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ATMOSPHERIC TIDE EFFECTS IN A TRIESTE KARST CAVE: PRELIMINARY RESULTS

SUMMARY

The preliminary results of the analysis of atmospheric pressure and air temperature data, recorded in the Trieste Karst cave “Abisso di Trebiciano” (n. 17 VG) from January 8th to July 9th 2006, are reported. The measurements were performed by means of a programmable data logger, placed at about 100 m below the cave entrance and with a sampling period of 5 minutes. The analysis of the recorded data evidenced the presence of a semidiurnal cycle whose amplitude is about 0.85 m°C and 44.4 Pa for temperature and pressure, respectively. Moreover, a phase-lag between temperature and pressure was observed, with temperature peaking about 1 h 45 min earlier than pressure. Finally, in the periodogram analysis of atmospheric pressure, a 34-h peak was observed; however more data are needed to validate this result.

RIASSUNTO

EFFETTI DELLE MAREE ATMOSFERICHE IN UNA CAVITÀ DEL CARSO TRIESTINO: RISULTATI PRELIMINARI

Vengono presentati i risultati preliminari dell’analisi delle misure di pressione atmosferica e temperatura dell’aria registrate dall’8 gennaio al 9 luglio 2006 nella grotta del Carso triestino denominata “Abisso di Trebiciano” (n. 17 VG). Le misure sono state effettuate ad una profondità di circa 100 m dalla superficie, mediante uno strumento digitale programmabile con un intervallo di campionamento di 5 minuti. Il numero totale di misure disponibili per ciascun canale, in seguito al controllo di qualità, è 51955. La statistica descrittiva relativa alla temperatura ha evidenziato la notevole stabilità termica della cavità, caratterizzata da un campo di variazione di soli 0,09 °C, dedotto da un valore minimo di 11,126 °C e da un valore massimo di 11,216 °C, mentre il valore medio è pari a 11,169 °C. Successivamente i dati di ciascun parametro sono stati filtrati mediante una media mobile calcolata su 288 punti, corrispondenti ad un intervallo di tempo pari a 24 ore, e sono stati confrontati. Da tale analisi è emerso che, in particolar modo nei mesi più freddi (febbraio e marzo), ad una diminuzione della pressione atmosferica è corrisposto un aumento di alcuni centesimi di grado della temperatura dell’aria, dovuto allo spostamento verso la superficie della massa d’aria più profonda, caratterizzata da una temperatura maggiore rispetto a quella degli strati superiori. Dai valori sperimentali di pressione e temperatura non filtrati sono state successivamente calcolate per ciascun parametro le medie orarie, la cui analisi ha evidenziato la presenza di un ciclo semidiurno di ampiezza pari a circa 0,85 m°C per la temperatura e a 44,4 Pa per la pressione. Il ciclo medio giornaliero delle pressione e della temperatura, dedotto dalle medie orarie, è stato quindi interpolato con una fun-

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zione trigonometrica costituita dalla somma delle armoniche diurna (periodo: 24 ore) e semidiurna (periodo: 12 ore): questa procedura ha permesso di rilevare una differenza di fase tra i due segnali semidiurni, con un anticipo della temperatura pari a 1 h 45 min. Infine, attraverso l'analisi dei periodogrammi, calcolati per entrambi i parametri, è stata osservata una componente armonica di periodo pari a circa 34 h nel segnale di pressione, la cui validazione necessita di ulteriori misure.

POVZETEK

VLIP ATMOSFERSKE BIBAVICE V JAMI NA TRŽAŠKEM KRASU

Predstavljajo se začetni rizultati analiz meritev atmosferskega pritiska in temperature zraka, ki so bile opravljene od 8. januarja do 9. julija 2006 v jami "Labodnici (Abisso di Trebiciano)" št. 17 VG na Tržaškem Krasu. Meritve so bile izvršene približno 100 m globoko od površja s pomočjo programirane digitalne naprave s časovnim presledkom petih minut. Analiza podatkov je pokazala prisotnost poldnevnega ciklusa z amplitudo 0.85 m°C za temperaturo in 44.4 Pa za pritisk. Poleg tega je bilo razbrati razliko v fazi med dvema poldnevnima signaloma s predčasnostjo temperature za 1 h in 45 min. Z analizo periodograma atmosferskega pritiska je bilo opaziti v signalu približno 34-urno harmonično komponento. Vsekakor so potrebni dodatni podatki za ugotovitev veljavnosti predstavljenih rizultatov.

Introduction

In recent years a considerable number of research campaigns, aiming at the acquisition of atmospheric pressure and air temperature data in Trieste Karst caves, have been carried out by means of programmable data loggers placed in selected hollows. The use of such instruments has permitted the collection of time series of temperature and pressure at short sampling period (5-20 minutes) and, for the best instruments, at high resolution (pressure: about 15 Pa; temperature: about 0.003 °C). The first analyses of the pressure data records collected during the research campaigns evidenced clearly the presence of atmospheric tides in the pressure signal, a well known phenomenon thoroughly described, for example, by Chapman and Lindzen (1970). Surprisingly, evidence of atmospheric tide was detected also in the air temperature measurements recorded in a Trieste Karst cave, where a semidiurnal signal with an amplitude of about 0.0022 °C was observed (Bussani, 2004). More unexpectedly, the comparison between such signal and the corresponding semidiurnal constituent of atmospheric pressure extracted from the 1961-1990 time series recorded at Trieste University (Stravisi, 1994), revealed the presence of a phase-lag, with the cave temperature reaching its maximum about 2.61 hours earlier than the external atmospheric pressure. These results are essentially comparable to those obtained by Sondag *et al.* (2003) who analysed air temperature and atmospheric pressure data collected in Karstic caves of two areas of Brazil, with temperature peaking about one hour earlier than pressure: the semidiurnal variation of temperature was interpreted as a consequence of the adiabatic expansions and compressions of the cave atmosphere, but no hints were given about the phase-lag between temperature and pressure. Very similar results were also obtained by Chen *et al.* (2003) from the analysis of air temperature and atmospheric pressure data recorded in an underground laboratory, but the presence of the phase-lag led to the conclusion that adiabatic expansions and compressions could not account for the whole phenomenon. The difference between the phases of the two signals was then explained by Wu *et al.* (2003) by means of a thermodynamic model that included the effect of heat conduction between air and rock.

It has to be kept in mind that the observed semidiurnal signals are caused by the so-called *thermal atmospheric tides*, i.e. tides induced by solar heating and resonance effects that take place in the atmosphere, while the *gravitational atmospheric tides*, originating from the lunisolar attraction on the atmospheric air mass, are comparatively negligible.

This paper deals with the effects of the thermal atmospheric tides (atmospheric tides, in the following) upon atmospheric pressure and air temperature data collected in the Trieste Karst cave "Abisso di Trebiciano" (n. 17 VG) during the first half of 2006. Descriptive statistics, mean daily cycles and harmonic analysis of both parameters are performed and compared to what is reported in the literature.

Data collection

A Driesen und Kern Plog 520 thermobarometer, originally designed for the marine environment, was placed in the Trieste Karst cave "Abisso di Trebiciano" n. 17 VG (fig. 1) at a depth of about 100 m below the surface. The cave entrance, sealed by a locked trap door, is at 341 m above sea level (a.s.l) and has a total depth of about 330 m. The instrument, whose technical characteristics are given in tab. 1, was placed at about 1 m above the cave floor and at about 2 m from the nearest rock walls.

Data recording started on January 8th 2006 with a sampling period of 5 minutes. Data retrieval occurred on July 9th 2006, when 52393 measurements for each channel were downloaded. Collected data underwent a quality check procedure consisting essentially in the removal of the recordings taken in the first two days, markedly affected by the presence of the experimenters who entered the cave the first day to set up the instrument, and those recorded during the retrieval. Moreover a visual check of all data was performed in order to remove possible spikes, though none was detected. The final number of recordings for each channel is 51955.

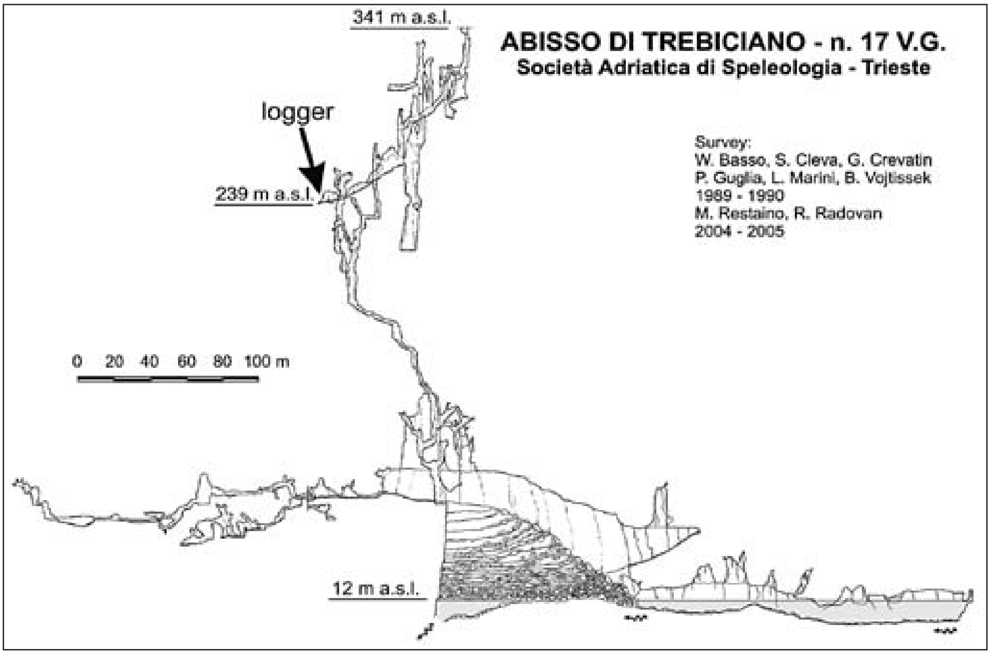

Fig. 1 – Cave survey and instrument location (picture by courtesy of Società Adriatica di Speleologia).

Length	200 mm
Diameter	23 mm
Memory	500000 measurements
Pressure accuracy	20 Pa
Pressure resolution	15 Pa
Temperature accuracy	0.1 °C
Temperature resolution	0.003 °C

Tab. 1 – Technical characteristics of the instrument.

Statistical analysis

The time-domain analysis consisted mainly in the definition of the mean daily cycles of each parameter: hourly means of pressure and temperature were computed, averaging all the measurements taken in the same 1-h time intervals, centred about integer hours (e.g. all measurements collected between 00:30 and 01:30 were averaged to give the mean value of 01:00). The mean daily cycles were then interpolated by means of the following trigonometric function, consisting in the sum of the diurnal and semidiurnal harmonics:

$$f(t) = A_0 + A_1 \cdot \cos\left(\frac{2\pi}{T}\left(x - \varphi_1\right)\right) + A_2 \cdot \cos\left(\frac{4\pi}{T}\left(x - \varphi_2\right)\right) \qquad (1)$$

where A_0 is the mean value of the considered parameter, T = 24 hours and A_1, A_2, φ_1 and φ_2 are the amplitudes and phases of the diurnal and semidiurnal signals, respectively.

A frequency-domain analysis was then carried out: data were smoothed using a running mean filter computed upon 288 points, corresponding to a time window of 24 h, centred on the 145th value. Residuals between experimental data and the filtered signals were then worked out for each parameter. Finally, periodograms were calculated both for pressure and temperature residuals in order to detect the presence of periodic constituents.

Results and discussion

The running-mean filtered time series of atmospheric pressure and air temperature signals, recorded in the cave by the thermobarometer, are reported in fig. 2, while descriptive statistics of unfiltered quality-checked data (i.e. after the removal of measurements influenced by the logger setup or retrieval), is given in tab. 2. Broad variations are evident in the pressure signal, presumably induced by the external atmospheric pressure; on the

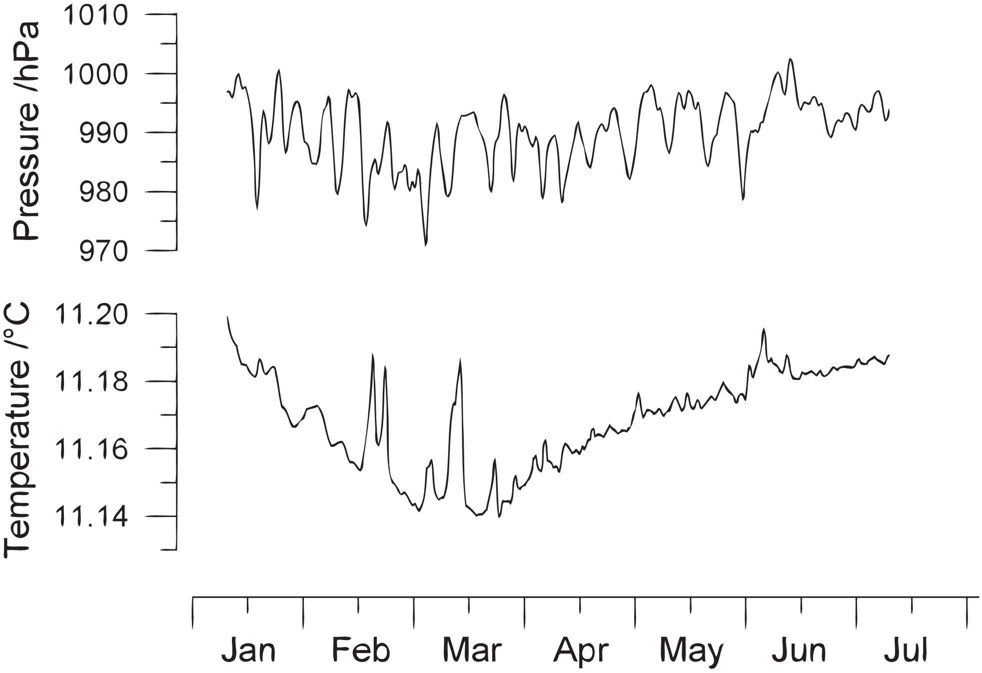

Fig. 2 – Smoothed time series of atmospheric pressure and air temperature.

	Temperature (°C)	Pressure (hPa)
Mean	11.169	990.195
Minimum	11.126	967.888
Maximum	11.216	1003.953
Standard deviation	0.015	5.923

Tab. 2 – Main statistics of pressure and temperature quality-checked measurements.

contrary, the temperature fluctuations are markedly damped with respect to the outside: in fact, one of the most striking features of the recorded data is the extreme stability of the cave temperature, whose range during the months under consideration is only 0.09 °C. Moreover, a careful cross-analysis of both the temperature and the pressure signals evidences that, especially in the coldest months, temperature frequently peaks in correspondence to drops in pressure: this phenomenon could be attributed to the upward displacement of deeper and, in winter months, warmer air, driven by an atmospheric pressure decrease.

The mean daily cycles of temperature and pressure and their respective semidiurnal constituents are reported in fig. 3, while the values of the best fit parameters are given in tab. 3. Both cycles show a clear semidiurnal pattern, however the temperature cycle is slightly less smooth than the pressure cycle: this is due to the fact that the amplitude of the temperature signal, unlike pressure, is one order of magnitude lower than the instrument

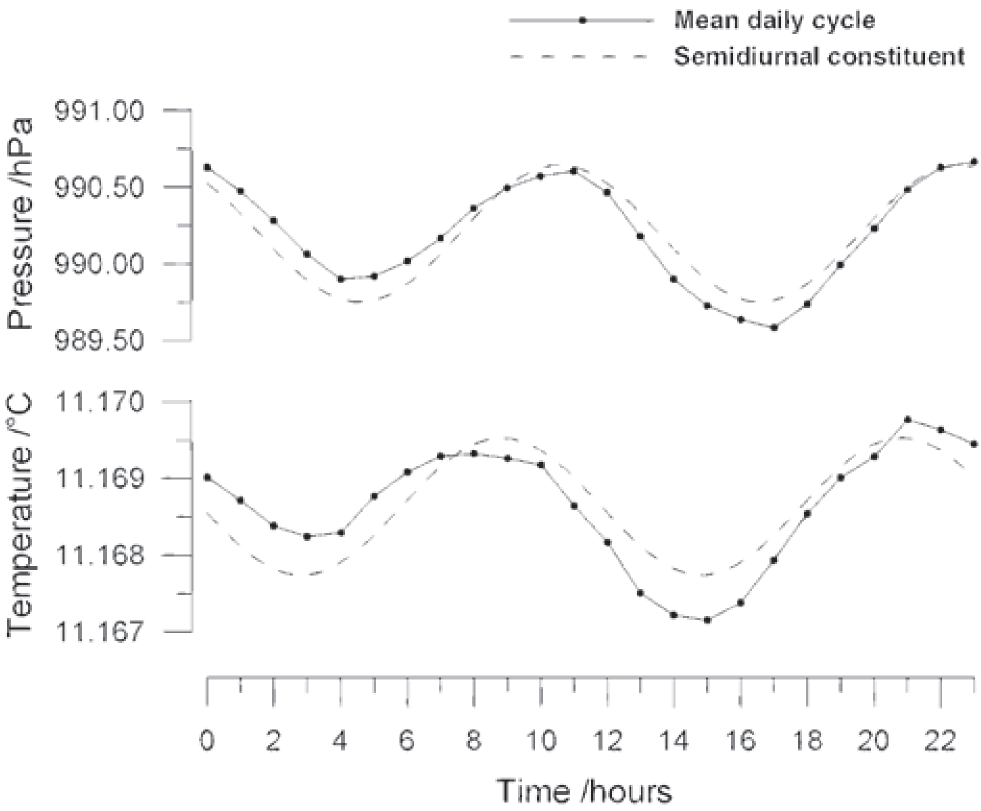

Fig. 3 – Mean daily cycles of temperature and pressure and semidiurnal constituents.

resolution. As a matter of fact, differences between subsequent hourly means of the temperature cycle can be even smaller. Nevertheless, the phase-lag between the two signals is fairly evident and the difference is even clearer for the semidiurnal constituents: applying eq. 1 to the mean daily cycles, it emerges that the first peaks of the semidiurnal constituents of pressure and temperature occur at 10:34 and 8:49, respectively. These results agree with what was reported by Wu *et al.* (2003), who found a phase-lag of 0.95 rad, corresponding to a difference of 1 h 48 min. However, the difference observed by Bussani (2004) in a different cave of Trieste Karst was considerably higher (2 h 36 min).

As a point of interest, according to Stravisi (1994) the first peak of the semidiurnal constituent of Trieste atmospheric pressure occurs at 10:29, which is consistent with the value obtained in the present work (10:34), allowing for the sampling period (5 minutes), while the phase of the diurnal constituent according to Stravisi (1994) is 5.89 hours (5:53), i.e. 2.41 hours greater than the phase observed in the considered cave. However, a good agreement is also present between the best fit values of the diurnal and semidiurnal amplitudes of the atmospheric pressure computed according to eq. 1 (tab. 3) and the corresponding values obtained by Stravisi (1994), who found diurnal and semidiurnal amplitudes of 15.5 Pa and 44.9 Pa respectively.

Pressure	A_0 (hPa)	A_1 (Pa)	φ_1 (hours)	A_2 (Pa)	φ_2 (hours)	R^2
Diurnal + semidiurnal (eq. 1)	990.195	16.7	3.48	44.4	10.58	0.995
Temperature	A_0 (°C)	A_1 (m°C)	φ_1 (hours)	A_2 (m°C)	φ_2 (hours)	R^2
Diurnal + semidiurnal (eq. 1)	11.169	0.56	1.96	0.85	8.83	0.987

Tab. 3 – Best fit coefficients and determination coefficient for the interpolating function (1) applied to the pressure and temperature residuals.

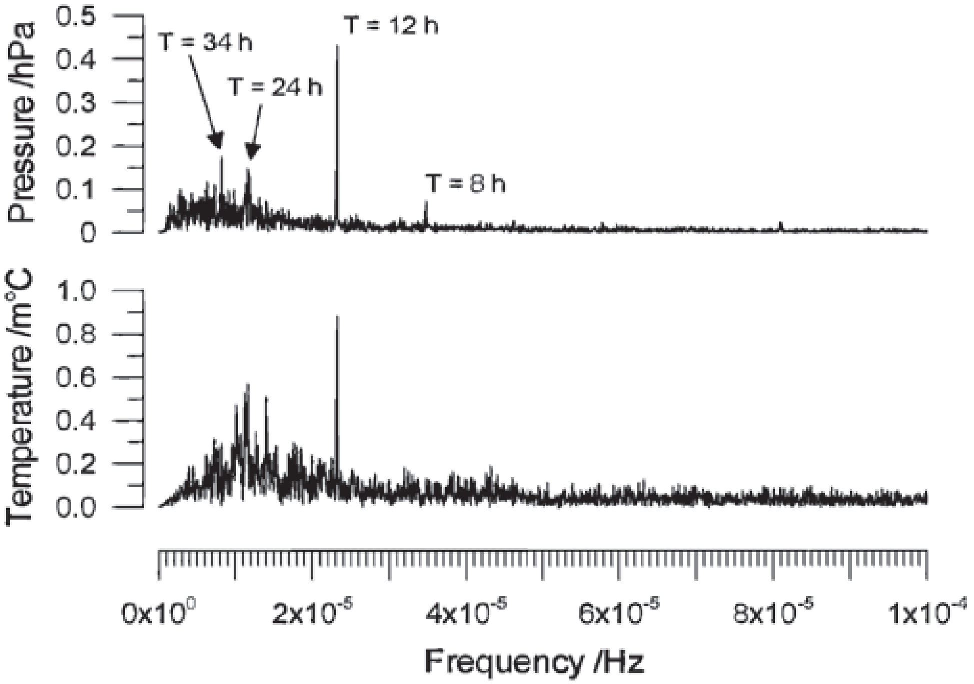

Fig. 4 – Periodograms of atmospheric pressure and air temperature residuals; the periods of the main peaks are reported.

The periodograms of atmospheric pressure and air temperature residuals (fig. 4) confirm the presence of a rather strong semidiurnal constituent and a smaller diurnal constituent in both signals; a terdiurnal constituent is also evident in the pressure signal. Some harmonics of smaller amplitude, present alternatively either in the pressure or in the temperature signal, are of dubious relevance and need more data in order to be validated. However, the amplitude of the 34-h peak observed in the pressure periodogram is clearly greater than that of the diurnal constituent, thus giving stronger grounds to the hypothesis that such peak corresponds to an actual signal and is not merely a spurious result of the data elaboration.

Conclusions

Though the aim of this research is to achieve and study a whole year of atmospheric pressure and air temperature data in a deep Karstic hollow at fine resolution and with a short sampling period, the data acquired in the first half of 2006 provide sufficient evidence to confirm the results recently attained by other authors either in Karstic caves (SONDAG *et al.*, 2003) or in underground laboratories (CHEN *et al.*, 2003; WU *et al.*, 2003), such as the influence of thermal atmospheric tides upon temperature signal and the presence of a phase-lag between temperature and pressure. Moreover, the large amount of precise measurements collected in the "Abisso di Trebiciano" cave permitted to obtain very accurate mean daily cycles of pressure and temperature; for the latter parameter, in particular, the differences between subsequent hourly mean values were often far below the detection threshold of the instrument, and only the availability of a considerable number of measurements, combined with the thermal stability of the cave, allowed to resolve the extremely small variations that occurred in the mean daily cycle of temperature.

However the results presented in this work are still to be considered as preliminary, especially as regards the spectral analysis of the atmospheric pressure, where the presence of the 34-h harmonic constituent needs more data in order to be validated: the periodograms of the 2nd half of 2006 will be likely either to confirm the detection of this constituent or to provide stronger grounds for its rejection.

In summary, the use of programmable data loggers for the collection of accurate and highly resolved measurements of atmospheric pressure and air temperature in deep caves has demonstrated to be a very effective tool for the detection and characterization of the influence of thermal atmospheric tides on the atmosphere of caves. Moreover, the exceptional thermal stability of the cave chosen for this study can possibly provide some evidence of atmospheric oscillations not yet observed in other studies, but more data are needed to support this hypothesis.

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