A BIOCLIMATOLOGICAL ANALYSIS OF HEAT AND HUMAN HEALTH: PROGRESS IN HEAT WATCH-WARNING SYSTEM TECHNOLOGY

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ABSTRACT

Among all atmospheric hazards, heat is the most deadly. With such recent notable heat events as the "Chicago Heat Wave" of 1995, much effort has gone into redeveloping both the methods by which it is determined whether a day will be "oppressive", as well as the mitigation plans that are implemented when an oppressive day is forecast to occur.

This article describes the techniques that have been implemented in the development of new synoptic-based heat watch-warning systems. These systems are presently running for over two dozen locations worldwide, including Chicago, Toronto, Rome, and Shanghai, with plans for continued expansion. Compared to traditional systems based on arbitrary thresholds of one or two meteorological variables, these new systems account for the local human response by focusing upon the identification of the weather conditions most strongly associated with historical increases in mortality. These systems must be constructed based on the premise that weather conditions associated with increased mortality show considerable variability on a spatial scale. In locales with consistently hot summers, weather/mortality relationships are weaker, and it is only the few hottest days each year that are associated with a response. In more temperate climates, relationships are stronger, and a greater percentage of days can be associated with an increase in mortality.

Considering the ease of data transfer via the world-wide web, the development of these systems includes internet file transfers and web page creation as components. Forecasts of mortality and recommendations to call excessive heat warnings are available to local meteorological forecasters, local health officials, and other civic authorities, who ultimately determine when warnings are called and when intervention plans are instituted.

Keywords: Heat, human mortality, heat watch-warning system, synoptic climatology.

1. INTRODUCTION

Heat is the deadliest of all atmospheric phenomena. From 1979 to 1999, the deaths of 8,015 Americans were directly associated with excessive heat exposure (Centers for Disease Control, 2002). This toll underestimates heat's true impact, however, as there is no consensus on what constitutes a "heat-related death", and death certificates often do not identify when heat has acted as a catalyst in exacerbating pre-existing cardiovascular, respiratory, and other conditions (e.g., Ellis and Nelson, 1978; Kalkstein and Valimont, 1987). Indeed, during the hot summer of 1980, across the US some 10,000 deaths may have been associated with the oppressive heat (National Climatic Data Center, 2002), and the hot summer of 2003 in Europe may have claimed nearly 15,000 lives in France alone (New York Times, 2003).

Exposure to the heat can be associated with heat syncope, cramps, exhaustion, and heatstroke (e.g., McGeehin and Mirabelli, 2001). The physiological response to excessive heat entails an increase in circulation, in order to increase heat loss through radiation, as well as evaporative cooling by sweat. An increase in cardiac output is needed to increase circulation, but is limited by maximum heart rate and vascular volume. Under excessive levels of stress, the body can thus no longer maintain temperature balance and death may occur.

Heat is primarily an acute problem. Oppressive ambient weather conditions are generally best correlated with negative health effects in the near-term. Lag correlations between heat and mortality generally diminish after one day (Kalkstein and Corrigan, 1986). Due to the acuteness of the problem, part of any attempt at mitigating the effects of heat involves understanding when ambient meteorological conditions are most likely to lead to an adverse health response. From this understanding, one can implement a warning system that identifies such conditions and a mitigation plan to protect those most vulnerable. Kalkstein *et al.* (1996) and Sheridan and Kalkstein (1998) described the premise behind the redeveloped Philadelphia Heat Watch-Warning System, which debuted in 1995. This system is based on the "synoptic methodology"; unlike previous heat warning systems, they first analyzed past weather conditions to identify those characteristics most likely to be associated with excess mortality. These characteristics were then used for predictive purposes with forecast meteorological data.

Since the Philadelphia system debuted, interest in the redevelopment of heat watch/warning systems has increased significantly. This interest has only been enhanced by notable events such as the Chicago heat wave of 1995 (Chagnon *et al.,* 1996), which claimed approximately 700 lives (Whitman *et al*., 1997). Over the past several years, many more synoptic-based systems have been developed, and the methodology has continued to improve. Systems are in place (Table 1) in a number of cities within the US, including Phoenix, Washington, Chicago, St. Louis, Cincinnati, Dayton, and a network of cities across Tennessee, Louisiana, Arkansas, and Mississippi. Systems have also been developed for cities outside the US, including four Italian cities, Toronto, and Shanghai. In total, over two dozen cities worldwide currently have synoptic-based heat watch-warning systems in operation.

Funding for these systems comes from numerous agencies. These include several within the federal government, most notably the National Oceanic and Atmospheric Administration / National Weather Service (NOAA/NWS) and the Environmental Protection Agency (EPA). In addition, several United Nations agencies have contributed to the overseas systems, especially the World Meteorological Organization (WMO), the World Health Organization (WHO), and the United

Nations Environment Programme (UNEP). Finally, several private corporations, particularly utility companies that need accurate information involving suspension of utility disconnects during oppressive weather, have provided monetary support. These include Entergy in the southern United States and the Salt River Project in the Southwest.

Table 1. Cities with synoptic-based heat watch/warning systems, and year of debut

Year	City
1995	Philadelphia, USA
1996	Washington, USA
2000	Rome, Italy
2001	Shanghai, P.R. China
2001	Southwest Ohio (Cincinnati, Columbus, Dayton), USA
2001	Toronto, Canada
2002	Phoenix, USA
2001-02	12 cities, including New Orleans and Memphis, Southeast USA
2003	Chicago and Saint Louis, USA
2003	Chicago, USA
2003	Turin, Milan, and Bologna, Italy
2004	Dallas-Fort Worth, Seattle, Yuma (Arizona), USA
2004	Palermo, Italy

Note: All systems are similar to those outlined here, except for Philadelphia and Washington, which are based on the methods described in Kalkstein *et al.* (1996)

This article describes in detail the general procedures that are utilized in the development and implementation of synoptic-based watch-warning systems. Included are descriptions of the methods used to understand the heat-health relationship, and how forecasting models are developed. The operational aspects of the system are discussed, including the identification of different levels of advisories and the development of web-based forecasting tools. Finally we describe potential intervention activities and the means to check system effectiveness.

2. THE SYNOPTIC METHODOLOGY

The premise behind heat watch-warning systems involves solid knowledge of the actual heat/health relationship at each locale that a system is implemented. Thus, those threshold conditions that induce an adverse health response need to be identified. Of great importance is the spatial nature of these thresholds and human responses: they are highly variable, which strongly suggests that systems must be location-specific, something that has been rarely attempted in the past. This requires the input of considerable amounts of health-related and meteorological data for each locale.

Health data

The health outcome data utilized in all of our watch-warning system development thus far has been mortality data. This choice is not meant to imply that mortality is the only possible negative response to the heat -Semenza *et al.* (1999) report an increase of greater than 1,000 hospital admissions in Chicago during the 1995 heat wave alone- and many more are doubtlessly affected, with a considerable cost in terms of health care and lost productivity. Nevertheless, mortality data have several clear advantages in their use, most notably their ease of availability, and the binary nature of the outcome ("dead" or "alive"). Further, their collection is far more established and standardized than any other health outcome. Mortality data for the entire US are available from the National Center for Health Statistics; similar agencies exist in other developed nations. Hospital admissions data are not similarly standardized, and there is no single collection agency. Particularly in the US, with public and private hospitals, the acquisition of such data can be difficult.

Daily mortality data within the US are available with information as to cause(s) of death. As mentioned above, however, mortality from numerous causes has been observed to rise during hot weather. Thus, total mortality of all causes has been utilized in these heat watch-warning systems, rather than attempting to segregate only those deaths that may be heat-related. Researchers as early as Gower (1938) have observed that "official" heat deaths dramatically underestimates heat's true toll.

Mortality data are summed into daily totals on a county-by-county basis in the US. In all US cities, the standardized metropolitan statistical area (SMSA) for each primary city is utilized. In all systems developed for locations outside the US, only daily totals of mortality data that occurred within city limits were analyzed.

These daily totals need to be standardized to account for demographic changes over the period of available record; not only for population growth (or decline), but aging as well. In the US, mortality data are available continuously in digital format since 1975; this has been the starting period used. To account for interannual changes, a "baseline" level of mortality is subtracted from each day within the period of record. This baseline is considered to be the three-year running mean of daily mortality, centered on the year in which the particular day lies. In cases such as Phoenix, dramatic growth and demographic shifts have resulted in a more than doubling of mean mortality over the period analyzed (Figure 1).

Mortality shows clear seasonal trends, with mean values typically about 10 percent higher in winter than summer. Yet in most cases, within the "summer" period analyzed, there is no trend - i.e., there is no statistically significantly greater mean number of deaths in May than August. In the case of Rome, however, a strong seasonal trend is observed, with much lower rates of mortality, near 15 percent, beginning around 10 August and continuing through early September (Figure 2). This seasonal shift is an apparent result of the seasonal migration out of Rome during the holiday month of August, and unrelated to meteorological phenomena. Thus, in the case of Rome, mortality was adjusted by including of an intra-seasonal mean daily mortality, based on an 11-day running mean.

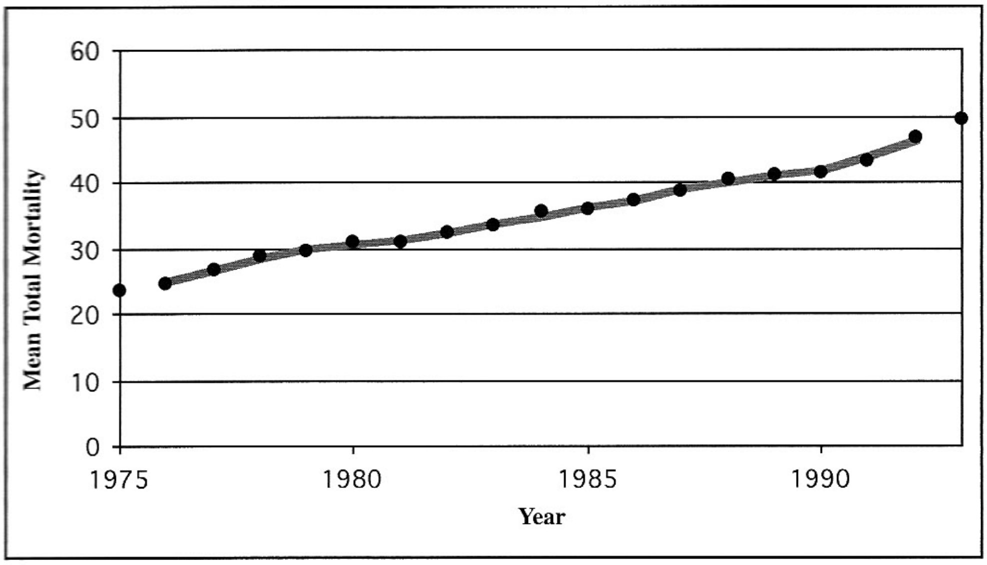


Figure 1. Mean daily summer (15 May - 30 September) mortality, Phoenix, Arizona, USA, metropolitan area, by year

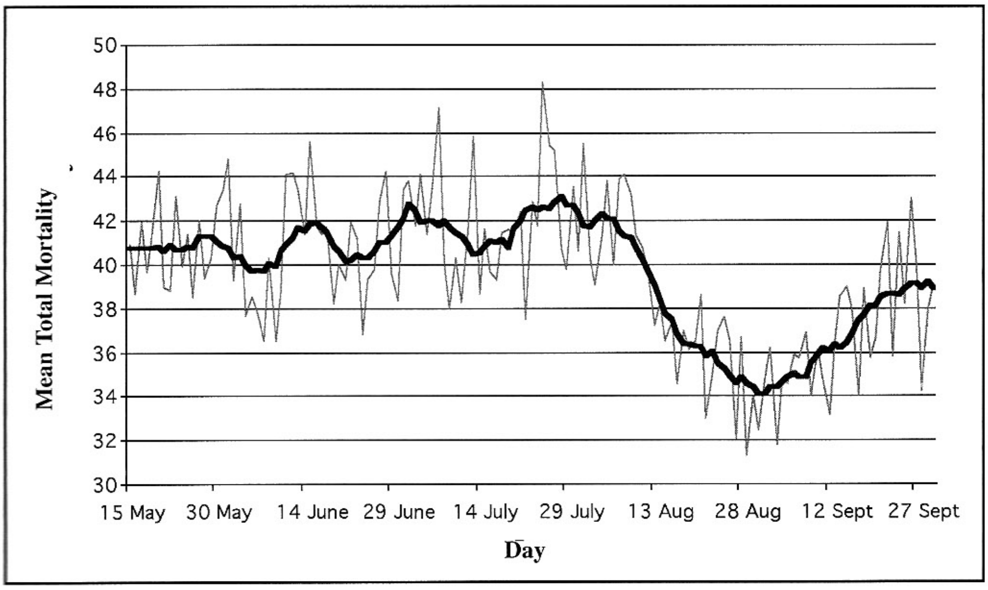


Figure 2. Mean daily mortality (1987-1997) by day of season, Rome, Italy.An 11-day running mean is superimposed

Weather data

Weather data are collected for the airport most representative of the city or metropolitan area as a whole. Utilizing airport data provides a suite of meteorological variables to consider: not only temperature on an hourly basis, but also dew point, pressure, cloud cover, and wind information, variables that have been related to human health in other research (e.g. Kalkstein and Davis, 1989).

All of these parameters are considered in analysis. As these systems are based on the synoptic methodology, and its assumption that the population responds to all weather variables concomitantly, the initial method of analysis involves the classification of all days in each city into one of several weather types, or air masses, that incorporate all meteorological variables together. The particular classification system utilized in all but the first two systems is the Spatial Synoptic Classification (SSC; Sheridan, 2002). The SSC incorporates observations of temperature, dew point, pressure, wind, and cloud cover four times daily for a particular location, and via a hybrid manual/automatic classification scheme, classifies each day into one of several weather types:

- Dry Polar (DP)
- Dry Moderate (DM)
- Dry Tropical (DT)
- Moist Polar (MP)
- Moist Moderate (MM)
- Moist Tropical (MT)
- Transition (TR)

Heat-related mortality has only been related to the occurrence of the two warmest weather types, the tropical DT and MT. As these are fairly common in the summer across much of the middle latitudes, subsets of these two weather types have been developed for certain locations:

- DT+ and MT+, subsets in which morning and afternoon apparent temperature (defined in Steadman, 1979) values are both above weather-type means for the location
- MT++, subsets in which morning and afternoon apparent temperature values are both more than one standard deviation above weather-type means for the location.

As different populations have different levels of acclimatization, the SSC categories are particularly useful in that the mean conditions associated with the weather types are different from place to place, as well as during different times of year. Thus, an MT+ day in July is warmer and more humid in New Orleans than Toronto, and an MT+ day anywhere in early June is cooler than what it would be at the same location in late July. Example mean conditions are shown in Table 2.

Table 2. Mean conditions associated with the two oppressive weather types

DRY TROPICAL												
City	15-31 May				15-30 June				15-31 July			
	Ta	Tp	Tdp	CC	Ta	Tp	Tdp	CC	Ta	Tp	Tdp	CC
Chicago	18	30	12	4	22	34	17	3	23	35	17	3
Cincinnati	16	30	14	4	20	34	16	3	22	35	16	4
Memphis	19	32	13	3	24	36	18	3	25	37	19	3
New Orleans	22	32	12	2	24	35	17	2	24	36	18	2
Phoenix*	24	37	0	2	28	41	3	2	31	43	8	3
Rome	22	30	12	3	22	32	14	2	24	34	16	1
Saint Louis	20	31	13	4	25	35	16	3	26	37	18	4
Shanghai	20	30	12	3	22	32	12	1	Does not occur			
Toronto	15	28	12	4	18	31	15	3	21	32	16	3

MOIST TROPICAL PLUS												
City	15-31 May				15-30 June				15-31 July			
	Ta	Tp	Tdp	CC	Ta	Tp	Tdp	CC	Ta	Tp	Tdp	CC
Chicago	20	29	19	6	23	31	21	6	25	33	23	5
Cincinnati	21	29	19	6	23	33	22	6	24	34	23	5
Memphis**	24	32	21	5	26	35	23	4	27	36	24	4
New Orleans**	25	33	23	5	26	35	24	5	27	35	25	6
Phoenix	27	33	11	8	30	37	16	6	31	38	17	4
Rome	21	27	16	4	22	30	19	4	25	32	21	3
Saint Louis**	23	31	20	6	26	34	23	6	27	35	23	5
Shanghai	23	29	23	7	28	33	25	7	29	35	26	6
Toronto	19	27	17	5	22	29	20	5	22	31	21	5

Dry Tropical (*Dry Tropical +) and Moist Tropical + (**Moist Tropical ++), across three periods of summer, for selected cities. Ta = temperature (°C) in early morning (02h-05h), Td = temperature in mid-afternoon (14h-17h), Tdp = dew point in mid-afternoon, and CC = cloud cover (tenths) in mid-afternoon.

Analysis

The development of the heat-mortality relationship involves several levels of analyses, the first of which is an initial assessment of the mean human response to the different weather types. In all locations, at least one weather type is associated with a statistically significant increase in mortality; in many locations more than one are. The response clearly varies from city to city (Table 3).

The more temperate cities are generally associated with a greater percentage increase in mortality on oppressive days. In contrast, in many of the warmer locales for which systems have been developed (e.g. New Orleans and Phoenix), the response is smaller. In these cities, a more stringent subdivision of the tropical weather types (Dry Tropical + and Moist Tropical ++) is necessary as the population is acclimatized to oppressive conditions, and only with a more rigorous subdivision is any response noted. Thus, there are fewer oppressive days and/or a lower mortality response on such days. Interestingly, compared with the systems developed for the US and Canada, a larger percentage increase in mortality has been generally observed outside North America, with a mean increase of nearly 20 percent in mortality in Shanghai on oppressive MT+ days, and increases above 10 percent at Rome and other Italian cities. The lesser availability of air conditioning in these cities may be at least partially responsible.

Table 3. Oppressive weather types by location

City	DRY TROPICAL			MOIST TROPICAL PLUS		
	Frequency	Mortality		Frequency	Mortality	
	percent	deaths	percent	percent	deaths	percent
Chicago	3.2	5.2	5.0	6.8	7.4	7.1
Cincinnati	1.9	2.2	9.6	6.5	1.0	4.3
Memphis	5.4	1.2	4.4	2.8**	1.7	6.3
New Orleans	-	-	-	2.4**	3.6	9.7
Phoenix	1.3*	2.7	6.6	-	-	-
Rome	6.8	6.2	15.5	3.9	5.0	12.5
Saint Louis	6.0	1.7	3.3	3.5**	2.1	3.7
Shanghai	-	-	-	11.0	42.4	19.9
Toronto	3.4	4.2	9.8	3.9	4.0	9.4

Note: Weather type frequency is mean for period 15 May-30 September; excess mortality is expressed as both mean total of deaths per day greater than normal, and the percentage increase this represents. '-' signifies this weather type is not associated with above-normal mortality at this location. * signifies Dry Tropical + and ** Moist Tropical ++.

In virtually all cases (e.g., Toronto, Table 4), the weather types that are associated with elevated mortality also exhibit larger variability in the day-to-day mortality response. To further refine the weather - mortality relationship, once the most oppressive weather types have been identified, several additional parameters are then correlated with days within this oppressive subset. These additional parameters fall into three categories: seasonality, persistence, and meteorological character of the weather type.

Table 4. Mean daily anomalous mortality, standard deviation of daily anomalous mortality, and likelihood of daily mortality being above the mean, by weather type, Toronto

Weather Type	Anomalous Mortality		
	Mean	S.D.	Likelihood (>0)
DM	-0.2	8.1	0.45
DP	-1.2	8.6	0.39
DT	4.2	11.0	0.63
MM	-0.9	7.2	0.43
MP	-0.6	8.3	0.45
MT	1.4	8.1	0.57
MT+	4.0	9.3	0.40
TR	-0.7	8.1	0.65

The most important additional criterion incorporated into the synoptic system is that of seasonality. It has been observed (e.g., Kalkstein and Davis, 1989; Kalkstein *et al.*, 1996; Kalkstein and Greene, 1997) that heat waves of similar character often evoke a greater human response earlier in the summer than later in the summer. Two factors are believed to contribute to this observation: the most heat-susceptible persons will perish in the first heat wave of a given summer, and the population as a whole will acclimatize to warmer meteorological conditions over the course of the summer. Many of the cities for which heat watch-warning systems have been developed (e.g., Rome, Figure 3) show clear trends in decreasing mortality response to oppressive conditions throughout the summer.

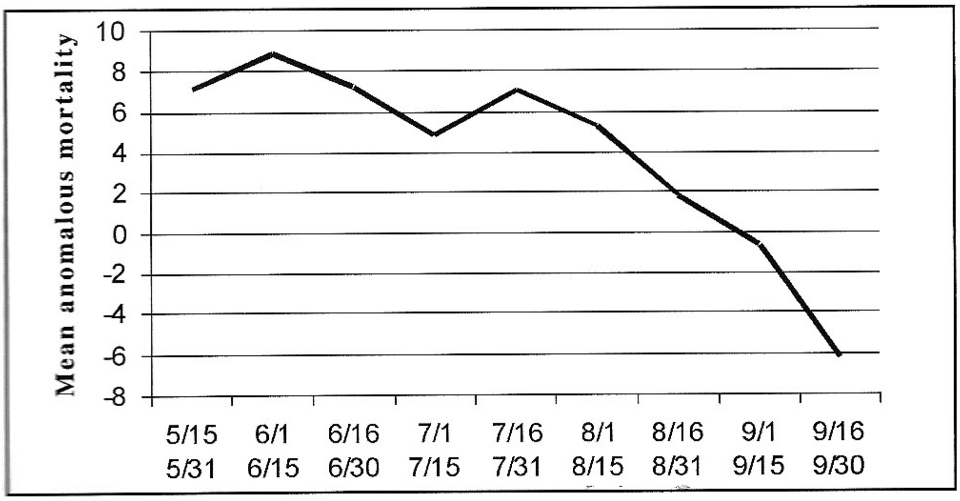


Figure 3. Mean anomalous daily mortality (1987-1997) during MT+ weather type, by period of season, Rome

The persistence of oppressive weather is another factor that is not traditionally included within heat watch-warning systems. A longer continuous exposure to oppressive weather places additional stress upon the human body. Further, even with outdoor temperatures remaining similar from day to day, during a heat wave indoor temperatures may continue to escalate, creating an excessive health hazard. In most temperate cities (e.g. Toronto, Table 5), though increases in mortality are statistically significant on the first day of oppressive weather, they increase up to tenfold on the rare occasion that offensive weather persists five consecutive days. In many of the warmer locations for which systems have been developed, there is no statistically significant increase in mortality on the first oppressive day; only when such conditions persist two or greater days is an increase in mortality noted.

Table 5. Mean daily anomalous mortality, by the number of days an oppressive weather type has persisted, Toronto

Day	Anomalous Mortality		Moist Tropical Plus	
	Mean	*n*	Mean	*n*
1	0.2	42	2.9	43
2	2.7	20	3.2	22
3	8.3	13	8.1	10
4	8.1	5	8.5	5
5+	27.8	2	8.7	3

Note: The number of times this has occurred is denoted by n.

Though the weather-type classification scheme delineates weather conditions into one of several categories, this does not mean that there is no variability within each category. For this reason, within each weather type, the correlation between several measures of meteorological character and mortality response is assessed. These measures include cloud cover, wind speed, temperature and moisture conditions, all of which have been previously related to mortality (Kalkstein and Davis, 1989; Kalkstein, 1991). Thus far, only measures of temperature or apparent temperature have been significantly correlated with mortality within-weather type. In many cases, within the oppressive weather types, morning temperature proves to be most significantly correlated with mortality, indicating that it is the lack of diurnal relief that often contributes most to significant heat-related mortality increases.

Algorithm development

Following the analyses described above, algorithms are developed to produce an estimate of mortality, based on meteorological conditions as well as the additional factors such as time of season. These algorithms are then used with forecast meteorological data in order to produce forecast levels of mortality.

It is important to note that any estimates of mortality are not made accessible to the general public and are issued on password-protected websites. While the mortality estimates are important as guidance to National Weather Service offices that are issuing excessive heat warnings, and to health and emergency management agencies that are instituting intervention activities, they are not to be transmitted to the media and to the general public.

The process by which forecast data yield a mortality forecast involves several steps (Figure 4). The first step involves the evaluation of whether forecast weather conditions place the future day into an "offensive" weather type, i.e. one that has been associated with elevated mortality. If this does occur, within weather-type algorithms are then utilized to forecast more precisely the expected increase in mortality. Most forecast algorithms forecast an actual number of excess deaths (deaths above normal levels) based on conditions. However, the Toronto system employs a different procedure, utilizing binary logistic regression to forecast the likelihood that at least one additional death will occur given forecast conditions. Example algorithms of these two approaches appear in Table 6.

By first segregating only the days that may be offensive, a much greater coefficient of determination (R2) results. In many cases, these algorithms are associated with R2 values of 0.20 to 0.50, much greater than regression equations that utilize all summer days, in which R2 values rarely exceed 0.10. The difficulty of verifying these algorithms, however, is discussed in Section 5.

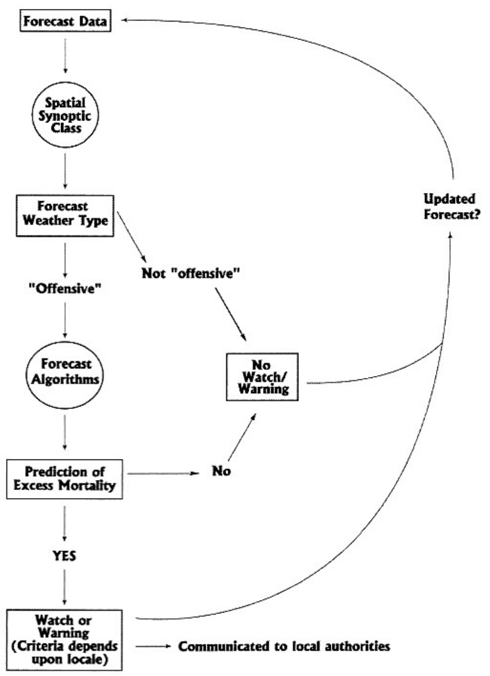


Figure 4. Flow chart for the determination of whether or not to call a heat watch/warning

Table 6. Mortality regression equations, Toronto and Rome

Toronto

L is the likelihood that mortality will be above average based on forecast:

MT+: $$L = \frac{\exp(-9.167 + 0.794SEQ + 0.290T_{17})}{1 + \exp(-9.167 + 0.794SEQ + 0.290T_{17})} \quad (r^2 = 0.18)$$

DT: $$L = \frac{\exp(-9.821 - 0.043TOS + 0.487H)}{1 + \exp(-9.821 - 0.043TOS + 0.487H)} \quad (r^2 = 0.29)$$

Rome

M is the anomalous mortality (in deaths) that is predicted to occur based on forecast:

MT+: $M = -4.84 - 0.13TOS + 0.82CH$ $(r^2 = 0.26)$

DT: $M = -45.92 - 0.08TOS + 2.05SEQ + 1.61AT_0 + 0.75AT_1$ $(r^2 = 0.46)$

Terms:

- AT_0: minimum apparent temperature (°C)
- AT_1: minimum apparent temperature (°C), following day
- CH: cooling degree hours (sum of degrees above 20°C, for 0300, 0900, 1500, 2100 LDT)
- H: the mean daily Humidex (an apparent temperature)
- SEQ: refers to the day in sequence of an oppressive weather type
- T_{17}: the 1700 LDT temperature (°C)
- TOS: time of season, where 1 May = 1, 2 May = 2, etc.

Threshold levels

Once algorithms have been developed for each location, the next stage in analysis includes the delineation of threshold levels, above which some alert or emergency is recommended. For most systems, there are two tiers, a higher "warning" or "emergency" level, and a lower, "alert" or "watch" level. The definitions and delineations of these levels vary by location. In Toronto, the levels are separated by the intensity of the heat; an "emergency" is associated with a forecast likelihood of excess mortality of 90 percent or greater, and an "alert" associated with a likelihood between 65 and 90 percent. In other locations, the levels are delineated temporally. In Rome, an "avviso (advisory)" is called when one or more excess death is forecast in the next 24 hours, and an "attenzione (attention)" when the same threshold of forecast excess mortality is met between 24 and 48 hours in the future.

3. OPERATIONAL ASPECTS

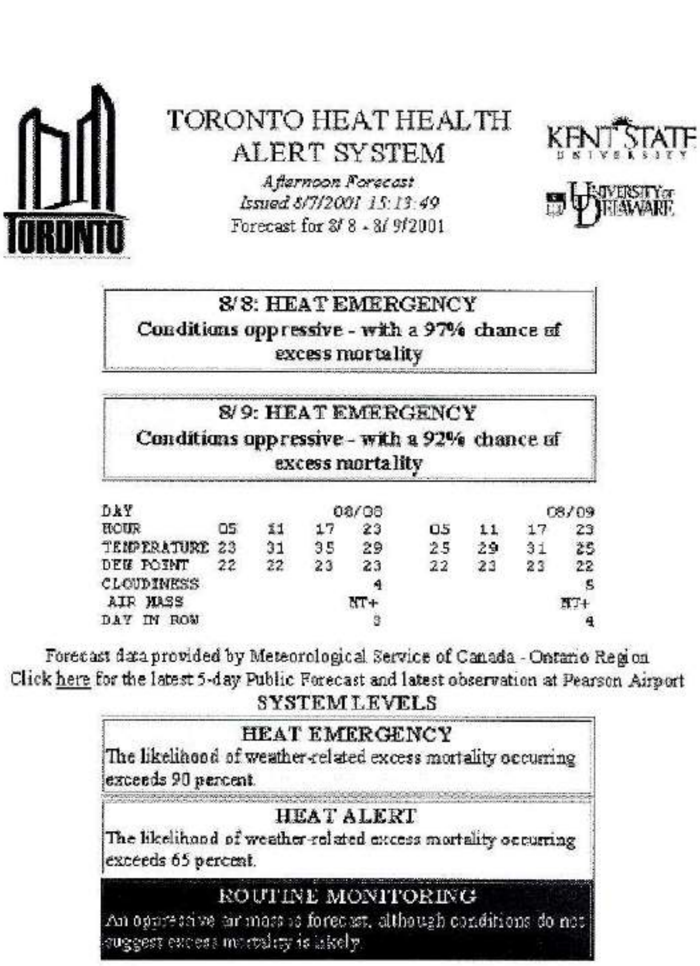
The implementation of a heat watch-warning system is one that involves several different agencies: meteorologists, health officials, and other civic agencies are all part of the process. Due to the need to keep several different groups of people informed simultaneously, all heat watch-warning systems are now entirely run real-time on the internet. There are several steps that are incorporated into this process:

- the acquisition of forecast data,
- the processing data and creation of a forecast,
- updating a forecast as needed, and
- the system's recommendation and the ultimate decision.

The first stage in running is the ingestion of forecast data. In this stage, the servers on which the site is hosted acquire the data. The transfer may either be initiated by the weather forecast office or by the host, and is usually done twice a day, mid-afternoon (near 1500 LST) and overnight (near 0300 LST). Required forecast data include values for temperature, dew point, wind speed and direction, and cloud cover, and are needed at six-hourly intervals over the duration of the forecast period. To account for persistence of oppressive weather, actual meteorological observations are updated through the time of the forecast as well.

For most US systems, the source of these data has been the Model Output Statistics (MOS) product issued by the National Center for Environmental Prediction. Output from the MOS contains all required variables. The selection of which forecast model to use has typically been left up to the local National Weather Service forecast office. Since 2002, however, NWS offices have been in the process of migrating towards the issuance of a Point Forecast Matrix (PFM), a product similar in form to the traditional MOS, but allowing for forecaster modification (Young, 2004). The digital forecast issued by Environment Canada for Toronto is similar in scope.

Once the data are acquired, a UNIX script runs a series of FORTRAN programs to process the data and create a web page that displays the forecast (Figure 5). The overnight forecast includes the upcoming day as well as the two after. The afternoon forecast includes only the two following days. This web page is password protected so that only the local weather forecast office and authorized agencies (such as health departments) may access the output.



TORONTO HEAT HEALTH ALERT SYSTEM

Afternoon Forecast
Issued 8/7/2001 15:13:49
Forecast for 8/8 - 8/9/2001

8/8: HEAT EMERGENCY
Conditions oppressive - with a 97% chance of excess mortality

8/9: HEAT EMERGENCY
Conditions oppressive - with a 92% chance of excess mortality

DAY				08/08				08/09
HOUR	05	11	17	23	05	11	17	23
TEMPERATURE	23	31	35	29	25	29	31	25
DEW POINT	22	22	23	23	22	23	23	22
CLOUDINESS				4				5
AIR MASS				MT+				MT+
DAY IN ROW				3				4

Forecast data provided by Meteorological Service of Canada - Ontario Region
Click here for the latest 5-day Public Forecast and latest observation at Pearson Airport

SYSTEM LEVELS

HEAT EMERGENCY
The likelihood of weather-related excess mortality occurring exceeds 90 percent.

HEAT ALERT
The likelihood of weather-related excess mortality occurring exceeds 65 percent.

ROUTINE MONITORING
An oppressive air mass is forecast, although conditions do not suggest excess mortality is likely.

Figure 5. The webpage for the Toronto Heat-Health Alert system

Frequently, forecasts need to be updated between the twelve-hour schedule for automated forecast updates, and several mechanisms are in place to assist. For locations where a PFM is issued, the update is easy, as a forecaster will issue a new PFM with updated conditions. The server on which the system resides checks every 15 minutes for an update, and downloads and processes forecasts as needed. For other systems, web pages have been created that allow forecasters to modify conditions manually, and then view the results of the modifications.

The ultimate decision as to whether to issue a "Heat Warning", "Heat Alert", or neither is then left up to the local National Weather Service office, or in the case of several international cities, including Toronto and Rome, the local health authority in consultation with meteorologists. All agencies have access to the web site, which is password protected as the forecast issued by the system is a recommendation and not the final decision.

4. MITIGATION ACTIVITIES

There is a wide variation in the sophistication of intervention plans employed by urban areas on days when heat emergencies are declared. In addition, there is also a range in terms of monetary costs that cities expend during emergency days (Kalkstein, 2003). Philadelphia has one of the most elaborate set of heat/health intervention activities that become effective anytime the National Weather Service calls a heat warning.

The following represents a summary of all activities pursued by the city of Philadelphia whenever a heat warning is called by the National Weather Service (Kalkstein, 2003):

- Media announcements: The media (TV, radio stations, and the newspapers) are informed of all declarations by the Health Commissioner and are provided with information on how to avoid heat-related illnesses during oppressive weather. The media have been active both in reporting watch/warning declarations and in providing information useful to the general public, including features highlighting various intervention activities.
- Promotion of the "Buddy System": Media announcements encourage friends, neighbors, relatives, block captains, town watch groups, church members, and other volunteers to make daily visits to elderly persons during hot weather. The "buddies" make certain that susceptible individuals have sufficient fluids, proper ventilation, and the amenities to cope with the heat wave.
- Activation of the "Heatline": When the Health Commissioner declares a warning, the Heatline, a hotline operated in conjunction with the Philadelphia Corporation for Aging, is activated to provide information and counseling to the general public on avoidance from heat stress. The Heatline number is publicized by the media. Callers are offered information on coping with the heat. Health Department nurses are available to speak with callers who are suffering medical problems. These nurses may make referrals to field teams who make home visits and directly evaluate situations.
- Home visits: Department of Public Health mobile field teams make home visits to persons requiring more attention than can be provided over the Heatline. Mobile teams consist of a nurse and a sanitarian, and operate during all hours that the Heatline is activated.
- Nursing and personal care boarding home intervention: When a warning is issued, the Department of Public Health contacts these facilities to inform them of an impending high-risk heat situation and to offer advice on the protection of residents. In addition, during warning periods, mobile field teams make inspection visits to these homes to ensure adequate hot weather care for residents.
- Halt of utility service suspensions: The local electric company (PECO) and the Philadelphia Water Department halt service suspensions during heat warning periods.
- Increased emergency medical service (EMS) staffing: The Fire Department Emergency Medical Service utilizes the issuance of a warning to schedule increased staffing in anticipation of increased service demand.
- Daytime outreach to the homeless: The City's agency for homeless services shifts its street outreach to the homeless from an evening activity to an intensive daytime outreach effort.

- Senior center services: The nearly fifty Senior Centers within city limits extend their hours of operation to evenings and weekends, coordinated by the Philadelphia Corporation for Aging.
- Air-conditioned shelter capability: The Department of Public Health has the capability to move persons at high risk out of dangerous living situations to an air-conditioned (overnight) shelter facility.

5. EVALUATION

An evaluation of the effectiveness of heat watch-warning systems is a difficult undertaking. As with many hazards, warning systems and mitigation plans can only go so far in educating the public; it is the decisions that an individual makes (e.g. seeking shelter in a cooler locale, minimizing intensive labor, increasing fluid intake) that determine a significant portion of one's vulnerability. Thus, it is difficult to predict a quantity of lives that were not lost. Moreover, some of the mortality increases during heat waves are deaths that naturally would have occurred in subsequent days or weeks, as is evidenced by below-normal mortality levels following many significant heat events (McMichael *et al.*, 1996). Last, final, “official” mortality totals are not publicly available until 3 to 5 years later, thus making real-time evaluation difficult for all but the most intense heat waves (such as the Chicago Heat Wave), for which mortality totals are sometimes expedited.

Three published studies have directly evaluated the benefits of the heat watch-warning system. Using actual mortality data from 1995 to 1998 for the city of Philadelphia, Teisberg *et al.* (2004) evaluated the effect of calling a heat warning on observed mortality. They ran a multiple linear regression model, including the binary variable of whether a heat warning was called or not. A regression coefficient of -2.6 was associated with this variable, suggesting that on average, with all other meteorological conditions being equal, 2.6 fewer people died on days when warnings were called than when one was not called. With 45 warning days during the 4-year period evaluated, they estimate 117 lives were saved by the implementation of the Philadelphia Heat Watch-Warning System. Another study was recently completed by Roman health officials to evaluate the effectiveness of their heat watch/warning system during the hot summer of 2003 (Michelozzi *et al.*, 2004). Their research indicated that the Rome system effectively forecasted most of the days when there were excess deaths in that city, although the system underestimated the actual number of deaths. The authors stipulate that this underestimation is due to the unprecedented intensity of the 2003 heat wave, with conditions more extreme than that of any period during the years that were used in developing the mortality relationships. A third manuscript, reviewing the Shanghai heat watch/warning system, indicated that there has been success in the operation and implementation of a synoptic based system in that city (Tan *et al.*, 2004).

There is clearly a greater need for system evaluation and verification. The authors, along with the National Weather Service, are discussing a plan for standardized verification and evaluation for the rapidly increasing number of systems that are now coming online.

6. CONCLUSIONS AND FUTURE PROSPECTS

Though some research has shown a general decline in heat susceptibility over recent decades (Davis *et al.*, 2002), other research has shown that among some of the most significant heat waves, events in recent decades have been associated with higher rates of mortality than those earlier in the century (Kunkel *et al.*, 1998). In either case, with a growing elderly population and increased social isolation, there remain significant numbers of people that will be susceptible to the heat, and in a potentially warmer world, heat susceptibility could increase further (Kalkstein and Greene, 1997).

For years, the US National Weather Service has operated under the following guidelines:

> *"A daytime HI (heat index) reaching 105°F (41°C) or above with nighttime lows at or above 80°F (27°C) for two consecutive days may significantly impact public safety and, therefore, generally requires the issuance of an advisory. Warnings may be issued under extreme conditions. The regions may adjust these values in Regional Operations Manual Letters to account for local effects."* (NWS, 1992)

An "Excessive Heat Warning" is often associated with a heat index of 115°F (46°C) or higher. In recent years, to account for local climatological conditions, a number of local offices have modified these thresholds downward, especially across much of the northern tier of the US, where such conditions are rare, and heat-related mortality occurs in significant numbers well before such thresholds are exceeded. Though these modifications have increased heat awareness, they have generally been haphazard, with different rules set up by each office, with little spatial cohesion. Moreover, few of these modifications are based upon an actual human response.

In line with minimizing heat-related health problems, and providing a spatially consistent heat-classification scheme, heat watch/warning systems are currently being developed for an increasing number of US cities. We are working with the National Weather Service toward the goal of having a system in place for each metropolitan area of over 500,000 people by 2007; there are 81 such areas across the coterminous US. When fully funded, these systems will ultimately be networked and run within the NWS mainframe, so that forecasts of excessive heat will be spatially cohesive from one weather service forecast office to another, reducing the subjectivity of individual forecast office thresholds currently in place. This "nationalization" of system development and operation is designed to retain the strengths already inherent in these systems: unique thresholds based on local urban response, advisories and warnings called on the basis of human health outcomes, and systems that are synoptically-based. We will also work with local health and other civic authorities in each metropolitan area to provide information on the new system, and assist in the development of heat mitigation plans for those for which plans do not currently exist. The National Weather Service properly realizes that,

> *"... A national heat health watch warning system will provide a more accurate and standardized guidance system to warn the public of excessive heat events"* (Tew *et al.*, 2004).

ACKNOWLEDGMENTS

There are many individuals and agencies that have contributed time and funding toward the development and operation of these heat watch/warning systems. These include the NOAA/National Weather Service, the U.S. Environmental Protection Agency, the World Meteorological Organization, the World Health Organization, the United Nations Environment Program, the Lazio (Rome) Health Department, the Toronto Atmospheric Fund, the public utilities Entergy and Salt River Project, and cooperation from numerous city agencies that provided suggestions in the development of these systems. The authors would like to especially thank Robert Livezey, Mark Tew, Douglas Young, and Michael Brewer, all of the NOAA/National Weather Service, for their dedication toward improving the National Weather Service's response to excessive heat. In addition, thanks go to Mr. Jerry Libby and Dr. Lawrence Robinson, Philadelphia Department of Public Health, who boldly encouraged initial system development for Philadelphia, and provided hours of advice and guidance.

7. REFERENCES

CENTER FOR DISEASE CONTROL (CDC), 2002: Heat-Related Deaths - Four States, July-August 2001, and United States, 1979-1999. *Morbid. Mortal. Week. Rep.*, 51, 567-570.

CHANGNON, S.A., K.E. KUNKEL, AND B.C. REINKE, 1996: Impact and Responses to the 1995 Heat Wave: A Call to Action. *Bull. Amer. Meteorol. Soc.*, 77, 1496-1506.

DAVIS, R.E., P.C. KNAPPENBERGER, W.M. NOVICOFF, and P.J. MICHAELS, 2002: Decadal changes in heat-related human mortality in the eastern United States. *Clim. Res.*, 22, 175-184.

ELLIS, F.P. AND F. NELSON, 1978: Mortality in the elderly in a heat wave in New York City, August, 1975. *Environ. Res.*, 15, 504-512.

GOVER, M.,1938: Mortality during periods of excessive temperature. *Pub. Heal. Rep.*, 53, 1112-1143.

KALKSTEIN, L.S., 1991: A New Approach to Evaluate the Impact of Climate on Human Mortality. *Environ. Heal. Persp.*, 96, 145-150.

KALKSTEIN L.S., 2003: Description of our heat/health watch-warning systems: their nature and extent, and required resources. Final report to Stratus Consulting Company, Boulder, Colorado, 31pp.

KALKSTEIN, L.S. and P. CORRIGAN, 1986: A synoptic climatological approach for geographical analysis: assessment of sulfur dioxide concentrations. *Ann. Assoc. Amer. Geog.*, 76, 381-395.

KALKSTEIN, L.S. and K.M. VALIMONT, 1987: Climate Effects on Human Health. In *Potential effects of future climate changes on forest and vegetation, agriculture, water resources, and human health*, EPA Science and Advisory Committee Monograph no. 25389, 122-52. Washington, D.C.: U.S. Environmental Protection Agency.

KALKSTEIN, L.S. and R.E. DAVIS, 1989: Weather and Human Mortality: An Evaluation of Demographic and Interregional Responses in the United States. *Ann. Assoc. Amer. Geog.*, 79, 44-64.

KALKSTEIN, L.S., P.F. JAMASON, J.S. GREENE, J. LIBBY, and L. ROBINSON, 1996: The Philadelphia Hot Weather-Health Watch/Warning System: Development and Application, Summer 1995. *Bull. Amer. Meteorol. Soc.*, 77, 1519-1528.

KALKSTEIN, L.S. and J.S. GREENE, 1997: An Evaluation of climate/mortality relationship in large U.S. cities and the possible impacts of a climate change. *Environ. Heal. Persp.*, 105, 84-93.

KUNKEL, K.E., R.A. PIELKE Jr., and S.A. CHANGNON, 1999: Temporal Fluctuation in Weather and Climate Extremes That Cause Economic and Human Health Impacts: A Review. *Bull. Amer. Meteorol. Soc.*, 80, 1077-1098.

McGEEHIN, M.A. and M. MIRABELLI, 2001: The Potential Impacts of Climate Variability and Change on Temperature-Related morbidity and Mortality in the United States." *Environ. Heal. Persp.*, 109, 185-189.

MCMICHAEL, A.J., L.S. KALKSTEIN and other lead authors, 1996. *Climate Change and Human Health,* (eds. A.J. McMICHAEL, A. HAINES, R. SLOOFF, S. KOVATS). World Health Organization, World Meteorological Organization, and United Nations Environment Programme (WHO/WMO/UNEP), Geneva, 297 pp.

MICHELOZZI, P., F. De'DONATO, G. ACCETTA, F. FORASTIERE, M. D'OVIDIO, C. PERUCCI, and L.S. KALKSTEIN, 2004: Impact of Heat Waves on Mortality - Rome, June 1-August 15, 2003. Mortal. Morbid. Week. Rev., in press.

NATIONAL CLIMATE DATA CENTER, 2002: Billion-dollar weather disasters, 1980-2002. Website: http://www.ncdc.noaa.gov/ol/reports/billionz.html. Accessed 12 September 2002.

National Weather Service (NWS), 1992: Non-Precipitation Weather Hazards (C-44). *Weather Service Operations Manual*, Issuance 92-5, 5.

NEW YORK TIMES, 2003: World Briefing: Europe: France: Heat Toll. September 26, 2003, Page A10.

SEMENZA, J.C., J.E. MCCULLOUGH, W.D. FLANDERS, M.A. MCGEEHIN, and J.R. LUMPKIN, 1999: Excess Hospital Admissions during the July 1995 Heat Wave in Chicago. *Amer. J. Prevent. Med.*, 16, 269-277.

SHERIDAN, S.C., 2002: The Redevelopment of a Weather-Type Classification Scheme for North America. *Int. J. Climatol.*, 22, 51-68.

SHERIDAN, S.C. and L.S. KALKSTEIN, 1998: Heat Watch-Warning Systems in Urban Areas. *World Resour. Rev.*, 10, 375-383.

STEADMAN, R.G., 1979: The Assessment of Sultriness. Part I: A Temperature-Humidity Index Based on Human Physiology and Clothing Science. *J. Appl. Meteorol.*, 18, 861-873.

TAN, J., L.S. KALKSTEIN, J. HUANG, S. LIN, H. YIN, and D. SHAO, 2004: An Operational Heat/Health Warning System in Shanghai. *Int. J. Biometeorol.*, 48, 157-162.

TEISBERG, T.J., K.L. EBI, L.S. KALKSTEIN, L. ROBINSON, and R.F. WEIHER, 2004: Heat Watch/Warning Systems Save Lives: Estimated Costs and Benefits for Philadelphia 1995-1998. *Bull. Amer. Meteorol. Soc.*, in press.

TEW, M.A., M.J. BREWER, and R.E. LIVEZEY, 2004: A National Heat/Health Warning System: Improvement over current system. *Proceedings, 14th Conference on Applied Climatology, Seattle, Washington*, American Meteorological Society.

WHITMAN S., G. GOOD, E.R. DONOGHUE, N. BENBOW, W. SHOU, and S. MOU, 1997: Mortality in Chicago attributed to the July 1995 heat wave. *Amer. J. Pub. Heal.*, 87, 1515-1518.
YOUNG, D.C., 2004: Forecast considerations: application of the point forecast matrices in heat/health warning systems. *Proceedings*, *14th Conference on Applied Climatology, Seattle, Washington*, American Meteorological Society.