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Assessing the relationship of ambient temperature and heat related illness in Florida: implications for setting heat advisories and warnings

Pilot study of Orlando and the surrounding area

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EXECUTIVE SUMMARY

A strong association between increasing ambient temperature and heat-related morbidity and mortality has been shown in the literature. In order to prevent excess mortality and morbidity associated with heat, the National Weather Service (NWS) provides communities with advanced warning when there is a high probability of an extreme heat event. This allows not only for individuals to protect themselves and their families but for local agencies to provide guidance to potentially impacted populations. Florida's Weather Forecasting Offices (WFO) have each developed their own regional climatology based criteria for issuing a heat advisory/warning. However, the cause of heat related morbidity and mortality is not solely due to high ambient outdoor temperature but also the behavioral/physical responses populations (and individuals) have to heat. As such, criteria based on both climatological and health outcome data may reduce the occurrence of heat-related morbidity and mortality. The purpose of this analysis was to examine the relationship between ambient outdoor temperature measured at the local level and heat-related hospitalizations and emergency department (ED) visits in surrounding populations.

The study examined the population surrounding three Orange county weather stations. This allowed for the examination of three population density areas; urban (Orlando), suburban (Avalon), and rural (Apopka). The health outcome data was heat-related illness (HRI) treated in the hospital or ED during the summer months (May-September) of 2005-2009. Both occupational and non-occupational HRI were examined as the two populations may have different responses to heat. The measure of exposure for this analysis was daily maximum temperature or daily maximum heat index.

During the study period 883 non-occupational (crude rate = 149.5/1,000,000 person-years) and 105 occupational (crude rate = 34.8/1,000,000 person-years) cases of HRI were hospitalized or treated in the ED. The Apopka area had the smallest number of persons at risk for HRI but had the highest rate of occupational and non-occupational HRI. When examining the HRI-maximum temperature relationship, the Apopka area continued to have the highest incidence rate (IR) of non-occupational and occupational HRI hospitalizations/ED visits as temperature increased followed by Orlando and Avalon. The highest rate of non-occupational HRI occurred when the maximum temperature was between 96°F and <98°F (IR = 4.01/1,000,000 person-days; 95% Confidence Interval [CI] = 2.60, 6.20). The relationship between HRI and maximum heat index was similar to temperature. The Apopka area had the highest incidence rate of both occupational and non-occupational HRI hospitalizations/ED visits as maximum heat index increased. Unlike the temperature findings where the incidence rate continued to increase with increasing temperature, the incidence rate for occupational HRI started to decrease at a heat index of 107°F. This decrease among occupational HRI may be related to the small number of occupationally related HRI seen in this pilot or may in part be due to increased protective actions taken in the workplace during extreme heat. The highest rate of non-occupational HRI occurred when the maximum heat index was between 108°F and <110°F (IR = 8.34/1,000,000 person-days; 95% CI = 4.07, 17.11).

A limitation of this study is the small sample size, especially for occupational HRI, leading to wide confidence intervals. However, these preliminary results based on a pilot area (Orange County) indicated that the current heat advisory/warning criteria may not be completely optimal for protecting health. The current temperature criterion for the study area requires an advisory to be issued when temperatures are ≥98°F for 48 hours. The study results indicate that the majority of the individuals experience symptoms when temperatures are ≥96°F for 48 hours. Currently, an advisory is also issued when the heat index is 105-110°F for 48 hours. The results of the pilot indicated that the majority of hospitalizations/ED visits occur when temperatures are in this range. Heat advisory/warning criteria based on health outcome data, as well as, climatological data are important in preventing HRI.

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ABBREVIATIONS

ACS = American Community Survey

AHCA = Agency for Health Care Administration

AIC = Akaike information criterion

CI = confidence interval

ED = Emergency department

F = Fahrenheit

HRI = Heat related illness

IR = Incidence rate

IRR = Incidence rate ratio

NWS = National Weather Service

WFO = Weather Forecasting Office

BACKGROUND

Over the last 30 years a strong association between increasing ambient temperature and increasing heat-related morbidity and mortality has been demonstrated in various epidemiologic studies considering information from various countries [1,2]. This relationship is especially striking during a heat wave, which is defined as multiple consecutive days of extreme heat [3,4]. Global climate forecasting models continue to predict an increase in extreme heat events [5], in turn leading to increased heat-related health outcomes. The excess mortality and morbidity attributed to heat are considered preventable [6,7]. As such, when there is a high probability of an extreme heat event, the National Weather Service (NWS) provides advanced warning so communities and local agencies can respond appropriately by providing guidance to impacted populations [8]. In its guidelines, the NWS uses both temperature and the heat index, a measure of perceived temperature based on relative humidity and actual temperature, to determine warning thresholds. For the southern United States, the NWS guidelines outline that an advisory should be issued when the one to two day forecast has the heat index at or above 105°F with a temperature night-time low at or above 75°F. As acclimatization may vary by region, the NWS encourages individual Weather Forecasting Offices (WFO) to develop local criteria [8] for heat warnings and advisories.

Florida is celebrated for its warm and sunny climate. The average statewide annual temperature is 71°F with an average summer temperature of 80°F [9]. The state of Florida is currently divided into seven WFOs **(Figure 1),** each using slightly different criteria for issuing heat advisories and warnings. Currently these criteria are based purely on climatological information. However, criteria based on both climatological and health outcomes could potentially reduce the occurrence of heat-related illness (HRI) by setting heat advisory levels that have taken into consideration temperature and other conditions that trigger emergency department (ED) and hospitalization events in local populations. For example, the current criteria that meet posting of a heat advisory in Orange County, Florida (Melbourne WFO) are: heat indices greater than 105°F for ≥ 3 hours, heat indices around 106°F for ≥ 2 hours, heat indices 107-109°F for ≥ 1 hour, heat index readings between 105-110°F, or temperature of 98°F or higher expected for two or more consecutive days. In Orange County, a heat warning (the highest severity warning) is issued when the heat Index is 110°F degrees for ≥2 hours.

The purpose of this analysis was to examine the relationship between ambient outdoor temperature measured at the local level and heat-related health outcomes (measured by related hospitalizations and ED visits) in order to potentially adjust threshold criteria for heat advisories and warnings. In addition, the literature has suggested that occupational HRI may occur at a lower temperature than non-occupational HRI [10]. Therefore, occupational and non-occupational cases were analyzed separately in order to have a better idea of the impact of sustained outdoor heat exposure on workers and to potentially target this group for additional preventive measures. However, before examining the entire state, a pilot study was completed in order to assess the data sets and methodology. For this pilot study, data from Orlando, Florida (Orange County) and surrounding areas were explored for 2005-2009.

METHODS

For this study ambient temperature was defined using maximum daily temperature and maximum daily heat index. The heat index is a measurement that combines air temperature and relative humidity to provide an estimation of perceived temperature (i.e. how hot it really feels). Data on daily maximum temperature and daily maximum heat index were obtained from the Florida NWS for May-September for the years 2005-2009 for weather stations located in Orange County, Florida. Three weather stations were identified in Orange County: Orlando Executive Airport (Orlando), Apopka, and Avalon. The stations in Apopka and Avalon are operated by the Florida automated weather network stations while the Orlando weather station is operated by the National Oceanic and Atmospheric Administration. In order to link the exposure (daily maximum temperature/heat index) with the health data, a temperature zone was created around each weather station **(Figure 2)**. Within each zone the exposure was assumed to be constant. Zip codes were used to define the zones, as this was the smallest geographic unit available in the health data. Each zone was created by drawing a circular buffer with a 10 mile radius around each weather station. All zip codes which fell completely within each station's 10 mile radius buffer were assigned to that station. Zip codes that did not fall completely within the buffered zoned were included only if the zip code centroid fell within the buffer zone. A further criterion for inclusion into the Orlando temperature zone was that the population density of the zip code had to be greater than or equal to 2000 people/square mile. This was done to account for a potential urban heat island effect; this effect may change the temperature and morbidity/mortality relationship in urban areas as compared to suburban or rural areas [2]. Additional decision points occurred when defining the three temperature zones: zip code 32779 was included in the Apopka temperature zone because the vast geographic majority of the zip code was in the buffer zone although the centroid was not. This same logic was applied to the Orlando temperature zone for zip codes 32828 and 32708 which also had a population greater than or equal to 2000 people/square mile. Zip code 32819 fell between the Orlando temperature zone and Avalon temperature zone and was assigned to Avalon because its population density was less than 2000 people/square mile (and therefore not considered part of the urban Orlando temperature zone). As can be seen in **Figure 2**, due to the location of the weather stations, the boundaries of the three zones were not restricted to Orange County but overlapped somewhat into Lake and Seminole counties.

Data on heat related hospitalizations and ED visits were obtained from the Florida Agency for Health Care Administration (AHCA) for the years 2005-2009. HRI was defined using the following International Classification of Diseases ninth revision Clinical Modification (ICD-9-CM) codes: 992.0-992.9, E900.0, and E900.9. Cases were identified if at least one of the HRI codes was found in the primary diagnosis field or in one of the secondary diagnosis fields. Cases were restricted to Florida residents and those individuals whose residential zip code (according to the AHCA record) fell within one of the three temperature zones. For this analysis, we examined occupational and non-occupational cases separately. Occupational cases were restricted to individuals age 16 or older who claimed workers' compensation, identified through principal payer, or whose medical record indicated a workplace injury, identified through ICD-9-CM

Ecodes*. The patient's residential zip code was used to assign each case to one of the three zones as defined above. Address and zipcode of exposure location or workplace were not recorded in the hospitalization or ED records and thus zipcode of home address was used to assign HRI cases to a temperature zone. Some misclassification is assumed to have occurred. In order to remove temporal confounding by season, the analysis was limited to the summer months, May-September. All cases with an admit date outside this range were excluded.

All analyses were done using SAS 9.2 (SAS Institute, Inc, Cary, NC). A parametric generalized linear model with a poisson distribution was used to analyze the relationship between daily heat morbidity and daily maximum temperature/heat index. As such, rates per 1,000,000 person-days for each temperature zone and rate ratios were generated. Rates were calculated for each temperature zone to account for the expected difference in number of cases due to population size. The occupational and non-occupational population was estimated from the American Community Survey (ACS) 2009 5 year estimate [12]. The non-occupational population was estimated as the total population in the temperature zones. The total Florida population was used because the population of individuals susceptible to non-occupational HRI includes both non-workers and workers who were not on the job at the time of exposure. The occupational population was restricted to workers and defined as the employed population age 16 years or older. The geographical unit for this study was zip codes, unfortunately, the ACS does not have information available by zip codes. ACS information is available by the 2000 US census tract. For the purpose of estimating the number of workers and the total population within each of these temperature zones, the three zones were redefined using the 2000 US census tracts. A map of the zip code defined temperature zones was overlayed on top of a map of the 2000 US census tracts within Orange, Lake, and Seminole County. Inclusion into a zone was restricted to the 2000 US census tract which had a centroid within one of the zip codes used to define the temperature zone. As can be seen in **Figure 3** the 2000 US census tract defined temperature zones were a close but not exact match to the zip code defined temperature zones. However, for this analysis the authors felt this representation was adequate for population estimates.

The long term and short term temporal trends were adjusted for in each model by including the following categorical variables: year, month and day of week†. The literature indicates that there may be a delayed health effect based upon exposure to the ambient temperature on prior days affecting hospital admissions, therefore the inclusion of 1-5 day lags were assessed [1,13]. The inclusion of individual variables for each lag day allowed for the assessment of the separate effects of each prior day's ambient temperature. For nested models, model fit was assessed using the likelihood ratio test and the Akaike information criterion (AIC) [14]. For non-nested models only the AIC was used. Model fit was assessed to determine: 1) the nature of the relationship (e.g. linear or quadratic) between ambient temperature and HRI and 2) if the inclusion of lag days better explained the relationship between ambient temperature measures

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* Work-related Ecodes: E000.0-E000.1, E800-E807 (4th digit = 0), E830-E838 (4th digit = 2 or 6) , E840-E845 (4th digit = 2 or 8), E846, E849.1-E849.3 [11]

† Other methods for adjusting for temporal trends were assessed including splines, cosine/sine terms, and various polynomial functions of time.

and HRI. To visualize the cumulative effect of the current ambient temperature and the ambient temperature on prior days, the ambient temperature for the current day plus lag days was also graphed. To facilitate graphing, each day (lag 1-5 and the current day [lag 0]) was modeled as having the same ambient temperature. The effectiveness of the current criteria for posting of heat advisories and warnings in the Melbourne WFO (Orange County) were also assessed **(Figure 1)**.

RESULTS

Description: Heat Related Illness (HRI)

The study areas for this analysis were three temperature zones whose center was an Orange County weather station. Due to the location of the weather stations, the zones crossed county boundaries and included Orange, Lake and Seminole counties. The study period included only summer months, May-September, for the years 2005-2009. Among Florida residents residing in one of the three temperature zones during the study period, a total of 998 HRI cases were hospitalized or were treated in the ED, 883 non-occupational HRI cases and 105 occupational HRI cases – a crude rate of 149.5 and 34.8 per 1,000,000 person-years[‡], respectively **(Table 1)**. According to the US census bureau definition[§] the Orlando temperature zone is an urban area with a population density of 3080 people per square mile. This zone had the largest population and the greatest number of HRI cases **(Table 1)**. However, the Apopka temperature zone, a rural area with a population density of 483 people per square mile, had the highest crude rate of both occupational and non-occupational HRI. The Avalon temperature zone is a mix of urban and rural areas with a population density of 1050 people per square mile. The crude rate of HRI observed in the Avalon temperature zone was similar to that of crude rate observed in the Orlando temperature zone; except that the crude rate of occupational HRI was slightly higher in the Avalon temperature zone and the crude rate of non-occupational HRI was slightly higher in the Orlando temperature zone. The majority of cases (occupational and non-occupational), for all temperature zones, were seen in July and August **(Figure 4)**.

Description: Maximum Temperature and Maximum Heat Index

During the study period, the average daily maximum temperature and average daily maximum heat index were similar among the three stations **(Table 2)**. There was greater variability between stations for the daily maximum heat index than for the daily maximum temperature. In general, the Orlando station had a lower daily maximum heat index than the other two stations

[‡] This is equivalent to a crude rate of 0.33 non-occupational and 0.08 occupational HRI cases per 1,000,000 person-days. Note that since the analysis was limited to May-September, each temperature zone contributed 153 days per year. For this analysis, it was assumed that individuals were not at risk for HRI on the other days of the year.

[§] A population density of at least 1,000 people per square mile and surrounding areas that have an overall density of at least 500 people per square mile [15] (data not shown). The overall average maximum temperature for the study period was 89°F, while the average maximum heat index was 95°F. **Table 3** presents information on the number of days during the study period which met or exceeded the criteria heat index/temperature for a heat advisory or a warning. The majority of these exceedances occurred within the Apopka or Avalon station. There is a strong correlation between daily maximum temperature and daily maximum heat index ($r = 0.79$; $p < 0.0001$). However, as can be seen in F**igure 5**, high temperatures (e.g. ≥95°F) do not always indicate a high heat index (e.g. ≥103°F).

Modeled Maximum Temperature and HRI

The relationship between occupational HRI and daily temperature was modeled and the impact of multiple lag days was assessed **(Table 4)**. The model that provided the best fit of the occupational HRI–temperature relationship included a single day lag, indicating that only current and the previous days' temperature had an impact on the rate of occupational HRI. Due to the small number of occupational HRI cases, the predictive ability of the model was moderate for days where the maximum temperature was 89°F or greater as indicated by the correlation between the raw (or observed) values of HRI hospitalizations/ED visits and the model estimated values ($r = 32\%$; $p<0.0001$). The maximum temperature on both days (lag 0-1) was modeled[**] as linear. Over the entire study area, for every 5°F increase in temperature, there was a 74% increase in the incidence rate of occupational HRI (95% CI = 1.15-2.64) for current day (lag 0). For instance, the rate of occupational HRI at 95°F was 0.95 per 1,000,000 person-days (95% CI = 0.46, 1.96) which is 74% higher than the rate of occupational HRI at 90°F (rate = 0.54 per 1,000,000 person-days; 95% CI = 0.29, 1.01). There was an additional 65% increase in the incidence rate of occupational HRI based the prior day's temperature (95% CI = 1.08-2.50). For instance, the rate of occupational HRI based only on the prior day's temperature of 95°F was 0.89 per 1,000,000 person-days (95% CI = 0.43, 1.84) while a rate of occupational HRI of 0.54 per 1,000,000 person-days was seen when the prior day's temperature was 90°F (95% CI = 0.29, 1.00). There did appear to be variation by temperature zone with the Apopka temperature zone having the largest incidence rate ratio (IRR) for both days (lag 0-1) followed by the Orlando temperature zone **(Table 5)**. This is also seen when the estimated cumulative HRI incidence rate per 1,000,000 person-days is graphed as maximum temperature increases stratified by temperature zone **(Figure 6)**. The curve for the HRI-temperature relationship is similar for the Orlando and Avalon temperature zones, while the curve for the Apopka temperature zone is consistently higher.

The best estimate of the relationship between temperature and non-occupational HRI was a model that included three lag days (lag 0-3) **(Table 4)**. In the best-fit model each temperature lag period was modeled as linear[**]. There was a 53% correlation between the model estimated values of hospitalizations/ED visits and the raw values for days where the maximum temperature was 89°F or greater ($p<0.0001$). The results of the best fit model, with the three lag days, can be found in T**able 6**. As the number of lag days increases, the effect of heat

[**] Data on the shape of the dose-response curve are not shown.

decreases. However, the temperature on the prior days does impact the rate of non-occupational HRI. While the current day's temperature has the largest impact on the rate of non-occupational HRI there is a 28% and 11% increase in non-occupational HRI for lag 1 (prior day) and lag 2, respectively. By lag 3, the apparent effect of temperature is no longer evident.

In order to compare the non-occupational results to the occupational results the model was reduced to include only a single lag day (lag 0-1). The non-occupational-temperature model with a single lag day will be used as the model for discussion for the remainder of the paper. The correlation between the estimated values of HRI hospitalizations/ED visits was approximately the same for the model with a single lag day and the model with five day lag (r = 53%; $p<0.0001$).

For the entire study area, a 93% increase in the incidence rate of non-occupational HRI was observed for every 5° F increase in maximum temperature (95% CI = 1.67, 2.23) for lag 0. For the prior day (lag 1) an additional, 29% increase in the incidence rate of non-occupational HRI was observed (95% CI = 1.13, 1.49). The same pattern of variation by temperature zone seen in the occupational results was also seen in the non-occupational results – the Apopka temperature zone had the largest IRR for both days (lag 0-1) followed by the Orlando temperature zone **(Table 5)**. In **Figure 7** the cumulative relationship between HRI and temperature on the current and prior day was modeled. The difference between the curves for non-occupational HRI in Apopka compared to the Orlando/Avalon temperature zones appears to be smaller than the difference between the same curves for occupational HRI **(Figure 6)**. However, for non-occupational HRI, the difference between the curves in the Orlando and Avalon temperature zones appears to be larger than the difference between the same curves for occupational HRI.

Regardless of temperature zone, the effect of temperature on HRI was smaller for non-occupational HRI than for occupational HRI **(Figure 6 and 7)**. Interestingly, as the maximum temperature increased, the increase in the incidence rate of occupational HRI was greater than the increase in the incidence rate of non-occupational HRI when compared with the respective incidence rate at 89°F, the average temperature for the study **(Figure 8)**. In each of these three figures (**Figure 6-8**) describing the relationship between temperature and HRI, there is a slightly different slope and threshold determined with no one consistent temperature where HRI rates sharply increase. What can be noted is that when viewed at the same temperature (98°F[††]), for both the current and prior day there is approximately a six-fold and five-fold increase in occupational and non-occupational HRI incidence rates, respectively, when compared with the respective HRI incidence rates at the average temperature (89°F) for the study.

To provide another view of the relationship between temperature and HRI, the estimated rate of individuals who would be hospitalized or treated in the ED for non-occupational HRI within temperature category (lag 0-1) for all temperature zones combined is presented in **Table 7**. A clear dose-response gradient is apparent, as the temperature on both the current and prior day

[††] Temperatures of 98 degrees F° or higher expected for two or more consecutive days triggers a heat advisory by the local WFO.

increase the rate of non-occupational HRI hospitalizations and ED visits also increases. It can be seen in the table that the highest rate of HRI occurs between 96°F and <98°F (IR = 4.01/1,000,000 person-days; 95% CI = 2.60, 6.20). The data were too sparse to examine occupational HRI by temperature category.

Modeled Maximum Heat Index and HRI

The best fitting model for occupational HRI and the maximum heat index included only a single day lag **(Table 4)**, indicating that only the current and the previous days' heat index had an impact on the rate of occupational HRI. For this model a quadratic relationship between occupational HRI and the maximum heat index on the current day (lag 0) was estimated. A linear relationship was estimated for the prior day (lag 1)[**]. Similar to the temperature model, the predictive ability of the occupational HRI – heat index model was moderate for days were the maximum heat index was 95°F or greater (r = 32%; p < 0.0001). For the entire study area and for each 5°F increase in the heat index there was a 51% increase in the incidence rate of occupational HRI (95% CI = 1.11, 2.07) for lag 0. On the previous day, a 5°F increase in the heat index produced an estimated 30% increase in the incidence rate of occupational HRI (95% CI = 0.99, 1.72). When examined by temperature zone, the largest effect on both days is seen in Apopka while the effect of the current day is small and the effect of the prior day is minimal for the Avalon temperature zone **(Table 5)**. The estimated cumulative occupational HRI incidence rate per 1,000,000 person-days as maximum temperature increases on both the current and prior day is presented in **Figure 9**. The same relationship between the temperature zones observed in **Table 5** is also seen in this figure, with the Apopka temperature zone having the greatest incidence rate followed by Orlando and Avalon temperature zones. It appears that at a maximum heat index of approximately 107°F, the occupational HRI incidence rate, for all temperature zones, starts to decline.

As with the temperature models, the best fitting model for non-occupational HRI and the maximum heat index was a model with five lag days **(Table 4)**. In this model the outcome-exposure relationship on the current day was modeled as quadratic while the relationship on prior days (lag 1-5) was modeled as linear[**]. Among days with a maximum heat index greater or equal to 95°F, the correlation between the predicted hospitalizations/ED visits values compared with the raw values was 55% (p<0.0001). The IRR for the current and prior days (lag 1-5) for a 5°F increase in maximum heat index can be seen in **Table 6**. The effect of maximum heat index decreases with increasing lag days. As with temperature, the current day's heat index has the largest impact on the rate of non-occupational HRI. However the prior days heat index do have an effect; the increase in the rate of non-occupational HRI for lag 1 (prior day) and lag 2 is 17% and 8%, respectively. Additionally, as with temperature, at lag 3 there no longer appears to be an increase in the non-occupational HRI rate as the heat index increases.

The remainder of the paper will model the non-occupational HRI–maximum heat index relationship with a single lag day in order to compare the results with the occupation-maximum heat index models. A model with a single lag day has a slightly smaller correlation between the values for predicted and raw hospitalizations/ED visit (r = 0.54%; p<0.0001) than the model with five lag days.

For the entire study area, a 48% increase in the incidence rate of non-occupational HRI was observed for every 5°F increase in the current day's maximum heat index (95% CI = 1.34, 1.64). On the prior day an additional 16% increase in the incidence rate of non-occupation HRI was observed (95% CI = 1.06, 1.27). When this effect was stratified by temperature zone, the largest effect on both days was seen in Orlando followed by Apopka **(Table 5)**. Almost no effect was seen in Avalon on the current day and a protective effect was seen on the prior day. Unlike the prior models, when the estimated cumulative non-occupational incidence rate per 1,000,000 person-days is graphed against increasing maximum heat index **(Figure 10)** the Orlando temperature zone has the greatest incidence rate followed closely by Apopka and distantly by Avalon.

The effect of the maximum heat index on HRI was much smaller for occupational HRI than for non-occupational HRI **(Figure 9 and 10).** The occupational and non-occupational HRI IRR graphed against increasing maximum heat index is presented in **Figure 11**. As with temperature, the increase in the incidence rate of occupational HRI was greater than the increase in the incidence rate of non-occupational HRI when compared with the respective incidence rates at 95°F, the average maximum heat index for the study. However, unlike the HRI-temperature relationship, at a heat index of 107°F the incidence rate of occupational HRI started to decline while the incidence rate of non-occupational HRI continued to increase. At a maximum heat index of 107°F for both the current and prior day, there was approximately a two-fold increase in both the occupational and non-occupational HRI incidence rate compared to the respective HRI incidence rate at the average maximum heat index (95°F) for the study.

For non-occupational HRI the majority of cases are seen in the hospital or ED when the heat index is greater than 108°F. This can be clearly seen in **Table 8** where the estimated rate of individual who would be hospitalized or treated in the ED for non-occupational HRI within heat index category (lag 0-1) for all temperature zones combined is presented. Again a general gradient is seen with the rate of HRI increasing as the heat index increases. However, this gradient is not as clear when the heat index is high (≥106°F). The highest rate of HRI occurs between 108°F and <110°F (IR = 8.34/1,000,000 person-days; 95% CI = 4.07, 17.11). The data were too sparse to examine occupational HRI by heat index category.

CONCLUSION

The objective of this study was to assess the relationship between HRI and ambient temperature. Before an analysis of the entire state was conducted this study, a pilot project, was done to assess the data sources and modeling strategy. The relationship between HRI and ambient temperature was examined in the population around three Orange County weather stations during the summer months (May-September) for years 2005 to 2009.

Two metrics of ambient temperature were used, daily maximum temperature and the daily maximum heat index. Although the exposure metrics were similar, they did vary by location. The heat index was higher in the suburban and rural areas of Avalon and Apopka as compared with the urban environment of Orlando. This may be due to the higher humidity levels caused by agricultural irrigation occurring in the more rural areas which results in a higher heat index compared with the urban environment. Overall, the models using maximum heat index provided a slightly better fit of the data than the models using maximum temperature. However, none of the models provided strong predictive information at the lower end of the temperature/heat index scale (data not shown). Prior published studies have used other metrics of ambient temperature (e.g. average/minimum temperature, apparent temperature, Humidex) without consensus on which metric provides a better understanding of the relationship between climate and health outcome [1,2,16]. Therefore, since the Florida WFO's currently use temperature and heat index for their heat warnings and advisories, these metrics were chosen to be examined when conducting a statewide analysis. The exposure metric used in the pilot study did not allow for the assessment of the specific heat advisory/warning criteria. For this to be done, hourly temperature/heat index data would be required.

The current study of Orange County indicates that the temperature/heat index at which the current heat advisory/warning criteria is set may not be completely optimal, because the results indicated that a portion of the population will already have suffered a HRI event before an advisory or warning is issued. Considering the health outcome data, it may be more effective for an advisory to be issued when the maximum temperature is expected to be greater than 96°F for a 48 hour period instead of the current criteria of two consecutive days of 98°F or greater. For the analysis period, there were zero days that met the current temperature criteria for issuing a heat advisory. However, there were a number of days during the study period which met the current heat index criteria for issuing a heat advisory/warning. As such, an evaluation of the effectiveness of the current criteria is difficult (even if we had hourly information), since the population under study is already receiving the heat advisories/warnings. If the heat advisory/warning system is completely effective, we would ideally estimate zero HRI cases when an advisory/warning was issued – this was not the case. For instance, a heat advisory is currently issued when the maximum heat index is 107-109°F for ≥ 1 hour[‡‡], the estimated rate of HRI for that heat index range is estimated to 8 per 1,000,000 person-days. Based on the data, it is unclear if the rate of HRI would be considerably higher if no advisory/warning had been given or if this is the approximate rate of HRI cases that would be seen if the advisories/warnings were not given (or ignored by the population). It is noteworthy, though, that the majority of HRI cases occur when the heat index is above the lowest current heat index advisory criteria of 105°F for ≥ 3 hours[§§]. This suggests that individuals are not heeding these advisories and warnings.

In general, HRI are not common and the actual number of individuals who are affected on a daily basis is quite low. Furthermore, the confidence intervals are extremely wide, especially for the occupational models. This may be due in large part to the small number of occupational HRI cases in this pilot study of one county. The best fitting models for the non-occupational

[‡‡] The maximum heat index for the day (daily) is equivalent to the daily 1-hour maximum heat index value.

[§§] This is an approximate estimation as hourly information was not available.

population include a number of lag days. Supporting the idea that there is a delayed effect of exposure and HRI may develop over a number of days. It is entirely possible that with a larger sample (i.e. state-wide data) the effect of the prior days' ambient temperature will also have an effect in the occupational group. The effect of the prior day's ambient temperature appeared to be larger in the occupational group then in the non-occupational group. This observation should be further analyzed using a larger sample.

Overall, the combination of heat and humidity (heat index) may be more important in the Florida population than temperature alone. The estimated incidence rates for both occupational and non-occupational HRI were lower when modeling maximum heat index as opposed to maximum temperature. The relationship seen between the heat index and occupational HRI is interesting, keeping in mind the results from the temperature model, and suggest that workers may be aware of how hot it feels as opposed to the recorded temperature. Additionally, the general public doing the same activity (e.g. landscaping) does not have the benefit of protective measures that employers, due to financial and regulatory reasons, would undertake in order to prevent injuries/HRI in their workers. In this pilot, the number of occupationally-related HRI cases was small and the reason for the drop in HRI at highest temperatures **(Figure 9)** may be related to small sample size and/or protective actions taken in the workplace at extreme temperatures. This finding will need to be evaluated with a larger sample size (e.g. state-wide data).

The relationship between HRI and ambient temperature also differed by temperature zone. In general, the Apopka temperature zone had the highest HRI incidence rate, except for the non-occupational HRI-heat index relationship. This may be due to the amount of and type of outdoor activities in each area (e.g. agricultural) as well as difference in access to indoor cooling. Further, it is also possible that an urban heat island effect may play a role in the difference between the Avalon and Orlando temperature zones, where the Orlando temperature zone always had a higher HRI incidence rate than the Avalon temperature zone. There is clear indication in the literature that urban areas may be at high risk of HRI due to the urban heat island effect [2]. However, there is little to no research on the effect of ambient temperature on HRI in rural areas. As seen in this pilot study, further investigation into the rural HRI-ambient temperature relationship is critical. As a result of further investigation, it may prove less effective in rural areas to set heat advisories and warnings based on data from ambient temperature monitors located in urban areas.

There are a few limitations of this analysis. The incidence rate presented for occupational HRI is most likely an underestimation of the true rate. The majority of occupational cases were identified through a primary payer code indicating workers compensation. There are many barriers to accessing workers compensation and a large number of individuals who are at high risk for HRI (e.g. agricultural workers or construction/landscape workers employed by a small business) may not file claims and therefore would not be classified in this study as an occupationally-related HRI case [17]. Additionally, the small number of occupational cases leads to imprecise results. A second limitation is related to exposure misclassification as the hospitalization/ED data only provide the individuals residential zip code and not the zip code of where the exposure actually occurred. Over 90% of individuals sought treatment at a facility within their county (Orange, Lake or Seminole) or the adjacent county of Osceola indicating the exposure misclassification in this population may be slight. It is unclear if we are over or underestimating the effect estimates especially when comparing the three different temperature zones. Regardless of the biased estimates the exposure in the three temperature zones, while varied, is similar enough that the overall results and implications of this analysis are still valid. Third, the health outcome variable used in the pilot analyses was solely HRI. Increasing ambient temperature is also associated with total morbidity and mortality and not only acute HRI. During numerous heat waves, an increase in diseases of the circulatory system, respiratory system, and disorders of the kidney have also been seen [1,2,18]. An excess of total mortality attributed to heat has also been seen outside of specific heat waves [19]. Furthermore, a statewide study should examine other subpopulations that are at high risk of suffering from a heat-related condition, such as the elderly [1,2] or young adults [20]. Finally, due to the data sources used (hospital discharge data and ED data); the rates of occupational and non-occupational HRI are likely underestimated as individuals who died without being seen in the hospital or ED, who were treated in a physician's office, or who do not seek treatment were not captured in this analysis. To provide more information on HRI, other data sources (e.g. death certificates, physicians' visits) would also need to be evaluated in future studies.

Heat related illness is preventable and heat warning/advisory criteria based both on ambient temperature and conditions that trigger ED and hospitalization events in local populations play an essential role in reducing the burden of disease. This pilot study served to validate the use of needed data sets and modeling techniques required to explore the relationship between heat criteria and HRI; specific recommendations for changes to thresholds and criteria for heat advisories and heat warnings are expected to be made once state-wide data has been evaluated.

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FIGURES and TABLES

Table 1. Frequency of heat-related cases* (HRI) and average population per year stratified by temperature zone (2005-2009)

Temperature Zone	Non-Occupational			Occupational		
	# HRI cases	Average population/year	Rate/1,000,000 person-years	# HRI cases	Average population†/year	Rate/1,000,000 person-years
Orlando	559	797,824	140.1	60	405,990	29.6
Apopka	220	232,682	189.1	33	116,777	56.5
Avalon	104	152,064	136.8	12	75,659	31.7
Total	*883*	*1,182,570*	*149.3*	*105*	*598,426*	*35.1*

*HRI treated in the hospital or ED during the summer months (May-September, which is equivalent to 153 days).
†Employed population age 16 years or older. Data Source: the AHCA and the ACS 2009 5-year estimate

Table 2. Average maximum temperature and maximum heat index stratified by year and station (May through September).

Year	Temperature (standard deviation)				Heat Index (standard deviation)			
	Apopka	Avalon	Orlando	Total	Apopka	Avalon	Orlando	Total
2005	88.6 (4.6)	89.5 (4.7)	88.7 (4.1)	88.9 (4.5)	97.0 (8.6)	96 (7.9)	94.3 (6.4)	95.8 (7.8)
2006	89.3 (3.5)	89.9 (3.8)	89.7 (3.3)	89.6 (3.5)	94.8 (5.8)	95.3 (6.6)	93.3 (4.8)	94.5 (5.8)
2007	88.5 (4.3)	89.5 (4.8)	89.5 (4.2)	89.2 (4.5)	94.8 (7.6)	95.4 (8.1)	93.1 (5.9)	94.4 (7.3)
2008	88.2 (3.5)	90.1 (3.9)	89.2 (3.4)	89.2 (3.7)	94.6 (6.0)	98.1 (7.3)	92.7 (4.5)	95.1 (6.4)
2009	89.4 (4.2)	89.6 (4.4)	89.6 (4.0)	89.5 (4.2)	98.5 (7.8)	97.0 (7.3)	94.7 (5.6)	96.7 (7.1)
Total	88.8 (4.1)	89.7 (4.3)	89.3 (3.8)	89.3 (4.1)	95.9 (7.4)	96.4 (7.5)	93.6 (5.5)	95.3 (7.0)

Data Source: NWS Florida WFO

Table 3. The total number and average number of days per year which met the Orange County temperature/heat index criteria* for a heat advisory or warning (2005-2009)

Heat Index	Apopka		Avalon		Orlando	
	Total Days	Average # of days/year (std dev)	Total Days	Average # of days/year (std dev)	Total Days	Average # of days/year (std dev)
>105 - <106	18	3.6 (2.5)	14	2.8 (2.3)	7	1.4 (1.1)
106 - <107	21	4.2 (3.3)	15	3.0 (1.2)	0	0 (0)
107 - <109	13	2.6 (2.9)	18	3.6 (2.6)	0	0 (0)
≥ 110	14	2.8 (2.6)	13	2.6 (1.5)	0	0 (0)

***Heat *warning* criterion**: heat index is 110°F for ≥2 hours; **Heat *advisory* criteria**: heat indices > 105°F for ≥ 3 hours, heat indices around 106°F for ≥ 2 hours, heat indices 107-109°F for ≥ 1 hour, heat index readings between 105-110°F, or ambient air temperature ≥ 98°F is expected for two or more consecutive days. (Note: There were zero days when max temp ≥ 98°F for two or more days. However, on 6/22/2009 the max temp was ~98.7°F at the Avalon station and 97.6°F the prior day.) Data Source: NWS Florida WFO

Table 4. Assessment of best model fit with regard to modification by multiple lag days for occupational and non-occupational HRI.

Model*	Occupational (N=2208)				Non-Occupational (N=2208)			
	AIC†	Log Likelihood	LRT‡	p-value	AIC†	Log Likelihood	LRT‡	p-value
Temperature: Lag 0-5	761.1	-359.5			3098.23	-1528.12		
Temperature: Lag 0-4	759.3	-359.7	0.2	0.6	3099.46	-1529.73	3.2	0.07
Temperature: Lag 0-3	761.0	-361.5	3.7	0.05	3097.50	-1529.75	0.05	0.8
Temperature: Lag 0-2	759.0	-361.5	0.02	0.9	3100.81	-1532.41	5.31	0.02
Temperature: Lag 0-1	757.4	-361.7	0.4	0.5	3098.83	-1532.41	0.02	0.9
Temperature: Lag 0	761.0	-364.5	5.6	0.02	3110.36	-1539.18	13.5	0.0002
Heat Index: Lag 0-5	764.9	-360.4			3135.15	-1545.58		
Heat Index: Lag 0-4	762.9	-360.4	0.004	0.9	3140.78	-1549.39	7.6	0.006
Heat Index: Lag 0-3	763.1	-361.6	2.2	0.1	3138.79	-1549.40	0.01	0.9
Heat Index: Lag 0-2	761.5	-361.8	0.4	0.5	3143.02	-1552.51	6.2	0.01
Heat Index: Lag 0-1	759.7	-361.8	0.1	0.7	3141.08	-1552.54	0.1	0.8
Heat Index: Lag 0	761.4	-363.6	3.4	0.06	3148.64	-1557.32	9.6	0.002

*Each model is adjusted for the following variables: year, month, and weekday. For each heat index model lag 0 is modeled as quadratic while each of the other lags are modeled as linear. For each temperature model lags are modeled as linear.
† Akaike information criterion (lower is better)
‡Likelihood ratio test; each model is compared with the previous model
Data Source: NWS Florida WFO, AHCA, and ACS 2009 5-year estimate

Table 5. Incidence rate ratios* and 95% confidence intervals of occupational and non-occupational HRI for every 5° F increase in maximum temperature or maximum heat index (2005-2009)

Group	Temperature Zone	Temperature: IRR (95% CI)		Heat Index: IRR (95% CI)	
		Lag 0	Lag 1	Lag 0	Lag 1
Occupational	Orlando	1.78 (1.17, 2.70)	1.69 (1.11, 2.58)	1.48 (1.08, 2.03)	1.28 (0.97, 1.70)
	Apopka	3.58 (1.96, 6.54)	3.40 (1.86, 6.25)	2.11 (1.26, 3.54)	1.83 (1.11, 3.02)
	Avalon	1.62 (0.78, 3.37)	1.54 (0.74, 3.22)	1.16 (0.58, 2.32)	1.01 (0.51, 1.97)
Non-Occupational	Orlando	1.96 (1.70, 2.27)	1.31 (1.14, 1.51)	1.53 (1.38, 1.69)	1.19 (1.08, 1.31)
	Apopka	2.81 (2.26, 3.48)	1.88 (1.52, 2.32)	1.45 (1.21, 1.75)	1.13 (0.94, 1.36)
	Avalon	1.69 (1.31, 2.16)	1.13 (0.88, 1.45)	1.01 (0.80, 1.28)	0.79 (0.62, 0.99)

*Each model is adjusted for the following variables: year, month, and weekday. In the temperature models lag 0 and lag 1 are modeled as linear while in the heat index models lag 0 is modeled as quadratic and lag 1 is modeled as linear.
Data Source: NWS Florida WFO, AHCA, and ACS 2009 5-year estimate

Table 6. Incidence rate ratios* and 95% confidence intervals of non-occupational HRI for every 5°F increase in maximum temperature or maximum heat index (2005-2009)

Day	Temperature: IRR (95% CI)	Heat Index: IRR (95% CI)
Lag 0	1.96 (1.69, 2.26)	1.52 (1.37, 1.68)
Lag 1	1.28 (1.09, 1.51)	1.17 (1.05, 1.30)
Lag 2	1.11 (0.95, 1.29)	1.08 (0.97, 1.21)
Lag 3	0.87 (0.76, 0.98)	0.89 (0.80, 0.98)
Lag 4		1.08 (0.97, 1.20)
Lag 5		0.89 (0.81, 0.97)

*Each model is adjusted for the following variables: year, month, and weekday. In the temperature models lags 0-5 are modeled as linear while in the heat index models lag 0 is modeled as quadratic and lags 1-5 are modeled as linear.
Data Source: NWS Florida WFO, AHCA, and ACS 2009 5-year estimate

Table 7. Estimated non-occupational HRI incidence rate per 1,000,000 person-days and 95% confidence interval stratified by increasing maximum temperature categories (2005-2009)

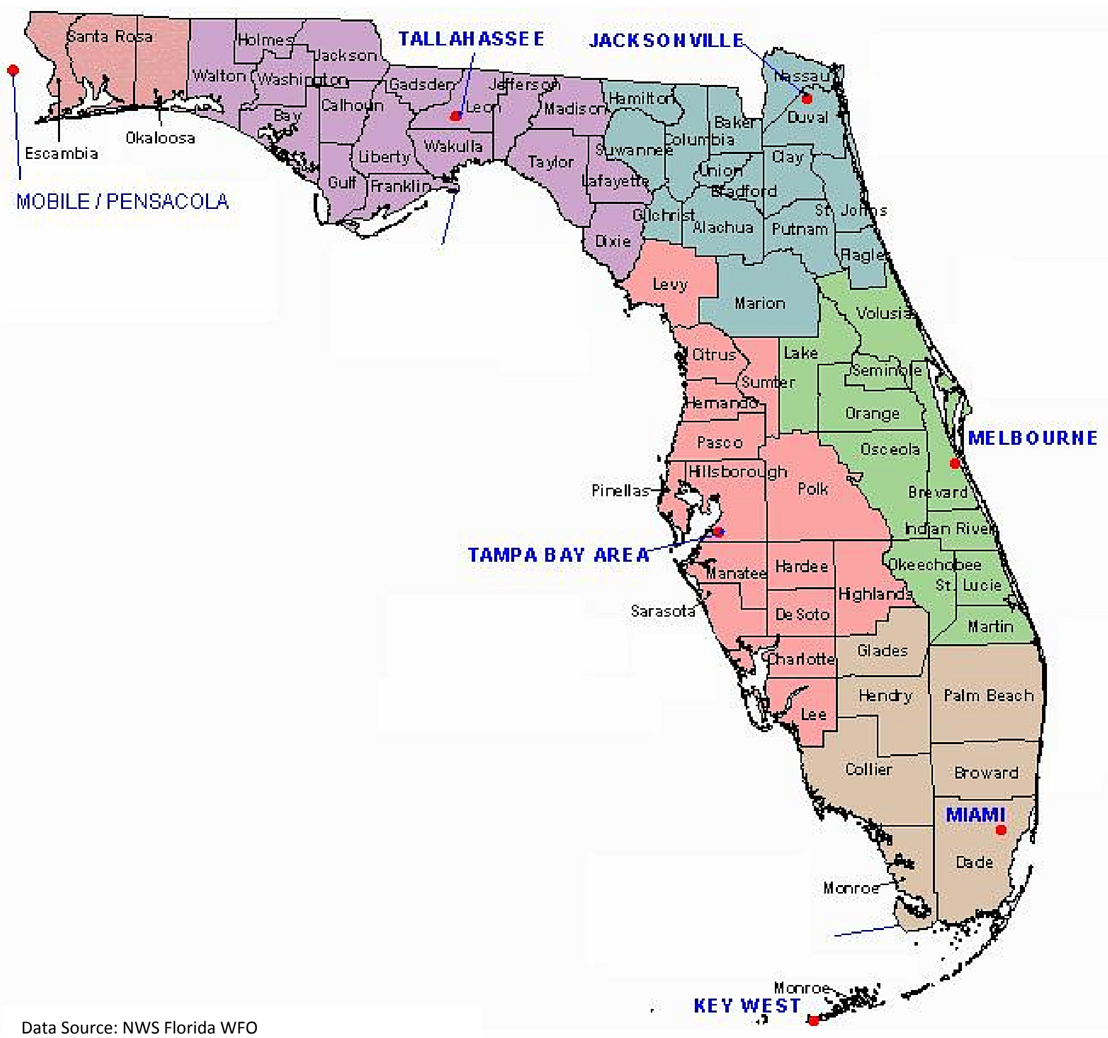
Temperature Category*	IR/1,000,000 person-yrs	95% CI
<80	0.09	(0.02, 0.45)
80-<82	0.14	(0.03, 0.62)
82-<84	0.36	(0.15, 0.87)
84-<86	0.24	(0.13, 0.47)
86-<88	0.59	(0.41, 0.86)
88-<90	0.98	(0.71, 1.34)
90-<92	1.26	(0.94, 1.70)
92-<94	2.01	(1.51, 2.68)
94-<96	2.36	(1.59, 3.50)
96-<98	4.01	(2.60, 6.20)
98+	2.91	(0.68, 12.36)

* Each model is adjusted for the following variables: year, month, and weekday. The modeled incidence rate has the same maximum temperature category on both the current and prior day (lag 0-1).
Data Source: NWS Florida WFO, AHCA, and ACS 2009 5-year estimate

Table 8. Estimated non-occupational HRI incidence rate per 1,000,000 person-days and 95% confidence interval with increasing maximum heat index categories (2005-2009).

Heat Index Category	IR/1,000,000 person-yrs	95% CI
<82	0.05	(0.01, 0.24)
82-<84	0.12	(0.03, 0.48)
84-<86	0.41	(0.17, 0.97)
86-<88	0.19	(0.08, 0.46)
88-<90	0.65	(0.38, 1.13)
90-<92	0.74	(0.45, 1.20)
92-<94	0.74	(0.50, 1.11)
94-<96	1.19	(0.83, 1.70)
96-<98	1.30	(0.93, 1.82)
98-<100	1.89	(1.40, 2.55)
100-<102	2.07	(1.48, 2.90)
102-<104	2.53	(1.71, 3.74)
104-<106	3.08	(1.85, 5.13)
106-<108	1.51	(0.70, 3.26)
108-<110	8.34	(4.07, 17.11)
110-<112	7.54	(3.20, 17.72)
112+	3.07	(0.91, 10.35)

* Each model is adjusted for the following variables: year, month, and weekday. The modeled incidence rate has the same maximum heat index category on both the current and prior day (lag 0-1).
Data Source: NWS Florida WFO, AHCA, and ACS 2009 5-year estimate



Data Source: NWS Florida WFO

Figure 1. Regional Weather Forecasting Offices (red dots) and the counties that they serve. Note the Key West weather forecasting office serves all of costal Monroe County.

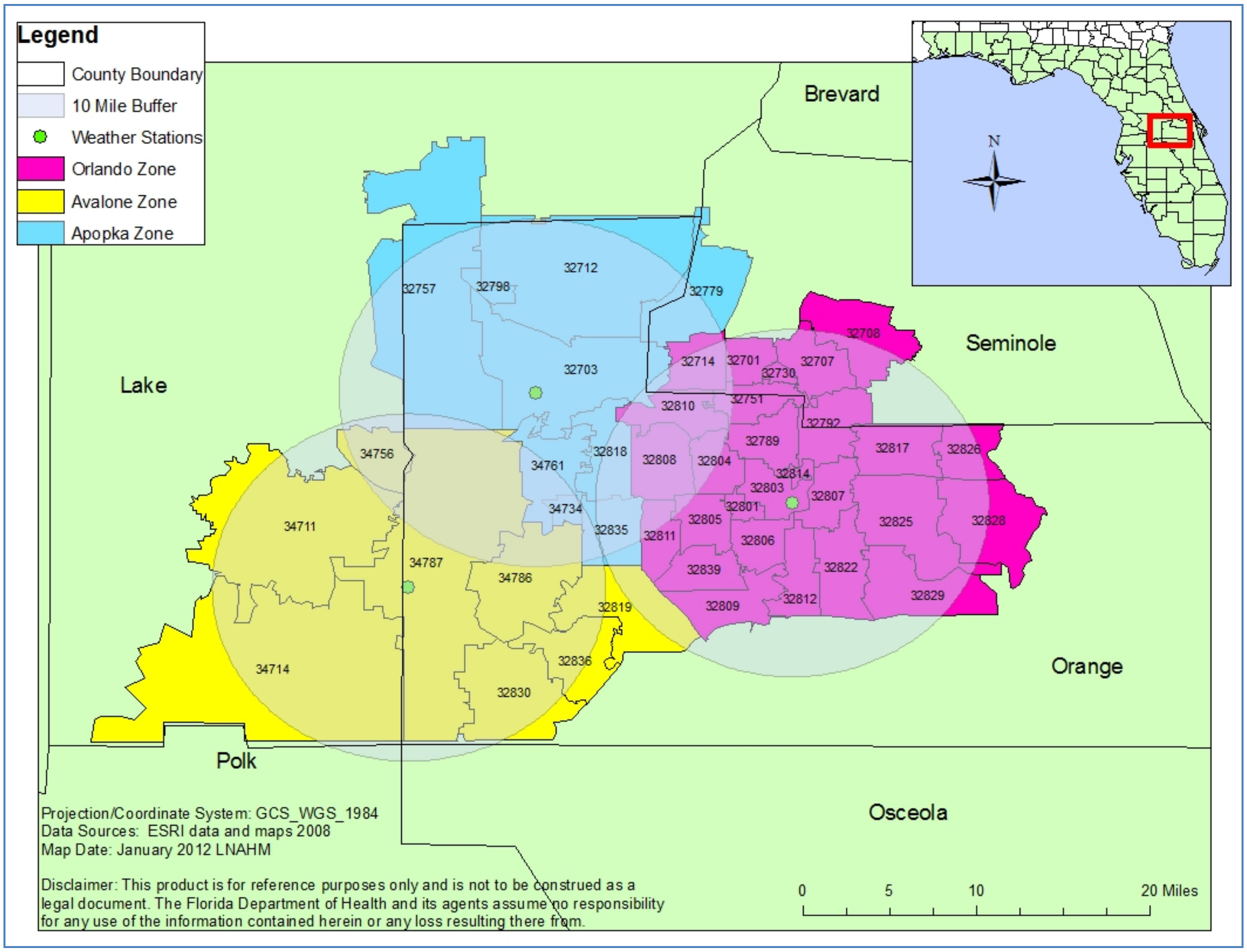


Figure 2. Temperature zones: The heat-related illness hospitalization/ED visit in each zone is associated with the recorded ambient temperature at the corresponding weather station. Each weather station has a buffer with a 10 mile radius.

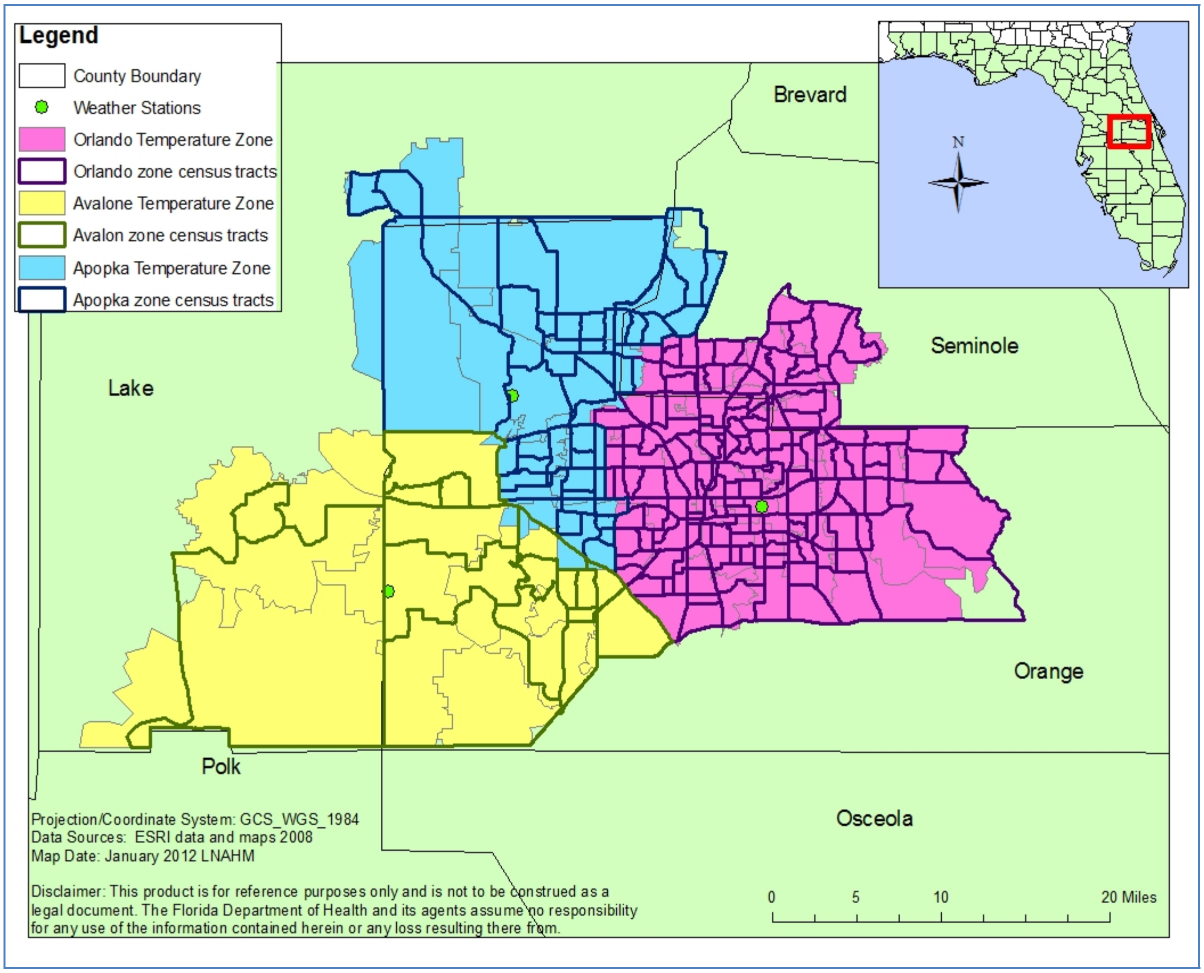


Figure 3. 2000 US census tract defined temperature zones overlayed on top of the zip code defined temperature zones. Zip codes were originally used to define the temperature zones as the smallest geographic units in the health data were zip codes. Population data not available at the zip code level; therefore the temperature zones were redefined using the 2000 US census tracts.

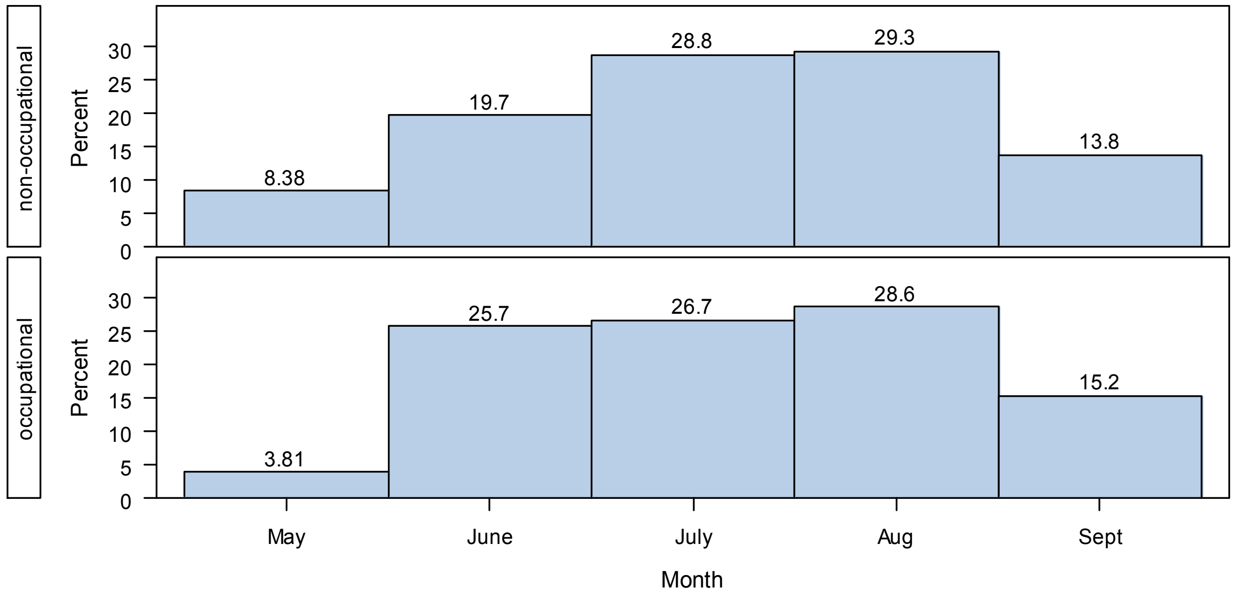


Figure 4. Distribution of cases of heat related illness by month and occupational status (2005-2009): non-occupational (N = 883), occupational (N= 105) (Data Source: AHCA)

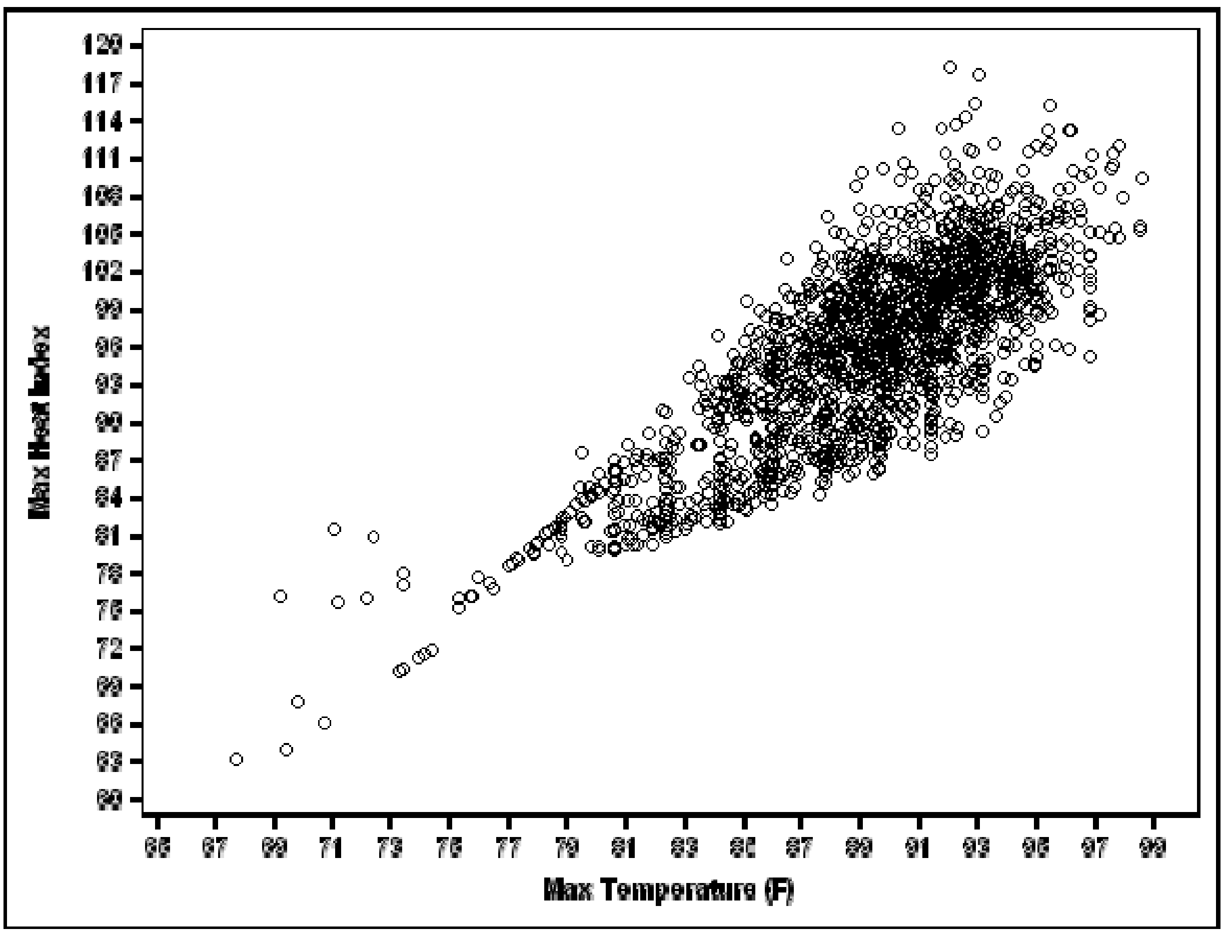


Figure 5. Scatter plot of daily maximum temperature by daily maximum heat index. The two metrics are highly correlated (r=0.79, p <0.0001). (Data Source: NWS Florida WFO)

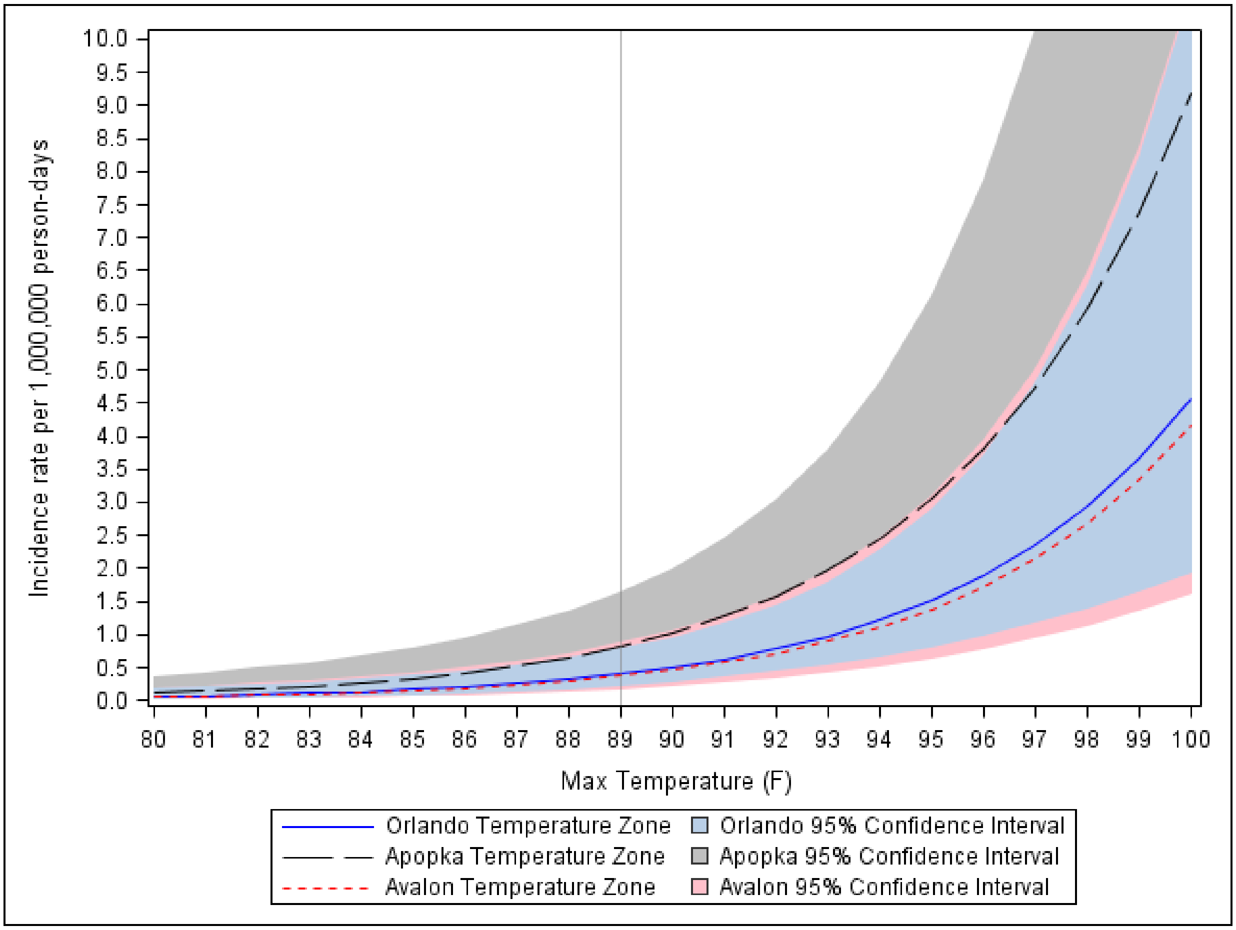


Figure 6. Modeled occupational HRI incidence rate with increasing temperature stratified by temperature zone (2005-2009). The modeled incidence rate has the same maximum temperature on both the current and prior day (lag 0-1).

(Data Source: NWS Florida WFO, AHCA, and ACS 2009 5-year estimate)

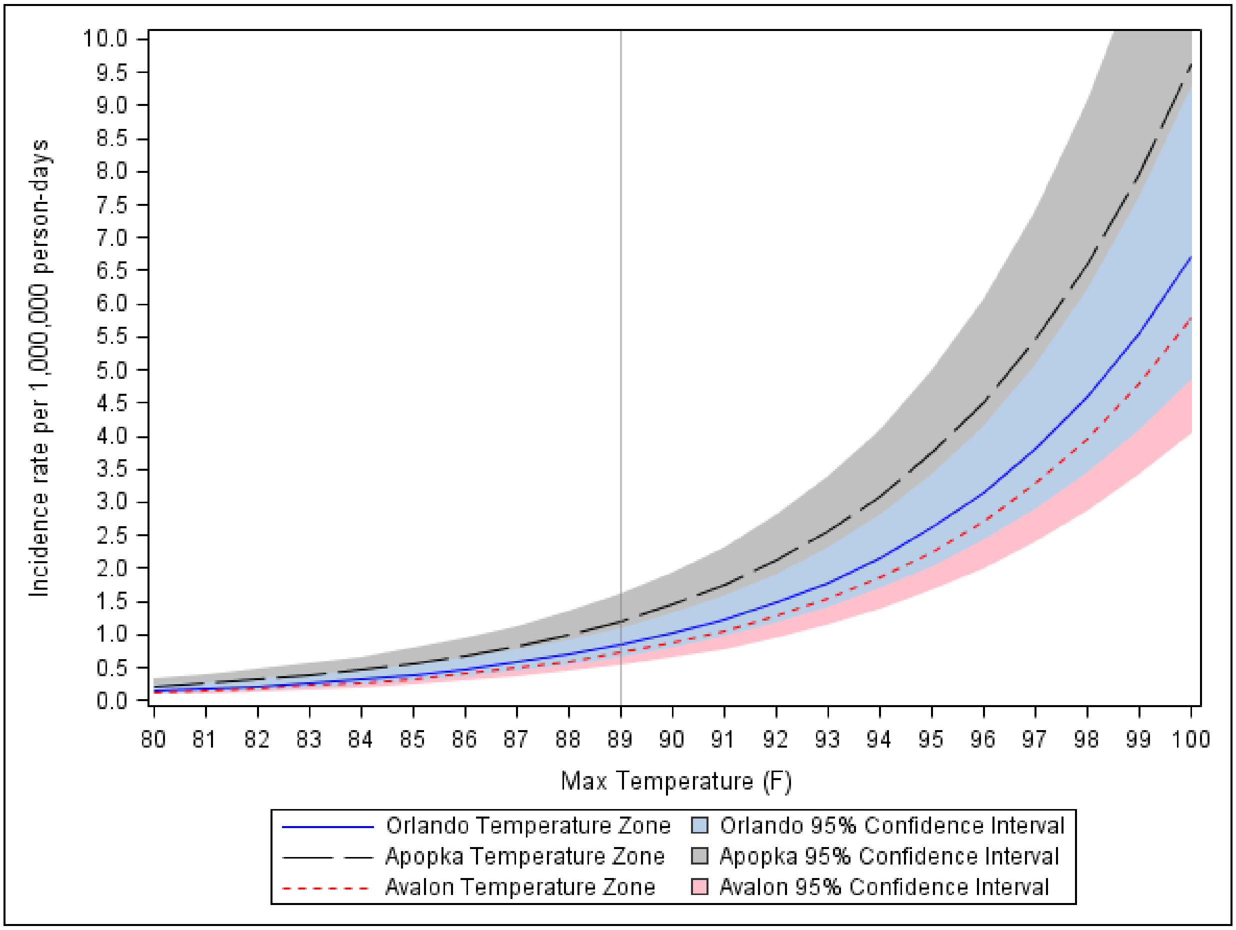


Figure 7. Modeled non-occupational HRI incidence rate with increasing temperature stratified by temperature zone (2005-2009). The modeled incidence rate has the same maximum temperature on both the current and prior day (lag 0-1).
(Data Source: NWS Florida WFO, AHCA, and ACS 2009 5-year estimate)

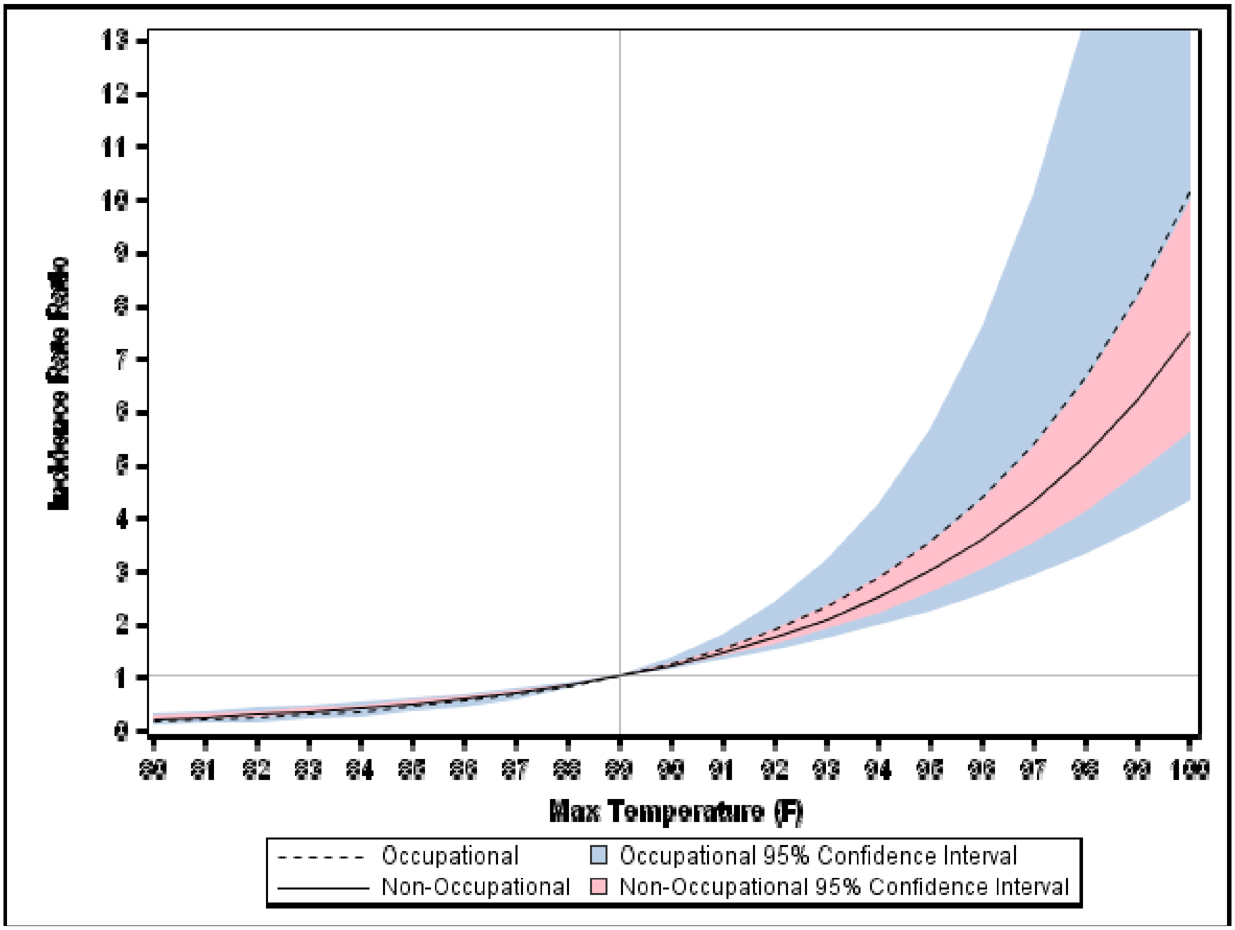


Figure 8. Modeled incidence rate ratio and 95% confidence intervals for occupational and non-occupational HRI as temperature increases (2005-2009). The modeled incidence rate has the same maximum temperature on both the current and prior day (lag 0-1). The comparison incidence rate is the rate when the maximum temperature is at 89°F.

(Data Source: NWS Florida WFO, AHCA, and ACS 2009 5-year estimate)

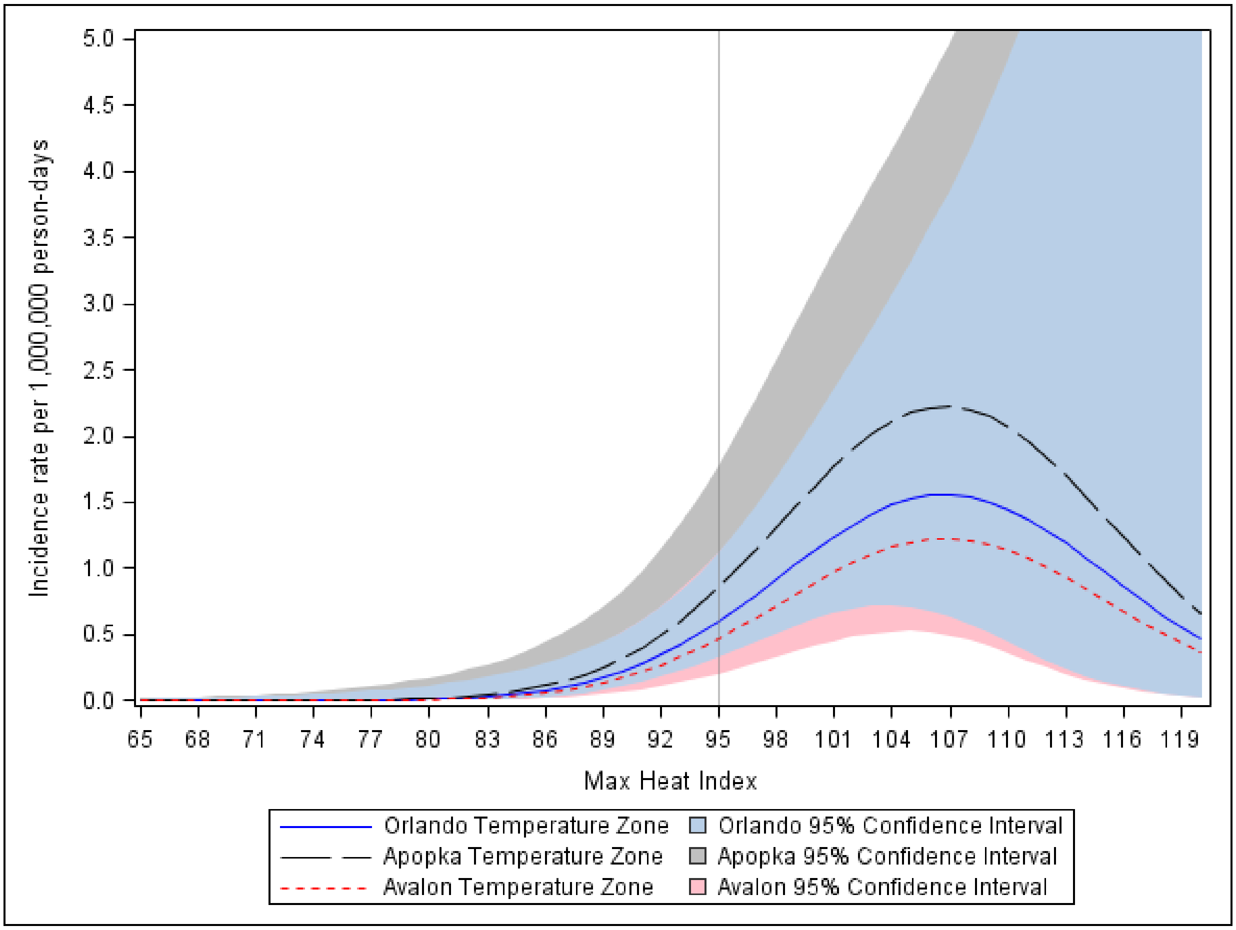


Figure 9. Modeled occupational HRI incidence rate with increasing heat index stratified by temperature zone (2005-2009). The modeled incidence rate has the same maximum heat index on both the current and prior day (lag 0-1).
(Data Source: NWS Florida WFO, AHCA, and ACS 2009 5-year estimate)

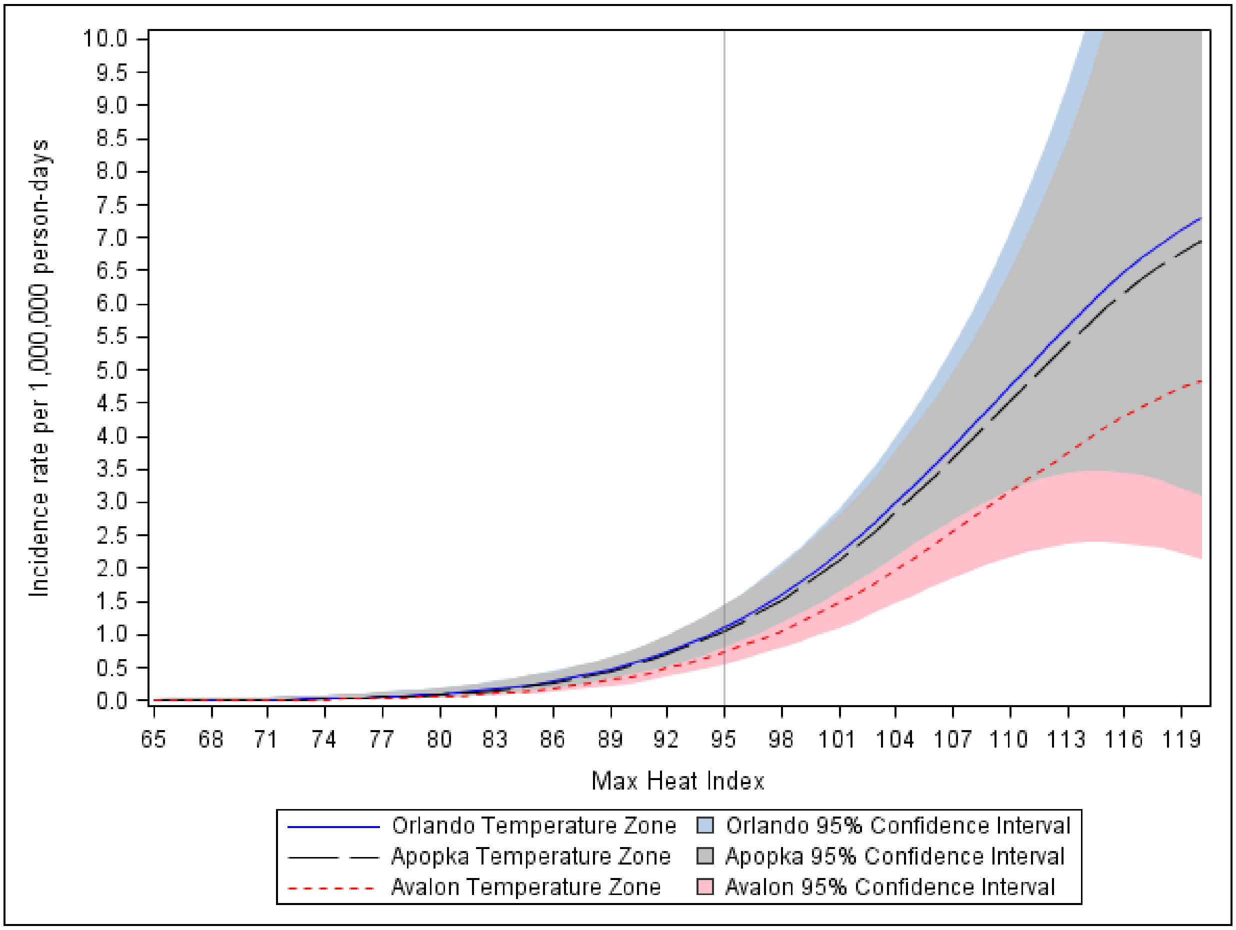


Figure 10. Modeled non-occupational HRI incidence rate with increasing heat index stratified by temperature zone (2005-2009). The modeled incidence rate has the same maximum heat index on both the current and prior day (lag 0-1).

(Data Source: NWS Florida WFO, AHCA, and ACS 2009 5-year estimate)

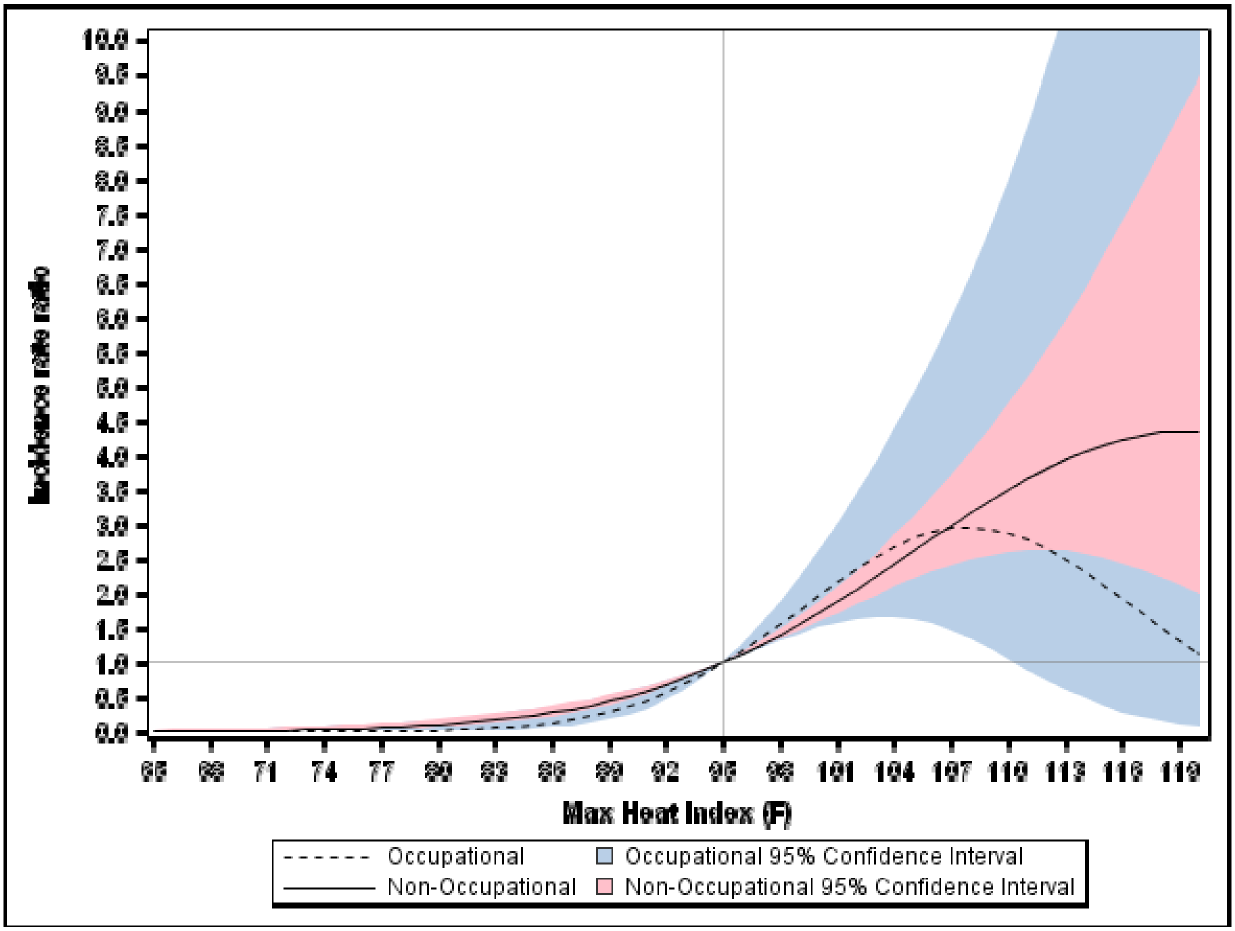


Figure 11. Modeled incidence rate ratio and 95% confidence intervals for occupational and non-occupational HRI as heat index increases (2005-2009). The modeled incidence rate has the same maximum heat index on both the current and prior day (lag 0-1). The comparison incidence rate is the rate when the maximum heat index is 95.
(Data Source: NWS Florida WFO, AHCA, and ACS 2009 5-year estimate)