Interpretation of the results of surveying works at one of the leading geoturist attraction - the Dobšinská Ice Cave

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ABSTRACT
The present paper deals with the formation of a spatial model of Dobšinská Ice Cave for the purpose of monitoring and documentation of its ice filling. Surveying work took place in the Small and the Large Hall of the Dobšinská Ice cave in two stages: in March and December 2011, during which geodetic network consisting of survey points on the surface and underground was stabilized and observed. For the purposes of drawing up the three-dimensional geographic cave model and for monitoring of its glaciations, points coordinates was determined in the current national reference frame of map projection JTSK03 and Baltic Vertical Datum - After Adjustment.

Key words: Dobšinská Ice Cave, ice-filled cave, ice filling, morphology, terrestrial laser scanning, 3D visualization

INTRODUCTION

Under the decree of Ministry of Economy of the Slovak Republic no. 1/1993 from 20 July 1993 on mining measurement documentation during mining activities and other activities carried this way, the provisions of decree apply to execution, keeping, completion and preserving of mining measurement documentation of cave accessing works and the works of keeping the caves in safe conditions. In the years 2010 and 2011, began deal with this problem in an innovative project VEGA No. 1/0786/10 based on cooperation of the Institute of Geodesy, Cartography and Geographic Information Systems, of Faculty BERG at the Technical University of Košice with the Slovak Caves Administration Liptovský Mikuláš. The main objective of the project was to digitally registering and exact modeling of changes in the caves of ice filling the need for their protection and operation.

DOBŠINSKÁ ICE CAVE

The cave spaces, their sinter and ice filling impress the visitors both emotionally and aesthetically. In Slovak Republic there are now more than 5500 caves known which are part of country‘s natural heritage. It is not only because of respect and admiration towards these nature‘s creations but also because of human natural attempt to discover the laws and regularities of their morphogenetic and speleogenesis or demanding conditions their fauna has to adapt to. All the mentioned above are the reasons for their thorough scientific research aimed to know and conserve them for future generations. Advanced civilized society features the interest in developing and protecting its natural heritage. Slovakia can be proud to unique resources and beauty of caves since 44 out of the total number are declared as national natural monuments. They are irreplaceable proof of live as well as inanimate part of nature development and adaptability and human beings as well as civilization's formation. Legislative protection of the caves is provided by the NR SR No. 543/2002 Statute on nature and nation protection according to which the caves are protected as natural monuments and the most important of them as national natural monuments. To prevent possible natural destructive or anthropogenic processes to the caves and their decor, flora and fauna the caves protection is based on exact scientific research.

Dobšinská Ice Cave ranks among the most important world's caves. Its magnificent ice filling had remained the same for thousands of years in the altitude of only 920 to 950 metres. It was with reason, in 2000, included among unique natural values of world's natural heritage. The cave is in territory of National Natural Reserve ***Stratená*** within ***Slovak Paradise National Park***. It had been modelled by paleocreek *Hnilec* in middle trias steinalm and wetterstein limestone of ***Stratená sheet*** [1]. Dobšinská Ice Cave is a part of cave system called Stratenská cave which consists of 6 independent caves: ***Dobšinská Ice Cave, Duča Cave, Stratenská Cave + Dog Holesy, Military Cave, Green Cave*** and ***Sinter Cave*** (Fig. 1).

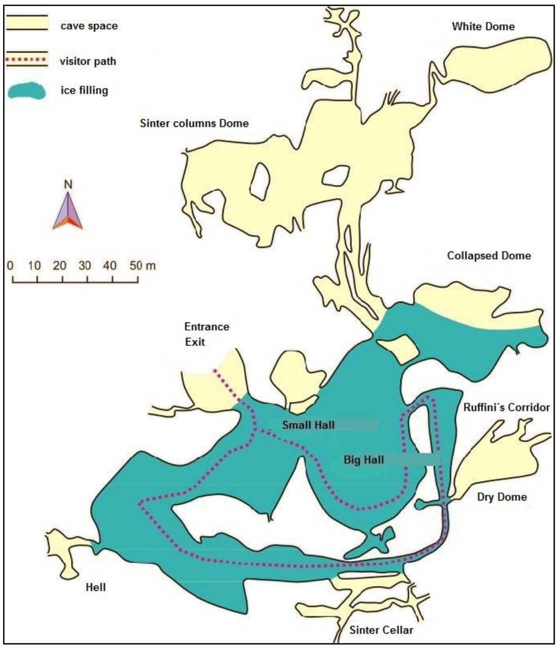

Fig. 1 Map of Dobšinská Ice Cave [1]

Currently is Dobšinská Ice Cave largely filled with ice, sometimes extending up to the ceiling and divisive upper part of the cave into two separate parts the Small and the Great Hall (Fig. 2).

Fig. 2 The Small and Great Hall of the Dobšinská Ice Cave

IMPLEMENTATION OF TERRAIN MEASUREMENTS IN SPACES OF DOBŠINSKÁ ICE CAVE

Surveying measurements was realized in cooperation with personnel Slovak Administration Caves. View of to the short, two-year duration of the project have been made only two stages of measurement. In the first phase of surveying work, which took place in March 2011, has been the focus of detailed spatial Small and Great Hall of the cave made terrestrial laser scanner Leica ScanStation C10 was used universal motorized measuring station Trimble ® VX ™ Spatial Station. Positional and vertical connecting was implemented in the maintained points of underground positional and vertical geodetic control on cartographic coordinate system of Datum of Uniform Trigonometric Cadastral Network (S-JTSK) and the Baltic Vertical Datum - After Adjustment (Bpv) [2].

Under the amendment decree of the Geodesy Cartography and Cadastre Authority of the Slovak Republic No. 300/2009 [6] as amended by Decree No. 75/2011 [7] from the 1st April 2011 declared the validity of the national implementation of the S- JTSK with name JTSK03. For that reason, all surveying measurements was realized in that coordinate system and the binding all previous measurements in this coordinate system recalculate the appropriate transformation procedures. Connecting the surface network points in the Dobšinská Ice Cave to the State Spatial Network is implemented by Slovak Permanent Observation Service - SKPOS , utilizing the signals of Global Navigation Satellite Systems (GNSS). For a static measurement about length of three hours we used two GNSS sets Leica GPS1200 and GPS900, which are determined orientation line from 5001 to 5002 points, located approximately 1047 m. The transformation to the national implementation JTSK 03 (Datum of Uniform Trigonometric Cadastral Network) and Baltic Vertical Datum - After Adjustment was realized by the authorized points of coordinate transformations between geodetic binding systems available on the website of the Institute of Geodesy and Cartography in Bratislava (http://awts.skgeodesy.sk). From orientation line from 5001 to 5002 have been stabilized the surface surveying points No. 8001 and 8002, points scoring box underground cave No. 5004 to 5012 stabilized in fixed, rock parts nezvetraných ceiling cave surveying nails (Fig. 3), and no. points 7013, 7018, 7020 and 7021 stabilized reflecting labels. The distribution of points built surveying network, together with illustration of the error ellipses demonstrated Fig. 4.

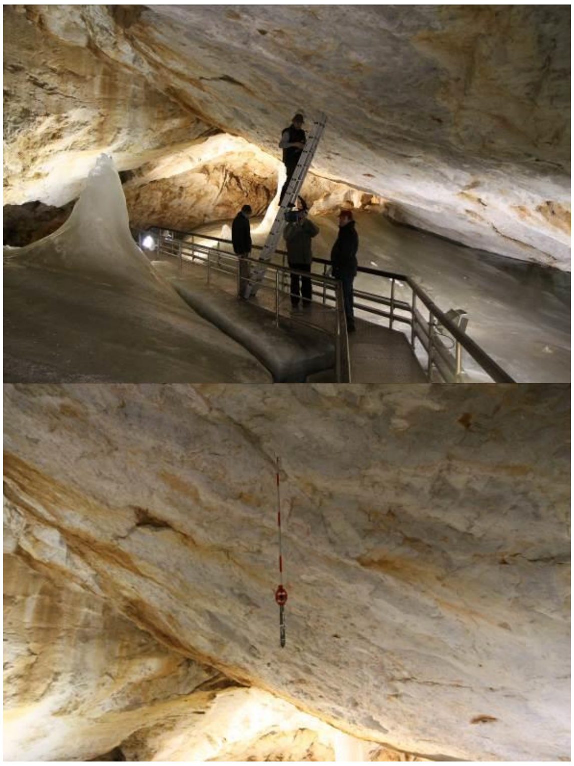

Fig. 3 Stabilization of surveying points in the rock ceiling Small Hall

ADJUSTMENT GEODETIC NETWORK

Estimation of the parameters of the first order local geodetic network caves in cartographic Křovák´s univers conform conic projection and the Baltic Vertical Datum - After adjustment was implemented by the standard method of least squares (Tab. 1). Testing a file of measured geodetic parameters for possible identification infiltrated outlying measurements was realized except the standard parametric tests and nonparametric tests, based on the M-robust methods and simplex method [8]. Network as a whole in 2D cartographic plane may be characterized mean standard error of position 4.9 mm and standard error of coordinate 3.5 mm. For vertical alignment was standard error of the hight 1.7 mm. Parameters of the 2nd order geodetic network were determined by the method MINQUE [6] and being represented by an estimated standard deviation of measured length 1.39 mm and 1.49 mgon directions for universal motorized measuring station Leica Viva TS 15.

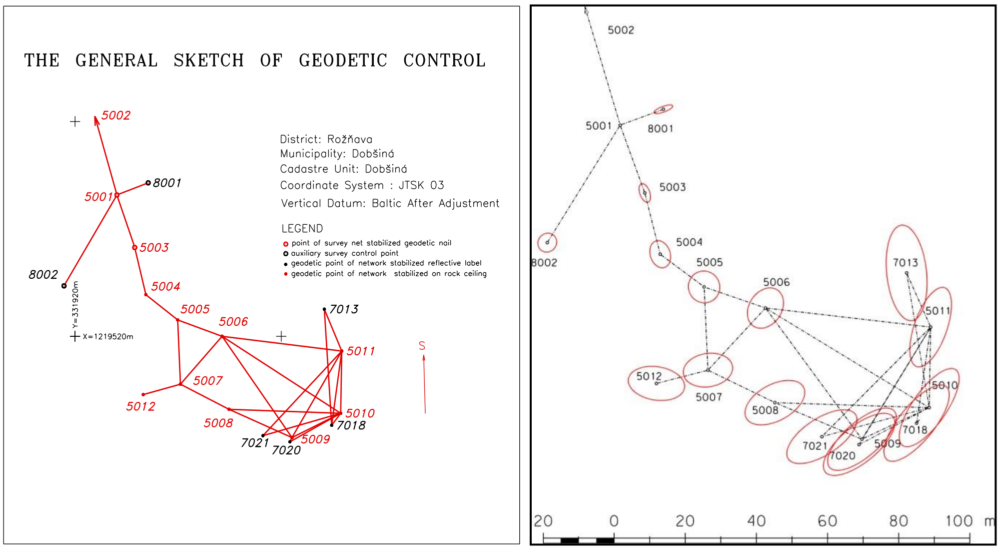

Fig. 4 The general sketch of geodetic control, Standard errors ellipses

Tab. 1 The adjustment coordinates of cave network points and their accurate characteristics

point	y	x	h	s_y	s_x	s_h	a	b	σ_a
	m	m	m	mm	mm	mm	mm	mm	g
5001	331903.770	1219467.368	969.349	0.0	0.0	0.0	0.0	0.0	0.00
5002	332193.576	1218472.831	871.125	0.0	0.0	0.0	0.0	0.0	0.00
5003	331896.848	1219486.894	969.368	0.9	2.2	0.9	1.4	0.7	378.31
5004	331892.524	1219504.504	965.336	1.2	3.2	1.3	2.0	1.4	381.07
5005	331880.173	1219513.896	957.751	2.0	3.5	1.5	2.3	2.2	380.99
5006	331862.936	1219519.964	957.678	2.3	3.6	1.7	3.1	2.3	34.84
5007	331879.117	1219537.835	957.145	2.5	3.6	1.7	3.5	2.4	89.22
5008	331860.277	1219547.165	951.639	3.1	3.7	1.9	4.6	2.6	67.92
5009	331835.844	1219557.686	951.198	3.2	4.1	1.9	6.1	2.5	53.24
5010	331816.941	1219548.609	951.023	3.0	4.5	1.9	6.6	2.4	37.98
5011	331816.515	1219525.461	950.920	2.6	4.5	1.9	6.0	2.3	21.10
5012	331893.566	1219541.652	950.614	4.1	3.7	1.9	4.0	2.4	310.48
7013	331823.296	1219509.858	951.619	2.6	5.2	2.0	6.9	2.8	393.52
7018	331820.460	1219553.084	950.548	3.2	4.5	1.9	6.7	2.5	42.44
7020	331836.647	1219559.236	950.680	3.5	4.1	2.0	6.2	2.6	55.35
7021	331847.100	1219556.971	950.712	3.5	4.0	2.1	5.7	2.6	61.86
8001	331891.636	1219462.819	969.581	3.1	1.2	0.8	1.4	0.4	77.17
8002	331924.258	1219501.165	967.238	1.9	3.0	1.3	1.4	1.3	34.69

Legend :

Y, X	Cartografphic coordinates
H	Heights of points
s_Y,s_X,s_H	Standard deviations of the corresponding coordinates
a,b ,σ_a	Primary, secondary half axis and twisting of standard error ellipse

COMPLEX DIGITAL MODEL OF ICE GROUND RELIEF

For reliable monitoring of the time changes of the ice floor and its modelling as a spatial structure the morphometric values of interpolation space *z=f(x,y)* from the scalar 2D field have to be determined. Out of known approximating functions the thin-plate spline function was used for morphometric analysis and rewritten into python language:

$$f(x,y) = a_0 + a_1 x + a_2 y + \sum_{k=1}^{n} b_k d_k^2 \ln d_k^2 \,, \tag{1}$$

where $d_k^2 = (x - x_k)^2 + (y - y_k)^2$ and minimizes functional

$$F(f)=\iint_R\left[\left(\frac{\partial^2 f(x,y)}{\partial x^2}\right)^2+\left(\frac{\partial^2 f(x,y)}{\partial y^2}\right)^2+\left(\frac{\partial^2 f(x,y)}{\partial x\,\partial y}\right)^2\right]dx\,dy \qquad (2)$$

in case of function coherence. Solution of *n+3* equations for the three unknowns *n+3*:

$$\begin{aligned}&\sum_{k=1}^{n} b_k = 0\\&\sum_{k=1}^{n} b_k x_k = 0\\&\sum_{k=1}^{n} b_k y_k = 0\\&a_0 + a_1 x + a_2 y + \sum_{k=1}^{n} b_k d_k^2 \ln d_k^2 = z_k\end{aligned} \qquad (3)$$

defines the unknown parameters a_0, a_1, a_2, $b_1 \ldots b_n$ which define the interpolation space of the scalar field of the state variables in n points B_k, $k=1 \ldots n$ field R. The solution *(3)* was done by inverse method in programming language Matlab . With regard to volume of data files processed from 3D scanner which is demanding on computer main memory, the area of ground ice was divided into interpolation areas (squares) with the size of 5×5 *m*. For the points measured in tacheometry way by the universal measuring station Trimble VX Spatial Station all the points measured to reflective miniprism were considered. In both examples the interpolation function *(1)* generated the altitude of points in interpolation area R, density of 1×1 *cm* (Fig. 5, Fig. 6).

Figures 7 and 8 present the spatial differentiation of the interpolation function in R area with the use of isolines.

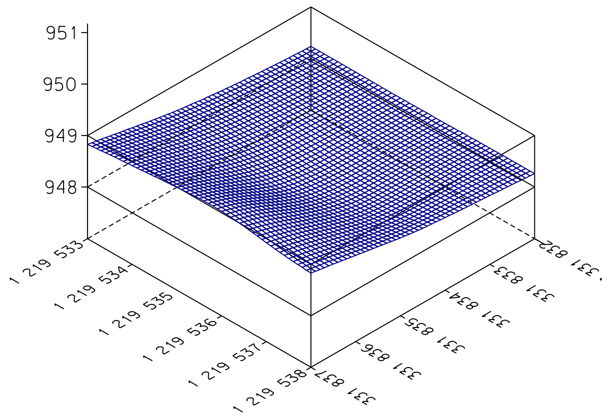

Fig. 5 The spatial model of ice surface obtained from the tacheometry

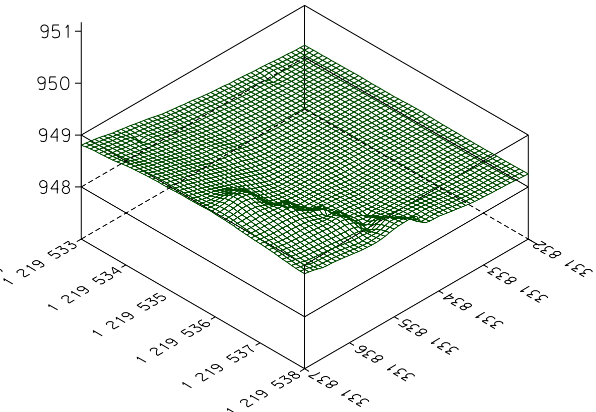

Fig. 6 The spatial model of ice surface obtained from the 3D scanner

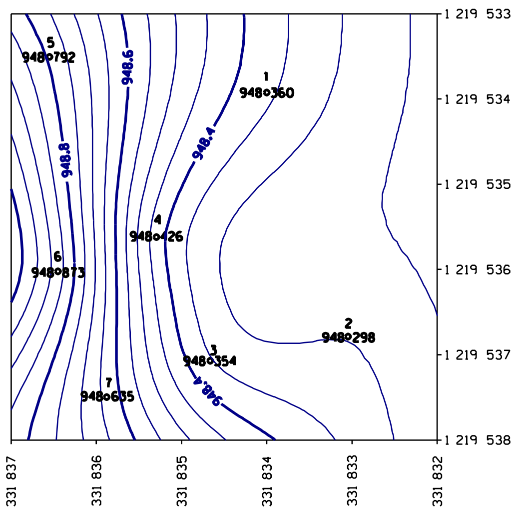

Fig. 7 The ice surface level lines obtained from the tacheometry

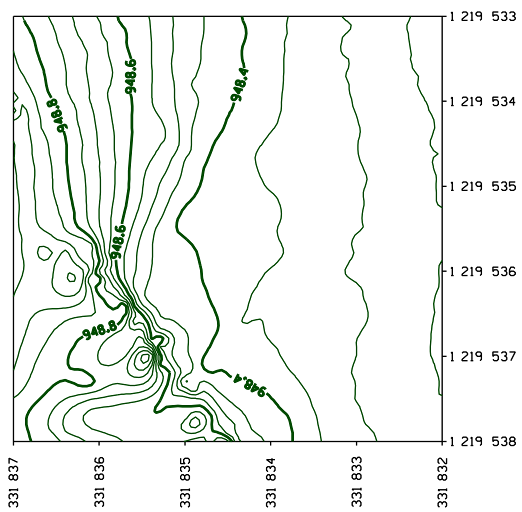

Fig. 8 The ice surface level lines obtained from the terrestrial laser scanning

In the studied area interpolation there are 7 checkpoints, the spatial coordinates of which were measured with a tachymetric universal measuring station. For these checkpoints, with the use of thin-plate spline interpolation method [5], [3] the heights $z_{(2)}$ were determined from the set of measured spatial points from terrestrial laser scanning with Leica ScanStation C10. The height differences in the interpolation area R lie in the interval *<-144,15>mm* (Tab. 2, Fig. 9).

Introducing values $\Delta z_{(2-1)}$ (Tab. 2) in 7 points of interpolation area R enables us, with the use of coefficients, to determine interpolation function of the shape *(1)* in order to generate corrections of the ice ground points of terrestrial laser scanning. The function is graphically presented in Fig. 9 and Fig.10.

To describe the mathematical surface ground ice (Fig. 13), a reliable quantification of temporal changes in ice thickness of floor surfaces (Fig. 12) and its modeling as a spatial structure, the values of morphometric parameters interpolation surface h = f (x, y) determined from tachymeter focused scalar 2D array. The known functions approximated was given the connection surface ground ice used for morphometric analysis of thin-plate spline function [4].

Tab. 2 Nodal points of the bottom ice surface interpolation section

	y [m]	**x [m]**	$z_{(1)}$ **[m]**	$z_{(2)}$ **[m]**	$\Delta z_{(2-1)}$ **[mm]**
1	331834.001	1219533.925	948.360	948.361	-1
2	331833.048	1219536.788	948.298	948.305	-7
3	331834.663	1219537.070	948.354	948.382	-28
4	331835.294	1219535.619	948.426	948.430	-4
5	331836.551	1219533.508	948.792	948.777	15
6	331836.451	1219536.021	948.873	949.017	-144
7	331835.880	1219537.496	948.635	948.711	-76

Legend:

$z_{(1)}$ The spatial coordinates of the points measured by a prism reflecting universal measuring station

$z_{(2)}$ Points heights defined with the use of thin-plate spline interpolation function (1) from the set of measured spatial points from terrestrial laser scanning with Leica ScanStation C10 $\Delta z_{(2-1)} = z_{(2)} - z_{(1)}$

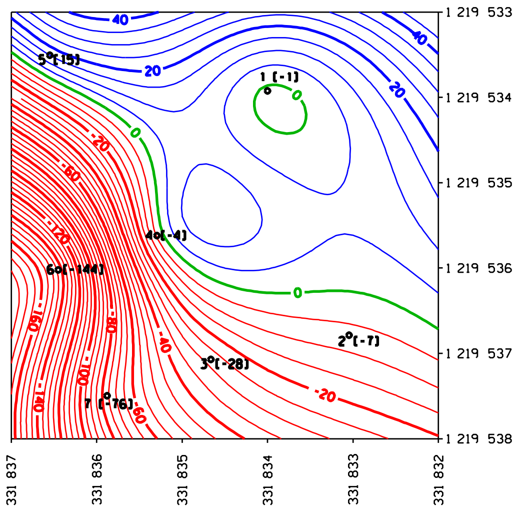

Fig. 9 The correction isolines for the points assigned by terrestrial laser scanner

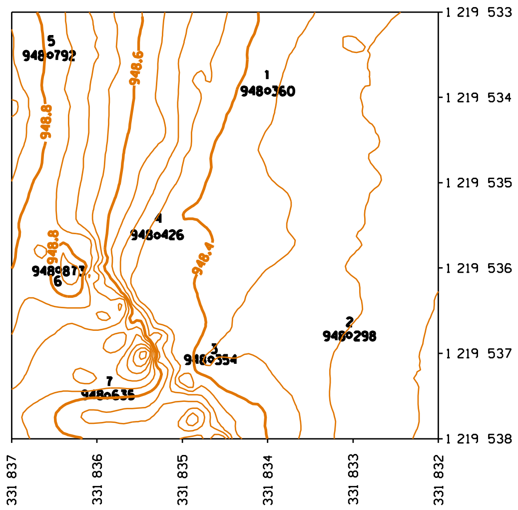

Fig. 10 The ice surface level lines obtained from the terrestrial laser scanning with correction $\Delta z_{(2-1)}$

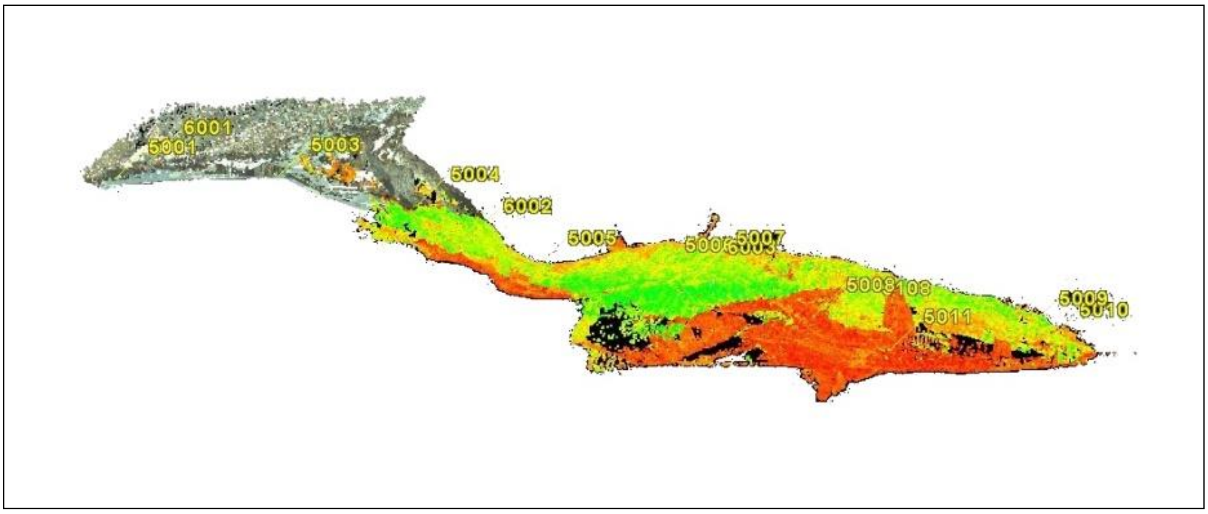

Fig. 11 Part of the cloud of data points from terrestrial laser scanning, Dobšinská Ice Cave - entrance part, Great Hall and Small Hall

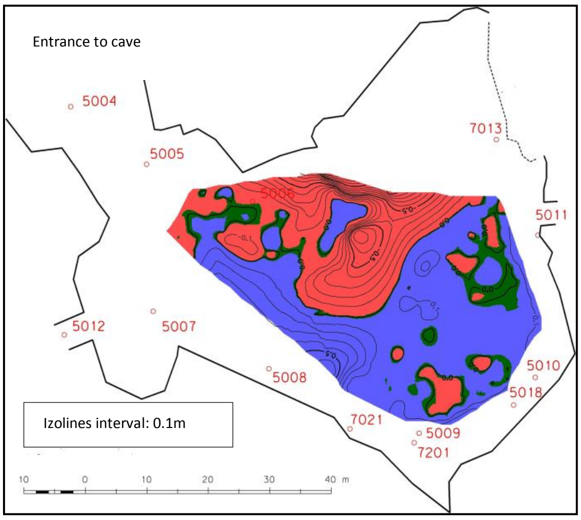

Fig. 12 Changes glaciation ground ice epochs between March 2011 and December 2011

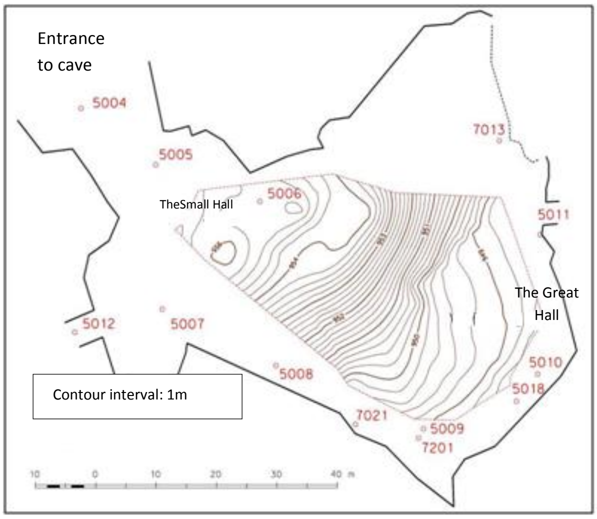

Fig. 13 Isolines of ground ice in interpolation in R

As seen in the pictures (Fig. 12, Fig. 13) during the nine months enclosed epochs in March and December 2011, the interpolation in the floor ice covering an area of *1607* m^2, representing 41% of the total area of Little and Great Hall, the decline in the volume of ground ice *127* m^3 if its gain *84* m^3. With increments of ice are located in the Great Hall, a loss of volume of ground ice was mainly the by about six meters higher located Small Hall caves. Cause loss of ice in the Small Hall can be deduced both from the higher location opposite the Great Hall, but mainly from the fact that it is located in the direction of wind flow between the entrance and the non-glaciated parts of the cave as Stalactite and White Hall and Collapsed Dome (Fig. 1).

CONCLUSION

Dobšinská Ice Cave is a popular tourist area. This article presents empirical experience obtained from the use of terrestrial laser scanners in the process of monitoring the ground ice of Dobšinská Ice Cave. Although the ground ice measurement with the method of terrestrial laser scanning or other measuring methods using laser telemeters is not suitable because of ice optical qualities, there are few places in Dobšinská Ice Cave where movement of people is limited due to safety reasons or it could be due to potential damage to ice filling and decor. The other reason for its use is the fact that laser scanning is a powerful measurement device which measures the object surface with incomparably higher density and efficiency than standard geodetic methods. The article has presented the case when the points of interpolation area are measured with sufficient accuracy with the use of tacheometry or other geodetic method which can define morphometric parameters of interpolation function in the certain area. The function assigns the corrections to the points of laser terrestrial scanning. In this context, it is necessary to raise the fact that the presented results of geodetic research have their substantiation, accumulated measured data and scientific methods of research empirically verified physical laws will be implemented after research into a geographic information system, between the unique capabilities should also include active predicting the load limits of acceptable tourist cave, just with respect to long-term changes in weather caused by climate change, which conduct training public have now questioned.

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