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Abigail Gates   Date

Short-Term Association Between Ambient Temperature and Homicide in South Africa

By

Abigail Gates
Master of Science in Public Health

Environmental Health - Epidemiology

_____

Noah Scovronick, PhD
Committee Chair

Short-Term Association Between Ambient Temperature and Homicide in South Africa

By

Abigail Gates

Bachelor of Science
Georgetown College
2015

Thesis Committee Chair: Noah Scovronick, PhD

An abstract of
a thesis submitted to the Faculty of the
Rollins School of Public Health of Emory University
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Abstract

Short-Term Association Between Ambient Temperature and Homicide in South Africa
By Abigail Gates

Purpose

Criminology research has traditionally examined sociodemographic predictors of crime, such as sex, race, age, and socioeconomic status. However, evidence suggests that short-term fluctuations in crime vary more than long-term trends, which sociodemographic factors often cannot explain. This has redirected researchers to explore how environmental factors, such as meteorological variables, influence criminal behavior. Current evidence on the relationship between temperature and homicide is relatively limited and uncertain. This study investigates the association between daily ambient temperature and homicide incidence in South Africa, a country with one of the highest homicide rates in the world.

Methods

Data were analyzed using a case-crossover design with conditional logistic regression. Cases (n=205,932) were deaths with an immediate or underlying cause of death recorded as either homicide (ICD-10 codes X85-Y09) or due to other violent causes of undetermined intent but likely to be homicides (ICD-10 codes Y22-Y25, Y28-Y29). Case periods were defined as the day on which a death occurred. Control periods were selected using a day-of-week match within the same month and district. Analyses investigated same-day and lagged effects of maximum, mean and minimum temperature as a linear relationship with an additional investigation of possible non-linearities.

Results

A one-degree Celsius increase in same-day maximum temperature was associated with a 1.3% (1.2-1.5%) increase in homicide. Significant positive associations remained when applying other temperature metrics (mean, minimum), lags (1, 0-1), and when stratifying by definite versus total homicides. The shape of the association did not display any clear non-linearities. There was no evidence of confounding by public holidays or interaction by district.

Conclusions

This study suggests a small but positive association between daily ambient temperature and homicide in South Africa and provides insight as to the shape of this relationship. This temperature-health relationship may be of particular concern in the context of climate change. The ability to include meteorological variables as a predictor of criminal activity and violent behavior could prove valuable in resource allocation for crime prevention efforts, policy, and preparedness.

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Introduction

Criminology research has traditionally examined sociodemographic predictors in relation to crime, such as sex, race, age, and socioeconomic status. However, the evidence suggests that short-term fluctuations in crime vary more than long-term trends, which sociodemographic factors often cannot explain[12]. This has redirected researchers to explore how environmental factors, such as meteorological variables, influence criminal behavior.

Several possible mechanisms have been proposed by which meteorological variables may influence violent crime. For example, weather changes or extremes may act as biological stressors that facilitate aggression by affecting an individual's cognitive state[3,4] or otherwise influence behaviors that alter the probability of convergence between a suitable target, a likely offender, and absence of capable guardians against a crime[11]. Theory also suggests some curvature to the shape of its relationship, as very extreme temperatures will likely preclude violence or aggression[2,12].

Previous research classifying several types of interpersonal violence into a broad category of 'violent crime' (often including homicide, assault, burglary, domestic violence and/or rape) indicates that violent crime may be positively associated with ambient temperature[2,4,7,8,12,13,17,18,22,24,29–32]. Some studies have demonstrated instances of linear associations[7,8,32], while others have indicated a nonlinear concave relationship[14,17,18,30]. However, evidence on the relationship between temperature and homicide specifically is more limited and uncertain; some studies support an association[2,12,13,15,17,22,24] while others do not [10,12,13,39].

Studies examining the relationship between temperature and crime in developing countries is even more limited, both on the investigation of broad categories of violent crime and homicide alone. To our knowledge, the only published evidence from South Africa has focused on violent crime in the city of Tshwane (Pretoria)[6,33]. For example, one study reported

a 50% increase in violent crime on hot days compared to very cold days[33]. In another study investigating the spatial distribution of seasonal assault across neighborhoods in Tshwane, researchers reported that less affluent neighborhoods had higher rates of assault in the summer than more affluent neighborhoods, while assault rates were similar between neighborhoods during the winter[6].

This study investigates the short-term association between daily ambient temperature and homicide incidence in South Africa as a whole using a national dataset that includes all recorded deaths in the country from 1997-2013. South Africa has one of the highest homicide rates on record at an estimated 34 per 100,000 individuals, over six times that of the average global rate of 5.3 per 100,000 individuals[41]. South Africa's climate varies considerably across the country but is generally considered subtropical[35,38]. Further, the country is disproportionately exposed to the effects of climate change, as it is experiencing warming at a faster rate compared to the global average[26].

Therefore, investigating the association between daily ambient temperature and homicide incidence across South Africa provides insight on a potential predictor of criminal behavior and related mortality that is understudied. This could increase understanding of potential future impacts to human health due to climate change and yield valuable information for crime prevention, policy, and preparedness.

Methods

We hypothesized a positive association between daily ambient temperature and homicide incidence in South Africa, and conducted analysis of the temperature-homicide relationship using a case-crossover study design with conditional logistic regression.

Data Sources and Preparation

Mortality data was derived from a dataset of all recorded deaths in South Africa from 1997 to 2013 (17 years) provided by Statistics South Africa. Reported deaths included cause and location of death at the level of district municipality, of which there are 52 in South Africa (hereafter referred to as "districts"). Cases were deaths with an immediate or underlying cause of death recorded as either homicide (ICD-10 codes X85-Y09) or due to other violent causes of undetermined intent that are likely to be homicides (ICD-10 codes Y22-Y25, Y28-Y29); we refer to these groupings as "definite" or "probable" homicides, respectively (see Appendix 1 for details).

Daily temperature data was derived from a dataset used for a prior study investigating daily maximum temperature and mortality from all and cardiorespiratory causes in South Africa, and was based on data from the National Oceanographic and Atmospheric Association (NOAA) of the United States and South Africa's Agricultural Research Council[34]. The dataset underwent a three-step quality control procedure to remove illogical and outlying measurements, duplicate sets (periods with at least five consecutive days recording the same temperature), and to correct for breaks in recording or changes/relocation of instruments[34]. This process yielded a final dataset of one measurement station representing each district. Missing data were reconstructed (daily maximum, 7%; daily minimum, 12%) using nearby comparison stations for data gaps less than or equal to six days in length. There was

temperature data available for 29 districts at the beginning of the study period, increasing to cover all 52 districts by 2013[34].

<u>Statistical Approach</u>

A case period was defined as the day on which a death by homicide occurred. Control periods were matched on day of the week, month and district, typically yielding 3-4 control periods per case. This approach controls for the day of the week, individual-level confounders and long-term trends, thus separating their influence in the data from the short-term temperature-homicide association that is of primary interest[5]. Our expanded dataset was linked with daily temperature data to produce our final dataset. Days with missing temperature data were excluded from analysis.

As the climate varies considerably across South Africa, we tested for interaction of the temperature-homicide relationship by district to determine whether to estimate location-specific associations. We evaluated possible confounding due to holidays, for which we do not otherwise control in our study design, by assessing for changes in the effect estimate when including versus excluding holidays from our model with the *a priori* criteria that a $\geq 10\%$ change in the estimate warrants inclusion in the final model.

We decided *a priori* to investigate maximum temperature as our preferred temperature metric due to the lower frequency of missing observations and because minimum temperature recordings often suffer a greater impact on quality due to improper instrument management[1,9,27,28,34,40,42]. Additional analyses were conducted to explore the effect of other temperature metrics (minimum, mean) and stratification by definite homicides versus total (definite plus probable) homicides. We initially investigated same-day temperature but also examined the effect of short lags (lag 1, lag 0-1).

Results were reported as odds ratios per °C increase in temperature. We also explored potential non-linearities in the effect by analyzing categories of maximum temperature using indicator variables for temperatures between 18-21.9 °C, 22-26.9 °C, 27-30.9 °C, 31-35.9 °C, and 36 °C and above. Temperatures below 18 °C served as the reference group. The reference group was chosen such that this group contains 10% of cases.

To control for the possibility of particularly high levels of underreporting in the early years of the study period, we also performed a restricted analysis for 2002-2013, thus omitting the first five years of data. Data were analyzed using SAS version 9.4 (SAS Institute Inc., Cary, North Carolina).

Results

Table 1 displays summary statistics for daily temperature and mortality data. The overall temperature distribution for maximum temperature spans a range from 0.5 °C to 47.8 °C. The mean number of daily cases (definite and probable homicides combined) was 33.2 ± 21.6, while the maximum recorded on a single day was 182. Figure 1 shows the annual counts of deaths for the entire study period. The final dataset consisted of 205,932 cases across all districts, including both definite (n=67,994) and probable (n=137,938) homicides.

There was no evidence of interaction by district (p > 0.05), supporting the decision to analyze all-country data together to identify the overall exposure-response association. A one-degree Celsius increase in same-day maximum temperature was associated with a 1.3% (1.2-1.5%) increase in homicide (Table 2). We also found significant positive associations between ambient temperature and odds of death by homicide in all other analyses (Table 2). Stratification by definite versus total homicides yielded similar results (Table 2). The temperature effect did not exhibit any clear non-linearities, although results in the highest

temperature group were more uncertain due to the small number of deaths occurring at these extreme temperatures (Figure 2). Excluding public holidays did not meaningfully change results (Table 3), nor did excluding the first five years of data (Table 4).

Discussion

Our findings present evidence of a positive association between short-term increases in ambient temperature and the odds of death by homicide in South Africa. Although the association is modest, it remained statistically significant when using any of the three temperature metrics and lags. The associations did not display any clear non-linearities.

Our study is among few addressing this relationship in developing countries, and to our knowledge, one of the first to address crime or homicide in relation to temperature in South Africa. This location itself is a strength, as the country's high rate of homicides combined with the extensive spatial and temporal coverage of our dataset provides suitable statistical power to address the research question with robust results. Also particularly noteworthy is our examination of short-term variation in temperature, whereas much of the literature addresses long-term changes or seasonality.

Overall, our findings align with research investigating temperature and broad categories of violent crime, which is mostly from developed countries. For example, one study in Baltimore, Maryland reported an association between maximum temperatures and increased rates of total and violent crime[24]. A study in Cleveland, Ohio reported a linear association between aggressive crime, including homicide, and apparent temperature[8]. In Philadelphia, Pennsylvania, researchers conducted a time series analysis of daily temperature and crime and reported that violent crime, including homicide, is highest when temperatures are "comfortable"[32].

A strength of our study is that it is one of the few studies to separate homicide from other types of violent crime, as the existing research on the topic is limited and with mixed results. Researchers in Dallas, Texas reported a very small (<0.1%) increase in homicide per °F increase through 89 °F, which reversed at higher temperatures[17]. Researchers examining numerous environmental factors in relation to daily crime in four U.S. cities (Chicago, Illinois; Houston, Texas; Philadelphia, Pennsylvania; and Seattle, Washington) reported a positive but non-significant association between apparent temperature and homicide[22]. In Mashhad, Iran, researchers did not find an association between homicide and temperature or any other meteorological variables[39]. This isolation of homicide from other violent crime is an important distinction, contrasting most research that includes homicide with other types of violent crime data and seemingly operating under the assumption that different types of violent crime are identical in their relationships to their predictors[2].

This study has some limitations. Potential underreporting in the mortality dataset poses certain challenges, as Statistics South Africa estimates the national registry captured ~89% of all deaths early in the study period, increasing to ~94% by the end[34,36,37]. We suspect that underreporting and misclassification may be a more complex issue for homicides, as the number of deaths captured during the study period (definite and probable homicides combined) may only constitute around two-thirds of the real homicide-related mortality for this time period[23,41]. This could influence our effect estimates if cause of death misclassifications were differential by temperature on the day of death, which seems unlikely. Otherwise, this underreporting means our reported effect estimates are likely conservative. Regardless, internal validity would not be compromised.

The temperature dataset posed additional challenges. Missing data were an issue, especially in the early years. This resulted in the further exclusion of deaths, as 9% - 11% of

deaths had no corresponding temperature data (dependent upon which temperature metric was applied). In addition, the dataset prescribed one temperature for an entire district, which may not adequately capture conditions across larger districts, or accurately differentiate conditions within a smaller district in which a portion may be subject to an urban heat island effect. This could lead to possible exposure misclassification, although we expect this issue is minimized by the fact that total mortality was concentrated in the smaller districts; 50% of cases occurred in the ten (19%) smallest districts.

Case-only study designs such as case-crossover may not lend an effect estimate that is representative of the general population in contexts where susceptibility to the outcome may not be homogenous[25]. However, our study design affords us other advantages, including allowing us to separate short-term variation from long-term changes, adjust for relevant potential confounders such as day of the week, control for individual-level confounders and allows the use of several and a varying number of control periods[19–21]. Therefore, combining the insights of this study with other types of designs could be particularly meaningful in the context of crime prevention efforts.

Future research should investigate the inclusion of other potential confounders or predictors such as humidity and air pollution. Some of these factors have been assessed in other studies with mixed results[2,12,16,17,22,31,39]. Including time-varying lifestyle factors that may influence behavior such as heavy episodic drinking and dates of paychecks or welfare checks may also glean information about the possible effect of these factors.

Conclusions and Recommendations

This study examines the effect of short-term variation in temperature on homicide incidence, providing insight on a potential predictor of criminal behavior that is understudied. This work is unique in its analysis of such an extensive dataset thus contributing to an otherwise limited body of literature on the relationship between environmental predictors and homicide. Likewise, it is among the first to address crime and death by homicide in relation to temperature in South Africa, a country historically experiencing high rates of homicide. This temperature-health relationship may be of particular concern in the context of climate change, especially in the absence of short-term adaptation. The ability to include meteorological variables as a predictor of criminal activity and violent behavior could prove valuable in resource allocation for crime prevention efforts and preparedness for first responders and healthcare providers.

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Table 1

Descriptive statistics for temperature and mortality data.

	Mean	Maximum	75%	Median	25%	Minimum
Daily Temperature (°C), 1997-2013 inclusive						
Maximum	25.2 ± 5.9	47.8	29.4	25.4	21.2	0.5
Mean	18.0 ± 5.4	34.7	22.0	18.4	14.0	-1.1
Minimum	10.8 ± 6.1	28.0	15.4	11.5	6.5	-15.9
Daily Temperature (°C), case and control periods only						
Maximum	24.7 ± 5.5	47.8	28.4	25.0	21.0	0.5
Mean	18.0 ± 5.1	34.7	21.8	18.5	14.4	-1.1
Minimum	11.4 ± 5.8	28.0	15.6	12.0	7.5	-13.8
Daily Homicides[a]	33.2 ± 21.6	182	43	27	18	1

[a] Homicide case counts include definite homicides (ICD-10: X85-Y09) and probable homicides (ICD-10: Y22-Y25, Y28-Y29).

Table 2

Association between ambient temperature and homicide incidence with odds ratios reported per °C increase in temperature.

Temperature Metric	Deaths Included		Odds Ratio	
	Definite[a]	Total[b]	Definite[a]	Total[b]
Maximum				
Lag 0	63,011	186,196	1.015 (1.013, 1.018)	1.013 (1.012, 1.015)
Lag 1	63,003	186,192	1.012 (1.009, 1.014)	1.009 (1.008, 1.011)
Lag 0-1	62,800	185,611	1.018 (1.015, 1.021)	1.015 (1.013, 1.017)
Mean				
Lag 0	62,274	183,800	1.021 (1.017, 1.024)	1.018 (1.016, 1.020)
Lag 1	62,332	183,895	1.016 (1.012, 1.019)	1.013 (1.011, 1.015)
Lag 0-1	61,874	182,466	1.023 (1.019, 1.027)	1.020 (1.017, 1.022)
Minimum				
Lag 0	63,523	184,522	1.010 (1.007, 1.013)	1.010 (1.008, 1.012)
Lag 1	62,561	184,595	1.007 (1.004, 1.010)	1.007 (1.005, 1.008)
Lag 0-1	62,176	183,351	1.011 (1.008, 1.015)	1.011 (1.009, 1.013)

[a] Definite homicides, ICD-10: X85-Y09.

[b] Includes definite homicides and probable homicides (ICD-10: Y22-Y25, Y28-Y29).

Table 3
Results for maximum temperature while excluding deaths reported as occurring on South African public holidays.

Lag	Deaths Included		Odds Ratio	
	Definite[a]	**Total**[b]	**Definite**[a]	**Total**[b]
Lag 0	58,699	175,696	1.015 (1.013, 1.018)	1.013 (1.012, 1.015)
Lag 1	58,688	175,682	1.011 (1.009, 1.014)	1.009 (1.007, 1.010)
Lag 0-1	58,518	175,178	1.018 (1.015, 1.021)	1.015 (1.013, 1.016)

[a] Definite homicides, ICD-10: X85-Y09.

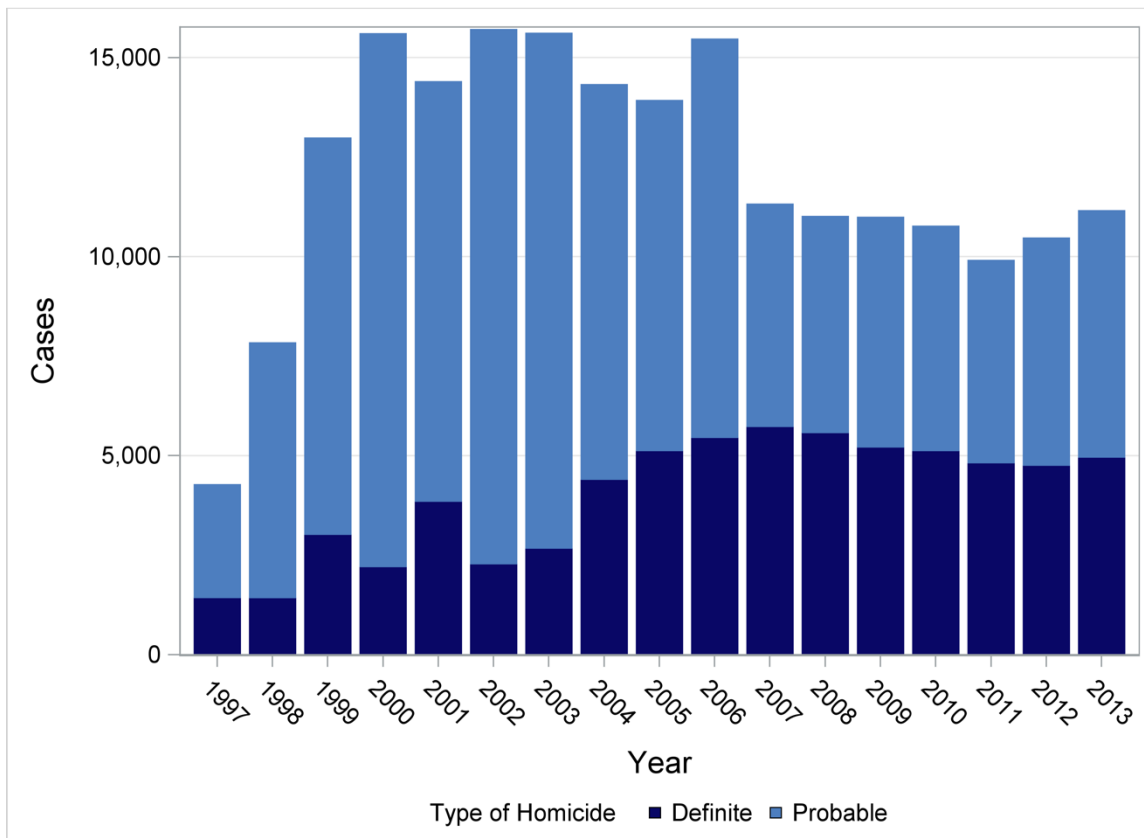[b] Includes definite homicides and probable homicides (ICD-10: Y22-Y25, Y28-Y29).

Table 4
Results for maximum temperature for deaths 2002-2013 (i.e., excluding the first five years of data).

| Lag	Deaths Included		Odds Ratio	
	Definite[a]	**Total**[b]	**Definite**[a]	**Total**[b]
Lag 0	53,802	143,208	1.016 (1.013, 1.018)	1.013 (1.012, 1.015)
Lag 1	52,800	143,218	1.011 (1.008, 1.014)	1.010 (1.008, 1.011)
Lag 0-1	53,616	142,716	1.018 (1.015, 1.021)	1.015 (1.013, 1.017)

[a] Definite homicides, ICD-10: X85-Y09.

[b] Includes definite homicides and probable homicides (ICD-10: Y22-Y25, Y28-Y29).

Figure 1. Counts of deaths recorded per year, including definite homicides (ICD-10: X85-Y09) and probable homicides (ICD-10: Y22-Y25, Y28-Y29). These counts include all registered deaths, including those excluded from the analysis due to missing temperature data.
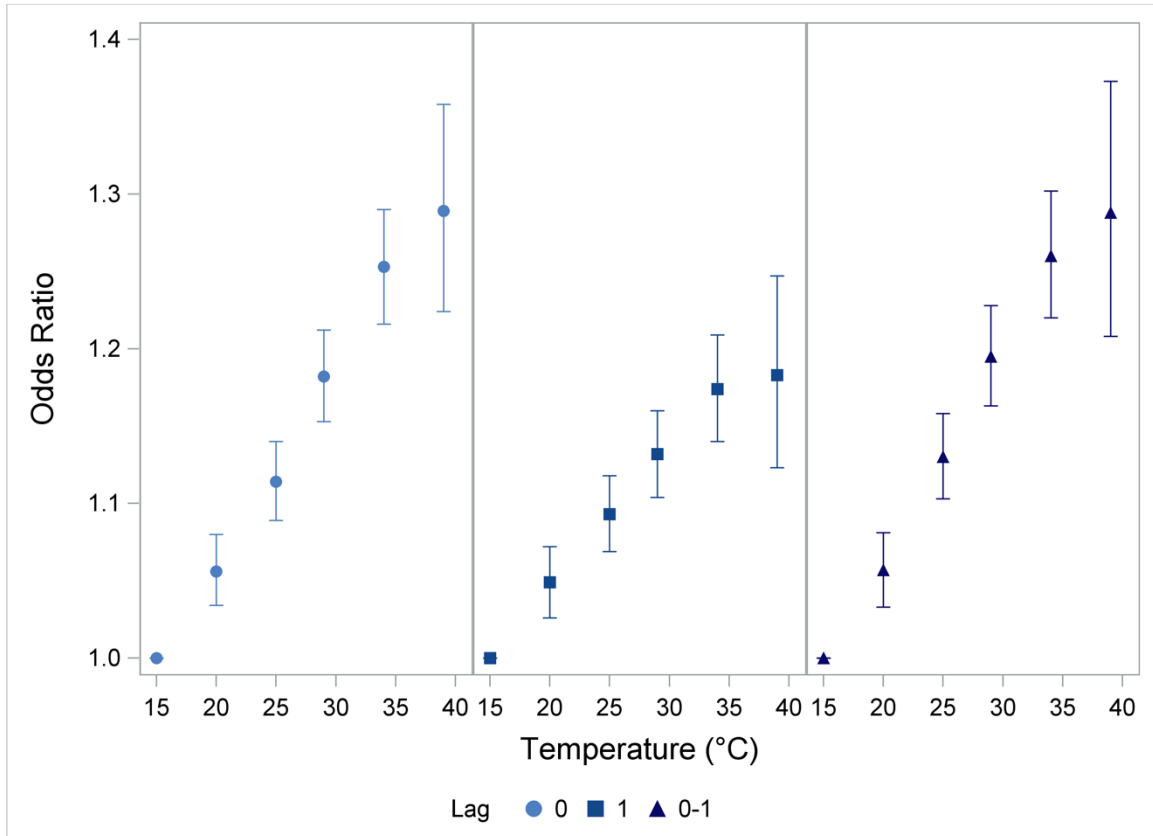
Figure 2. Association between maximum temperature and homicide incidence using categories of temperature in comparison to the reference group of <18 °C. Odds ratios are plotted at the mean temperature within each interval. Exact numerical results are reported in Appendix 2.

Appendix 1

ICD-10 codes of deaths selected for this study.

Code	Description
Definite homicides	
X85	Assault by drugs, medicaments, and biological substances. Includes: homicidal poisoning by (any): biological substances, drug, medicament.
X86	Assault by corrosive substances. Excludes: corrosive gas (X88).
X87	Assault by pesticides. Includes: wood preservatives. Excludes: plant food and fertilizers (X89).
X88	Assault by gases and vapors.
X89	Assault by other specified chemicals and noxious substances. Includes plant food and fertilizers.
X90	Assault by unspecified chemical or noxious substance. Includes: homicidal poisoning NOS
X91	Assault by hanging, strangulation and suffocation.
X92	Assault by drowning and submersion.
X93	Assault by handgun discharge.
X94	Assault by rifle, shotgun and larger firearm discharge.
X95	Assault by other and unspecified firearm discharge.
X96	Assault by explosive material. Excludes: incendiary device (X97).
X97	Assault by smoke, fire and flames. Includes: arson, cigarettes, incendiary device.
X98	Assault by steam, hot vapors and hot objects.
X99	Assault by sharp object. Includes: stabbed NOS
Y00	Assault by blunt object.
Y01	Assault by pushing from high place.
Y02	Assault by pushing or placing victim before moving object.
Y03	Assault by crashing of motor vehicle. Includes: deliberately hitting or running over with motor vehicle.
Y04	Assault by bodily force. Includes: unarmed brawl or fight. Excludes: assault by strangulation (X91); submersion (X92); use of weapon (X93-X95, X99, Y00); sexual assault by bodily force (Y05).
Y05	Sexual assault by bodily force. Includes: rape (attempted), sodomy (attempted).
Y06	Neglect and abandonment.
Y07	Other maltreatment. Includes: mental cruelty, physical abuse, sexual abuse, torture. Excludes: neglect and abandonment (Y06), sexual assault by bodily force (Y05).
Y08	Assault by other specified means.
Y09	Assault by unspecified means. Includes: assassination (attempt); homicide (attempt) NOS; manslaughter (nonaccidental); murder (attempt) NOS.

Probable homicides

Y22	Handgun discharge, undetermined intent.
Y23	Rifle, shotgun and larger firearm discharge, undetermined intent.
Y24	Other and unspecified firearm discharge, undetermined intent.
Y25	Contact with explosive material, undetermined intent.
Y28	Contact with sharp object, undetermined intent.
Y29	Contact with blunt object, undetermined intent.

NOS: not otherwise specified.

Appendix 2
Association between maximum temperature and homicide incidence using categories of temperature. Cases include definite and probable homicides.

Temperature Range (°C)	Odds Ratio		
	Lag 0	Lag 1	Lag 0-1
<18[a]	1.000	1.000	1.000
18-21.9	1.056 (1.034, 1.080)	1.049 (1.026, 1.072)	1.057 (1.033, 1.081)
22-26.9	1.114 (1.089, 1.140)	1.093 (1.069, 1.118)	1.130 (1.103, 1.158)
27-30.9	1.182 (1.153, 1.212)	1.132 (1.104, 1.160)	1.195 (1.163, 1.228)
31-35.9	1.253 (1.216, 1.290)	1.174 (1.140, 1.209)	1.260 (1.220, 1.302)
36+	1.289 (1.224, 1.358)	1.183 (1.123, 1.247)	1.288 (1.208, 1.373)

[a] Reference group