Experimental Research using Thermography To Locate Heat Signatures from Caves

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ABSTRACT

We have long known that there are thermal differences between cave entrances and the surrounding landscape. Speleologists traditionally ridge walked in cave-likely temperate regions in cold mid-winter with a falling barometer in order to visually detect 'fog-plumes' of escaping subterranean air from crevices and unknown earth openings in order to locate caves. We are experimenting with a high-technology solution to this cave detection method applying infrared thermography, a useful tool in fire detection, human body location and other building examination remote sensing to the surface of the earth. Early trials during 2005 with a ThermaCAM TM B20 HSV infrared camera, even under foliage-filled and warm atmospheric conditions, resulted in promising results in initial trials in New Mexico, West Virginia and Greece. Further research is underway at Fisher Cave, Franklin County, Missouri and in the Atacama Desert-- San Pedro de Atacama, Chile. The research in the Atacama is undertaken as a member of the NASA Atacama Desert Chile Science Team 2006. The aim of this research is to develop protocol for the use of infrared thermography to locate caves on Mars. As life might exist in caves on Mars, sheltered from radiation, this is an area of great interest to NASA astrobiologists and other scientists.

This research began by documenting temperatures of cave openings and surrounding substrates. Atmospheric, ambient conditions (temperature, relative humidity, specific humidity and dew point) were recorded inside Fisher Cave, at the entrance and at intervals up to 183 meters. Normal images were contrasted with thermograms showing full temperature gradients of the openings. At 118 meters, the opening could no longer be seen with the naked eye. The thermograms showed distinct images of cave openings. Trials continued to 388 meters. In excess of 300 meters, thermograms showed the distinct cave opening of Fisher Cave. At 388 meters, the thermograms showed signatures that could be that of a cave entrance. The initial results indicate that individual cave entrances have separate and unique temperature gradients. Thus, individual cave thermograms are a "fingerprint" or signature of that cave. Thermograms can be used to isolate and identify caves entrances from surrounding terrain features. Once standardized procedures have been established, thermograms may become an important tool for cave location and exploration terrestrially and via remote sensing on other planets.

INTRODUCTION

Thermographic technology has advanced considerably in the last few years. Current uses include building-energy audits, building diagnosis, medical applications, fire detection, military night vision, computer heat scans, industry, surveillance and other utilitarian uses where heat production and dissipation are a factor. It is hypothesized that this technology can be used under the correct conditions to locate potential caves. By taking thermograms of land masses such as hillsides and valleys, heat signature changes in the images which would reveal cave openings, swallets, seeps and other karst features.

SPELEOLOGY AND THERMOGRAPHY

The natural meteorological conditions of temperate latitude caves make infrared thermographic investigation possible. Differences in temperature and humidity make cave entrances discrete from the surface, and visible to thermography. As the inside of the cave maintains a constant temperature and the outside ambient temperature fluctuates with the seasons the cave entrance temperatures are normally different then outside conditions. It is this premise that directs this research. Moore and Sullivan put this most succinctly:

> "The air in most caves is nearly saturated with water vapor – in other words, the relative humidity is close to 100 percent. This is so because seeping water moistens the ceilings, wall, and floor and that the air must pass by as it moves slowly through the cave. The constant temperature of the inner part of the cave permits this high humidity to be maintained indefinitely.
>
> Near the entrances to caves however, the humidity may be lower, partly because the outside humidity is usually lower, and partly because the cave temperature differs from the outside temperature.
>
> In the summer, warm air entering a cool cave soon becomes saturated without absorbing water from the cave walls. In the winter the air becomes warmer as it enters the cave, and for a short distance its relative humidity falls."[1]

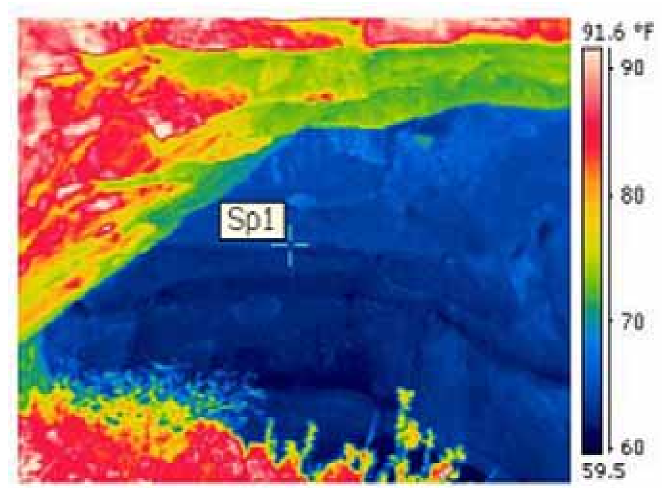
Research assumptions:

1. Cave entrance substrate temperatures are normally different from other outside substrate temperatures. The air blowing from a cave or into a cave is at a different temperature and humidity level than the outside ambient temperature and humidity.
2. Cave humidity alters moisture on cave entrance substrates compared to other surface substrates.
3. An infrared camera measures and images the emitted infrared radiation from an object. Since radiation is a function of object surface temperature it is possible for the camera to calculate and display this temperature.
4. Cave entrances can have their surface temperatures displayed by thermo imaging infrared camera.

THREE TRIAL LOCATIONS

Carlsbad Caverns National Park, Carlsbad, NM, was the first trial location, just to see if thermography would work in a natural situation, where the temperature range from cave to outside is quite pronounced. This initial trial was rather crude, but the photo/thermogram pair below shows that that our hypothesis wherein we detected a cold source within a warm environment was successful. This first trial was experimental, and not all environmental data were retained. However, it was a successful test.

Carlsbad Caverns, New Mexico
+/-75 ft +/-22.9 m



Carlsbad Caverns, New Mexico
+/-75 ft +/-22.9 m

Figure 1. Sample photo/thermogram pair at Carlsbad Caverns (2005) showing cave detection abilities of the technique.

TRIAL NUMBER TWO – FISHER CAVE MISSOURI

Fisher Cave is a lantern-toured show cave located in Meramec State Park, Franklin County, Missouri, USA.. The cave entrance is approximately 3 m high by 11 m wide, gated, and easily accessible. This wide mouthed cave entrance allows ample atmospheric exchange. The cave entrance is at a slightly oblique angle to its containing bluff, making it 'vanish' visually within a short distance, despite proximity to a parking lot. These factors selected it as our experimental site. This location does not have the wide variance of temperatures as at Carlsbad; in fact, on some days, less than 1 degree F separates the inside and outside of the cave. It is also close to the senior author's home, making it ideal for repeat visits.

The camera used for this research is the ThermaCAM™ B20 HSV, which is one of the most sophisticated of the infrared-thermographic image cameras made by the FLIR Company. A steady tripod was necessary to get accurate signatures.

We also used:

- Nikon D1X Camera and lenses.
- Delmhorst HT 3000 A Thermo Hygrometer & Dickson TH 550 Thermo Hygrometer to measure temperature, humidity and dew point at cave entrances and distances from the entrance.
- Data Log Recorders (HOBO brand: timed temp, dew point, relative and specific humidity at prescribed intervals and distances from the entrance.)
- Fluke 52 II Thermocouple Thermometer to measure temperature readings of the substrates at cave entrances and stream water temperatures.

METHODS

Radiation measured by the IR camera not only depends on the temperature of the object but is also a function of emissivity. Radiation also originates from the surroundings and is reflected by the object. Radiation from the object and the reflected radiation will also be altered by atmospheric adsorption. C. Warren Campbell was consulted on the methods used. [2]

To measure temperature accurately, one must compensate for the effects of different radiation sources. This is done electronically and automatically by camera. The following parameters must be supplied for the camera:

- The emissivity of the object
- The reflected temperature
- The distance between the object and the camera
- The relative humidity

These parameters were established for the IR camera with the use of handheld thermo hygrometers at the cave entrances. Data loggers were then set up to ensure accurate monitoring during the thermography, and to provide data for the FLIR camera manufacturer, which is in process of establishing standard emissivity tables for limestone based on this research.

RESULTS

Measurements of temperature, relative humidity and dew point at different distances were taken from known cave entrances and locations. The data were used to calibrate the B20 HSV. A tripod was required for steady images as the B20 HSV does not have a fast "shutter speed."

FISHER CAVE TRIALS

On May 11, 2005 with a cloudy sky and recent light rain, Fisher Cave had a entrance temperature of 16.4 C (61.6 F) with Relative Humidity (RH) of 66.8%, Dew Point (DP) 10 C (50.2 F) with a substrate at entrance temperature of 19.2 C (66.5F). Ambient conditions at 15.2 m (50 ft.) from the entrance were 15. 6C (60.1 F), RH of 62.4% DP C (46.2 F). At 182.9 meters from the entrance (600 ft.): Temperature 26.4 C (79.5 F) RH 20 DP (68 F)

At 118 meters, the opening could no longer be seen with the naked eye. The thermograms showed distinct images of cave openings. Trials continued to 388 meters. In excess of 300 meters, thermograms showed the distinct cave opening of Fisher Cave. At 388 meters, the thermograms showed signatures that could be that of a cave entrance. The following image pairs show thermograms and digital photos taken of the cave from different distances.

Figure 2. Fisher Cave Meramec S.P., Missouri
600 ft 182.9 m

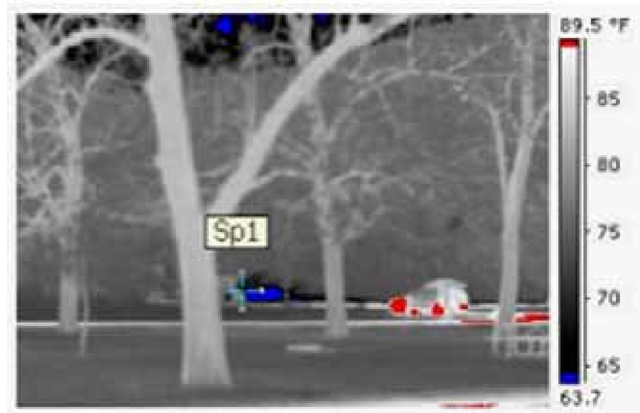


Figure 2a. Fisher Cave Meramec S.P., Missouri
600 ft 182.9 m

Figure 3. Fisher Cave Meramec S.P., Missouri
1,000 ft 304.8 m

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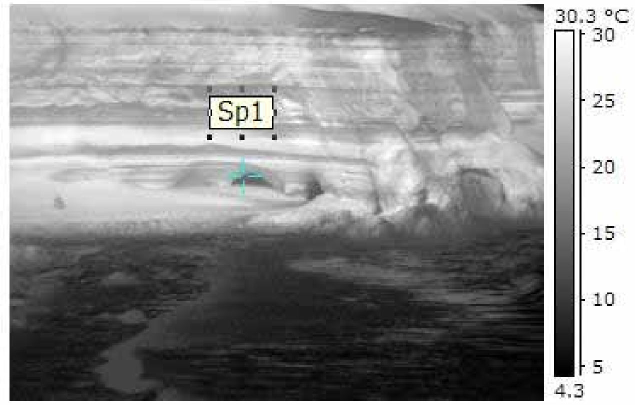
TRIAL LOCATION THREE – ATACAMA DESERT

There was a different objective in the work in the Atacama Desert in Chile. The senior author was asked to join a NASA expedition to the driest desert on earth. Scientists on this expedition were looking at possible astrobiological analogues in this location. Long distance thermography was attempted such as that which would be used via a Mars flyover vehicle, or a rover type thermography equipped device to detect caves on Mars. The trial was successful, as the images below indicate. One does not need to be close to caves or karst features to see them via thermography. Ambient temperature at this location was 15.6° C with a relative humidity of 77%, but this trial was near the sea, not on the high desert itself, where it often does not rain for years. This research is ongoing.

Antofagasta Arch Sea Caves, Chile



Cave on left at Sp 1 is 35 meters deep. Cave on right is a tunnel to the sea

Figure 4.Detecting caves in the Atacama Desert from approximately 1000 meters away. Caves stand out utilizing thermography, rock shelters tend to disappear.

Thus, individual cave thermograms are a "fingerprint" or signature of that cave. Thermograms can be used to isolate and identify caves entrances from surrounding terrain. We found that taking the thermograms was easier if the remote control was removed from the camera and used to adjust the setting and take the shots, as it helped reduced camera shake.

In future trials the following conditions must be taken into consideration and compensated for: a) Shooting thermograms through tree foliage will pick up reflective signatures off the leaves b) Shadows on hills do not show the same temp gradient as actual cave openings c) Images without a tripod are susceptible to camera shake which can alter the image result.

ANALYSIS OF THE RESULTS

It is believed that thermography shows great promise as a cave entrance location method. Thermograms will expedite fieldwork in locating cave sites, especially in temperate climates, where the mean annual temperature (and therefore the temperature of the cave air) is stable but local surface atmospheric conditions reflect wide seasonal variation. The ability of a thermogram to penetrate vegetative cover (once we learn to norm for reflective signatures) may turn ridge walking into a year round activity, not one confined to late fall through early spring. Thermographic imaging may be useful in recording cave entrance meteorological data as it relates to monitoring trogloxene and troglophile species.

CONCLUSION

Thermography can remotely sense potentially karst topography by imaging hillsides and aerial perspectives. Remote sensing using thermography may be a viable option for locating caves on Mars long before a manned mission is possible. This paper documents fundamental field research being done to demonstrate that this technology is a viable tool to assist scientists in finding caves and other karst features. As this technology and its field use improves, so will its efficiency. As an ongoing project baseline standards for professional use are being established.

SUMMARY

Thermography can remotely sense potentially karst topography by imaging hillsides and aerial perspectives. This paper documents fundamental field research being done to demonstrate that this technology is a viable tool to assist scientists in finding caves and other karst features. As this technology and its field use improves, so will its efficiency. As an ongoing project our fieldwork is establishing baseline standards for professional use.

REFERENCES

l, C. Warren. “Application of Thermography to Karst Hydrology.” Journal of Cave and Karst Studies. Vol. 58 No. 3, pp. 163-167.

2) Sullivan, G. N. and G.W. Moore. Speleology: The Study of Caves. Cave Books, St. Louis, MO 1978.

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