

An Evaluation of Climate/Mortality Relationships in Large U.S. Cities and the Possible Impacts of a Climate Change

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A new air mass-based synoptic procedure is used to evaluate climate/mortality relationships as they presently exist and to estimate how a predicted global warming might alter these values. Forty-four large U.S. cities with metropolitan areas exceeding 1 million in population are analyzed. Sharp increases in mortality are noted in summer for most cities in the East and Midwest when two particular air masses are present. A very warm air mass of maritime origin is most important in the eastern United States, which when present can increase daily mortality by as many as 30 deaths in large cities. A hot, dry air mass is important in many cities, and, although rare in the East, can increase daily mortality by up to 50 deaths. Cities in the South and Southwest show lesser weather/mortality relationships in summer. During winter, air mass-induced increases in mortality are considerably less than in summer. Although daily winter mortality is usually higher than summer, the causes of death that are responsible for most winter mortality do not vary much with temperature. Using models that estimate climate change for the years 2020 and 2050, it is estimated that summer mortality will increase dramatically and winter mortality will decrease slightly, even if people acclimatize to the increased warmth. Thus, a sizable net increase in weather-related mortality is estimated if the climate warms as the models predict. *Key words:* acclimatization, air mass, climate and human mortality, climate change, human health, synoptic climatology. *Environ Health Perspect* 105:84–93 (1997)

The impact of climate on human health continues to draw increased attention as it becomes apparent that human sensitivity to weather is considerable and varies through time and space. The health implications of a possible human-induced climate change has only served to heighten awareness, and two recently published volumes developed by international experts have compiled research to date on retrospective climate/health associations and potential future outcomes (1,2).

One of the most intensely studied aspects of climate/health relationships concerns the impact of heat and cold on human mortality. Such studies have taken on increased sophistication, especially in the use of climate modeling, to develop empirical relationships among heat stress, extreme cold, and variations in mortality. In addition, many studies are beginning to consider a number of confounding factors that may alter climate/mortality relationships and may have major implications if the climate warms. For example, what is the role of air conditioning in affecting heat-related human mortality? Do people acclimatize to the heat in warmer locales? Can acclimatization occur within a single summer season? Would many people who die during heat waves have died shortly afterward, regardless of the weather (mortality displacement)? Will decreases in cold-related mortality compensate for increases in heat-related mortality if the earth warms, as many climatologists predict? These are just a sample of the questions that have led to disagreement

among scientists who study the impact of climate on mortality.

The goal of this study is to introduce a new, more sophisticated climatological procedure to evaluate the impact of climate on human mortality in 44 cities in the United States. These cities represent all the standard metropolitan statistical areas (SMSAs) in the country with populations of 1 million or greater. In addition, we will discuss the possible implications of a climate warming on mortality totals within these cities, using the most recent climate change scenarios provided by the Intergovernmental Panel on Climate Change (IPCC) for use in its recent impacts assessment (1). Although some of the confounding issues described above will be addressed, it is not the aim of this paper to produce estimates that take all of these factors into account. Thus, estimates of climate-related mortality provided here should serve as a springboard for scientists to determine the quantitative impact of various factors described above. However, we are confident that the use of a new climatological procedure which evaluates weather in a more realistic fashion, and the incorporation of updated climate change scenarios designed specifically for impacts analysis, will lead to more accurate estimates of summer and winter weather-related mortality.

Previous Research

Most mortality studies to date have focused on the impact of extremely high and low temperatures on death. Although the most

direct impact of heat on the human body is the onset of heat exhaustion or heat stroke, the increase in mortality associated with hot weather cuts across many causes of death. For example, deaths from cardiovascular and respiratory disorders and from some types of accidents typically increase during stressful weather conditions (3,4). Heat stroke and heat exhaustion represent only a small proportion of the mortality increase. During hot weather, the total death rate from all causes, and especially from cardiovascular diseases, may be more than double the long-term mean death rate. Because of this diversity in cause of death, in many studies the number of heat-related deaths is determined empirically as the number of deaths occurring in excess of the background expected number (2). Thus, total deaths above a baseline, rather than disaggregated causes of death, are often evaluated in weather/mortality studies (5,6).

The most recent analyses of heat-related deaths in cities in the United States, Canada, the Netherlands, China, Greece, Germany, and the Middle East provide supporting evidence that overall death rates rise during heatwaves (6–10). Virtually all of these studies have documented a threshold temperature beyond which mortality rises rapidly. However, some studies, especially in Western Europe, suggest that mortality rises linearly with increasing temperature, and even moderate heat can lead to excess deaths (2,6). We have consistently noted a threshold effect in U.S. cities, and our research does not support the linear increases found in several European studies. Some evaluations have noted the importance of several consecutive days above the threshold temperature, and it appears that the impact of heat becomes most important 1–3 days after the onset of the heat wave.

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Previous studies suggest that a human-induced climate change would increase summer mortality, even if the population adapted somewhat to such a change (2,11). The increased frequency and intensity of heatwaves would probably lead to dramatic increases in summer deaths, and because urban structures would not be greatly modified to account for climate alterations, populations would be unable to adapt completely to increasing temperatures. In addition, the recent IPCC Working Group II report suggests that decreases in winter mortality related to a global warming would probably not compensate for predicted summer increases, although there is some uncertainty about this (1).

In temperate regions, there is a clear-cut seasonal variation in mortality, and the death rate in winter is 10–25% higher than during the rest of the year (12). However, the extent of winter-associated mortality that is directly attributed to low temperatures (and not to seasonal patterns of respiratory infections) has been difficult to determine. Many studies have suggested that, in many locations, daily deaths increase as daily winter temperatures decrease (13). However, the existence of a temperature threshold is less evident in winter than in summer (6,10,14). In some cold weather locales, such as Montreal and Minneapolis, the increase in mortality with decreasing winter temperature is slight (15,16). In less extreme climates, such as The Netherlands and Brisbane, Australia, mortality rates rise linearly with decreasing wintertime temperature (6,16,17).

In winter in temperate countries, along with a heightened rate of cardiovascular disease, there are increased deaths from influenza, pneumonia, and accidents (18,19). Since these respiratory infections depend upon aerosol transmission, usually in confined, poorly ventilated places, a small rise in winter temperatures may reduce this risk if it encourages outdoor activities and improved ventilation. Conversely, annual influenza outbreaks do not appear to correlate with mean winter monthly temperatures (18,20), and the relationship between winter temperatures and deaths from respiratory infection remains uncertain. Thus, the impact of a global warming on winter mortality is more difficult to ascertain than impacts on summer mortality.

The recent use of a synoptic climatological methodology to evaluate weather/mortality relationships has supported and expanded the findings from the temperature-oriented research described above (21,22). The synoptic procedure assumes that the population responds to the entire

umbrella of air (or air mass) that surrounds them rather than to individual weather elements such as temperature. Thus, the synoptic procedure permits an evaluation of synergistic relations among weather elements; the combined impact of several elements is more significant than the sum of their individual impacts. The synoptic approach involves the development of an automated index that describes the air mass over an area every day (e.g., continental polar air mass, maritime tropical air mass). Days considered homogeneous meteorologically are grouped into air mass categories, and their impact on mortality can then be assessed more logically. The initial use of the synoptic approach (the Temporal Synoptic Index, or TSI) revealed that, for many U.S. cities, a single high risk summer air mass is associated with unusually high mortality (9,22). In addition, the synoptic analysis confirmed earlier work which indicated that a climate change, as expressed by general circulation model (GCM) scenarios, would greatly increase summer mortality, even if partial acclimatization occurred (22).

The synoptic procedures, such as TSI, used in earlier work are place-specific only; air masses are developed for a locale without regard to other places. Thus, it has been troublesome to compare results from one region to the next using the TSI procedure developed by Kalkstein (21), as it is very difficult to identify the same air masses in different locales using this place-specific procedure. In the study described here, a more sophisticated synoptic approach which identifies the same air mass types for a continental-sized area, has been employed. Thus, this new procedure will permit an interregional comparison of high risk air masses, something that has never been attempted before. It is possible that a certain air mass type is high risk in the eastern United States, while it is rather benign in the West. One of the recent breakthroughs in synoptic climatology has been the development of an automated means to identify the same air masses across a large region (23); this methodology will be applied here for the first time.

Procedure

The spatial synoptic classification. Unlike most existing air mass-based techniques such as TSI, the spatial synoptic classification (SSC) requires initial identification of the major air masses that traverse the nation, as well as their typical meteorological characteristics. Thus, the SSC, used here to identify air masses associated with unusually high mortality, was developed specifically to classify all days at numerous

locales into one of seven predetermined, readily identifiable air mass categories (23). These air mass categories are dry polar (DP), dry temperate (DM), dry tropical (DT), moist polar (MP), moist temperate (MM), moist tropical (MT), and transition (T; transitions represent days in which the air mass changes from one type to another). Dry polar air is synonymous with continental polar; it is the coldest, and sometimes the driest, air mass in a region. Cloud cover is often minimal. Dry temperate air is typically an adiabatically warmed Pacific air mass that has descended the lee side of the Rocky Mountains. The air mass is associated with mild, dry conditions in the eastern and midwestern sections of the nation and intrudes most frequently when there is a strong west–east flow aloft. Dry tropical defines the hot and very dry air mass that most often originates from the Desert Southwest or northern Mexico. It is most commonly associated with the hottest and driest conditions and is rather frequent in the Midwest. Moist polar air is cool and humid, with overcast conditions and, frequently, easterly winds. In the eastern United States this air mass is synonymous with maritime polar conditions around the northern flank of a low pressure system. Moist temperate is also associated with overcast, humid conditions, but temperatures and dew points are much higher owing to the close proximity of the responsible front. Moist tropical air masses, commonly recognized as maritime tropical, represent warm, humid conditions found frequently in the warm sector of an open wave cyclone or the western flank of a subtropical anticyclone. Atmospheric instability and convective activity are common within this uncomfortable air mass.

Although there are character similarities within the air masses at different locations, it is noteworthy that significant differences also exist. For example, summer moist tropical air masses are warm and humid at all locales, but mean afternoon temperatures vary from over 33°C in central Texas to about 29°C in New England. Mean dew points range from about 23°C in Florida to 17°C in North Dakota. The frequency occurrence of the air masses are highly variable; for example, moist tropical air occurs on over 70% of summer days in Florida to less than 10% in the high plains of the Dakotas and Nebraska (24).

The foundation for the development of the SSC is the proper selection of seed days, which represent the typical meteorological character of each air mass at a location. Each group of seed days for every air mass is chosen by the specification of ranges in afternoon surface temperature,

dew point, dew point depression, wind speed, wind direction, cloud cover, diurnal temperature change, and dew point changes every 6 hr. Initial estimates of these criteria are specified for each air mass at each location after careful evaluation of surface meteorological data and maps, and days that satisfy the criteria are selected to represent seed days for the air mass. These seed days are used to classify all other days, and a number of seed days for each air mass is used to develop a robust sample of the typical character of each air mass at each location (23,24).

Following seed day selection, discriminant function analysis is used to generate a linear function for each air mass from its group of seed days. Because the goal is to classify each day into one of the pre-existing air masses described above and to use the seed day means as input into the classification, discriminant function analysis was selected as the appropriate classification tool (25,26). The day is classified into the category possessing the highest discriminant function score. This results in a calendar listing the air mass to which each day has been assigned.

While a majority of these air mass designations are correct, a significant number of days may be incorrectly classified because of the occurrence of a transition between air masses. Transitions represent changing situations when one air mass is displacing another; a day with a cold front passage represents a good example. To account for this possibility, the SSC performs a second discriminant function analysis to determine whether a transition between air masses occurred during each day [refer to Kalkstein et al. (23) for further details].

At many locations in summer, MT air accounts for over 50% of the total daily occurrences (24); thus, the MT air mass was subdivided using the procedures described above into three subcategories designated MT1, MT2, and MT3. The dominant characteristic of each of these air masses is moist tropical; however, MT1 is very warm and humid, MT2 is slightly cooler, and MT3 is significantly drier.

Unlike previous synoptic/mortality studies, the SSC provides the unique ability to identify the same air masses across a continental-sized area. Thus, SSC is the ideal synoptic tool to evaluate relationships between air mass type and mortality in this 44-city study.

Mortality data. Mortality data were obtained from the National Center for Health Statistics (NCHS) and contain information on cause, place, and date of death; age; and race of every individual who died in the United States from 1964

Table 1. Summer high risk air masses

City	Air mass type	Total		Elderly	
		Ratio ^a	Deaths/day	Ratio ^a	Deaths/day
Anaheim, CA	No high risk air masses	—	—	—	—
Atlanta, GA	DP	1.7	3.6	—	—
	MT1	1.9	2.6	1.8	1.5
Baltimore, MD	MT1	2.7	4.6	—	—
	MT2	1.8	1.4	—	—
	MT3	2.1	2.8	1.9	2.1
Birmingham, AL	MT1	2	1.6	3.4	1.6
Boston, MA	DT	—	—	2.3	5.7*
	MT1	2.3	7.8*	2	6.1*
	MT2	1.8	2.4	—	—
	MT3	1.9	4.0	—	—
Buffalo, NY	MT1	4.8	3.3	2.8	3.2
Chicago, IL	DT	2.7	8.6*	2	5.7*
	MT1	4.1	14.0*	3.1	8.3*
	MT3	2.2	6.8*	2.1	4.8
Cincinnati, OH	MT1	2.7	2.1	2.2	3.4
Cleveland, OH	DT	—	—	7.1	6.7*
	MT3	—	—	2.9	2.1
Columbus, OH	T	—	—	2	0.5
	MT1	2	3.3	—	—
	MT3	1.7	1.0	—	—
Dallas-Ft. Worth, TX	DT	2.6	3.0	2.7	2.0
Denver, CO	No high risk air masses	—	—	—	—
Detroit, MI	DT	2.2	10.1*	2.2	6.2*
	MT1	—	—	5.8	9.4*
	MT2	—	—	1.9	3.5
	MT3	—	—	2.4	4.8
Ft. Lauderdale, FL	No high risk air masses	—	—	—	—
Greensboro, NC	MP	—	—	2	1.5
Hartford, CT	MT1	2.6	2.7	2.5	2.0
	MT3	1.7	1.2	—	—
Houston, TX	DT	8.2	7.6*	—	—
	T	—	—	2.3	1.0
Indianapolis, IN	MT1	3.1	3.1	2.5	2.2
Jacksonville, FL	No high risk air masses	—	—	—	—
Kansas City, MO	DT	2.7	5.1*	2.2	2.3
	MT1	1.9	2.6	1.9	1.7
Los Angeles, CA	MT1	2.1	9.1*	—	—
	DM	2.3	3.2	1.7	2.6
Louisville, KY	MP	—	—	1.8	0.4
	MT1	2.8	2.1	1.9	1.6
Memphis, TN	DP	—	—	2.1	0.3
	DT	13	3.3	7	2.9
	MT1	1.7	1.4	2	1.3
Miami, FL	No high risk air masses	—	—	—	—
Minneapolis, MN	DT	2.1	4.1	2	2.6
	MT1	3.5	6.1*	4	4.6
	MT3	1.8	1.3	2	0.9
Nassau County, NY	DT	5.6	5.9*	—	—
	MT1	2.8	4.9	1.8	3.6
New York, NY	DT	8.4	49.2*	7.1	38.0*
	MT1	6.3	30.2*	6.3	21.9*
	MT3	1.7	8.4*	1.9	6.3*

to 1991 (27). A daily mortality calendar was constructed for total and elderly (>65 years old) deaths for the period of record for summer (June, July, and August) and winter (December, January, and February). Although certain causes of death, such as respiratory and cardiovascular disease, are deemed to be more sensitive to variations in meteorology, a number of studies such as this one do not subdivide mortality data into these specific categories. Recent analyses indicate that a wide range of causes of death are impacted by weather, which suggests that disaggregation of mortality causes will not necessarily lead to improved relationships (2). However, additional research on the impact of weather situations upon specific causes of death is most desirable and will be an outgrowth of this study. All mortality data were standardized to

account for changes in the total population of the SMSA of the individual cities during the period of record. A direct standardization procedure was used, and a mortality trend line was constructed for the period of record based on mean daily mortality for each year of record. Mortality was then expressed as a deviation around the temporal baseline level (21).

The mean daily mortality for each synoptic category, along with the standard deviation (SD), was determined to ascertain whether particular categories exhibited distinctively high or low mortality values. Daily mortality was also sorted from highest to lowest during the period of record to determine whether certain synoptic categories were prevalent during the highest and lowest mortality days for each of the cities. To determine which air masses are high risk, the

ratio of frequency during the highest 50 mortality days to total frequency of each air mass was determined for the 44 cities. If the ratio was determined to be statistically significantly greater than one (at 95% CI), that air mass was determined to be high risk. It may be argued that, using a procedure such as this, a number of air masses might be considered high risk based simply on statistical significance, resulting in some spurious identification of high risk air masses. However, if it appears that the same air masses are deemed high risk within the different cities, or if there is some regional homogeneity in high risk air masses, it is likely that this represents a true physical relationship between air mass type and mortality, rather than a statistical artifact.

Mortality associated with a particular weather episode may not occur immediately, and there may be a significant lag time between oppressive weather and deaths. Thus, analyses included synoptic category/mortality relationships for 0, 1, 2, and 3 day lags; the lag that resulted in the highest mortality for the high risk category was retained.

One interesting feature about high risk air masses is their large standard deviation in daily mortality. Thus, although these air masses contain virtually all the high mortality days for a given locale, they also include days when mortality may be at or below mean levels (21). Thus, a within-category stepwise multiple regression analysis was performed on all days within the high risk synoptic category with daily mortality as the dependent variable. The independent variables included several meteorological elements that vary considerably within synoptic category: maximum temperature, minimum temperature, mean daily cloud cover, maximum dew point temperature, minimum dew point temperature, morning and afternoon windspeed, and morning and afternoon visibility. In addition, two non-meteorological independent variables were included. The first, day in sequence, notes how a particular high risk category day is positioned within a consecutive day sequence. For example, if the day in question is the third consecutive day of a high risk synoptic category, it is assigned a value of 3 (all single day occurrences of high risk category days are assigned a value of 1). The second non-meteorological independent variable, time of season, evaluates the intraseasonal timing of the high risk category day, as previous studies have shown that oppressive weather in August might exert less influence on mortality than similar weather in June (9). For example, a high risk category day on June 1 (first day of summer) is assigned a value of 1, June 2 is

Table 1 Continued. Summer high risk air masses

City	Air mass type	Total		Elderly	
		Ratio ^a	Deaths/day	Ratio ^a	Deaths/day
New Orleans, LA	MT1	1.9	1.5	1.8	1.5
Newark, NJ	DT	4.4	5.7*	2.8	4.0
	MT1	1.8	4.2	—	—
Philadelphia, PA	DT	21.1	32.0*	9.4	23.2*
	MT1	3.5	10.1*	3.1	6.6*
	MT3	2	3.3	1.8	2.7
Phoenix, AZ	MT1	1.8	0.9	—	—
Pittsburgh, PA	MT1	—	3.9	—	3.4
	DT	—	14.8*	—	2.3
	MT3	—	—	—	2.3
Portland, OR	DT	5.1	5.0*	5.9	3.7
Providence, RI	MT1	6.7	6.8*	7.8	5.4
	MT2	3.5	0.2	—	—
	MT3	1.8	2.6	1.8	2.2
Riverside, CA	DT	3.0	1.7	—	—
Salt Lake City, UT	T	—	—	1.8	0.5
	MM	—	—	1.9	0.3
San Antonio, TX	DT	2.5	1.1	—	—
	MM	—	—	—	—
San Diego, CA	No high risk air masses	—	—	—	—
San Francisco, CA	DT	8.8	9.3*	—	—
	T	2.1	2.0	—	—
San Jose, CA	No high risk air masses	—	—	—	—
Seattle, WA	No high risk air masses	—	—	—	—
St. Louis, MO	DT	5.2	15.0*	5.3	11.3
	MT1	2.2	2.3	2.5	2.0
Tampa, FL	MM	2.3	1.1	—	—
	T	1.8	1.3	2.2	1.1
	MT1	2.1	2.9	—	—
Washington, DC	MT1	—	—	1.8	2.3

Abbreviations: DP, dry polar; MT, moist tropical; DT, dry tropical; T, transition; MP, moist polar; DM, dry temperate; MM, moist temperate. See text for subcategories of MT.

^aPercentage of top 50 mortality days within the air mass/percent frequency of air mass occurrence. Expected value equals 1.0; a value of 2.0 indicates that air mass occurs twice as frequently within the top 50 mortality days than would be expected based on seasonal frequency of air mass.

*High risk air masses with mean excess mortality >5.0.

assigned a value of 2, and so on. The algorithms developed from the within-high risk category regressions are used to provide estimates of the number of deaths attributed to heat for each category day.

Once relationships between retrospective synoptic events and mortality have been established, it is possible to apply this information to estimate the impact of climate change on human mortality. This was achieved by using scenarios from general circulation models (GCMs) to estimate the frequency of air masses under various climate change situations. GCMs are dynamic mathematical models that simulate the physical processes of the atmosphere and oceans in an attempt to predict future global and regional climate (2,28). They incorporate representations of land surface processes, sea-ice related processes, and many more complex processes of the climate system. GCMs take the form of mathematical equations, which are then solved with computers using a three-dimensional global grid. Typical resolutions are about 250 km in the horizontal and 1 km in the vertical. Many physical processes, such as those related to clouds and precipitation, take place on much smaller spatial scales and therefore are modeled with less precision.

Although the weather elements necessary to run the SSC can be extracted from GCM output, it should be noted that the veracity of GCMs is a matter of much debate and controversy (2). Thus, the estimates of mortality using the climate change scenarios should be viewed with caution, although we believe that they provide information regarding possible outcomes if the climate changes as suggested by GCMs.

Three GCM scenarios recommended for use by the IPCC were incorporated into this study: the Geophysical Fluid Dynamics Laboratory (GFDL) model, the United Kingdom Meteorological Office (UKMO) model, and the Max Planck Institute for Meteorology Model (29). Each model provided two sets of transient runs: one for the decades centered around 2020 and the other centered around 2050. Using the new sets of weather data provided by the GCMs, estimates of air mass frequencies were developed for each model. High risk air masses were isolated, and estimates of mortality under the scenarios were developed using the algorithms described above.

When measuring the impact of a climate change on future mortality, the question of acclimatization must be considered. Will people within each city respond to heat as they do today? Or will their reactions be similar to those people who presently live in hotter climates? To

Table 2. Winter high risk air masses

City	Air mass type	Total Deaths/day	Elderly Deaths/day	City	Air mass type	Total Deaths/day	Elderly Deaths/day
Anaheim, CA	DP	1.1	—	Memphis, TN	DP	1.7	—
	DT	—	2.0		DM	—	0.2
Atlanta, GA	DP	1.3	1.5		DT	—	2.0
Baltimore, MD	No high risk air masses	—	—	Miami, FL	DP	7.5*	1.5
Birmingham, AL	DT	0.6	0.4		DM	3.1	2.5
	DP	1.4	—		MP	3.7	3.3
Boston, MA	No high risk air masses	—	—		T	—	0.5
Buffalo, NY	DP	—	0.5	Minneapolis, MN	No high risk air masses	—	—
Chicago, IL	DM	0.4	—	Nassau County, NY	DP	—	1.2
Cleveland, OH	MT	0.8	—	New York, NY	MP	4.6	3.6
Cincinnati, OH	No high risk air masses	—	—	New Orleans, LA	DP	2.9	2.0
Columbus, OH	T	0.2	—		MP	1.9	1.4
Dallas-Ft. Worth, TX	DP	—	1.7		T	0.5	0.8
	MP	—	1.0	Newark, NJ	DP	2.1	1.7
Denver, CO	MP	0.4	—	Philadelphia, PA	DP	—	3.5
	T	0.1	—	Phoenix, AZ	DT	0.9	0.7
Detroit, MI	DP	1.1	1.6	Pittsburgh, PA	DP	—	2.5
	DM	0.8	—		T	1.5	1.2
Ft. Lauderdale, FL	DM	2.7	2.6	Portland, OR	DP	1.3	0.9
	DP	2.1	3.5		T	—	0.8
Greensboro, NC	No high risk air masses	—	—	Providence, RI	DP	1.0	—
Hartford, CT	No high risk air masses	—	—		MT	1.3	2.0
Houston, TX	DT	2.2	—	Riverside, CA	DP	—	0.6
	MP	—	1.7		MP	—	0.6
	DP	—	1.1		MT	6.2*	1.7
Indianapolis, IN	MT	1.5	—	Salt Lake City, UT	T	0.4	0.6
	DP	0.8	0.8	San Antonio, TX	DP	1.7	1.4
Jacksonville, FL	No high risk air masses	—	—	San Diego, CA	DT	—	1.5
Kansas City, MO	DT	5.2*	0.1	San Francisco, CA	DP	2.8	2.8
	MT	2.0	1.5		DT	7.5*	6.1*
Los Angeles, CA	DT	12.2*	5.1		MP	—	2.2
	DP	8.4*	8.5	San Jose, CA	DT	3.1	3.4
	MP	—	1.5	Seattle, WA	DM	0.5	—
Louisville, KY	DP	0.4	0.7		DP	3.1	1.9
	T	—	0.4	St. Louis, MO	DP	3.0	2.9
					T	1.6	—
				Tampa, FL	DP	5.5*	3.7
				Washington, DC	DM	0.5	0.8
					MT	—	1.3

Abbreviations: DP, dry polar; MT, moist tropical; DT, dry tropical; T, transition; MP, moist polar; DM, dry temperate; MM, moist temperate. See text for subcategories of MT.

*High risk air masses with mean excess mortality >5.0.

account for the acclimatization possibility, analog cities were established for each evaluated city. These analogs represent cities whose present climate approximates the estimated climate of a target city as expressed by the GCMs. For example, the use of the GFDL 2050 scenario to estimate the future climate in New York City yields results similar to the present climate of St. Louis. Because St. Louis residents are fully acclimatized to this regime, the weather/

mortality algorithm developed for St. Louis is used for New York City to account for full acclimatization.

It is unlikely that the population will fully acclimatize to increasing warmth associated with a global warming because urban structures, especially for the vulnerable poor, will likely not be modified to account for temperature increases (2). However, it is difficult to assess to what degree acclimatization will actually occur,

and the range of acclimatization is likely to vary on a regional basis. Thus, unlike our previous evaluations, this study will present mortality figures that represent full acclimatization only as these constitute rather conservative estimates. In addition, for the first time we will present guidelines on how air conditioning and mortality displacement might modify these acclimatized estimates of mortality.

Results

Air mass/mortality relationships. High risk air mass categories were uncovered for a significant majority of the 44 cities, especially for summer (Tables 1, 2). Although particular high risk categories vary somewhat from one city to the next, there is clearly a high level of spatial consistency. For summer, the two hottest air masses, MT1 and DT, appear as high risk in a large majority of the cities. Of 35 cities that possessed at least one high risk air mass, MT1 was high risk in 27 cities and DT was high risk in 19. These similar responses among cities suggest that MT1 and DT air masses are often beyond a human threshold of tolerance and consistently represent conditions which impose great stress on the body. Ranking third in frequency as a high risk air mass was MT3, which is considerably drier than its MT1 counterpart.

There is some spatial homogeneity among the high risk air masses. MT1 is important in virtually all of the large cities of the East and Midwest. New York, Chicago, Philadelphia, Boston, Washington, and St. Louis are among numerous very large industrial cities where MT1 is high risk. The greatest impact of MT1 air appears to be east of the Mississippi River; of 27 cities where MT1 is high risk, only 5 are west of the river (2 of these are St. Louis and Minneapolis, located adjacent to the river). MT3 air also has its greatest impact east of the Mississippi River and is generally associated with lower mortality anomalies than MT1. The cities where MT3 air is important are all in the north central United States (Chicago, Detroit, Minneapolis, Columbus, Cleveland) or the northeastern United States (Boston, New York, Pittsburgh, Philadelphia). DT air has a dramatic impact on major cities such as New York, Philadelphia, and Chicago, but more western cities seem affected by this air mass, especially in the Southwest. Half of the cities where DT air is high risk are west of the Mississippi River, including all the important Texas cities in this study (MT1 is not a significant mortality factor in these cities).

The DT and MT air masses create different stresses on the body. MT air, with its relatively high humidity, lessens the body's

ability to increase evaporative heat loss by perspiration and vasodilatation (30). Latent heat loss from the body (which is necessary to maintain a body core temperature within a narrow range) is partially dependent upon the rate of perspiration evaporation; high humidities decrease vapor pressure gradients, which are directly proportional to evaporation rate (31). Thus, the rate of perspiration evaporation is diminished during MT episodes as humidity gradients between the body and atmosphere are diminished. During dry DT episodes vapor pressure gradients are sufficiently high, but desiccating conditions increase evaporation opportunity to such a level that perspiration production is insufficient; hypothermal conditions may then result in death (32,33).

In most cities where both MT1 and DT air masses are considered high risk, DT is associated with the higher mortality anomalies. For example, the mean excess mortality in New York City associated with MT1 is about 30 deaths; for DT, this value approaches 50 (Table 1). Considering population differences, variation from baseline mortality for DT air is even greater in Philadelphia, St. Louis, and Pittsburgh. However, it is noteworthy that DT air occurs on less than 2% of summer days east of a line from Minneapolis to Birmingham. Conversely, the three MT air masses occur on over 50% of summer days south of Memphis and Atlanta and on more than 25% of the summer days south of Chicago and New York (24). Although DT air is associated with very high excess mortality values, it is very rare in the eastern United States.

In a few cases, certain counter-intuitive summer air masses appear as significant in impacting human mortality. For example, there is a relationship between Atlanta DP and total mortality and Tampa MM and total mortality. It is possible that a few spurious relationships will be uncovered using an empirical analysis such as the one presented here. However, for summer mortality relationships, we are quite impressed with the dominance of DT air and MT1 air in most cities where weather has a significant impact on mortality; it can be strongly suggested that these relationships are truly important.

As was demonstrated in previous research (9,14), many cities in the South and on the West Coast show weak weather/mortality relationships in summer. Of eight cities with no high risk summer air masses, three are in Florida and three are in California. Other southern cities that are associated with high risk air masses show weaker relationships than northern counterparts; excess mortality values are relative-

ly low for New Orleans, Birmingham, and Atlanta. There is speculation that urban housing amenable to hot weather in southern cities renders them less vulnerable to heat-related mortality (22).

Determination of winter high risk air masses is more difficult, and mortality increases are less dramatic within these air masses. However, there is evidence that the cold, dry DP air masses increase winter mortality slightly in a number of cities, although the spatial continuity is relatively poor (Table 2). There is no locale where DP air is associated with more than 10 deaths above the baseline; these values are much lower than the excess deaths associated with MT1 and DT air in summer, especially within the large midwestern and eastern cities. Most winter DP mortality increases range from one to three extra deaths per day, with Miami exhibiting the highest total of 7.5. Interestingly, DP air appears unimportant in most of the cities where summer high risk air masses were found. For Chicago, New York City, and Boston, DP is not a high risk air mass. For Philadelphia and St. Louis, DP air contributes to slightly elevated mortality, but only represents about three extra deaths in both cities. Cool, damp MP air appears important in New York City (only associated with 4.6 deaths above the baseline), Miami, and New Orleans, and transition situations lead to slightly elevated mortality in a few scattered cities.

Some other air masses, including warm ones, appear to be high risk during winter in certain cities. For example, warm, dry DT air surprisingly contributes to some excess winter mortality in the Southwest and on the West Coast (DT temperatures can get very warm, even in winter). Some of the most dramatic winter anomalies are associated with this warm air mass, as indicated by Los Angeles (12.2 excess deaths), San Francisco (7.5 excess deaths), and San Jose (3.1 excess deaths). Considering this warm-weather winter effect, the potential impact of warmer winter temperatures on mortality is much less clear-cut, but appears unlikely to offset large summer increases.

Unlike the summer results, it is much more probable that a larger proportion of air mass/mortality relationships uncovered for winter are spurious. Although there is some indication that DP air is associated with higher winter mortality, the spatial consistency of its impact is much less than MT1 or DT air masses during summer. The location of cities possessing no high risk air masses is not nearly as systematic as in summer. Thus, the role of weather on winter mortality appears to be much more

indirect, possibly attributed to causes (such as indoor confinement) that are not readily apparent using an air mass analysis or any other meteorological procedures.

These results generally support our earlier work on winter mortality, which indicates that threshold meteorological conditions leading to higher mortality are either nonexistent or difficult to find (14). In addition, the coldest air mass is only associated with slightly increasing mortality. A number of winter studies in Europe seem to suggest that colder temperatures lead to higher mortality, but even some of these have had difficulty in determining specific threshold conditions similar to those found in summer (5). However, it is clear that there are differences in findings relating to weather/winter mortality between European and U.S. studies, and more collaborative research in this area is necessary. Professor W.R. Keatinge of the University of London Department of Physiology is attempting to gather experts from around the world to discuss the winter mortality question, and the results of this conference will be forthcoming.

The impact of climate change. The GCM scenarios suggest major changes in the frequencies of high-risk air mass categories, especially in summer (Table 3). For example, MT1 presently occurs on about 5% of days during an average summer in New York. The most conservative scenario (GFDL 2020) shows a doubling in frequency, and others suggest that this air mass will occur up to six times more frequently (UKMO 2050). The DT air mass shows similar increases in New York. Considering that, on a typical DT day, mortality is almost 50 deaths above the baseline level in New York, such increases could be devastating on mortality rates. Similar magnitude increases in summer high-risk air masses are noted for virtually all of the large midwestern and eastern cities where weather/mortality relationships are so strong.

Using the high-risk air mass algorithms and the acclimatization procedure discussed earlier, mortality estimates were developed for summer and winter for the six GCM scenarios (Tables 4 and 5). Results suggest that summer mortality will increase considerably for cities where high risk summer air masses were found. For example, during a present-day typical summer, it is estimated that 1,840 excess deaths occur due to the presence of high-risk air masses. These values increase under the three 2020 GCM scenarios. The GFDL scenario shows an increase of less than 10%, but the UKMO and Max Planck scenarios estimate much more dramatic increases (over 4,000 excess deaths

Table 3. General circulation model estimates of summer air mass frequencies for selected cities

City/air mass	Present climate	2020 climate			2050 climate		
		GFDL 89	UKMO	Max Planck	GFDL 89	UKMO	Max Planck
Chicago							
MP	5.00	3.01	0.87	1.92	1.67	0.87	1.52
DP	10.20	5.47	2.28	3.91	3.33	2.28	2.72
DT	1.80	3.23	7.54	5.58	4.82	9.06	7.94
DM	29.40	30.26	21.20	24.47	26.86	18.92	20.08
MM	13.40	13.08	10.55	10.98	12.07	9.68	9.75
MT1	5.20	10.76	30.26	23.67	18.90	33.16	31.42
MT2	7.90	4.86	1.96	2.97	3.91	1.63	1.88
MT3	15.50	17.33	13.16	14.46	16.85	11.82	12.03
T	11.60	11.24	10.95	11.16	11.42	11.42	11.49
New York							
MP	7.90	4.72	2.21	4.32	2.29	1.85	3.19
DP	2.70	1.60	0.73	1.34	0.76	0.65	0.98
DT	1.30	2.03	4.10	2.61	3.45	6.03	4.07
DM	24.60	21.52	15.06	18.95	16.66	11.76	15.61
MM	25.60	23.59	19.27	21.31	20.33	16.66	19.56
MT1	4.90	10.74	24.03	15.90	21.78	30.56	23.12
MT2	5.60	4.50	3.12	4.10	3.01	2.58	2.69
MT3	11.20	13.32	12.41	13.10	12.67	10.71	11.76
T	16.50	17.64	18.11	17.75	18.26	18.19	18.04
Los Angeles							
MP	14.20	9.60	24.54	6.02	17.14	31.06	11.92
DP	16.80	3.52	3.01	6.38	0.83	1.41	2.54
DT	0.00	24.03	15.15	23.41	20.91	13.95	22.80
DM	16.90	44.29	37.59	42.55	43.93	36.39	44.76
MM	33.10	2.97	2.94	5.91	0.40	0.91	2.28
MT1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MT2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MT3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T	16.50	15.59	16.78	15.73	16.78	16.27	15.69

Abbreviations: GFDL, Geophysical Fluid Dynamics Laboratory; UKMO, United Kingdom Meteorological Office; MP, moist polar; DP, dry polar; DT, dry tropical; DM, dry temperate; MM, moist temperate; MT, moist tropical; T, transition. See text for subcategories of MT.

and 2,800 excess deaths, respectively). Cities such as New York, Philadelphia, Chicago, and Detroit appear most vulnerable, especially if the UKMO scenario is used. For New York, excess mortality increases from the present 307 deaths to over 750 under the UKMO 2020 scenario.

The 2050 scenarios paint an even bleaker picture. The relatively conservative GFDL scenario indicates a summer mortality increase of over 70% for the cities used in this study. Mortality estimates using the UKMO and Max Planck 2050 scenarios are more than double present-day values. As was the case with the 2020 scenarios, the large eastern and midwestern cities appear most vulnerable. For New York City, summer mortality estimates are more than triple present values using the UKMO scenario. Similar increases are estimated for Philadelphia, Chicago, Minneapolis, and Detroit.

One of the most disputed questions is whether winter mortality decreases will offset these large summer increases. This study suggests that this will not be the case (Table 5). At present, slightly over 1,000 excess deaths are attributed to high risk air masses for the 44-city sample during win-

ter. Of course, winter mortality is generally higher than summer, but variation in meteorology appears not to be the responsible agent. Previous studies indicate that prevalence of infectious and respiratory diseases, which are largely responsible for the higher winter mortality, is not correlated well with winter temperature (2). Repeated attempts to correlate annual outbreaks of winter diseases such as influenza with monthly winter temperatures have been unsuccessful (18,20). Thus, meteorological variation has little impact on the increased baseline in deaths that occur in winter, but does contribute to the 1,000 excess deaths associated with the high-risk air masses.

Surprisingly, application of the GCM scenarios to estimate winter mortality shows little change from present conditions. Using the 2020 scenarios, winter mortality is about the same as that for the GFDL and Max Planck GCMs and slightly lower for the UKMO scenario. All three 2050 scenarios yield a slight drop in winter mortality, especially for the UKMO GCM, where a decrease from the present of about 15% is noted. However, the 100–200 death drop in winter mortality is much less than the large increases of 1,300 to almost 3,000

Table 4. Estimated total excess mortality for an average summer season, assuming full acclimatization

SMSA	2020 climate			2050 climate		
	Present climate	GFDL 89	UKMO	Max Planck	GFDL 89	UKMO
Anaheim	0	0	0	0	0	0
Atlanta	25	43	62	22	60	138
Baltimore	84	57	148	63	124	164
Birmingham	42	28	47	14	40	47
Boston	96	113	165	134	155	194
Buffalo	33	15	52	36	34	73
Chicago	191	243	538	421	359	583
Cincinnati	14	16	90	49	54	81
Cleveland	29	21	55	44	46	58
Columbus	33	24	83	51	51	90
Dallas	36	45	62	45	107	64
Denver	42	29	41	30	35	39
Detroit	110	84	240	164	130	271
Ft. Lauderdale	0	0	0	0	0	0
Greensboro	22	28	43	27	37	45
Hartford	38	21	42	32	38	50
Houston	7	7	16	7	15	17
Indianapolis	36	23	93	51	55	86
Jacksonville	0	0	0	0	0	0
Kansas City	49	79	173	93	121	156
Los Angeles	68	74	123	83	110	128
Louisville	17	0	2	0	0	1
Memphis	25	42	27	57	40	29
Miami	0	0	0	0	0	0
Minneapolis	59	55	185	148	123	215
Nassau	29	59	84	84	110	116
New Orleans	20	0	0	0	0	0
New York	307	363	753	498	460	999
Newark	26	83	173	111	150	127
Philadelphia	129	99	362	191	246	477
Phoenix	0	0	0	0	0	0
Pittsburgh	39	32	66	64	61	83
Portland	9	13	22	11	23	31
Providence	47	39	80	52	73	96
Riverside	4	6	10	6	8	11
Salt Lake City	0	0	0	0	0	0
San Antonio	4	0	0	0	0	0
San Diego	0	0	0	0	0	0
San Francisco	28	24	23	23	18	24
San Jose	0	0	0	0	0	0
Seattle	5	1	0	2	0	0
St. Louis	79	149	173	158	212	155
Tampa	28	68	95	28	95	100
Washington, DC	0	0	0	0	0	0
Total	1,840	1,981	4,128	2,799	3,190	4,748

Abbreviations: SMSA, standard metropolitan statistical area; GFDL, Geophysical Fluid Dynamics Laboratory; UKMO, United Kingdom Meteorological Office. Values given are estimated deaths.

deaths in summer mortality under the 2050 scenarios. The lack of a more significant winter drop is possibly attributed to the weak winter/mortality relationships within the high-risk categories. There is much less variation in mortality around the baseline within the winter categories when compared to high-risk summer categories. Thus, even though the GCMs suggest decreases in the frequencies of cold winter high-risk categories, the concomitant decreases in mortality are not very large. In addition, some of the winter high-risk categories are not the coldest and will not necessarily decrease in frequency if the climate warms. For example, the high-risk category for New York City is MP, which is not particularly

cold. MP frequencies are estimated to increase under the various climate change scenarios. MP currently occurs on about 25% of winter days presently in New York; the GCMs point to increases of about 33% using 2050 scenarios. For Los Angeles, the high-risk category with the greatest mortality excess in winter is DT. This category will increase in frequency from the present 5% to about 9% during warmer winters, and this is reflected in the minimal mortality change in Los Angeles mortality as estimated by the GCMs (Table 5).

Two socioeconomic factors complicate the impact of climate change on mortality. The first, air conditioning, may result in reduced summer mortality if use becomes

more widespread. The second, mortality displacement, suggests that some of the deaths attributed to heat and cold might be individuals who would have died shortly afterward regardless of the weather.

In an attempt to determine if air conditioning will be a mitigating factor, a recent study has compared mortality totals in several cities over a 25-year period in which access to air conditioning increased strikingly (2). The proportion of U.S. urban homes with air conditioning increased rapidly during this period; for example, in St. Louis, estimates indicate a rise in air conditioning in 40% of homes in 1965 to 91% in 1992. Air conditioning saturation (where virtually 100% of homes have air conditioning) is expected in most major U.S. urban areas by the early twenty-first century (Stern et al., unpublished data). The study suggests that, for New York City, approximately a 21% reduction in heat-related deaths may have occurred from 1964 to 1988 because of increased access to air conditioning (22). It is suggested in the study that other vulnerable U.S. cities may have experienced similar reductions, and these findings imply that air conditioning saturation in the twenty-first century could reduce somewhat the heat-related mortality totals presented in Table 4 (2). However, the degree of mitigation offered by air conditioning in a warmer world is difficult to quantify, and no study has, as of yet, developed estimates of the possible reduction of future heat-related deaths attributed to air conditioning.

The question of mortality displacement has been discussed more fully, and it has been demonstrated that a proportion of people who die during heat waves would have died shortly afterward, regardless of weather. In addition, it has been suggested that the impact of successive heat waves within a single season is likely to be subject to the effects of progressive selection and adaptation (2). Studies suggest that the proportion of deaths during a heat wave that represent short-term mortality displacement varies between about 20 and 40% (22). For a given city, displacement proportions seem rather consistent, with 20% values determined for two heat waves in St. Louis, and 40% values for three heat waves in New York City. There is reason to believe that these figures would be representative even in a warmer world, and the acclimatized mortality estimates presented in Table 4 could be reduced by 20–40%. However, even if this is the case, these studies indicate that a majority of heat-related deaths are not simply short-term displacements, but represent individuals who would otherwise not have died shortly after the heatwave. Thus, even when air

Table 5. Estimated total excess mortality for an average winter season, assuming full acclimatization

SMSA	2020 climate			2050 climate			
	Present climate	GFDL 89	UKMO	Max Planck	GFDL 89	UKMO	Max Planck
Anaheim	2	0	0	1	0	0	0
Atlanta	37	53	48	52	50	47	52
Baltimore	0	0	0	0	0	0	0
Birmingham	25	12	8	11	11	7	12
Boston	0	0	0	0	0	0	0
Buffalo	7	18	8	17	5	5	18
Chicago	2	4	3	4	4	2	5
Cincinnati	0	0	0	0	0	0	0
Cleveland	2	9	10	10	15	10	9
Columbus	12	1	2	1	3	2	1
Dallas	32	41	33	43	36	31	41
Denver	9	10	11	10	11	11	11
Detroit	34	15	20	15	18	26	14
Ft. Lauderdale	36	4	4	5	3	3	5
Greensboro	0	0	0	0	0	0	0
Hartford	0	0	0	0	0	0	0
Houston	24	33	29	35	29	27	33
Indianapolis	16	32	28	33	34	28	32
Jacksonville	0	0	0	0	0	0	0
Kansas City	12	51	36	46	42	35	46
Los Angeles	100	102	78	100	77	88	81
Louisville	16	12	17	12	19	15	12
Memphis	23	20	17	19	19	15	19
Miami	46	35	35	37	32	32	36
Minneapolis	0	0	0	0	0	0	0
Nassau	24	21	4	20	5	3	21
New Orleans	52	56	51	54	51	47	54
New York	102	123	150	120	152	93	121
Newark	48	23	8	20	10	6	23
Philadelphia	85	80	14	73	36	9	82
Phoenix	26	25	26	25	26	27	26
Pittsburgh	19	20	29	21	24	31	21
Portland	17	15	12	15	12	10	13
Providence	27	21	34	33	35	36	21
Riverside	10	26	29	26	27	27	26
Salt Lake City	5	7	9	8	8	10	9
San Antonio	9	10	6	11	5	4	9
San Diego	17	26	16	24	16	18	16
San Francisco	85	39	30	42	30	21	26
San Jose	3	2	4	2	3	5	4
Seattle	13	40	45	37	46	47	43
St. Louis	50	61	68	60	53	61	61
Tampa	21	26	24	26	22	20	25
Washington, DC	19	31	38	30	20	35	31
Total	1,067	1,104	984	1,098	989	894	1,059

Abbreviations: SMSA, standard metropolitan statistical area; GFDL, Geophysical Fluid Dynamics Laboratory; UKMO, United Kingdom Meteorological Office. Values given are estimated deaths.

conditioning mitigation and displacement are considered, heat-related mortality should nevertheless increase substantially in a warmer world. The estimates presented in Table 4 should be deemed conservative, as they assume full acclimatization, and the increases are generally substantially greater than the combined estimated reduction offered by air conditioning and mortality displacement.

Conclusions

The objective of this paper was to utilize a new air mass-based synoptic procedure to evaluate climate/mortality relationships as they presently exist and to estimate how climate change, as suggested by IPCC-

applied GCMs, might alter these values. Forty-four cities with SMSA populations exceeding 1 million were analyzed in this study. The following are some of the most salient results.

- During summer, two air masses consistently appear as high-risk: hot, dry DT and very warm, humid MT1. The latter is most important in the large eastern and midwestern cities, while the former impacts western cities as well. In some cases, average daily mortality increases by over 15 when these air masses are present.
- Many cities in the South and Southwest show weaker summer weather/mortality relationships than their eastern and midwestern counterparts. This supports ear-

lier research and is probably attributed to acclimatization to less variable summer weather and differences in urban structure between regions.

- Winter high-risk air masses are more difficult to discern, and variation from the baseline is much less. The greater winter mortality (when compared to summer) is primarily attributed to causes of death that do not vary much with ambient temperature; thus, the coldest winter days are not associated with mortality spikes that are present during summer.
 - High-risk winter air masses include cold, dry DP, but warm, dry DT is associated with high winter mortality in the West, and moist MP contributes to greater deaths in some large eastern and southern cities. However, the spatial consistency of high-risk air masses is much worse than summer, and some of these winter relationships may be spurious.
 - GCM scenarios suggest that great increases in frequency of summer high-risk air masses could contribute to significantly higher summer mortality, especially for the 2050 models. Increases using 2050 models range from 70% for the most conservative GCM to over 100% for the other GCMs, even if the population acclimatizes to the increased warmth.
 - The scenarios suggest that winter mortality will drop slightly, but will not offset summer increases to any significant degree. This is attributed to weaker weather-mortality relationships during winter and to the fact that many high-risk winter air masses are not the coldest and thus will not decrease in frequency if climate change occurs.
 - The impact of air conditioning mitigation and mortality displacement may reduce somewhat the above estimates. However, the number of present-day heat-related deaths in U.S. cities is still considerable in spite of these mitigating factors, even in cities where air conditioning is presently found in more than 90% of the households. Thus, we suggest that the combined impacts of these factors will only partially offset the very large increases estimated by the GCMs, and a substantial rise in weather-related mortality is the most likely outcome of a global warming.
- There is a need for additional research to sharpen these estimates and to further comprehend the impact of extreme heat and cold on human mortality. Considerable work is in progress relating to the impact of air conditioning and mortality displacement in altering the estimates provided here. In addition, work is in progress to assess the possibly synergistic role of air pollution and extreme weather on mortality (2).

As suggested by the IPCC Working Group II (1), this research suggests the need for improved health impact assessment capability, including local monitoring systems for the early detection of climate-induced changes on human health. Regardless of whether the climate changes, this work underscores the importance of developing more sophisticated watch/warning systems so urban areas can reduce the risk of heat-related deaths and minimize the possibility of a tragedy similar to that which occurred in Chicago during the summer of 1995 (34). As stated in the recent National Disaster Survey Report (35), extreme heat may be one of the most underrated of the deadly weather phenomena, and timely warnings are of utmost importance to provide city officials with information necessary for the development of proper mitigating actions.

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