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Analysis or radon concentration in Slovenian thermal waters for earthquake prediction

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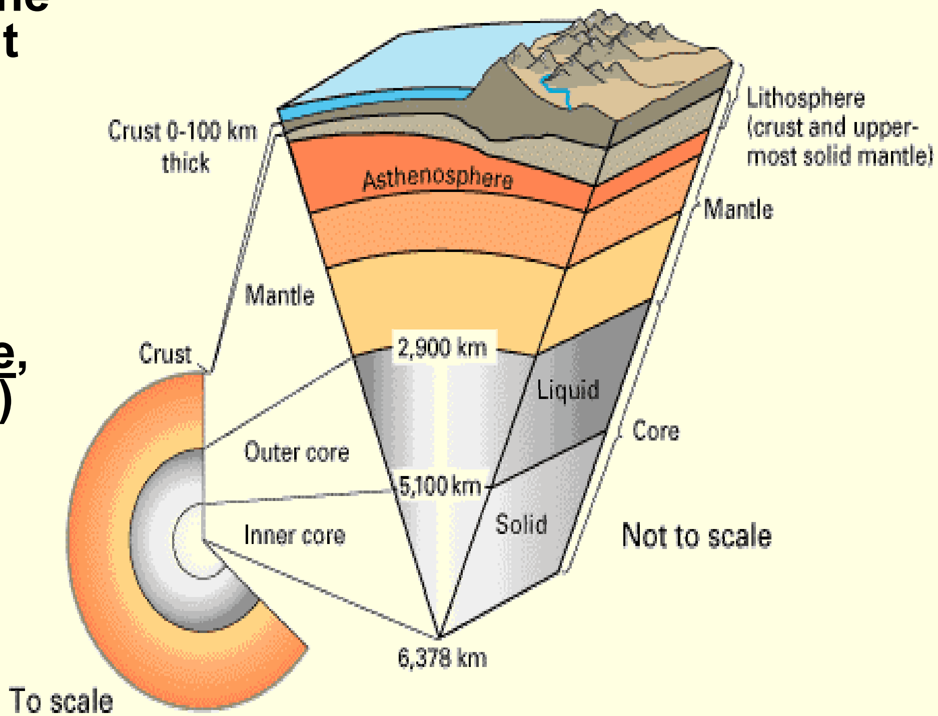
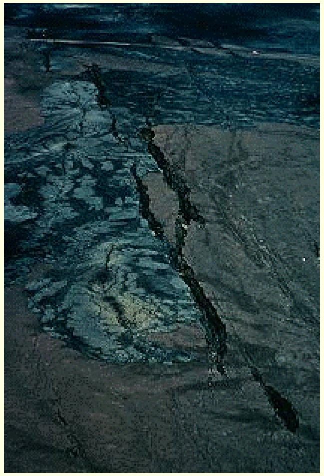
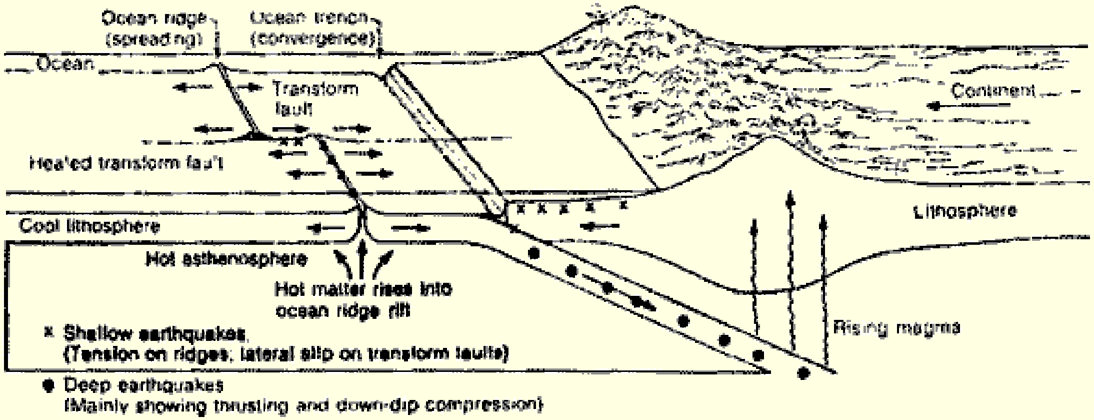
Mechanism of the earthquake formation

- Earth litosphere (the crust and the solid mantle) on the ocean about 80 km thick, and on the continents about 200 km thick (in solid state).
- Under the litosphere it is about 200 – 300 km thick astenosphere, high temperature (900 – 3000 °C) and pressure, (in plastic to half-liquid state).
- Important source of the heath is radioactive decay of ^{238}U, ^{235}U, ^{232}Th decay series.



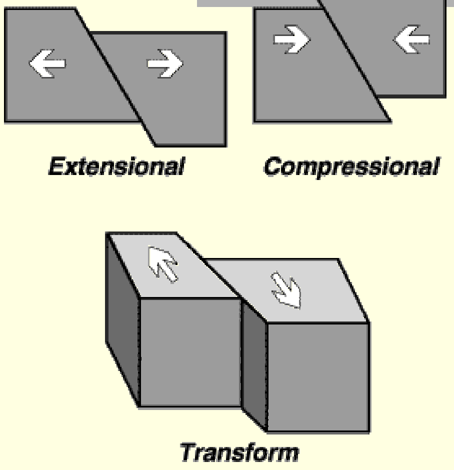
Mechanism of the earthquake formation





- **Thermal gradients induce convection flows of molten rocks in the astenosphere and lifting of huge masses of hot and less dense material up to the surface. Where the litosphere is the thinnest, divergent litospheric margins and rift zones occure.**
- **Where more dense and heaviear litospheric plate (i.e. oceanic pl.) sinks under another plate (i.e. continental, or rarely another ocenic plate) a subduction takes place.**

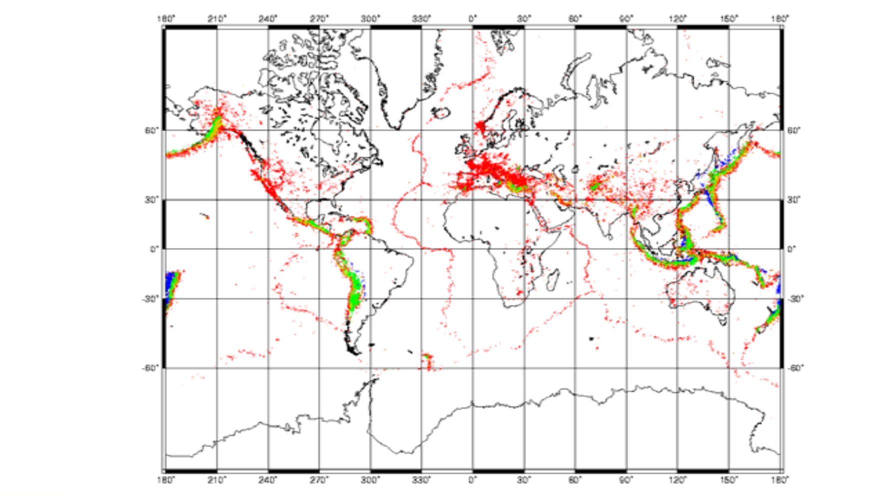
Mechanism of the earthquake formation



- Continuous convection of molten magma in the Earth's mantle induced formation of divergent (rift zones), convergent (subduction zones) and transform faults, which have cut the entire litosphere to about 7 tectonic plates.

- The stress in the Earth's crust during the movement of the tectonic plates is released us an earthquake.

- > 95 % of the earthquakes occure on the tectonic plate boundaries



A few months, days, or hours before an earthquake:

- tectonic stress in the Earth's crust builds up
- rock deformation and microfracturing occures
- ^{222}Rn emanation increases

(a decay product of ^{238}U decay series)

- if fractures are filled with groundwater, leaching of rocks on the newly-formed rock surfaces increases and ground water composition changes

Review of geochemical and geophysical monitoring in Slovenia in relation to seismic activity

- <u>from 1981-82 thermal waters in the Ljubljana basin</u>

radon concentration, water temperature (weekly),
Cl^-, SO_4^{2-}, hardness, pH (monthly)

- <u>from 1999 – 2001 soil gas along the fault in the Krško basin</u>

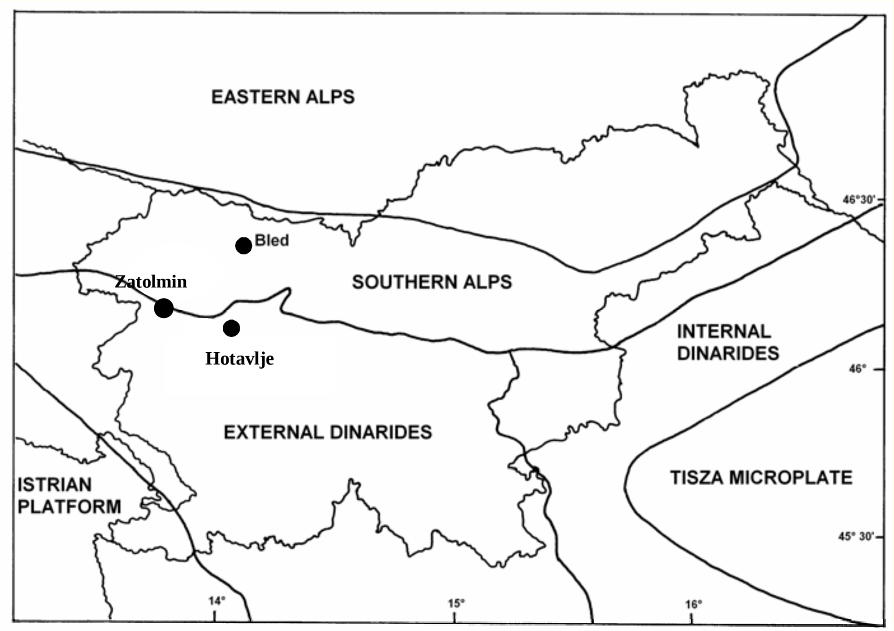
radon concentration, air temperature and pressure (once per hour)

- <u>from 1998 – thermal waters in NW and E Slovenia</u>

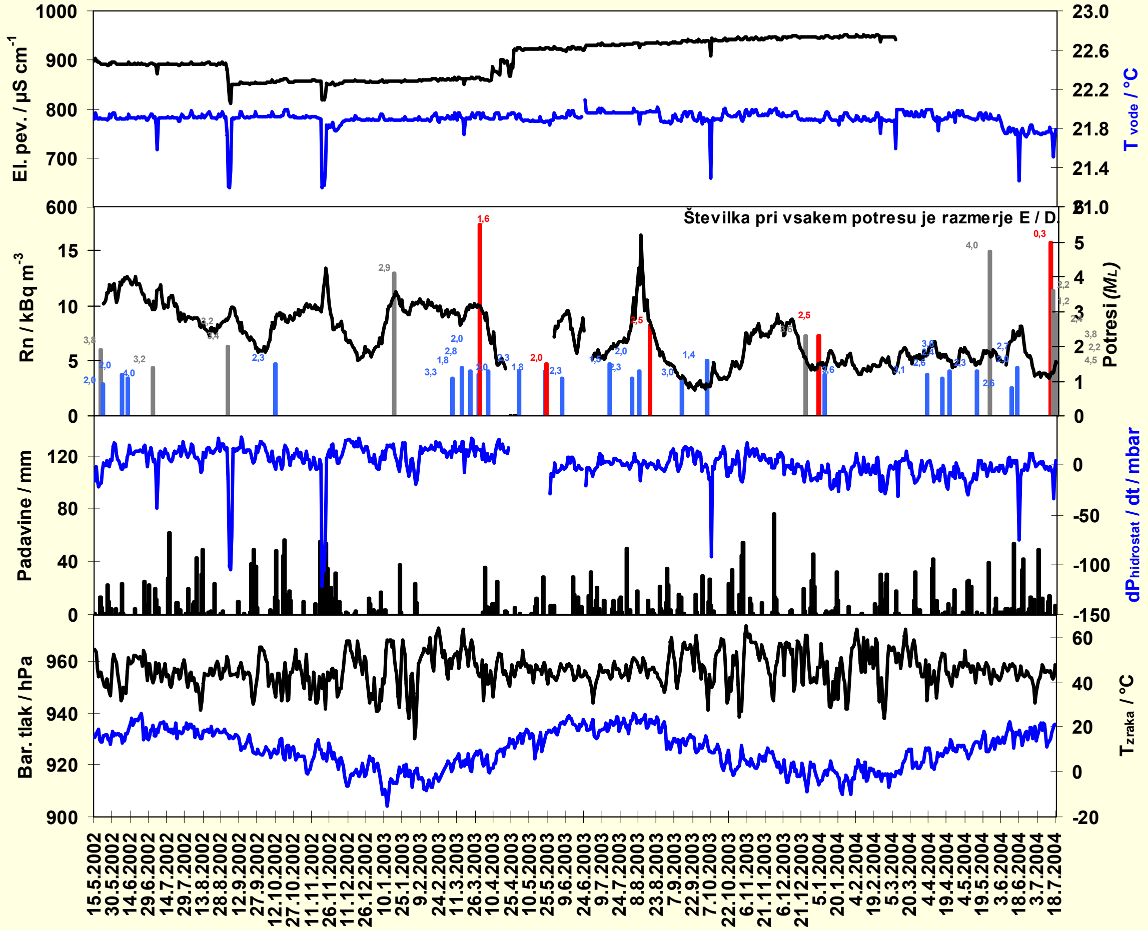
radon concentration, electrical conductivity, water temperature
and water pressure (once per hour)

-Bled from 1998 –
-Zatolmin from 1999 –
-Rogaška Slatina from 1999 – 2001
-Cerkno from 2000 – 2002
-Hotavlje from 2003 –

Geotectonic situation of Slovenia and locations of measuring stations

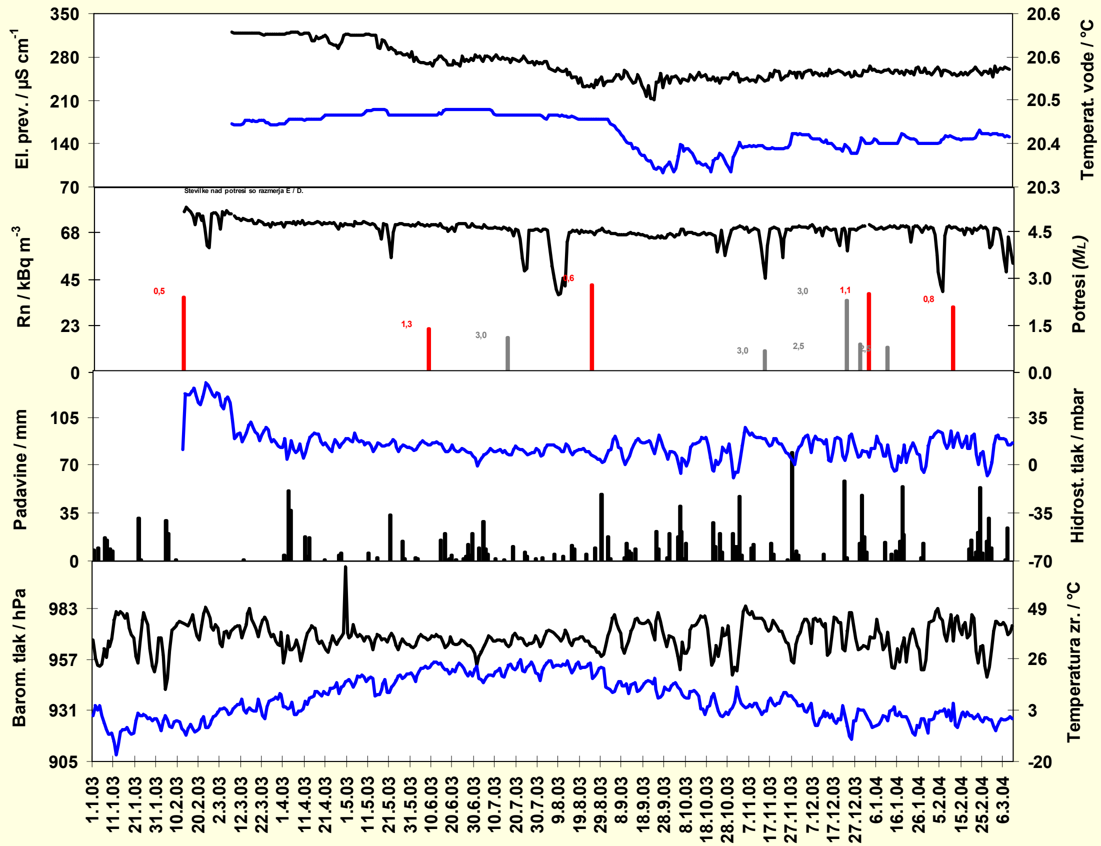


Bled



El. pev. / µS cm-1
T vode / °C
Številka pri vsakem potresu je razmerje E / D.
Rn / kBq m-3
Potresi (ML)
Padavine / mm
dPhidrostat / dt / mbar
Bar. tlak / hPa
Tzraka / °C

Hotavlje


El. prev. / µS cm-1
Temperat. vode / °C
Rn / kBq m-3
Potresi (ML)
Padavine / mm
Hidrost. tlak / mbar
Barom. tlak / hPa
Temperatura zr. / °C
350
280
210
140
70
20.6
20.6
20.5
20.4
20.3
68
45
23
0
4.5
3.0
1.5
0.0
105
70
35
0
35
0
-35
-70
983
957
931
905
49
26
3
-20
0,5
1,3
3,0
3,0
2,5
3,0
1,1
0,8
1.1.03
11.1.03
21.1.03
31.1.03
10.2.03
20.2.03
2.3.03
12.3.03
22.3.03
1.4.03
11.4.03
21.4.03
1.5.03
11.5.03
21.5.03
31.5.03
10.6.03
20.6.03
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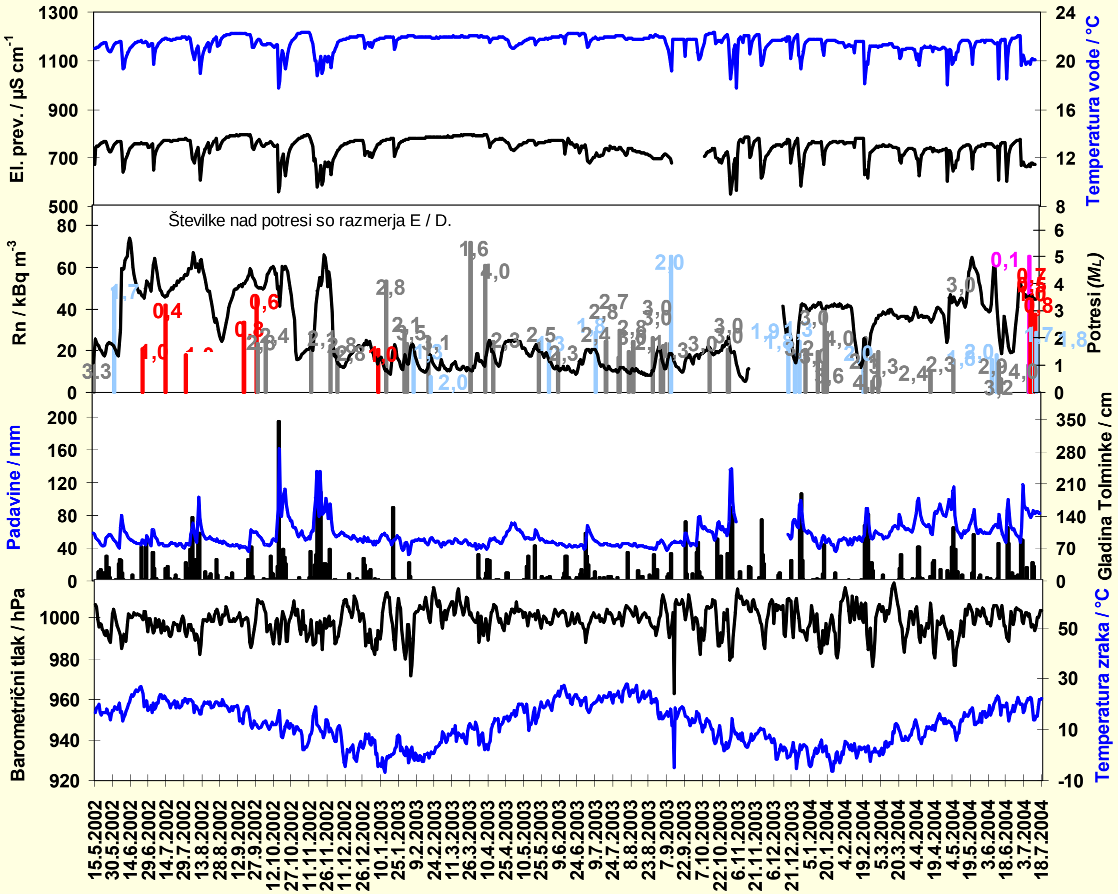
10.7.03
20.7.03
30.7.03
9.8.03
19.8.03
29.8.03
8.9.03
18.9.03
28.9.03
8.10.03
18.10.03
28.10.03
7.11.03
17.11.03
27.11.03
7.12.03
17.12.03
27.12.03
6.1.04
16.1.04
26.1.04
5.2.04
15.2.04
25.2.04
6.3.04

Zatolmin



El. prev. / µS cm⁻¹
Temperatura vode / °C
Rn / kBq m⁻³
Potresi (ML)
Številke nad potresi so razmerja E / D.
Padavine / mm
Gladina Tolminke / cm
Barometrični tlak / hPa
Temperatura zraka / °C
15.5.2002
30.5.2002
14.6.2002
29.6.2002
14.7.2002
29.7.2002
13.8.2002
28.8.2002
12.9.2002
27.9.2002
12.10.2002
27.10.2002
11.11.2002
26.11.2002
11.12.2002
26.12.2002
10.1.2003
25.1.2003
9.2.2003
24.2.2003
11.3.2003
26.3.2003
10.4.2003
25.4.2003
10.5.2003
25.5.2003
9.6.2003
24.6.2003
9.7.2003
24.7.2003
8.8.2003
23.8.2003
7.9.2003
22.9.2003
7.10.2003
22.10.2003
6.11.2003
21.11.2003
6.12.2003
21.12.2003
5.1.2004
20.1.2004
4.2.2004
19.2.2004
5.3.2004
20.3.2004
4.4.2004
19.4.2004
4.5.2004
19.5.2004
3.6.2004
18.6.2004
3.7.2004
18.7.2004

Data analysis - methodology

- Prediction of radon concentration in the thermal water on the basis of measured physical, chemical, meteorological and hydrological parameters

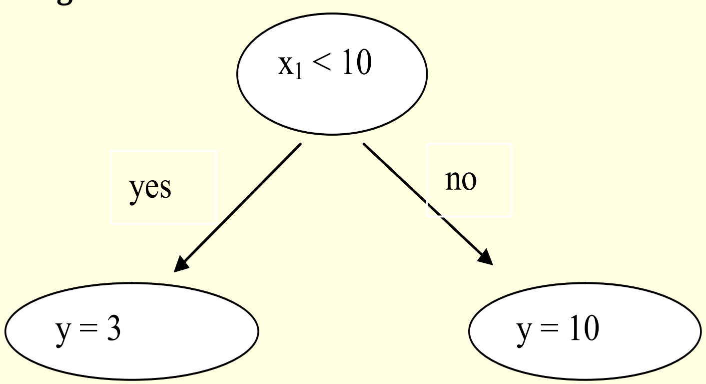
- Regression methods:
  linear regression (lr)
  (lr1 = nfs nfe, lr2 = fs nfe, lr3 = nfs fe, lr4 = fs fe)
  instance – based regression (nn)
  (nn01, nn05, nn10, nn25, nn50 and nn99)
  model / regression trees (mt / rt)
  baging (bag lr, bag mt, bag mt)

Linear regression, regression and model trees

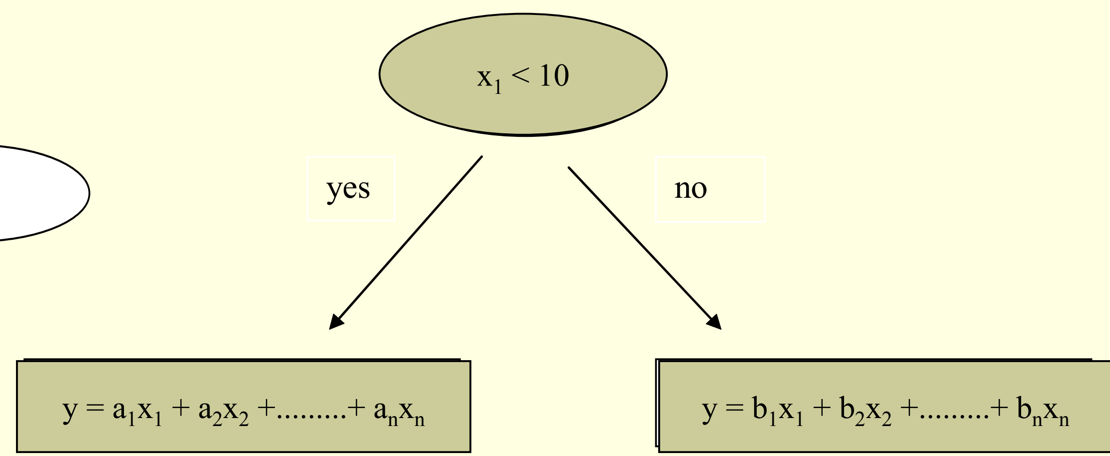
- **linear regression**

  $y = a_1x_1 + a_2x_2 + \ldots\ldots\ldots + a_nx_n$

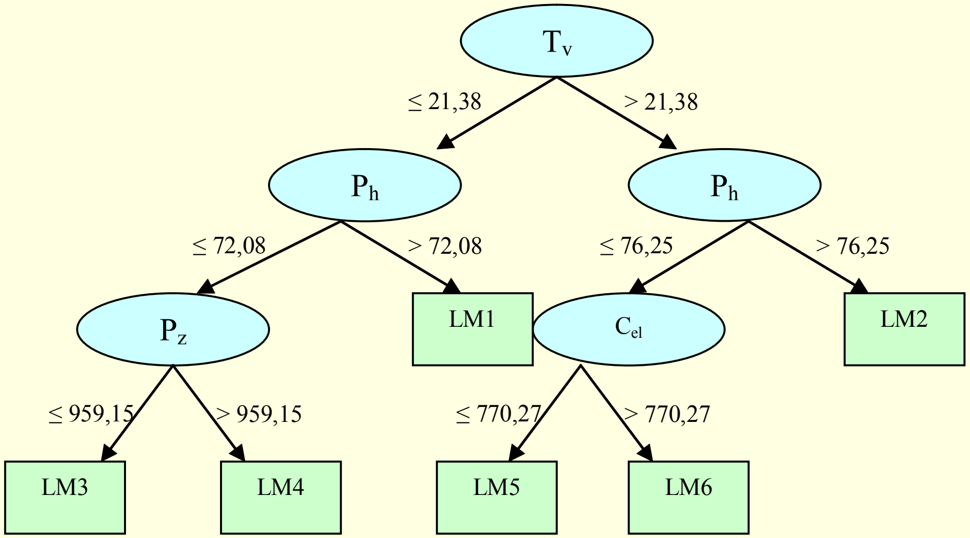
- **regression tree**



- **model tree**



Model tree



LM1: CRn = –0,14Ph + 0,02ΔPh – 0,43Pb + 0,06ΔPb + 1,50Tv – 0,03Tz – 0,29(Tz – Tv) + 0,01Cel – 0,06D + 437,97
LM2: CRn = –0,01Ph + 0,04ΔPh – 0,14Pb + 0,06ΔPb + 2,73Tv – 0,38Tz – 0,09(Tz – Tv) + 0,01Cel – 0,01D + 225,83
LM3: CRn = –0,21Ph + 0,24ΔPh – 1,34Pb + 0,36ΔPb + 13,48Tv – 0,49Tz – 0,01(Tz – Tv) + 0,26Cel – 0,33D + 1460,23
LM4: CRn = –0,42Ph + 0,37ΔPh – 0,06Pb – 0,69ΔPb – 85,83Tv + 0,25Tz – 0,05(Tz – Tv) + 0,17Cel – 0,55D + 1875,07
LM5: CRn = –0,56Ph + 0,28ΔPh – 0,06Pb + 0,07ΔPb – 20,23Tv + 0,18Tz – 0,03(Tz – Tv) + 0,21Cel – 0,15D + 425,98
LM6: CRn = –0,58Ph + 0,29ΔPh – 0,06Pb + 0,07ΔPb + 18,21Tv – 0,21Tz – 0,04(Tz – Tv) + 0,24Cel – 0,19D + 428,63

Data analysis:

Test the hypothesis that radon concentration in thermal water is related to measured chemical, physical, meteorological and hydrological parameters and that the predictability of radon concentartion fails (or is worse) during seismic activity

The input data:

- **water characteristics:**
  temperature, pressure, electrical conductivity and Rn conc.

- **meteorological parameters:**
  atmospheric pressure and temperature, rainfall

- **seismic activity:**
  earthquake magnitude

Accuracy was measured with correlation coefficient (r) and root mean squared error (RMSE)

The first part of data analyse:
selection of the most accuarte regression methods

Predictive performance of different regression methods on entire data set at Hotavlje, using 10-fold cross correlation

Regression methods	r_1	r_2	$r_2 - r_1$ (%)
mt	0,4702	0,5461	13,90
rt	0,3419	0,4023	15,01
bag mt	0,4936	0,6172	20,03
lr 1	0,3633	0,4383	17,11
lr 2	0,3809	0,4396	13,35
lr 3	0,3633	0,4383	17,11
lr 4	0,3809	0,4396	13,35
nn 01	0,0014	0,0894	98,43
nn 05	0,1716	0,1527	-12,38
nn 10	0,1961	0,1751	-11,99
nn 25	0,0913	0,2552	64,22
nn 50	0,2566	0,2772	7,43
nn 99	0,2006	0,2545	21,18

Predictive performance of different regression methods on entire data set at Bled, using 10-fold cross correlation

Regression methods	r	RMSE
mt	0,9237	1,8544
rt	0,9176	1,9490
bag mt	0,9342	1,7300
bag rt	0,9175	1,9551
lr 1	0,7674	3,1485
lr 2	0,7662	3,1571
lr 3	0,8199	2,7712
lr 4	0,8204	2,7677
bag lr 1	0,7885	2,9942
nn 01	0,7517	3,4531
nn 05	0,8238	2,8358
nn 10	0,8561	2,5629
nn 25	0,8706	2,4336
nn 50	0,8663	2,4688
nn 99	0,8510	2,6000

Predictive performance of different regression methods on entire data set at Zatolmin, using 10-fold cross correlation

Regression methods	**r**	**RMSE**
mt	0,7316	12,1896
rt	0,7018	12,7909
bag mt	0,7580	11,7093
bag rt	0,7283	12,4451
lr 1	0,5283	15,1799
lr 2	0,5270	15,1950
lr 3	0,5283	15,1799
lr 4	0,5270	15,1950
bag lr 1	0,5235	15,2403
nn 01	0,6425	14,4678
nn 05	0,7308	12,2343
nn 10	0,7183	12,5541
nn 25	0,6668	13,6019
nn 50	0,6148	14,5467
nn 99	0,5345	15,6593

The second part of the data analyse:

- **Test of the hypothesis about the predictability of C_{Rn} in SN and SA periods (C_{Rn} should become unpredictable during the SA periods)**
- **The data split into two parts: SN & SA (SW 7)**
- **Model for C_{Rn} prediction built on SN data, using cross-validation with different regression methods.**
- **This model later tested on SA data**
- **Selection of 2 – 3 most accurate regression methods in the case of SW 7 that they were the most accurate also in the first part of the data analyse**
- **Then the HYPOTHESIS tested with SW 1-7**

The second part of data analyse:

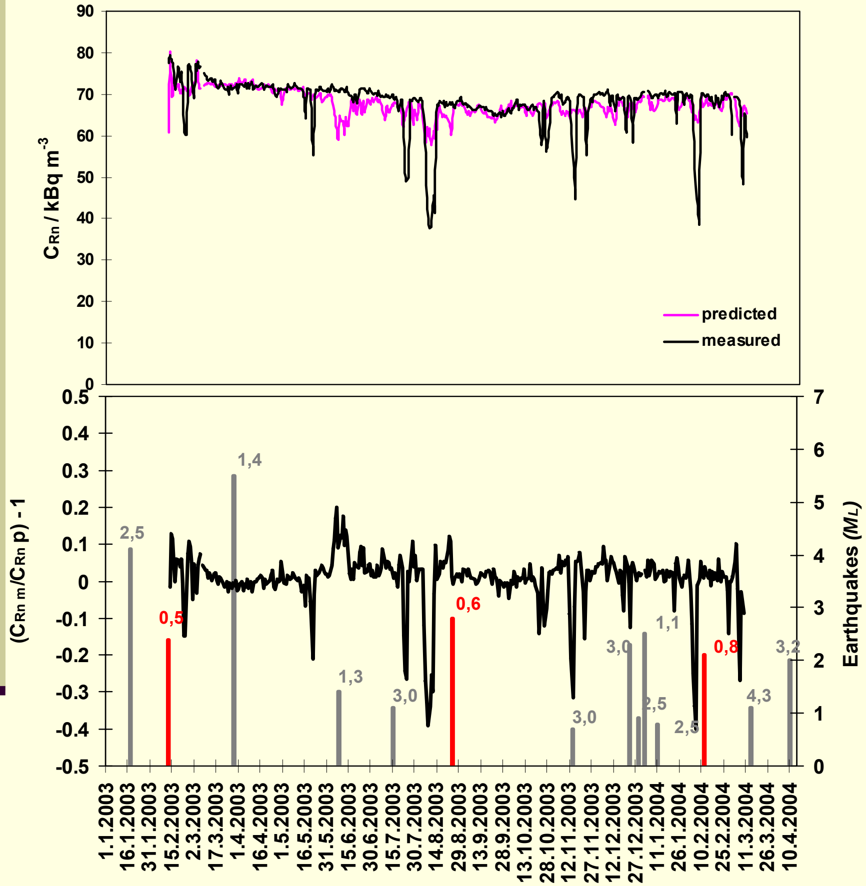
Selection of the most accurate methods with SW 7 at Hotavlje

Regression methods	SW	SN periods		SA periods		difference (%)	
		r	RMSE	r	RMSE	r	RMSE
bag mt	7	0,6379	4,4824	0,3033	6,5852	-52,45	46,91
mt	7	0,5793	4,7309	0,2808	7,1568	-51,53	51,28
rt	7	0,5250	5,0041	0,0252	7,2188	-95,20	44,26
nn 25	7	0,4779	5,2122	0,0709	6,8662	-85,16	31,73
bag lr 1	7	0,4551	5,1841	0,1646	6,8623	-63,83	32,37
lr 4	7	0,4517	5,1891	0,2370	6,6643	-47,53	28,43
lr 2	7	0,4517	5,1891	0,2370	6,6643	-47,53	28,43
lr 3	7	0,4513	5,1928	0,1709	6,8183	-62,13	31,30
lr 1	7	0,4513	5,1928	0,1709	6,8183	-62,13	31,30
nn 10	7	0,4315	5,3293	0,0967	6,4342	-77,59	20,73
nn 50	7	0,3817	5,3932	0,0562	6,8239	-85,28	26,53
nn 99	7	0,3240	5,5379	0,2357	6,5602	-27,25	18,46
nn 05	7	0,2565	5,6164	-0,0740	6,7883	-128,85	20,87
nn 01	7	0,0388	8,0975	0,1197	6,6637	208,51	-17,71

Test of the hypothesis about the predictability of C_{Rn} in SN and SA periods at Hotavlje, with mt and bag mt, SW 1-7

Regression methods	SW	SN periods		SA periods		difference (%)	
		r	RMSE	r	RMSE	r	RMSE
mt	7	0,5793	4,7309	0,2808	7,1568	-51,53	51,28
mt	6	0,5875	4,7438	0,3024	6,1677	-48,53	30,02
mt	5	0,5245	5,1903	0,1872	5,8758	-64,31	13,21
mt	4	0,5454	5,1127	0,4460	6,8650	-18,23	34,27
mt	3	0,4132	5,5708	0,3920	6,8714	-5,13	23,35
mt	2	0,4316	5,4570	0,7118	4,4704	64,92	-18,08
mt	1	0,4670	5,2665	0,5922	4,9308	26,81	-6,37
bag mt	7	0,6379	4,4824	0,3033	6,5852	-52,45	46,91
bag mt	6	0,6038	4,6930	0,3111	6,2761	-48,48	33,73
bag mt	5	0,5918	4,8119	0,4277	5,4787	-27,73	13,86
bag mt	4	0,4698	5,3979	0,5732	5,0797	22,00	-5,89
bag mt	3	0,5447	5,0680	0,5326	5,1823	-2,22	2,26
bag mt	2	0,6052	4,8036	0,4709	5,2004	-22,19	8,26
bag mt	1	0,5689	4,9051	0,5970	4,6088	4,94	-6,04

Measured and predicted C_{Rn} and $(C_{Rn\ m}/C_{Rn\ p}) - 1$ at Hotavlje, with the method bag mt, SW 7



Upper limit	A	ME	FA
0,1	21	0	0
0,2	7	1	0
0,3	4	1	0

- **predicted C_{Rn} mainly lower than the measured**
- **discrepancies occured 13 ± 12 days before the earthquake**
- **duration of A on the avreage 3 ± 2 days**
- **the time of occurence of anomaly (A) before the earthquake, its duration, and amplitude have grown with increasing magnitude and decreasing E/D ratio**

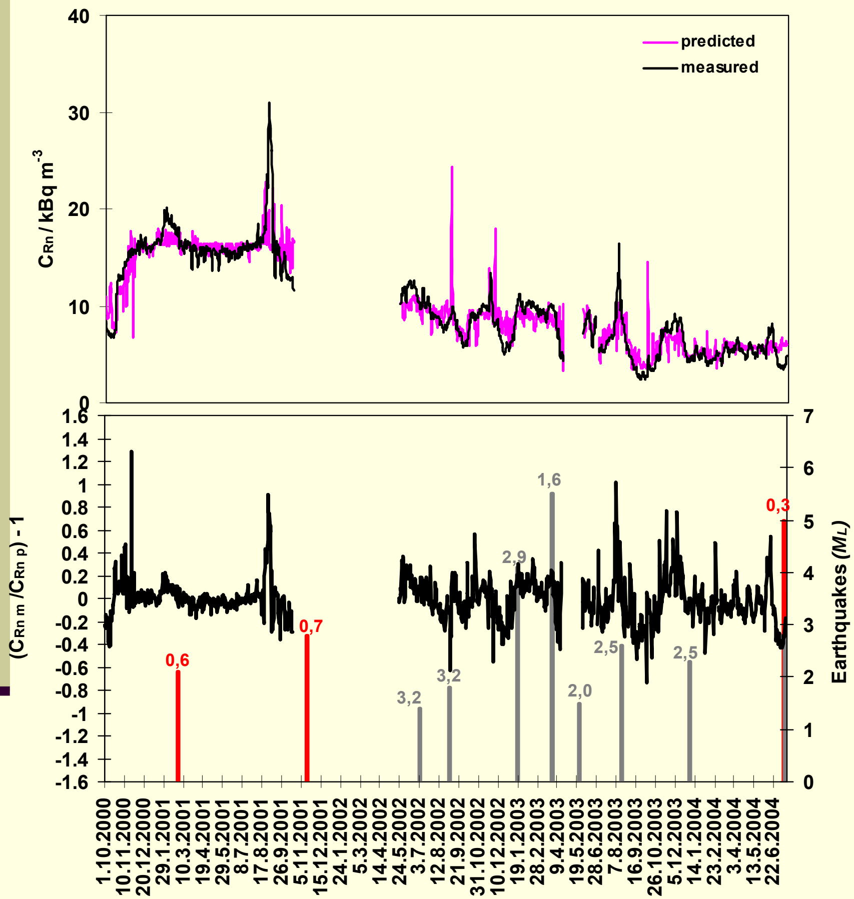
Selection of the most accurate methods with SW 7 at Bled

Regression methods	SW	SN periods		SA periods		difference (%)	
		r	RMSE	r	RMSE	r	RMSE
mt	7	0,9286	1,8321	0,8776	1,8813	-5,49	2,69
bag rt	7	0,9158	2,0112	0,8702	1,9559	-4,98	-2,75
rt	7	0,9114	2,0526	0,8403	2,1456	-7,80	4,53
nn 25	7	0,8764	2,4289	0,7633	2,5114	-12,91	3,40
nn 50	7	0,8713	2,4704	0,7510	2,5620	-13,81	3,71
nn 10	7	0,8677	2,5052	0,7580	2,5698	-12,64	2,58
nn99	7	0,8515	2,6494	0,7344	2,6234	-13,75	-0,98
nn05	7	0,8452	2,7110	0,7585	2,6015	-10,26	-4,04
lr 4	7	0,8334	2,7283	0,6063	3,1820	-27,25	16,63
lr 3	7	0,8324	2,7358	0,6040	3,1950	-27,44	16,78
bag lr 1	7	0,8237	2,8018	0,6038	3,1939	-26,70	13,99
lr 2	7	0,8141	2,8742	0,6063	3,1820	-25,53	10,71
lr 1	7	0,8073	2,9253	0,6040	3,1950	-25,18	9,22
bag mt	7	0,8026	3,2050	0,8864	1,8087	10,44	-43,57
nn 01	7	0,7811	3,3254	0,6335	3,3430	-18,90	0,53

Test of the hypothesis about the predictability of C_{Rn} in SN and SA periods at Bled, with mt, bag rt and rt, SW 1-7

Regression methods	SW	SN periods		SA periods		difference (%)	
		r	RMSE	r	RMSE	r	RMSE
mt	7	0,9286	1,8321	0,8776	1,8813	-5,49	2,69
mt	6	0,9261	1,8594	0,8933	1,7469	-3,54	-6,05
mt	5	0,9239	1,8802	0,8427	2,0945	-8,79	11,40
mt	4	0,9056	2,0801	0,8532	2,0249	-5,79	-2,65
mt	3	0,9282	1,8189	0,8350	2,1759	-10,04	19,63
mt	2	0,9210	1,8974	0,7532	2,7620	-18,22	45,57
mt	1	0,9217	1,8841	0,7056	3,2145	-23,45	70,61
bag rt	7	0,9158	2,0112	0,8702	1,9559	-4,98	-2,75
bag rt	6	0,9143	2,0291	0,8702	1,9254	-4,82	-5,11
bag rt	5	0,9154	2,0074	0,8924	1,7585	-2,51	-12,40
bag rt	4	0,9148	2,0065	0,8966	1,7010	-1,99	-15,23
bag rt	3	0,9159	1,9910	0,8817	1,8015	-3,73	-9,52
bag rt	2	0,9152	1,9887	0,8981	1,7049	-1,87	-14,25
bag rt	1	0,9172	1,9627	0,9427	1,4010	2,78	-28,62
rt	7	0,9114	2,0526	0,8403	2,1456	-7,80	4,53
rt	6	0,9094	2,0677	0,8544	2,0359	-6,05	-1,54
rt	5	0,9070	2,0882	0,9009	1,7018	-0,67	-18,50
rt	4	0,9135	2,0138	0,8985	1,6852	-1,64	-16,32
rt	3	0,9122	2,0214	0,8956	1,6998	-1,82	-15,91
rt	2	0,9125	2,0096	0,9040	1,6760	-0,93	-16,60
rt	1	0,9083	2,0447	0,9398	1,4047	3,47	-31,30

Measured and predicted C_{Rn} and $(C_{Rn\,m}/C_{Rn\,p}) - 1$ at Bled, with the method mt, SW 1



Upper limit	A	ME	FA
0,44	12	2	11
0,54	7	2	4
0,64	3	3	4

- predicted C_{Rn} alternating below and above the measured
- discrepancies occured 28 ± 17 days before the earthquake
- duration of A on the avreage 1 ± 0 days
- magnitude was not related with the time of occurence of anomaly (A) before the earthquake, or its amplitude or duration

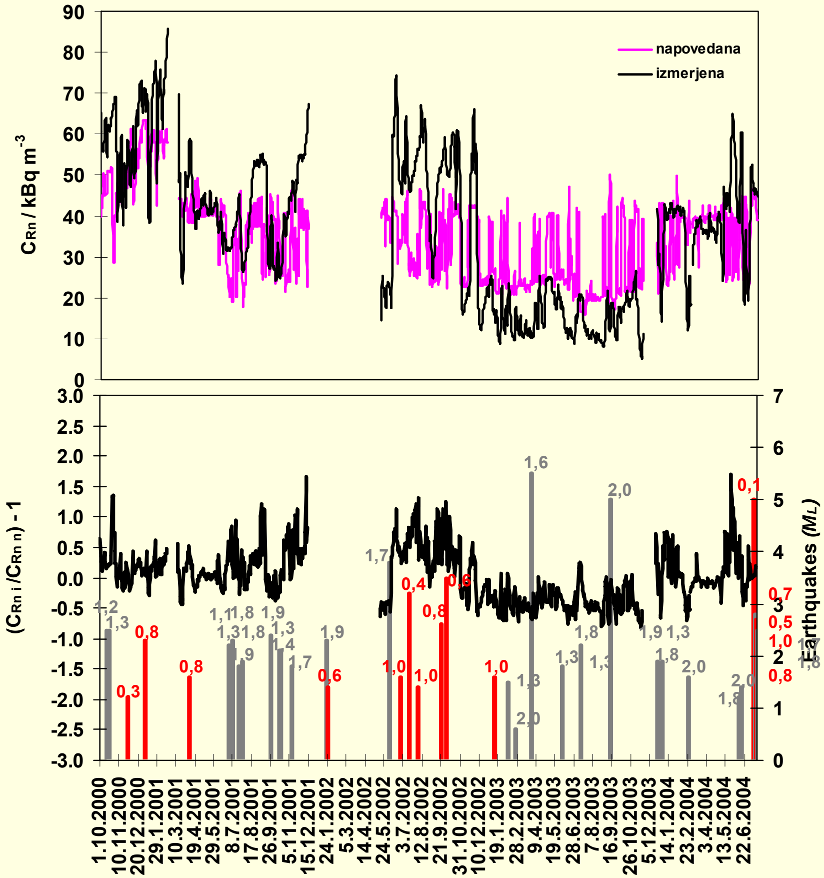
Selection of the most accurate methods with SW 7 at Zatolmin

Regression methods	SW	SN periods		SA periods		difference (%)	
		r	RMSE	r	RMSE	r	RMSE
bag mt	7	0,7061	13,1078	0,6235	13,2915	-11,70	1,40
bag rt	7	0,6805	13,7333	0,6012	13,5402	-11,65	-1,41
rt	7	0,6315	14,3880	0,5358	14,3686	-15,15	-0,13
nn 05	7	0,6277	14,4733	0,3976	16,3772	-36,66	13,15
nn 10	7	0,5950	15,0430	0,4507	15,2394	-24,25	1,31
mt	7	0,5908	14,9848	0,5880	13,8845	-0,47	-7,34
nn01	7	0,5672	16,2127	0,3503	19,7040	-38,24	21,53
nn 25	7	0,5285	16,0382	0,4292	15,2224	-18,79	-5,09
lr 3	7	0,5183	15,8077	0,4738	14,8051	-8,59	-6,34
lr 1	7	0,5183	15,8077	0,4738	14,8051	-8,59	-6,34
bag lr 1	7	0,5153	15,8572	0,4765	14,7824	-7,53	-6,78
lr 4	7	0,5079	15,9394	0,4737	14,8060	-6,73	-7,11
lr 2	7	0,5079	15,9394	0,4737	14,8060	-6,73	-7,11
nn50	7	0,4763	16,7110	0,3836	15,5568	-19,46	-6,91
nn99	7	0,4387	17,0890	0,4015	15,5649	-8,48	-8,92

Test of the hypothesis about the predictability of CRn in SN and SA periods at Zatolmin, with bag mt, bag rt and rt, SW 1-7

Regression methods	SW	SN periods		SA periods		difference (%)	
		r	RMSE	r	RMSE	r	RMSE
bag mt	7	0,7061	13,1078	0,6235	13,2915	-11,70	1,40
bag mt	6	0,7455	12,3178	0,6225	13,2167	-16,50	7,30
bag mt	5	0,7571	12,0427	0,6008	13,4946	-20,64	12,06
bag mt	4	0,7397	12,3426	0,6169	13,0561	-16,60	5,78
bag mt	3	0,7607	11,8818	0,6717	12,1295	-11,70	2,08
bag mt	2	0,7585	11,8792	0,7146	11,3034	-5,79	-4,85
bag mt	1	0,7782	11,4307	0,6947	11,4572	-10,73	0,23
bag rt	7	0,6805	13,7333	0,6012	13,5402	-11,65	-1,41
bag rt	6	0,6956	13,4780	0,6058	13,2971	-12,91	-1,34
bag rt	5	0,7221	12,9783	0,6071	13,2448	-15,93	2,05
bag rt	4	0,7122	13,1011	0,6452	12,6340	-9,41	-3,57
bag rt	3	0,7265	12,7846	0,6508	12,4680	-10,42	-2,48
bag rt	2	0,7182	12,8478	0,6873	11,8151	-4,30	-8,04
bag rt	1	0,7340	12,5032	0,6617	12,0348	-9,85	-3,75
rt	7	0,6315	14,3880	0,5358	14,3686	-15,15	-0,13
rt	6	0,6721	13,7446	0,5784	13,7871	-13,94	0,31
rt	5	0,6711	13,6517	0,5814	13,7271	-13,37	0,55
rt	4	0,6870	13,3548	0,6061	13,2997	-11,78	-0,41
rt	3	0,6808	13,3978	0,6697	12,2823	-1,63	-8,33
rt	2	0,6924	13,1679	0,6811	12,1061	-1,63	-8,06
rt	1	0,6964	13,0126	0,6868	11,8219	-1,38	-9,15

Measured and predicted C_{Rn} and $(C_{Rn\,m}/C_{Rn\,p}) – 1$ at Zatolmin, with the method bag rd, SW 7



Upper limit	A	ME	FA
0,8	27	3	0
1,0	17	3	0
1,2	7	6	0

- predicted C_{Rn} below the measured before the earthquakes E/D < 1
- discrepancies occured 20 ± 18 days before the earthquake
- duration of A on the avreage 2 ± 1 days
- the time of occurence of anomaly (A) before the earthquake, its duration and amplitude have grown with increasing magnitude and decreasing E/D ratio

The third part of the data analyse:

- In second part of data analyses radon concentration was predicted (numerically) from measured chemical, physical, hydrological and meteorological parameters using regression or model trees.

- The next step was to evaluate the possibility to predict an earthquake from observed discrepancies between the measured and the predicted radon values using classification trees.

The third part of the data analyse:

- **Three data sets were used for this purpose:**

1. **measured parameters (C_{Rn}, T_v, P_h, EC, T_a, P_b, rainfall)**
2. **predicted C_{Rn}**
3. **difference$_i$ = measured $C_{Rn\ i}$ – predicted $C_{Rn\ i}$, i = 1, 2,..., n**
   quotient = (measured $C_{Rn\ i}$/predicted $C_{Rn\ i}$) – 1
   averages of differences and quotiens for 1 – 7 days,
   and upper limit with the regression method with which,
   the hypothesis was the best confirmed

- **The test was made combinating all 3 data sets in this order:**
  1, 3, 1+2+3, 1/C_{Rn}+3, 1/met+2+3,
  at SW 0, 3 and 7
  with confidence factor 0.01, 0.05, 0.10, 0.25, 0.50 and 0.99.

The third part of the data analyse:

- **The result was classification tree and confusion matrix:**

		predicted values	
		yes	no
mesured values	yes	**C yes**	**ME**
	no	**FA**	**C no**

Earthquake prediction:

- **At Hotavlje; 389 instances, 38 SA days, 351 SN days;**

in the case of 1/met+2+3, SW 3, c.f 0.25;

50 % correct predictions / 50 % missed / 5 FA

- **At Bled; 944 instances, 85 SA days, 909 SN days;**

in the case of 1+2+3, SW 7, c.f. 0.99;

65 % correct predictions / 35 % missed / 21 FA

- **At Bled; 1122 instances, 118 SA days, 1004 SN days;**

in the case of 1/met+2+3, SW 7, c.f. 0.25;

44 % correct predictions / 56 % missed / 37 FA

- **At Zatolmin; 1183 instances,413 SA days, 770 SN days;**

in the case of 1+2+3, SW 7, c.f. 0.99;

71 % correct predictions / 29 % missed / 99 FA

Conclusions

- These results of applying regression methods to relate radon concentration to environmental data and seismic activity are encouraging.
- Better results were obtained with model and regression trees than with the other regression methods: with correlations above 0,6 at Hotavlje, 0,9 at Bled and 0,7 at Zatolmin. Longer than the data base, better the correlation coefficient.
- The most influencing parameters with *md* method on entire data sets at all three stations were: electrical conductivity, followed by water temperature, water and barometric pressure and air tempearture.
- Our hypothesis, that predictive performance of our model for radon prediction on SA data is higher than on the SN data, was the best confirmed with bag md SW 7 at Hotavlje, with md SW 1 at Bled and with bag rd SO 7 at Zatolmin, where radon concentration became unpredictable or less-predictable during SA periods.
- The time of appearance of an anomaly before an earthquake, as well as its duration and amplitude, grew with increasing M_L and decreasing ratio of E/D.
- With the regression methods it was possible to trace even earthquakes with magnitude lower than 3, when the influence of meteorological and hydrological parameters on observed radon concentration interfere with effects caused by seismic activity.

Future work:

- **Continuation of Rn data regression analyses at all three monitoring stations**
- **Application of these regression methods in different environments, like vulcanic regions along subduction zones in Japan, in the Friuli mountains in Italy, at Etna vulcano in Sicilly...**
- **Further evaluation of the ability of earthquake prediction at all mentioned locations.**

Electrical Conductivity Sensor (Greenspan, Australia)

- The EC sensor uses an electromagnetic field for measuring conductivity. An increase in concentration causes a decrease in the resistivity and a corresponding increase in the output of the EC sensor.

- Water temperature is monitored by a separate sensor, which provides both a temperature output and a signal to normalise and compensate temperature dependence of the electrical conductivity.

- The sensitivities for the EC and temperature sensor are $0.01 \mu S cm^{-1}$ and 0.01°C, respectively.

Barasol MC 450 (Algade, France)

- Radon enters the detection chamber through a filter, which prevents radon decay products from entering the chamber.
- The detection unit is a solid-state silicon detector.
- The measurement is carried out by gross alpha counting. The counts were integrated over an hour.
- In addition to measurement of radon, water temperature and water pressure is measured at the same time periods.
- The sensitivity of the radon detector is 50 Bq m^{-3}, temperature is measured at accuracy of ± 0.01°C and pressure of ± 1 mbar.