SOLAR - ATMOSPHERIC INTERACTIONS OVER TERRITORIES OCCUPIED BY KARST GEOSYSTEMS

Alexey Stoev[1], Penka Stoeva[1], Boyan Benev[1] and Alexander Mikhalev[2]

[1]Space Research and Technology Institute – Bulgarian Academy of Sciences
[2]Institute of Solar-Terrestrial Physics, Russian Academy of Sciences, Irkutsk
e-mail: stoev52@abv.bg

Keywords: *Caves, climate, solar and geomagnetic activity, cave atmosphere; microclimate*

Abstract: *Research on the air temperature course of the of ground atmospheric layer, located near the entrances of four show caves - Saeva dupka, Ledenika, Snezhanka and Uhlovitsa for the 1968 - 2014 period is presented in this work. The data are derived within the detailed micro-climatic monitoring of the caves and Karst areas at which they are developed.*

Mean annual Sunspot Number and Apmax indices of solar and geomagnetic activity have been taken from the National Geophysical Data Centre, Boulder, CO. It was found that different lengths of solar cycles and different lengths of the upstream and downstream part of the curve complicate coordination of the duration of one cycle to another.

Just because of this, procedure was used to bring the individual solar cycles to a standard using the years of maximum and minimum as a reference points. The adjusted to one length cycles were divided into 10 phase intervals. All the data were normalized in such a way that in the course of every 11 years solar cycle, the maximum value of the studied variable by module was equal to one.

The results of the research showed that there is a positive correlation between the deviations of the average annual, summer and autumn temperatures of the Karst regions and solar activity in western phase of the quasi biannual variations. Periods with eastern phase correlation practically absent from the annual seasonal distribution of temperatures. The average annual temperatures in the four caves reach their maximum three years after the peak of solar activity. Negative correlations between the values of temperatures and Sunspot Number and Apmax are observed in winter and spring.

СЛЪНЧЕВО - АТМОСФЕРНИ ВЗАИМОДЕЙСТВИЯ НАД ТЕРИТОРИИ, ЗАЕТИ ОТ КАРСТОВИ ГЕОСИСТЕМИ

Алексей Стоев[1], Пенка Стоева[1], Боян Бенев[1], Александър Михальов[2]

[1]Институт за космически изследвания и технологии – Българска академия на науките
[2]Институт по слънчево - земна физика, Руска академия на науките, Иркутск
e-mail: stoev52@abv.bg

Ключови думи: *Пещерен микроклмат, слънчева и геомагнитна активност, пещерна атмосфера, микроклимат*

Резюме: *В работата е представено изследване на температурата на въздуха на приземния атмосферен слой, разположен в близост до входовете на четири благоустроени пещери - Съева дупка, Леденика, Снежанка и Ухловица за периода 1968 -2014 г. Данните са получени в рамките на дълговременен микроклиматичен мониторинг на пещерите и карстовите райони, в които те са развити.*

Средногодишните брой на слънчевите петна (SN) и Apmax индекси на слънчевата и геомагнитната активност са взети от Националния център за геофизични данни в Боулдер, Съединени щати (National Geophysical Data Centre, Boulder, CO, USA).

Установено бе, че различната продължителност на слънчевите цикли и различната дължина на възходящата и низходящата част на кривата усложняват операцията по съгласуване на продължителността на един цикъл с друг. Точно поради това бе използван процедура по привеждане на отделните слънчеви цикли към един стандарт, използвайки за реперни точки годините на максимум и минимум. Така приведените към една дължина цикли бяха разделени на 10 фазови

интервала. Всички данни бяха нормирани по такъв начин, че в хода на всеки 11 годишен слънчев цикъл максималната по модул стойност на изследваната величина бе равна на единица.

Резултатите от изследванията показаха, че съществува положителна корелация между отклоненията на средногодишните, летни и есенни температури и слънчевата активност (W) при западна фаза на квазидвугодишните вариации. Периоди с източна фаза на корелацията практически отсъстват от годишното сезонно разпределение на температурите. Средногодишните температури и при четирите пещери достигат своя максимум три години след максимума на слънчевата активност. През зимата и пролетта се наблюдават отрицателни корелации между стойностите на температурите и W.

Introduction

Problem of helioclimatic links is interesting and topical, despite the enormous amount of articles on their study. The conclusion drawn from these studies showed that if the sun - Earth interactions exist, they are characterized by a strong regionalism and instability on time. Regional manifestation of solar - terrestrial relations in climate changes can be explained by the complex nature of the circulation of air masses in the Earth's atmosphere. Many of these studies show that in some areas there are positive correlations between indices of solar activity and weather parameters. In other investigations the correlation is negative and in third – it is absent at all. Moreover, the response of the meteorological parameters to the change of solar activity varies with seasons and manifests in different way during odd and even 11-year cycles of solar activity. Phase shifts are detected in most cases. They are different not only with respect to meteoparameters. They also change during the transition from cycle to cycle, or from one geographical region to another (Webb, D.F., 2002).

Quasi-biennial oscillations (QBO) are regarded as the prominent feature of many processes in the Earth's atmosphere. The QBO phase (west or east) is determined by the zonal wind direction in the equatorial stratosphere. The QBO reversals are not precisely enough determined to specify the date and the day-to-day noise is smoothed in the monthly averages of wind velocity at specified pressure heights from 10 to 90 hPa (about 35 to 17 km). Series of works of the group of K. Labitski have significant contribution to the study of these problems. They show that the response of atmospheric parameters to solar activity changes (in stratosphere and troposphere) is better expressed if years with different phases of Quasi-biennial oscillations (QBO) of western and eastern winds in the equatorial stratosphere existing at levels of 10-40 hPa are separately considered.

The purpose of this work is to investigate the links between variations of surface air temperature of local areas located near the entrances of four show caves - Saeva dupka, Ledenika, Snezhanka and Uhlovitsa for the period 1968 – 2014. The data are derived from air temperature measurements in the ground atmospheric layer made in the frames of detailed micro-climatic monitoring of the caves and Karst areas, at which they are developed. Mean annual Sunspot Number and Apmax indices of solar and geomagnetic activity have been taken from the National Geophysical Data Centre, Boulder, CO.

Data for meteorological parameters of the ground atmospheric layer obtained from measurements of weather stations located near the entrances of four show caves - Saeva dupka, Ledenika, Snezhanka and Uhlovitsa for the period 1968 – 2014 are used in the work. They are taken from meteorological journals of the show caves. Trends related to the overall warming of the territory of Bulgaria were removed from the initial curves of mean annual and mean seasonal temperature variations. Variations with a period shorter than the solar cycle and periods for which the temperature deviations were smoothed by moving average method (with 4 years interval of averaging) were also excluded. Temperature variations throughout the year and for each season were considered as far as local climate in warm and cold months differently reacts to variations in solar activity.

Method of research

In order to assess trends in the examined air temperatures, linear regression is applied.easonal 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 Ap 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 Ap indices have been examined via autocorrelograms (Tsekov M., 2002).

In order to uncover the correlations between air ZCT temperatures in the caves and solar and geomagnetic activity, cross-spectrum analysis has been applied.

Method of juxtaposition of ages (method commonly used in heliophysics) was used to determine is there a connection between changes of surface air temperature and solar activity. It allows separation of the contribution of the investigated events in the ground atmospheric layer obtained against the background of great random noise and tropospheric temperature variations near the studied periods of time (Bramberg, S. A., 1973).

It is generally known that the solar cycles have different absolute duration. Also, they have a different length of the ascending and descending part of the curve, which changes during the transition from cycle to cycle. All this complicates the comparison of periods from one cycle with the other ones. That is why the 11 year cycles have been standardized. The years of their maxima and minima have been taken as reference marks. Five solar cycles - from 20^{th} to 24^{th} – have been considered. The calculations were made by the method of juxtaposition of ages in two ways:

On the first way, the years of minima of all cycles were brought to one and the same length and were divided in 10 phase intervals. Some of the longer cycles (for example Cycle №20) needed to be shortened.

On the second way all the minima and maxima have been juxtaposed - the ascending and descending part of the curve were shortened or extended. The length of 4 phase intervals was accepted as standard length of the ascending part of the curve and for the descending part of the curve - 7 phase intervals. All data were normalized in such a way that for every 11 year solar cycle maximum modulus value of the studied magnitude was accepted for a unit. The data for all five solar cycles in the period 1968 – 2014 were averaged.

The results obtained in two ways are in good correlation. Further we'll discuss the results from the analysis conducted by the second way.

Experimental data

Our investigation includes four show caves in Bulgaria - Ledenika, Saeva dupka, Snezhanka and Uhlovitsa. Data cover a period of 46 years (1968 – 2013). The caves are situated at different altitude and geographic latitude. The caves are formed in the limestone nearly 400 000 years ago.

Temperature of the air in the ZCT is daily measured, at noon, by mercury thermometers with an accuracy of 0.1°C. Monthly and yearly mean values of the air temperatures have been derived from the averaged everyday data (Stoeva et al., 2006).

Air temperature data 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 – and situated nearly at the same latitude as Bulgarian caves.

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, (elevation 1719 m) (428733).

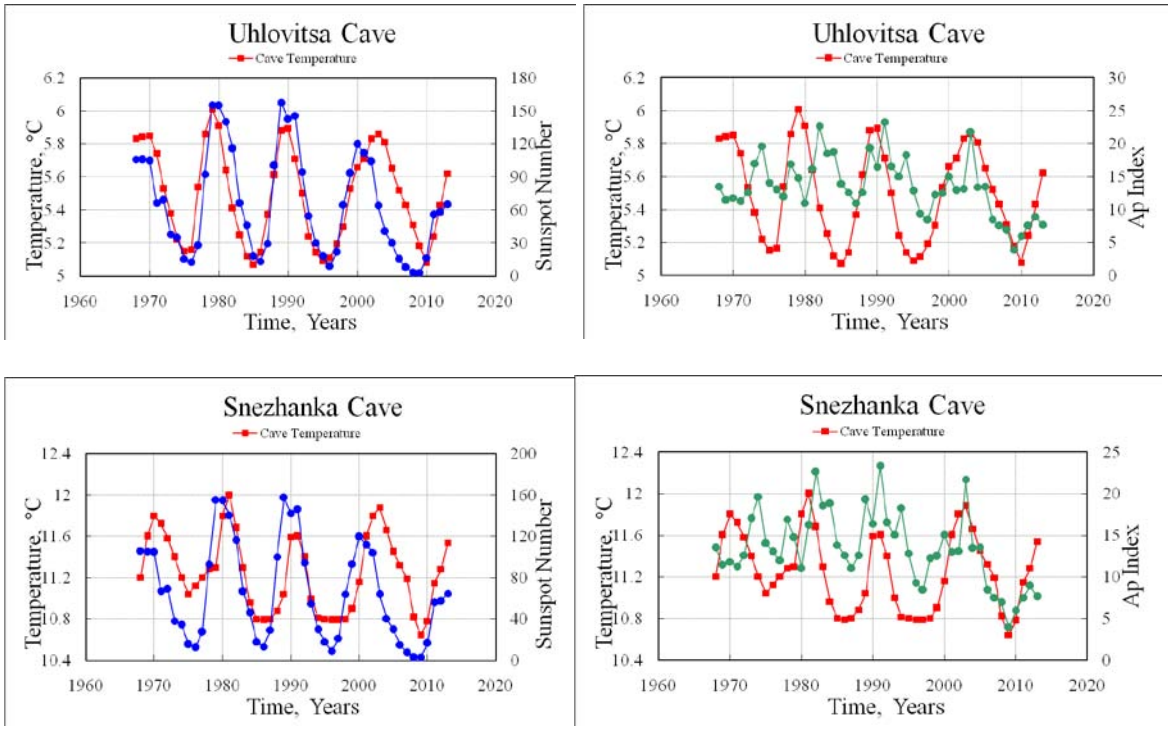
Mean annual Sunspot Number and Apmax indices have been taken from the National Geophysical Data Centre, Boulder, CO.

Results and Discussion

- The air ZCT(Zone of constant temperatures) 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. These are plots for the Uhlovitsa and Snezhanka caves. 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.

For increasing the reliability of the results only the courses of the temperature deviations Δt were compared for two weather stations, those located in front of the entrances of Snezhanka and

Uhlovitsa caves, which have a similar nature and are in one and the same climatic region. The coefficient of correlation between the changes in the mean annual temperatures there, for these stations is equal to 0.9 (p = 99%).



Reliability coefficient of correlation was determined by the criterion of Student. It is difficult to find correlation between sunspot number and mean annual temperature fluctuations Δt at direct juxtaposition of these variables. Correlation coefficients are small (r Snezhanka = 0.32 r Uhlovitsa = 0,30, p = 95%), correlations are practically not detected.

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.

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

Labitski research group have investigated the correlation between changes in the temperature of Karst regions and phases of QBO for the period 1964 – 2010. Studies show that if for years with Western phase of QBO there is a link between Δt and Sunspot Number and calculated correlation coefficients are $r_{Snezhanka}$ = 0.55 and $r_{Uhlovitsa}$ = 0,59 (p = 98%), then for years with Eastern phase change in the nature of solar-terrestrial relations from cycle to cycle could be observed.

At division of quasi-biennial variations in temperature by phases, separately for each season of the year, there is a positive correlation - (r_{summer} = 0.46; r_{autumn} = 0.52 for the Snezhanka cave and r_{summer} = 0.41; r_{autumn} = 0 58 for the Uhlovitsa cave) during the summer and autumn, at 95% significance in a period with western phase. Correlation is practically not detected for each season during periods of eastern phase of QBO in temperature. Maxima of the curves of mean annual temperatures for both weather stations (Snezhanka and Uhlovitsa cave) are shifted against the maximums of the Sunspot Number with four years. We obtain significant correlation coefficients moving the curves relative to each other with 2-3 years (see Table 1).

Table 1. Correlation coefficients R between temperature variations and Sunspot Number, as well as their level of statistical significance p

Cave	Snezhanka	Snezhanka	Uhlovitsa	Uhlovitsa
Season	R	p	R	p
Annual	0.34	-	0.42	-
Shifting with 2 years	-	-	0.92	99%
Shifting with 3 years	0.96	99%	0.86	99%
Winter	-0.77	98%	0.31	-
Shifting with 2 years	-	98%	0.84	99%
Spring	-0.75	98%	-0.31	-
Shifting with 3 years	-	-	0.95	99%
Summer	0.88	99%	0.65	96%
Autumn	0.85	99%	0.95	99%

The most controversial solar-terrestrial links are in the winter. If can be assumed that the coldest winters correspond to the era of maximum solar activity for the station at Snezhanka cave, for the Uhlovitsa cave this is not confirmed. It should be noted that the positive correlations between solar activity and mean winter temperatures have been observed by shifting of the curves for two years. The question of the cause of such differences remains open.

Conclusion

1. In this work we show that there is a positive correlation between the deviations of the mean annual, summer and autumn temperatures of the Karst regions and solar activity in Western phase of the Quasi-biennial oscillations (QBO). For years, when Quasi-biennial oscillations (QBO) are with Eastern phase, correlation is absent in every season.

2. Mean annual air temperatures within the caves Snezhanka and Uhlovitsa located at different altitudes in the Rhodope Mountains, Bulgaria reach maximum four years after the peak of solar activity.

3. Surface air temperature around the entrances of both caves varies depending on the seasons. The results of the analysis made by the method of juxtaposing eras allows to assume that during solar activity maxima, in the summer and autumn, in the local areas around the caves higest temperatures are recorded in comparison with solar activity minima.

4. Negative correlations between temperatures and Sunspot Number are registered during the winter and spring.

References:

1. Bramberg, S. A., April 1973. Environments in Lehman Caves, Nevada. *Bulletin of the National Speleological Society*, v. 35, N 2, pp. 35-47.
2. 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.
3. 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.
4. 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.
5. Stark, N., July 1969. Microecosystems in Lehman Cave, Nevada, *Bulletin of the National Speleological Society*, v. 31, N 3, pp. 73-81.
6. Stoeva, P., A. Stoev, N. Kiskinova, 2006. 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, Physics and Chemistry of the Earth, Parts A / B / C, Volume 31, Issues 1-3, 2006, Pages 123-128.
7. 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.
8. 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.