Monitoring climatic changes and carbon cycle in canyons and caves: the C6 project.

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Abstract: - The acronym C6 means "Climatic Changes and Carbon Cycle in Canyons and Caves". It is a monitoring project, for the evaluation of climate change signals, based on measuring sites located inside canyons and caves; it merged in the year 2005, under the scientific supervision of the Palermo Branch of the Italian National Institute for Geophysics and Volcanology (I.N.G.V.), two different monitoring programs active since 1999.
The choice of these environments is based on their morphological structure: being them more or less segregated respect the outer atmosphere, they act as low-pass filters respect the variations of the monitored parameters, which are rainfall and dropping water amounts and rates, air temperatures and relative humidity and carbon dioxide concentrations in the atmosphere.
On the basis of the preliminary data, reported and discussed in the paper, the C6 network seems to be capable to give useful information on the local effects of global changes, even if at the moment the monitored parameters concern only the abiotic components of the studied ecosystems.

Key-Words: - Air temperature**,** Canyon, Carbon Dioxide, Cave, Climatic Change, Infiltration, Rainfall

1 Introduction

The acronym C6 means "Climatic Changes and Carbon Cycle in Canyons and Caves". It is a monitoring project for the evaluation of climate change signals, based on measuring sites located inside canyons and caves. The choice of these environments is based on their morphological structure: being more or less segregated respect the outer atmosphere, they act as low-pass filters respect the variations of the monitored parameters, suppressing or strongly lowering the high frequency noise, like the circadian thermal cycles.
The C6 project merged in the year 2005, under the scientific supervision of the Palermo Branch of the Italian National Institute for Geophysics and Volcanology (I.N.G.V.), two different monitoring programs, active since 1999,
The former, devoted to environmental monitoring of canyons, was promoted by the Scientific Commission of the Italian Canyoning Association (A.I.C.) and the no-profit association Al Qantara (Palermo, Italy); it was based on three continuous monitoring sites in Wadi al Ghurab (Southern Jordan, since 1999), in the Rio Grande Canyon (Northern Appennines, Italy, since 2001) and in the Rio Grande Canyon (Vulcano Island, Southern Italy, since 2003). In the year 2005 the Royal Society for the Conservation of Nature of Jordan joined the C6 program, and a new site, substituting the Whadi Al Ghurab station, was established inside the Shagher Daghleh Canyon (Wadi Dana Reserve).
The latter, active since the year 1999, was focused on environmental monitoring of karst caves; the Italian NGO Legambiente, managing the natural reserves of Santa Ninfa, Carburangeli and Sant'Angelo Muxaro caves, all three located in Sicily (Southern Italy), promoted a monitoring program focused to verify the existence of a possible environmental negative feedback of human fruition. Continuous and discontinuous meteorological parameters and carbon dioxide concentrations, inside and outside the caves, have been collected since that time.
The network was further developed on October 2006, after the Speleological Federation of Bosnia Herzegovina joined the project, with a site inside a cave not far from the city of Sarajevo.
Finally, on December 2007 a new measuring point was established inside the Corleone Creek Canyon (Sicily, Italy).
The map in Fig.1 shows the location of all the sites.

2 Structure and aims of the monitoring network

The C6 network is nowadays articulated into 8 sites, equally distributed among canyons and caves; Table 1 shows

names, localities and monitored parameters for each of them.
Measures may be subdivided into three main groups:
1) Air temperature and relative humidity are continuously acquired by miniature-low power consumption dataloggers, except the sites located inside caves, where humidity is measured during discrete sessions. Continuous stations are not used inside caves due to the condensation of water vapor on the surface of the capacitive sensors used by this kind of loggers.
2) Rainfall and dropping water rates (inside caves only) continuously measured by the same kind of loggers
3) Static concentrations of carbon dioxide, measured by infrared spectrometers coupled with miniature loggers. The sampling frequency is not higher than 1 measure per day, in order to reduce the maintenance of these stations, located in underground environments characterized by a difficult access.
Three different research lines are based on the abovementioned parameters, with the common goal of identifying local evidences of global climatic changes:

2.1 Air temperatures

Caves have to be considered as very complex thermal systems lying at the interface atmosphere-hydrosphere-lithosphere, described under the theoretical point of view by Badino [1] in a very exhaustive way.
In general, underground air temperatures show values more or less equal to the outside yearly averages, modulated by small (few degrees) seasonal oscillations. Particular morphologic conditions may influence the thermal equilibrium of the caves. Inner average temperatures colder then the outer (the so called "cold trap" effect) are recorded in blind caves with a dominant vertical development and/or lying at the bottom of closed surface morphologies, like dolines or blind-valleys.
The analysis of the dynamic relationships between inner and outer air temperatures, as better explained in the examples reported in the next chapter, may allow the recognition of climatic change signals.
Microclimatic data recorded inside canyons are not very common in the literature, especially because of the very difficult access to these environments. Some preliminary data from Jordan have been reported by Bellanca et al. [2], whereas Madonia [3] illustrated two study cases in Italy.
Canyons are less isolated than caves respect the outer atmosphere, so their intra-annual microclimatic variability is higher; for this reason, as explained in the next chapter, possible climatic changes may be reflected by indicators more sensible than rough parameters as the simple yearly averages of air temperatures.

2.2 Rainfall dynamic

One of the most evident signals of the climatic change processes is the increase in rainfall intensity. Being the dimension of rock permeability a velocity (m/s), an increase in rainfall intensity (commonly expressed in mm/hour) causes a faster saturation of the first soil horizons, increasing runoff and depleting infiltration; at least, this process is responsible of an acceleration of soil erosion and a depletion of the recharge of underground aquifers.
A contemporary measurement of rain intensity at the surface and of dropping water rate inside a cave, this last being a direct measurement of infiltration, allows to directly monitor these kind of climatic changes phenomena under a quantitative point of view, giving useful information for the calibration of more complex theoretical models.
Moreover, the isotopic composition measurements of Oxygen and Hydrogen in rains and underground waters are indicative of possible alteration in the hydrological cycle, as reported by Gat and Gonfiantini [4].

2.3 Carbon dioxide cycle

The primary source for carbon dioxide in underground environments, with the only exception of the anthropic contribution, is linked to the interaction processes between infiltrating waters and organic matter contained into the soil. As already evidenced by Madonia and Di Pietro [5], release of carbon dioxide from dropping waters may lead to static concentrations in cave atmosphere up to more then 1%vol.
The monitoring of underground carbon dioxide cycle is then an useful tool in better understanding the soil respiration phenomena, which have been studied until now without taking into account the amount of CO2 produced by the soil and not released in the atmosphere because fixed in underground water circulation

The research lines active nowadays within the C6 project are dedicated to micro-meteorology and geochemistry, with specific reference to the abiotic components of the cave and canyon ecosystems.
These activities have to be considered only as an initial step of a more complex and extended path, providing for the next future an expansion to eco-hydrological themes .
As an example of a possible bridge from micrometeorology to eco-hydrology, let us to consider the effect of a modification of rainfall dynamics on bedrock channels in a riverine ecosystem. An increment in rainfall rates, favoring the surface runoff respect to the infiltration, causes enhanced erosion and transportation of sediments along the river.
The negative eco-hydrological feedback of such phenomenon is the obliteration, caused by deposition of sediments, of the residual water-pools on the rocky river beds. The disappearance of these micro-environments, very common inside canyons, is a strong disturbance for those living communities needing the constant presence of water for their vital cycles. .Then, the coupled monitoring of the rainfall dynamic (abiotic component) and of the water-pool living communities (biotic component) represents a

paradigmatic example of how copying with climatic changes studies under the light of a holistic perspective.
In the next chapter some preliminary results from C6 project will be described, in order to better explain the above mentioned skills.

3 Preliminary results

The below reported graphs illustrate some preliminary data from the C6 network: the relationships between rainfall and infiltration and among the inner and outer air temperatures and the static concentrations of carbon dioxide, measured in the Carburangeli Cave, are illustrated in Figures 2 and 3 respectively. On the contrary, Figure 4 describes the relationships between the inner and outer microclimates in the Rio Grande Canyon (Vulcano Island).
Data reported in Fig.2 account for a dynamic approach in the analysis of the infiltration coefficient, highlighting the different response of the same hydro-geologic circuit to rainfall events occurred with different rates and under different seasonal conditions. The amount of the effective infiltration, that is the amount of rain available for the recharge of the underground aquifers after the evapo-transpiration process, is slightly different in spring rather than in summer.
Rainfall events characterized by low intensities and occurred between March and April 2003 (main graph) generated a fast infiltration (less than 24 hours of delay), testified by a huge increase in the dropping water rate inside the cave, from 5 to 40 mm/hour. On the contrary (inserted graph) a heavy rain in August 2004 was completely transformed into surface run-off: the total absence of infiltration is testified by the invariance of the dropping water curve.
These data, derived from a direct measure and not from a theoretical model, clearly highlight the negative feedback on the underground water resources of the incoming hydrologic scenario, characterized by concentration of the same amount of rain into a smaller number of much more intense events. Under these conditions, the main part of precipitation is transformed into surface run-off, causing a progressive depletion of the underground water resources.
Figure 3 illustrates air temperatures and relative humidity measured between September and November 2005 in the Rio Grande Canyon at Vulcano Island (Italy). The comparison between the inner and the outer stations clearly demonstrate that the daily thermal variability is much more reduced inside the canyon than outside, with a sensible diminution of the maxima and a more reduced lowering of the minima.
Moreover, during the hottest hours of the day, a more humid atmosphere is maintained inside the canyon, due to the reduced solar insolation on its own provoked by the shield effect of the side rock-walls closely facing each other.
Especially in arid regions, stable conditions of air temperature and relative humidity are fundamental for the maintenance of ecological niches inhabited by sensible living specimens, including the human settlements. One of the most famous and splendid example in the world of what just described, not only by the ecological but also by the artistic and architectural point of view, is represented by Petra, the city carved into the rock inside a canyon system in Southern Jordan.
According to these preliminary data, canyons seem to be sites strongly resistant to climatic variations. So, they represent a good location for microclimatic measurements in the frame of long term climatic change monitoring programs: recording sensible variations inside canyons means that climatic changes are so evident to modify one of the much resistant ecological niche in the continental environment.
Finally, the role of karst environments in the governance of the carbon dioxide global cycle is evidenced in the graph reported in Fig.4, illustrating the relationships between outer and inner air temperatures and carbon dioxide static concentrations in the Carburangeli Cave.
Static concentrations of carbon dioxide, up to 1%, are recorded in the cave atmosphere when the inner air temperature is lower than the outer. Under this condition, the outflow of underground air is inhibited because of the density differential respect to the outside atmosphere: the colder and denser air is trapped inside the cave.
The primary source for carbon dioxide is the diffusion from dropping water, which is strongly enriched in CO2 during the percolation trough the soil. Excess CO2 is fixed in speleothemes under vadose conditions, while it interacts with carbonatic aquifers in the phreatic zone. In both cases carbon dioxide is subtracted to the respiration budget of the soil; if this amount is not measured or modeled, the effects of climatic changes on soil respiration can’t be correctly evaluated.

4 Conclusions

At the moment, data acquired in the behalf of the C6 project refer to its initial step, whose aim has been the acknowledgement of its performances as a climatic changes long term monitoring network.
On the basis of the preliminary acquired data, partially reported and discussed in the previous chapter, our opinion is that the C6 network is capable to give useful information on the local effects of global changes, even if only at the level of the abiotic components of the studied ecosystems.
Next steps of the C6 project will copy with the acquisition of data series more consistent under the statistical point of view and, at the same time, the development of researches more properly dealing with ecological skills.
Further information on the future developing of the C6 project may be obtained at the URL www.c-six.org.

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Table 1: Name, description, geographic localization and monitored parameters of the C6 network; the letters between brackets indicate the sampling frequencies (**h**our, **d**ay).

Site name (Id)	Type (start)	Lat, Long, Altitude	OUT Air t	OUT Rh	Rain rate	IN air t	IN Rh	CO_2	Drop. water
Carburangeli (CAR)	Cave (1999)	38°10’00” N 13°09’30” E 22 m	1 h	1 h	1 h	1 h	NO	1 d	1 h
Santa Ninfa (SNI)	Cave (1999)	37°47’00” N 12°54’00” E 400 m	1 h	1 h	1 h	1 h	NO	NO	NO
Rio Grande (RGA)	Canyon (2002)	44°40’00” N 09°24’00” E 600 m	1 h	1 h	NO	1 h	1 h	NO	NO
Rio Grande (RGS)	Canyon (2003)	38°24’00” N 14°28’30” E 100 m	1 h	1 h	1 h	1 h	1 h	NO	NO
Sant’Angelo (SAM)	Cave (2005)	37°28’42” N 13°32’45” E 170 m	1 h	1 h	1 h	1 h	NO	NO	NO
Bijambare (BIJ)	Cave (2006)	44° 5'43" N 18°30'14" E 990 m	1 h	1 h	NO	1 h	NO	NO	NO
Shagher Daghleh (SDA)	Canyon (2005)	30°40'47" N 23°15'09" E 700 m	1 h	1 h	NO	1 h	NO	NO	NO
Corleone Creek (COR)	Canyon (2007)	37°48’33” N 13°18’40” E 630 m	1 h	1 h	1 h	1 h	1 h	NO	NO

Figure 1: Location of C6 measuring sites

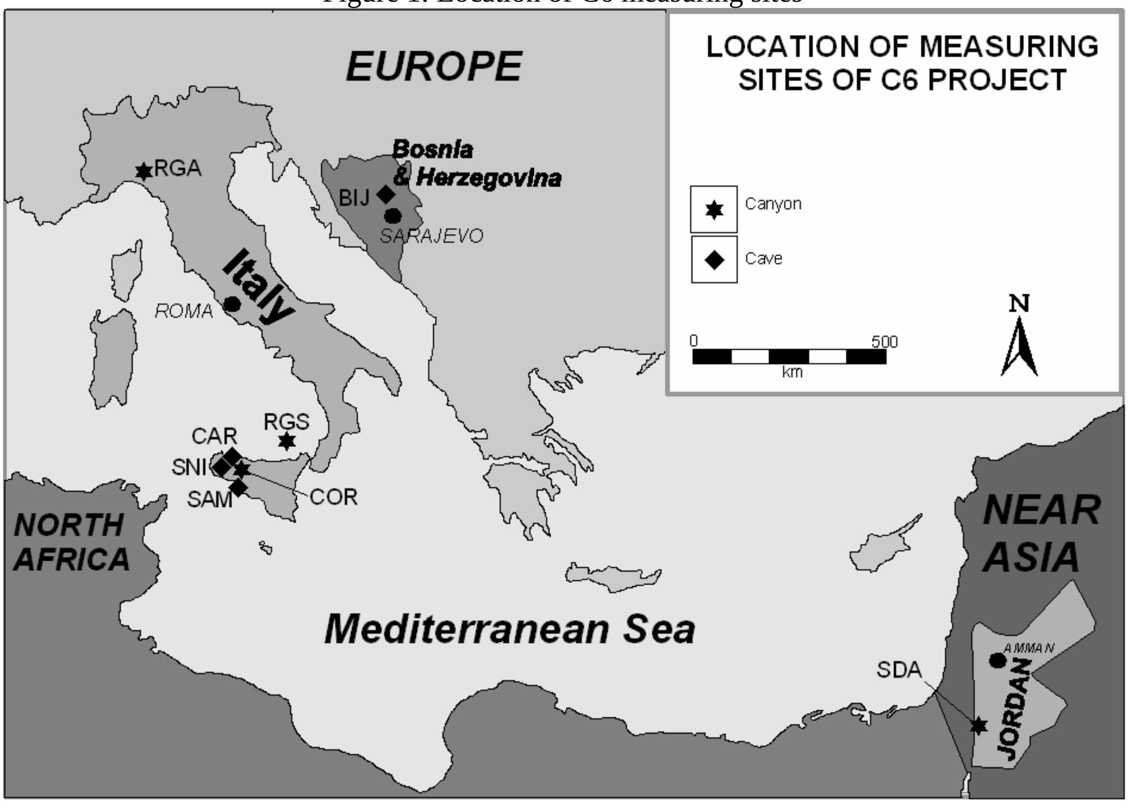

Figure 2: Daily rainfall amounts (grey bars) and dropping water rates (black line with filled circles) measured in the Carburangeli Cave (Italy); for two events the rainfall maximum rate is also reported. The main graph refers to the period comprised between February and April 2003, the insert to the month of July 2004.

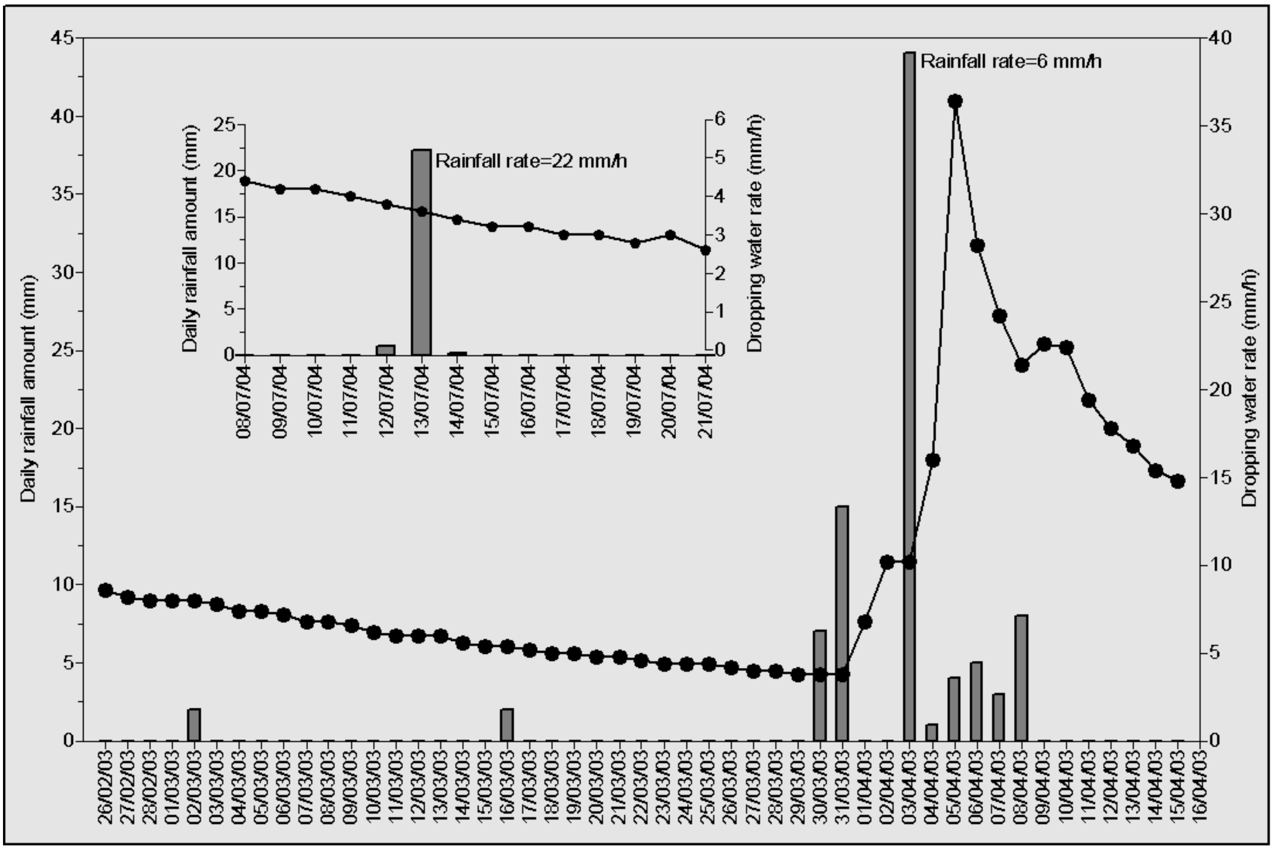

Figure 3: Hourly values of air temperature (lower graph) and relative humidity (upper graph) measured inside (black lines) and outside (grey lines) the Rio Grande Canyon at Vulcano Island (Italy). The graph refers to the period comprised between September and November 2005.

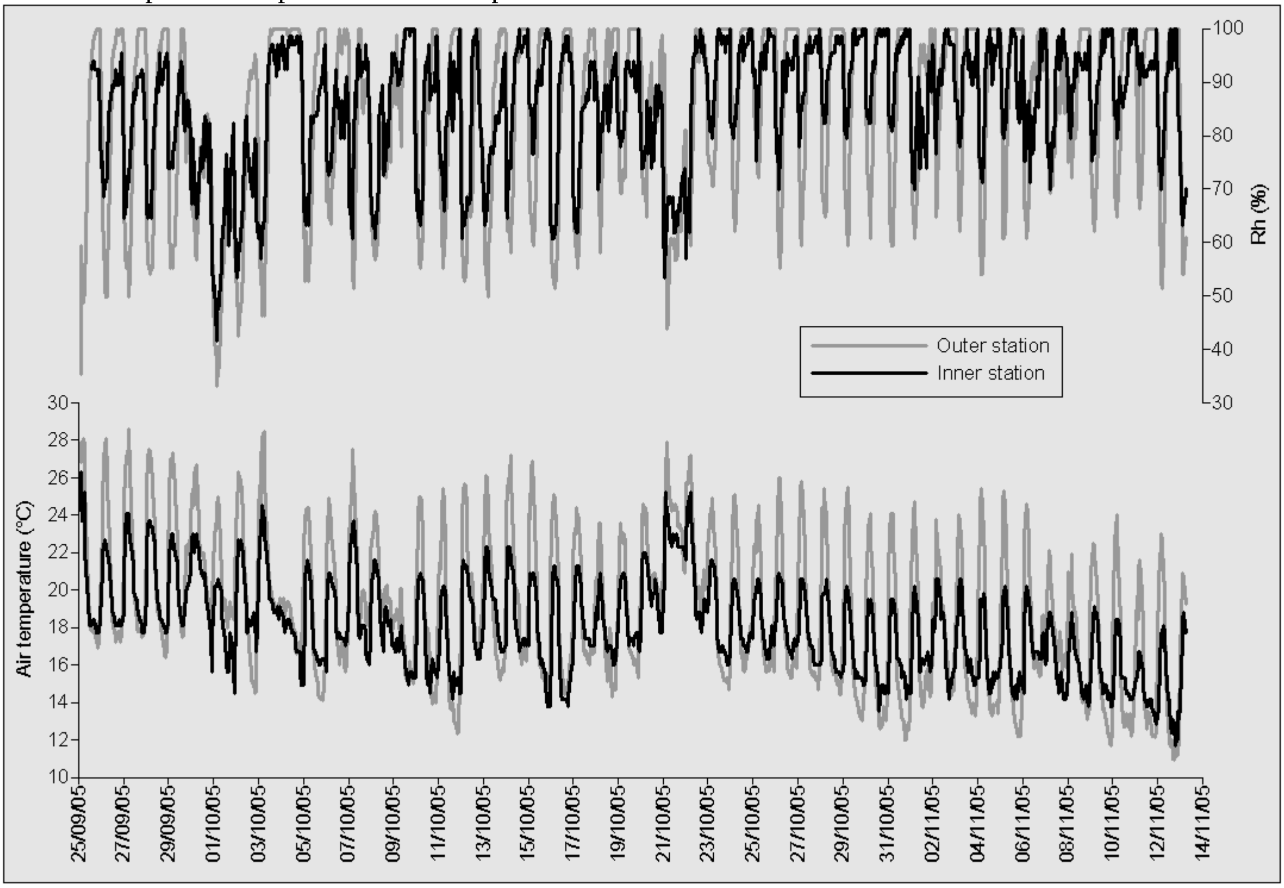

Figure 4: Daily values of outside air temperature (black line with filled diamonds), spot values of underground air temperature (black line with grey triangles) and spot values of carbon dioxide static concentration (black line with grey circles). Graph refers to the period comprised between March and July 2002.