developed springsheds while this study compared spring discharge temperatures and specific conductance values to the receiving stream values.

Knowing the flow in the spring compared to the flow in the stream was helpful but not necessary to ascertain potential habitat locations. Seasonal flooding often removed aquatic vegetation within the habitat areas defined by temperatures, but the vegetation returned shortly after the flooding at rates that depended upon magnitude of the flood scouring and the season.

Whether water is surrounded by vegetation or rock material is important when using the Infrared imagery and can determine optimum time to collect thermal images or take stream measurements. Although the camera data can be used quantitatively it is important to know that recreational use allows human induced changes and the flashy nature of the stream results in natural changes to the spring and stream flow regimes making quantitative comparisons difficult. Cold temperatures such as near freezing affected the distances that were practical because the cold air would absorb the heat energy emanating from the warm groundwater more quickly.

The shallow nature of the spring runs and the creek made a two-dimensional approach to habitat assessment practical and the use of the FLIR infrared camera more appropriate. If deeper waters are encountered the FLIR camera would only sense the surface temperatures and a more detailed profiling at variable depths may prove necessary.

Conclusions

Studying the observed relationships among temperature, specific conductance, and thermal imagery can be helpful in identifying potential habitat for temperature dependent aquatic organisms. Measurements from temperature and specific conductance cross sections provide quantitative data that can help delineate potential habitat for aquatic organisms that prefer constant temperatures. The use of the thermal imagery is also helpful in understanding some of the temperature dependent habitat dynamics and appear useful in communicating information for management decisions or strategies.

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THE RELATIONSHIP BETWEEN CAVE TEMPERATURE AND LOCAL ATMOSPHERIC MEAN TEMPERATURE IN MONSOONAL CHINA

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Abstract

It is widely claimed that temperature inside a deep karst cave without significant human influence is similar to local mean atmospheric temperature. To test this hypothesis, we collected temperature data for caves through China from published documents. The difference between cave temperature and local annual mean temperature (ΔT) were then calculated. Results show that the ΔT is larger than 2° Celsius for nearly half of the caves. Among these caves, ΔT is larger for caves from Northern China than those from southern China. Many of them have flowing water or subterranean streams. This indicates that flowing water may be one of the influencing factors of cave temperature. This observation that cave temperature may excure from local mean atmospheric temperature should be considered in paleoclimate reconstruction using cave deposits such as speleothems.

Introduction

Speleothems have been widely used for paleo-climate and paleo-environment reconstruction due to their precise ages determined by U-Th dating and broad distribution. In Eastern Asian Summer Monsoon (EASM) dominant area, long term variability of EASM on orbital scale has been well indicated by oxygen isotope records of cave stalagmites (Wang et al., 2008; Cheng et al., 2016). These stalagmites with long and continuous chronology are potential materials for absolute temperature reconstruction to determine the amplitude of temperature changes on glacial-interglacial cycles. Efforts to reconstruct temperatures using stalagmites have long been attempted and were determined by newly developed approaches, e.g. $\Delta 47$ (Ghosh et al., 2006) and hydrogen isotope signals in inclusion water of speleothems (Uemura et al., 2016). In general, speleothem-based tem-

perature reconstruction assumes that cave temperature is stable throughout the year and is similar to the mean annual temperature of outside atmosphere. However, our monitoring data of a cave located in northeastern China showed that cave air temperature could be significantly higher than mean annual temperature of outside atmosphere (Wang et al., 2016). This offset is not a special case. It has been reported in studies of some caves in Northern China (Cai et al., 2009 & 2011). The objective of this research is to investigate the extent and magnitude of this offset in Monsoonal China.

In this study, we collected published temperature data of cave air through the monsoonal China. The difference (ΔT) between cave temperature and local mean annual temperature is then calculated. The spatial distribution of those caves with significant ΔT is analyzed.

Data Source and Analysis

All data used in this study are extracted from published journal papers, of which most were written in Chinese with English abstracts. A total of 97 effective datasets (caves) are finally selected for further analysis (Figure 1).

Each dataset represents one cave with parameters including cave air temperature, mean annual atmospheric temperature, cave location, length, as well as elevation, orientation and number of entrances. Whether it has flowing water is also noted. Due to space limitation, the original references of these data are not included in this paper.

The criteria to choose cases of cave air temperature are (1) The temperature at the site without significant sea-

Figure 1. Schematic map showing locations of caves involved in this study.

sonal variability is adopted in case several sites had been surveyed in one cave; (2) The mean value is adopted from long term (seasonal or yearly) monitoring data. For the mean annual atmospheric temperature, we use the long term mean temperature calculated with instrumental data from the closest meteorological station.

Results and Classification

Cave air temperature varies from 1°C to 37°C with a mean value of 15.6°C, and outside atmospheric mean temperature varies from 7.8°C to 23.5°C. Values of ΔT vary between -10.2°C and 18.31°C .

The relationship of cave air temperature and outside atmospheric mean temperature is shown in Figure 2. In general, cave air temperature is positively correlated to atmospheric mean temperature, except for three special caves (Figure 2). In two of these caves, there are hot springs in the cave (Deng et al., 2013), causing much higher ΔT values. Therefore, we exclude them from further analysis and discussion. For the other cave from northern China, it exhibited more negative ΔT value (10.2°C). This cave connects to a narrow doline and is located at much higher elevation than nearby meteorological station (Meng et al., 2006).

Considering the errors arising from measurements of cave air temperature and from different distances of meteorological station to each cave, we define absolute value of 2°C as the confidence interval of ΔT . Absolute values of ΔT larger than 2°C indicate significant differences, while absolute values of ΔT less than 2°C mean insignificant difference or similar temperatures between cave air and outside atmosphere. With this criterion, all caves, except for two special caves with hot spring water pool inside, are classified into three groups, positive off-

set, negative offset and similar temperatures to the outside atmosphere (Figure 3).

The group with positive offset includes 39 caves, while negative offset exists in only 6 caves. There are 50 caves showing no significant difference between cave air tem-

Figure 2. Scatter plot of cave air Temperature against local atmospheric mean temperature by difference Temperature (ΔT).

Figure 3. Scatter plot of temperature difference (ΔT) vs. latitude classified by ΔT (excepting for two special caves with hot springs).

perature and local atmospheric mean temperature (Figure 4). Totally there are 47% of caves have significant ΔT , within these, there are many more caves exhibit positive offset of ΔT than those with negative offset.

Spatial Distribution of ΔT

The ΔT in monsoonal China exhibits clear spatial distribution. Nearly all caves from Northern China show positive offset of cave air temperature versus local long term mean annual atmospheric temperature (Figures 3 and 5). The only exception is the cave from Shanxi Province (Figures 3–5). Its abnormal negative value of ΔT is more likely due to bias arising from high elevation of the cave site which is far away from meteorological station. The zonal boundary of this kind of cave with positive offset is around 34° in latitude (Figure 3), coinciding with the QinLing Mountain range, the geographical boundary between northern and southern China.

In contrast, there is no distinct tendency of ΔT in southern China (Figures 3 and 5). Both positive offset and similar ΔT can be found in caves from southern China. A few of them show negative offset.

Potential Influencing Factors

There are a number of factors which influence cave climate, e.g. cave location (elevation, latitude and longi-

Figure 4. Pie chart of three groups of caves. The figures of 50, 39, and 6 correspond to the number of caves for cave air temperatures with similar, positive offset and negative offset to local mean atmospheric temperature.

Figure 5. Schematic map showing locations of caves whose cave temperatures are similar to (blue circle), greater than (red triangle), and lower than (yellow star) local mean annual atmospheric temperatures.

tude), orientation, number and size of cave entrances, geothermal gradients. Some of these factors differ from one cave to the other. Because of the limitation of original information, it's difficult to estimate influencing factors in this study. Furthermore, the special factor that influences ΔT is not the main purpose of this study. It is critical to identify the discrepancy between cave temperature and local mean annual atmospheric temperature. Indeed, it is quite interesting that cave air temperature in caves from northern China is clearly offset from local mean atmospheric temperature. This pattern may indicate a universal phenomenon because there is no significant correlation between ΔT and elevation (Figure 6). Considering that the climate in monsoonal northern China has more seasonal variation with cold-dry winter and wet-warm summer, this positive offset of cave air temperature may correlate to seasonal climate pattern related to EASM.

It is noticeable that nearly half of caves from northern China have flowing water. We suggest investigate the influence of subterranean streams on cave energy balance. It should be noted that data involved in this study are limited both in sample size and in influencing factors for statistical analysis. Further study should increase sample size and improve the method to identify this spatial distribution. A case study may also be necessary to explore its broader impacts.

Conclusions

There are 47% of caves from monsoonal China exhibit significant difference between cave air temperature and local long term mean atmospheric temperature. Most of them have positive offset (41%), while few show negative offset.

Figure 6. Temperature difference (ΔT) plotted against elevation above sea level at cave entrance (excluding two special caves with hot springs inside).

Positive offset is found for nearly all caves from northern China. This spatial pattern indicates that the behavior of cave air temperature for caves from northern China could be a universal phenomenon. It may correlate to more distinct seasonal climate than those of monsoonal southern China. This fact should be considered when using speleothems for paleoclimate reconstruction, especially for paleo-temperature estimation. More data and intensive monitoring, as well as case studies are necessary for further investigations.

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