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Meteorological Comparison of Three Cave Systems

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METEOROLOGICAL COMPARISON OF THREE CAVE SYSTEMS

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ABSTRACT

Cave systems are home to delicate underground ecosystems that can be affected by changes in surface atmospheric conditions which in turn affect underground meteorology. Modern human use of caves is typically for tourism, so understanding surface-underground weather-climate interactions is important when caves carry streams that are prone to flooding in response to surface precipitation. The purpose of this research is to document the effects of surface weather conditions on cave meteorology in three different cave system types located in different geographic locations including an island, the central USA, and at high elevations in British Columbia. The study caves include Kaumana Cave in Hawaii, Coldwater Cave in Iowa, and Cody Caves in British Columbia. All harbor unique ecosystems, carry cave streams, and see tourist activity. Data loggers measuring temperature and relative humidity were installed in each cave system with a sampling interval of 5 to 10 minutes for a span of 5-7 days depending on the cave. Additional long-term sampling was conducted for Coldwater and Cody Caves. The data for all three caves, and local surface meteorological data from all locations were statistically analyzed and compared with results showing that there is a statistically significant relationship between surface meteorological conditions and cave system meteorology.

ACKNOWLEDGEMENTS

I would like to profusely thank Dr. Patricia Kambesis for far more than her assistance with this project. She took me on a potentially once-in-a-lifetime trip to be the first person that has ever explored portions of the 1880-1881 lava flow in Hawaii. Beyond that, she has always been in my corner ready to pick me up when I thought I couldn't go any further. I will truly be forever in debt to you, PK. Much of the same can be said for Dr. Goodrich: he set an example of a true man while going through extremely difficult circumstances, and I needed to see that. I needed to know that I could be stronger and put a better foot forward than what I presented my Junior year. Also, much thanks to John Pollack for all of his data from Cody Caves and for the personal encouragement while we were in Hawaii. Shout out to the whole team from the Hawaii exploration trip! Finally, thanks to the entire staff at the Kentucky MESONET at WKU, but specifically Dr. Foster and Patrick Collins for the instrumentation used in the research of the lava tube. An extra thanks to Patrick for the help analyzing the lava tube data and for being available at all times of the day for my constant questions.

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1. Introduction

This investigation conducted analysis of the meteorological conditions inside of the Kaumana 1880-1881 lava flow during October 2018. The purpose of the research was to compare the conditions of 3 caves and determine to what extent a cave system's atmosphere changes throughout the day and to what degree those changes came directly from the surface conditions present just prior to the observed changes. Analysis was conducted in a recently discovered upper portion of the lava tube as well as in the lower portion of the lava tube which is a tourist attraction. Much of this lava flow has yet to be mapped, so continued researched will be necessary in order to determine what combination of entrances or other cave characteristics influence the weather inside the lava tube. Beyond the scope of the original project, the team ran into a fortuitous flooding event after heavy rainfall overcame the lower portion of the cave. Research conducted on this fortunate circumstance included the rate of flow of the stream and also where the water seeped into a secondary passage under the main tube. Preliminary results from the sensors indicate that both temperature and relative humidity did in fact fluctuate slightly in both portions of the cave throughout the time period. The meteorological conditions also differed distinctly between the upper and lower portions of the cave system.

2. Literature Review

Cave meteorology has long been considered unchanging, but recent research has proven that the atmospheric conditions inside of caves can change quite a bit depending on many different factors of the cave itself. Caves that change drastically in elevation can experience large swings in temperature and other conditions just as one would expect the atmosphere above ground to do

(Covington and Perne 2015). Deep caves saw significant decreases in temperature for the first 50-100 meters in cave depth. Beyond the 100m mark, all the caves studied had an increase in temperature to the deepest point measured (Covington and Perne 2015). Conditions along a lateral profile of the cave will also change depending on the proximity of the sensor to the opening of the cave. The further a location is away from an opening to the cave, the less change there is in that location's meteorological conditions (McCann 2013).

Cave airflow changes depending on multiple other factors including the temperature gradient near the main opening of the cave, the width of the tunnel itself, and if there are any sunlight openings or other minor entrances into the cave (Covington and Perne 2015). Another factor is allogenic properties of the cave: if a large amount of water seeps into the cave, this will change both the humidity and temperature of the cave system (McCann 2013). A study on the extent of allogenic effects conducted on the Iowa and Minnesota border showed that water introduced into the cave closely resembled the temperature of the soil above the cave. The effects of the stream on the air conditions inside the cave were felt primarily at points less than 500 meters from the start of the stream, but tiny effects were felt all the way to 820 meters from the stream's start (Kambesis 2013). Data collected from the start of the stream's entrance to a data logger 198 meters away showed a significant range of temperatures when compared to the mean annual stream outlet temperature; therefore, the stream was capable of having significant effects on the air conditions up to that point in the cave (Kambesis 2013). Diurnal changes in relative humidity (RH) and temperature were observed and followed that of the changing conditions outside of the day with distinct maximum and minimum temperatures and RH values (Forbes 1998). Multiple studies studied beyond the short-term changes in cave conditions and logged data for months and even years (Kambesis 2013; Sanderson and Bourne 2002). These studies showed that clear seasonal changes in temperature and RH also occurred within the caves. These changes were not limited to the openings of the caves but went as far as at least 150 meters as evidenced by data collected from Bat Cave in Australia (Sanderson and Bourne 2002).

Another fascinating area of study using weather parameters is measuring the volume of caves without stepping foot inside them (Cigna). This can be useful no matter the size of the entrance to the cave but even more useful if the entrance is too small for a person to move through. Another way that pressure can affect conditions inside the cave is the drip rate of speleothem (McCann 2013). It was discovered by McCann that there is a weak correlation between outside cave pressure and the drip rate inside the cave.

The range of reasons to collect the atmospheric conditions inside of caves is extensive. Many animals use caves as homes, thus it is necessary to understand if a change in the cave's weather is the reason for a change in an animal's hibernation patterns or if it's something else. One study specifically wanted to know the prime conditions for the growth of gypsum inside caves, so sensors were used extensively in a vertical profile throughout the cave's rooms (Forbes 1998). Plants, bacteria, and fungi are often very limited in the conditions under which they can grow successfully. Knowing the conditions of the cave can help suggest what species of these smaller organisms might exist inside the cave or what organisms would thrive there.

3. Site Description

The study caves are located in three geographically distinct areas as follows. Cody Cave System is an alpine cave (high elevation) located in a provincial park of British Columbia in the Selkirk Mountains above Ainsworth Hot Springs. The Cody Cave System contains an underground stream that flows through limestone passages for over a kilometer. Tourism occurs in this cave during the summer months. Besides the main entrance, no other entrance has been recorded for this cave system. A map of the location along with sensor placement was provided by John Pollack (Figure 1).

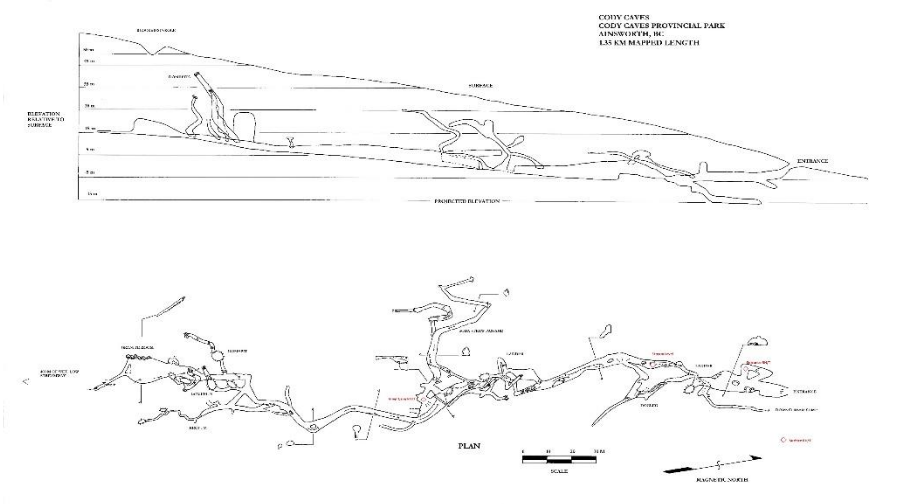

Figure 1: Map of Cody Caves with sensor locations. Courtesy of John Pollack.

Coldwater Cave System is located on the border of Iowa and Minnesota. Surface creeks drain through the karst and into the cave system. During heavy rain events and freeze-thaw evets, sinkholes throughout the region contribute to the recharge of the groundwater basin. The cave has been mapped to a total of 28km, and it is the longest cave in Iowa (Kambesis 2013). There are two access points into the cave. The primary access is a 29m man-made shaft located in the Flatland portion of the cave and was made in the 1970s for research. A secondary access point, created in 2003, is a privately-owned shaft 2km south of the other access point. When no research is being conducted, both are airlock sealed. No other entrances, manmade or otherwise, have been recorded for Coldwater Cave System (Kambesis 2013).

The 1880-1881 lava flow on Hawaii’s Big Island has not yet been fully explored, but recent attempts at mapping the entirety of the cave have seen much progress in the past couple years. The lava tube is about 40 kilometers long with only 3km open to the general public. This lower portion, called Kaumana Caves, is one of 3 major portions surveyed to date: the others are a 4km portion called Puka Palace and a 24km portion called Emesine. The tubes that connect the three pieces have yet to be found. The lava tube has isolated sunlight openings throughout the upper portion and at least one large opening that the team utilized for entrance and exit during the study. The lower portion also has a large opening, and the immediate entrance is very tall and wide. Within the main tube, there is a secondary, smaller tube that resulted from a secondary flow after the primary flow created the original tube. This secondary tube allowed for water seepage in at least the Kaumana Cave portion of the lava tube and was often broken down in the upper portion.

4. Methods

For the Hawaiian lava tube system, two thermistors were placed inside the cave and covered with a radiation shield to protect the sensors from water dripping directly onto them. Thermistors measure both temperature and relative humidity, so water contact would likely skew data. Two CR3000 data loggers from Campbell Scientific were used to store the data. A sensor was placed first in the upper portion of the lava tube and remained there for approximately 5 days. It sat on a naturally formed shelf where it could receive ample airflow and not be in the way of other ongoing research. The second sensor was placed in the lower portion of the cave system and hidden behind a large rock on the floor of the lava tube in order to prevent tourists from corrupting the data. It is a common tourist attraction, so there were fears that people would attempt to corrupt the data; however, examination of the data collected does not indicate any form of malicious human interaction. After heavy rainfall, the second sensor had to be moved to a higher location as well as slightly further into the cave due to fears that water would overcome the sensor and the data logger thus eliminating our data for the lower portion of the cave. It remained in that spot for the next 3 days. Data collectors were examined 6-12 hours after the initial placement to ensure they were properly collecting data. The data was downloaded every 24 hours to reduce loss of data if any outside circumstances were to affect the collection process such as undesired human interaction, water inundation, or loss of battery power. At the conclusion of the data collection period, data was immediately sent to the Patrick Collins who works for the Kentucky MESONET at WKU in the Environmental Science and Technology building on campus. Through Excel, Patrick created the graph for each site depicting temperature and RH.

For Cody Cave in British Columbia, data was collected by John Pollack of the Cave Research Foundation with the Royal Canadian Research Society. The data collected came from two sites: one sensor placed 20m inside the cave and the other placed 140m inside the cave (Figure 1). They will be referred to as the Entrance and Conservancy sensors respectively throughout the study. These Extech RHT 10 sensors collected data at 10-minute intervals from March to December 2018. The short-term data focused on a week-long period between October and November.

Data gathered for the Coldwater Cave system came from Dr. Patricia Kambesis of WKU. The Onset-Brand Optic Stowaway temperature data loggers collected data at 10-minute intervals and spanned an 8-year period from 2003-2010. However, the current study used just one year of data with a focus on a week-long period between March and April. Data was downloaded every other month or once every 3 months depending on the remoteness of the location of the logger. Charts and graphs of this data came directly from Dr. Kambesis's research. Six sensors were placed throughout the cave system at distances from 10m to 820m from the source of the stream that ran through the cave.

Surface data was gathered from the Midwestern Regional Climate Center located in University of Illinois at Urbana-Champaign for the locations at daily, hourly, and/or at 5-minute intervals depending on the availability of data. Hourly surface data for Cody Caves could not be retrieved from this particular resource. Hourly surface data was collected from the Decorah Municipal Airport weather station in Iowa, which is about 20 miles from Coldwater Cave. Surface data at 5-minute intervals for the Hawaiian lava tube came from a sensor 5 miles to the ESE of the opening to Kaumana Cave and 10 miles E of the upper portion of the cave. Daily surface data collected for Cody Caves came from a station in Nelson, British Columbia, located 37 miles to the SW of the cave. Precipitation data was collected by Dr. Kambesis for Coldwater Cave System from the web page for Minnesota Climatology Working Group.

5. Results

Data collected is depicted for Cody Caves at the entrance (Figure 2) and at the conservancy (Figure 3) over a 7-day period. A temperature decrease of .4°C is recorded in Cody Caves at the

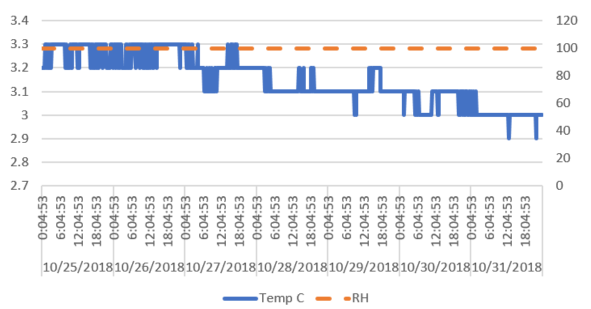

Fig. 2: T and RH Entrance sensor of Cody Cave Oct. 25th – 31st

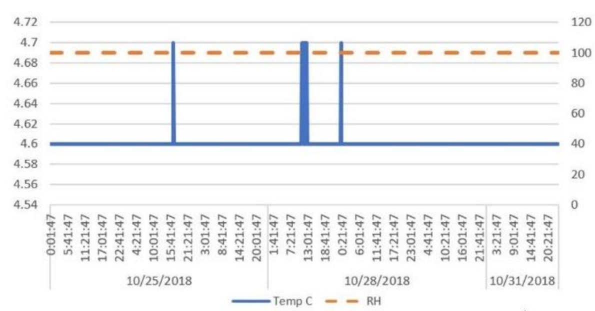

Fig. 3: T and RH Conservancy sensor of Cody Cave Oct. 25th – 31st

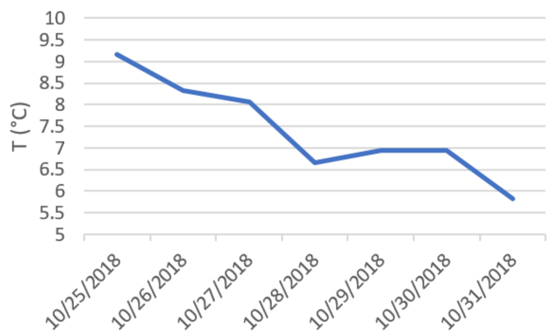

Figure 4: Average surface temp in Nelson, B.C.

entrance from the 25th-31st of October and clearly reflects the decreasing average temperature at the surface during that time period (Figure 4). The conservancy did not record a significant temperature change during this timeframe. Coldwater Cave air and water temps at the entrance of the stream are also depicted over a 7 day period (Figure 5). The air inside this portion of the cave follows the temperature pattern of the water flowing into the cave. This occurred during a multi-day diurnal freeze-thaw event. Hawaii data (Figures 6 and 7) is depicted over a 4-5 day period to show data along a similar temporal scale as the other two locations. The lower portion of the lava tube (Figure 6) experienced a slight change in temperature over the time period while the upper portion (Figure 7) experienced a more significant response to surface conditions. RH for both graphs is represented by the straighter line with a value of nearly 100% while temperature is represented by the line that wavers. Temperatures were higher for the lower portion of the lava tube which would be expected as air temperatures at the surface decrease with an increase in elevation. Additional

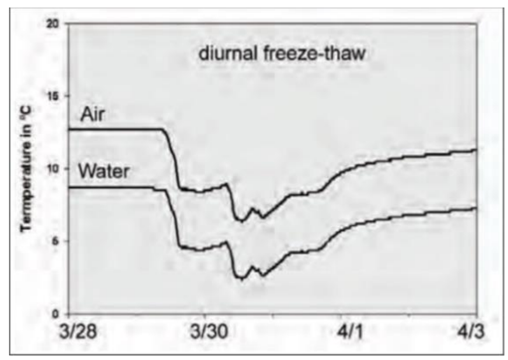

Figure 5: Air and Water Temps Coldwater Cave Courtesy of Kambesis, 2013

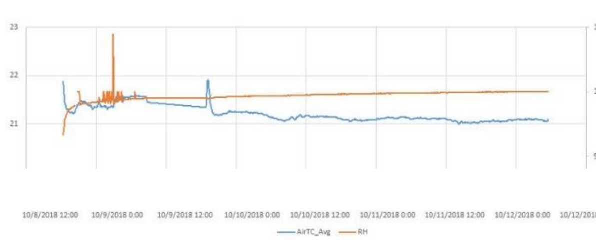

Figure 6: Kaumana Cave Sensor

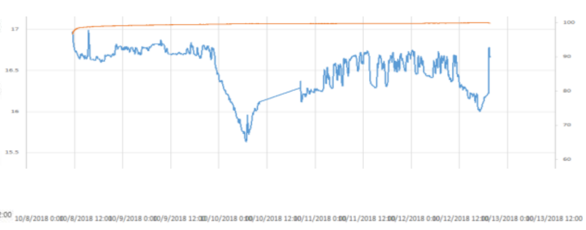

Figure 7: Upper Portion lava tube sensor

data to show the maximum change in cave conditions spans a multi-month period for Cody Caves (Figure 8 and 9) and the Coldwater Cave System (Figure 10).

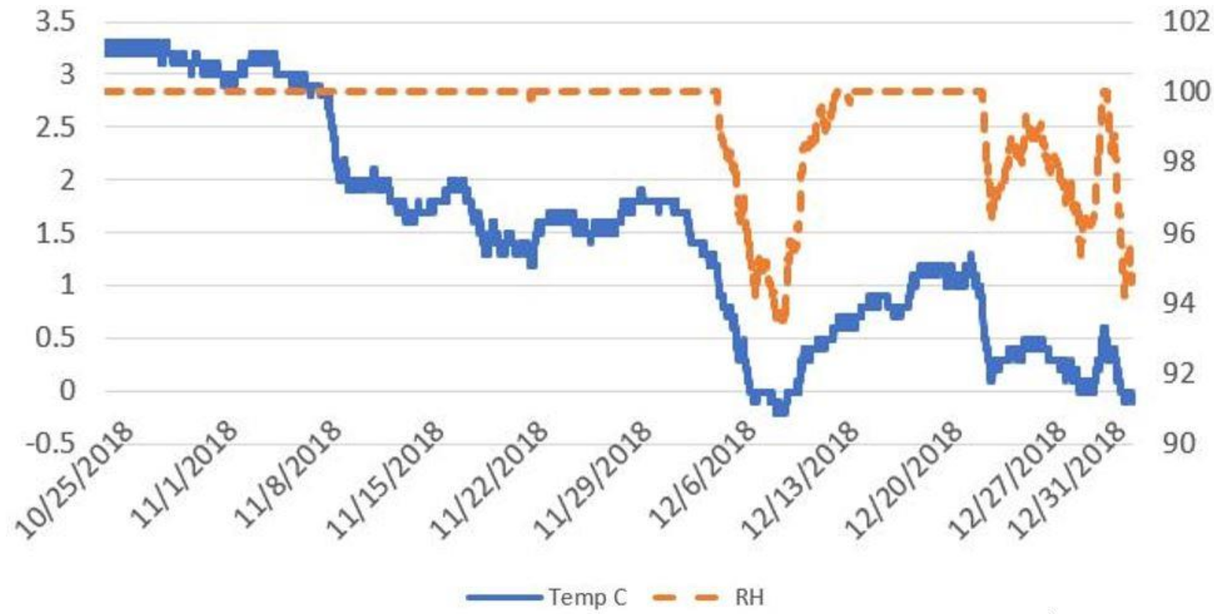

Figure 8: Entrance sensor of Cody Cave Oct.-Dec. 2018

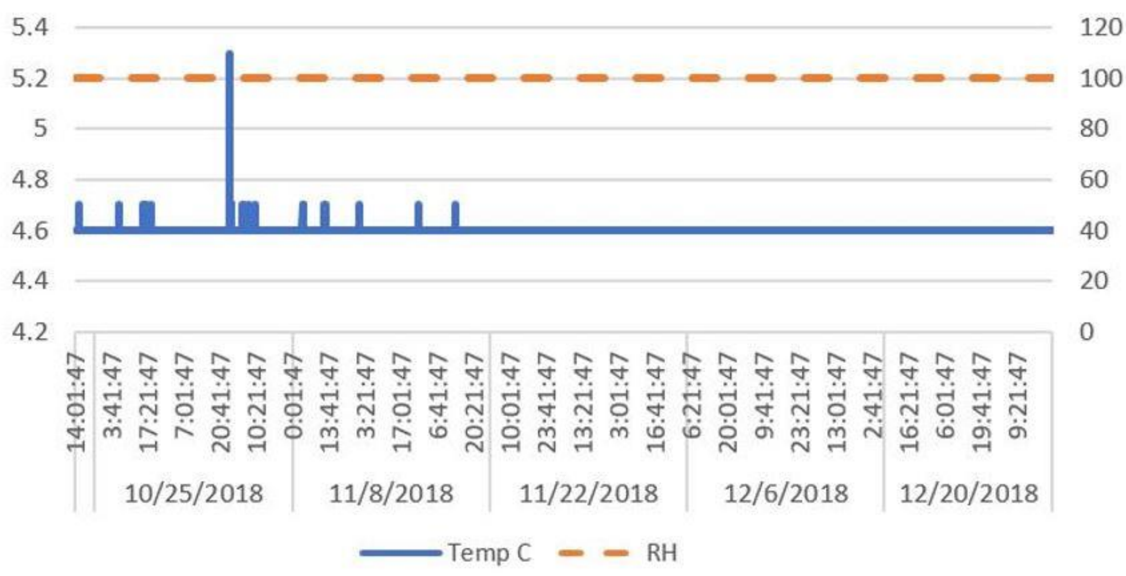

Figure 9: Conservancy sensor of Cody Cave from Oct. – Dec. 2018

The temperature response in Cody Caves is seen very clearly from the latter half of October to the end of December 2018: as surface temperatures dropped, the temperature near the cave entrance responded in a similar manner within a reasonable timeframe (Figure 8).

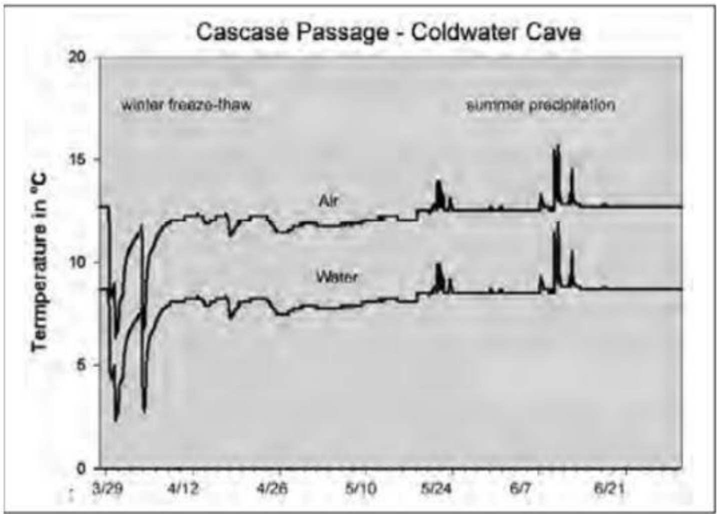

Figure 10: Long-term Cascase Passage - Coldwater Cave Courtesy of Kambesis, 2013

The largest changes in temperatures occurred within the Coldwater Cave system. This was due to the stream flowing through the cave. Cave air temperatures responded with a 3-4 hour lag to the temperature of the water flowing through the cave (Kambesis 2013). This is most evident in the diurnal freeze-thaw of late March to early April (Figure 10). The sensors closer to the entrances of each cave system (Figure 8) or stream entrance (Figure 11) into the cave show an increased response to surface changes compared to those located further in the cave (Figures 9 and 11).

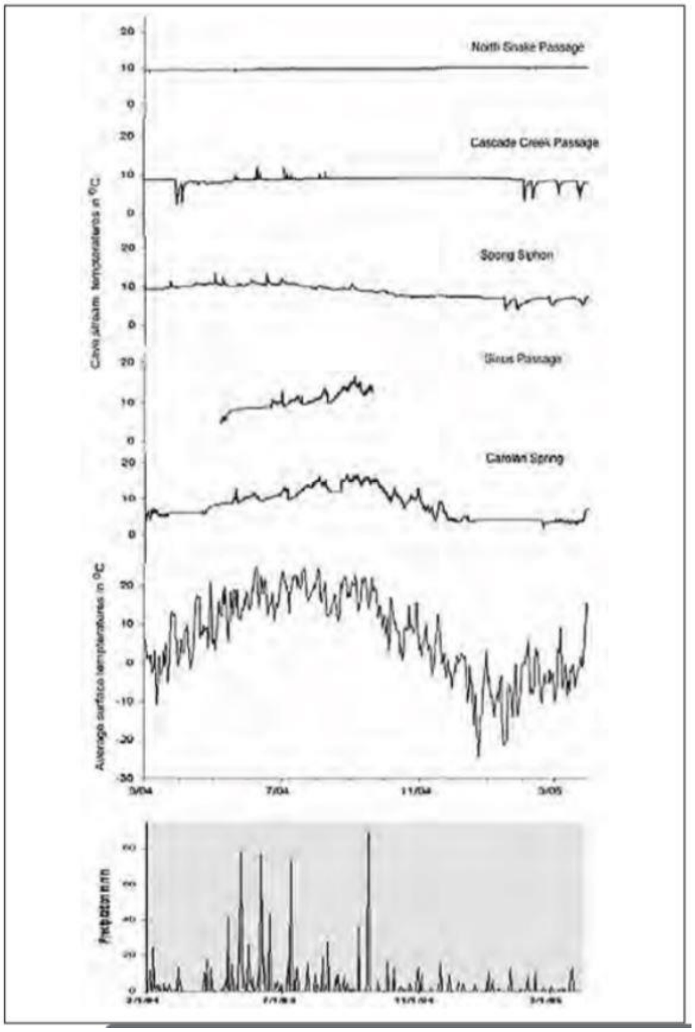

Figure 11: Spatial variation of cave stream temperature and precipitation events Courtesy of Kambesis, 2013

6. Discussion

A very distinct decrease in surface air temperature is seen within the Hawaii data on the morning of Oct. 10th as the low temperature dropped to just below 17°C at 6am (Figure 12). This decrease in temperature can be seen primarily on the graph for the upper portion of the lava tube as the air inside the cave dropped from 16.75°C at 11pm to 15.7°C around 7:30am (Figure 7). This was the fastest response to surface changes recorded in the study, which likely was due to the location of the sensor between two openings. The first opening was the large entrance researchers used during the study, but the second was only approximately a meter in diameter. Both openings were at least 50m from the sensor; however, they still proved capable of providing additional airflow to this portion of the lava tube. One thing that must be noted within the data collected for the lower portion of the lava tube is a spike in humidity values over 100% (Figure 6). This was due to water droplets splashing onto the thermistor during the flooding event that occurred just hours after we had placed the sensor in the tube. The instrumentation did recalibrate itself once it was placed in an area high above the newly formed stream. Temperatures in the lower tube (Figure 6) still reflected changes in surface temperatures (Figure 12); however, they were to a lesser magnitude and at a slower rate than the upper portion (Figure 7). Also note that the upper portion is much cooler than the lower portion by about 5-6°C throughout the time period. This is a direct result of cooler temperatures with respect to increased elevation.

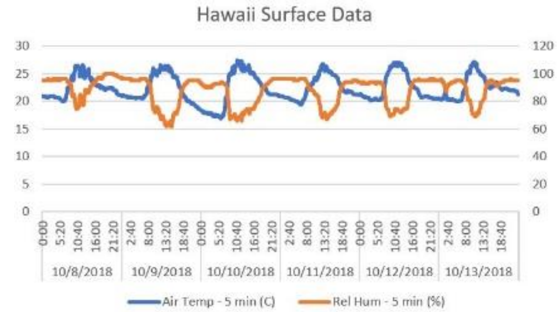

Figure 12: 5-min surface data located near lava tube

The entrance to Cody Cave also experienced a very distinct response to changes at the surface along both the short and long temporal scales. As average daily temperatures dropped from 9.2°C to 5.8° from October 25th-31st (Figure 13), the cave temperature dropped from 3.3°C to 2.9°C (Figure 2). This timeframe was expanded to show October-December, and there is a

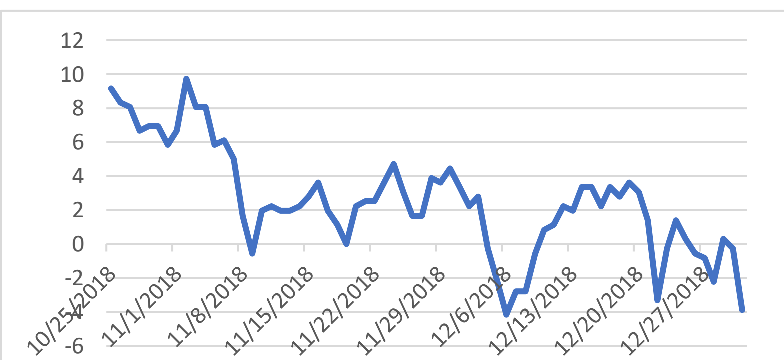

Figure 13: Cody Cave average daily temperature in degrees Celsius

clear response to surface conditions throughout the time period (Figure 8). Additionally, this cave saw the largest fluctuation in relative humidity at its entrance.

The largest temperature changes were recorded within the Coldwater Cave System. These changes were influenced directly and entirely by the stream that flowed through the cave. With no openings to the cave except those used by researchers during the study, airflow is not responsible for any changes in cave conditions. Temperature fluctuation was greatest during the freeze-thaw events between November and March (Kambesis 2013). Figure 4 shows a 7°C drop in cave air temperature in about 36 hours as cold water flowed through the cave during a March freeze-thaw event. Figure 14 shows the transition of temperatures from freezing to above freezing thus producing the freeze-thaw event two days in a row on the 29th and 30th.

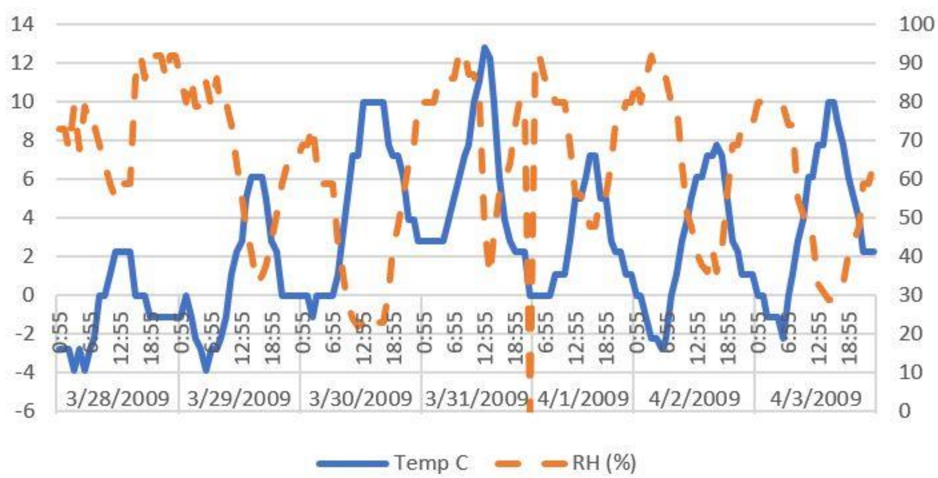

Figure 14: Hourly surface data near Coldwater Cave

Deep portions of Cody Caves (Figure 9) and the Coldwater Cave System (Figure 15) saw little to relatively no changes in their temperatures. The lower portion of the Hawaiian lava tube also saw little variation to the surface primarily due to the sheer magnitude of this portion of the tube and the lack of a secondary opening to allow more airflow (Figure 6).

Data logger location	Distance (meters) of data logger location from surface stream input	Associated surface stream (confirmed via dye trace)
North Snake Passage	820*	Pine Creek
Entrance Platform	730*	Deer and Pine Creeks
Cascade Creek	198**	Pine Creek
Sinus Passage	133**	Pine Creek
Spong Siphon	30**	Deer Creek
Carolan Spring	10	Pine Creek

* very little variation in stream and air temperature
** water temperature variations five degrees above and seven degrees below mean annual spring outlet temperature

Figure 15: Data logger locations and distance from surface water inputs Courtesy of Kambesis, 2013

7. Conclusions

The largest changes in temperature within a cave occurred in two facets. The first observed difference in cave temp is a decrease in response to the surface diurnal and even seasonal temperature change the further into a cave a sensor is located. Cave entrances experience the largest change in temperature and RH due to the ability of air to sink into the cave or rush out of the cave. The second observed difference is a change in temperature in response to streams flowing through caves (allogenic recharge). This produces changes in temperature further into the cave more efficiently than airflow into or out of the cave through a spotlight or cave entrance.

8. Future Work

While sensors underground determined a change in conditions with elevation between the two lava tube passages as well as small daily variations, it would be beneficial to know the exact surface conditions at the time of the readings. The use of nearby sensors sufficed for this preliminary study, but more exact data could be used to produce more exact comparisons. Besides the applications for determining what kind of organisms might thrive inside of the cave systems, there exists the potential impact surface conditions might have on tourist activity. As noted in the Kaumana Cave example, caves can flood without much notice depending on the rate of rainfall. There have been numerous news stories over the years of how floodwaters trapped people inside caves for long periods of time. Knowing the soil saturation and exactly how much rain/ the rate of rainfall it takes to start flooding a cave can help save lives by allowing caving companies to shut down cave tours as those thresholds are approached.

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