SPELEOCLIMATE AND ITS APPLICATIONS IN TOURISM MANAGEMENT IN CAVES

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Abstract: *This paper presents a review on the studies of atmospheric systems in caves, focused on the presentation of its main characteristics and its relationship with the management of tourism in caves. Some inherent aspects of the temperature patterns, relative humidity, carbon dioxide and radon concentration and the energy flows will be addressed. The article highlights the lack of long-term speleoclimatic studies in Brazilian caves, both focused on management issues and the basic knowledge of its atmospheric variability patterns.*

Keywords: *Underground Atmosphere; Cave; Speleological Management; Microclimate; Speleoclimate.*

INTRODUCTION

The caves are subterranean spaces in the middle of rocks, which dimensions may vary horizontally or vertically, ranging from a few meters to hundreds of kilometers, with one or more accesses to the surface. The caves are constituted as key elements of a karst system, intervening both is transformation processes in the surface and subsurface of the physical environment (CIGNA; FORTI, 1986; FREITAS; SCHMEKAL, 2003) and in the maintenance of cave wildlife (HOENEN; MARQUES, 2000; TRAJANO; BICHUETTE, 2006). The cave atmosphere is marked by singularities that differentiate it from the other natural atmospheric systems, due to factors such as the spatial confinement, the absence of light and the low incidence of direct solar energy (BUECHER, 1999; CIGNA, 2004).

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In several studies (e.g. HOYOS *et al.*, 1998; SÁNCHEZ-MORAL *et al.*, 1999; FREITAS; SCHMEKAL, 2003; FERNÁNDEZ-CORTÉS, 2006 a, 2006 b), the cave atmosphere has been treated as a microclimate, considering primarily the spatial scale and the proportional reduction of the exchange of energy and mass processes. However, the caves physiographic characteristics demand a terminology focused on underground atmospheric systems. Terms such as cave microclimate or speleoclimate are highlighted for better representing such specifics. In this work the term speleoclimate was adopted, aiming the differentiation comparing to the general meanings of a microclimate. Thus, inserted in the speleoclimatic research context, this article brings a review on the speleoclimate general characteristics, as well as its application in studies of tourism management in caves.

Speleoclimate characterization

The underground atmosphere presents physical and chemical processes of transfer and conservation of energy and mass similar to those found in atmospheric systems of the terrestrial surface, but in reduced intensities in most cases (LUETSCHER *et al.*, 2008). The energy replacement occurs from gaseous and hydric streams exchanges with the external environment, which receives direct solar radiation incidence, as well as under geothermal influence. Although the underground atmosphere is marked by a relatively greater thermal and compositional stability compared to the external environment (LUETSCHER *et al.*, 2008), this condition does not denote in its classification as a closed system (BOURGES *et al.,* 2006). Therefore, it is an open and homeostatic system, with adjustments controlled by interrelated regulation mechanisms, enabling the maintenance of a primary condition of stability, as described by Watson e Lovelock (1983) and Lovelock (2006), generating the standard modeling steady state of the atmosphere. This dynamic and homeostatic modeling should be observed with caution, because of the risk of structural instability, which can be caused by small changes in the model (ABRAHAM, 2009). In the case of underground environments, this fundamental change in the model can be understood by the biosphere simplification, most likely unable to regulate the environment in feedback process, as well as it is suggested, for general cases, by Williams (1992) and Lenton (1998) –despite the example mentioned by Moreira and

Trajano (1992), for bats colonies acting in the air temperature increase in some caves. However, recent studies have demonstrated the existing feedback between the biosphere and the atmosphere, as in the case of the oceanic cyanobacteria and the formation of clouds, corroborating in part with the geophysiologic assumptions of Lovelock (2006). This new perspective has been used more frequently in climatic dynamics studies, on the basis of the environment vulnerability relating to anthropization (MERTZ *et al.,* 2009).

The spatial-temporal, geophysiologic and geophysiographic characteristics mentioned allow the understanding of the differentiation of the underground atmospheric systems. In surface atmospheric studies, the main elements considered in the movement dynamic analysis and the definition of patterns are the temperature, relative humidity and atmospheric pressure, as well as the phenomena resulting from the interaction between these elements, such as rainfall, winds, sky (clouds) and the active atmospheric systems. This is noticed in the rhythmic geographic climatology analysis school of the geographer Carlos Augusto de Figueiredo Monteiro (ZAVATTINI, 2004) and in other methodologies (MENDONÇA; DANNI-OLIVEIRA, 2007). In the case of the caves, the main variables considered in atmospheric studies are presented in Table 1, from a review of several papers already published.

The variability of the atmospheric dynamics of the elements mentioned in Table 1 receives the influence of spatial confinement (GEIGER, 1951; POULSON; WHITE, 1969; BAILEY, 2005), of its vertical stratification (TARHULE-LIPS; FORD, 1998; LUETSCHER; JEANNIN, 2004; BOURGES *et al.,* 2006) the relatively small mass and energy movement (CIGNA, 1967), the lower availability or total absence of light (GEIGER, 1951; POULSON; WHITE, 1969; BADINO, 2004; STOEVA; STOEV, 2005) and the relative stability of physiochemical parameters, which in turn is proportional to the spatial confinement, the depth and distance from the external environment and the number and position of accesses to the external environment (GEIGER, 1951; CHOPPY; CIGNA, 1994; BAKER; GENTY, 1998; BAILEY, 2005; BOURGES *et al*., 2006).

Table 1: Physical and chemical parameters considered in the speleoclimate study

Studied work	Environment Parameters										
	Temperature				Humidity (Relative/absolute)	Atmospheric Pressure	Flows		Concentration of gas		Condensation
	Air	Water	Rock/ Speleothems/Soil	Ice (when existing)			Water	Air	CO_2	^{222}Rn	
Baker; Genty (1998)									x		
Bourges et al.(2001)							x				
Buecher (1999)			x		x			x			
Calaforra et al.(2003)	x										
Carrasco et al. (2002)					x				x		x
Cigna (1967)						x		x			
Cigna (2002a)	x				x						
Cigna (2002b)		x									
Cigna (2004)	x				x			x			
Cigna (2005)										x	
Cigna; Forti (1986)								x			
Cigna; Choppy (2001)							x	x			
Colazzo et al.(2007a, b)						x					
Dragovich; Grose (1990)									x		
Dublyansky; Dublyansky (1998)					x						
Fernández-Cortés et al.(2006a)			x								
Fernández-Cortés et al.(2006b)									x		
Freitas; Schmekal (2003)											x
Freitas; Schmekal (2006)									x		x
Hakl et al. (1996)										x	
Heaton (1986)							x				
Hoyos et al. (1998)									x		
Kranjc; Opara (2002)	x										
Liñan et al. (2008)									x		
Luetscher; Jeannin (2004)			x				x	x			
Mangin; Andrieux (1988)	x	x				x					
Mangin et al.(1999)	x										
Pflitsch; Piasecki (2003)								x			
Pflitsch et al.(2006)				x							
Piasecki et al. (2006)				x							
Pulido-Bosch et al. (1997)			x								
Sánchez-Moral et al. (1999)	x								x		x
Villar et al.(1984a, b)	x										

The speleoclimate stability and the air circulation inside also depend on the underground system dimensions, air movement by barometric effect(POULSON; WHITE, 1969) and the complexity of possible levels of existing galleries. Figure 1 illustrates examples of different basic patterns of air circulation that interfere in the speleoclimate, in function of the seasons of the year and/or lasting duration. In complex systems, it is common to experience a mixture between these different patterns.

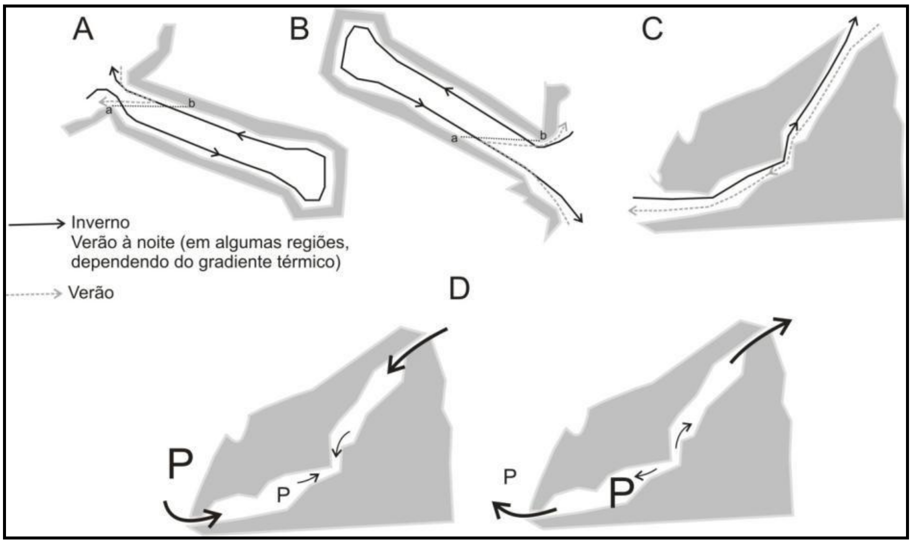

Figure 1: Conceptual model based on Eraso (1969), Mangin; Andrieux (1988) and Cigna (2004), without scale and with vertical exaggeration in A and B, illustrating in cross sections different patterns of underground atmospheric circulation. In A and B, caves like "air bag", being - a trap for cold air; and B - trap for the hot air. Examples C and D refer to caves with greater atmospheric dynamics, and C a circulation model per temperature difference and D of barometric caves.

The caves with downward development in relation to the horizontal axis (Figure 1A) are classified as traps for cold air catching. In winter, the heated air from the interior of the cave flows to the external environment. In summer, there is a blister of cooler air inside it (axis a-b), limiting the air circulation to a zone extremely restricted, close to the mouth (ERASO, 1969; MANGIN; ANDRIEUX, 1988; CIGNA, 2004). In caves with this development profile, in colder regions of the globe (higher latitudes or altitudes), it is common the formation of ice bodies - in many cases, perennial - inside these caves (PFLITSCH *et al.,* 2006; PIASECKI *et al*., 2006). In the case of caves with ascendant development (Figure 1B), the situation is reverted: the flow in the summer is down. In winter, the warm air blister is formed from the a-b axis, in the inner zone, forming a trap to catch hot air (ERASO, 1969; MANGIN; ANDRIEUX, 1988; CIGNA, 2004).

In caves with more than one entry, the air circulation generates streams through two mechanisms: the thermal gradient and the atmospheric pressure. In the case of the thermal gradient, the movement occurs on the basis of a thermobalanced process, between the air temperature inside and outside the caves. In the warm seasons of the year, when the outside air is warmer than inside the cave, the cooler and dense air leaves from the inside through its lower access. In winter, the air outside the cave is relatively cooler than inside - therefore, denser -, preventing its escape through the lower access (ERASO, 1969; BADINO, 2010; PFLITSCH *et al.,* 2010). In these circumstances, the cave air is relatively warmer, leaving by the top access, in a movement called “chimney effect” (Figure 1C). Badino (2010) makes restrictions regarding the use of this term, given that the caves are not similar to chimneys, since these have a source of air heating inside. Pflitsch *et al*.(2010) add that the caves temperature with this dynamic presents a remarkable vertical gradient, being greater close to the superior access comparing to the bottom, considering the annual average.

Finally, the barometric caves, where the atmospheric pressure has a key role in the air circulation dynamics. This type of movement is common in large underground systems (BADINO, 2010; PFLITSCH *et al.,* 2010), like the caves with hundreds of kilometers in the United States. On the other hand, Pflitsch *et al*.(2010) report its occurrence in smaller caves, of a few meters, which led them to conclude that this type of air circulation in caves requires many studies to be better understood. The example of Figure 1D shows the basic scheme of the barometric caves, which should at least have two accesses, in addition to the internal volume much larger than its restricted accesses – although Badino (2010) explains that the barometric air circulation mechanism is also important in caves with a single entry and/or small. In them, when the external atmospheric pressure is greater than the internal, the air streams converge into the system through all its accesses. On the other hand, when the external atmospheric pressure decreases and is smaller than inside the cave, the inside air escapes through all accesses. Pflitsch *et al*.(2010) complement that the air velocity is greater near the accesses than inside the cave, as represented by the thickness of the arrows in Figure 1D.The authors also remind that in thermal or barometric movement caves, the reference is given to the dominant process in the analyzed system. This is because only in a theoretical perspective the air circulation occurs due to only one of the mechanisms. In practice, both coexist and interfere in different proportions in the air circulation in the underground atmospheric systems.

Another form of air movement is the convection. Baldino (2010) explains that the impacts generated in small and restricted parts of a cave can be propagated to the whole environment, through convective flows, drastically changing the air circulation and the thermal balance in the environment. A similar phenomenon was observed in the Penhasco cave, in Buritinópolis-GO, where the hygrothermal impact generated by three carbide lamps was registered in sensors at various points of the cave (LOBO; ZAGO, 2010).

Cigna (1967) and Badino (2010) explain that the air circulation in caves occurs by static and dynamic causes. As static causes, the differences between the density of air inside and outside the caves can be mentioned, considering the air temperature, the relative humidity and its chemical composition; and the atmospheric pressure variation. As dynamic causes, the water flows in and out the caves. Choppy and Cigna (1994) also mention that the speleoclimate of entire caves or parts of caves isolated from the contact with external atmosphere can be different from the usual speleoclimate. The authors refer to galleries isolated by siphons, landslides or very narrow ducts. The underground atmospheric system of these areas results, typically, from the exchanges between the percolating water - and the gas it transports - and the casing rock.

In complex caves the air circulation also varies depending on the number of accesses to external environment, the difference in the dimensions between the galleries and halls and the distance between the accesses (CIGNA, 2004). The lower the solar incidence on the cave – by the accesses restrictions, depending on the thickness of the rock layer that protects it or by the water and air circulation in relation to the external environment – the greater it will be: and its climatic stability (RACOVITA, 1975; STOEVA; STOEV, 2005) and the influence received from geothermal energy (LUETSCHER; JEANNIN, 2004).

The speleoclimate is traditionally classified in three categories:(RACOVITA,1975; LUETSCHER; JEANNIN, 2004; STOEVA; STOEV, 2005), depending on the temperature. The heterothermic zone is located near the accesses to the external environment and receives external atmospheric influences. The constant temperature zone (or homeothermic) is located in the relatively deeper areas, where prevails a greater thermal stability. After all, the unsaturated transitional zone, which has intermediate characteristics between the other two. Recent studies (e.g. LUETSCHER *et al.,* 2008) have shown that the atmospheric parameters variation in relation to the external environment can occur even in the most remote areas of a cave, putting questions about the effectiveness of this traditional classification.

The relationship between the thermal parameters (air, water and rock) in a cave is constant and dynamic, occurring through conduction, convection, advection, condensation and radiation processes (ERASO, 1969), varying depending on factors such as:the depth in relation to the surface and the degree of containment in the cave (FREITAS; SCHMEKAL, 2003; CIGNA, 2004; FERNÁNDEZ-CORTÉS *et al*., 2006a; LUETSCHER *et al*., 2008); the rock temperature (FREITAS; SCHMEKAL, 2003; LUETSCHER; JEANNIN, 2004); the air flows originated outside and/or by convection (CIGNA; FORTI, 1986; STOEVA; STOEV, 2005); and the water flow in the system (STOEVA; STOEV, 2005). The rock temperature reflects, in depths up to 50 m – exceptionally, in depths greater than 100m – the historic annual average of the air temperature in the external environment (PFLITSCH; PIASECKI, 2003; LUETSCHER, JEANNIN, 2004), in addition to being the prevailing factor in the speleoclimate temperature (PFLITSCH; PIASECKI, 2003).

Other relevant factors to the understanding of speleoclimate are humidity and carbon dioxide (CO_2). The genesis and the behavior of these elements in the environment are somehow, interconnected (BATIOT-GUILHE *et al*., 2007). The water dissolved in the air is from underground and/or meteoric flows, through the underground movement and the percolation. These same processes enable the CO_2 accumulation, either by organic material entrainment in rivers–which subsequently comes into decomposition, and either by meteoric waters transport of CO_2originated in the soil above the cave(BUECHER, 1999; CARRASCO *et al*., 2002; LIÑÁN *et al*., 2008).

The relative humidity is the percentage of water contained in the air at a certain temperature relative to its maximum capacity of humidity retention (HILL; FORTI, 1997; PALMER, 2007). In deep areas of caves, in most cases, the relative and absolute humidity tend to be high, close to the saturation point, due to the existing humidity due to the percolation in the rock, leading to the water condensation on the walls, ceiling and speleothems (HILL; FORTI, 1997; PALMER, 2007). The relative humidity is one of the main atmospheric factors which influence the growth or reduction of speleothems (HILL; FORTI, 1997).

The hygric study is also subject to certain complications. Some instruments that measure the air humidity has problems with water condensation in its reading sensor, interfering in the results obtained (CIGNA, 2002a).In addition, there is hygric variability in the air, caused by katabatic movements (BAILEY, 2005; FERNÁNDEZ-CORTÉS et al., 2006b), so that the relative humidity is greater near the ceiling. Studies developed by Forbes (1998) show the existence of a vertical stratification of humidity. At a height of 1.2 m above the ground, the relative humidity is lower – depending on the air circulation increase. From this height the humidity increases, probably, influenced by the proximity to the existing condensation on the caves walls and ceiling.

For the condensation measurement there are no methods widely spread. Up to the present, the works of Freitas and Schmekal (2003, 2006) present the most effective results. On the other hand, the air humidity has not been widely used as a basic parameter of environmental management. The exceptions found are those related to the condensation and with CO_2 concentration.

About CO_2, Simon *et al.*(2007) detail its origin in caves, considering the input of organic carbon particulate (POC) and dissolved organic carbon (DOC).The latter predominates in underground environments, depending on the entry of water bodies, by the process of $CaCO_3$ dissolution through percolation, which releases CO_2 when the saturated solution comes in contact with the underground atmosphere (FORD; WILLIAMS, 2007; LIÑÁN *et al.*, 2008). The percolation is also responsible for the liberation of ^{222}Rn from the rocks, an element that is always present in soils and rocks through which water seeps (BUECHER, 1999; ALBERIGI, 2006; CAMPOS *et al.*, 2006; ALBERIGI; PECEQUILO, 2008).

Speleoclimate and tourist management

In addition to the intrinsic reasons for understanding the speleoclimate, as the knowledge of the current and past climate(LUESTSCHER *et al.,* 2008; BADINO, 2010), the application of knowledge in confined spaces in surface (BAILEY, 2005) and the interferences of possible climate changes on Earth in underground environments (BADINO, 2004; STOEVA; STOEV, 2005), its study is also important for environmental conservation purposes (CIGNA FORTI, 1988; ZELINKA, 2002; MANGIN, 2010). In many caves, the existence and maintenance of certain elements depend on the stability of the usual natural cycle of atmospheric conditions, as in the case of the rupestrian paintings (VILLAR *et al.*, 1984b; PULIDO-BOSCH *et al.*, 1997; MANGIN *et al.*, 1999; SÁNCHEZ-MORAL *et al.*, 1999; MANGIN, 2010), the speleothems and rocks (CABROL, 1997; PULIDO-BOSCH *et al.*, 1997;

FERNÁNDEZ-CORTÉS *et al.,*2006a), the cave biota (HOENEN; MARQUES, 2000;RUSSELL; MACLEAN, 2007) and the interaction between these elements (BASTIAN; ALABOUVETTE,2009).

Due to these factors, the speleoclimate has received substantial attention in the case of caves opened to tourism. In a recent past, the negligence to changes in climatic parameters has lead certain cavities to the prohibition of public use, such as the Candamo cave, in Spain, which visitation structure was implemented in 1925, including an artificial lighting system. The exacerbated environmental degradation led to its closure in 1979. In 1989, the reopening was considered and conditioned to studies of cargo capacity based on speleoclimatic parameters (HOYOS *et al.*1998). Other examples of speleoclimate or physical environmental degradation as a result of atmospheric parameters are observed in the works of Pulido-Bosch *et al*.(1997) and Sánchez-Moral *et al.* (1999).

The use of speleoclimatic studies on the cargo capacity in caves is also notorious in various parts of the world, such as Spain, France, Italy, Slovakia and the United States, among others. Pioneering studies on the subject, in a deterministic perspective of analysis – where the variability of an atmospheric parameter is considered sufficient for the demarcation of the visitation limits – were presented in the works of Hoyos *et al.*(1998), Calaforra *et al.*(2003), Fernández-Cortés (2004), Fernández-Cortés *et al.*(2006a) and Lario and Soler (2010). In Brazil, this type of study is still in its beginning stage. There are also cases where the modifications and improvements carried out to facilitate the tourist use generate environmental damage in the caves, leading to changes in the underground atmosphere dynamic. As an example, the Glowworm cave, in New Zealand, a sealed door was placed at the upper entrance. With this, it was necessary a rigorous control between openings and closures, so as not to generate excess or shortage of condensation on the walls, harming, thus, the natural processes of mineral deposition, condensation and evaporation (FREITAS; SCHMEKAL, 2003). In the case of cave wildlife, the possible impacts of speleoclimate changes are still unknown, due to the notorious difficulty of establishing monitoring standards (CULVER; SKET, 2002) and the lack of researches directed to the theme.

Another important characteristic in the use of speleoclimate for the environmental management is the technical and technological innovation. At the present time, real-time measurement equipment and simultaneous data register allow faster analysis of broader series of data, at an affordable cost (CIGNA, 2002a).Such equipment must be robust, resistant to adverse environmental conditions and with great accuracy in reading sensors(CIGNA, 2002a; MANGIN, 2010). The use of statistical techniques has also been consolidated from procedures such as time series analysis (MANGIN *et al.*, 1999; CALAFORRA *et al.,* 2003; MANGIN, 2010), the geostatistics (FERNÁNDEZ-CORTÉS *et al.*, 2006b; PIASECKI *et al.*, 2006; LOBO; ZAGO, 2010) and the correlation coefficients (PULIDO-BOSCH *et al.*, 1997; LIÑÁN *et al.,* 2008). The accuracy in data collection is also of supreme importance for obtaining reliable results. The use of automatic recorders is critical, distributed throughout the area under anthropogenic influence, for a period of at least one year (CIGNA, 2002b).Cigna (2002b) points the minimum need of four daily records; Zelinka (2002) presents variable ranges between ten minutes and one hour, depending on the study purpose; and Mangin (2010) presents examples with collection intervals of fifteen minutes, but with historical series variables between fifteen and twenty years.

The studies that relate the speleoclimate to environmental management are focused on three distinct analysis lines: I) the atmospheric temperature based management; II) the CO_2 and ^{222}Rn concentrations and its implications to the environment and the human health; and III) the flows of energy and material and the dispersion of anthropic impacts.

Cave touristic management based on atmospheric temperature

In several places in the world, the climate monitoring in the caves began due to tourist use, as in Slovakia, in 1870 (ZELINKA, 2002) or in Slovenia, in 1884 (KRANJC; OPARA, 2002). The speleoclimate attributes in the more practical use parameters and applicable to the tourist management of caves. The most used element for this purpose is the temperature, considering as parameters its variability in the air, rock and water, which is the thermal subsystem.

The study of the thermal subsystem is based on the periodic monitoring of these variables in predefined timescales, also considering aspects such as interaction with the external climate, the morphological variability of the caves, the pressure of the touristic use, and the artificial heat sources introduced, such as lighting systems (PULIDO-BOSCH *et al.,* 1997; CIGNA; BURRI, 2000; KRANJC; OPARA, 2002; RUSSELL; MACLEAN, 2007).

Among these subsystem parameters, the air temperature is widely used for management purposes, in particular in order to determine the touristic load capacity. Its application has been made, generally, in three ways. The first of them is the space limitation of the visitation as a result of temperature impacts. In these cases, in areas where the thermal stability is greater, the access is not recommended (e.g. FERNÁNDEZ-CORTÉS *et al.,* 2006a, c).The second is the temporal access limitation, depending on the air temperature change caused by excessive permanence of people in a particular place (e.g. FERNÁNDEZ-CORTÉS *et al*., 2006a, b).In the caves studied in France, it was observed a modification in the speleothems due to the temperature variation from some limits of people permanence in the environment (CABROL, 1997). In another study (LOBO, 2011), in Santana cave, Brazil, it was observed that the predominant factor of relation between the temperature and the visitors presence was not the size of the groups or the total number of daily visits, but the maximum time of stay at specific points of the cave. Finally, the limitation of the total of allowed daily visits or persons in a group, depending on the maintenance of the natural climate variation (e.g. HOYOS *et al.,* 1998; CALAFORRA *et al*., 2003; LARIO; SOLER, 2010).

Chemical parameters of atmosphere: environmental management and risks to visitors

Generally speaking, the most relevant chemical parameters of the cave atmosphere for management purposes are the water dissolved in the air and the CO_2 and ^{222}Rn concentrations. Its study is justified for two primary reasons: the environment conservation and the potential risks to human health.

The studies carried out in the Candamo cave, Spain, Hoyos *et al.* (1998) found CO_2 concentrations in the water that were from three to seven times greater than the underground atmosphere. Pulido-Bosch *et al.*(1997) mention that, in some cases, this proportion can reach values exceeding twenty times. In the same work, the authors also indicate a close relation between the CO_2 concentration in the air and the distance from the monitored point in relation to the Candamo cave entrance, in Spain - the farther away, the higher the concentration. Song *et al.*(2000) found the same spatial correlation in Bayun cave, China, as well as Fernández-Cortés *et al.*(2006a) in d'Água cave, Spain. Dragovitch and Grose (1990) mention that the minimum concentration for the occurrence of calcite corrosion in speleothems is 2400 ppm. However, the studies done in Spanish caves empirically demonstrate the occurrence of corrosion by condensation induced by human presence, considering variations in the order of 500ppm (SÁNCHEZ-MORAL *et al.,* 1999) and even 100 ppm (HOYOS *et al.,* 1998), based on values far below the 2400 ppm.

As mentioned, the tourist visitation may result in a momentary increase of CO_2 concentration in the air. Milanolo and Grabrovsek (2009) calculated in two experiments additions of human origin variables between 0.35 and 0.45l CO_2 $min.^{-1}person^{-1}$. This increase in CO_2concentration,even though punctual, theoretically can be dissolved in an aqueous medium, in drips and condensation. The resulting solution of this phenomenon can become aggressive again, eroding the carbonate rocks, in a process known as corrosion by condensation (PULIDO-BOSCH *et al*., 1997; BAKER; GENTY, 1998; SARBU; LASCU, 1997; HOYOS *et al*., 1998; CARRASCO *et al*., 2002; JAMES, 2004a, b, c; COLLAZO *et al*., 2007b; FERNÁNDEZ-CORTÉS *et al*., 2006b). Thus, the dissolution that occurs mostly in bedrock is intensified in environments of deposition, where the dominant process is the precipitation of minerals. With this, the process is partially reversed in this case.

The monitoring of relative humidity and air temperature jointly with the variation in the CO_2 concentration is essential for speleological environmental management purposes. Fernández-Cortés (2004) adds that the calcite precipitation is greater in lower air humidity, favoring the evaporation of water from percolation. On the other hand, the temperature has an important role in the rate of CO_2 solubility in water, which is inversely proportional to temperature. Monitoring must also obey a seasonal cycle at least yearly. The researches of Liñán *et al*.(2008) in the cave Nerja cave, Spain, demonstrate that human interference in the CO_2 concentration in the air can vary not only in terms of visitation flow, but also depending on the time of the year. The existence of thermal amplitude is essential for the occurrence of condensation and possible subsequent corrosion (JAMES, 2004c; DREYBRODT *et al.,* 2005), so that variations in the order of 10°C can generate amounts of corrosion in the order of 0.3 µm/year–if this value corresponds to the annual amplitude - à 3 µm/year–if the value matches the daily amplitude (DREYBRODT *et al.,* 2005). In a research conducted in Caribbean caves, Tahule-Lips and Ford (1998) noted the occurrence of corrosion by condensation in the entrance zoneof monitored caves, where the influence of external climate is greater and there is a daily thermal variation.

The air and water flows also need to be monitored. The gas movement is responsible for the dispersion or accumulation of physical and chemical variations of the air.TheCO_2 concentration has great air flow dependency, which interferes directly in the processes of CO_2 releasing into the atmosphere through percolation and/or carbonates deposition (KOWALCZK; FROLICH, 2010).

In addition, the existence of gas dispersion patterns contributes to the faster return of natural patterns of CO_2 concentration in the air from the tourist visitation. This factor is critical, considering the transfer speed of CO_2 from the air to the water for the calcite dissolution. At this point, the authors consulted did not show consensus, given that for James (2004b), this speed is slow, while for Dreybrodt *et al.*(2005) the condensed water on the walls quickly comes in equilibrium with the CO_2dissolved in the air. Based on data collected in the Candamo cave, Spain, Hoyos *et al.*(1998) theoretically demonstrated that an increase of 0.15°C and of 110 ppm of CO_2 in the air – considering the relative humidity always constant, near 100% - would allow an increase in the calcite dissolution rate in the rock to the order of approximately 7.3%.Despite not having obtained the empirical evidence, the value serves as an initial reference. Although the change has occurred despite a quick stabilization – two hours for the temperature and seven hours to CO_2 -, the data were obtained in the time of the year with lower CO_2 concentration in the cave, when the anthropogenic changes may have been more substantial. In another study, conducted in the Cisarska cave, in the Czech Republic, Faimon *et al.*(2006) concluded that the anthropic origin CO_2 concentration would only reach critical levels in extreme conditions of visitation – for example, to the case studied, groups of more than 100 people staying for more than 4 h inside the cave.

CO_2 in high concentrations also presents risks to human health, even because its production comes from an oxidation process, which, consequently, decreases the availability of O_2 in the environment. This process can be worsened in caves that are like “thermal traps” (Figure 1), as well as by the availability of organic material (BADINO, 2009).

Another great atmospheric risk in caves is related to the concentration of the isotope ^{222}Rn.This is a gas of Uranium (^{238}U) series, which is released from the rocks by diffusion or transport in aqueous medium (CIGNA, 2005). Its decay occurs in 3.82 days, generating a series of atomic particles known as sons of^{222}Rn.They are quickly fixed to dust or water dissolved in the air, and may be inhaled and concentrate in the lung, being considered as carcinogenic(BUECHER, 1999; CRAVEN; SMITH, 2006). The increased focus of concern, as already noted in studies of compilation (CIGNA, 2005; CRAVEN; SMITH, 2006), is the health of people who are exposed for a longer time in the underground environment, such as tour guides, but researchers, speleologists and tourists do not show alarming levels of frequency to the environment.

In addition to the issues related to human health, studying the ^{222}Rn concentration in caves is also important for understanding the air circulation inside them (HAKL *et al.,* 1996; BUECHER, 1999; BATIOT-GUILHE *et al.*, 2007). In horizontal caves, the ^{222}Rn concentration correlates to the thermal gradient, whereas in vertical caves, the predominant factor of concentration is the atmospheric pressure (HAKL *et al.*, 1996).

Flows of energy and material and the dispersion of human impacts

The existence of water and air flows towards the external environment is possibly the prevention and dispersion of anthropic impacts, making the caves with these characteristics more appropriate to tourist use of low environmental impact.In addition, Bourges *et al.*(2001), Fernández-Cortés *et al.*(2006b), Liñán *et al.*(2008) and Kowalczk; Frolich (2010) add that the underground atmospheric circulation is critical to understand the CO_2 accumulation in the air. On the other hand, ascendant air flowing towards the cavities interior can lead to cumulative impacts on the environment, which reinforces the importance of the underground atmospheric dynamics knowledge.

The air flows jointly with water flows are the main responsible for the thermal balance by advection in the underground atmosphere. In inactive galleries, without the presence of rivers, the air flows – although very tenuous – are typically the most relevant (LUETSCHER *et al.,* 2008).

The difficulty for air flow measurement is the scale of accuracy required in the used instruments, since the air speed in the caves, with exceptions, is in the order of tenths of meters per second. On the other hand, flows can also be inferred from the existence and position of some speleothems, such as some helictites and coralloids (HILL; FORTI, 1997; PALMER, 2007), or even calculated, on the basis of differences in the atmospheric parameters found in the internal and external environments of a cave (LUETSCHER *et al*., 2008; KOWALCZK; FROLICH, 2010). Generally speaking, the air flows are induced by thermal, density and pressure differences between the internal and external atmosphere of the caves (BUECHER, 1999; CIGNA, 2002a, 2004; PALMER, 2007). Another reliable indicator is the rate of gases concentration, such as CO_2 and ^{222}Rn, which are considered as good tracers for analyzing air streams in caves(HAKL *et al*., 1996; CIGNA, 2005; BADINO, 2009). Also, the position of certain types of speleothems, such as coralloids, can be used for the identification of patters of gas circulation (QUEEN, 1981, 2009).

Finally, there is also the possibility of using chemical tracers, such as Perfluorocarbon (PFT), tested with success in caves on the work of Christoforou *et al.*(1996).

The measurement of the intensity and flow of air streams should be made periodically. As already observed, at different times of the year, the air streams direct to different areas, sometimes to outside or inside the cave (MANGIN; ANDRIEUX, 1988; CIGNA, 2004; COLLAZO *et al*., 2007b; KOWALCZK; FROLICH, 2010). Given this seasonality, theoretically, the atmospheric impacts generated by human presence can acquire cumulative pattern at certain times, rather than dispersive.

The water flows towards the system resurgences also contribute to the renewal of cave atmosphere and to the dispersion of visitation impacts. The movement generates the displacement of air layers in contact with water, in addition to changing its temperature and humidity (CIGNA, 1967, 2002a).Even in caves with lakes inside, the variation in the water level interferes in the atmospheric circulation by “piston effect”, generating air streams (PULIDO-BOSCH *et al*., 1997).

Generally speaking, these flows are classified into levels of energy circulation, with three distinct classes. The low-level of energy circulation corresponds to the minimum water movement, like dips and flowing. The moderate level corresponds to the perennial watercourses and with regular movement. The high level corresponds to watercourses that pass through flooding and/or have sections with waterfalls, periodically changing the natural conditions of atmosphere and even in the physical environment, promoting a genuine renewal of the environment (HEATON, 1986).

FINAL CONSIDERATIONS

The general patterns of atmospheric circulation and its relation with the touristic management in caves were presented in this review. For the most part, the researches already carried out took place in temperate zones of the globe, with a clear emphasis to the air temperature as an essential parameter of application to the tourism management in caves, and with the CO_2 as the second parameter in order of quantity of studies accomplished. Most likely, the focus on temperature and CO_2 is related to the low temperatures related to the temperate regions in which the studies were conducted, associated to the concern with the dissolution by corrosion of delicate speleothems and paintings inside the caves.

On the other hand, it is remarkable the gap existing on studies that allow the verification of atmospheric attributes in tropical and subtropical regions, like Brazil. The most systematic studies in these regions are still very limited, being just a few examples of more extensive series of speleoclimatic monitoring data in the country, with at least one year of field collection (e.g. CARVALHO, 2001; VIANA Jr., 2002; VERÍSSIMO *et al.*, 2003; BOGGIANI *et al.*, 2007; LOBO, 2011). Even though, individual responses have been obtained by such studies, such as the definition of cargo capacity in the Lago Azul cave (BOGGIANI *et al.*, 2007), in Bonito-MS, the cave of Santana (LOBO, 2008, 2011), in Iporanga-SP and several caves of the Parque Estadual Intervales (SP), based on speleoclimatic studies of Rocha (2010) and other complementary environmental studies. All these works emphasized the air temperature, for other reasons, because of the great difficulty for obtaining adequate instrumentation for monitoring other atmospheric parameters compatible with the Brazilian caves, which largely have constant saturation of hygric saturation. In this way, the importance of further and continuous speleoclimatic studies in Brazil is concluded, for allowing a wider knowledge about their speleoclimatic variability and future comparisons with studies conducted in other countries, and the development of new methods focused on the cave environment conservation.

BIBLIOGRAPHICAL REFERENCES

ABRAHAM, R. The misuse of mathematics. In: EMMER, M.; QUARTERONI, A. (Eds.) *Mathknow:* Mathematics, applied sciences and real life. Milão: Springer, 2009. v.3, p.1-8.

ALBERIGI, S. *Avaliação da exposição ao ^{222}Rn nas cavernas do Parque Estadual Turístico do Alto Ribeira (PETAR).* 2006. 63 p. Dissertação (Mestrado em Tecnologia Nuclear - Aplicações) - Instituto de Pesquisa em Energia Nuclear, Universidade de São Paulo, São Paulo. 2006.

ALBERIGI, S.; PECEQUILO, B.R.S. Níveis de Radônio em cavernas do Parque Estadual Turístico do Alto Ribeira (PETAR). *Pesquisas em Turismo e Paisagens Cársticas*, Campinas, v.1, n.1, p.43-55, 2008.

BADINO, G. Cave temperatures and global climatic change. *International Journal of Speleology*, Bologna, v.33, n.1, p.103-114, 2004.

BADINO, G. The legend of carbon dioxide heaviness. *Journal of Cave and Karst Studies*, Huntsville, v.71, n.1, p.100-107, 2009.

BADINO, G. Underground meteorology - "What´s the weather underground ?" *Acta Carsologica*, Postojna, v.39, n.3, p.427-448, 2010.

BAILEY, W.G. Microclimatology. In: OLIVER, J.E. (Ed.) *Encyclopedia of world climatology.* Dordrecht: Springer, 2005. p.486-499.

BAKER, A.; GENTY, D. Environmental pressures on conserving cave speleothems: effects of changing surface land use and increased cave tourism. *Journal of Environmental Management*, v.53, p.165-175, 1998.

BASTIAN, F.; ALABOUVETTE, C. Lights and shadows on the conservation of a rock art cave: the case of Lascaux cave. *International Journal of Speleology*, Bologna, v.38, n.1, p.55-60, 2009.

BATIOT-GUILHE, C.; SEIDEL, J.L.; JOURDE, H.; HÉBRARD, O.; BAILLY-COMTE, V. Seasonal variations of CO_2 and ^{222}Rn in a Mediterranean sinkhole - spring (Causse d' umelas, SE France). *International Journal of Speleology*, Bologna, v.36, n.1, p.51-56, 2007.

BOGGIANI, P.C.; SILVA, O.J.; GESICKI, A.L.D.; GALATI, E.; SALLES, L.O.; LIMA, M.M.E.R. Definição de capacidade de carga turística das cavernas do Monumento Natural Gruta do Lago Azul (Bonito, MS). *Geociências*, Rio Claro, v.26, n.4, p.333-348, 2007.

BOURGES, F.; MANGIN, .; D'HULST, D. Le gaz carbonique danz la dynamique de l'atmosphère des cavités karstiques : l'exemple de l'Aven d'Ornac (Ardèche). *Earth and Planetary Sciences*, v.333, p.685-692, 2001.

BOURGES, F.; GENTHON, P.; MANGIN, .; D'HULST, D. Microclimates of l'Aven d'Ornac and other French limestone caves (Chauvet, Esparros, Marsoulas). *International Journal of Climatology*, v.26, p.1651-1670, 2006.

BUECHER, R.H. Microclimate study of Kartchner caverns, Arizona. *Journal of Cave and Karst Studies*, Huntsville, v.61, n.2, p.108-120, 1999.

CABROL, P. Protection of speleothems. In: HILL, C.A.; FORTI, P. *Cave minerals of the world.* Huntsville: NSS, 1997. p. 294-300.

CALAFORRA, J.M.; FERNÁNDEZ-CORTÉS, A.; SÁNCHEZ-MARTOS, F.; GISBERT, J.; PULIDO-BOSCH, A. Environmental control for determining human impact and permanent visitor capacity in a potential show cave before tourist use. *Environmental Conservation*, v.30, n.2, p.160-167, 2003.

CAMPOS, M.P.; PECEQUILO, B.R.S.; ALBERIGI, S.; MAZZILLI, B.P. Thoron exposure among tour guides in southern Brazilian show caves. *International Journal Low Radiation*, v.3, n.2/3, p.217-223, 2006.

CARRASCO, F.; VADILLO, I.; LIÑÁN, C.; ANDREO, B.; DURÁN, J.J. Control of environmental parameters for management and conservation of Nerja cave (Malaga, Spain). *Acta Carsologica*, Ljubljana, v.31, n.1, p.105-122, 2002.

CARVALHO, S.M. Microclimatologia subterrânea da gruta Olhos d'Água (Castro, PR) In: DITZEL, C. de H.M.; SAHR, C.L.L. *Espaço e cultura:*Ponta Grossa e os Campos Gerais. Ponta Grossa: UEPG, 2001. p.443-462.

CÉSAR JÚNIOR, N. da S. Estudo meteorológico do laboratório subterrâneo. In: CONGRESSO BRASILEIRO DE ESPELEOLOGIA, 14, Belo Horizonte. *Anais.* Belo Horizonte: SBE/CPG, 1980. p.140-147.

CHOPPY, J.; CIGNA, A.A. Proposition pour une etude micro-climatique en zones souterraines profondes. *International Journal of Speleology*, Bologna, v.23, n.1/2, p.91-93, 1994.

CHRISTOFOROU, C.S.; SALMON, L.G.; CASS, G.R. Air exchange within the Buddhist cave temples at Yungang, China. *Atmospheric Environment*, v.30, n.23, p. 3995-4006, 1996.

CIGNA, A. A. An analytical study of air circulation in caves. *International Journal of Speleology*, Bologna, v.3B, n.1/2, p.42-54, 1967.

CIGNA, A. A. Modern trend in cave monitoring. *Acta Carsologica*, Ljubljana, v.31, n.1, p.35-54, 2002a.

CIGNA, A. A. Monitoring of caves: conclusions and recommendations. *Acta Carsologica*, Ljubljana, v.31, n.1, p.175-177. 2002b.

CIGNA, A.A. Climate of caves. In: GUNN, J. (Ed.) *Encyclopedia of caves and karst science.* London: Taylor and Francis, 2004. p.467-475.

CIGNA, A. A. Radon in caves. *International Journal of Speleology*, Bologna, v.34, n.1/2, p.1-18, 2005.

CIGNA, A.A.; CHOPPY, J. The climate in deep zones of karst. In: INTERNATIONAL CONFERENCE ON ENVIRONMENTAL CHANGES IN KARST AREAS, 1, 2001, Padova. *Proceedings of…* Padova: IGU/UIS, 2001. p.305-306.

CIGNA, A.A.; FORTI, P. The speleogenetic role of air flow caused by convection. 1st. contribution. *International Journal of Speleology*, Bologna, v.15, p.41-52, 1986.

CIGNA, A.A.; FORTI, P. The environmental impact assessment of a tourist cave. In: UIS (ed.) CAVE TOURISM INTERNATIONAL SYMPOSIUM AT-170 ANNIVERSARY OF POSTOJNSKA JAMA, 1988, Postojna (Yugoslavia), *Proceedings.*Postojna: UIS, 1988. p. 29-38.

CIGNA, A.A.; BURRI, E. Development, management and economy of show caves. *International Journal of Speleology*,Bologna, v.29, n.1, p.1-27, 2000.

COLLAZO,V.O.; ORTIZ DE PINEDO, J.L.; RUIZ, R.M. Estudio del microclima de la cueva de Mendukilo. Astiz. Nafarroa. Periodo Enero - Deciembre 2006. *Sociedad de ciências espeleológicas Alfonso Antxia.* Disponível em <http://www.sociedadalfonsoantxia.org/Mendukilo.pdf>. Acesso em: 25 abr. 2007a. p.1-47.

COLLAZO,V.O.; ORTIZ DE PINEDO, J.L.; RUIZ, R.M. Estudio del microclima de la cueva Pozalagua. Período de medición 2004-2006. *Sociedad de ciências espeleológicas Alfonso Antxia.* Disponível em < http://www.sociedadalfonsoantxia.org/Estudio%20del%20microclima%20de%20la%20cueva%20de%20%20Pozalagua%202004-2006.pdf>. Acesso em: 25 abr. 2007b. p.1-53.

CRAVEN, S.A.; SMITH, B.J. Radon in caves: clinical aspects. *International Journal of Speleology*, Bologna, v.35, n.2, p.93-101, 2006.

CULVER, D.C.; SKET, B. Biological monitoring in caves. *Acta Carsologica*, Ljubljana, v.31, n.1, p.55-64, 2002.

DRAGOVITCH, D.; GROSE, J. Impact of tourism in carbon dioxide levels at Jenolan caves, Australia: an examination of microclimatic constraints on tourist cave management. *Geoforum*, v.21, n.1, p.111-120, 1990.

DREYBRODT, W.; GRABROVSEK, F.; PERNE, M. Condensation corrosion: a theoretical approach. *Acta Carsologica*, Ljubljana, v.34, n.2, p.317-348, 2005.

DUBLYANSKY, V.N.; DUBLYANSKY, Y.V. The problem of condensation in karst studies. *Journal of Cave and Karst Studies*, Huntsville, v.60, n.1, p.3-17, 1998.

ERASO, A. La corrosión climática em las cavernas. *Boletín Geológico y Minero*, v.80, n.6, p.564-581, 1969.

FAIMON, J.; STELEL. J.; SAS. D. Anthropogenic CO_2-flux into cave atmosphere and its environmental impact: a case study in the Cisarska cave (Moravian Karst, Czech Republic). *Science of the Total Environment*, v.369, p.231-245, 2006.

FERNÁNDEZ-CORTÉS, A. *Caracterización microclimática de cavidades y análisis de la influencia antrópica de su uso turístico.*2004. 424 p. Tese (Doutorado em Hidrogeologia e Química Analítica) - Universidad de Almería, Almería. 2004.

FERNÁNDEZ-CORTÉS, A.; CALAFORRA, J.M.; SÁNCHEZ-MARTOS, F.; GISBERT, J. Microclimate processes characterization of the giant geode of Pulpí (Almería, Spain): technical criteria for conservation. *International Journal of Climatology*, v.26, p.691-706, 2006a.

FERNÁNDEZ-CORTÉS, A.; CALAFORRA, J.M.; SÁNCHEZ-MARTOS, F. Spatiotemporal analysis of air condition as a tool for the environmental management of a show cave (Cueva del Agua, Spain). *Atmospheric Environment*, v.40, p. 7378-7394, 2006b.

FERNÁNDEZ-CORTÉS, A.; CALAFORRA, J.M.; JIMÉNEZ-ESPINOSA, R.; SÁNCHEZ-MARTOS, F. Geostatistical spatiotemporal analysis of air temperature as na aid to delineating thermal stability zones in a potential show cave: implications for environmental management. *Journal of Environmental Management*, v.81, p.371-383, 2006c.

FOKEN, T. *Micrometeorology.* Berlin: Springer-Verlag, 2008. 306 p.

FORBES, J. Air temperature and relative humidity study: Torgac cave, New Mexico. *Journal of Cave and Karst Studies*, Huntsville, v.60, n.1, p.27-32, 1998.

FORD, D.; WILLIAMS, P. *Karst Hidrogeology and Geomorphology.*2.ed. rev. e atual. West Sussex: Wiley, 2007. 562 p.

FORTI, P. Speleothems (palestra). INTERNATIONAL CONGRESS OF SPELEOLOGY, 15, 2009, Kerrville. *CD-ROM.* Kerrville: UIS/NSS, 2009.

FREITAS, C.R. de; SCHMEKAL, A. Condensation as a microclimate process: measurement, numerical simulation and prediction in the Glowworm cave, New Zealand. *International Journal of Climatology*, v.23, p.557-575, 2003.

FREITAS, C.R. de; SCHMEKAL, A. Studies of condensation/evaporation processes in the Glowworm cave, New Zealand. *International Journal of Speleology*, Bologna, v.35, n.2, p.75-81, 2006.

GEIGER, R. Microclimatology. In: MALONE T.F. (ed.) *Compendium of meteorology.* Boston: American Meteorological Society, 1951. p. 993-1003.

HAKL, J.; CSIGE, I.; HUNYADI, I.; VÁRHEGYI, A.; GÉCZY, Z. Radon transport in fractured porous media - experimental study in caves. Environmental International, v.22, n.1, p.S433-S437, 1996.

HEATON, T. Caves: a tremendous range in energy environments on earth. *National Speleological Society News*, Huntsville, v.08, n.44, p.301-304, 1986.

HILL, C.A.; FORTI, P. *Cave minerals of the world.* Huntsville: NSS, 1997. 464 p.

HOENEN, S.; MARQUES,M.D. Adaptação temporal e o ambiente cavernícola: uma interpretação. *Biotemas*, v.13, n.1, p.129-144, 2000.

HOYOS, M.; SOLER, V.; CAÑAVERAS, J.C.; SÁNCHEZ-MORAL, S.; SANZ-RUBIO, E. Microclimatic characterization of a karstic cave: human impact on microenvironmental parameters of a prehistoric rock art cave (Candamo cave, Northern Spain). *Environmental Geology*, Berlin, v.33, n.4, p.231-242, 1998.

JAMES, J. Tourist caves: air quality. In: GUNN, J. (Ed.) *Encyclopedia of caves and karst science.* London: Taylor and Francis, 2004a. p.1561-1563.

JAMES, J. Carbon dioxide-enriched cave air. In: GUNN, J. (Ed.) *Encyclopedia of caves and karst science.*London: Taylor and Francis, 2004b. p.376-378.

JAMES, J. Condensation corrosion. In: GUNN, J. (Ed.) *Encyclopedia of caves and karst science.* London: Taylor and Francis, 2004c. p.492-494.

KOWALCZK, A.J.; FROLICH, P.N. Cave air ventilation and CO_2 outgassing by radon-222 modeling: how fast do caves breathe? *Earth and Planetary Science Letters*, v.289, p.209-219, 2010.

KRANJC, A.; OPARA, B. Temperature monitoring in Skocjanske Jame caves. *Acta Carsologica*, Ljubljana, v.31, n.1, p.85-96, 2002.

LARIO, J.; SOLER, V. Microclimate monitoring of Pozalagua cave (Vizcaya, Spain): Application to management and protection of show caves. *Journal of Cave and Karst Studies*, Huntsville, v.72, n.3, p.169-180, 2010.

LENTON, T.M. Gaia and natural selection. *Nature*, v.394, p.439-447, 1998.

LIÑÁN, C.; VADILLO, I.; CARRASCO, F. Carbon dioxide concentration in air within the Nerja cave (Malaga, Andalusia, Spain). *International Journal of Speleology*, v.37, n.2, p.99-106, 2008.

LOBO, H.A.S. Capacidade de carga real (CCR) da caverna de Santana, PETAR-SP e indicações para o seu manejo turístico. *Geociências*, Rio Claro, v.27, n.3, p.369-385, 2008.

LOBO, H.A.S. *Estudo da dinâmica atmosférica subterrânea na determinação da capacidade de carga turística na caverna de Santana (PETAR, Iporanga-SP).* 2011. 392 p. Tese (Doutorado em Geociências e Meio Ambiente) - Instituto de Geociências e Ciências Exatas, Universidade Estadual Paulista, Rio Claro. 2011.

LOBO, H.A.S.; ZAGO, S. Iluminação com carbureteiras e impactos ambientais no microclima de cavernas: estudo de caso da lapa do Penhasco, Buritinópolis-GO. *Geografia*, Rio Claro, v.35, n.1, p.183-196, 2010.

LOVELOCK , J. *Gaia:* cura para um planeta doente. São Paulo: Cultrix, 2006. 192 p.

LUETSCHER, M.; JEANNIN, P.Y. Temperature distribution in karst systems: the role of air and water fluxes. *Terra Nova*, v.16, n.6, p.344-350, 2004.

LUETSCHER, M.; LISMONDE, B.; JEANNIN, P.Y. Heat exchanges in the heterothermic zone of a karst system: Monlesi cave, Swiss Jura mountains. *Journal of Geophysical Research*, v.113, p.1-13, 2008.

MANGIN, A. Cave management, visitation limits and environmental preserving. In: BELLA, P.; GAZIK, P.; VLCEK, L. (Eds.). INTERNATIONAL SHOW CAVES ASSOCIATION CONGRESS, 6, 2010, Liptovsky Mikulas. *Abstracts Excursion Guide.* Liptovsky Mikulas: Slovak Caves Administration, 2010. p.25.

M NGIN, ˙; NDRIEUX, C˙ Infiltration et environnement souterrain , le role de l'eau sur les paramètres climatiques. *Actes des Jounées Félix Trombe*, Moulis, p.79-95, 1988.

M NGIN, ˙; BOURGES, F˙; D'HULST, D˙ La conservation des grottes ornées : um problème de stabilité d´un système naturel (l´e exemple de la grotte préhistorique de Gargas, Pyrénées françaises). *Earth and Planetary Sciences*, London, p.295-301, 1999.

MENDONÇA, F.; DANNI-OLIVEIRA, I.M. *Climatologia:* noções básicas e climas do Brasil. São Paulo: Oficina de Textos, 2007. 206p.

MERTZ, O.; HALSNÆS, K.; OLESEN, J.E.; RASMUSSEN, K. Adaptation to climate change in developing countries. *Environmental Management*, v.43, p.743-752, 2009.

MILANOLO, S.; GRABROVSEK, F. Analysis of carbon dioxide variations in the atmosphere of Srednja Bijambarska cave, Bosnia and Herzegovina. *Boundary-Layer Meteorology*, v.131, p.479-493, 2009.

MOREIRA, J.R. de A.; TRAJANO, E. Estudo do topoclima de cavernas da província espeleológica arenítica Altamita-Itaituba, Pará. *Espeleo-Tema*, São Paulo, v.16, p.75-82, 1992.

PALMER, A.N. *Cave geology.*Dayton: Cave Books, 2007. 454 p.

PIASECKI, J.; SAWINSKI, T.; STRUG, K.; ZELINKA, J. Selected characteristics of the microclimate of the Demänovská Ice cave (Slovakia). In: ZELINKA, J. (Ed.) INTERNATIONAL WORKSHOP ON ICE CAVES, 2, Liptovsky Mikulas, 2006. *Proceedings.* Liptovsky Mikulas, Slovak Caves Administration, 2006. p.50-61.

PFLITSCH, A.; PIASECKI, J. Detection of an airflow system in Niedzwiedzia (Bear) cave, Kletno, Poland. *Journal of Cave and Karst Studies*, v.65, n.3, p.160-173, 2003.

PFLITSCH, A.; PIASECKI, J.; SAWINSKI, T.; STRUG, K.; ZELINKA, J. Development and degradation of ice crystals sediment in Dobsinska ice cave (Slovakia). In: ZELINKA, J. (Ed.) INTERNATIONAL WORKSHOP ON ICE CAVES, 2, Liptovsky Mikulas, 2006. *Proceedings.* LIptovsky Mikulas, Slovak Caves Administration, 2006. p.38-49.

PFLITSCH, A.; WILES, M.; HORROCKS, R.; PIASECKI, J.; RINGEIS, J. Dynamic climatologic processes of barometric cave systems using the example of Jewel cave and wind cave in South Dakota, USA. *Acta Carsologica*, Postojna, v.39, n.3, p.449-462, 2010.

POULSON, T.L.; WHITE, W.B. The cave environment. *Science*, v.165, n.3867, p.971-981, 1969.

PULIDO-BOSCH, A.; MARTÍN-ROSALES, W.; LÓPEZ-CHICANO, M.; RODRÍGUEZ-NAVARRO, M.; VALLEJOS, A. Human impact in a tourist karstic cave (Aracena, Spain). *Environmental Geology*, Berlin, v.31 n.3/4, p.142-149, 1997.

QUEEN, J.M. *A discussion and field guide to the geology of Carlsbad caverns.* Carlsbad: NPS, 1981. 64 p.

QUEEN, J.M. Post-drainage evolution of the caves of the Guadalupe mountains, Southeastern New Mexico and West Texas, USA. In: WHITE, W. (Ed.) INTERNATIONAL CONGRESS OF SPELEOLOGY, 15, 2009, Kerrville. *Proceedings.*Kerrville: UIS/NSS, 2009, v.1, p.964-970.

RACOVITA, G. La classification topoclimatique des cavités souterraines. *Travaux de L'Institute de Speologie Emil Racovita*, v.14, p.197-216, 1975.

ROCHA, B.N. *Estudo microclimático do ambiente de cavernas, Parque Estadual Intervales, SP.* 2010. 107 p. Dissertação (Mestrado em Geografia Física) - Faculdade de Filosofia, Letras e Ciências Humanas, Universidade de São Paulo, São Paulo. 2010.

RUSSELL, M.J.; MACLEAN, V.L. Management issues in a Tasmanian tourist cave: potential microclimatic impacts of cave modifications. *Journal of Environmental Management*, v.87, p.474-483, 2007.

SÁNCHEZ-MORAL, S.; SOLER, V.; CAÑAVERAS, J.C.; SANZ-RUBIO, E.; VAN GRIEKEN, R.; GYSELS, K. Inorganic deterioration affecting Altamira cave, N Spain: quantitative approach to wall-corrosion (solutional etching) processes induced by visitors. *The Science of the Total Environment*, v.243/244, p.67-84, 1999.

SARBU, S.M.; LASCU, C. Condensation corrosion in Movile cave, Romania. *Journal of Cave and Karst Studies*, Huntsville, v.59 n.3, p.99-102, 1997.

SIMON, K.S.; PIPAN, T.; CULVER, D.C. A conceptual model of the flow and distribution of organic carbon in caves. *Journal of Cave and Karst Studies*, Huntsville, v.69, n.2, p.279-284, 2007.

SONG, L.; WEI, X.; LIANG, F. The influences of cave tourism on CO_2 and temperature in Baiyun Cave, Hebei, China. *International Journal of Speleology*,Bologna, v.29, n.1, p.77-87, 2000.

STOEVA, P.; STOEV, A. Cave air temperature response to climate and solar and geomagnetic activity. *Memorie Della Societá Astronomica Italiana*, v.76, p.1042-1047, 2005.

TARHULE-LIPS, R.F.A.; FORD, D.C. Condensation corrosion in caves on Cayman Brac and isla de Mona. *Journal of Cave and Karst Studies*, Huntsville, v.60, n.2, p.84-95, 1998.

TRAJANO, E.; BICHUETTE, M.E. *Biologia subterrânea:* introdução. São Paulo: Redespeleo, 2006. 92 p.

VERÍSSIMO, C.U.V.; SOUZA, A.E.B.A.; RICARDO, J.M.; BARCELOS, A.C.; NOGUEIRA NETO, J.A.; REIS, M.G. Microclima e espeleoturismo na gruta de Ubajara, CE. In: CONGRESSO BRASILEIRO DE ESPELEOLOGIA, 27, Januária. *Anais.* Januária: SBE, 2003. p.1-9.

VIANA JÚNIOR, O. *Hidroquímica, hidrologia e geoquímica isotópica (O e H) da fácies de percolação vadosa autogênica, caverna Santana, Município de Iporanga, Estado de São Paulo.* 2002. 113 p. Dissertação (Mestrado em Geoquímica) - Instituto de Geociências, Universidade de São Paulo, São Paulo. 2002.

VILLAR, E; FERNANDEZ, P.L.; QUINDOS, L.S.; SOLANA, J.R.; SOTO, J. Air temperatura and air interchanges at Altamira cave (Spain). *Cave Science*, v.11, n.2, p.92-98, 1984a.

VILLAR, E; BONET, A.; DIAZ-CANEJA,, B.; FERNANDEZ, P.L.; GUTIERREZ, I.; QUINDOS, L.S.; SOLANA, J.R.; SOTO, J. Ambient temperature variations in the hall of paintings of Altamira cave due to the presence of visitors. *Cave Science*, v.11, n.2, p.99-104, 1984b.

WATSON,A.J.; LOVELOCK, J.E. Biological homeostasis of the global environment: the parable of Daisyworld. *Tellus*, v.35B, p.284-289, 1983.

WILLIAMS, G.C. Gaia, nature worship and biocentric fallacies. *The Quarterly Review of Biology*, v.67, n.4, p.479-486, 1992.

ZAVATTINI, J.A. *Estudos do clima no Brasil.*Campinas: Alínea, 2004. 398p.

ZELINKA, J. Microclimatic research in the Slovakian show caves. *Acta Carsologica*, Ljubljana, v.31, n.1, p.151-163, 2002.

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