QUANTITATIVE RESEARCH

A Data-driven Approach to Setting Trigger Temperatures for Heat Health Emergencies

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ABSTRACT

Objectives: Unprecedentedly hot weather during the summer of 2009 resulted in considerable excess mortality in Greater Vancouver, Canada. Local municipalities and public health authorities requested a rapid, evidence-based recommendation for the temperature above which emergency action plans should be triggered to reduce potentially-avoidable mortality during future events.

Methods: Candidate trigger temperatures were identified by examining the coincidence of extreme mortality days with extreme temperature days, using temperatures observed at two regional airports. Days when the two coincided between 2005 and 2009 were defined as historical heat health emergencies. Forecast and observed temperatures were combined in multiple early warning scenarios to retrospectively test the capacity to predict those heat health emergency dates, and results were expressed in terms of true positive (emergency predicted when one occurred) and false positive (emergency predicted when one did not occur) triggers.

Results: Extreme mortality was observed when the 2-day average of maximum temperatures was ≥31°C at the coastal airport and ≥36°C at the inland airport. When observed and forecast temperatures were combined in different early warning scenarios, all historical heat health emergencies were correctly identified in four of twelve cases, with a minimum of two false positive triggers.

Conclusions: A heat health emergency should be triggered for Greater Vancouver when the average of the current day's 14:00 observed temperature and the next day's forecast high is ≥29°C on the coast and/or ≥34°C inland. This condition provided 19 hours of lead time for preparation and was clearly understood by emergency responders and other users.

Key words: Hot temperature; environment; public health; information dissemination

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

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Excessive mortality during unusually hot weather has been described for several cities worldwide, including Moscow in 2010,[1] Paris in 2003,[2] and Chicago in 1995.[3] Many cities have developed heat health warning systems to trigger emergency responses and to inform their populations about upcoming episodes.[4] Most systems use a two-stage approach, with lower threshold conditions triggering a "heat health advisory" and higher threshold conditions triggering a "heat health emergency".[4] One challenge in developing heat health warning systems is establishing the threshold conditions under which advisories and emergencies are triggered. Hajat et al.[5] describe the two principal approaches of synoptic classification and epidemiologic evaluation. In brief, synoptic classification combines multiple meteorological measurements (temperature, humidity, air pressure, etc.) to identify the air masses most associated with excessive local mortality.[4] Epidemiologic evaluation assumes that mortality is a smooth function of observed temperatures, and uses time series models to quantify the local effects. Regardless of the underlying methods, most heat health warning systems are developed using observed temperature data and implemented using forecast temperature data, with little consideration of the relationship between them. This has been highlighted as a limitation.[5]

Here we describe a different, more data-driven approach used to identify the trigger temperatures for heat health emergencies in Greater Vancouver, Canada. An unprecedented period of extreme hot weather resulted in excessive mortality during the summer of 2009 (Figure 1),[6,7] and local municipalities developed comprehensive heat health emergency action plans to mitigate the effects of future events. The plans call for actions such as modifying or cancelling outdoor public gatherings, allowing free access to public pools, opening cooling centres, and asking management of air-conditioned buildings (malls, theatres, etc.) to maintain longer hours. Much of this planning was done in collaboration with local public health authorities, and in early 2010 the British Columbia Centre for Disease Control (BCCDC) was asked to provide a rapid, evidence-based recommendation for emergency trigger conditions to be used that summer. Given the human and financial resources necessary to implement the action plans, the stakeholders made it clear that tolerance for false positive events (i.e., calling a heat health emergency during weather that was not unusually hot) would be low.

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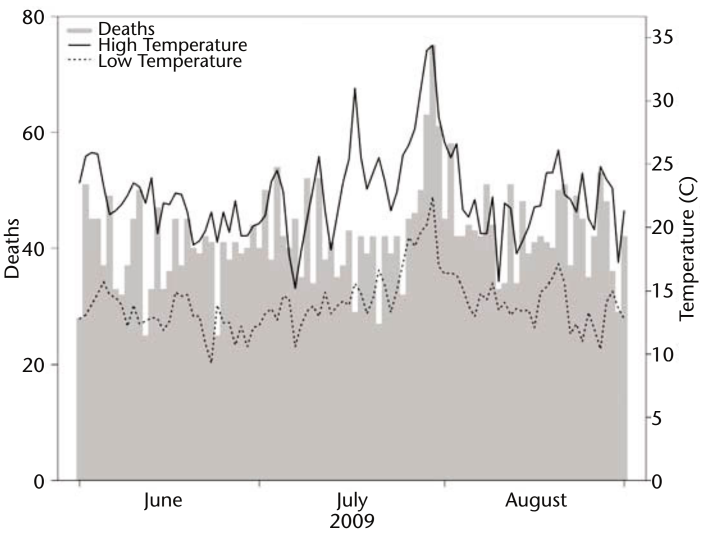
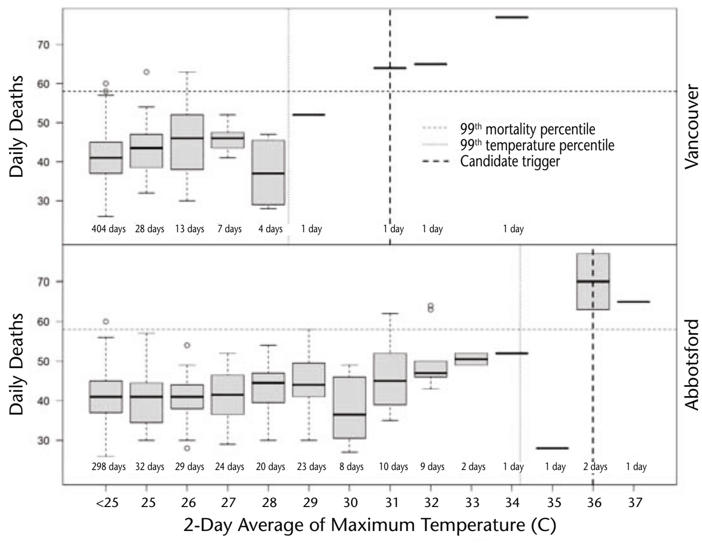
Figure 1. Daily mortality in Greater Vancouver during the summer of 2009, showing daily low and high temperatures observed at the Vancouver Airport



Temperatures of 34°C at the end of July were the highest on record at this location.

Figure 2. Daily summer (June through August) mortality in Greater Vancouver for the years 2005 through 2009, box plotted by one-degree bins of the 2-day average of maximum temperatures observed at Vancouver (coastal) and Abbotsford (inland) International Airports



The values under each box indicate the number of days in that bin. Lines indicate the 99th percentile of daily regional mortality (58 deaths), the 99th percentile of the 2-day average of maximum temperature observations (28.5 and 34.2°C at Vancouver and Abbotsford airports, respectively), and the candidate trigger values (≥31 and ≥36°C at Vancouver and Abbotsford airports, respectively) where values greater than the two 99th percentile values coincide.

METHODS

Data sources

Daily all-age, all-cause mortality counts in Greater Vancouver were obtained from the BC Vital Statistics Agency for 2005 through 2009. Daily temperatures were downloaded from Environment Canada for the Vancouver (coastal, 10 km from the city centre) and Abbotsford (inland, 70 km from the city centre) International Airports during the same period. Historically-issued forecasts for Vancouver and Abbotsford were obtained from Environment Canada for the years of 2005 through 2009. Temperature forecasts for *today* and *tomorrow* are made by Environment Canada meteorologists using various computer models and output as well as conceptual knowledge of local weather. For metropolitan-area Vancouver in summertime, meteorologists consider whether high temperatures forecast across the city vary by ≥4°C from the waterfront to the inland suburbs. If so, they assign a range in the forecast (near the water and inland), and we used "near water" highs whenever this was done. If not, they assign a single, regional high based on an average of temperatures across the region. A single high value is usually assigned for Abbotsford, where temperatures are less variable [Personal Communication. Lundquist D, Senior Meteorologist, Environment Canada, Kelowna, BC. Telephone conversation (October 21, 2011) with Henderson re temperature forecasting process for Greater Vancouver, BC]. During the summer months (June through August), forecasts were issued three times daily at approximately 05:00, 11:00 and 16:00. The 05:00 and 11:00 forecasts included high and low temperatures for *today* and *tomorrow*, while the 16:00 forecast included high and low temperatures for *tomorrow* only. Average temperatures were not forecast.

Identification of candidate triggers

Candidate triggers were identified by examining the coincidence of extreme regional mortality days (≥99th percentile of all mortality between June and August) with extreme temperature days (≥99th percentile of all temperatures between June and August, evaluated separately for each airport). The dates on which they coincided were defined as historical heat health emergencies, and the lowest temperature at which they coincided was identified as the candidate trigger for each airport (rounded down to the nearest degree). Analyses were conducted using the two-day average of maximum temperatures, and were restricted to the summers of 2005 through 2009 to ensure that we used the most current data over a period of relative demographic stability. Although hot-weather mortality was associated with low and high temperatures (Figure 1), we used maximum temperatures because the correlation between observed and forecast highs was stronger than the correlation between observed and forecast lows.

Predictability of historical emergencies

Days with coincident extreme temperatures and extreme mortality were defined as historical heat health emergencies. We attempted to retrospectively predict those dates using observed and forecast temperatures in the following early warning scenarios (for an emergency response starting at the beginning of the business day *tomorrow*):

- 28-hour lead time: The average of *today's* 05:00 forecast for *today's* high and *today's* 05:00 forecast for *tomorrow's* high.
- 22-hour lead time: The average of *today's* 11:00 forecast for *today's* high and *today's* 11:00 forecast for *tomorrow's* high.
- 19-hour lead time: The average of *today's* observed 14:00 temperature and *today's* 11:00 forecast for *tomorrow's* high.
- 16-hour lead time: The average of *today's* observed high and *today's* 16:00 forecast for *tomorrow's* high (which usually occurs at 16:00 or 17:00).

Historical heat health emergencies predicted by these scenarios were classified as true positive (heat health emergency predicted when one occurred) and false positive (heat health emergency predicted when one did not occur).

Table 1. Summary of the Historical Heat Health Emergencies for the Vancouver and Abbotsford Candidate Triggers

Date	Number of Deaths	True Positive for Vancouver Trigger (≥31°C)	2-day Average of Maximum Temperatures Observed at Vancouver Airport (°C)	True Positive for Abbotsford Trigger (≥36°C)	2-day Average of Maximum Temperatures Observed at Abbotsford Airport (°C)
July 11, 2007	58	No	26.2	Yes	36.4
July 29, 2009	63	Yes	32.5	Yes	37.1
July 30, 2009	75	Yes	34.2	Yes	36.8
July 31, 2009	61	Yes	31.6	No	32.2

Table 2. Summary of the Prediction Results for Both Triggers Under Different Lead-time Scenarios

		Vancouver (candidate trigger ≥31°C)		Abbotsford (candidate trigger ≥36°C)		Combined	
Predicting	Lead Time	True Positive (max = 3)	False Positive	True Positive (max = 3)	False Positive	True Positive (max = 4)	False Positive
Candidate trigger temperature	28-hour	0	0	1	2	1	2
	22-hour	0	0	1	1	1	1
	19-hour	0	0	1	0	1	0
	16-hour	1	0	1	2	2	2
1°C less than candidate trigger temperature	28-hour	1	0	1	2	2	2
	22-hour	2	0	2	2	3	2
	19-hour	1	0	1	2	2	2
	16-hour	**3**	**0**	**3**	**3**	**4**	**3**
2°C less than candidate trigger temperature	28-hour	2	1	**3**	**4**	3	5
	22-hour	**3**	**1**	**3**	**5**	**4**	**6**
	19-hour	**3***	**0***	**3***	**2***	**4***	**2***
	16-hour	**3**	**0**	**3**	**4**	**4**	**4**

Scenarios in which all historical heat health emergencies were identified are marked in **bold**. The scenarios that minimize false positive triggers while maximizing lead time are marked with an asterisk (*). The incidence of false positives was higher using data for Abbotsford airport because forecast temperatures sometimes overestimated the observed temperatures.

RESULTS

Candidate triggers

For the summer months in the period 2005 to 2009, daily regional all-age, all-cause mortality in Greater Vancouver (population ~2.5 million) ranged from 25 to 75 deaths, with a mean (SD) of 40 (6.8) deaths and a 99th percentile of 58 deaths. Over the same time period, the two-day average of maximum observed temperatures at the Vancouver (coastal) airport ranged from 13.0°C to 34.2°C, with a mean (SD) of 21.6°C (3.0°C) and a 99th percentile of 28.5°C. The two-day average of maximum observed temperatures at Abbotsford (inland) airport ranged from 12.5°C to 37.1°C, with a mean (SD) of 23.5°C (4.4°C) and a 99th percentile of 34.2°C. Candidate triggers for Vancouver and Abbotsford, respectively, were a two-day average of maximum temperatures ≥31°C and ≥36°C (Figure 2).

Prediction of historical emergencies

Historical heat health emergency dates based on the Vancouver trigger were July 29 through 31, 2009. Historical heat health emergency dates based on the Abbotsford trigger were July 11, 2007 and July 29 through 30, 2009. Thus, we were attempting to predict two different (but overlapping) sets of dates for each candidate trigger (Table 1). All historical heat health emergencies were accurately predicted in four out of twelve early warning scenarios for the Vancouver trigger and five out of twelve scenarios for the Abbotsford trigger (Table 2). There were more false positives for the Abbotsford trigger because forecast high temperatures sometimes overestimated the high temperatures observed at Abbottsford airport. On the other hand, high temperatures forecast for coastal Vancouver systematically underestimated the high temperatures observed at Vancouver airport. The minimum number of false positives for the Abbotsford trigger was two, predicted for July 22, 2006 (27 deaths, 35.8°C) and July 12, 2007 (47 deaths, 32.8°C). There were no false positives for the Vancouver trigger in three of four scenarios that correctly identified the three historical heat health emergencies.

DISCUSSION

Based on these analyses, the BCCDC recommended that a heat health emergency should be triggered for Greater Vancouver *tomorrow* when: 1) the average of *today's* 14:00 observed temperature at Vancouver International Airport and *today's* 11:00 forecast for *tomorrow's* high in coastal Vancouver is ≥29°C, *and/or* 2) the average of *today's* 14:00 observed temperature at Abbotsford International Airport and *today's* 11:00 forecast for *tomorrow's* inland high is ≥34°C. These were reliable indicators of the two-day average of maximum observed temperatures actually being ≥31°C at the Vancouver airport or ≥36°C at the Abbotsford airport (i.e., the candidate trigger conditions). This 19-hour lead-time scenario predicted all four historical heat health emergencies (Table 1) while minimizing the number of false positives based on the Abbotsford trigger. The two-day average of maximum observed temperatures on the first false positive date (July 22, 2006) was 35.8°C, which is close to the candidate trigger condition. The second false positive (July 12, 2007) would have unnecessarily extended one historical heat health emergency into a second day. This characterization of false positive triggers was important to stakeholders, who felt that emergency responders would be frustrated if multiple emergencies were triggered under temperature conditions that were perceived as unlikely to cause excess mortality.

The decision to define the 99th percentiles as extreme was based on previous work.[8] We repeated all analyses using the 95th and 97th temperature and mortality percentiles to examine the sensitivity of our results to this decision. At the 95th percentiles, the candidate trigger temperatures for Vancouver and Abbotsford would have been 26°C and 31°C, respectively, yielding a total of nine historical heat health emergencies with an impracticable minimum of 38 false positive triggers. At the 97th percentiles, the candidate trigger temperatures would have been 26°C and 31°C, respectively, capturing one more historical heat health emergency and resulting in eight more false positive triggers. Although this error rate was unacceptable to the stakeholders in Greater Vancouver, decisions related to trigger sensitivity should be informed by city-specific conditions and needs.

It was also important to stakeholders that a heat health emergency *tomorrow* could be reliably predicted before the end of the business day *today* so that responders would have as much time as possible to mobilize. Two of the 16-hour lead-time scenarios in Vancouver and Abbotsford reliably predicted all historical heat health emergencies (Table 2), but stakeholders were adamant that they needed at least a few more hours of warning; we therefore began to explore the relationship between hourly temperatures and daily high temperatures. Although the 12:00, 13:00 and 14:00 temperatures were all strongly correlated with all daily highs (typically observed at 16:00 or 17:00), only the 14:00 temperature was strongly correlated with the daily highs on very hot days (≥32°C). This relationship allowed us to extend the lead time to 19 hours, giving responders 2-3 business hours to prepare for a heat health emergency on the following day.

We also suggested using temperature data from other regional weather stations, but stakeholders expressed a strong aversion to this option, preferring to keep the trigger simple and easy for all of its users (health authorities, municipalities and emergency responders) to understand. This echoes concerns the authors have heard about the complex synoptic classification system used in Toronto,[9] and is consistent with the recommendation that heat health warning systems "should be developed with all relevant stakeholders to ensure that the issues of greatest concern are identified and addressed, thus increasing the likelihood of success".[10] Most trigger-setting approaches are quite complex,[4,5] and there is little discussion in the descriptive literature about how that complexity affects their users. For example, the heat health watch warning established in the city of Philadelphia uses a complicated, multi-stage algorithm for identifying heat health advisory and emergency days, but the regional health commissioner (likely an individual without meteorological training) has ultimate responsibility for making final judgement calls.[11] This is not to suggest that such systems are limited because they are complex, but to highlight another strength of the simpler approach described here.

The summers of 2010 and 2011 were not unusually hot in Greater Vancouver, with no heat health emergencies triggered and no excessive mortality observed on moderately hot days. We therefore cannot evaluate the efficacy of the system since its initiation. Regardless, the BCCDC used these methods to provide rapid, data-driven, and evidence-based recommendations about trigger conditions for regional heat health emergencies, thereby enabling the implementation of already-existing emergency action plans to protect public health during any hot-weather events that might have occurred. Stakeholder engagement at all stages ensured that our approach maximized the likelihood of identifying real heat health emergencies, minimized the impact of false positive triggers, and remained clearly understood by its users. The use of forecast temperatures in the development stage ensured that the triggers were tested under the most realistic conditions. The Greater Vancouver system and its triggers will be continually evaluated and revised as new data become available, as has been identified as a key component of any heat health early warning system.

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RÉSUMÉ

Objectifs : Les épisodes de chaleur sans précédent de l'été 2009 ont entraîné une surmortalité considérable dans la région du Grand Vancouver, au Canada. Les municipalités et les autorités de santé publique locales ont demandé qu'on leur recommande, preuves à l'appui, la température à partir de laquelle déclencher des plans d'urgence pour réduire les décès potentiellement évitables au cours d'épisodes futurs.

Méthode : Nous avons identifié des températures de déclenchement possibles en examinant la coïncidence des jours de mortalité extrême et des jours de température extrême, à l'aide des températures relevées dans deux aéroports régionaux. Les jours où ces deux éléments ont coïncidé entre 2005 et 2009 ont été définis comme étant des épisodes passés d'urgence sanitaire avec chaleur extrême. Les températures prévues et réelles ont été combinées selon plusieurs scénarios d'alerte rapide afin de tester rétrospectivement la capacité de prédire ces dates d'urgence sanitaire avec chaleur extrême, et les résultats ont été exprimés en termes de déclencheurs vrais positifs (prédiction d'une urgence qui s'est bien manifestée) et faux positifs (prédiction d'une urgence qui ne s'est pas manifestée).

Résultats : Une mortalité extrême a été observée lorsque la moyenne des températures maximales sur deux jours était ≥31 °C à l'aéroport côtier et ≥36 °C à l'aéroport de l'intérieur des terres. En combinant les températures réelles et prévues selon différents scénarios d'alerte rapide, tous les épisodes passés d'urgence sanitaire avec chaleur extrême ont été correctement identifiés dans quatre cas sur 12, avec au moins deux déclencheurs faux positifs.

Conclusion : Une urgence sanitaire avec chaleur extrême doit être déclenchée pour la région du Grand Vancouver lorsque la moyenne de la température du jour observée à 14 h et de la température prévue pour le lendemain est ≥29 °C sur la côte et/ou ≥34 °C à l'intérieur des terres. Ce critère laisse un délai de 19 heures pour se préparer, et il est clairement compris par les intervenants d'urgence et les autres utilisateurs.

Mots clés : température chaude; environnement; santé publique; diffusion de l'information