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Global warming evidence in long-term temperature monitoring of heritage karstic caves

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The outstanding preservation of Paleolithic decorated caves is related to the buffering properties of their karstic environment. However, long-term monitoring of air/wall temperatures and gas compositions has recently revealed disruption signs in cave microclimates that had been maintained stable for hundreds of centuries.

High precision and continuous temperature data records are currently monitored in various prehistoric caves in the South of France. Such operations have been promoted since the late 1990s by the French government for risk assessment and conservation.

The most striking feature is the positive drift of underground temperatures (air and wall) which is now obvious in most sites except for Niaux Cave (> 300 m undersurface) and in the deepest parts of Mas-d'Azil and Chauvet Caves (> 50 m undersurface). In tourist caves (Pech-Merle, Mas-d'Azil, Gargas, Villars), the positive thermal trends could not be related to the energy increase brought by visitors which number is now stable, nor to the lighting systems whose energy demand was strongly reduced. In addition, the underground thermal drift nearly starts at the same time in many caves with uncertainties of +/- 1 year: 2012 for Chauvet with +0.4 °C/decade, 2011 for Pech Merle with +0.32 °C/decade, 2011 for Marsoulas Cave with +1.09 to +0.36 °C/decade from the entrance to the deep gallery, 2011 for Gargas with +0.69 °C, +0.54 °C and +0.36 °C for the deeper station. It is worth noting that a 0.3-0.4 °C thermal drift is consistent with that predicted from global warming in these regions. The thermal drifts were already in progress when monitoring began in Villars Cave in 1996 (+0.17 °C to +0.39 °C/decade), in Mas-d'Azil in 2012 and in Bruniquel in 2015. Marsoulas (+1.09 °C/decade) and Mas-d'Azil (more than +1 °C/decade in 6 of the 16 stations) present a much higher drift rate compared with that of surface, which suggests a thermal

amplification process.

As measurements are performed in heterothermal zones, the long-term thermal drifts are modulated by persisting smoothed and out-of-phase yearly variations. A notable exception is the case of Bruniquel main gallery where the temperature records show a quasi-linear increase. In that case, the decadal evolutions of temperature +0.31 °C, +0.175 °C, and +0.24 °C, are not related to the depth of monitoring stations (32 m, 55 m, and 38 m, respectively) nor to their distances from the entrance. In 2018, those drift rates induced a permanent inversion of thermal gradient in the main gallery. In Gargas, the drift rate is more pronounced in the outer parts of the karst body, thus inducing a continuous evolution of the thermal gradients within the galleries.

Such underground microclimate disruption of patrimonial caves is a warning signal of direct threat on the preservation of remains. Karst physical organization and its related underground environment are themselves legacies of past climates; the current functioning of transfer zones of karst aquifers which includes the caves, are directly dependent on the outside climate. A more comprehensive approach and modelling of possible tipping points are urgently needed for conservation issues.