THE ENVIRONMENTAL EFFECT OF MUMMIFICATION

IN TEXAS AND COLORADO

by

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I. INTRODUCTION

Background and Literature Review

Desiccation of soft tissue can occur in varied environments, and extrinsic environmental factors are generally identified as the primary cause (Arriaza 1995, Aufderheide 2003, 2011, Connor 2017, Dix and Graham 2000, Introna et al. 2011, Janaway et al. 2009, Pratz-Muñoz et al. 2013, Reinhard 2016, Vidale et al. 2016, Wescott et al. 2016). Studies have also shown that a lack of or minimal insect activity creates optimal circumstances for mummification and desiccation to occur (Dix and Graham 2000, Janaway et al. 2009, Rivers 2013) (See APPENDIX A for Donation Insect Activity Notes).[1]However, little research has examined how environmental factors combine in different climatic zones to cause mummification. Therefore, research is needed to examine these factors. The purpose of this study is to examine skin and other soft tissue desiccation in two climate zones to determine how desiccation correlates with environmental variables, and if these variables are the same in both environments. The goal is to tease out the possible causal factors in each environment. The study will also examine if the pattern of mummification (e.g., skin only, skin and internal organs, exposed skin only, or all skin) differs by climatic zone. To my knowledge this study is the first attempt to examine the relationship between mummification and multiple, quantifiable environmental factors in two different climate zones (Brooks et al. 2016). This research is important to forensic anthropology because the rate, extent, and pattern of soft tissue desiccation can influence the estimation of the postmortem interval (PMI)

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[1]). Minimal/mild insect activity is defined as one insect to numerous insects that roughly covered the body but are well spaced-out (moderate). Heavy ranges from just after moderate to the body being completely covered with insects.

and possibly the interpretation of trauma in medicolegal death investigations involving surface remains. By first understanding the environmental variables that influence the rate and pattern of desiccation in different regions, we may then be able to make adjustments to methods that use morphological changes of the body to provide more accurate and reliable estimations of the PMI.

Soft Tissue Desiccation

Mummification is the process whereby human remains are preserved due to drying (Cockburn et al. 1998). Desiccation is a process within mummification in which loss of moisture occurs. Mummification and desiccation of soft tissues can either occur naturally during the decomposition process or artificially as the result of human action (Samadelli et al. 2013). This thesis will focus on natural mummification. While there is a body of forensic and archaeological literature on mummies and the phenomenon of mummification (Arriaza 1995, Dix and Graham 2000, Aufderheide 2003, 2011, Introna et al. 2011, Pratz-Muñoz et al. 2013, Brooks et al. 2016, Reinhard 2016, and Vidale 2016), there has been very little attempt to analyze the relationship between quantitative environmental variables and the desiccation of soft tissues. The literature is generally vague and only suggests that natural mummification can occur when the body is interred in sand or soils rich in nitrates or exposed to hot and arid, windy, or extremely cold environments (Aufderheide 2003, 2011, Janaway et al. 2009, Introna et al. 2011, Brooks et al. 2016). Natural mummification, especially of the skin, can occur in numerous climates as long as bacterial and insect proliferation is limited (Dix and Graham 2000, Janaway et al. 2009). Research at human decomposition facilities at Texas State University and Colorado Mesa University, for example, has demonstrated that desiccation of the skin can occur in both a subtropical climate with adequate moisture and temperature for bacterial and insect activity as well as a cold arid climate (Suckling et al. 2016, Bates and Wescott 2016, Connor et al. 2017). Work by Lennartz (2018) in Texas suggests that high temperature may be the driving factor in desiccation in more humid environments such as central Texas.

Climate Zones

Climate is the average of weather recorded over a long period and has a significant effect on natural soft tissue desiccation during the decomposition process. In the United States, there are numerous climate zones (Figure 1). Each climate zone has a different combination of environmental factors such as temperature, humidity, and precipitation. The most commonly used climate classification scheme is the Köppen system which uses five major climatic types (i.e., tropical or equatorial, dry or arid, temperate, snow, and polar or alpine) and 14 climate subtypes based on averages of temperature, precipitation, and humidity in a region (Kottek et al. 2006). These climatic types and subtypes combine to create 31 distinct climatic zones located all over the world. Each climate type and subtype are designated by a letter (Table 1). Most of these zones are present within the United States, but the most common are Cfa (warm temperate climate, fully humid, with hot summers), and BSk (arid climate, steppe, with cold arid temperatures) (Kottek et al. 2006). The two climate regions in which research was conducted are Cfa in San Marcos, Texas and BSk in Whitewater, Colorado.

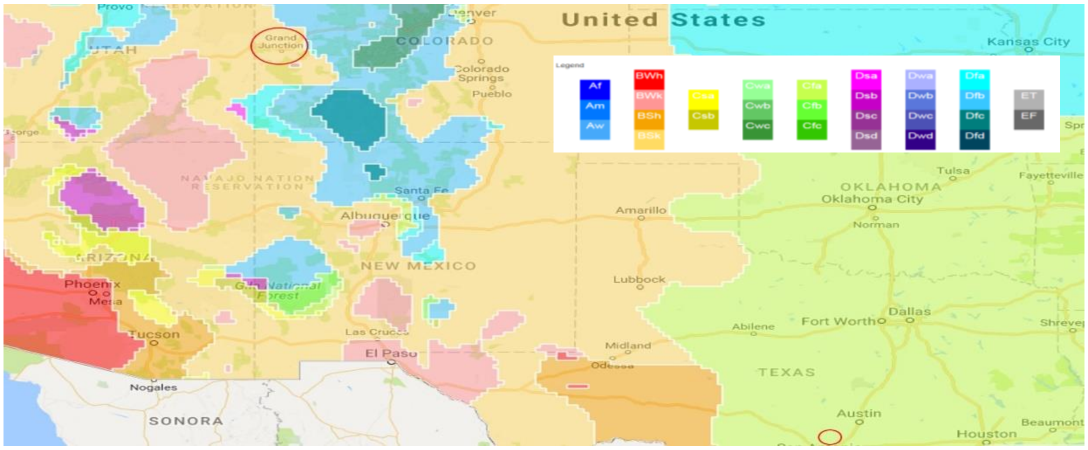

Figure 1: Map of Köppen Climate Classifications for Whitewater, Colorado, and San Marcos, Texas Indicated by Red Circles (PlantMaps 2016)

Table 1: Köppen Classification System (Kottek et al. 2006)

Major Type		Precipitation Type		Temperature Type	
Letter	Description	Letter	Description	Letter	Description
A	Equatorial	W	desert	h	Hot arid
B	Arid	S	steppe	k	Cold arid
C	Warm	f	Fully humid	a	Hot summers
D	Snow	s	Summer dry	b	Warm summers
E	Polar	w	Winter dry	c	Cool summers
		m	monsoonal	d	Extremely continental
				F	Polar frost
				T	Polar Tundra

Relationship Between Desiccation and Environmental Variables

Mummification of soft tissue can occur in a variety of environmental conditions such as aridity, acidity, salinity, and extreme cold. If microbial and insect activity is minimized, natural mummification can occur (Aufderheide 2011). Unfortunately, we have little knowledge of how extrinsic abiotic environmental factors such as humidity, temperature, ventilation (wind), solar radiation, and other environmental factors combine to cause desiccation of soft tissues in different climate zones. Therefore, research examining the relationship between extrinsic abiotic environmental variables and soft tissue desiccation in different climates is needed to fully understand how mummification of soft tissues occurs naturally, what environmental factors cause mummification, and if these variables have a similar effect on desiccation in different climatic areas.

Moisture Analysis

The loss of moisture during decomposition plays an important role in the preservation of soft tissues. In the food industry, for example, moisture content is considered very important in food preservation because the level of moisture present in different types of foods has a strong influence on quality and stability. Increased moisture content can lead to mold growth and increased bacterial activity that can make food unsafe to consume (Global Marcom Switzerland 2017). During the human decomposition process, moisture can also influence the rate of soft tissue loss by limiting or increasing bacterial activity.

There are many ways to measure the moisture content of different products. These include thermogravimetric analysis, chemical analysis, spectroscopic analysis, and others (Global Marcom Switzerland 2017). Thermogravimetric analyses include loss-on-drying methods in ovens, microwaves, and halogen/IR. Chemical analyses include Karl Fischer titration and calcium carbide testing (Global Marcom Switzerland 2017). Spectroscopic analyses include IR spectroscopy, microwave spectroscopy, and H-NMR spectroscopy (Global Marcom Switzerland 2017). Other types of analysis include gas chromatography, density determination, and refractometry (Global Marcom Switzerland 2017). Ideally, the water activity of mummified skin would be recorded. Water activity provides a measure of the water that is available in a material to react with organisms (e.g., bacteria and mold), elements in the air, and other materials. However, the analysis of water activity requires removing large samples of tissue and costly equipment, which would not have allowed other research to be done on donations. Therefore, in this thesis, moisture content was used. The moisture content provides a quantitative measure of the percent of water in the soft tissue.

Purpose and Research Questions

The purpose of this research is to examine the relationship between extrinsic abiotic environmental variables and soft tissue moisture during the decomposition process in human remains allowed to decompose naturally in two distinct climatic zones. There are two primary aspects of this research. First, the study seeks to compare the overall pattern of desiccation in bodies allowed to decompose in the humid, subtropical climate in Texas and the cold, semi-arid climate in Colorado. Second, the study examines the relationship between quantifiable extrinsic environmental factors within these two climatic regions with moisture loss in the skin. The environmental factors that will be considered are ambient temperature, humidity, solar radiation, cloud cover, precipitation, dew point, wind speed, and altitude. Therefore, the following research questions will be addressed:

1) Does the visual pattern of desiccation or rate of moisture loss differ between the two climates? The visual pattern of desiccation has two parts: part one refers to whether all skin or just exposed skin has dried out; part two refers to whether skin and organs or just skin has desiccated.
2) Is there a correlation between actual level of soft tissue moisture loss and extrinsic environmental variables?
3) Is the correlation between extrinsic environmental variables and soft tissue moisture loss the same in the two climatic regions?

Impact Statement and Summary

The research conducted in this thesis is important to forensic anthropology because it will increase our understanding of the different relationships between moisture loss (i.e., desiccation) during decomposition and extrinsic environmental variables in different climates. Measurements of the soft tissue moisture content in human skin before, during, and after decomposition were correlated with environmental factors to examine the relationship between these two factors and if they are consistent in the two climates. Knowing which factors have a correlational effect on mummification will allow researchers to know in which climates that mummification will more likely occur and the environmental factors that contribute to desiccation in the region. This knowledge will aid estimations of the postmortem interval in medicolegal death investigations.

II. MATERIALS AND METHODS

Decomposition Facilities

Data were collected at two human decomposition facilities. The Forensic Investigation Research Station (FIRS) is associated with Colorado Mesa University in Grand Junction, Colorado. The facility is located approximately 20 minutes away in the town of Whitewater, Colorado. The Forensic Anthropology Research Facility (FARF) associated with the Forensic Anthropology Center at Texas State University in San Marcos, Texas is located in the Texas Hill Country. The closest weather station to FIRS is approximately 7 miles away in Orchard Mesa. There is a weather station located at FIRS, but it does not collect all the necessary data. This is the same for FARF; however, the nearest weather station is located in San Marcos. Because these two decomposition facilities are in such distinct geographical areas, they are each represented by different Köppen Climate Zones. The Köppen classification for Whitewater, Colorado is BSk or cold semi-arid (Kottek et al. 2006). The Köppen classification for the San Marcos region is Cfa or humid subtropical (Kottek et al. 2006).

In Colorado the temperature generally ranges from 20 °F to 94 °F (-6.6 to 34.4 °C) throughout the year. On the hottest day of the year, the average high temperature is about 94 °F (34.4 °C), and the average low temperature is about 66 F (19 °C) (WeatherSpark for Orchard Mesa, CO 2017). On the coldest day of the year, 37 °F (2.8 °C) is the average high temperature and 20 °F (-6.7 °C) is the average low (WeatherSpark 2017). The average probability of precipitation during the year ranges from 8%-21% (WeatherSpark 2017). This area receives on average about 9 inches of rain per year and 19 inches of snow. Relative humidity throughout the year is near 0%. Wind speed can range from 1.1-11.3 miles per hour throughout the course of the year, with the average ranging between 3.3 and 4.5 miles per hour (WeatherSpark for Orchard Mesa, Colorado 2017). The sun in Orchard Mesa is at its brightest (meaning higher solar energy and radiation) during the summer, especially June, when the solar energy is 8.4 kilowatt hours (kwh). It is at its darkest during the winter, particularly December, when the solar energy is 2.5 kwh (Weatherspark for Orchard Mesa, Colorado 2017). The altitude in this region is approximately 4,673 feet above sea level (On/Board Informatics 2017).

During the course of the year, the average temperature in San Marcos, Texas ranges from 41 °F to 96 °F (5-35.5 °C). On the hottest day of the year, the average high temperature is about 96 °F (35.6 °C), and the average low temperature is about 74 F (23.3 °C). On the coldest day of the year, 61 °F (16.1 °C) is the average high temperature and 41 °F (5 °C) is the average low (WeatherSpark 2017). The average probability of precipitation during the year ranges from 14%-33%, and when precipitation occurs, it is generally in the form of severe thunderstorms. This area receives an average of about 32 inches per year. San Marcos is, on average, relatively humid, with the humidity during the summer months ranging from 20% to 79%. During the winter, however, the humidity is considerably lower (at around 0%-20%), but the average humidity level for the year is 67%. The wind speed at San Marcos throughout the course of a year generally ranges from 1.3-11.1 miles per hour, with the average ranging from 4.2-5.8 miles per hour. The solar energy, or radiation, in San Marcos, Texas, is at its highest in the summer, especially in June, when the level of radiation is 7.0 kwh. It is at its lowest during the winter, particularly in December, with a radiation level 3.1 kwh (Weatherspark for San

Marcos 2017). The altitude of this region is approximately 619 feet above sea level (On/Board Informantics 2017).

Materials

The final sample size of this research project consisted of 7 donated individuals: 3 donations from Colorado Mesa University and 4 donations from Texas State University. The original proposal for sample size was a total of ten donations: 5 from each decomposition facility. However, FIRS only had one donation when I first visited. Therefore, I chose to stay for a month and see if they received any more; they did not. They did, however, receive more donations roughly a week after I left. Because of the lag between the donations received by FIRS, I needed to train a Colorado Mesa University undergraduate student to take measurements in my absence (See APPENDIX B for Data Collection Protocol). As for donations to FARF, there was a relative slow period in October and the beginning of November with receiving donations. At the same time, another project was being performed which limited the donations available. Table 2 provides basic demographic information about the seven donor bodies used in the study. There were some discrepancies in body size and sex between the different donations. In one previous study, it was shown that body size effects the rate of decomposition (Sutherland et al. 2013). However, that study was done using pigs as a proxy, and there was another study using human remains that showed that although there were some minor differences between large and small individuals in relation to decomposition, there were no statistically significant differences (Roberts et al. 2017). Body size was not considered for this thesis project due to the lacking sample sizes from both decomposition facilities. There have been very few, if any, studies that test the effect of sex on the rate of human decomposition. However, sex may influence the body size of an individual because in the United States, males tend to be larger than females. However, because there seem to be no significant effects of body size on the rate of decomposition, this possibility is negligible.

Table 2: Demographic Information for Donations Used

Donation Number	**Biological Information**		
Colorado	**Sex**	**Age**	**Weight**
17-07	Male	55	203 lbs (92.08 kg)
17-09	Female	75	153 lbs (6.94 kg)
17-10	Male	74	118 lbs (53.52 kg)
Texas	**Sex**	**Age**	**Weight**
D57-2017	Male	71	185 lbs (83.91 kg)
D61-2017	Female	23	75 lbs (34.02 kg)
D63-2017	Male	74	254 lbs (115.21 kg)
D70-2017	Female	61	81 lbs (36.74 kg)

Methods

Weather Data

Weather data were collected for each site during the study period. The environmental variables collected included ambient temperature, humidity, solar radiation, cloud cover, precipitation, dew point, wind speed, and altitude. Table 3 contains information about the dates in which data was collected as well as average weather information in Colorado and Texas.

At FARF there are two weather stations that record this information every 30 minutes. Because the weather stations do not collect information on the dew point, cloud cover, or altitude, the former two as well as wind speed were collected from MesoWest (https://mesowest.utah.edu/) twice daily, and the latter was collected using the Altimeter+ on a cell phone (once at the beginning of each placement)(Sichtwerk AG 2017). There is one weather station at FIRS that collects data every hour. The same three environmental variables were not collected from the station in Colorado, so using the MesoWest website, this additional data was included in the analysis (Table 4). Using ambient temperature, Accumulated Degree Days (ADD) was calculated. ADD is a standardized temperature scale for the study of human decomposition. It is calculated by totaling the average daily temperatures since a body has been exposed to the elements. The baseline temperature is 0 degrees °C. Because this temperature scale has been standardized for decomposition studies, ADD was used as one of the environmental variables (McDaneld 2016).

Table 3: Dates and Environmental Data for Each Donation

Donation Number	Dates and Environmental Data
17-07 / GJ (Grand Junction) Body 1	June 29, 2017 – August 10, 2018 Average Temperature: 80.784 °F (27.102 °C) Average Humidity: 36.76% Average Cloud Cover: 32% Average Rainfall: 0.00155 mm (0.000061 in) Average Solar Radiation: 464.108 Wm^2 Average Dew Point: 45.873 °F (7.707 °C) Average Wind Speed: 12.46 mph (20.06 kph)
17-09 / GJ Body 2	August 10, 2017 – September 21, 2017

	Average Temperature: 75.966 °F (24.425 °C) Average Humidity: 32.281% Average Cloud Cover: 26.456% Average Rainfall: 0.101 mm (0.004 in) Average Solar Radiation: 418.548 Wm^2 Average Dew Point: 40.494 °F (4.719 °C) Average Wind Speed: 10.861 mph (17.479 kph)
17-10 / GJ Body 3	August 10, 2017 – September 21, 2017 Average Temperature: 75.966 °F (24.425 °C) Average Humidity: 32.281% Average Cloud Cover: 26.456% Average Rainfall: 0.101 mm (0.004 in) Average Solar Radiation: 418.548 Wm^2 Average Dew Point: 40.494 °F (4.719 °C) Average Wind Speed: 10.861 mph (17.479 kph)
D57-2017 / TX State Body 1	September 22, 2017 – November 3, 2017 Average Temperature: 68.897 °F (20.498 °C) Average Humidity: 76.992%

	Average Cloud Cover: 40.04% Average Rainfall: 0.043 mm (0.002 in) Average Solar Radiation: 176.75 Wm^2 Average Dew Point: 58.356 °F (14.642 °C) Average Wind Speed: 8.848 mph (14.239 kph)
D61-2017 / TX State Body 2	October 4, 2017 – November 15, 2017 Average Temperature: 66.313 °F (19.063 °C) Average Humidity: 76.21% Average Cloud Cover: 46.81% Average Rainfall: 0.01437 mm (0.0006 in) Average Solar Radiation: 164.885 Wm^2 Average Dew Point: 55.777 °F (13.209 °C) Average Wind Speed: 8.787 mph (14.142 kph)
D63-2017 / TX State Body 3	October 18, 2017 – November 29, 2017 Average Temperature: 62.356 °F (16.865 °C) Average Humidity: 73.785% Average Cloud Cover: 43.513%

	Average Rainfall: 0.353 mm (0.014 in) Average Solar Radiation: 149.147 Wm^2 Average Dew Point: 52.465 °F (11.37 °C) Average Wind Speed: 8.694 mph (14.142 kph)
D70-2017 / TX State Body 4	November 28, 2017 – January 5, 2018 Average Temperature: 48.353 °F (9.085 °C) Average Humidity: 79.076% Average Cloud Cover: 53.741% Average Rainfall: 0.0538 mm (0.0021 in) Average Solar Radiation: 97.617 Average Dew Point: 41.072 °F (5.04 °C) Average Wind Speed: 8.71 mph (14.018 kph)

Table 4: Environmental Variables and the Methods Used to Record Them

Recording Method	On-Site Weather Station	MesoWest	Cell Phone
Environmental Variable	Ambient Temperature	Cloud Cover	Altitude
	Humidity	Dew Point	
	Solar Radiation	Wind Speed	
	Precipitation		

Tissue Moisture

Soft tissue moisture was examined using a Delmhorst RDM3 moisture content meter, which is commonly used for wood (Delmhorst Instrument Co. 2017). Attached to this meter were 15E electrodes from Delmhorst Instrument Co. The electrodes have a maximum penetration of 1/8 of an inch (Delmhorst Instrument Co. 2017). These electrodes are pointed but, in this study, only enough pressure was applied for them to create a superficial indentation – the electrodes did not puncture the skin. However, it was shown that the needles on the actual meter did no damage to the skin either. Therefore, the electrodes were not necessary. Another set of electrodes was not purchased for San Marcos, and the needles on the meter itself were used to collect moisture data at FARF. A minimum moisture content level of five percent and a maximum of 60% was chosen because these values represent the range of moisture content levels for these meters (Delmhorst Instrument Co. 2017). If the measurement is lower than 5% moisture content, the screen said low. If a measurement is higher than 60%, the screen said high.

Moisture measurements were taken from the left side—nose, left ear, forehead, chest, left arm, left finger, left leg left toe, and sole of the left foot—with a few exceptions (Figure 2). These areas were chosen so that a relatively accurate measurement of the whole body could be taken. The left side was used because it is standardized. With the first donation from FIRS (17-07), the body was placed on an incline, with the left side facing downslope. It was determined that because of gravity acting on the fluids within the body during decomposition, the moisture level would be greater on the left side and affect the measurements. Therefore, the right side was chosen, except for the ear (the left ear was chosen because when the individual was placed, he was already beginning rigor, and his head was laying with his face toward the right; an attempt was made to reposition the head, but it was difficult if not impossible to do so). After each individual moisture content measurement was recorded from the different regions of the body, the median was calculated as a way to quantify the process of mummification and desiccation. The median moisture content is what was eventually run against environmental variables. If a particular measurement is low (<5%) or high (>60%), the variables of 4.90% and 61.0% were used in determining the median. This was because many of the individual measurements were lower than 5% (especially in Colorado) as well as higher than 60%, and not including these high and low measurements would skew the medians. Measurements were taken once at placement and then twice a day for a total of six weeks.

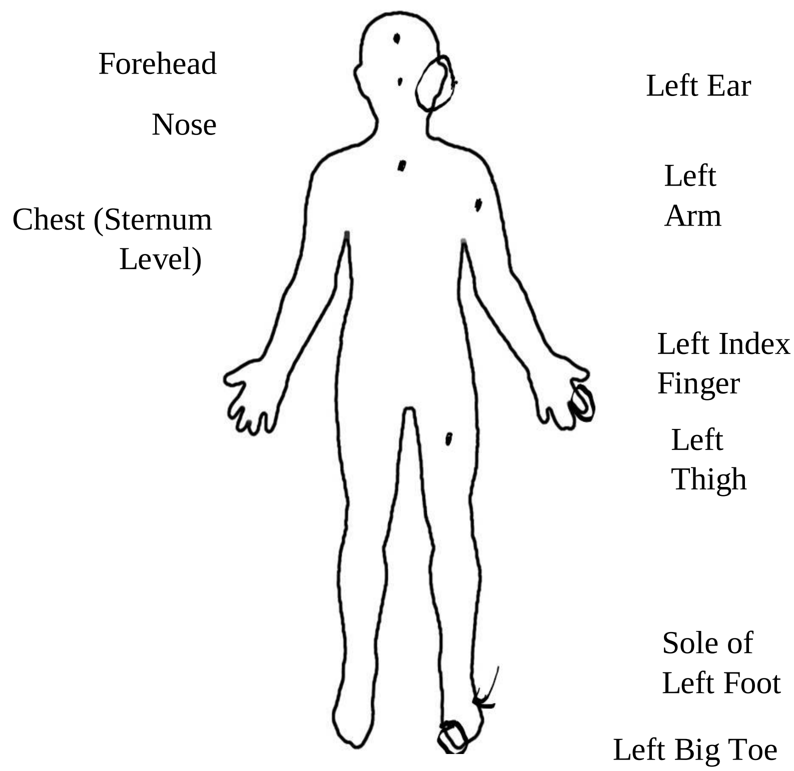

Figure 2: Diagram of Body Areas

<u>*Data Analysis*</u>

To answer the three research questions posed earlier in this section, seven statistical tests were performed. To address the first question regarding the difference in desiccation pattern between Colorado and Texas, the overall pattern of mummification from donor bodies at FIRS and FARF was examined through longitudinal observation of each of the three donations at FIRS and four donations at FARF. The bodies were examined to determine if soft tissue preservation includes skin only or skin and other soft tissues such as organs. The bodies were also examined to determine if all regions of the body undergo skin desiccation or only the exposed regions. That is, do the portions in contact with the ground surface desiccate? This was tested by rotating the remains onto the front side (once at the end of data collection) to see if the back side has mummified. Differences in the pattern of desiccation in the two climate zones were tested using a Wilcoxon Rank Sum test. In order to quantify the categorical variables pertinent to the first research question, all skin was marked with a 1 and only exposed skin was marked with a 0. For the second part of this question, the category of skin and organs was marked with a 1, and only skin was marked with a 0.

To address the second question, regarding whether there is a correlation between environmental variables and soft tissue desiccation, the package lme4 in R was used to create formulae and run multilevel linear regressions with fixed effects. This type of test was used because, unlike single-level linear regressions, it allows for control variables to be taken into consideration. These controls (or "fixed effects") help to reduce bias within recorded data, especially in situations with such a small sample size (Ma et al. 2018). Two assumptions for this type of test are independence of random effects (in this project, the environmental variables) and a normal distribution (Finch et al. 2014). While multilevel linear regression was the overall test to answer the second question, there were many steps to take before running these regressions.

First a linear regression was created in R to compare each of the environmental variables with one another to test whether there was dependence. Linear regression looks at how variables change in relation to each other (Olive 2017). For example, if a particular variable increases as another increases or decreases, there is a significant relationship between the two, and they are said to be dependent on one another. If any of the variables were found to be significantly dependent, they were removed from the final formulae.

In all, after this dependence testing, I had a total of ten final combination multilevel regression formulae. These are considered “combination” formulae because they compare a combination of at least two environmental variables to the moisture content. The fixed effect included in these formulae is Control Body, which is the identification given to the donation column in the data spreadsheet. The final formulae used in the multiple linear regression consisted of how the median moisture content was related to a combination of ADD and cloud cover; a combination of ADD and precipitation and ADD and dew point; a combination of humidity and solar radiation; a combination of cloud cover and solar radiation and cloud cover and wind speed; a combination of solar radiation and precipitation, and solar radiation and dew point; a combination of wind speed and precipitation; and a combination between altitude and precipitation (Table 5). The same types of formulae were created that compare the moisture content to each individual environmental variable (Table 6).

Table 5: Multilevel Regression Combination Formulae

Environmental Variables	Formulae
ADD and Cloud Cover	df.lmer<-lmer(Median~ADD+Cloud.Cover+(1|Control.Body),df)
ADD and Precipitation	df.lmer1<-lmer(Median~ADD+Precipitation..in.mm.+(1|Control.Body),df)
ADD and Dew Point	df.lmer2<-lmer(Median~ADD+Dew.Point..in..C.+(1|Control.Body),df)
Humidity and Solar Radiation	df.lmer3<-lmer(Median~Humidity+Solar.Radiation..in.W.m2.+(1|Control.Body),df)
Cloud Cover and Solar Radiation	df.lmer4<-lmer(Median~Cloud.Cover+Solar.Radiation..in.W.m2.+(1|Control.Body),df)
Cloud Cover and Wind Speed	df.lmer5<-lmer(Median~Cloud.Cover+Wind.Speed..in.kph.+(1|Control.Body),df)
Solar Radiation and Precipitation	df.lmer6<-lmer(Median~Solar.Radiation..in.W.m2.+Precipitation..in.mm.+(1|Control.Body),df)
Solar Radiation and Dew Point	df.lmer7<-lmer(Median~Solar.Radiation..in.W.m2.+Dew.Point..in..C.+(1|Control.Body),df)
Wind Speed and Precipitation	df.lmer8<-lmer(Median~Wind.Speed..in.kph.+Precipitation..in.kph.+(1|Control.Body),df)
Altitude and Precipitation	df.lmer9<-lmer(Median~Altitude..in.m.+Precipitation..in.mm.+(1|Control.Body),df)

Table 6: Multilevel Regression Individual Environmental Variable Formulae

Environmental Variables	Formulae
Cloud Cover	df.lmer<-lmer(Median~Cloud.Cover+(1|Control.Body),df)
ADD	df.lmer<-lmer(Median~ADD+(1|Control.Body),df)
Solar Radiation	df.lmer<-lmer(Median~Solar.Radiation..in.W.m2.+(1|Control.Body),df)
Humidity	df.lmer<-lmer(Median~Humidity+(1|Control.Body),df)
Precipitation	df.lmer<-lmer(Median~Precipitation..in.mm.+(1|Control.Body),df)
Dew Point	df.lmer<-lmer(Median~Dew.Point..in..C.+(1|Control.Body),df)
Wind Speed	df.lmer<-lmer(Median~Wind.Speed..in.kph.+(1|Control.Body),df)
Altitude	df.lmer<-lmer(Median~Altitude..in.m.+(1|Control.Body),df)

The median moisture content was then calculated using the different anatomical areas of the body. The median moisture content was chosen as a measure of central tendency instead of average because there were many donations whose moisture content measurements were below 5% and above 60%. Taking out these measurements for the average would have skewed the final measurements. After these initial steps were taken, multilevel linear regressions with fixed effects were run with the 10 final formulae, as well as with each individual environmental variable formula. When running the multilevel linear regressions with fixed effects, correlations were also given for each of the environmental variables included in a particular formula. Finally, ANOVAs were created to compare each of the combination multiple regression formulae with one that has had an environmental variable removed. This was done to test the significant impact that a particular environmental variable has on the formulae and, in turn, soft tissue desiccation.

The third question asks whether the correlation between environmental factors and moisture content is the same in two different climates. To answer this question, once again using the package lme4 in R, ANOVAs were run to compare the combination formulae with Control Body included as a fixed effect to ones with Control Body still included and Climate Region added as a second fixed effect (Tables 7 and 8). These tests were also performed for the individual environmental variable formulae. Boxplots were also created to show the difference between the environmental variables in each climate.

Table 7: Multilevel Regression Combination Formulae with Climate Region Added as Second Fixed Effect

Environmental Variables	**Formulae**
ADD and Cloud Cover	df.lmer<-lmer(Median~ADD+Cloud.Cover+(1|Control.Body)+(1|Climate.Region),df)
ADD and Precipitation	df.lmer1<-lmer(Median~ADD+Precipitation+(1|Control.Body)+(1|Climate.Region),df)
ADD and Dew Point	df.lmer2<-lmer(Median~ADD+Dew.Point+(1|Control.Body)+(1|Climate.Region),df)
Humidity and Solar Radiation	df.lmer3<-lmer(Median~Humidity+Solar.Radiation+(1|Control.Body)+(1|Climate.Region),df)
Cloud Cover and Solar Radiation	df.lmer4<-lmer(Median~Cloud+and+Radiation+(1|Control.Body)+(1|Climate.Region),df)
Cloud Cover and Wind Speed	df.lmer5<-lmer(Median~Cloud+and+Speed+(1|Control.Body)+(1|Climate.Region),df)
Solar Radiation and Precipitation	df.lmer6<-lmer(Median~Solar+and.Precipitation+(1|Control.Body)+(1|Climate.Region),df)
Solar Radiation and Dew Point	df.lmer7<-lmer(Median~Solar+and+Point+(1|Control.Body)+(1|Climate.Region),df)
Wind Speed and Precipitaiton	df.lmer8<-lmer(Median~Wind+and.Precipitaiton+(1|Control.Body)+(1|Climate.Region),df)
Altitude and Precipitation	df.lmer9<-lmer(Median~Altitude+Precipitation+(1|Control.Body)+(1|Climate.Region),df)

Table 8: Multilevel Regression Individual Environmental Variable Formulae with Climate Region Added as Second Fixed Effect

Environmental Variables	**Formulae**
Cloud Cover	df.lmer<-lmer(Median~Cloud.Cover+(1|Control.Body)+(1|Climate.Region),df)
ADD	df.lmer1<-lmer(Median~ADD+(1|Control.Body)+(1|Climate.Region),df)
Solar Radiation	df.lmer2<-lmer(Median~Solar.Radiation..in.W.m2.+(1|Control.Body)+(1|Climate.Region),df)
Humidity	df.lmer3<-lmer(Median~Humidity+(1|Control.Body)+(1|Climate.Region),df)
Precipitation	df.lmer4<-lmer(Median~Precipitation..in.mm.+(1|Control.Body)+(1|Climate.Region),df)
Dew Point	df.lmer5<-lmer(Median~Dew.Point..in..C.+(1|Control.Body)+(1|Climate.Region),df)
Wind Speed	df.lmer6<-lmer(Median~Wind.Speed..kph.+(1|Control.Body)+(1|Climate.Region),df)
Altitude	df.lmer7<-lmer(Median~Altitude..in.m.+(1|Control.Body)+(1|Climate.Region),df)

III. RESULTS

A threshold of 9% moisture content was used as a quantification for desiccation because this was the lowest moisture content that all of the donations reached (Figure 3). The moisture content is more variable and decreases more slowly in Texas compared to Colorado (Figure 3) (See also APPENDIX D for Overall Moisture Loss), especially based on ADD (Figures 4 and 5). In Colorado there is a rapid loss of moisture for the first 300 ADD but then it becomes relatively fixed at approximately 9% around 400 ADD (Figures 4 and 5). A similar pattern is followed in Texas, but the moisture content fluctuates throughout the ADD range of 100 to 900 ADD. In general, during this study, it took the bodies in Colorado roughly 9.3 days on average to dry out. On the other hand, the bodies placed in Texas took about 17.5 days. The lowest moisture content for Texas was also higher than for Colorado. The average lowest for Colorado was around 5.9% and for Texas it was about 7.1% (Table 7).

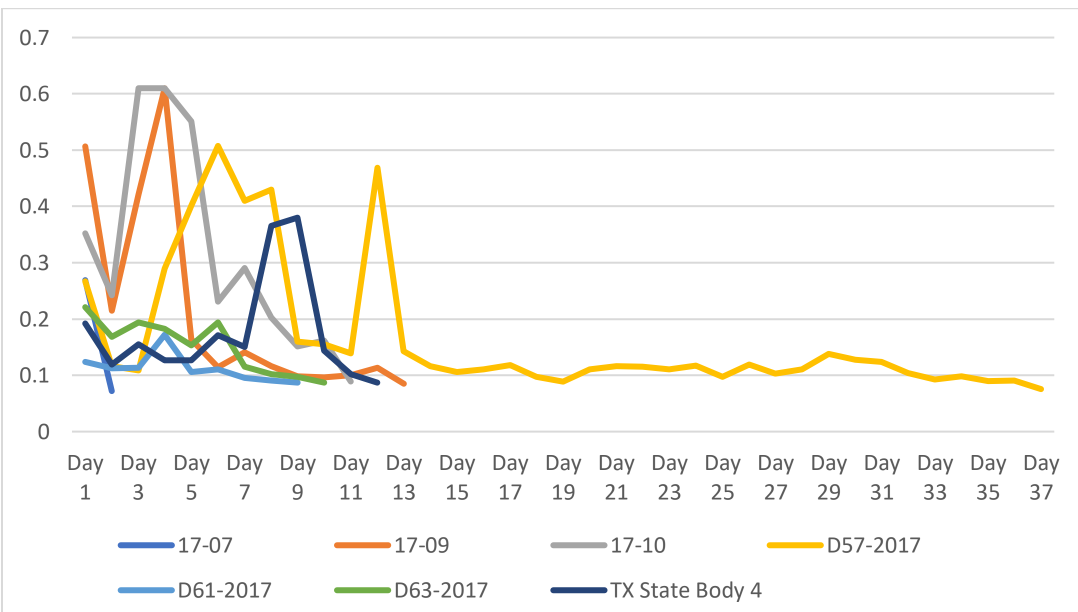

Figure 3: The Length of Time for Each Donation to Reach a Threshold of 9% Moisture Content

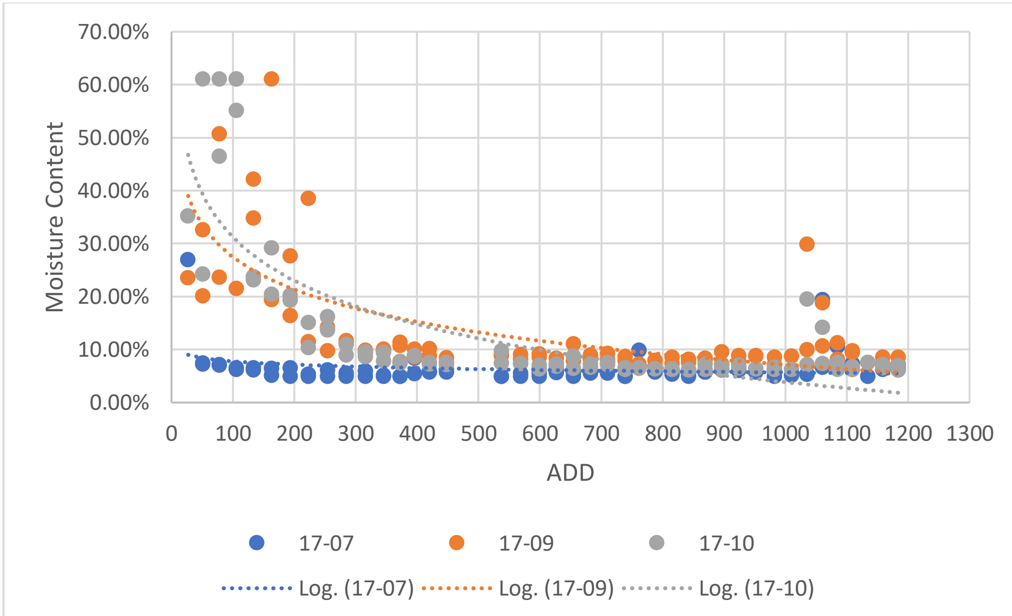

Figure 4: ADD in Relation to Moisture Content for Colorado Subjects

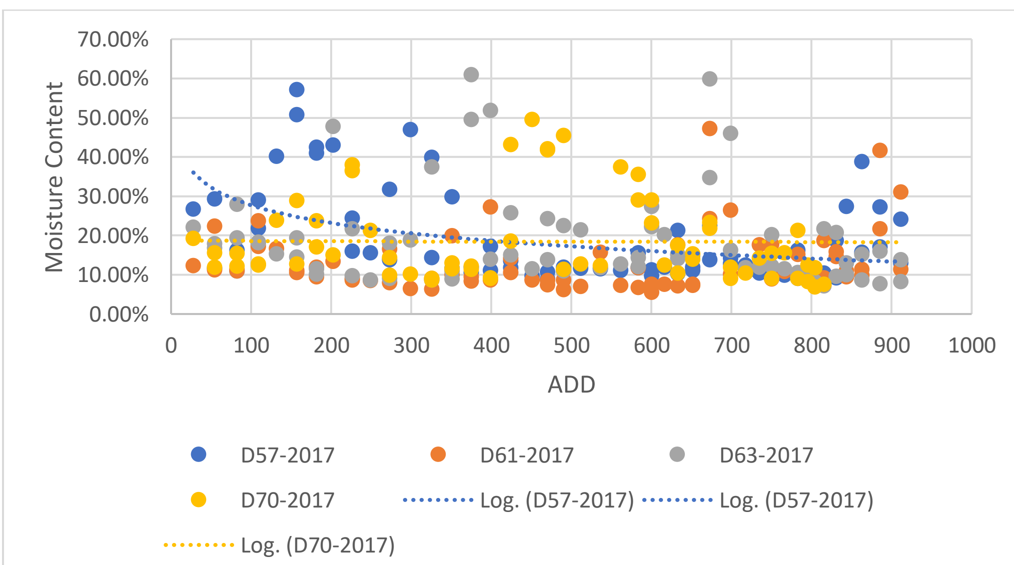

Figure 5: ADD in Relation to Moisture Content for Texas Subjects

Table 9: Rate of Desiccation in Colorado and Texas

Body	17-07	17-09	17-10	D57-2017	D61-2017	D63-2017	D70-2017
Moisture Content	7.20%	8.50%	8.90%	7.55%	8.70%	8.70%	8.70%
Date	30-Jun	24-Aug	20-Aug	28-Oct	12-Oct	27-Oct	11-Dec
Days	2	15	11	37	9	10	14
Samples	2	27	19	61	15	15	21
Average Days	9.333			17.5			
Average Samples	16			26.25			
Lowest Moisture Content	4.90%	6.60%	6.10%	7.55%	5.50%	7.10%	8.30%
Average Lowest	5.90%			7.10%			

<u>*Question 1*</u>

For the first part of this question, regarding the mummification of all skin versus exposed skin, a Wilcoxon Rank Sum Test was not able to be performed, as there was no p-value. This is due to the fact that all donations were labeled with 0 because they had some relatively severe skeletonization on the portion of the body against the ground (usually the back). For all donations the majority were completely missing skin on the back or stuck to the ground. For the second part, regarding the mummification of solely skin versus skin and organs, although a Wilcoxon Rank Sum Test was able to be performed, it showed no significant difference (W: 10 and p-value: 0.1175).

<u>*Question 2*</u>

Dependence testing between each of the different environmental variables was performed first. It is clear that ADD is dependent with humidity, solar radiation, wind speed, and altitude. This would leave ADD, cloud cover, precipitation, and dew point for the final formulae. However, cloud cover is also dependent with both dew point and precipitation, and dew point and precipitation are dependent with each other. This means that, instead of having one formula for ADD, there is now a need for three. When looking at humidity, it is clear that it is dependent with every environmental variable except for solar radiation, leaving one final formula for humidity. Because cloud cover is dependent with every environmental variable except for wind speed and solar radiation, but these two variables are dependent with one another, there should be two cloud cover formulae other than the original one with ADD. Solar radiation is clearly dependent on ADD, wind speed, and altitude, leaving solar radiation, precipitation, and dew point for the final formula. However, as mentioned previously, precipitation and dew point are dependent with each other, leaving two formulae for solar radiation other than the original two with humidity and cloud cover. Wind speed was found to be dependent with every environmental variable except for precipitation and cloud cover. As there is already a formula with cloud cover, this leaves one other formula for wind speed. Altitude was found to be dependent with every environmental variable except for precipitation, leaving one final formula (APPENDIX C; Table C1).

Looking at the boxplot (Figure 6), it is clear that there are no extreme differences in the moisture content percentages between the body parts. For this reason, all the measurements were used to find the median moisture content. When using the final ten multilevel linear regression formulae, it was determined that the median moisture content decreased as ADD, solar radiation, and altitude increase, and increased as humidity, cloud cover, precipitation, and dew point increase (Appendix C; Table C2). However, when looking at the t-values provided for each of the environmental variables within these formulae, it was determined that both wind speed and altitude were not statistically significant. When looking at the R^2 values, though, they showed that, despite the insignificance of these formulae, both environmental variables have a low to moderate correlation with moisture content (Appendix C; Tables C3 and C6). The R^2 values also show that there is a greater correlation between moisture content and ADD than moisture content and cloud cover, precipitation, and dew point. Humidity has a greater correlation with moisture content than does solar radiation. There is also a greater correlation with solar radiation with moisture content compared to cloud cover, precipitation, and dew point, and that there is a greater correlation between moisture content and altitude than between moisture content and precipitation. However, despite the lower significance of the other environmental variables, they still have a significant impact on soft tissue desiccation (Appendix C).

When comparing the median moisture content with each environmental factor separately, the median moisture content increases as humidity (Figures 7 and 8), cloud cover, precipitation, and dew point (APPENDIX C; Figures C1-C6) increase. The median moisture content also decreases as ADD, solar radiation (Figures 9 and 10), wind speed and altitude (APPENDIX E; Figures E7-E11) increase. Therefore, both types of formulae show that there was a positive relationship between moisture content and cloud cover, humidity, precipitation, and dew point, but a negative relationship between moisture content and ADD, solar radiation, and altitude (APPENDIX C; Table C5). When looking at the t-values of each environmental factor after performing multilevel linear regressions, it is also possible to rank the environmental variables by their significant impact on mummification (APPENDIX C; Tables C4 and C7).

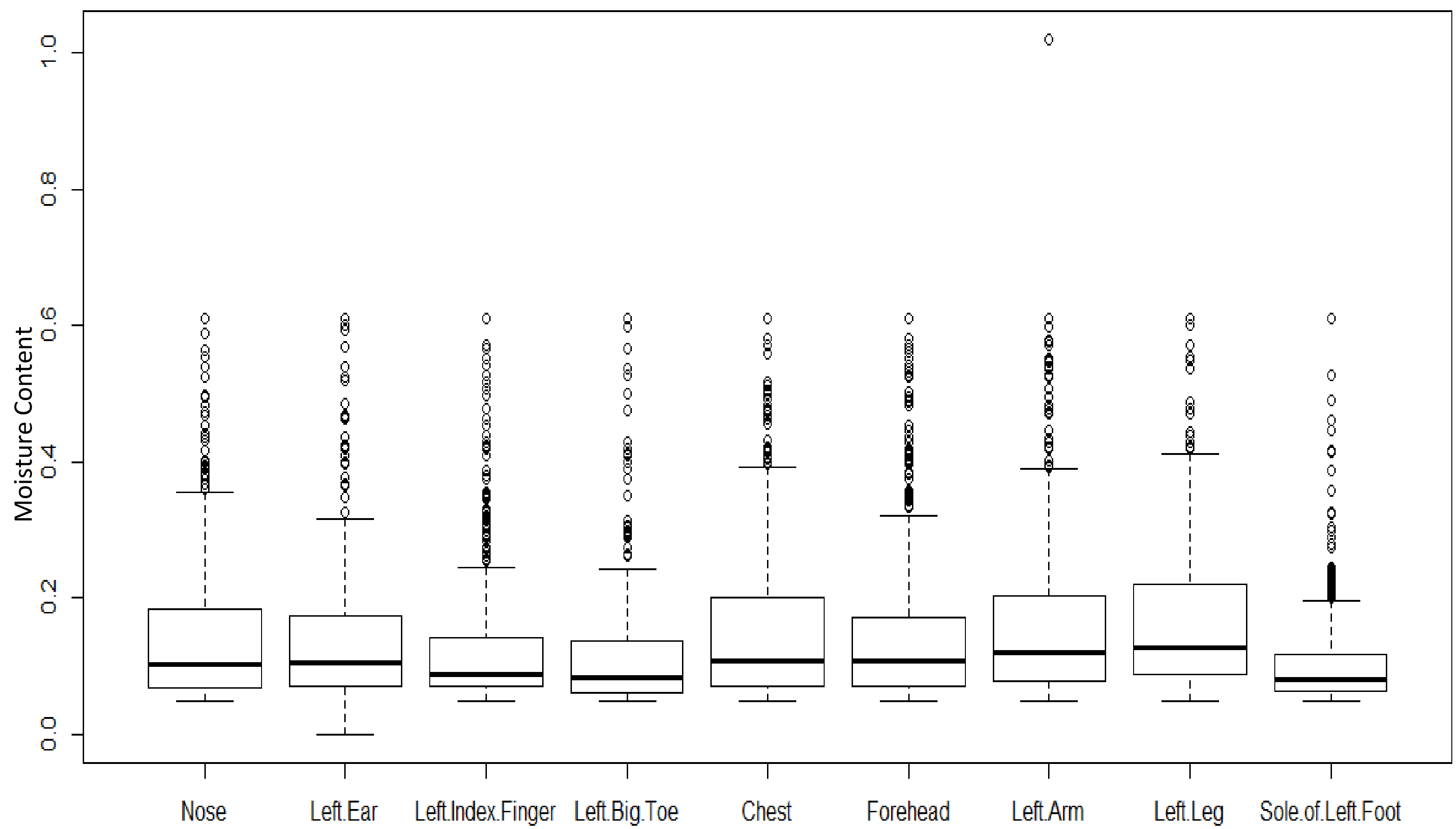

Figure 6: Comparison Between the Average of Each Moisture Content Measurement Throughout the Study from Different Areas of the Body from All Donated Individuals

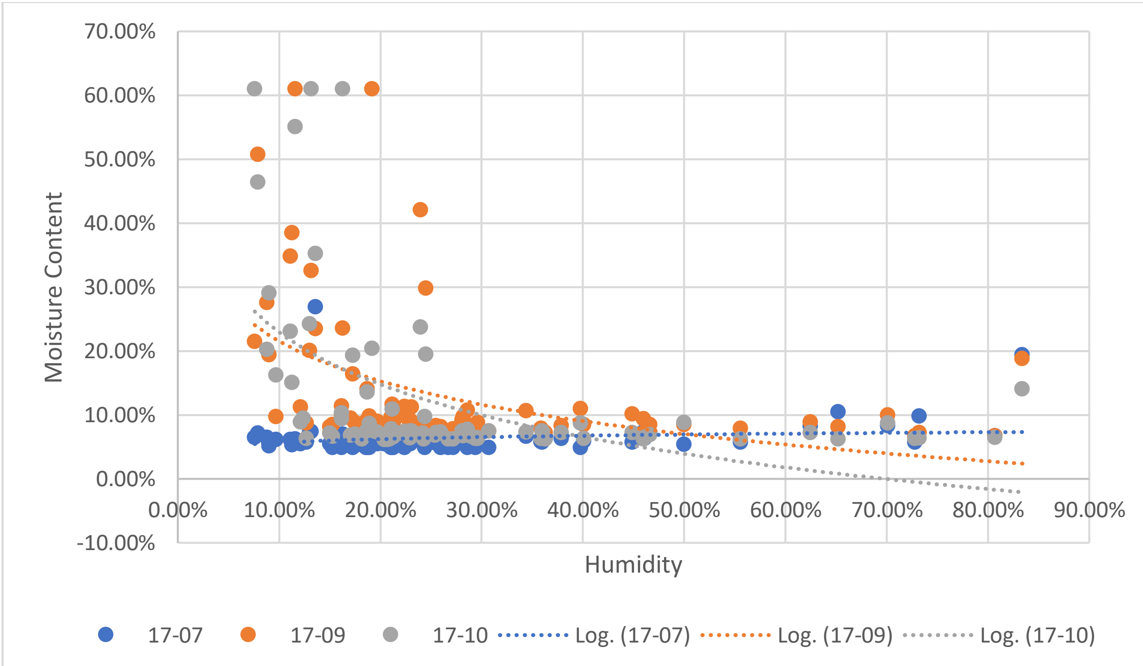

Figure 7: Humidity in Relation to Moisture Content for Colorado Subjects

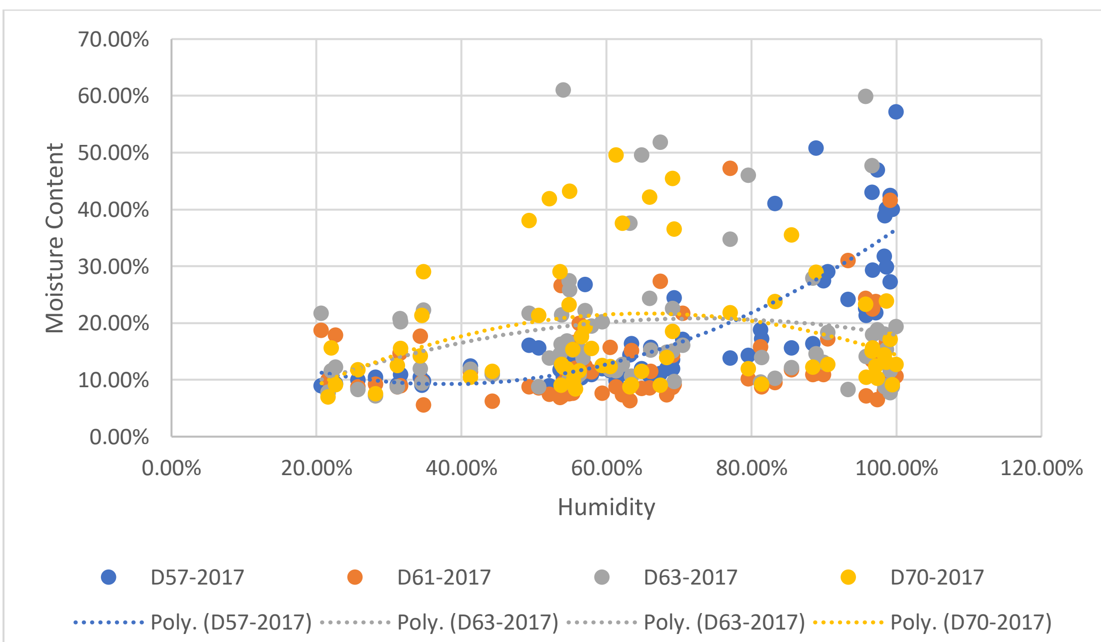

Figure 8: Humidity in Relation to Moisture Content for Texas Subjects

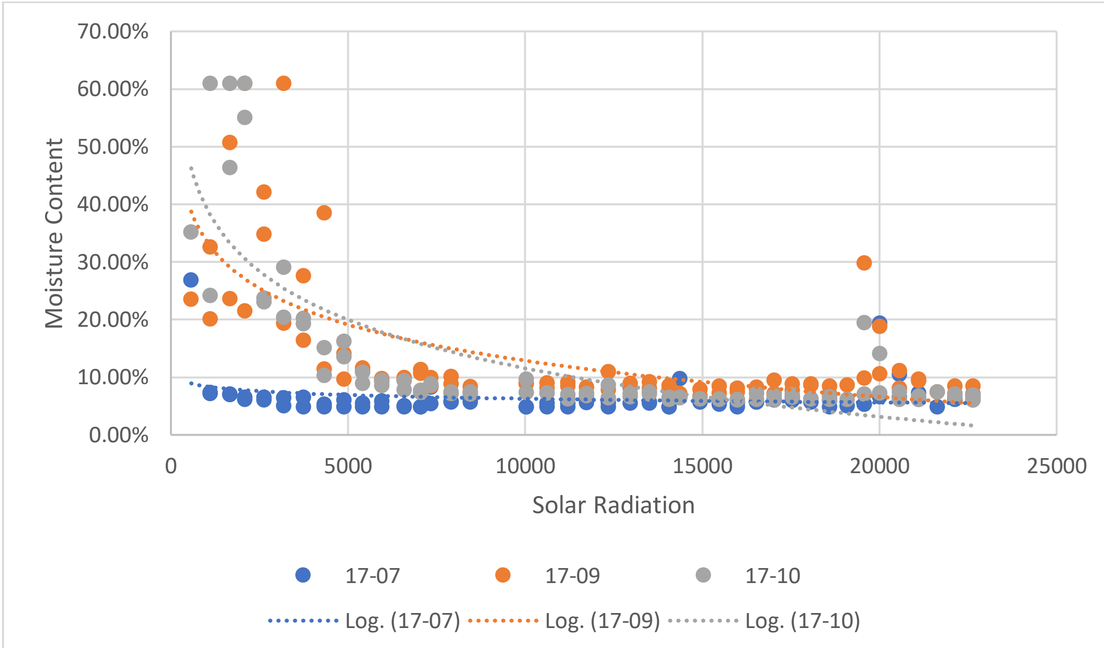

Figure 9: Solar Radiation in Relation to Moisture Content for Colorado Subjects

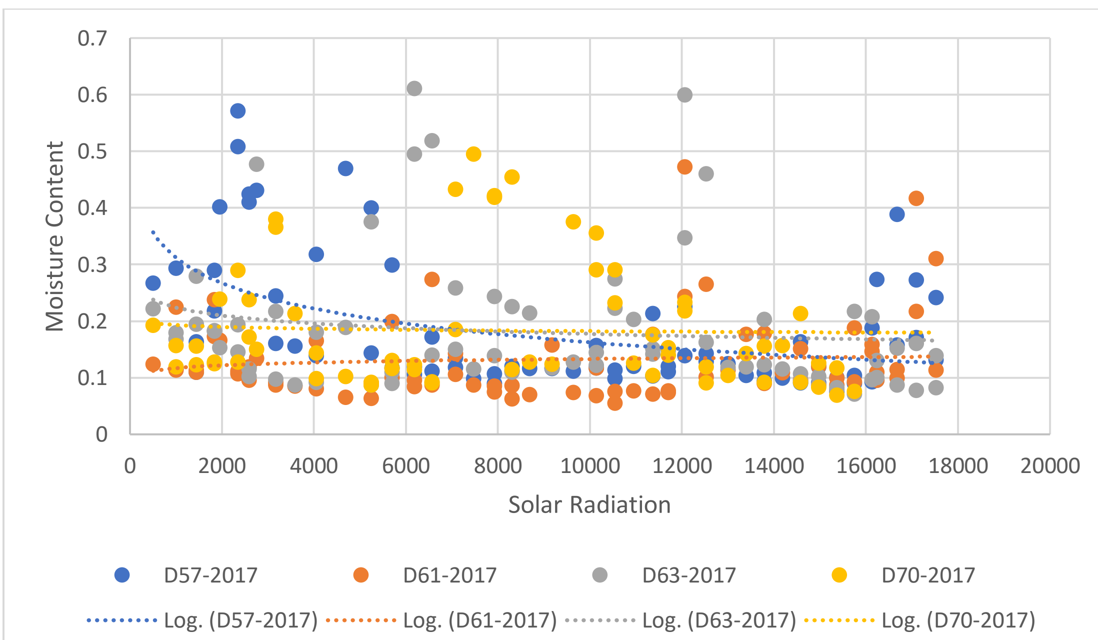

Figure 10: Solar Radiation in Relation to Moisture Content for Texas Subjects

After the formulae with a combination of environmental variables were created and run, ANOVAs were run in which each environmental variable was taken out and tested against the original formula. Removing each of the environmental variables from their particular formulae show the significance level of the variable and how removing the variable affects the intercept. When all environmental variables are removed from their respective formulae (except for altitude and wind speed) there is a significant difference. The same can be said of the R^2 values, which, for the most part, changed significantly (APPENDIX C; Tables C8 and C9).

Question 3

The third question asks if the correlation between environmental variables and desiccation is the same for the two climate zones. Comparing the combination formulae as well as the formulae with just one environmental variable with just Control Body as a fixed effect with formulae with Control Body included and Climate Region as a second fixed effect, none of the formulae were found to be significantly different. This is the same for the individual environmental variable formulae. This is also shown in the R^2 values, as, for the most part there are very few or minor changes to the correlations between certain environmental variables and median moisture content (Appendix C; Tables C10-C13). However, as can be seen in Figures 11-18, the different climate regions have a significant effect on how much of a specific environmental variable occurs.

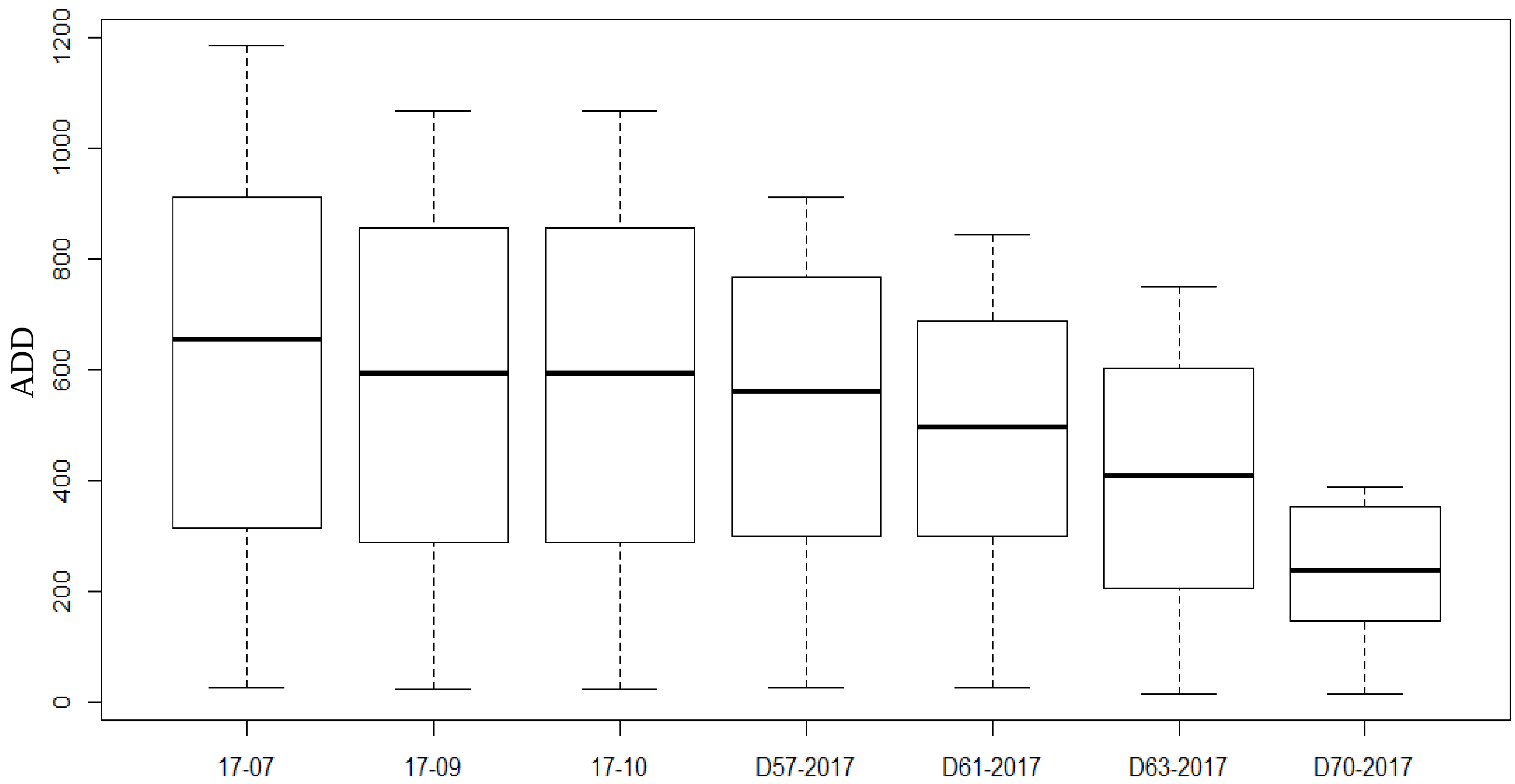

Figure 11: ADD Recorded at the Facility where Each Donation was Placed

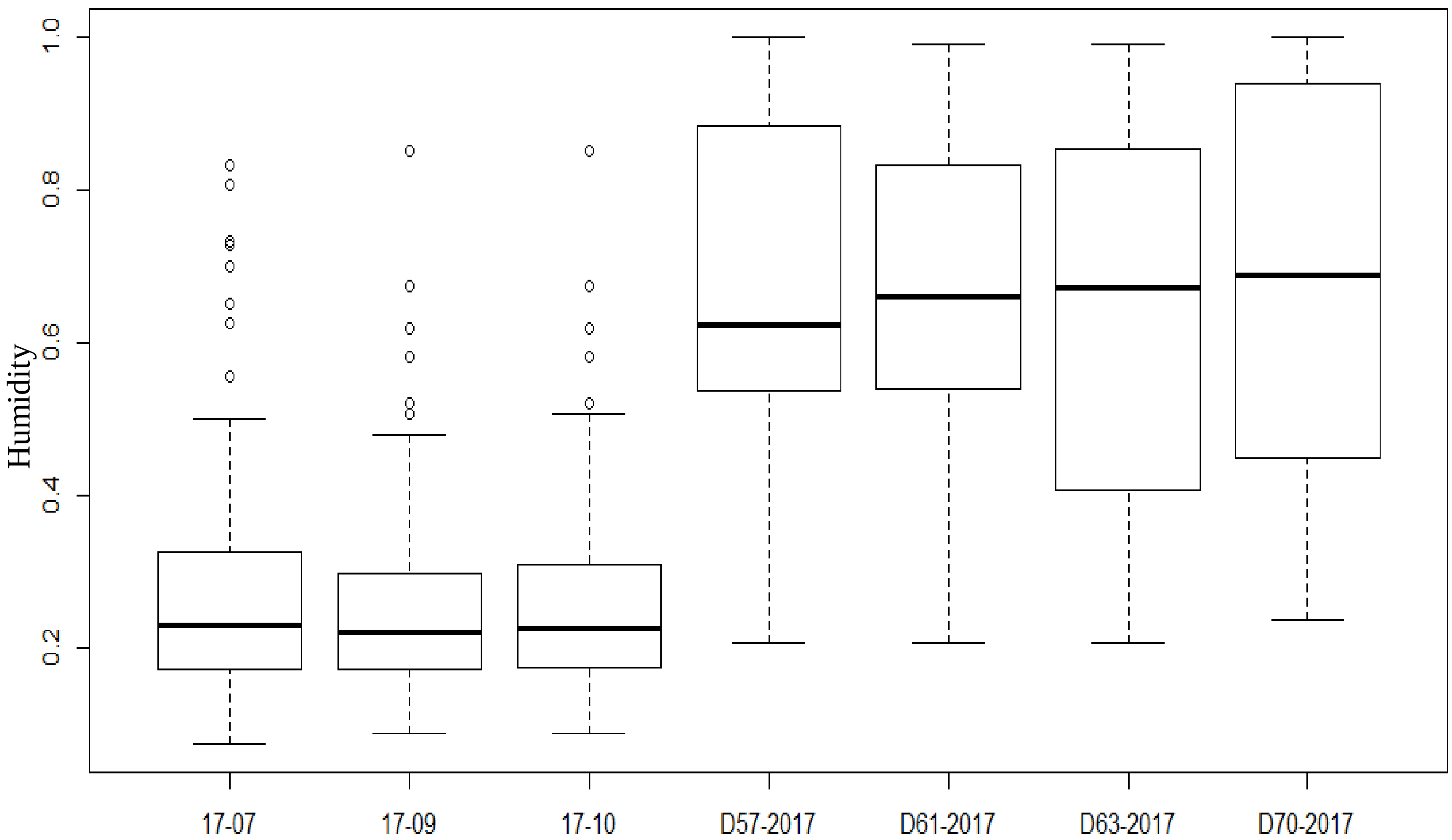

Figure 12: Humidity Recorded at the Facility where Each Donation was Placed

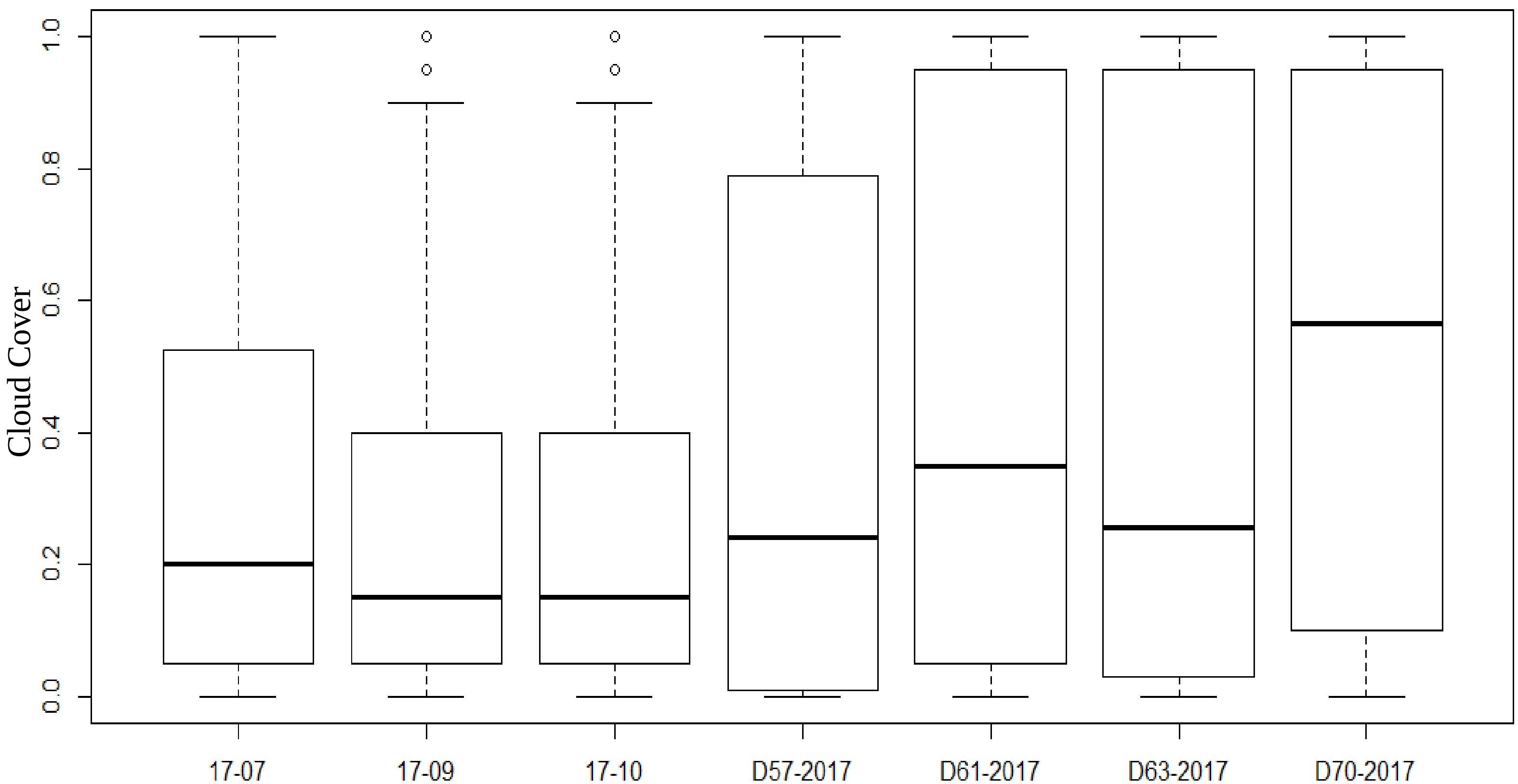

Figure 13: Cloud Cover Recorded at the Facility where Each Donation was Placed

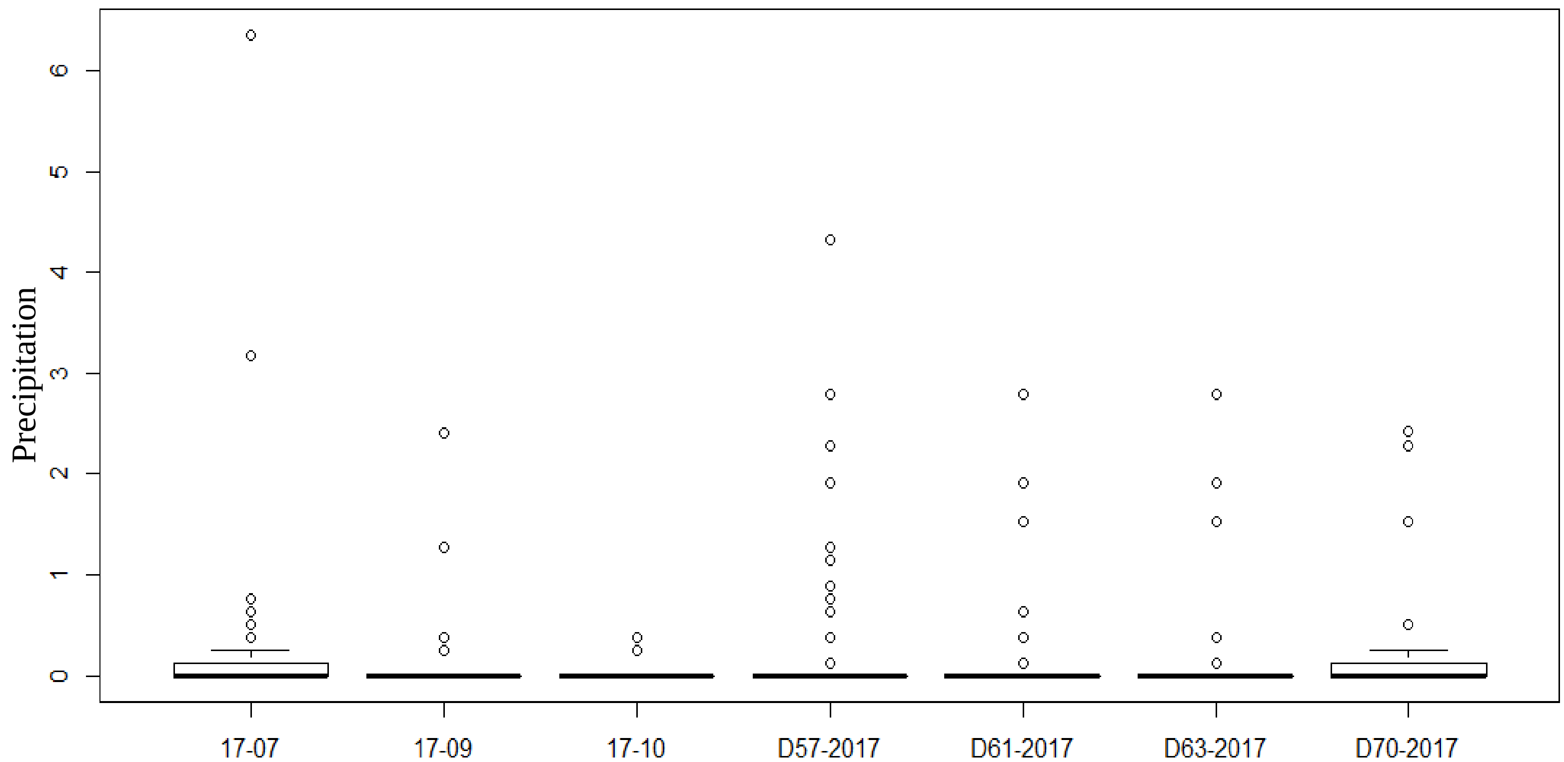

Figure 14: Precipitation Recorded at the Facility where Each Donation was placed

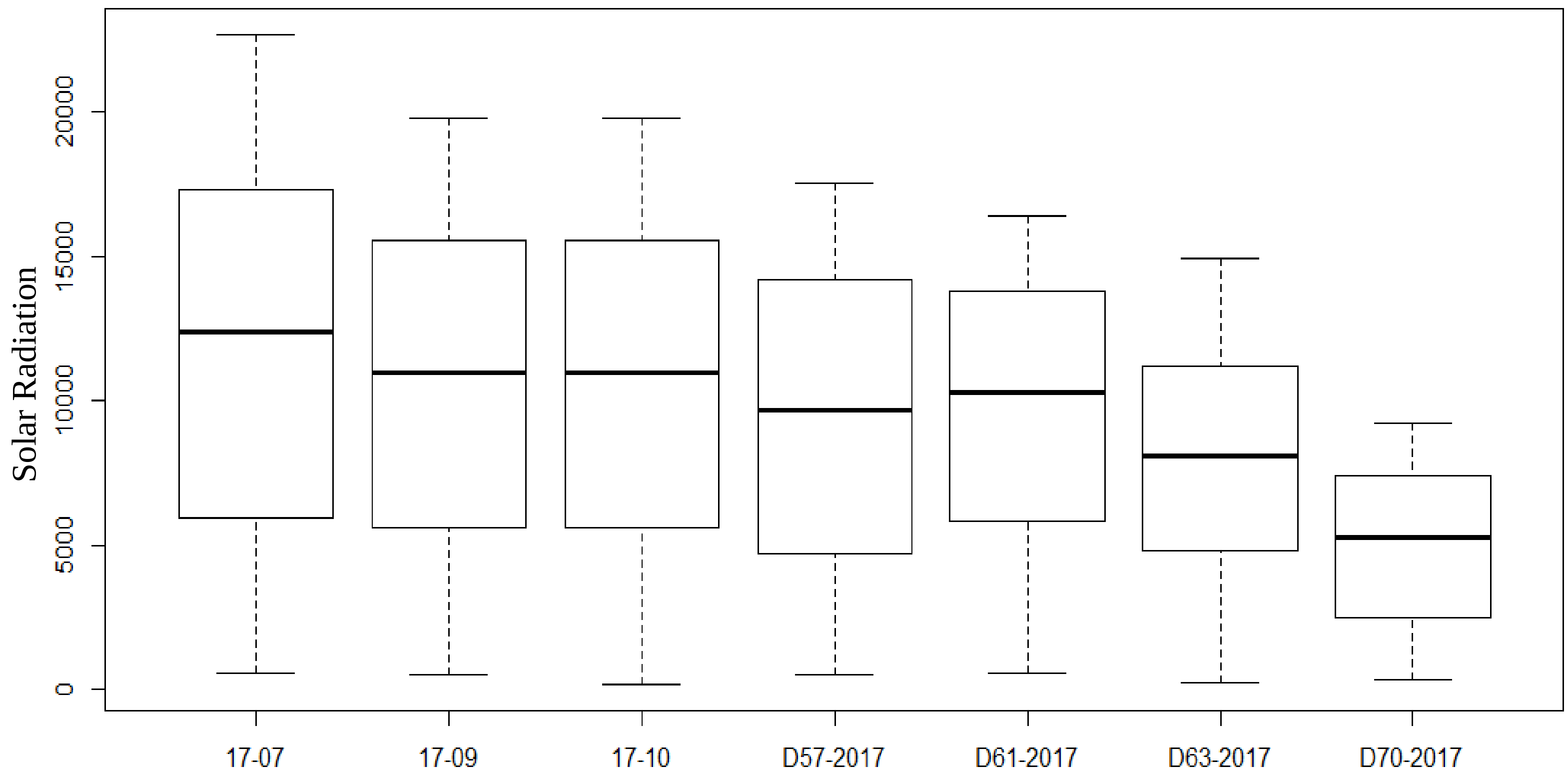

Figure 15: Solar Radiation Recorded at the Facility where Each Donation was Placed

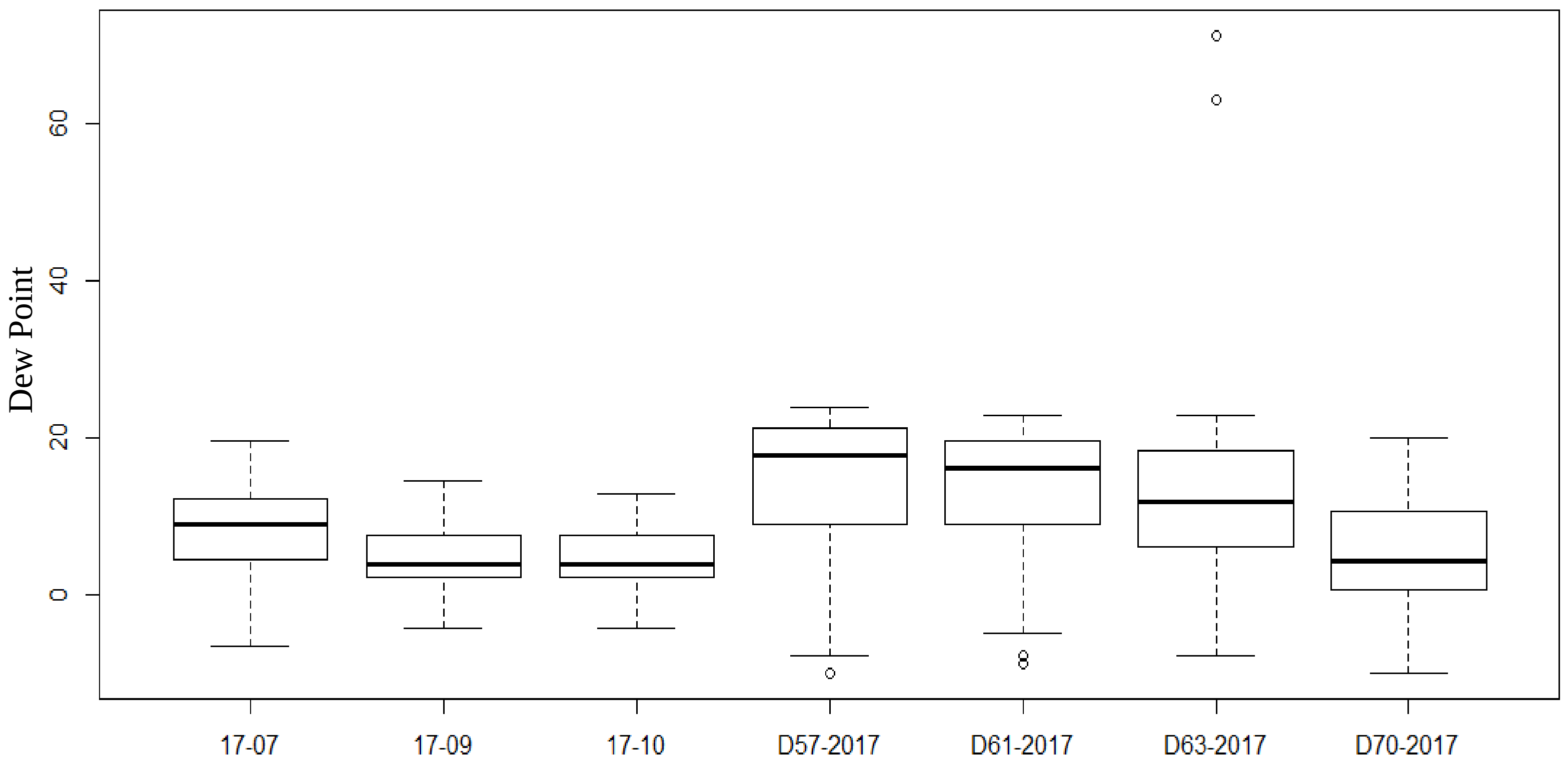

Figure 16: Dew Point Recorded at the Facility where Each Donation was Placed

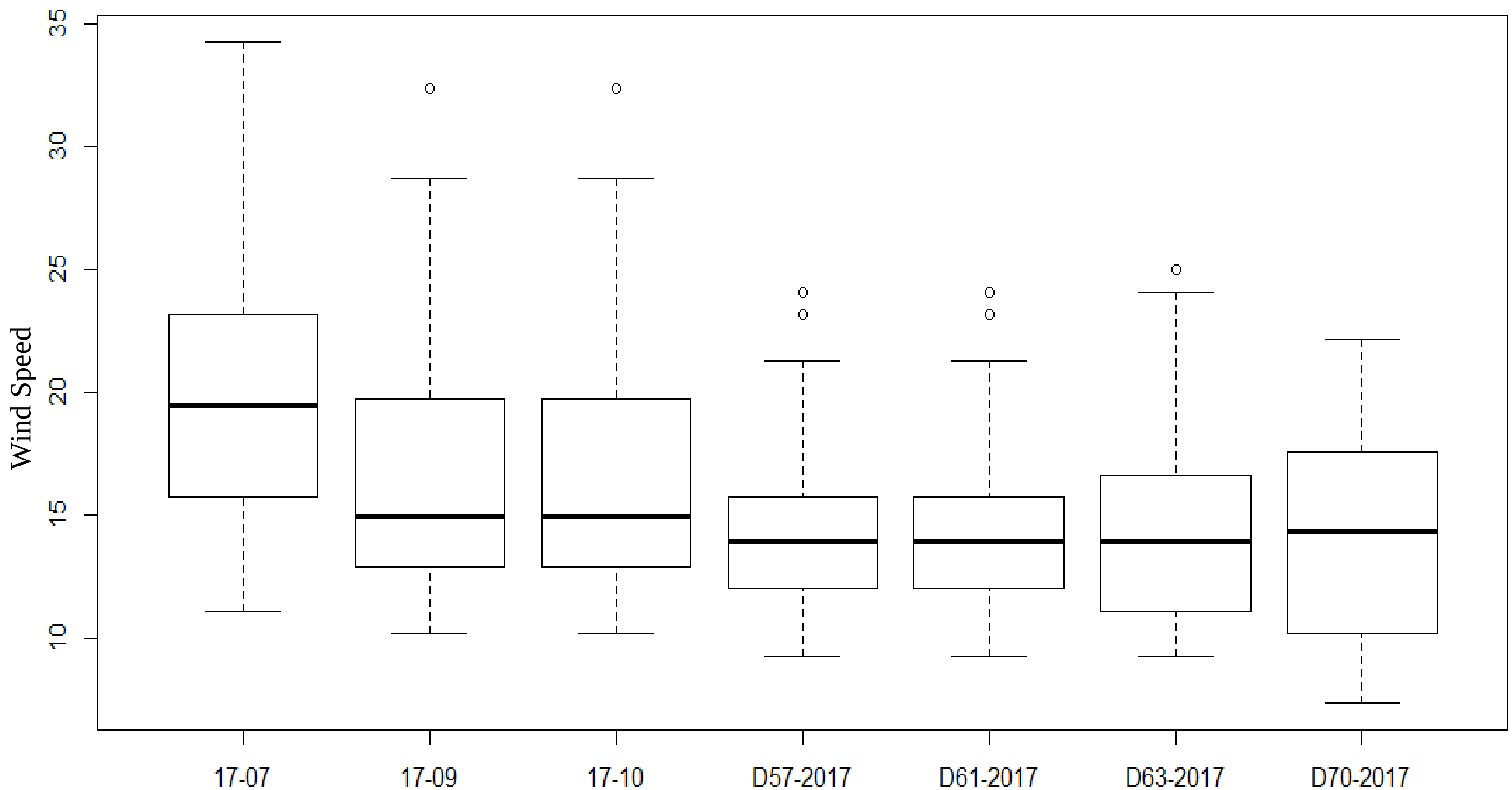

Figure 17: Wind Speed Recorded at the Facility where Each Donation was Placed

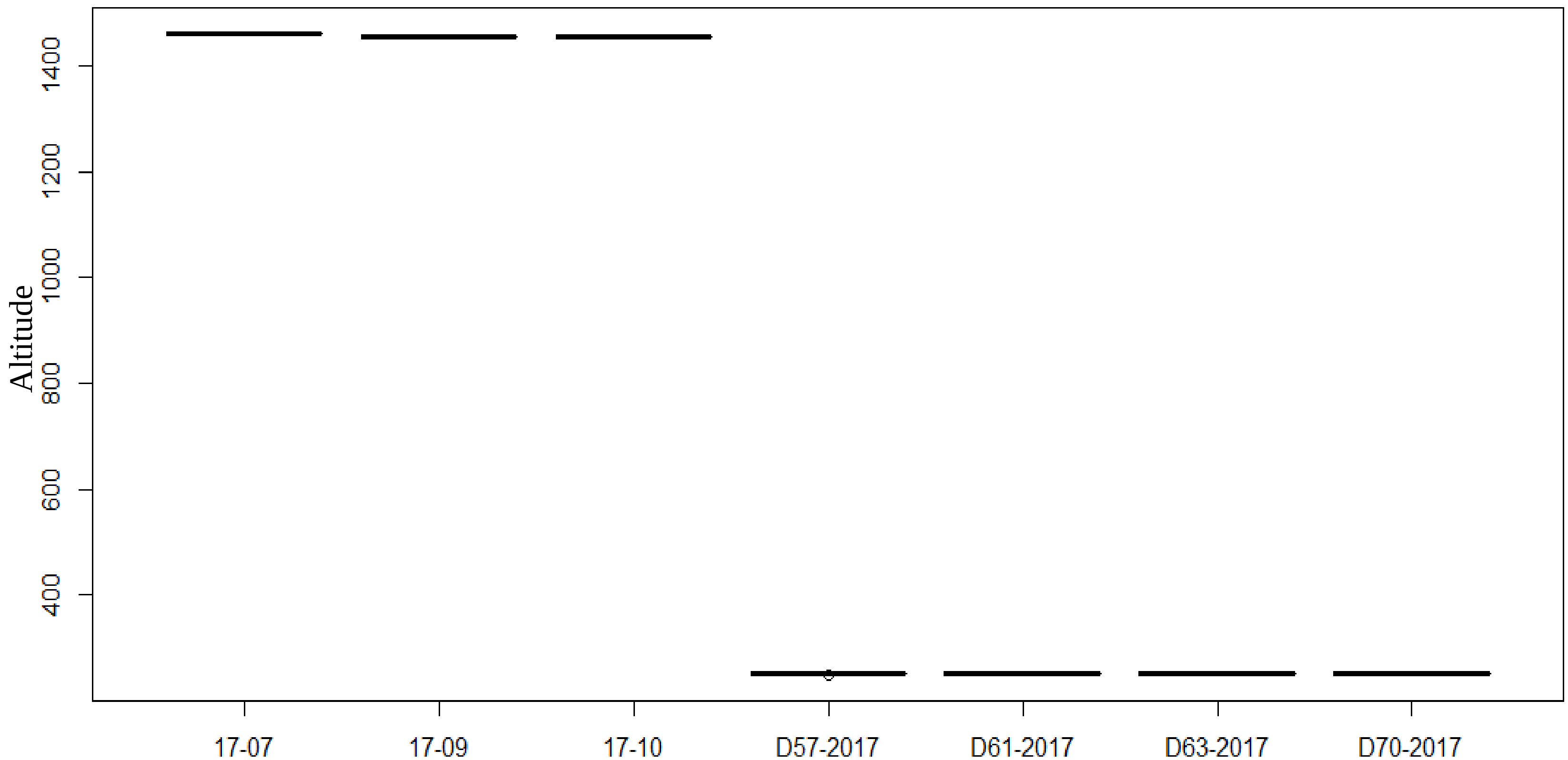

Figure 18: Altitude Recorded at the Facility where Each Donation was Placed

IV. DISCUSSION

The primary goals of this project were to discover whether there is a difference in the rate of mummification in the different climatic regions of Colorado and Texas, as well as which environmental factors have a more significant effect on mummification and whether these factors are the same in both climates. Another important aspect of this research is whether the visible pattern of mummification differs between Colorado and Texas. These goals are important because knowing how individuals will mummify and desiccate differently in distinct climate regions will allow forensic anthropologists to approach the process for estimating how long an individual has been dead differently. There is a standardized process for estimating this length of time (post-mortem interval, or PMI), but it does not take into account how different climate affect the human decomposition process (Megyesi et al. 2005). For example, during advanced decomposition the investigators score the body as “mummification with bone exposure less than one half of the area being scored” (Megyesi et al. 2005. P. 4). However, there is no clear definition of mummification and how to distinguish this from desiccation. There are also few studies that demonstrate when or if mummification will occur or what environments and climates have the environmental variables necessary to cause mummificationt (Connor 2017, Lennartz 2018, Brooks et al. 2016, Wescott et al. 2013). Furthermore, the description by Megyesi and colleagues (2005) does not indicate if both the exposed and unexposed surfaces should be included in the examination. For, example, you could have half of the exposed area mummified if you include both the exposed and unexposed surfaces but less than half bone exposure if you only include the exposed surface.

Question 1

In answer to the first research question of this study, there is no significant difference between the pattern of mummification in donations placed in Texas, and those placed in Colorado. There were some differences between the bodies when it came to desiccation of organs, but none when it came to all skin versus exposed skin desiccation. Whereas two of the three donations from Colorado had organs that were desiccated (because the individual was autopsied, it was clear that the viscera had dried out), all of the ones from Texas only showed evidence of skin desiccation, but not organs. At both locations the skin in contact with the ground surface did not preserve as well as the skin not in contact with the ground. The fact that skin in contact with the ground seems to not be preserved as well as exposed skin is most likely associated with moisture retention as well as insect activity and bacteria within the body; however, this is not known for certain. This might suggest that methods such as the Total Body Score proposed by Megyesi et al. (2005) could be improved by distinguishing between the exposed and unexposed surfaces. It also suggests that the basic pattern of mummification is similar in very extreme climates regardless of the process.

Question 2

Overall, median moisture content decreases as Accumulated Degree Days (ADD) and solar radiation increase (APPENDIX C; Tables C2 and C5). With regards to ADD, moisture content decreases more rapidly for the Colorado bodies compared to the Texas bodies, and there is greater variability in moisture content in Texas compared to Colorado. Because of the low t-value (and, therefore, lack of statistical significance) and the high correlation of altitude within the formula, it does seem to show that moisture content decreases as altitude increases as well, but this may be due to the effect altitude has on other environmental variables such as solar radiation and humidity. Wind speed, on the other hand, shows a negative relationship with moisture content when using the combination multilevel regression formulae, and a positive relationship when using the single environmental variable formulae. However, despite this discrepancy, both altitude and wind speed show high correlations with moisture content, especially when compared to other environmental variables. This means that both altitude and wind speed can essentially account for much of the variability, but the particular models are essentially meaningless and can be removed. However, it does seems likely that a body found in a high-altitude region (which generally have higher wind speeds), would desiccate more rapidly, meaning that these environmental variables could have an effect on how TBS is scored. Median moisture content also increases as cloud cover, humidity, precipitation, and dew point increase (APPENDIX BC Tables C2 and C5).

Taking ADD, cloud cover, precipitation, dew point, humidity, and solar radiation out of any formula makes a significant difference, suggesting that all these variables contribute to moisture loss and skin preservation. Removing ADD and solar radiation from the original formulae decreases the t-value as well as the estimate of the intercept, meaning that the formulae without ADD and solar radiation has a much less significant impact on median moisture content than the one with it. This would indicate that ADD, which incorporates both time and temperature, plays a large role in desiccation and preservation, similar to the findings by Lennartz (2018) and Megyesi et al. (2005). Overall, humidity seems to play the largest role in predicting desiccation followed by solar radiation, ADD, cloud cover, dew point, precipitation, and altitude (Appendix C;

Tables C4 and C7). This would suggest that in a low humidity environment such as Colorado that the lack of air moisture is a main driver of skin desiccation. In more subtropical climates such as in Texas, ADD and solar radiation are probably more important to skin desiccation (Kottek et al. 2016). The results of this study suggest that the regression formulae such as developed by Megyesi and colleagues could be improved by incorporating solar radiation and humidity when calculating the ADD necessary to reach a particular TBS.

Removing cloud cover, precipitation, dew point, or humidity from any of the original formulae increases the t-value as well as the estimate of the intercept, meaning that the formulae without these environmental variables have a more significant impact on median moisture content than the ones with them. This indicates that, although the t-values for each of these variables are high enough to be considered statistically significant, they are less significant than the other variables in the formulae (namely ADD and solar radiation).

Removing wind speed and altitude from their respective formulae does not result in a statistically significant change, indicating that, although each of these environmental variables show a correlation with moisture content, the models that employ them are essentially useless and should not be considered when looking at mummification and desiccation.

Question 3

In answer to the third research question, regarding whether the correlation between extrinsic environmental variables and soft-tissue mummification (median moisture content), is the same in the two climates; in short, the answer is “yes”. The rate of desiccation is greater in Colorado, probably due to low humidity. Once it becomes fixed at around 9% there is also less fluctuation than seen in Texas. Again, this is probably due to the lower humidity in Colorado compared to Texas. However, when climatic region is introduced as a fixed effect in the multiple linear regression formulae, there are no significant changes from the formulae that do not include climate (APPENDIX C; Tables C10-C13). This means that climatic region does not have a statistically significant impact on moisture content and, therefore, mummification and desiccation. However, as can be seen by the earlier boxplots, climatic region does have a significant impact on the specific environmental variables themselves (Figures 11-18). For the most part, climate seems to have an impact on how much of a particular variable you observe. For example, while low humidity greatly contributes to desiccation, if the humidity is high then other variables such as solar radiation and ADD become more important. This is shown by the fact that when the humidity is particularly high, it is still possible to have a relatively low median moisture content. As was established previously, these environmental variables do have a significant impact on moisture content, meaning that climate may possibly indirectly affect the level of mummification.

Originally, in order to quantify mummification and desiccation, this research project was going to use water activity, which is the way that the Food and Drug Administration (FDA) measures the shelf-life of different foods, particularly perishable items. This was going to be used because the FDA has a set water activity level for foods to have a stable shelf-life (U.S. Food and Drug Administration 1984). In a way, if human tissue could get to a particular water activity level, then a mummified individual would become stable. However, in order to measure water activity, the majority of water activity meters require a sample to be taken from a subject that is approximately three or four centimeters in diameter. This would not have worked with Colorado's donations, because this institution receives a limited number per year and repeatedly taking a large portion of skin from the body would have made it impossible from simultaneous research to be done, which hinders information that can be gathered by the program. For this reason, moisture content was then chosen as a way to quantify mummification and desiccation.

In all, it seems as though human remains lose moisture more quickly in Colorado than they do in Texas. Colorado has higher temperatures (and, therefore, ADD) and solar radiation, and lower humidity, cloud cover, and dew point than Texas. And because the human remains placed in Colorado dry out more quickly than those in Texas, it shows that these environmental variables have not only a significant impact on mummification and desiccation, but a more significant impact in Colorado than in Texas. However, this may also be due to the fact that measurements were taken in different seasons. Data were collected for 17-07 at the Forensic Investigation Research Station (FIRS), where the solar radiation is immense, during the summer months, when the temperatures are generally much higher. This seems to be corroborated by the fact that 17-09 and 17-10 measurements, which were collected during August and September (which tends to be referred to as "monsoon season" in this region of Colorado) showed a longer timeframe for the remains to dry out (Melissa Connor, personal communication, July 2017). The donation that took the longest to lose moisture was D57-2017 from the Forensic Anthropology Research Facility (FARF), which is most likely due to the relatively heavy rains, and, therefore, high humidity, experienced during the month of September 2017. Cloud cover was also higher for all of the donations placed at FARF. It is most likely due to these moisture-causing environmental variables that caused moisture loss to occur more slowly here. It also appears that once a body becomes desiccated in Colorado it is more likely to be preserved for a longer duration than in Texas. As an example, one donation that was placed at Colorado in 2014 was still there when data collection began in summer 2017. While there was moderate bone exposure, there was also a great deal of preserved tissue still present.

As mentioned earlier, although there have been many articles and books that mention mummification/desiccation, not many of them performed actual research on how specific environmental factors affect it. There has mainly been a general consensus that hot and dry, as well as cold and dry environments are ideal for its occurrence. The research conducted in this thesis suggests that extrinsic environmental factors seem to be the primary cause of mummification and desiccation, which is in concordance with much of the previous research on the process of human decomposition (Arriaza 1995, Dix and Graham 2000, Aufderheide 2003, 2011, Connor 2017, Dix and Graham 2000, Introna et al. 2011, Janaway et al. 2009, Pratz-Muñoz et al. 2013, Samadelli et al. 2013, Reinhard 2016, Vidale et al. 2016, Wescott et al. 2016). It is also true that ADD (a combination of time and ambient temperature), as well as humidity (which can create aridity or moistness within a geographical region), and solar radiation (the strength of the sun) were the three most important factors in determining the rate of mummification of human remains for both Colorado and Texas. This seems to suggest that the hot and dry, as well as cold and dry climates tend to both have the environmental factors necessary for a body to mummify more quickly, which is in agreement with the current consensus. However, because other environmental factors also had a significant effect on mummification, as well as the fact that it still occurred (albeit more slowly) in a more hot and humid area (such as San Marcos, Texas), the extremes agreed upon are not the only environments in which human remains can mummify (Lennartz et al. 2018).

Postmortem Interval

One of the most frequently cited methods to estimate the postmortem interval (PMI) of individuals during the process of decomposition was developed by Megyesi et al. (2005). This method has generally been standardized for forensic anthropologists and medicolegal investigators alike since its inception. One problem with this method is that its categories, especially those for mummification and desiccation are extremely broad. For head, neck, trunk, and limbs, mummification is included under advanced decomposition with no distinct definition as to what constitutes mummification (Megyesi et al. 2005). This method also does not take into account how the differences in environment across different geographical regions affect decomposition. There have been recent studies to test the validity of the Megyesi et al. (2005) method, but they mostly focus on other factors pertinent to decomposition, while ignoring or at least paying minimal attention to how mummification and desiccation affect PMI (Vass 2011, Suckling et al. 2016, Marhoff-Beard et al. 2018, Wescott et al. 2018).

The findings from this research project show that not only does environment have an enormous impact on how likely it will be for a body to dry out, but mummification has just as large an effect on how long it takes a body to fully decompose. It is a good idea for the forensic anthropologists and medicolegal investigators to keep this in mind when attempting to estimate the PMI of unidentified human remains. Decomposition facilities generally use written notes based primarily on the Megyesi et al. (2005) method. The mummification/desiccation section is basically labeled yes or no, and, therefore, is extremely subjective. A possible solution to this problem is to develop a standardized definition of mummification itself as well as to distinguish between mummification and desiccation so that decomposition notes can become more quantifiable.

While this research project answered many questions, there are still ways to improve upon it in the future. The sample size is one issue that needs to be addressed in future research. Seven individuals are considered very small and it is important to increase this when a researcher has an extended timeframe. Next, it is a good idea to do measurements with the moisture meter with a training donation before data is actually collected. While I did not do this for my thesis, I did test it out on myself before beginning to take measurements from donated individuals. Collecting data during the same time is essential to further this research. If multiple people can work on this project at the same time, it will be beneficial and reduce the possibility of seasonal bias. Because there was essentially only one individual taking measurements for this project, the first measurements from the initial donation in Colorado were taken in the summer months, and the last measurements from the final donation in Texas were taken in the winter months. Finally, it is important to collect data for the same length of time. There were times when I or the individual collecting measurements for me could not collect data (generally due to weather constraints; in Colorado, there were very high winds, and in Texas, it rained a number of days during data collection) and it may have thrown off the final measurements.

VI. CONCLUSION

Mummification can partly occur in any climate, depending on the time of year and which environmental variables are most prominent. However, it is most likely going to occur in areas that are extremely arid with high temperatures and low precipitation and brighter sunshine. There seem to be no significant differences between the pattern of mummification based on climate. However, scoring the exposed and unexposed regions of the body could make a difference in how we estimate the PMI. The findings from this project could greatly improve the fields of forensic anthropology and medicolegal death investigation. Whereas there is a standard in place for estimating the postmortem interval (PMI), it is extremely subjective and can vary by geographical location. This research project brings the field one step closer to quantifying these estimations and possibly making them more accurate. However, this research project was relatively limited in scope, due to the dearth of donations in Colorado as well as the limited timeframe. Therefore, in order to test this result, more in-depth research is necessary.

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APPENDIX A: Insect Activity Notes for Each Donation

Table A1: Insect Activity Notes for 17-07 from FIRS

17-07	**Date**	**29-Jun**	**30-Jun**	**30-Jun**	**1-Jul**	**1-Jul**	**2-Jul**	**2-Jul**	**3-Jul**	**4-Jul**	**6-Jul**
	Insect Activity	None	Mild	Mild	Mild	Mild	Moderate	Heavy	Heavy	Heavy	Moderate
	Date	**6-Jul**	**7-Jul**	**7-Jul**	**8-Jul**	**8-Jul**	**9-Jul**	**10-Jul**	**10-Jul**	**11-Jul**	**11-Jul**
	Insect Activity	Mild	Mild	Mild	Mild	Very Mild	Mild	Mild	Very Mild	Mild	Very Mild
	Date	**12-Jul**	**12-Jul**	**13-Jul**	**14-Jul**	**17-Jul**	**17-Jul**	**18-Jul**	**18-Jul**	**19-Jul**	**19-Jul**
	Insect Activity	Very Mild	MIld	Very Mild	Mild	Mild	Mid	Mild	Mild	Moderate	Mild
	Date	**20-Jul**	**20-Jul**	**21-Jul**	**21-Jul**	**22-Jul**	**22-Jul**	**23-Jul**	**23-Jul**	**24-Jul**	**24-Jul**
	Insect Activity	Mild	Mild	Moderate	Mild	Mild	Very Mild	Mild	Very Mild	Mild	Very Mild
	Date	**25-Jul**	**25-Jul**	**26-Jul**	**26-Jul**	**27-Jul**	**27-Jul**	**28-Jul**	**28-Jul**	**29-Jul**	**29-Jul**
	Insect Activity	Moderate	Very Mild	Mild	Mild	Mild	None	Mild	Mild	Mild	Mild
	Date	**30-Jul**	**31-Jul**	**1-Aug**	**2-Aug**	**4-Aug**	**4-Aug**	**5-Aug**	**7-Aug**	**7-Aug**	**8-Aug**
	Insect Activity	Mild	Mild	Mild	Mild	Mild	Very Mild	Mild	Mild	Mild	Mild
	Date	**9-Aug**	**10-Aug**	**10-Aug**							
	Insect Activity	Mild	Mild	None							

Table A2: Decomposition Notes for 17-09 from FIRS

17-09	**Date**	**10-Aug**	**11-Aug**	**12-Aug**	**13-Aug**	**13-Aug**	**14-Aug**	**14-Aug**	**15-Aug**	**15-Aug**
	Insect Activity	Mild	Mild	Mild	Mild	None	Mild	Moderate	Mild	Mild
	Date	**16-Aug**	**16-Aug**	**17-Aug**	**17-Aug**	**18-Aug**	**18-Aug**	**19-Aug**	**19-Aug**	**20-Aug**
	Insect Activity	None	None	Mild	None	Mild	None	Moderate	None	Mild
	Date	**20-Aug**	**21-Aug**	**21-Aug**	**22-Aug**	**23-Aug**	**23-Aug**	**24-Aug**	**24-Aug**	**25-Aug**
	Insect Activity	None	Mild	None	Mild	None	None	None	None	None
	Date	**25-Aug**	**26-Aug**	**26-Aug**	**27-Aug**	**27-Aug**	**28-Aug**	**28-Aug**	**29-Aug**	**29-Aug**
	Insect Activity	None	Mild	None	None	None	Mild	None	Mild	None
	Date	**30-Aug**	**31-Aug**	**1-Sep**	**1-Sep**	**2-Sep**	**2-Sep**	**3-Sep**	**3-Sep**	**4-Sep**
	Insect Activity	None	None	Mild	None	None	None	Mild	None	None
	Date	**4-Sep**	**5-Sep**	**5-Sep**	**6-Sep**	**6-Sep**	**7-Sep**	**7-Sep**	**8-Sep**	**8-Sep**
	Insect Activity	None	None	Mild	None	None	Mild	None	None	None
	Date	**9-Sep**	**10-Sep**	**10-Sep**	**11-Sep**	**11-Sep**	**12-Sep**	**12-Sep**	**13-Sep**	**13-Sep**
	Insect Activity	None	Mild	None	Moderate	None	Mild	None	None	None
	Date	**14-Sep**	**14-Sep**	**15-Sep**	**15-Sep**	**16-Sep**	**16-Sep**	**17-Sep**	**18-Sep**	**18-Sep**
	Insect Activity	None	None	Mild	None	Mild	None	None	Mild	None
	Date	**19-Sep**	**19-Sep**	**20-Sep**	**20-Sep**	**21-Sep**	**21-Sep**			
	Insect Activity	Mild	None	None	None	None	None			

Table A3: Insect Activity Notes for 17-10 from FIRS

17-10	**Date**	**10-Aug**	**11-Aug**	**12-Aug**	**13-Aug**	**13-Aug**	**14-Aug**	**14-Aug**	**15-Aug**	**15-Aug**	**16-Aug**
	Insect Activity	Mild	Mild	Mild	Moderate	Moderate	None	Heavy	Moderate	Mild	None
	Date	**16-Aug**	**17-Aug**	**17-Aug**	**18-Aug**	**18-Aug**	**19-Aug**	**19-Aug**	**20-Aug**	**20-Aug**	**21-Aug**
	Insect Activity	None	Moderate	None	Heavy	None	Heavy	None	Moderate	None	Moderate
	Date	**22-Aug**	**23-Aug**	**24-Aug**	**24-Aug**	**25-Aug**	**25-Aug**	**26-Aug**	**26-Aug**	**27-Aug**	**27-Aug**
	Insect Activity	Mild	None	None	None	None	None	Mild	None	Mild	None
	Date	**28-Aug**	**28-Aug**	**29-Aug**	**29-Aug**	**30-Aug**	**31-Aug**	**1-Sep**	**1-Sep**	**2-Sep**	**2-Sep**
	Insect Activity	Mild	None	Mild	None	None	None	Mild	None	None	None
	Date	**3-Sep**	**3-Sep**	**4-Sep**	**4-Sep**	**5-Sep**	**5-Sep**	**6-Sep**	**6-Sep**	**7-Sep**	**7-Sep**
	Insect Activity	Mild	None	None	None	Moderate	None	None	None	Very Mild	None
	Date	**8-Sep**	**8-Sep**	**9-Sep**	**10-Sep**	**10-Sep**	**11-Sep**	**11-Sep**	**12-Sep**	**12-Sep**	**13-Sep**
	Insect Activity	None	None	None	Mild	None	Heavy	None	Mild	None	None
	Date	**13-Sep**	**14-Sep**	**14-Sep**	**15-Sep**	**15-Sep**	**16-Sep**	**16-Sep**	**17-Sep**	**18-Sep**	**18-Sep**
	Insect Activity	None	Mild	None	Very Mild	None	Mild	None	None	Mild	None
	Date	**19-Sep**	**19-Sep**	**20-Sep**	**20-Sep**	**21-Sep**	**21-Sep**				
	Insect Activity	Mild	None	None	None	Mild	None				

Table A4: Insect Activity Notes for D57-2017 from FARF

D57-2017	**Date**	**22-Sep**	**23-Sep**	**23-Sep**	**24-Sep**	**24-Sep**	**25-Sep**	**26-Sep**	**27-Sep**	**27-Sep**	**28-Sep**
	Insect Activity	None	Mild	Mild	Mild	Moderate	Heavy	Heavy	Heavy	Heavy	Heavy
	Date	**28-Sep**	**29-Sep**	**30-Sep**	**30-Sep**	**1-Oct**	**2-Oct**	**2-Oct**	**3-Oct**	**4-Oct**	**4-Oct**
	Insect Activity	Heavy	Heavy	Moderate	Moderate	Moderate	Mild	Moderate	Moderate	Moderate	Mild
	Date	**5-Oct**	**5-Oct**	**6-Oct**	**6-Oct**	**7-Oct**	**7-Oct**	**8-Oct**	**8-Oct**	**9-Oct**	**10-Oct**
	Insect Activity	Mild	Mild	Mild	Mild	Moderate	Mild	Very Mild	Very Mild	Mild	Very Mild
	Date	**10-Oct**	**11-Oct**	**11-Oct**	**12-Oct**	**13-Oct**	**13-Oct**	**14-Oct**	**15-Oct**	**15-Oct**	**16-Oct**
	Insect Activity	Moderate	Mild	Moderate	Moderate	Mild	Mild	Mild	Mild	Mild	Mild
	Date	**16-Oct**	**17-Oct**	**18-Oct**	**18-Oct**	**19-Oct**	**19-Oct**	**20-Oct**	**20-Oct**	**21-Oct**	**21-Oct**
	Insect Activity	Mild	Mild	None	Mild	Mild	Mild	Mild	Mild	Mild	Mild
	Date	**22-Oct**	**23-Oct**	**24-Oct**	**24-Oct**	**25-Oct**	**26-Oct**	**26-Oct**	**27-Oct**	**27-Oct**	**28-Oct**
	Insect Activity	Mild	Mild	Mild	Mild	Mild	None	None	None	None	None
	Date	**28-Oct**	**29-Oct**	**29-Oct**	**30-Oct**	**30-Oct**	**31-Oct**	**31-Oct**	**1-Nov**	**1-Nov**	**2-Nov**
	Insect Activity	Mild	Mild	Mild	None	Mild	None	None	Mild	Mild	Mild
	Date	**2-Nov**	**3-Nov**	**3-Nov**	**15-Nov**	**15-Nov**	**16-Nov**	**17-Nov**			
	Insect Activity	Mild	Mild	Moderate	Mild	Mild	Mild	Mild			

Table A5: Insect Activity Notes for D61-2017 from FARF

D61-2017	**Date**	**4-Oct**	**5-Oct**	**5-Oct**	**6-Oct**	**6-Oct**	**7-Oct**	**7-Oct**	**8-Oct**	**8-Oct**	**9-Oct**
	Insect Activity	Mild	Mild	Mild	Heavy	Heavy	Heavy	Heavy	Heavy	Moderate	Moderate
	Date	**10-Oct**	**10-Oct**	**11-Oct**	**11-Oct**	**12-Oct**	**13-Oct**	**13-Oct**	**14-Oct**	**15-Oct**	**15-Oct**
	Insect Activity	Mild	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Mild	Moderate	Mild
	Date	**16-Oct**	**16-Oct**	**17-Oct**	**18-Oct**	**18-Oct**	**19-Oct**	**19-Oct**	**20-Oct**	**20-Oct**	**21-Oct**
	Insect Activity	Moderate	Moderate	Very Mild	Mild	Mild	Mild	Mild	Mild	Mild	Mild
	Date	**21-Oct**	**22-Oct**	**23-Oct**	**24-Oct**	**24-Oct**	**25-Oct**	**26-Oct**	**26-Oct**	**27-Oct**	**28-Oct**
	Insect Activity	Mild	Mild	Mild	Mild	Mild	Mild	Mild	Mild	Mild	Mild
	Date	**28-Oct**	**29-Oct**	**29-Oct**	**30-Oct**	**30-Oct**	**31-Oct**	**31-Oct**	**1-Nov**	**1-Nov**	**2-Nov**
	Insect Activity	Mild	Mild	Mild	Mild	Mild	Mild	Very Mild	Mild	Mild	Mild
	Date	**2-Nov**	**3-Nov**	**3-Nov**	**4-Nov**	**4-Nov**	**5-Nov**	**5-Nov**	**6-Nov**	**6-Nov**	**7-Nov**
	Insect Activity	Mild	Mild	Mild	Mild	Mild	Mild	Mild	Mild	Mild	Mild
	Date	**8-Nov**	**8-Nov**	**9-Nov**	**9-Nov**	**10-Nov**	**11-Nov**	**11-Nov**	**12-Nov**	**12-Nov**	**13-Nov**
	Insect Activity	Mild	None	Mild	Mild	Mild	Mild	Mild	Mild	Mild	Mild
	Date	**13-Nov**	**14-Nov**	**14-Nov**	**15-Nov**	**15-Nov**					
	Insect Activity	Mild	Mild	Mild	Mild	Mild					

Table A6: Insect Activity Notes for D63-2017 from FARF

D63-2017	**Date**	**18-Oct**	**19-Oct**	**19-Oct**	**20-Oct**	**20-Oct**	**21-Oct**	**21-Oct**	**22-Oct**	**23-Oct**	**24-Oct**
	Insect Activity	None	Mild	Mild	Mild	Moderate	Heavy	Heavy	Heavy	Heavy	Heavy
	Date	**24-Oct**	**25-Oct**	**26-Oct**	**26-Oct**	**27-Oct**	**27-Oct**	**28-Oct**	**28-Oct**	**29-Oct**	**29-Oct**
	Insect Activity	Heavy	Heavy	Heavy	Heavy	Heavy	Moderate	Moderate	Moderate	Moderate	Moderate
	Date	**30-Oct**	**30-Oct**	**31-Oct**	**31-Oct**	**1-Nov**	**1-Nov**	**2-Nov**	**2-Nov**	**3-Nov**	**3-Nov**
	Insect Activity	Moderate	Moderate	Moderate	Mild	Mild	Moderate	Moderate	Mild	Moderate	Moderate
	Date	**4-Nov**	**4-Nov**	**5-Nov**	**5-Nov**	**6-Nov**	**6-Nov**	**7-Nov**	**7-Nov**	**8-Nov**	**8-Nov**
	Insect Activity	Heavy	Mild	Heavy	Heavy	Heavy	Heavy	Moderate	Moderate	Mild	Mild
	Date	**9-Nov**	**9-Nov**	**10-Nov**	**10-Nov**	**11-Nov**	**11-Nov**	**12-Nov**	**12-Nov**	**13-Nov**	**13-Nov**
	Insect Activity	Moderate	Moderate	Heavy	Moderate	Heavy	Heavy	Moderate	Moderate	Moderate	Heavy
	Date	**14-Nov**	**14-Nov**	**15-Nov**	**15-Nov**	**16-Nov**	**16-Nov**	**17-Nov**	**17-Nov**	**18-Nov**	**18-Nov**
	Insect Activity	Moderate	Moderate	Moderate	Mild	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
	Date	**19-Nov**	**19-Nov**	**20-Nov**	**20-Nov**	**21-Nov**	**21-Nov**	**22-Nov**	**22-Nov**	**24-Nov**	**24-Nov**
	Insect Activity	Moderate	Moderate	None	Moderate	Moderate	Moderate	Mild	Moderate	Mild	Moderate
	Date	**25-Nov**	**25-Nov**	**26-Nov**	**27-Nov**	**27-Nov**	**28-Nov**	**28-Nov**	**29-Nov**	**29-Oct**	
	Insect Activity	Mild	Mild	Mild	Mild	Moderate	Mild	Mild	Mild	Moderate	

Table A7: Insect Activity Notes for D70-2017 from FARF

D70-2017	**Date**	**28-Dec**	**28-Dec**	**29-Dec**	**29-Dec**	**30-Dec**	**30-Dec**	**1-Nov**	**1-Nov**	**2-Nov**	**2-Nov**
	Insect Activity	Mild	Mild	None	Mild	Very Mild	Mild	Mild	Mild	Moderate	Mild
	Date	**3-Dec**	**3-Dec**	**4-Dec**	**4-Dec**	**6-Dec**	**7-Dec**	**9-Dec**	**9-Dec**	**10-Dec**	**10-Dec**
	Insect Activity	Mild	Moderate	Very Mild	Moderate	None	None	Moderate	Moderate	Moderate	Moderate
	Date	**11-Dec**	**11-Dec**	**12-Dec**	**12-Dec**	**14-Dec**	**14-Dec**	**15-Dec**	**15-Dec**	**16-Dec**	**17-Dec**
	Insect Activity	Moderate	Moderate	Very Mild	Mild	Moderate	Mild	Mild	None	Very Mild	Mild
	Date	**18-Dec**	**19-Dec**	**19-Dec**	**20-Dec**	**20-Dec**	**21-Dec**	**21-Dec**	**22-Dec**	**22-Dec**	**26-Dec**
	Insect Activity	Mild	Very Mild	Mild	Mild	Moderate	Mild	Moderate	Mild	Mild	Mild
	Date	**27-Dec**	**27-Dec**	**28-Dec**	**28-Dec**	**29-Dec**	**29-Dec**	**30-Dec**	**31-Dec**	**31-Dec**	**1-Jan**
	Insect Activity	None	None	very Mild	Mild	Mild	Mild	Moderate	Mild	None	None
	Date	**1-Jan**	**2-Jan**	**2-Jan**	**3-Jan**	**3-Jan**	**4-Jan**	**4-Jan**	**5-Jan**	**5-Jan**	**24-Jan**
	Insect Activity	None	None	None	Very Mild	Very Mild	Mild	Mild	MIld	Mild	Mild
	Date	**24-Jan**									
	Insect Activity	Mild									

APPENDIX B: Data Collection Protocol

At Placement:

- Decide which side to take measurements from based on where the moisture will fall
    - If the individual is placed with the left side facing downhill, this is where the moisture will fall, so you would then take measurements will fall, so you would then take measurements from the right side, and vice versa.

Every Time:

- Put up the table
- Take out all clean items and place on table
    - Clipboard
    - Gloves
    - Alcohol Wipes
    - Pen
    - Journal
    - Timekeeping device (phone, watch, etc.)
- Put on gloves and take out dirty items
    - First, just the moisture meter
    - Second, the probes inside the smaller cardboard box

Taking Measurements:

- There will be 9 areas of the body from which you will take moisture content readings (nose, left/right ear, left/right fingers, left/right toes, chest (sternum level), forehead, left/right arm, left/right leg, and sole of the left/right foot).

  - For the first two (nose and ear), use only the moisture meter without the probes, as it will fit more easily this way.
  - For the next 7 measurements, attach the probe via the cable to the moisture meter

- In order to turn on the moisture meter, hold down on the center circular button
  - Once it is powered up, press the center button to select MC reading (moisture content)
  - You will then find the main page where you will see the MC percentages
  - First, use the down button to go down to job
    - You will change this every set of 9 measurements that you will take
  - Select job using center button
  - Use right button to increase the job
  - Use down button to go down until cursor is on done
  - Hit center button
  - This will lead you to the area where it asks if you want to change any information or settings
  - These are the default settings and do not need to be changed
  - Use down button to go down to done

- Hit center button and you are ready to take measurements

- In taking measurements, you hold down the center button until you cansee a percentage on the screen
    - If the measurements wavers between just two numbers, choose the one that comes up most often; example → if the measurement wavers between 6.1% and 6.2%, but 6.1% comes up seven times and 6.2% came up three, you would choose 6.1%
    - If the measurement avers between multiple numbers that are still within approximately two percentages, choose the measurement that is closest to the middle out of all of these numbers
    - <5% is the moisture content that is being chosen for mummification in this thesis
    - When the device has a reading of LOW, this means that the moisture content is <5%
        - Because this is what is desired for this thesis, if a reading is <5%, make sure to press the button at least 10 times to see if it wavers more than twice
            - If it does not, choose <5%
            - If it does, choose the reading that is in the middle of all of the numbers onto the screen
    - It is a good idea to take measurements a couple of times in order to get a more accurate measurement

        - If these measurements vary by too wide of a margin, then two things could be possible:
            - There could be a piece of tissue stuck to the needles of the moisture meter or the probe
            - Just clean it off using your glove and try again
        - The machine could be moving too much in your hand
            - If this is the case, squat as close to the ground as possible to try and hold it steady

- The 9 areas of the body that you will measure are: nose, left/right ear, left/right fingers, left/right toes, chest (at sternum level); forehead; left/right arm; left/right leg; and sole of the left/right foot.
    - You will measure nose as close to the middle as possible
    - You will measure the ear right on the edge as close to the middle as possible
    - You will measure the fingers on the most easily accessible area depending on how rigor has set in
    - For the toes, you will measure the big toe
    - You will measure the chest as close to sternum level as possible
    - You will measure the nose just above glabella
        - On the last body, an indention occurred that affected the measurements occasionally

        - If measurements become slightly off in such an indentation, adjust the position of the moisture meter accordingly
    - You will measure the arm using the upper arm, halfway between the shoulder and the elbow
    - You will measure the leg using the upper leg, halfway between the hip and the knee
    - You will measure the sole of the foot on the heel
- After each measurement, record it and the time that it was taken on the data sheet
- After all measurements have been collected, using alcohol wipes, clean off the measurement devices
    - First, clean off the probe
        - Disconnect the probe from the moisture meter
        - Open one alcohol wipe
        - Wipe down the needles, cable, cable connector, and the glass body
        - Then, place the probe back inside the smaller cardboard box
    - Next, clean the moisture meter
        - Open the other alcohol wipe
        - Clean off the needles, cable connect, and every surface of the device

        - Clean off the lid to the black case before placing the device back onto it
        - Pick up the yellow lid for the device, clean it, and place it back onto the device
        - Clean off the latch on the black case
        - Put the device back into the case
    - Pick up all alcohol wipes and paper packs and dispose of them in one glove
    - Put black case with moisture meter back into the cardboard box
    - Gather all gloves and combine into your last glove, and place into the bottom of the box
- After clean-up is complete, take as many notes regarding the surrounding scene as possible
    - The weather station will collect the majority of the environmental data
        - The weather station does not collect cloud cover, dew point, or altitude
            - Using the website Accuweather.com, collect the dew point and cloud cover from Orchard Mesa
                - For cloud cover, adjust accordingly from what is noted for Orchard Mesa based upon what is over you at that moment

            - Altitude will not change, as you continue measurements on the body, but it is important to get it when the body is first placed.
    - Make note of whether there is a breeze, whether it is hot, and whether or not the sun is blocked by the clouds.
    - Make note of anything important you see on and in the body (insect activity, etc.)
- Pack everything up, put the table down, and you are done for one data collection session

APPENDIX C: Statistical Results

Table C1: Linear Tests of Dependence Between Different Environmental Variables

ADD	Humidity	Cloud Cover	Precipitation	Solar Radiation	Dew Point	Wind Speed	Altitude
F-statistic	7.306	2.607	1.128	2.469X10^{4}	3.272	18.63	46.61
P-value	0.007097	0.107	0.288	<2.2X10^{-16}	0.02647	1.898X10^{-5}	2.404X10^{-1}
Humidity	ADD	Cloud Cover	Precipitation	Solar Radiation	Dew Point	Wind Speed	Altitude
F-statistic	7.306	205	16.35	4.745	258.9	49.78	486.9
P-value	0.007097	<2.2X10^{-16}	6.064X10^{-5}	0.02984	<2.2X10^{-16}	5.49X10^{-12}	<2.2X10^{-16}
Cloud Cover	ADD	Humidity	Precipitation	Solar Radiation	Dew Point	Wind Speed	Altitude
F-statistic	2.607	205	38.56	1.68	46.38	0.557	30.61
P-value	0.107	<2.2X10^{-16}	1.082X10^{-9}	0.1955	2.685X10^{-11}	0.4558	4.994X10^{-8}
Solar Radiation	ADD	Humidity	Cloud Cover	Precipitation	Dew Point	Wind Speed	Altitude
F-statistic	2.469X10^{4}	4.745	1.68	1.517	6.053	16.18	36.21
P-value	<2.2X10^{-16}	0.02984	0.1955	0.2186	0.01421	6.594X10^{-5}	3.33X10^{-9}
Dew Point	ADD	Humidity	Cloud Cover	Precipitation	Solar Radiation	Wind Speed	Altitude
F-statistic	3.272	258.9	46.38	8.347	6.053	22.91	71.61
P-value	0.02647	<2.2X10^{-16}	2.685X10^{-11}	0.004024	0.01421	2.211X10^{-6}	2.646X10^{-16}
Wind Speed	ADD	Humidity	Cloud Cover	Precipitation	Solar Radiation	Dew Point	Altitude
F-statistic	18.63	49.78	0.557	3.432	16.18	22.91	80.89
P-value	1.898X10^{-5}	5.49X10^{-12}	0.4558	0.0479	6.594X10^{-5}	2.211X10^{-6}	<2.2X10^{-16}
Altitude	ADD	Humidity	Cloud Cover	Precipitation	Solar Radiation	Dew Point	Wind Speed
F-statistic	46.61	486.9	30.61	1.563	36.21	71.61	80.89
P-value	2.404X10^{-1}	<2.2X10^{-16}	4.994X10^{-8}	0.2118	3.33X10^{-9}	2.646X10^{-16}	<2.2X10^{-16}

Table C2: Multilevel Regressions for How Different Environmental Variables Affect the Median Moisture Content in Relation to Other Environmental Variables

Formula	Environmental Effect On Mummification (Multilevel Regressions)		
ADD+Cloud Cover	Environmental Variables	Residuals	T-Value
	ADD	$-1.282X10^{-4} \pm 1.474X10^{-5}$	-8.696
	Cloud Cover	$9.345X10^{-2} \pm 1.136X10^{-2}$	8.228
ADD+Precipitation			
	ADD	$-1.306X10^{-4} \pm 1.532X10^{-5}$	-8.525
	Precipitation	$3.205X10^{-2} \pm 6.434X10^{-3}$	4.981
ADD+Dew Point			
	ADD	$-1.179X10^{-4} \pm 1.508X10^{-5}$	-7.819
	Dew Point	$3.516X10^{-3} \pm 5.187X10^{-4}$	6.779
Humidity+Solar Radiation			
	Humidity	$2.76X10^{-1} \pm 1.744X10^{-2}$	15.823
	Solar Radiation	$-7.566X10^{-6} \pm 6.887X10^{-4}$	-10.986
Cloud Cover+Solar Radiation			
	Cloud Cover	$9.372X10^{-2} \pm 1.141X10^{-2}$	8.211
	Solar Radiation	$-6.542X10^{-6} \pm 7.824X10^{-7}$	-8.362

Table C2 (Cont.): Multilevel Regressions for How Different Environmental Variables Affect the Median Moisture Content in Relation to Other Environmental Variables

Formula	Environmental Effect On Mummification (Multilevel Regressions)		
Cloud Cover+Wind Speed	Environmental Variables	Residuals	T-Value
	Cloud Cover	0.0927034 ± 0.0121536	7.628
	Wind Speed	-0.0001678 ± 0.009124	-0.184
Solar Radiation+Precipitation			
	Solar Radiation	$-6.682X10^{-6} \pm 8.133X10^{-7}$	-8.216
	Precipitation	$3.239X10^{-2} \pm 6.465X10^{-3}$	5.009
Solar Radiation+Dew Point			
	Solar Radiation	$-5.91X10^{-6} \pm 8.028X10^{-7}$	-7.362
	Dew Point	$3.484X10^{-3} \pm 5.225X10^{-4}$	6.667
Wind Speed+Precipitation			
	Wind Speed	-0.0001773 ± 0.0009481	-0.187
	Precipitation	0.0298536 ± 0.0068734	4.343
Altitude+Precipitation			
	Altitude	$-4.978X10^{-5} \pm 2.208X10^{-5}$	-2.254
	Precipitation	$2.937X10^{-2} \pm 6.834X10^{-3}$	4.298

Table C3: Correlations for How Different Environmental Variables Affect the Median Moisture Content in Relation to Other Environmental Variables

Formula	Environmental Effect On Mummification (Correlation)		
ADD+Cloud Cover	Environmental Variables	R2	%
	ADD	0.23232	23.232%
	Cloud Cover	0.08468	8.468%
ADD+Precipitation			
	ADD	0.2401	24.010%
	Precipitation	0.00325	0.325%
ADD+Dew Point			
	ADD	0.25503	25.503%
	Dew Point	0.1225	12.250%
Humidity+Solar Radiation			
	Humidity	0.15761	15.761%
	Solar Radiation	0.07618	7.618%
Cloud Cover+Solar Radiation			
	Cloud Cover	0.08762	8.762%
	Solar Radiation	0.24503	24.503%

Table C3 (Cont.): Correlations for How Different Environmental Variables Affect the Median Moisture Content in Relation to Other Environmental Variables

Formula	Environmental Effect On Mummification (Correlation)		
Cloud Cover+Wind Speed	Environmental Variables	R^2	%
	Cloud Cover	0.03534	3.534%
	Wind Speed	0.45563	45.563%
Solar Radiation+Precipitation			
	Solar Radiation	0.24503	24.503%
	Precipitation	0.00292	0.292%
Solar Radiation+Dew Point			
	Solar Radiation	0.26214	26.214%
	Dew Point	0.12745	12.745%
Wind Speed+Precipitation			
	Wind Speed	0.43692	43.692%
	Precipitation	0.00003	0.003%
Altitude+Precipitation			
	Altitude	0.62568	62.568%
	Precipitation	0.00533	0.533%

Table C4: List of Environmental Variables by Significant Effect on Median Moisture Content Using Combination Formulae

Environmental Variable	T-value
Humidity	15.823
Solar Radiation	-10.986
ADD	-8.696
Cloud Cover	-8.228
Dew Point	6.779
Precipitation	5.009
Altitude	-2.254
Wind Speed	-0.187

Table C5: Multilevel Regressions for How Individual Environmental Variables Affect Median Moisture Content

Environmental Variable	Environmental Effect On Mummification (Multilevel Regression)	
	Residuals	T-value
Cloud Cover	0.09259 ± 0.01213	7.633
ADD	$-1.725X10^{-4} \pm 1.565X10^{-5}$	-8.146
Solar Radiation	$-6.483X10^{-6} \pm 8.307X10^{-7}$	-7.805
Humidity	0.25199 ± 0.01896	13.294
Precipitation	0.029738 ± 0.006838	4.349
Dew Point	0.0039071 ± 0.005466	0.08468
Wind Speed	0.0001923 ± 0.0009602	0.2
Altitude	$-5.148X10^{-5} \pm 2.079X10^{-5}$	-2.476

Table C6: Correlations for How Individual Environmental Variables Affect Median Moisture Content

Environmental Variable	Environmental Effect on Mummification (Correlation)	
	R2	%
Cloud Cover	0.08762	8.76%
ADD	0.25503	25.50%
Solar Radiation	0.25908	25.91%
Humidity	0.31136	31.14%
Precipitation	0.00548	0.55%
Dew Point	0.08468	8.47%
Wind Speed	0.44622	44.62%
Altitude	0.62726	62.73%

Table C7: List of Environmental Variables by Significant Effect on Median Moisture Content Using Individual Environmental Variable Formulae

Environmental Variable	T-value
Humidity	13.294
ADD	-8.146
Solar Radiation	-7.805
Cloud Cover	7.633
Dew Point	7.148
Precipitation	4.349
Altitude	-2.476
Wind Speed	0.2

Table C8: Analyses of Variance within Formulae with Specific Environmental Variables Removed

Formula	Environmental Variable Removed	Chi squared	P-value	Change in intercept (+ or -)	T-value (Original)	T-value (New)	Intercept Estimate (Original)	Intercept Estimate (New)
ADD + Cloud Cover								
	ADD	71.043	$<2.2X10^{-16}$	-	11.518	6.914	$1.705X10^{-1} \pm 1.48X10^{-2}$	0.10862 ± 0.01571
	Cloud Cover	65.029	$1.226X10^{-15}$	+	11.518	13.674	$1.705X10^{-1} \pm 1.48X10^{-2}$	$2.059X10^{-1} \pm 1.506X10^{-2}$
ADD + Precipitation								
	ADD	68.265	$<2.2X10^{-16}$	-	13.366	8.11	$2.015X10^{-1} \pm 1.508X10^{-2}$	0.138612 ± 0.017091
	Precipitation	24.306	$8.219X10^{-7}$	+	13.366	13.674	$2.015X10^{-1} \pm 1.508X10^{-2}$	$2.059X10^{-1} \pm 1.506X10^{-2}$
ADD + Dew Point								
	ADD	57.935	$2.71X10^{-14}$	-	11.015	6.398	$1.694X10^{-1} \pm 1.538X10^{-2}$	0.1087433 ± 0.0169959
	Dew Point	44.306	$2.809X10^{-11}$	+	11.015	13.674	$1.694X10^{-1} \pm 1.538X10^{-2}$	$2.059X10^{-1} \pm 1.506X10^{-2}$
Humidity + Solar Radiation								
	Humidity	202.86	$<2.2X10^{-16}$	+	4.054	13.528	$7.968X10^{-2} \pm 1.965X10^{-2}$	$2.039X10^{-1} \pm 1.507X10^{-2}$
	Solar Radiation	107.59	$<2.2X10^{-16}$	-	4.054	1.303	$7.968X10^{-2} \pm 1.965X10^{-2}$	0.02152 ± 0.01651
Cloud Cover + Solar Radiation								
	Cloud Cover	63.816	$1.366X10^{-15}$	+	11.586	13.528	$1.686X10^{-1} \pm 1.455X10^{-2}$	$2.039X10^{-1} \pm 1.507X10^{-2}$
	Solar Radiation	65.939	$4.652X10^{-16}$	-	11.586	6.914	$1.686X10^{-1} \pm 1.455X10^{-2}$	0.10862 ± 0.01571

Table C8 (Cont.): Analyses of Variance within Formulae with Specific Environmental Variables Removed

Formula	Environmental Variable Removed	Chi squared	P-value	Change in intercept (+ or -)	T-value (Original)	T-value (New)	Intercept Estimate (Original)	Intercept Estimate (New)
Cloud Cover + Wind Speed								
	Cloud Cover	55.558	$9.075X10^{-14}$	+	5.252	6.165	0.1112483 ± 0.0211835	0.141036 ± 0.0228785
	Wind Speed	0.0506	0.8219	Not Significant	NS	NS	Not Significant	Not Significant
Solar Radiation + Precipitation								
	Solar Radiation	63.65	$1.486X10^{-15}$	-	13.252	8.11	$1.998X10^{-1} \pm 1.508X10^{-2}$	0.138612 ± 0.017091
	Precipitation	24.582	$7.121X10^{-7}$	+	13.252	13.528	$1.998X10^{-1} \pm 1.508X10^{-2}$	$2.039X10^{-1} \pm 1.507X10^{-2}$
Solar Radiation + Dew Point								
	Solar Radiation	51.646	$6.647X10^{-13}$	-	10.782	6.398	$1.671X10^{-1}$ $1.55X10^{-2}$	0.1087433 ± 0.0169969
	Dew Point	42.909	$5.736X10^{-11}$	+	10.782	13.528	$1.671X10^{-1} \pm 1.55X10^{-2}$	$2.039X10^{-1} \pm 1.507X10^{-2}$
Wind Speed + Precipitation								
	Wind Speed	0.0515	0.8204	Not Significant	NS	NS	Not Significant	Not Significant
	Precipitation	18.613	$1.601X10^{-5}$	-	6.247	6.165	0.1414098 ± 0.0226375	0.141036 ± 0.228785
Altitude + Precipitation								
	Altitude	4.9171	0.02659	Not Significant	NS	NS	Not Significant	Not Significant
	Precipitation	17.891	$2.339X10^{-5}$	+	8.197	9.054	$1.77X10^{-1} \pm 2.16X10^{-2}$	$1.837X10^{-1} \pm 2.029X10^{-2}$

Table C9: How Correlations Changed After ANOVAs Were Performed

Formula	Environmental Variable Removed	Environmental Variable Affected	Original Correlation		New Correlation	
ADD + Cloud Cover			R2	%	R2	%
	ADD					
		Cloud Cover	0.08468	8.4680%	0.08762	8.7620%
	Cloud Cover					
		ADD	0.23232	23.2320%	0.25503	25.5030%
ADD + Precipitation						
	ADD					
		Precipitation	0.00325	0.3250%	0.00548	0.5480%
	Precipitation					
		ADD	0.2401	24.0100%	0.25503	25.5030%
ADD + Dew Point						
	ADD					
		Dew Point	0.1225	12.2500%	0.08468	8.4680%
	Dew Point					
		ADD	0.25503	25.5030%	No Change	No Change
Humidity + Solar Radiation						
	Humidity					
		Solar Radiation	0.07618	7.6180%	0.25908	25.9080%
	Solar Radiation					
		Humidity	0.15761	15.7610%	0.31136	31.1360%
Cloud Cover + Solar Radiation						
	Cloud Cover					
		Solar Radiation	0.24503	24.5030%	0.25908	25.9080%
	Solar Radiation					
		Cloud Cover	0.08762	8.7620%	No Change	No Change

Table C9 (Cont.): How Correlations Changed After ANOVAs Were Performed

Formula	Environmental Variable Removed	Environmental Variable Affected	Original Correlation		New Correlation	
Cloud Cover + Wind Speed						
	Cloud Cover					
		Wind Speed	0.45563	45.5630%	0.44622	44.6220%
	Wind Speed					
		Cloud Cover	0.22563	22.5630%	0.24305	24.3050%
Solar Radiation + Precipitation						
	Solar Radiation					
		Precipitation	0.00292	0.2920%	0.00548	0.5480%
	Precipitation					
		Solar Radiation	0.24503	23.5030%	0.25908	25.9080%
Solar Radiation + Dew Point						
	Solar Radiation					
		Dew Point	0.12745	12.7450%	0.08468	8.4680%
	Dew Point					
		Solar Radiation	0.26214	26.2140%	0.25908	25.9080%
Wind Speed + Precipitation						
	Wind Speed					
		Precipitation	0.0003	0.0030%	0.00548	0.5480%
	Precipitation					
		Wind Speed	0.43692	43.6920%	0.44622	44.6220%
Altitude + Precipitation						
	Altitude					
		Precipitation	0.00533	0.5330%	0.00548	0.5480%
	Precipitation					
		Altitude	0.62568	62.5680%	0.62726	62.7260%

Table C10: Analysis of Variance Between Overall Formulae with Body and Body Combined with Climate Region

Formula	Chi Squared	P-value	Variance
ADD + Cloud Cover	0	1	0
ADD + Precipitation	0	1	0.0003861 ± 0.01965
ADD + Dew Point	0	1	0
Humidity + Solar Radiation	1.7602	0.1846	0.002121 ± 0.04605
Cloud Cover + Solar Radiation	0	1	$6.517 X 10^{-5}$ ± 0.008073
Cloud Cover + Wind Speed	0.0981	0.7542	0.0006856 ± 0.02618
Solar Radiation + Precipitation	0.1293	0.7192	0.000543 ± 0.0233
Solar Radiation + Dew Point	0	1	0
Wind Speed + Precipitation	0.6411	0.4233	0.001416 ± 0.03763
Altitude + Precipitation	0	1	$1.211 X 10^{2}$ ± 11.00522

Table C11: How Correlations Change Between Overall Formulae with Body and Body Combined with Climate Region

Formula	Environmental Variable	Original Correlations		New Correlations	
ADD + Cloud Cover		R2	%	R2	%
	ADD	0.23232	23.232%	No Change	No Change
	Cloud Cover	0.08468	8.468%	No Change	No Change
ADD + Precipitation					
	ADD	0.2401	24.010%	0.14364	14.364%
	Precipitation	0.00325	0.325%	0.00176	0.176%
ADD + Dew Point					
	ADD	0.25503	25.503%	No Change	No Change
	Dew Point	0.1225	12.250%	No Change	No Change
Humidity + Solar Radiation					
	Humidity	0.15761	15.761%	0.04285	4.285%
	Solar Radiation	0.07618	7.618%	0.02372	2.372%
Cloud Cover + Solar Radiation					
	Cloud Cover	0.08762	8.762%	0.07618	7.618%
	Solar Radiation	0.24503	24.503%	0.21809	21.809%
Cloud Cover + Wind Speed					
	Cloud Cover	0.03534	3.534%	0.0196	1.960%
	Wind Speed	0.45563	45.563%	0.28196	28.196%
Solar Radiation + Precipitation					
	Solar Radiation	0.24503	24.503%	0.12532	12.532%
	Precipitation	0.00292	0.292%	0.0013	0.130%
Solar Radiation + Dew Point					
	Solar Radiation	0.26214	26.214%	No Change	No Change
	Dew Point	0.12745	12.745%	No Change	No Change
Wind Speed + Precipitation					
	Wind Speed	0.43692	43.692%	0.20703	20.703%
	Precipitation	0.00003	0.003%	0.00004	0.004%
Altitude + Precipitation					
	Altitude	0.62568	62.568%	0.21344	21.344%
	Precipitation	0.00533	0.533%	0.00084	0.084%

Table C12: Analysis of Variance Between Individual Environmental Variables with Body and Body Combined with Climate Region

Environmental Variable	Chi squared	P-value	Variance
Cloud Cover	0.1125	0.7373	0.0006958 ± 0.02638
ADD	0.1802	0.7422	0.0005231 ± 0.02287
Solar Radiation	0.3543	0.5517	0.0006917 ± 0.0263
Humidity	0	1	0.0003334 ± 0.01826
Precipitation	0.6648	0.4149	0.001431 ± 0.03783
Dew Point	0	1	0.0002787 ± 0.01669
Wind Speed	1.0084	0.3153	0.0016635 ± 0.04079
Altitude	0	1	1.044×10^{2} ± 10.2152

Table C13: How Correlations Change Between Individual Environmental Variables with Body and Body Combined with Climate Region

Environmental Variable	Original Correlations		New Correlations	
	R2	%	R2	%
Cloud Cover	0.08762	8.762%	0.03842	3.842%
ADD	0.25503	25.503%	0.13323	13.323%
Solar Radiation	0.25908	25.908%	0.11696	11.696%
Humidity	0.31136	31.136%	0.19981	19.981%
Precipitation	0.00548	0.548%	0.00168	0.168%
Dew Point	0.08468	8.468%	0.05856	5.856%
Wind Speed	0.44622	44.622%	0.19625	19.625%
Altitude	0.62726	62.726%	0.2401	24.010%

APPENDIX D

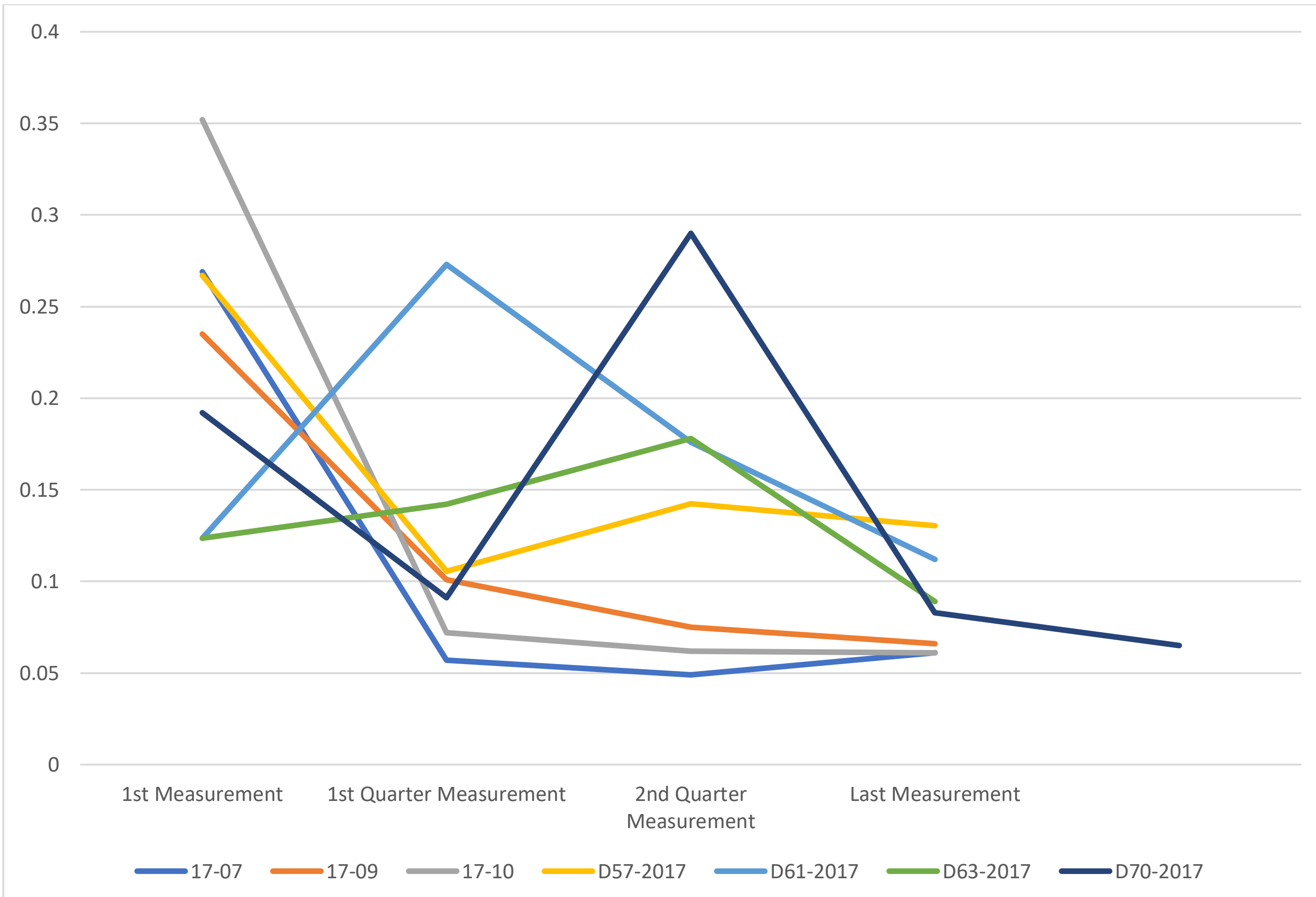

Figure D1: Change Over Time in Moisture Content From all Donations Used

APPENDIX E

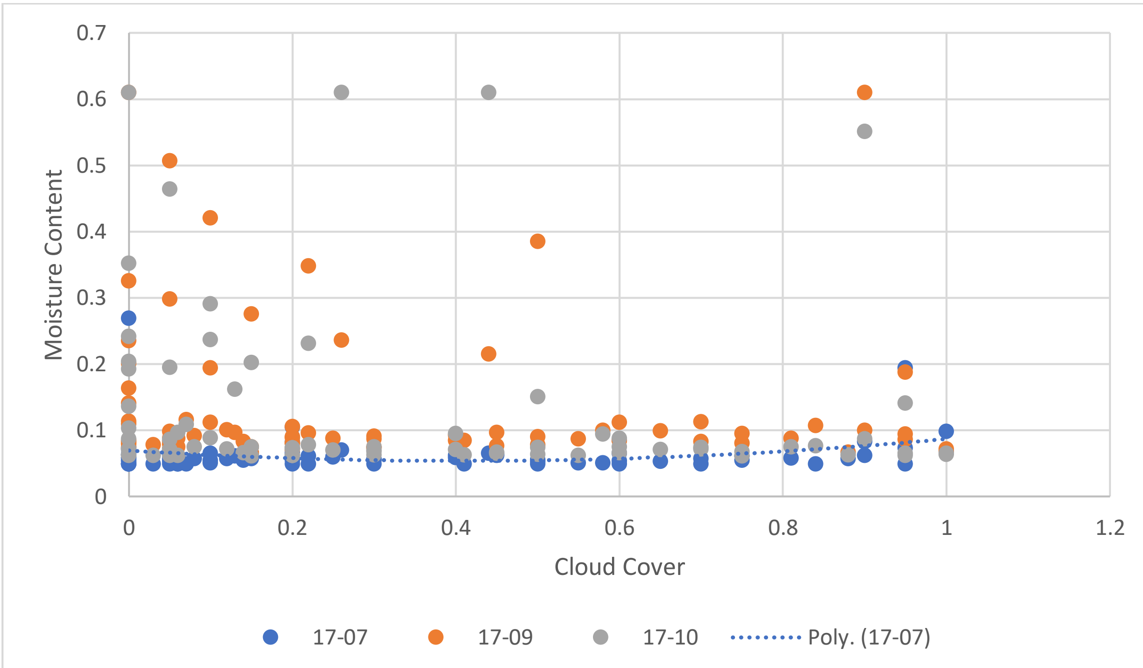

Figure E1: Cloud Cover in Relation to Colorado Subjects

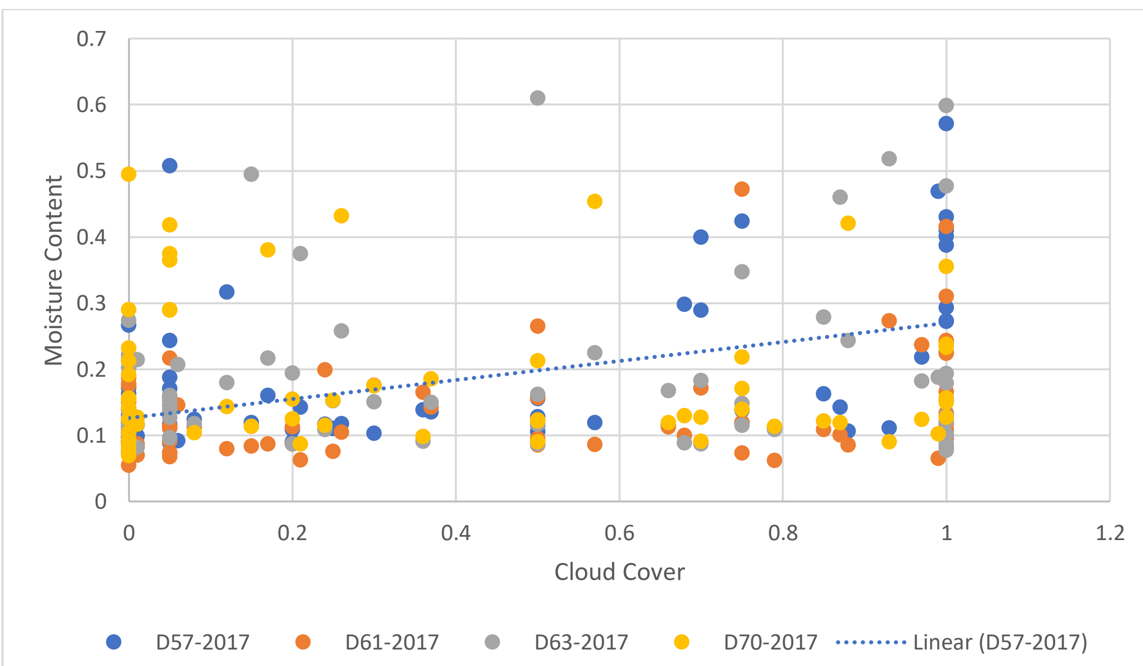

Figure E2: Cloud Cover in Relation to Texas Subjects

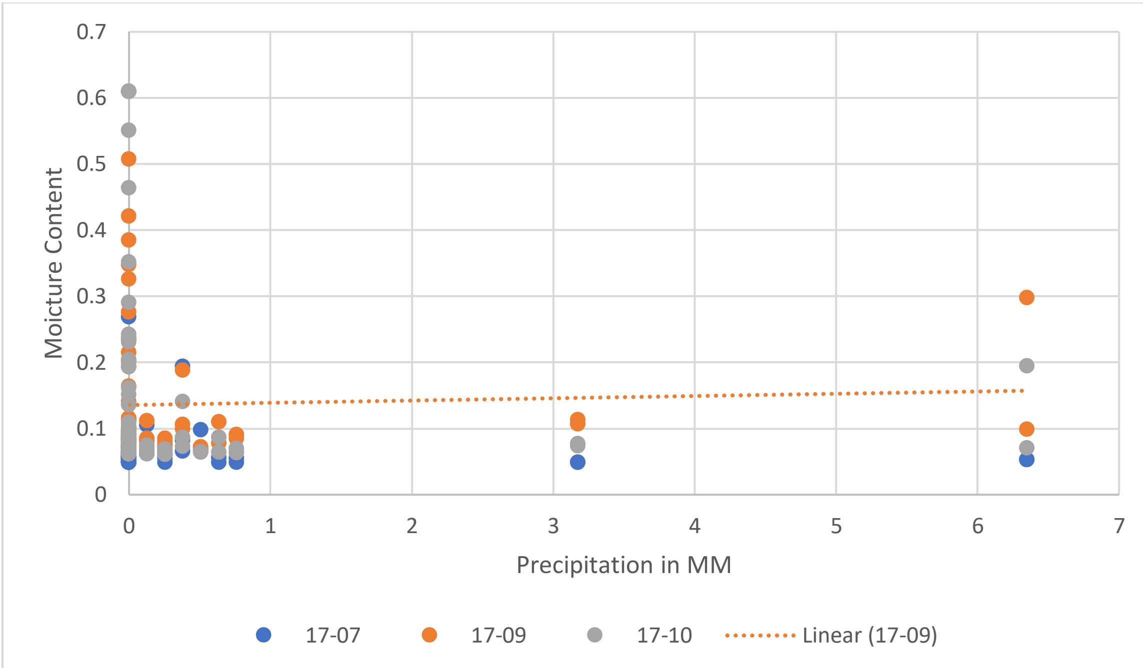

Figure E3: Precipitation in Relation to Colorado Subjects

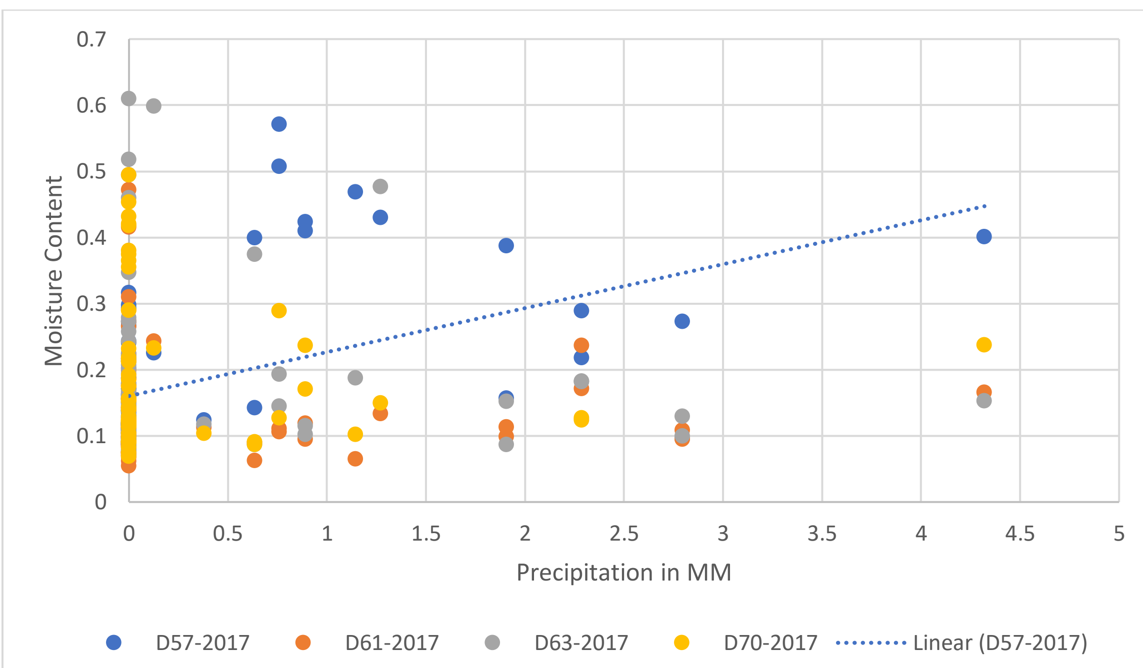

Figure E4: Precipitation in Relation to Texas Subjects

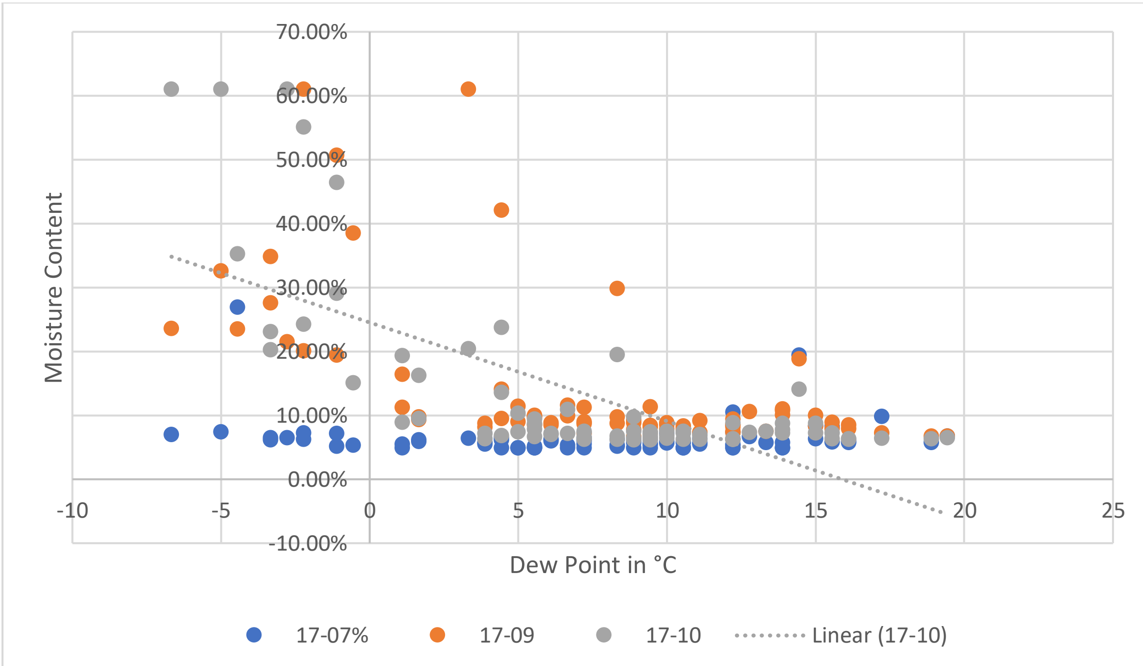

Figure E5: Dew Point in Relation to Colorado Subjects

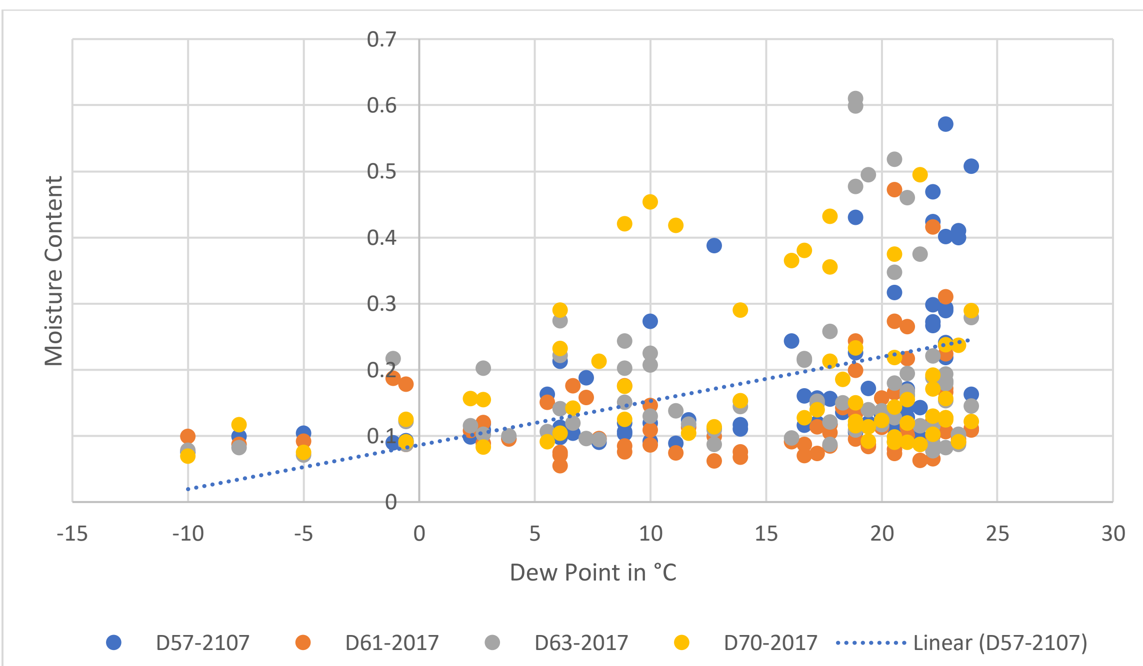

Figure E6: Dew Point in Relation to Texas Subjects

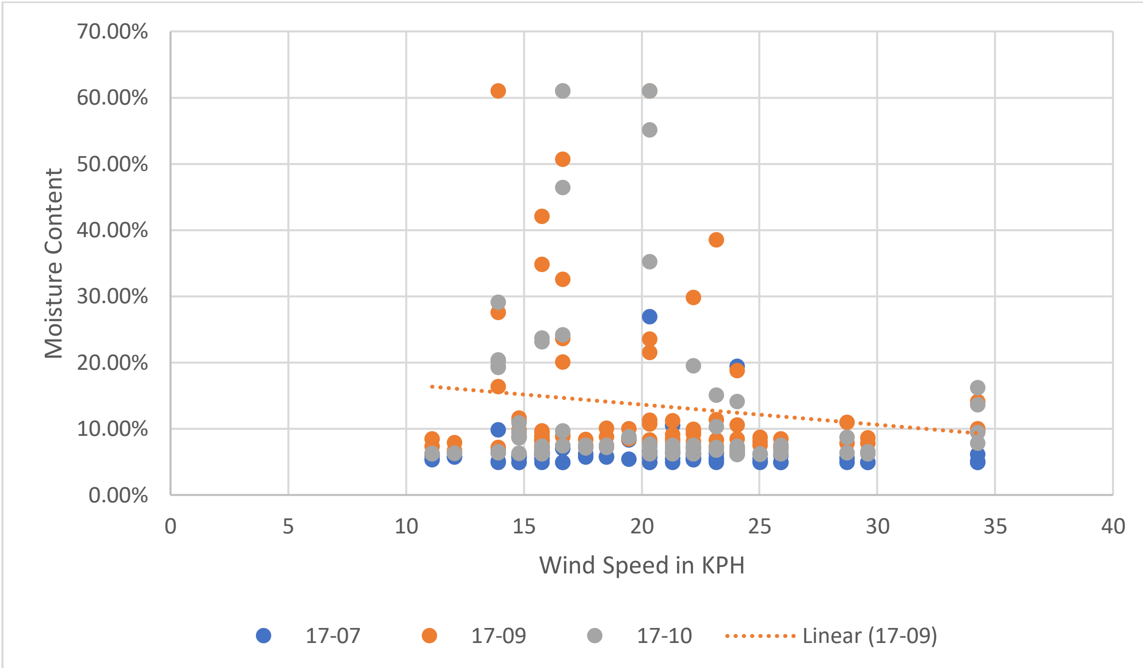

Figure E7: Wind Speed in Relation to Colorado Subjects

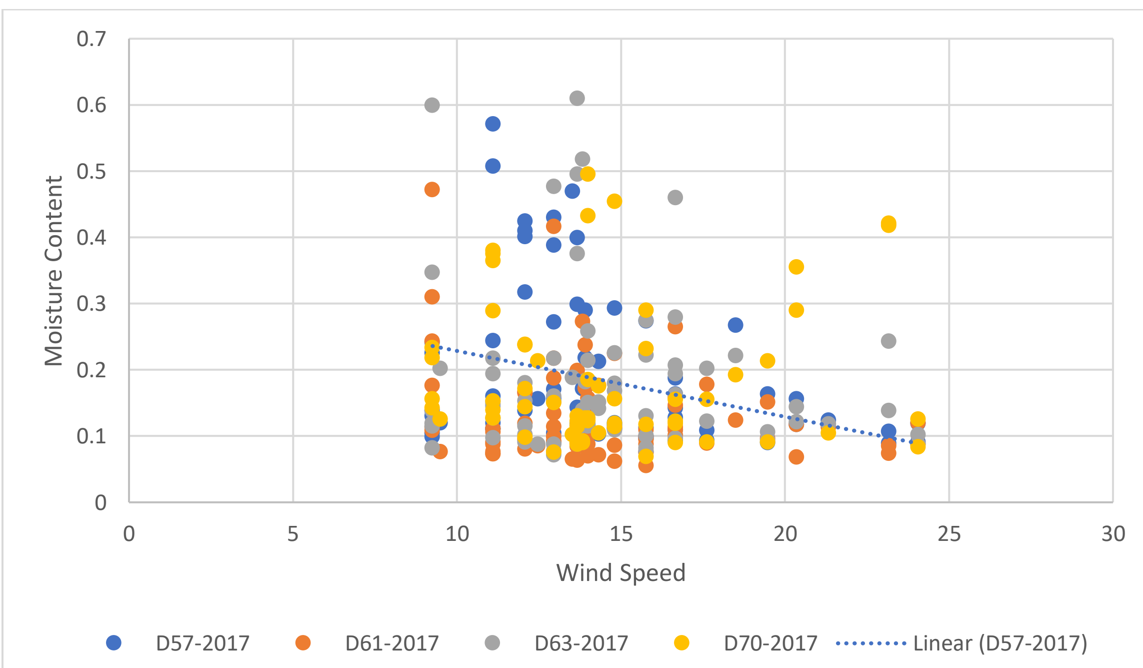

Figure E8: Wind Speed in Relation to Texas Subjects

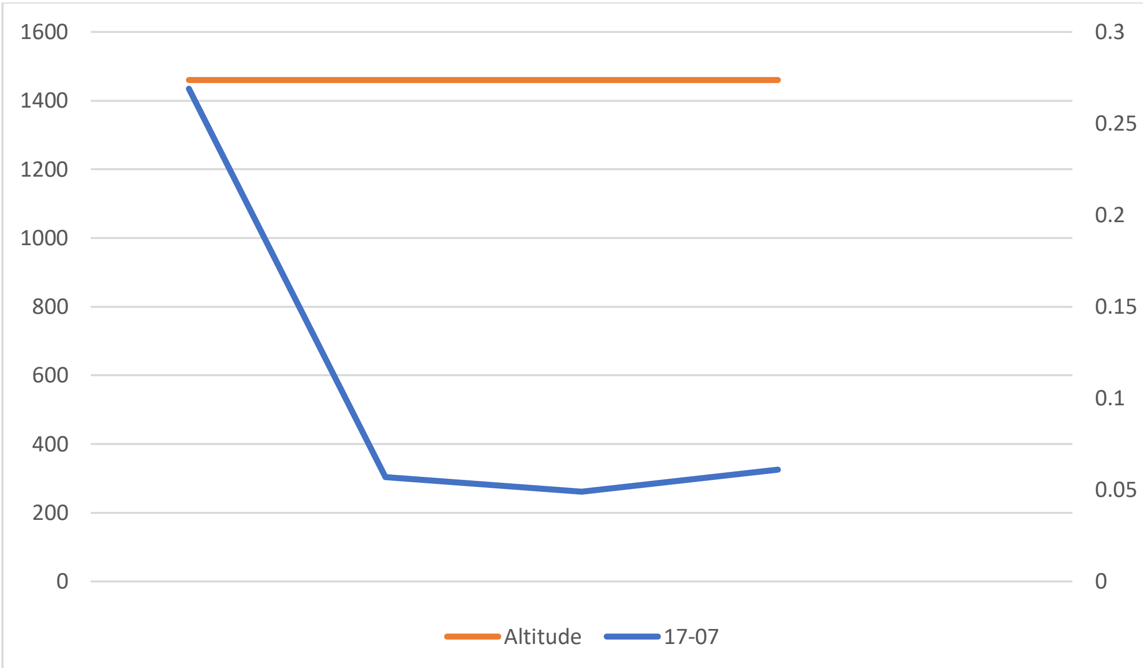

Figure E9: Altitude In Relation to 17-07, the First Colorado Subject

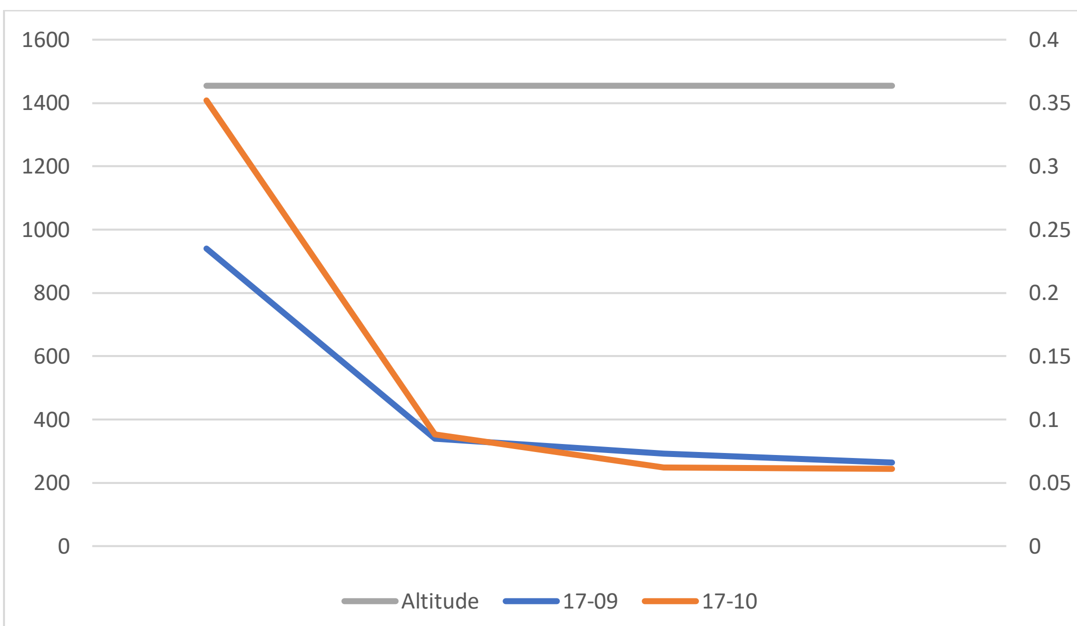

Figure E10: Altitude in Relation to 17-09 and 17-10, the Second and Third Colorado Subjects

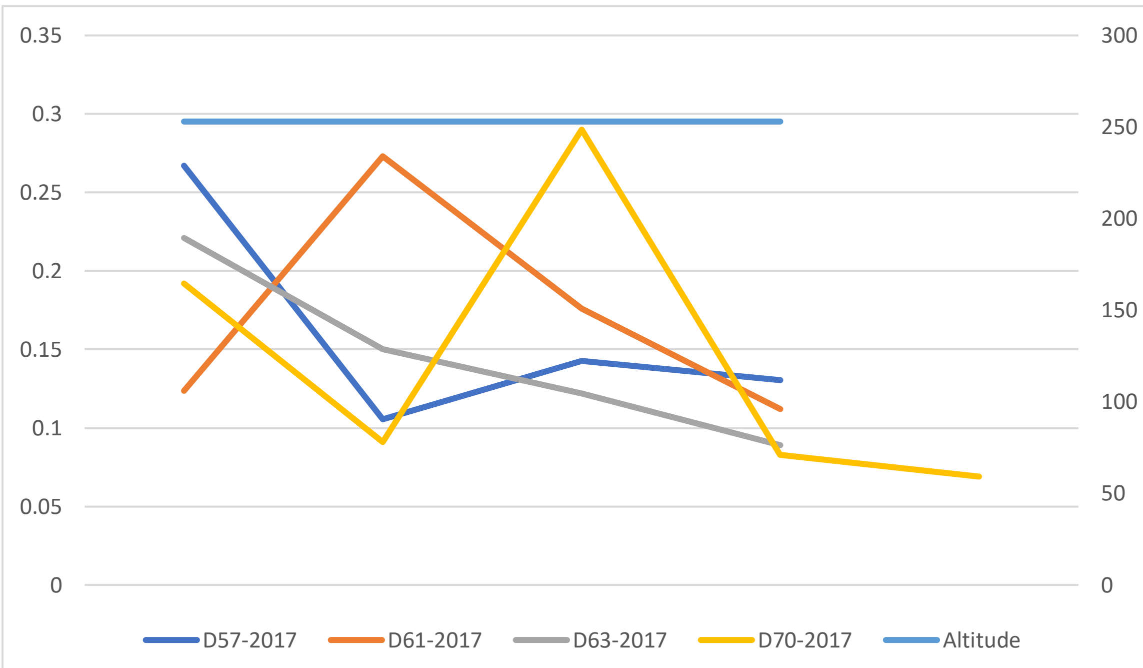

Figure E11: Altitude in Relation to Texas Subjects

LITERATURE CITED

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