Postojna Cave as possible Near Fault Observatory mini site in SW Slovenia

Giovanni Costa[1], Jurij Pahor[2], Stanka Šebela[3], Janja Vaupotič[4], Blaž Vičič[5], Mladen Živčić[2]

[1] SeisRaM group, Università degli Studi di Trieste, Dipartimento di Matematica e Geoscienze, via Weiss 2 - 34128 Trieste, Italy, costa@units.it
[2] Slovenian Environment Agency, Vojkova 1b, 1000 Ljubljana, jurij.pahor@gov.si, mladen.zivcic@gov.si
[3] ZRC SAZU, Karst Research Institute, Titov trg 2, 6230 Postojna, Slovenia, sebela@zrc-sazu.si
[4] Jožef Stefan Institute, IJS, Jamova cesta 39, 1000 Ljubljana, Slovenia, janja.vaupotic@ijs.si
[5] Università degli Studi di Trieste, Dipartimento di Matematica e Geoscienze, via Weiss 2 - 34128 Trieste, Italy, blaz.vicic@gmail.com

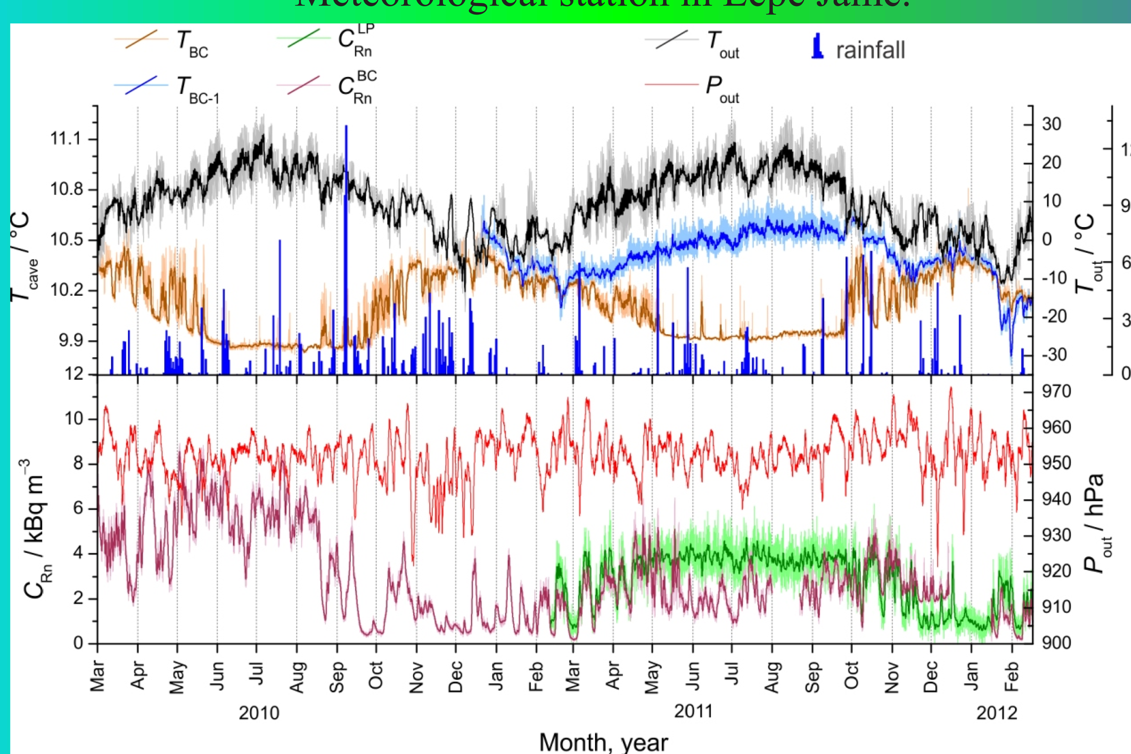
Within EPOS IP (H2020 project, no. 676564) four organizations (ZRC SAZU as EPOS IP partner, University of Trieste as member of EPOS Italy, Jožef Stefan Institute as member of consortium EPOS-SI and Slovenian Environment Agency as member of consortium EPOS-SI) are ready to participate in development of Postojna Cave (SW Slovenia) mini site as possible future Near Fault Observatory (NFO). NFO is included in EPOS IP as WP (TCS) – 9. Intensive geological, hydrogeological, seismological and karstological studies are taking place in Postojna Cave. Being a show cave the Postojna Cave has good infrastructure (electricity, cave train, optical cable etc.) what is positive for on-line scientific measurements inside the cave and transfer of data.

Postojna Cave is situated in SW part of Slovenia in External Dinarides with tectonically active Alpine thrusts and Dinaric (NW-SE) and cross-Dinaric (NE-SW) faults. It belongs to NE part of Adria microplate. Detailed tectonic-lithological map of Postojna Cave was published in 1998 (Šebela) and presented as general geological map in 2012 (Šebela). Postojna Cave is situated between Dinaric-oriented Idrija Fault in the North and Predjama Fault in the South. Idrija Fault was responsible for 1511 earthquake (M=6.8), which is the strongest earthquake in the territory of Slovenia. In Postojna Cave there are numerous broken speleothems, some of them can be due to tectonic activity (Šebela 2008).

Postojna Cave mini site will include:

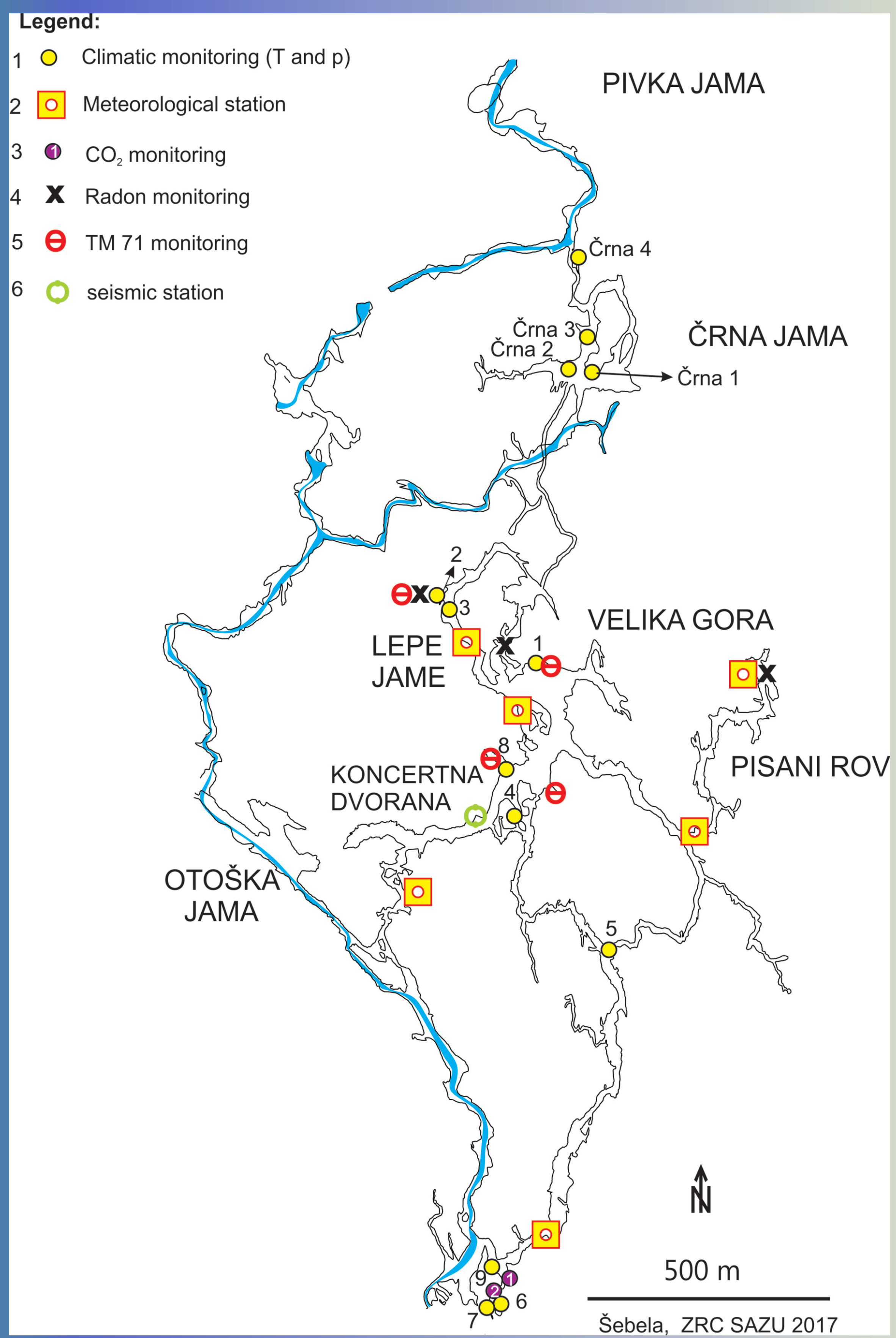
1. Regular micro-climatic monitoring (cave air temperature, water temperature, rock temperature, CO_2, humidity, air pressure, wind speed and direction) at several locations is going on since 2009 to assess impact of tourism on cave environment (Gregorič et al. 2013; Šebela & Turk 2011, 2014; Šebela et al. 2015; Mulec et al. 2012; Mulec 2014). Monitoring responsible is ZRC SAZU.
2. Radon monitoring in cave atmosphere started in 1995. In the first period seasonal measurements of radon activity concentration, equilibrium factor, radon progeny activity concentrations in attached and unattached form have been carried out to establish the reliable methodology for dose estimates of cave workers (Vaupotič et al., 2001, Vaupotič, 2008, Gregorič et al. 2011). Contemporary measurements of radon progeny activity concentrations and number concentrations and size distribution of general aerosol particles started in 2010 and are carried out periodically (Iskra et al., 2010, Bezek et al., 2013). Since 2011 continuous radon monitoring (once an hour) is going on, using radon as a tracer for cave ventilation (Gregorič et al. 2013, 2014; Šebela et al. 2010). Monitoring responsible is Jožef Stefan Institute.
3. 3D micro-displacement monitoring on two Dinaric oriented fault zones in the cave with four TM 71 extensometers (Gosar et al. 2009; Šebela et al. 2009, 2010; Briestenský et al. 2015). Monitoring responsible is ZRC SAZU.
4. Seismic station in Postojna Cave (Živčić et al. 2014) is operating since 2010, with large periods of inoperability due to power supply problems and hardware malfunctions. The station in the Tartarus tunnel (TTPJ) recorded more than hundred earthquakes of the sequence near Ilirska Bistrica that started on 15 September 2010, with two MLV = 3.5 earthquakes and lasted till the end of the year 2010, without accurate timing at that time. A fibre optic cable was installed later on and a Quanterra Q330 datalogger with accurate timing and real-time telemetry was installed with an Episensor accelerometer and a Lennartz 5 s seismometer. The instrument has been installed by the University of Trieste, Italy, which operates accelerometric and broadband stations in the NE Italy (Costa et al., 2010), some of which are installed near the Slovenian border not far from the cave, with the collaboration of the Slovenian Environment Agency which operates Seismic Network of the Republic of Slovenia and ZRC SAZU.

Meteorological station in Lepe Jame.



Time series of radon concentration recorded at two measurement locations (Beautiful Caves – C_{Rn}^{BC}) and the lowest point – C_{Rn}^{LP}, cave temperature (T_{cave}) recorded at measurement location BC and BC-1. Time series of main atmospheric parameters controlling radon concentration in the cave: outside air temperature (T_{out}), air pressure (P_{out}) and daily amount of rainfall. Radon concentration and atmospheric parameters are expressed in hourly values, 24h weighted average smoothing is applied to radon concentration and temperature; rainfall is expressed as absolute daily values (Gregorič et al. 2014).

Seismic noise measurements at Velika Gora.

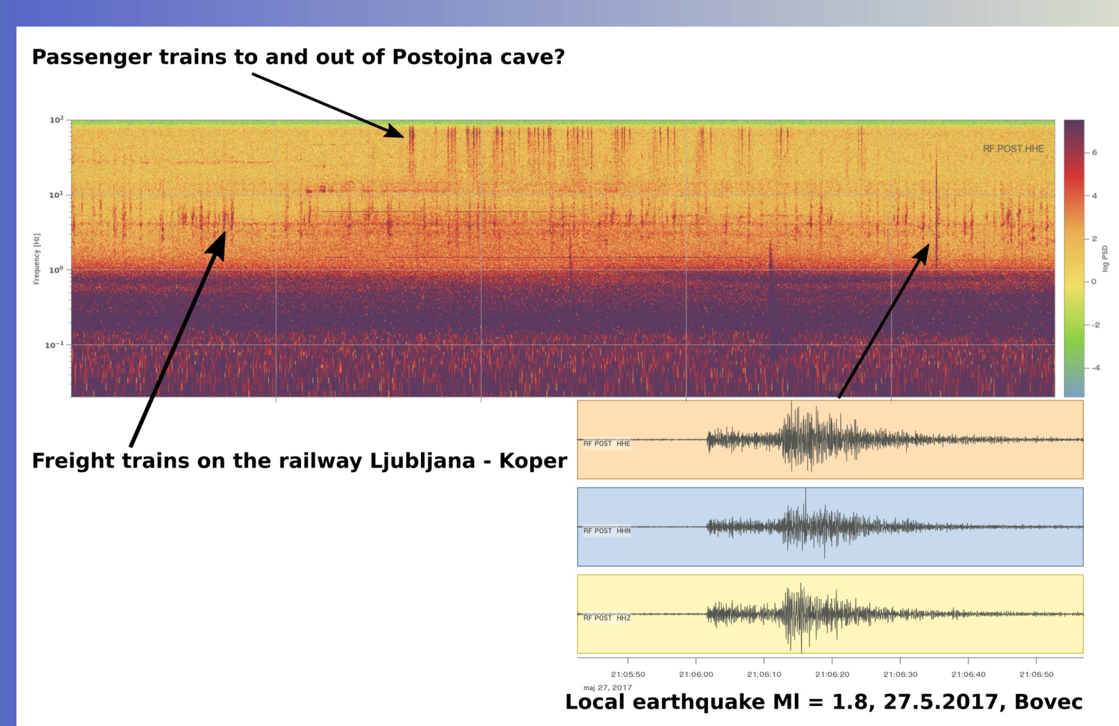


Postojna Cave as possible NFO with existing monitoring locations.

Within EPOS-SI consortium scientific cooperation between more institutions from Slovenia on the same site is possible. University of Trieste (Italy) is not part of Slovenian consortium, but is included in EPOS Italy and due to the near vicinity of Trieste (50 km far from Postojna) has good options to be actively involved in Postojna Cave mini site.

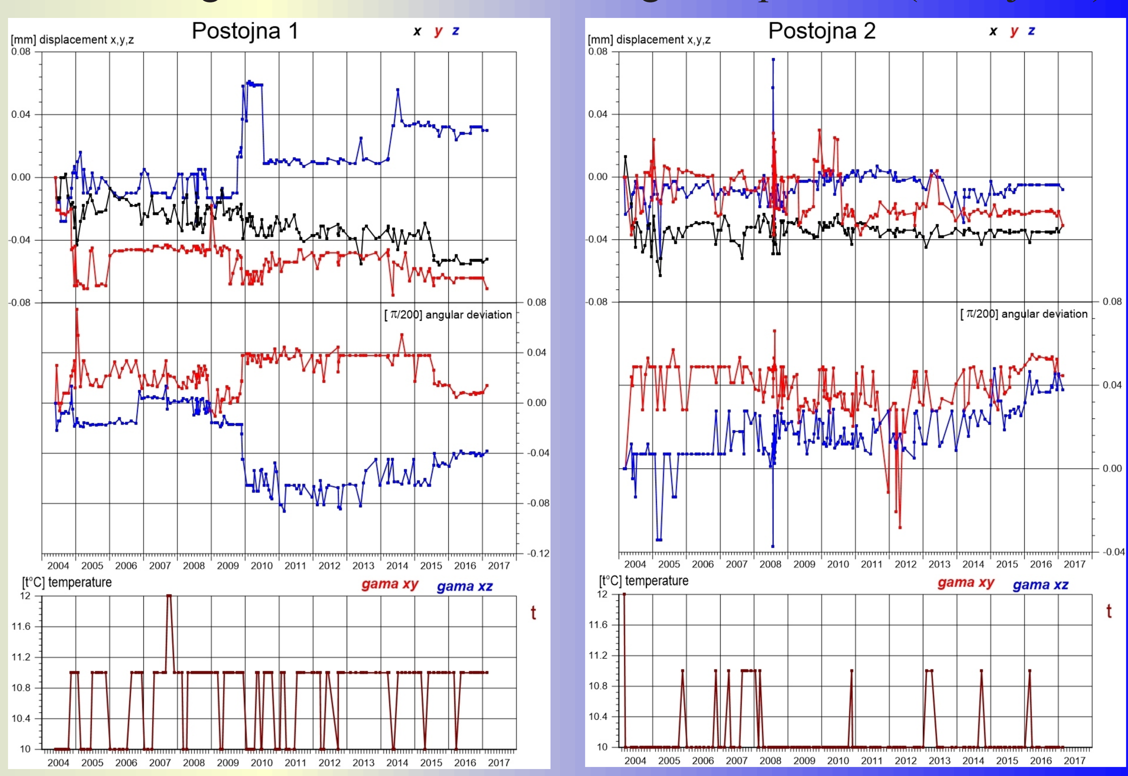
In the future we would like to enlarge mini site to »regular« NFO site (SW Slovenia, area between Trieste, Italy and Ljubljana, Slovenia). We will need to put more seismic stations and also GNSS stations, what will help to understand active tectonic displacements along Dinaric oriented faults in SW Slovenia (Kraški Rob Fault, Divača Fault, Raša Fault, Predjama Fault, Idrija Fault, Ravne Fault, Borovnica Fault etc.).

Seismic station in Tartarus.



Spectrogram of the whole day data from Postojna Cave seismic station.
We can clearly observe freight trains on the railway Ljubljana – Koper as a low frequency (2 – 10 Hz) events through all the day. In the higher frequencies (20 – 80 Hz) We can probably observe passenger trains going into and out of the Postojna Cave. On the same day, there was a M_L = 1.8 earthquake in Bovec region (75 km away), which is clearly observed on spectrogram (1 - 25 Hz) and on the waveform.

Micro-displacement monitoring with TM 71, radon monitoring and cave air T monitoring in Lepe Jame (Postojna 2).



Micro-displacement monitoring with TM 71 extensometer at Velika Gora (Postojna 1) and in Lepe Jame (Postojna 2).

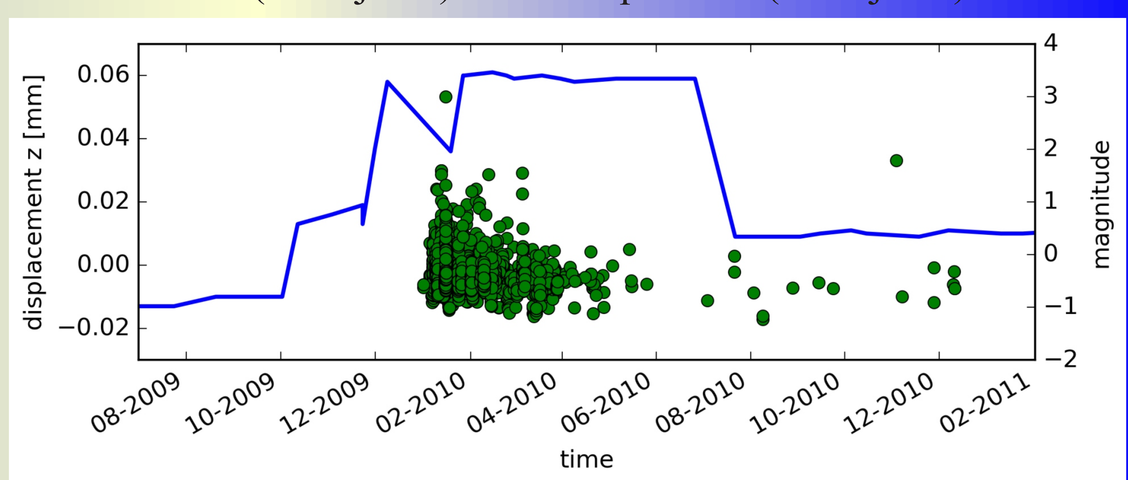


Figure shows extension along the Postojna TM 71 extensometer (Velika Gora) in z direction. As observed, extension starts 2 months prior to the earthquake swarm activity in Pivka Valley with the mainshock happening at the depth of 16 km. When majority of seismic activity is over the extension returns to the similar previous values. During the swarm seismic activity more then 3000 earthquakes happened. The activity lasts for more then one year.

REFERENCES

Bezek, M., Gregorič, A., Vaupotič, J. 2013. Radon decay products and 10-1100 nm aerosol particles in Postojna Cave. *Natural Hazards and Earth System Sciences*, 13, 3, 823-831.
Briestenský, M., Rowberry, M. D., Stemberk, J., Stefanov, P., Vozár, J., Šebela, S., Petro, Ľ., Bella, P., Gaál, Ľ., Ormukov, C. 2015. Evidence of a plate-wide tectonic pressure pulse provided by extensometric monitoring in the Balkan Mountains (Bulgaria). *Geologica Carpathica*, 66, 5, 427-438, doi: 10.1515/geoca-2015-0035.
Costa G, Moratto L, Suhadolc P 2010. The Friuli Venezia Giulia accelerometric network: RAF. Bull Earthq Eng 8:1141–1157
Gosar, A., Šebela, S., Košťák, B., Stemberk, J. 2009. Surface versus underground measurements of active tectonic displacements detected with TM 71 extensometers in Western Slovenia. *Acta carsologica*, 38, 2/3, 213-226.
Gregorič, A., Zidanšek, A., Vaupotič, J. 2011. Dependence of radon levels in Postojna Cave on outside air temperature. *Natural Hazards and Earth System Sciences*, 11, 5, 1523-1528.
Gregorič, A., Vaupotič, J., Gabrovšek, F. 2013. Reasons for large fluctuation of radon and CO_2 levels in a dead-end passage of a karst cave (Postojna Cave, Slovenia). *Natural Hazards and Earth System Sciences*, 13, 2, 287-297.
Gregorič, A., Vaupotič, J., and S. Šebela. 2014. The role of cave ventilation in governing cave air temperature and radon levels (Postojna Cave, Slovenia). *International Journal of Climatology* 34: 1488–1500.
Iskra, I., Kávási, N., Vaupotič, J. 2010. Nano aerosols in the Postojna Cave. *Acta Carsologica*, 39, 3, 523-528.
Mulec, J., Vaupotič, J., and J., Walonchik. 2012. Prokaryotic and Eukaryotic Airborne Microorganisms as Tracers of Microclimatic Changes in the Underground (Postojna Cave, Slovenia). *Microbial Ecology* 64: 654–667.
Mulec, J. 2014. Human impact on underground cultural and natural heritage sites, biological parameters of monitoring and remediation actions for insensitive surfaces: Case of Slovenian show caves. *Journal for Nature Conservation*, 22, 132-141.
Šebela, S. 1998. Tectonic structure of Postojnska jama cave system, 112 pp., Ljubljana.
Šebela, S. 2008. Broken speleothems as indicators of tectonic movements. *Acta carsologica*, 37, 1, 51-62.
Šebela, S., Turk, J., Mulec, J., Košťák, B., Stemberk, J. 2009. Statistical evaluation of the 3D monitoring of displacements of Dinaric fault zone in Postojna Cave, Slovenia. *Acta geodynamica et geomaterialia*, 6, 2, 163-176.
Šebela, S., Vaupotič, J., Košt'ák, B., Stemberk, J. 2010. Direct measurement of present-day tectonic movement and associated radon flux in Postojna cave, Slovenia. *Journal of caves and karst studies*, 72, 1, 21-34.
Šebela, S. & Turk, J., 2011. Local characteristic of Postojna Cave climate, air temperature, and pressure monitoring. *Theoretical and Applied Climatology*, 105, 371-386.
Šebela, S. 2012. Postojna Planina Cave System, Slovenia. In W.B. White, & D. C. Culver (Eds.), *Encyclopedia of Caves* (pp. 618–624). Amsterdam, Boston, Heidelberg, London, New York, Oxford, Paris, San Diego, San Francisco, Sydney, Tokyo: Academic Press, Elsevier.
Šebela, S. & Turk, J, 2014. Natural and anthropogenic influences on the year-round temperature dynamics of air and water in Postojna show cave, Slovenia. *Tourism Management*, 40, 233-243. DOI: 10.1016/j.tourman.2013.06.011
Šebela, S., Turk J. & Pipan T. 2015. Cave micro-climate and tourism: towards 200 years (1819 – 2015) at Postojnska jama (Slovenia). *Cave and Karst Science*, 42/2, 78-85.
Vaupotič, J., Csige, I., Radolić, V., Hunyadi, I., Planinić, J., Kobal, I. 2001. Methodology of radon monitoring and dose estimates in Postojna Cave, Slovenia. *Health Physics*, 80, 142-147.
Vaupotič, J. 2008. Nanosize radon short-lived decay products in the air of the Postojna Cave. *Science of the Total Environment*, 393, 1, 27-38.
Živčić, M., Costa, G., Suhadolc, P., Šebela, S. 2014. Temporary seismological measurements in Postojna cave system, 43, 1, 149-157, http://ojs.zrc-sazu.si/carsologica/article/view/569/713, doi: 10.3986/ac.v43i1.569.

25th International Karstological School „Classical Karst“, Postojna, 19-23 June 2017