Acclimation's Influence on Physically-fit Individuals: Marathon Race Results as a Function of Meteorological Variables and Indices

by

Kimberly Michelle DeBiasse

A Dissertation Presented in Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy

Approved April 2011 by the
Graduate Supervisory Committee:

Randall Cerveny, Chair
Anthony Brazel
Nancy Selover

ARIZONA STATE UNVERSITY

May 2011

ABSTRACT

While there are many elements to consider when determining one's risk of heat or cold stress, acclimation could prove to be an important factor to consider. Individuals who are participating in more strenuous activities, while being at a lower risk, will still feel the impacts of acclimation to an extreme climate. To evaluate acclimation in strenuous conditions, I collected finishing times from six different marathon races: the New York City Marathon (New York City, New York), Equinox Marathon (Fairbanks, Alaska), California International Marathon (Sacramento, California), LIVESTRONG Austin Marathon (Austin, Texas), Cincinnati Flying Pig Marathon (Cincinnati, Ohio), and the Ocala Marathon (Ocala, Florida). Additionally, I collected meteorological variables for each race day and the five days leading up to the race (baseline). I tested these values against the finishing times for the local runners, those from the race state, and visitors, those from other locations. Effects of local acclimation could be evaluated by comparing finishing times of local runners to the change between the race day and baseline weather conditions. Locals experienced a significant impact on finishing times for large changes between race day and the baseline conditions for humidity variables, dew point temperature, vapor pressure, relative humidity, and temperature based variables such as the heat index, temperature and the saturation vapor pressure. Wind speed and pressure values also marked a change in performance, however; pressure was determined to be a larger psychological factor than acclimation factor. The locals also demonstrated an acclimation effect as performance improved when conditions were similar on race day to baseline conditions for the three larger races. Humidity variables had the largest impact on runners when those values increased from training and acclimation values; however increased wind speed appeared to offset increased humidity values. These findings support previous acclimation research stating warm wet conditions are more difficult to acclimate to than warm dry conditions. This research while primarily pertaining to those participating physically demanding activities may also be applied to other large scale events such as festivals, fairs, or concerts.

ACKNOWLEDGEMENTS

I would like to thank my Committee Chair, Dr. Randy Cerveny, for his time and patience through the writing process. His guidance and encouragement were greatly appreciated and instrumental in the completion of this thesis. I would also like to thank my committee members for their time, insight and feedback. Additionally, I would like to thank John Estle and Matias Saari for their help with gathering information and data for the Equinox Marathon held in Fairbanks, Alaska. Lastly, I would like to thank Jesse Martin and Matthew Pace for their support and feedback.

TABLE OF CONTENTS

CHAPTER Page

CHAPTER Page

CHAPTER Page

APPENDIX

APPENDIX Page

LIST OF TABLES

LIST OF FIGURES

Figure	Page

1. Introduction

a. Research Justification

As more and more people are living longer and undertaking outdoor activities, researchers and health officials have been attempting to create a way to measure a person's risk and vulnerability to heat or cold stress. Heat accounts for more deaths each year than floods, hurricanes, tornadoes, and lightning combined (NWS 2010). There are many variables that need to be taken into consideration when determining a person's risk of heat stress, which include and are not limited to: weather conditions, income, age, prior health conditions, and time spent in a location. Studies have begun to evaluate many of these individually or by looking at groupings of social factors or physical factors (e.g. MeGeehin and Miarabelli 2001; Harlen et al. 2006; Lee et al. 2008; Chau et al. 2009; Greene et al. 2009). To evaluate heat and cold risk there are several indices that have been created to quantify the outdoor conditions on a given day. These range from simplistic indices that use only two meteorological variables, like the wind chill index, to the complex that consider heat transfer mechanisms between the body and the environment, such as the physiological equivalent temperature.

One key aspect of heat or cold risk and vulnerability that is just beginning to be considered is acclimation to weather conditions. Currently, the National Weather Service uses a sliding scale that implicitly addresses acclimation when issuing heat watches/warnings during the summer months because temperatures considered dangerous at the beginning of the summer are not as dangerous as the summer progresses.

Acclimation to climate, or acclimatization, is defined as an organism's ability to perform increased work in warmer temperatures as a result of improvement in heat dissipation brought on by repeated elevations of core temperatures (Moseley 1997). While many past studies have examined the effects of acclimation on the elderly and infirm (e.g., MeGeehin and Mirabelli 2001; Basu and Samet 2002; Sheridan et al. 2009), for this study, the concept of acclimation will be examined by viewing the results of several marathon races based on the difference in conditions on race day compared to the days leading up to the race (in essence, a baseline for 'acclimated' conditions).

Such analysis is important in today's world of increased participation in outdoor activities. Over the past 41 years, for example, the NYC Marathon has increased its runner participation from 170 runners to 39,000 runners. Consequently, knowledge of how runners are influenced by acclimation can be important to a variety of users.

For example, runners can use this information to gauge how their training conditions may impact their success or comfort during a race, thus allowing them to adjust their travel plans for every race they choose to participate in. Additionally, they can cater their training to the location where the race is being held in an effort to reduce the impact the meteorological conditions will have on them compared to if they had not considered weather differences.

Furthermore, event planners, organizers, and emergency services can use this information when planning for large scale events. Events such as concerts, athletic events, and festivals draw people from all different locations throughout the United States and the world. Understanding how the weather, or changes in the weather, can impact local residents and visitors will allow those agencies to be better prepared to handle any situations that may arise.

b. Problem Statement

As defined above, acclimation is a descriptor of biological response to varying environmental conditions that combines both natural factors such as temperature, humidity and wind speed and social factors such as income and employment. It is based on the meteorological conditions of a particular geographic location and the impact the difference in meteorological conditions may have on an individual due to the movement of people between various geographic locations.

A critical issue with acclimation is the prerequisite meteorological conditions required for adaptation. Previous studies have tended to examine the concept of acclimation as an aspect of heat stress through study of the ill and/or infirm. For example, literature indicates that the number of heat related morbidity and mortality cases that occur increases when temperature changes abruptly or remains elevated for an extended period of time (e.g., MeGeehin and Mirabelli 2001; Basu and Samet 2002; Sheridan et al. 2009). There has been a move recently to address this acclimation aspect of heat stress by adding a sliding scale acknowledging the importance of adaptation into calculations by way of the heat watch/warning system used by the National Weather Service and developed by Kalkstein and Sheridan (1997).

Although that aspect of acclimation is important, an equally valid characteristic of acclimation is the degree to which physically fit people must accustom themselves to the environmental conditions in order to undertake strenuous activity. As mentioned above, the NWS Phoenix, Arizona heat watch and warning system recognizes that a high temperature at the beginning of the summer season will impact those living in that area more than the same temperature would later in the summer. For example, a temperature of ninety degrees in the beginning of the summer in Phoenix poses a greater threat of heat stress than the same temperature in July or August, as normal temperatures are much higher that time of year. However, the heat watch/warning system does not view acclimation in terms of an individual visiting an area or even just an extreme change in persistent conditions. At this time, there has not been a study that examines various individuals with different social backgrounds participating in the same type of activity in various locations across the country.

As a result, I propose to address the concept of acclimation based on changes in persistent temperature and moisture values through measurements obtained leading up to and during a marathon event. Consequently, my research question is: To what degree can acclimation be discriminated within both local and visiting populations as measured within the marathon running community through comparison of their finishing times under varying weather conditions?

By using data from the marathon running community, I will establish a different viewpoint than many previous studies which have concentrated on elderly and/or infirm populations (e.g., Kalkstein and Greene 1997; Sheridan and

Kalkstein 2004; Shedian et al. 2009). A runner's finishing time is based on many factors which are not limited to: prior training, weather, natural ability, and psychological outlook. Running the standard marathon distance of 26.2 miles is an accomplishment in itself and even the most veteran runners can find that finishing the race can be a struggle. While those running are not necessarily world class athletes, a certain amount of physical conditioning is required to complete the long distance as the limits of physical exertion may be tested during a marathon. The importance of acclimation to a particular weather type may be seen in finishing times of runners performing during a certain type of weather condition.

I hypothesize that if those that are running are impacted by a lack of acclimation to the weather conditions of that area, their finishing time may suffer or improve, depending on the condition. For example, I expect the local population will find their finishing times more significantly impacted when race day conditions vary from the five previous day conditions (baseline), as they may not be acclimated to the conditions of race day. Additionally, I expect that those who are acclimatized to the race day conditions, specifically the local runners, will find their finishing times may not be significantly impacted by the weather, if the race day conditions are the same as the previous days.

c. Organization

In order to evaluate my research question stated above, I will first review previous literature addressing acclimation and its associated elements (Chapter 2). To begin, I will focus on the physiological science of acclimatization, evaluating how the body reacts in different meteorological environments. Additionally, the history in development of heat indices, along with other social factors that can impact heat stress vulnerability, will be addressed within the literature review.

Chapter 3 will include a description of the marathon races chosen as well as the data used for this study. The data include race finishing times from the New York City Marathon (New York City, New York), Equinox Marathon (Fairbanks, Alaska), California International Marathon (Sacramento, California), LIVESTRONG Austin Marathon (Austin, Texas), Cincinnati Flying Pig Marathon (Cincinnati, Ohio) and Ocala Marathon (Ocala, Florida). The weather data used for the study include weather variables recorded at stations near the race site and calculations of various heat stress indices.

Chapter 4 will focus on the statistical tests performed on the data. These data are segregated by "local" and "visitor" classifications, and race finishing times are compared for two situations: (a) when race day conditions are similar to the average weather of the previous five days (baseline) and (b) when race day conditions are different from that baseline. I will also discuss and interpret those results. Statistical tests performed include a simple linear regression, z-score calculation, correlation analysis, and two-way t-test. Following the discussion of the findings, chapter 5 will summarize the results, and I will suggest possible further testing and research on this topic.

d. Research Significance

A greater understanding of how acclimation can impact a person's heat risk or vulnerability—particularly for the relatively unresearched class of ‘physically-fit’ people—has the potential to have a large impact on planners, emergency medical personal, and organizers/coordinators of various types of events from races to large outdoor concerts to fairs. It is already known that an abrupt change in the weather increases the risk of heat or cold stress (MeGeehin and Mirabelli 2001; Basu and Samet 2002; Sheridan et al. 2009). As a result the heat watch/warning system was developed. This system is very helpful to the locals that monitor the weather and are familiar with a certain type of weather.

However, those people that seem to be neglected by the current system in some instances are those that are visiting an area with significantly different weather conditions than they are used to. Many visitors do not give much thought to how their bodies will react when traveling to another location. This study views one of the most strenuous activities a person can participate in and as a result can demonstrate how acclimation to particular weather conditions may increase or decrease their finishing time. My investigation also examines different groups of runners based on finishing speeds, such as elite (fifth percentile), average, median, and slowest (ninety-fifth percentile), which unlike previous studies which examined participants at a higher fitness level, excluding the slower runners who can represent the “average” population of people who are at a lower physical fitness level. Additionally, organizers/coordinators and emergency services can use the findings to gauge the risk of participants feeling ill or suffering from a heat or cold illness. While evaluating a population participating in a strenuous event, this research can apply to larger events such as concerts or conferences where a large number of people will not be accustomed to the weather they may experience.

2. Literature Review

a. Introduction

As stated in chapter one, the goal of this study is to evaluate the role of acclimation based on persistent weather conditions by viewing finishing times of participants running the marathon distance of 26.2 miles. As such, is it important to first understand the current literature on acclimation followed by the other factors including: meteorological conditions, prior health conditions, and various social factors all of which can influence a person's vulnerability to heat stress. Indeed, there are multiple factors that can influence a person's vulnerability to heat stress including: weather conditions, prior health conditions, employment, and income and living conditions.

Researchers and health officials have been attempting to create an index value to quantify the impact of meteorological conditions on the health and comfort of individuals for many years. Human thermal comfort, with respect to its energetic definition, is the balance of heat flowing to and from the body while skin temperature and sweat are in a comfortable range as a result of metabolism (Fanger 1972). Indices to measure human thermal comfort range from the simplistic, those using only two variables (e.g. wind chill temperature), to the complex, such as those considering complete heat exchange between humans and their environments (e.g. physiological equivalent temperature). Human thermal comfort itself is complex due to the fact that many people in the same meteorological environment will experience those conditions in a different manner (e. g. Blazejczyk and Krawczyk 1991; Blazejczyk 2001; Spanglo and de

Dear 2003; Ali-Toudert et al. 2005; Watts and Kalkstein 2002; 2004). Although these indices are not faultless, looking at variables in combination may be more indicative of heat stress risk.

In addition to meteorological variables, there are many other factors to consider when determining a person's human thermal comfort. These include physiological factors as well as social factors ranging from age to prior health conditions to time spent in a certain climate. Many studies have evaluated particular social groups that are 'at risk' for higher levels of heat illness (Harlan et al. 2006); however, the role of acclimation has yet to be considered. Traditional heat stress indices do not include acclimation in their calculation, although the most widely used comfort index, the 'heat index', which is used for the heat watch/warning systems distributed during the summer months by the National Weather Service, does include a sliding scale to manipulate acclimation as the summer season progresses. Acclimation may prove to be a very important social factor when determining heat stress risk as even those that are not normally considered to be "at risk" may experience heat stress symptoms when visiting locations with weather conditions they are not accustomed to.

In this chapter, I will first discuss the basics of heat acclimation. After discussing acclimation I examine the many other factors that can influence a person's vulnerability to heat stress. One factor is the climate itself including temperature, humidity and wind speed. A person's prior health conditions impact their risk of heat illness in addition to the climate of an area or the meteorological conditions of a particular day. Common ailments that are linked or commonly seen along with heat illness are respiratory disease, cardiovascular disease and stroke (Lee et al. 2008; Chau et al. 2009). Lastly, there are several social factors that impact one's risk to heat duress including age, race, income, and occupation (Harlan et al. 2006).

The second portion of this chapter discusses the current heat stress indices I will use for this acclimation study. This includes a focus on the heat index and its use by the National Weather Service as a precursor to the release of a heat watch or warning. The heat watch and warning system is framed off of an air mass based system which will also be discussed. This chapter will finish with an in depth look at the idea of acclimation to particular types of weather conditions and finally how acclimation has been evaluated during physical activity.

b. Acclimation

Acclimation to climate, or acclimatization, is an organism' ability to perform increased work in warmer temperatures as a result of improvement in heat dissipation brought on by repeated elevations of core temperatures (Moseley 1997). While acclimation is commonly referred to in adapting to warmer conditions (e.g. Maughan et al. 1997; Carter et al. 2005), there is also research examining acclimation to cooler temperatures (e.g., Lepplauoto and Hassi 1991; Hanna 1999) There are three main forms of acclimatization discussed within the literature including simple and reversible, irreversible and developmental.

First, simple and reversible acclimatization involves the changes in one's physical being once removed from the environment (Hanna 1999). This can be linked to situations such as sweating for a period of time while in a warm environment. Second, irreversible acclimatization occurs when physiological or anatomical changes extend beyond the period of exposure and do not return to pre-exposure levels. This is linked to the capacity to sweat increasing, increased plasma volume and a lower core temperature needed for the onset of sweating to occur, which will all be discussed in greater detail below. Third and finally, developmental acclimatization occurs when the change is channeled during a particular growth part of the life cycle. In essence this change is channeled into a new pathway and cannot be changed at that point (Hanna 1999).

The body can have two different types of responses to heat stress given the length of time under stress. Thermal tolerance occurs when heat exposure is over a short duration of time, a few hours to a few days rather than the beginning of an acclimation process. This tolerance is a cellular adaptation that allows an organism to survive in lethal heat stress (Moseley 1997). Subsequently, heat acclimation begins once heat stress continues for periods of time when the physiological oriented response begins in addition to just temporary survival. Under some forms of climate stress bodily fluid loss increases, potentially resulting in reduced plasma volume and blood pressure (Thauer 1965; Hanna 1999). With heat acclimation, several physiological reactions can be modified increasing plasma volume and efficiency of sweat production. Evidence of acclimation includes (a) an increase in an individual's capacity to sweat, (b) sweat glands becoming more efficient in their production, (c) cutaneous dilation beginning at a lower temperature and (d) increased levels of aldosterone and plasma protein leading to increased plasma volume.

c. Acclimation in running and sports

Most commonly the idea of heat acclimation is discussed when evaluating physical activity and exercise, typically when studying athletes and military personnel (Carter et al. 2005). Heat acclimation is particularly important when activity or work will be performed in an environment warmer than one is used to, but depending on a person's fitness level, the amount of strenuous or physical activity needed to be considered can be much less. Many exercise studies focus on elevated temperature conditions, while some studies additionally considered the humidity level.

For example, Kenefick (2009) found that there was a 17 per cent decrease in performance between activities in 40°C conditions from equivalent performance at 22°C. A decrease in performance has also been found in warm, wet conditions. Hue et al. (2004) determined that both heart rate and sweat rate of triathletes were greater in conditions of 33.4°C and 75.5 per cent relative humidity than in 14°C and 45 per cent relative humidity. The athletes were evaluated after two days and eight days after exposure to the warm, wet conditions. Results showed that, after eight days, blood plasma volume and heart rate of the participants were reduced, but researchers felt that after eight days the athletes were still not acclimated to the warm, wet conditions. As these results demonstrate, it may take longer than eight days to acclimate to certain conditions, which suggests that traveling to the city where an event is being held the week prior to the race may not be adequate for participants to fully acclimatize to the conditions of that area. Maxwell et al. (1996) evaluated sprinters under varying conditions between a warm-up period and a sprint trial. The conditions tested were a warm-up and sprint in cool conditions, a warm-up in cool conditions with a sprint in warm, wet conditions, and finally a warm-up and sprint in both warm, wet conditions. Performance in the cold, cold conditions was highest followed by the cool, warm and then warm, warm, though there was no significant difference in performance between the cool, warm and warm, warm trials. This finding suggests that perhaps an increase in temperature to any degree, either small or large, can have an impact on performance, though the larger the temperature change the greater the impact on performance.

Exercising in warmer and/or more humid conditions has been found to increase performance in cooler conditions. Swimmers asked to practice in tropical conditions for thirty days experienced an improvement in times and ability when compared by as assessment at day thirty compared to day ten (Hue et al. 2007). Additionally, participants in a study evaluating performance in conditions, 17°C and 63 per cent relative humidity, compared to hot conditions, 33°C and 28 per cent relative humidity, found that participants were able to almost double in the distance they were able to run at various speeds until exhaustion in moderated conditions after performing the same trial in the hot conditions (Morris et al. 2005). This finding may suggest that runners or participants training in warmer conditions than those of the city where the race is held should see an improvement in their performance.

Heat acclimation in aerobic fitness has been determined by two different factors. The first is proper hydration, as any acclimation benefits can be overwhelmed by the stress imposed by dehydration (Cheung 1998). The intake of fluids during performance can also have a positive impact on physiological and psychophysical strain during performance (Hargreaves 2008). The second is the clothing type that the participant is wearing when performing. Certain clothing can result in extreme heat stress as it can limit evaporative heat loss. This stress can lead to less effective evaporative cooling which may be less than is required to maintain a thermal equilibrium of the body (Cheung 1998). Clothing choice can play a large factor in a participant in an event, people may find that they over or under dress for an event, either of which may impact any acclimation to and comfort in a particular climate. A person may acclimate to colder temperatures by training outdoors during the winter, only to find themselves over dressed for the race if the weather is warmer. As they are accustomed to colder weather their heat loss through sweating may be hampered by their choice of clothing (Cheung 1998). Under dressing for a race can also pose a risk of heat stress, as a runner may wear lighter or less clothing running in a warmer location, only to find that they are not acclimated to the warm temperatures and need to slow or stop during the race. This slowing or stopping can be linked to hypothermia as the body loses energy faster than it creates heat (Spellman 1996).

Exercise studies researching acclimation have also found that those people who are fitter or in better shape to begin with will acclimatize more rapidly to heat exposure than others. Those who are at moderate or low fitness level will reap more benefits from heat acclimation than those that are very highly trained or in great shape (Cheung 1998; Binkley et al 2002). This finding was based on breaking a small group, fifteen male subjects, into two groups, one moderate fitness and one high fitness group. The groups were determined by an interview based on fitness practice and a treadmill test of maximal aerobic power. Therefore, this finding suggests that within a running population, the faster runners may not find their performance as impacted by a change in meteorological conditions than the average and slower runners. As such, I would expect to see the slower groups: average, median, and ninety-fifth percentiles runners to not only acclimatize more slowly if they are visiting the race state, but also for the local runners to reap more benefits if the weather conditions are similar. Additionally, this study will look at multiple locations over multiple years, unlike other studies that follow a small group of participants over a period of weeks. Viewing acclimation in such a way may show that over a longer training time period the conditions under which one trains becomes more or less important to their performance.

Armstrong et al. (1987) found that, in terms of exercise, all fitness levels benefit from training in the conditions in which they will be competing. However, while evaluating five highly trained marathon and ultra marathon runners, their findings revealed that under spring and summer conditions in the Northeastern United States there was not a large difference in performance. The authors did question whether they would find the same results if they moved to another region such as the southeast with much more humid conditions. This again suggests that in certain conditions the fastest runners may not be as impacted by the conditions of the race, as they are at a high physical fitness level.

It is important though to view the average and slower runners as their training, while not at the same high level, may lead to other influences on their performance. It has also been found that cold acclimation has less of a connection with physical fitness than heat acclimation (Hanna 1999). Exercise in a cool environment will not result in complete cross-adaption with heat acclimation (Armstrong et al. 1987). As of yet, no research has been performed using the same type of subjects in another region as the earlier Armstrong et al. setting. I propose to look at different groups of runners in various weather conditions from hot, humid in central Florida, to colder conditions in Fairbanks, Alaska. This study may find that Armstrong et al.'s finding hold true regardless of the climate type for faster runners or that one type of climate will impact all levels of runners.

d. Climate Factors and acclimation

When quantifying heat vulnerability, one must consider the climate of an area. Geographically, climates vary across the country and those visiting locations with different climates need to consider how being acclimated to a specific type of weather may increase their vulnerability to heat stress under different climate conditions. While a person may respond differently than an adjacent person experiencing the same climate conditions (e.g., Blazejczyk and Krawczyk 1991; Blazejczyk 2001; Spanglo and de Dear 2003, Ali-Toudert et al. 2005; Watts and Kalkstein 2002; 2004), persistent air masses and climate conditions can increase heat vulnerability of a person (Segal and Pielke 1981, Sheridan and Kalkstein 1997). Persistent air masses link to acclimation as an increase in heat related mortality and morbidity has been found when a change or influx of a different type of air mass into an area occurs (Sheridan and Kalkstien 1997). Heat stress indices use the meteorological conditions of an area to measure heat stress and easily communicate the risks a person may face on that particular day. Indices range from simplistic, such as using only two variables (e.g., Baldwin 1973, Steadman 1984), to complex, such as those considering heat exchange between humans and their environment (e.g., Hoppe 1999; 2002). The two most common variables used in the calculation of heat stress indices are temperature and humidity (Steadman 1979; Segal and Pielke 1981). Additionally, solar radiation and average wind speed are frequently included in the calculations.

Wind speed and humidity levels in the atmosphere can greatly impact comfort by either increasing or inhibiting the body's ability for evaporative cooling. When atmospheric moisture levels are low, a person sweats and the atmosphere readily evaporates the sweat, thereby cooling the surface of the person's skin (Hanna 1999). When atmospheric moisture is high, evaporative cooling is not effective, leaving sweat behind. Psychologically this makes a person feel uncomfortable as the sweat remains on the skin surface so that the person typically describes the feeling as 'sticky'. Evaporative cooling is also ineffective when temperatures are extreme. In these cases, sweat evaporates so quickly that the cooling has little or no effect on a person's overall comfort (Kenney et al. 2004).

In addition to moisture values, temperature has been greatly blamed for increased heat illness, specifically increased nighttime temperature frequently associated with the urban heat island. As will be discussed with social factors, studies are finding the maximum daytime temperatures are not increasing at the rate that the overnight temperatures are increasing (Balling and Brazel 1985; Voogt 2002). The increase in nighttime temperature brings little relief to the warm temperatures experienced during the day thus decreasing the ability for the surrounding land and infrastructure to cool at night.

Wind speed not only plays a role physically in someone's comfort, it is also linked to psychological comfort. While it can directly aid in the evaporation of sweat from the body, many people psychologically associate wind with a cooling effect (Yang et al. 2009). In cold weather situations wind can decrease a person's comfort by decreasing the temperature one feels. The wind chill index was developed to help gauge how a person will feel in cold, windy conditions and will be discussed in the heat index section (2g) of this chapter.

e. Health Factors and Acclimation

In addition to climate and meteorological conditions impacting a person's risk to heat stress, a person's medical history can also play a role. Medical history has been a factor linked to heat illness repeatedly in the literature. Additionally, medical history can impact one's ability to acclimate to different types of climates, particularly in cold acclimation settings (Lepplauoto and Hassi 1991). One issue frequently encountered when determining a person's cause of death from heat-related extremes is that heat is very rarely listed as the cause of death or as a contributing factor on the death certificate. When accounting for the number of deaths by heat, it is important to realize that only counting those that have 'heat' listed as the cause of death would greatly underestimate the number of people that actually were impacted by heat (Witman 1997; Dixon et al. 2005; Sheridan et al. 2009). Common causes of death that are exacerbated by heat include cardiovascular disease and respiratory disease. Several studies in China and Hong Kong have examined stroke in addition to cardiovascular and respiratory as ailments that are aggravated by heat as well (Lee et al. 2008, Chau et al. 2009). Those with prior medical conditions are at greater risk of heat related death or illness and need to be aware of this when experiencing meteorological conditions they may not be accustomed to.

Additional studies (Greene et al. 2009) have evaluated the impact of heat as an aggravator or stressor for those that suffer from other ailments. Respiratory, cardiovascular, and cerebrovascular illnesses (stroke) are the most common ailments that are listed as the primary cause or listed along with heat as cause for death in many instances. A study by Greene et al. (2009) focused on apparent temperature increases and the impact they have had on hospital admissions within a 10 km radius of the temperature sensor in California. Greene et al. found that there was a 3.5 per cent increase in stroke, two per cent increase in respiratory diseases, and 7.4 per cent in acute renal failure admissions with an increase of 10°F mean apparent temperature. A similar study performed by Lin et al. (2009) in New York City focused on hospital admissions relating to cardiovascular and respiratory diseases specifically. Again, an increase in admissions was found; around three per cent for same day respiratory disease and about two per cent increase delayed over a three-day period for cardiovascular disease with temperature above a threshold of 29° to 36°C.

While this study is examining a physically fit population, as most participants train to run the 26.2 mile distance, the fitness level of the participants can still vary from elite runners to "weekend runners." It is not uncommon for both athletes and non-athletes to suffer from mild respiratory disease, such as asthma, which can be aggravated by cooler temperatures as their airways cool. These participants, in particular, not only need to prepare during the race, such as carrying an inhaler, but also need to consider how the weather conditions of the race day may aggravate their health condition.

f. Social Factors and Acclimation

As shown, health can be added to the list of indicators of heat stress with acclimation to weather conditions, climate conditions, and prior health conditions. There are, however, many other social factors such as age, living conditions, and working conditions that must be considered when evaluating risk of heat stress (MeGeehin and Mirabelli 2001; Harlan et al. 2006). Living conditions have been found to be a major factor of risk within a metropolitan area as neighborhoods can vary from high density urban living to more suburban type living, with large amounts of vegetation and single family homes. Those living in the urban environment are typically considered to have a higher risk of heat vulnerability given the urban heat island effect and the characteristics of materials found in those areas.

The materials found within an urban area tend to be impervious and absorb short wave radiation during the day while continuing to emit long-wave radiation back into the atmosphere into the night (e.g., Voogt 2002; Harlan et al.

2006; Yip et al. 2008; O'Neill and Ebi 2009). This thermal radiation is not only occurring in the vertical direction, but also horizontally as structures absorb heat at many angles during the day (EPA 2009). People within the urban area are not only exposed to shortwave radiation from the sun, but counter radiation from the structures surrounding them and the ground below. Some urban areas also may have a lack of wind flow given their street orientation or building design. A lack of wind flow in addition to direct radiation can increase the heat index almost 15°F, as the heat index issued by the National Weather Service is calculated in the shade, assuming a slight breeze or air movement (Selover 2009). A person visiting a location with warmer temperatures than they are accustomed to as well as spending time in the urban area may not realize the impact on ambient conditions. An abundance of impervious surfaces also increases nighttime minimum temperatures (Balling and Brazel 1985; Voogt 2002). Although daytime and maximum temperatures may not have increased, the increases in minimum nighttime temperatures allow little relief for those living in the urban area (Harlan et al. 2006). This increase in nighttime temperatures may also play a role in the importance of acclimation, as people unaccustomed to the heat will find less relief at night if temperatures stay elevated.

In addition to the location of the city, urban versus rural, where a person lives within a metropolitan area plays a large role in a person's exposure to heat stress. A person's living conditions within an area can also increase risk of heat stress. Those that live in high density apartment buildings are at higher risks of heat stress than those living in single family or detached homes (Harlan et al.

2006). In cases when many people are living within a building or building complex, while seemingly more efficient, the impact of other people's actions, such as cooking or operating an oven, can impact the environment around them. Those living on the higher stories are typically more vulnerable as any hot air within the building will expand and rise to the top floors. Additionally, air conditioning units use a great amount of energy to run, and in buildings with multiple units, heat generated from the air conditioners may also impact those living on the top floors.

Additionally, age and income also impact risk of heat stress. Those that are most at risk and most impacted by heat incidents are the elderly and those who are unable to find shelter from the heat, including the homeless and individuals whose job requires them to work outdoors (e.g., MeGeehin and Mirabelli 2001; Harlen et al. 2006; Yip et al. 2008; O'Neill and Ebi 2009). Many people work in positions that require them to remain outdoors during the warmest periods of the day, thus not allowing their body to get relief from the increased temperatures. While those that are characteristically under mild heat stress tend to not be as impacted by heat events, when the body is under constant heat stress the risks increase (MeGeehin and Mirabelli 2001; Watts and Kalkstein 2002; 2004). The body is also able to cope with hot, dry air much more successfully than hot, moist air (Kenney et al. 2004), but again not for prolonged time periods. Lack of relief from high temperatures is also an issue for those whose income does not allow them to use cooling methods, like air conditioners as often or as long as would be desired.

g. Current Heat Stress Indices

i. Individual Index

There are many different heat stress indices currently used to measure a person's risk of heat illness. These indices are based only on meteorological variables and while they are important, do not consider other social factors. However despite their faults, these indices will be used in this study to help evaluate the impact of acclimation. Many indices have limitations whether it be the variables omitted from their calculation or the assumptions used in their calculations. The current index used by the National Weather Service, the heat index, does include many variables including the two which have been found to be most important in human thermal comfort, temperature and humidity (Steadman 1979; Segal and Pielke 1981). Other indices, such as the wind chill index, were originally created in a lab environment and are thought to not be representative of a human body's reaction. The wet bulb globe temperature, which is used by both the military and NCAA, does not take into consideration the activity level of a person, but is used for determining if it is safe to take part in physical activity (Minard 1961; Moran 2001; Wallace 2005; Radakovic 2007). Below several indices currently in use will be discussed as they will be used in this study when evaluating acclimation of marathon runners in addition to individual meteorological variables.

ii. Heat Index

In attempts to quantify a person's thermal comfort several heat indices have been developed for both cold and warm weather situations. The most basic thermal comfort indices combine two or three meteorological variables in their calculation. The heat index (Rothfursz 1990) contains both temperature in Fahrenheit (T) and relative humidity (R) in its calculation (2.1).

$$\begin{aligned} HeatIndex = & -42.379 + 2.0491523T + 10.14333127R - 0.22475541TR \\ & - 6.8378x10^{-3}T^2 - 5.481717x10^{-2}R^2 + 1.2287x10^{-3}T^2R \\ & + 8.5282x10^{-4}TR^2 - 1.99x10^{-6}T^2R^2 \end{aligned} \qquad (2.1)$$

Both temperature and humidity have been found to be the most important factors when assessing indoor thermal comfort (Segal and Pielke 1981). One of the constraints of the heat index is that the temperature needs to have reached at least 80°F, or 26.67°C, for its use. The reference temperature of 80°F (26.67°C) limits its use in some locations as the temperature may not be that warm but a high humidity level may also put people at risk of heat illness. Researchers have been working to improve upon the heat index as it does not include other important factors in its calculation such as wind speed, cloud cover, and solar radiation when used outdoors (Watts and Kalkstein 2004). Though it is simplistic in its calculation, the heat index is easy to understand and as a result is distributed by the National Weather Service. The heat index also looks at two of the most influential factors in acclimation, again temperature and humidity. The combination of the two variables may be found to be a better indicator of acclimation than either temperature or moisture in the atmosphere alone. As of yet, the heat index has not been used when looking specifically at running in multiple studies; however it was found to explain the most variance of finishing times of the New York City Marathon (DeBiasse 2008). Looking at outdoor athletic activities in general, one could postulate that the heat watch and warning system issued by the National Weather Service, which is based on the heat index value, has most likely been used by coaches and parents when determining the safety of participating in an outdoor activity on a given day.

iii. Apparent Temperature

The apparent temperature (AT) developed by Steadman (1984) was intended for indoor use, but was later expanded for outdoor use (BOM, 2008). The AT strongly correlates with dry-bulb temperature, but considers both wind speed and humidity in its calculation (2.2) where T_a is temperature (in Celsius), e is vapor pressure (in kilopascals), and V_a is wind speed (in meters per second).

$$AT = T_a + 0.33e - 0.7V_a - 4 \tag{2.2}$$

The reference absolute humidity is 14°C, meaning if the humidity is greater than the reference humidity the apparent temperature will be greater than the ambient temperature and vice versa. This index again considers both humidity and temperature into its calculation; however the addition of wind speed may also suggest how effective evaporative cooling may be on a given day, which can again impact acclimation and how comfortable a person feels.

iv. Wind Chill Index

The empirically derived wind chill index (2.3) uses the air temperature (T_a in Fahrenheit) and the wind velocity (V_a in meters per second) to assess convective cooling. It can be defined as:

$$WCI = 13.12 + 0.6215xT_a - 11.37V^{0.16} + 0.3965T_aV^{0.16} \tag{2.3}$$

This index has been found to have limited use on humans due to its development using a plastic tube filled with water, therefore not taking into consideration heat generated from the body and any skin covering a runner may wear (Moran 2001). In order to address these problems the wind chill temperature index was developed taking convective heat transfer coefficients into account (2.4).

$$WCI = 35.74 + 0.6215T - 25.75V^{0.16} + 0.4275TV^{0.16} \quad (2.4)$$

The wind chill temperature better reflects heat transfer from the human body than the wind chill index and again utilizes temperature in Fahrenheit (T) and wind velocity in meters per second (V) (Moran, 2001).

v. Wet Bulb Globe Temperature

The wet bulb globe temperature (WBGT) uses ambient temperature (T_a), wet bulb temperature (T_w), and black globe temperature (T_g), a temperature that integrates radiation and wind speed into its reading, all in degrees Celsius to describe environmental heat stress (2.5).

$$WBGT = 0.7T_w + 0.2T_g + 0.1T_a \quad (2.5)$$

This index is the most commonly used, specifically in running studies (Ely et al. 2007) and for setting the limits for military training exercises in hot weather (Minard 1961; Moran 2001; Wallace 2005; Budd 2008; Radakovic et al. 2007). A potential fault of this index is that it fails to consider the clothing worn by those participating and it presents difficulties for non-meteorologists in measuring the black globe temperature (Budd 2008)

Using the WBGT, a flag system was developed to determine what level of activity was safe for the trainees to participate in. This system has expanded to include many outdoor events, and has been accepted by the American College of Sports Medicine (ACSM 1987). Using this system as a base, the military has gone on to do further studies to see how, or if, the system needs to be updated. They have found that the more physically fit the person or athlete is going into training or competition the less affected they are by a higher WBGT (Minard 1965; Ely et al. 2007). Hence by dividing the military trainees into groups based on their physical fitness level they are able to work with the WBGT allowing those that have a higher fitness level to continue to do exercises when individuals with lower fitness levels should stop for their safety. The military also found success in allowing a break-in period of trainees to acclimate to the climate (Minard 1965).

vi. Wind Chill Equivalent Temperature

Quayle and Steadman (1998) suggested a further update to the wind chill index, citing while it did use human subjects to assess heat loss from exposed skin, it did not account for metabolic heat generation from the body. Thus, the Steadman wind chill temperature was developed (2.6). The equation uses the dry bulb temperature in Celsius (T_a) and wind speed in meters per second (V_a) in its formulation.

$$WET = 1.41 - 1.162V_a + 0.98T_a + 0.0124V_a^2 + 0.0185(V_a T_a) \tag{2.6}$$

vii. Physiological equivalent temperature

The physiologic equivalent temperature is often simplified to represent the "average man" in studies (Hoppe 1999; 2002; Ali-Toudert et al. 2005). It is arguably one of the most complex indices in that it incorporates a person's height, activity level, weight, and clothing type and as such will not be used for this study. The physiological equivalent temperature has limitations as it is difficult to use when considering large groups of people as assuming the ‘average person’ would represent the whole population (Matzarakis et al. 1999; Hoppe 1999; 2002; Gualyas and Matzarakis 2007). Additionally, it is one of many indices that are computed from a base relative humidity value of 50%. In some locations this component of the index would not cause values to be over- or under-estimated to a large degree, but locations such as the Southwest very rarely have relative humidity values of that magnitude thus calculations would result in inaccurate estimations.

h. Improvements on Current Indices

While the short-term meteorological elements of the calculation are important, in order for an index to be used by the National Weather Service, there should be a type of sliding scale aspect to it as well to take into consideration the progression of the seasons. In other words, the idea of acclimation should be taken into consideration, as heat has been found to be most dangerous when it comes on suddenly or after a mild period (e.g., MeGeehin and Mirabelli 2001; Basu and Samet 2002; Sheridan et al. 2009). Additionally, social factors such as age, prior health conditions, living and working conditions, and income are important when identifying one’s risk to heat stress.

These factors become important in many ways. First, no single person perceives heat in the same manner as another. For instance, heat in the Southwest is perceived by those living there differently than the same heat would be perceived by people in the Southeast. A heat index that includes various aspects of human thermal comfort may be more successful than those currently used. Taking into consideration the differences of regional and seasonal heat perception, including social variables, will make the index more personalized for those using it. A more personalized heat index could be developed to identify heat risk, which might be more successful than those currently used.

A heat risk value, while a potentially good idea, logically does have some limitations. No index at this point has been able to be used universally given the complexity of calculation and the regional differences in weather and climate. Additionally, an index created for the general public must be one that is easy both to use and to understand. One of the successes of the current heat watch and warning system is its attention to regional differences and how heat perception varies from one location to another, as well as its dissemination in a textual manner that carries meaning to those that hear it. When creating a new index, it is important to consider meteorological and social factors that can help personalize the given value as much as possible, while still making it easy to understand and use.

i. National Weather Service Heat Index

The acclimation process not only applies to people visiting a new location or moving to a new location, but citizens of an area acclimate to heat as the summer progresses and to cold as winter progresses. One group that has begun to consider this is the National Weather Service (NWS), who must communicate their forecasts to the general public. As such, the National Weather Service disseminates the heat index during the summer months and the wind chill index in the winter in degrees Fahrenheit similar to how the daily temperature is reported. The heat index value calculated for each city for each day is calculated by using equation (2.1) for an exact value, but is also determined by using the heat index chart seen in Figure 1. This chart identifies a person's risk of heat stress if they are outdoors for a prolonged period of time or are outdoors performing strenuous activity.

NOAA's National Weather Service

Heat Index

Temperature (°F)

Relative Humidity (%)	80	82	84	86	88	90	92	94	96	98	100	102	104	106	118	110
40	80	81	83	85	88	91	94	97	101	105	109	114	119	124	130	136
45	80	82	84	87	89	93	96	100	104	109	114	119	124	130	137	
50	81	83	85	88	91	95	99	103	108	113	118	124	131	137		
55	81	84	86	89	93	97	101	106	112	117	124	130	137			
60	82	84	88	91	95	100	105	110	116	123	129	137				
65	82	85	89	93	98	103	108	114	121	126	130					
70	83	86	90	95	100	105	112	119	126	134						
75	84	88	92	97	103	109	116	124	132							
80	84	89	94	100	106	113	121	129								
85	85	90	96	102	110	117	126	135								
90	86	91	98	105	113	122	131									
95	86	93	100	108	117	127										
100	87	95	103	112	121	132										

Likelihood of Heat Disorders with Prolonged Exposure or Streuous Activity

Caution Extreme Caution Danger Extreme Danger

Fig. 1 NOAA's National Weather Service heat index chart which is linked to danger of heat stress in prolonged exposure or strenuous activity (NWS 2010).

The NWS will issue several different types of weather statements given the conditions over a period of time. An excessive heat outlook is issued when an excessive heat event is forecasted to occur within the next three to seven days. When an excessive heat event is forecast for the next twelve to forty eight hours an excessive heat watch will be issued. Lastly, an excessive heat warning/advisory will be issued when excessive heat events are forecast to occur in the next thirty-six hours. Differing from an excessive heat watch, an excessive heat warning is issued when the event is currently occurring and is forecast to continue, an event is imminent or there is a very high probability of an event occurring (NOAA Heat Wave 2010).

Throughout the summer months, people begin to slowly acclimate to heat. For example, at the beginning of the summer 80°F is generally very uncomfortable in many locations to the majority of the population, but by the middle of July and August most people will ‘feel’ that temperature is relatively cool compared to the higher temperatures typical for this time of year. As a result, there needs to be a sliding aspect within the NWS watch/warning system to accommodate temperature changes as the summer progresses. In other words, the idea of acclimation should be taken into consideration, as heat has been found to be most dangerous when it comes on suddenly or after a mild period (MeGeehin and Mirabelli 2001; Basu and Samet 2002; Sheridan et al. 2009). As found with the synoptic air mass classification by Kalkstein and Sheridan (1997), heat in the Southwest is perceived by those living there differently than the same heat in the Southeast would be perceived. This is another example of how heat is perceived differently by people, and as such will be an important factor in viewing the idea of acclimation when considering marathon runners. It supports the need to classify the runners into groups to separate those that live within that geographic region and those that do not. Those that do not live in that geographic area or region may not have the same response to temperature or humidity values based on the weather they are accustomed to.

j. Air Masses and Acclimation

The heat watch and warning system used by the National Weather Service and created by Kalkstein and Sheridan is based on the idea that an oppressive air mass over an area increases the risk of a population, both urban and rural, of heat illness (Sheridan and Kalkstein 2004; Kalkstein and Sheridan 2007). Factoring in the average climate or weather of a location can impact a person's vulnerability to heat. Additionally, the air mass model considers that people living in particular parts of the country are acclimated to particular conditions and can be negatively impacted with the advection of oppressive air masses into the area.

The excessive heat watch and warning system is based on gridded forecast data from the National Weather Service National Digital Forecast Database (NOAA 2010). Using an air mass based approach is a more holistic way of viewing how the weather impacts a body as air masses are characterized by spatial and temporal aspects. The oppressive air masses identified have been known to historically diminish people's health. This method begins to recognize the importance of acclimation to heat, as it identifies air masses that develop in geographic areas which typically do not experience those moisture or heat levels, as well as identifies the timing of these air masses.

Sheridan and Kalkstein (2004; 2009) found that Moist Tropical (MT) and Dry Tropical (DT) were the two air masses most frequently correlated with an increase in heat-related deaths. Moist Tropical air masses are marked by hot and humid conditions with frequent convective showers, while Dry Tropical air masses are warmer and dryer than the moist tropical air mass. These two air masses are present across much of the United States and are most common in the east and southwest. Hot humid conditions are more difficult to acclimate compared to hot dry conditions.

k. Acclimation to specific types of climate regions

Heat stress can be individualistic given that two different people in the same conditions will react and feel differently (e.g.,Blazejczyk and Krawczyk 1991; Blazejczyk 2001; Spanglo and de Dear 2003; Ail-Toudert et al. 2005; Watts and Kalkstein 2002; 2004). Additionally, the type of weather can impact the time needed to feel comfortable or lower the risk of heat stress. The amount of moisture in the air can impact heat acclimation as it has been found that the acclimation period to a hot, dry condition is shorter than that of a hot, wet or humid type climate (Sawka et al. 1996; Hanna 1999). In exercise studies individuals that are of the high or moderate fitness level plateau in four and a half to seven days, respectively, in hot dry conditions, while it takes longer to plateau in hot wet conditions (Cheung 1998). In all types of climates, hot dry, hot wet, and cold, the body experiences physiological changes in terms of prolonged exposure. In this study, understanding the acclimation process to different types of environments is important as races take place in cold weather, such as the Equinox Marathon in Fairbanks, Alaska, as well as more humid environments, such as the Ocala Marathon in Ocala, Florida. Both of these races draw participants from their local areas and from regions and climates significantly different than their own.

i. Hot and Dry

In terms of heat stress, hot dry conditions are the easiest to acclimate to and take the shortest period of time to do so. Average acclimation to hot dry conditions ranges from a few days to two weeks (Maughan et al. 1997; Carter et al. 2005), though it can be shorter given physical fitness in those conditions. One of the main reasons hot dry acclimation appears to occur more rapidly is the body's physiological response to hot dry conditions: perspiration. This results in decreases in plasma volume and decreased arterial pressure (Thauer 1965; Hanna 1999). In hot dry climates evaporative cooling is very effective as the atmosphere has low humidity and readily takes up moisture.

Acclimation to hot dry conditions includes increasing the capacity to sweat, the sweat gland becoming more efficient in sweat production and cutaneous dilation to begin at a lower temperature to resist heat build-up. Each of these changes is only helpful given that evaporative cooling is able to take place. There are two factors that control this: proper hydration and temperatures that are not too extreme. Cheung (1998) found that the stress created by dehydration can overwhelm even an acclimated body. Evaporative cooling will only continue to occur when a person takes in enough water to help regulate their systems allowing them to tolerate increased temperatures.

ii. Hot and Wet

Heat acclimation is more difficult with added water in the atmosphere. As discussed above, evaporative cooling aids in making a person feel comfortable and many of the benefits of heat acclimation act on improving the body's ability to begin sweating at a lower temperature. This results in acclimation to hot wet conditions taking a longer period of time than acclimation to hot dry conditions. Coping with hot wet conditions at rest can be tolerated, but once physical activity increases the stress on thermal regulation begins immediately.

In hot wet climates it has been found that women acclimatize better in these types environments than in hot dry climates (Kenney 1985). After acclimation, sweating will begin at the same time for both men and women, however men will have a shorter tolerance for hot wet conditions prior to acclimation (Kenney et al. 1985). Additionally, the heat production is dependent on body mass, while heat loss is dependent on surface area. Dennis and Noakes (1999) found that smaller runner's were able to maintain thermal balance at a faster pace than larger runners, who needed to runner at a slower pace to maintain thermal balance. Distance runners have also found that running in hot wet conditions is the most demanding again due to the properties of evaporative cooling (Armstrong et al. 1987).

iii. Cold

Cold climates or seasonal changes to cooler temperatures may not increase the stress placed on the body as much as hotter conditions, but there are notable physiological changes. During the winter months, there is a mild cooling over the body surface. If there is exposure of body parts to extreme cold, injuries such as tissue damage and loss of excessive body heat may occur. Exposure can also result in cardiovascular responses that can be detrimental, as heat balance of the body becomes difficult (Hanna 1999). The blood pressure measured in people will be higher during the winter months and as such, those that are exposed to cold weather often are also at the risk of developing cardiovascular diseases with the increased blood pressure values (Lepplauoto and Hassi 1991; Hanna 1999).

Acclimation to cold weather has been examined by researchers. Six weeks of mild cold exposure can help acclimatize a person to extreme cold situations, while extreme cold exposure over a shorter period of days can lead to extreme cold acclimation. With repeated exposure to extreme cold a physiological change in vascular reactivity to those areas exposed has been seen (Hanna 1999).

l. Summary and conclusions

As the goal of this study is to view the role of acclimation through persistent weather conditions during marathon distance races, it is first important to understand characteristics of acclimation, as well as the other natural and physical factors that influence a person's risk to heat stress. Understanding the current methods of quantifying heat stress or risk of heat stress is a necessity, although these methods primarily consider meteorological values only and generally do not account for acclimation effects. The variables most commonly used in these calculations are ambient temperature, a measure of moisture in the atmosphere either given as the dew point temperature, vapor pressure, or relative humidity and the wind speed. While many measures of human thermal comfort exist, from the heat index to the physiological equivalent temperature, it is unlikely that any measure will ever be fully representative of each individual as they do not consider the concept of acclimation. Recently there appears to be a move to try to incorporate the concept of acclimation into the heat watch and warning systems disseminated by the National Weather Service, but viewing acclimation as an important social factor based on meteorological variables has yet to be evaluated.

As suggested in previous acclimation literature, people at a higher fitness level acclimatize more quickly to warmer temperatures than other populations. However, there is benefit for all physical fitness levels to train or live in the conditions they will be exposed to during competition. As such, I will attempt to fill in the gaps of the previous literature by examining at a much larger population a week long period over multiple years, rather than one week only. Additionally, choosing marathon races in many different climate areas of the United States, will allow me to determine if there is a particular climate area that will impact the runners, particularly the fastest runners, more so than another.

Temperature and moisture will be evaluated as primary indicators of acclimation, but wind speed, pressure, and several heat stress indices will also be evaluated. Additionally, the literature suggests that in terms of heat stress indices the combinations of variables are better reflective of risk of heat/cold illness than individual meteorological variables alone.

Based on previous literature, race and weather data were chosen for six marathon races. To evaluate these participants in terms of acclimation, races held in different geographic locations throughout the United States will be divided into "locals," or those that live in the race state, and "visitors," those that reside in a state other than the race state. Specific attention will be placed on the meteorological conditions leading up to the race, the five days prior, and the race day, as it is believed that sudden changes in the weather on race day may influence participants' performance. Each group will be evaluated against the meteorological conditions for the race day and conditions leading up to that day. The specific data used will be further discussed in the next chapter.

3. Study Area, Data, and Descriptive Statistics

a. Introduction

The previous chapter evaluated current acclimation research, as well discussed the current heat indices that have been developed to assess human comfort. My research focuses on evaluating the role of acclimation on marathon runners, based on changes in meteorological variables and indices on race day from the conditions of the five days leading up to the race. In this chapter I will discuss (a) the six marathon races courses; the New York City Marathon (New York City, New York), Equinox Marathon (Fairbanks, Alaska), California International Marathon (Sacramento, California), LIVESTRONG Austin Marathon (Austin, Texas), Cincinnati Flying Pig Marathon (Cincinnati, Ohio), and Ocala Marathon (Ocala, Florida), (b) the data provided from each race, (c), the weather data I will be using, and (d) the descriptive statistics of the data used for this study.

In order to fully test if acclimation plays a role in the success of those running in a marathon, I selected several races from various parts of the country occurring at different times during the year (Fig. 2).

Fig. 2 Geographic locations of each race- California International Marathon (Sacramento, California), LIVESTRONG Austin Marathon (Austin, Texas), Cincinnati Flying Pig Marathon (Cincinnati, Ohio), Ocala Marathon (Ocala, Florida), New York City Marathon (New York City, New York). In parenthesis under each race name are the weather stations used for meteorological data.

The races that I selected to be examined listed in Table 1.

Table 1 The races used for this study, including the city which they are held and what time of year each occurs.

Race	City, State	Date/Time of Year
Ocala Marathon	Ocala, Florida	Late January -Early February
LIVESTRONG Austin Marathon	Austin, Texas	Mid- February
The Flying Pig Marathon	Cincinnati, Ohio	Early May
Equinox Marathon	Fairbanks, Alaska	Mid-September
ING New York City Marathon	New York City, New York	Late October – Early November

Table 1 (continued)

California International Marathon	Sacramento, California	Late November

Many marathons are held from fall into late spring because many locations have summer conditions considered too warm by organizers and planners to have a successful race, either in terms of safety or in participation levels. Winter races are also less common, though locations in the Southwest and California that record mild temperatures consequently draw runners from cooler winter locations to participate in races at those locales. Below each race area and course will be discussed with a brief history of the race and course. I will discuss the data, both race participant information and the corresponding recorded pre- and race-day weather, and also examine the descriptive statistics of the data.

b. Study Area

There are hundreds of marathons held each year in the United States and many more worldwide on all seven continents. While a “weekend” or recreational runner may only participate in a few, if any, marathons in their lifetime, there are several elite “clubs” in the marathon world including, but not limited to running a marathon in every state or a marathon on each continent (50 States Marathon Club 2011; Seven Continents Club 2011). The organizational component of each marathon race requires multiple people to help organize and plan the route before a race can be run and many volunteers and city police/workers to regulate the course on race day. While it is a big effort to organize and hold a race, there are many marathon races held each year that range from under one hundred participants to over thirty thousand like the ING New York City Marathon. In this study the races chosen reflect this aspect, featuring smaller races with fewer than five hundred participants to over thirty thousand participants.

The races for this study were also chosen to examine different climates of the United States. As my research question looks to address if acclimation to a particular type of climate impacts a runners finishing time, it was important to address varying climatic conditions. This idea is based on the synoptic air mass classification developed by Kalkstein and Sheridan (1997) where they found that certain oppressive air masses are associated with higher incidents of heat illness or distress. By choosing to look at different areas of the country at different points during the year I hope to capture locations that are marked by different air masses or by varying dominate temperature and moisture characteristics. And I anticipate that these conditions will link to the race in the following manner.

c. Marathon Races

i. ING New York City MARATHON (New York City, New York)

The largest race of the selected races for this research is the ING New York City Marathon. It is held each year in late October or early November. The race began in 1970 and was originally run as five circuits around Central Park (ING Marathon 2010). Beginning in 1976, however, the race course was altered to take the runners through all five boroughs of New York City (Fig. 3). As of 2010, the race begins on Staten Island passing over a bridge to Brooklyn continuing through Queens, then to Manhattan before passing through the Bronx and finishing back on Manhattan in Central Park.

Fig. 3 The current course of the ING New York City Marathon Race course which passes through the five boroughs of New York City. (Image courtesy of http://www.ingnycmarathon.org/ 2010)

The course itself begins an uphill climb of about a mile with the largest elevation gain about 250 feet (76.2 meters). Once runners have reached the initial hill, the course fluctuates between 50 - 100 feet (15.24 – 30.48 meters) of elevation change (Fig. 4).

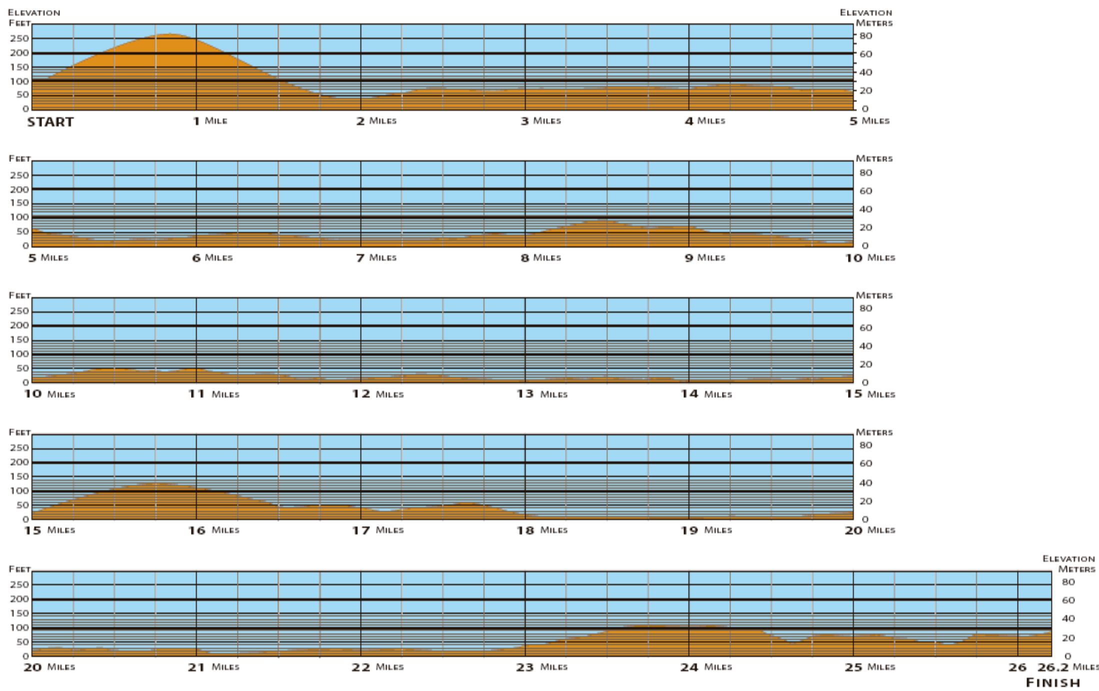


Fig. 4 Current elevation profile for the ING New York City Marathon. (Image courtesy of http://www.ingnycmarathon.org/ 2010)

The ING New York City marathon (NYC marathon) is one of the most popular races held within the United States and throughout the world. As a result, participation in the race is one of the most coveted by runners across the United States and around the world; many coming from climatically diverse locations. It is not uncommon for each race year to have at least one runner from each state and numerous countries. The race is currently capped at 38,000 runners but receives almost 100,000 applicants each year (ING New York City Marathon 2011). One of the main reasons for the race's popularity is the prestige of the event itself, but also the lack of qualification time to participate in the race. Other major races, such as the Boston Marathon, require a minimum qualification time at one of the many approved races held around the country within a year and half prior to the race (Boston Marathon 2011).

There are several ways in which a person can gain access to the New York City marathon (New York City Marathon 2011). The first means is by joining the New York City Road Runners (NYRR) and then participating in nine NYRR-scored races during the year and either volunteering at another NYRR event or donating $1,000 to the NYRR's charity programs. The second method is to post a qualifying time for a runners age group. The third alternative is re-entry after having to cancel running in the previous year's race. Fourth, if a runner has been denied the three previous years, they will be admitted the next year. A runner also warrants guaranteed entry if they have competed in fifteen or more NYC marathons. Most runners can put their name in the lottery system, drawn in late April and hope they are chosen to participate. A final, fifth and newer option to gain guarantee entry is through a charity option where the runner will raise money for any of the charities sponsored by the NYC marathon. This system allows runners from all levels of fitness compete in the race, not just top or seasoned marathon runners. It should be noted that all runners that participate in the New York City Marathon are required to be 18 years or older. In the cases of smaller races there is not always an age restriction.

Race results for the ING New York City marathon were collected for the years 1976 to 2010. I did not incorporate data from the first five years of the race into this study given the geographic differences in the course. Further details about the data used are provided in section c of this chapter.

ii. EQUINOX MARATHON (Fairbanks, Alaska)

The Equinox Marathon is held each year in mid-September in Fairbanks Alaska. The race began in 1963 as a small race drawing only about 117 runners (Bainbridge 2009). In the following years in which the race has been run, the number of participants has grown to 442 runners in the 2010 race (Equinox Marathon 2010). Given the subarctic locale, it is not surprising the setting for a given year can range from reported conditions of "sunny, warm, and clear—temperatures of 60°F" (Bainbridge 2009) described of the first run of the race to event conditions for several years impacted by snowfall. These years include 1970, 1985, 1992, 1993, 1995, and 1996 (Saari 2010). In fact, the race was not timed in 1992 due to the large snowfall recorded on September 10, but it is said that a few "die-hard runners" still ran the course (Estle 2010).

The marathon race course starts and ends on the University of Alaska Fairbanks campus making a loop with an out-and-back leg of the race (Fig. 5).

Fig. 5 Topographic Map displaying the course of the Equinox Marathon run in Fairbanks, Alaska. The Course features an out and back section within the main loop which allows the race to begin and end at the same location. (Image courtesy of the Equinox Marathon 2010).

The race is run on variety of surfaces throughout the 26.22 mile course including hiking trails, bike paths, and asphalt roads with portions of the course traversing rough terrain and within wooded areas. The middle of the course is marked by an ascent over Ester Dome around mile eight of the race which includes a 1,800 feet (0.548 kilometer) climb. Once on top of Ester Dome what is known as the famous "out and back" (in which the leg of the course which leaves the circuit) part of the course by participants is marked by a narrowing trail creating a single lane on rougher terrain (Equinox Marathon 2010). The elevation change aside from the large ascent over Ester Dome ranges between 100 feet (30.48 meters) and 400 feet (121.92 meters) (Fig. 6).

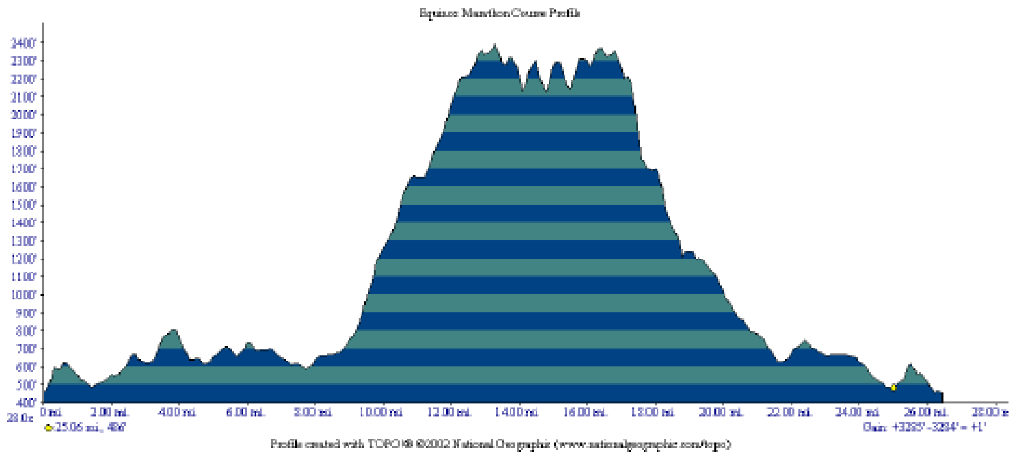


Fig. 6 Race profile for the Equinox Marathon held in Fairbanks Alaska. (Image courtesy of the Equinox Marathon 2010).

Unlike the New York City Marathon there are no qualifications participants must meet to run the race including age. Additionally, an ultra marathon (a fifty kilometer race) and a kids marathon, which is a multi-month event where children run a marathon a mile at a time, running the last 1.2 miles on race day are available to participants if they choose. The ultra marathon was first held in 2009 (Equinox Marathon 2010). Data for the Equinox marathon are available for the years 1963 to 2010. For this study, only the years 1976 to 2010 will be evaluated with the exclusion of 1992 which the race was not timed due to inclement weather conditions.

iii. CALIFORNIA INTERNATIONAL MARATHON (Sacramento, California)

The California International Marathon (CIM) has been run since 1983 with its 29th race to be held in 2011 in Sacramento, California in late November. The race was created by distance runners John Mansoor and Sally Edwards following the boycotting of the United States to the 1980 Olympic Games in

Moscow (California International Marathon 2010). The 1984 Olympics marked the first-ever Olympic Women's Marathon and the 1982 US Outdoor Track Championships being held in Sacramento encouraged the two to develop a world-class marathon in a running friendly community. The first race was held in 1983, two weeks after the United States observance of Thanksgiving, so the race would fall into the time window necessary for an Olympic Marathon Trials qualifier.

The course was originally chosen by Mansoor as he regularly trained on a route that he felt supplied a picturesque view of the downtown area. The race has currently been set to run from the Folsom Dam to the California State Capitol. While the race was originally planned to begin from the top of the dam, once measured it was realized that would make the course one mile too long. As a result the race course begins at the base of the dam (Fig. 7).

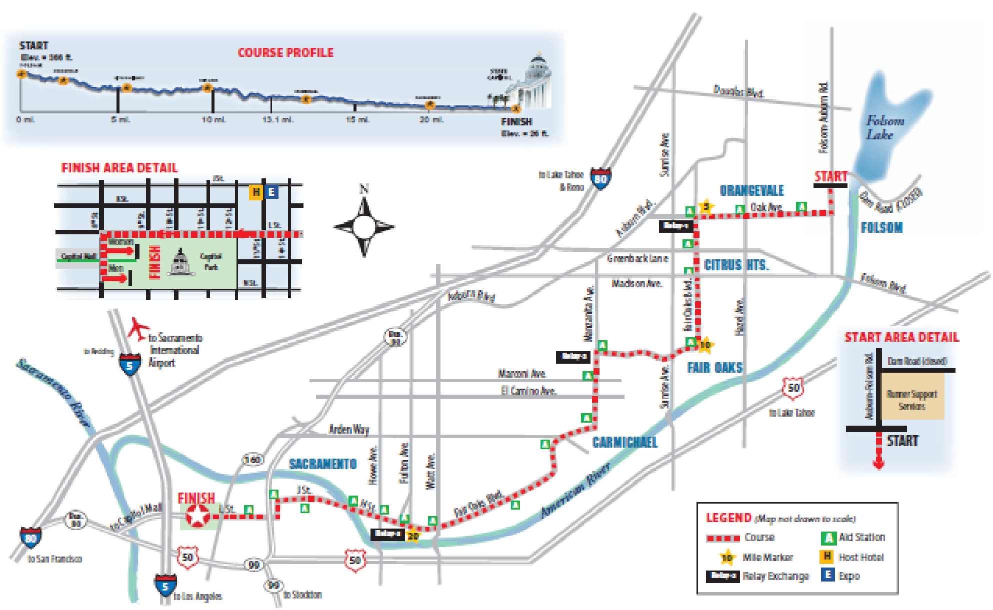


Fig. 7 The California International Marathon Course. (Image courtesy of the California International Marathon 2011).

The race is an overall downhill course that begins at an elevation of about 366 feet (111.56 meters) and ends at an elevation of about 26 feet (7.92 meters) above sea level. As such, the organizers have nicknamed the course "the Fastest Course in the West" (California International Marathon 2010). However, there are several hills throughout the course, with the steepest elevation change being an almost 110 feet (33.53 meters) drop at mile twelve followed by a slightly smaller uphill climb (Fig. 8).

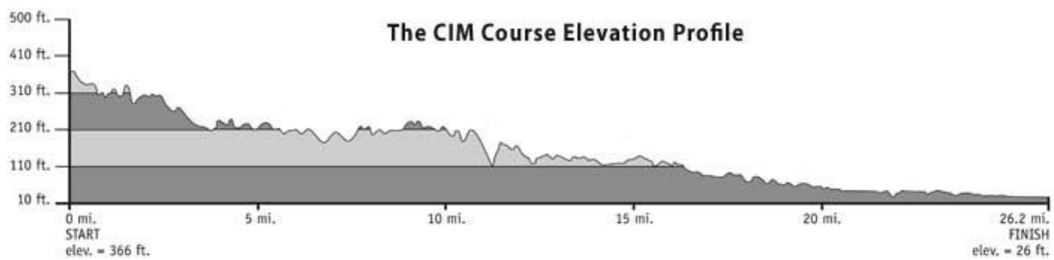


Fig. 8 California International Marathon course profile. The course is referred to as one of the fastest marathon courses given its overall downhill nature. (Image Courtsey of the California International Marathon, 2010).

The CIM race is capped at 7,500 participants and employs a pace-vehicle traveling at 13:44 minute per mile pace to mark the "end" of services for the race. This means, while there is no official cutoff for the marathon, any racers traveling at a rate slower than the pace car will not be guaranteed aid stations or the open run being forced to move to the sidewalk or road shoulder to continue their race. There are no age limits on the race, but the organizers strongly encourage racers be at least sixteen years of age. Data from the CIM race used for this study will be the years 1983 to 2010.

iv. LIVESTRONG AUSTIN MARATHON (Austin, Texas)

The LIVESTRONG Austin Marathon is held each February within the downtown area of Austin Texas. The first race was run in 1992 and has changed sponsors throughout that time. The course of this race has also been changed multiple times within the almost twenty year history that the race has been run. More recently, the course has been frequently moved due to construction within the city but generally varies only slightly from year to year. Currently, the marathon course is a loop that begins and ends in the downtown area (Fig. 9).

Fig. 9 LIVESTRONG Austin Marathon course for the 2011 race. (Image courtesy of the Austin Marathon 2011)

The course is a looping course that gains steadily in elevation for the first nineteen miles, but finishes with a downhill stretch. The steepest elevation change occurs just before mile three covering an elevation gain of about 300 feet

(91.44 meters) over three miles (Fig. 10).

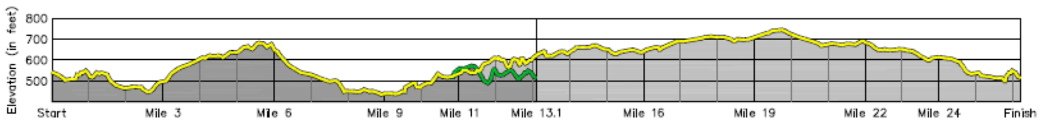


Fig. 10 The elevation profile for the 2011 LIVESTRONG Austin Marathon shown in the light color (green marks the half marathon elevation). (Image courtesy of the Austin Marathon 2011).

The course is a USA Track and Field (USATF) certified course that is conducted on a ninety per cent asphalt surface (Austin Marathon 2011). As such, it can be used as both a Boston and Olympic qualifying race (Adventure Marathon 2011) and consequently, the race draws a combination of elite and first time runners. The marathon race is capped at 6,000 participants. There is no age restriction on participants, but it is again recommended by officials that racers under 16 years of age do not participate (Austin Marathon 2011). Race data from the years 2000 to 2010 will be used for this study. However, the data from the 2001 race do contain geographic residency information about runners and therefore will not be included. Further importance of the runner's geographic information is explained in section d of this chapter.

v. CINCINNATI FLYING PIG MARATHON (Cincinnati, Ohio)

The first Cincinnati Flying Pig Marathon was run in 1999 and has been called one of the most fun marathons in America by Runner's World Magazine (Cincinnati Flying Pig Marathon 2011). The race is comprised of many different options for racers ranging from a five kilometer race to the 26. 22 mile marathon course, including relay races, held the first weekend of May each year.   The course has changed only slightly, specifically on the tenth anniversary of the race to increase the width of the finishing section and ease confusion between the half and full marathon courses at the beginning of the race (Nash 2008). The course begins near the Paul Brown Stadium and finishes near the start at Sawyer Point (Fig. 11).

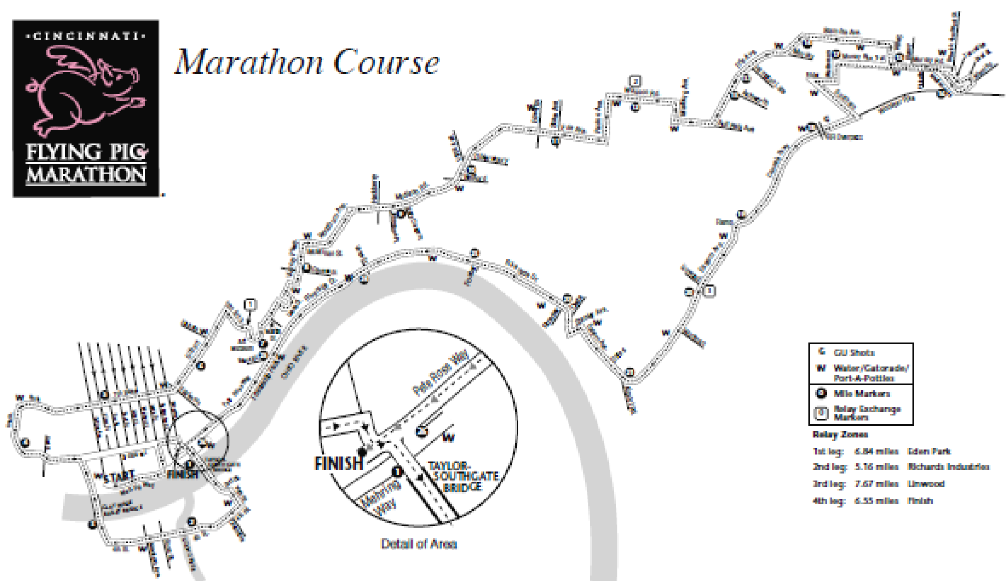


Fig. 11 Cincinnati Flying Pig Marathon course held each year the first week in May. (Image courtesy of the Cincinnati Flying Pig Marathon 2011).

The course consists of mostly flat terrain with a large climb beginning around mile five and a half (Fig. 12). The climb of about 300 feet (91.44 meters) covers three miles with a long downhill beginning at mile eight with only a few smaller hills with elevation gains of 50 -100 feet (15.24 – 30.48 meters) .

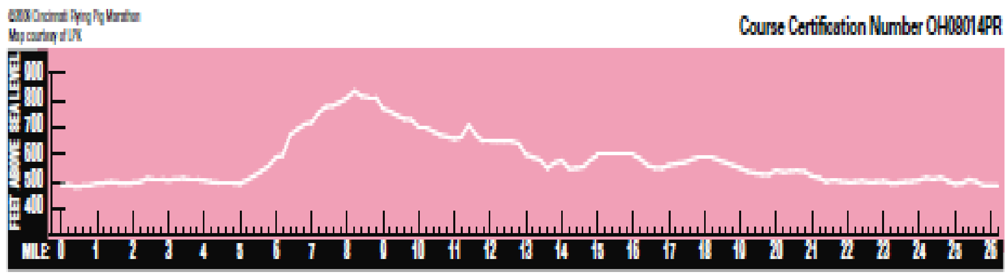


Fig. 12 The elevation profile for the Cincinnati Flying Pig Marathon. (Image courtesy of the Cincinnati Flying Pig Marathon 2011).

This marathon course can be used as a Boston qualifying race, but is also noted to be the third-largest first-time marathon in the country (Cincinnati Flying Pig Marathon 2011). There are no ability requirements for the course, but the race organizers do suggest that if a racer reaches the half marathon mark at over a seven-hour pace, they should follow the half marathon course to the finish. If a runner realizes later in the race, they will not complete the race in the seven-hour time limit they are directed to the sidewalks to finish. The race does have a minimum race age of 18 to participate in the race, though in prior races it has been suggested that a parental consent form will allow racers to be under the age of 18 to participate (Cincinnati Flying Pig Marathon 2011). Data for the Cincinnati Flying Pig Marathon are available from 2000 to 2010, however 2009 and 2010 will not be used as geographic residency information for each participant were not provided.

iv. OCALA MARATHON (Ocala, Florida)

The Ocala marathon is held in central Florida each year since 2000 (except 2007) at the end of January and has been called one of the most scenic races in

America (Ocala Marathon 2010). Although the race is small, only drawing 130 participants in 2011, racers from more than forty states and seven countries have run in a single race (Ocala Marathon 2010). The race has changed organizers over its history and was not held in 2007. In addition to the 26.22 mile marathon, racers have the choice of participating in a half marathon or five kilometer race. The race begins at Boyd Marketplace in Ocala Florida and is made up of two loops with an out-and-back section similar to the LIVESTRONG Austin Marathon (Fig. 13).

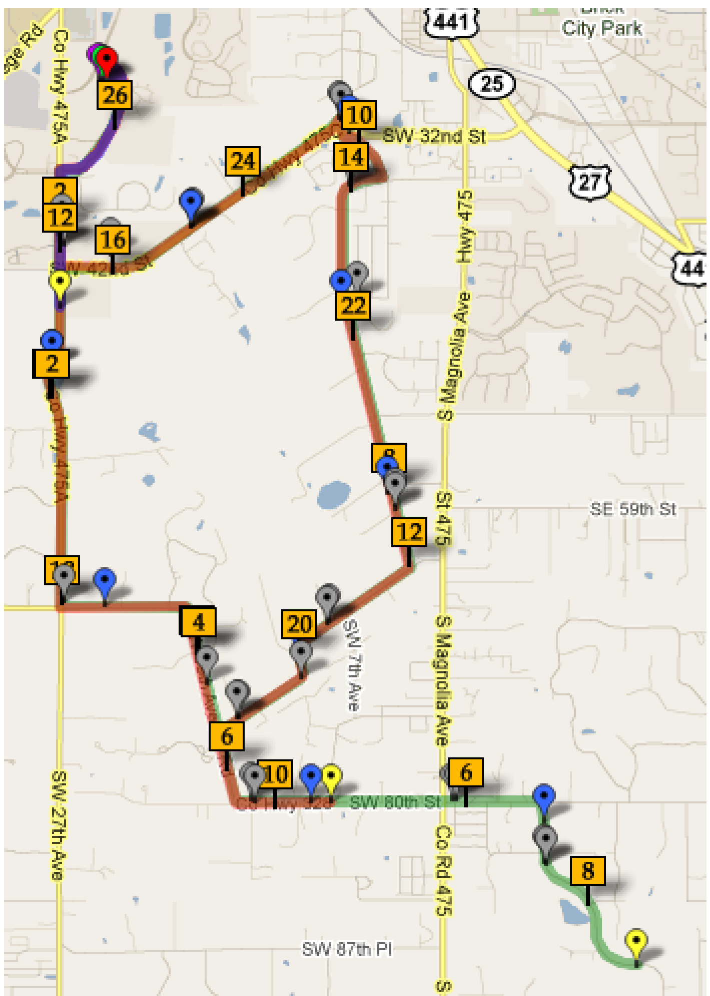


Fig. 13 The Ocala Marathon course completed as two loops with an out-and-back section. (Image courtesy of the Ocala Marathon 2010).

The course is marked by many hills that create a challenging course (Fig. 14). The steepest climb occurs three and a half miles into each loop with an elevation gain or about 130 feet (39.62 meters) in under a half of a mile. The rest of the loop is marked by a three mile gentle downhill followed by another uphill climb. The course ranges in total elevation of 152 feet (46.33 meters) with is lowest elevation at 72 feet (21.95 meters) and highest elevation of 224 feet (68.28 meters).

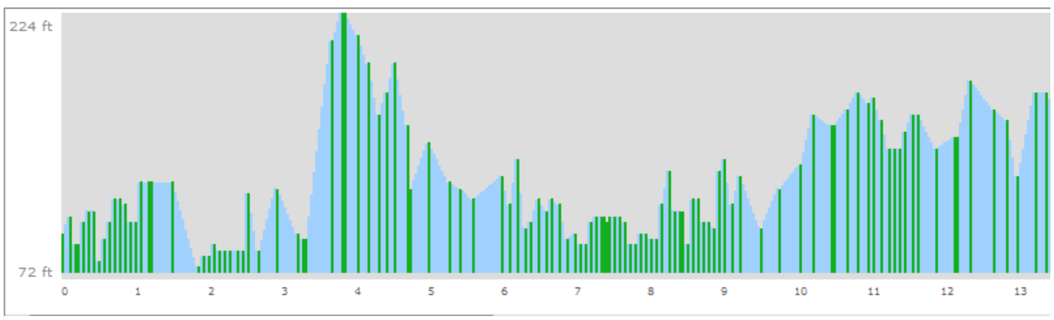


Fig. 14 The elevation profile for the Ocala Marathon. Notice that the race is a repeated loop requiring racers to run this profile twice during the race. (Image courtesy of the Ocala Marathon 2010)

The Ocala Marathon is a qualifying race for the Boston Marathon and draws racers from various parts of the country. There are no restrictions for participants entering the race. Data are available for the race from 2000 to 2010, except for the year 2007 when the race was not held.

d. Marathon Data

The races chosen for this study were selected first for their varying locations around the country and times held during the year, but also for the availability of long-term data, comprising a length of at least ten years. Each race reports different results, therefore in different formats, though all events report the participants' first and last names, their finishing times and overall places. Race record-keeping has improved in accuracy, particularly finishing times, as technology has improved. Early races were hand-timed only at the finishing line, thereby assuming all runners begat the race at the starting line when the starting gun was fired. Currently, with races involving so many participants, this form of record-keeping is not sufficiently accurate as a racer can in some cases start fifteen minutes after the first runner has crossed the starting line. For example, the ING New York City Marathon has three different start times, creating three separate waves of racers, given the number of participants.

A few years ago a device called a "chip timer" was introduced in races allowing for a more precise means of computing individual race finishing times (Sinha 2011). Chip timers range from a piece of equipment that is attached to a runner's shoelaces that is returned at the end of a race to a disposable chip that is attached to the bib or shoe. Chip timing allows the timing of racers to begin when the cross the start and finish lines with electronic pads that activate the chips. Chip timing and the electronic pads can also allow races to record split times of other distances within a race, for example a half marathon time in a marathon race. In any case, in this study for data where chip time and clock time were both given, the chip time was used as it accurately accounts for the official starting an ending time for each participant. The clock time can be seconds to many minutes behind the actual finishing time again depending on the size and the delay of a runner reaching the start line. Below the details of each race and the data available are described.

i. ING NEW YORK CITY MARATHON (New York City, New York)

The ING New York City Marathon reports various components of a runner's race and personal information all available on the ING New York City Marathon website (http://www.ingnycmarathon.org/). The personal information includes name, sex, age, team (if they are part of a running club), the city, state, and country in which they reside, and bib number. Knowing the state in which a participant originates is critical for this study and if those data were not provided for a race or year, the race data would be eliminated from the data set. Race statistics provided for each runner include places for age division, gender, and overall finishing place. The more recent races include data for various split times including the five kilometer, ten kilometer, and half kilometer race, along with finishing time and pace per mile. An example of race results provided for the 1991 ING New York City Marathon can be seen in Table 2. Race results for the ING New York City Marathon were collected for the years 1976 to 2010. The first five years the race was run were not used given the difference in the course.

Table 2 An example of race results available on the ING New York City Marathon for 1991. (Source: http://www.ingnycmarathon.org/)

First	Last	Sex/Age	Bib	City	State	Country	Place	Time	Pace
Salvador	Garcia	M31	16		.	Mexico	1	2:09:28	5:18
Andres	Espinoza	M28	40		.	Mexico	2	2:10:00	5:19
Ibrahim	Hussein	M33	2		.	Kenya	3	2:11:07	5:21

Table 2 (continued)

Peter	Maher	M31	24	.	Canada	4	2:11:55	5:22
Isidrio	Rico	M30	32	.	Mexico	5	2:11:58	5:23
Rex	Wilson	M31	17	.	New Zealand	6	2:12:04	5:26
Daniel	Boltz	M29	21	.	Switzerland	7	2:14:36	5:26
Jean-Baptiste	Protais	M31	30	.	France	8	2:14:54	5:27
John	Treacy	M34	4	.	Ireland	9	2:15:09	5:27
Peter	Renner	M32	29	.	New Zealand	10	2:15:45	5:27

ii. EQUINOX MARATHON (Fairbanks, Alaska)

Although the Equinox Marathon was first run in 1963, for this study, I will only use race results beginning in 1976 so as to compliment the New York City Marathon data available. The race results were provided by John Estle for the years 1976 to 1999 through personal communication, with results for the years 2000 to 2010 available on the race website (http://www.equinoxmarathon.org/). As with the NYC Marathon, information collected for the Equinox Marathon includes personal and race information. While the amount of information varied from year-to-year, personal information typically included name, city of residence, and age. Race data typically only included overall place and finishing time (Table 3). Race results for 1985, 1991 and 1996 cannot be used in this study as the current race director did not have them in his possession. Race results from 1990 and 1995 will not be used as geographic residency information about participants was not collected. Lastly, 1992 will not be used as a snow storm early in the week caused only few “die-hard” runners to participate and no official times were recorded.

Table 3 An example of race results for Equinox Marathon held in 1986 in Fairbanks, Alaska. (Source: John Estle 2010)

Overall Rank	Bib Number	Last	First	City	State	Age	Class Rank	Time
1	999	Justice	Stan	Fairbanks	AK	37	1	2:45:12
2	988	Johnson	Mike	Fairbanks	AK	28	1	2:54:27
3	998	Murphy	Bob	Fairbanks	AK	34	2	2:59:28
4	996	Warder	Glenn	Ft. Wainwright	AK	29	2	3:02:28
5	721	Burleigh	Roger	College	AK	30	3	3:04:30
6	987	Bloom	David	Fairbanks	AK	28	3	3:04:48
7	981	Egan	Tom	Fairbanks	AK	40	1	3:08:30
8	992	Doyle	Allen	Fairbanks	AK	28	4	3:10:31
9	980	Mendes	Luis	Ft. Wainwright	AK	24	5	3:12:04
10	993	Lyle	John	Fairbanks	AK	33	4	3:13:24

iii. CALIFORNIA INTERNATIONAL MARATHON (Sacramento, California)

The California International Marathon (CIM) held in Sacramento California reports all race results from its original race in 1983 to present on its website (http://www.runcim.org/). The personal information includes name, city and state of residence, and running club if applicable. The race information includes overall place, divisional place, and finishing times. It should be noted that for three years a city of residence was given without state information (Table 4). Consequently, if the states were not given, I conducted a search of the state by either locating the city or the participant's name to determine state of residence.

Table 4 An example of race results for California International Marathon held in 1990 in Sacramento California (Source: http://www.runcim.org)

Place	Name	Time	City	State	Age	Club	Div pl
1	Renner, Peter	2:12:35	Christchurch	NZ	31		1
2	Hudson, Brad	2:13:24	Eugene	OR	24		1
3	Silva, Jose	2:14:42	Maccio	Brazil	26		1
4	Perry, James M.	2:17:46	Victoria	BC	26	BC. Athletic	2
8	Deacon, Bruce W.	2:19:40	Burnaby	BC, Can	23		2
10	Petersen, David E.	2:20:03	Bend	OR	35		1
11	Valdez, Jesus	2:22:40	Mexico		26		6
16	Fuller, Christopher M.	2:26:01	St. Paul	MN	31		4
17	Arkes Jr., Robert B.	2:27:36	Portland	OR	30	Nike Portland	5

Table 4 (continued)

18	Soffker, Andreas	2:27:51	Germany	30	6

iv. LIVESTRONG AUSTIN MARATHON (Austin Texas)

The LIVESTRONG Austin Marathon data were collected from the marathon organization's main webpage for the race (http://www.youraustinmarathon.com/). Again the webpage provided both personal and race data. Personal data includes name, bib number, city and state of residence, and age. Race information includes finishing time, official and chip, a split time and division place. It should be noted that residency information was not given for the 2001 race and as a result those data were not used given the necessity of residency information to evaluate the research question. Results from the 2000 race are shown in table 5.

Table 5 An example of race results for the LIVESTRONG Austin Marathon in 2000 in Austin, Texas. (Source: http://www.youraustinmarathon.com/).

Place	Bib	Name	City	State	Age	Official Time	Chip Time	Split Time
1	99	Janko Bensa	Albuquerque	NM	22	2:14:10	2:14:08	04:10.0
3	10	Jacob Kirwa	Chapel Hill	NC	23	2:16:01	2:15:59	06:09.1
5	13	Reuben Chesang	Chapel Hill	NC	37	2:18:13	2:18:11	06:52.6
1	26	Steve Wilson	Clearwater	FL	41	2:18:30	2:18:27	07:08.1
7	9	Julius Randich			32	2:18:32	2:18:29	06:08.1
9	20	Dennis Simonaitis	Salt Lake City	UT	37	2:19:13	2:19:10	08:50.3
1	3426	Dzmitry Sivou	Libertyville	IL	28	2:19:51		06:53.9
3	14	Cesar Perez Rodriguez	San Sebastian	Ouipuzco	42	2:20:08	2:20:06	08:53.5
2	4	Narciso Flores	Tolvca	Mexico	29	2:20:58	2:20:56	06:20.5
1	89	Sergei Karasev	Austin	TX	34	2:21:42	2:21:41	09:45.2

v. CINCINNATI FLYING PIG MARATHON (Cincinnati Ohio)

The Cincinnati Flying Pig Marathon also provides race results from 2000 to 2010 on their organization homepage (http://www.flyingpigmarathon.com/). The information involving the participants includes name, gender, age, city and state of residency. Race timing results include times for participants 10K, half marathon, 30K and marathon finish, as well as overall finish and class rank (Table 6). It should be noted that residency information for 2009 and 2010 were not given and as a result will not be used in this study.

Table 6 An example of race results for the Cincinnati Flying Pig Marathon in 2000. (Source: http://www.flyingpigmarathon.com/)

First	Last	Age	Gender	City	State	Final	Chip Final	Over. Rank
Robert	Hilderbrand	51	M	Fairbanks	AK	5:24:55	5:22:41	3347
Deane	Feetham	62	F	Anchorage	AK	5:50:53	5:47:34	3521
Michael	Brass	39	M	Tuscaloose	AL	3:08:59	3:08:38	95
Craig	Kelly	51	M	Huntsville	AL	3:29:22	3:29:14	392
Terry	Wettig	42	M	Prattville	AL	3:30:42	3:30:28	424
John	Lehrter	32	M	Mobile	AL	3:59:09	3:58:46	1257
Joseph	Kozusko	26	M	Tuscaloosa	AL	4:47:38	4:47:38	2758
Pat	Hamilton	48	F	Vinemont	AL	5:42:53	5:40:04	3478
Laura	Saucer	41	F	Montgomery	AL	6:13:26	6:10:09	3594
Lisa	Reilly	40	F	Hot Springs Nat. Park	AR	4:01:37	4:00:26	1373

vi. OCALA MARTHON (Ocala Florida)

The Ocala Marathon organization's main webpage provided race results for 2000 to 2010 (http://www.drcsports.com/standalones/Ocalamarathon/index.php). The race results include name, gender, division, city, state, and country of residence, overall place, finishing time as well as gender place (Table 7). It should be noted the race was not held in 2007 and as such no data were available for that year.

Table 7 An example of race results for the Ocala Marathon in 2000.(Source: http://www.drcsports.com/standalones/Ocalamarathon/)

Last, First	Time	Over All	Gender Place	DIV	City	State	Country
Helio Teixeira (M)	3:36:01	53	42 / 7	M45-49	Pocos De Caldas		Brazil
Scott Vail (M)	3:42:13	64	51 / 5	M50-54	Placerville	CA	USA
Brent MacDonald (M)	3:02:41	11	11 / 3	M35-39	Brandon	CN	USA
Bonnie Skov (F)	4:38:20	180	46 / 2	F50-54	Calgary Alberta	CN	USA
Cindy Hazen (F)	3:14:10	22	3 / 2	F30-34	Littleton	CO	USA
John Hazen (M)	3:58:59	105	81 / 17	M35-39	Littleton	CO	USA
Rocky Holly (M)	4:20:21	152	116 / 19	M45-49	Aurora	CO	USA
Lisa Woods (F)	3:56:39	100	24 / 6	F35-39	Shelton	CT	USA
Mary Stettmeier (F)	4:30:14	172	43 / 12	F40-44	Berlin	CT	USA
Martin Guthrie (M)	2:59:51	7	7 / 2	M30-34	Flowery Branch	GA	USA

e. Marathon Data Management and Quality Control

Once I had collected the marathon finishing times converted them into a decimal time, I then separated the data for each race into two categories, “locals” and” visitors.” A “local” is defined as any racer who resided in the state in which the race was held and a “visitor” is any racer who does not specify in their race information to be from that state. In some situations the number of “visitors” far surpassed the number of “locals”, such as the New York City Marathon (New York City, New York), but in other races, specifically the Equinox Marathon (Fairbanks, Alaska), the number of “locals” was much greater than those visiting to run the race.

Segregation of the racers into these two categories, 'locals' and 'visitors,' allows for an examination of the impacts of training conditions versus conditions that occur on race day. The research question of this study is to determine to what degree acclimation can be discriminated within a local and visiting population. The aim is to determine how "local" and "visiting" runners react in terms of finishing times in a marathon if the weather greatly differs or is very similar to the conditions five days prior to the race in that city. By segregating the runners I will be able to compare each group to the various conditions. For example, are the finishing times of the locals faster than those of the visitors when there was little change in weather conditions between race day and the days leading up to the race? Or, alternatively, do the locals finishing times slow when the weather conditions on the race day are significantly different than the conditions of the five days leading up to the race? If the racers were not separated into the two groups, any impact of the weather conditions on the local and visiting population would be much harder to discriminate.

Next, I categorized the race finishing times by geographic location and then calculated the fifth percentile, average, median, and ninety-fifth percentile values for each race, each group and each year. These categorical breakdowns of finishers were used so as not to base the study on only one type of runner, such as the fastest or the slowest. In many cases the fastest runners are elite runners who rigorously train to prepare for races and are in top running condition, such as Meb Keflezighi, an American who won the New York City Marathon in 2009 but who also won the silver medal when he competed in the marathon in the 2004 summer Olympic Games (Patrick 2009).

As such, all of the marathon races chosen for this study include racers of all skill levels, unlike the Boston Marathon where each runner must qualify to participate. In terms of being impacted by the weather, the elite runners are not on the course as long as those who are not as well-trained or who are running for the accomplishment alone and not a particular finishing times. By breaking the finishing data into the fifth percentile, average, median, and ninety-fifth percentile, I believe the overall demographics of the whole race population are better represented, particularly influences outside of athletic ability. I then compiled those values into one matrix for each race to be used for any statistical testing, where the rows represented each year and each column was a time category.

Again, the elite runners are typically superbly trained and I believe are less likely to be impacted by outside influences such as the weather. A “weekend” or “everyday” runner may be specifically training for a particular distance, in this case 26.2 miles, which may result in factors outside of running to impact their race. In many cases a person will not be participating in such a demanding activity when visiting a location in which they are not accustomed and as a result, it is important to look at all types of runners to gauge how much of an impact acclimation can have to heat stress vulnerability. Additionally, by dividing the runners into categories, particular factors impacting each type of runner may be discovered. For example, faster runners may be impacted more by temperature while the slower runners are more impacted by humidity or a combination of meteorological variables. This type of result could suggest that acclimation to climate conditions depends on the type activity one is partaking in and may assist event planners in being better prepared to handle particular types of heat stress.

My previous research has established that there is an upward trend in marathon race data (DeBiasse 2008), which has held true in each race used in the study. As with many sports, the popularity fluctuates up or down at any given time. Marathon running began as an activity which only top or serious runners were participating in the 1960s and early 1970s. During the late 1970s however, marathon running became very popular among the class colloquially referred to as "weekend runners," those runners who took up running as a hobby or a way to get exercise (Muldowney 2008). As a result of this influx of less talented runners, there is a noticeable increase in finishing times. This trend in more recreational runners participating in races has continued causing overall finishing times to increase. The removal of this trend is important to this study and will be discussed in chapter 4.

f. Weather Data

The meteorological data used in this study are obtained from the National Climatic Data Center Integrated Surface Database (ISD-Lite). These data from the ISD-Lite product are derived from the integrated surface database as a subset of the full database on an hourly basis (http://www.ncdc.noaa.gov/oa/climate/isd/index.php?name=isd-lite). The database includes world-wide hourly data coverage. For each race event, I collected weather data for the race day, as well as the five days directly preceding the race from the closest reporting weather station for each year. Table 8 lists the race and the weather station from which data were collected and the distance between the city center where the race is held and that weather reporting location.

Table 8 Weather stations used for each location and the distances between the station and the city center.

Race	Weather Station	Distance between the city center and reporting station
ING New York City Marathon	La Guardia International Airport	10 miles
Equinox Marathon	Fairbanks International Airport	5 miles
California International Marathon	Sacramento International Airport	12 miles
	Sacramento Executive Airport	6.5 miles
LIVESTRONG Austin Marathon	Austin/Mueller International Airport	5 miles
Cincinnati Flying Pig Marathon	Cincinnati Municipal Luken Airport	8 miles
Ocala Marathon	Gainesville Regional Airport	41 miles

While not all of the races are held in the immediate city center, the distance between the locations and the city center demonstrates the degree to which the weather information collected at a site would be considered representative for the city and therefore representative of race day conditions. I selected weather stations not only for their relative location to the race area, but also for their completeness of the data available. For example, while there is a municipal airport within the city of Ocala, Florida, there were several years/days of missing data. As a result, Gainesville Regional Airport, which geographically was the next closest station with a complete data set, was a better selection. Additionally, meteorological data from Sacramento International Airport for the years 1996 and 1997 included many missing values. Therefore, Sacramento

Executive Airport data replaced those missing data for that two year period. Data reported at Sacramento Executive Airport were within one unit of measurement when compared to data collected at Sacramento International Airport. Pressure values for the each race day and the five days leading to race day for 1997 have been eliminated as there were too few recorded values.

For each station, I collected meteorological information for the race day and the five days leading up to race day. The hourly data included: dry bulb (in Celsius), dew point (in Celsius), station pressure (in hectopascals), wind speed (in meters per second) and wind direction (in degrees from true north). I also calculated other meteorological values such as vapor pressure (in kilopascals), saturation vapor pressure (in kilopascals) and relative humidity using equations 3.1, 3.2 and 3.3 from the collected data where temperature (T) and dew point temperature (T_d) are in Celsius and vapor pressure (e) and saturation vapor pressure (e_s) are in kilopascals. Relative humidity (RH) is a percentage value (Western Region Headquarters NWS 2010).

$$e = 0.611 x 10^{\frac{7.5T_d}{287.7+T_d}} \tag{3.1}$$

$$e_s = 0.611 x 10^{\frac{7.5T}{287.7+T}} \tag{3.2}$$

$$RH = \frac{e}{e_s} x 100 \tag{3.3}$$

I calculated the average daily values for each of the hourly data variables for the race day and over the five day period prior to the race day. I also calculated the hourly heat index, wind chill temperature, wet bulb globe temperature (WBGT), apparent temperature and wind chill equivalent temperature which were then also averaged for a daily value; each of which are defined below.

As the literature suggests (Carter et al. 2005; Hanna 1999; Kenney 1985), temperature and moisture play a large role in acclimation to one's environment. As such, I collected temperature and dew point temperature for each race and were used to calculate other moisture variables including vapor pressure, saturation vapor pressure, and relative humidity. Additionally, wind speed values are important data as wind can aid in evaporative cooling of the body, which on a hot day can be appreciated by those running a marathon. Wind speed also plays a role in finishing speed, as a very windy day may help or hinder a runner depending on the direction both the wind and runner are moving. While each of these variables will be evaluated separately, they will also be addressed in the form of biometeorological heat stress indices.

The use of biometeorological heat stress indices allows for meteorological variables to be used in combination. Temperature and humidity are the two most common variables to be used together (Steadman 1979; Segal and Pielke 1981). The heat index (3.4) combines these two variables using temperature, in Fahrenheit, (T) and relative humidity (R). The coefficient values are based on a multiple regression analysis that was performed on the data from Steadman's table (Rothfusz 1990).

$$HeatIndex = -42.379 + 2.0491523T + 10.14333127R - 0.22475541TR - 6.8378x10^{-3}T^2 - 5.481717x10^{-2}R^2 + 1.2287x10^{-3}T^2R + 8.5282x10^{-4}TR^2 - 1.99x10^{-6}T^2R^2 \quad (3.4)$$

While the heat index is normally only calculated once the temperature has reached 80°F (26.6ºC) (NWS Louisville, Kentucky 2011), I will calculate it for each race in this study. If the temperature is below 80°F, the heat index for that day is reported as the ambient temperature, effectively ignoring the humidity value. By including the actual calculation of the heat index in this study, I can assess the effect that humidity may have on a person, regardless of temperature.

Additionally, wind speed can greatly affect human comfort as it can increase the process of evaporative cooling. An increased wind speed can help circulate saturated air over the body allowing for drier air to increase evaporation off the body or other surface. The current wind chill temperature index used by the National Weather Service (NWS) calculates the wind speed based on a person of five-foot height and incorporates heat transfer between the body and the surroundings, unlike the original wind chill index which was empirically derived and did not consider heat generation by the body (Moran 2001). The wind chill temperature index uses temperature in degrees Fahrenheit (T) and wind speed in miles per hour (V) in its calculation (3.5).

$$WCI = 35.74 + 0.6215T - 25.75V^{0.16} + 0.4275TV^{0.16} \qquad (3.5)$$

While evaporative cooling may be a benefit under warmer conditions, wind can also have negative implications on a human body under cooler conditions. Hypothermia is a common ailment suffered by inexperienced athletes who may not know how to pace themselves for the full race distance. A runner may begin at an unsustainable pace, which later in the race requires them to slow down to a walk or stop completely. Once the body is no longer moving at the faster pace, the heat production within the body decreases while the runner continues to lose heat (Spellman 1996). Increased wind speed can increase the pace at which the body loses heat leading to a greater risk of hypothermia occurring when the heat loss is greater than the heat production (Armstrong et al. 1996).

Quayle and Steadman (1998) suggested a further update to the wind chill index, citing while it did use human subjects to assess heat loss from exposed skin (NWS 2006), it did not account for metabolic heat generation from the body. Thus, the Steadman wind chill temperature (WET) was developed (3.6). The equation uses the dry bulb temperature in Celsius (T_a) and wind speed in meters per second (V_a) in its formulation.

$$WET = 1.41 - 1.162V_a + 0.98T_a + 0.0124{V_a}^2 + 0.0185(V_a T_a) \quad (3.6)$$

The wet bulb globe temperature (WBGT) will also be evaluated for this study. The WBGT uses ambient air temperature (Ta), wet bulb temperature (Tw), and the black globe temperature (Tg) all in degrees Celsius to describe environmental heat stress as seen in equation (3.7) (BOM Weather Services 2007).

$$WBGT = 0.7T_w + 0.2T_g + 0.1T_a \quad (3.7)$$

Globe thermometers which measure the globe temperature, a temperature that integrates radiation and wind speed into its reading, are available commercially, but require regular maintenance and are fairly expensive (BOM Weather Services 2007). As a result an approximation of the wet bulb globe temperature is commonly used and I will be using it in this study. The approximation uses ambient temperature (T_a) in Celsius and vapor pressure (e) in hectopascals (3.8).

$$WBGT = 0.567T_a + 0.393e + 3.94 \quad (3.8)$$

Lastly, I included the Apparent Temperature for each race, both for race day and the five days prior to the race. The apparent temperature is closely related to ambient temperature but includes vapor pressure (e) in kilopascals and wind speed (V_a) in meters per second ten meters above the surface in addition to ambient temperature in Celsius (T_a) using equation (3.9) (BOM Weather Services 2007).

$$AT = T_a + 0.33e - 0.7V_a - 4 \quad (3.9)$$

Once all of the data were collected and variables calculated, I organized the values into a matrix for each race. Each race matrix consisted of the average variables for the race day and the five days leading up to the race. Table 9 and 10 is the race matrix created for the LIVESTRONG Austin Marathon (Austin, Texas).

Table 9 Sample matrix for the LIVESTRONG Austin Marathon. The averages of each meteorological variable for the five days prior to the race and the averages for the race day are displayed.

Five Day	Wind speed (m/s)	Air Temp (C)	Dew Point (C)	Pressures (hpa)	Vapor Press. (kpa)	Sat. Vapor Press. (kpa)	Relative Humidity
2000	4.847	19.292	13.663	1017.599	1.563	2.235	69.928
2002	3.160	9.041	0.597	1023.961	0.638	1.151	55.460
2003	3.725	16.077	14.454	1016.057	1.645	1.825	90.115
2004	5.800	5.894	3.791	1021.781	0.802	0.928	86.352
2005	3.113	10.918	6.463	1023.534	0.965	1.305	73.990
2006	6.121	13.388	5.711	1011.209	0.917	1.535	59.710
2007	5.585	5.264	-2.781	1022.113	0.498	0.889	56.066
2008	4.774	13.076	6.660	1015.411	0.979	1.504	65.067

Table 9 (continued)

2009	3.810	16.569	6.632	1015.099	0.977	1.883	51.861
2010	3.810	4.016	0.217	1020.649	0.621	0.814	76.251

Race Day

	Wind speed (m/s)	Air Temp (C)	Dew Point (C)	Pressures (hpa)	Vapor Press. (kpa)	Sat. Vapor Press. (kpa)	Relative Humidity
2000	2.732	12.425	3.829	1029.821	0.804	1.441	55.760
2002	1.504	7.682	-1.936	1023.671	0.530	1.050	50.538
2003	7.774	7.256	0.537	1020.893	0.635	1.019	62.339
2004	2.411	4.607	0.125	1021.689	0.617	0.849	72.667
2005	5.345	19.869	14.824	1011.141	1.684	2.316	72.732
2006	4.847	-0.190	-2.273	1028.720	0.517	0.603	85.818
2007	3.117	10.153	-4.342	1029.300	0.443	1.240	35.746
2008	2.719	10.811	4.096	1008.367	0.819	1.296	63.209
2009	5.318	13.618	2.286	1019.200	0.720	1.558	46.242
2010	2.900	7.938	4.559	1015.716	0.846	1.068	79.207

Table 10 Sample matrix for the LIVESTRONG Austin Marathon. The averages of each heat stress indices for the five days prior to the race and the averages for the race day are displayed.

Five Day

	Heat Index	Wind Chill	Wet bulb Globe Temperature	Apparent Temperature	Wind Chill Equivalent Temperature
2000	73.945	66.631	21.020	17.056	16.705
2002	103.987	45.076	11.574	4.935	7.250
2003	64.981	59.997	19.520	14.897	14.117
2004	109.359	35.798	10.432	0.479	1.496
2005	91.313	49.196	13.924	7.925	9.241
2006	87.559	52.719	15.133	8.128	9.399
2007	123.524	34.527	8.883	-1.001	1.010
2008	87.202	52.715	15.200	8.963	10.114
2009	81.072	61.033	17.173	13.125	14.568
2010	130.802	33.379	8.657	-0.602	1.382

Race Day

	Heat Index	Wind Chill	Wet bulb Globe Temperature	Apparent Temperature	Wind Chill Equivalent Temperature
2000	91.012	52.817	14.143	9.165	11.132
2002	108.805	44.603	10.380	4.380	7.433
2003	113.194	37.708	10.551	-0.089	1.280
2004	127.987	36.525	8.976	0.955	3.401
2005	72.860	67.770	21.826	17.686	16.990

Table 10 (continued)

2006	161.617	22.885	5.865	-5.876	-4.134
2007	91.360	47.533	11.438	5.434	8.444
2008	95.988	49.367	13.288	7.611	9.481
2009	87.004	53.636	14.493	8.273	10.267
2010	102.741	42.980	11.765	4.699	6.350

g. Descriptive Statistics

Descriptive statistics provide valuable information about the data including the distribution and the spread of the data. Therefore I performed calculations of the descriptive statistics for each meteorological variable and human comfort indices, as well as the race times. Missing values given for either meteorological values or race values were not included in the calculations and are shown in Table 11. If race times were missing for a particular year the meteorological data were not used for that year as well.

Table 11 The missing values for each race including the year the values are missing and the reason for the missing value.

Race Values		
	Equinox Marathon (Fairbanks, Alaska)	
Missing	Years	Reasons
Race Times	1985, 1991, 1996	Data not available
Race Times	1990, 1995	No geographic residency of participants
Race Times	1992	No official race results recorded
	California International Marathon (Sacramento, California)	
Missing	Years	Reasons
Pressure	1997	Too few recorded values
	LIVESTRONG Austin Marathon (Austin, Texas)	
Missing	Years	Reasons
Race results	2001	No geographic residency of participants
	Cincinnati Flying Pig Marathon (Cincinnati, Ohio)	
Missing	Years	Reasons
Race results	2009, 2010	No geographic residency of participants
	Ocala Marathon (Ocala, Florida)	
Missing	Years	Reasons
Race results	2007	Race was not held

Once I created a matrix for each race, I computed the mean (X) using the following equation, where X_i represents each of the values and N is the sample size (McKenzie and Golman 2005).

$$X = \frac{\sum X_i}{N} \tag{3.10}$$

I also computed the median to determine if there were any outliers within the data set. If the mean and median were within one unit of measurement of each other, I established that there were no significant outliers within the dataset.

I identified outliers in all data sets with the exception of the Ocala Marathon, which did not have any outlying values. Outliers within the data set can suggest an error in measurement or in the case of meteorological data it can suggest weather uncommon for what is typically expected during that time of year. This occurrence may suggest a year when the race results may reflect the change in weather. As a result, the difference may address the hypothesis that if the weather is significantly different on race day than the weather leading up to the marathon, race results may be impacted. This may also be true from year to year, where if weather one year is much cooler or warmer than what is typical, the overall race results are impacted. The heat index was an outlier on race day for both the Equinox Marathon (Fairbanks, Alaska) and the LIVESTRONG Austin Marathon (Austin, Texas), and leading up to race day for the Cincinnati Flying Pig Marathon (Cincinnati, Ohio) and the LIVESTRONG Austin Marathon (Austin, Texas).

I then calculated the standard deviation (σ), or the spread about the mean, for each value, where X_i refers to each sample value and N is the sample size (McKenzie and Golman 2005).

$$\sigma = \sqrt{\frac{\sum X_i^2 - \left(\sum X_i^2\right)/N}{N-1}} \tag{3.11}$$

I found that the heat index for all locations had the highest standard deviation for all meteorological variables. Relative humidity had the next largest standard deviation. As such, these two variables also recorded the two highest variances (σ^2), a measure of the spread of the data (McKenzie and Golman 2005). Where X_i is the *i*th observation and N is the sample size.

$$\sigma^2 = \frac{\sum X_i^2 - \left(\sum X_i^2\right)/N}{N-1} \tag{3.12}$$

I also computed the skewness and kurtosis to determine the normality of each variable. Determining the normality of the data is a necessity when performing parametric statistical tests. If the data are not normally distributed and parametric statistics are performed on the data, the results may be misleading. A skewness value of zero suggests the data distribution is symmetric. A positive skewness value suggests the distribution is skewed to the right, while a negative value suggests the distribution is skewed to the left. A normally distributed variable can be assumed when the skewness calculated falls between -1.96 and +1.96, within one standard deviation from the mean (McKenzie 2005). Two races experienced skewness values out of what would be considered normal—the pressure value for the five days leading up to the Ocala Marathon (skewed to the left) and the vapor pressure on race day for the Cincinnati Flying Pig Marathon (skewed to the right).

Skewness (b_i) is calculated by using the mean and standard deviation as follows, where N is the sample size, X_i is the observation value, X is the mean of the observations and σ is the standard deviation.

$$b_1 = \frac{N}{(N-1)(N-2)} \sum \left[(X_i - X) / \sigma \right]^3 \tag{3.13}$$

In addition to skewness, I evaluated the kurtosis values for each variable to determine the peakedness of the data and, subsequently, the normality. A positive value refers to a sharper peak, while a negative value refers to a flatter curve. Again, a kurtosis value between -1.96 and +1.96 suggests a normal distribution (McKenzie and Golman 2005). Kurtosis (b_l) may be computed using the following formula where N is the sample size, X_i is the observation value X is the mean of the observations, and σ is the standard deviation.

$$b_1 = \frac{N}{(N-1)(N-2)(N-3)} \sum \left[(X_i - X) / \sigma \right]^4 - \frac{3(N-1)^2}{(N-2)(N-3)} \tag{3.14}$$

Several variables in the data set returned a kurtosis value outside of the range of one standard deviation from the mean. The non-normal values for the race data can be found in Table 11 while the weather values can be found in Tables 12 and 13 as well as appendix A. The races with a smaller n-size, specifically the LIVESTRONG Austin Marathon, Cincinnati Flying Pig Marathon, and Ocala Marathon, were more impacted by the outliers within the data than races with a longer evaluation period, New York City Marathon, Equinox Marathon and California International Marathon. As a result, I will transform the data that are not normally distributed to achieve a normal distribution. The specific transforms performed on each variable are discussed in section b of Chapter 4. Tables 12, 13, 14 demonstrate the descriptive statistics found for the participants' finishing times and the Equinox Marathon and Ocala Marathon descriptive statistics for the meteorological variables. The other race meteorological variable descriptive statistics are given in Appendix A.

Table 12 The descriptive statistics for each races' participants both 'local' and 'visitor.' Any values outside of the range accepted as a normal distribution, skewness or kurtosis values between -1.96 and +1.96 are bolded.

	Mean	Median	Std. Dev.	Variance	Skewness	Kurtosis
NYC Marathon Locals - New York						
5%	3.158	3.236	0.178	0.032	-1.092	-0.054
Average	4.326	4.457	0.295	0.087	-1.069	0.192
Median	4.241	4.367	0.281	0.079	-0.915	0.017
95%	5.790	5.949	0.473	0.223	-1.166	0.344
NYC Marathon Visitors						
5%	3.059	3.159	0.223	0.050	-0.529	-0.667
Average	4.199	4.339	0.352	0.124	-0.698	-0.242
Median	4.123	4.245	0.341	0.117	-0.619	-0.204
95%	5.605	5.767	0.533	0.284	-0.820	-0.150
Equinox Marathon Locals – Alaska						
5%	3.409	3.390	0.187	0.035	-0.230	-0.976
Average	5.022	4.791	0.475	0.226	0.271	-1.818
Median	4.836	4.707	0.385	0.148	0.175	-1.711
95%	7.309	6.711	1.110	1.233	0.394	-1.718
Equinox Marathon Visitors						
5%	3.731	3.658	0.330	0.109	0.132	-0.408
Average	4.926	4.982	0.760	0.577	-0.788	0.104
Median	4.875	4.974	0.749	0.561	-0.568	0.133
95%	6.362	6.518	1.481	2.196	-0.600	-0.294
California International Marathon Locals - California						
5%	2.943	2.943	0.164	0.027	-0.148	-1.537
Average	3.963	3.978	0.264	0.070	-0.011	-1.443

Table 12 (continued)

Median	3.919	3.993	0.238	0.057	0.016	-1.224
95%	5.161	5.267	0.440	0.194	-0.040	-1.591
California International Marathon Visitors						
5%	2.578	2.585	0.202	0.041	0.179	-0.386
Average	3.627	3.362	0.267	0.071	-0.322	-0.548
Median	3.568	3.583	0.253	0.064	-0.556	-0.270
95%	4.879	4.926	0.412	0.170	-0.284	-1.083
LIVESTRONG Austin Marathon Locals - Texas						
5%	3.270	3.267	0.070	0.005	-0.323	-1.376
Average	4.457	4.491	0.149	0.022	-1.029	0.912
Median	4.381	4.387	0.111	0.012	-0.075	-1.239
95%	6.084	6.167	0.247	0.061	-1.941	**4.095**
LIVESTRONG Austin Visitors						
5%	2.897	2.867	0.179	0.032	0.493	-0.337
Average	4.121	4.115	0.138	0.019	0.049	0.500
Median	4.019	4.002	0.127	0.016	0.913	0.213
95%	5.735	5.759	0.255	0.065	-1.144	**3.180**
Cincinnati Flying Pig Marathon Locals - Ohio						
5%	3.330	3.322	0.330	0.001	-0.054	0.238
Average	4.528	4.523	0.118	0.014	0.161	-0.312
Median	5.375	4.370	0.838	0.007	0.225	-1.552
95%	6.374	6.371	0.417	0.174	-0.710	1.260
Cincinnati Flying Pig Marathon Visitors						
5%	3.313	3.315	0.025	0.001	-0.116	-0.959
Average	4.458	4.477	0.085	0.007	-0.401	-1.214
Median	4.347	4.354	0.060	0.004	-0.338	-0.166
95%	6.103	6.150	0.268	0.072	-0.715	-0.312
Ocala Marathon Locals- Florida						
5%	3.289	3.284	0.126	0.016	-0.127	-0.778
Average	4.357	4.354	0.129	0.017	-0.213	-0.653
Median	4.283	4.253	0.160	0.026	0.652	-0.357
95%	5.654	5.689	0.150	0.022	-0.892	0.806
Ocala Marathon Visitors - Other						
5%	3.251	3.226	0.130	0.020	-0.183	-0.384
Average	4.420	4.381	0.242	0.058	1.099	1.407
Median	4.273	4.259	0.249	0.062	0.981	0.102
95%	5.843	5.908	0.448	0.221	0.812	**2.205**

Table 13 The descriptive statistics for race day conditions and the five days prior to race day for the Equinox Marathon (Fairbanks, Alaska).

Equinox Marathon Race Day	Mean	Median	Std. Dev.	Variance	Skewness	Kurtosis
Temperature	7.021	7.777	3.434	11.795	-0.179	0.834
Dew Point	1.361	1.535	3.230	10.435	-0.567	0.472
Wind Speed	2.407	2.233	1.027	1.054	0.538	0.006
Pressure	1007.600	1005.800	9.700	95.000	0.386	-0.566
Vapor Pressure	0.689	0.683	0.152	0.023	-0.019	-0.365
Sat. Vapor Pressure	1.027	1.057	0.236	0.056	0.188	-0.586
Relative Humidity	67.914	69.824	9.500	90.247	-0.426	-0.402
Heat Index	114.290	108.570	19.200	384.870	0.595	-0.740
Wind Chill Index	45.123	44.079	9.595	92.064	0.240	-0.568
WBGT	10.630	11.133	2.456	6.030	-0.184	-0.725
Appt. Temp.	3.612	4.176	4.171	17.398	-0.101	-0.655
WET	5.870	6.355	3.956	15.651	-0.112	-0.622
Equinox Marathon Five Day						
Temperature	8.520	8.326	2.944	8.667	0.093	0.635
Dew Point	2.907	3.462	3.514	12.347	-1.385	2.212
Wind Speed	2.391	2.298	1.007	1.013	0.400	-0.044
Pressure	1008.500	1006.700	6.100	37.200	0.232	0.234
Vapor Pressure	0.772	0.783	0.168	0.028	-0.727	0.662
Sat. Vapor Pressure	1.113	1.097	0.228	0.052	0.737	1.432
Relative Humidity	68.513	70.098	10.195	103.934	-0.934	0.327
Heat Index	114.290	108.570	19.200	384.870	0.595	-0.740
Wind Chill Index	45.123	44.079	9.595	92.064	0.240	-0.568
WBGT	11.803	11.500	2.220	4.930	-0.286	0.449
Appt. Temp.	5.392	5.146	3.548	12.588	-0.380	0.067
WET	7.437	7.295	3.261	10.632	-0.209	-0.093

Table 14 Descriptive statistics for race day conditions and the five days prior to race day for the Ocala Marathon. Skewness and kurtosis values that fall outside the accepted range for normality (-1.96 to +1.96) are bolded.

Ocala Race Day						
	Mean	Median	Std. Dev.	Variance	Skewness	Kurtosis
Temperature	10.772	10.365	3.397	11.542	-0.219	-0.143
Dew Point	5.625	6.501	5.767	33.259	-0.389	-1.166
Wind Speed	2.669	2.186	1.723	2.968	0.752	-0.833
Pressure	1020.800	1020.500	4.400	19.500	0.672	-0.263
Vapor Pressure	0.968	0.969	0.358	0.128	-0.015	-1.581
Sat. Vapor Pressure	1.318	1.258	0.292	0.085	0.202	-0.502
Relative Humidity	71.503	76.656	14.572	212.345	-0.274	-1.774
Heat Index	92.533	89.539	22.142	490.280	0.893	0.157
Wind Chill Index	54.462	53.666	7.870	61.940	0.762	0.749
WBGT	13.850	13.256	3.268	10.680	-0.094	-0.744
Appt. Temp.	8.096	7.419	4.592	21.084	0.418	-0.590
WET	9.523	8.704	3.665	13.430	0.681	-0.462
Ocala Five Day						
Temperature	13.563	13.614	3.065	9.392	1.162	*2.265*
Dew Point	7.944	7.884	4.482	20.092	0.545	0.908
Wind Speed	2.576	2.380	0.615	0.379	1.500	2.604
Pressure	1019.600	1020.400	3.000	9.300	**-2.002**	**4.687**
Vapor Pressure	1.109	1.066	0.359	0.129	1.317	**2.567**
Sat. Vapor Pressure	1.578	1.560	0.341	0.117	1.667	**3.854**
Relative Humidity	69.048	68.148	8.029	64.463	-0.017	-0.012
Heat Index	86.093	85.853	10.984	120.644	-0.183	-0.484
Wind Chill Index	60.014	60.628	5.681	32.274	0.453	0.987
WBGT	15.990	15.918	3.138	9.847	1.237	**2.476**
Appt. Temp.	11.421	10.820	4.291	18.412	1.293	**2.600**
WET	12.439	11.995	3.215	10.339	1.265	**2.433**

h. Summary and conclusions

Six races are evaluated to determine the importance of acclimation to marathon runners. Those races, the New York City Marathon (New York City, New York), Equinox Marathon (Fairbanks, Alaska), California International Marathon (Sacramento, California), LIVESTRONG Austin Marathon (Austin, Texas), Cincinnati Flying Pig Marathon (Cincinnati, Ohio), and the Ocala Marathon

(Ocala, Florida), are marathons that attract runners from both within the state in which they are held and from other states and/or countries (Table 1). I separated the finishing times for each race into ‘locals,’ that is, individuals who reside in the state where the race is held and ‘visitors,’ that is those that reside in a different state. Those two categories were then further separated into groups based on finish times – the fifth percentile, the average, the median, and the ninety-fifth percentile. A critical aspect of this study is to investigate all types of runners and not just the fastest or the slowest. While using the marathon data to evaluate acclimation I believe that acclimation will impact people participating in any type of activity, and as such those that are participating at a higher and lower activity levels should be evaluated.

I collected weather data from the National Climatic Data Center’s ISD-Lite hourly database for each year that race data were available. Additionally, I computed the vapor pressure, saturation vapor pressure, relative humidity and five heat stress indices. I then averaged the heat index, wind chill temperature index, wet bulb globe temperature , apparent temperature, and wind chill equivalent index, in addition to the individual weather variables over the race day and the five days leading up to the race. By evaluating the weather on race day versus the weather leading up to the race I will be able to examine if the differences in weather conditions result in a difference in finishing times. The five days prior to the race in this study act as the acclimation factor, in other words if there is a change in the weather on race day from the previous days I expect the finishing times of the “locals” will be impacted, either positively or negatively depending on the change in weather.

Chapter 4 discusses through a series of statistical analyses whether acclimation is present and identifiable in marathon data when those data are compared with meteorological data. The statistical tests performed on the above data and those results will addressed in detail. The first test will address those variables that are not normally distributed. Additionally, I will run a simple linear regression test on the race results to remove the trend that is a result of the running boom in the late 1970’s. Following the detrending of the race data, I will determine the z-score of that data to standardize the data allowing for comparison between the race days of varying weather conditions. Once the data are standardized, I will perform a correlation analysis. The correlation analysis will be performed between the race data and meteorological variables and indices, for the years when race day conditions were similar to the five days prior (baseline) and the years when race day conditions were different than baseline conditions. Finally, I will perform a two-way t-test to determine a difference in means of the race times based on the notable variables from the correlation analysis.

4. Results and Discussion

a. Introduction

In this chapter I discuss the statistical tests performed on the data which were described in Chapter 3. To evaluate my research question on discerning the effects of acclimation on physically fit individuals, I compared two sets of data: hourly meteorological readings and marathon race results from six different marathons held across the United States. A set of meteorological variables potentially capable of discriminating acclimation including temperature, dew point temperature, station pressure, wind speed and direction were collected from the National Oceanic and Atmospheric Association (NOAA) ISD-Lite database (http://www.ncdc.noaa.gov/oa/climate/isd/index.php?name=isd-lite) and used to calculate associated variables such as vapor pressure, saturation vapor pressure, and several heat stress indices.

A key to the establishment of the effects of acclimation on physically fit individuals is to discern whether the race day conditions are similar or different to the preceding days. My assumption is that the averaged weather conditions of the five day prior to the race provide a baseline set of weather conditions (the conditions to which individuals would acclimate) to which the actual race day conditions can be compared. I selected an interval of five days prior to the race because as many runners will begin to arrive at a race city up to a week before to participate in any pre-race activities. Arriving for a race within the week would suggest that most runners would continue to participate in a few shorter runs in those conditions. Five days may not be a long enough period of time to fully acclimate to all type of conditions including cold, which can take up to six weeks (Hanna 1999), and warm humid conditions (Hue et al 2004). However, it is very rare that any visiting runner would arrive to a race location more than a week ahead of the race unless they had personal reasons, such as family or a scheduled vacation. My results may provide validation or refutation of such an interval.

Comparison of these data from the preceding days prior to a given race to the actual weather conditions of the race provide a potential means of discriminating the effects of acclimation. Different responses of my test groups to the differences between the pre-existing weather conditions and those of the race day may be the result of acclimation or failure to acclimate to the given race day conditions. Therefore, I then averaged the meteorological data to determine a daily value for each meteorological variable for each of the race days, as well as an average value for the five days leading up to the race.

The race data were collected from the six different marathons discussed in earlier chapters: The New York City Marathon (New York City, New York), the Equinox Marathon (Fairbanks, Alaska), California International Marathon (Sacramento, California), the LIVESTRONG Austin Marathon (Austin, Texas), Cincinnati Flying Pig Marathon (Cincinnati, Ohio), and the Ocala Marathon (Ocala, Florida). The data are information available from the individual race website or, in the case of the Equinox Marathon, from personal contact with a race administrator. Segregation into two groups, the “locals,” participants who reside in the state in which the race is held, and the “visitors,” those that are visiting from another state or country, allows further discrimination of the effects of acclimation. Once the data were classified into the two groups, I then further categorized the data into the groups based on the finish times of the racers, specifically the fifth percentile, average, median and ninety-fifth percentiles. Both the meteorological data and the marathon finishing times provide the means to test my research question as to what degree acclimation can be discriminated within both local and visiting populations as measure within the marathon running community.

Using those data, I conducted a set of specific statistical tests to evaluate the impact of variations in baseline weather conditions on participants' finishing times of a marathon. The specifics of those tests and their results are given in this chapter. First, I transformed the variables that were not normally distributed in attempts to get a normal distribution so that certain statistical tests are valid. Second, I conducted a simple regression analysis to remove the trend from the race data. As running became more popular in the 1970s the finishing times increased leading to a trend in the data. This trend may obscure the effects of acclimation and so it was removed from the race data. Third, I calculated a z-score for each variable to standardize the data and allow for comparisons between years. Fourth, I performed a Pearson's product-moment correlation analysis on the standardized values to determine the relationship between a change in conditions between the race day and the five days leading up to the race. Finally, I performed a Student's t-test for difference of means to determine if the means of the notable variables found through the correlation analysis were significantly different. Critical results from these tests are given in the concluding summary of this chapter.

b. Normalizing data

In order to perform any parametric statistical test on a dataset, the data need to be normally distributed (Ebdon 1985). Chapter 3 described the data as well as the descriptive statistics of those data. Several of those data were not normally distributed as their skewness or kurtosis values were not within one standard deviation of the mean (-1.96 or +1.96), (McKenzie and Golman 2005).

I evaluated these variables for normality (a Gaussian distribution) using the standardized coefficients of skewness, z_1, and kurtosis, z_2, calculated as:

$$z_1 = \frac{\left[\sum_{i=1}^{N}(x_i - \overline{X})^3 / N\right]\left[\sum_{i=1}^{N}(x_i - \overline{X})^2 / N\right]^{-3/2}}{(6/N)^{1/2}} \quad (4.1)$$

and

$$z_2 = \frac{\left\{\left[\sum_{i=1}^{N}(x_i - \overline{X})^4 / N\right]\left[\sum_{i=1}^{N}(x_i - \overline{X})^2 / N\right]^{-2}\right\} - 3}{(24 / N)^{1/2}} \quad (4.2)$$

where the resulting z values are compared against a t-value deemed appropriate for a selected level of confidence (e.g., for N=50, t=2.01 for the 0.95 confidence level and t=2.67 for the 0.99 level). If the absolute value of z_1 or z_2 exceeds the selected value of t, a significant deviation from the normal curve is confirmed. Otherwise, no statistically significant deviation from a normal distribution is determined (the null hypothesis that the samples came from a normal distribution cannot be rejected) (Granger 1979).

As a result, I applied a mathematical transformation on those particular data to achieve a normal distribution (Table 15). The specific transformation listed produced a normalized distribution for the given variable. The resultant descriptive statistics for each of the transformed variables can be found in Appendix B.

Table 15 The non-normally distributed variables within the data set for each location, the value that is not within the accepted range suggesting a non-normal distribution and the transformation performed on the data that resulted in a normally distributed value.

Location	Variable	Non-normal value	Transformation
LaGuardia International Airport (New York)			
	Race day wind speed	Kurtosis	$\sqrt[3]{x}$
	Five Day Heat Index	Kurtosis	None
LIVESTRONG Austin Marathon (Austin TX)			
	Texas 95%	Kurtosis	None
	Visitors 95%	Kurtosis	None
Austin-Mueller Airport (Texas)			
	Five day vapor pressure	Skewness/kurtosis	$\frac{1}{x}$
	Five day saturation vapor pressure	Kurtosis	$\sqrt{x}$
	Five day WBGT	Kurtosis	$\sqrt{x}$
Cincinnati Municipal Luken Airport (Ohio)			
	Race day vapor pressure	Skewness/kurtosis	$\frac{1}{x}$
	Race day saturation vapor pressure	Kurtosis	$\sqrt{x}$
	Race day WBGT	Kurtosis	$\sqrt[4]{x}$
	Race day AT	Kurtosis	$\sqrt{x}$
	Race day WET	Kurtosis	$\sqrt{x}$
Ocala Marathon (Florida)			

Table 15 (continued)

	Visitors 95%	Kurtosis	$\sqrt{x}$
Gainesville Municipal Airport (Florida)			
	Five day pressure	Skewness/kurtosis	None
	Five day vapor pressure	Kurtosis	$\sqrt{x}$
	Five day saturation vapor pressure	Kurtosis	$\frac{1}{x}$
	Five day wind chill	Kurtosis	$\sqrt{x}$
	Five day WBGT	Kurtosis	$\sqrt{x}$
	Five day AT	Kurtosis	$\sqrt{x}$
	Five day WET	Kurtosis	$\sqrt{x}$

As shown in Table 15, I was unable to determine a transformation that would result in a normal distribution for four variables: the five day heat index for LaGuardia International Airport (New York), both 'local' and 'visiting' finishing times in the ninety-fifth percentile for the LIVESTRONG Austin Marathon (Austin, Texas), and the five day pressure recorded at Gainesville Municipal Airport (Florida). As such, although the results of my statistical analyses are robust (Ebdon 1985) and the degree of non-normality was relatively small, results from a statistical test using these particular variables may need to be evaluated closely.

b. Linear regression detrending analysis

The above analysis allows for parametric statistical analysis to be used to assess the stated research question. However, before analysis can begin using both the race data and the weather data, a simple linear regression test needs to be applied to the race data as a previous study has shown an upward trend or slowing in race times since the 1970s (DeBiasse 2008). That finding and corresponding adjustment is discussed below. However, I must first discuss why trend may exist in the marathon data.

After American Frank Shorter won the marathon race in the 1972 Summer Olympic Games, running began to grow in popularity, resulting in all levels of runners participating in races ranging from five kilometers in distance to 26.2 miles (Muldonwey 2009). As a result, the finishing times of those running have increased, although the fastest runners have not recorded this same trend (DeBiasse 2008). Figure 15 demonstrates the upward trend of finishing times recorded since 1976 for the New York City Marathon for both New York residents and visitors. The other races can be found in C

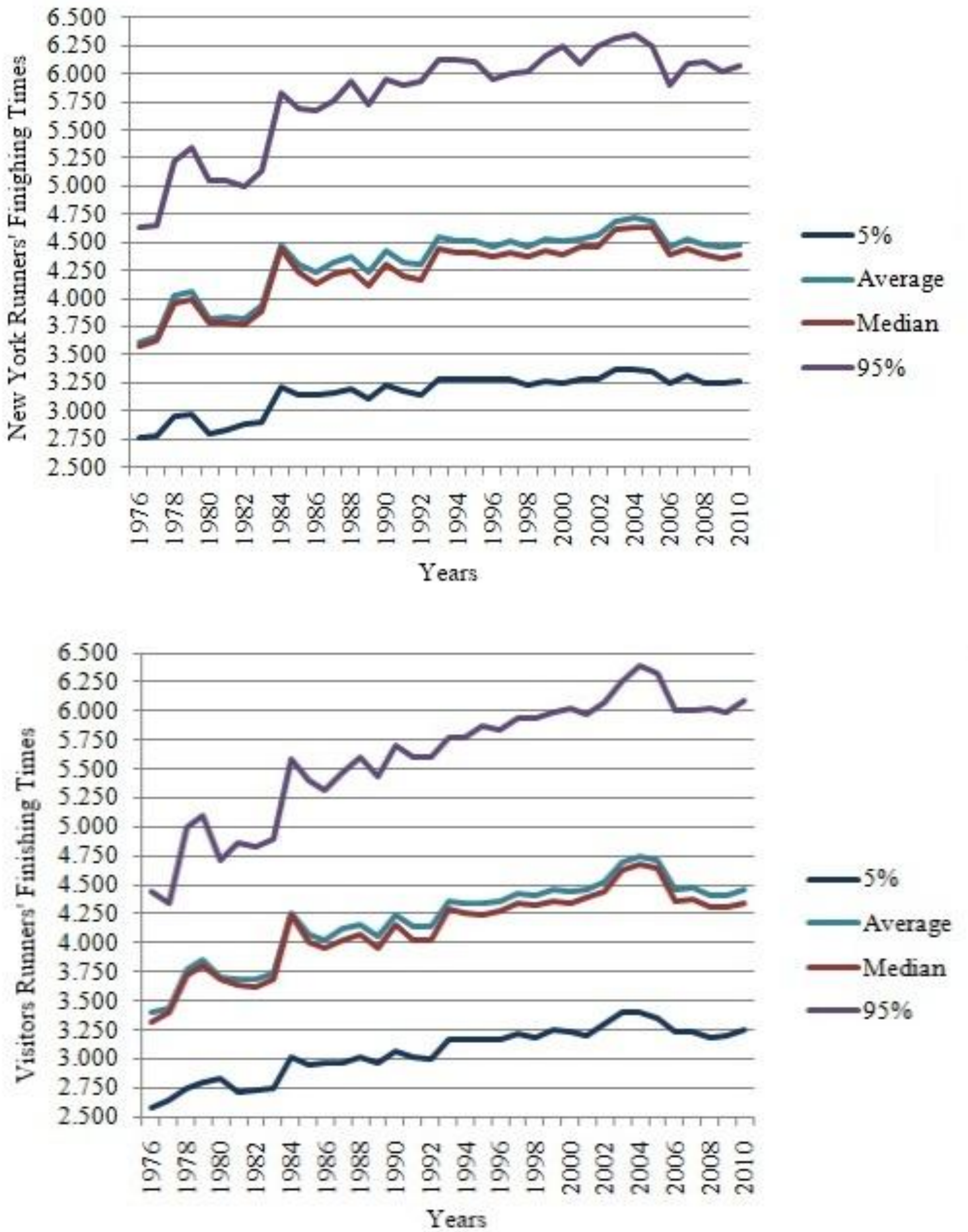


Fig. 15 The runners' finishing times, both locals (top) and visitors (bottom) for the New York City Marathon for the years 1976 to 2010 (Data available online at http://www.ingnycmarathon.org/).

The trend in runners' finishing times can lead to a masking effect when a correlation test is being performed. The trend within the data could be significant enough to diminish or mask the correlation between the meteorological variables and the finishing times. Therefore, I performed a simple regression analysis on the finishing times for the "locals" and "visitors" for each race to calculate the residual values thereby removing the trend. The residual values are the difference between the predicted value and the observed values, in other words the distance between the plotted value and the trend line. A simple linear regression analysis calculates the residual values (Y) by using equation 4.3, where β_o is the y-intercept, β_1 is the slope, X_1 is independent variable, time/year, and e is the error value (McKenzie and Golman 2005).

$$y = \beta_o + \beta_1 X_1 + e \tag{4.3}$$

Such a simple linear regression analysis on each of the six races provides the means to determine if the increase in finishing time was significant over the period of time used for this study. The results of the analyses include a regression equation which describes the statistical relationship between the predictors and in the response variable, an adjusted R^2 value, F-value and a *p*-value (Table 16). The regression equation, in this case, describes the race year's influence on the runners' finishing time to predict new observations.

Table 16 Linear regression detrending statistics for the four categories of runners in the six races; New York City Marathon (New York City), Equinox Marathon (Fairbanks, Alaska), California International Marathon (Sacramento, California), LIVESTRONG Austin Marathon, Cincinnati Flying Pig Marathon (Cincinnati, Ohio), and the Ocala Marathon (Ocala, Florida). The bolded p-values highlight races where there was not significant trend in the data.

	Regression Equation	Adjusted R^2	F-Value	*p*-value
New York City Marathon (New York City, New York)				
Locals				
Fifth Percentile	Y = -25.5 + 0.0144 (Year)	.678	72.65	0.000
Average	Y = -43 + 0.0237(Year)	.670	70.14	0.000
Median	Y= -40.9 + 0.0226(Year)	.670	70.04	0.000
Ninety-fifth percentile	Y = -70.8 + 0.0384 (Year)	.685	75.07	0.000
Visitors				
Fifth Percentile	Y = -36.4 + 0.0198 (Year)	.825	160.81	0.000
Average	Y = --56.8 + 0.0306 (Year)	.788	127.55	0.000
Median	Y= -54.1 + 0.0292(Year)	.762	110.10	0.000
Ninety-fifth percentile	Y = -88.7 + 0.0473 (Year)	.822	157.77	0.000
Equinox Marathon (Fairbanks, Alaska)				
Locals				
Fifth Percentile	Y = -24.1 + 0.0138(Year)	.666	56.76	0.000
Average	Y = -68.8 + 0.037 (Year)	.745	82.83	0.000
Median	Y = -54.9 + 0.0300(Year)	.746	83.11	0.000
Ninety-fifth percentile	Y = -158 + 0.0830 (Year)	.682	61.11	0.000
Visitors				
Fifth Percentile	Y = -21.1 +0.0124 (Year)	.144	5.69	0.024
Average	Y = -88.8+0.0470 (Year)	.457	24.55	0.000
Median	Y = -71.3 +0.0382 (Year)	.301	13.07	0.001
Ninety-fifth percentile	Y = -189 +0.0982 (Year)	.510	30.31	0.000
California International Marathon (Sacramento, California)				
Locals				
Fifth Percentile	Y = -33.7 + 0.0184 (Year)	.840	142.32	0.000
Average	Y = -55.5 + 0.0298 (Year)	.854	158.70	0.000
Median	Y= -48.2 + 0.0261 (Year)	.806	113.37	0.000
Ninety-fifth percentile	Y = -94.8 + 0.051 (Year)	.872	185.00	0.000
Visitors				
Fifth Percentile	Y = -36.6 +0.0196 (Year)	.627	46.32	0.000
Average	Y =-51.7 +0.0227 (Year)	.722	70.97	0.000
Median	Y= -48.8 + 0.0263(Year)	.717	69.49	0.000
Ninety-fifth percentile	Y = -82.5 +0.0438 (Year)	.754	83.81	0.000
LIVESTRONG Austin Marathon (Austin, Texas)				
Locals				
Fifth Percentile	Y= -23.6 + 0.0179 (Year)	.6310	16.42	0.004
Average	Y = -70.3 + 0.0373(Year)	.6010	14.57	0.005
Median	Y = -47.1 + 0.0257(Year)	.4950	9.81	0.014
Ninety-fifth percentile	Y = -91.5 + 0.0487(Year)	.3250	5.33	0.050
Visitors				
Fifth Percentile	Y=-83.1 +0.0429 (Year)	.540	11.55	0.009
Average	Y = -76.4 +.0401(Year)	.846	50.38	0.000
Median	Y = -62.6 +0.0332 (Year)	.665	18.86	0.002
Ninety-fifth percentile	Y = -108+0.0567(Year)	.445	8.21	0.021
Cincinnati Flying Pig Marathon (Cincinnati, Ohio)				
Locals				
Fifth Percentile	Y = -7.58 + 0.00544(Year)	.900	1.79	**0.223**
Average	Y = -12.2 + 0.0084(Year)	.000	0.27	**0.617**

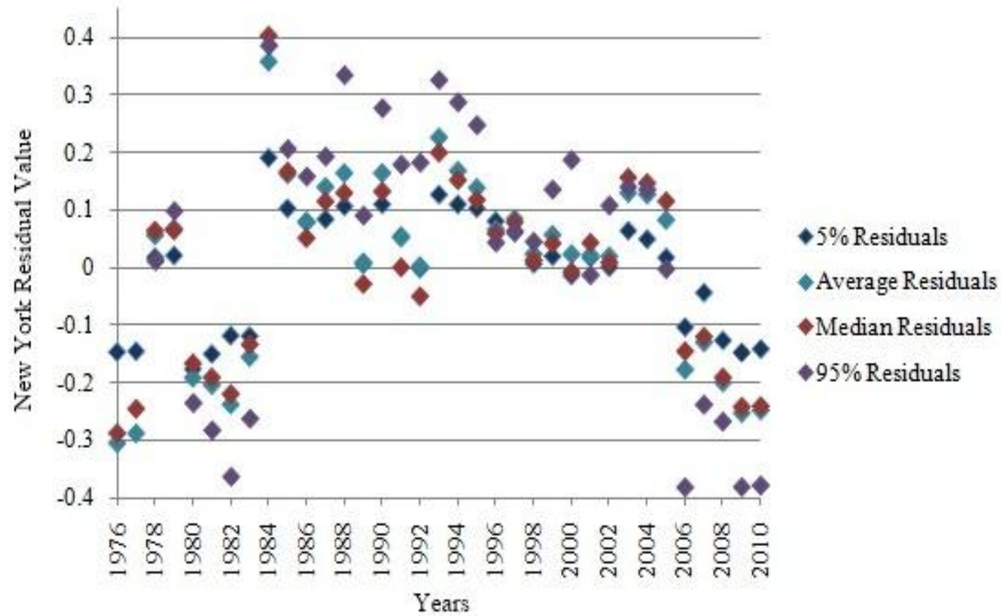
Table 16 (continued)

Median	Y = -3.6 + 0.004 (Year)	.000	0.12	**0.740**
Ninety-fifth percentile	Y = -77.0.0417(Year)	.000	0.57	**0.476**
Visitors				
Fifth Percentile	Y = -5.48 + 0.00439 (Year)	.126	2.16	**0.185**
Average	Y = -35 + 0.0197 (Year)	.316	4.69	**0.067**
Median	Y = -24.3 + 0.0143 (Year)	.346	5.28	**0.055**
Ninety-fifth percentile	Y = -95.1 +0.0505 (Year)	.161	2.54	**0.155**
Ocala Marathon (Ocala, Florida)				
Locals				
Fifth Percentile	Y =-44.7 + 0.024(Year)	.350	5.84	0.042
Average	Y =-66.4 + 00353(Year)	.870	61.43	0.000
Median	Y= -79.9 + 0.042(Year)	.785	33.92	0.000
Ninety-fifth percentile	Y = -51.7 + 0.0286(Year)	.357	5.99	0.040
Visitors				
Fifth Percentile	Y =-24.9 +0.014(Year)	.080	1.07	**0.330**
Average	Y =-20.5 + 0.0124(Year)	.000	0.26	**0.627**
Median	Y= -57.1 + 0.0306(Year)	.750	1.73	**0.224**
Ninety-fifth percentile	Y = 65.4 - 0.0297 (Year)	.000	0.44	**0.528**

The R^2 value identifies the amount of variance explained by the predictor and the *p*-value identifies the significance of the explained variance. The significance value I selected for the simple linear regression test was the ninety-ninth per cent confidence level ($\alpha = 0.050$). As shown in Table 16, the Cincinnati Flying Pig Marathon local runners and the visitor runners at the Ocala Marathon (Ocala, Florida) did not show a significant increase in finishing for the years used for this study.

In contrast, several of the other races showed substantial variance explained based on the year. The New York City Marathon displays greater than sixty per cent explained variance for both the locals and the visitors due to the year, while the Equinox Marathon (Fairbanks, Alaska) shows sixty to sixty five per cent explained variance in finishing time for the local runners. The visiting runners display a wide range of variance in finishing time with the fifth percentile showing the least at fourteen per cent, while the ninety-fifth percentile having fifty one per cent of the variance explained by the year. The California International Marathon (Sacramento California) runners, again both local and visiting, have a range of sixty two to eighty seven per cent of the variance in finishing time explained by the year. The three long term races seem to be more impacted by the passing of time than the other three newer races, as the data for the older races include the years prior to and following the running boom in the 1970s.

The other three races, except for the Cincinnati Flying Pig Marathon have less explained variance over the period of time beginning in 2000, with the LIVESTRONG Austin Marathon (Austin, Texas)resulting in thirty to eighty per cent of the variance explained and the locals running the Ocala Marathon (Ocala, Florida) displaying thirty five to eighty seven per cent explained variance in finishing times. The significance value used for the simple linear regression test was to the ninety-ninth per cent confidence level. As an example of the completed simple regression analysis, figure 16 displays the plotted residual values for the New York City Marathon locals and visitors, showing the trend has been removed from the data. The detrended data for the other races can be found in Appendix C.



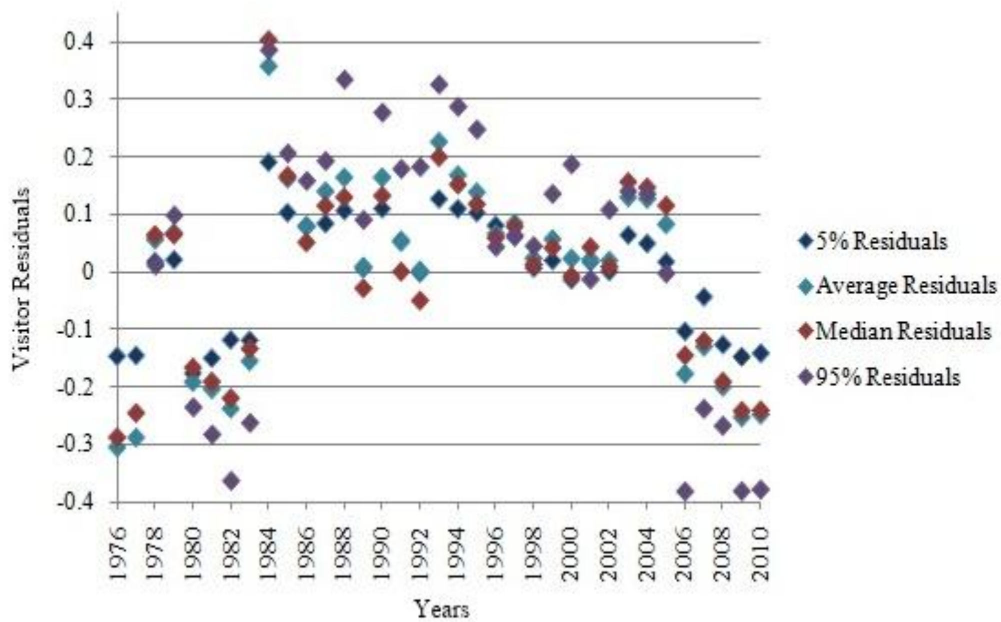


Fig. 16 Example of the detrending process: the residual values of the racer's finishing times, both locals (top) and visitors (bottom), for the New York City Marathon from 1976 to 2010 after linear detrending as a function of the year of the race.

c. Data standardization through a z-score analysis

In order to determine the impact of the meteorological conditions on the finishing times of the racers the values for both the five days leading up to the race and the day of the race must be standardized to allow for comparison. To standardize the values I computed the z-score for each meteorological value. The z-score for each value is found by using equation 4.4 (McKenzie and Golman 2005) where X is the value to normalize, μ is the mean of the distribution, and σ is the standard deviation of the distribution.

$$z = \frac{x - \mu}{\sigma} \tag{4.4}$$

The returned values are the difference between the standardized z-scores for the five days prior to the race and the race day for each meteorological variable. Since I am only concerned with the adjustment or lack of adjustment from baseline to race day results, I used the absolute value of the difference, which measures the magnitude of difference between the baseline and race day values, rather than the actual difference. Ranking the differences for each variable provides the discrimination for largest versus smallest differences in ambient weather conditions experienced by the racers. This procedure was completed for each of the six races resulting in a matrix similar to that of Table 17.

Table 17 The ranked results of the standardized differences between the baseline (average of five days prior) and the actual race day conditions, Δ (xb-xr) is the difference for a given meteorological variable or index between the baseline (average of the previous five days) and the race day conditions for the wind speed, temperature, and dew point temperature conditions for New York City.

The years were divided into quartiles with the first quartile (bolded) determined as the race days most similar to prior conditions and the last quartile (bolded) determined as the race days most different to the prior conditions.

Δ (x_b-x_r) year	z wind speed	Δ (x_b-x_r) **year**	z temp	Δ (x_b-x_r) **year**	z dew pt
1983	**0.025**	**1987**	**0.018**	**1991**	**0.069**
1998	**0.027**	**1991**	**0.024**	**1987**	**0.075**
1977	**0.029**	**1979**	**0.127**	**1983**	**0.080**
1985	**0.051**	**2001**	**0.155**	**2000**	**0.139**
1982	**0.107**	**2007**	**0.235**	**1984**	**0.173**
1997	**0.159**	**1977**	**0.237**	**1980**	**0.193**
1978	**0.261**	**2000**	**0.276**	**2010**	**0.240**
1999	**0.271**	**1976**	**0.294**	**1998**	**0.247**
2002	0.315	1983	0.319	2003	0.340
2003	0.363	1998	0.347	2004	0.397
2007	0.422	2009	0.426	1976	0.523
2001	0.458	2005	0.519	2008	0.542
1984	0.483	1995	0.589	1981	0.551
1986	0.529	1986	0.681	1999	0.557
1990	0.530	1999	0.701	1996	0.559
1996	0.548	2008	0.730	1986	0.570
1988	0.590	2004	0.782	2002	0.572
2005	0.752	1985	0.787	1994	0.589
2009	0.758	1981	0.804	2007	0.590
1994	0.796	1980	0.806	1990	0.661
1981	0.960	1997	0.839	2001	0.709
1989	1.050	1988	0.858	1992	0.714
2004	1.055	1989	0.925	2006	0.757
1993	1.057	2010	0.936	1982	0.977
2000	1.139	2002	1.045	1989	0.992
2010	1.309	1982	1.046	1995	1.101
1992	1.339	1993	1.056	1977	1.108
1995	**1.370**	**1992**	**1.061**	**1988**	**1.142**
2008	**1.384**	**1978**	**1.163**	**2005**	**1.177**
1980	**1.442**	**2006**	**1.231**	**2009**	**1.222**
2006	**1.490**	**1994**	**1.274**	**1985**	**1.361**
1987	**1.631**	**1984**	**1.416**	**1978**	**1.410**
1991	**1.673**	**2003**	**1.419**	**1997**	**1.492**
1976	**2.367**	**1996**	**1.609**	**1979**	**2.151**
1979	**2.402**	**1990**	**1.694**	**1993**	**2.374**

I then classified the ranked values into quartiles, with the first quartile marking smallest absolute difference between race day and the baseline conditions (e.g., the race day conditions are most similar to the previous five days) and the last quartile marking the largest differences between the two (e.g., the race day conditions most different from the previous five days). The quartile system was used on each data set and those tables as well as the rest of the variables from the New York City data can be found in appendix D. Table 18 shows the number of races in each quartile for each marathon.

Table 18 The number of total years of data impacted the number of years placed in each quartile. The number ranged from eight for the New York City Marathon to two for the Cincinnati Flying Pig Marathon which only has eight years of data available.

	Total Years	First Quartile	Fourth Quartile
New York City Marathon (New York City, New York)	35	8	8
Equinox Marathon (Fairbanks, Alaska)	28	7	7
California International Marathon (Sacramento, California)	28	7	7
LIVESTRONG Austin Marathon (Austin, Texas)	10	3	3
Cincinnati Flying Pig Marathon (Cincinnati, Ohio)	8	3*	3*
Ocala Marathon (Ocala, Florida)	10	3	3

*Cincinnati Flying Pig Marathon broken into tercials due to a smaller sample size

Once the difference data were ranked, the finishing time data for both the locals and the visitors were added into the matrix, resulting in a matrix each for both the locals and the visitors for each race (Table 19).

Table 19 Example of the first, most similar, and last, most different, quartile z-scores for wind speed recorded given marathon race, the New York City Marathon (New York City, New York), with the local runners' finishing times(segregated by fifth percentile, average, median, ninety-fifth percentile).

Small Δ (x_b-x_r)	5%	Average	Median	95%	z wind speed
1983	-0.1182	-0.1560	-0.1332	-0.2633	0.0252
1998	0.0068	0.0225	0.0128	0.0450	0.0269
1977	-0.1443	-0.2889	-0.2448	-0.5276	0.0293
1985	0.1025	0.1611	0.1668	0.2064	0.0511
1982	-0.1174	-0.2385	-0.2191	-0.3641	0.1068
1997	0.0603	0.0838	0.0788	0.0634	0.1590
1978	0.0176	0.0554	0.0642	0.0114	0.2610
1999	0.0196	0.0559	0.0422	0.1357	0.2706
Large Δ (x_b-x_r)					
1995	0.1025	0.1375	0.1179	0.2479	1.3698
2008	-0.1256	-0.2006	-0.1904	-0.2682	1.3843
1980	-0.1754	-0.1923	-0.1660	-0.2360	1.4417
2006	-0.1028	-0.1782	-0.1448	-0.3827	1.4895
1987	0.0839	0.1389	0.1150	0.1931	1.6308
1991	0.0545	0.0513	0.0007	0.1791	1.6732
1976	-0.1458	-0.3061	-0.2872	-0.4977	2.3673
1979	0.0213	0.0668	0.0649	0.0984	2.4022

Consequently, I constructed a set of twelve matrices, two for each race with one each for the local and visiting participants. These matrices were then used for the correlation analysis that will be discussed in the next section.

c. Pearson's Product-Moment Correlation Analysis

A Pearson's product-moment correlation analysis is a test that measures the linear association between two variables or the variance between "X" and "Y" (McKenzie and Golman 2005). The degree of linearity between the variables is given as the Pearson product-moment coefficient, 'r', which can range from +1 to -1. Such a correlation requires data that are normally distributed as it is parametric statistical test (Edmon 1985). A similar study by the author used such an analysis (DeBiasse 2008).

Given the assumption of normality for the data, a Pearson product-moment coefficient of zero indicates no linear relationship, while a value of +1 represent a perfect direct relationship and a value of -1 indicates a perfect inverse relationship. Equation 4.5 calculates the Pearson product-moment coefficient where X is the mean of the first variable, Y is the mean of the second variable, σ_x and σ_y are the standard deviations of each variable and n is the sample size (McKenzie and Golman 2005).

$$r = \frac{\sum_{i=1}^{n} (X_i - X)(Y_i - Y)}{(n-1)\sigma_x \sigma_y} \tag{4.5}$$

From the Pearson product-moment coefficient and the n-size of the sample, a significance value or *p*-value can be calculated to measure the significance of the correlation between the two variables (McKenzie and Golman 2005). The smaller the *p*-value the more significant the correlation, or the smaller the probability of error in rejecting the null hypothesis that the variables are not related.

For this study those values with the highest and lowest z-score values for each meteorological variable and index were correlated with each of the race categories for both of the two race groups, the locals and the visitors. This correlation will determine when the runners' finishing times are most impacted by the meteorological variables by assessing when the conditions are similar or different on race day compared to the days leading up to the race. The values with the lowest z-score are the days with the smallest change in each meteorological variable or each index between the baseline conditions (the average of five days leading up to the race and race day. The largest z-score values represent the days with the largest change in conditions between the five days prior to the race and race day which should represent conditions moving away from the conditions the locals are acclimated to therefore impacting their finishing times.

First, I will present and discuss the correlations for each group of runners, fifth percentile, the average, the median, and the ninety-fifth percentile with similar and different conditions by locals and visitors. By determining the correlation values for each speed group for the locals and visitors, I will be able to determine which meteorological variables impact the finishing times of the runners. Additionally, comparing the significance of similar and differing race day conditions from the baseline conditions will suggest the implication of acclimation.

Second, I will compare the race times of locals and visitors for a small change in weather conditions. Comparing the locals and visitors under similar conditions will also show a level of acclimation. If the locals are more significantly impacted by the similar conditions it can suggest how important acclimation is to the local runners. For each race, I identified the variables that had greatest significance, change in correlation relationship or change in significance of the variable from the small change in conditions to a large change in conditions or local and visitors. These findings will be presented for each race below.

i. New York City Marathon (New York City, New York)

The Pearson product-moment correlation values for the New York City Marathon between the baseline conditions (average of the five days prior to the race) and the race day did not return any statistically significant values for any of the meteorological variables or indices. However, there were several variables that displayed a marked or consistent difference in significance or a change in the correlation relationship. For example, the heat index showed a consistent positive correlation between the runners' times for baseline and race day conditions suggesting the higher the heat index value, the slower the racer's finish time or the lower the heat index values the faster the finishing time for the participants.

Importantly, when the heat index remained close to the value that was calculated for the previous five days, the heat index value was not significant when determining the finishing time. However, when the heat index value for the race day was markedly different from the five day values, the significance value for the correlation dropped considerably, especially when referencing the slower runners, those within the ninety-fifth percentile (Table 20). While correlations were not statistically significant, the increase in the *p*-values does suggest that if the heat index value changes largely from the conditions leading up to the race, local runners may see a corresponding impact in their time.

Table 20 Correlation values for the New York City Marathon (New York City, New York) here Δ (xb-xr) is the difference for a given meteorological variable or index between the baseline (average of the previous five days) and the race day conditions, segregated by the speed of the runners into four categories; fifth percentile, average, median and ninety-fifth percentile. (A negative relationship suggests as the value decreases the finishing time increase (slower finishing times) and a positive relationship suggest as the value increases the finishing time increases (slower finishing times)). Significant correlations are bolded.

New York City Marathon Locals	0.05	Average	Median	0.95
Heat Index				
Small Δ (HI_b-HI_r)				
r value	0.137	0.075	0.056	0.007
p-value	0.746	0.859	0.895	0.986
Large Δ (HI_b-HI_r)				
r value	0.597	0.666	0.672	-0.552
p-value	**0.118**	**0.071**	**0.068**	**0.156**

New York City Marathon Visitors	0.05	Average	Median	0.95
Heat Index				
Small Δ (HI_b-HI_r)				
r value	0.034	0.046	0.011	0.110
p-value	0.937	0.913	0.980	0.796
Large Δ (HI_b-HI_r)				
r value	0.809	0.794	0.837	0.338
p-value	**0.015**	**0.019**	**0.010**	**0.413**
Wet bulb Globe Temperature				
Small ($WBGT_b$-$WBGT_r$)				
r value	-0.033	-0.028	-0.016	-0.050
p-value	0.938	0.948	0.970	0.906
Large ($WBGT_b$-$WBGT_r$)				
r value	0.513	0.635	0.690	0.645
p-value	**0.193**	**0.091**	**0.058**	**0.084**

The fact that the heat index appears to be an important factor in this correlation analysis where average race day temperatures are 54°F(12°C) calls into question its previous limiting use for temperatures exclusively above 80°F (US Heat Stress Index 2011). It has been reported that when a body is running muscles can generate at least eleven times more heat than muscles at rest (Spellman 1996). This may be the reason that the heat index appears important when related to marathon finishing times even though the temperature is not at or above the 80°F threshold. Heat generated by the body may actually make up for the difference in ambient temperature when evaluating a person's personal comfort. Additionally, the heat index includes both temperature and humidity values in its calculation (see chapter 2g).

Prior acclimation studies (e.g., Hanna 1999; Morris et al. 2005; Hue et al. 2007) and heat stress studies (e.g., Steadman 1979; Segal and Pielke 1981) have determined the importance of the interaction of these two variables. In acclimation studies, hot dry conditions have been found to be easier to adapt to, as in they typically take less time and exposure, compared to hot wet conditions. Consequently, the heat index may be a possible gauge of acclimation. However, an increase in the heat index, can be determined by either an increase in temperature or atmospheric moisture. It may be the case that if the temperature value dominates the heat index equation rather than a moisture variable, the locals runners are able to continue to perform at a higher performance level given evaporative cooling. However, if the heat index is dominated by the moisture characteristic, the local participants may find themselves feeling the impact of a decreased ability to evaporate sweat.

The visitor group returned similar results to the local group for the correlation test involving meteorological variables between baseline and race day conditions, with both the relationship between the variables and significance with the heat index and the wet bulb globe temperature. In the two cases the visiting racers were more significantly impacted when there was a large change in value from the average of the five days prior to the race to race day. This may suggest that conditions changed in favor of the "visitor" running group's training conditions thereby decreasing their race time. However the opposite could be true, if race day conditions moved further away from the visitors' training or acclimation conditions, thereby increasing their race times.

The correlation results for the visitors' group for the heat index value for large and small differences between baseline and race conditions again showed a positive relationship between the heat index value and finishing times for each race category (higher heat index values = slower finishing times). This suggests that, for the visitors, as the heat index value increased, their finishing times increased (i.e., greater heat = slower times). This relationship supports the idea that increased values of temperature and humidity would impact the runners, supported by previous research (e.g., Hanna 1999; Morris et al. 2005; Hue et al. 2007). Many runners preparing for a marathon will start training anywhere from a year to four months prior to the race (Marathon Training 2011) and will thereby acclimate their running patterns to warmer summertime conditions; however those conditions may be less humid than the conditions they experience on race day

Lastly, the visitors recorded a higher significance on finishing times when there was a large change in the wet bulb globe temperature (WBGT) between the baseline and race day conditions. If there was a small change between the previous five days and race day, a higher WBGT value resulted in a faster time for the visitor runners and vice versa (increased WBGT = increased finishing times and decreased WBGT = decreased finishing times). If there was a large change between baseline and race day conditions, the relationship between WBGT and the finishing time was positive for all racers (hotter WBGT temperatures = slower finish times).

The wet bulb globe temperature, like the heat index, includes both temperature and moisture as variables. As discussed previously, when viewing more than one variable in the calculation of the index, one variable may be more dominant than another and thus play a more significant role. While the WBGT typically uses the black globe thermometer in its calculation to incorporate radiation, the approximation most commonly used (and employed in this study) does not. The military uses the WBGT index to determine the level of activity of its trainees they have tested, and they have found the more physically fit that a cadet is coming into training, the less that cadet is impacted by a higher WBGT (Minard 1965; Ely et al. 2007). This finding is reflected by the significance values found in this study's correlation between WBGT and race times for differences between baseline and race day conditions (Table 20). The fastest runners have the lowest significance value between race times and WBGT under both big and small changes in race day to baseline conditions, suggesting, as the military has found, more physically fit participants are less affected by a higher WBGT.

The New York City Marathon is a race that takes prides in including participants of all levels and from all around the world. With that in mind, the visitors in this race come from a variety of climate backgrounds. This even includes some racers that are coming out of winter training locations from the southern hemisphere. With such a wide variety of likely training conditions, less conclusive evidence of acclimation is found when viewing the time results of visitors for large and small differences between race day and local baseline conditions. In other words, the huge variety of training potential may in the end obscure the acclimation impacts of not being from that area.

Additionally, a race of this size would have people around the world training in conditions very similar to those that live in New York. It would be difficult to identify those runners if their training locations were outside of the United States. Therefore, when comparing the correlations in weather conditions for the locals and visitors when there is only a small change between the race day conditions and those of the five days prior the race day, none of the variables prove to have any bearing significant or otherwise on the finishing times between the two groups. Additionally, no particular variables for the locals and visitors participating in the NYC Marathon showed a dominate direction of change (Table 21). This suggests that the change in the values is increasing or decreasing over the years viewed.

Table 21 Directional differences in z-score values where Δ (xb-xr) is the difference in a given meteorological variable between the pre-existing five-day baseline conditions and the actual race day conditions.

New York City Marathon	Small Δ (x_b-x_r)		Large Δ (x_b-x_r)	
	Positive years	Negative years	Positive years	Negative years
Variable				
Heat Index	5	3	5	3
Wet Bulb Globe Temperature	3	5	4	4

Results from the New York City Marathon do lead to some inferences concerning acclimation. First, the local runners were less significantly impacted by small changes between baseline and race day conditions compared to a larger change, thereby supporting one of my hypotheses that locals will be most impacted when the weather conditions largely differ from the baseline conditions. This suggests that, as weather conditions vary between baseline and race day, local racers are acclimated to the baseline conditions by their training, and therefore the local runners do see an impact on their performance on race day when the race day is significantly different from their baseline.

More surprisingly, the visitors are also impacted more considerably when the race conditions vary greatly from the average conditions of the five days leading up to the race. Many visiting runners will arrive to the race location anywhere from five days to the day before the race. The New York City Marathon, being one of the most prestigious and largest races, holds many events through the week leading up to the race including speakers and seminars on running (NYCM 2010). While visiting runners may have a few shorter distance runs within the environment leading up to the race, many acclimation studies show that five days is not enough time to fully acclimate to all types of conditions (e.g., Maughan et al. 1997; Hue et al. 2004; Carter et al. 2005,). As such, meteorological variables differing on the race day from the baseline conditions may suggest conditions that are similar to the visiting runners' training and acclimation conditions. When the conditions more greatly vary from the baseline conditions of the five days prior to the race day, the visitors are again more significantly impacted. This may be the case as the conditions may shift in favor to the training conditions or the type of conditions those participants are acclimated to. However, it is also possible that in some cases, the shift in conditions may move even further from the participants' training conditions. As the race is held in the fall, many runners have trained during the summer months and for many visitors this could include warm, moist conditions that have been found to be more difficult to acclimate to than warm dry conditions (Armstrong et al. 1987; Kenney et al. 2004). Additionally, if conditions are similar to the baseline conditions this may be further indication that five days is not long enough to acclimate to particular types of conditions, specifically warm wet (Hue et al. 2004).

ii. Equinox Marathon (Fairbanks, Alaska)

The Equinox Marathon hosted in Fairbanks, Alaska is held each year in September. Therefore, like those racers taking part in the New York City Marathon, the runners planning on participating in this Alaska race typically begin training during the summer months. With respect to the local participants, this actually means training in weather conditions that may be more similar to fall and spring conditions throughout the majority of the continental United States. For example, summer temperatures in Alaska remain cooler than those recorded in most of the continental United States; the average maximum temperature recorded during the summer is between 70°F and 80°F. The correlation analysis of weather variables and indices for large and small differences between the baseline (average of five-day prior to race) and race day conditions returned results suggesting that the dew point temperature, wind chill index, apparent temperature and the wind chill equivalent temperature were most important as impacting finishing times for the local competitors. However, the relationship was not statistically significant in all cases (Table 22).

Table 22 Correlation values for the Equinox Marathon (Fairbanks, Alaska) where Δ (xb-xr) is the difference for a given meteorological variable or index between the baseline (average of the previous five days) and the race day conditions, segregated by the speed of the runners into four categories; fifth percentile, average, median and ninety-fifth percentile. Significant values are bolded.

Equinox Marathon (Fairbanks, Alaska) Locals	0.05	Average	Median	0.95
Dew Point Temperature				
Small Δ (Td_b-Td_r)				
r value	-0.829	-0.956	-0.988	-0.974
p –value	**0.021**	**0.001**	**0.000**	**0.000**
Large Δ (Td_b-Td_r)				
r value	0.359	-0.582	-0.690	-0.678
p-value	0.429	0.171	0.086	0.094
Wind Chill Index				
Small Δ (WCI_b-WCI_r)				
r value	0.222	0.699	0.539	0.824
p-value	0.632	0.081	0.212	0.023
Large Δ (WCI_b-WCI_r)				
r value	0.453	-0.685	-0.683	-0.76
p-value	0.307	0.09	0.091	0.047
Apparent Temperature				
Small Δ (AT_b-AT_r)				
r value	0.752	0.904	0.800	0.861
p-value	**0.051**	**0.005**	**0.031**	**0.013**
Large Δ (At_b-At_r)				
r value	0.117	-0.0142	-0.180	-0.136
p-value	0.803	0.761	0.699	0.772
Wind chill Equivalent Temperature				
Small Δ (WET_b-WET_r)				
r value	0.739	0.844	0.728	0.879
p-value	**0.058**	**0.017**	**0.064**	**0.009**

Table 22 (continued)

Large Δ (WET_b-WET_r)				
r value	0.049	-0.219	-0.311	-0.164
p-value	0.917	0.637	0.498	0.725
Equinox Marathon Visitors				
	0.05	Average	Median	0.95
Pressure				
Small Δ (P_b-P_r)				
r value	-0.581	-0.348	-0.350	-0.136
p-value	**0.171**	0.444	0.442	0.771
Large Δ (P_b-P_r)				
r value	0.133	0.726	0.622	0.808
p-value	0.777	**0.065**	**0.136**	**0.028**
Saturation Vapor Pressure				
Small Δ (vp_b-vp_r)				
r value	0.429	0.564	0.381	0.775
p-value	0.337	0.188	0.399	0.041
Large Δ (vp_b-vp_r)				
r value	-0.142	-0.284	-0.749	-0.011
p-value	0.761	0.536	0.053	0.982
Wind Chill Index				
Small Δ (WCI_b-WCI_r)				
r value	-0.269	-0.092	-0.198	0.010
p-value	0.560	0.845	0.670	0.983
Large Δ (WCI_b-WCI_r)				
r value	0.362	-0.161	-0.316	-0.331
p-value	0.425	0.731	0.490	0.468

The dew point temperature for local runners was statistically significant for all race groups when the dew point value on race day remained similar to the baseline conditions (average of the five days leading up to the race). The relationship between race finishing time and dew point temperature was an inverse relationship suggesting that, as dew point increased, the racers' finishing time decreased (i.e., faster finishing time) and as dew point decreased race time increased (slower finishing time). Given that the locals are most likely to be acclimated to the baseline conditions, this result initially appears to indicate a contradictory acclimation effect. However, while acclimation studies typically discuss the role of moisture in the atmosphere when discussing increased temperatures (Hue et al. 2004; Kenefick 2009), they do not typically mention atmospheric humidity when discussing cold weather acclimation. Cold air masses can be very dry due to the capacity for cold air to hold less moisture than warm air (Pidwirny and Jones 1999). This seemingly counterintuitive inverse relationship may suggest that further drying of the atmosphere may actually make the runners feel uncomfortable as it may cause drying of their airways and make it more difficult to breathe.

When the dew point temperature changed more significantly from the baseline conditions to the race day, the relationships between the two variables were less significant for all four race groups of the local runners. All weather variables remained inversely related for the average, median and ninety fifth percentile groups, while being positively related for the fastest runners (higher heat index values = slower finishing times). This would be the expectation of acclimation differences: the less proficient local runners should be more (and negatively) impacted by differences between the baseline and race conditions. The positive, more counterintuitive, relationship recorded for the fastest runners may relate to the pace they are moving. When running the body can produce eleven times more heat as it does when the body is at rest (Spellman 1996). As such, the fastest runners may benefit from lower humidity values when there is a large change in baseline conditions to the race day in terms of evaporative cooling. Additionally, if the dew point temperature increases a large amount between race day and the baseline values, the fastest runners may feel as though the atmosphere is too moist and more humid than they are accustomed to running in and acclimated to.

For the Alaskan marathon, the differences in race times as a function of the wind chill index were more significant to the locals when the race day conditions was more similar to the previous conditions. When the race day wind chill value was more similar to the baseline conditions, all runners experienced a positive relationship between the wind chill and their finishing times, suggesting the higher the wind chill, the slower the finishing time or the cooler the wind chill, the faster the finishing time. As such this shows that the locals are acclimated to cooler conditions and as the wind chill index increases the racers are impacted by the warmer/calm conditions. Just as a move from warm to hot conditions would impact runners, a move from cooler to warmed conditions can also decrease performance (Maxwell et al. 1996).

When there was a large change in the wind chill value between baseline and race day conditions, the fastest runners of the locals group continued to have a positive relationship (larger wind chill = slower finishing times), while the other groups of local runners recorded an inverse relationship between their times and the wind chill (larger wind chill = faster finishing times). The positive relationship suggests that training in cooler conditions prepares the local runners to run in cooler conditions even if the local runners are colder on race day than what they are acclimated to. This is evident in data from other acclimation studies (Hanna 1999). Further support for this relationship can be seen when viewing the breakdown of years where the wind chill was most similar, as in five out of seven years that value increased in the positive direction suggesting warming (Table 23).

Table 23 Directional differences in z-score values where Δ (xb-xr) is the difference in a given meteorological variable between the pre-existing five-day baseline conditions and the actual race day conditions.

Equinox Marathon (Fairbanks, Alaska)	Small Δ (x_b-x_r)		Large Δ (x_b-x_r)	
	Positive years	Negative years	Positive years	Negative years
Variable				
Dew Point Temperature	5	2	3	4
Pressure	3	4	3	4
Saturation Vapor Pressure	3	4	3	4
Wind Chill Index	3	4	4	3
Apparent Temperature	4	3	3	4
Wind Chill Equivalent Temperature	6	1	3	4

Many past exercise science studies have not examined acclimation to cooler climates. However, it has been found by Maxwell et al. (1996) that performance of sprinters in cold conditions, after warming up in cold conditions, resulted in a better performance compared to other combinations of temperatures such as warm /cold or warm/warm. Again, this suggests that the local runners in Alaska are better acclimatized to cooler conditions and, when conditions may increase even slightly, they may become uncomfortable and therefore those conditions will adversely impact their finishing times.

For the slower local groups (the remaining three groups; average, median, and ninety-fifth percentile), the relationship between the wind chill and the finishing times becomes an inverse relationship when the wind chill undergoes a large change from the baseline conditions to race day. This suggests that there is a threshold point in training such that the slower runners will actually be positively impacted by a large drop in the wind chill. The explanation for this may go back to work done by Spellman (1996), who found that runners who slowed or even stopped during the race increased their risk to hypothermia. The physical reasoning of such an increased risk is that the heat production in the body decreases although heat loss continues at a high rate. With the cooler temperatures and higher wind speeds, runners may find themselves feeling cooler although they are participating in a physically demanding event.

For the local runners, the apparent temperature, which is a combination of temperature and humidity values, returned similar correlation values as seen with the wind chill index. Again the relationship between race finish times and apparent temperature is positive (i.e., lower apparent temperature = faster race times) when the apparent temperature changes only a small amount between the baseline and race day conditions. There is an inverse relationship between race finish times and apparent temperature for the average, median, and ninety-fifth percentile groups when the apparent temperature changes by a greater extent between the baseline and race day conditions. The physical explanation likely relates to the moisture holding capacity of air (Pidwirny and Jones 1999). In cooler climates, the amount of water vapor in the air, while resulting in a higher relative humidity, may still remain quite low given the temperature. As a result, locals training for the race are better acclimated to the cold—and most likely drier—conditions. If the humidity levels were to increase, the local runners may begin to feel the adverse impacts of the increased moisture in the air as evaporative cooling may decrease. Physiologically, this may be similar to how someone acclimated to warm dry conditions would feel if they ran in warm wet conditions.

The wind chill equivalent temperature (WET) also resulted in similar results compared to wind chill index and apparent temperature. WET, which is very similar to the wind chill index developed by Steadman and Qualye (1998) to better assess the influence on humans, includes temperature and wind speed in its calculation. A small change in WET between the baseline and race day conditions resulted in a more significant correlation between race finish times and WET than when there was a larger change between the baseline and race day conditions. The relationship for all runners with a small race day change from the baseline conditions was a positive relationship (i.e., higher WET values = faster finishing speeds), while with a large change between baseline and race day conditions, the average, median, and ninety-fifth percentile racers demonstrated an inverse relationship (higher WET times = slower finishing times). The same reasoning for the wind chill index would likely be valid for the wind chill equivalent temperature and is again seen by a warming of the WET values in six out of the seven years (Table 24). For the slower runners there appears to be a threshold point at which a change in WET becomes too cold, even for an acclimated population. This may be a factor of clothing worn by the runners as further discussed below.

Many of the visitors running in the Equinox Marathon are typically from states such as Oregon, Washington, and the Canadian Provinces. While these areas may be closer geographically to Alaska than the home states of others runners, these runners are still preparing in conditions and acclimated to conditions that may be much warmer than what they will experience on race day. As a result, the best correlations between race times and meteorological variables highlighted different variables that impacted the visitors compared to the locals. The first variable that resulted in a difference in significance between finishing race times and meteorological variables was the barometric pressure, although only for slower runners (e.g., the average, median, and the ninety-fifth percentile runners). The fastest runners, the fifth percentile, were adversely significantly impacted in their race times when the pressure stayed more consistent between the race day and the five days leading up to the race. This inverse relationship suggests that in cloudier conditions the fastest runners increased their pace (faster finishing time), while when pressure increased, or a clearing of the skies occurred, the race time increased (Ely et al. 2007).

The pressure became more significant on the finishing times of the other runners (average, median, ninety-fifth percentile) when there was a larger change in pressure between race day and the baseline conditions. The relationship between the two variables was negative (faster times = higher pressure) with a small change between baseline and race day conditions for all runners and positive (faster times = lower pressure) with a large race day change from baseline conditions for all runners. This suggests an increase in pressure decreased the finishing times (faster finishing times) and a decrease in pressure increased the finishing times (slower finishing times).

The rationale for such a finding is that pressure may have a psychological impact on the runners, as a higher pressure situation making runners feel warmer as the solar radiation reaching the surface is greater (Ely et al. 2007). Runners may feel that running in cloudier conditions, resulting in more diffuse radiation, makes them feel cooler. Visitors may also be psychologically impacted as more solar radiation reaches the surface and is reflected off the snow cover. Such occurrence is not uncommon for Alaska this time of year. When pressure undergoes a greater change between the days leading up to the race and race day (possible indication of a frontal system passage) consequently resulting in cloudy skies with a clearing following. In these cases an increase in cloud cover after a few clear days may improve a person's mental outlook or the clearing skies may have the same psychological impact if the days leading up to the racer were cloudy.

For visitors, the saturation vapor pressure returned a greater correlated significance to race finishing times when there was a smaller change between baseline and race day conditions, as compared to a larger race day change from baseline conditions. In all groups, a small change between race day and baseline resulted in a positive relationship (higher vapor pressure = faster finishing times), while a large change from baseline to race day resulted in an inverse relationship (higher vapor pressure = slower finishing times) (Table 22). Again, the rationale for these findings relates to basic hydrodynamics. Saturation vapor pressure is indicative of how much water vapor the air can hold (i.e., the Claussis-Clapeyron relationship). Therefore, a positive relationship with saturation vapor pressure suggests the value is increasing and resulting in slower finishing times or decreasing and resulting in faster finishing times. As the saturation vapor pressure increases the amount of moisture the air can hold also increases and if this value increases without the vapor pressure following suit, the runners may feel the impact of drier conditions. A drying of the atmosphere will allow for the evaporation of sweat to cool runners more effectively as the atmosphere is capable of taking in more moisture. As more humid locations are more difficult to acclimate to than dry conditions (Armstrong et al. 1987, Kenney et al. 2004) those acclimated to drier conditions would be less impacted by humid locations if the atmosphere's capacity for water vapor increased.

The last variable capable of discriminating the acclimation effect for the visitors is the wind chill index. While not more or less significant with either a small or large change in value between the days leading up to the race and race day, the change in direction of the relationship of the correlation value is notable. When viewing a smaller change between race day and baseline conditions, I found that, as wind chill increased, the fifth percentile, the average, and the median runners' finishing times decreased and, as wind chill decreased, their finishing time increased. This would suggest that visitors are not as acclimated to local conditions, with regard to wind chill, as the locals and are therefore more sensitive to wind/temperature changes. Additionally, when there is a larger change in the wind chill index between race day and baseline conditions, this relationship changes such that, as wind chill decreases, the finishing time increases (slower finishing times) and, as wind chill increases, the finishing time decreases (faster finishing times).

The ninety-fifth percentile (slowest running group) demonstrates this counterintuitive positive relationship when there is a small change between baseline and race day conditions. A psychological rather than physical explanation can be offered. This seemingly odd result (wind chill increases = slower finishing times) may be a result of what the visitors wear when participating in the race. As many are training in and are acclimated to much warmer conditions they may find themselves overdressed for the race as they are expecting much cooler conditions than that to which they are accustomed. When the wind chill index records a higher value, the participants may find themselves warmer than they anticipated and therefore over dressed. This could impact the body's ability to cool itself, but it may also impact the mobility of a person. Additionally, the slower runners may also find themselves at risk for feeling cold if they slow or stop during the race, as the heat generation within the body decreases.

When comparing the correlations of finish times for locals and the visitors with meteorological variables and indices for similar race day conditions compared to the baseline, the locals resulted in all variables having a more significant impact on finishing times. This would be expected as the locals should be acclimated to those conditions, while the visitors should see a significant impact on their race times when conditions vary from baseline conditions as it would suggest values moving toward the conditions they are acclimated to.

Five variables: temperature, dew point temperature, wind chill index, apparent temperature, and wind chill equivalent temperature all recorded a more significant relationship for the locals compared to the visitors. Some of these relationships were statistically significant, such as the dew point temperature. In terms of temperature, for the local groupings, if temperature increased the race finishing times were faster and if temperature decreased the race time slowed. This relationship holds true for the fastest and median visitors, but is inverse for the average and ninety-fifth percentile visiting runners. While it would seem as though natives to Alaska would prefer running in cooler conditions as that is what they are acclimated to, there may be a temperature that becomes too cool based on other factors such as wind speed or humidity levels. Additionally, clothing and course conditions may be an impact and will be discussed below.

The locals were also more impacted by dew point temperature in comparison to the visitors. Dew point temperature is a measure of humidity in the atmosphere and as such the visitors possibly being acclimated to drier conditions would be more affected by humidity levels that are not similar to the areas where they are running. Again, all local runners' finishing times were inversely influenced by the dew point temperature. The reasoning may again be that the conditions become dry enough to be uncomfortable. The relationship with the dew point is positive for the fastest visiting runners, but remains an inverse relationship for the other visiting runners. Increased moisture in the air may be more comfortable for the visiting runners as they are accustomed to more humid conditions.

Local runners were also more significantly impacted by the wind chill index. Both the locals' and visitors' finishing times were positively impacted by the wind chill index. For the locals this may suggest they are acclimated to a certain set of conditions and if those conditions are warmer or calmer in terms of wind their times will increase (slower finishing times). As temperatures should be warmer in the locations where the locals are training and therefore acclimated to, one would expect that the visitors would show an improvement with a higher wind chill index as it would suggest a move toward their training conditions. However, the positive relationship between the variables may suggest that the visiting runners are overdressed for the race and appreciate the lower temperature and/or increased wind speed. Although a runner may be acclimated to warmer temperatures, overdressing can inhibit heat loss and therefore make the runners uncomfortable. Clothing choices of the runners will be discussed further below as for this particular race it may play a large role in human comfort.

The apparent temperature and wind chill equivalent temperature were also significantly correlated for the locals compared to the visitors. For all racers, excluding the fastest visitors, the relationships between both the apparent temperature and wind chill index and finishing times are positive. Just as with the wind chill index, this suggests that the locals are acclimated to cooler temperatures or windier conditions and if the conditions vary from that their finishing times suffer. As for the visitors the positive relationship again suggests there may be external factors that are playing a role rather than an acclimation factor. The inverse relationship for the fastest visitors suggests that the lower the wind chill equivalent temperature and apparent temperature the slower the finishing times and the higher the wind chill equivalent temperature and apparent temperature the faster the finishing times. When race day conditions move more toward their training conditions the participants' times improve.

Two major external considerations for the Fairbanks Equinox Marathon that may be obscuring or biasing these results are the course conditions and the clothing choice of the runners. This course, as described in Chapter two, is run on a combination of hard surfaces, such as roads, and soft surfaces, such as trails, either of which may be potentially covered in snow. If there happens to be snowfall on the course or if there was a rain event, portions of the trail may be muddy and icy. Additionally, as the participants run on those surfaces, the course may begin to deteriorate, especially as the day progresses. This type of course may especially impact those moving at a slower pace as many people running on the trail will shift rocks or create divots in the mud or soil on parts of the course. If there happens to be snow on the course an increase of temperature during the day may cause the melting of that snow and further deterioration of the running surface.

Dress for this race can also be an obscuring or biasing factor for interpretation of these results with regard to acclimation. The first impact that clothing choice may have is the relative abundance of clothing, e.g., dressing too warmly or wearing not enough clothing. Many people who are not accustomed to Alaskan weather may naively assume it will be cold and not give much consideration to how challenging the course is and how that may impact their body's heat generation. On the other hand, participants may also assume they will generate enough heat while running to keep them from feeling cool, but may not sufficiently consider the elevation change and the wind that they may experience as they climb Ester Dome. It is recommended by the race organizers for participants to dress in many layers, carry extra layers or have a crew to provide extra clothing for that particular part of the course (Equinox Marathon 2011).

Of the six marathon races that are being examined the Equinox Marathon is coldest race, making it probable that most of the visitors are training in significantly warmer conditions (Figure 17)

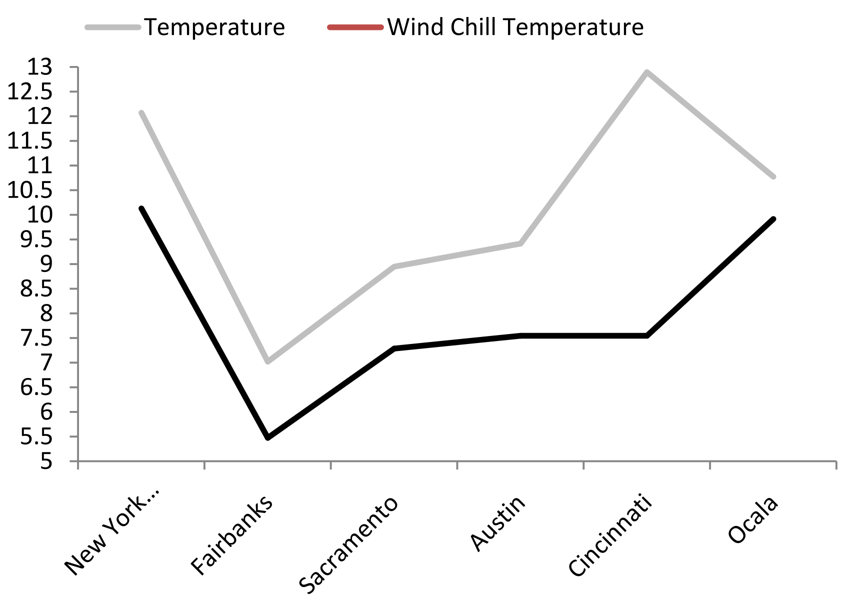


Fig. 17 Average race day and wind chill index temperature temperatures in degrees Celsius, where the y-axis it the temperature and the x-axis is the various races.

This analysis of the Alaskan Marathon suggests that locals participating in this race are more acclimated to colder conditions, even coming out of the summer months, and verifies one of my original hypotheses. As the correlation for race finishing times and weather variables results suggests a smaller change between the various weather conditions of the baseline and race day, dew point temperature, wind chill index, apparent temperature, and wind chill equivalent temperature, have a greater impact on their finishing times than a larger change between the baseline and race day conditions. In this most extreme race of my study set, this relationship supports the hypothesis that when the race day conditions are similar to the training conditions the locals will perform at a higher level as they are acclimated to those types of conditions. The visitors are impacted by different variables: the pressure, saturation vapor pressure and the wind chill index. In the case of pressure, the greater the change from the days leading to the race the more impact it has on the visitor's performance. This supports the idea that, if the visitors are not acclimated to a particular set of conditions, they will perform better if the conditions greatly change as they may move more toward familiar training conditions. When there is a small change in the meteorological conditions even arriving five days prior to the race may not allow enough time for acclimation to occur. Acclimation studies suggest that cold conditions are difficult to acclimatize to and may take as long as six weeks (Hanna 1999).

iii. California International Marathon (Sacramento, California)

The California International Marathon is held each year on the first Saturday of December in Sacramento, California. Many runners preparing for this race may begin training during the summer months and continue into the fall season as temperatures begin to drop. The correlation analysis between race finish times and meteorological variables performed on the four speed categories of local finishers resulted in three variables, specifically wind speed, pressure, and relative humidity, displaying either a change in significance from similar conditions to different conditions, or a change in the direction of the correlation relationship (Table 24).

Table 24 Correlation values for the California International Marathon (Sacramento, California): Δ (xb-xr) is the difference for a given meteorological variable or index between the baseline (average of the previous five days) and the race day conditions, segregated by the speed of the runners into four categories; fifth percentile, average, median and ninety-fifth percentile. Significant values are bolded

California International Marathon Locals	0.05	Average	Median	0.95
Wind Speed				
Small Δ (WS_b-WS_r)				
r value	-0.109	-0.039	-0.087	-0.081
p-value	0.817	0.934	0.853	0.863
Large Δ (WS_b-WS_r)				
r value	-0.643	-0.498	-0.444	-0.591
p-value	**0.119**	**0.255**	**0.318**	**0.162**
Pressure				
Small Δ (P_b-P_r)				
r value	-0.117	-0.167	-0.228	0.066
p-value	0.803	0.720	0.623	0.888
Large Δ (P_b-P_r)				
r value	-0.509	-0.240	-0.445	0.678
p-value	0.243	0.603	0.318	0.094

Table 24 (continued)

Relative Humidity				
Small Δ (RH_b-RH_r)				
r value	0.527	0.488	0.358	-0.042
p-value	0.224	0.267	0.430	0.928
Large Δ (RH_b-RH_r)				
r value	-0.709	-0.941	-0.902	-0.612
p-value	**0.074**	**0.002**	**0.005**	**0.144**
California International Marathon Visitors				
	0.05	Average	Median	0.95
Vapor Pressure				
Small Δ (VP_b-VP_r)				
r value	-0.445	0.078	0.154	0.185
p-value	0.317	0.868	0.741	0.691
Large Δ (VP_b-VP_r)				
r value	-0.659	0.660	0.615	0.496
p-value	**0.107**	**0.107**	**0.142**	**0.258**

For local runners, the wind speed correlation values show that a large race day change in wind speed compared to the previous five days is more significant compared to a smaller change from the baseline conditions. The inverse relationship between race times and wind speeds indicates faster winds speeds result in slower finishing times and slower wind speeds result in faster finishing times. This relationship is to be expected when evaluating wind speed, as a head wind can slow a runner by five per cent (Spellman 1996). While it is rarely the case that a runner will have either a headwind or a tailwind the entire race, wind can aid or hinder a runner. Windy conditions, no matter the direction, can psychologically impact a runner's performance as well. Increased wind speeds can make a runner feel as though they are using more energy to continue to progress through the course. More importantly, such a relationship also indicates that acclimation may play a role. Because of the effects of acclimation, deviations from the underlying baseline wind conditions are more likely to impact locals, whether psychologically or physiologically, as opposed to the visitors.

Pressure also displayed a difference in significance between the two correlation tests for race times and barometric pressure, especially when viewing the slowest local group, the ninety-fifth percentile. When a large change in pressure was measured between the preceding five-day baseline and the race day conditions, there was a more significant impact on the slower local runners than when the change in pressure was small. The relationship between the finishing times and the pressure was positive for this group, suggesting the higher the pressure the slower the finishing time and the lower the pressure the faster the finishing time. Higher pressure suggests clear skies, which may lead to increased solar radiation reaching the surface. Those runners who are on the course for a longer period of time may feel as though the sun is directly shinning on them, especially if the race progresses into the late morning and early afternoon when the sun is highest in the sky. The increased solar radiation reaching the surface may also make the runner feel warmer. In the absence of any wind direct solar radiation can increase the heat index by 15°F (8.33 °C) (Selover 2009). Therefore, the conditions may be warmer than what participants are acclimated to, which may impact their finishing time. As expected with such an acclimation effect, the locals were more influenced that the visitors.

When the relative humidity was different on race day compared to the baseline conditions, the locals were more significantly impacted, especially the fifth percentile, average and median groups. Again, it is likely that this finding demonstrates aspects of acclimation. When the race day relative humidity was more similar to the baseline value, there was a positive relationship with the speed groups (excluding the slowest group); however, when the relative humidity differed from the baseline conditions there was an inverse relationship for all speed groups. The positive relationship between race times and relative humidity suggests that, as relative humidity increased, the finishing times also increased. This positive relationship supports past acclimation research as hot humid conditions are more difficult to acclimate to (Armstrong et al. 1987; Kenney et al 2004), so if the humidity increased to a higher level the racers may begin to feel uncomfortable as evaporative cooling would decrease in comparison to what they were acclimatized to.

The more significant inverse relationship for local runners between finish times and relative humidity suggests an increase in relative humidity leads to a faster finishing time and a decrease results in a slower finishing time. In this case, the direction of change will need to be addressed, as an increase in relative humidity may actually return the value to one similar to the runners' acclimatized values. This would suggest the values recorded for the five days leading up to the race may not represent "normal" relative humidity values. Additionally, the locals may be acclimated to humid conditions and consequently feel comfortable running when the humidity increases and more uncomfortable as the atmosphere dries (Figure 18).

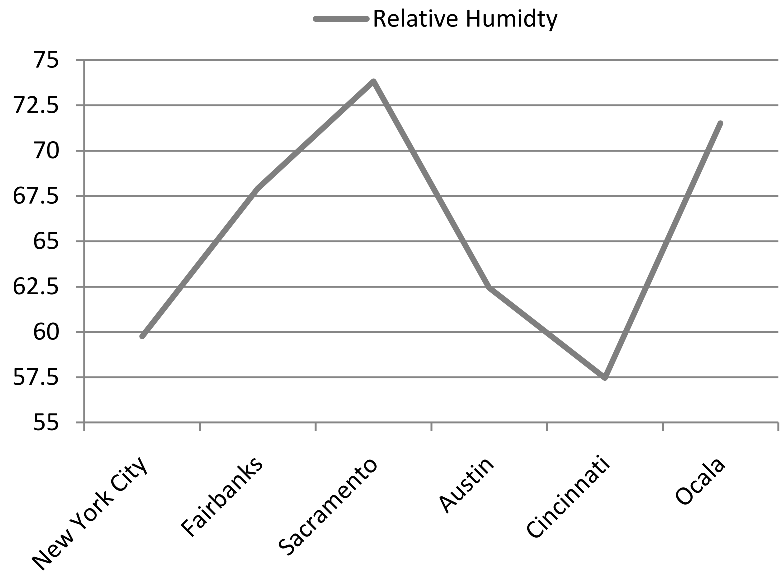


Fig. 18 The average race day relative humidity values for the six races where the x-axis is the six races and the y-axis is the relative humidity value as a percentage.

Visitors competing in the California International Marathon appear to be most impacted by the vapor pressure. While not statistically significant these two variables are notable for the change in significance of the correlation relationship for vapor pressure between similar and different (baseline to race day) conditions. The vapor pressure for both similar and different (baseline to race day) conditions displayed an inverse relationship for the fastest runners and a positive relationship for all other runners. For the slower groups, an increased vapor pressure suggests an increase in moisture within the atmosphere. Sacramento, while not on the coast, is a more humid location than many states runners are visiting from, such as Nevada and Colorado. Therefore, the increased humidity may make visiting runners more uncomfortable as added moisture in the atmosphere will decrease evaporative cooling. Additionally, warm wet conditions are the most difficult conditions to which to acclimate (Armstrong el at. 1987; Kenney et al. 2004). As the conditions may already be more humid than some visitors are accustomed to, a further increase may make the runners even more uncomfortable and impact their performance

Table 25 Directional differences in z-score values where Δ (xb-xr) is the difference in a given meteorological variable between the pre-existing five-day baseline conditions and the actual race day conditions.

California International Marathon	Small Δ (x_b-x_r)		Large Δ (x_b-x_r)	
	Positive years	Negative years	Positive years	Negative years
Variable				
Wind Speed	4	3	4	3
Pressure	3	4	3	4
Vapor Pressure	4	3	4	3
Relative Humidity	4	3	4	3

When comparing the correlations of race time with weather conditions for the locals with visitors for the situation where the race day conditions remain similar from the five days preceding, wind speed is the most notable weather variable that discriminates between the two groups of runners. Specifically, wind speed is a more significant influence on finishing times for visitors than local runners. Additionally, for the visitors, the relationship between wind speed and finishing times is an inverse relationship, suggesting faster finishing times when wind speeds increase and slower finishing times when wind speed decreases.

This finding may be explained by the fact that wind can be a large factor to runners' comfort as it can influence the amount of cooling through evaporation. For the visitors, some runners may be acclimated to more arid conditions.

Although Sacramento is not located on the coast, the conditions may be more humid than runners from more inland locations are acclimated to. If the wind speed increases the ability for sweat to be evaporated from the body increases. This increase in wind speed may help decrease the impact of more humid conditions. If the wind speed is lower, evaporative cooling may decrease, especially if the atmosphere is moister. Those visiting may begin to feel uncomfortable as their sweat does not evaporate from their skin. Additionally, runners acclimated to warm dry conditions, which increase their body's ability to sweat and begin sweating at a lower temperature (Thauer 1965; Hanna 1999), such as those from Arizona or Nevada, a small increase in moisture with calm winds may greatly impact their performance.

The California International Marathon held in December each year draws around 7,500 participants from across the country. The locals for this race were most significantly impacted by wind speed, pressure and relative humidity, while the visitors were most impacted by a change in vapor pressure and heat index. For this race when the conditions remained similar on race day in comparison to the five days leading up to the race, wind speed, pressure and relative humidity were not as significant as when there was a larger change. This finding proves my hypothesis that the locals notice the greatest impact on their finishing time if conditions are different on the race day from the baseline conditions as they would be acclimated to the baseline conditions. Wind speeds inverse relationship to the finishing times may imply that in a demanding type of activity, such as running a marathon, air movement has a positive impact on the runners as it can increase evaporative cooling, and also psychologically makes runners feel cooler (Yang et al. 2009).

The pressure played the most important role for the ninety-fifth percentile runners. This again may not only be a result of spending the longest time out on the course, where clear skies could impact the amount of solar radiation reaching the surface, but also effect the runners' psychological outlook of the race. The relative humidity is most significant in discriminating race times when the race day humidity significantly differed from the baseline, yielding an inverse relationship (higher relative humidity = faster race times). Local runners may be acclimated to warm wet conditions, which may make them more comfortable running in a more humid environment.

The visitors' finishing times were impacted more significantly when vapor pressure changed greatly on race day from preceding baseline value. Vapor pressure is another measure of moisture in the atmosphere and as a result the positive relationship between the vapor pressure and finishing times (higher vapor pressure = slower finishing times) for the average, median, and ninety-fifth percentile, may be indicative of the difficulty for non-elite runners to acclimating to warm wet conditions. Additionally, the increase in moisture decreases the ability for evaporative cooling, which has physical and potentially psychological ramifications (Hanna 1999; Yang et al. 2009).

As the California International Marathon attracts 7,500 runners each year, the visiting runners come from many different locations across the continental United States, Alaska, Hawaii and Canada. While not nearly as diverse as a population of runners like the New York City Marathon can boast, the visiting racers are more diverse in this race than the Equinox Marathon which draws less visitors and less total runners. However, the results linking weather conditions to finishing for similar race day-to-baseline conditions between locals and visitors only produced one variable of note - wind speed. Wind speed was more significant for the visitors than the locals. Both groups finishing times resulted in an inverse relationship with wind speed, suggesting that added wind speed may have increased evaporative cooling for the participants, but did not have a fast enough velocity or directional component to greatly impact the speed at which the runners were able to run. The visitors seemed to receive added benefits of the increased wind speed due to the fact that they may not be acclimated to the more humid conditions and the increased evaporation aided by increased wind speed may have made them more comfortable

iv. LIVESTRONG Austin Marathon (Austin, Texas)

The LIVESTRONG Austin marathon is held each year in February. Consequently, many runners participating in this the race will have trained through the fall and into the winter to prepare. I ran a correlation analysis between the weather variables and racer finishing times for when race day conditions were similar and were different to the baseline conditions of the preceding five days. The results of the analysis suggested that for the local runners the dew point, relative humidity and the wet bulb globe temperature were the most notable variables, while for the visitors only the wet bulb globe temperature was of note (Table 26).

Table 26 Correlation values for the LIVESTRONG Austin Marathon (Austin, Texas): Δ (xb-xr) is the difference for a given meteorological variable or index between the baseline (average of the previous five days) and the race day conditions, segregated by the speed of the runners into four categories; fifth percentile, average, median and ninety-fifth percentile. Significant values are bolded.

LIVESTRONG Austin Marathon Locals (Austin, Texas)				
	0.05	Average	Median	0.95
Dew Point				
Small Δ (DP_b-DP_r)				
r value	0.94	-0.998	-0.068	-0.942
p-value	**0.222**	**0.043**	0.957	0.218
Large Δ (DP_b-DP_r)				
r value	0.891	0.737	0.773	0.984
p-value	0.299	0.473	**0.438**	**0.113**
Relative Humidity				
Small Δ (RH_b-RH_r)				
r value	0.999	0.962	0.999	1.000
p-value	**0.022**	**0.177**	**0.027**	**0.013**
Large Δ (RH_b-RH_r)				
r value	-0.647	-0.932	-0.673	0.857
p-value	0.552	0.236	0.530	0.345
Wet bulb globe temperature				
Small Δ ($WBGT_b$-$WBGT_r$)				
r value	-0.47	-0.346	-0.297	-0.877
p-value	0.688	0.775	0.808	0.320
Large Δ ($WBGT_b$-$WBGT_r$)				
r value	0.996	0.993	1.000	0.968
p-value	**0.057**	**0.074**	**0.016**	**0.161**

LIVESTRONG Austin Marathon Visitors				
	0.05	Average	Median	0.95
Wet bulb globe temperature				
Small Δ ($WBGT_b$-$WBGT_r$)				
r value	0.897	-0.964	0.956	-0.945
p-value	**0.291**	**0.171**	**0.190**	**0.212**
Large Δ ($WBGT_b$-$WBGT_r$)				
r value	-0.319	0.004	0.294	0.545
p-value	0.793	0.998	0.810	0.633

The dew point temperature returned differing results depending on the speed of the runners. The fifth percentile and the average runners (good but non-elite runners) showed a more significant relationship between the dew point and their finishing times when the dew point temperature remained similar between race day and the baseline. The other two race groups, median and slowest group, resulted in a more significant relationship when the conditions were markedly different between race day and the preceding five-day baseline. The relationship between the finishing times and the dew point was positive (slower finish times = higher dew point) for the elite fastest runners (fifth percentile) when race day-to-baseline conditions were similar and for all race groups when the race day-to-baseline conditions varied to a larger extent. An inverse relationship (faster finish times = higher dew points) existed when race day-to-baseline conditions were similar for the non-elite average, median and ninety-fifth percentile. While the relationship between the finishing times and dew point temperature is seemingly odd given the acclimation literature, the median and ninety-fifth percentile groups resulting in a more significant impact when race day conditions differed from the base line conditions supports my hypothesis.

The physical rationale for such findings may the body's response to humidity. As dew point measures the amount of moisture within the atmosphere, a positive relationship would support the findings in previous acclimation research that warm wet conditions are more difficult to acclimate to than warm dry conditions (Armstrong et al 1987; Kenney et a 2004). As moisture in the atmosphere increases the body's ability to cool through evaporation decreases as sweat is not as readily evaporated from the skin. An inverse relationship suggests that the non-elite runners increase their speed with higher dew point values may imply that the values are not increasing to a large enough extent to greatly impact the finishing times. Additionally, if the dew point is higher the temperature value must also be higher. As such the non-elite local runners may be acclimated to these warm wet conditions and therefore are comfortable running in those types of conditions.

When the race day recorded similar values of relative humidity as compared to the five days leading up to the race, all speed groups for the locals experienced a more significant impact on their finishing times. The relationship between the relative humidity and the finishing times was positive; as the relative humidity increased the finishing times of the participants increased as well and vice versa. As relative humidity is also a measure of atmospheric moisture, increases in relative humidity decrease the body's ability to cool through evaporation, which may make the runners more uncomfortable as their bodies are not able to use sweating as an effective means of cooling. If the relative humidity decreases the ability for evaporative cooling would increase and for the three years that were most similar to race day conditions, the race day relative humidity were lower than the days leading up to the race (Table 27).

Table 27 Directional differences in z-score values where Δ (xb-xr) is the difference in a given meteorological variable between the pre-existing five-day baseline conditions and the actual race day conditions.

LIVESTRONG Austin Marathon (Austin, Texas)				
	Small Δ (x_b-x_r)		Large Δ (x_b-x_r)	
	Positive years	Negative years	Positive years	Negative years
Variable				
Dew Point	1	2	2	1
Relative Humidity	0	3	2	1
Wet Bulb Globe Temperature	1	2	0	3

When the difference in relative humidity was large between the baseline of five days prior and the race day, the relationship for the locals was less significant, but also inverse. An inverse relationship suggests that decreases in relative humidity increase final finishing times (slower times) while increases in relative humidity lead to faster finishing times. This relationship may be explained by the direction of change (Table 27). It may be likely that an increase in relative humidity may move toward conditions more similar to those that the local runners are acclimated to. Additionally, it has been found that a lack of hydration, no matter if the person is acclimated to a particular type of climate or not, will cancel out the acclimation effects (Cheung 1998). As such, local runners may find themselves not hydrating enough in the drier-than-accustomed conditions.

Lastly, the locals' finishing race times were impacted by the wet bulb globe temperature (WBGT). A large difference in WBGT between race day and the baseline conditions resulted in more significant correlations than when the race day conditions remained similar to the five days preceding the race. However, when the race day-to-baseline WBGT changed more significantly, the relationship between the values was positive (i.e., an increase in WBGT resulted in slower finishing times and a lower WBGT resulted in faster finishing times).

This finding supports my hypothesis, as the locals were significantly impacted by a larger change in the WBGT.

For the years evaluated with the largest change in WBGT from the five days leading up to the race day and race day, the three years displayed a decrease in WBGT (Table 27). The direction suggests that the lower WBGT would be beneficial to the runners' finishing times; however, these values may still be elevated from the conditions to which the local runners are acclimated. This explanation for my findings is supported by research by Minard (1965) and Ely et al. (2007) using the WBGT as a heat stress indicator for military trainees. Often trainees are forced to participate in a reduced intensity workout if the WBGT has an increased value and the trainees are not acclimated or accustomed to the exercise conditions. However, Minard (1965) and Ely et al. (2007) found that the trainees that were in better shape were less impacted by small changes in the WBGT. This supports my finding of an inverse relationship between the WBGT and the finishing times. There is a high level of fitness required to run a marathon race. While the slowest group, the ninety-fifth percentile, is often composed of participants who are undertaking the activity simply for the accomplishment and not worrying much about their finishing times, even walking 26.2 miles requires a certain fitness level. The inverse relationship, while not statistically significant, does suggest that small changes in the WBGT do not have as large of an impact on elite runners when runners are acclimated.

The correlation analysis between weather variables and finishing times for the visitors to the Texas Marathon only resulted in one relationship. Similar to the locals, the WBGT was the most significant relationship; however, when the race day WBGT was similar to the five days leading up to the race, the visitors finishing times were more significantly impacted. However, the direction of correlation between race time and WBGT varied according to the skill of the runner. The fifth percentile and the median resulted in a positive relationship, while the average and the ninety-fifth percentile resulted in an inverse relationship. A positive increase suggests an increase in WBGT results in slower finishing times, while an inverse relationship suggests an increase in WBGT results in faster finishing times. The impact of a smaller change may suggest that regardless of the direction of the change the WBGT for the visitors is at a value at which the visitors are not acclimatized to. When there is a large change between race day and baseline conditions in the WBGT, the non-elite (average, median, and ninety-fifth percentile) runners experienced a positive relationship in their finishing times, while the elite (fifth percentile) experienced an inverse relationship. The relationship with the larger change from baseline-to-race day is less significant, but may suggest that conditions are moving more toward the visitors acclimatized conditions. This explanation again may be seen as the WBGT was lower on race day then the five previous days when there was a larger change in the WBGT value (Table 26).

When comparing the locals and the visitors, for the situation in which weather conditions were similar between race day and the five days preceding the race, there were several relationships of note; temperature (fifth percentile and average), dew point (fifth percentile and average), relative humidity and WBGT.

For the situation when race day was similar to the baseline, the locals experienced a more significant impact from temperature, dew point, and relative humidity, than did the visitors; this supports my hypothesis that the locals, under similar race day-to-baseline conditions, are more acclimated to the conditions than visitors.

The temperature and dew point had the most impact on the local more elite (fifth percentile and average) runners. The inverse relationship implies that the faster runners have slower finishing times when the temperature is cooler and faster finishing times when the temperature is warmer. Based on past acclimation research, it would seem as though this relationship is the opposite of what would be expected. The literature shows that typically runners are more comfortable running in more moderate or cooler conditions, rather than warm or hot conditions (Maxwell et al. 1996; Kenefick 2009). An explanation may be posed that the fastest runners are so well trained that the small changes in the temperature may not have a large impact. This finding may be further explained by the fact faster runners are moving at a faster pace, so apparent wind speed on the body, in other words, the combination of natural wind and the wind they essentially create for themselves, increases and at a certain speed this wind chill effect may make elite runners too cool than they would otherwise be based solely on the air temperature.

The average runners on the other hand experience a relationship between finishing times and temperature that is more expected given past acclimation research, as the temperature increases, the average runners' finishing times also increase and vice versa. The average runners, not moving at a pace as fast as the elite (fifth percentile) runners may psychologically appreciate a decrease in temperature even if it is cooler than the temperature to which they are acclimated. This could be related to the study of Maxwell et al. (1996) who tested various runners warming up at a particular temperature and running sprints at another temperature. Their experiment revealed that the best results were achieved when the runners both warmed up and sprinted with cooler conditions; however, when the runners warmed up in cooler conditions and sprinted in warmer conditions their performance was not as strong as the prior conditions. Consequently, with a small increase in temperature compared to the conditions the average runners are acclimatized to, the average runners' finishing times may be slower.

The dew point temperature also demonstrated a more significant response in the correlations between dew point and race time for the locals in the better (fifth percentile and average groups) running groups. The elite (fifth percentile) experienced a positive relationship (higher dew points = slower finish times), while the average runners noted an inverse relationship (higher dew points = faster finish times). Increasing moisture in the atmosphere can decrease the effectiveness of evaporative cooling. When running the body can produce eleven times the heat than the body at rest (Spellman 1996), which can increase the rate of perspiration by the runner. A decrease in atmospheric moisture may be appreciated by those running at a faster speed, such as the elite (fifth percentile) runners. The average runner's finishing time is inversely impacted by the dew point, as an increase in dew point temperature results in a faster running time (decreased total finishing time). In terms of acclimation, while a visiting runner may be hindered by these types of conditions, a local who is acclimated to more humid conditions may not find an increase in humidity a hindrance on their finishing time. This again seems to go against past research; however, given the location of the race (Austin, Texas), some of the runners may be more acclimated to warm wet conditions. In this case, a drying of the atmosphere may impact their running by either drying their airways or lack of hydration can overwhelm any of the benefits of their prior acclimation (Cheung 1998).

Lastly, the locals' finishing times were impacted by the relative humidity compared to the visitors when race day conditions were similar to the five days leading up to the race. All local groups resulted in a positive relationship between the finishing times and relative humidity. This suggests that increases in relative humidity slow the local runners finishing times. In the three years which recorded the most similar conditions all saw a decrease in relative humidity between baseline conditions and the race day. This supports the research done by Morris et al. (2005) where more moderate conditions can result in higher performance levels. In terms of acclimation, this again supports that acclimating to warm wet conditions is more difficult than acclimating to warm dry conditions. As the local runners trained through the winter months, residents may be acclimatized to running in drier conditions as cold air can hold less moisture than warmer air. This may then result in the runners feeling the impact of an increased relative humidity value.

The visitors' finishing times responded to greater extent from the WBGT temperature when similar conditions existed from race day to baseline conditions. The relationship between the WBGT and the finishing times was positive for the fifth percentile and median runners, while inverse for the slower average and ninety-fifth percentile runners. When the there was larger change in WBGT values from baseline to the race day all three years used showed a decrease in the WBGT. When the WBGT was similar to baseline conditions two of the three years resulted in a decrease in the WBGT. As such, as the WBGT decreased it is likely that the decreased value was more similar to the visitors' acclimation conditions that they had trained in.

Additionally, Minard (1965) and Ely et al. (2007) found that a small change in WBGT does not impact those that are more physically fit than others. This supports the positive relationship with the elite runners (the fifth percentile) where a smaller increase in the WBGT would not impact finishing time. In the instances of the years viewed the overall result may be impacted by the decrease in the WBGT from the baseline conditions. The inverse relationship may suggest that the average and ninety-fifth percentile are acclimated to a certain WBGT value and do not perform as successfully if that value drops. Participating in a marathon requires a certain fitness level even if walking the 26.2 mile distance. This may explain why the relationship varies between the running groups. For this variable to be less significant for the locals also implies similar reasoning, which adds to the fact that they are most acclimated to the conditions from their training.

v. The Cincinnati Flying Pig Marathon (Cincinnati, Ohio)

The Cincinnati Flying Pig is held each year in May and is known for being a popular marathon for first time runners. For the correlation analysis between finishing times and weather variables for this race, the years of available data were separated into three, rather than four, groups given there were only eight years of data available for use. The results of the analysis suggested the most notable variables for the local runners were the temperature, pressure, vapor pressure and relative humidity. For the visitors, temperature, pressure, vapor pressure, saturation vapor pressure, heat index and wind chill index were indicated as notable variables by the correlation analysis (Table 28). These notable variables will be evaluated to see if the changes are relevant under acclimated conditions.

Table 28 Correlation values for the Cincinnati Flying Pig Marathon (Cincinnati, Ohio): Δ (xb-xr) is the difference for a given meteorological variable or index between the baseline (average of the previous five days) and the race day conditions, segregated by the speed of the runners into four categories; fifth percentile, average, median and ninety-fifth percentile. Significant values are bolded.

Cincinnati Flying Pig Locals	0.05	Average	Median	0.95
Temperature				
Small Δ (T_b-T_r)				
r value	0.994	0.920	0.933	-0.016
p-value	**0.069**	0.256	0.234	0.990
Large Δ (T_b-T_r)				
r value	-0.806	-0.966	-0.995	-0.900
p-value	0.403	**0.166**	**0.065**	**0.287**
Pressure				

Table 28 (continued)

Small Δ (P_b-P_r)				
r value	-0.950	-1.000	-0.998	-0.998
p-value	**0.203**	**0.009**	**0.038**	**0.042**
Large Δ (P_b-P_r)				
r value	-0.410	0.032	0.328	-0.898
p-value	0.731	0.979	0.787	0.290
Vapor Pressure				
Small Δ (VP_b-VP_r)				
r value	0.292	0.356	0.570	-0.179
p-value	0.811	0.768	0.614	0.886
Large Δ (VP_b-VP_r)				
r value	0.967	0.999	0.998	0.996
p-value	**0.164**	**0.021**	**0.041**	**0.060**
Relative Humidity				
Small Δ (RH_b-RH_r)				
r value	-0.942	-0.823	-0.700	-0.875
p-value	0.218	0.384	0.506	0.322
Large Δ (RH_b-RH_r)				
r value	0.992	0.871	0.771	0.963
p-value	**0.083**	**0.326**	**0.440**	**0.173**

Cincinnati Flying Pig Marathon Visitors	0.05	Average	Median	0.95
Temperature				
Small Δ (T_b-T_r)				
r value	0.710	0.991	0.992	0.397
p-value	0.498	0.085	**0.082**	0.740
Large Δ (T_b-T_r)				
r value	-0.965	-1.00	-0.895	-0.930
p-value	**0.168**	**0.017**	0.294	0.240
Pressure				
Small Δ (P_b-P_r)				
r value	-0.236	-0.954	-0.954	-0.988
p-value	0.849	**0.194**	**0.194**	**0.099**
Large Δ (P_b-P_r)				
r value	-0.902	-0.666	-0.639	-0.913
p-value	0.284	0.536	0.559	0.267
Vapor Pressure				
Small Δ (VP_b-VP_r)				
r value	-0.411	-0.341	-0.684	-0.305
p-value	0.730	0.779	0.521	0.803
Large Δ (VP_b-VP_r)				
r value	0.348	0.999	0.997	-0.572
p-value	0.774	**0.032**	**0.048**	0.613
Heat Index				
Small Δ (HI_b-HI_r)				
r value	0.991	-0.622	-0.619	0.648
p-value	**0.086**	0.573	0.575	0.551
Large Δ (HI_b-HI_r)				

Table 28 (continued)

r value	-0.980	-0.992	-0.764	-0.962
p-value	0.126	**0.082**	**0.447**	**0.177**
Wind Chill Index				
Most similar (WCI_b-$WCII_r$)				
r value	-0.991	-0.967	-0.957	-0.987
p-value	**0.088**	**0.164**	**0.187**	**0.105**
Most different (WCI_b-WCI_r)				
r value	-0.141	0.177	0.025	0.469
p-value	0.910	0.887	0.984	0.689

Temperature impacted all local runners; although a smaller change in baseline-to-race day temperature conditions was more significant for the elite (fifth percentile) runners while a larger change from baseline-to-race day temperatures was more significant for the slower (average, median and ninety-fifth percentile) runners. The elite (fifth percentile) recorded a positive relationship with temperature implying that warmer temperatures resulted in slower finishing times and cooler temperatures resulted in faster finishing times. This is consistent with a study by Morris et al. (2005) demonstrating that runners under moderate conditions were able to double their distance run compared to running under hot conditions. However, when there is a larger change in temperature on race day compared to the baseline, all local runners' finishing times record an inverse relationship with temperature (higher temperature = faster times). This type of change may be a more psychological response. When viewing the direction of change two out of the three years resulted in an increase of temperature. This may be an indication of a frontal system passing through and as such a clearing of the skies which may give the runners a better psychological outlook on the race.

Correlation between finishing times and barometric pressure indicated that a small change in pressure between race day and the baseline is more significant on the local runners' finishing times than a larger change. Each local running group resulted in an inverse relationship with pressure when the baseline-to-race day values remained similar. This implies that a decrease in pressure results in slower finishing times and an increase in pressure results in faster finishing times. The pressure values for all three of the years having similar values to the five days previous showed a slight increase in pressure, suggesting that the conditions were cloudier prior to the race (Table 29).

Table 29 Directional differences in z-score values where Δ (xb-xr) is the difference in a given meteorological variable between the pre-existing five-day baseline conditions and the actual race day conditions.

Cincinnati Flying Pig Marathon	Small Δ (x_b-x_r)		Large Δ (x_b-x_r)	
	Positive years	Negative years	Positive years	Negative years
Variable				
Temperature	2	1	2	1
Pressure	3	0	2	1
Vapor Pressure	2	1	3	0
Relative Humidity	0	3	2	1
Heat Index	1	2	1	2
Wind Chill Index	2	1	2	1

Higher pressure suggests the clearing of the sky or clearer skies which may make the runners feel more optimistic about their run (Ely et al. 2007). This may hold specifically true for those running the race for the first time, as their psychological outlook may play a large role in their race. When pressure values changed more significantly, an inverse relationship remained for the extreme (fastest and slowest; fifth and ninety-fifth percentile) runners, but the average and median groups resulted in a positive relationship. This suggests that most runners fare better when there is lower pressure and possibly an introduction of clouds. While most runners are not out on the course as long as the ninety-fifth percentile or as short of time as the elite runners, they may psychologically appreciate a decrease in solar radiation reaching the surface which may impact the temperature. So this appears to be a psychological rather than an acclimation response.

Vapor pressure, a measure of moisture in the atmosphere, was significant for the local non-elite (average, median, and ninety-fifth percentile) runners when there was a larger difference between race day and the previous five days, supporting my hypothesis. The results are more difficult to interpret as the vapor pressure values for the race day for the Cincinnati marathon were deemed non-normally distributed by the skewness and kurtosis normality tests and were therefore transformed to result in a normal distribution by using an inverse transformation ($^1/_x$). The positive relationship between transformed vapor pressure and finishing times implies that the local runners' finishing times increase as vapor pressure increases, and an increase in vapor pressure results in faster finishing times for race days with a large change from baseline conditions. In many acclimation studies those participating in any physically demanding activity have a reduced performance level when humidity increases (e.g. Hue et al. 2007, Morris et al. 2005); however, this correlation suggests the opposite. One possible explanation for this relationship is the directional change of the vapor pressure. For the three years recording the most different values between race day and the five days previous, the value was higher on race day than the days leading up to the race (Table 29).

Another measure of moisture, relative humidity, returned a notable correlation with the local runners' finishing times. Relative humidity was most significant for elite (the fifth percentile) when the race day value was different from the baseline, but most significant for the other non-elite local runners (average, median ninety-fifth percentile) when the race day value was similar to the baseline. All runners' finish times recorded a positive relationship with relative humidity, except for the slowest (ninety-fifth percentile) runners who recorded an inverse relationship. A positive relationship suggests that as relative humidity increases so do finishing times and vice versa. This relationship supports prior research (e.g. Morris et al. 2005; Hue et al. 2007) suggesting that more humid conditions result in a decrease in performance. Additionally, an small increase in relative humidity may suggest a slight decrease in evaporative cooling which can leave a runner feeling uncomfortable during their run as sweat will remain on the skin and cause them to not receive as much cooling benefit.

The inverse relationship for the slowest runners may be explained in a variety of ways (higher relative humidity = faster finishing times). First, those runners may begin the race too quickly therefore having to stop or slow, which results in continued energy loss, but less energy production (Spellman 1996). As such, they may begin to feel uncomfortable as they slow and their body is cooling not only from lack of heat production but also from evaporative cooling. If the atmosphere is more humid it may decrease the speed at which their sweat evaporates. Second, as they are out on the course for a longer period of time, they may experience a wider range of relative humidity values, as the value will change as temperature increases into the afternoon, which may also hold true for their training runs therefore suggesting they are acclimated to those types of conditions. While not an acclimation effect, a larger change in relative humidity is more significant than a smaller change or more similar conditions. This supports my hypothesis that the locals will be more significantly impacted by a larger change in the values suggesting a move from the conditions they are acclimated to.

The visitors' race times, like those of the locals, were also impacted by a change in temperature. Most visitors, specifically the fifth percentile, average, and ninety-fifth percentile, were impacted by temperature when there was a large change in temperature from race day to baseline. All racers experienced a positive relationship between their finishing times and the temperature when the race day temperature was markedly different from the baseline. This may suggest given these are visiting runners that an increase takes the temperature above a comfortable level and the temperature at which they are acclimated to. It also suggests the inverse conclusion, that as temperature decreases their finishing times also decrease (faster finishing times). An explanation for this is that the conditions may be more comparable to the conditions they are acclimated to and trained in to prepare for the race.

The average and median visiting runners' race times were also impacted when the race day's vapor pressure values were different from the baseline of the five previous days. Again, the vapor pressure values were transformed to reach a normal distribution and, as such, the positive relationship suggests that as vapor pressure increases the finishing times decrease (faster finishing times). Past acclimation research suggests humid conditions are more difficult to acclimate to than drier conditions (Armstrong et al 1987; Kenney et al. 2004), thus these groups of visitors may have acclimated to more humid conditions given their training location. As a result, they do not feel the ill effects others not acclimated to humid conditions would feel. Additionally, depending on the amount of moisture in the air to begin with (the five days leading up to the race) there may be a psychological impact of increased humidity as well.

The race times of the visiting average and median runners were impacted more significantly when race day saturation vapor pressure was similar to the baseline. This relationship was positive suggesting that as saturation vapor pressure increases their finishing time also increases (slower race time) and vice versa. As saturation vapor pressure measures the maximum amount of moisture in the air, it is possible that as the saturation vapor pressure increases evaporative cooling also increases. While in many cases an increase in evaporative cooling would positively aid the runner in cooling down the benefit of evaporative cooling may be downplayed given the rate at which sweat is evaporating if the atmosphere is extremely dry (Kenny et al. 2004). In this case, any acclimation to either warm wet or warm dry conditions may be outweighed by the increase in evaporation.

The heat index was another variable that influenced race times for all visiting runners, when there was a larger change between race day and the baseline conditions. All runners experienced an inverse relationship between the heat index and their finishing times, implying that an increase in heat index value resulted in faster finishing times. This relationship may be the result of the visitors being acclimated to conditions over than that experienced by the locals and so were not uncomfortable running in local conditions. Lastly, the visitors' race times were impacted by changes in the wind chill index (WCI). All runners were most impacted when there was a smaller change in wind chill between the race day and the previous days (baseline). These runners' race times experienced an inverse relationship to WCI, suggesting a decrease in the wind chill index (cooler values) results in slower finishing times and an increase in wind chill index (warmer values) results in faster finishing times. This may suggest that the visitors participating in this race were acclimated to warmer conditions and therefore a lower wind chill value made the runners feel cooler than they would like. Additionally, if the WCI is dominated by the wind speed component of the equation, this may suggest ineffective evaporative cooling. When there was a larger change in WCI the average, median, and ninety-fifth percentiles runners had a positive relationship between their finishing times and wind chill index, suggesting that as the wind chill increases (warmer values) their finishing times also slowed. These runners seem to appreciate the cooling benefits of a reduced WCI when they are running whether it is due to increased wind speeds or a decrease in sensible temperature.

If race day conditions are similar to the baseline, visitors are most impacted by temperature, pressure, and the wind chill index. . However, for the elite (fifth percentile) locals and the visiting average and median runners, temperature and saturation vapor pressure were most significant. All three correlations with finish times were positive suggesting that the elite (fifth percentile) locals' race times, although acclimated to those conditions, likely improved with cooler temperatures as those elite runners were producing significantly more heat internally given their faster speed. Conversely, the visiting runners may have improved with lower temperatures given they may have acclimated and trained in a cool location. The visitors may have begun to feel the stress of the warmer temperatures as they progress through the course and the day warms. As saturation vapor pressure is related to temperature, increased saturation vapor pressure values suggests the atmosphere can hold more moisture, which may lead to ineffective evaporative cooling if the amount of water vapor also increases.

Pressure was more significant for all locals when compared to visitors with an inverse relationship. This suggests that clearer skies lead to faster finishing times and cloudy skies result in slower finishing times. Clearer skies may psychologically impact the outlook the runners have making them more optimistic about the race. Additionally, increased solar radiation may aid in raising the temperature and increasing evaporative cooling which would make the runners feel more comfortable out on the course.

Pressure impacted all local runners when race day conditions were similar to the baseline. The pressure and the finishing times were inversely related suggesting faster finishing times under high pressure or clear skies. This may be a more psychological response in the runners with clearer skies making them feel more optimistic about the race. All local runners, except the fastest runners, were impacted by a large change in vapor pressure. As the vapor pressure increased the finishing times decreased (faster finishing times) and as the vapor pressure decreased the finishing times increased (slower finishing times). As vapor pressure is a measure of humidity, it may be that if the atmosphere becomes too dry the runners are impacted by ineffective evaporative cooling given the speed of evaporation or could be hampered by improper hydration.

vi. The Ocala Marathon (Ocala, Florida)

The Ocala Marathon which is held during the first week of February is notable by having a diverse visitor population of participants from forty-seven states and seven countries. Like the Equinox Marathon, the Ocala marathon draws a small number of total participants, unlike the other races that attract thousands of runners. When viewing local runners for this race, variables of note were the temperature, saturation vapor pressure, and the wind chill equivalent temperature for the ninety-fifth percentile runners and barometric pressure for all running groups. The correlation analysis on the visitors running times resulted in relative humidity and apparent temperature as being variables of note (Table 30)

Table 30 Correlation values for the Ocala Marathon (Ocala, Florida) where Δ (xb-xr) is the difference for a given meteorological variable or index between the baseline (average of the previous five days) and the race day conditions, segregated by the speed of the runners into four categories; fifth percentile, average, median and ninety-fifth percentile. Significant values are bolded.

Ocala Marathon Locals	0.05	Average	Median	0.95
Temperature				
Most similar (five day/race day)				
r value	-0.353	-0.980	-0.869	0.379
p-value	0.770	0.129	0.330	0.753
Most different (five day/race day)				
r value	-0.524	1.000	0.867	1.000
p-value	0.649	**0.017**	0.332	**0.005**
Pressure				
Most similar (five day/race day)				
r value	0.995	-0.573	-0.787	-0.997
p-value	**0.063**	0.611	0.423	**0.047**
Most different (five day/race day)				
r value	-0.886	-0.023	-0.289	0.488
p-value	0.306	0.985	0.813	0.676
Saturation Vapor Pressure				
Most similar (five day/race day)				
r value	-0.526	0.643	-0.155	0.488
p-value	0.648	0.555	0.901	0.675
Most different (five day/race day)				
r value	-0.922	-0.782	-0.187	-0.993
p-value	0.253	0.428	0.880	**0.076**
Wind Chill Equivalent Temperature				
Most similar (five day/race day)				
r value	0.726	-0.564	-0.793	1.000
p-value	0.483	0.618	0.417	**0.006**
Most different (five day/race day)				
r value	-0.011	-0.192	0.001	-0.870
p-value	0.993	0.877	0.999	0.329

Ocala Marathon Visitors	0.05	Average	Median	0.95
Relative Humidity				
Most similar (five day/race day)				
r value	0.998	0.467	0.992	0.040
p-value	0.042	0.690	0.079	0.974
Most different (five day/race day)				
r value	-0.592	0.999	0.989	0.523
p-value	0.597	0.025	0.093	0.650
Apparent Temperature				
Most similar (five day/race day)				
r value	0.394	0.777	-0.292	0.997

Table 30 (continued)

p-value	0.742	0.434	0.812	0.053
Most different (five day/race day)				
r value	0.995	0.999	0.999	0.940
p-value	**0.065**	**0.025**	**0.022**	**0.221**

The slowest locals (ninety-fifth percentile) runners' finishing times were most impacted by a large race day change in temperature and saturation vapor pressures from baseline values. This is reasonable given that it is likely that the slowest runners are the least likely of the local runners to be adaptable to the changes from the local conditions. Armstrong et al. (1987) found that all runners can benefit from training in the conditions they plan to compete in; however, it has also been found that those that are in better shape will acclimatize more rapidly than those at a lesser physical fitness level (Cheung 1998; Binkley et al 2002).

These variables are related in such as way that the saturation vapor pressure is a measure of how much water vapor the atmosphere can hold at a given temperature. Although the correlation relationship is an inverse relationship, it should be noted that the transformation performed on saturation vapor pressure to return a normal distribution based on kurtosis value was one divided by the saturation vapor pressure value. As such, as saturation vapor pressure increases the finishing time also increases and as saturation vapor pressure decreases the race time also decreases. The same relationship is true for temperature and finishing times, as the correlation relationship was positive. For the slowest runners, they are out on the course for the longest period of time of all the participants and as such they experience increases in temperature as the day continues. The temperature may increase past the conditions they are acclimated to, therefore putting more stress on their bodies. As these runners may not be as fit as the other runners participating in the race, they may be more impacted by changes in the conditions.

As a repudiation of my hypothesis in this case, the ninety-fifth percentile was more significantly impacted by the wind chill equivalent temperature when the values were similar on race day to the days leading up to the race. However, this may further support that those that are not as physically fit acclimate at a slower rate than those that are at a higher physical fitness level (Cheung 1998; Binkley et al 2002). The relationship for the correlation analysis was positive, implying that and increase in wind chill equivalent temperature (WET) will slow the runner or a decrease in WET will decrease the finishing times. As the WET is a combination of temperature and wind speed, for this group of runners it is not surprising that the runners would react in this manner. As the conditions for this race are more humid than other races examined in this study a decrease in WET may help cool the runners off and encourage evaporative cooling. These runners also spend the most time out on the course exposed to increased solar radiation and increased temperature as the day progresses from early morning into the afternoon. An increase in wind speed can assist the runners in cooling off. Additionally, it has been found that people psychologically associate wind with cooling and therefore feel cooler with a breeze (Yang et al. 2009).

Barometric pressure had a more significant impact on the local runners' finishing times when the race day conditions were similar the baseline, which again may suggest pressure is a psychological influence rather than an acclimation factor. However, it must be noted that the skewness and kurtosis values for pressure suggested an abnormal distribution and were not able to be transformed to return a normal distribution. The relationship with the barometric pressure was positive for the fifth percentile and inverse for the other runners (average, median, and ninety-fifth percentile). The positive relationship suggests that higher pressure values result in slower finishing times and vice versa. The faster runners may appreciate lower barometric pressures as it may suggest cloud cover. An inverse relationship suggests that the lower the pressure the slower the finishing time and the higher the pressure the faster the finishing time. Unlike in other races where higher pressure resulted in slower finishing times the runners that remain on the course later into the morning and early afternoon may be more greatly impacted by increased radiation reaching the surface as the sun moves higher in the sky, these runners seem to benefit from clearer skies. However, psychologically these runners may feel optimistic about their run with clearer skies.

The visiting runners' race times were most notably impacted by relative humidity and apparent temperature. The fifth percentile and median groups were more significantly impacted when race day relative humidities were similar to the baseline. As the relative humidity decreases the race time also decreases. Given that Ocala, Florida is one of the most humid locations examined in this study the runners may not be acclimated to warm wet conditions and any further increase may impact their comfort and as a result slow their finishing times. A decrease in relative humidity may come as a relief for the runners and in terms of acclimation the more moderate conditions may improve their performance (Morris et al. 2005) and potentially move toward their training conditions.

Apparent temperature values also impacted the performance of the visiting runners. The relationship was more significant for the slowest runners, ninety-fifth percentile, when the race day conditions were similar to the baseline, this suggests that the slowest visiting runners are least likely to achieve acclimation to the local conditions and so their times are more sensitive to the local variations. Those runners that are at a higher fitness level are more likely to acclimate at a faster rate than the slower runners (Cheung 1998; Binkley et al 2002). As such, the slower runners, the non-elite, may appreciate similar training conditions day-after-day, therefore running under similar conditions to their training runs is more comfortable. If they arrived and ran a few shorter runs under the baseline conditions, a change no matter how small or large may impact their comfort on race day.

Pressure and relative humidity resulted in a notable difference in correlation significance values between the local and visiting runners if the conditions were similar between the race day and the baseline. Again, it should be noted that the skewness and kurtosis values suggest that pressure is not normally distributed. Pressure correlation values were more significant for the local runners for the fifth and ninety-fifth percentile groups. The relationship was positive for the fifth percentile and the relationship inverse for the slowest groups. This result would again indicate the lack of acclimation by the visitors. When the race conditions are similar to the previous days, the visitors' race times are influenced by the changes in pressure and relative humidity. For example given that the Ocala Marathon is held in one of the most humid locales of the six races being evaluated, it is not surprising that the visitors would feel the impact of humidity to a greater extent than the locals. Many visiting runners training outside of Florida and even the southeast would be acclimated to the less humid conditions. As such, a change in humidity however small may greatly impact their performance.

While the Ocala Marathon is the smallest race in terms of population used for this study, the race attracts visiting runners from across the country. This race also sets itself apart from the other races in the study as it experiences some of the most humid conditions of all the races and as such locals to this area are acclimated to warm wet conditions. The locals are acclimated to the most difficult set of conditions to become acclimated to, warm wet. As a result, the correlation analysis of race times to humidity suggests that the locals are able to cope with small changes in moisture and temperature, therefore requiring a larger change in conditions to have a significant impact on their finishing times.

For temperature, and saturation vapor pressure, the slowest (ninety-fifth percentile) local runners was the group most impacted by a large race day change from the baseline conditions. This is reasonable given that it is likely that the slowest runners are the least likely of the local runners to be adaptable to the changes from the local conditions, supporting my hypothesis. The ninety-fifth percentile runners were also impacted when the WET remained similar on race day to the days leading up to the race. As it takes longer for those that are less fit take longer to acclimate and therefore are the group which would be most sensitive to change. This positive relationship suggests that those participants out on the course for a longer period of time in warm wet conditions appreciate an increase in wind speed as it will aid in evaporative cooling and decrease the temperature. Additionally, the locals were impacted by changes in pressure when the pressure remained similar on race day compared to the days leading up to the race. This may be attributed to cloud cover and the amount of solar radiation that reaches the surface and the runners.

The visitors, as would be expected, were impacted by the amount of moisture within the atmosphere, specifically by relative humidity and apparent temperature. The visiting elite runners (fifth percentile) were impacted when the relative humidity values were similar to the baseline conditions, while the other groups were more greatly impacted when the values were different from the baseline. With the apparent temperature all runners except the ninety-fifth percentile were more greatly impacted by changes in the apparent temperature when the values differed from the baseline conditions. With both variables the relationship with finishing times was positive implying that more humid conditions resulted in slower finishing times and decreased humidity resulted in faster finishing times. This relationship also suggests that the visiting runners' performance increased as the conditions moved to conditions they were acclimated to, which in many cases were drier conditions.

vii. Correlation Analysis Summary

My interpretation of the correlation analysis identified several variables demonstrating a potential acclimation signal. Below is the summary of each race and the specific variables influenced by acclimation for each of the races.

New York City Marathon (New York City, New York)

- Locals
    - The runners experienced a positive relationship with a large change in the heat index even though the temperature was not at or above the 80°F threshold. This may be due to heat generated by the body may actually make up for the difference in ambient temperature when evaluating a person's personal comfort (Spellman 1996). Additionally, the heat index includes both temperature and humidity values in its calculation. In acclimation studies, hot dry conditions have been found to be easier to adapt to, as in they typically take less time and exposure, compared to hot wet conditions. Consequently, the heat index may be a possible gauge of acclimation
    - When the race day heat index was similar to the baseline heat index, the heat index value was not significant factor in determining the finishing time. This indicates that the locals are acclimated to the conditions measured by local heat index and it therefore did not contribute to their race times.
- Visitors

    - The visitors were impacted when the race day value varied greatly from baseline conditions, which may signify conditions moving more toward the conditions the visitors are acclimated to and accustomed to running in. The runners had a positive relationship with the heat index and a positive relationship with the wet bulb globe temperature.

Equinox Marathon (Fairbanks, Alaska)

- Locals
    - The locals were most significantly impacted when the race day conditions were similar to the baseline, except for the wind chill index (average and ninety-fifth percentile runners). Given that my hypothesis is that locals are most likely to be acclimated to the baseline conditions, this result initially appears to indicate a contradictory acclimation effect. However, while acclimation studies typically discuss the role of moisture in the atmosphere when discussing increased temperatures (Hue et al. 2004; Kenefick 2009), they do not typically mention atmospheric humidity when discussing cold weather acclimation. Cold air masses can be very dry due to the capacity for cold air to hold less moisture than warm air (Pidwirny and Jones 1999).
    - The wind chill index results support my hypothesis that the average and ninety-fifth percentile locals will be more greatly impacted when the conditions differ on race day from the baseline

conditions. The positive relationship suggests that the locals are acclimated to particular values of the wind chill index and an increase in that value actually negatively impacts their finishing times.

- Visitors
    - The visitors showed a wider range of variables impacting their finishing times, depending on the race group. The fifth percentile runners had and inverse relationship with similar conditions in pressures, while the average, median, and ninety-fifth percentile runners had a positive relationship with pressure when the baseline-to-race day conditions were different. Pressure may have more of a psychological impact on the runners and relate less to acclimation, as the clearing or introduction of clouds may impact the runners' outlook on the race (Ely et al. 2007).
    - Saturation vapor pressure was inversely impacted with the median runners when the saturation vapor pressure changed greatly from baseline to race day, while similar conditions were more significant for the fifth percentile, average, and ninety-fifth percentile with an inverse relationship. As saturation vapor pressure is suggestive of both of the temperature and the amount of water vapor the air can hold, those visiting a race location who are acclimated to drier conditions may find an increase in temperature and drying of the atmosphere aids evaporative cooling, thus

helping the runners feel more comfortable in conditions they are not acclimated to.

    - Just as the locals experienced an inverse relationship with the wind chill index when the change was large from the baseline conditions (except the fifth percentile), the visiting runners resulted in this same relationship. The wind chill index can impact sensible temperature which can make visiting runners feel cooler. However, this decrease in sensible temperature may be welcome to some visiting runners if they have overdressed as a response to not being acclimated to the cooler conditions. Overdressing can inhibit heat exchange from the body, which may leave the runners feeling too warm (Cheung 1998). Although some visiting runners may feel too cool with a decreased wind chill value, negatively impacting their finishing time.

California International Marathon (Sacramento, California)

- Locals
    - All local runners experienced an inverse relationship when there was a large change from baseline-to-race day conditions in wind speed and relative humidity values. Pressure impacted the fifth percentile, average, and median runners inversely, with the ninety-fifth percentile had a positive relationship. These findings support my hypothesis as the local runners were more significantly impacted when the wind speed and relative humidity differed from

the baseline, or acclimated, conditions. Pressure, once again, seems to have a greater psychological impact on the runners rather than an acclimation factor.

- Visitors
  - The fifth percentile visiting runners' finishing times were inversely related to a large change in vapor pressure from baseline-to-race day, while the other runners' finishing times (average, median, and ninety-fifth percentile) had a positive relationship. Vapor pressure is a measure of how much moisture is in the atmosphere and therefore can impact the visitors depending on their training conditions. Visitors training in and being acclimated to drier conditions would find it difficult to acclimate to the moister conditions in a short period of time (five days). Warm wet conditions are the most difficult to acclimate to (Armstrong et al. 1987, Kenney et al. 2004) and research has found that acclimating to these conditions can take longer than eight days (Hue et al. 2004).

LIVESTRONG Austin Marathon

- Locals
  - Dew point influenced the runners' finishing times when race day-to-baseline conditions were similar for the fifth percentile (inverse) and average (positive) and different for the median and ninety-fifth percentile (positive). Those runners impacted by a larger change

in the dew point temperature, median and ninety-fifth percentile, reflect my hypothesis, as the runners should be acclimated to the baseline conditions. However, a small change in dew point was more significant for the faster runners which may be a reflection of increased heat production while running (Spellman 1996). Increased heat production may lead to increased perspiration, which would lead the elite runners to be more sensitive to changes in the dew point temperature.

- The median and slowest groups resulted in a more significant relationship when the conditions were markedly different between race day and the preceding five-day baseline supporting my hypothesis. All runners had a positive relationship with relative humidity values when race day-to-baseline conditions were similar, contrary to my hypothesis. However, studies have shown that warm wet conditions are more difficult to acclimate to (Armstrong et al. 1987; Kenney et al. 2004), and it is possible that increased humidity levels were above a threshold for the locals to feel comfortable.
- All runners also had positive relationship with WBGT when the race day conditions varied from the five days prior to race day. This relationship supports my hypothesis that the local runners would be significantly impacted when the value differed greatly from the baseline or acclimation conditions. Additionally, this

finding supports research by Ely et al. (2007) and Minard (1965) that found those who are more physical fit will be less impacted by smaller changes in WBGT.

- Visitors
  - The visiting runners were only notably impacted by similar values of the WBGT between race day and baseline; fifth percentile and median groups positively and average and ninety-fifth percentile inversely. This finding demonstrates how the visitors are not acclimated to the conditions of the race city (Austin, Texas). As such, a small change in temperature and humidity impacted their finishing times.

Cincinnati Flying Pig Marathon

- Locals
  - All locals returned notable positive relationships with large changes in vapor pressure and relative humidity between race day and baseline. Additionally, the average, median, and ninety-fifth percentile were more significantly impacted by a large change in temperature. These findings support my hypothesis, as the locals will be more significantly impacted when the conditions change from those they are acclimated to.
  - Additionally, all runners had an inverse relationship with pressure when the value remained similar between race day and the previous five days. Pressure seems to have a larger psychological

impact on the runners rather than an acclimation impact. While the pressure can suggest how much solar radiation is reaching the surface thereby impacting temperature, the amount of cloud cover seems to impact the psychological outlook a runner has on the race as noted by Ely et al. (2007).

    - The average, and median, and ninety-fifth percentile runners resulted in an inverse relationship with temperature when it was different on race day, while the fifth percentile resulted in a positive relationship when the temperature value was similar.

- Visitors
    - The visiting population was impacted by many different variables including temperature, pressure, vapor pressure, heat index and wind chill index. The relationship for finishing times was positive for the average and median with similar temperatures between race day and baseline and inverse for the fifth and ninety-fifth percentiles with larger changes in race day temperatures from the baseline. A large change in temperature significantly impacting the visitors suggests the temperature may have moved more toward the conditions they are more acclimated to.
    - A small change in pressure from baseline to race day was more significant for the average, median, and ninety-fifth percentiles runners while a smaller race day change from baseline conditions was more significant for the fifth percentile. All relationships were

inversely related. Again, pressure seems to have a larger psychological impact on the runners rather than an acclimation factor

- A large change in vapor pressure from baseline to race day was positively related to average and median runners' finishing times. A change in vapor pressure having a significant impact on the visitors backs the importance of moisture in the atmosphere to acclimation. As the conditions became more humid the visiting runners saw a negative impact on their time with their finishing times increasing; as warm wet conditions are the most difficult conditions to acclimate to (Armstrong et al. 1987; Kenney et al. 2004).
- The heat index was positively related to the ninety-fifth percentile runners when the baseline and race day values remained similar and inversely related to the fifth percentile when those conditions differed. As another combination of temperature and humidity, these results again show the impact warm wet conditions can have on those runners that are acclimated to different conditions.
- The wind chill index had a positive relationship will all runners' finishing times when there was a large change in value from the previous five days and race day. A large change in wind chill index from baseline to race day with a positive relationship suggests that the decreased sensible temperature and addition of wind speed may

aid in evaporative cooling. While the visiting runners may not be acclimated to the warm wet conditions, an increase in wind speed may aid in evaporation although the atmosphere is more humid.

Ocala Marathon (Ocala, Florida)

- Locals
    - The local runners' finishing times were impacted by temperature, pressure, saturation vapor pressure and wind chill equivalent temperature. A large change in temperature between race day and baseline positively impacted the average, median and ninety-fifth percentile runners. This finding supports my hypothesis as temperature moved away from the baseline conditions it had a large impacted on the runners' finishing times, as higher temperatures resulted in increased finishing times.
    - A small change in pressure from baseline to race day impacted the fifth percentile (positive) and the ninety-fifth percentile (inversely). Pressure is a variable that seems to impact the runners more psychologically rather than be a result of acclimation to a particular barometric pressure (Ely et al 2007).
    - The slowest runners, the ninety-fifth percentile, were inversely related to a large change in saturation vapor pressure from baseline to race day while having a positive relationship with a small change in wind chill equivalent temperature. The significant impact with a large change in vapor pressure supports my

hypothesis. As saturation vapor pressure moves further from the baseline conditions, these finding suggest that the locals become more uncomfortable as the conditions are not similar to those they are acclimated to.

- Visitors
    - The fifth percentile (similar), average and median runners (different) had a positive relationship with relative humidity values. This positive relationship with both a small and large race day changes in relative humidity from baseline conditions suggests the runners are not acclimated to the increase in humidity. Warm and wet conditions are more difficult to acclimate to than warm dry conditions (Armstrong et al. 1987; Kenney et al. 2004).
    - When apparent temperature values were similar between race day and baseline, the ninety-fifth percentile had a positive relationship the variables, and a larger change also resulted in a positive relationship with the average and median runners. Apparent temperature, which is also a measure of temperature and humidity, resulted in the visitors having a slowing of their finishing times, again suggesting the visitors are not acclimated to the warmer and more humid conditions.

In addition to the findings for various running groups, a few overarching conclusions can also be made from the correlations analysis. The first is, as my original hypothesis posed, acclimation appears to be a major factor in the performance of local runners. When race day conditions change dramatically from the acclimated conditions (measured as the average of the previous five days), the local runners' finishing times generally declined. This was particularly true with the following variables and races: the heat index at the New York City Marathon (New York City, New York), wind speed and pressure at the California International Marathon (Sacramento, California), wet bulb globe temperature and dew point temperature (median and ninety-fifth percentile) at the LIVESTRONG Austin Marathon (Austin, Texas), temperature (average and median), vapor pressure, and relative humidity at the Cincinnati Flying Pig Marathon (Cincinnati, Ohio), and temperature (average and ninety-fifth percentile) and saturation vapor pressure (fifth and ninety-fifth percentile) at the Ocala Marathon (Ocala, Florida).

Second, the correlation analysis resulting in several variables that seemed to have the largest impact on the runners. Humidity variables, dew point temperature, vapor pressure and relative humidity repeatedly influenced the runners' finishing times. These findings support previous research evaluating runners and other athletics performing in warm dry and warm wet conditions (e.g. Armstrong et al. 1987; Hue et al. 2004; Morris et al. 2005; Hue et al. 2007). Additionally, the wind chill index also influenced the runners' finishing times. Past research has not noted evaluating wind speed independently or in conjunction with temperature and humidity. The results suggest that added wind may impact not only the sensible temperature a runner feels, but also increase the effectiveness of evaporative cooling even in more humid conditions.

The third finding is the confirmation of other acclimation studies stating that acclimating to warm wet conditions takes a longer period of time and is more difficult that acclimating to warm dry conditions. The correlation results of increased finishing times with an increase in humidity values such as dew point temperature, vapor pressure or relative humidity was found across races including the California International Marathon locals and visitors (average, median, ninety-fifth percentile), LIVESTRONG Austin Marathon locals, and Cincinnati Flying Pig Marathon locals and visitors (average and median). Additionally, the correlation analysis suggested that a small change in humidity may not impact the runners significantly enough to influence the runners' performance as was seen with locals participating in the California International Marathon and the Cincinnati Flying Pig Marathon. In these two races it was not until a large change in humidity that the runners saw an impact on their finishing times.

A fourth notable finding was the influence that wind speed can have on the runners' finishing times. While an increased wind speed can directly increase or decrease the finishing time, the role of wind can also be seen in the wind chill index and the wind chill equivalent temperature. In some cases, such as the New York City visitors and the Cincinnati Flying Pig visitors, the relationship with the wind chill index (WCI) was inversely related to the finishing time suggesting that the introduction of wind would make the runners feel cooler than what they were acclimated to and therefore slow their finishing times. However, the locals for the Equinox Marathon demonstrated a positive relationship with the WCI suggesting that those that are local appreciated cooler sensible temperatures and those visiting (small change: ninety fifth percentile and large change: fifth percentile) may be overdressed for their run and also appreciated the cooler sensible temperatures. Additionally, wind may help aid in conditions when the humidity is higher than what the runners are acclimated to. Current acclimation studies do not address how wind speed may play a role in acclimation. The results of this correlation analysis, while not statistically significant, may suggest that the presence of wind may help relieve some of the discomfort runners feel when the conditions are more humid than they are acclimated to.

Lastly, the correlation analysis suggests that more extreme conditions, like the Equinox Marathon held in Fairbanks, Alaska, may be most representative of when acclimation to an extreme climate is important. The results suggest that the locals are acclimated to the cooler conditions and therefore respond well in terms of race performance when those conditions are cooler or drier. In addition, the visiting racers also seemed to have their performance impacted by warmer sensible temperatures based on the results with wind chill index. As discussed above, the clothing worn and the conditions of the course may greatly impact the visitors' performance. As cold weather acclimation can take up to six weeks (Hanna 1999), visitors planning on participating in a cold weather race may benefit from controlled training conditions.

As an anecdotal example, Mike Pierce, a San Diego, California resident, was looking to run a marathon on Antarctica's mainland, but was worried that his lack of exposure to extreme, let alone very cold temperatures, would hinder his ability to successfully complete the race. As a result, he contacted a commercial refrigeration facility to inquire about training for the impending marathon. He was able to train in an ice cream refrigeration compartment, which was roughly twenty-acres large and kept at minus ten degrees Fahrenheit. He trained within the compartment working his way up to running twenty-six miles, while also including stationary bike riding into his training. Pierce successfully completed the marathon in seven hours and reported that he felt overdressed as the temperature reported at race day was zero degrees Fahrenheit, ten degrees warmer than his training compartment (Hanc 2009).

e. Two- sample T-test analysis

The aforementioned correlation analysis suggested the notable variables associated with acclimation for each race for locals and visitors as well as each speed grouping. These variables for the New York City Marathon (New York City, New York), Equinox Marathon (Fairbanks, Alaska), and California International Marathon (Sacramento, California) were then used to test the difference in means of the four race groupings finishing times (other races were not tested due to the limited period of race data available). An earlier simple regression was performed on race times given the trend in these data, as there is an increase in overall finishing times as running became more popular. As such, the residuals calculated for the race times are also used for this analysis. A two-sample t-test was used to calculate the difference of means of two groups: finishing times when conditions were similar to baseline and finishing times when conditions were different from baseline (Ebdon 1985). A t-test returns a t-value which is calculated by equation 4.4, where X_1 is the mean of the finishing times when conditions were similar, X_2 is the mean of the finishing times when conditions were different, σ_1 is the standard deviation of the first group of finishing times, σ_2 is the standard deviation of the second group of finishing times, and n_1 and n_2 are the sample sizes of the two groups (McKenzie and Golman 2005).

$$t = \frac{X_1 - X_2}{\sqrt{\left(\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}\right)}} \qquad (4.6)$$

The New York City Marathon (New York City, New York), Equinox Marathon (Fairbanks, Alaska), and California International Marathon (Sacramento, California) were the three races analyzed in the two-sample t-test as the other three races, the LIVESTRONG Austin Marathon (Austin, Texas), Cincinnati Flying Pig Marathon (Cincinnati, Ohio) and Ocala Marathon (Ocala, Florida), had limited period of race data available. The three larger races were split in half rather than quartiles to place fourteen years (Equinox and California International Marathons) and seventeen years (New York City Marathon) in each sample mean. The t-test was performed using the notable variables for each race given the correlation analysis and on all running groups for the locals and visitors (Table 31).

Table 31 The notable variables for the locals and visitors from the correlation analysis (4d) for the three largest races which include: the New York City Marathon (New York City, New York), Equinox Marathon (Fairbanks, Alaska), and California International Marathon (Sacramento, California).

Notable variables from correlation analysis		
	Locals	Visitors
New York City Marathon (New York City, New York)		
	Heat Index	Heat Index
		Wet bulb Globe Temperature
Equinox Marathon (Fairbanks, Alaska)		
	Dew Point	Pressure
	Wind Chill Index	Sat. Vapor Pressure
	Apparent Temperature	Wind Chill Index
	Wind Chill Equivalent	
California International Marathon (Sacramento, California)		
	Wind Speed	Vapor Pressure
	Pressure	Heat Index
	Relative Humidity	

i. New York City Marathon (New York City, New York)

The notable variables from the correlation analysis for the New York City Marathon were heat index and wind chill index for both the locals and visitors, with wet bulb globe temperature noteworthy for the visitors. When performing a t-test to compare the means of the finishing times for similar and varying conditions for the local runners, neither variable produced a significant difference of means for the residuals of finishing times for any of the speed categories. This suggests that while these variables are notable for some subclasses of the locals (e.g., the elite runners), the entire local population was not impacted enough by a change in value to produce a prominent increase or decrease in finishing times. Consequently, the t-test analysis for the NYC Marathon was not able to extract a significant acclimation signal in the data.

The visiting runners however, did result in marginally significant difference of means of the residual running times for the wet bulb globe temperature. The results were not statistically significant to the ninety five per cent confidence level, but did return a *p*-value suggesting a significant difference in the means (Table 32)

Table 32 Student's t-test results for the New York City Marathon (New York City, New York).

Wet bulb Globe Temperature New York City Visitors	Conditions	N size	Mean	t-value	*p*-value
Time Group					
5%	Small Δ ($WBGT_b$-$WBGT_r$)	18	-0.0234	-1.560	0.128
	Large Δ ($WBGT_b$-$WBGT_r$)	17	0.0235		
Average	Small Δ ($WBGT_b$-$WBGT_r$)	18	-0.037	-1.450	0.159
	Large Δ ($WBGT_b$-$WBGT_r$)	17	0.038		
Median	Small Δ ($WBGT_b$-$WBGT_r$)	18	-0.036	-1.350	0.187
	Large Δ ($WBGT_b$-$WBGT_r$)	17	0.037		
95%	Small Δ ($WBGT_b$-$WBGT_r$)	18	-0.059	-1.630	0.114
	Large Δ ($WBGT_b$-$WBGT_r$)	17	0.058		

All race groups for the visitors, i.e., the fifth percentile, average, median, and ninety-fifth percentile, returned findings that when under race day conditions similar to baseline conditions, the runners had faster finishing times based on the residual means for the wet bulb globe temperature. Under varying race day conditions from baseline, the runners recorded slower finishing times for the wet bulb globe temperature. The wet bulb globe temperature recorded warmer values on race day compared to the baseline conditions for ten out of the eighteen years. I would expect that the visiting racers would likely have performed better under conditions that were different from the baseline conditions as they may move toward conditions they acclimated to or are accustomed to training in. However, it is possible that conditions favor either the weather the visitors trained in or that the conditions of the race day are more moderate than their training values which can improve performance as seen in research by Morris et al. (2005). This may further be explained as the New York City Marathon has a large population of visiting runners from every state within the United States and multiple countries, and as such results from the visitors may not be as conclusive as range of training and acclimated conditions vary greatly across all runners.

ii. Equinox Marathon (Fairbanks, Alaska)

The notable meteorological variables and indices from the Equinox Marathon correlation analysis were dew point temperature, wind chill index, apparent temperature and wind chill equivalent temperature for the locals and pressure, saturation vapor pressure and wind chill index for the visitors. Of those variables for the locals, the wind chill index and wind chill equivalent temperature returned marginally significant results for the two-way t-test comparing similar and different race day conditions with the baseline for the residuals of the runners' times for the average and ninety-fifth percentile groups and dew point temperature for the fifth percentile. T-test results comparing similar and different race day conditions with the baseline for the visitors running times (residuals) resulted in pressure showing a marginally significant difference of means for the average, median and ninety-fifth percentile groups and saturation vapor pressure being significant for the fifth percentile (Table 33).

Table 33 Student's t-test results for the Equinox Marathon (Fairbanks, Alaska).

Dew Point	Fairbanks Locals				
	Conditions	N size	Mean	t-value	*p*-value
Time Group					
5%	Small Δ (Dp_b-Dp_r)	14	-0.0198	-1.120	0.275
	Large Δ (Dp_b-Dp_r)	14	0.0250		
Wind Chill Index	Fairbanks Locals				
	Conditions	N size	Mean	t-value	*p*-value
Time Group					

Table 33 (continued)

	Conditions	N size	Mean	t-value	*p*-value
5%	Small Δ (WCI_b-WCI_r)	14	-0.015	-0.890	0.383
	Large Δ (WCI_b-WCI_r)	14	0.021		
Wind Chill Equivalent Temperature Locals					
	Conditions	N size	Mean	t-value	*p*-value
Time Group					
Average	Small Δ (WET_b-WET_r)	14	0.069	1.380	0.181
	Large Δ (WET_b-WET_r)	14	-0.051		
95%	Small Δ (WET_b-WET_r)	14	0.178	1.410	0.172
	Large Δ (WET_b-WET_r)	14	-0.146		
Pressure Visitors					
	Conditions	N size	Mean	t-value	*p*-value
Time Group					
Average	Small Δ (P_b-P_r)	14	0.119	1.260	0.220
	Large Δ (P_b-P_r)	14	-0.140		
Median	Small Δ (P_b-P_r)	14	0.137	1.200	0.241
	Large Δ (P_b-P_r)	14	-0.141		
95%	Small Δ (P_b-P_r)	14	0.176	1.210	0.239
	Large Δ (P_b-P_r)	14	-0.280		
Saturation Vapor Pressure Visitors					
	Conditions	N size	Mean	t-value	*p*-value
5%	Small Δ ($Sat.VP_b$-$Sat.VP_r$)	14	-0.234	1.200	0.248
	Large Δ ($Sat.VP_b$-$Sat.VP_r$)	14	-0.323		
Wind Chill Index					
	Conditions	N size	Mean	t-value	*p*-value
Time Group					
5%	Small Δ (WCI_b-WCI_r)	14	0.014	1.300	0.208
	Large Δ (WCI_b-WCI_r)	14	-0.062		

The dew point, which only resulted in a difference in means of the residuals of the fifth percentile (elite) runners, resulted in a faster performance when race day-to-baseline conditions were similar and a slower performance when race day conditions varied from baseline conditions, thus supporting my hypothesis. Again when viewing direction, in cases where race day conditions remained similar to baseline, there was a decrease in dew point temperature recorded for nine of the fourteen years.

A decrease in dew point temperature suggests a drying of the atmosphere. A drying of the atmosphere would imply that evaporative cooling would be more effective which would help cool the runners. An increase in race time due to a larger change in dew point temperature may be the result of two factors. The first is a decrease in the effectiveness of evaporative cooling. If the atmosphere dries to a point at which the sweat that is evaporated occurs at a faster rate the cooling benefits are very small (Kenney et al. 2004). Second, Cheung (1998) states that inadequate fluid intake can result in any benefit of acclimation to be lost.

Similarly, for the fastest runners, the fifth percentile, resulted in faster finishing times when the wind chill temperature remained similar to the base line conditions on race day. When viewing the direction of change when the conditions were similar the race day recorded higher wind chill values seven of the fourteen years. This relationship supports my hypothesis as when the runners are acclimated to a particular wind chill index, if that value remains similar on race day conditions the fastest runners saw a improvement on their finishing times (faster finishing times).

Conversely, for the local runners, the wind chill equivalent temperature resulted in slower finishing times when race day-to-baseline conditions were similar and faster finishing times when race day conditions varied from the baseline. The slowing of local runners when the conditions are similar disproves my hypothesis that local runners should see an increase in performance when conditions are similar, as they should therefore be similar to the conditions they are acclimated to.

However, when viewing the direction of change for the similar conditions instead of just the magnitude of change, the wind chill equivalent temperature had eight years that were warmer than baseline conditions and six years that were cooler. These results suggest that a cooling of sensible temperature by the addition of wind is more welcomed by the runners, especially while running their body is producing up to eleven times the energy and heat as it does at rest (Spellman 1996). This is further supported by viewing the direction of change when conditions were different from baseline conditions, as eight out of the fourteen years resulted in a cooling of temperatures. As discussed earlier appropriate clothing choices for this race play a large role in the comfort of those participating. While locals are most accustomed to training in the cooler conditions of Alaska, they may still find themselves slightly over dressed, which would cause them to welcome the decrease in sensible temperature in terms of comfort.

The visiting runners showed a difference in means of the residual finishing times between similar and different race day-to-baseline conditions for the slower runners (e.g, average, median and ninety-fifth percentile) for barometric pressure and the fifth percentile with saturation vapor pressure. For all three speed groups, average, median, and ninety-fifth percentile, if pressure was similar to baseline conditions on race day finishing times were slower than if there was a change in conditions. Under similar conditions, nine of the fourteen years were slightly higher in pressure on race day compared to baseline conditions.

Under clearer conditions this finding suggests that increased solar radiation may impact the runners. It may make the runners feel warmer as direct radiation can increase the sensible temperature. Additionally, if there is snow cover the increased solar radiation reflected off the snow may impact their comfort as they may feel their vision is impaired if they do not have sunglasses. When the pressure changed from baseline conditions, the direction of change was split between seven years with increasing pressure values and seven years of pressure values decreasing. When pressure changes greatly, it may have more of an impact on the runners' psychological outlook on the race, as clearing skies from cloudy conditions or increased cloud cover from clear conditions may be a welcome change.

The elite (fifth percentile) runners saw a difference in residual means with similar race day values of saturation vapor pressure compared to baseline. This resulted in slower finishing times and a difference in saturation vapor pressure resulting in faster finishing times for the similar race day-to-baseline conditions. In years when race day conditions were similar to baseline, the saturation vapor pressure was lower for nine of the fourteen years, indicating that the atmosphere could hold less water vapor. This may impact the runners by decreasing the effectiveness of evaporative cooling as the atmosphere cannot hold as much water vapor. As such, the runners may find themselves more uncomfortable as these types of conditions would act like more humid conditions which are more difficult to acclimate to. Additionally, being over dressed can decrease the body's ability to cool through heat loss as it can be hampered by clothing choice (Cheung 1998).

That in combination with a decrease in the atmospheric moisture capacity may greatly impact the runners. When the conditions varied from baseline conditions the years were evenly split between an increase and a decrease of the saturation vapor pressure value.

The fastest runners (fifth percentile) also saw an improvement in their finishing times (faster finishing times) when the wind chill value differed on race day from the baseline conditions. This type of relationship suggests the conditions may be moving more toward their acclimated and training conditions. The directional change of the wind chill index was split with seven years having race day values recording higher values and seven years recording lower race day values. As such, the clothing worn by the races may assist in keeping the runners warm in cooler conditions than they are acclimated to, or overdressing may interfere with evaporative cooling.

iii. California International Marathon (Sacramento, California)

The correlation analysis resulted in several notable variables including: wind speed, pressure, and relative humidity for the locals and vapor pressure and heat index for the visitors. Of those wind speed and pressure resulted in a notable difference in residual means between similar and different race day-to-baseline conditions for the locals as did both vapor pressure and heat index for the visitors (Table 34)

Table 34 Student's t-test results for the California International Marathon (Sacramento, California).

Wind Speed California International Marathon Locals					
	Conditions	N size	Mean	t-value	*p*-value
Time Group					
Average	Small Δ (WS_b-WS_r)	14	-0.021	-1.150	0.262
	Large Δ (WS_b-WS_r)	14	0.021		
95%	Small Δ (WS_b-WS_r)	14	-0.045	-1.590	0.124
	Large Δ (WS_b-WS_r)	14	0.045		

Pressure California International Marathon Locals					
	Conditions	N size	Mean	t-value	*p*-value
Time Group					
95%	Small Δ (P_b-P_r)	14	-0.046	-1.740	0.096
	Large Δ (P_b-P_r)	14	0.053		

Vapor Pressure California International Marathon Visitors					
	Conditions	N size	Mean	t-value	*p*-value
Time Group					
Average	Small Δ (VP_b-VP_r)	14	0.040	1.430	0.170
	Large Δ (VP_b-VP_r)	14	-0.031		
Median	Small Δ (VP_b-VP_r)	14	0.036	1.330	0.196
	Large Δ (VP_b-VP_r)	14	-0.028		
95%	Small Δ (VP_b-VP_r)	14	0.063	1.650	0.113
	Large Δ (VP_b-VP_r)	14	-0.057		

The results of the two-value t-test between similar and different race day-to-baseline conditions for the local runners supports my hypothesis that the more similar conditions on race day compared to baseline conditions, the better the runners' performance. The average and ninety-fifth percentile had faster finishing times when the wind speed was similar to the baseline conditions. When conditions were similar on race day to the baseline conditions nine of the fourteen years experienced an increase wind speed on race day. While an increased wind speed can slow a runner by five per cent (Spellman 1996), it is rare to have a head wind for the entire race. Increased wind speed can have a positive impact on runners if it encourages evaporative cooling thereby leaving runners feeling more comfortable as their sweat is evaporated at a faster rate.

Pressure also led to a difference of residual means between similar and different race day-to-baseline conditions for the slowest (ninety-fifth percentile) group, again supporting my hypothesis that the runner would see an increase in performance when pressure values were similar to baseline conditions on race day. There was no directional difference that dominated the fourteen years, as the pressure rose on race day seven years and dropped on race day seven years. When pressure varied from baseline conditions the pressure dropped eight of the fourteen years suggesting increased cloud cover. As such, it again may be based on psychological outlook, as these runners are most comfortable running under the conditions to which they are accustomed.

The visiting runners' finishing times were impacted by both vapor pressure and heat index. For the better (i.e., average, median, and ninety-fifth percentile) runners, similar race day values of vapor pressure to baseline conditions resulted in slower finishing times, while differing values resulted in faster finishing times. When conditions were similar, vapor pressure recorded on race day increased ten out of the fourteen years, which suggests an increase in moisture in the atmosphere. As visiting runners, they may be training in and acclimatized to drier conditions and this slight increase in vapor pressure results in a slowing of their times. Not only may the runners be unacclimatized to more humid conditions, but those that are may still feel an impact given a decrease in evaporative cooling efficiency. With increased moisture in the atmosphere sweat produced will be evaporated at a decreased rate.

iv. Conclusion

The Student's t-test determines if there is a significant difference in the means of the two populations tested. In this case, I tested whether the weather variables between similar and different race day-to-baseline conditions were significant in discriminating race finishing times. Notable correlation variables determined which variables would be used to determine if there was a difference in finishing time when conditions were similar to baseline conditions versus when conditions were different than baseline conditions. The three longest record races were used and divided into halves to increase the n-size of the samples. This test was also used to determine the validity of my hypothesis stating that when race day conditions are similar to baseline conditions the locals will see a decrease in their finishing times (faster finishing times).

New York City Marathon (New York City, New York)

- Locals
    - There was no significant difference of means in the finishing times of the two groups (similar conditions to baseline and differing conditions from baseline). This suggests that the local runners as an entire population were not impacted by a change in the conditions. Consequently, these analyses for the NYC Marathon were not able to extract a significant acclimation signal in the data.
- Visitors
    - Visiting runners recorded faster finishing times when the race day wet bulb globe temperatures were similar to baseline conditions. These findings seem contradictory to what one might expect, as a change in conditions from baseline conditions may suggest that the values are moving toward conditions the visiting runners are

acclimated to, thus decreasing their finishing times. These findings may be impacted by the large variations in training and acclimation conditions given the diversity in the visiting population.

Equinox Marathon (Fairbanks, Alaska)

- Locals
    - Dew point, which only suggested in a difference in means of the residuals of the elite (fifth percentile) runners, resulted in a faster performance when race day-to-baseline conditions were similar and a slower performance when conditions varied from baseline conditions, thus supporting my hypothesis. A decrease in dew point temperature suggests a drying of the atmosphere. A drying of the atmosphere would imply that evaporative cooling would be more effective which would help cool the runners.
    - Wind chill index recorded in a difference of means of the fastest runners (fifth percentile) when wind chill values were similar on race day to the baseline conditions. The runners resulted in faster finishing times when the conditions were similar to baseline conditions supporting my hypothesis.
    - Wind chill equivalent temperature resulted in slower finishing times when race day-to-baseline conditions were similar and faster finishing times when conditions varied from baseline. However, the slowing of local runners when conditions are similar argues

against my hypothesis that local runners will see an increase in performance when conditions are similar, as they should therefore be similar to conditions they are acclimated to. These results suggest that a cooling of sensible temperature by the addition of wind is more welcomed by the runners, especially while running as their body is producing up to eleven times the energy and heat as it does at rest (Spellman 1996).

- Visitors
    - Visiting runners showed a difference in means of the residual finishing times for the slower (average, median and ninety-fifth percentile) runners for barometric pressure with slower finishing times when race day conditions were similar to the baseline. Changes in barometric pressure may have a psychological impact on the runners and are therefore less related to acclimation. When pressure changes greatly from the baseline to race day, it may have more of an impact on the runners' psychological outlook on the race, as clearing skies from cloudy conditions or increased cloud cover from clear conditions may be a welcome change. This type of psychological effect was also seen in a study performed by Ely et al. (2007).
    - The fifth percentile runners saw a difference in residual means with similar race day-to-baseline values of saturation vapor pressure resulting in slower finishing times and a difference in race

day saturation vapor pressure from baseline conditions resulting in faster finishing times. Saturation vapor pressure not only relates to temperature, but also influences the moisture capacity of the atmosphere. Decreased capacity to hold moisture may decrease the effectiveness of evaporative cooling.

    - The wind chill index also returned a difference of residual means for the wind chill index for the fastest runners (fifth percentile). The visiting runners' experience faster finishing time when the race day conditions varied from the baseline conditions. As such, the finding suggest that the race day conditions moved toward the values of the wind chill index they were acclimated to.

California International Marathon (Sacramento, California)

- Locals
    - The average and ninety-fifth percentile speed groups had faster finishing times when the race day wind speed was similar to baseline conditions. This finding supports my hypothesis stating that similar conditions will result in faster finishing times for the locals. Increased wind speed can have a positive impact on the runners if it encourages evaporative cooling leaving the runners feeling more comfortable as their sweat is evaporated at a faster rate.
    - Pressure also led to a difference of residual means between similar and different race day-to-baseline conditions for the slowest

(ninety-fifth percentile) group. While increased speed supports my hypothesis, pressure again seems to have a greater impact psychologically, rather than act as an acclimation factor.

- Visitors
    - The slower (average, median, and ninety-fifth percentile) runners recorded slower finishing times with similar race day values of vapor pressure to baseline conditions, while differing values between race day and baseline conditions resulted in faster finishing times. As visiting runners, these slower runners may be training in and acclimatized to drier conditions and this slight increase in vapor pressure results in a slowing of their times. Not only may the slower runners be unacclimatized to more humid conditions, but those that are acclimatized may still feel an impact given a decrease in the efficiency of evaporative cooling. With increased moisture in the atmosphere the sweat produced will be evaporated at a decreased rate.

A two-way t-test determines if there is a significant difference in means of two groups, which for this study were the runners' finishing times. Using the notable variables from the prior correlation analysis the finishing times were divided into two groups: those years the conditions were most similar to baseline conditions and those years the conditions were different from the baseline conditions. The t-test was used to evaluate my hypothesis that if the conditions on race day were similar to the baseline conditions the locals would see an increase in performance. Two variables supported my hypothesis: dew point temperature for the Equinox Marathon (Fairbanks, Alaska) and wind speed for the California International Marathon (Sacramento, California). Barometric pressure, which resulted in a difference of means for locals (Equinox Marathon) and visitors (California International Marathon), once again seemed to have a greater psychological impact which supports findings by Ely et al. (2007) rather than be an indication of acclimation.

f. Conclusions

My research question, specifically "to what degree can acclimation be discriminated within both local and visiting populations as measured within the marathon running community," resulted in two primary hypotheses. The first was that locals runners' finishing times would be more significantly impacted when the meteorological variables and indices on race day were different from those of the five days prior to the race (baseline conditions) as they would not be acclimated to those conditions. My second hypothesis was that when conditions on race day were similar to the baseline conditions the locals would see an increase in performance (faster finishing times), as those were the conditions they were acclimated to.

In order to evaluate my research question I first performed mathematical transformations on the data that were not normally distributed, as parametric statistical tests can only be performed with normally distributed data (Ebdon 1985). I then performed a simple linear regression test to remove the trend in the race data as all speed groups (fifth percentile, average, median, and ninety-fifth percentile) experienced an increase in finishing times (slower finishing times) from the 1970s to the present. This test produced residual values for the finishing times which were then used for statistical analysis.

A correlation analysis determined the variables which resulted in a difference in significance to the runners' finishing times (both local and visitor groups) from when conditions were similar to baseline (averaged weather of the five days previous to the race) conditions and when conditions differed from baseline conditions. Finally, a two-way t-test was performed to determine a difference in means between the runners' finishing times when the meteorological variables and indices were similar on race day to baseline conditions and when they were different than baseline conditions.

These statistical tests which I performed on the six marathon races indicate that:

a) Although a generally weak signal (due likely to the small population of race years), an acclimation signal can be extracted from many of the races through several meteorological variables and indices.

b) The best meteorological indicator of acclimation appears to be a measure of humidity, dew point temperature, vapor pressure, or relative humidity. These findings support previous research evaluating runners and other athletics performing in warm dry and warm wet conditions (e.g. Armstrong et al. 1987; Hue et al. 2004; Morris et al. 2005; Hue et al. 2007). The amount of moisture in the atmosphere impacts human comfort by impacting the effectiveness of evaporative cooling. Runners' heat production can be up to eleven times of that of a person at rest (Spellman 1996) which can result in increased sweat production as a method of cooling. When humidity levels increase, they can impact a person's ability to feel cooler and comfortable by decreasing the effectiveness of evaporative cooling.

c) The best race to extract the acclimation signal appears to be the New York City Marathon given the amount of data available, both in terms of population size and length of available data (1976 to present). The results from this race suggested that the heat index and the wet bulb globe temperature were important meteorological indices for determining heat acclimation. Additionally, the Equinox Marathon (Fairbanks, Alaska) allowed for an evaluation of acclimation in an 'extreme' climate. The findings suggested the importance of extreme conditions on the locals as well as external factors such as dressing appropriately for a race as both a local and a visitor.

d) The t-test results suggested that if conditions on race day are similar to the training or acclimated conditions for a runner, the runner would likely to see an improvement in his or her finishing time.

Consequently, these findings allow me to assess my primary hypothesis that the local runners' finishing times would be more significantly impacted if race day conditions were different from the five days leading up to the race (baseline). This assessment was particularly valid with the following variables and races: heat index at the New York City Marathon (New York

City, New York), wind speed and pressure at the California International Marathon (Sacramento, California), wet bulb globe temperature and dew point temperature (median and ninety-fifth percentile) at the LIVESTRONG Austin Marathon (Austin, Texas), temperature (average and median), vapor pressure and relative humidity at the Cincinnati Flying Pig Marathon (Cincinnati, Ohio), and temperature (average and ninety-fifth percentile and saturation vapor pressure (fifth and ninety-fifth percentile at the Ocala Marathon (Ocala, Florida).

Additionally, findings suggest that wind speed can have an effect on the runners' finishing times. While an increased wind speed can directly increase or decrease the finishing time, the role of wind can also be seen in the wind chill index and the wind chill equivalent temperature. Wind may help aid in conditions when the humidity is higher than what the runners are acclimated to.

My second hypothesis that the locals would see an increase in performance when conditions on race day were similar to the five days leading up to the race (baseline) condition was also supported by the following races and variables: wet bulb globe temperature at the New York City Marathon (New York City, New York), dew point (fifth percentile) at the Equinox Marathon (Fairbanks, Alaska) and wind speed (average and ninety-fifth percentile) at the California International Marathon (Sacramento, California).The implications of these results will be addressed in the next chapter.

5. Summary and Conclusions

a. Justification

While this research was designed to give insight to runners on how their training conditions and the type of conditions they are acclimated to will impact their finishing times in races inside and outside of their training area, it can also be applied to other athletes and the many people involved with races from planners to volunteers to emergency services. Runners can use this information to plan what races they will compete in based on location and time of the year to ensure the most comfort and best performance. This insight can be extremely important to runners looking to qualify for races such as the Boston Marathon. Additionally, runners can use this information to help them adjust their travel plans for a race based on the type of conditions of the host race city.

Emergency services and planners can not only use this information when planning races but also when planning large scale events that draw a large visiting population. Being aware of who is coming to an event and how they may be impacted by the weather conditions can allow organizers and emergency services to ensure they have enough supplies, like water and ice, to address any health issues that may arise.

b. Hypothesis

Previous research has found that acclimation to different weather conditions can take anywhere from a few days to multiple weeks (Sawka et al. 1996; Cheung 1998; Hanna 1999). Additionally, it has been found by many researchers that warm dry conditions are easier to acclimate to than warm wet conditions (e.g. Armstrong et al. 1987; Hue et al. 2004; Morris et al. 2005; Hue et al. 2007). Therefore, a person running in conditions they are not acclimated to may see an impact on their finishing time. To address acclimation, I evaluated the changes in persistent meteorological conditions by analyzing the conditions on the five days leading to race day. I hypothesized that the locals would see an impact on their finishing time if the race day conditions varied significantly from the five days prior to the race (baseline conditions). I believe that the locals should be acclimated to a particular set of conditions and if those conditions vary to a large extent on race day the runners will not feel as comfortable. Additionally, I hypothesized that the local runners would see an increase in performance (faster finishing times) when the conditions remained similar to the baseline conditions. I feel this is the case as the runners will be acclimated to the race day conditions, thus resulting in runners feeling comfortable during their run and less impacted by the race day weather conditions.

c. Data

The data for this study consist of marathon finishing times and weather variables for the race day and the five days leading up to the race. The marathons used for this study are the New York City Marathon (New York City, New York), Equinox Marathon (Fairbanks, Alaska), California International Marathon (Sacramento, California), LIVESTRONG Austin Marathon (Austin, Texas), Cincinnati Flying Pig Marathon (Cincinnati, Ohio) and Ocala Marathon (Ocala, Florida). The data from each race consist of first and last name, city, state, and country of residence, and finishing time. Some races provide additional data such as overall place, gender place, and various split times, however they were not used for this study. Three of the races had almost thirty years of finishing data: New York City Marathon (1973-2010), Equinox Marathon (1976-1984, 1986-1990, 1993-1995, 1997-2010), and California International Marathon (1983-2010). The other races had less than ten years of data: LIVESTRONG Austin Marathon (2000, 2002-2010), Cincinnati Flying Pig Marathon (2000-2008), and Ocala Marathon (2000-2006, 2008-2010). Missing race data were due to several reasons including: cancelation of race due to weather, cancelation of race by the organizers, and missing state of residence. The race data for all races and all years were divided into the locals, those that reside in the state where the race is being held, and visitors, those who do not reside in the state of the race city. Once divided into locals and visitors, the finishing times were broken into four classes: the fifth percentile, average, median, and ninety-fifth percentile. This break down of runners allowed for further study of the slower runners who have not been included in other athletic acclimation studies (e.g., Armstrong et al. 1987; Hue et al. 2004; Morris et al. 2005; Maxwell et al. 2006).

The weather data were collected from the closest weather station to the race location, which was typically an international or regional airport, from the ISD-Lite hourly weather integrated surface data base (http://www.ncdc.noaa.gov/oa/climate/isd/index.php?name=isd-lite). The data were collected at the following locations for each of the races: La Guardia International Airport (New York City Marathon), Fairbanks International Airport (Equinox Marathon), Sacramento International and Executive Airports (California

International Marathon), Austin/Mueller International Airport (LIVESTRONG Austin Marathon), Cincinnati Municipal Luken Airport (Cincinnati Flying Pig Marathon) and Gainesville Regional Airport (Ocala Marathon). Data were collected for the race day and the prior five days for each of the races. Several meteorological variables such as temperature, humidity and pressure, and heat stress indices such as the Heat Index and Wind Chill Index were averaged for race day and for the five days leading up to the race (baseline conditions).

d. Statistical analyses

Given the above data, I performed four different statistical tests. The first test was a simple linear regression to detrend the race data. De-trending the data ensured the statistical tests would not be masked by the influence of the year on the race times, as finishing times increased as running has become more popular.

I then calculated a z-score for each of the meteorological variables and indices to standardize each of the values for the race day average and the five day average. The difference between the five days leading up to the race (baseline) and race day values were calculated and then ranked for each variable to determine those years when the race day conditions were most similar to the baseline conditions and those years when the race day conditions were different from the baseline conditions. For each race the z-scores were divided into quartiles, allowing for the first and fourth quartile to be included in the correlation analysis (the Cincinnati Flying Pig Marathon was divided into thirds).

Next, I performed a correlation analysis for each race, for all speed groups (fifth percentile, average, median, ninety-fifth percentile) and for both locals and visitors with the various meteorological variables and indices for the years the race day conditions were most similar and different from the baseline conditions. A summary of the correlation analysis is as follows:

- When race day conditions changed dramatically from the acclimated conditions (as measured as the average of the previous five days) the locals' finishing times were impacted. This was particularly true for the following variables and races: the heat index at the New York City Marathon (New York City, New York), wind speed and pressure at the California International Marathon (Sacramento, California), wet bulb globe temperature and dew point temperature (median and ninety-fifth percentile) at the LIVESTRONG Austin Marathon (Austin, Texas), temperature (average and median), vapor pressure, and relative humidity at the Cincinnati Flying Pig Marathon (Cincinnati, Ohio), and temperature (average and ninety-fifth percentile) and saturation vapor pressure (fifth and ninety-fifth percentile) at the Ocala Marathon (Ocala, Florida).
- Humidity variables, dew point temperatures, vapor pressure, and relative humidity repeatedly influenced the runners' finishing times, supporting previous research evaluating athletes in warm dry and warm wet conditions (e.g. Armstrong et al. 1987; Hue et al. 2004; Morris et al. 2005; Hue et al. 2007).
- The visitors were impacted when visiting more humid locations, as they were not acclimated to warm wet conditions, supporting previous research that warm wet conditions are more difficult to acclimate to than warm dry

conditions (Armstrong et al. 1996, Kenny et al. 2004). The following groups of visitors experienced an increase in time with an increase in humidity: California International Marathon locals and visitors (average, median, ninety-fifth percentile), LIVESTRONG Austin Marathon locals, and Cincinnati Flying Pig Marathon locals and visitors (average and median).

- Wind speed or indices which include wind speed in their calculation, wind chill index and the wind chill equivalent temperature, impacted the runners' finishing times. In many cases, such as the New York City visitors and the Cincinnati Flying Pig visitors, an increase in wind speed or sensible temperature appeared to increase the effectiveness of evaporative cooling making runners feel more comfortable.
- In more extreme races, such as the Equinox Marathon (Fairbanks, Alaska), clothing choice impacted both the locals and the visitors, as over dressing can result in a decrease of heat exchange from the body.

Using the notable variables from the correlation analysis, I next performed a two-way t-test was on the three long term races: the New York City Marathon (New York City, New York), Equinox Marathon (Fairbanks, Alaska), and California International Marathon (Sacramento, California). The two-way t-test evaluated if there was a difference of means in finishing times when the race day conditions remained similar or differed from the baseline conditions. A summary of the two-way t-test is as follows:

- The local runners saw an improvement in performance, or faster finishing times, for the following variables and races: wet bulb globe temperature at the New York City Marathon (New York City, New York), dew point (fifth percentile) at the Equinox Marathon (Fairbanks, Alaska) and wind speed (average and ninety-fifth percentile) at the California International Marathon (Sacramento, California). Barometric pressure resulted in a difference of means for locals (Equinox Marathon) and visitors (California International Marathon), however pressure seems to have less to do with acclimation and is more of a psychological factor.

The results of the correlation analysis proved my hypothesis that the local racers would be more significantly impacted when the conditions on race day were different from the baseline conditions. This held specifically true for the following races and variables: the heat index and wind chill index at the New York City Marathon (New York City, New York), wind speed and pressure at the California International Marathon (Sacramento, California), wet bulb globe temperature and dew point temperature (median and ninety-fifth percentile) at the LIVESTRONG Austin Marathon (Austin, Texas), temperature (average and median), vapor pressure, and relative humidity at the Cincinnati Flying Pig Marathon (Cincinnati, Ohio), and temperature (average and ninety-fifth percentile) and saturation vapor pressure (fifth and ninety-fifth percentile) at the Ocala Marathon (Ocala, Florida).

My second hypothesis, that locals would see an improvement in their performance when race day conditions were similar to the baseline conditions, was supported by the following variables and races: wind chill index and wet bulb globe temperature at the New York City Marathon (New York City, New York), dew point (fifth percentile) at the Equinox Marathon (Fairbanks, Alaska) and wind speed (average and ninety-fifth percentile) at the California International Marathon (Sacramento, California).

e. Future work

I would suggest the following future work on this or similar research:

- Studying additional longer term races with thirty years or more of data.
- Examining a race that is held in a more “extreme” climate, such as Phoenix or Las Vegas which is in a warm climate or Minneapolis in a cold climate.
- Divide the race data into regional categories rather than locals (those that live in the city where the race is being held) and visitors (those visiting from another state or country). By dividing these data regionally, a stronger acclimation signal may be seen, while additionally other statistical methods such as geographically weighted regression could be applied.

f. Significance

Given the results of this study, a heretofore relatively neglected group of the general population, members of a ‘physically-fit’ population, are impacted by their conditions. Runners may not realize how their training and living conditions, those that they are acclimated to, may impact their performance if they participate in a race under conditions they are not accustomed to. The results support previous research that demonstrated how warm wet conditions are more difficult to acclimate to than warm dry conditions (Armstrong et al. 1987; Kenney et al. 2004). These findings were supported as the racers' finishing times were impacted by humidity variables including dew point temperature, vapor pressure, and relative humidity. Both locals and visitors responded to a change in performance based on increased or decreased humidity values.

One finding that has not been extensively researched in athletic studies acclimation or other acclimation studies is the role of wind. This study found that an increase in wind speed, or variables that included wind speed in their calculations such as wind chill temperature or wind chill equivalent temperature, can increase the effectiveness of evaporative cooling. This finding suggests that the negative effects that increased humidity may have on the effectiveness of evaporative cooling may be reduced if the presence of wind can increase movement of the air. Not only can moving air increase the effectiveness of evaporative cooling, but psychologically, people feel cooler with the presence of wind (Yang et al. 2009).

Additionally, planners, organizers and emergency services can use this information to better plan for the amount of supplies and personnel they may need on a race day. Not only may the visiting racers be impacted by the weather conditions they are not acclimated to, but when conditions on race day are different than those conditions leading up to the race, the locals have been found to also be impacted. Therefore, even when planning smaller races where a majority of the racers are local, the planners and emergency services should pay attention to the weather conditions and how they compare to the previous days.

While this research was primarily focused on the marathon runners, the results may be applied to other large scale events, such as fairs, concerts, or festivals. Although, those events are less strenuous, they draw a large population of both locals and visitors who may find themselves impacted by the meteorological conditions and be at a higher risk of heat vulnerability or stress due to a lack of acclimation to those conditions.

REFERENCES

50 State Marathon Club (2011) 50 State Marathon Club http://www.50statesmarathonclub.com/50dc/index.html Accessed January 2011

Adventure Marathon (2011) Adventure Marathon. http://www.adventure marathon.com/Austin-Marathon.aspx Accessed January 2011

Ali-Toudert F, Djenane M, Bensalem R, Meyer H (2005) Outdoor thermal comfort in the old desert city of Beni-Isguen, Algeria. Climate Res 28:243-256

American College of Sports Medicine (1984) Prevention of Thermal-Injuries during Distance Running - Position Stand. Med J Aust 141:876-879

Armstrong LE, Hubbard RW, DeLuca JP, Christensen E L (1987) Heat acclimatization during summer running in the northeastern United States. Med Sci Sports Exerc 19:131- 136

Austin Marathon (2010) LIVESTRONG Austin Marathon. youraustinmarathon.com. Accessed September 2010

Bainbridge S (2009) The First Years: 1963-1966 http://www.equinoxmarathon.org/index.php?option=com_content&task=view&id=45&Itemid=37. Accessed 12 January 2011

Baldwin, J (1973) Climates of the Unites States, ed. E. D. Service, 113. Washington DC

Balling RC, Brazel SW (1987) Diurnal-variations in Arizona Monsoon precipitation frequencies. Mon Weather Rev 115:342-346.

Basu R, Samet JM (2002) An exposure assessment study of ambient heat exposure in an elderly population in Baltimore, Maryland. Environl Health Perspect 110: 1219-1224

Binkley HM, Beckett J, Casa DJ, Kleiner DM, Plummer PE (2002) National Athletic Trainers' Association Position Statement: Exertional Heat Illnesses. J Athl Train 37:329-343

Blazejczyk K (2001) Assessment of recreational potential of bioclimate based on the human heat balance. Paper read at The First International Workshop on Climate, Tourism and Recreation

Blazejczyk K, Krawczyk B (1991) The Influence of climatic conditions on the heat-balance of the human body. Int J Biometeorolo 35:103-106

Boston Marathon (2011) Boston Marathon. http://www.baa.org/races/boston marathon.aspx Accessed January 2011

Budd GM (2008) Wet-bulb globe temperature (WBGT) – its history and its limitations. J Sci Med Sport 11:32

Bureau of Meteorology (2008) About the WBGT and Apparent Temperature Indices. http://www.bom.gov.au/. Accessed June 2010

California International Marathon (2010) California International Marathon. http://www.runcim.org/. Accessed January 2011

Carter III R, Cheuvront SN, Williams JO, Kolka MA, Stephenson LA, Sawka MN, Amoroso PJ (2005) Epidemiology of Hospitalizations and Deaths from Heat Illness in Soldiers. Med Sci in Sprts Exerc 37:1338 -1344

Chau PH, Chan KC, Woo J (2009) Hot weather warning might help to reduce elderly mortality in Hong Kong. Int J Biometeorolo 53:461-468

Cheung, S.S., T. M. McLellan. (1998) Heat acclimation , aerobic fitness, and hydration effects on tolerance during uncompensable heat stress. J Appl Physiolo 84:1731-1739

Cincinnati Flying Pig Marathon (2010) Cincinnati Flying Pig Marathon. http://www.flyingpigmarathon.com/. Accessed October 2010

DeBiasse KM (2008) A Critical Examination of Meteorolgical Heat Stress Indices in Predicting Performance at the ING New York City Marathon. Masters Thesis, Arizona State University

Dennis SC, Noakes TD (1999) Advantages of a smaller bodymass in humans when distance-running in warm, humid conditions. Eur J App Physiolo Occup Physiolo 79:280-284

Dixon PG, Broomer D M, Hedquist C, Kalkstein AJ, Goodrich GB, Walter JC, Dickerson CCIV, Penny SJ, Cerveny RS (2005) Heat mortality versus cold mortality: A study of conflicting databases in the United States. Bul Am Meteorolo Soc 86:937-943

Ebdon D (1985) Statistics in Geography. Blackwell, Massachusetts

Ely MR, Cheuvront SN, Roberts WO, Montain SJ (2007) Impact of weather on marathon-running performance. Med Sci Sports Exerc 39:487-493

Environmental Protection Agency (2009) Heat Island Effect. http://www.epa.gov/heatisld/

Equinox Marathon (2010) Equinox Marathon. http://www.equinoxmarathon.org/index.php?option=com_frontpage&Iteid=1. Accessed September 2010

Estle J (2010) Equinox Marathon. Personal Communication.

Fanger P (1972) *Thermal Comfort*. McGraw-Hill, New York

Granger O (1979) Increasing variability in California precipitation. Ann Assoc Am Geogr 69:533-543

Greene JS, Kalkstein L, Samenow J (2009) Heat-attributable mortality in a changing world: accounting for climate change and adaptation. *Fourth Symposium on Policay and Socio-Economic Reasearch* January 2009.

Gulyas A, Matzarakis A (2007) Selected Examples of Bioclimatic Analysis Applying the Physiologically Equivalent Temperature in Hungary. Acta Climatologica et Chorologica 37-46

Hanna JM (1999) Climate, Altitude, and Blood Pressure. Hum Bio 7:553

Hargreaves M (2008) Physiological limits to exercise performance in the heat. J Sci Med Sport 11:66-71

Harlan SL, Brazel AJ, Prashad L Stefano WL, Larsen L (2006) Neighborhood microclimates and vulnerability to heat stress. Soc Sci Med 63:2847-2863

Hoppe P (1999) The physiological equivalent temperature - A universal index for the biometeorological assessment of the thermal environment. Int J Biometeorolo 43:71-75

Hoppe P (2002) Different aspects of assessing indoor and outdoor thermal comfort. Eng Buildings 34:661-665

Hue O, Voltaire B, Galy O, Costes O, Callis A, Hertogh C, Blonc S (2004) Effect of 8 days of acclimation on biological and performance response in a tropical climate. J Sports Med Phys Fitness 4430-37

Hue O, Antoine-Jonville S, Sara F (2007) The effect of 8 days of training in tropical environment on performance in neutral climate in swimmers. Int J Sports Med 28:48-52

ING New York City Marathon (2010) ING New York City Marathon http://nycmarathon.org/ Accessed September 2010

ISD-Lite (2010) ISD-Lite Hourly Weather Data base. http://www.ncdc.noaa.gov/oa/climate/isd/index.php?name=isd-lite Accessed September 2010

Kalkstein AJ, Sheridan SC (2007) The social impacts of the heat-health watch/warning system in Phoenix, Arizona: assessing the perceived risk and response of the public. Int J Biometeorolo 52:43-55

Kalkstein L, Greene JS (1997) An Evaluation of Climate/Mortality Relationships in large U.S. Cities and the Possible Impacts of a Climate Change. Environ Health Perspect 105:84-93

Kenefick RW, Ely FR, Cheuvront FR, Palombo LJ, Goodman DA, Sawka MN (2009) Prior Heat Stress: Effect on Subsequent 15-min Time Trial Performance in the Heat. Med Sci Sports Exerc 41: 1311-1316

Kenney WL (1985) A Review of Comparative Responses of Men and Women to Heat Stress Environ Res 37:1-11

Kenney WL, DeGroot DW, Holowatz LA (2004) Extremes of human heat tolerance: life at the precipice of thermoregulatory failure. J of Therm Bio 29:479-485

Lee J, Bae J, Matsumoto T, Yang H, Min Y (2008) Tropical Malaysians and temperate Koreans exhibit significant differences in sweating sensitivity in response to iontophoretically administered acetylcholine. Int J Biometeorolo 53:149-157

Leppaluoto J, Hassi J (1991) Human Physiological Adaptations to the Arctic Climate. Arctic 44:139-145

Lin SM, Luo M, Walker RJ, Liu , Hwang S, Chinery R (2009) Extreme High Temperatures and Hospital Admissions for Respiratory and Cardiovascular Diseases. Epidemiol 20:738- 746

Marathon Training (2011) Marathon Training Program. http://www.marathontraining.com/marathon/m_sch_2.html Accessed March 2011

Matzarakis A, Mayer H, Iziomon MG (1999) Applications of a universal thermal index: physiological equivalent temperature. Int J Biometeorolo 43:76-84.

Maughan RJ, Shirreffs SM (1997) Preparing athletes for competition in the heat: developing an effective acclimization strategy Sports Sci Exchange 10:1-4

Maxwell NS, Aitchison TC, Mimmo MA (1996) The effect of climatic heat stress on intermittent supramaximal running performance in humans. Experimental Physiolo 81:833-845

McGeehin MA, Mirabelli M (2001) The potential impacts of climate variability and change on temperature-related morbidity and mortality in the United States. Environ Health Perspec 109:185-189

McKenzie JD, Golman R (2005) *The Student Guide to Minitab Release 14.* Pearson Addison Wesley

Minard D (1961) Prevention of Heat Casualties in Marine Corps Recruits – Period of 1955-60, with Comparative Incidence Rates and Climatic Heat Stresses in Other Training Categories. Mil Med 126:261-

Moran DS (2001) Potential Applications of Heat and Cold Stress Indices to Sporting Events. Sports Med 31:909-917

Morris JG, Nevill ME, Boobis LH, Macdonald IA, Williams C (2005) Muscle metabolism, temperature, and function during prolonged, intermittent, high-intensity running in ari temperature of 33 degress and 17 degrees C. Int J Sports Med 26:805-814

Moseley PL (1997) Heat shock proteins and heat adaptation of the whole organism. J App Physiol 83:1413-1417

Muldowney (2008) U.S. in another 'running boom' http://republicanherald.com/sports/u-s-in-another-running-boom-1.469153 Accessed January 2011

Nash B (2008) Fling Pig 2008 Course Tour. http://www.flyingpigmarathon.com/race_information/course/2008_course_tour.html. Accessed October 2010

National Oceanic and Atmospheric Administration (2010) Heat Wave: A Major Summer Killer. http://www.noaawatch.gov/themes/heat.php Accessed October 2010

National Weather Service (2010) Heat: A Major Killer http://www.nws.noaa.gov/os/heat/index.shtml#heatindexAccessed June 2010

Ocala Marathon (2010) Ocala Marathon. http://www.drcsports.com/standalones/Ocalamarathon/. Accessed November 2010

O'Neill MS, Ebi KL (2009) Temperature Extremes and health: impact of climate variability and change in the United States. J Occup Environ Med Radakovic SS, Maric J, Surbatovic M, Radjen S, Stefanova E, Stankovic N, Filipovic N (2007) Effects of acclimation on cognitive performance in soldiers during exertional heat stress. Mil Med 172:133-136

Patrick D (2009) Keflezighi breaks 27-year NYC Marathon drought for USA. http://www.usatoday.com/sports/olympics/2009-11-01-nyc-marathon-live_N.htm Accessed March 2011

Pidwirny M, Jones S (2011) Physical Geography. http://physicalgeography.net/ Accessed March 2011

Quayle RG, Steadman RG (1998) The Steadman wind chill: An improvement over present scales. Weather Forecasting 13:1187-1193

Radakovic SS, Donja S, Maric J, Subatovic M, Radjen S, Stefanova E, Stankovic N, Filipovic N (2007) Effects of Acclimation on Cognitive Performance in Soldiers during Exertional Heat Stress. Mil Med 172:133-136

Rothfursz LP (1990) The Heat Index "Equation" (or, More Than You Ever Wanted to Know About Heat Index). NWS Southern Region Headquarters Technical Attachment SR90-23

Saari M (2010) Equinox Marathon Personal Communication

Segal M, Pielke RA (1981) Numerical-model simulation of human biometeorlogical heat load conditions – Study for the Chesapeake Bay Area. J App Meteorolo 20:735-749

Selover N (2009) City of Phoenix: Exterme Heat. 2009. Personal Communication.

Seven Continents Club (2011) Seven Continents Club http://www.sevencontinentsclub.com/. Accessed January 2011

Sheridan SC, Kalkstein AJ, Kalkstein LS (2009) Trends in heat-related mortality in the United States, 1975-2004. Nal Hazards 50:145-160

Sheridan SC, Kalkstein LS (2004) Progress in heat watch-warning system technology. Bul Am Meteorolo Soc 85:1931-1941

Sinha A (2011) Chip Timing – What it does and How it Works. http://www.marathonguide.com/features/Articles/RaceTimingWithChip.cfm. Accessed February 2011

Spagnolo JC, De Dear RJ (2003) A human thermal climatology of subtropical Sydney. Inl J Climatolo 23:1383-1395

Steadman RG (1979) Assessment of Sultriness. 1. Temperature-humidity index based on human physiology and clothing science. J App Meteorolo 18:861-873

Steadman RG (1984) A Universal Scale of Apparent Temperature. J Clim App Meteorolo 23:1674-1687

Thauer R (1995) Circulatory adjustments to climate requirements. In *Handbook of Physiology*, sec. 2, vol. 3, *Circulation*, ,W. F. Hamilton and P. Dow, eds. Washinginton, DC: American Physiological Society, 1921-1966

Thom E (1959) The discomfort index. *Weatherwise* 12:57-60

U.S. Heat Stress Index (2001) U.S. Heat Stress Index http://www.ncdc.noaa.gov/temp-and-precip/heat-stress.html Accessed March 2011

Voogt JA (2002) Urban Heat Island. In I. Douglas (Ed.),Causes and consequences of global environmental change, Vol. 3. Encyclopedia of global environmental change (pp. 660-666). Chirchester: Wiley

Wallace RF, Kriebel D, Punnett L, Wegman DH, Wenger CB, Gardner JW, Gonzales RR (2005) The effects of continuous hot weather training on risk of exertional heat illness. Med.Sci.Sports Exerc 37:84-90

Watts JD, Kalkstein LS (2002) A new relative comfort index for warm weather. Bul Am Meteorolo Soc 83:1572-1574

Watts JD, Kalkstein LS (2004) The Development of a Warm-Weather Relative Stress Index for Environmental Applications. J App Meteorolo 43:503-513

Witman S, Good G, Donoghue ER, Benbow N, Shou W, Mou S (1997) Mortality in Chicago attributed to the July 1995 heat wave. Am J Pub Health 87:151-1518

Yang W, Zhang GQ (2009) Air movement presences observed initially ventilated buildings in humid subtropical climate zones in China. Int J Biometeorolo 53:563-573

Yip FY, Flanders WD, Wolkin A, Engelthaler D, Humble W, Neri A, Lewis L, Backer L, Rubin C (2008) The impact of excess heat events in Maricopa County, Arizona: 2000-2005. *Int J* Biometeorolo 52:765-772

APPENDIX A

DECRIPTIVE STATISTICS

DESCRIPTIVE STATISTICS FOR RACE DAY AND FIVE DAYS

PRIOR TO RACE DAY FOR THE NEW YORK CITY MARATHON

New York City Marathon Race Day	Mean	Median	Std. Dev.	Variance	Skewness	Kurtosis
Temperature	12.072	11.313	3.891	15.140	0.214	-1.022
Dew Point	4.273	2.642	5.891	34.698	0.455	-0.723
Wind Speed	5.329	5.079	2.060	4.242	1.603	4.022
Pressure	1018.400	1019.700	9.500	90.300	-0.469	-0.211
Vapor Pressure	0.897	0.739	0.396	0.157	1.004	0.109
Sat. Vapor Pressure	1.462	1.349	0.386	0.149	0.546	-0.658
Relative Humidity	59.761	55.011	14.184	201.184	0.693	-0.199
Heat Index	91.176	93.293	15.026	225.784	-0.112	-0.939
Wind Chill Index	50.665	49.582	9.140	83.546	0.183	-0.882
WBGT	14.296	13.239	3.580	12.815	0.447	-0.825
Appt. Temp.	7.290	6.271	5.587	31.215	0.266	-0.728
WET	8.590	8.186	4.896	23.975	0.017	-0.651
New York City Marathon Five Day						
Temperature	12.091	11.812	2.417	5.842	0.321	1.066
Dew Point	4.493	4.579	3.353	11.242	0.754	1.020
Wind Speed	5.267	5.170	0.911	0.831	0.064	-1.055
Pressure	1018.400	1017.700	5.600	31.700	-0.055	-0.629
Vapor Pressure	0.865	0.848	0.222	0.049	1.491	3.055
Sat. Vapor Pressure	1.437	1.395	0.239	0.057	0.899	1.736
Relative Humidity	59.795	59.836	8.221	67.581	0.575	-0.264
Heat Index	90.367	90.151	8.677	75.293	0.565	2.371
Wind Chill Index	50.814	50.019	5.454	29.744	0.485	1.190
WBGT	14.187	13.959	2.134	4.555	0.809	1.902
Appt. Temp.	7.252	6.878	3.337	11.132	0.796	1.490
WET	8.658	8.534	2.924	8.551	0.560	0.830

DESCRIPTIVE STATISTICS FOR RACE DAY AND FIVE DAYS PRIOR TO RACE DAY FOR THE CALIFORNIA INTERNATIONAL MARATHON

California International Marathon Race Day	Mean	Median	Std. Dev.	Variance	Skewness	Kurtosis
Temperature	8.946	8.551	2.685	7.207	0.353	-0.524
Dew Point	4.359	4.336	3.742	14.003	-0.202	-0.217
Wind Speed	3.481	3.350	2.039	4.125	0.837	0.262
Pressure	1018.600	1019.100	6.900	48.200	-0.446	-0.488
Vapor Pressure	0.860	0.834	0.223	0.050	0.340	-0.409
Sat. Vapor Pressure	1.166	1.118	0.219	0.048	0.680	-0.021
Relative Humidity	73.822	75.117	13.504	182.367	-0.092	-0.890
Heat Index	98.874	99.047	15.187	230.638	-0.040	-0.600
Wind Chill Index	48.665	49.551	6.818	46.484	-0.437	-0.249
WBGT	12.386	11.915	2.223	4.943	0.359	-0.508
Appt. Temp.	5.342	5.380	3.116	9.709	-0.240	-0.150
WET	6.944	7.247	2.748	7.552	-0.526	0.286
California International Marathon Five Day						
Temperature	9.058	8.843	2.468	6.092	0.609	0.414
Dew Point	5.151	5.450	2.957	8.741	-0.286	0.149
Wind Speed	2.872	2.704	1.335	1.783	0.781	0.313
Pressure	1019.900	1019.900	4.200	17.500	-0.518	0.291
Vapor Pressure	0.900	0.902	0.183	0.033	0.267	0.308
Sat. Vapor Pressure	0.900	1.141	0.206	0.043	1.018	0.988
Relative Humidity	77.010	78.846	10.666	113.768	-0.622	0.042
Heat Index	97.290	96.350	12.740	162.308	0.561	0.767
Wind Chill Index	50.786	50.760	5.600	31.358	0.285	-0.008
WBGT	12.602	12.420	1.981	3.925	0.531	0.363
Appt. Temp.	6.008	5.353	2.739	7.504	0.587	0.219
WET	7.575	7.066	2.394	5.731	0.755	0.656

DESCRIPTIVE STATISTICS FOR RACE DAY AND FIVE DAYS PRIOR TO RACE DAY FOR THE LIVESTRONG AUSTIN MARATHON

LIVESTRONG Austin Marathon Race Day	Mean	Median	Std. Dev	Variance	Skewness	Kurtosis
Temperature	9.417	9.045	5.413	29.302	0.213	1.106
Dew Point	2.170	1.411	5.356	28.685	1.451	*3.138*
Wind Speed	3.867	3.008	1.895	3.592	0.945	0.458
Pressure	1020.900	1021.300	7.500	55.700	-0.390	-0.872
Vapor Pressure	0.762	0.678	0.352	0.124	*2.295*	*6.185*
Sat. Vapor Pressure	1.244	1.154	0.469	0.220	1.244	*2.590*
Relative Humidity	62.436	62.774	15.635	244.442	-0.200	-0.693
Heat Index	108.030	104.650	25.590	654.970	0.681	1.475
Wind Chill Index	50.591	53.567	14.058	197.619	-0.01	0.323
WBGT	12.273	11.602	4.218	17.793	1.071	2.687
Appt. Temp.	5.224	5.067	6.294	39.613	0.247	1.334
WET	7.064	7.939	5.831	33.998	-0.387	0.787
LIVESTRONG Austin Marathon Five Day						
Temperature	11.353	11.997	5.227	27.323	-0.034	-1.291
Dew Point	5.541	6.087	5.516	30.427	0.326	-0.361
Wind Speed	4.475	4.292	1.103	1.217	0.252	-1.524
Pressure	1018.700	1019.100	4.300	18.200	-0.271	-1.010
Vapor Pressure	0.960	0.941	0.379	0.144	0.929	0.126
Sat. Vapor Pressure	1.407	1.404	0.476	0.226	0.357	-0.915
Relative Humidity	68.480	67.498	13.202	174.302	0.426	-1.031
Heat Index	98.002	93.395	20.083	403.341	0.394	-1.056
Wind Chill Index	52.664	53.879	13.618	185.452	0.242	-0.453
WBGT	14.152	14.529	4.290	18.406	0.224	-1.081
Appt. Temp.	7.391	8.027	6.447	41.561	0.038	-1.263
WET	8.528	9.320	5.745	33.004	-0.142	-1.327

DESCRIPTIVE STATISTICS FOR RACE DAY AND FIVE DAYS PRIOR TO

RACE DAY FOR THE CINCINNATI FLYING PIG MARATHON

Cincinnati Flying Pig Marathon Race Day	Mean	Median	Std. Dev.	Variance	Skewness	Kurtosis
Temperature	12.897	12.608	4.140	17.141	0.832	1.212
Dew Point	4.516	3.920	4.051	16.407	1.383	3.185
Wind Speed	2.509	1.975	1.147	1.315	1.232	0.351
Pressure	1020.200	1019.700	2.200	4.900	0.765	1.081
Vapor Pressure	0.872	0.809	0.283	0.080	2.037	5.111
Sat. Vapor Pressure	1.531	1.459	0.447	0.199	1.439	2.735
Relative Humidity	57.468	57.406	10.160	103.225	1.009	0.766
Heat Index	90.055	90.853	9.353	87.478	-0.098	-0.551
Wind Chill Index	37.768	39.271	9.201	84.663	-0.158	-0.337
WBGT	14.681	13.968	3.317	11.002	1.386	3.092
Appt. Temp.	10.019	9.654	5.030	25.297	1.253	3.069
WET	11.827	11.980	4.310	18. 58	0.926	2.185
Cincinnati Flying Pig Marathon Five Day						
Temperature	16.406	17.172	4.013	16.107	-0.319	-0.593
Dew Point	10.724	10.410	3.506	12.290	-0.328	-1.670
Wind Speed	2.860	2.893	1.051	1.104	0.653	-0.045
Pressure	1014.600	1013.900	3.200	10.400	0.425	0.799
Vapor Pressure	1.315	1.261	0.296	0.087	-0.174	-1.895
Sat. Vapor Pressure	1.910	1.957	0.471	0.222	0.053	-0.940
Relative Humidity	69.410	68.962	6.378	40.685	0.447	-1.405
Heat Index	80.318	78.242	7.910	62.563	0.343	-1.590
Wind Chill Index	40.835	38.167	8.897	79.160	0.961	-0.306
WBGT	18.410	18.634	3.383	11.443	-0.284	-1.066
Appt. Temp.	14.743	15.716	5.087	25.873	-0.358	-1.259
WET	15.138	16.353	4.337	18.813	-0.353	-1.118

APPENDIX B

DESCRIPTIVE STATISTICS FOR THE MATHEMATICALLY TRANSFORMED VARIABLES

DESCRIPTIVE STATISTICS OF MATHEMATICALLY

TRANSFORMED VARIABLES FOR THE NEW YORK CITY

MARATHON

New York City Marathon Race day						
	Mean	Median	Std. Dev.	Variance	Skewness	Kurtosis
Wind Speed$^{(1/3)}$	1.722	1.719	0.209	0.044	0.573	1.579
New York City Marathon Five Day						
$^{1}/_{\text{vapor pressure}}$	1.222	1.181	0.268	0.072	0.055	0.005

DESCRIPTIVE STATISTICS OF MATHEMATICALLY

TRANSFORMED VARIABLES FOR LIVESTRONG AUSTIN

MARATHON

LIVESTRONG Austin Marathon Local Runners							
Runners		Mean	Median	Std. Dev.	Variance	Skewness	Kurtosis
	95%	6.084	6.167	0.247	0.061	-1.941	4.095
LIVESTRONG Austin Marathon Visiting Runners							
	95%	5.735	5.759	0.255	0.065	-1.144	3.180
LIVESTRONG Austin Marathon Race Day							
$^{1}/_{\text{vapor pressure}}$		1.490	1.481	0.472	0.223	-0.241	0.371
SQRT sat. vapor pressure		1.099	1.074	0.202	0.041	0.671	1.521
SQRT WBGT		2.459	3.406	0.588	0.346	0.427	1.849

DESCRIPTIVE STATISTICS OF MATHEMATICALLY

TRANSFORMED VARIABLES FOR THE LIVESTRONG AUSTIN

MARATHON

Cincinnati Flying Pig Marathon Race Day	Mean	Median	Std. Dev.	Variance	Skewness	Kurtosis
$^{1}/_{\text{vapor pressure}}$	1.229	1.236	0.304	0.093	-0.355	1.437
SQRT sat. vapor press	1.227	1.208	0.171	0.029	1.100	1.814
WBGT $^{(1/4)}$	1.950	1.933	0.105	0.011	0.896	1.922
SQRT AT	3.080	3.107	0.774	0.598	0.431	1.380
SQRT WET	3.390	3.461	0.617	0.380	0.346	1.080

DESCRIPTIVE STATISTICS OF MATHEMATICALLY

TRANSFORMED VARIABLES FOR THE OCALA MARATHON

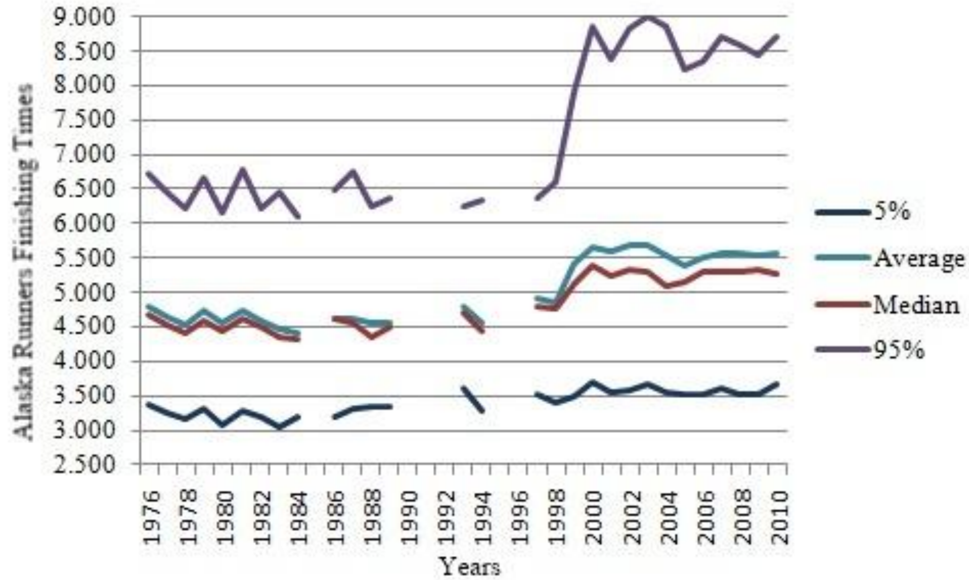
Ocala Marathon Visiting Runners	Mean	Median	Std. Dev.	Variance	Skewness	Kurtosis
SQRT 95%	2.416	2.431	0.092	0.008	0.671	1.933
Ocala Marathon Five Day						
Pressure	1019.600	1020.400	3.000	9.300	**-2.002**	**4.687**
SQRT vapor pressure	1.042	1.032	0.163	0.026	0.885	1.514
$^{1}/_{\text{sat. vapor pressure}}$	0.656	0.643	0.200	0.014	-0.510	0.722
sqrt WCI	7.435	7.394	0.430	0.185	1.050	1.947
sqrt WBGT	3.983	3.989	0.379	0.144	0.960	1.752
sqrt AT	3.330	3.283	0.606	0.367	0.781	1.330
sqrt WET	3.502	3.461	0.438	0.192	0.923	1.507

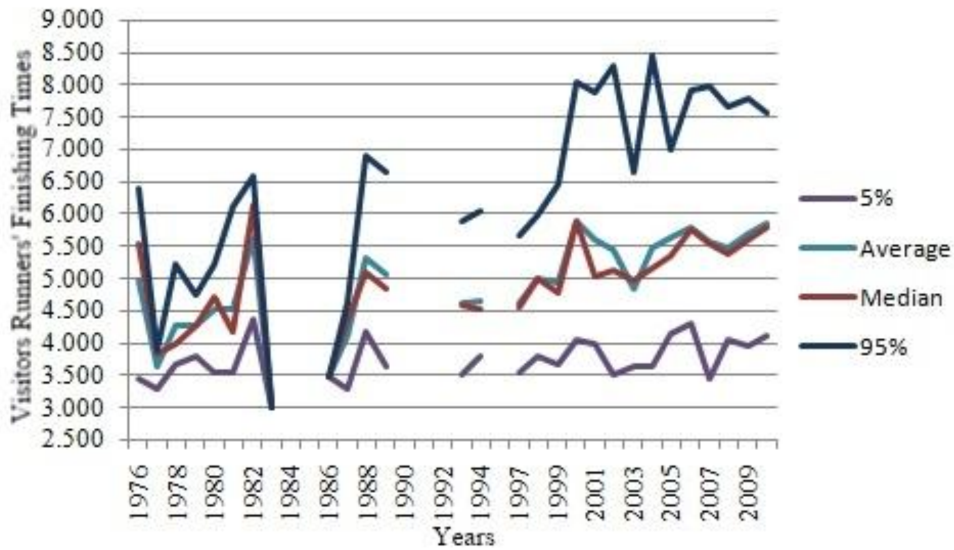
APPENDIX C

LOCAL AND VISINTING FINISHING TIMES WITH DETRENDED RESIDUAL VALUES

LOCAL AND VISITING FINISHING TIMES FOR THE EQUINOX

MARATHON (FAIRBANKS, ALASKA)

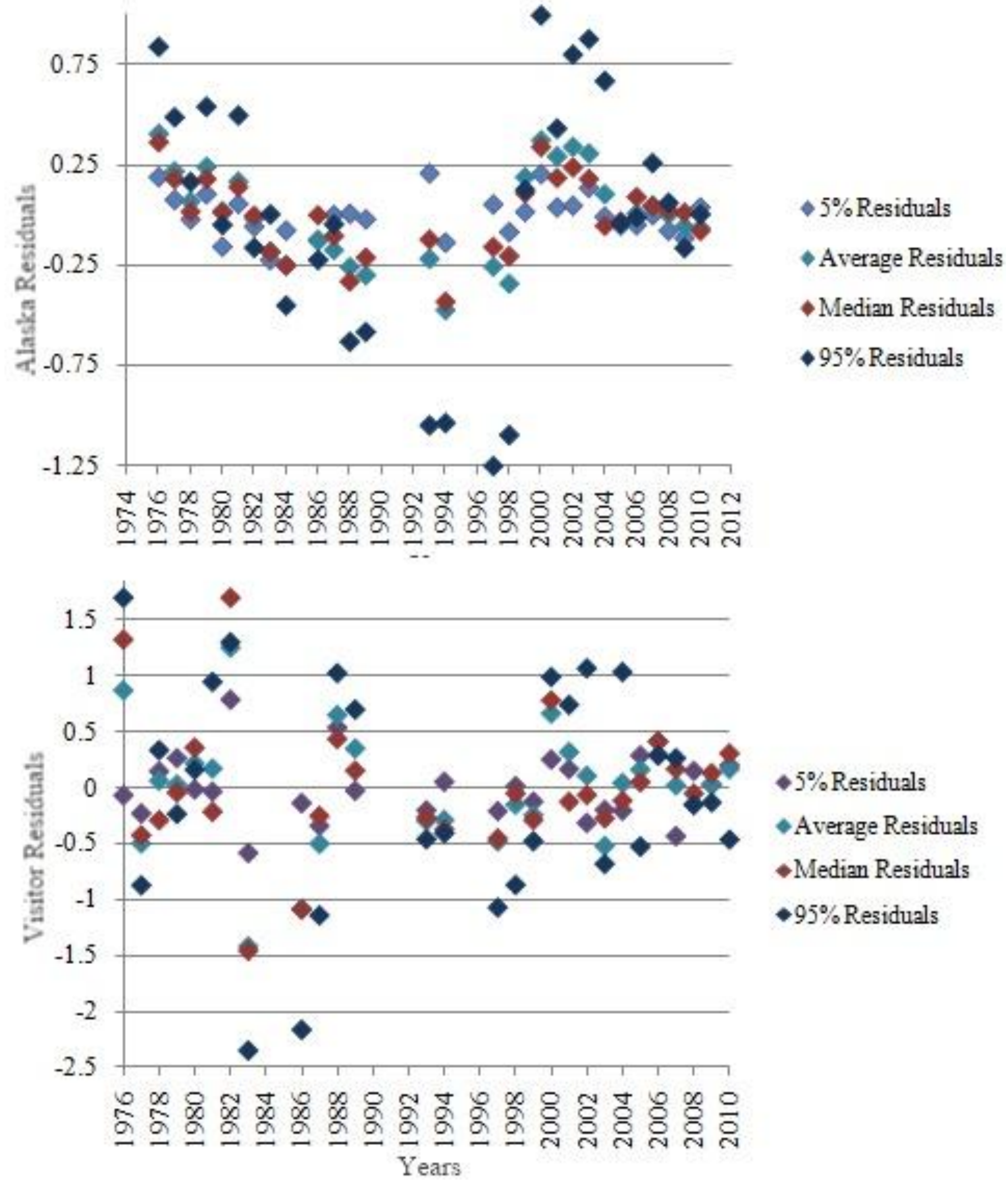




DETRENDED RESIDUAL VALUES FOR LOCAL AND VISITOR

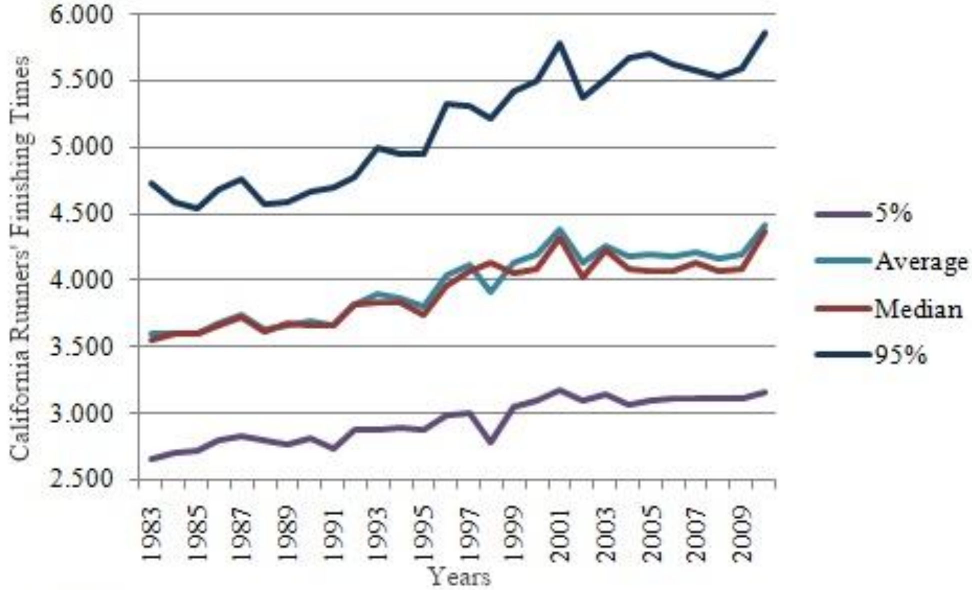
RUNNERS' FINISHING TIMES FOR THE EQUINOX MARATHON

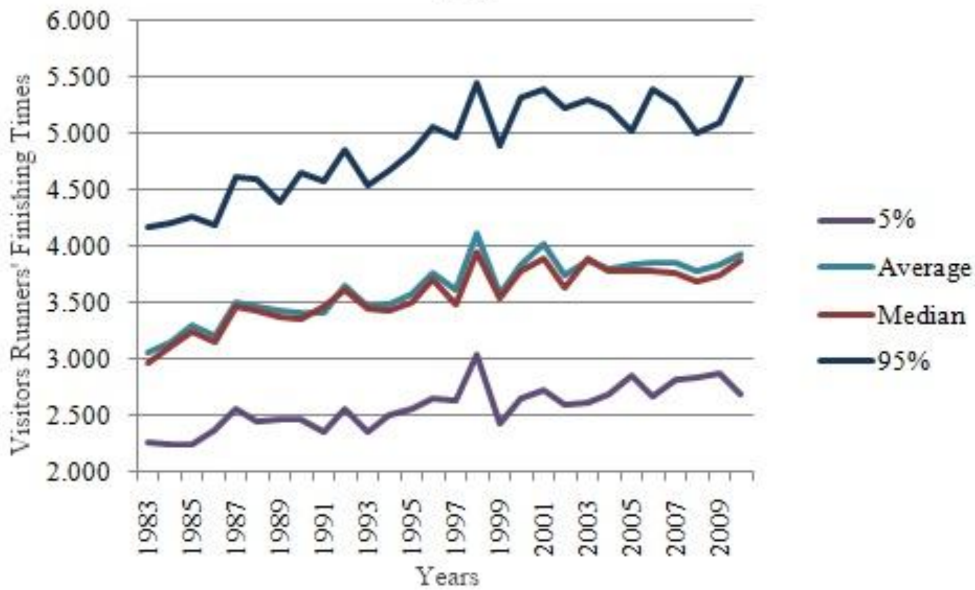
(FAIRBANKS, ALASKA)



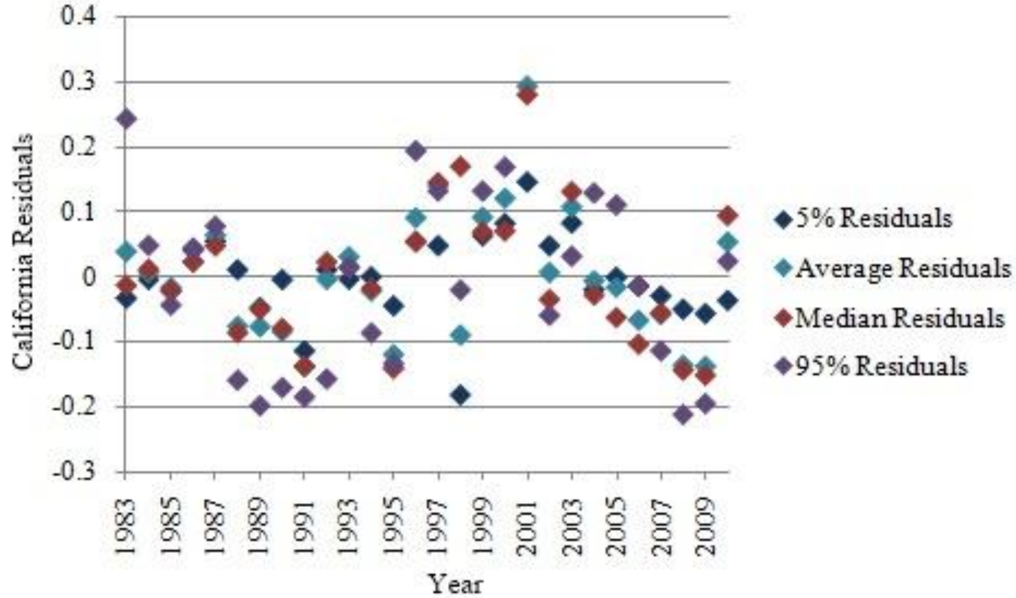
LOCAL AND VISITING FINISHING TIMES FOR THE CALIFORNIA

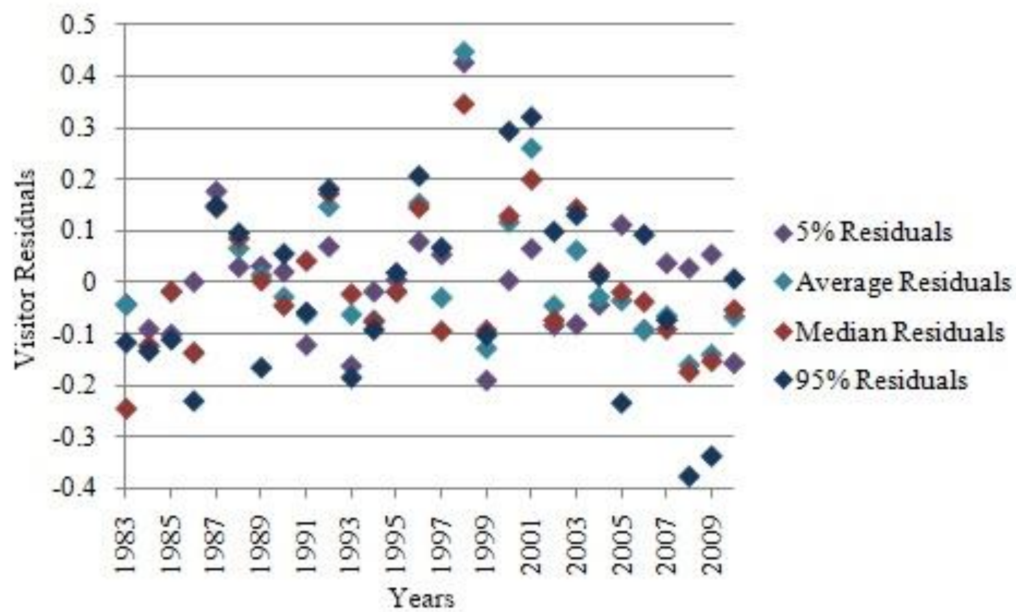
INTERNATIONAL MARATHON (SACRAMENTO, CALIFORNIA)





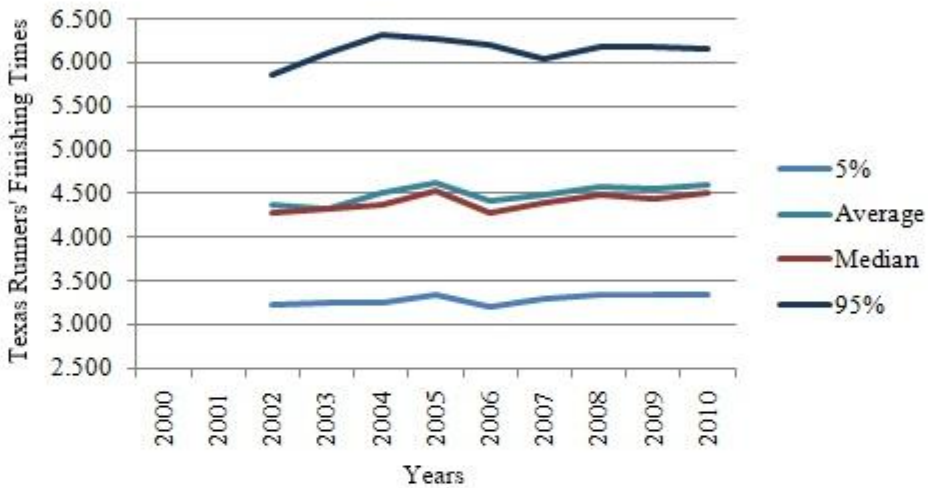
DETRENDED RESIDUAL VALUES FOR LOCAL AND VISITOR RUNNERS' FINISHING TIMES FOR THE CALIFORNIA INTERNATIONAL MARATHON (SACRAMENTO, CALIFORNIA)

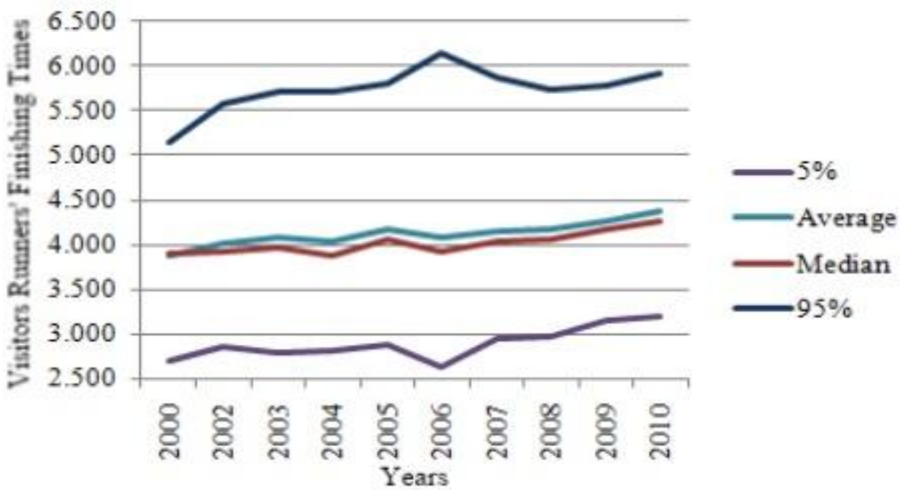




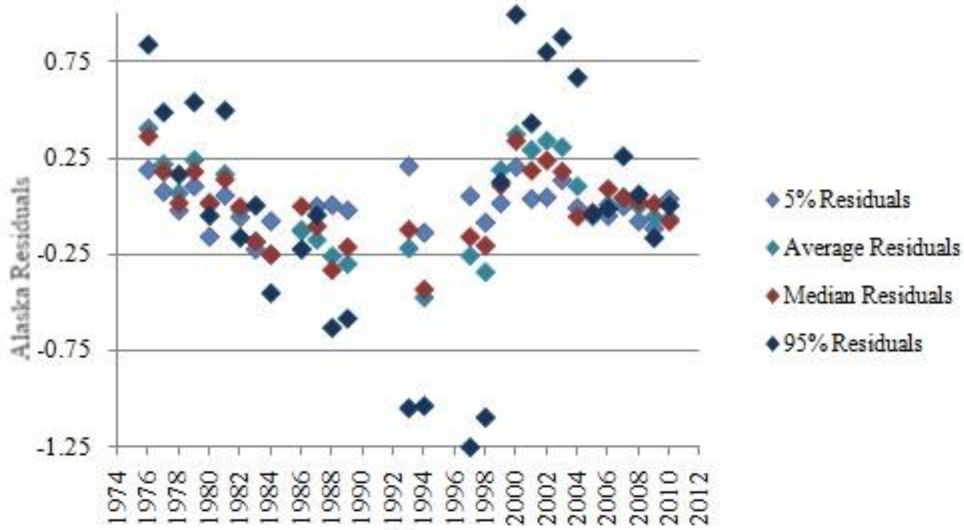
LOCAL AND VISITING FINISHING TIMES FOR THE LIVESTRONG

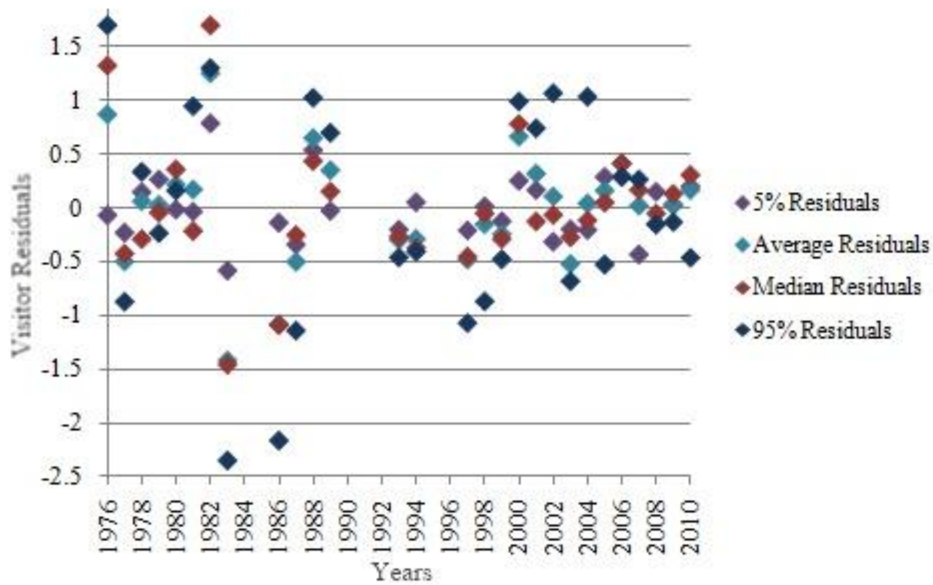
AUSTIN MARATHON (AUSTIN, TEXAS)





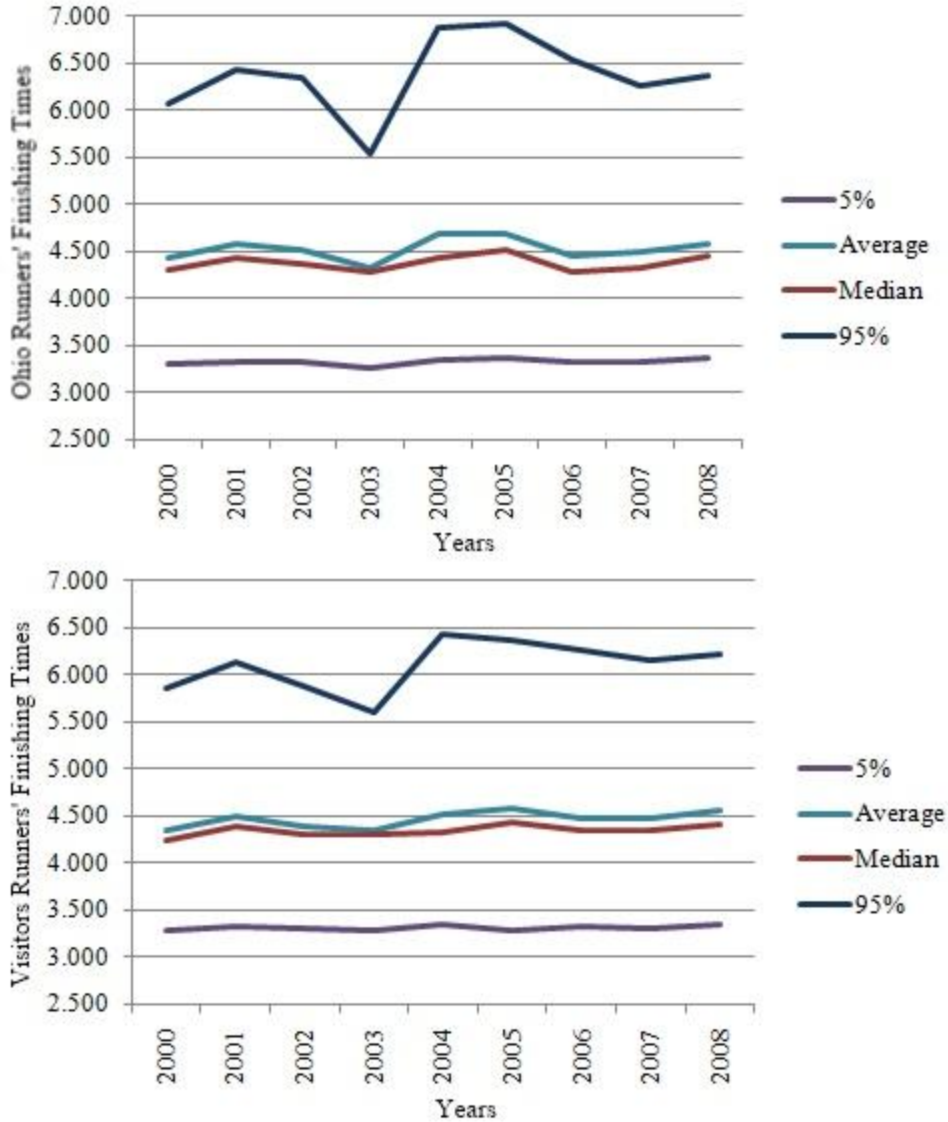
DETRENDED RESIDUAL VALUES FOR LOCAL AND VISITOR RUNNERS' FINISHING TIMES FOR THE LIVESTRONG AUSTIN MARATHON (AUSTIN, TEXAS)



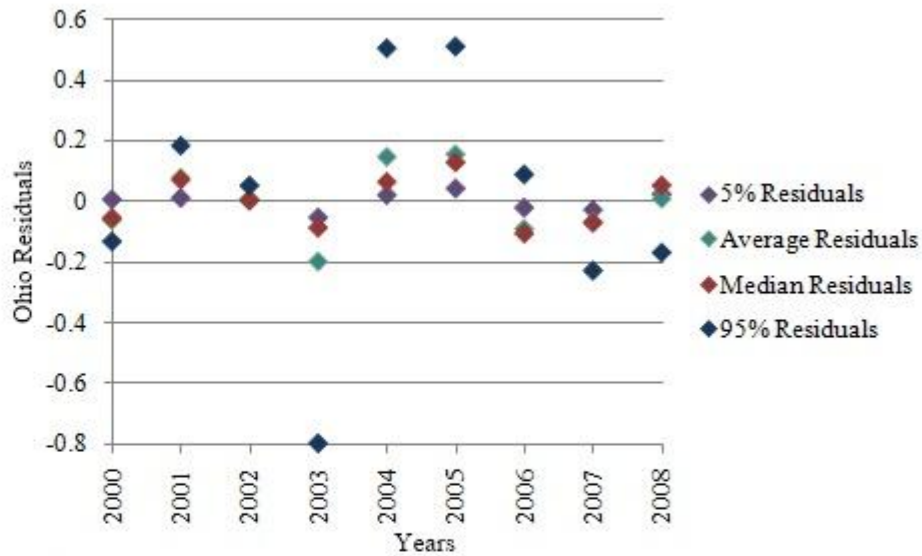


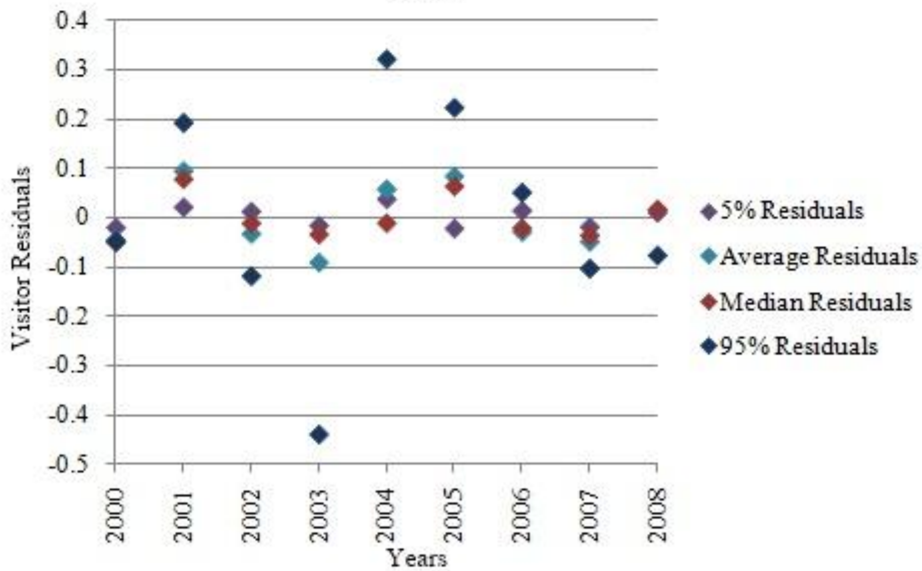
LOCAL AND VISITING FINISHING TIMES FOR THE CINCINNATI

FLYING PIG MARATHON (CINCINNATI, OHIO)



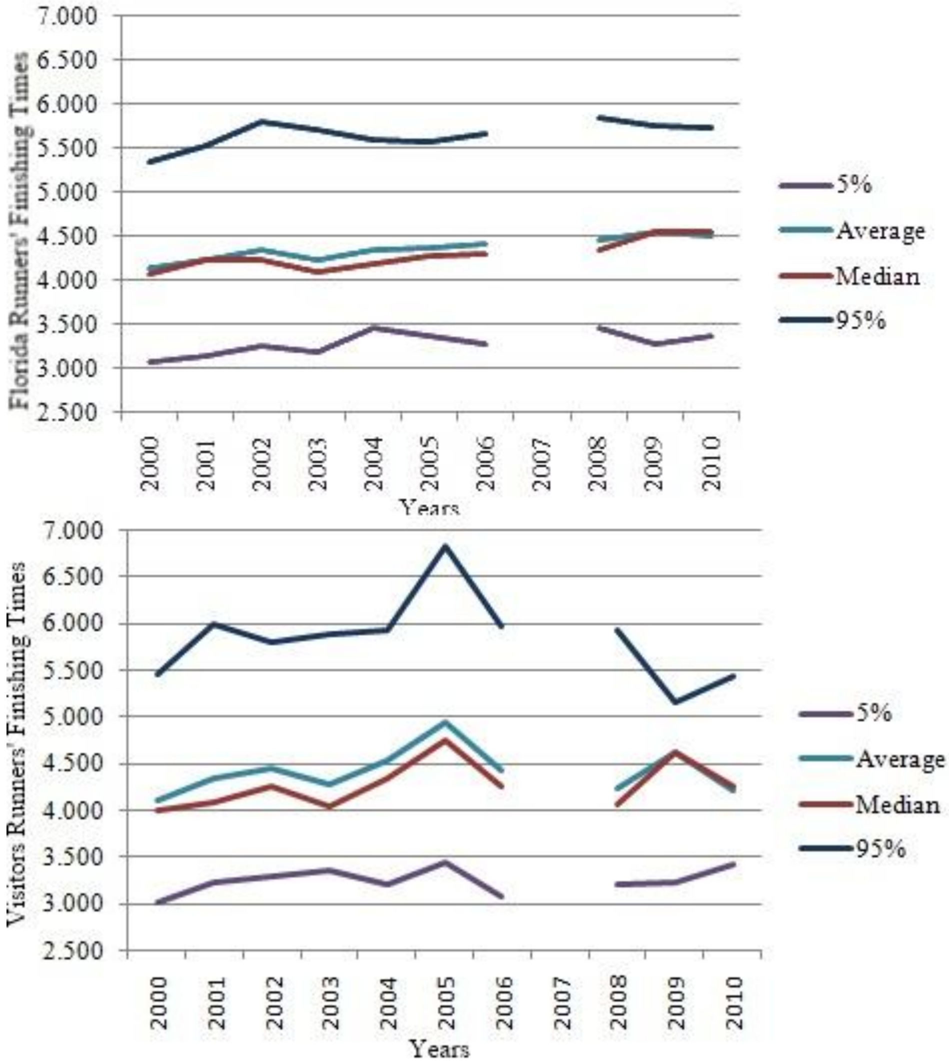
DETRENDED RESIDUAL VALUES FOR LOCAL AND VISITOR RUNNERS' FINISHING TIMES FOR THE CINCINNATI FLYING PIG MARATHON (CINCINNATI, OHIO)



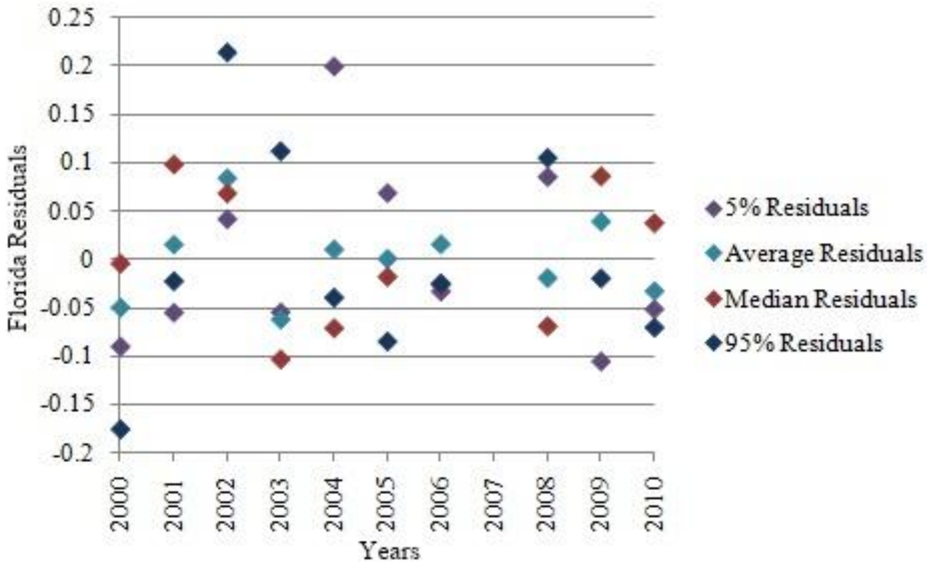


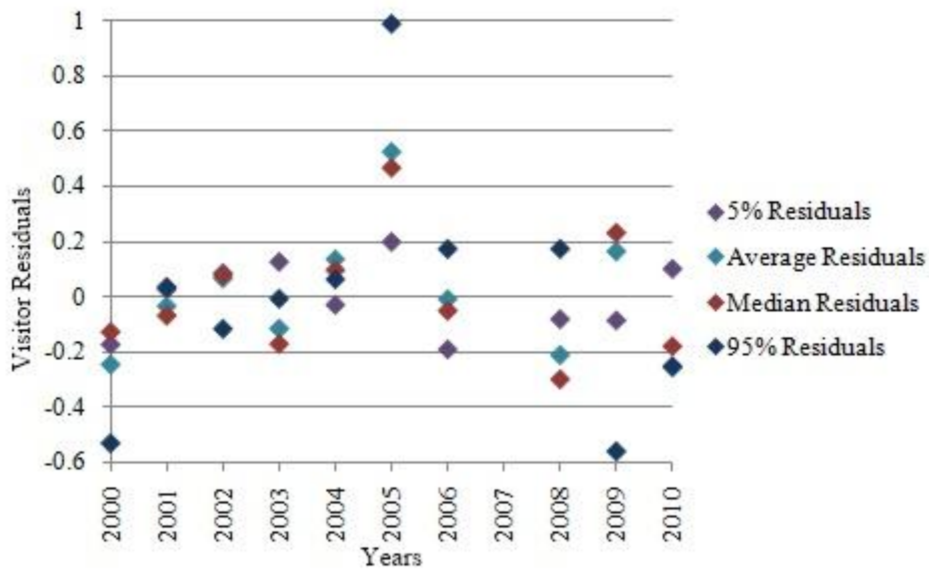
LOCAL AND VISITING FINISHING TIMES FOR THE OCALA MARATHON

(OCALA, FLORIDA)



DETRENDED RESIDUAL VALUES FOR LOCAL AND VISITOR RUNNERS' FINISHING TIMES FOR THE OCALA MARATHON (OCALA, FLORIDA)





APPENDIX D

Z-SCORE VALUES FOR EACH VARIABLE WHEN RACE DAY CONDITIONS WERE SIMILAR AND DIFFERENT TO BASELINE CONDITIONS

YEARS WHEN CONDTIONS ON RACE DAY WERE SIMILAR TO THE CONDTIONS FIVE DAYS PRIOR TO THE NEW YORK CITY MARATHON (SMALLEST Z-SCORE)

Year	Wind sp.	Year	Temp	Year	Dew pt	Year	press	Year	$^1/_e$	Year	e_s	Year	RH	Year	HI	Year	WCI	Year	WBGT	Year	AT	Year	WET
1983	0.03	1987	0.02	1991	0.07	2004	0.00	1981	0.00	1991	0.06	1981	0.04	2000	0.03	2006	0.04	2010	0.01	1984	0.06	1995	0.02
1998	0.03	1991	0.02	1987	0.08	2005	0.01	2001	0.09	2010	0.09	1984	0.05	2007	0.05	1984	0.05	1991	0.03	2005	0.13	1977	0.06
1977	0.03	1979	0.13	1983	0.08	1982	0.01	1983	0.11	2009	0.10	1980	0.05	2008	0.07	2009	0.06	1984	0.04	1983	0.18	2009	0.07
1985	0.05	2001	0.16	2000	0.14	1998	0.19	1987	0.14	1984	0.10	1999	0.06	1994	0.11	2010	0.08	1983	0.12	2010	0.19	1984	0.16
1982	0.11	2007	0.24	1984	0.17	1981	0.30	1993	0.19	2008	0.14	1991	0.10	2003	0.12	2008	0.09	1987	0.18	1995	0.20	1985	0.20
1997	0.16	1977	0.24	1980	0.19	1988	0.30	1998	0.20	1983	0.14	2006	0.11	1987	0.13	1977	0.09	2000	0.21	1998	0.27	2005	0.21
1978	0.26	2000	0.28	2010	0.24	1991	0.32	1977	0.39	1977	0.15	1998	0.12	1991	0.17	1994	0.13	2005	0.25	1977	0.30	2010	0.23
1999	0.27	1976	0.29	1998	0.25	1978	0.36	1991	0.43	1985	0.20	1983	0.14	2010	0.17	1991	0.16	2008	0.26	1991	0.32	1983	0.23

YEARS WHEN CONDTIONS ON RACE DAY WERE DIFFERENT TO THE CONDTIONS FIVE DAYS PRIOR TO THE NEW YORK CITY MARATHON, NEW YORK CITY, NEW YORK (LARGEST Z-SCORE)

Year	Wind sp.	Year	Temp	Year	Dew pt	Year	press	Year	$^1/_e$	Year	e_s	Year	RH	Year	HI	Year	WCI	Year	WBGT	Year	AT	Year	WET
1995	1.37	1992	1.06	1988	1.14	1983	1.47	1995	2.21	2003	1.03	1979	1.38	1989	1.18	1999	0.94	2006	0.90	1980	0.92	1992	0.97
2008	1.38	1978	1.16	2005	1.18	1987	1.52	1996	2.38	1996	1.04	1985	1.70	1978	1.25	1992	1.15	1982	0.91	1997	1.00	1980	1.08
1980	1.44	2006	1.23	2009	1.22	2007	1.70	1994	2.47	1990	1.09	1977	1.93	1988	1.38	2004	1.29	1996	0.98	2004	1.13	1978	1.28
2006	1.49	1994	1.27	1985	1.36	1997	1.71	2003	2.61	2004	1.11	1997	1.99	1979	1.40	1996	1.42	1997	1.28	1996	1.15	2004	1.34
1987	1.63	1984	1.42	1978	1.41	1979	1.80	1979	2.63	1988	1.35	1993	2.06	1996	1.43	1978	1.43	1988	1.41	1978	1.32	1996	1.36
1991	1.67	2003	1.42	1997	1.49	1977	1.93	2008	2.78	1978	1.51	2009	2.51	2002	1.49	1988	1.45	1978	1.43	1988	1.35	1988	1.38
1976	2.37	1996	1.61	1979	2.15	2008	2.16	2002	3.06	1993	1.77	2005	2.75	1997	1.55	1993	1.50	1993	2.15	1993	1.69	1993	1.41
1979	2.40	1990	1.69	1993	2.37	1980	2.21	19984	4.57	1979	2.42	2010	5.36	1993	2.69	1979	2.26	1979	2.44	1979	2.58	1979	2.40

YEARS WHEN CONDTIONS ON RACE DAY WERE SIMILAR TO THE CONDTIONS FIVE DAYS PRIOR TO THE EQUINOX MARATHON, FAIRBANKS, ALASKA (SMALLEST Z-SCORE)

Year	Wind sp.	Year	Temp	Year	Dew Pt.	Year	Press	Year	e	Year	e_s	Year	RH	Year	HI	Year	WCI	Year	WBGT	Year	AT	Year	WET
1994	0.01	1986	0.07	1981	0.01	2008	0.11	2009	0.01	2010	0.01	1993	0.10	1988	0.08	1994	0.02	1988	0.09	1986	0.00	1982	0.03
1979	0.01	2010	0.07	1977	0.02	1989	0.17	2007	0.02	1986	0.03	2006	0.15	2010	0.08	1986	0.05	1986	0.11	2010	0.02	1986	0.03
2002	0.03	1982	0.11	2001	0.03	1982	0.18	1981	0.02	1983	0.07	2003	0.20	1999	0.09	1982	0.07	1981	0.16	1983	0.02	1988	0.05
2000	0.04	1983	0.17	1999	0.06	2009	0.24	2001	0.02	1994	0.15	1979	0.21	1994	0.10	1988	0.10	1982	0.16	1988	0.04	1983	0.07
1999	0.13	1981	0.21	2007	0.07	1980	0.30	1977	0.04	1982	0.18	1986	0.22	1976	0.10	2008	0.13	2010	0.17	1982	0.05	2010	0.13
1986	0.17	1988	0.24	2009	0.08	2004	0.34	2004	0.10	1981	0.29	1983	0.36	2004	0.11	1983	0.16	1994	0.21	1981	0.23	2000	0.26
2006	0.20	1994	0.30	1994	0.26	1993	0.35	1999	0.11	1988	0.31	2010	0.42	1982	0.11	2001	0.19	1983	0.22	1976	0.26	1981	0.27

YEARS WHEN CONDTIONS ON RACE DAY WERE DIFFERENT TO THE CONDTIONS FIVE DAYS PRIOR TO THE EQUINOX MARATHON, FAIRBANKS, ALASKA (LARGEST Z-SCORE)

Year	Wind sp.	Year	Temp	Year	Dew Pt.	Year	Press	Year	e	Year	e_s	Year	RH	Year	HI	Year	WCI	Year	WBGT	Year	AT	Year	WET
2003	0.87	1979	1.12	1979	1.04	1997	1.39	1979	1.10	2006	1.23	1989	1.18	2002	0.86	2007	0.91	1979	1.16	1979	1.09	1979	1.05
1980	0.98	1998	1.43	2006	1.06	1986	1.44	1980	1.12	1989	1.37	1980	1.18	1997	1.04	2002	0.93	1998	1.18	1998	1.23	1998	1.31
1983	1.01	1989	1.59	1980	1.21	2003	1.47	1987	1.19	1998	1.39	1978	1.21	2000	1.15	1998	1.17	2004	1.48	2004	1.54	2004	1.68
2009	1.11	2004	1.95	1987	1.31	1978	1.65	2006	1.32	2004	1.80	1976	1.24	1979	1.19	1987	1.21	1989	1.79	1987	1.92	1987	1.82
1987	1.25	1993	2.26	1978	2.17	1976	2.08	1989	1.92	1987	2.05	1988	1.25	1989	1.23	2009	1.21	1987	2.17	1989	1.99	1989	2.04
1978	1.57	1987	2.34	1989	2.18	2006	2.11	1993	2.34	1993	2.07	1998	1.82	1987	2.40	1989	1.50	1993	2.40	1993	2.21	1993	2.10
1989	1.79	1978	3.13	1993	2.26	2002	2.45	1978	2.56	1978	3.22	2004	2.32	1993	**2.50**	1993	1.67	1978	3.13	1978	2.66	1978	2.42

YEARS WHEN CONDTIONS ON RACE DAY WERE SIMILAR TO THE CONDTIONS FIVE DAYS PRIOR TO THE CALIFORNIA INTERNATIONAL MARATHON, SACRAMENTO, CALIFORNIA (SMALLEST Z-SCORE)

Year	Wind sp.	Year	Temp	Year	Dew Pt.	Year	Press	Year	e	Year	e_s	Year	RH	Year	HI	Year	WCI	Year	WBGT	Year	AT	Year	WET
1988	0.10	2007	0.02	1988	0.03	2008	0.00	2005	0.16	2001	0.10	1991	0.09	1990	0.00	1987	0.05	1990	0.05	1990	0.07	1990	0.12
1990	0.11	1987	0.07	2000	0.10	1999	0.03	1998	0.17	2010	0.11	1997	0.13	1988	0.01	2002	0.12	1984	0.07	1986	0.11	1983	0.20
2000	0.11	2008	0.09	1990	0.11	1997	0.04	1986	0.18	1994	0.44	1990	0.14	2000	0.08	1990	0.19	2008	0.09	2008	0.12	1986	0.23
2010	0.16	1990	0.09	2008	0.13	2002	0.04	1994	0.39	1997	0.46	1987	0.19	1987	0.28	2008	0.22	2007	0.13	2000	0.21	1992	0.25
1995	0.17	1984	0.13	1999	0.17	1987	0.06	1989	0.43	1996	0.46	2002	0.19	2007	0.28	1992	0.24	2000	0.23	2007	0.26	2000	0.25
2008	0.18	1989	0.14	1995	0.30	1990	0.07	2001	0.46	1986	0.47	1993	0.25	1986	0.33	2004	0.25	1987	0.25	1999	0.30	2008	0.25
2002	0.25	2009	0.31	1986	0.30	2006	0.13	1992	0.54	1991	0.56	1996	0.29	1884	0.34	2000	0.36	1989	0.35	2002	0.41	2002	0.34

YEARS WHEN CONDTIONS ON RACE DAY WERE DIFFERENT TO THE CONDTIONS FIVE DAYS PRIOR TO THE CALIFORNIA INTERNATIONAL MARATHON, SACRAMENTO, CALIFORNIA (LARGEST Z-SCORE)

Year	Wind sp.	Year	Temp	Year	Dew Pt.	Year	Press	Year	e	Year	e_s	Year	RH	Year	HI	Year	WCI	Year	WBGT	Year	AT	Year	WET
2006	1.00	2001	1.19	1983	1.02	2003	0.98	2008	1.16	1983	1.97	1986	0.86	1994	1.00	2003	1.19	2005	1.04	2009	1.37	1985	1.42
2001	1.34	1995	1.42	1992	1.21	1994	0.99	2004	1.25	2005	2.02	2010	0.87	2004	1.12	1989	1.37	1994	1.07	1998	1.37	1998	1.43
1986	1.79	1998	1.48	2005	1.47	2007	1.04	1983	1.31	1993	2.15	1992	1.16	1998	1.27	1996	1.48	1998	1.32	2001	1.42	2010	1.57
1984	1.89	2010	1.51	2009	1.57	1993	1.10	1991	1.70	1998	2.54	1988	1.22	2005	1.32	2001	1.58	1996	1.53	1985	1.76	2009	1.69
1999	2.13	1996	1.60	2010	1.69	2005	1.67	2007	1.99	1995	2.94	2005	1.26	1985	1.90	1991	1.62	2010	1.83	2010	1.84	2001	1.71
2009	2.26	2003	1.74	2003	1.86	1983	1.98	2003	2.23	2003	3.07	1995	1.87	2010	2.11	2006	2.04	2003	2.01	2003	1.94	2003	1.73
1991	3.18	1985	1.81	1985	1.89	2004	2.36	1985	2.49	1985	3.20	2009	1.97	2003	2.15	2009	2.21	1985	2.07	1996	1.96	1996	2.09

YEARS WHEN CONDTIONS ON RACE DAY WERE SIMILAR TO THE CONDTIONS FIVE DAYS PRIOR TO THE LIVESTRONG AUSTIN MARATHON, AUSTIN, TEXAS (SMALLEST Z-SCORE)

Year	Wind sp.	Year	Temp	Year	Dew Pt.	Year	Press	Year	e	Year	e_s	Year	RH	Year	HI	Year	WCI	Year	WBGT	Year	AT	Year	WET
2002	0.06	2008	0.07	2004	0.06	2007	0.33	2010	0.24	2008	0.01	2009	0.22	2009	0.02	2004	0.20	2003	0.09	2008	0.14	2008	0.14
2010	0.09	2002	0.12	2002	0.13	2009	0.61	2009	0.26	2004	0.13	2002	0.23	2008	0.09	2008	0.28	2006	0.29	2002	0.25	2002	0.29
2008	0.88	2004	0.16	2008	0.16	2004	0.61	2008	0.62	2002	0.17	2005	0.24	2002	0.15	2000	0.46	2000	0.61	2004	0.39	2009	0.50

YEARS WHEN CONDTIONS ON RACE DAY WERE DIFFERENT TO THE CONDTIONS FIVE DAYS PRIOR TO THE LIVESTRONG AUSTIN MARATHON, AUSTIN, TEXAS (LARGEST Z-SCORE)

Year	Wind sp.	Year	Temp	Year	Dew Pt.	Year	Press	Year	e	Year	e_s	Year	RH	Year	HI	Year	WCI	Year	WBGT	Year	AT	Year	WET
2004	1.97	2003	1.30	2010	1.41	2000	1.45	2005	1.91	2003	1.32	2007	0.77	2003	1.60	2009	1.21	2007	2.80	2006	1.88	2005	1.58
2006	2.01	2005	2.01	2003	1.92	2006	2.43	2000	2.11	2006	1.87	2003	1.65	2007	1.76	2003	1.82	2010	2.93	2005	1.90	2003	1.96
2003	2.74	2006	2.16	2005	2.20	2005	2.78	2007	2.84	2005	2.31	2006	2.16	2006	2.06	2006	2.44	2005	3.82	2003	2.01	2006	2.07

YEARS WHEN CONDTIONS ON RACE DAY WERE SIMILAR TO THE CONDTIONS FIVE DAYS PRIOR TO THE CINCINNATI FLYING PIG MARATHON, CINCINNATI, OHIO (SMALLEST Z-SCORE)

Year	Wind sp.	Year	Temp	Year	Dew Pt.	Year	Press	Year	e	Year	e_s	Year	RH	Year	HI	Year	WCI	Year	WBGT	Year	AT	Year	WET
2006	0.07	2007	0.00	2006	-0.28	2005	0.18	2006	0.17	2006	0.02	2004	0.07	2005	0.09	2006	0.17	2006	0.12	2006	0.13	2006	0.05
2003	0.13	2006	0.07	2005	0.17	2008	0.23	2004	1.01	2007	0.03	2000	0.11	2007	0.09	2001	0.23	2007	0.28	2005	0.30	2005	0.32
2004	0.49	2008	0.44	2003	0.36	2003	0.34	2000	1.09	2008	0.47	2003	0.40	2006	0.10	2000	0.65	2005	0.52	2007	0.52	2007	0.47

YEARS WHEN CONDTIONS ON RACE DAY WERE DIFFERENT TO THE CONDTIONS FIVE DAYS PRIOR TO THE CINCINNATI FLYING PIG MARATHON, CINCINNATI, OHIO (LARGEST Z-SCORE)

Year	Wind sp.	Year	Temp	Year	Dew Pt.	Year	Press	Year	e	Year	e_s	Year	RH	Year	HI	Year	WCI	Year	WBGT	Year	AT	Year	WET
2000	1.24	2004	0.96	2007	0.99	2006	1.66	2003	1.58	2003	0.78	2001	1.38	2008	1.03	2003	1.19	2004	1.00	2008	0.92	2008	0.92
2008	1.98	2001	0.98	2000	1.35	2001	2.14	2001	2.67	2001	1.03	2007	1.39	2004	1.04	2008	1.38	2001	1.14	2002	0.93	2004	0.98
2007	2.85	2000	1.10	2001	1.49	2000	2.41	2005	3.07	2000	1.29	2005	1.79	2003	1.30	2007	2.23	2000	1.16	2004	1.01	2002	0.98

YEARS WHEN CONDTIONS ON RACE DAY WERE SIMILAR TO THE CONDTIONS FIVE DAYS PRIOR TO THE OCALA MARATHON, OCALA, FLORIDA (SMALLEST Z-SCORE)

Year	Wind Sp.	Year	Temp	Year	Dew Pt	Year	Press	Year	Sqrt e	Year	$^1/_{es}$	Year	RH	Year	HI	Year	Sqrt WCI	Year	Sqrt WBGT	Year	Sqrt AT	Year	Sqrt WET
2009	0.00	2010	0.36	2003	0.15	2002	0.42	2000	0.05	2004	0.11	2000	0.45	2010	0.28	2003	0.21	2003	0.25	2000	0.02	2000	0.11
2002	0.09	2000	0.54	2000	0.17	2008	0.46	2003	0.24	2001	0.14	2001	0.48	2003	0.39	2009	0.27	2000	0.33	2010	0.03	2010	0.25
2006	0.23	2003	0.61	2010	0.50	2004	0.52	2010	0.36	2006	0.38	2010	0.51	2000	0.63	2004	0.51	2010	0.36	2003	0.32	2003	0.50

YEARS WHEN CONDTIONS ON RACE DAY WERE DIFFERENT TO THE CONDTIONS FIVE DAYS PRIOR TO THE OCALA MARATHON, OCALA, FLORIDA (LARGEST Z-SCORE)

Year	Wind Sp.	Year	Temp	Year	Dew Pt	Year	Press	Year	Sqrt e	Year	$^{1}/_{es}$	Year	RH	Year	HI	Year	Sqrt WCI	Year	Sqrt WBGT	Year	Sqrt AT	Year	Sqrt WET
2004	1.65	2005	1.49	2002	1.39	2005	1.19	2005	1.52	2002	1.77	2003	0.99	2005	1.07	2002	1.69	2005	1.52	2008	1.29	2008	1.33
2010	1.71	2004	1.51	2006	1.43	2003	1.41	2002	1.58	2008	1.89	2006	1.82	2009	1.43	2006	1.70	2002	1.59	2002	1.41	2002	1.42
2005	2.54	2002	1.65	2004	2.02	2006	1.51	2004	2.01	2000	2.52	2004	2.42	2004	2.26	2005	2.10	2004	1.75	2005	1.76	2005	1.88