



Cumberland Piedmont Network's Cave Meteorology Report for Mammoth Cave National Park

Annual Report 2009 – 2010

Natural Resource Data Series NPS/CUPN/NRDS—2011/218



ON THE COVER

The instrument lift system that was designed by Western Kentucky University's Engineering Department as it was installed in a passage adjacent to the elevator in Mammoth Cave at Mammoth Cave NP.

Photograph by: Kurt Helf (NPS)

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Johnathan Jernigan and Bobby C. Carson

National Park Service

P.O. Box 7

Mammoth Cave, KY 42259

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Natural Resource Stewardship and Science

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The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado publishes a range of reports that address natural resource topics of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Data Series is intended for timely release of basic data sets and data summaries. Care has been taken to assure accuracy of raw data values, but a thorough analysis and interpretation of the data has not been completed. Consequently, the initial analyses of data in this report are provisional and subject to change.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner. Data in this report were collected and analyzed using methods based on established, peer-reviewed protocols and were analyzed and interpreted within the guidelines of the protocols.

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Abstract

This is the Cumberland Piedmont Network's (CUPN's) second report on cave meteorology. The time period covered by this report is calendar year 2009-2010 (CY2009-CY2010). Mammoth Cave National Park (MACA) was the only park at which data were collected by the CUPN during that time. Data analyses are presented for the network of air temperature and relative humidity sensors that was located in the Historic Section of Mammoth Cave as well as the datalogger near the Frozen Niagara Entrance to Mammoth Cave. Further, a similar network was placed in some of MACA's approximately 400 lesser caves (smaller caves that are not part of the larger cave systems within Mammoth Cave National Park). The data from seven such caves are presented in this report along with data from a tree and two man-made structures. Lastly, we discuss our experimental use of the CUPN's instrument lift system in Mammoth Cave.

Acknowledgments

The investigators would like to thank Lillian Scoggins (CUPN) and Nathan Talley (Mammoth Cave Resource Conservation and Development Council) for their help with the installation of the instrument lift system in 2008. When the instrument lift system was uninstalled in February 2010, Rick Olson (Mammoth Cave NP) and Rick Toomey (Western Kentucky University) assisted. Thanks to Rick and Rick for their help in removing the system from the cave.

Thanks also to Steve Thomas (CUPN) for installing and servicing the network of HOBO dataloggers in MACA's lesser caves and artificial bat roosts. Thanks to Kurt Helf (CUPN) for helping with photographs of monitoring sites in the Historic Mammoth Cave/Frozen Niagara area. And lastly, thanks to Lillian Scoggins (CUPN) for her help with one of the maps found in this report.

Introduction

This is the second report on cave meteorology generated by the Cumberland Piedmont Network (CUPN). This report includes those data collected in calendar years (CY) 2009 – 2010, displays these results in graphic form and concludes with a summary of the key results and recommendations. The CUPN's cave meteorology efforts in CY2009 – 2010 were focused on Mammoth Cave National Park (MACA). The parameters monitored were limited to air temperature and relative humidity; no airflow data were collected even though a CUPN protocol for airflow data collection is available. Further, while CUPN's cave meteorology protocol (Woodman et al 2007) contains instructions for assessing spatial heterogeneity at each site through collection of data in a grid at that site, no such grid-based spatial sampling was conducted at any of the sites during the time period covered in this report.

Generally, air temperature and relative humidity data were collected as described in CUPN's cave meteorology protocol (Woodman et al 2007) under the section titled "Air temperature and relative humidity temporal sampling by a HOBO." That section recommends using the HOBO Pro RH/Temp system. The HOBO Pro RH/Temp system by Onset Computer Corporation consists of a datalogger with integrated air temperature and relative humidity sensors. The complete system is commonly referred to as the datalogger and is shown in Figure 1. This "datalogger" was used to collect data "continuously" every fifteen minutes at nine sites in the Mammoth Cave system. The datalogger was chosen for its relative low cost and ease of use.



Figure 1 – Onset Computer Corporation's HOBO Pro RH/Temp Datalogger. Image downloaded from www.onsetcomp.com.

Instrument lift system data were collected using a Vaisala HMP45C air temperature and relative humidity sensor wired to a Campbell Scientific datalogger. This sensor and datalogger are the same units discussed in the cave meteorology protocol (Woodman et al 2007) under the section "Sampling Methods – Dataloggers and Sensors Used to Collect Atmospheric Data". Figures 2 and 3 show the sensor and datalogger, respectively.



Figure 2 – Vaisala's HMP45C air temperature and relative humidity Probe. Image downloaded from www.campbellsci.com.

Table 1 – Sites for which 2009 – 2010 cave meteorology data are currently available. “****” adjacent to site name indicates that no data are available in 2009 or 2010 due to datalogger malfunction.

Cave System	Cave Section or Passage	Site Name	Justification for Site Selection
Mammoth Cave	Historic	Houchins' Narrows	Access point for surface weather's influence on cave weather. Provides good correlate data for sites that are farther in-cave.
Mammoth Cave	Historic	Rotunda	Directly impacted by airflow through Houchins' Narrows (Jernigan and Fry 2007).
Mammoth Cave	Historic	Little Bat Avenue	Site was historically a bat hibernation site.
Mammoth Cave	Historic	River Hall	At the base of the Corkscrew and is the access point for surface weather's influence on cave weather in lower sections of the cave.
Mammoth Cave	Historic	Wright's Rotunda	Deep-cave site with relatively stable air temperature and relative humidity.
Mammoth Cave	Historic	Booth's Amphitheater Vat	Cultural resource site with direct impacts from meteorology (condensate drips onto wooden artifacts).
Mammoth Cave	Historic	Booth's Amphitheater High	Cultural resource site with direct impacts from meteorology (condensate drips onto wooden artifacts).
Mammoth Cave	Historic	Corkscrew	Access point to lower portions of the cave system for effects from surface weather. The site is at the top of the Corkscrew which leads down to the River Hall site.
Mammoth Cave	Frozen Niagara	Frozen Niagara	Site is near an artificial entrance that was retrofitted with an airlock system. The airlock was meant to restore natural interactions between the surface and the subsurface meteorological systems in that part of the cave system.
Blight Cave	"Lesser Cave"	Blight Cave	Summer roost for Rafinesque's big-eared bats.
Blood Cave	"Lesser Cave"	Blood Cave Lower	Summer roost for Rafinesque's big-eared bats.
Blood Cave	"Lesser Cave"	Blood Cave Upper	Summer roost for Rafinesque's big-eared bats.
Luna Cave	"Lesser Cave"	Luna Cave	Summer roost for Rafinesque's big-eared bats.
Misty Hole	"Lesser Cave"	Misty Hole	Summer roost for Rafinesque's big-eared bats.
Saucer Cave	"Lesser Cave"	Saucer Cave	Summer roost for Rafinesque's big-eared bats.
Haunted Cave	"Lesser Cave"	Haunted Cave Lower	Hibernaculum for Rafinesque's big-eared bats.
Haunted Cave	"Lesser Cave"	Haunted Cave Upper****	Hibernaculum for Rafinesque's big-eared bats.
N/A	N/A	Floyd Collins Ticket Office Attic	Artificial summer roost for Rafinesque's big-eared bats.
N/A	N/A	Wondering Woods Silo (a.k.a. Wondering Woods Chapel). Three loggers: the first being 17' above floor, the second 23'6" above floor and the third 29'6" above floor)	Artificial summer roost for Rafinesque's big-eared bats.
N/A	N/A	Keebler Tree	Summer roost for Rafinesque's big-eared bats.
N/A	N/A	Keebler Tree Pole	Summer roost for Rafinesque's big-eared bats.
Hickory Flat	"Lesser Cave"	Hickory Flat	Rafinesque's big-eared bat hibernaculum and probable home to a small summer bachelor colony of gray bats.
Hickory Flat	"Lesser Cave"	Hickory Flat Side Passage	Rafinesque's big-eared bat hibernaculum and probable home to a small summer bachelor colony of gray bats.
Mammoth Cave	Marion Avenue	Elevator Ceiling	Site used to test stability of the instrument lift system.
Mammoth Cave	Marion Avenue	Elevator Floor	Site used to test stability of the instrument lift system.



Figure 3 – Campbell Scientific's CR10X Datalogger for Measurement and Control. Image downloaded from www.campbellsci.com.

CY2009/2010 monitoring sites are shown in Table 1. Each of the Mammoth Cave system sites had been previously monitored by MACA using slightly different methods (Jernigan and Fry 2007). The CUPN chose to continue monitoring at most of the same sites that MACA had established.

Sampling Sites and Parameters Measured

Site descriptions, maps and photographs follow for all of the Historic Mammoth Cave/Frozen Niagara sites. The same is not true, however, for the lesser cave sites. This absence of site information about MACA's lesser caves is due to the fact that MACA, as a general rule and to protect these caves from disturbance, does not want the locations of lesser caves disclosed. Information about surface sites is absent for the same reason. All site maps for Historic Mammoth Cave were drafted by the first author by tracing passages from the Kaemper map (Kemper 1908).

Houchins' Narrows (HN)

The Houchins' Narrows site is located near the Historic Entrance to Mammoth Cave. The CUPN is collecting air temperature and relative humidity at the site. This site was part of MACA's Cave Atmospheric Monitoring Program from 1996 to 2000. During that period, MACA collected air temperature, rock temperature, wind speed and wind direction data.



Figure 4 – Photo of Houchins' Narrows sampling site. NPS photo by Kurt Helf.

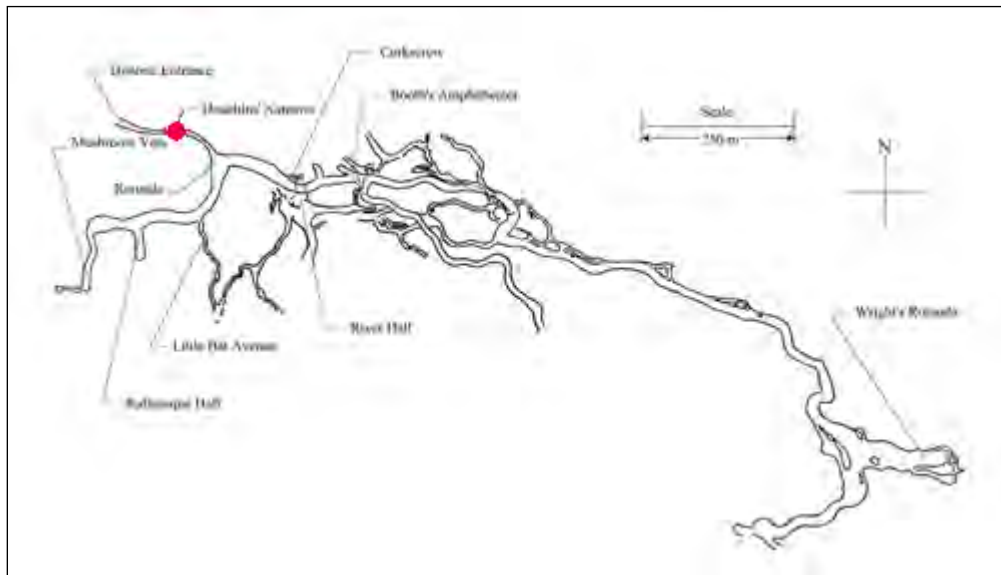


Figure 5 – Map of the Historic Section of Mammoth Cave. The Houchins' Narrows sampling site is indicated by a red dot.

Rotunda (RO)

The Rotunda site is located near the Historic Entrance to Mammoth Cave, at the in-cave end of Houchins' Narrows. The CUPN is collecting air temperature and relative humidity at the site. This site was part of MACA's Cave Atmospheric Monitoring Program from 1998 to 2000. During that period, MACA collected air temperature and relative humidity data.



Figure 6 – Photo of Rotunda sampling site. NPS photo by Kurt Helf.

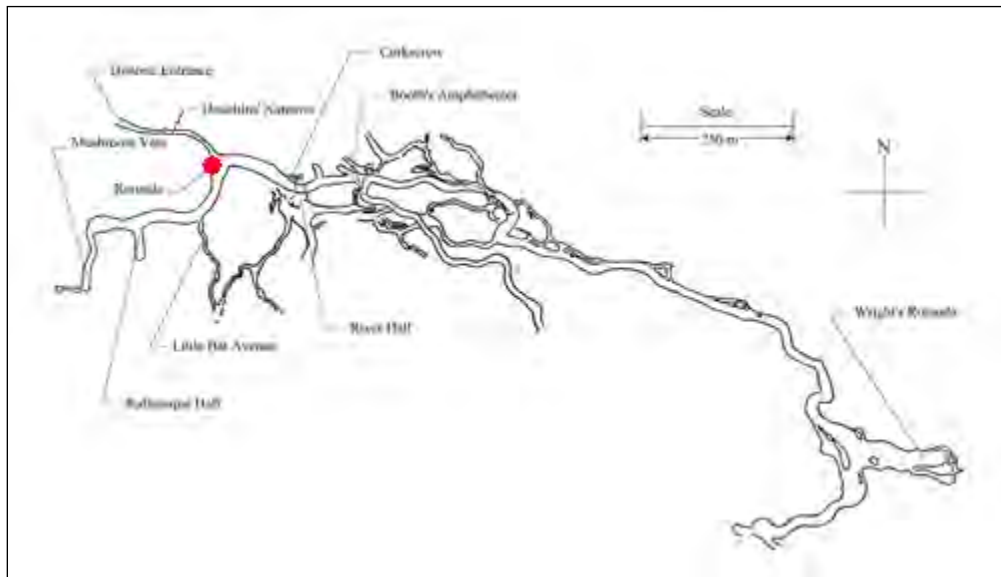


Figure 7 – Map of the Historic Section of Mammoth Cave. The Rotunda sampling site is indicated by a red dot.

Little Bat Avenue (LB)

The Little Bat Avenue site is located in the passage between Mammoth Dome and Audubon Avenue. The CUPN is collecting air temperature and relative humidity at the site. This site was part of MACA's Cave Atmospheric Monitoring Program from 1997 to 2000. During that period, MACA collected air temperature and relative humidity data. Please note that in the site photograph (Figure 8), there are two HOBO dataloggers shown. The HOBO near the ceiling (farthest from the photographer) is not the one used by CUPN; the CUPN's logger is shown in the foreground of the photograph and is being pointed to with a red arrow.



Figure 8 – Photo of Little Bat Avenue sampling site. NPS photo by Kurt Helf.

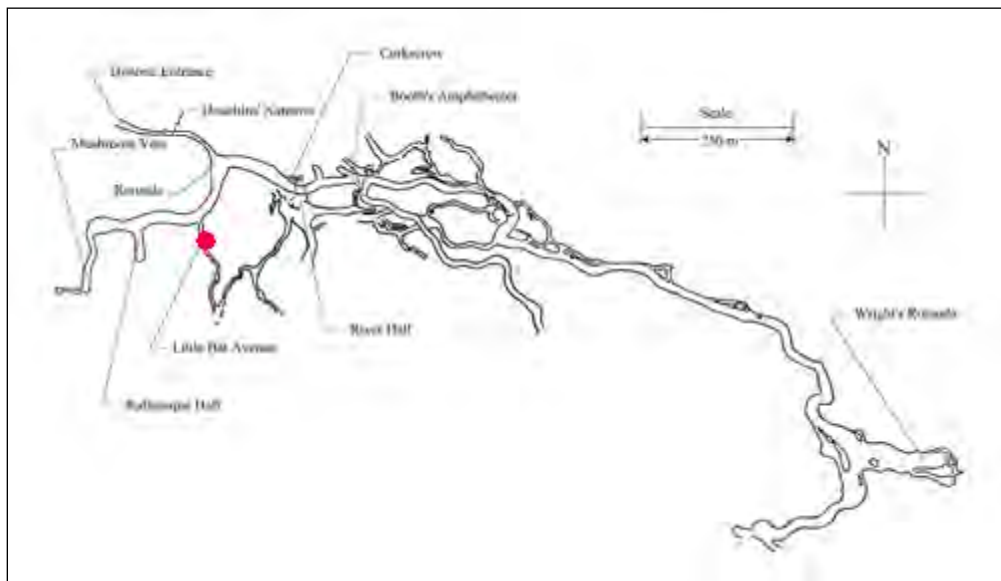


Figure 9 – Map of the Historic Section of Mammoth Cave. The Little Bat Avenue sampling site is indicated by a red dot.

River Hall (RH)

The River Hall site is located in the lower level of Mammoth Cave at the base of the Corkscrew. The CUPN is collecting air temperature and relative humidity at the site. This site was part of MACA's Cave Atmospheric Monitoring Program from 1994 to 2000. During that period, MACA collected air temperature and relative humidity data.



Figure 10 – Photo of River Hall sampling site. NPS photo by Kurt Helf.

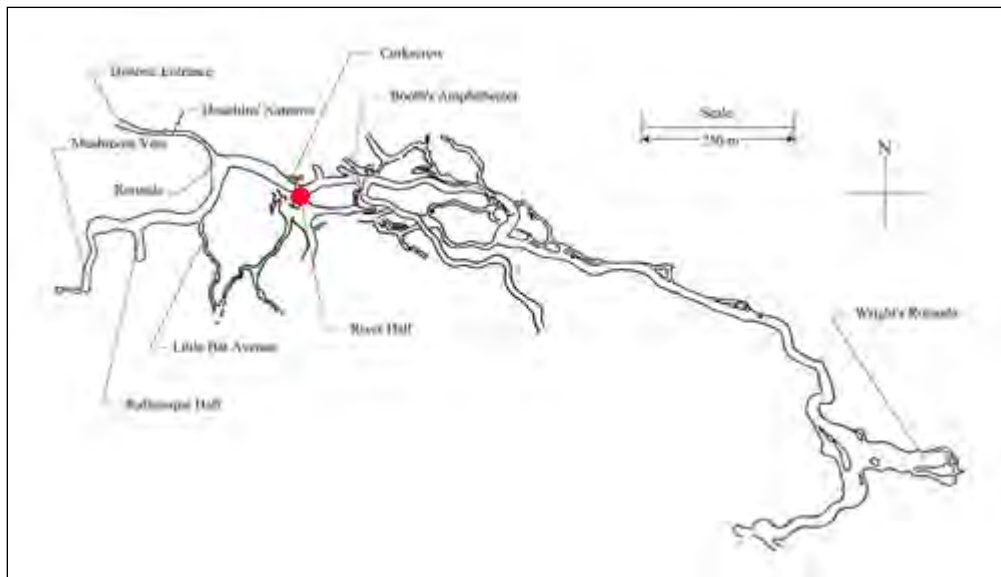


Figure 11 – Map of the Historic Section of Mammoth Cave. The River Hall sampling site is indicated by a red dot.

Wright's Rotunda (WR)

The Wright's Rotunda site is located in the upper level of Mammoth Cave and is approximately at the midpoint of the trail between the Historic Entrance and the Violet City Entrance. The CUPN is collecting air temperature and relative humidity at the site. This site was part of MACA's Cave Atmospheric Monitoring Program from 1996 to 2000. During that period, MACA collected air temperature and relative humidity data.



Figure 12 – Photo of Wright's Rotunda sampling site. NPS photo by Kurt Helf.

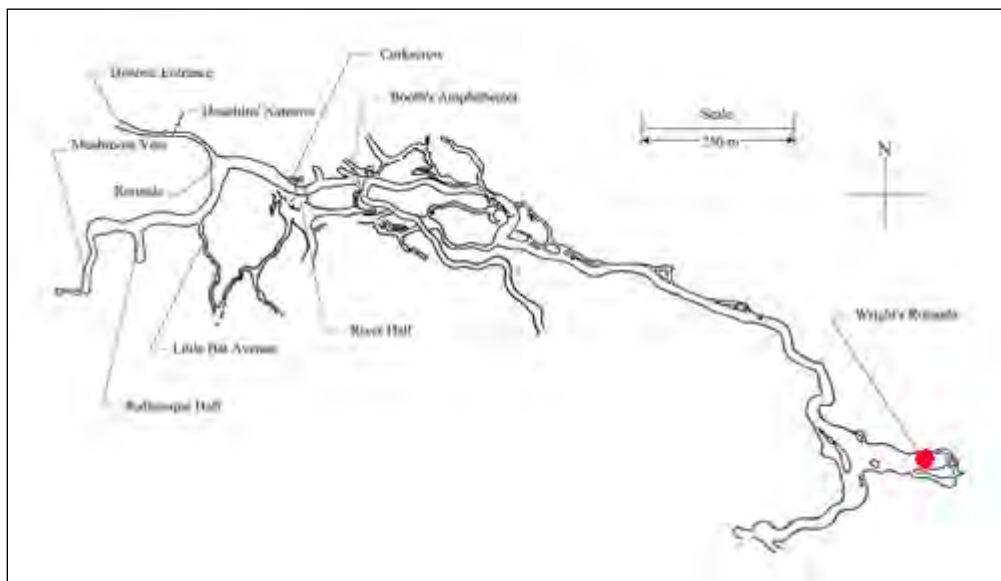


Figure 13 – Map of the Historic Section of Mammoth Cave. The Wright's Rotunda sampling site is indicated by a red dot.

Booth's Amphitheater Vat (BAV)

The Booth's Amphitheater Vat site is located in the upper level of Mammoth Cave in the room known as Booth's Amphitheater. The vat datalogger is located on the floor of the room. It is located between the wall on the Gothic Avenue side of the room and one of the historic saltpeter leaching vats. The CUPN is collecting air temperature and relative humidity at the site. This site was part of MACA's Cave Atmospheric Monitoring Program from 1995 to 2000. During that period, MACA collected air temperature data.



Figure 14 – Photo of Booth's Amphitheater Vat sampling site. NPS photo by Kurt Helf.

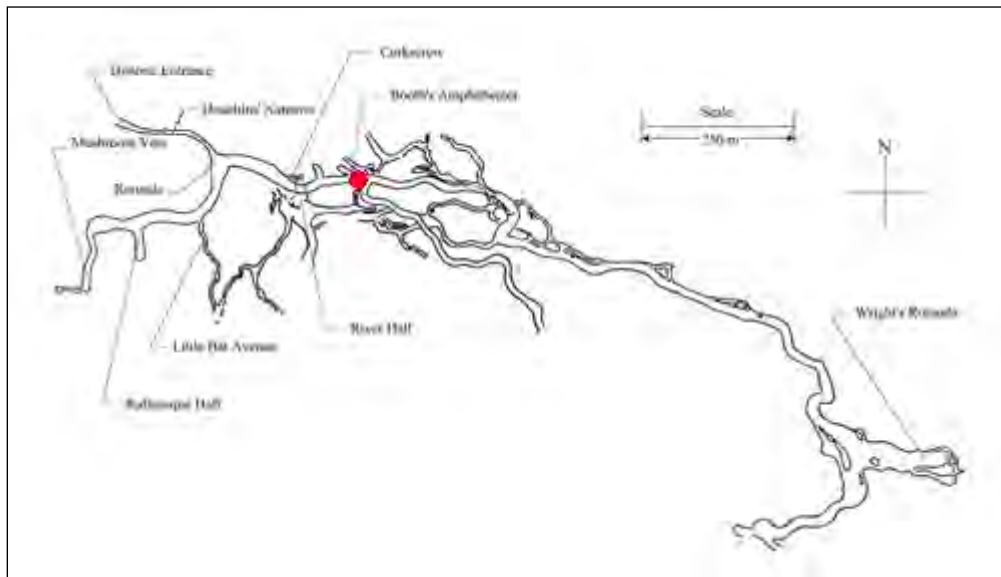


Figure 15 – Map of the Historic Section of Mammoth Cave. The Booth's Amphitheater Vat sampling site is indicated by a red dot.

Booth's Amphitheater High (BAH)

The Booth's Amphitheater High site is located in the upper level of Mammoth Cave in the room known as Booth's Amphitheater. The high datalogger is located in the upper part of the room just within the Gothic Avenue passage. The CUPN is collecting air temperature and relative humidity at the site. This site was part of MACA's Cave Atmospheric Monitoring Program from 1995 to 2000. During that period, MACA collected air temperature data.



Figure 16 – Photo of Booth's Amphitheater High sampling site. NPS photo by Kurt Helf.

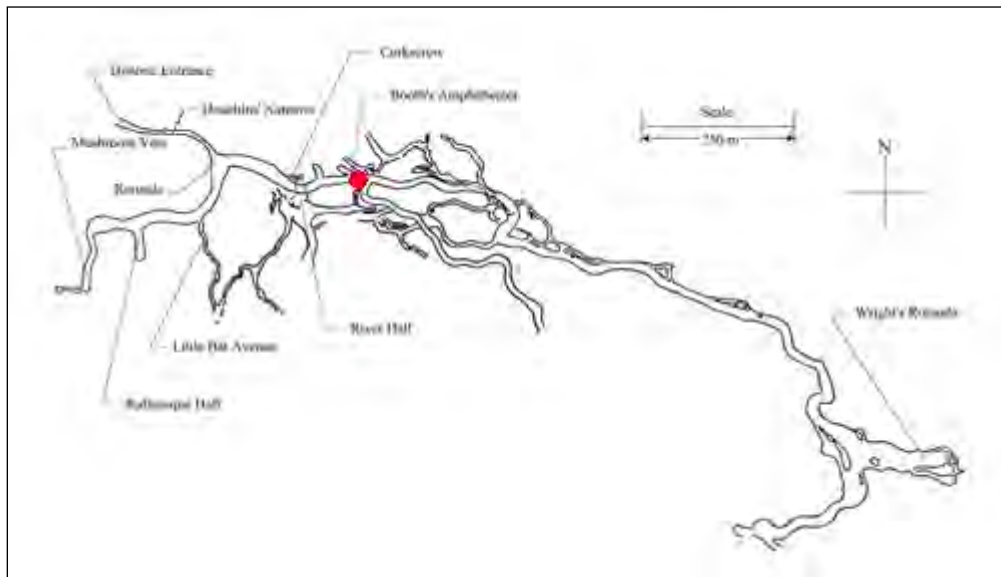


Figure 17 – Map of the Historic Section of Mammoth Cave. The Booth's Amphitheater High sampling site is indicated by a red dot.

Corkscrew (CO)

The Corkscrew site is located at the top of the Corkscrew. The CUPN is collecting air temperature and relative humidity at the site. This site was part of MACA's Cave Atmospheric Monitoring Program from 1995 to 2000. During that period, MACA collected air temperature and relative humidity data.



Figure 18 – Photo of Corkscrew sampling site. NPS photo by Kurt Helf.

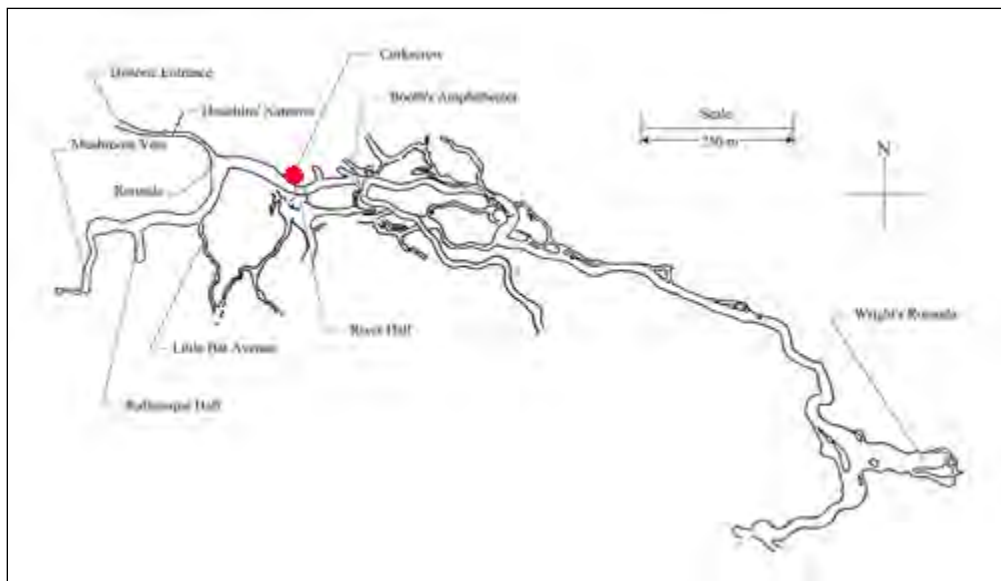


Figure 19 – Map of the Historic Section of Mammoth Cave. The Corkscrew sampling site is indicated by a red dot.

Frozen Niagara (FN)

The Frozen Niagara site is located near the Frozen Niagara Entrance to Mammoth Cave (in Moonlight Dome which is adjacent to the view of Crystal Lake). The CUPN is collecting air temperature and relative humidity at the site. Note that the datalogger is attached to a heavy piece of plastic lumber to prevent woodrats from carrying the logger away. This site was part of MACA's Cave Atmospheric Monitoring Program from 1994 to 1999. During that period, MACA collected air temperature and relative humidity data.



Figure 20 – Photo of Frozen Niagara sampling site. NPS photo by Kurt Helf.

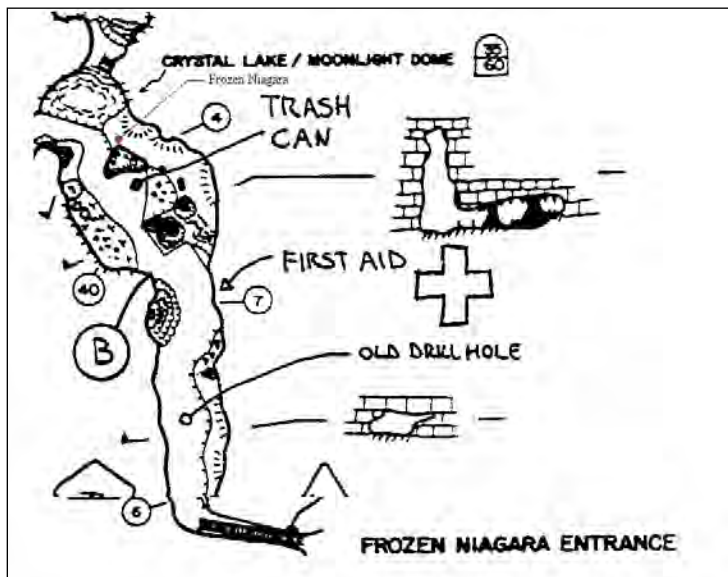


Figure 21 – Map of Frozen Niagara sampling site (the datalogger's location is indicated by red dot). This map is an edited version of a map by the Cave Research Foundation (1985).

Instrument Lift Site

The instrument lift system was designed and constructed by faculty, staff and students within the Department of Engineering at Western Kentucky University. Delivered to the CUPN in 2007, the instrument lift system was designed to provide mounting points for meteorology sensors and, through the use of a computerized control system, automatically move those sensors along the system's height. This movement along a vertical axis allows sampling within horizontally-oriented layers of air (each with its own air temperature, relative humidity and wind speed/direction).



Figure 22 – Photo of instrument lift system. Air temperature and relative humidity sensors are attached to the tower, one at the top of the tower and one on the back-left leg of the tower base. NPS photo by Kurt Helf.

The instrument lift system was installed in the Mammoth Cave system in 2008. The investigators' goal was to test the system's ability to be used in a cave system. This test was necessary since, prior to that date, the system had only been used in a laboratory facility at Western Kentucky University. A secondary goal that the investigators pursued was the collection of air temperature and relative humidity data using the system. Two sensors were attached to the lift system: one at the top (and therefore near the cave ceiling) and one at the base of the tower (and therefore near the cave floor).

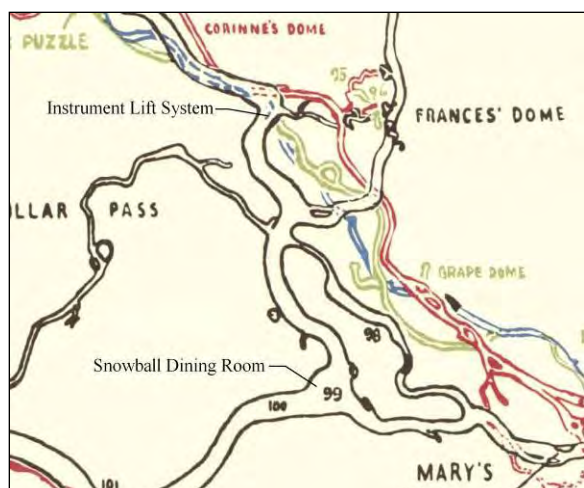


Figure 23 – Location of the instrument lift system shown on the Kaemper map (Kaemper 1908).

Data were collected using the methods described in the CUPN's cave meteorology protocol (Woodman et al 2007) under the section titled "Sampling Methods – Dataloggers and Sensors Used to Collect Atmospheric Data". Those methods include the use of a Campbell Scientific Inc. datalogging system and the Vaisala HMP45C air temperature and relative humidity sensor. In Figure 22, the sensors are located on the top platform of the tower and on the back-left leg of the tower base.

Results

The CUPN's monitoring efforts in 2009 – 2010 resulted in three groups of datasets:

- Air temperature and relative humidity data from sites in the Historic Section of Mammoth Cave and from one site near the Frozen Niagara entrance.
- Air temperature and relative humidity data from sites in MACA's lesser caves and other sites located on the surface.
- Air temperature and relative humidity data that were collected using the CUPN's instrument lift system.

Historic Mammoth Cave/Frozen Niagara Entrance Data

Air temperature and relative humidity time series for each of the sites in Historic Mammoth Cave/Frozen Niagara are shown below (Figures 24 – 32). Please note that most sites have no missing data for the two years, but there are a few sites with a few months of missing data. These missing data are usually caused by malfunctioning HOBO dataloggers.

The accuracy of relative humidity data using a HOBO is, according to the manufacturer, $\pm 4\%$ in condensing environments. It is the primary author's experience that in such environments HOBOs tend to read about 104% and flatline at that value. This behavior is exhibited in several of the subsequent plots. In these cases, the authors simply interpret relative humidity as “saturated”.

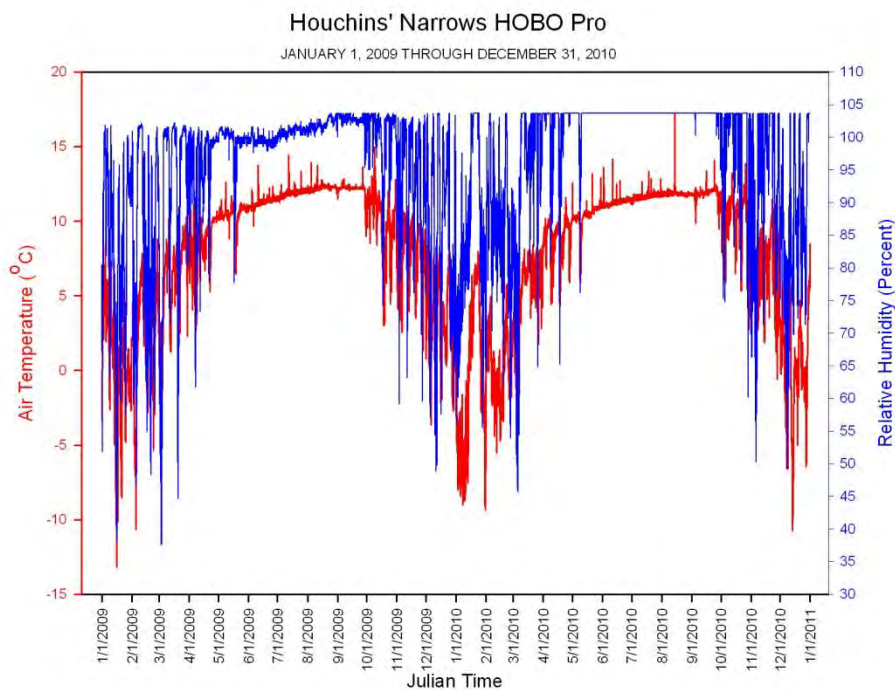


Figure 24 – Air temperature and relative humidity time series for the Houchins' Narrows site.

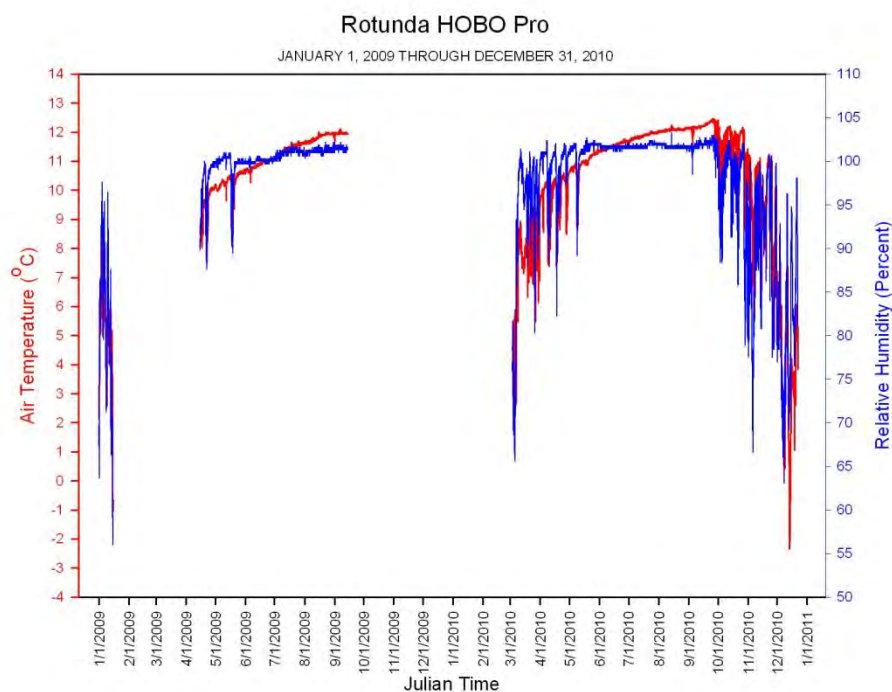


Figure 25 – Air temperature and relative humidity time series for the Rotunda site. Missing data are due to datalogger malfunction.

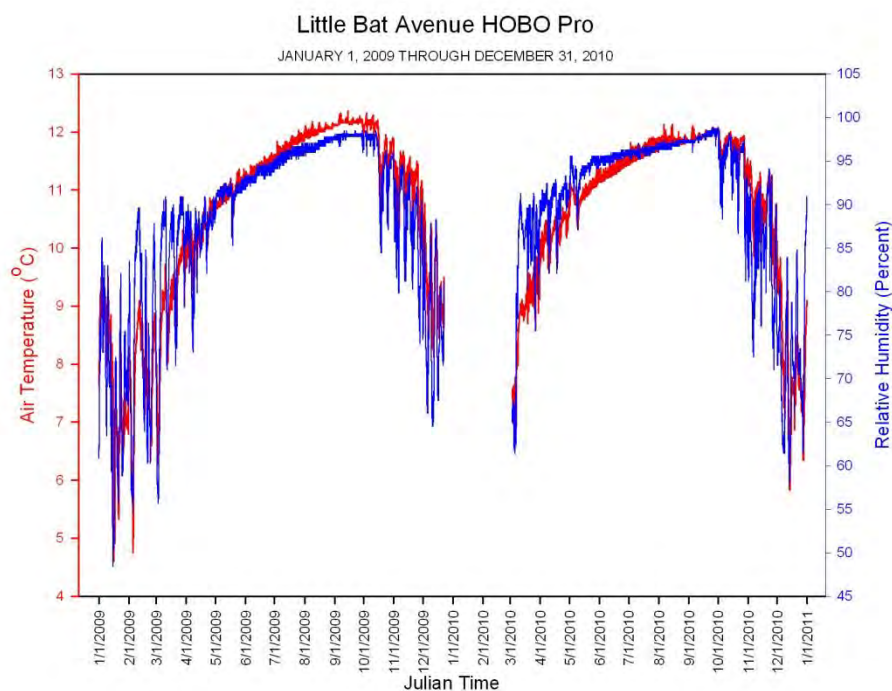


Figure 26 – Air temperature and relative humidity time series for the Little Bat Avenue site. Missing data are due to datalogger malfunction.

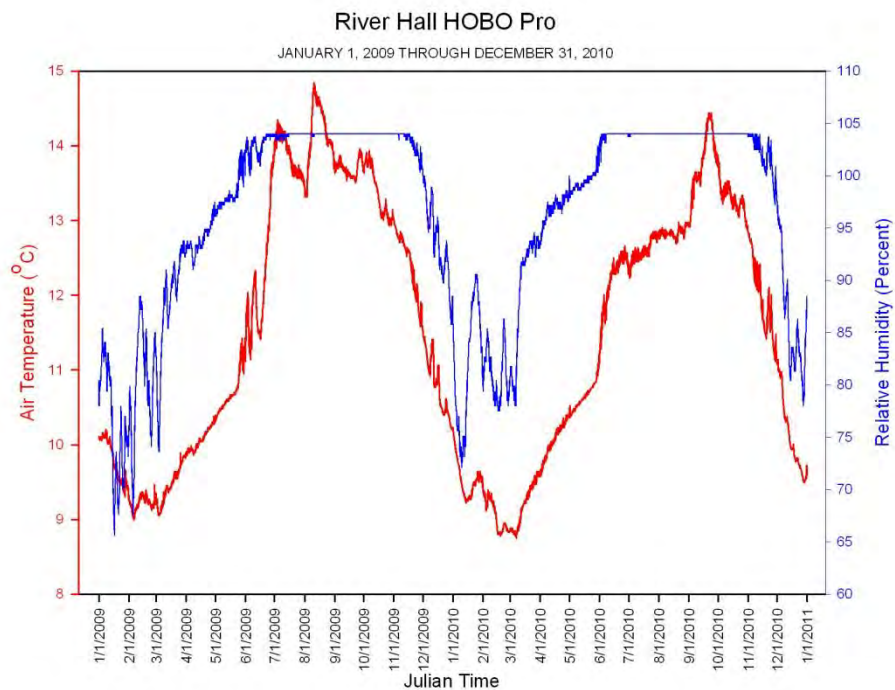


Figure 27 – Air temperature and relative humidity time series for the River Hall site.

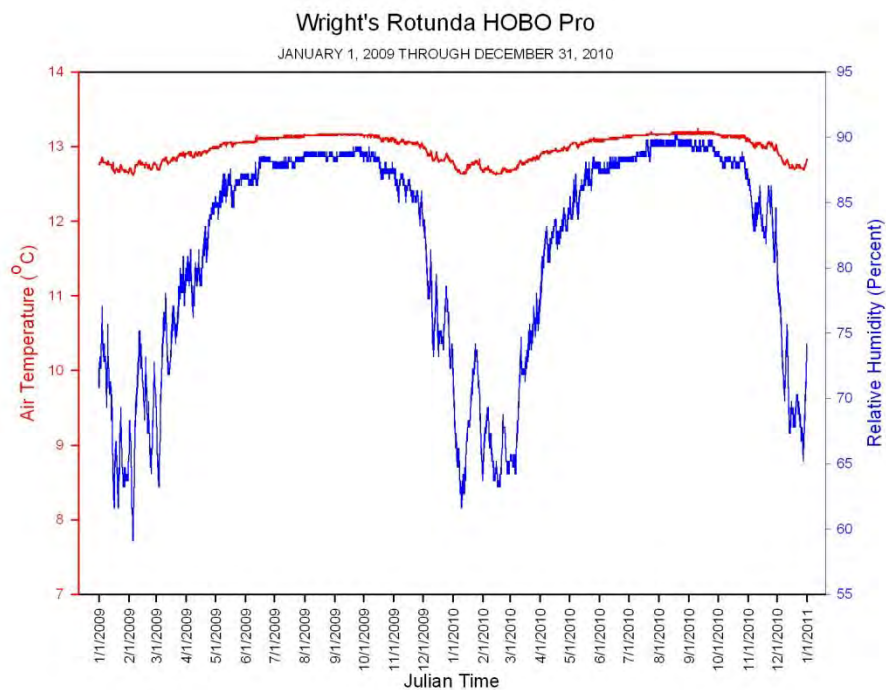


Figure 28 – Air temperature and relative humidity time series for the Wright's Rotunda site.

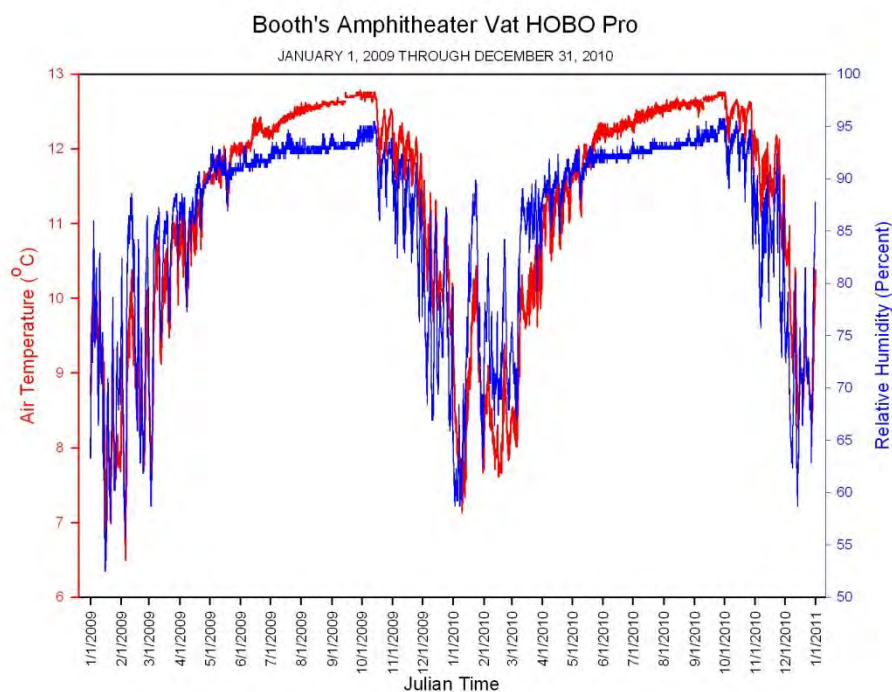


Figure 29 – Air temperature and relative humidity time series for the Booth's Amphitheater Vat site.

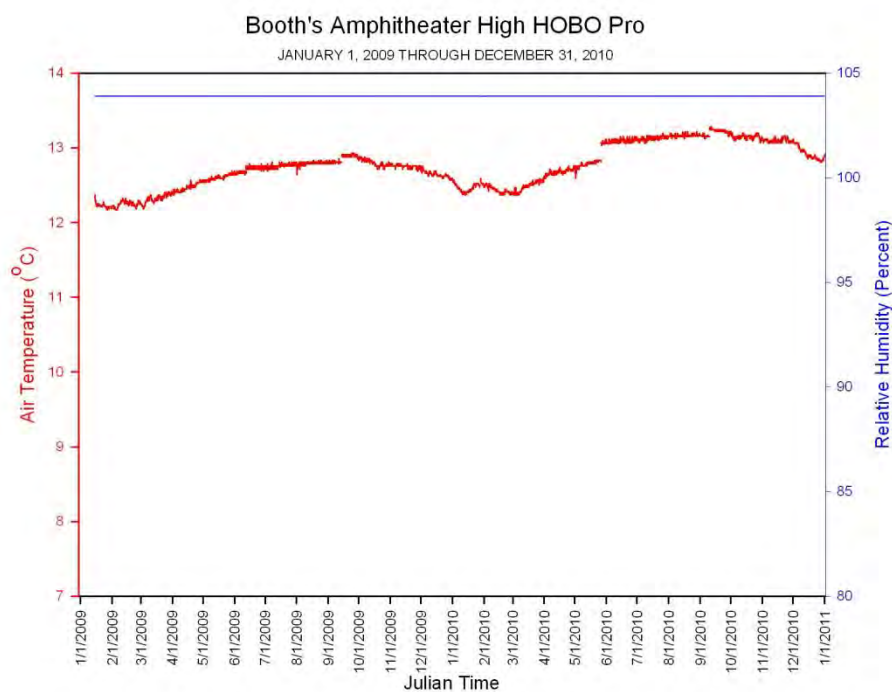


Figure 30 – Air temperature and relative humidity time series for the Booth's Amphitheater High site.

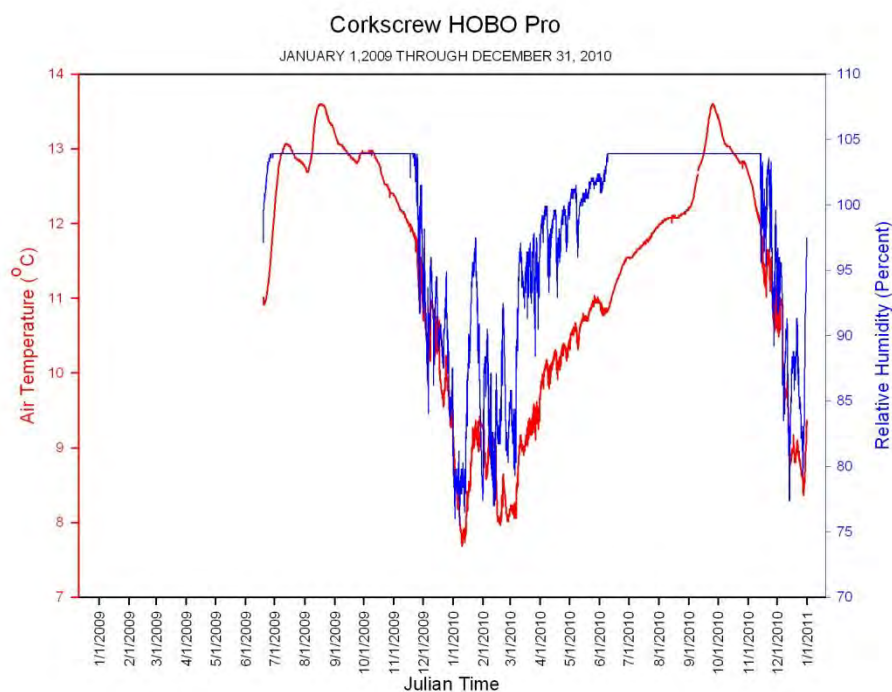


Figure 31 – Air temperature and relative humidity time series for the Corkscrew site. Missing data are due to datalogger malfunction.

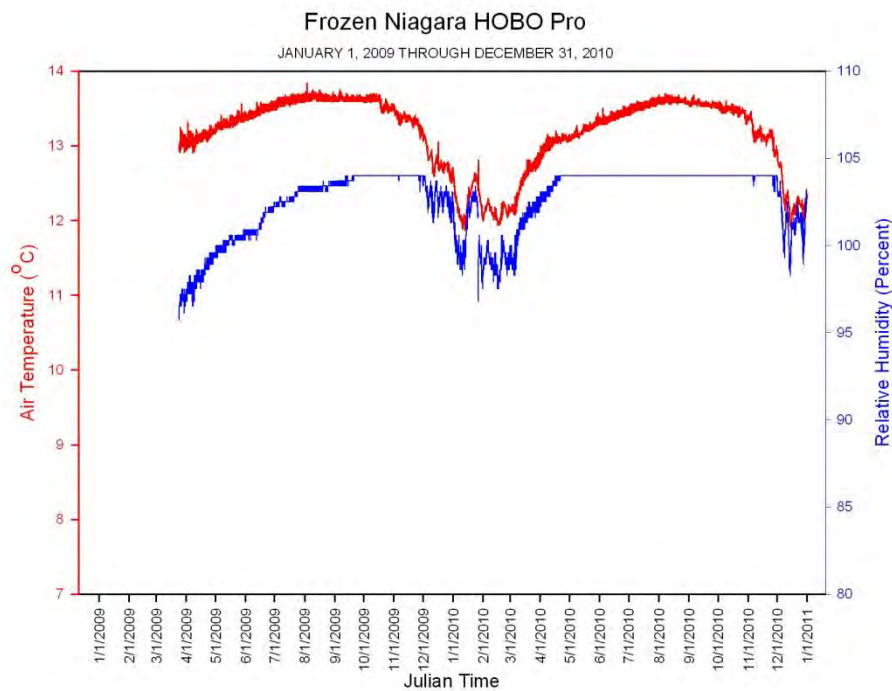


Figure 32 – Air temperature and relative humidity time series for the Frozen Niagara site. Missing data are due to datalogger malfunction.

Lesser Caves and Bat Roosts on the Surface

Air temperature and relative humidity time series for each of the sites in MACA's lesser caves and surface bat roosts (artificial roosts and trees) are shown below (Figures 33 – 46). Please note that most sites have no missing data for the sampling period, but there are a few sites with a few months of missing data. These missing data are usually caused by malfunctioning HOBO dataloggers. Also, a few of the sites were started early in 2009, so data are not available for those sites early in the sampling period.

The accuracy of relative humidity data using a HOBO is, according to the manufacturer, $\pm 4\%$ in condensing environments. It is the authors' experience that in such environments HOBOs tend to read about 104% and flatline at that value. This behavior is exhibited in several of the subsequent plots. In these cases, the authors simply interpret relative humidity as "saturated".

Summer Roosts in Caves for Rafinesque's Big Eared Bats

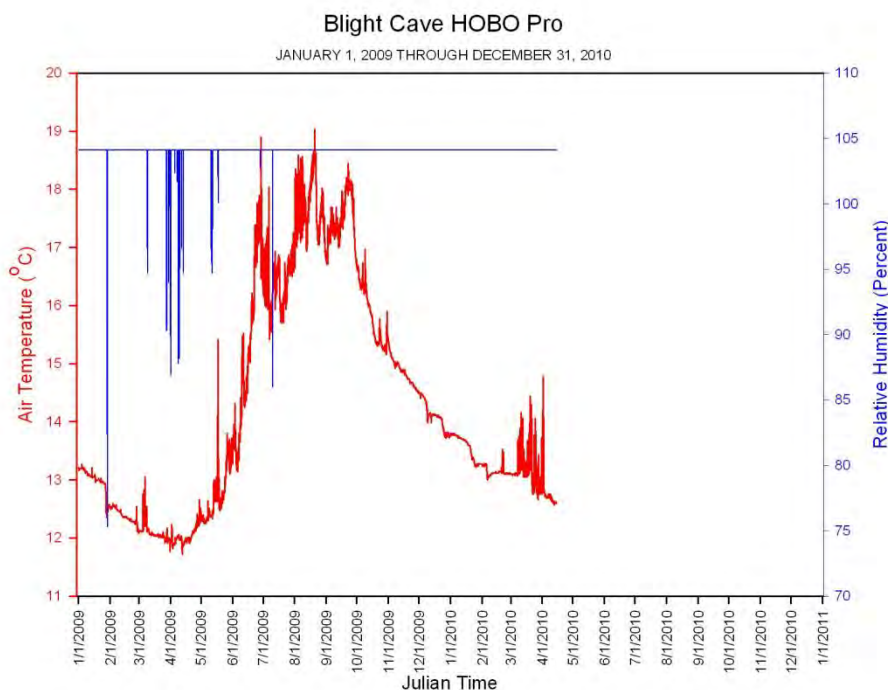


Figure 33 – Blight Cave data. Missing data were caused by datalogger malfunction.

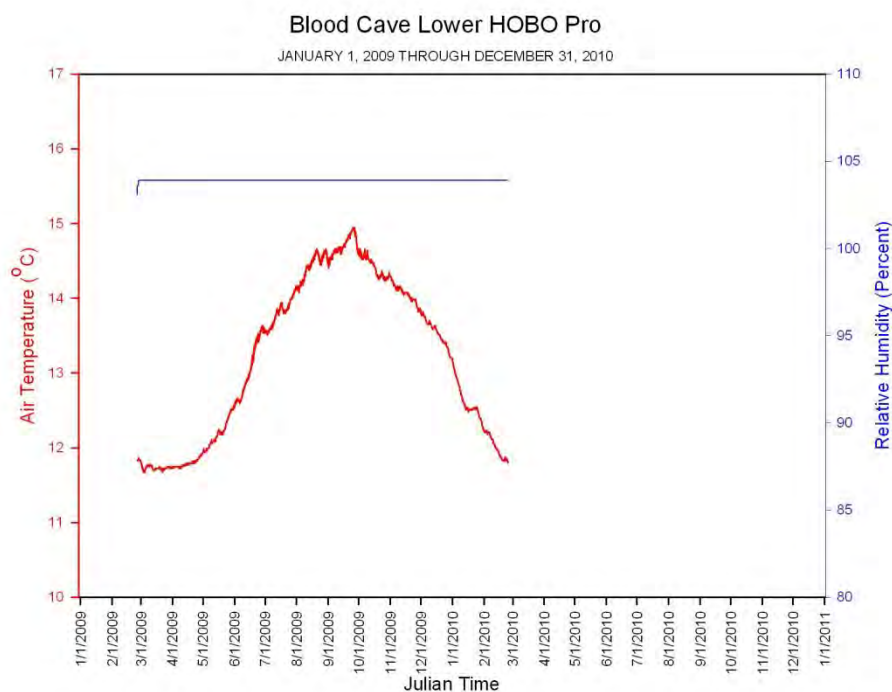


Figure 34 – Blood Cave Lower data. Missing data in early 2009 were caused by datalogger malfunction. Blood Cave Lower datalogger has not been serviced since February 2010.

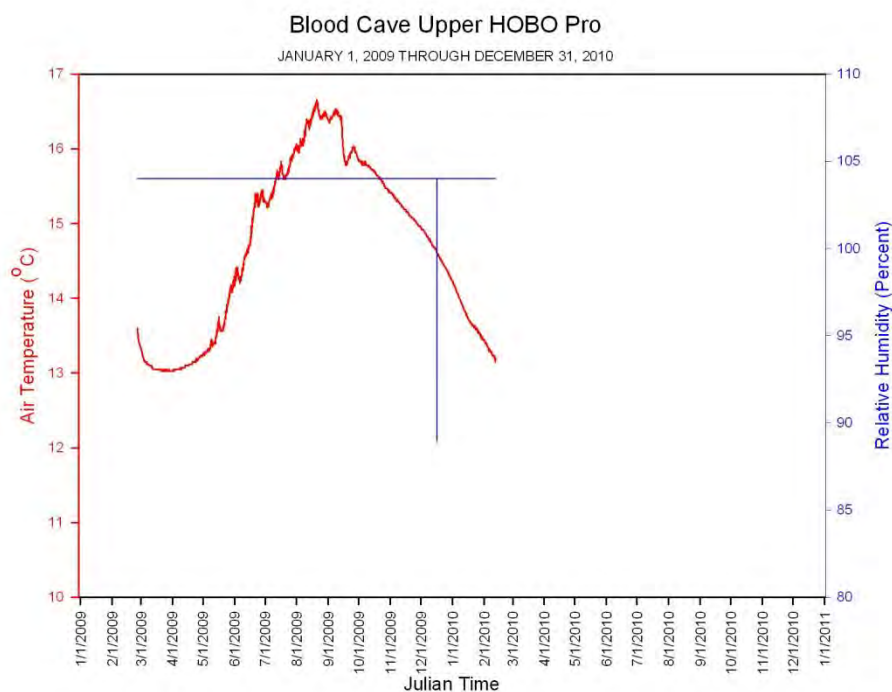


Figure 35 –Blood Cave Upper data. Missing data in early 2009 were caused by datalogger malfunction. Blood Cave Upper datalogger has not been serviced since February 2010.

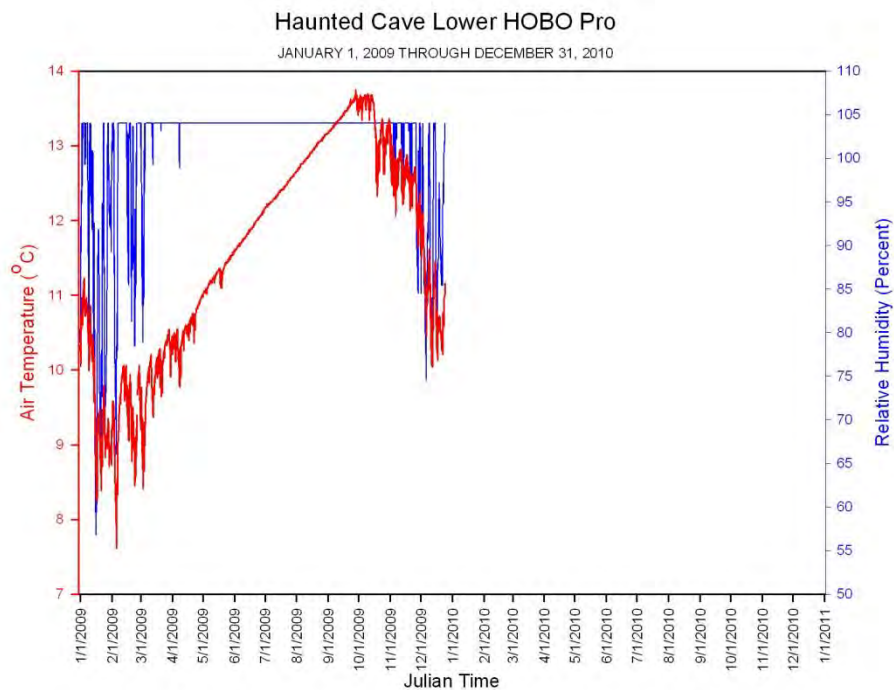


Figure 36 – Haunted Cave Lower data. January and February 2010 are missing due to datalogger malfunction. Haunted Cave Lower datalogger has not been serviced since February 2010.

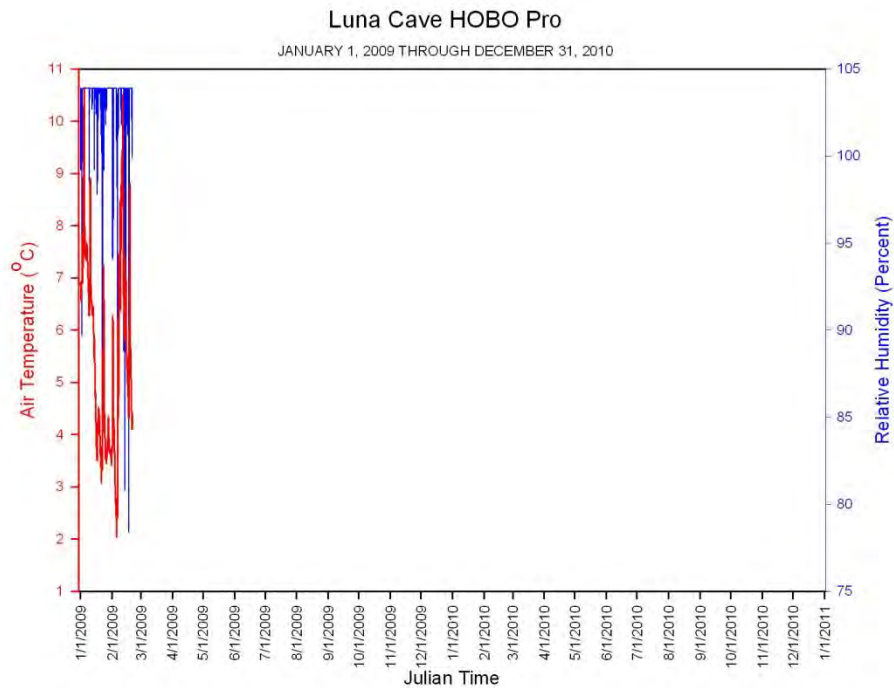


Figure 37 – Luna Cave data. Luna Cave datalogger has not been serviced since February 2009.

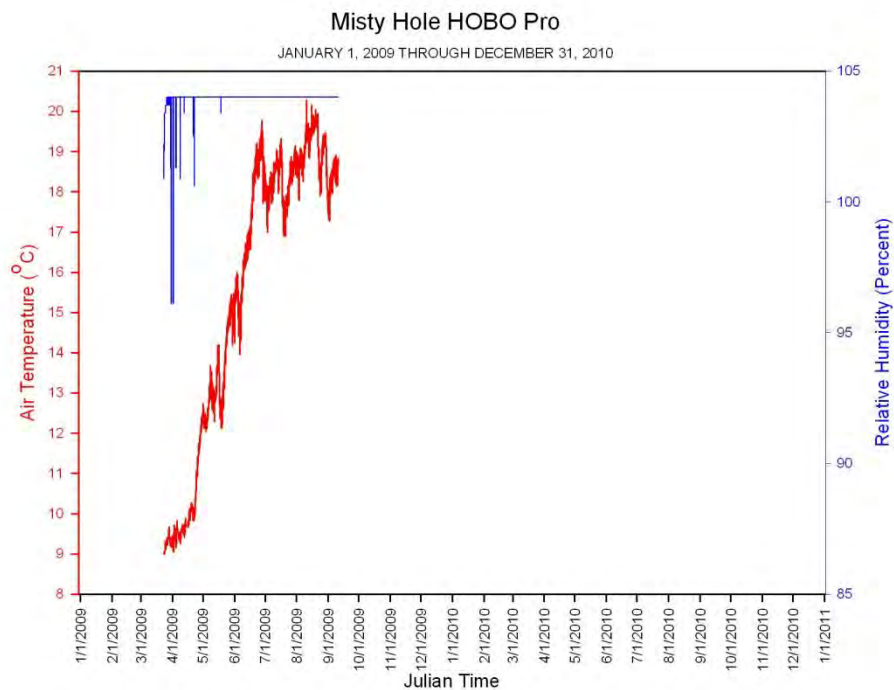


Figure 38 – Misty Hole data. Early data are missing due to datalogger malfunction. Misty Hole datalogger has not been serviced since September 2009.

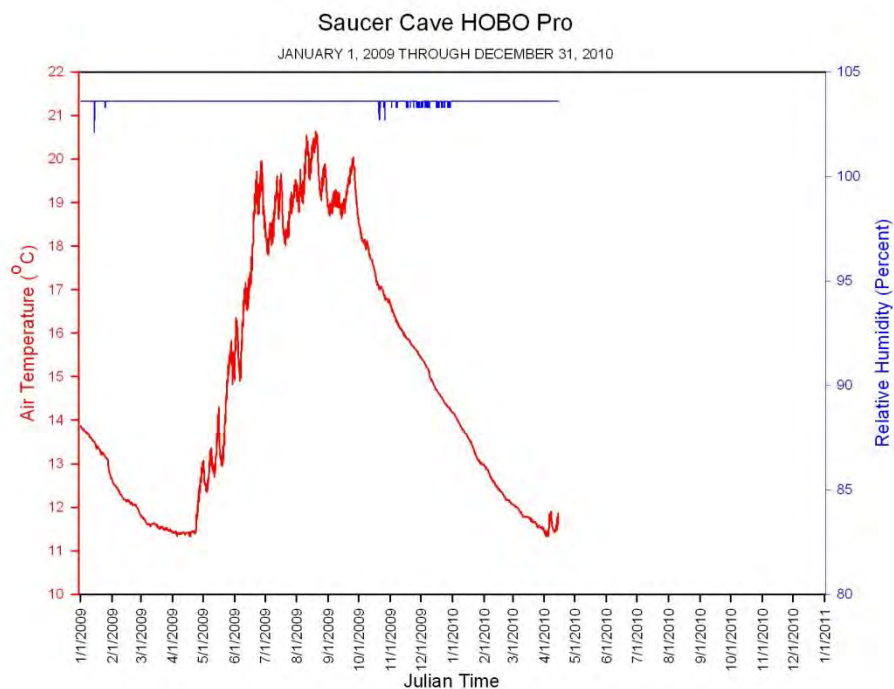


Figure 39 –Saucer Cave data. Saucer Cave datalogger has not been serviced since April 2010.

Artificial Summer Roosts for Rafinesque's Big Eared Bats

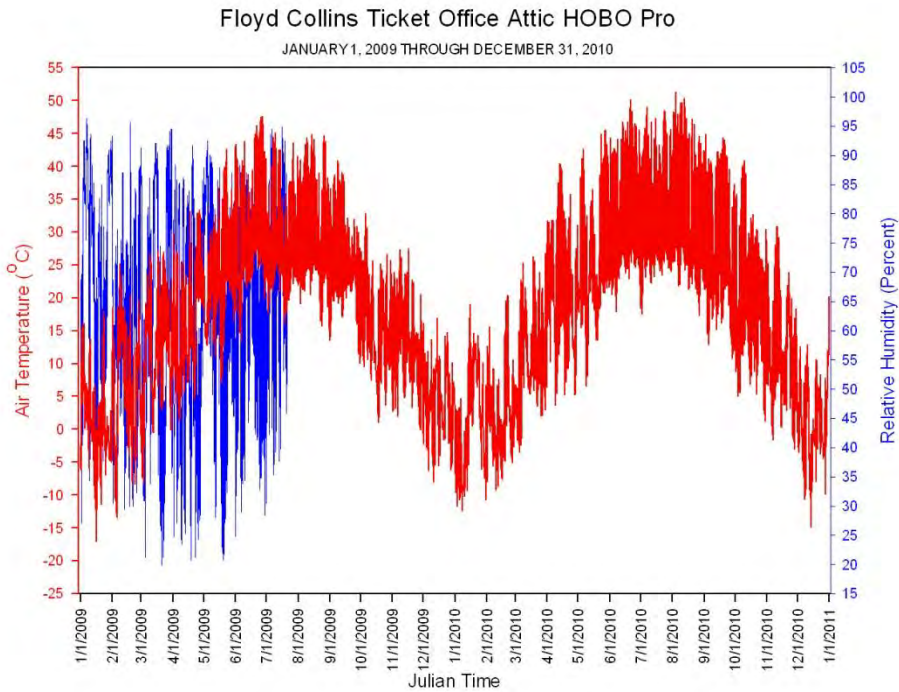


Figure 40 – Floyd Collins Ticket Office Attic data. Missing relative humidity data were caused by sensor malfunction.

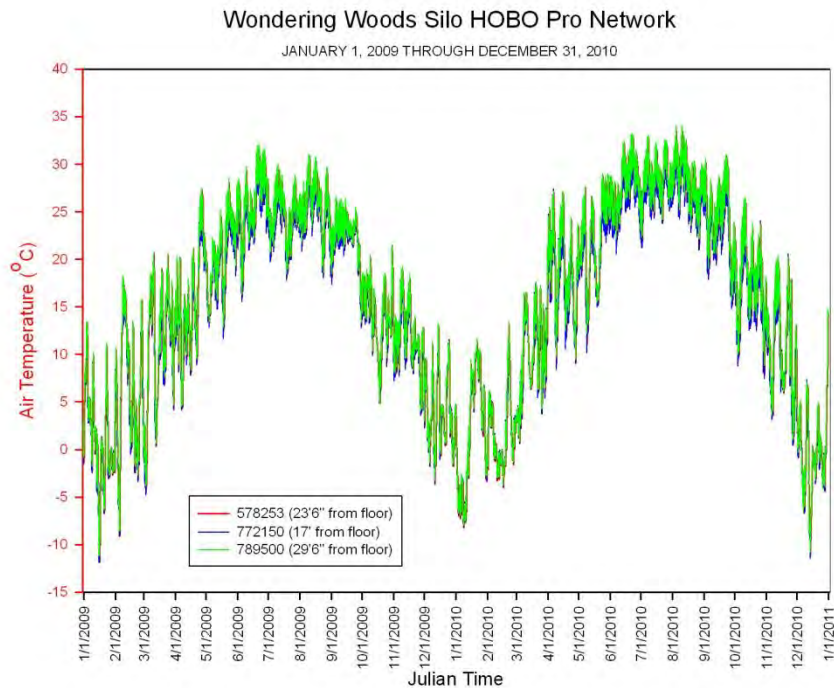


Figure 41 –Wondering Woods Silo air temperature data.

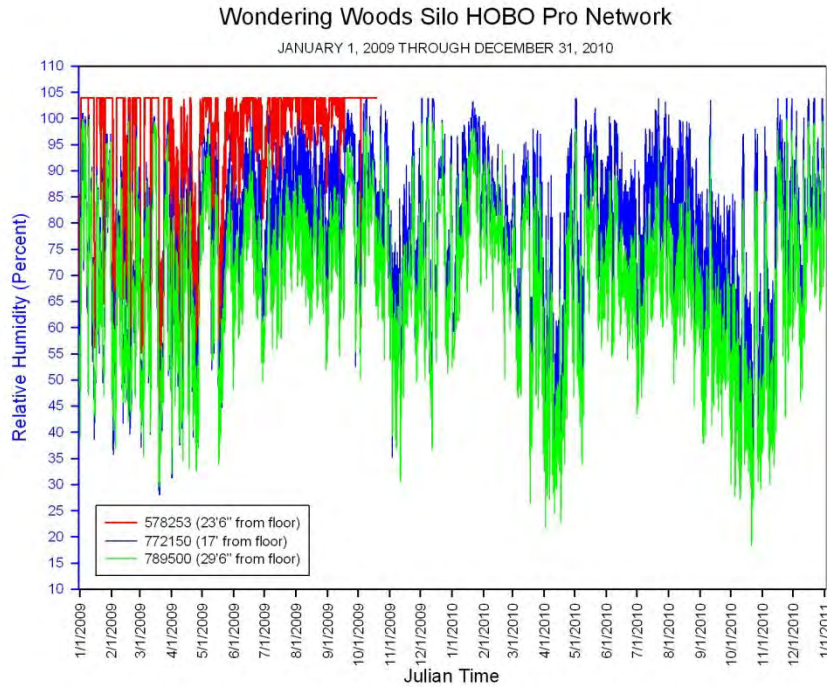


Figure 42 –Wondering Woods Silo relative humidity data. Missing data from the 23'6" datalogger are due to sensor malfunction (temperature sensor on that same datalogger was functional during the same period).

Summer Roost Trees for Rafinesque's Big Eared Bats

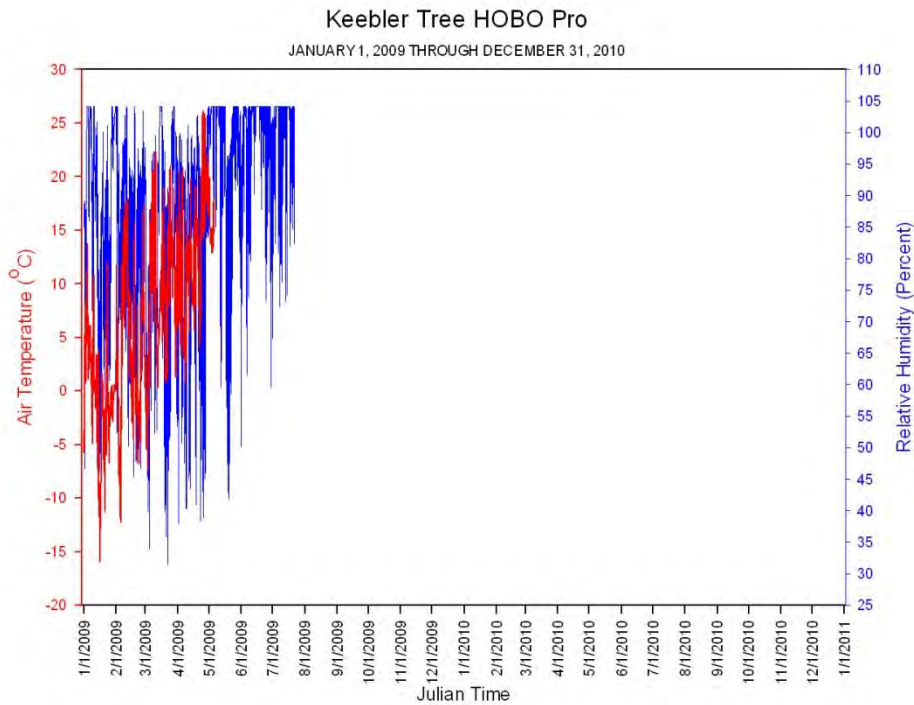


Figure 43 –Keebler Tree (a large hollow American sycamore tree that is located on the Green River) data. Keebler Tree datalogger data were irretrievable since last servicing. Datalogger will be sent to manufacturer to attempt data retrieval.

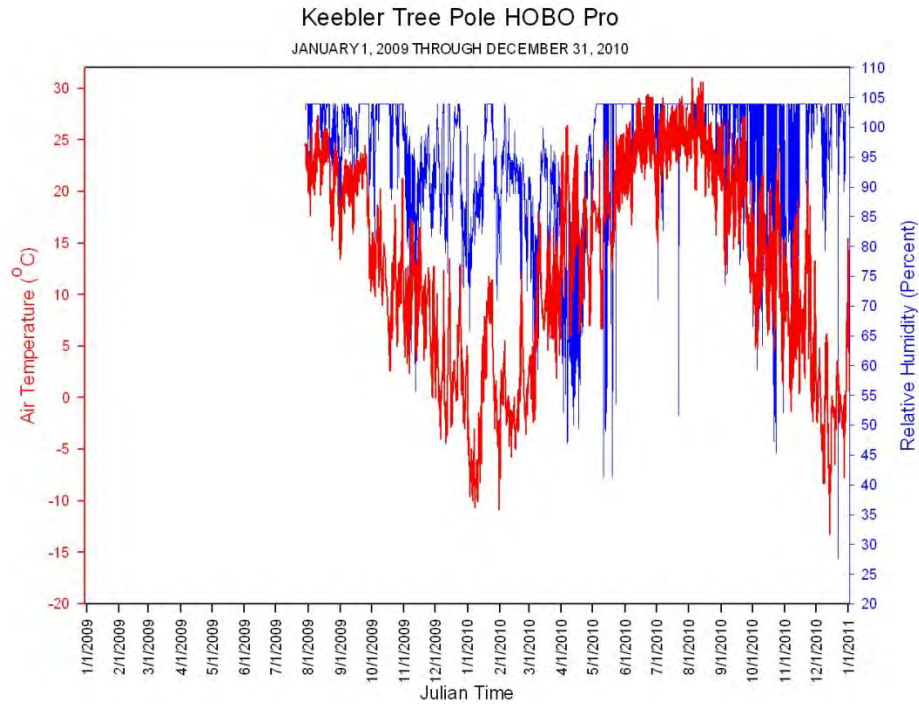


Figure 44 – Keebler Tree Pole data. The datalogger is located in the Keebler Tree (Figure 43), but attached to a pole to enable placement higher in the tree. The site was established July 2009.

Rafinesque's Big Eared Bat Hibernacula in Caves

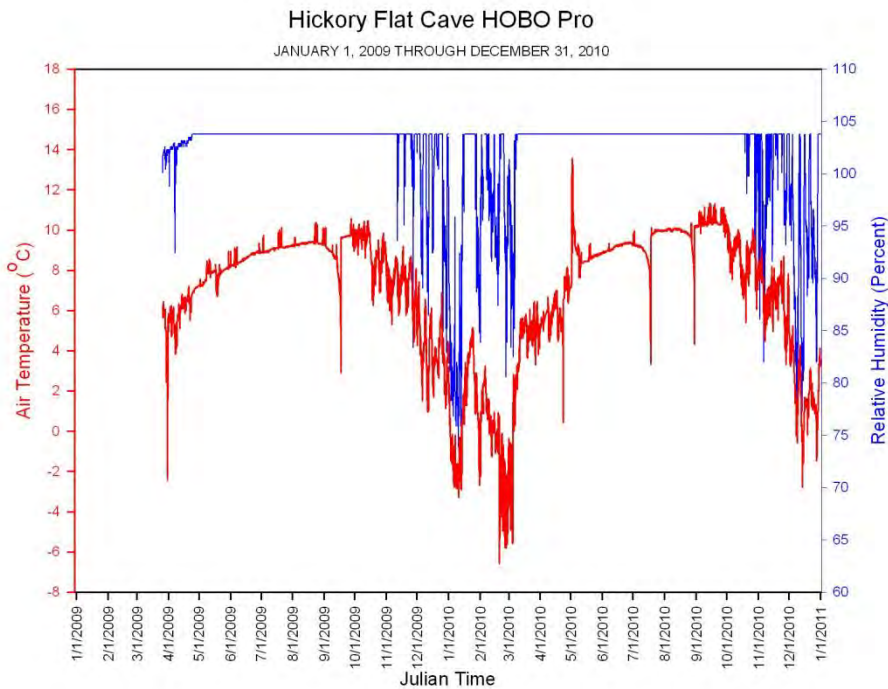


Figure 45 – Hickory Flat data. The datalogger was installed in March 2009.

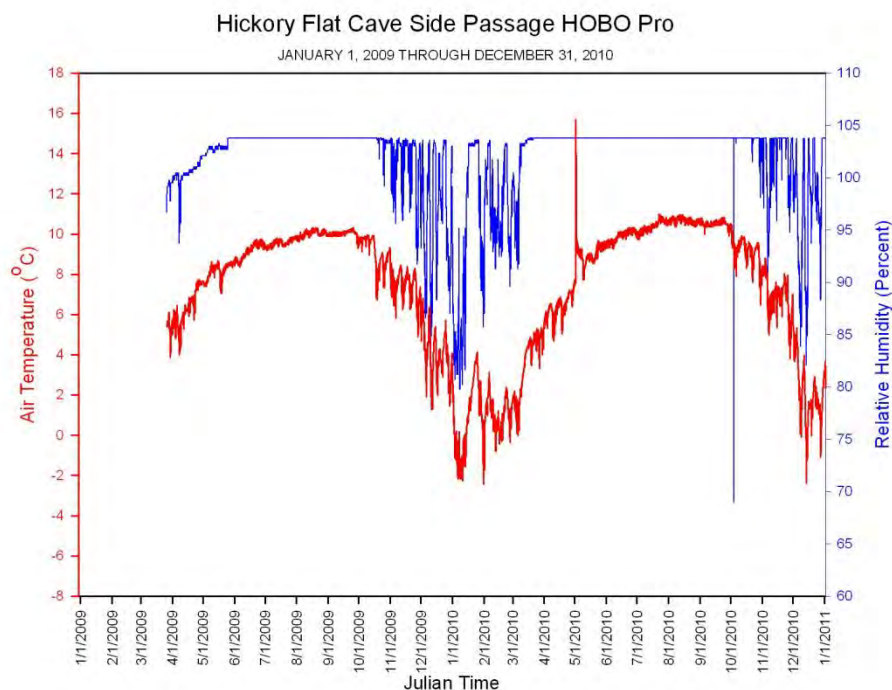


Figure 46 – Hickory Flat Side Passage data. The datalogger was installed in March 2009.

Instrument Lift System

Air temperature and relative humidity data from the instrument lift system are shown in Figures 46 and 47, respectively. The instrument lift system was removed from the site on February 17, 2010. Note that the air mass near the ceiling is warmer than the air mass at the floor. It cannot be inferred, however, that relative humidity of the upper air mass is greater than that of the lower air mass despite the fact that the ceiling humidity sensor showed higher readings. Note that both the ceiling and floor sensors are collecting relative humidity data above 95% (the ceiling sensor is above 100%). The accuracy of the HMP45C in an air mass with relative humidity above 90% is $\pm 3\%$. The safe interpretation of the relative humidity data shown in Figure 47 is that both air masses are saturated or nearly saturated.

Also note that, for the ceiling probe, data are missing due to instrumentation malfunction. It is unknown what was causing the readings to be erroneous. The faulty readings could have been caused by either the sensors or the datalogger (or its wiring panel) malfunctioning. Readings seemed to return to normal for no apparent reason. For this reason, all 2009 and 2010 ceiling probe data should be viewed as suspect.

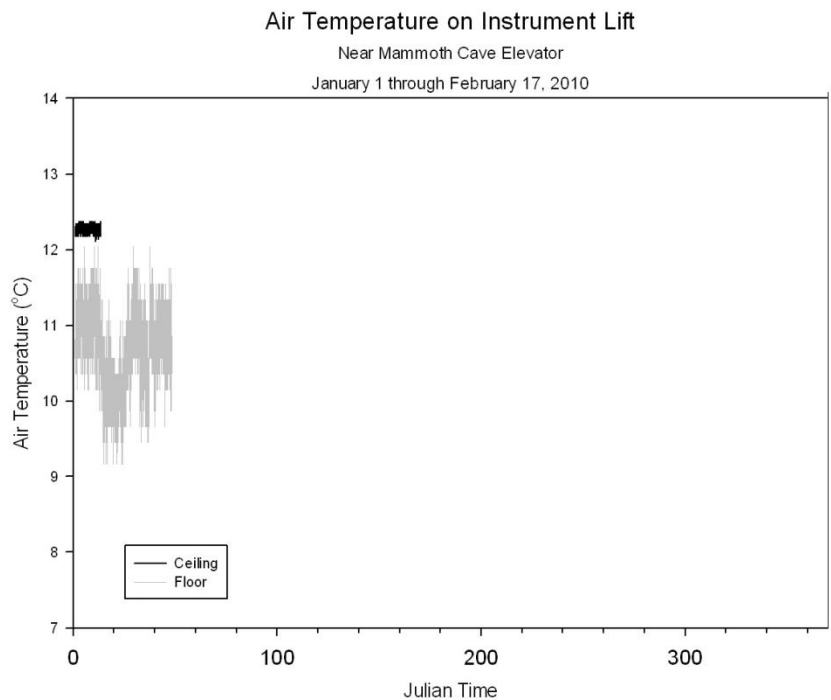
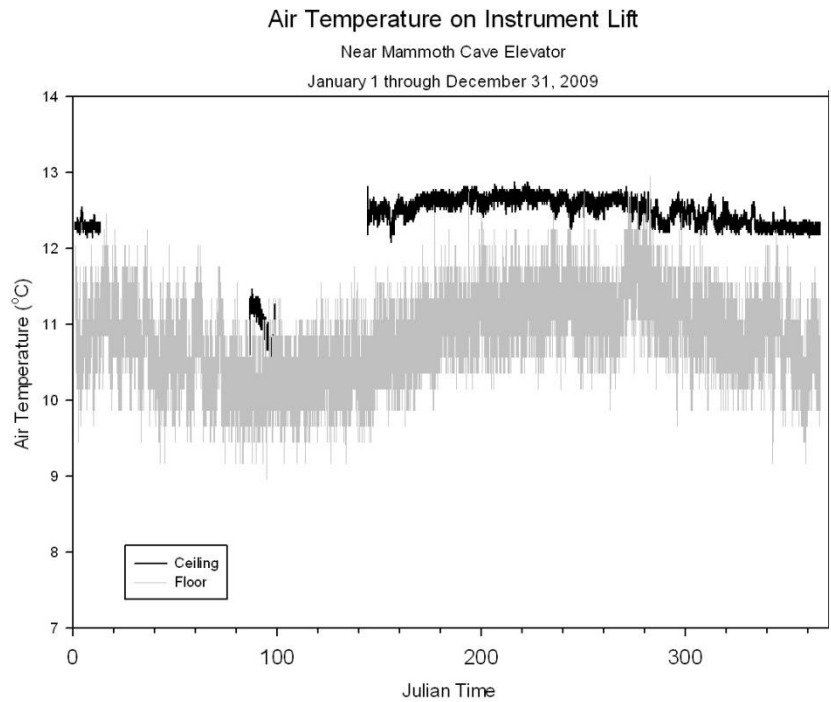


Figure 47 – Air temperature at the two instrument lift system sensors. Missing ceiling data are due to sensor malfunction.

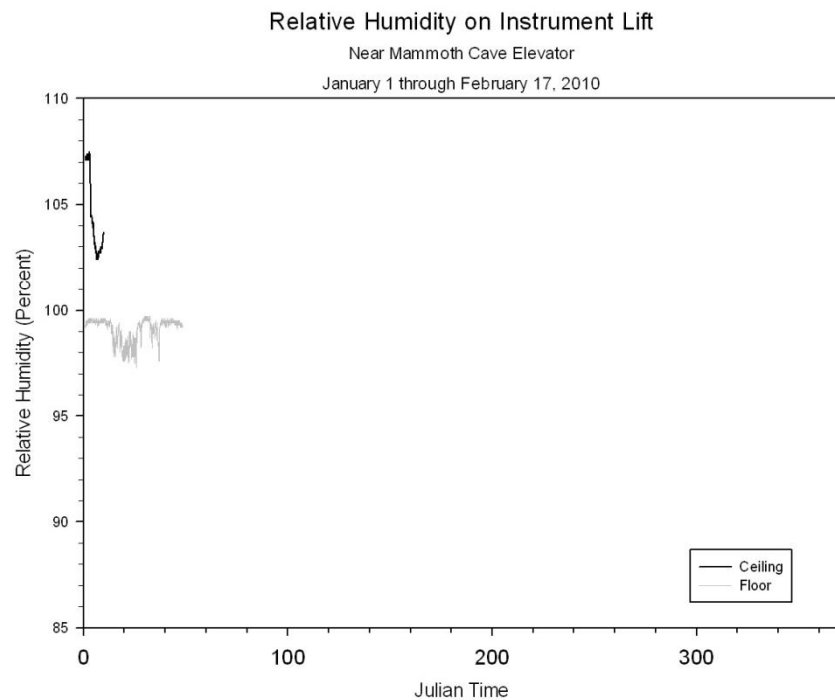
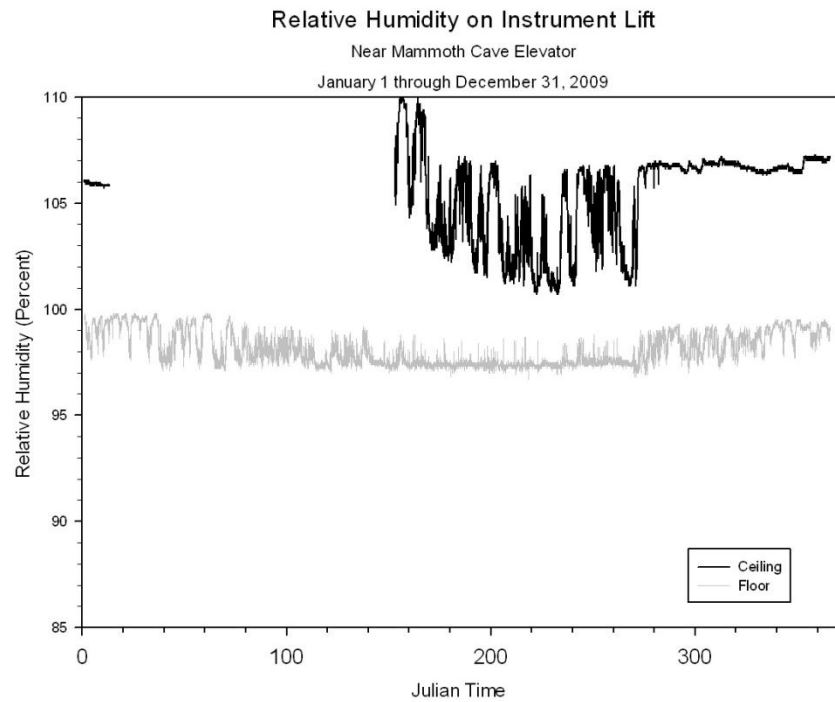


Figure 48 – Relative humidity at the two instrument lift system sensors. Missing ceiling data are due to sensor malfunction.

General Cave Meteorology Status

Cave meteorological sampling is continuing at MACA. All sites (with the exception of the instrument lift site which was shut down in February 2010) discussed in this report are currently active. Data presented in this report are archived and available upon request. To request these data, please contact the report's first author.

Future Cave Meteorology Monitoring Recommendations

The investigators recommend that monitoring should continue at the sites listed in Table 1 (with the exception of the instrument lift site). For lesser caves in that list, caves may be added and dropped as necessary. Some caves, for example, may be added in the future if it is learned that they support bats either during the summer or during the winter. Other such caves may be removed once sufficient data have been collected to determine the conditions under which bats are using those locations. The data provided through the Historic Mammoth Cave/Frozen Niagara network are useful in understanding the long-term behavior of the meteorological system in those parts of the Mammoth Cave system and continued monitoring is therefore recommended.

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- Kaemper, Max. 1908. Map of the Mammoth Cave Kentucky. Map. Redrafted in 1981 by Diana O. Daunt for the Cave Research Foundation with Cooperation of Mammoth Cave National Park.
- Woodman, R.L., J.W. Jernigan, B.C. Carson, and B.J. Moore. 2007. A Protocol on Sampling Designs and Methodologies for Selective and Adaptive Monitoring in Caves of Air Temperature, Relative Humidity, and Cross-Sectional Air Velocity throughout the Cumberland Piedmont Network. Unpublished protocol draft, Mammoth Cave, KY.