# PROGRESS IN HEAT WATCH–WARNING SYSTEM TECHNOLOGY

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Over the past several years, a number of synoptic climatology-based heat watch–warning systems have been implemented across the United States and internationally, each based on local health response to past weather conditions.

Heat is the deadliest of all atmospheric phenomena. From 1979 to 1999, the deaths of 8015 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 United States 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, Pennsylvania 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

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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 United States, including Phoenix, Arizona; Washington, D.C.; Chicago, Illinois; St. Louis, Missouri; and Cincinnati and Dayton, Ohio, and a network of cities across Tennessee, Louisiana, Arkansas, and Mississippi. Systems have also been developed for cities outside the United States, including four Italian cities; Toronto, Ontario, Canada; and Shanghai, China. In total, over two dozen cities worldwide currently have synoptic-based heat watch–warning systems in operation.

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

| Year | City |
|---|---|
| 1995 | Philadelphia, USA |
| 1996 | Washington, USA |
| 2000 | Rome, Italy |
| 2001 | Shanghai, People's Republic of 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 St. Louis, USA |
| 2003 | Turin, Milan, and Bologna, Italy |
| 2004 | Dallas–Fort Worth, Seattle, Yuma (AZ), USA |
| 2004 | Palermo, Italy |

Funding for these systems comes from numerous agencies. These include several within the federal government, most notably the National Oceanic and Atmospheric Administration (NOAA)/National Weather Service (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 the 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.

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.

## 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 1000 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 United States 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 United States with public and private hospitals, the acquisition of such data can be difficult.

Daily mortality data within the United States are available with information as to the 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 underestimate heat's true toll.

Mortality data are summed into daily totals on a county-by-county basis in the United States. In all U.S. cities, the standardized metropolitan statistical area (SMSA) for each primary city is utilized. In all systems developed for locations outside of the United States 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 United States, 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 3-yr 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 (Fig. 1).

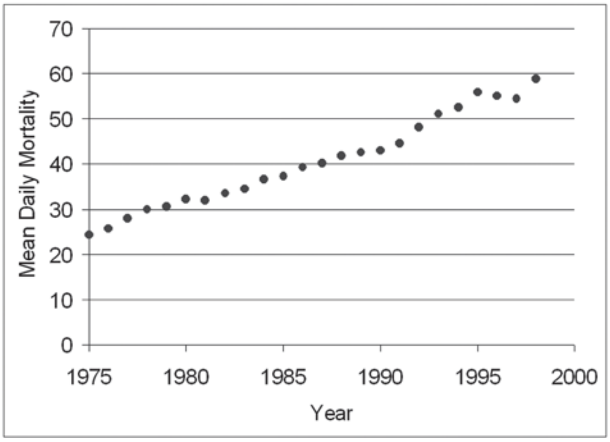


**Fig. 1. Mean daily summer (15 May–30 Sep) mortality, Phoenix, AZ, metropolitan area by year.**

Mortality shows clear seasonal trends, with mean values typically about 10% higher in winter than summer. Yet in most cases, within the "summer" period analyzed, there is no trend; that is, there is no statistically significantly greater mean number of deaths in May than August. In the case of Rome, Italy, however, a strong seasonal trend is observed, with much lower rates of mortality, near 15%, beginning around 10 August and continuing through early September (Fig. 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 inclusion of an intraseasonal mean daily mortality, based on an 11-day running mean.

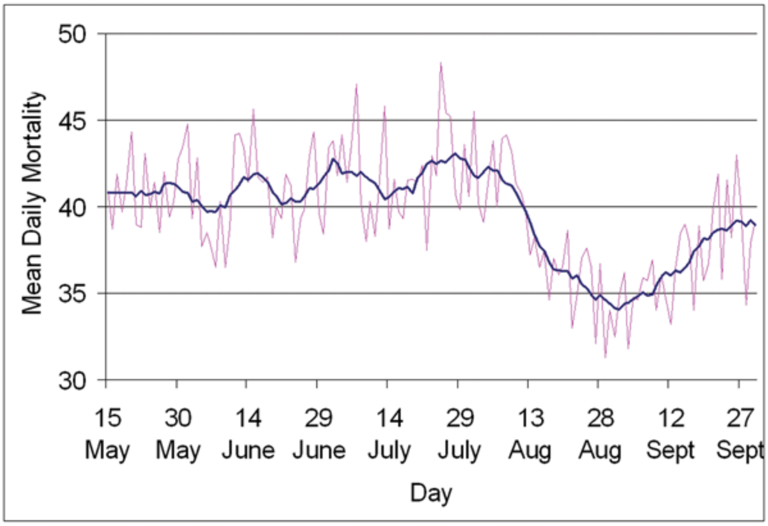


**Fig. 2. Mean daily mortality (1987–97) by day of season, Rome. An 11-day running mean is superimposed.**

*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 dewpoint, 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 the 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, dewpoint, 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; and
- 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

**TABLE 2. Mean conditions associated with the two oppressive weather types, (top) Dry tropical (* signifies Dry tropical +) and (bottom) Moist tropical + (** signifies Moist tropical ++), across three periods of summer, for selected cities. Ta = temperature (°C) in early morning (0200 LST–0500 LST), Td = temperature in midafternoon (1400 LST–1700 LST), Tdp = dewpoint in midafternoon, and CC = cloud cover (tenths) in midafternoon.**

| | 15–31 May | | | | 15–30 Jun | | | | 15–31 Jul | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| City | Ta | Tp | Tdp | CC | Ta | Tp | Tdp | CC | Ta | Tp | Tdp | CC |
| **Dry Tropical** | | | | | | | | | | | | |
| 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 +** | | | | | | | | | | | | |
| 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 |

July is warmer and more humid in New Orleans, Louisiana 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 3. Oppressive weather types by location. Weather type frequency is mean for period 15 May–30 Sep; excess mortality is expressed as both mean total of deaths per day greater than normal, and the percentage increase this represents. A dash signifies this weather type is not associated with above-normal mortality at this location; * signifies Dry tropical + and ** signifies Moist tropical ++.**

| | Dry tropical | | | Moist tropical + | | |
|---|---|---|---|---|---|---|
| | Frequency | Mortality | | Frequency | Mortality | |
| City | (%) | Deaths | (%) | (%) | Deaths | (%) |
| 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 |

*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 United States and Canada, a larger percentage increase in mortality has been generally observed outside North America, with a mean increase of nearly 20% in mortality in Shanghai on oppressive MT+ days, and increases above 10% in Rome and other Italian cities. The lesser availability of air conditioning in these cities may be at least partially responsible.

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.

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; Fig. 3) show

**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.**

| | Anomalous mortality | | |
|---|---|---|---|
| Weather type | Mean | Std dev | 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 |

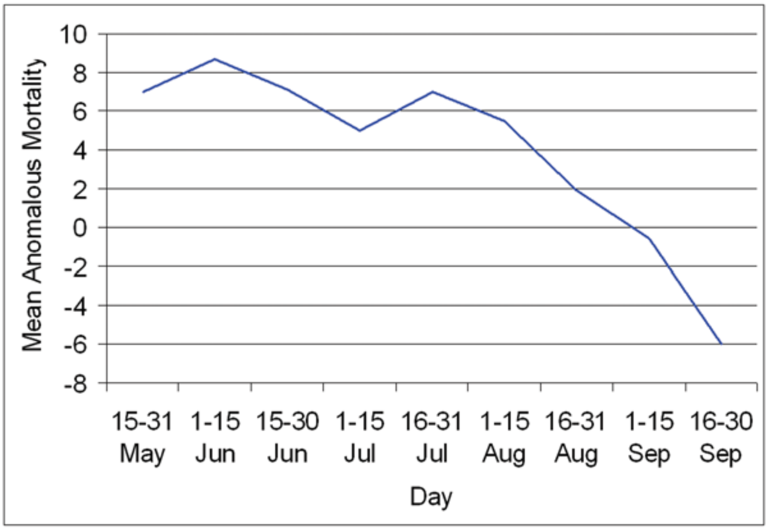


**Fig. 3. Mean anomalous daily mortality (1987–97) during MT+ weather type, by period of season, Rome.**

clear trends in decreasing mortality response to oppressive conditions throughout the summer.

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 for 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 for two or more 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. The number of times this has occurred is denoted by *n*.**

| | Dry tropical | | Moist tropical + | |
|---|---|---|---|---|
| **Day** | **Mean** | ***n*** | **Mean** | ***n*** |
| 1 | 2.0 | 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 | 5.7 | 3 |

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 Web sites. 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 (Fig. 4). The first step involves the evaluation of whether forecast weather conditions place the future day into an "offensive" weather type, that is, 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 ($r^2$) results. In many cases, these algorithms are associated with $r^2$ values of 0.20–0.50, much greater than regression equations that utilize all summer days, in which $r^2$ values rarely exceed 0.10. The difficulty of verifying these algorithms, however, is discussed in later in the paper.

*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% or greater, and an "alert" associated with a likelihood between 65% and 90%. 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 h, and an "attenzione (attention)" when the same threshold of forecast excess mortality is met between 24 and 48 h in the future.

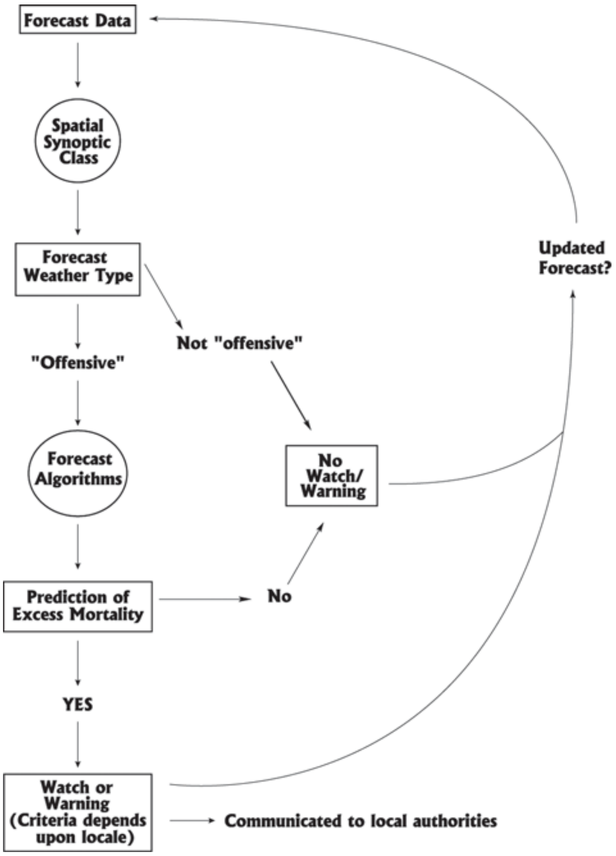


**FIG. 4. Flow chart for the determination of whether or not to call a heat watch–warning.**

**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 in 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, at midafternoon (near 1500 LST) and overnight (near 0300 LST). Required forecast data include values for temperature, dewpoint, wind speed and direction, and cloud cover, and are needed at 6-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 U.S. 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 toward 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 (Fig. 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 pass-

**TABLE 6. Mortality regression equations, Toronto and Rome.**

**Toronto**

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

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

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

**Rome**

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

MT+ $$M = -4.84 - 0.13\mathrm{TOS} + 0.82\mathrm{CH} \qquad (r^2 = 0.26)$$

DT $$M = -45.92 - 0.08\mathrm{TOS} + 2.05\mathrm{SEQ} + 1.61\mathrm{AT}_0 + 0.75\mathrm{AT}_1 \qquad (r^2 = 0.46)$$

**Terms:**

| | |
|---|---|
| **$\mathrm{AT}_0$** | Minimum apparent temperature (°C) |
| **$\mathrm{AT}_1$** | 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 |
| **$\mathrm{T}_{17}$** | The 1700 LDT temperature (°C) |
| **TOS** | Time of season, where 1 May = 1, 2 May = 2, etc. |

word protected so that only the local weather forecast office and authorized agencies (such as health departments) may access the output.

Frequently, forecasts need to be updated between the 12-h schedule for automated forecast updates, and several mechanisms are in place to provide assistance. 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 min 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.

**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.

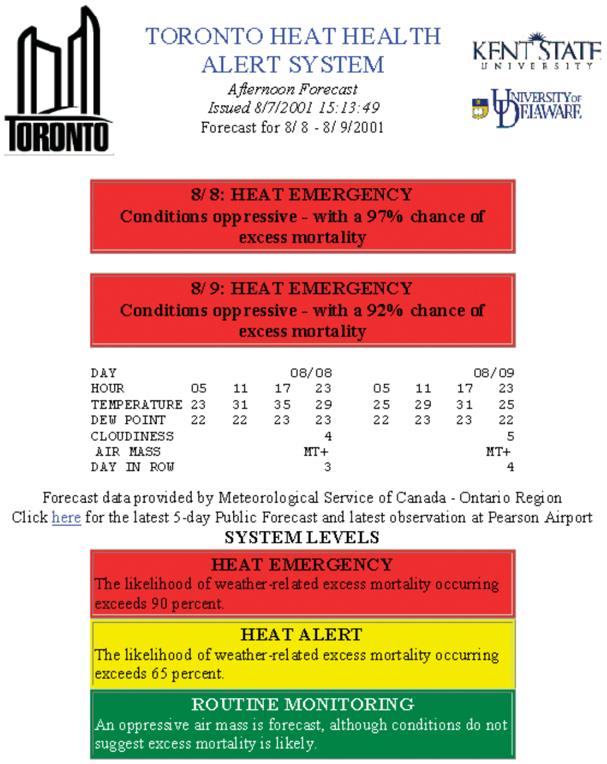
The following represents a summary of all activities pursued by the city of Philadelphia whenever a heat warning is called by the National Weather Service (Kalkstein 2003):

- *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 50 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.

**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 3–5-yr 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.



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.

**FIG. 5. The Web page for the Toronto Heat–Health Alert system.**

Three published studies have directly evaluated the benefits of the heat watch–warning system. Using actual mortality data from 1995–98 for the city of Philadelphia, Ebi 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. Within 45 warning days during the 4-yr 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 under-estimated 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.

## 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 United States, which 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 U.S. 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 United States. 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).

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