NON-LINEAR RESPONSE OF CAVE TEMPERATURE CAUSED BY TOURIST VISITATION IN THE CAVE OF SANTANA (PETAR – BRAZIL): IMPLICATIONS FOR CARRYING CAPACITY OF SHOW CAVES

VARIAÇÕES NÃO LINEARES DA TEMPERATURA AMBIENTE CAUSADAS PELA VISITAÇÃO TURÍSTICA NA CAVERNA DE SANTANA (PETAR-SP): IMPLICAÇÕES PARA A CAPACIDADE DE CARGA ESPELEOTURÍSTICA

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Abstract

The monitoring of the atmosphere of show caves is frequently used to provide support for the evaluation of changes evoked by the visitation by tourists. Such measurements are generally taken at specific points along the routes established for visitation and reflect the effect of the time spent by visitors. A program for monitoring the atmosphere of the cave of Santana was undertaken for this purpose, thus providing support for the evaluation of the carrying capacity established for tourism in that cave. The studies were conducted during regular visitation of the cave, so that the impacts of this visitation on the air temperature at two specific points could be evaluated. The increase was found to be up to 1.1ºC in Cristo room and up to 1.3ºC in Encontro room. This article shows, however, that the impact of the number of visitors is not linear, nor is that of the total number of visitors during a day, although the length of time spent at specific points in the cave was found to be critical. The number of visits per day to be permitted can thus be determined from the time which groups actually spend at strategic points along the route of visitation, and the size of groups can vary as a function of other factors, such as greater demands during holiday periods.

Key-Words: Air temperature; speleoclimate; tourism in caves; tourist carrying capacity, show cave.

Resumo

O monitoramento atmosférico em cavernas turísticas tem sido empregado no intuito de verificar as alterações causadas em função da visitação. Os procedimentos de monitoramento são feitos de forma a considerar os roteiros turísticos estabelecidos nas cavernas e refletir o efeito do tempo de permanência dos visitantes em seu interior. Com este propósito, foi estabelecido um programa de monitoramento atmosférico na caverna de Santana, de forma a oferecer suporte ao estudo de sua capacidade de carga espeleoturística. As pesquisas foram realizadas durante os procedimentos de visitação turística, permitindo a análise dos impactos da visitação em dois trechos específicos da caverna. O incremento térmico identificado foi de 1,1ºC no salão do Cristo e de 1,3ºC no salão do Encontro. No entanto, os dados e discussões apresentados neste artigo evidenciam que o impacto da visitação não apresenta linearidade entre a quantidade de pessoas presentes em um grupo de visitantes ou de seu total diário com a variação térmica. Observou-se que o tempo de permanência dos grupos em determinados pontos é um fator crítico na visitação espeleoturística. Das conclusões, evidencia-se que o número de visitas permitidas por dia deve considerar o tempo em que os grupos de visitantes ficam parados em determinados pontos do roteiro de visitação, bem como que o tamanho dos grupos de visitantes deve variar em função de flutuações atmosféricas e da sazonalidade turística.

Palavras-Chave: *Temperatura do ar; espeleoclima; espeleoturismo; capacidade de carga turística; cavernas turísticas.*

1. INTRODUCTION

Techniques for the monitoring of atmospheric parameters in caves are useful in the analysis of alterations in the environment due to tourist activities and, more recently, as a basis for paleoclimatic investigations.

Monitoring of cave conditions has been practiced since the 19th century in the region of Skocjanske jame, in Slovenia, where it was initiated in 1886 (Kranjc & Opara 2002), and it has long been used in Italian caves, such as the grotta Gigante (Cigna 1993) and Spanish caves such as those of

Altamira (Pulido-Bosch *et al*. 1997) and Águia (Domínguez-Villar *et al.* 2010), as well as in many others. In Brazil, however, regular studies monitoring the climate inside caves are rare, and mainly designed for the analysis of the impact of tourist visitation. The best examples with the most extensive data available are those for the cave Olhos d'Água (Carvalho 2001), the cave of Santana (Viana Jr. 2002), the cave of Ubajara (Veríssimo *et al.* 2003), the cave of Lago Azul (Boggiani *et al.* 2001, 2007) and the cave Colorida (Rocha, 2010), as well as those linked to paleoclimate studies based on the geochemical investigation of stalagmites (Sondag *et al.* 2003; Karmann *et al.* 2007).

The present study was developed for the investigation of the use of the monitoring of atmospheric parameters for management of show caves. The data, collected during various stages over a two-year period, was designed to identify the dynamics of the circulation of the air in the cave and its relationship with possible impacts due to visitation. The underground atmosphere is assumed to act dynamically, with variation on various scales controlled by spatial aspects such as the quantity and extension of the galleries and the distance from the outside environment (Freitas & Schmekal 2003; Fernández-Cortés *et al.* 2006a; Luetscher *et al.* 2008), as well as the daily and seasonal variations (Pulido-Bosch *et al.* 1997; Kranjc & Opara 2002; Russell & MacLean 2007).

2. MATERIAL AND METHODS

The field work was conducted in the cave of Santana (Fig. 1), located in the State Tourist Park of the Upper Ribeira (PETAR), in the southeastern part of the state of São Paulo, in Brazil. This cave is one of the most-visited show caves in Brazil, with an annual visitation varying from 20,000 to 30,000 in the past few decades. it is one of the largest caves in the state, with a horizontal development exceeding 7 km already mapped, The first 480 m are visited on a regular basis, including part of the lower gallery along the Roncador river and various galleries on upper levels (Fig. 2).

The monitoring of the air in the cave of Santana was initiated in 2008, and these studies were terminated in 2010; they included measures of temperature and relative humidity of the air, temperature of the water and the surface of the speleothems, and the concentration of CO_2, as well as air flow. Previous research results were published in the works of Lobo (2015) and Lobo et al. (2015). However, the continuity of the data analysis allowed to highlight the aspects discussed in this article. The points monitored and the characteristics measured at each are identified in Fig. 2.

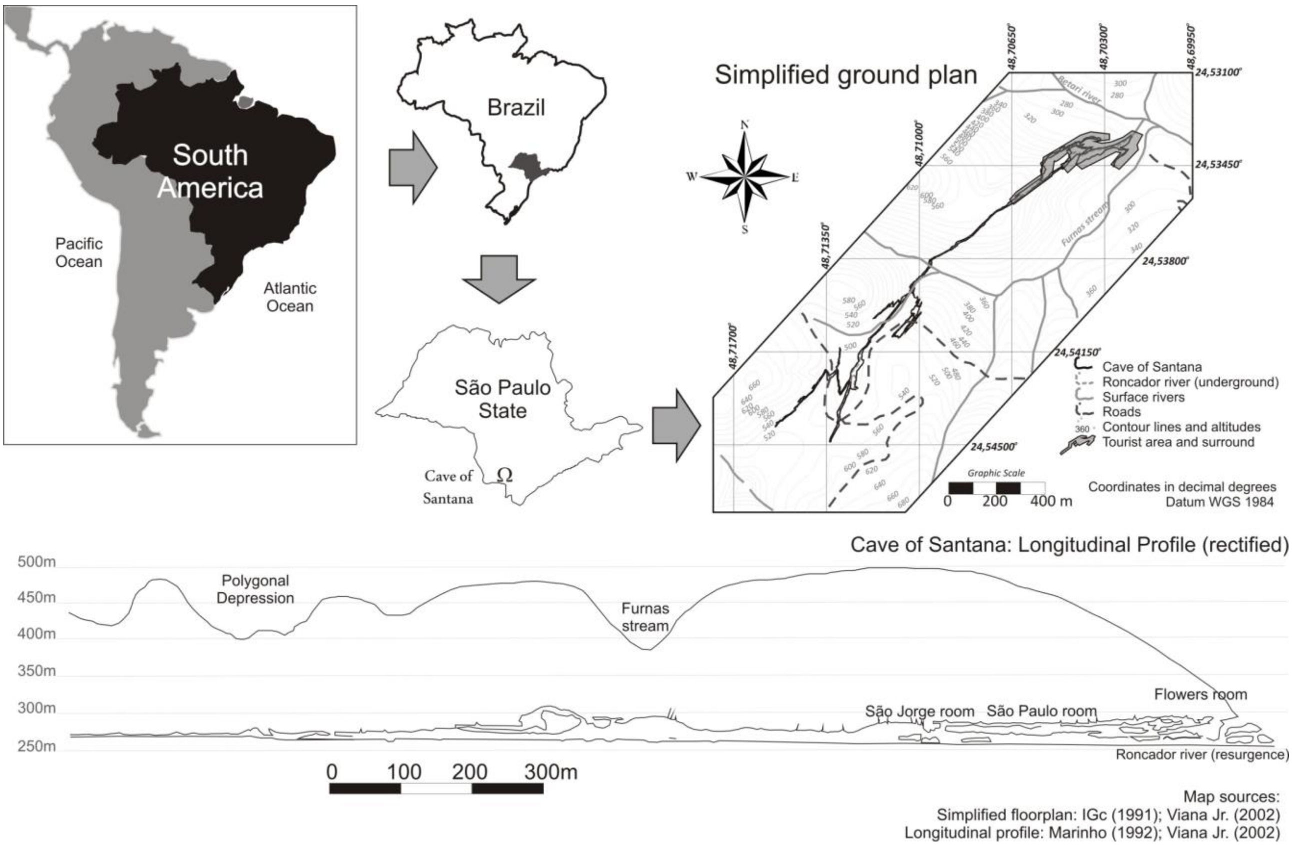

Figure 1: Location of cave of Santana.

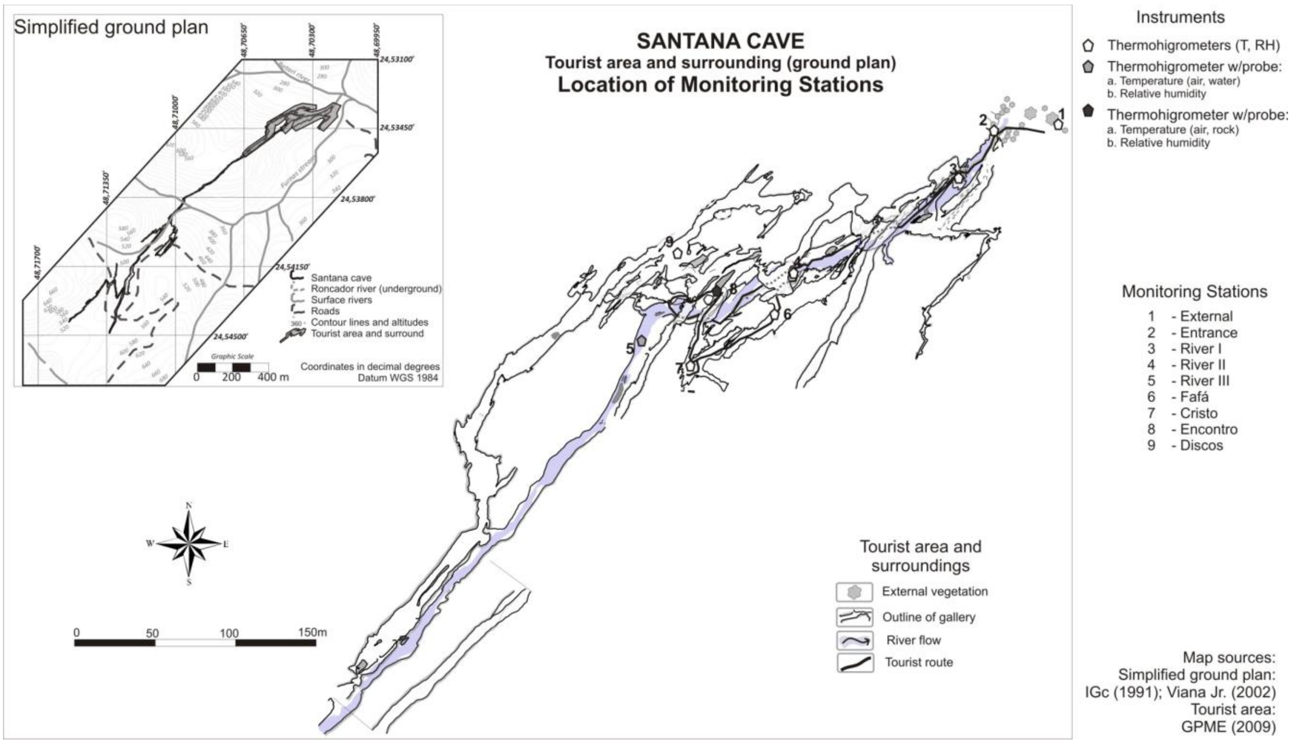

Figure 2: Details of tourist area and surroundings, including the monitoring stations.

The measurement of the air involved the use of Testo thermohygrometers. Nine points were monitored (Fig. 2), including one outside the cave and one at the immediate interface between the internal and external areas. The time between data collections varied from 15 to 30 min., depending on the phase of the research. The longest series obtained was an entire annual cycle of climatic seasons, including information about the rains which fell outside the cave, as rainfall is quite elevated throughout the year in the region, even in the drier winter months of June to August.

The analysis of the data used statistical procedures for dispersion and central trends (mean, median, mode, maximum, minimum, amplitude, and standard deviation), as well as procedures for the analysis of temporal series (autocorrelation, spectral density, and cross correlations).

3. RESULTS AND DISCUSSION

The results obtained for the cave of Santana are presented and discussed as a function of the monitoring stations (Fig. 2), considering the data of the period from 2009-2010 (Fig. 3a, b).

Figure 3 shows the data obtained, divided between the monitoring stations with higher (Figure 3a) and lower (Figure 3b) thermal amplitude. The annual average of this period for the air temperature in the external environment was 19.9 °C, with a maximum of 32.9 °C and a minimum of 6.1 °C. The average relative humidity was 98.9%, varying between 99.9% and 60.2%. Inside the cave, River station III (located in a place not subject to tourism) revealed a minimum temperature of 17.3 °C, and a maximum of 19.3 °C, with an average of 18.28 °C. The relative humidity of the air was constant at 99.9% throughout the entire period of monitoring, with variation observed until the surrounding area of River station II.

Most of the stations monitored were found to fit into two general patterns of variation in relation to the air temperature: relatively large variations between day and night at the external stations and those along the Roncador river, and slight variations, only barely visible upon visual analysis of the graph, found at the stations in the upper galleries. This pattern was similar to that presented by Kranjc and Opara (2002) for the caves of Skocjanske jame in Slovenia; there the variation was related to distance from the external atmosphere, as well as to differences related to the level of galleries, which implies a certain stratification of the underground atmosphere. However, the patterns of temperature variation at the stations of the Cristo and the Encontro room were totally different from the others, with the registration of anomalous data. The variations observed coincided with the passage of groups of visitors, as has already been demonstrated in studies of other caves (e.g. Pulido-Bosch *et al.* 1997; Carrasco *et al.* 2002; Calaforra *et al.* 2003), which can alter the temperature of the air at specific points. The time required for stabilization after the passage of visitors varied depending on the level of circulation of energy and mass at the specific point in the cave, as shown in papers such as those of Fernández-Cortés *et al*. (2006a) and Lobo and Zago (2010). Fig. 4 presents conceptual models to illustrate these patterns of variability.

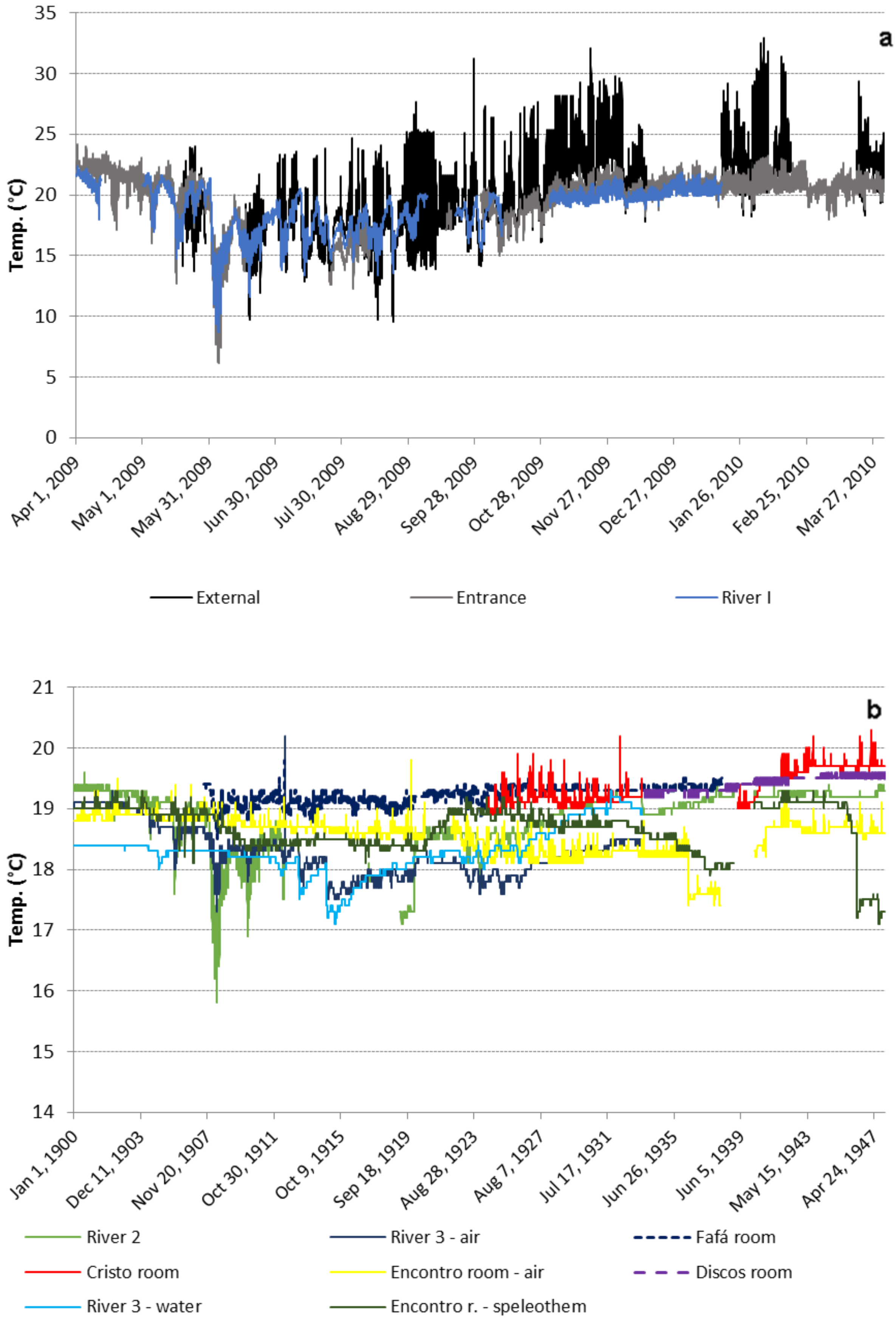

Figure 3: Original series of annual temperature during speleoclimatic monitoring of the cave of Santana (2009-2010): a) monitoring stations with higher thermal variation; b) monitoring stations with lower thermal variation.

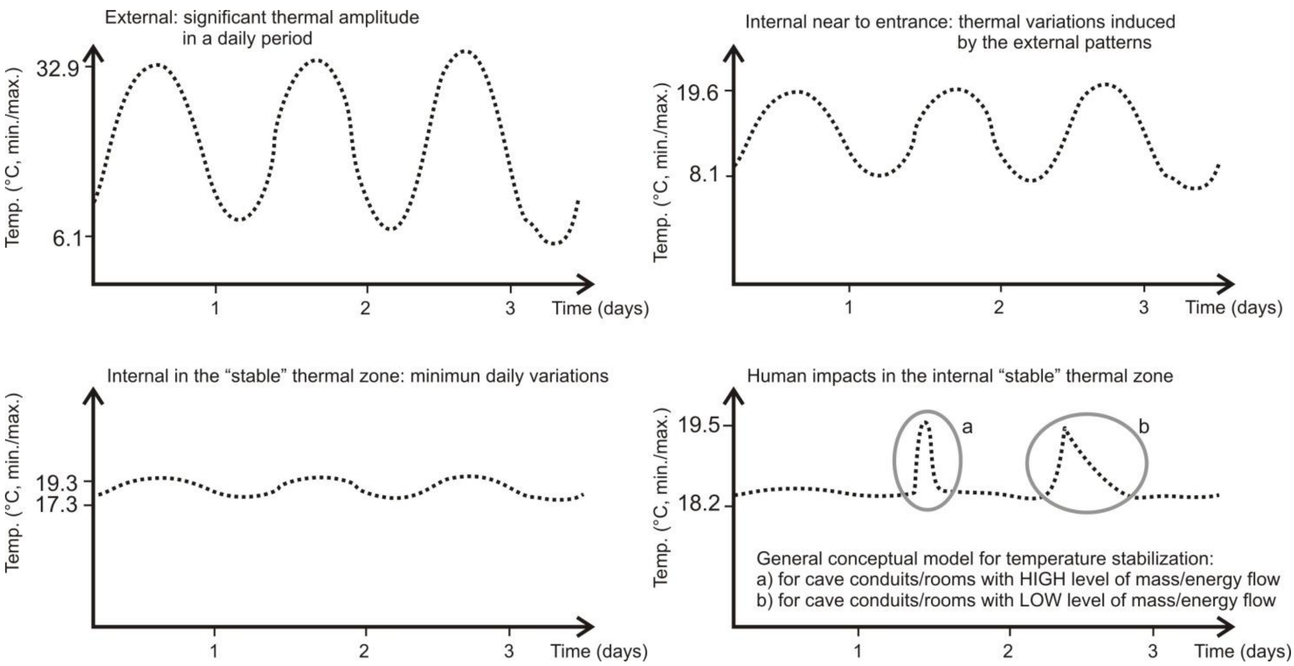

Figure 4: Conceptual models of the basic patterns of variability in twenty-four hours periods in the air of the cave of Santana.

As seen in Fig. 4, the variation in temperature follow a twenty-four hour cycle, with great variation at the external station. It is attenuated as one moves deeper into the cave. In the cave of Santana, in the access gallery (which houses the Roncador river) after station III on the river and in the upper galleries, temperature variation was quite limited, providing a visual sensation of "stability", although this must be viewed with certain reservations since natural variations do still occur. In these zones, the impacts of visitation on the temperature could be observed.

During the monitored period, experiments were conducted to verify the degree of influence of the visitors presence on the analyzed atmospheric parameters. The data of visitation were then correlated with those of the daily maximums of the stations of the Cristo and Encontro room, which registered variations in temperature outside the natural patterns of atmospheric variation (Fig. 5), not only for the air itself, but also for the host rock, for which the temperature was also monitored.

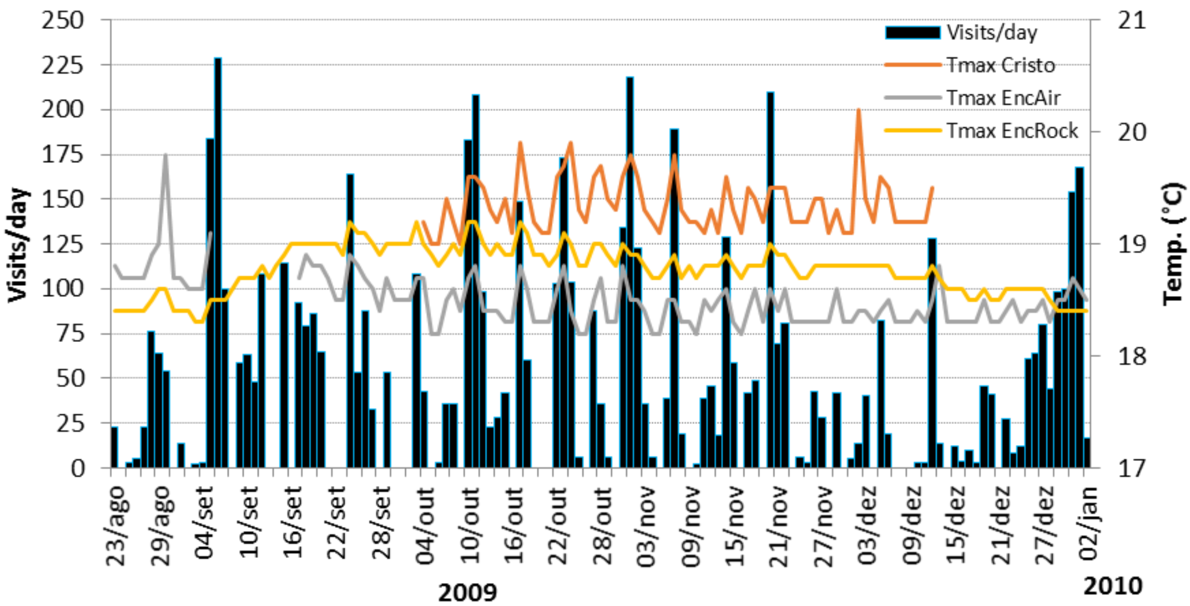

Figure 5: Number of visits / day x maximal temperature at the stations of the Cristo and the Encontro room from August 23, 2009, to January 2, 2010.

Fig. 5 makes possible the visualization of these correlations. The series of collected data were than submitted to a descriptive statistical analysis using a Pearson Correlation Coefficient (*r*). The coefficients for the stations of the Cristo (0.706) and Encontro room (0.622) were highly correlated, showing the existence of the interference of the human presence on the values measured. For these data, a descriptive statistical analysis using cross correlations was also made (Fig. 6).

The correlation between daily visitation and the data of the series of observations is quite significant. For the station of the Cristo (Fig. 6a), a maximum index of 0.706, with no lag, was obtained. At the station of the Encontro room (6b), the correlation was 0.622, also without any temporal lag. These indices, in conjunction with the Pearson's *r*, show the linearity between the entrance of elements external to the system (the visitation) and the respective response (the local increase in temperature). Although the graphics and the statistical analyses suggest a direct relation between alterations in temperature and the presence of groups of visitors, a more detailed analysis for the period between October 30 and November 3, 2009, was also made (Fig. 7).

Fig. 7 provides the proof of the anthropic origin of the impact on the temperature at the stations analyzed. The more detailed study shows that a temperature increase of from 0.3 °C to 0.6 °C occurs right after the visitation of groups containing up to 23 visitors. On October 30, a day in which no visitation to the cave was permitted, only a very slight variation was observed, similar to the pattern observed for the other rooms monitored. The variations on November 3 are especially important, since only two groups of 18 visitors each visited the area, but they consisted of students in special activities which involved a longer stay inside the cave, and significant temperature alterations were registered. This shows that in general both the number of persons and the time of residence are relevant in the occurrence of impacts on the underground atmosphere.

The statistical analyses of the correlation of these data confirm the conclusions reached above. The coefficients found prove the existence of a statistically significant correlation between the presence of visitors and the temperature of the air at the stations of the Cristo and the Encontro room. The correlation indices of the crossed correlations confirm this interpretation, with values of 0.721 for the station of the Cristo, with a lag of one hour and 0.595 for the station of the Encontro room, also with a time lag of one hour.

The temporal lags observed are coherent with the condition of use of the cave, given the normal time between entrance and visitation in these rooms, since groups generally take about an hour to get at the rooms of the Cristo and Encontro. Based on the found data, a preliminary conclusion is that the air temperature at the station of the Encontro room drops to normal after 6-7 hours after an increase of up to 0.6 °C.

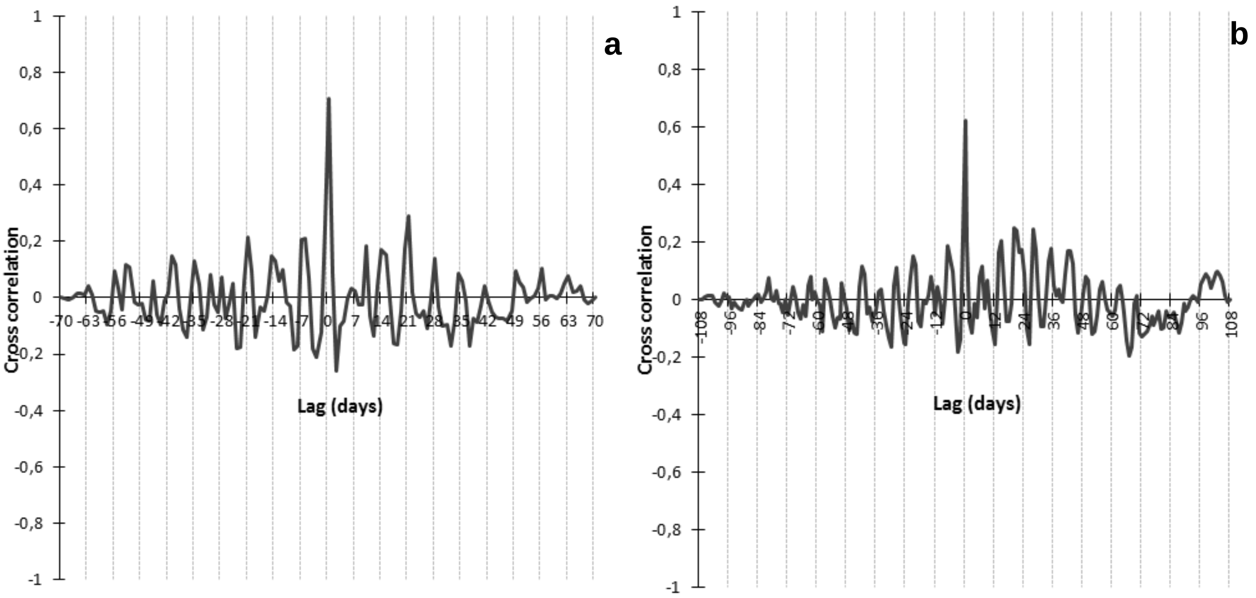

Figure 6: Crossed correlograms relating daily visitation with the temperature at the stations of the Cristo (a) and the Encontro room (b) during September and December, 2009.

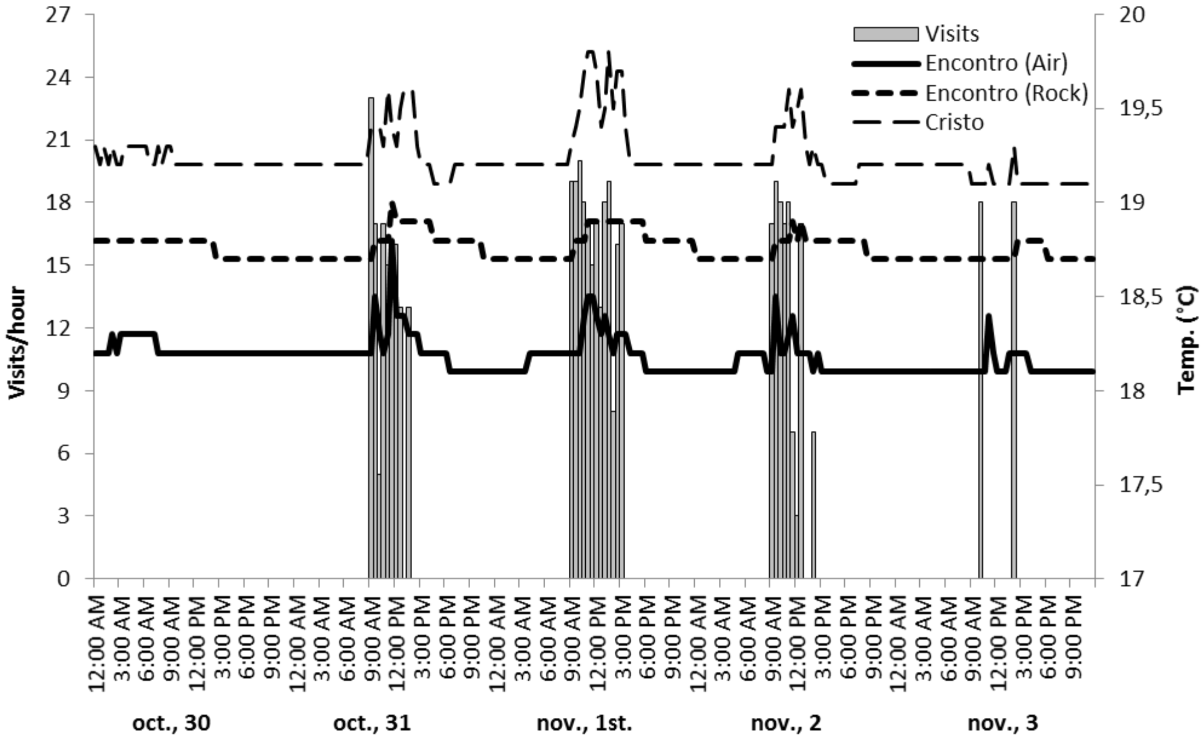

Figure 7: Hourly variation in temperature at the stations of the Cristo and the Encontro room between October 30 and November 3, 2009, correlated with visitation.

Changes in the elementary physico-chemical characteristics of the underground atmosphere have been widely researched, especially in European and North American caves. In some cases, the presence of humans has been totally avoided, such as in those containing especially fragile rupestrian paintings, such as the cave of Lascaux in France (Bastian & Alabouvette 2009) or when instable secondary chemical deposits are involved, such as in the geode of Pulpí in Spain (Fernández-Cortés *et al.* 2006b), since even minimal atmospheric alterations can generate irreversible damages to the paintings and the host rocks or to the minerals in the caves. In other cases, the human presence can be tolerated, with the challenge being that of identifying the limits of tolerance for frequency and permanence necessary to protect the biological and geological aspects of the underground environment. In the cave of Santana, at least along the traditional tour circuit, there are no rupestrian paintings, nor rare mineral formations justifying *a priori* the adoption of inflexible limitations on the number of visitors, especially when the dimensions of the cave and the internal infra-structure are considered. The challenge consists of reaching a better understanding of the dynamics of the atmosphere. With this, acceptable limits for the main atmospheric characteristics can be identified and models can be established, which will mitigate as much as possible the impacts. Thus, the number of visits permitted will be as many as can safely be allowed, without permanently affecting the atmosphere.

In order to determine these levels, an initial analysis of the characteristics at the monitoring stations was made. For temperature, the data were analyzed as a function of the daily thermal variation. This decision was based on the work of Hoyos *et al.* (1998), Sánchez-Moral *et al.* (1999), Calaforra *et al.* (2003) and Fernández-Cortés *et al.* (2006a), which identified the natural variations in the environments researched to then correlate them directly with visitation and, based on these results, establish daily limits for visitation. For the present paper, it is argued that, in the absence of special environmental aspects which can under no circumstances be submitted to extreme variation, these limits may be too limiting, since they do not consider the dynamics of equilibrium.

The daily thermal amplitude for the stations of the Cristo and Encontro for the period of August 23, 2009, to January 1, 2010, as well as for the period of July 1 to September 14, 2010, for the station Cristo were then correlated with the data available about daily visitation. The results for air temperature are given in Fig. 8.

For the comparison of the data provided in Fig. 8, separate statistical analyses were conducted for days with and without visitation (Tabs. 1 and 2).

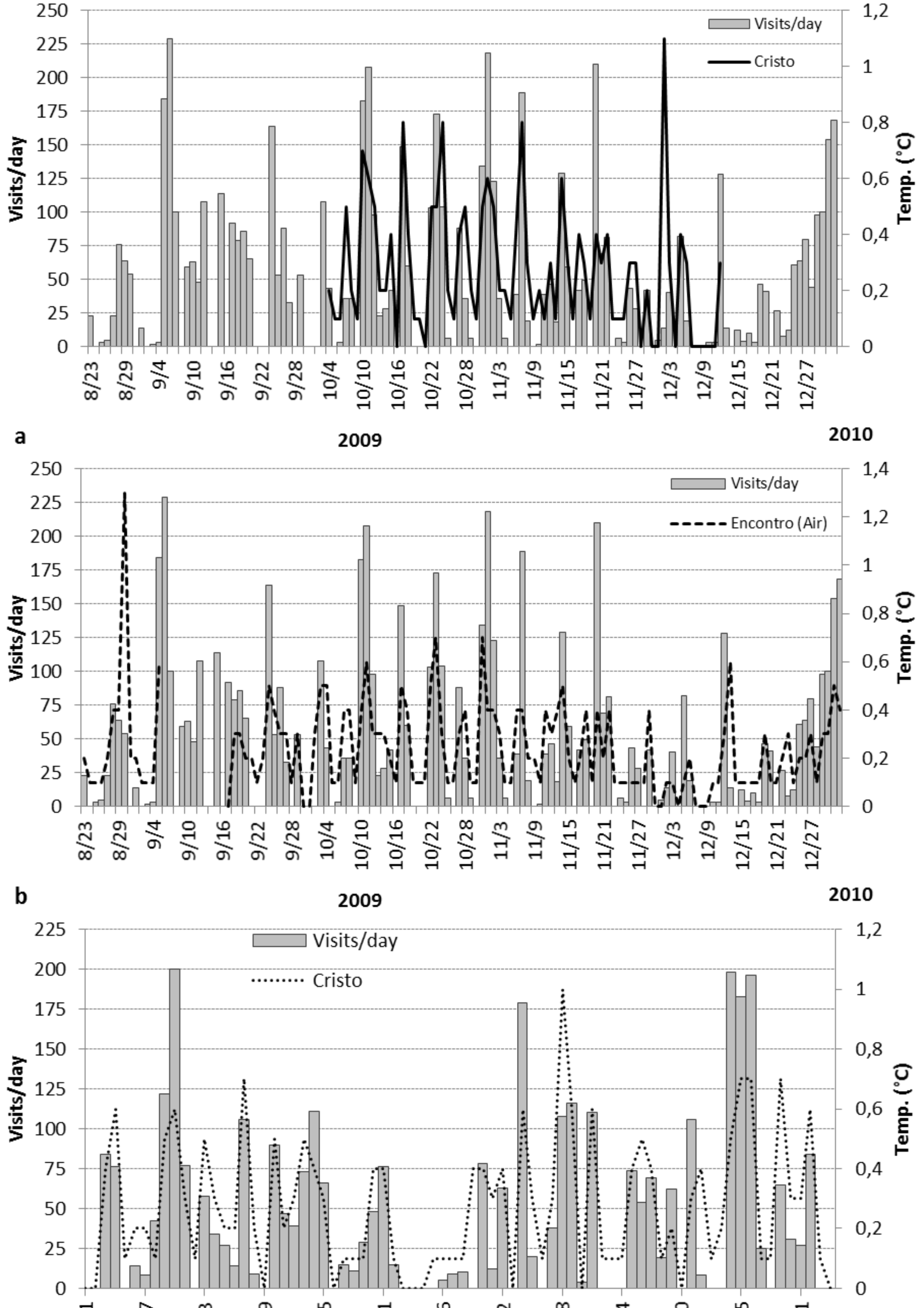

Figure 8: Daily thermal amplitude in air temperature for the stations of the Cristo (a) and Encontro room (b) for the period from August 23, 2009, to January 1, 2010, as well as for that of the Cristo from July 1 to September 14, 2010 (c) and their relation to visitation.

Table 1: Daily variation (air temperature) and presence of visitors in the room of the Cristo.

Daily variation (°C)	Cristo Room			
	Number of days		Number of visitors	
	Without visits	With visits	Mínimum	Máximum
0	18	4	3	5
0.1	21	15	3	42
0.2	1	17	2	62
0.3	-	20	12	128
0.4	1	17	8	210
0.5	-	13	36	198
0.6	-	9	76	218
0.7	-	5	65	196
0.8	-	3	104	189
1.0	-	1	108	108
1.1	-	1	14	14

Table 2: Daily variation (air temperature) and presence of visitors in the Encontro room.

Daily variation (°C)	Encontro room (Air)			
	Number of days		Number of visitors	
	Without visits	With visits	Minimum	Maximum
0	8	3	5	92
0.1	19	26	2	82
0.2	4	13	14	69
0.3	1	18	8	128
0.4	-	19	18	218
0.5	-	8	43	164
0.6	-	3	14	208
0.7	-	2	134	173
1.3	-	1	54	54

As can be seen in Tab. 1 and 2, for these two rooms, the daily variation in temperature without visitation was limited to 0.1 °C. The presence of visitors led to maximum daily variations of 1.1 °C (Cristo room) to 1.3 °C (Encontro room), although most were in the range of 0.1 to 0.5 °C (Cristo room) and 0,1 to 0.4 °C (Encontro room), which are larger than those reported for other caves (e.g. Domínguez-Villar *et al.* 2010). These variations were generated by groups of varying sizes, with only 2 visitors in the Cristo room being sufficient to increase the temperature 0.2 °C, while 12 raised it 0.3 °C and 8 to 0.4 °C. Despite the fact that a variation of 0.4 °C was also registered without the presence of visitors, it seems likely that individuals involved in research or inspection may have been present, since such activities are not always registered in the control of visitation. In the Encontro room, the presence of two individuals generated an increase of 0.1 °C, while that of 18 persons raised it 0.4 °C.

Two basic options are available for dealing with the atmospheric dynamics of these two rooms, and they both would have repercussions for, among other things, the definition of carrying capacity. The first would be that anthropically-caused variations should be allowed to surpass natural variation (Hoyos *et al.* 1998; Cigna 2010; Calaforra *et al.* 2003); and the second that the carrying capacity should be based on the temperature, since this is the critical factor in relation to the immediate response to the presence of people (Cigna & Forti 1988), although in this case visitation would be limited to a single visitor in the room of the Cristo, since 2 people led to an increase of 0.2 °C and to 14 for the Encontro room, since this number generated enough heat to increase the normal variation by 0.1 °C.

However, the carrying capacity Should not be the main issue in the management of tourism in caves (Freitas 2010), since it is necessary to consider not only the ideal conditions for the environment, but also the most adequate techniques of management for each situation. The application of techniques developed for other realities should not necessarily be adopted. Techniques developed for caves with a restricted circulation of air would not be especially relevant for the reality of the cave of Santana, even though great variation in the environmental response to the pressure exercised by visitation was observed. For example, Tab. 4 shows that with the passage of 92 persons in a single day did not alter the temperature of the air in the Encontro room, which shows that the adoption of the traditional approach would be problematic – a situation possibly due to the complex and diversified atmospheric dynamics of the cave. Moreover, theresponse to visitation is not linear, since in one case a group of only 14 persons generated a daily increase of 1.1 °C in the room of the Cristo, while the visitation of 210, divided into various groups in a single day, caused an increase of only 0.4 °C. It seems more likely that the increase of temperature is directly linked to the length of time in which visitors remain in the rooms, rather than the number of persons, as such. This hypothesis is based on the fact that the guides tend to show a specific speleothem (resembling the face of Jesus Christ) to the visitors, but this is visible only after entering a small lateral gallery, and must be done one at a time, which leaves all the other visitors sitting the larger room waiting their turn. In the Encontro room, a similarly time-consuming tradition has developed, with the guides grouping the visitors so all lights can be extinguished and they can experience the total darkness of the cave environment.

It should be noted that even with these practices the temperature of the air in the room of the Cristo is reestablished within a maximum of 8 hours, whereas in the Encontro room this is reestablished within 7 hours. Moreover, there is no accumulative effect as a function of daily visitation, so that the air temperature, after the impact, returns to the original value, or with minimal variations of ±0.1 °C in certain cases. The data were thus reorganized (Tabs. 3 and 4) to show the total time required for a stabilization after thermal impacts generated in the stations of the Cristo and Encontro room.

Table 3: Analysis of total time for air temperature stabilization on days of greatest temperature increase – station of the Cristo room.

Date	Temp. (°C) prior to visitation (9h)	Peak temperature (°C)	Time of peak	Time for temperature stabilization	Recovery interval (min.)
10.Oct. 2009	19	19.5	15h 00min.	21h 30min.	390
11.Oct. 2009	19	19.6	13h 30min.	17h 30min.	240
12.Oct. 2009	19.1	19.5	10h 30min.	15h 00min.	270
17.Oct. 2009	19.1	19.9	14h 30min.	2h 30min.	720
18.Oct. 2009	19.1	19.5	10h 00min.	13h 30min.	210
27.Oct. 2009	19.2	19.6	14h 00min.	23h 30min.	570
31.Oct. 2009	19.2	19.6	14h 00min.	16h 30min.	150
1.Nov.2009	19.2	19.8	13h 30min.	16h 00min.	150
2.Nov.2009	19.2	19.6	12h 30min.	15h 30min.	180
7.Nov.2009	19	19.8	15h 00min.	17h 00min.	120
14.Nov.2009	19.1	19.6	11h 00min.	14h 30min.	210
20.Nov.2009	19.1	19.5	14h 30min.	16h 30min.	120
4.July 2010	19.1	19.7	15h 00min.	17h 20min.	260
17.July 2010	19.5	20.2	11h 20min.	19h 20min.	180[1]
23.July 2010	19.7	20.1	11h 00min.	13h 40min.	160
25.July 2010	19.7	20	11h 20min.	16h 40min.	140[1]
30.July 2010	19.7	20.1	11h 00min.	13h 00min.	120
12.Aug. 2010	20	20.4	11h 40min.	13h 20min.	100
14.Aug. 2010	20	20.5	16h 20min.	19h 20min.	180
18.Aug. 2010	20	20.9	16h 00min.	19h 40min.	220
19.Aug. 2010	19,9	20.5	15h 00min.	19h 00min.	360
21.Aug. 2010	20	20.4	15h 00min.	18h 20min.	200
5.Sept. 2010	20	20.7	13h 00min.	0h 40min.	700
6.Sept. 2010	20	20.7	14h 20min.	19h 20min.	300
9.Sept. 2010	20	20.7	15h 40min.	18h 00min.	140

[1] On July 14 and 25, the stabilization time was not computed as a function of the highest peak, but rather for a second, later peak.

Table 4: Analysis of total time for air temperature stabilization on days of greatest temperature increase – station of the Encontro room.

Date	Temp. (°C) prior to visitation (9h)	Peak temperature (°C)	Time of peak	Time for temperature stabilization	Recovery interval (min.)
4.Oct.2009	18.3	18.7	12h 30min.	16h 00min.	150
10.Oct.2009	18.4	18.7	12h 30min.	16h 30min.	240
11.Oct.2009	18.4	18.8	13h 00min.	16h 30min.	210
12.Oct.2009	18.2	18.4	12h 30min.	16h 30min.	240
17.Oct.2009	18.4	18.8	13h 00min.	16h 00min.	180
18.Oct.2009	18.3	18.6	10h 00min.	13h 00min.	180
31.Oct.2009	18.2	18.8	11h 30min.	15h 00min.	210
1.Nov.2009	18.2	18.5	11h 30min.	16h 00min.	270
2.Nov.2009	18.1	18.5	9h 30min.	14h 00min.	180[1]
7.Nov.2009	18.1	18.5	15h 00min.	18h 00min.	180
14.Nov.2009	18.2	18.6	11h 30min.	16h 00min.	270
20.Nov.2009	18.2	18.6	15h 00min.	18h 30min.	210

[1] On Nov. 2, the time for stabilization was not computed as a function of the highest peak, But rather for a later, second peak.

An initial qualitative analysis of the data was used to organize Tabs. 3 and 4. This considered the impacts with a magnitude close to the margin of error of the instruments (0.1 to 0.2 °C), as well as those for which the time of stabilization was less than 1 hour after the impact.

The longest recovery time registered for the station of the Cristo was 720 min., on October 17, 2009. At the station of the Encontro room, a time of 270 min. was registered on two occasions: on November 1 and 14, 2009. At both stations, the largest values were obtained on weekends and holidays.

The average recovery time of the station of the Cristo was 255.6 min., while for the station of the Encontro room it was 210 min. This comparison of the recuperation from the largest temperature increases showed that the room of the Cristo is the main “bottleneck” in relation to avoiding anthropic impacts on the air temperature along the route of visitation of the cave of Santana. The data in Tab. 3 were thus described using a histogram (Fig. 9).

Most of the time, the total time for stabilization of air temperature at the Cristo station was less than 300 min. The average for the series was 255.6 min., and the median was 200 min. The extreme values, 550 min. and 700 min. were exceptions to the general pattern of environmental response. The peaks occurred on October 17 (720 min. for stabilization, with an accumulated visitation of 149 visits/day) and October 27 (570 min.; 88 visits/day) in 2009 and September 5, 2010 (700 min.; 183 visits/day). However, no direct relation was found between the total number of visits and the time of stabilization. For example, on October 11, 2009, and July 10, 2010, a total of 208 and 200 visits per day were received, respectively, but the total stabilization time was only 240 min. and 180 min., for each of these days. The raise in temperature was thus deemed not to be the best value for understanding total stabilization time.

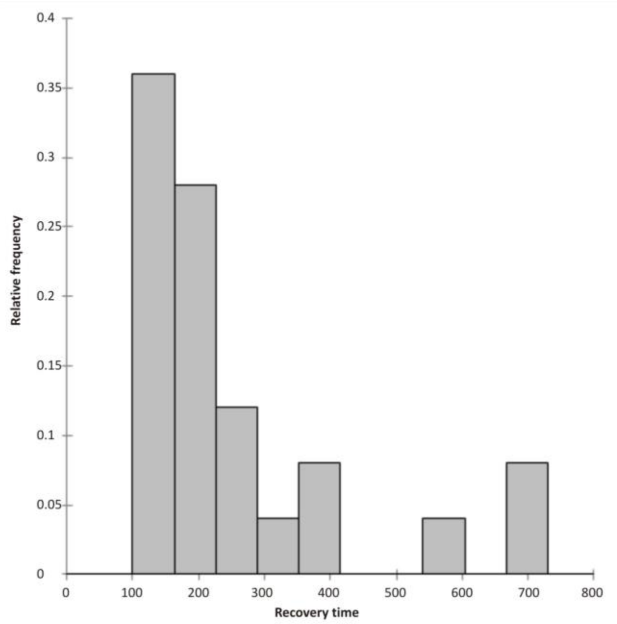

Figure 9: Analysis of total stabilization time for air temperature on the days with greatest temperature increase –station of the Cristo.

4. CONCLUSIONS

The monitoring permitted the identification of a varying pattern of atmospheric responses for the air temperature in relation to the input generated by visitation of the cave of Santana. Considering the use of atmospheric data for the limitation of visitation, various reservations arise in relation to the correlation of atmospheric variables with the presence of visitors during a single event, or even over slightly longer intervals of time. The adoption of this single event for modeling the carrying capacity may lead to exaggerations in the limits imposed. If the limits are too lenient, the environment will suffer, whereas if they are too strict, it is the society and management which will confront unnecessary restrictions.

It is also important to point out that the variation in air temperature is not proportional to the number of persons per group, or even the total number of visits per day. This is important because of the traditional paradigm linearly correlating carrying capacity to these parameters. In the case of the cave of Santana, and presumably in others with similar environmental characteristics, the key parameter seems to be the time spent by a group at a specific location, which suggests a new option for the management of tourist visitation in which it is the time spent at the various points along the trail in the cave which should be prioritized. The number of people in a group is still important, especially for questions of comfort, safety, and the quality of the experience, but this number is only secondary in relation to the carrying capacity as such. Moreover, the total number of visits per day can be established as a result of the interaction between the time spent in the cave, the time needed by the cave for a return to the stable state, and the number of people per group, with variations possible depending on the season of the year and visitation demands.

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