Anatomy of Heat Waves and Mortality in Toronto

Lessons for Public Health Protection

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ABSTRACT

Background: Periods of unusually hot weather, especially in temperate climates, carry with them a burden of morbidity and mortality, particularly in urban areas. With lessening debate on its origins, and signs of global warming already apparent, it is becoming imperative for public health practitioners to recognize and predict the risks of "heat waves", and to develop protective community responses to them. This study makes use of historical data and a methodology developed previously to examine the pattern of hot weather experienced over the last five decades in the City of Toronto, and to assess the associated burden of mortality.

Methods: Synoptic classification of air masses based on meteorological data for Toronto was used, to assign the *annual mean* burden of illness (in terms of elevated mortality) associated with hot weather and air pollution. Then, coefficients relating daily mortality risk to historical daily weather and air quality data were determined with a model system that (for each air mass) assessed the factors that contributed to *day-to-day variability* in mortality.

Results: Over the period of study, there were 120 (95% CI: 105-135) heat-related deaths on average per year, with great variability from year to year, reflecting the variability of hot weather. Mortality was greatest in July and August, when the greatest number of multi-day heat episodes occurred. Furthermore, the longer the episode, the greater was the daily risk for mortality.

Interpretation: The method can be used to forecast the risk of heat-related mortality, and to facilitate the development of public health responses to mitigate that risk.

MeSH terms: Heat; mortality; environment; public health; climate

La traduction du résumé se trouve à la fin de l'article.

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Extreme heat claims more lives than hurricanes, lightning, tornados, floods and earthquakes combined and is an environmental hazard that can have serious public health consequences.[1] During an average summer, hundreds of people across the United States die due to exposure to high temperatures. Heat-related illness can be prevented by knowing who is at risk and what prevention measures to take.[2]

There is strong consensus in the scientific community that climate change is occurring and that global temperatures will rise substantially during this century. In the period from 1977-2001, there has been an increase in the North American annual average surface temperature of 0.75°C. This was by far the greatest change in the last 100 years of record-keeping, with the greatest change occurring during the 1990s.[3] Globally, and particularly in North America, 2005 was the warmest year on record.[4] This makes addressing the impacts of oppressive hot weather on population health even more imperative.

Toronto Public Health (TPH) has coordinated a Hot Weather Response Plan since 1999, which has been revised periodically as new information and research became available. In 1999, the protocol called for activation of a Heat Warning (alert) using a threshold of a one-day forecast of Humidex (a Canadian summer temperature and humidity index) over 40°C.[5] Subsequently, in 2000 and 2001, TPH (with the Toronto Atmospheric Fund and the University of Delaware) developed a Heat Health Alert system, based on temperature, humidity and a number of other factors.[6] Toronto's Medical Officer of Health declares a Heat Alert when an "oppressive" air mass is forecast and a likelihood of excess, heat-related deaths would occur.

The declaration of a heat alert activates the City's Hot Weather Response Plan that coordinates the efforts of the City and community agencies to provide services to socially isolated individuals (including homeless people), seniors and medically-at-risk persons. If the air mass continues for a prolonged period of time, the Medical Officer of Health may declare an Extreme Heat Alert with additional measures, including the opening of City-operated heat relief centres.

Toronto Public Health, in collaboration with researchers from Environment

Canada, Health Canada and McMaster University, recently conducted a study to assess the combined impacts of air pollution and extreme temperatures on human mortality.[7-9] Data and methodology of the previous study were used to further examine the temporal structure and distribution of hot weather events in Toronto, the mortality associated with these events, and how these might influence future preparation for the public health implications of climate change.

Most recent epidemiological studies of the burden of illness associated with air pollution, and to a lesser extent hot or cold weather, have relied upon analysis of time-series data using statistical techniques that have treated the influence of the other major variable (weather or air pollution, respectively) as a confounder. Our approach has been to treat both of these components as important co-determinants of premature mortality.

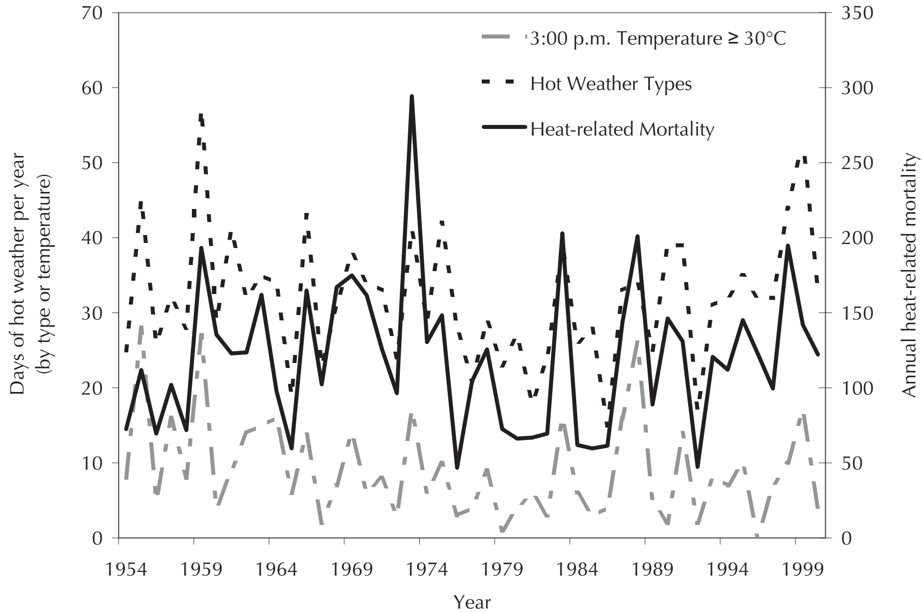

Figure 1. Historical trend in hot weather and related mortality (Toronto: 1954-2000)

METHODS

In brief, synoptic classification of air masses was used based on meteorological data for Toronto, to assign the *annual mean* burden of illness (in terms of elevated mortality) associated with hot weather and air pollution. Then, the coefficients relating daily mortality risk to historical daily weather and air quality data were determined with a model system that (for each air mass) assessed the changing factors that contributed to the *day-to-day variability* in mortality.

The present study builds upon the method of Kalkstein et al.,[10] in this case using principal component analysis, agglomerative hierarchical clustering and discriminant function analysis. A summary of this work[7] as well as the full report[8] may be found on the Toronto Public Health website, and the methodology used is the subject of another article.[9]

Hourly surface meteorological data from the international airport in Toronto were obtained from Environment Canada for the period 1953-2000. The meteorological data observed four times each day included: air temperature, dew point temperature, sea-level air pressure, total cloud cover, wind speed and direction. There were 24 meteorological variables for each day of the 47-year period entered into the classification process. The synoptic method assigned days to one of ten weather types: three “hot”, one “cold”, five “air pollution” (one for each pollutant), and one “other”(comfortable, low pollutant). For the analysis of hot weather, only data during the “warm season” (April-September) were used, and the three “hot” weather types were combined into one.

Atmospheric pollution data collected by the National Air Pollution Surveillance (NAPS) network were available from Environment Canada for several locations in Toronto. The data consist of hourly measurements of ozone (O_3), sulphur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO), and coefficient of haze (COH). All available data records of air pollutants from 1974 to 2000 except for O_3 were used in the analysis. Because of insufficient reliable data, O_3 observations were only included in the study for the period 1980-2000. $PM_{2.5}$ and PM_{10} data were excluded, and COH was used in the study as a proxy measure for particulate matter. Several monitoring sites were chosen to calculate mean concentrations representing average air pollution. These data were used in the air mass classification process, but are not in themselves the subject of this report.

For aggregation of daily total non-traumatic mortality counts, data from the City of Toronto and the other five former municipalities which were amalgamated with the City in 1998 were combined. Daily record-level mortality data (i.e., data for each death) for the study area from 1954 to 2000 were provided by Statistics Canada. Based on all non-traumatic deaths that occurred from 1954 to 1999, the average number of daily deaths for Toronto was 37.6.

Variations in mortality occur from year to year, and upward trends over time are observed for total non-traumatic mortality. This trend reflects the influence of several factors, including increases in total population, changes in population age structure, and improvements to health care.[11] These “non-environmental” factors represent confounding influences within the mortality data for our purposes, and were adjusted for by fitting a polynomial regression through daily mean mortality rates against time in years. To avoid removing health impacts of extreme temperatures and air pollution from the analysis, further adjustment was carried out based on the air mass classification. Seasonal fluctuations were excluded from mortality data by removing inter-annual trends on a monthly basis with monthly polynomial regression models, which were found to be very significant and usually explained over 80% of the data variance. The predicted mean daily mortality counts for each year (as derived from the regression models) were taken as the “base-

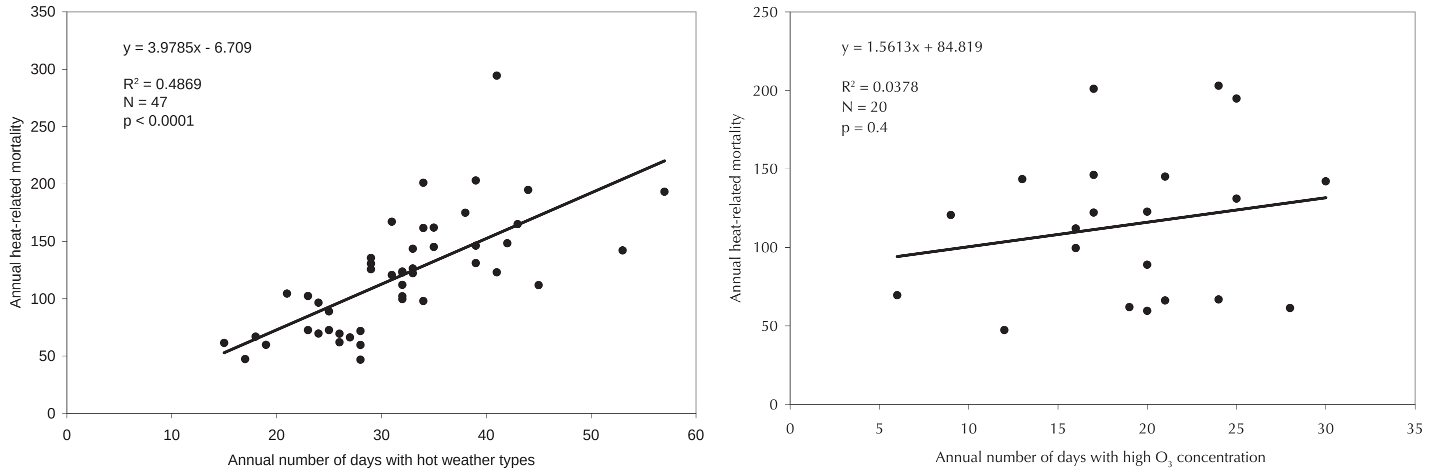

Figure 2. Relationship of heat-related mortality to days with hot weather-type ("oppressive") air mass (Figure 2a, left), and days with elevated ozone (Figure 2b, right)

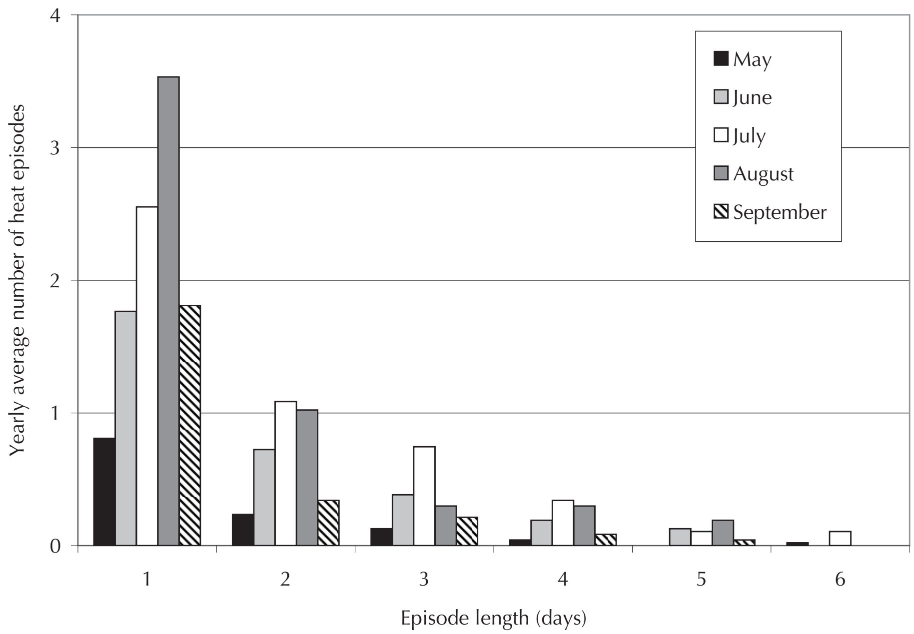

Figure 3. Temporal pattern of heat episodes (Toronto: 1954-2000)

line" value, and the difference between each day's actual mortality count and this baseline was then calculated and used for the analysis. Thus "heat-related mortality" was the excess mortality related to the combined three hot weather synoptic types.

RESULTS

In Figure 1, it can be seen that there are large variations in the yearly number of hot weather type days over the period of study. On average, there were 120 (95% CI: 105-135) heat-related deaths per year, but large variations in heat-related mortality from year to year. Moreover, it appears that there is an association between heat-related mortality and both indicators of days with heat stress: days with 3 p.m. temperature ≥30°C and hot weather type days.

A scatter plot of the association between heat-related mortality and the annual number of days with hot weather types is shown in Figure 2(a). The relationship between heat-related mortality and number of days with 3 p.m. temperature ≥30°C (not shown) was also examined. Both regression models demonstrated highly statistically significant relationships, but the strongest was that found between heat-related mortality and the annual number of days with a hot weather-type air mass. The parameters of this relationship are shown on the panel.

It is common for high concentrations of ground-level ozone to occur on hot days in the summer. Since there is evidence of an association of premature mortality with high ozone levels, it would be reasonable to expect that part of the association between excess mortality and hot weather might be due to ozone. The methodology used was designed to separate the influences of ozone and hot weather on mortality, and to demonstrate this, the relationship between the estimate of heat-related mortality and ozone is shown in Figure 2(b). Statistical analysis of these data indicated that no significant relationship was found between the estimate of heat-related mortality and high ozone levels. Similar analysis also failed to show a relationship between heat-related mortality and days with high NO_2 exposure.

Having demonstrated a relationship between hot weather type days and mortality in Toronto, the temporal patterns of these days were examined, and the influence of these patterns on mortality. An "episode" is defined as a sequence of hot days meeting a defined criterion (e.g., "hot weather-type air mass"). Figure 3 shows the average number of heat episodes per year in a given category of episode length, over the 47-year period of interest. For example, in the month of July there were, on average, 1.1 heat episodes per year in the category of 2-day episodes, over the 47-year period. The most frequent occurrence was a "one-day" heat episode, with a progressively smaller frequency of longer episodes. July and August showed the greatest number of oppressively hot days, and also the greatest number of prolonged periods of hot weather. Episodes as long as four days have occurred in all five months, May to September, with up to six days in May and July. Heat episodes longer than six days have occurred infrequently in June to September in this 47-year period (not shown).

Figure 4 shows the results of further analysis, where mortality on a given day is related to its sequence in the hot spell. It is clear that the more prolonged the episode, the greater the risk of daily mortality. The slope of a linear regression line shows a significant upward trend in daily mean heat-related mortality, at a significance level of 0.0006 (slope 0.74, adjusted R^2 for linear trend 0.86).

Since the revised heat alert system was implemented in Toronto in 2001, Heat Alerts have been declared by TPH. In 2005, there were three prolonged heat alerts, one of which lasted nine days. Figure 5 shows that high heat episodes occurred in the five previous years, and that the frequency varied greatly from year to year.

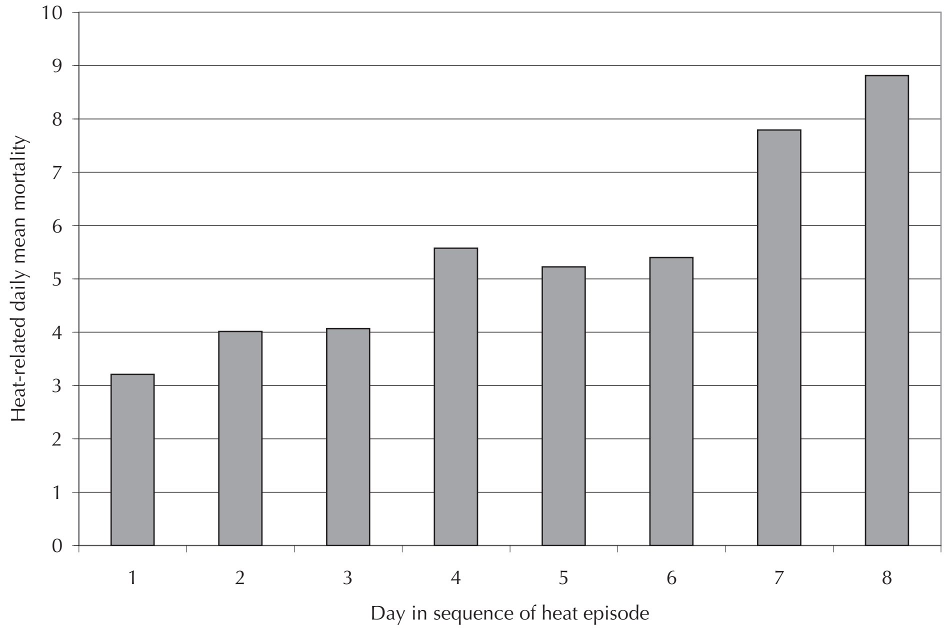

Figure 4. Heat mortality related to episode length

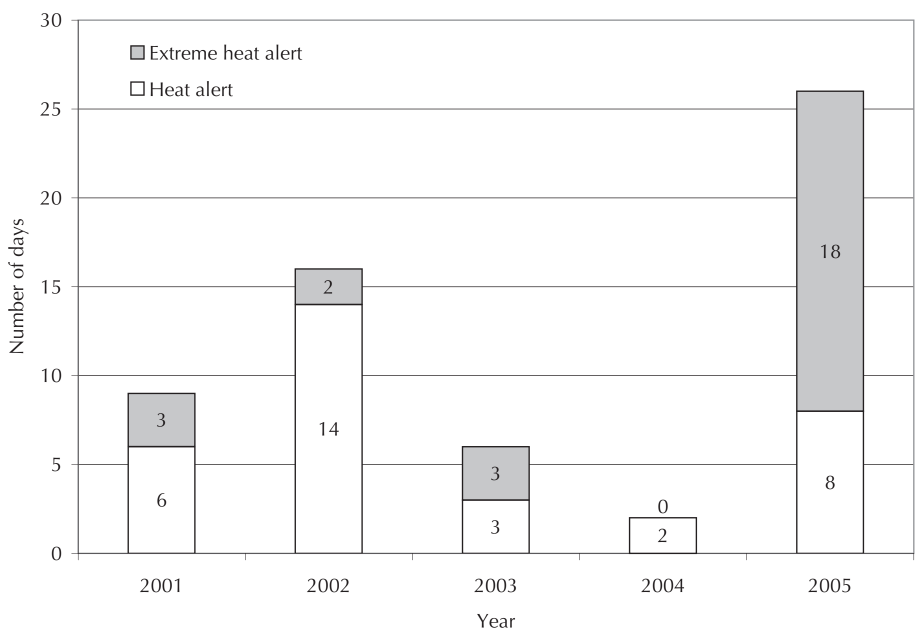

Figure 5. Frequency of heat alerts (Toronto: 2001-2005)

DISCUSSION

Through an analysis of almost five decades of meteorological and mortality data for Toronto, Canada, this study has shown that in the late spring and summer months, episodes of oppressively hot weather one to several days in length occur frequently. Data from the most recent year (2005) show longer hot-weather episodes in Toronto, compared with the previous five decades. This study has quantified the burden of excess heat-related mortality that these episodes carry with them, and has demonstrated that it is not attributable to air pollution. (In the earlier study where this was examined explicitly, daily mortality associated with the hottest air mass was approximately 60% greater than mortality associated with "air pollution" air masses. However, since there were fewer hot air masses than "air pollution" air masses on a yearly basis, oppressive heat accounted for 12% of the increased mortality, compared with 80% for air pollution.[8]) Furthermore, during a prolonged period of oppressive heat, every additional day carries with it a proportionally greater burden of excess heat-related mortality. In addition, from one year to the next there can be a two- to fourfold change in the number of days of oppressively hot weather. From a public health planning point of view, there is no "average" summer for heat.

These observations underline the importance of determining a unique public health response to hot weather episodes for each community. There is evidence that the structure of hot weather episodes varies from one community to another, as well as from one year to the next. Kalkstein and his colleagues have demonstrated major differences in the mortality response to hot weather in cities in the United States.[12,13] In general, several days of unusually hot weather are associated with greater mortality in cities in the northern US, compared with those in the south. However, the potential role of air pollution as a determinant of these differences was not examined explicitly in these studies.

In Toronto, as shown in Figure 4, excess heat-related mortality is observed on the first day of a sequence of hot days, and the excess mortality per day increases with the length of the episode. Sheridan and Kalkstein recently published observations for Toronto with data covering an unspecified period since 1975, using a related design with different methods of air mass categorization and selection.[6] However, they did not discuss the influence of air pollution on their estimate of heat-related mortality. This might explain the greater increase they found in excess mortality associated with prolongation of episode length than has been demonstrated in the present study. Further research that quantifies hot weather and air pollution mortality separately is needed to corroborate our findings.

Using models similar to those developed for this study, and existing weather and air pollution forecasting techniques and data available for most urban Canadian communities, it is possible to predict in the short term (a few days) the likelihood of oppressive hot weather. This, combined with well-designed, planned community responses could reduce the amount of heat-related morbidity and associated number of deaths which, in the current circumstances of global climate change, are bound to increase otherwise.

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RÉSUMÉ

Contexte : Les périodes de canicule, surtout sous les climats tempérés, font peser un fardeau de morbidité et de mortalité sur la population, particulièrement en zone urbaine. Maintenant que la polémique sur les origines du réchauffement planétaire, dont les signes sont déjà apparents, commence à s'estomper, les praticiens de la santé publique doivent impérativement savoir reconnaître et prédire les risques de « vagues de chaleur » et les combattre par des mesures de protection de la population. Sur la base de données historiques et d'une méthode élaborée antérieurement, nous avons examiné les périodes de temps chaud observées au cours des 50 dernières années à Toronto et évalué le fardeau de mortalité connexe.

Méthode : Grâce à la classification synoptique des masses d'air d'après les données météorologiques pour Toronto, nous avons estimé la proportion du fardeau annuel moyen des maladies (la mortalité accrue) associée au temps chaud et à la pollution atmosphérique. Nous avons ensuite établi des coefficients reliant le risque quotidien de mortalité aux températures quotidiennes historiques et aux données sur la qualité de l'air à l'aide d'un modèle qui (pour chaque masse d'air) évaluait les facteurs ayant contribué aux variations quotidiennes de la mortalité.

Résultats : Pendant la période à l'étude, 120 décès par année en moyenne étaient liés à la chaleur (IC de 95 % = 105–135), avec une grande variabilité d'une année à l'autre, laquelle reflétait la variabilité du temps chaud. La mortalité était au maximum en juillet et en août, période où l'on a observé le plus grand nombre d'épisodes de plusieurs jours de temps chaud. Plus les épisodes étaient longs, plus le risque quotidien de mortalité était élevé.

Interprétation : Cette méthode peut servir à prévoir le risque de mortalité liée à la chaleur et faciliter l'élaboration de mesures de santé publique pour atténuer ce risque.