigenvalues correspond to persistent oscillations)

FM → prediction on reconstructed series using combination of eigenvectors.

Selection criteria

Selection of anomaly in original signal:

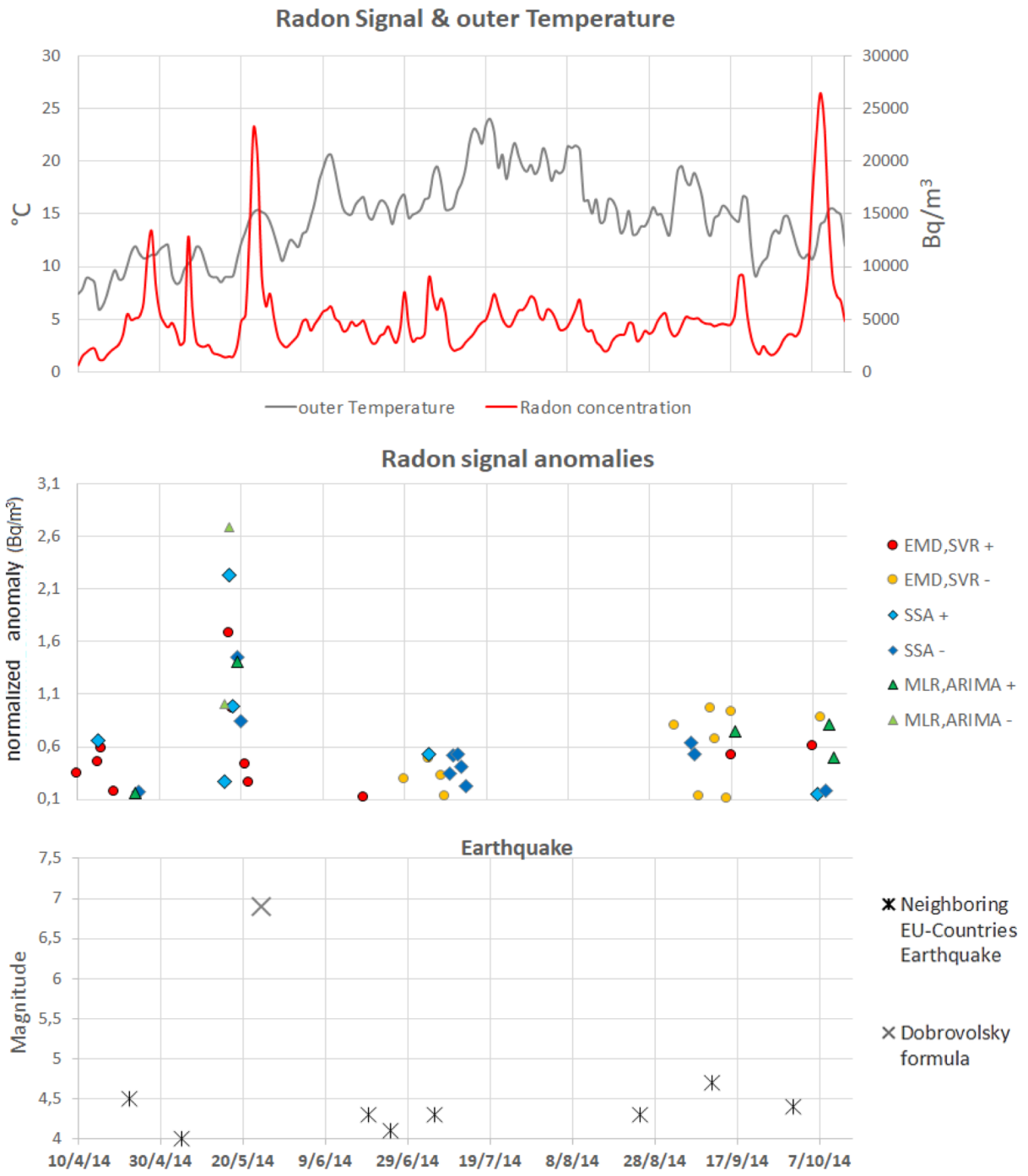
- values not within the 95% confidence of forecasting series,
- positive (negative) when is above (below) the upper (lower) confidence levels.

Selection of earthquake from USGS database:

- Dobrovolsky earthquake preparation zone formula $R=10^{0.43M}$,

  (M = earthquake magnitude, R = radius of tectonic deformation area).
- local seismic events (magnitude ≥*4*) occurred in the European Countries neighboring to Radon monitoring sites.

Results at Driny Cave - SK



1. A particular result: Radon vs fumarolic tremor of Phlegrean Fields Caldera - Italy

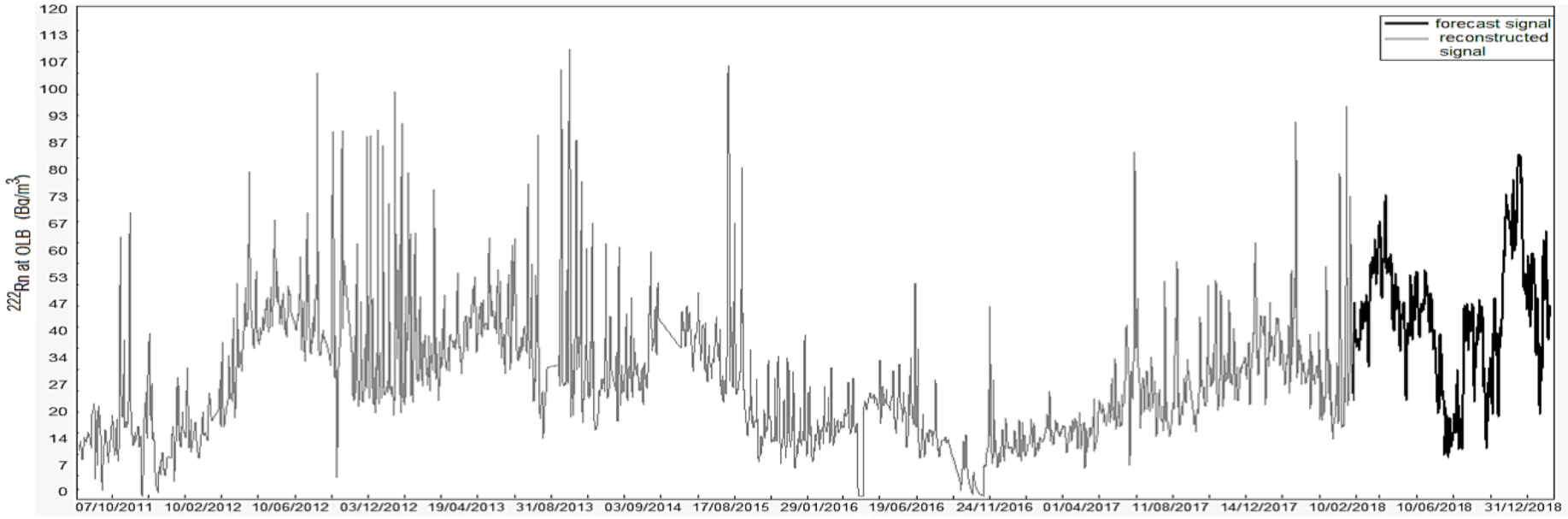
Hybrid method for anomaly detection:
CLEVELAND (STL)+EMD+SVR
CLEVELAND make decomposition into trend, seasonal, remainder through sequence of loess smoothing operations employing locally weighted regression; on remainder is applied EMD

Cross-correlation between the two events of 88%.

Study of trend of signal has been also carried out
CLEVELAND (STL)+EMD .

1. An example of forecast signal based on the known one

Hybrid method for forecasting: EMD+SVR

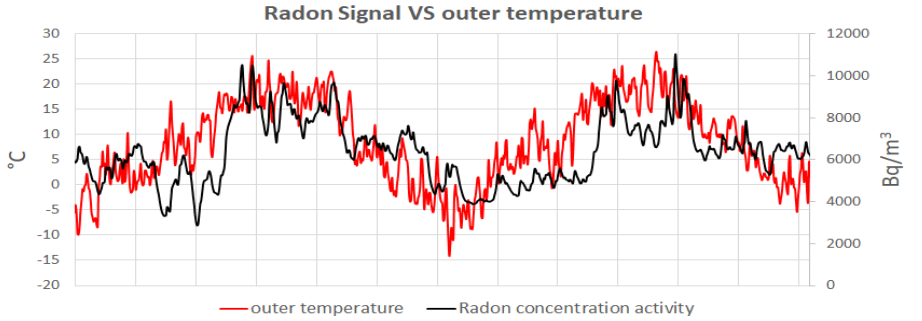


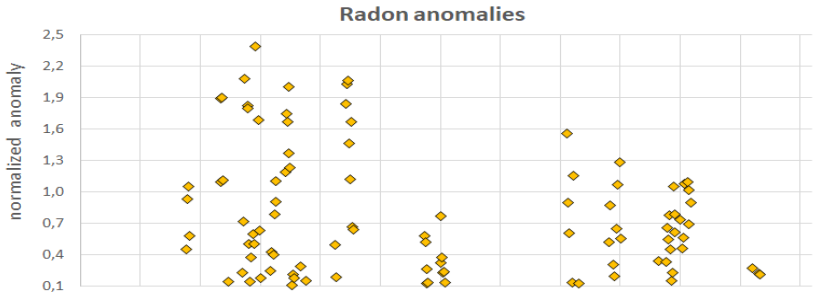
2. A particular result: Radon vs fault displacements at Mladeč caves - CZ

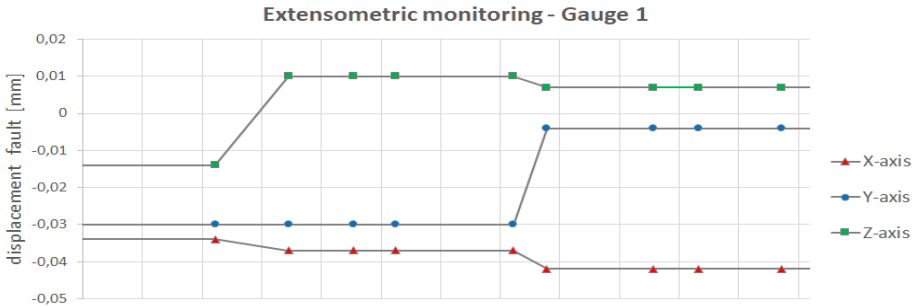
Hybrid method for anomaly detection:
EMD+SVR

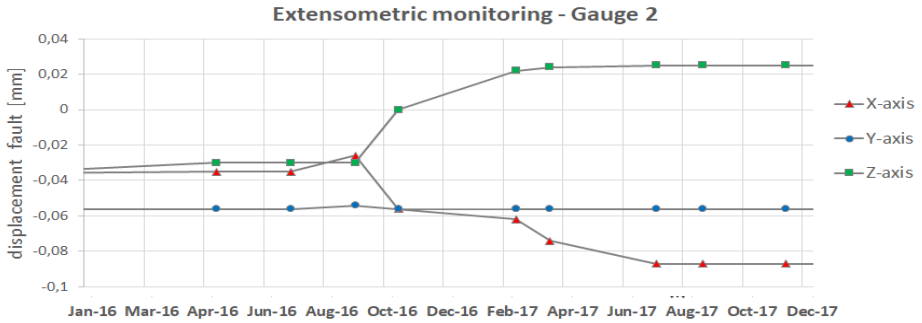
Active fault displacement monitoring:
performed using two extensometric gauges,

Cross-correlaction Radon-fault of 78%









Conclusions

1. Temperature is the main Radon influencing driving-force (among pressure, relative humidity, rainfall, wind speed);

2. Equivalency among hybrid methods;

3. EMD+SVR is the best method according to forecast error;

4. Ability to unmask anomalous peak in signal;

5. Strong cross-correlation factor (85% - 90%) between Radon-earthquake as well as between Radon and fumarolic tremor and fault displacement.

Thank you for attention