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INFLUENCE OF THE SOLAR ACTIVITY ON CAVE AIR TEMPERATURE REGIMES

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Abstract. Caves and their evolution are influenced by solar activity as all the natural processes. The study of this influence needs constant monitoring of the air temperature and physical parameters of the cave – rock temperature, condense processes, heat exchange etc. We consider cave air temperature response to climate and solar and geomagnetic activity for four show caves in Bulgaria (latitude φ=42.50°, longitude λ=25.30°) for a period of 46 years (1968 – 2013). 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 φ=40.27°, longitude λ=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 their unique microclimate.

Introduction

The relation solar activity – regional climate is well studied from observations of the Sun in astronomical observatories and registration of meteorological conditions in the Earth's atmosphere in meteorological stations. It is also well known that basic reason for global climate changes are changes in the Earth's cloud cover.

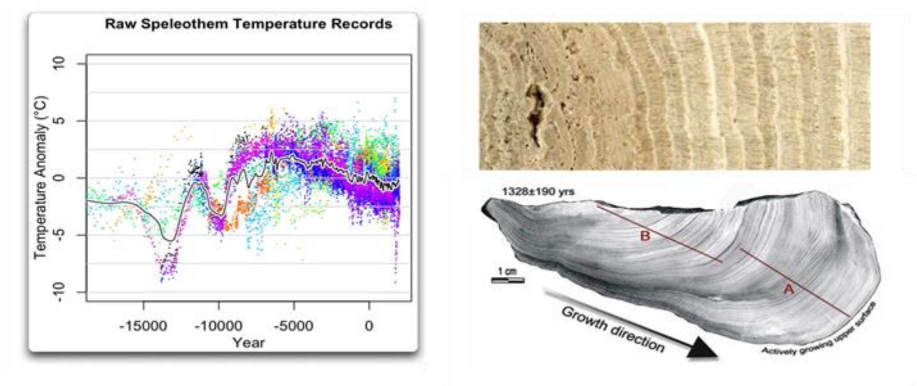

Figure 1. Climate changes over the last two glacial periods (*https://www.ncdc.noaa.gov/data-access/paleoclimatology-data*). Cave speleothem and densitogram of luminescence intensity, cave Duhlata.

High negative correlation is ascertained between galactic and solar cosmic ray fluxes and the tropospheric temperature. It comes into evidence that the more long lasting powerful active events on the Sun, the larger number of days without clouds on Earth, and the higher temperature of the boundary layer.

Speleothems are secondary mineral deposits formed in caves. They are used for estimation of past climate conditions. Studying the evolution of secondary Karst formations, we find direct connection between their enlargement and the cave air temperature. On the other hand, we know about the direct connection between cave air temperature and solar activity. Thus, we can define an indirect index of solar activity, determining the influence of solar activity on formation and enlargement of secondary Karst formations.

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 60%. The drier air evaporates water from the cave environment, further cooling the cave since evaporation requires large amount of heat.

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 & 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.

Climate changes over the last two glacial periods - a quarter million years - are presented by the calculated temperatures from various speleothem records from all over the world caves at the NOAA Paleoclimatology web site (*https://www.ncdc.noaa.gov/data-access/paleoclimatology-data*).

Temperature, past precipitations, nature of soil and vegetation cover, pollution, air composition, glaciation, fluvial erosion and deposition, and groundwater flows can be usually read by luminescence from cave speleothems and deposits (an example from the cave Duhlata, near the village of Bosnek).

The obtained time series are with duration of hundreds of thousands years and should be calibrated by instrumental records. Thus, large number of global change parameters can be reconstructed.

Experimental data

We used the data of four show caves related to the 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 & 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/MonitoringData.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.

Methods of the research

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 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.

Results and discussion

The air ZCT temperature and Sunspot number or Apmax indices for the period of 46 years, for the caves Saeva dupka, Snezhanka, Ledenika and Uhlovitsa are simultaneously presented as two dimensional scatterplots. The curves are very similar and some of them are mutually shifted. Here, plots for the Uhlovitsa cave are presented at Fig. 2 and 3. 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, 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 for the yearly mean and minimal temperatures in Bulgaria.

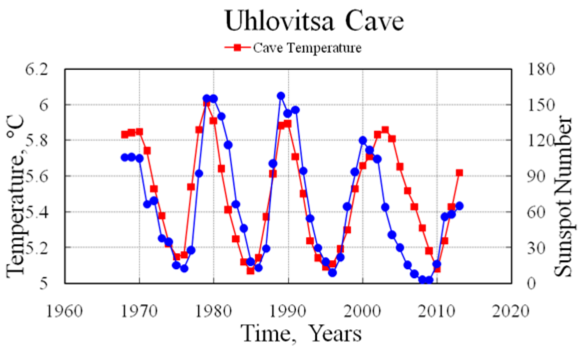

Figure 2. Mean annual air ZCT temperature (○) versus Mean annual Sunspot Number (■) for the 1968 – 2003 period, for the Uhlovitsa cave, Bulgaria.

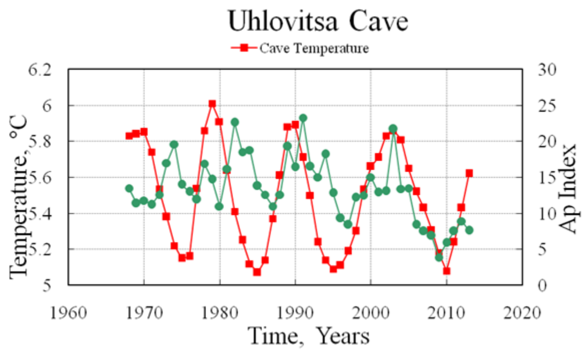

Figure 3. Mean annual air ZCT temperature (○) versus annual Apmax indices (■) for the 1968 – 2003 period, for the Uhlovitsa cave, Bulgaria.

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).

Table 1

Cave	Altitude, m	Periodicity in $t°_{ZCT}$, Years	Phase shift, Years	Correlation coefficient at 0.05 level of statistical significance
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

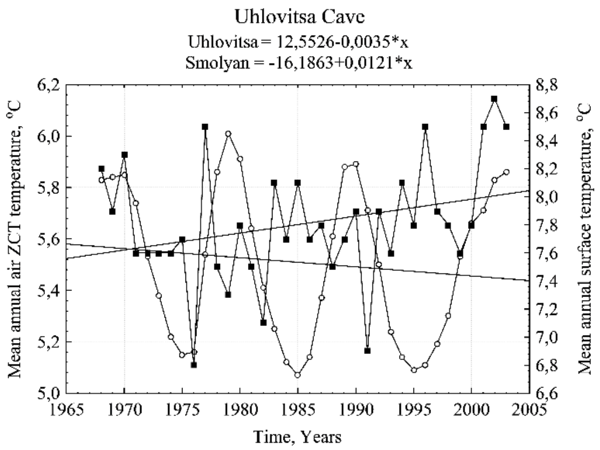

Figure 4. Mean annual air ZCT temperature (○) versus Mean annual surface temperature (■) recorded at meteorological station situated near about the the Uhlovitsa cave (Smolyan), Bulgaria, for the 1968 – 2003 period.

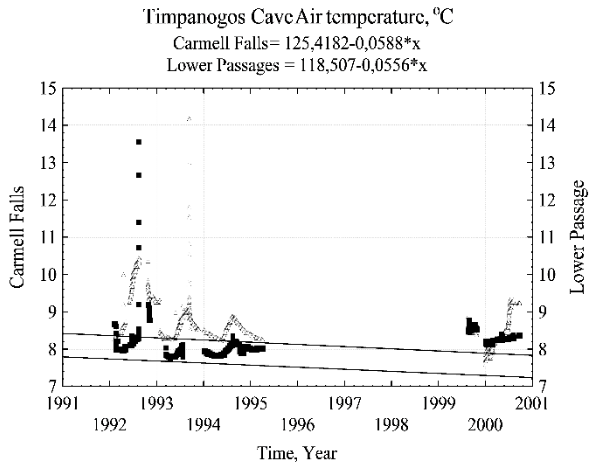

Figure 5. Air temperatures in the Timpanogos cave (Carmell Falls (Δ) and Lower Passage (■)), Utah, USA for the 1991 – 2000 period.

The course of the air ZCT temperature and the surface temperature recorded at meteorological station situated near about the respective cave have been investigated. 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 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. For the Timpanogos region decreasing temperature trend have 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 & Pisarowicz*, 1989]. It can be concluded that surface temperature trends depend on the climatic zone, in which the cave is situated.

Conclusion

Investigations of the cave air temperature response to variations of the climate and solar and geomagnetic activity show that cave systems very faithfully preserves a record of environmental changes, which is very important for prognosis of their future and ecological protection.

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.

References

Bramberg S.A., April 1973. Environments in Lehman Caves, Nevada. *Bulletin of the National Speleological Society*, v. 35, N 2, pp. 35-47.

Cropley, January 1965. Influence of surface conditions on temperatures in Large cave systems. *Bulletin of the National Speleological Society*, v. 27, N 1, pp. 1-10.

Davies W.E., January 1960. Meteorological Observations in Martens Cave, West Virginia. *Bulletin of the National Speleological Society*, v. 22, Part 1, pp. 92-100.

Geography of Bulgaria (Physical and socio-economical geography), 2002. Geographical Institute – Bullgarian Academy of Sciences (in Bulgarian). ForKom. Sofia, Bulgaria.

Nepstad J. and J. Pisarowicz, 1989. Wind cave, South Dakota: Temperature and Humidity Variations, Bulletin of the National Speleological Society, v. 51, pp. 125-128.

Stark N., July 1969. Microecosystems in Lehman Cave, Nevada, *Bulletin of the National Speleological Society*, v. 31, N 3, pp. 73-81.

Stoev A. and Muglova (Stoeva), P., 2002. *Cave microclimate in Bulgaria*. Ter ART Press. Sofia (in press).

Stoeva P., A. Stoev, N. Kiskinova, 2004 Long-term changes in the cave atmosphere air temperature as a result of periodic heliophysical processes, IAGA & ICMA Conference on Long Term Changes and Trends in the Atmosphere, 09-14 June 2004, Sozopol, Bulgaria, accepted by the Journal: *Physics and Chemistry of the Earth*, (in press).

Tsekov M., 2002, Analyses of the climate change in a local place in south Bulgaria, *Comptes Rendus de l'Academie Bulgarie des Sciences*, T. 55, No 10, pp. 21-26.

Webb D.F., 2002. CMEs and the solar cycle variation in their geoeffectiveness In: *Proceedings of the SOHO 11 Symposium on From Solar Min to Max: Half a Solar Cycle with SOHO, 11-15 March 2002, Davos, Switzerland. A symposium dedicated to Roger M. Bonnet. Edited by A. Wilson, ESA SP-508, Noordwijk: ESA Publications Division*, ISBN 92-9092-818-2, 2002, pp. 409 – 419.

https://www.ncdc.noaa.gov/data-access/paleoclimatology-data

http://www.nps.gov/tica/RMweb/MonitoringData.html