Research Square

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Effect of Maximum Average Temperature on Suicide Rates in California, 2008-2017: Public Health Implications of Climate Change

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Abstract

Background

Suicide prevention is a salient public health responsibility, as it is one of the top ten leading causes of premature mortality in the United States. Risk factors of suicide transcend the individual and societal level as risk can increase based on climatic variables. Previous studies have been country-based. Currently, studies focused solely on regions, provinces, or states, such as California, are limited. The present study holds two purposes: i) to assess the effect of maximum temperature on suicides, and ii) to evaluate the effect of number of monthly heat events on suicide rates, in California from 2008-2017.

Methods

The exposure was measured as the average Californian daily maximum temperature within each month, and the number of monthly heat events, which was calculated as a count of the days exhibiting a >15% increase from the historical monthly temperature. The outcome was measured as California's monthly suicide rate. Negative binomial regression models assessed the relationship between maximum temperature and suicides, and heat events and suicide. A seasonal decomposition of a time series and auto-correlogram further analyzed the seasonality of suicide and the trend from 2008-2017.

Results

There were 40,315 deaths by suicide in California between 2008-2017. Negative binomial regression indicated a 6.1% increase in suicide incidence rate ratio (IRR) per 10°F increase in maximum temperature (IRR=1.00590 per 1°F, 95% CI: 1.00387, 1.00793, p<0.0001) and a positive, non-significant association between suicide rates and number of heat events adjusted for month of occurrence (IRR 1.00148 per heat event, 95% CI: 0.99636, 1.00661, p=0.572). The time series analysis and auto-correlogram suggested seasonality of deaths by suicide.

Conclusion

The present study provided preliminary evidence that will generate future directions for research. We must seek to further illuminate the relationship of interest and apply our findings to public health interventions that will lower the rates of death by suicide as we are confronted with the effects of climate change.

Background

Suicide is defined as the act of deliberately ending one's own life.[1] Suicide prevention is a salient public health responsibility as one of the top ten leading causes of premature mortality in the United States.[2] Suicide is a complex psychopathological phenomenon driven by biological variables, psychological variables and interactions between individuals and their social environment.[3, 4] Risk factors of suicide transcend the individual and societal level as risk can increase based on climatic variables. The effect of environmental temperature on suicide is an important issue, particularly with the rise in global temperatures due to climate change.[5]

The association of weather variables and human health date back to Hippocrates' assertion that cold and warm winds can affect physical and psychological health.[3, 6] Contemporary analyses have found an influence of meteorological patterns on human conditions and behaviours including migraine, ischemic stroke, multiple sclerosis, coronary disease, asthma, mortality and suicide.[6] However, the biological mechanism linking temperature and suicide is not well understood.[5, 7] Speculation reflects that the seasonal variations in serotonin influence impulsivity and aggression leading to suicide.[7]

Understanding the association between climate and human behavior is challenging due to the inherent complexity of suicide and environmental variables.[3, 6] No individual suicide can be attributed to a single event and can be compounded by the number of risk factors an individual has.[3] However, weather variables can further exacerbate the risk of suicide.[8] Climate is multidimensional and to truly understand the effects of climate on human behavior, a breadth of climatic variables should be accounted for, though, this is not simple to do.

Effects of weather variables on suicide are well-documented. Previous studies that have assessed this association have been country-based analyses and have been conducted in nations including India, Japan, New Zealand, and the US.[3, 5, 7, 9] There is still inconsistency amongst the results of most studies due to different methods used in analyses.[3] Specifically, studies concerned with temporal variation in temperature and suicide tend to find a positive association, while those concerned with geographical variations tend to find a negative relationship.[5] Furthermore, varying climatic and social conditions of the geographic region of focus may reflect the association exhibited by different studies. Generally, most studies have demonstrated a peak in suicide in late spring and early summer. [6, 10, 11, 12, 13, 14] Currently, studies focused solely on regions, provinces, or states, such as California, are limited.

California is the most populous state in the US as it is home to 39,536,653 individuals.[15] This, along with California being a fairly progressive state and the states participation in the Centers for Disease Control and Prevention (CDC) National Violent Death Reporting System, indicates that the data on suicide incidence is less likely to be subject to underreporting. This study aimed to assess the association between temperature and suicide rates in California from 2008–2017. Specifically, the purpose of the present study is twofold: i) to assess the effects of maximum temperature on suicides, and ii) to evaluate the effect of the number of monthly heat events on suicide rates in California from 2008–2017. A heat event is classified to be an episode or occurrence in which temperatures surpass the historical average of a given area [16]. We hypothesized that with increasing average temperature (F^{o}), there is an increase in incidence of suicides in the state of California. Furthermore, it was hypothesized that heat events positively increase the suicide rate.

Methods

Data Sources

Suicide, weather, and population data used for the present study are publicly available. Monthly suicide data from January 2008 to December 2017 was collected for California from the CDC Multiple Causes of Death Database.[18] ICD-10 codes including X60 to X84 were used to reflect any death by suicide (Appendix: Table 3).[19] Daily maximum temperature data was collected from the National Oceanic and Atmospheric Administration (NOAA).[19] Eight weather stations with diverse elevations, longitudes and latitudes around California were specifically chosen to represent the greatest geographical spread across the state as possible: Long Beach, Pasos Robles, Los Angeles downtown, New Cuyama, Santa Maria, Camarillo, San Francisco, and Monterey. Lastly, the mid-year Californian population was collected from the United States Census Bureau.[21]

Table 3
ICD-10 codes and definitions for suicide methods

Suicide Definition
ICD-10 Codes
X60 - X65, X-68-X69 Poisoning by solid or liquid substances
X66-X67 Other poisoning
X70 Hanging, strangulation and suffocation
X71 Drowning and submersion
X72-X75 Firearms and explosives
X80 Jumping from high place
X76-X79, X81-X84 Other injury, including sharp objects

Data Cleaning and Handling

Mid-year population and monthly suicide data were used to compute monthly crude suicide rates per 10,000 people for each month from 2008–2017. Next, daily temperature data from the eight chosen weather stations were averaged to calculate state-wide temperature averages from 2008–2017. Out of the 3,654 observations within the 10-year period, there were 159 observations with temperature data from one missing weather station. In these cases, seven weather stations were used to compute a daily average instead of eight stations.

Using daily California temperatures, average monthly maximum temperatures were calculated and were used to assess the association of temperature and suicide rates. Next, to classify a heat event, historical averages calculated from 2008–2017 for the same eight weather stations were averaged to create historical monthly averages. Percent change from the observed daily temperatures and the historical average maximum temperatures was calculated, and a heat event was identified if the percent change from the historical average was greater than a 15% threshold [16]. These relative heat events were used to assess high temperature anomalies year-round. This threshold was chosen upon running sensitivity analyses on various cut-off points. A count of heat events per month was calculated to reflect the number of days in each month that exceeded a 15% departure from the historical average.

Statistical Analyses

All statistical analysis was conducted in R version 3.6.2 and Stata/IC version 16.0. The threshold for significance was evaluated against a p-value of 0.05.

To assess the baseline characteristics of the study population, descriptive statistics were computed. Key descriptive statistics included age, gender, and race/ethnicity. Next, a descriptive analysis was performed to illustrate the primary outcome, monthly suicide rates per 10,000 people, between 2008–2017. The same analysis was performed to describe both exposure variables, average monthly maximum temperature, and the count of monthly heat events over the same 10-year period. A boxplot evaluating the distribution of monthly number of heat events was created to show the crude association between the number of monthly heat events and the month of occurrence. Lastly, a boxplot was created to display the monthly suicide rate per 10,000 people and the month they occurred to summarize the 2008–2017 data.

A seasonal decomposition of a time series was conducted to model the relationship of suicide rates per 10,000 people in California from 2008–2017. This time series decomposes the data in order to evaluate the seasonality component and the trend over time separately. Furthermore, it pinpoints what features of the data could not be explained by seasonality and trend over time, providing a further analysis of the important trends and the remaining noise in the data.

An auto-correlogram was used to assess the autocorrelation of deaths over the specified time period. The analysis evaluated the degree of correlation between monthly suicide rates across different observations in the data. If the suicide rates that occurred closer in time were more similar to the suicide rates that were further apart in time, this would further indicate a seasonal component to suicide occurrence in California.

A Poisson regression model would be deemed appropriate if a Pearson goodness-of-fit test was non-significant ($p > 0.05$) and the variance of the outcome was equal to the mean indicating no overdispersion. If overdispersed, a negative binomial regression would be used. These regression models assessed the number of suicides over time with a population offset and assessed the relationship between the number of suicides and the average monthly maximum temperature with a population offset. For both regression models, incidence rate ratios (IRRs) and their 95% confidence intervals (CIs) were also calculated. Sensitivity analyses comparing the number of suicides to the average monthly minimum temperature with population offset were conducted. Likelihood ratio tests (LRTs) compared these models against intercept-only models. If significant, the full models explained significantly more variance. Akaike information criterion (AIC) and Bayesian information criterion (BIC) values were computed for each model with lower models indicating a more likely or better model.

To assess the impact of a heat event on suicide rates, a negative binomial regression model was used with adjustment for the month of occurrence to evaluate the effect of a heat event independent of the month it occurred, to solely investigate how an increase in that month's number of heat events affects suicide rates.

Results

There were 40,315 deaths by suicide in California between 2008–2017. Demographics of these individuals are presented in Table 1. Of note, more males (77%) died by suicide compared to females and those in the 45–54 age group had the highest incidence of suicide (20.72%). We did not have the level of data required to stratify analyses by age and gender.

Table 1
Demographics of those who died by suicide in California, 2008–2017 (N = 40,315)

	Deaths (%)	Population (%)	Crude Rate per 10,000
Age Group			
<1	0	5,031,691 (1.32)	-
1–4	0	20,176,607 (5.29)	-
5–14	256 (0.63)	50,763,337 (13.3)	0.05
15–24	4,448 (11.03)	55,254,454 (14.48)	0.81
25–34	5,744 (14.25)	55,811,444 (14.62)	1.03
35–44	6,150 (15.25)	51,896,776 (13.60)	1.19
45–54	8,354 (20.72)	52,174,211 (13.67)	1.6
55–66	7,389 (18.33)	43,218,852 (11.33)	1.71
65–74	3,825 (9.49)	26,326,044 (6.90)	1.45
75–84	2,644 (6.56)	14,411,304 (3.78)	1.83
85+	1,495 (3.71)	6,554,653 (1.72)	2.28
Not Stated	10 (0.02)	-	-
Gender			
Female	9,316 (23.11)	191,932,051 (50.29)	0.49
Male	30,999 (76.89)	189,687,322 (49.71)	1.63
Hispanic Origin			
Hispanic or Latino	6,930 (17.19)	145,769,464 (38.2)	0.48
Not Hispanic or Latino	33,316 (82.64)	235,849,909 (61.8)	1.41
Not Stated	69 (0.17)	-	-
Race			
American Indian or Alaska Native	360 (0.89)	7,489,909 (1.96)	0.48
Asian or Pacific Islander	3,658 (9.07)	58,860,332 (15.42)	0.62
Black or African American	1,705 (4.23)	27,676,040 (7.25)	0.62
White	34,592 (85.80)	287,593,092 (75.36)	1.2

Figure 1A demonstrates the distribution of suicides per month (aggregated for the 10-year period). Figure 1B demonstrates the crude monthly suicide rates per 10,000 between 2008–2017 showing an overall upward trend over time. Figure 2 portrays suicide rates over time, suggesting seasonality as well as an overall positive trend. Average monthly maximum temperature also appeared to be increasing over time (median: 71.61°F, IQR:66.73°F to 78.43°F; Fig. 2) as well as the number of heat events (median: 2°F, IQR:0 to 4.5; Fig. 3B). Heat events were less frequent in the summer months and most frequent in winter months (Fig. 3A) and therefore did not establish any meaningful relationship with suicide rates.

The seasonal decomposition of a time series analysis demonstrated further evidence of potential seasonality in the number of suicides over time (Fig. 4). The trend component suggested a possible increase in suicides over time. The remainder component indicated that the suicides are not completely accounted for by seasonality and trend over time, indicating further analysis could be done to evaluate this residual effect.

Autocorrelation of suicides appeared to peak every 12 months suggesting periodicity and seasonality (Fig. 5). Additionally, autocorrelation dropped below 0 approximately every 12 months, indicating seasonality.

The negative binomial regression model on suicide rates and number of heat events adjusted for month indicate a positive association. Although not statistically significant ($p = 0.572$), it was suggested that with every two additional heat events the suicide incidence rate ratio increased by 0.30%, adjusted for month of occurrence (IRR 1.00148 per heat event, 95% CI: 0.99636, 1.00661). Overall, since there was no statistical significance in the relationship between heat events and suicide rates, there was no further analysis for this exposure variable, and maximum temperature was used instead.

Pearson goodness-of-fit tests of Poisson models suggested the suicide data is not Poisson distributed ($p < 0.05$). It was concluded the data was overdispersed as the variance of the suicides (959.79) was almost three times the mean of the data (335.96). Thus, a negative binomial regression was used. Compared to intercept only models, there was strong evidence that all models adjusted for the independent variable (either time in months, average maximum temperature by month or average minimum temperature by month) and population offset explained significantly more variance than the intercept-only models ($p < 0.0001$ for all LRT; Table 2). These full models also had lower AIC and BIC values, further implying better fit compared to intercept-only models.

Table 2
Count-based regression models

	Negative Binomial Regression					Poisson Regression				
	IRR (95% CI)	p-value	AIC	BIC	LR Test[2] p-value	IRR (95% CI)	p-value	AIC	BIC	LR Test[2] p-value
Suicides by time (months)										
Intercept only-model	-	-	1167.24	1172.81	< 0.0001	-	-	1260.27	1263.06	< 0.0001
Full model[1]	1.00054 (1.00012–1.00096)	0.011	1139.27	1147.63		1.00054 (1.00026–1.00083)	< 0.0001	1187.05	1192.62	
Suicides by monthly average maximum temperature (°F)										
Intercept only-model	-	-	1167.24	1172.81	< 0.0001	-	-	1260.27	1263.06	< 0.0001
Full model[1]	1.00590 (1.00387–1.00793)	< 0.0001	1116.67	1125.03		1.0059 (1.00441–1.00741)	< 0.0001	1141.38	1146.96	
Suicides by monthly average minimum temperature (°F)										
Intercept only-model	-	-	1167.24	1172.81	< 0.0001	-	-	1260.27	1263.06	< 0.0001
Full model[1]	1.00754 (1.00521–1.00988)	0	1110.63	1118.99		1.00755 (1.00579–1.00932)	0	1130.60	1136.18	

IRR = incidence rate ratio for effect of the independent variable on suicides, CI = confidence interval, AIC = Akaike information criterion, BIC = Bayesian information criterion.

[1]Full model = model with independent variable (time, monthly average maximum temperature, or monthly average minimum temperature) and with population offset. Model coefficient for offset variables are always 1 and therefore IRR is also 1.

[2]LR Test = Likelihood Ratio Test comparing intercept only model and full model.

All IRRs for the independent variables were statistically significant ($p < 0.0001$; Table 2). The negative binomial regression demonstrated an increase of 6.1% in suicide rate per 10°F increase in maximum temperature (IRR = 1.00590 per 1°F, 95% CI: 1.00387, 1.00793). This corresponds to 331.29 predicted deaths per month at 70°F and 402.56 predicted deaths per month at 100°F. A sensitivity analysis using minimum temperature showed an increase of 7.8% in suicide rate per 10°F increase (IRR = 1.00754 per 1°F, 95% CI: 1.00521, 1.00988). Overall, there was a 0.65% increase in suicide rate per year from 2008–2017 (IRR = 1.00054 per month, 95% CI: 1.00012, 1.00096), corresponding to an increase from 3912.72 predicted deaths in 2008 to 4148.61 predicted deaths in 2017. All Poisson and negative binomial regression results were very similar (Table 2, Fig. 6, Appendix: Figs. 7–8).

Discussion

This study assessed the association between average maximum temperature and suicide and investigated whether the number of monthly heat events affected suicide rates in California. This information will become increasingly important as climate

change will continue to increase both the average temperature and number of heat events that occur. To our knowledge, this research is novel as it is the first to investigate the association between temperature and suicide rate in California, whereas other studies have focused on nation-wide temporal associations or geographic disparities. [7, 21]

A negative binomial regression suggested that maximum temperature was significantly related to suicide such that there was an increase of 6.1% in suicide rate per 10°F increase. Additionally, there was no significant evidence to support a relationship between heat events and suicide.

The results indicated seasonality of suicide incidence in California, which is similar to other studies that have found suicide rate increases with warmer temperatures.[22] The American Psychological Association and ecoAmerica reported on the acute and chronic mental health impact of climate change which includes exacerbated stress, depression, anxiety, and violence.[23] Extensive research on the causal relationship between heat and aggression reveal this may be due to an increase in arousal, negative and hostile thoughts, and reduced cognitive function.[23, 24] In addition to decreased self-regulation, social factors such as the beginning and end of the school year, agricultural cycles, and major holidays may also contribute to this seasonal trend.[3]

The findings of this study suggest that the average temperature in California continues to rise due to climate change, and so does the rate of suicide. This study contributes to the literature that assesses the relationship between temperature and suicide and provides empirical evidence for the need for more research to evaluate the effects of climate change on mental health.[24] Further investigation into environmental, biological and societal contexts that influence this relationship is imperative for the development and implementation of preventative suicide strategies and policies in this population.

There were several methodological limitations to this study due to its exploratory nature and restrictions in data availability. First, this analysis did not adjust for covariates such as gender and age. Similar research that has shown a significant association between temperature and suicide has demonstrated its relationship is influenced by gender, such that suicide is more common in males than females in warmer temperatures, and age, such that it is more common in elderly populations.[22] A combination of biological and societal mechanisms are posited to be responsible for the gendered and age phenomenon.[22] Social predictors such as socioeconomic status, mental health diagnoses, housing and employment opportunities, and weather-related variables such as humidity and altitude, were not accounted for and are known to be related to increased risk of suicide. [22, 26] Such variables were not included in this analysis as they were not readily accessible. Thus, the study can only offer a basic understanding of the role that temperature has on suicide incidence in California, while further research may address these mechanisms that remain unstudied.

Second, suicide surveillance has inherent limitations due to the sensitive nature of the topic. Stigma remains a major barrier to suicide prevention. As such, it is difficult to collect and access accurate suicide data; not all suicides are reported if there is inconclusive evidence, if the social and economic interests of the victim and their family need to be protected, or due to misclassification bias. As a result, it is challenging to achieve a holistic picture of the incidence of suicide. In an effort to decrease the likelihood of underreporting, California was purposefully selected for being a socially progressive state with a large, diverse population, and participating in the CDC National Violent Death Reporting System. Furthermore, the study used data from CDC Wonder, the primary data repository for health statistics in the US, which added reliability to our analyses. Similarly, a more contemporary time frame of 2008 to 2017 was selected to decrease the effect of stigma on reports of death by suicide.

A common pitfall in time series analysis is that secular trends can induce strong, but spurious, correlations.[27] A time series decomposition method of analysis was employed demonstrating clear trend and seasonal components. The analysis provided evidence that seasonal variation in temperature may be a factor in observed patterns of suicide; however, it was insufficient on its own to establish a causal link between longitudinal changes in temperature (i.e., climate change) and suicide. While we cannot eliminate the possibility of a spurious relationship between temperature and suicide in its entirety, there remains a strong argument for the association between temperature and suicide.

This study attempted to conduct analyses on two different temperature variables to glean insight into its strength of association with suicide. However, it was identified that heat events were more likely to occur in the winter months and therefore did not

establish a significant relationship between what was classified as a heat event and the suicide rates in California. This represents a greater distribution of temperatures in the winter months and faster warming in the winter months compared to the summer months over the 10-year period. It is possible that heat events were found to be less frequent in the summer months and most frequent in winter months due to the study's operational definition of heat events being related to relative rather than absolute temperature. Heat events are traditionally defined as related to absolute temperature to account for high temperatures in the summer half-year whereas this study identified high temperature anomalies year round.[28] Future research can investigate absolute temperatures to evaluate the relationship between heat events in the summer and suicide, and assess consistency with these results. Also, because this trend indicates that climate change will have the greatest impact on the severity and frequency of heat events in winter compared to summer, further analysis can determine the specific impacts on suicide rates and predict changes to suicide rates in the future.

Conclusion And Future Directions

Despite aforementioned limitations, there was rationale to conduct a simple investigation of the association between temperature and suicide prior to undertaking a more complex approach. The present study provided preliminary evidence that would generate future directions for research. In summary, seasonality and warmer temperatures were related to death by suicide, and potential high-risk populations such as males were identified. These results suggest that suicide rates may be affected by climate change.[22] Future research could adjust for covariates that mediate or modify the association between suicide and temperature to offer a less biased estimate and use absolute temperature. To conclude, we must seek to further illuminate this relationship and apply our findings to public health interventions that will lower the rates of death by suicide as we are confronted with the effects of climate change.

Abbreviations

IRR – Incidence Rate Ratio

CDC - Centers for Disease Control and Prevention

LRT - Likelihood Ratio Tests

AIC - Akaike information criterion

BIC - Bayesian information criterion

Declarations

Ethics Approval and Consent to Participate –

Not Applicable

Consent for Publication –

Not Applicable

Competing Interests -

The authors declare that they have no competing interests

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Authors Contributions –

MQ conducted background research, wrote the background section, aided in the discussion, aided with data collection and analyses, created table and figures, and editing, RP wrote the methods section, aided with data collection and analyses, created tables and figures and editing, SC wrote the results section, aided in the methods, conducted primary analyses, aided with data collection, created tables and figures and editing, SN conducted literature review and wrote the discussion, aided with data collection, conducted primary analyses, created tables and figures and editing, DF provided guidance and critical review of the manuscript, JPS provided direction on the study design, interpretation of results, and critical review of the manuscript

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Not Applicable

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Figures

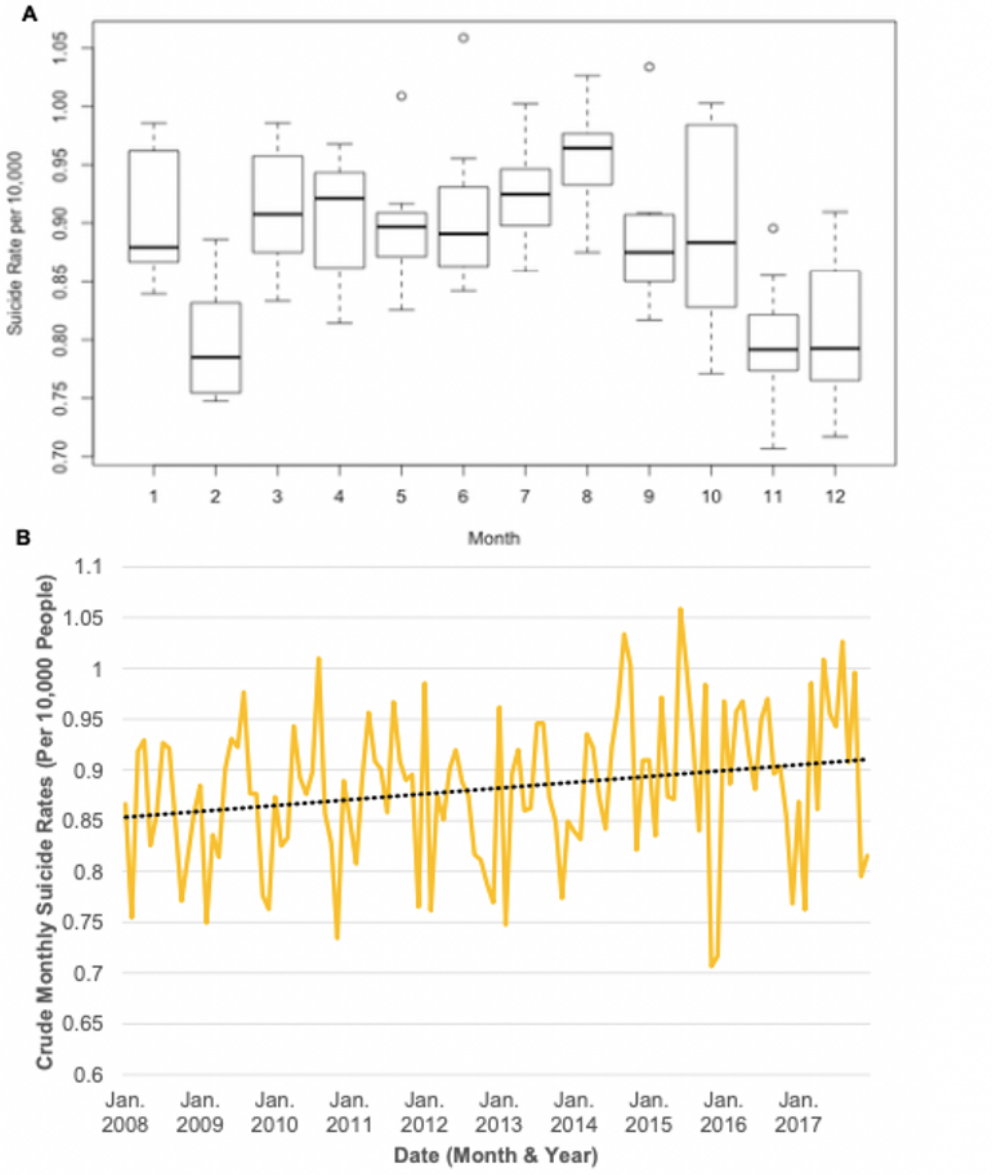


Figure 1

A) Mean, distribution and outliers of the suicide rates (per 10,000 people) per month and B) suicide rate (per 10,000 people) over time (2008–2017).

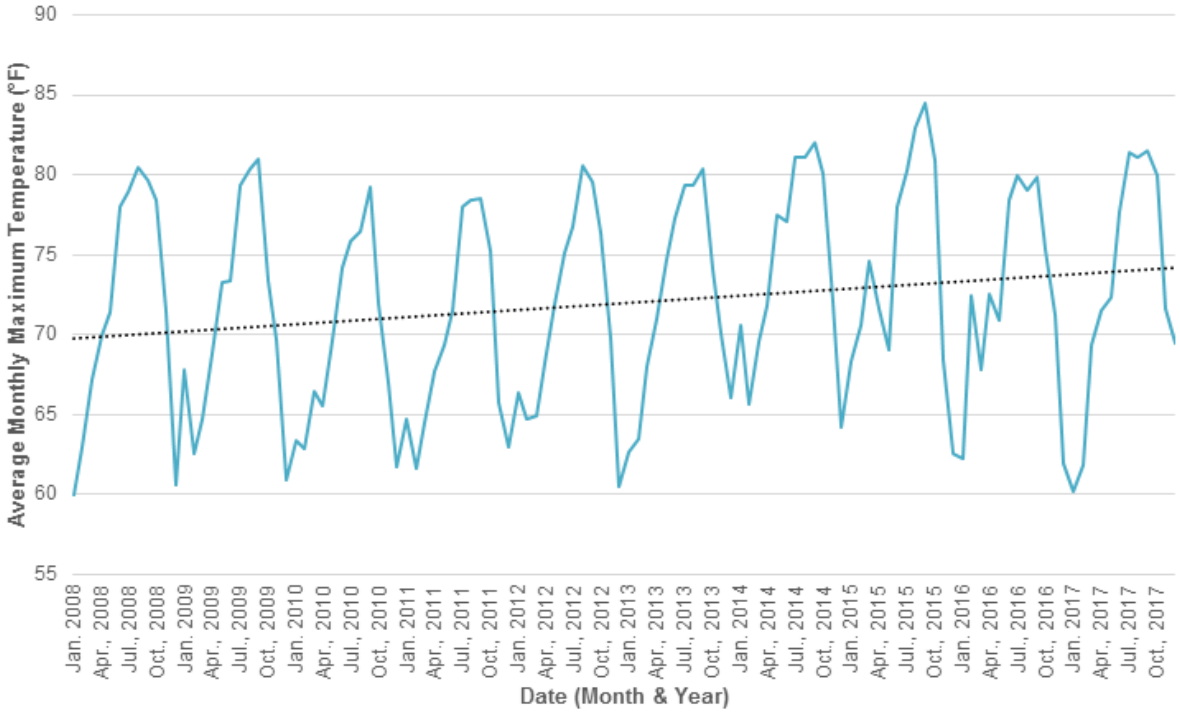


Figure 2

Average monthly maximum temperature in California from January 2008 to December 2017.

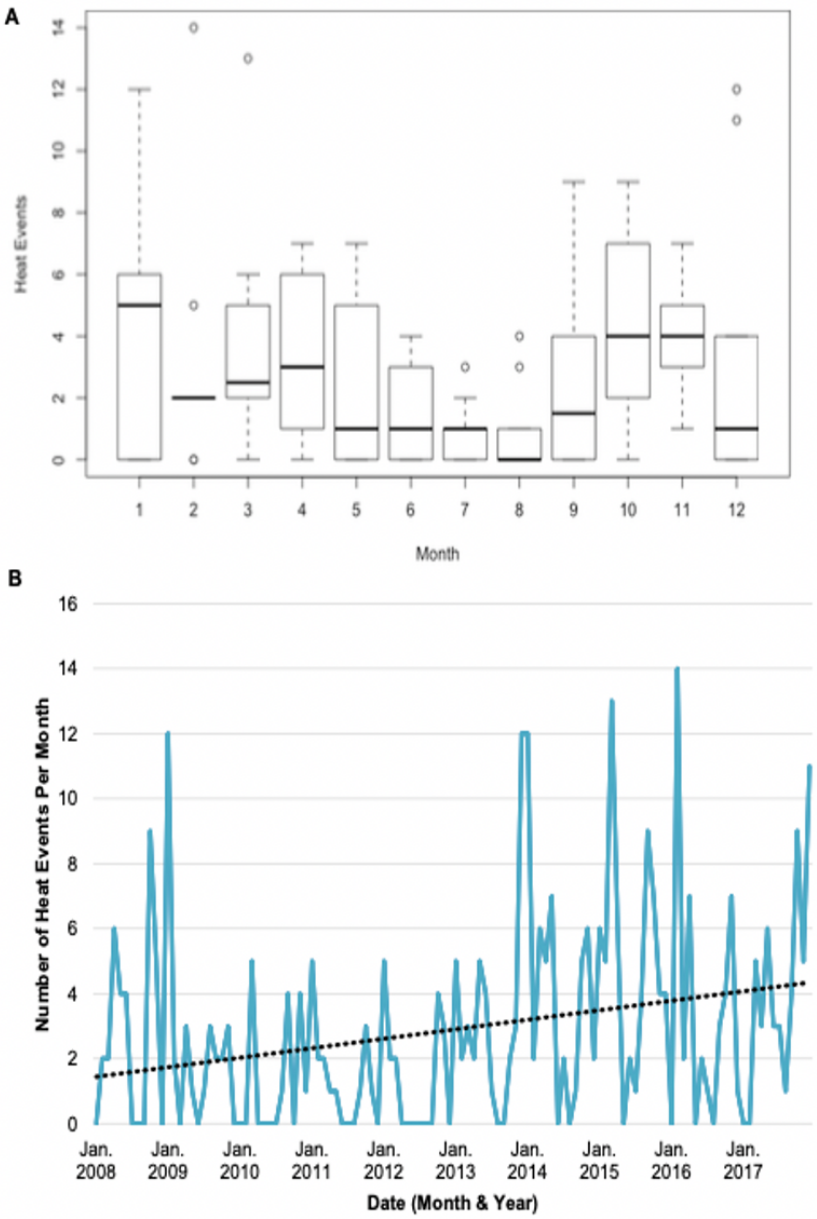


Figure 3

A) Mean, distribution, and outliers of the number of heat events (per 10,000 people) per month and B) the number of heat events (per 10,000 people) per month over time (2008–2017).

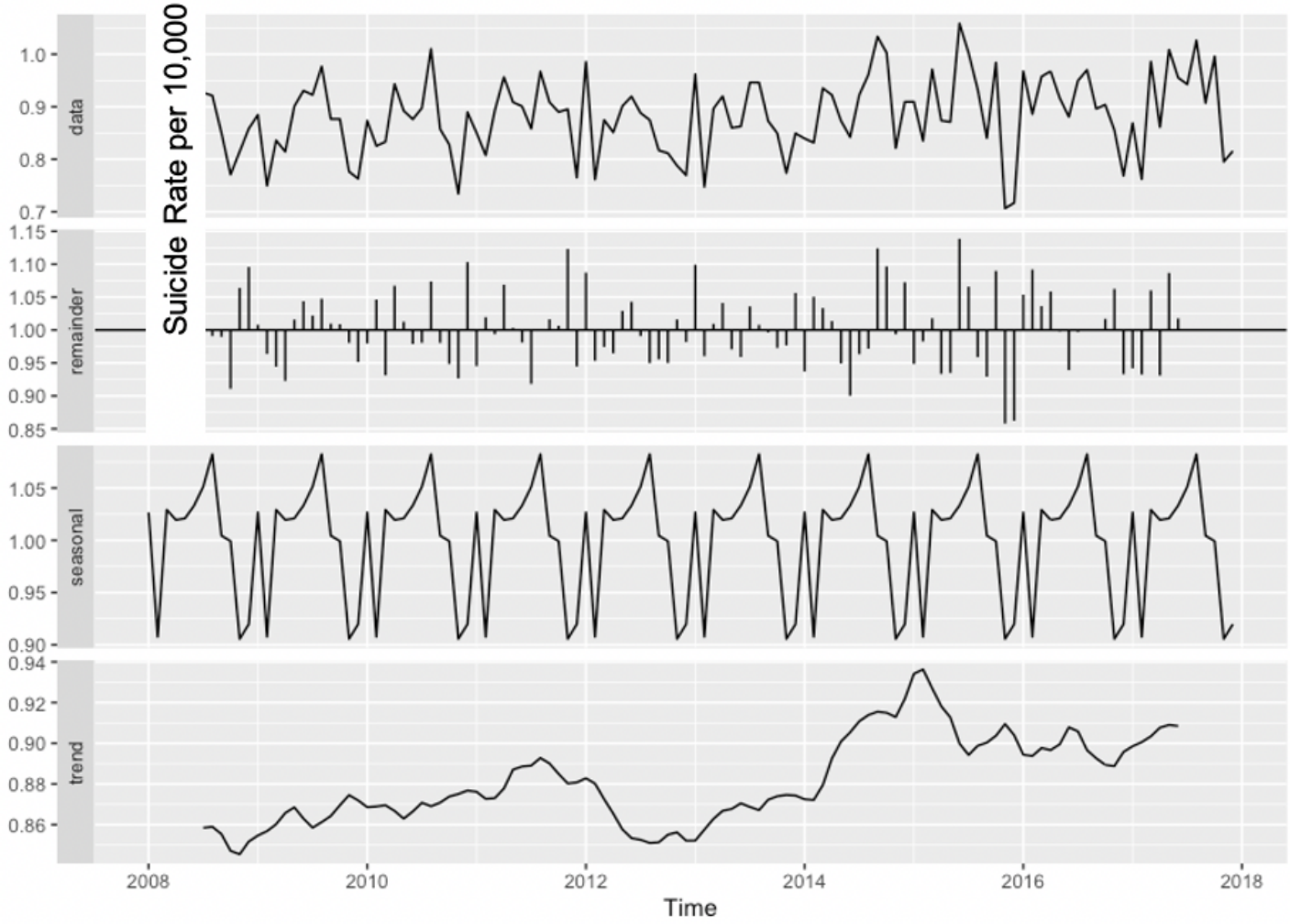


Figure 4

Seasonal decomposition of a time series. Data = Crude relationship of suicide rates (per 10,00 people) over time (2008-2017) Remainder = Data that is otherwise unexplained by the seasonal trend and trend over time Seasonal = Seasonal component of the data independent of the trend over time Trend = Trend over time independent of the seasonal component

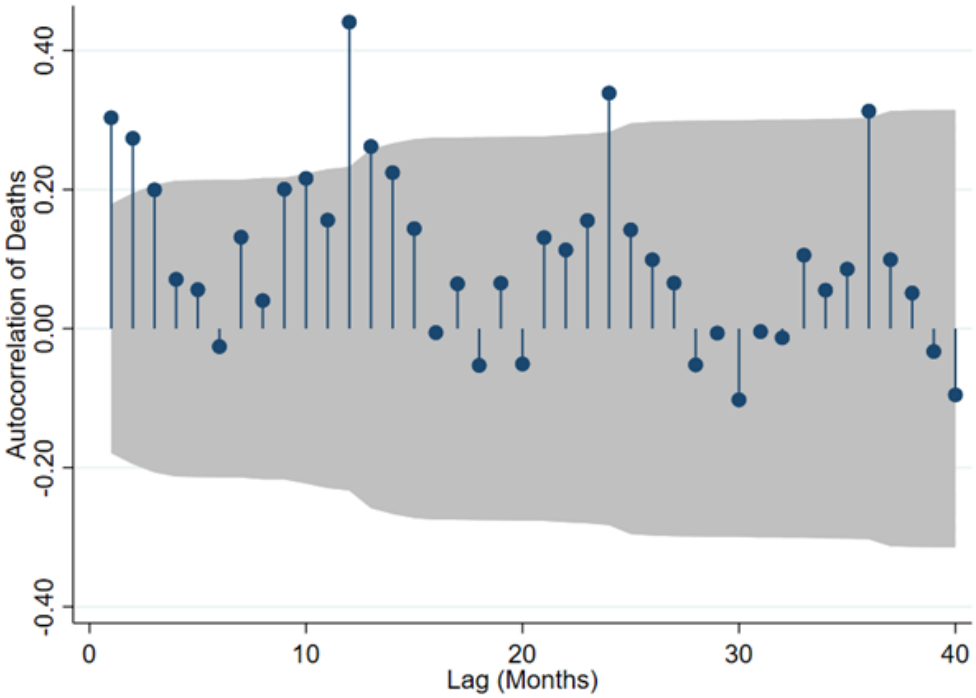


Figure 5

Correlogram of death by suicide and month. Barletts' formula was used for MA(q) and a 95% confidence band is included.

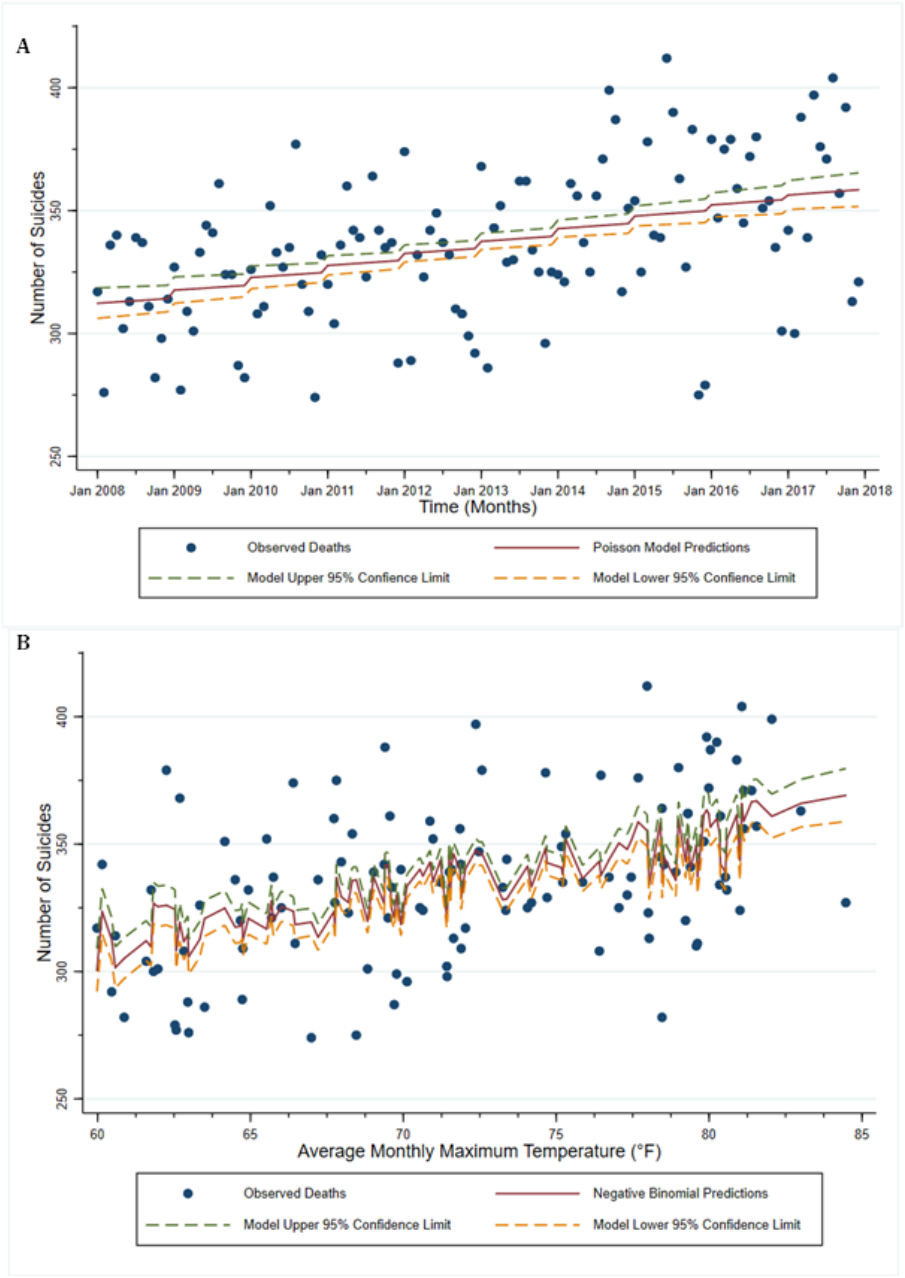


Figure 6

Negative binomial regression models evaluating A) the number of suicides over time (2008-2017) with a population offset (IRR = 1.00054, 95% CI: 1.00012 - 1.00096) and B) the number of suicides by average monthly minimum temperature with a population offset (IRR = 1.00590, 95% CI: 1.00387 - 1.00793).

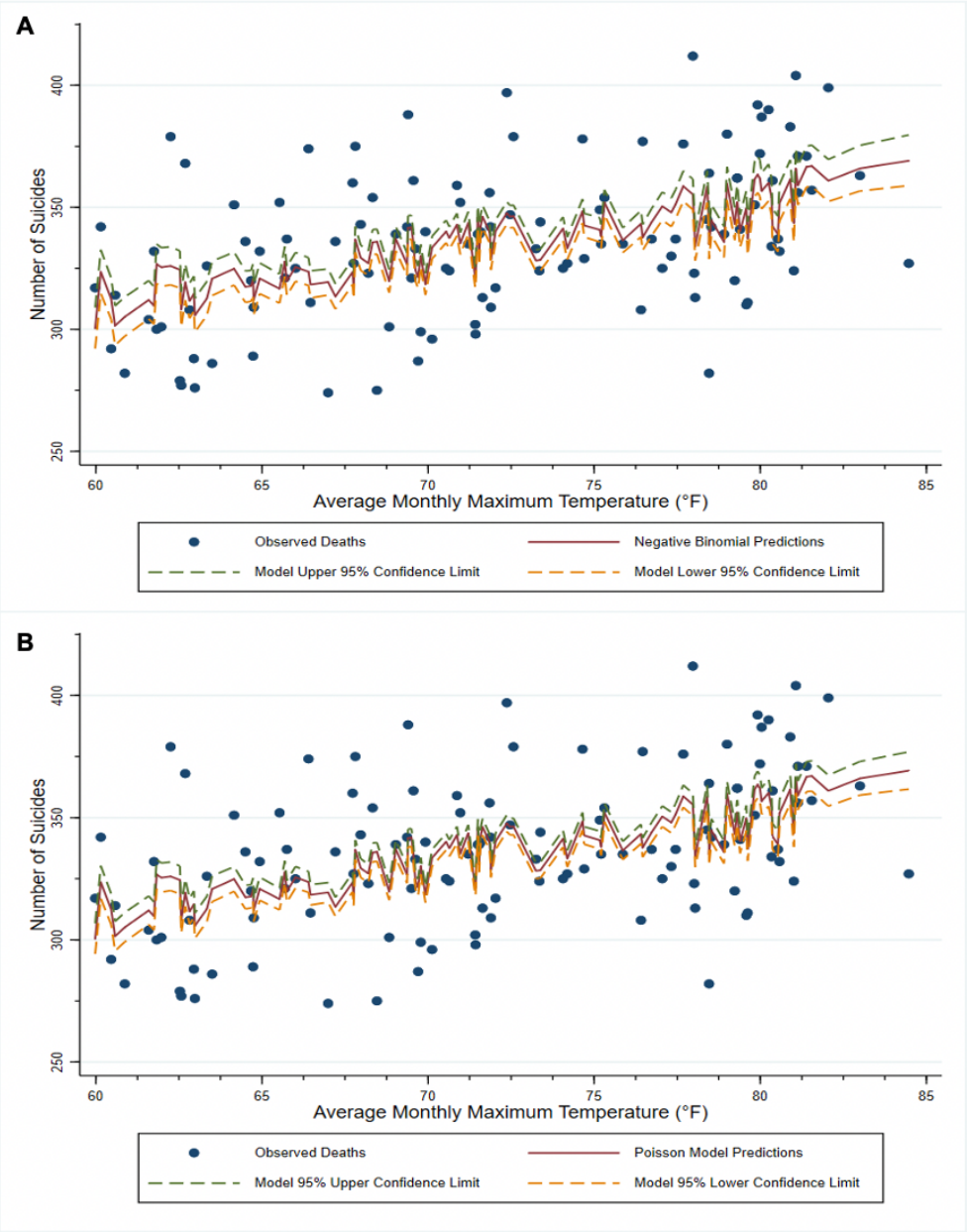


Figure 7

Regression models evaluating the number of suicides by average monthly minimum temperature with a population offset using A) negative binomial regression (IRR = 1.00590, 95% CI: 1.00387 - 1.00793) and B) Poisson regression (IRR = 1.0059, 95% CI: 1.00441 - 1.00741). Upper and lower confidence limits are included.

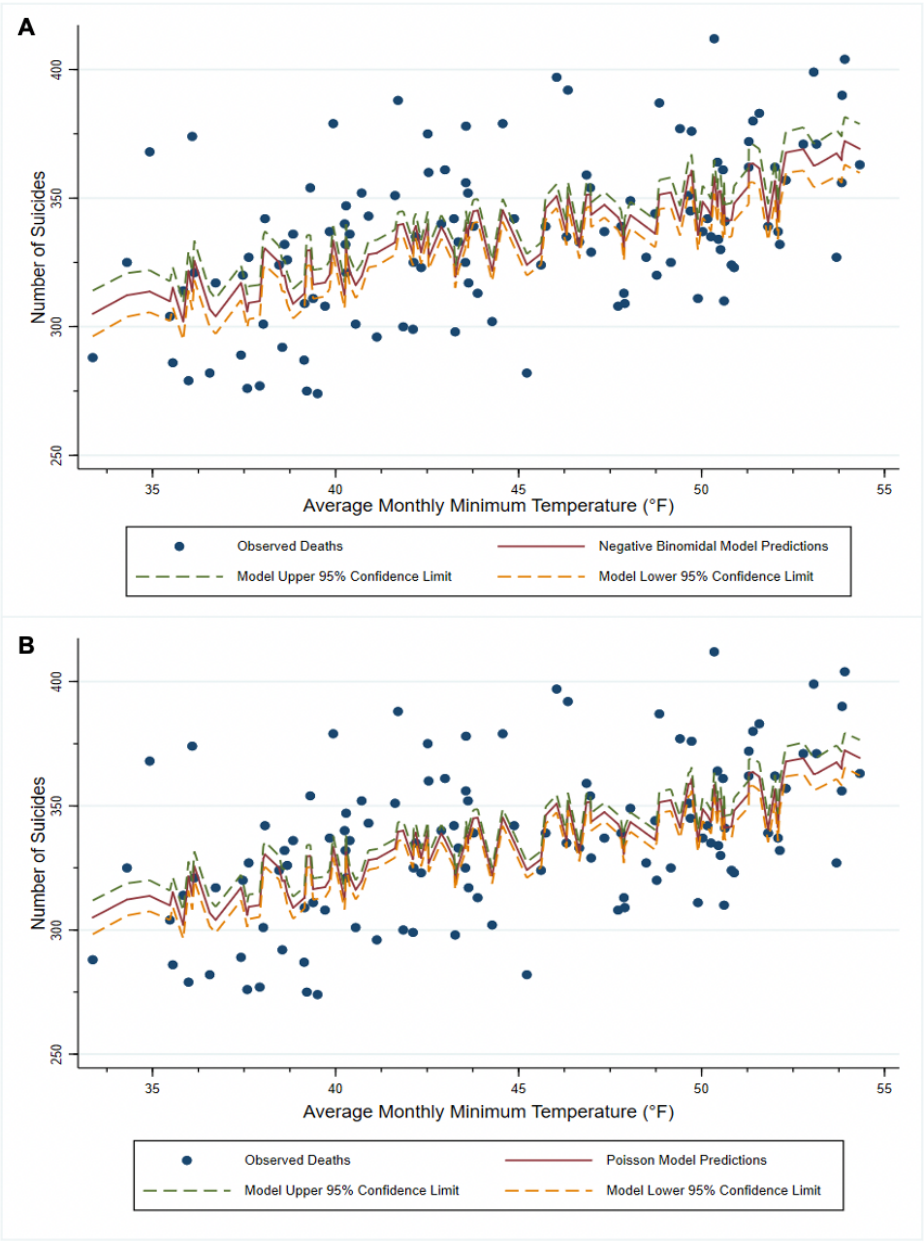


Figure 8

Regression models evaluating the number of suicides by average monthly maximum temperature with a population offset using A) negative binomial regression (IRR = 1.00754, 95% CI: 1.00521 - 1.00988) and B) Poisson regression (IRR = 1.00755, 95% CI: 1.00579 -1.00932). Upper and lower confidence limits are included.