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Cave air temperature response to climate and solar and geomagnetic activity

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Abstract. The atmosphere of caves is generally included in the processes that happen in the external atmosphere. Circulation of the air in caves is a fragment of the most general circulation of the air in the atmosphere. Even such conservative media as the air volumes of karst caves response to the variations of climate and solar and geomagnetic activity. Cave air temperature response to climate and solar and geomagnetic activity for four show caves in Bulgaria (latitude 42.50 degrees, longitude 25.30 degrees) have been studied for a period of 36 years (1968 - 2003). Everyday noon measurements in Ledenika, Saeva dupka, Snezhanka and Uhlovitsa cave have been used. Cave temperatures in the zone of constant temperatures (ZCT) are compared with surface temperatures recorded at meteorological stations situated near about the caves - in the towns of Vratsa, Lovech, Peshtera and Smolyan, respectively. The Hansen cave, Middle cave and Timpanogos cave from the Timpanogos Cave National Monument, Utah, USA have also been examined for comparison (latitude 40.27, longitude 111.43). It has been found that the correlation between cave air temperature time series and sunspot number is better than that between the cave air temperature and Apmax indices; that t ZCT is rather connected with the first peak in geomagnetic activity, which is associated with transient solar activity (CMEs) than with the second one, which is higher and connected with the recurrent high speed streams from coronal holes. Decreasing trends in the air temperatures of all examined show caves have been identified, except for the Ledenika cave, which is ice cave. The well known mechanism of cooling is clearly expressed - the dry surface air lowers the temperature of the cave air and the drier air evaporates water from the cave environment, which further cools the cave. On the contrary, increasing trends in the air temperatures on the surface, measured at the meteorological stations near about the show caves in Bulgaria have been identified. The trend is decreasing for the Timpanogos cave system, USA. It can be concluded that surface temperature trends depend on the climatic zone, in which the cave is situated, and there is no apparent relation between temperatures inside and outside the caves. Our results can help in studying heat exchange between the surface and subsurface air and its influence on cave ecosystems.

Key words. Caves, climate, solar and geomagnetic activity, cave atmosphere; microclimate

1. Introduction

Most of the Earth's atmospheric mass resides below about 15 km, in the troposphere. It contains 75% of atmosphere's total mass and the most of the atmosphere's water vapour. On the bottom of troposphere is the surface of the Earth. But inside the mountains, beneath the surface - in caverns, great air masses are moved, which are also from the troposphere. Solar irradiance is the ultimate source of the energy that powers the climate system and enables the biosphere. Climate varies in response to both anthropogenic and natural forcings, as well as from internal oscillations. Caves are usually developed in karst massifs - a special type of landscape that is formed by the dissolution of soluble rocks, including limestone and dolomite. That is why karst more faithfully preserves a record of environmental changes than most other geological settings. Karst systems are composed from three main zones: heterothermic zone near the surface, unsaturated transitional zone and zone of the constant temperatures (ZCT), which secure the heat and humidity transport from and towards the cave atmosphere. Air, water and rock temperature tend to equilibrium in each zone. Therefore, heat exchange between air, water and walls is the dominant process acting in all three zones. In order to know what environmental changes may be due to human activities, it is necessary to identify those arising from natural causes. It is important to investigate the response of the zone of constant temperatures (part of caves with the most stable microclimatic parameters) to solar and geomagnetic activity. As the air movement is the most significant agent for transmission of external climate influence inside the caves, it is also interesting to compare the course of the cave air temperature with that of the surface temperature.

2. Cave weather and climate

The weather in cave can be defined as the present state of the atmosphere in an area with respect to heat, wind, pressure, and moisture. Heat is the most important since changes in heat quite often bring changes in the other parameters. Weather on the surface is driven by the Sun, which heats some areas of the Earth more than others. Temperature differences lead to pressure differences, which lead to winds and precipitation. Heat exchange is the most important factor for changes in the weather of a dark sunless cave. Significant amounts of heat can enter a cave in four possible ways: from the overlying rock, from the underlying rock, from air flowing into the cave or from water flowing into the cave. Not only does inflowing air affect cave temperature, but it is also affects cave humidity. Natural cave humidity is about 95-100%. Cold air is usually dry, and when it enters the cave environment and warms it becomes even drier. Some areas could reach humidity as low as 60water from the cave environment, further cooling the cave since evaporation requires large amount of heat. The greatest harm to the cave itself may come from the evaporation, which takes place in the winter when rising barometric pressure forces this colder, drier air into the cave. Many of the cave's speleothems are directly dependent on the amount of water available. Stalactite growth may be slowed or even stopped because of the less dripping water. Mineral deposits in the cave also reply on the stability of the cave environment. Unnatural changes can affect the mineral's growth, crystal structure, and even the type of mineral deposits (Hill and Forti 1997). Aragonite (in the form of popcorn or frostwork) tends to form in preference to calcite in areas with high evaporation rates. The cave fauna has adapted to living in a stable environment that does not undergo many fluctuations. Even the smallest temperature changes can have dramatic impacts. Most caves exhibit enough variations of the temperatures and humidity during periods of extreme temperature fluctuations on the surface and warrant serious investigation (Bramberg 1973; Davies 1960; Nepstad and Pisarowicz 1989). Although temperature readings within many show caves have been taken, little research has been conducted to determine what effects the modifications and human presence in the cave are having on the cave climate and environment.

3. Experimental data

We used the data of four show caves related to a 36 year period (1968 - 2003). Those caves are situated at different altitude and geographic latitude. The caves were formed in the limestone around 400 000 years ago. Air temperature in the ZCT is daily measured, at noon, by mercury thermometers with an accuracy of 0.1 C. Everyday data have been averaged and monthly and yearly mean values of the air temperatures have been derived (Stoev and Stoeva 2002). Data for the air temperature outside the caves have been taken from meteorological stations situated near about the caves: in the towns of Vratsa (Ledenika cave), Lovech (Saeva dupka cave), Peshtera (Snezhanka cave) and Smolyan (Uhlovitsa cave), National Institute of Meteorology and Hydrology, Bulgarian Academy of Sciences, Sofia. Timpanogos Cave National Monument protects three interlinked limestone caverns - Hansen Cave (elevation 1920m), Middle Cave, and Timpanogos Cave. The caves are relatively new - they were formed along fractures in the limestone around 200 000 years ago and are still actively changing. The temperatures in Hansen Cave, Middle Cave, and Timpanogos Cave (Carmell Falls and Lower Passage) have been taken from the Western Regional Climate Centre (http://www.nps.gov/tica/RMweb/Monitoring-Data.html). For the 1991- 2000 period data were collected every 2 hours by a Campbell Scientific network. The annual average temperatures on the surface, for the same period of 36 years (1968 - 2003) have been taken from the Timpanogos Cave Station, UTAH (428733). Mean annual Sunspot Number and Apmax indices have been taken from the National Geophysical Data Centre, Boulder, CO.

4. Method of analysis

In order to assess trends in the examined air temperatures, linear regression is applied. Seasonal fluctuations of the mean annual air temperature in the ZCT of the caves have been identified by Fourier analysis, which could

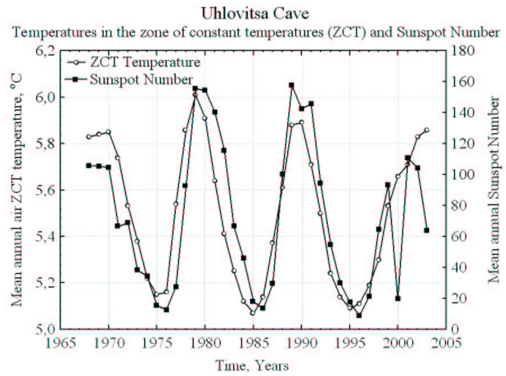

Fig. 1. Mean annual air ZCT temperature (o) versus Mean annual Sunspot Number (symbol) for the 1968 - 2003 period, for the Uhlovitsa cave, Bulgaria.

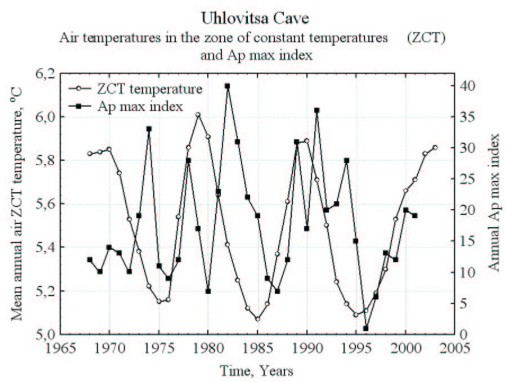

Fig. 2. Mean annual air ZCT temperature (o) versus annual Apmax indices (symbol) for the 1968 - 2003 period, for the Uhlovitsa cave, Bulgaria.

be applied as the time series is with equally spaced values. The same analysis has also been applied for the Sunspot number and Apmax indices (representatives of the solar and geomagnetic activity) for the same period of data available. Seasonal patterns of both the air temperatures in the ZCT in every cave, and Sunspot number and Apmax indices have been examined via autocorrelograms. In order to uncover the correlations between air ZCT temperatures in the caves and solar and geomagnetic activity, cross-spectrum analysis has been applied.

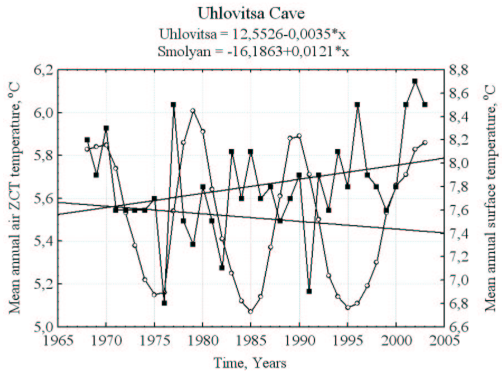

Fig. 3. Mean annual air ZCT temperature (o) versus Mean annual surface temperature (symbol) recorded at meteorological station situated near about the the Uhlovitsa cave (Smolyan), Bulgaria, for the 1968 - 2003 period.

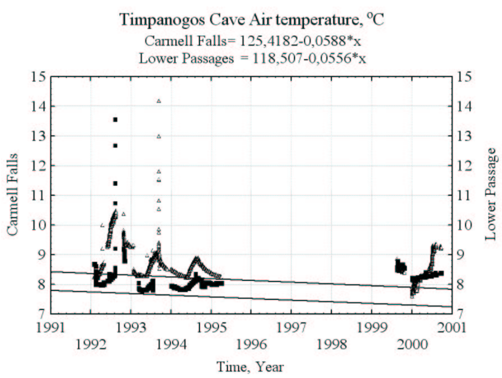

Fig. 4. Air temperatures in the Timpanogos cave (Carmell Falls and Lower Passage), Utah, USA for the 1991 - 2000 period.

5. Results and discussion

The air ZCT temperature and Sunspot number or Apmax indices for the period of 36 years, for the caves Saeva dupka, Snezhanka, Ledenika and Uhlovitsa are simultaneously presented as two dimensional scatterplots obtained by using the programme STATISTICA. The curves are very similar and some of them are mutually shifted. Here we show plots only for the Uhlovitsa cave (Fig. 1 and 2). All the maxima in the temperature coincide or lag the respective Sunspot or Apmax maxima by a period of 1-3 years. t ZCT is rather connected with the first peak in geomagnetic activity, which is associated with transient solar activity, i.e., coronal mass ejections (CMEs) than with the second one (Fig. 2), which is higher and connected with the recurrent high speed streams from coronal holes (Webb 2002). By the Fourier analysis we have uncovered two recurring cycles in the temperature time series for the four caves - with a period of about 10 years, and a small one - about 5 years. The 10 year periodicity coincides with the mean cycles of solar and geomagnetic activity. The cycle with a period of 5 years in the yearly mean air temperature in the ZCT of the examined caves coincides with that found by Komitov (1986) and Valev (1989) for the yearly mean and minimal temperatures in Bulgaria, respectively. Autocorrelation functions show that the periodicities in the examined period are of 10 years in the time series of ZCT temperatures of Saeva dupka, Snezhanka and Ledenika cave as well as of the Sunspot Number. For the Uhlovitsa cave the periodicity is 11 years and for the geomagnetic activity it is 9 years. It has been found by cross-spectrum analysis that the correlation between temperature time series and sunspot number is closer than that between the cave air temperature and Apmax indices (Stoeva et al. 2004). We can compare altitudes, periodicities in the t ZCT, phase shifts of the temperature and sunspot time series, and correlation coefficients obtained for the studied caves (Table 1).

The course of the air ZCT temperature and the surface temperature recorded at meteorological station situated near about the respective cave have been investigated for a period of 36 years, for the caves Saeva dupka (Lovech), Snezhanka (Peshtera), Ledenika (Vratsa) and Uhlovitsa (Smolyan, Fig. 3), Bulgaria. Temperatures in the Hansen Cave, Middle Cave, and Timpanogos Cave (Carmell Falls and Lower Passage, Fig. 4) have been plotted for the 1991 - 2000 period. Mean annual surface temperatures of the Timpanogos region for the same period of 36 years (1968 - 2003) used for Bulgarian caves have been also studied. Decreasing trends in the air temperatures of all the examined caves have been identified, except for the Ledenika cave, which is an ice cave. On the contrary, increasing

Table 1. The annual average of the turbidity (t) for each stations. In column one the name of the station, in columns 2-4 the altitude, latitude and the longitude of the places respectively. In column 5 the averaged t. The errors are represented in columns 6.

Cave	Altitude (m)	Periodicity (years)	Phase shift (years)	Corr. coeff. (at 0.05 stat. sign. lev.)
Saeva dupka	320	10	3	r = 0.8253
Snezhanka	540	10	1	r = 0.7292
Ledenika	1260	10	0	r = 0.7172
Uhlovitsa	1480	11	0	r = 0.8021

trends in the air temperatures on the surface, measured at the meteorological stations near about the caves, have been identified. This is in accordance with increasing trends in the extreme temperatures in Southern Bulgaria (Uhlovitsa cave), during the 1931-2000 period and expectations for wormer climate (Tsekov 2002). But caves are situated in different climatic zones - Temperate Continental (Ledenika and Saeva dupka), Ttransitional and Continental (Snezhanka), and Continental and Mediterranean (Uhlovitsa) (Geography of Bulgaria, 2002). Timpanogos Cave System is in a zone with wet continental climate. We have discussed that increasing or decreasing trends exist in absolute minimum or maximum temperatures in different climatic zones. For the Ledenika and Saeva dupka caves (Temperate Continental climate) the absolute minimum temperatures increase and absolute maximum temperatures decrease (Valev, private communication). For the Timpanogos region decreasing temperature trend has been identified. Cave temperature decrease could be explained with the fact that the examined caves are show caves. Because of the greater open entrances and artificial passages they experience greater volume of airflow than the other caves. The dry surface air lowers the temperature of the cave air and the drier air evaporates water from the cave environment, which further cools the cave. The same mechanism of cooling has been previously noted at Lehman Cave (Stark 1969), at the Greenbrier Caverns (Cropley 1965) and at Wind Cave (Nepstad and Pisarowicz 1989).

6. Conclusions

Cave air temperature response to climate and solar and geomagnetic activity have been studied for the period of 36 years (1968 - 2003), for four show caves in Bulgaria. The mean annual air temperatures in the zone of constant temperatures t ZCT have been compared with the mean annual surface temperatures. Temperatures in Timpanogos cave system, Utah, USA have been examined for comparison.

The correlation between temperature time series and sunspot number is closer than that between the cave air temperature and Apmax indices.

t_{ZCT} is rather connected with the first peak in geomagnetic activity, which is associated with transient solar activity, i.e., coronal mass ejections (CMEs) than with the second one, which is higher and connected with the recurrent high speed streams from coronal holes.

Decreasing trends in the air temperatures of all examined show caves have been identified, except for the Ledenika cave, which is ice cave. The dry surface air lowers the temperature of the cave air and the drier air evaporates water from the cave environment, which further cools the cave.

On the contrary, increasing trends in the mean annual surface temperature recorded at meteorological stations near about the caves in Bulgaria have been identified. But for the Timpanogos cave system, USA the trend is decreasing. Surface temperature trends depend on the climatic zone, in which the cave is situated.

There is no apparent relation between temperatures inside and outside the caves.

This work can contribute to studying the mechanisms of heat transport in the subsurface and calibration of long period climatic data read from speleothems and deposits in caves. It is an example of how the cave and its fragile ecosystem depend on the cave climate changes.

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