THERMAL BEHAVIOR OF EARTH CAVES: A PROXY FOR GAINING INFERENCE INTO MARTIAN CAVE DETECTION. J.J. Wynne[1,2], T.N. Titus[1], M.G. Chapman[1], G. Chong[3], C.A. Drost[1], J.S. Kargel[4], and R.S. Toomey III[5] ([1]US Geological Survey, 2255 N. Gemini Drive, Flagstaff, AZ 86001, jut.wynne@nau.edu; [2]Merriam-Powell Center for Environmental Research, NAU, Flagstaff, AZ 86011; [3]Dept. of Geologic Sciences, Catholic University of the North, Antofagasta, Chile; [4]Dept. of Hydrology, U. of A., Tucson, AZ 85721; [5]Mammoth Cave International Center for Science and Learning, Bowling Green, KY 42101).

Introduction: The purpose of this study is to increase our understanding of terrestrial cave thermal behavior and to identify optimal times for detecting these features using thermal remote sensing. Techniques developed through this research will ultimately be applied to locating subterranean cavities on the Martian surface. We anticipate one of the best techniques for systematically finding caves on Mars will be via remotely sensed thermal imagery.

Basis for Detection on Earth. Cave wall temperatures represent the mean annual ambient temperature [1,2] while ground surface temperature, influenced by direct solar insolation and to a lesser extent by ambient air temperature, fluctuates diurnally and seasonally. As a result, optimal detectability in the thermal infrared will occur when differences between thermal radiance of the cave entrance (i.e., cave walls) and surface are greatest.

Importance of Finding Martian Caves. (A) Martian caves are important features for the exploration of life [3,4,5,6] because they offer protection from low surface temperatures, unfiltered ultraviolet radiation [3,4] and violent windstorms, which may degrade and decompose organic materials. (B) A manned mission to Mars currently lacks the fuel capacity for the return trip back to Earth. Thus, location of significant H_2O deposits for conversion to liquid hydrogen fuel will be required. If these deposits exist, caves may provide the best access to these resources [7]. (C) Future human exploration and possible establishment of a permanent settlement on Mars will require construction of habitation pods that offer protection from harsh surface conditions. Natural subterranean features with a protective rock ceiling provide an ideal environment where these shelters may be built [8].

Results: We used remote data loggers to collect hourly temperature measurements at the entrance, dark zone and surface of two caves in the Atacama Desert, Chile, and 10 caves in the southwestern United States. We conducted best-fit regression analysis using a series of sines and cosines. Models were fit with temperature series as a function of local time of day. For Atacama Desert study sites, we found a time series with periodicities of 24, 12 and 8 hrs to be sufficient for modeling average daily trends (Fig. 1).

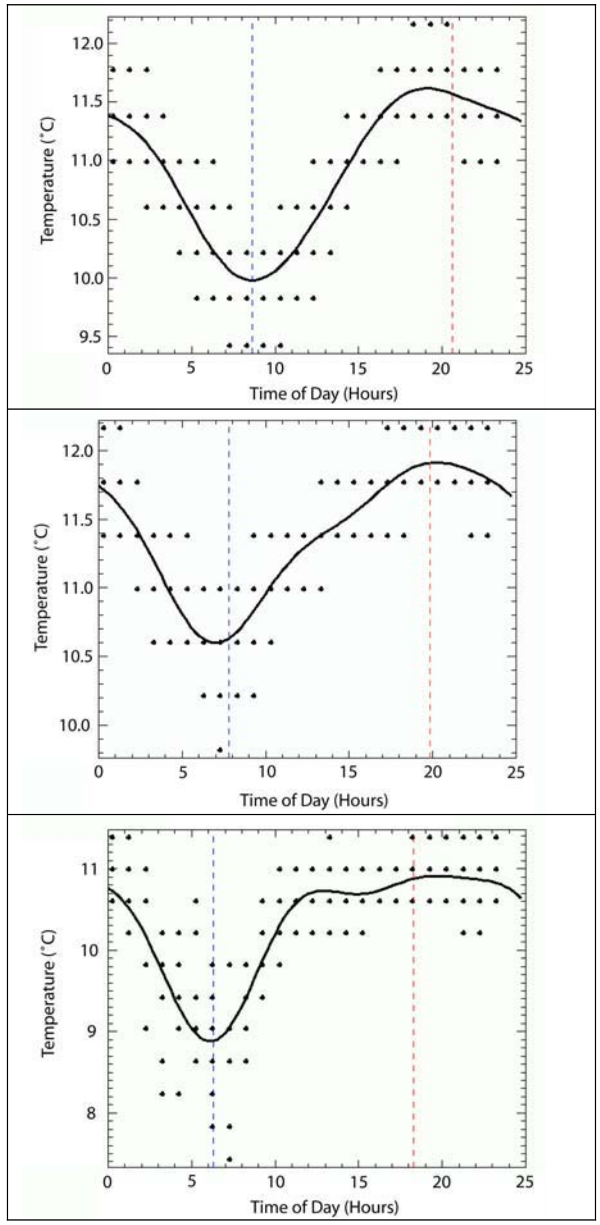

Fig. 1. Plot of temperature vs. time of day with best fit regressions for periods of 24, 12 and 8 hrs with models of Quitor with lateral entrance (top), Quitor with sinkhole entrance (middle) and Cueva Mina Chulacao (bottom) presented. Cave dark zone (blue), entrance (red), and surface (black) temperatures are modeled on each graph. Data were collected during the southern hemispheric winter (19-30 June 2006).

Cavernas de Quitor is a small tunnel-like system (passage length: ~87 m) with two entrances, and several skylights at the cavern's midpoint. Minimum nighttime temperatures show an approximate 90-minute phase shift between the two entrances and the surface. The sinkhole entrance demonstrates the longest phase shift.

Cueva Mina Chulacao is a large complex system (passage length: ~1,025 m) with minimum entrance temperature tracking closely to minimum nighttime surface temperature. This suggests the entrance is cold trapping ambient air at night. Air retained at the entrance remains cool throughout the day.

Results from models developed to identify optimal times of detection suggest both caverns will be most detectable at mid-day. Greatest thermal contrasts occur at ~1200 hr for Quitor (Fig. 2) and ~1400 hr for Chulacao (Fig. 3). Temperature differentials between entrance and surface are ~20° C and ~10° C for Quitor and Chulacao, respectively.

We will also present summaries of the thermal behavior models of 10 southwestern U.S. caves.

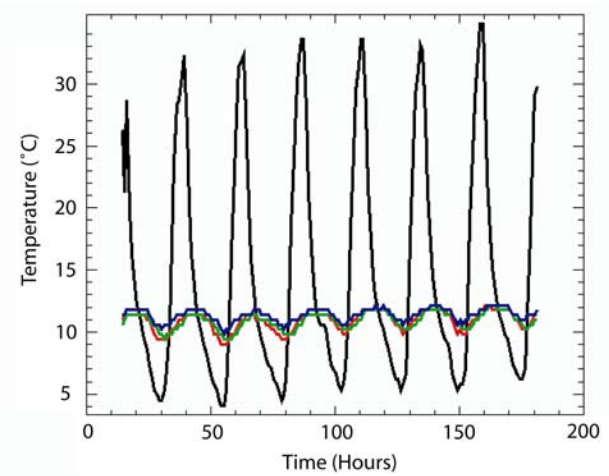

Fig. 2. Thermal behavior data of Cavernas de Quitor - lateral (red) and sinkhole (green) entrances, midpoint (blue), and surface (black) temperatures are shown.

Discussion: We have identified times of day when some of our study sites will be optimally detectable in the thermal infrared. While we have shown detection times for these caverns, we have only a nascent understanding of thermal behavior as it relates to cave detection. Signal strength of the entrance, and thus detectability, will be driven by several structural parameters including obstructions at entrance, configuration of passage (sinkhole, lateral entrance, and articulation of entrance into cliff face, steep-sided canyons, hill sides, etc), volume, slope and aspect, elevation, and potentially latitude.

These results reflect some of the efforts from Phase 1 of the Earth-Mars cave detection program. Phase 2 will involve data collection and analysis of a larger sample size of terrestrial caves at four Mars-analog sites. Consequently, this approach will give us stronger inference into terrestrial cave thermal behavior and detection in the thermal infrared. Terrestrial data will be used to build models of cave thermal behavior under Martian surface and atmospheric conditions. Ultimately, these models will provide some of the information necessary to identify mission and instrumentation requirements for detecting caves on the Red Planet using thermal imaging.

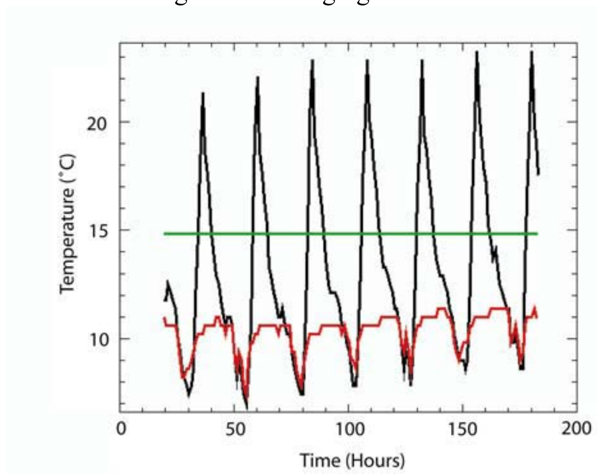

Fig. 3. Winter thermal behavior data from late-June 2006 for Cueva Mina Chulacao are presented with entrance (red), dark zone (green) and surface (black) temperatures.

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