Temperature monitoring in Slovene ice caves - Can less tell more?

Jure Kosutnik, Bachelor of Science in Geography

PhD Student of Karstology, University of Nova Gorica; Domzale municipallity; jurekosutnik@gmail.com; jure.kosutnik@domzale.si

CC BY

Introduction

Almost half of Slovenia is covered with rocks in which karst has developed. Chemical solubility of rock, mainly limestone and dolomite allows the combination of processes, leading to the formation of typical karst groundwater hydrology and characteristic surface and underground karst formations. Caves are common feature on Slovene karst and Slovene cave cadastre holds more than 10.000 registered caves, longer or deeper than ten meters. A simple calculation tells us that Slovenia has on average almost four cave entrances per square kilometer of karst surface. In reality, however, this figure can be more than 100 caves per square kilometer, for example, on the northeastern outskirts of Planina polje (Gams, 2003).

Among all Slovene caves 549 were registered as ice caves, but only 115 of them lie below 1500 meters of altitude and furthermore only a few caves in the lower altitudes contain perennial ice or snow deposits. Ice caves can be found in all Slovene mountainous regions – the Alps, the Prealps and in the Dinaric Mountains (Cave cadastre of Karst research Institute, 2010). According to Mihevc Laniško brezno (645 m a.s.l.) is the lowest-lying cave with perennial ice filling in Slovenia (Mihevc, 2008). The number of ice caves is not accurate or certain. The main reasons are the knowledge of cavers who registered the cave, the time and year of exploration, region in which cave lie and the cave's historic importance.

Karst areas coincide with higher relief of western Slovenia, where average altitudes are above 800 meters (Average altitude of Slovenia is 557 meters). Higher altitudes and dominant westerlies bring more than 3000 mm of rainfall per year to Slovene Alps (Kladnik, Geografski Geografski atlas). Average mean annual temperatures for selected measuring stations are Postojna (533m a.s.l.) +10ºC, Vojsko (1067 m a.s.l.) +7ºC, Vogel (1535 m a.s.l.) +4ºC and Kredarica (2514 m a.s.l.) -1ºC. On average the mean annual temperature drops 5,3ºC on every 1000 meters of elevation (Environmental Agency of the Republic of Slovenia, 2011).


Fig. 3: Ice crystals.


Fig. 4: Ablated ice with cryogenic calcite

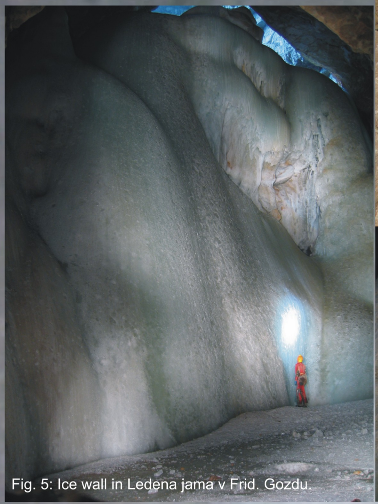


Fig. 5: Ice wall in Ledena jama v Frid. Gozdu.


Fig. 6: Manual T measurements.


Fig. 7: I-Button data logger

With this study attempt will be made to see how Slovene ice caves can be integrated into speleological and cryospheric sciences. To see what information can be deducted by using just one or a few methods correlated to a higher number of caves with different background and geographical position.

Measurements

Our aims are going to be reached by measuring temperatures in several caves with temperature anomaly which were selected because of their low altitude, their geographical location, amount of ice or historic importance. Some investigated caves contain various amounts of perennial ice deposits and other, the so called cold caves (Slovene: ledenica), are ice free in summer but significant because older literature suggest they once held perennial ice deposits.

Temperatures are being monitored with I-button type data-loggers, with 0,1ºC resolution and 60 minutes interval. First data-loggers were placed in august 2009 and the last in January 2011, in total 40 (2-3 per cave, with an additional one outside the cave). The goal is to obtain temperatures for at least two full years. Along with temperature monitoring ice genesis and ice mass balance are being studied and additionally also the extent and pace of periglacial processes in ice caves.

REFERENCES

- Cave cadastre. Inštitut za raziskovanje krasa ZRC SAZU
- Gams, I., 2003. Kras v prostoru in času (in Slovene). Ljubljana, Inštitut za raziskovanje krasa ZRC SAZU, Založba ZRC SAZU, 516 p.
- Gams, I., Mihevc, A., 1979. Nova odkritja v Veliki ledeni jami v Paradani (in Slovene). Naše jame 20, p. 7-20.
- Geographical Atlas of Slovenia, 1998. DZS, p.360.
- Habe, F., 1971. Die Eishöhlen im Slowenischen Karst (in German). Slovensky kras 9, p. 135-145.
- Habič, P., 1963. O podzemeljskih ledenikih na Nanosu (in Slovene). Naše jame, 5/1-2, DZRJS, p. 19-29.
- Hribar, F., 1960. Temperatur und vegetationsumkehrungen in Trnovski gozd (in German). VI. Int. Tagung f. Alpine meteorologie, Bled.
- Kranjc, A., 2004. Alpine and ice caves in Slovenia in older literature (17th to 19th century). Acta Carsologica 33/1, str. 61-71.
- Luetscher, M., 2005. Processes in ice caves. Swiss Institute for Speleology and Karst Studies, 154 p.
- Meteorological data, Environmental Agency of the Republic of Slovenia.
- Midhler, I., 1952. Velika ledena jam v Paradani (in Slovene). Proteus, l. 14, no. 9, p. 310-315.
- Michler, I., 1952. Ledene jame (in Slovene). Planinski vestnik, l. 52, no. 8, p. 212-219.
- Mihevc, A., 1993. Ledene in snežne jame (in Slovene). Geografski obzornik let. 40, št. 4, str. 32-35.
- Mihevc, A., Distribution and characteristics of ice caves in Slovenia. International Workshop on Ice Caves, IWIC-III, Kungur Ice Cave, Perm Region, Russia, May 12-17, 2008. - Perm : State University, Mining Institute, 2008
- Novak, D., 1973. Ledena jama na Stojni pri Kočevju (in Slovene). Naše jame 14, p. 35-42.
- Valvasor, J.V., 1689. Slava Vojvodine Kranjske.

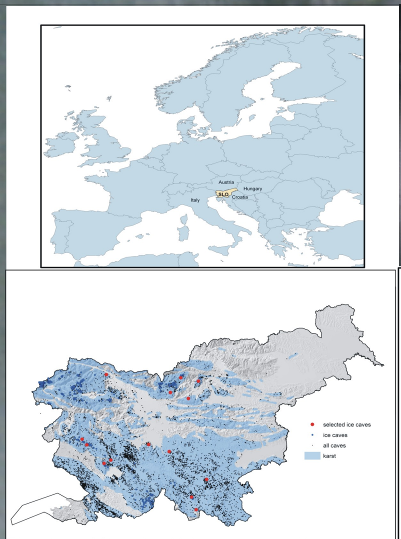


Fig.1: Map of Slovenia with karst, caves and ice caves.

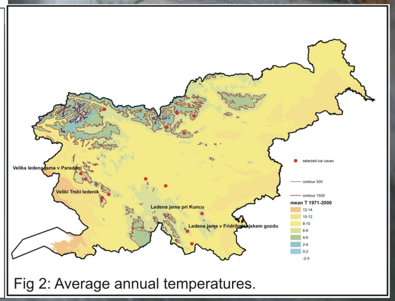


Fig 2: Average annual temperatures.

Ice caves in Slovenia

First three Slovene ice caves were mentioned in "Die Ehre Deß Hertzogthums Crain" by Valvasor in 1689. One is sealed by a wall and the other two no longer contain perennial ice but in both temperature measurements are being carried out. In the first half of the 19th century various ice caves were mentioned in important Slovene newspapers of that time (e.g. Die Eisgrotte im Hornwalde bei Toplitz in Unterkrain - Illyrisches Blatt nr. 28, 11. July 1829) and in the second half of the same century also in publications on ice caves, written mainly by German speaking scholars, who published lists of Slovene ice caves (e.g. Petruzzi 1850, Boue 1867, Schwalbe 1887, Moser 1889, Fugger 1894, Balch 1900; Kranjc, 2004).

However Slovene ice caves were never systematically investigated. Most published data on Slovene ice caves derives from caving excursion reports and from investigations done by members of Karst research institute and consists of random temperature measurements, assessment of ice volume, information on cave fauna and some other general remarks.

With this in mind a project of systematic temperature measurements in Slovene ice and cold caves was launched in 2009. The aims of the project are:

- To put literature on Slovene ice caves in perspective, with detailed analysis of the work done so far.
- To present the main characteristic of the studied ice caves, their location, overall morphology, morphology of their entrances, speleothems, sediments and other deposits in the caves, water in the caves, surrounding of the cave and other.
- To identify the main characteristics of ice caves microclimate and the relationship of external and internal air temperatures.
- To determine regional differences and similarities of the studied ice caves
- To determine origin (ice genesis) and volume of ice and its changes (ice balance) in selected ice caves
- To identify the importance of subzero temperatures for cave morphology and interpret periglacial phenomenon in selected ice caves.
- To asses the age of ice and the potential of Slovene ice caves for climate changes research.

Investigation of ice caves in the World is concentrated on small number of well known and usually show cave with developed infrastructures. Measurements include versatile methods which yield huge amount of data. Approach of our work consist of temperature measurements in 14 caves, all below 1600 meters above sea level, with cold thermal anomaly and ice occurrence long into the warm part of the year. Caves in lower altitudes are not only easily accessible, but changes in temperatures and ice volume are more profound because of higher average outside air temperatures, which makes these caves significant for science.


Fig. 8: frost shattered flowstone.


Fig. 9: Polygonal floor on a slope.

Fig. 10: Table with the main characteristic of selected ice caves.

name of the cave	cadastre no.	year of registration	region	altitude	lenght	depth	no. of entrances	morphology
Ledenica pod Taborom	33	1926	Dinaric karst	442	102	26	2	descending cave
Ledenica pri Planinci	77	1927	Dinaric karst	482	125	70	1	descending cave
Mala Veternica	122	1928	The Alps	1605	30	20	3	descending cave
Ledena jama v Fridrihštanjskem gozdu	142	1930	Dinaric karst	870	180	105	1	descending cave
Jespa	355	1934	The Alps	1420	57	42	1	collapse doline with cave
Ledena jama pri Ograji	400	1936	Dinaric karst	530	42	24	2	descending cave
Ledenica na Golteh	562	1938	The Alps	1530	80	60	1	abyss
Ledena jama pri Kunču	669	1939	Dinaric karst	785	81	42	1	descending cave
Velika ledena jama v Paradani	742	1917	Dinaric karst	1135	4090	650	1	abyss
Ledenica pri Dolu	751	1949	Dinaric karst	995	180	80	1	abyss
Veliki trški ledenik	912	1963	Dinaric karst	960	50	50	1	descending cave
Ledenica pod Hrušico	920	1952	Dinaric karst	750	60	28	1	collapse doline with cave
Snežna jama na Obranci	976	1959	The Alps	1130	72	20	1	abyss
Snežna jama na planini Arto	1254	1939	The Alps	1556	1327	75	1	horizontal cave

Ice cave on Stojna karst plateau lies in the dense forests in the elevation of 805 m. The entrance is a huge collapse that leads into an ice filled hall. Interestingly the entrance is oriented towards SE, so sun rays can play on the ice sculptures. A single hall developed along a fault zone. The hall is 30 meters high and filled with ice lake, dimensions 20 by 30 meters. At the sides of the ice block two continuations are possible, the deeper western and the shallower eastern. The cave is 105 meters deep descending ice filled cave. The estimated volume of ice is 20.000 m3, which makes Ledena jama v Fridrihštanjskem gozdu the most important Slovene static ice cave. It seams that ice is composed from two main components, congelation ice from dripping water and firn from snow avalanches in the entrance part. Under the snow cone in the entrance part is a small void. According to the literature it is obvious that the level of the ice lake is lowering. One can observe the bolts for rope attachment far above the frozen ground and unreachable. Also the annual ice speleothems on the walls in the great hall disappear sooner every year. The average T inside the cave (end of August 2009 – end of October 2010; 11,500 measurements) is below 0ºC, outside average T was 7,35ºC.

In the cave three data loggers were installed, one in the entrance hall, one under the entrance snow cone and one in the bottom of the eastern crack. Additional data logger was placed outside. The chart gives us T for all data loggers and additionally precipitation by days, from the nearby meteorological station. The outside T show daily fluctuations, while the inside T show usual open state in winter and closed state in summer. In the closed period the T in the great hall were the highest, with small fluctuations associated with the warmer rain water infiltration. Interestingly in the closed period the T were not the lowest in the bottom, but under the entrance snow cone. We think the reason for this is the possible closure of the small opening that leads under the snow cone and smaller and obstructed air movement in general. The fish bone pattern observed on the lower part of the snow cone is the result of movement. Because of the already mentioned reasons the T under the snow cone suffer the smallest drop during the open period in winter and present no fluctuations in the transitional period or as a result of precipitation infiltration.


Fig. 11: Fishbone pattern in snow.


Fig. 12: The sun shines on the ice plug.


Fig. 13: Vertival ice cliff.

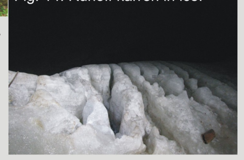
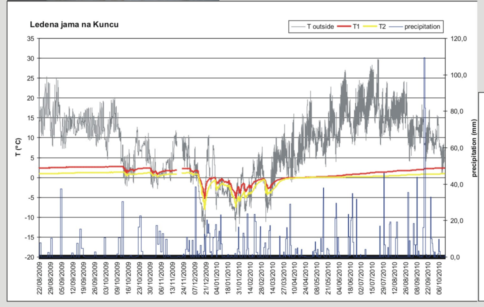


Fig. 14: Runoff karren in ice.



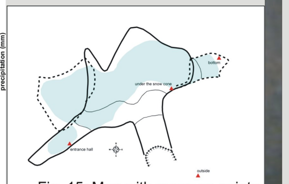


Fig. 15: Map with measure points.

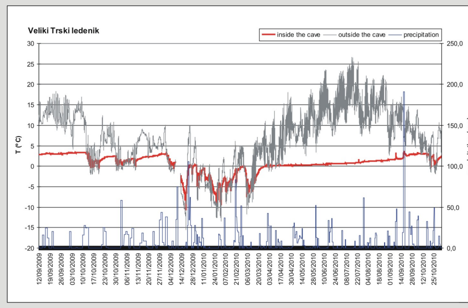
Ledena jama v Fridrihštanjskem gozdu

Veliki Trški ledenik lies on top of high Dinaric karst plateau Nanos in the elevation of 960 meters and some 45 kilometers W of Ljubljana. The cave is a 50 meters deep shaft that developed when more vadose shafts merges along a fault zone. Two natural bridges remain standing to confirm the hypothesis. Cave consists of one hall (25 meters long and 35 meters wide), with no ceiling and with vertical corroded walls; inside no artificial light is necessary. The floor of the cave has a shape of a cone and is composed of snow and organic matter. There are many ice caves on Nanos all with "ledenik" in their name. This Slovene word means glacier and it tells us that there is ice inside this caves and that local inhabitants exploited it. The owners of the cave and the forest around it were inhabitants of the market town Vipava (trg, trški = market). The cave acts as a cold trap with the average temperatures (September 2009 – October 2010; 11.900 measurements) in the lowest part is 0,67ºC. Inside the cave we can find perennial snow deposit, which is isolated by organic matter. It is believed that under the thick organic deposit an ice plug exists, consisting of firn. Unfortunately no lateral approach to the ice plug is possible. From December to March, when T inside and outside are usually below 0ºC ice is forming on the walls of the cave. The ice masses are melting slowly and can be seen in June. Usually with the rise of the T in the cave, the ice becomes unstable and readily detaches itself and drops to the bottom. Falling ice makes the descent into the cave dangerous.

In September 2009 a data logger was installed at the bottom of the cave and additional one outside the cave. T are presented on the chart. Average T outside the cave was 6,7ºC and inside 0,67ºC. The temperature lines are as expected. We see that from April to the second half of October cave is in a closed state, the T inside is slowly rising and reaches 4ºC, the outside T shows daily fluctuations. Open period lasts from December to the end of March and shows good correlation with outside T. In the closed state the inside T raises constantly and the main energy source can be attributed to precipitation. The lack of ceiling means that warm rain water caries all its energy directly to the bottom of the cave.


Fig. 16: The bottom in the automn.


Fig. 17: Spring conditions.



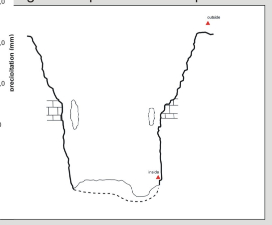
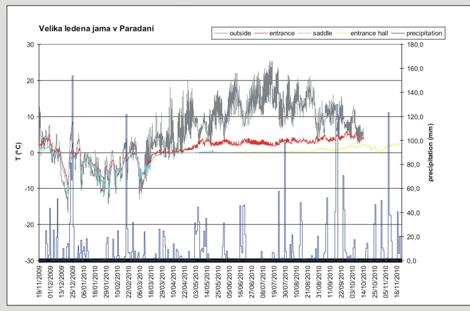
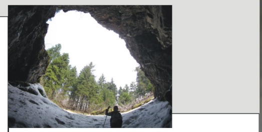


Fig. 18: Map with measure points.

Veliki Trški ledenik

Velika ledena jama v Paradani





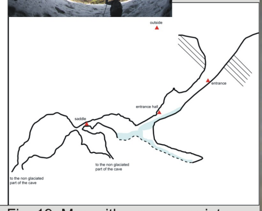


Fig. 19: Map with measure points.

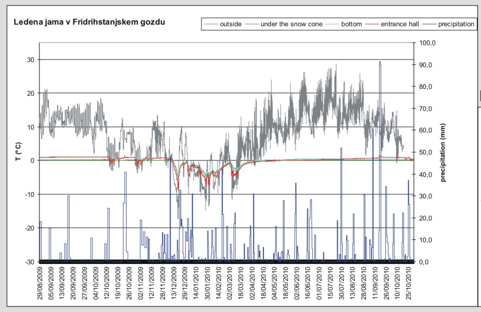

Fig. 20: Glacier and the entrance.


Fig. 21: Ice layers.

Velika ledena jama lies in the uvala called Paradana on the plateau Trnovski gozd, some 50 km W of Ljubljana. The NE facing entrance to this 650 meters deep and 4090 meters long dynamic ice cave is situated at 1135 m a.s.l. The entrance brings us to the Entrance hall with a snow avalanche and ice underneath. The glacier continues to the Great ice hall, where the ice surface flattens and is frequently flooded. From the Great ice hall the cave continues into a system of vertical shafts. The maximum thickness of ice is 20 meters, the estimated volume is 8.000 m^3. The collapse doline that leads to the cave is, with its pool of cold air, a locus typicus for the investigation of inverted flora habitats. The entrance part of the cave was explored by cavers during the First World War, because the ice was used as a fresh water source for the front. With the development of Trieste as an important seaport and before border changes and invention of artificial ice, caves on Trnovski gozd were important also as mean of additional income for Slovene peasants. In warm winters and sometimes in summers people used to cut ice, transport it by night and sell it to the port, brewery and bars in Trieste.

In November 2009 two data loggers were placed inside the cave, on in the entrance part and the other on the saddle, the point with constant draft where Great ice hall continues to the rest of the cave. Additional data logger was placed outside the cave. Because the Great ice hall was flooded from May until deep into the autumn, the unreachable saddle data logger was replaced by an additional one in the Entrance hall. Older studies have showed that Velika ledena jama v Paradani acts as a dynamic ice cave, with strong cold air inflow in the winter and weak summer outward currents. All data loggers show high correlation in winter, when cold air flow causes water to freeze up to the depth of 200 m. In the summer temperatures in the Entrance hall show increasing trend and reach their peak in early November. Daily fluctuations of around 1ºC were measured in the entrance part of the cave in summer, with the minimum in early afternoon. Fluctuations are either caused by the delayed effect of outside T or by delayed worm outflow from the cave.

Ledena jama na Kunču



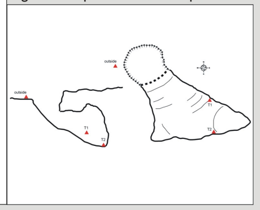


Fig. 22: Map with measure points.


Fig. 23: Floor ice.


Fig. 24: Entrance.

Ledena jama na Kunču ice cave is a static descending cave with entrance in the altitude of 785 m a.s.l. The cave lies in Kočevski rog high karst plateau, part of the Dinaric Mountains. The plateau is 25 km long in the NW-SE direction and 14 km across, the cave lies approximately 55 km SE from Ljubljana. The caves only entrance leads to a single hall, 81 meters long and 42 meters deep. Entrance is of collapse origin, with vertical walls on the southern side and less steep northern side, where a narrow path equipped with a steel rope leads into the cave. The descending floor of the cave is composed of gravel that results from the collapse and tree trunks that fell or were thrown in the cave. Bigger blocks of rock, also part of the collapse material, lie in the deepest part of the cave. The cave is a cold trap, with average T (September 2009 – October 2010; 11.915 measurements) in the lowest part below OºC (-0,08ºC). Flowstone in the cave shows signs of frost shattering and periglacial movements can be observed on the gravel slope.

Perennial ice is present in the caves bottom and fills gaps between blocks and boulders. Congelation ice results from drops of water from the ceiling. The total amount of ice is small, it grows from the end of November to early May. From historic sources we know that ice level is dropping rapidly.

In the end of August 2009 two data loggers were installed in the cave, one in the lowest part and one in the slope, half way from the bottom to the entrance. Additional data logger was installed outside the cave. On the chart temperature measurements from August 2009 to October 2010 are presented. Average T in the bottom of the cave is -0,08ºC, in the slope 0,97ºC and outside 8,2ºC. The temperature lines are as expected. Outside T show daily fluctuations, while inside T drop in accordance to the outside T. At the end of winter in April, T of both data loggers inside the cave are aligned, the pool of cold air is the deepest. The cold air worms up, the T of the higher data logger jumps up and the lower data logger follows in July. From end of summer, autumn and until the first subzero T outside the cave the two data loggers are synchronized, with constant difference of 1,2-1,5ºC.